GEOLOCALISATION ET NAVIGATION
DANS L'ESPACE ET LE TEMPS

Antennes compactes en cavité pour applications GNSS
Compact Antennas in Cavities for GNSS Applications

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Mots clés : antenne, cavité, métamateriaux, GNSS.
Key words: antenna, cavity, metamaterials, GNSS.

Abstract

L'objectif de ce travail est le développement d'une antenne miniature intégrée dans une cavité métallique rectangulaire. Cette antenne doit couvrir simultanément trois systèmes GNSS (Galileo E1, GLONASS G1 et GPS L1). De ce fait, la bande passante doit être au moins de 60 MHz. Un modèle à base de métasurfaces sera présenté, ainsi que les résultats obtenus en simulation.

The objective of this work is the development of a miniature antenna integrated inside a rectangular metal cavity. This antenna must cover three of the GNSS systems at the same time (Galileo E1, GLONASS G1 and GPS L1). To this end, the bandwidth must be at least 60 MHz. A model based on metasurfaces will be presented, as well as the results obtained in simulation.

1 Introduction

Geolocalization of flight systems, like projectiles, often need small antennas embedded in metal cavities [1]. In this case, a small square or nearly square antenna, which has the ability to cover three GNSS systems simultaneously, is needed. In order to cover the frequencies used by Galileo E1, GLONASS G1 and GPS L1 with a small single antenna, a device with at least a 60-MHz bandwidth is required with a central frequency of 1.578 GHz. Due to metallic environment, the bandwidth (BW) reduction is the immediate and main drawback [2].

First, it has been demonstrated that it is not possible to obtain the above-mentioned requirements with a standard microstrip patch antenna because of the reduced dimensions of the cavity (maximum 0.21 $\lambda_{0,}$ 40 mm). Another option to achieve the desired bandwidth consists in using stacked patches, although, for very small aperture size. This configuration can offer a substantial increase of bandwidth compared to a single-layer patch. The use of a metasurface is also an attractive solution, it is possible to increase the bandwidth without increasing the dimensions of the cavity. Therefore, the goal is to develop the metasurface-based design of a compact antenna with the widest possible bandwidth. This bandwidth must be higher than 60 MHz and the width of the antenna can not exceed 40 mm.

In previous studies a square antenna in cavity based on metasurfaces has been presented [3]. The metasurface consists of small patches of equal size printed on the same surface. This concept leads to a decrease in the inductance and to a purely capacitive system. In the study mentioned above, stacking these metasurfaces has also been studied. This approach helps to increase even more the capacitive effect of the cavity antenna. This concept was introduced in [4]. Here, due to the fixed width of the antenna carrier, 0.21 λ_0 (40 mm), it was not possible to use a square metasurface antenna to reach the desired bandwidth. Because of this, a rectangular antenna of size $0.21 \times 0.24 \times 0.11\ \lambda_0$ has been selected in order to design an antenna with an aperture size as close as possible to a square. As we are targeting a platform flying in altitude, radio propagation does not suffer from multipath propagation, and the antenna polarization is chosen to be linear.

The presentation of this study is organized as follows. Firstly, the design and optimization results of the stacked patch antenna are presented in Section 2. Second, the metasurface-inspired antenna is exposed in Section 3. Finally, the two previous designs are compared and discussed in the Conclusion.

2 Stacked patch antenna

To verify if it is possible or not to meet the requirements set out above, a stacked patch design has been studied. Figure 2 shows the cross-section view of a square cavity antenna based on two stacked patches of different size with a cavity dimensions $a \times a \times h$, where a is the aperture size and h the depth. A parametric study has been carried out by varying the variable a. The depth of the cavity is a fixed value, h = 20 mm and the patches (lengths l_1 and l_2) are printed on a dielectric material. The gap between both patches is filled by air. Finally, the feed point is displaced a distance fp respect of the center of the cavity.

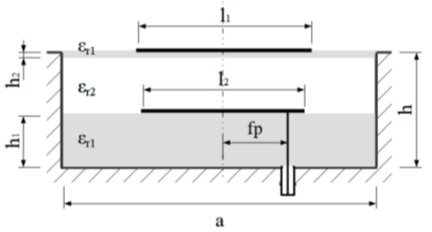

Figure 2 : Cross-section view of the stacked patch antenna in a metallic cavity.

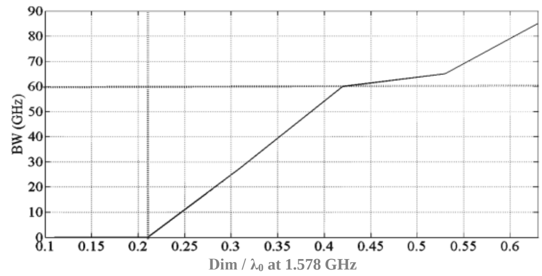

Figure 1 : Antenna bandwidth as a function of the aperture size of a square cavity for stacked patches.

Figure 1 shows the maximum achievable bandwidth depending on the aperture-size of the cavity. A comparative study has been performed using the commercial software CST Studio Suite [5]. As the limits of the requirements show, it can be concluded that it is not possible to use a stack-based design to reach the desired 60-MHz of bandwidth at 1.578 GHz with aperture dimensions lower than 0.43 λ_0 (a = 81 mm), moreover, it is not possible to match this antenna to the frequency of 1.578 GHz for dimensions lower than 0.21 λ_0.

3 Metasurface geometry

A schematic view of the rectangular metasurface-inspired antenna is shown in Figure 3(a). The design is based on a metallic cavity with a depth h = 20 mm and with a rectangular aperture of 40 × 45 ($a \times b$) mm^2 (0.21 × 0.24 λ_0). Most of the cavity, 90%, can be filled with air (h_1 = 18.08 mm), or with a solid material with low permittivity, as for example polypropylene (ε_r = 2.3) [6], which will be finally used in the manufacturing process for mechanical issues. The upper part of the cavity is composed by the metasurface arranged in two parallel layers, as shown in Figure 3(b). The metasurface provides a capacitive effect to the structure of the antenna to balance the inductance provided by the cavity, and to make the antenna resonate. Each layer is composed of three rectangular patches of equal size ($l_1 \times l_2$), with the aim of obtaining the maximum capacity without reaching the coupling, and they are printed on a thin substrate of high permittivity (ε_r = 10.2). Finally, the feeding of the antenna is made by a coaxial probe located 11 mm from the edge of the cavity and 9 mm from the center, on one of the side patches.

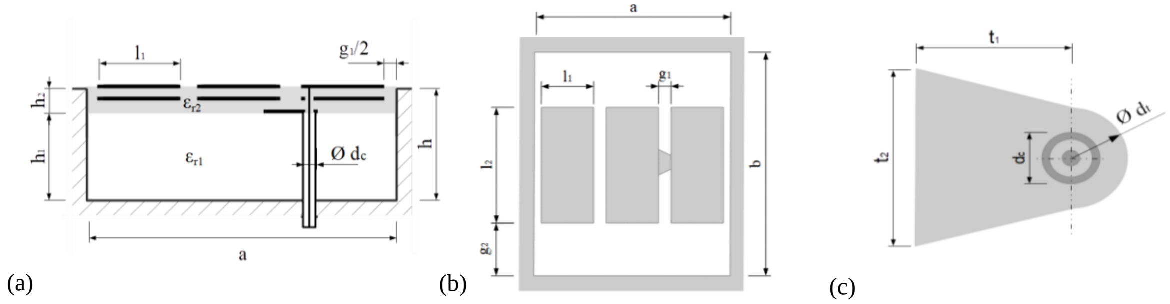

Figure 3 : (a) Cavity antenna cross section. (b) Top view of the metasurface-inspired cavity antenna. (c) Detail of the metal part welded to the feeding point.

Additionally, a small piece of metal is added to the bottom of the high permittivity substrate to match the antenna and facilitate soldering process, Figure 3(c).

Figure 4(a) shows the reflection coefficient S11 obtained in simulation. The BW is 68 MHz (FBW = 4.1% at the center of 1.578 GHz) around the central frequency which gives us a slightly higher bandwidth than the minimum required. The variables used in to optimize the antenna performance are the dimensions of the small metal part (t_2, t_1), the position of the feed point (fp) and the gap between patches (g).

This antenna has a high efficiency shown in Figure 4(b). Simulated gain is 4.54 dBi at the central frequency 1.578 GHz with an efficiency of 96.5%.

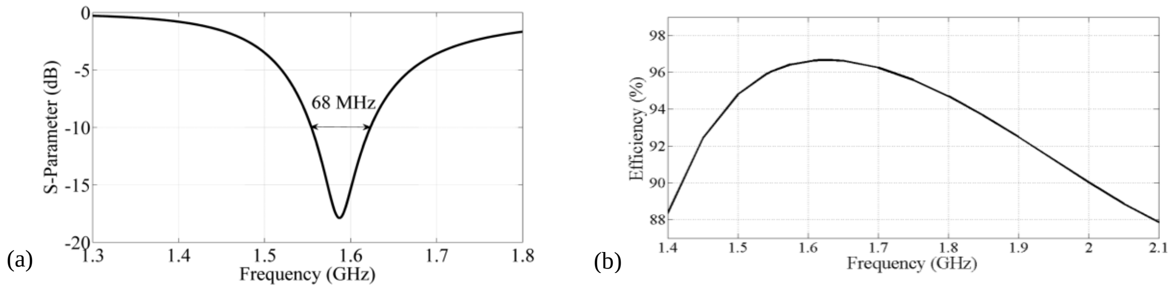

Figure 4 : (a) Simulated S11 for metasurface-inspired cavity antenna of dimensions 0.21 × 0.24 × 0.11 λ0 at 1.578 GHz (40 × 45 × 20 mm). (b) Antenna efficiency for metasurface-inspired rectangular cavity antenna at maximum directivity.

4 Conclusion

In conclusion, this paper shows two different studies to realize an antenna that covers the bands used by Galileo E1, GLONASS G1 and GPS L1 (60-MHz bandwidth) with a single antenna embedded in small metallic cavity. With a constraint on dimensions, the only possible solution to fulfil the bandwidth condition consists of a metasurface-inspired patch antenna. The antenna based on stacked patches is a well-known solution to increase the bandwidth of a certain system. For the specific case of metallic cavities of small size, the stack up of two patches do not give satisfying results to reach a sufficient BW (60 MHz).

On the other hand, the use of metasurfaces allows to increase the bandwidth due to the capacitive effect that they introduce. In other words, it is possible to minimize the size of the antenna for a required BW. The numerical results have shown that a square cavity of 0.21 × 0.21 λ_0 did not reach the specified BW of 60 MHz, but a rectangular cavity of 0.21 × 0.24 λ_0 is sufficient to reach a BW of 68 MHz. In comparison to the stacked patch configuration, the aperture reduction is of 72%. This result illustrates the advantage of a metasurface-inspired antenna for integration into a metallic cavity. Prototypes are currently under fabrication.

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