A Novel High-Gain Quad-Band Antenna with AMC Metasurface for Satellite Positioning Systems

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Abstract—**In this paper, a new design single feed multi-band antenna is presented. The proposed antenna is designed to operate at the 1.278GHz, 2.8GHz, 5.7GHz, and 10GHz frequency bands *which* cover the G*alileo* satellite positioning system (1.278GHz), WLAN (2.8GHz), WIMAX (5.7GHz) and the radar applications (10GHz), respectively. The antenna has a compact size, it is printed on an FR4 substrate of dimensions (60*mm*×27.5*mm*×1.67mm) placed on a ground plane of 60mm×17.5mm×0.035mm dimensions. To improve the radiation performance of the proposed antenna, an artificial magnetic conductor (AMC) was used as a reflector plane with dimensions of 13.5*mm* × 13.5*mm* × 1mm. The simulated and measured results are in good agreement and show the significant improvement of the gain value of the multiband antenna with AMC which is a required propriety for novel wireless communications systems.**

Keywords-antenna design; multiband antenna; Galileo; AMC metasurface

I. Introduction

Due to the strong appearance of future generations of mobile communication systems, such as Wireless Local Area Network (WLAN) and/or worldwide interoperability for microwave access (WiMAX), low cost, multi- band, and compact size antennas are required [1-2]. In recent years, a new system of navigation has been developed by the European Union named Galileo which is expected to be rolled out in 2020. A high level of quality will be provided as part of the fee-based services offered to professionals, guaranteed global positioning service under civilian control [3-4]. It will be able to exchange with GPS and GLONASS, the two other global satellite navigation systems [5]. For this reason, many techniques have been used recently to design planar multi-band antennas [6-9]. In [6], a planar dual band monopole antenna has been proposed, the radiator of the antenna was consisted of a short stem connecting to two branches and generating two frequency bands at around 2.4 and 3.4GHz for WiMAX applications. In [7], a three band square slot antenna with symmetrical L strips has been discussed. The antenna was able to operate at 2.5, 3.5, and 5.2GHz, which include WLAN and WiMAX. A four-band slot antenna was proposed in [8] using several stubs on the ultra-wideband slot radiator. Although the size of the antenna was compact, a low gain of only -6 to -4dBi in the frequency band of 1.5 to 3 GHzwas achieved, which is not required for many practical uses.

In this paper a quad- band antenna is proposed. The planar antenna consists of two rectangular patches forming an L shape and implemented on an FR4 substrate and covered by ground plan. The size of the ground plan is reduced to generate the two first resonance frequencies. Thus, the proposed design covers the Galileo (1.278GHz), WLAN (2.8GHz) bandwidth [2.79-3.1], WIMAX (5.7GHz) bandwidth [5.65-5.75] and radar applications (10GHz). Measured and simulated results of the fabricated prototype are showing good agreement. Then, in order to further improve the radiation performances of the proposed design, especially the gain, an artificial magnetic conductor (AMC) structure acting as reflector plane was employed. The AMC has been extensively used in recent decades for its outstanding advantages and its ability to increase the gain, efficiency and to reduce the size of antennas [9-11]. Therefore, a significant improvement in the gain value at the four operation bands of the proposed quad band antenna with AMC was figured out in both measurement and simulation.

II. Quad- band antenna without AMC meta-surface

A. Antenna Design

The designed structure of the quad-band antenna is presented in Figure 1 where the top and the bottom views are shown. The antenna is built on a FR-4 substrate with dielectric permittivity εr=4.4, loss tangent δ=0.025 and thickness equal to 1.6mm including the copper thickness of 0.035mm at both sides of the substrate. The size of the ground plane is reduced to obtain the quad-band operation where its dimension is 60mm×17.5mm×0.035mm. Besides, two rectangular patch slots forming an L shape are created to generate both two higher resonant frequencies. To verify the proposed antenna design, a prototype is fabricated (Figure 2) and measured. Table I summarizes all the geometric parameters of the proposed design.

B. Results of the Quad Band Antenna Without AMC

The antenna was designed using the electromagnetic simulation software CST. A prototype was fabricated and

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experimentally tested. The reflection coefficient of the fabricated quad-band antenna measured by a Rohde Schwarz ZVA 67 vector network analyzer is compared with the simulation results and shown in Figure 3. A good agreement is observed between the results. The proposed design should operate at four frequency bands, 1.278GHz, 2.8GHz, 5.8GHz and 10GHz, whereas the measured ones are 1.3GHz, 2.82GHz, 5.5GHz and 9.5GHz, the small discrepancy obtained at the higher resonance frequency is attributed to the fabrication tolerances provided by the SMA connector which are not considered in the simulation. More details about the simulated and the measured return losses results are recapitulated in Table II.

(a)

(b)

(c)

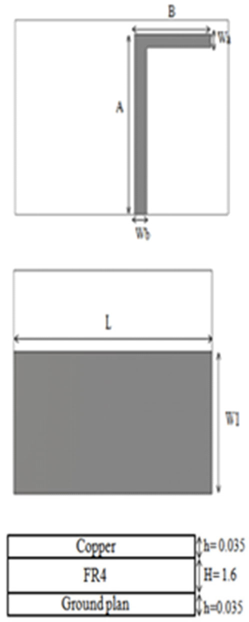

Fig. 1. The geometry of the proposed quad band antenna: (a) top view, (b) bottom view (c) left side

(a)

(b)

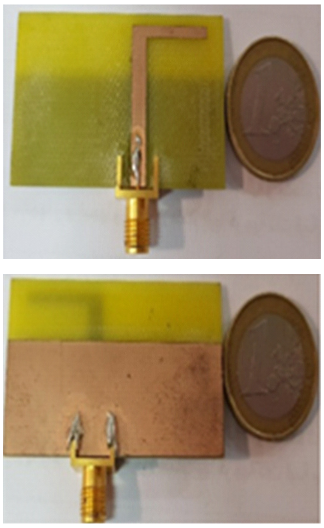

Fig. 2. The fabricated prototype of the quad band antenna, (a) Top view, (b) bottom view

TABLE I. ANTENNA DIMENSIONS

Parameter	Value (mm)
L	60
W	27.5
a	25.5
b	20.6
W a	1.90
W b	1.4
W1	17.5

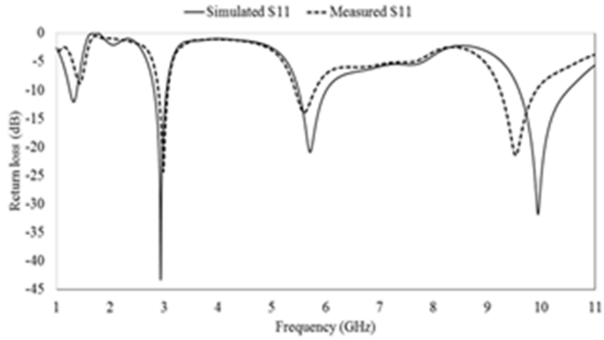

Fig. 3. Measured and simulated S_{11} result of the proposed multiband antenna without AMC

TABLE II. MEASURED AND SIMULATED RETURN LOSS OF THE QUAD BAND ANTENNA

		Simulated	Measured
First band (Galileo)	Resonant frequency(GHz)	1.278	2.82
	Bandwidth (GHz)	0.15	0.15
	Matching level(dB)	-13	-23
Second band (WLAN)	Resonant frequency(GHz)	2.8	1.3
	Bandwidth (GHz)	0.31	0.58
	Matching level(dB)	-25	-9
Third band (WIMAX)	Resonant frequency (GHz)	5.7	5.5
	Bandwidth (GHz)	1	1.2
	Matching level(dB)	-20.47	-15
Fourth band (Radars)	Resonant frequency (GHz)	10	9.5
	Bandwidth (GHz)	1.1	2.3
	Matching level(dB)	-30.7	-20

Figure 4 shows the simulated 3D gain of the antenna without AMC given at the four resonance frequencies. It is noted that the gain is about -4.24dB in the lower band of 1.278GHz, -0.74dB in the second band of 2.8GHz, 1.29dB in the third band of 5.7GHz and 2.89dB in the upper band of 10GHz. In addition, an omnidirectional radiation pattern is presented at all resonant frequencies. The proposed design achieves a low gain value, especially for the first two resonances, which may not be suitable for many modern communication applications. Therefore, a solution to increase the gain value and the radiation performance of the design will be described below.

C. Parametric Effect

This section shows a parametric study for the elements of the antenna to understand their operation and the various radiating elements. The first parameter is the second slot width. For the first band, the parameter has no effect on the variation of the frequency. For the other three bands, if we increase the value of the parameter, the resonant frequencies of 2.8GHz, 5.7GHz and 10GHz increase. We find that 0 is the ideal value for optimizing the antenna.

(a)

(b)

(c)

(d)

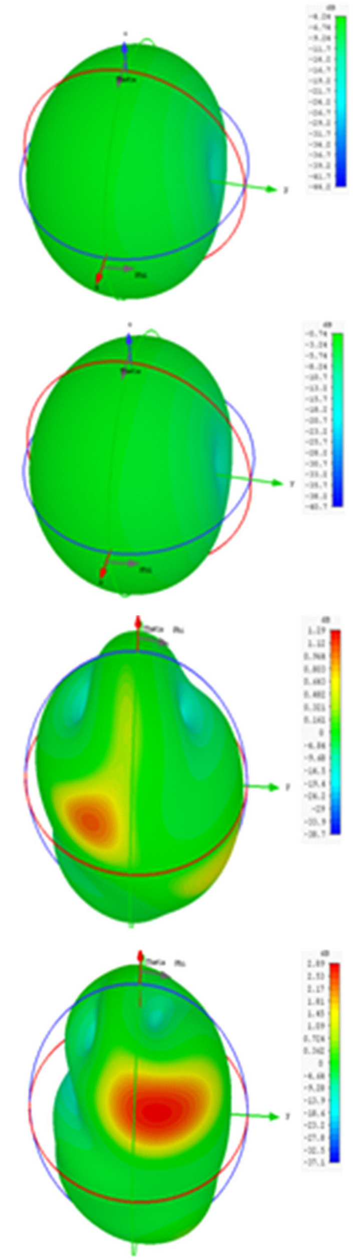

Fig. 4. Simulated gain of the proposed quad band antenna at the resonance frequencies, (a) 1.278GHz, (b) 2.8GHz, (c) 5.7GHz, (d) 10 GHz

The second parameter is the width of the vertical slot, the change in this parameter from (0 to 3mm) shows the variation of the reflection coefficient for the proposed antenna. For the first band, the value of the parameter has no effect on the variation of the resonance frequency. For the second band, if we increase the value of b the resonance frequency decreases while keeping the same bandwidth. For the third band, if we increase the value of b then the bandwidth increases. The same stands for the last band with resonance frequency reduction. We find that b=1.5 is the ideal value for optimizing the antenna. The decrease of the length of the second slot reacts on the higher frequencies.

III. QUAD BAND ANTENNA WITH AMC METASURFACE FOR GAIN IMPROVEMENT

The AMC structure can be used as a reflector plane employed to improve radiation performance and antenna gain. Indeed, these structures allow obtaining more compact antennas by favoring their directivity.

A. Design of the Quad Band Antenna With AMC

Generally, an AMC is defined on the frequency band in which the phase of the reflection coefficient is given between −90° and 90°, i.e. in the frequency band where the interferences occur between the incident and the reflected wave [12]. This characterization is usually performed by illuminating with a plane wave at normal incidence and for an AMC consisting of an infinite number of cells. To reduce the interaction between the AMC and the antenna that will be associated with, it is important that the size of the unit cells composing the AMC will be smaller than the dimension of the antenna. Figure 5 presents the designed and fabricated prototype of the AMC unit cell.

(a)

(b)

(c)

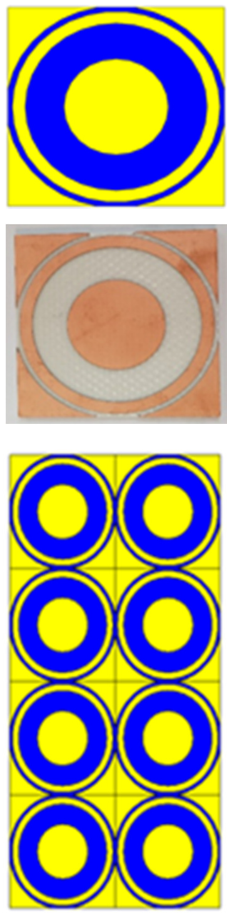

Fig. 5. The proposed AMC unit cell, (a) geometric (b) fabricated unit cell, (c) top view of the metasurface plan

The AMC structure consists of two rings where the inner ring allows the operation of the lower frequency and the outer ring provides the third resonance frequency. The radii of the outer and inner rings are equal to 9.7mm and 1.1mm, respectively. The AMC cell is built on the Rogers RO4003 substrate. To obtain the operation at the four desired frequency bands, the unit cell is arranged into a 2×4 array to form the AMC plane, as shown Figure 5(c). The overall quad-band AMC structure with dimensions of 108mm×54mm consists of eight unit cells with dimensions 27mm×27mm. This configuration is selected through several parametric studies. The simulated result of the phase reflection of the AMC unit cell used as a reference plane allows revealing its operating bands. The frequency bands are marked by the ± 90° variations around the 0° phase values, as shown in Figure 6. Hence, it can be noted that 0° of phase reflection is obtained at the 1.278, 2.8, 5.7 and 10GHz operating frequencies which correspond with the performances of the proposed quad –band antenna.

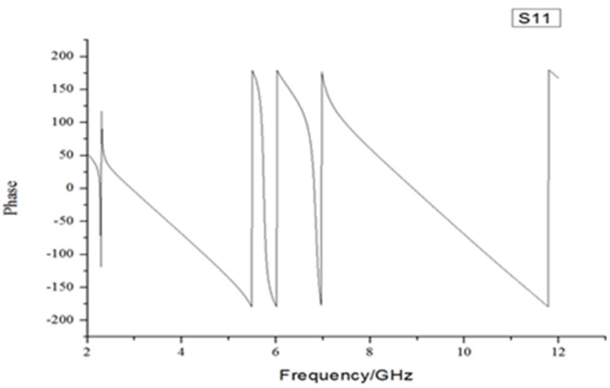

Fig. 6. Reflection phase of the proposed AMC unit cell

B. *Results of the Quad Band Antenna Witht AMC*

Figure 7 presents the configuration of the proposed quad-band antenna integrated with the AMC plane surface. The distance of the spacing g given between the AMC place and the antenna is well optimized to avoid the mutual coupling and also to keep the antenna as thin as possible. In practice, a foam substrate is used to separate the AMC and the antenna. This configuration aims to improve the gain and efficiency of the antenna without reducing its bandwidth.

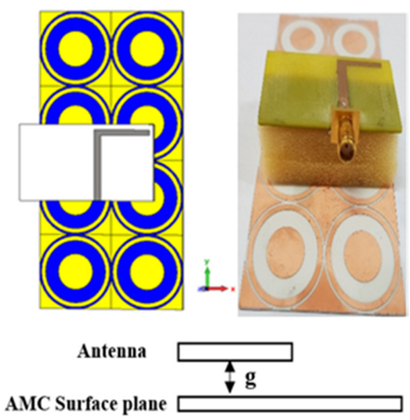

Fig. 7. Fabricated multiband antenna placed above the AMC plane

The S-parameters of the quad band antenna with AMC were tested by the vector network analyzer. The measured results of S11 of the antenna with the AMC are compared with the obtained results without AMC and are exhibited in Figure 8. It can be observed that a good agreement is obtained which indicates that the emplacement of the AMC surface does not perturb the resonance frequencies of the proposed antenna.

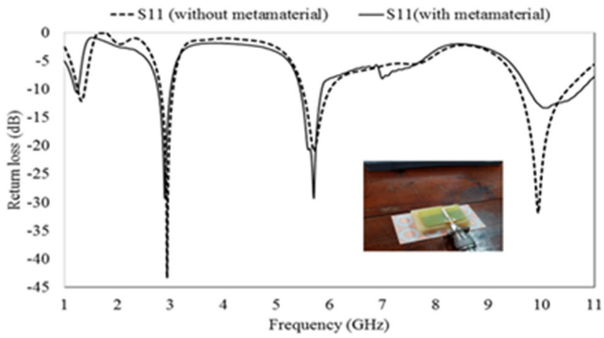

Fig. 8. Measured results of the multiband antenna with and without the AMC metasurface

The radiation performance of the fabricated antenna with the presence of the AMC is measured in an anechoic chamber. Figure 9 compares the measured gain and directivity over the frequency of the proposed design in both discussed cases, with and without the AMC plane. It is noted that a significant increase in the gain of more than 4dB is observed at all the operating frequency bands. At the resonance frequencies 1.278, 2.8, 5.7 and 10GHz, the gain values are increased to 1.12, 4.5, 4.92 and 5.66dB respectively. Results indicate the expected behavior aimed by the emplacement of the artificial magnetic conductors.

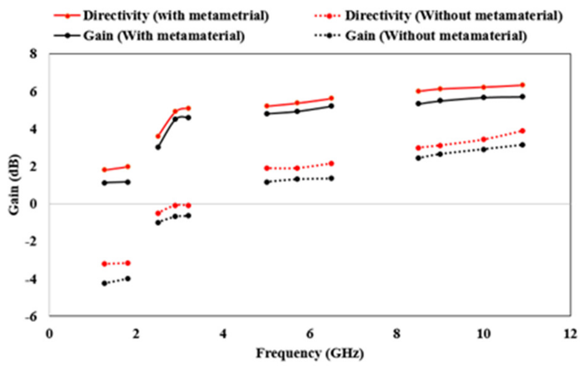

Fig. 9. Measured gain and directivity of the quad band antenna with and without AMC metasurface

The performances of the proposed quad band antenna and some other reported multi-band antennas [13-15] are compared in Table III. It is evident that the proposed design described in this study is characterized by high gain values which make it suitable for modern communication systems.

TABLE III. COMPARISON OF THE PROPOSED QUAD-BAND ANTENNA WITH OTHER MULTI BAND ANTENNAS

Ref	Frequencies (GHz)	Gain (dBi)
[13] Tri band	2.46	2.33
	3.59	3.134
	5.69	2.89
[14] Four band	1.5	-6
	1.8	Not reported
	2.4	Not reported
	5.5	2.5
[15] Four band	1.57	3.55
	2.45	3.93
	3.55	5.02
	5.2	4.86
Proposed	1.278	1.12
	2.8	4.5
	5.7	4.92
	10	5.66

IV. CONCLUSION

The main objective of this paper is the design, fabrication and measurement of a new multiband antenna operating in the Galileo E6, WLAN, WIMAX and radar application bands. The design was fabricated and tested and the measured results showed a favorable agreement with the simulated ones. An AMC metasurface was employed to increase the gain of the antenna by more than 4dB at all operating frequencies. The proposed antenna is suitable for satellite positioning systems.

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