

UVDual-Band Circularly Polarized Ferrite Antenna

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Abstract— This work presents the development of a dual-band antenna operating in a right-hand circular polarization (RHCP) in GPS and Galileo frequency bands, L2 (1.227 GHz) and E6 (1.278 GHz). The antenna exploits the potential of biased ferrite materials to naturally generate a circular polarization. Ferrite material also allows the reduction of antenna dimensions due to their high permittivity. All performances in terms of impedance matching and radiation pattern are reported and the concept is validated by prototype measurements.

Index Terms— circular polarization, ferrite material, multiband antenna.

I. INTRODUCTION

Nowadays, with the development of multi-standard wireless communication systems, there is a growing need for multi-band compact antennas. In addition, circular polarization radiation represents an interesting solution in civil and military fields for bypassing misalignments between transmitters and receivers, mitigating polarization losses caused by multipath, and overcoming the effects of deflection, propagation and ground reflection for satellite applications [1].

A common technique to obtain circular polarization within an antenna, consists of using a feeding line to excite two orthogonal linearly polarized modes with a phase difference of 90° [2], [3]. Other techniques rely on the integration of disturbance zones on the antenna or on the use of agile materials, including magnetic materials [1], [4], [5].

In this context, ferrite-based antennas are a good alternative because these materials have, when polarized by a continuous (DC) magnetic field, specific properties, in particular anisotropy, which enable the natural generation of circularly polarized waves. In addition, their permeability often greater than 1, associated with high permittivities (typically between 12 and 16), make ferrites suitable substrates for the miniaturization of antennas [6].

Thus, in this work a dual-band antenna with right hand circular polarization (RHCP) operating in the L2 (1.227 GHz) and E6 (1.278 GHz) frequency bands, is developed using a ferrite material. The device is excited by a single microstrip line and the patch is etched on a ferrite polarized by two permanent magnets. The characteristics of the ferrite material, the simulation results, the

realization as well as the measurements results of the fabricated device are presented.

II. FERRITE SUBSTRATE CHARACTERISTICS

The anisotropic, non-reciprocal behavior of ferrites magnetized to saturation by a DC magnetic field is characterized by the permeability tensor, also known as the Polder tensor. (1) [7], [8]:

$$[\mu_r(\omega)] = \begin{bmatrix} \mu & -j\kappa & 0 \\ j\kappa & \mu & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Where the Polder tensor elements are given by:

$$\begin{aligned} \mu &= 1 + \frac{\omega_m(\omega_0 + j\omega\alpha)}{(\omega_0 + j\omega\alpha)^2 - \omega^2} = \mu' - j\mu'' \\ \kappa &= \frac{\omega_m\omega}{(\omega_0 + j\omega\alpha)^2 - \omega^2} = \kappa' - j\kappa'' \end{aligned} \quad (2)$$

With: $\omega = 2\pi f$, ω_m is the gyrotropic pulsation defined by $\omega_m = \gamma\mu_0 M_s$, ω_0 is the Larmor pulsation given by $\omega_0 = \gamma\mu_0 H_i$ and the magnetic losses are modelled through the damping factor given by $\alpha = \frac{\gamma\Delta H}{2f_a}$ with ΔH the ferrite line width and $\gamma = 2.8$ MHz/Oe. Therefore, μ and κ depend on the internal magnetic field in the ferrite H_i , the saturation magnetization M_s and the frequency f . When the real and imaginary parts of μ (μ' and μ'' respectively) are plotted, the gyromagnetic resonance ($f_0 = \gamma H_i$) appears. Around this resonance frequency, the magnetic losses of the material are too high to allow efficient operation of an antenna. As long as antennas operate outside this band, two distinct operating regions are discussed: below (strong field region) and above (weak field region) the gyromagnetic resonance. In each of these regions two circularly polarized modes (RHCP and LHCP respectively) exist in a ferrite resonator [6]. The novelty of this paper is to obtain the radiation of a right circular polarization (RHCP) at two very close frequencies (L2 and E6) with a single feed point. We used the Y39 ferrite whose properties are summarized in Table I.

TABLE I. FERRITE PROPERTIES

Ferrite	$4\pi M_s$ (Gauss)	ΔH_{eff} (Oe)	ΔH (Oe)	ϵ_r	$\tan\delta$ (10^{-4})	Fonct.
Y39	800	4	40	14.6	2	Strong field

A dual-band antenna is then designed. The magnetic field to be applied to the ferrite is determined, in order to obtain the desired working frequency bands for the antenna. The next part describes the realization of the patch antenna with this type of material.

III. DESIGN AND SIMULATION RESULTS

The antenna design has been done in several steps using CST Studio Suite. The first step considers the ferrite substrate with a homogenous internal magnetic field while the second step uses magnetostatic (MS) and electromagnetic (EM) co-simulation that allows us to consider the real field delivered by the magnet that will be used to bias and saturate the material.

The proposed device is shown in Fig. 1. It consists of a metallic patch (gold) etched on the top of a rectangular ferrite substrate. This patch is excited by a microstrip line etched on a $110 \times 114 \times 0.787$ mm rectangular RT5880 substrate ($\epsilon_r=2.2$ and $\tan\delta = 9 \times 10^{-4}$). The bottom metallization acts as a ground plane. This antenna is fed by a coaxial connector that is connected to the microstrip line through the ground plane and the RT5880 substrate. Two permanent magnets (Samarium Cobalt) are integrated on the top of the antenna and under the ground plane (GND) with magnetic field strengths B_r of 1.04 T. They are chosen to provide the necessary internal magnetic field in the ferrites for strong-field operation. The magnetic steel plates (Steel - 1010) under the magnets were added in order to homogenize the internal field in the ferrite. An LC impedance matching circuit has been integrated on the feed line to match the antenna. In order to avoid losses linked to the integration of capacitances and inductances which could possibly disrupt and deteriorate the antenna radiation efficiency, an equivalent circuit was designed and optimized. This circuit is made up of interdigital capacitors (C1, C2 and C3) and inductive lines (L1 and L2) as shown in Fig. 1 and is developed thanks to well-known studies in the literature [9], [10]. This antenna has overall dimensions of $\lambda_0/2.3 \times \lambda_0/31$ (ground plane length x total height) for the L2 band.

The corresponding co-simulation results of the $|S_{11}|$ parameters and the axial ratio (AR in the $\varphi = 0^\circ$ and $\theta = 0^\circ$ axes) as a function of frequency are plotted in Fig. 2 with an internal magnetic field H_i of 635 Oe oriented along the positive z axis. The antenna has an RHCP in both operating bands (L2 and E6). The matching bandwidths ($|S_{11}| < -10$ dB) are equal to 0.5 % and 0.8 % respectively and the $AR < 3$ dB which cover beyond the entire matching bands of the antenna.

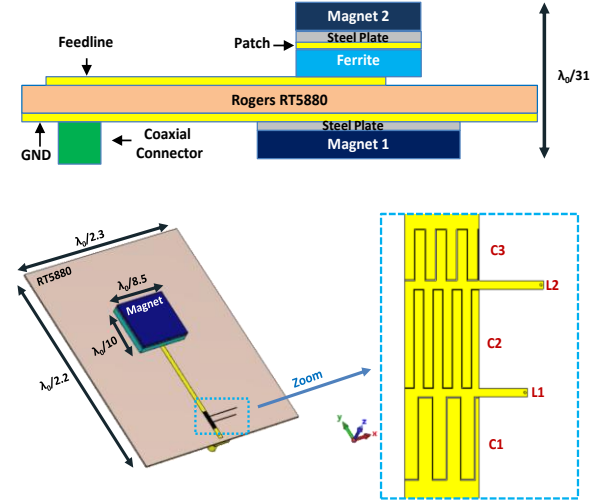


Fig. 1. Proposed antenna device topology.

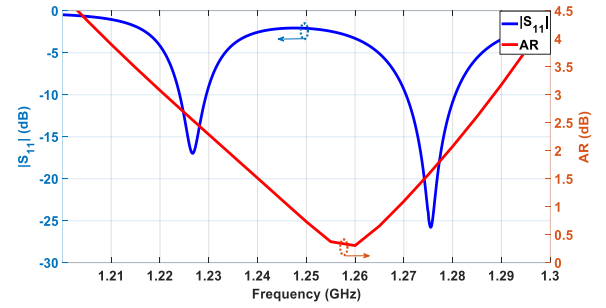


Fig. 2. $|S_{11}|$ and AR in MS-EM co-simulation considering the real field delivered by the magnet in the ferrite (H_i).

After the simulations, the validation of the performances is accomplished by measuring a prototype. Metallization was carried out using various microfabrication techniques in a clean room at the Xlim Laboratory. All the device components were aligned as shown in Fig. 3.

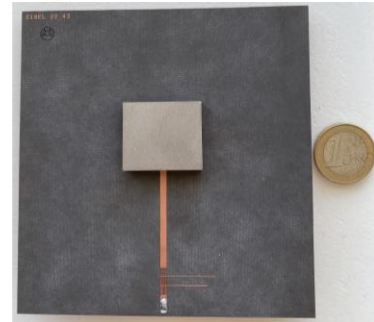


Fig. 3. Fabricated antenna prototype.

IV. MEASUREMENTS OF THE FABRICATED DEVICE

The measured $|S_{11}|$ parameters and AR as a function of frequency are plotted in Fig. 4. The two operating bands are around 1.237 GHz and 1.279 GHz respectively with good agreement between measured and simulated parameters. However, there is a slight frequency offset of 0.8 % between the simulations and the measurements of the $|S_{11}|$. This can be explained by the tolerances (5 %) on the permittivity of the ferrite material, the dimensional and manufacturing tolerances of the various antenna elements, and also the differences between the properties of the simulated and measured magnets. Indeed, the theoretical field of the magnets (used for the co-simulations) is slightly weaker than the real field (the one provided for the measurements). The theoretical and practical magnetizations of the material are therefore different. The antenna AR is in the range of 1.33 to 2.9 dB on the L2 and E6 bands.

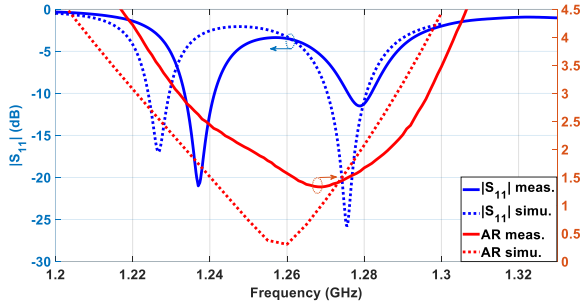


Fig. 4. Measurement results and MS-EM co-simulation of $|S_{11}|$ parameters and AR for the two operating frequencies.

Fig. 5 shows the measured RCHP (main polarization) and LHCP (cross polarization) at frequencies 1.237 GHz and 1.279 GHz for different cut planes ($\phi = 0^\circ$ and $\phi = 90^\circ$). The LHCP gain level is about 15 dB lower than the RHCP gain between -45° and 45° for the L2 band and between -55° and 55° for the E6 band. In this case, the maximum gain value achieved is 2.7 dBi (first mode) and 4.4 dBi (second mode).

Table II summarizes the obtained performances in terms of gain, efficiency and AR according to the device matching frequency bands at 1.237 GHz and 1.279 GHz.

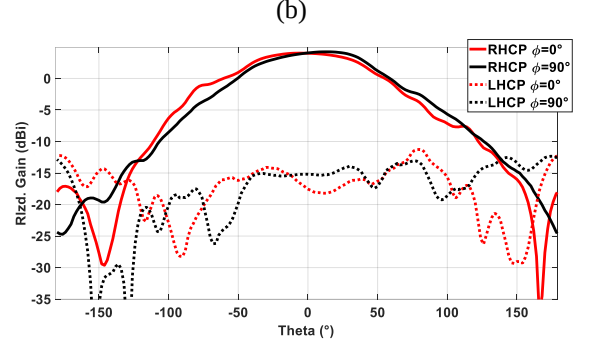
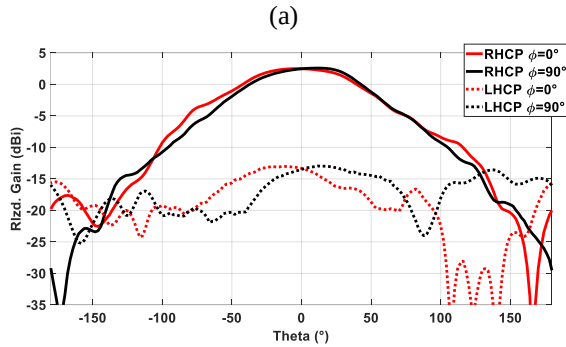


Fig. 5. Realized gain of right-hand circular polarizations (RHCP) and left-hand circular polarizations (LHCP) at: (a) 1.237 GHz and (b) 1.279 GHz.

TABLE II. SUMMARY OF THE MEASURED PERFORMANCES OF THE FABRICATED ANTENNA DEVICE

Frequency	1.237 GHz	1.279 GHz
AR ($\phi=0^\circ$, $\theta=0^\circ$)	2.6 dB	1.6 dB
Rlzd. Gain	2.7 dBi	4.4 dBi
Tot. Eff.	45 %	65 %

It can be noted that the antenna radiates 45 % of the accepted power for the first mode and 65 % for the second one. These radiation losses are explained by the miniaturization of the antenna ($\lambda_0/10$ for the ferrite and the patch) at these frequencies, but also, by the magnetic losses on the ferrite material and the metallic and dielectric losses of the others circuits elements. Indeed, electrical currents flowing through the matching circuit on the feeding line (interdigital capacitances and inductances) can cause that some of the RF signal power will be lost in the metal. A high concentration of E-field existing around this feeding line will affect the efficiency of the antenna.

V. CONCLUSION

We have exploited the potential of ferrite material to create a compact, space-saving multiband antenna for GNSS applications, radiating right-hand circular polarization over two frequency bands with a single feed point and a single ferrite substrate. MS-EM co-simulations have been carried out, the antenna has been manufactured, and the measured performances demonstrate good AR over the device's operating frequency bands. Matching bandwidth and frequency offset need to be improved. This will be achieved by better control of magnetization, by operating in other regions (weak field) and by optimizing the feeder circuit.

In the future, this antenna will be integrated into a 4-element array in order to achieve a radiation pattern reconfigurability while keeping a right-hand circular polarization in the same ferrite device. The performance and measurement results of this array antenna will be shown during the conference.

ACKNOWLEDGMENT

This work is carried out as part of the ANR ASTRID CONTACT project and the INOGYRO joint laboratory between the SME Inoveos and the XLIM Research Institut (<https://inogyro.xlim.fr/>). The measurements were carried out within the PLATINOM platform, supported by the European Regional Development Foundation and the French government with the Nouvelle-Aquitaine region.

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