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Compact GNSS Metasurface-inspired Cavity Antennas

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***Abstract*—This paper presents an innovative circularly-polarized compact cavity antenna based on metasurfaces; the proposed design is explained starting from a linearly-polarized antenna based on similar concepts. The main objective is to cover three different GNSS systems, namely Galileo E1, GLONASS G1 and GPS L1, with a single antenna embedded in a metallic cavity. The aperture dimension is set to $0.26\lambda_0 \times 0.26\lambda_0$, with a central frequency of 1578 MHz. Loading the aperture with a metasurface allows an efficient radiation within such a small aperture size. Our experimental results are in very good agreement with the simulations, with an axial ratio lower than 2 dB between 1540 MHz and 1655 MHz.**

***Index Terms*—circular polarization, compact antenna, GNSS, metasurface.**

I. Introduction

MINIATURE antennas have been studied for a plethora of applications, like mobile communication, radionavigation or geolocation systems. They are also used for accurate positioning and tracking of fastly-flying vehicles (e.g. projectiles). In many configurations, such antennas are embedded in compact metallic cavities with a typical aperture size smaller than $0.3\times\lambda_0$, where λ_0 is the wavelength in vacuum at the operating frequency; this strategy allows to guarantee its mechanical robustness and maintain the carrier aerodynamic properties. In practice, the radionavigation antenna module (which operates in right-hand circular polarization (RHCP)) must cooperate with at least three GNSS systems, namely the L1 GPS, E1 Galileo and G1 Glonass bands, whose carrier frequencies equal 1575.42 MHz for GPS and Galileo, and 1602 MHz for Glonass. This corresponds to a minimum acceptable antenna bandwidth of 60 MHz (3.7% at 1600 MHz).

Various compact antennas have been proposed for GNSS applications, e.g. [2]-[5]. Compact circularly-polarized (CP) configurations have been designed in [4] and [5] at 1.6 GHz, their dimensions equal $0.373\lambda_0\times0.373\lambda_0\times0.016\lambda_0$ and $0.32\lambda_0\times0.32\lambda_0\times0.026\lambda_0$, respectively. An even more compact structure ($0.177\lambda_0\times0.1810\lambda_0\times0.025\lambda_0$) has been proposed in [6], with a radiation efficiency around 72%. Nevertheless, none of these solutions are integrated into metallic cavities. Such a constrained environment has a very strong impact on the overall antenna performance [7]; in particular, it is responsible for a significant reduction of the antenna bandwidth. Various attempts have been proposed to overcome this limitation. In [8], a stacked linearly-polarized (LP) configuration is introduced to enhance the antenna bandwidth by a factor 3.3, compared to a single-layer patch. Similarly the stacked-patch configuration proposed in [9] exhibits a -10-dB reflection bandwidth of 23%. The LP magneto-electric dipole antenna integrated into a low-profile cavity described in [10] exhibits an impedance bandwidth of 54%. Artificial magnetic conductors (AMC) have been investigated in [11] to design a low profile CP antenna, with a thickness lower than $0.1\times\lambda_0$; an axial ratio bandwidth of 33.2% has been achieved with an impedance bandwidth of 36.2%. Finally, the quality of circular polarization can be improved [12] by employing a parasitic patch with an aperture antenna, leading to an impedance bandwidth of more than 70% and a 3-dB axial ratio bandwidth of 43.3%. Nevertheless, in all reported studies, the minimum antenna aperture size is in the order of $0.6\lambda_0\times0.6\lambda_0$, or larger (the overall antenna dimensions equal $0.967\lambda_0\times0.967\lambda_0\times0.173\lambda_0$, $0.72\lambda_0\times0.60\lambda_0\times0.19\lambda_0$, and $0.80\lambda_0\times0.80\lambda_0\times0.30\lambda_0$ in [10], [11] and [12] respectively).

Bandwidth limitations of small cavity antennas have been studied in [13]-[16]. In particular, it has been demonstrated in [15] and [16] that stacked patch antennas cannot exhibit the desired bandwidth (at least 60 MHz here) when embedded in a metallic cavity of size $0.245\lambda_0\times0.245\lambda_0\times0.115\lambda_0$. Metasurface-inspired solutions have thus been proposed by the authors to approach the theoretical bounds defined in [17], and a LP metasurface antenna has been first introduced in [13] as a practical implementation (at the frequency of 1575 MHz) of the theoretical developments given in [17].

We propose here two compact metasurface-inspired antennas operating at 1578 MHz and embedded in a very small square metallic cavity of size $0.26\lambda_0$. The first one, linearly-polarized, is briefly described in Section II to better explain the operation principle of the RHCP counterpart that is excited by four separate feed ports (Section III). Conclusions are drawn in Section IV.

II. Linearly-polarized antenna

A. Antenna geometry

The antenna geometry, provided in Fig. 1, is embedded in a square cavity whose dimensions ($50\times50\times20$ mm^3, i.e. $0.26\lambda_0\times0.26\lambda_0\times0.11\lambda_0$) are dictated by the flying platform

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in glue among others). The measured -10-dB reflection bandwidth is about 260 MHz. This quite large bandwidth (compared to the LP antenna) is attributed to the strong mutual coupling between ports, especially between two opposite ports, as shown in [22].

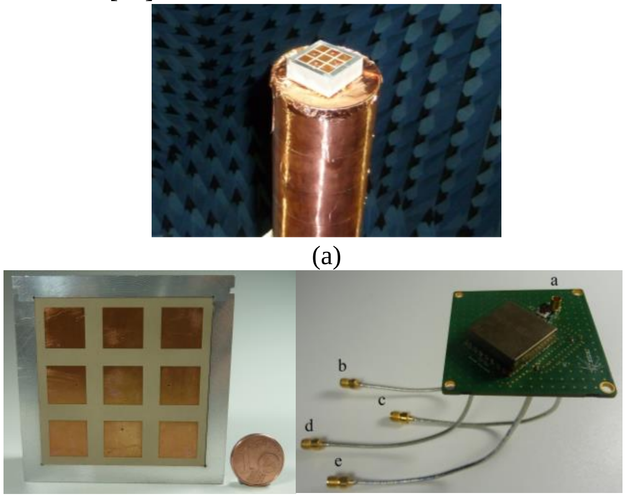

Fig. 8. Antenna prototype. (a) Antenna mounted on the rotating mast of the near-field anechoic chamber. (b) Top view. (c) Combiner system with four independent ports.

The feeding circuit, used to assess the antenna performance in CP, is shown in Fig. 8c. It is based on a commercial surface mounted four-port power splitter/combiner SCQ-4-1650+ [23] cascaded with a low noise amplifier BGA725L6 [24] developed for GNSS applications. The LNA is biased using the bias tee TCBT-6G+ [25]. This feeding system size has a total footprint of 60×60 mm². It has been characterized in amplitude and phase. The results, not shown here for the sake of brevity, show a maximum phase difference of ±3° between all ports from 1300 to 1700 MHz, while maintaining a very low amplitude imbalance.

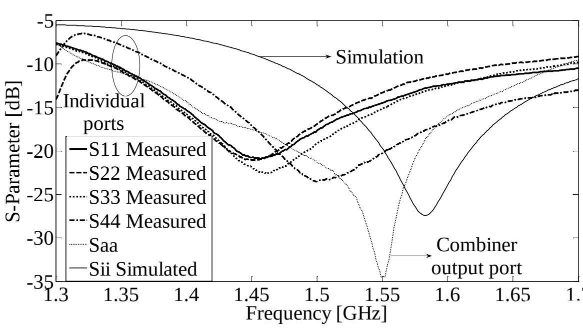

Fig. 9. Reflection coefficients measured at each input port of the CP antenna, and comparison with the simulated data. The reflection coefficient measured at the combiner out port is also shown.

The total gain of the antenna module, including the LNA gain, is plotted in Fig. 10 (left scale). Its average value is around 15 dBic at the center frequency. The axial ratio measured at broadside (Fig. 10, right scale) remains below 3 dB between 1380 MHz and more than 1700 MHz, and below 2 dB between 1540 MHz and 1655 MHz. The axial ratio value at 45° in elevation remains below 3 dB between 1500 MHz and 1650 MHz.

The normalized radiation patterns measured and simulated at 1578 MHz are plotted in Fig. 11 in RHCP (co-polarization) and LHCP (cross-polarization). The agreement between simulations and experiments is very good, with a very low cross-polarization discrimination level (< 18 dB for elevation angles smaller than 60°).

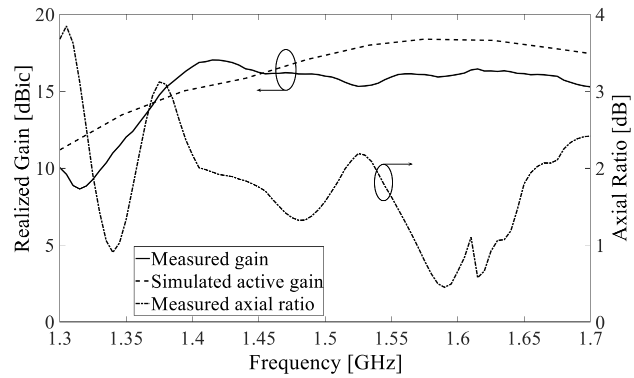

Fig. 10. Performance of the antenna module with its feeding system (Fig. 8c). Left: measured and computed gain. Right: measured axial ratio.

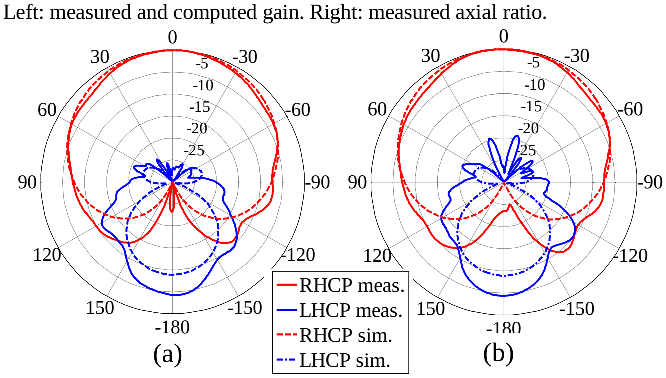

Fig. 11. CP antenna: measured (solid line) and computed (dotted line) normalized radiation patterns in dBic at 1578 MHz in two vertical cut planes: (a) φ=0°, (b) φ=90°. RHCP in red, and LHCP in blue.

IV. Conclusion

A compact RHCP metasurface-inspired cavity antenna $0.26\lambda_0\times0.26\lambda_0\times0.11\lambda_0$, covering three different GNSS bands with a single radiating aperture, has been proposed at 1578 MHz. The radiating aperture is loaded by a two-layer array of square patches excited by four feed ports in phase quadrature. This antenna concept has been introduced by first studying a similar antenna system, but operating in linear polarization. The LP antenna can be used onboard flying platforms in multipath-free-environments, while the CP version provides a better carrier-to-noise ratio (*C/N*), which is also required for ground purposes.

The experimental results obtained in RHCP have shown an excellent agreement with the numerical predictions. The proposed antenna is able to sufficiently cover the three GNSS bands (L1, E1, G1) with an active gain of 16 dBic and an axial ratio lower than 1.6 dB over this frequency range ([1550 – 1610] MHz).

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