Low-Profile Dual-band Circularly Polarized Microstrip Antenna for GNSS Applications

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***Abstract*—This paper presents a design of a micro-strip circularly polarized antenna intended for the Global Navigation Satellite Systems (GNSS). The presented device is composed of a micro-strip slotted patch antenna printed on a Rogers RO3006 substrate, a foam layer of 2 mm thick and a wideband commercial 3-dB SMT coupler. The combined fullwave antenna results with the measured S-Parameters of the coupler shows very good performances in terms of antenna matching and axial ratio on larger bandwidths.**

***Index Terms*—Circularly polarized antenna, dual-band microstrip antenna, wideband SMT coupler.**

I. INTRODUCTION

Electronic communication terminal, such as antenna for communication applications is required to be as small as possible. To reach this objective, circularly polarized (CP) microstrip multi-band antennas are the best solution. As they can satisfy the increasing demands for more capacity and higher data rate in wireless systems, when bands are wide enough. Recently, microstrip antennas have been receiving a lot of attention in terms of research and development activities from research institutes and industrial companies thanks to their numerous advantages. Printed CP antennas can provide flat profile, very low weight, low cost of production and can reduce the loss between the transmitter and the receiver in comparison with the linearly polarized antennas [1].

The CP antenna can also be used to reduce the multipath effect around a GPS system [2]. In general, the CP microstrip antennas are classified as a single feed type, dual feed type or more, depending on the number of feeding points used to generate the CP waves. An example presented in [3] propose a single feed dual-band antenna with crossed slots inserted at the center of the radiating element, resulting in circular polarization. To achieve a good axial quality ratio versus the scanning angle, the use of two or four feed probes with phases arranged as 0°, 90°, 180° and 270° becomes necessary, which results in suppressing the cross-polarization level. In a recent work of Chen Lin, a three-fed microstrip circularly polarized antenna has been published with a 3-dB axial ratio bandwidth of 47.88% [4]. This wide bandwidth has been achieved by the use of three central symmetrical feeds with equal amplitude and 120° phase shift. Otherwise, to achieve this large bandwidth, two air gaps of 11.4mm and 9mm have been introduced in the structure. But it becomes cumbersome when it must be integrated in a very low profile GPS communication system. In our case, the global height of the proposed antenna doesn't exceed 9mm. Besides the feeding techniques, the multi-band characteristic can be achieved using different methods. The most common way is the use of two or more patches printed on several stacked substrate layers [4]–[8]. Another method would be inserting slots in the antenna structure, which results in a single dual-band radiating element [3]. In [9], two stacked patches have been used on an FR4 substrate to achieve a dual-band (1.227 GHz and 1.575 GHz) GPS system. In this example, we note the use of an air gap of about 0.45 mm between the two layers to obtain a good impedance matching at the two frequency bands. The measured results of this kind of CP antenna shows that the obtained 10-dB return loss bandwidth cannot be larger than 53 MHz (4.3% at 1.227 GHz) and its even lower for the upper band (2.8% at 1.575 GHz), even with the use of the air gap [9]. Even though with the narrow return loss bandwidth, the 3-dB axial ratio bandwidths of the lower and the upper bands reached a maximum of 15 MHz (1.2%) and 17 MHz (1.1%) respectively [9]. Other solutions with dielectric resonator can be used to obtain wideband antenna for GNSS systems [10]. The unique inconvenient with these designs is the height of the resonator which is very important.

The objective of the work presented in this paper is to propose a design configuration of a CP antenna linked with a miniature wideband SMT coupler that can meet the requirements of GNSS systems. The device is intended to operate simultaneously on three GNSS frequencies: 1.227 GHz (or L2 band), 1.278 GHz (or E6 band) and 1.575 GHz (or L1 band). The antenna design will be used in a four elements array configuration in order to obtain a controlled reception pattern antenna (CRPA).

II. ANTENNA DESIGN AND DISCUSSION

A. *Antenna design description*

The proposed design, shown in Fig. 1, is based on the study and the development presented in [11] and [3], respectively. The theory about this design is then studied by many

This work is funded by the DGA (French Defense Agency) and the ANR (French Research Agency) under an ASTRID-ANR French program entitled COCORAM.

researchers as A. Heidari [12] and W. Liao [13] for example to produce two microstrip GPS antenna in rectangular and circular forms always with edge slots to enable dual band behavior.

The simulated design is composed of a slotted patch antenna printed on a 5.42 mm thick Rogers RO3006 substrate (ε_r = 6.15 and tanδ = 0.002).

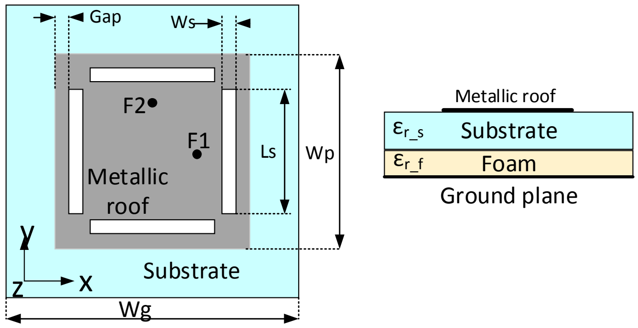

Fig. 1. Front view (left) and cut view (right) of the proposed structure of the dual-band GNSS microstrip antenna.

A Rohacell HF51 (ε_r = 1.07) material of 2 mm thick is inserted between the Rogers substrate and the ground plane. The patch is printed on a 170x170 mm^2 (Wg) large substrate. The radiating element is 56x56 mm^2 (Wp). The slots have a width of 0.5 mm and a length of 51 mm. In this design, the Rogers substrate is used to reduce the dimensions of the patch (compared to the half-wavelength in the free space) while the foam (Rohacell HF51) is used to obtain relatively large bandwidth. Since the frequency ratio between the higher and the lower frequency is equal to 1.28, the gap between the slots and the edges of the square patch must be small. In our design this value has been chosen to be equal to 0.8 mm. In fact, the lower the frequency ratio between the higher and the lower frequencies the lower the Gap value must be.

B. *Excitation circuit details*

The simulated design of the excitation circuit including the Hybrid SMT coupler position and the 50Ω RF resistance one is presented in Fig. 2. The two phase shifted output access of the SMT coupler are connected to the antenna ports (port 1 and port 2) using two metallic via hole while the isolated access is connected to the RF resistance. This circuit is designed on a Rogers RO4350 dielectric substrate with 3.48 relative permittivity and 0.762mm thickness.

The circular polarization characteristic of the antenna is obtained with the use of two orthogonal modes, which are achieved through the use of two feeds that are placed in the F1 and F2 positions and have equal amplitudes, but 90° out of phase. All the details concerning the SMT coupler are available on the Anaren website (reference: XC1400P-03S) [14]. This coupler has many advantages such as the 90 degrees phase shift bandwidth (from 1.2 GHz to 1.6 GHz), the neglected insertion losses (0.12-dB), the phase balance (less than 2 degrees), the 30-dB isolation and the miniaturized size (6x4x2 mm^3).

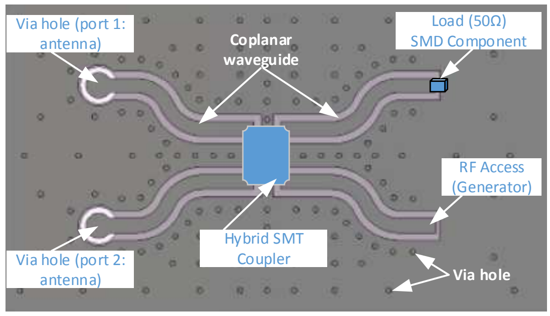

Fig. 2. Design view of the excitation circuit including the SMT hybrid coupler placement, the 50Ω SMD RF resistance and the RF access for feeding.

To obtain good performances with a printed circuit, dual-band microstrip hybrid coupler must be used. As an example, the circuit presented in [15] but the length of the two cells is about $\lambda_g/2$ which is very large compared to the selected SMT one. The SMT coupler is used to provide RHCP through the first input, which is connected to the RF generator and the second input, which is connected to a 50 Ω characteristic resistance. To obtain LHCP, the reverse configuration must be applied.

III. Results and Discussion

The performances of the presented antenna are studied and discussed in this section. All simulation results are carried out using the commercial electromagnetic software CST-MWS. The simulated reflection coefficient and axial ratio versus frequency in the forward direction are shown in Fig. 3. The radiation patterns in terms of directivity for the three studied central frequencies (f1, f2 and f3) are presented in Fig. 4. Fig. 5 shows the axial ratio versus the scanning angle (θ) in two planes Φ=0° and Φ=90° while Fig. 6 illustrates this parameter (axial ratio) in all the Φ planes for θ_{scan} between 0° and 40° which is the objective in this project.

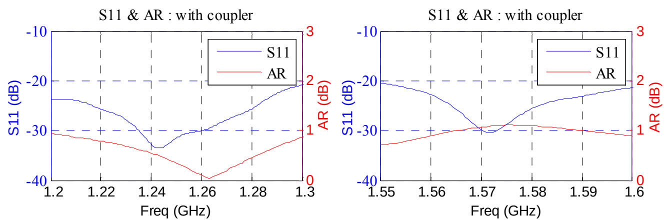

Fig. 3. Return loss and axial ratio with and without coupler for (θ=0°; Φ=0°).

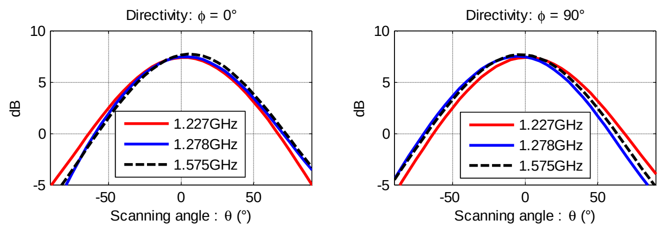

Fig. 4. Radiation patterns in two ϕ-Planes for TM_{100} and TM_{300} modes.

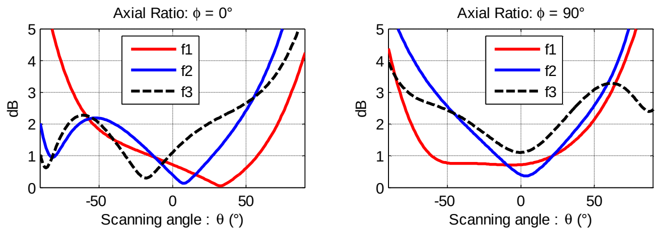

Fig. 5. Axial ratio for f_1=1.227 GHz, f_2=1.278 GHz and f_3=1.575 GHz.

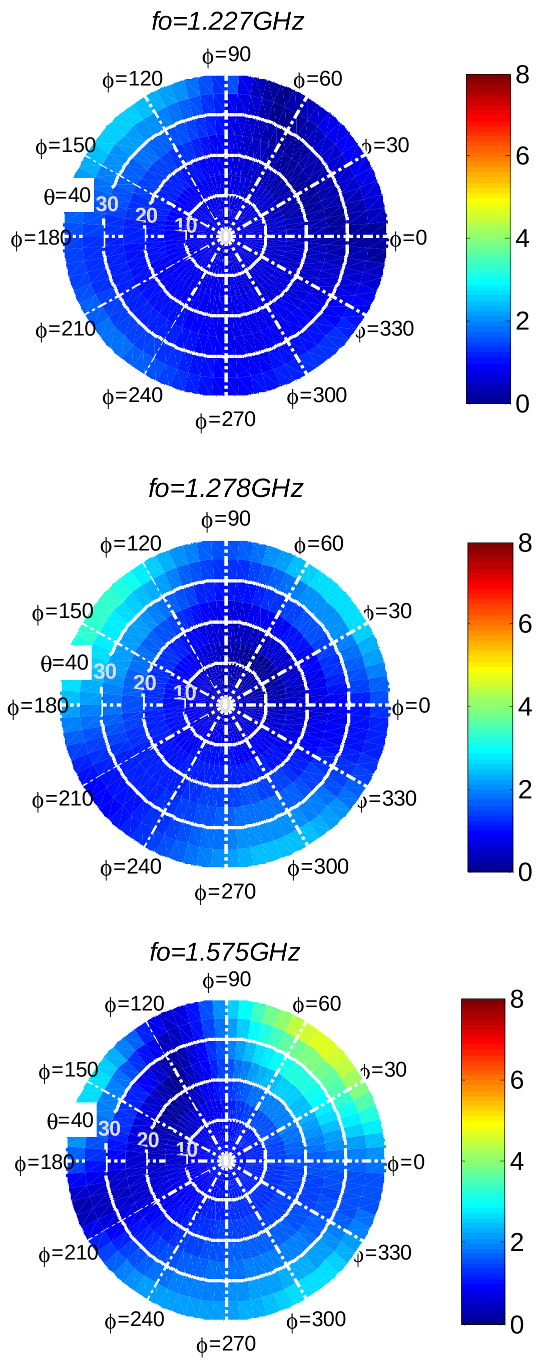

Fig. 6. Axial ratio for the three central frequencies of GNSS systems on 360 degree scanning angle (θ_{max}=40°): L2 band (f1=1.227GHz), E6 band (f2=1.278GHz) and L1 band (f3=1.575GHz).

The radiation pattern (directivity), presented in Fig. 4, was found to be higher than 7.4 dBi for all frequency bands. The RHCP realized gains are approximately 5.4 dB, 5.5 dB and 7.67 dB for the L2, E6 and L1 bands respectively. The total system efficiencies are higher than 61% for the L2 and the E6 bands, while reaching 90% for L1 band. These differences are due to the impedance mismatching between the output ports of the coupler and the input feeds of the patch. The obtained results show that it's possible to satisfy all the GNSS requirements. Good CP performance of the studied antenna is achieved by adjusting the positions of the probes on the x and y-axis. The best results were obtained when the distances between the feed probes and the antenna's center is equal to 9.5 mm. The designed antenna exhibits excellent frequency response with resonance at 1.24 GHz and 1.575 GHz. The simulated reflection levels were always lower than -20 dB.

Furthermore, the structure exhibited radiation patterns similar to the mode TM_{100} and TM_{300} of a conventional patch. In fact, it's found that the resonance of the first operating mode (TM_{100}) is slightly affected while the resonance of the second mode (TM_{300}) is significantly decreasing due to the rectangular slots [11]. The advantage seen here is that these two modes show similar radiation properties. The obtained axial ratio in the forward direction for this antenna structure is lower than 3-dB for an angle width higher than ±50°. As the structure is not completely symmetrical due to the excitation locations of the two feeds, the plots of the axial ratio versus the scanning angle are not symmetrical.

IV. Conclusion

In this paper, a design of a microstrip circularly polarized dual-band microstrip antenna that meets with all of the requirements of GNSS (GPS/GALILEO/GLONASS) systems is presented. This antenna design presents a good axial ratio versus frequency, high directivity of about 7.6 dBi and a total efficiency of 90%. A comparison between the simulated and the measured results will be published as soon as possible.

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