MAGICA project: Development of a Multi-frequency Automotive GNSS Integrated Cost effective Antenna

Evgenii Filatov[a], Marco Antonio Vélez[a], Joan Gemio[a], Jose Javier Vicente[a], Roser Capdevila[a], Laura Tantinyà[a], Alberto Gil[b], Adrián Cardalda[c], Daniel Baños[a], Pere Mogas[a] and Joaquín Reyes[d]

[a] *FICOSA International, P.I. Can Mitjans s/n, E08232 Viladecavalls (Barcelona), Spain*
[b] *SEAT, Autovia A-2, km 585, E08760 Martorell (Barcelona), Spain*
[c] *Rohde & Schwarz GmbH & Co. KG, Muehldorfstrasse 15, E81671 Munich, Germany*
[d] GSA, European Global Navigation Satellite Systems Agency, Janovskeho 438/2, E17000 Prague 7, Holesovice, Czech Republic

Abstract

The present work describes the Multi-frequency Automotive GNSS Integrated Cost-effective Antenna (MAGICA) project and the first results. This is a two years project that started in August 2020 under the sponsorship of the European GNSS Agency (GSA) and within the framework of Fundamental Elements.

The main objective of the project is to go beyond the state of the art. For the first time, it will provide a cost-effective high precision positioning antenna providing multi-frequency (L1/E1, L5/E5a/E5b & E6), multi-constellation (Galileo, GPS, BeiDou & GLONASS) characteristics, and phase stability as the most relevant performance features. Moreover, the antenna will be commercially ready to be integrated into a vehicle for Autonomous Driving operation.

The proposed antenna will increase the number of frequency bands that are offered to the GNSS receivers of the vehicles today. It will include the E6 band of Galileo, providing, in this manner, not only more accurate but also safer positioning due to the authentication service

Keywords 1

Antenna, Multi-frequency, Multi-band, Multi-constellation, GNSS, Low-Cost, Automotive, Galileo E6 band.

1. Introduction

A key aspect of the autonomous vehicle of the future is that it will be able to position itself very precisely on a map. For this to be possible, two things must happen: first of all, the car must be able to situate itself in its environment starting from a known and universal position, which in technical terms is referred to as an absolute position and second, the position of the vehicle must be estimated with high precision and accuracy.

The only technology that can provide absolute positioning information is the one based on GNSS systems, so the efforts of the industry to develop increasingly reliable systems with this purpose have been capitalized in recent years.

In some specific markets, the use of GNSS receivers capable of processing more than one frequency band has been consolidated for a long time. However, the automotive sector is quite different since the market demands make the implementation of high-performance GNSS receivers and antennas more difficult. The automotive market requires robust and high-performance antennas with compact

ICL-GNSS 2021 WiP Proceedings, June 01–03, 2021, Tampere, Finland
EMAIL: evgenii.filatov@ficosa.com (A. 1); marco.velez@ficosa.com (A. 2); joan.gemio@ficosa.com (A. 3); josejavier.vicente@ficosa.com (A. 4); roser.capdevila@ficosa.com (A. 5); laura.tantina@ficosa.com (A. 6); alberto.gil@seat.es (A. 7); Adrian.Cardalda-Garcia@rohde-schwarz.com (A. 8); daniel.banos@ficosa.com (A. 9); pere.mogas@ficosa.com (A. 10); joaquin.reyes@gsa.europa.eu (A. 11)

CEUR Workshop Proceedings (CEUR-WS.org) Proceedings

dimensions and reduced cost. The autonomous car that we are imagining today shall be a vehicle affordable for most part of the population. However, the adoption of these cars will not be possible while the systems that are integrated into autonomous cars are not able to reach the market price.

The high-precision multi-frequency and multi-constellation antenna systems available nowadays on markets different from automotive, typically belong to Geodetic antennas type used for stationary GNSS applications, such as the ones produced by Leica Geosystems (Hexagon) [1] or Trimble [2] They provide the user with the highest possible position accuracy. Typically, geodetic antennas cover at least L1 and L2 frequency bands. Coverage of L5 is found in some newer designs, as well as coverage of the Galileo and GLONASS frequencies. The use of choke rings allows good radiation pattern control, excellent multipath suppression, high front-to-back ratio, good Axial Ratio (AR) at low elevations and stable phase centre. Combined with a state-of-the-art LNA, these antennas provide the highest possible performance, however the big dimensions of such an antenna system (about 400 mm in diameter) and extremely high cost of this solution makes it absolutely unsuitable for the automotive market.

In contrast, the most popular antenna type used in the autonomous market is a ceramic patch antenna available from multiple suppliers as Inpaq Technologies [3] and Amotech [4]. Small ceramic patch elements offer nearly perfect single-frequency receive characteristics and have become the standard for GPS L1 antennas for the automotive sector. However, the new generation of multi-frequency GNSS receivers can track many satellites in multiple constellations. As patch antennas are narrow-band antennas, they become not suitable for wider bandwidths and multi-frequency characteristics required.

Small single-feed patch antennas have good circular polarization (CP) characteristics over a bandwidth up to about 16 MHz.When multi-frequency response is required, a Stacked patch solution may be used, where particular ceramic patch, stacked one on top of another, is in charge of operation in a particular frequency band. However, the bandwidth is still significantly limited for multi-constellation applications.

There are existing patents in the public domain describing different topologies of a multi-frequency and multi-constellation GNSS antenna proposals but they not fulfil the strict automotive requirements (cost, integrability, robustness) and/or not include the E6 band.
An example of a multi-band GNSS antenna is shown in the patent "DE202018002095U1. Controlled Radiation pattern antenna" [5].

This document discloses a dual band GNSS antenna, based on the dielectric resonators antenna principle. According to Claim 1 four dielectric resonator antennas operate at L1/E1 frequency band and the central element operates in one of the bands L2 or E6. The dimensions of the solution are quite big, as well as the cost of the solution due to the usage of multiple dielectric resonator antennas, making them not suitable for the automotive sector.

This is why one of the main objectives of this project, is to design an antenna that, besides being technically competitive for the most advanced systems, is a cost-competitive antenna for the automotive market that fulfils mechanical and electronic design requirements of the automotive sector.

For such purpose, the project has mainly the following technical objectives:

1. Explore 3 new multi-frequency GNSS antenna topologies able to receive at least L1/E1, L5/E5, and E6 bands that fulfill defined requirements
2. To develop a new antenna amplifier with multi-frequency response, low noise behavior, and low group delay variations between bands to ensure antenna phase center stability.
3. Validate the developed antenna prototype in free-space in all the RF parameters commonly required for the Original Equipment Manufacturer (OEM) for the High precision GNSS antennas. Especially on radiation pattern characteristics and noise performance.
4. Validate the developed antenna prototype with antenna connected to the automated testing bench (including GNSS high-precision receivers) designed and automated during the project to receive GNSS signals for GPS and Galileo L1/E1, L5/E5 and E6.
5. Validate the developed antenna prototype with the antenna being integrated on a vehicle.
6. Development of an antenna prototype close to commercialization.

The main challenge and novelty of the project is to develop, for the first time, a mass production ready multiband antenna design to fulfill the automotive sector requirements (cost, weight, dimensions and robustness) and that also includes support for the Galileo E6 band. It is important to highlight, that as of today, there is not in production in the market with any OEM an antenna with these characteristics, but it is a real need that will arrive with the arrival of autonomous vehicles.

2. Consortium

To carry out these objectives the consortium includes the most relevant stakeholders in the automotive value chain: an OEM (SEAT), a Tier-1 (FICOSA) and a Tier-2 (Rohde & Schwarz), key automotive technology providers as well as standardization and manufacturing experts.

Ficosa coordinates the project and as a highly experienced antenna & telematics Tier-1 supplier performs the antenna design and development with the consequent business development and dissemination of the product.

SEAT as a car manufacturer provides the proper antenna requirements in terms of cost and antenna integration on the vehicle, as well as, it will provide the testing vehicle.

Rohde & Schwarz works on the proper Radio Frequency (RF) test equipment and lab environment for the antenna plus GNSS high-precision receiver testing and validation for the different frequencies L1/E1, L5/E5a/E5b, and E6 and GNSS signals.

3. Methodology

The overall project methodology is built up around 5 major technical activities:

1. Theoretical antenna concept definition

Based on GNSS multi-frequency and multi-constellation antenna requirements for high precision, and restrictions for its integration in vehicles, the antenna concept is defined. Several antenna geometries are selected to analyze its electrical performance and reliability.

2. Antenna electromagnetic simulation

Using a 3D Full Wave Electromagnetic simulation software (FEKO), the different theoretical concepts previously proposed are simulated. Different antenna parameters such as Voltage Standing Wave Ratio (VSWR), gain, radiation pattern and phase center are adjusted before prototyping. The effect of the antenna integration on the vehicle is also considered in the Electromagnetic simulation.

3. RF front end design definition and components selection

Based on the amplifier requirements, the key RF elements are selected and the RF front end design is defined to assure optimal multiband RF performance.

4. Amplifier electrical simulation

The RF design performance is evaluated and adjusted by using an electrical RF simulator with non-linear mode for transistor modelling as AWR Microwave Office, and using as well the [S] parameters of the components such as Surface Acoustic Wave (SAW) filters and passive elements. Complete report of amplifier performance in terms of Gain, Noise Figure, linearity and group delay is obtained and adjusted before prototyping.

5. Antenna test and validation

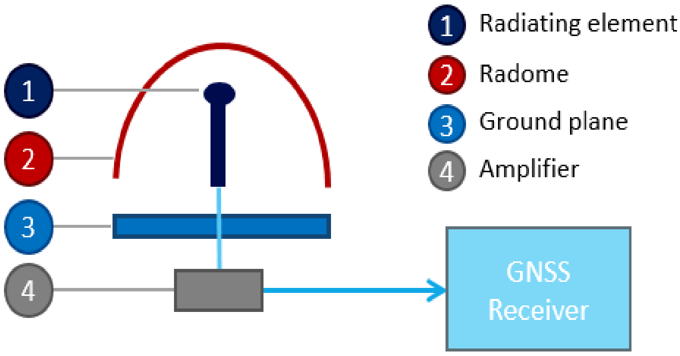
After previous phases of design definition and simulations, prototypes of the selected designs will be built and tested on the different antenna environments. A full antenna design validation will be done considering three different scenarios: “antenna on free-space”, “antenna integrated on vehicle” and “antenna connected to high precision GNSS receivers”.

4. Technical approach

The MAGICA antenna includes mainly three different parts:

- Radiating element
- Polariser circuit or hybrid couplers for RHCP electromagnetic field generation
- Antenna front end with a low noise amplifier circuit and FAKRA interface to allow the connection to a GNSS receiver.

Furthermore, the final installation in the vehicle has to be as well considered in order to have optimized performance, minimizing the size and visual impact.



9

Figure 1. Scheme of GNSS Antenna

4.1. Radiating element

The radiating element is responsible for antenna bandwidth, polarization, radiation pattern, phase center and multi-frequency characteristics. The radome is a dielectric physical element that protects the radiating element. Proper selection to avoid any electrical influence on the antenna performance is required. The ground plane has an effect on the shape of the radiation pattern, especially at lower elevations with an effect on multipath rejection. The Low Noise Amplifier (LNA) with its frequency response defines frequency selectivity, noise factor, total antenna gain, phase center stability, and complete antenna bandwidth.

There are two approaches for a multiband antenna solution creation, the broadband approach where a single radiating element covers all frequency bands, and a selective band approach with several radiating elements, where each specific radiating element covers a particular frequency band of operation.

These two approaches have their advantages and disadvantages, and during the development of MAGICA GNSS antenna system, they are being studied and the best solution will be selected.

During the project, different antenna topologies are being analyzed. The study is focused on the comparison between the well-known Automotive GNSS antenna solutions, such as stacked ceramic patch antennas, and fully-custom designs in terms of RF performance and cost effectiveness.

The following main RF antenna requirements will have to be fulfilled in order to achieve the project objectives:

Table 1

Standard antenna requirements in the automotive sector.

Frequency bands	1164 -1215 MHz (L5/E5a/E5b), 1260 - 1300 MHz (E6), 1559 - 1610 MHz (L1/E1).
Antenna Input Impedance	50**Ω**
VSWR	2:1
Peak Realized Antenna Gain	> 2dBic at zenith
Axial Ratio at zenith	≤ 3 dB
GNSS Amplifier Gain	30 ± 2dB
Noise Figure (50Ω)	≤ 3.0dB @ nominal
Phantom Supply Voltage	4.5 V – 5.5 V
Current Consumption	≤ 40 mA
Overall antenna dimensions	Less than 100x100x30 mm

4.2. Polarizer circuit

In order to feed the antenna radiating element and achieve the Right-handed Circular Polarization (RHCP) radiation pattern, the following polarizer circuit is used.

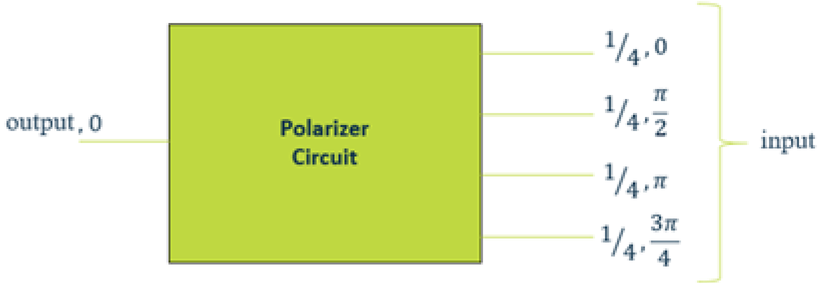


Figure 2. Polarizer circuit diagram.

To achieve this particular functionality, there are several design approaches (i.e. by means of transmission lines, discrete components, hybrid models, etc.). The model based on discrete components has been selected in order to have a more accurate control on the signal phase shift over the whole operation bandwidth. Thanks to the implementation of left-handed transmission lines combined with the conventional or right-handed transmission lines, very little deviations in phase shift can be attained, in comparison to a polariser based on conventional transmission lines design. This fact is crucial to boost antenna efficiency as much as possible.

The polarizer circuit is able to properly combine the incoming signal from its four inputs (antenna feeding points) to a single output, thereby delivering a single ended signal to the antenna front-end for the following amplification and filtering stages.

If the final antenna concept includes two radiating elements, then two polarizer circuits are required.

4.3. Antenna RF Front-End

The antenna front-end aims to compensate the GNSS signal propagation loss and coaxial cable loss and ensure a good signal level at the receiver port. Moreover, the front-end has to be able to reject any possible interference and has to assure good noise figure and signal integrity.

Different approaches for the RF front-end should be used depending on if the radiating element follows a broadband approach (one single antenna output for all the bands) or if it follows a selective band approach (one antenna output for the lower frequency bands and one output for the higher frequency bands).

The front-end for the broadband approach consists of a single GNSS signal input for E5a/E5b/L5+E6+E1/L1 and a single output. The block diagram for the front-end architecture is depicted in Figure 3.

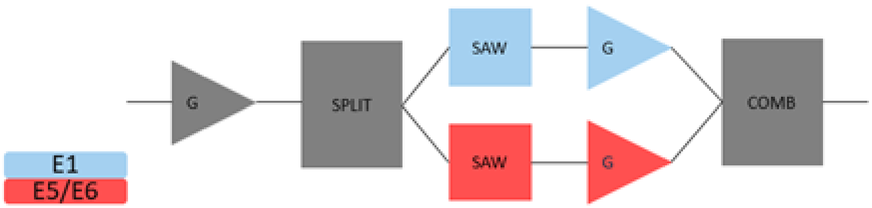


Figure 3. Broadband front-end block diagram

The front-end for a selective band approach consists of two GNSS input signals, one for E5a/E5b/L5+E6 and another for E1/L1, and a single output. The block diagram for the front-end architecture is presented in Figure 4.

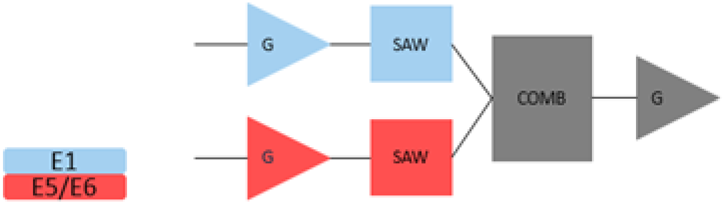


Figure 4. Selective band front-end block diagram.

4.4. Antenna integration

The current antennas used in the automotive market are normally single band patch antennas with very reduced dimensions. With the introduction of the additional bands, antenna dimensions and integration requirements increase, therefore an important work together with a real OEM (Seat) have been done in order to assure optimal performance and good integrability in the real cars.

The final prototype developed in the project will be integrated in a vehicle provided by SEAT, assuring the minimal possible impact on the style of the vehicle and fulfilling all the standard requirements for a GNSS automotive antenna system.

Depending on the final antenna system topology selected for the prototyping stage, one of the potential following vehicle locations for antenna integration will be selected:

- Dashboard environment
- Roof surface
- Spoiler environment

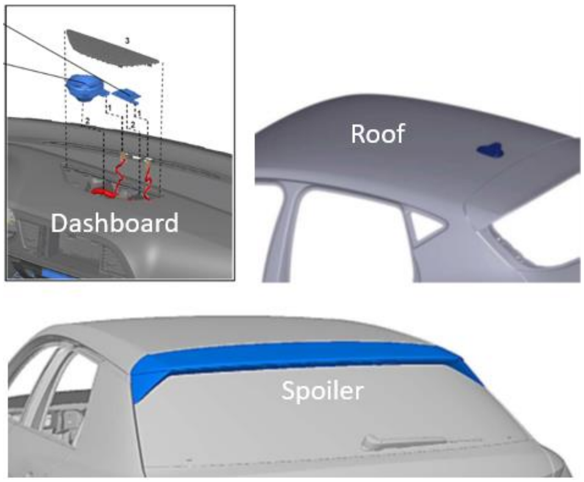


Figure 5. Potential antenna integration locations.

5. Preliminary results

During the project, 3 different novel antenna topologies are being analyzed: Crossed Dipoles concept, Crosseed IFAs concept and Stacked Patches concept. The goal is to select the most suitable in terms of price, integrability, and performance for further prototyping and complete validation. In this chapter the first preliminary simulation results of the most promising antenna topology so far (Crossed IFAs concept) are presented.

5.1. Radiating element performance

In order to prove the performance of the antenna radiating element several main parameters have to be analyzed.

One of the most important antenna parameters is the VSWR (Voltage Standing Wave Ratio). It is a measure of how efficiently radio-frequency power is transmitted from a power source, through a transmission line, into the antenna. In an ideal system, 100% of the energy is transmitted, however in real systems, mismatched impedances cause some of the power to be reflected back toward the source (echo). VSWR of an ideal system is 1:1 since the voltage does not vary. For real antenna systems, when reflections occur, the voltages vary and VSWR is higher.

Typically, the VSWR of the antenna has to be below 2:1 for each frequency band in order to operate properly. Note that the VSWR result in Figure 6 shows the output matching of the antenna including the polarizer.

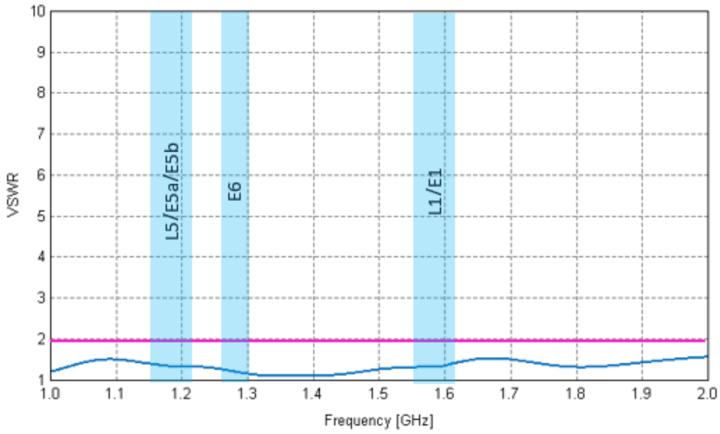


Figure 6. VSWR of designed Crossed IFAs antenna

Another important antenna parameter is Antenna Efficiency - the ratio of power radiated by the antenna to the power supplied to the antenna. The efficiency of an antenna is usually measured in an anechoic chamber where an antenna is fed with some power and the strength of the radiated electromagnetic field in the surrounding space is measured.

In Figure 7, the blue trace represents the simulated efficiency of the single radiating element for L1/E1, L5/E5a/E5b, and E6 frequency bands. The blue regions on the plot represent the required frequency bands of operation.

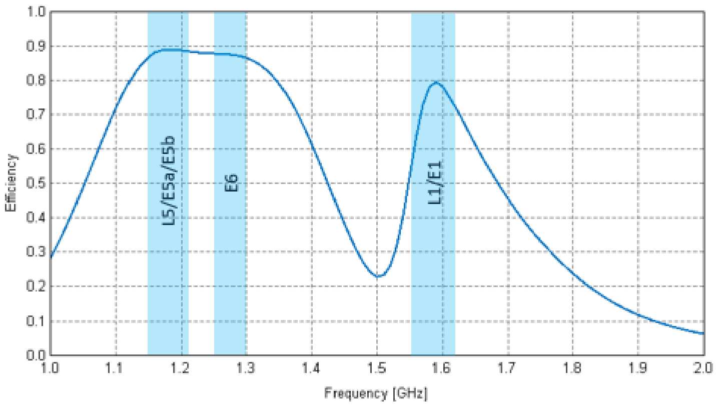


Figure 7. Efficiency of designed Crossed IFAs antenna

GNSS signals are transmitted by the satellites as Right Hand Circularly Polarized (RHCP) which means that the GNSS receiver antenna should also be RHCP, and strongly reject signals of the opposite rotational sense Left-handed Circular Polarization (LHCP).

The following plots show the far-field radiation patterns of the preliminary solution in both RHCP and LHCP for each frequency band.

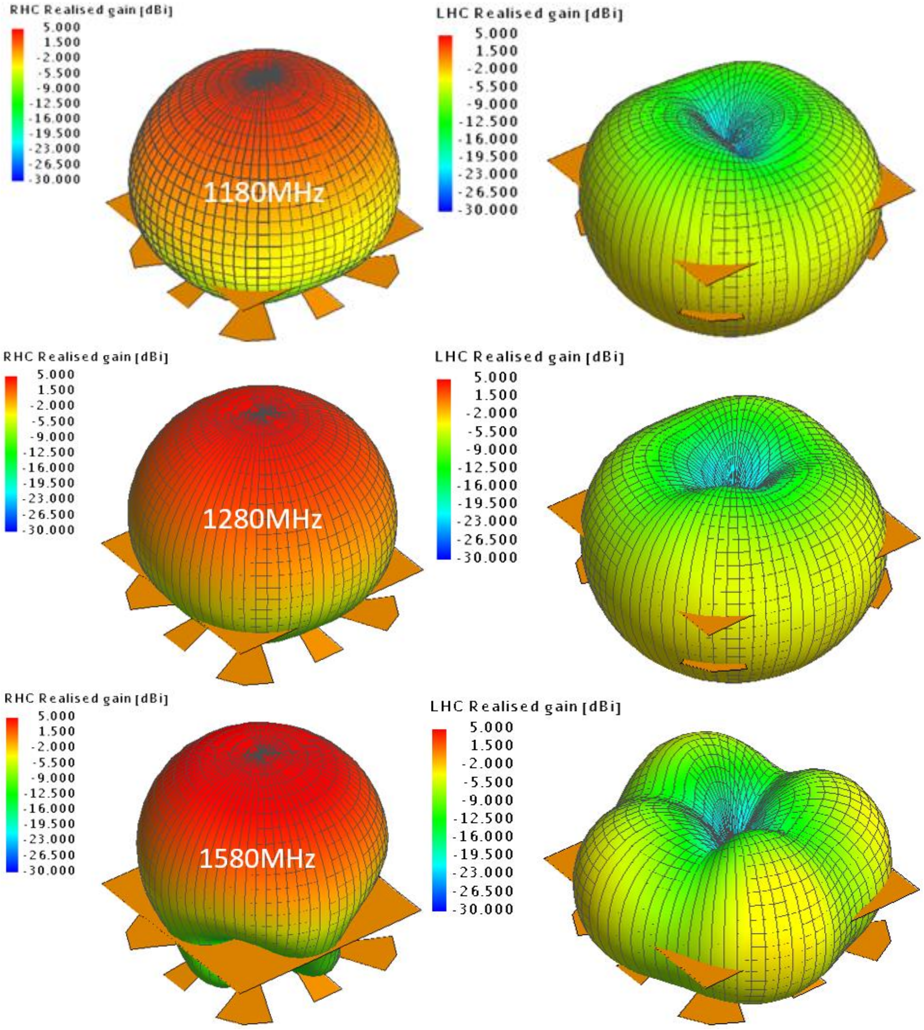


Figure 8. RHCP and LHCP radiation patterns of designed Crossed IFAs antenna

The axial ratio is the ratio between the semi major and semi minor axis of a circularly polarized antenna pattern. For a perfect CP antenna, both values should be the same (i.e. equal to 1) or 0dB, over all azimuth and elevation angles and all frequencies within the antenna bandwidth. According to the requirements shown in Table 1, the Axial Ratio at the zenith has to be ≤ 3 dB. The Axial Ratio at the zenith plot is presented below in Figure 9. As it can be seen, the Axial Ratio is below 3 dB.

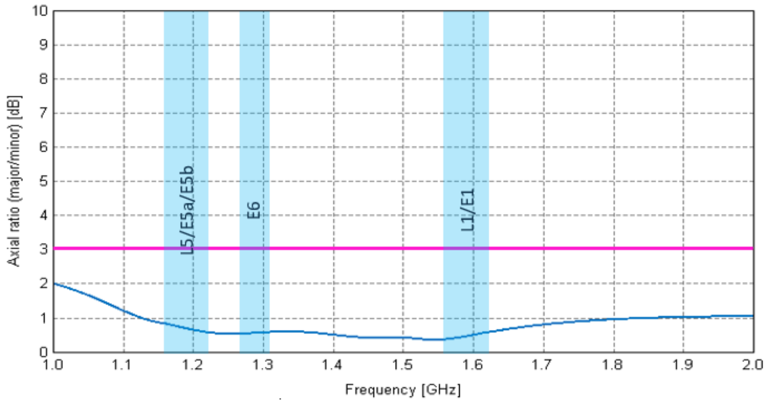


Figure 9. Axial Ratio at zenith of designed Crossed IFAs antenna

The peak realized antenna gain is another key performance parameter that combines the antenna's directivity and electrical efficiency. In a receiving antenna such as GNSS, the gain describes how well the antenna converts radio waves arriving from a specified direction into electrical power. According to the requirements, the peak realized antenna gain at zenith has to be > 2 dBic. The peak realized antenna gain plot is presented below in Figure 10.

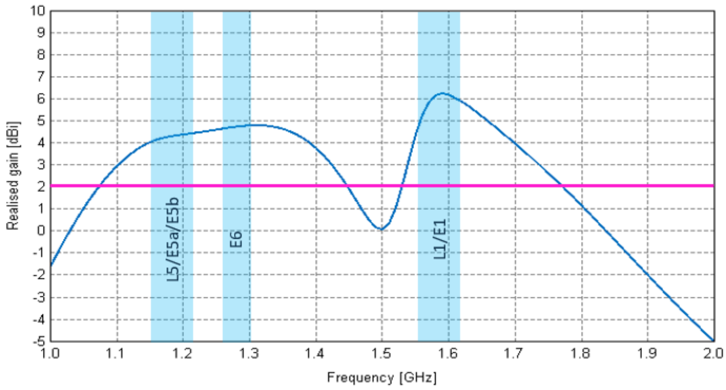


Figure 10. Peak realized antenna gain of designed Crossed IFAs antenna.

5.2. RF Front-end performance

The following key RF front-end parameters have to be analyzed in order to prove the active antenna circuit performance.

Transmission coefficient is the ratio of the amplitude of the complex transmitted wave to that of the incident wave at a discontinuity in the transmission medium.

The reflection coefficient is defined as the figure that quantifies how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium. The reflection coefficient is equal to the ratio of the amplitude of the reflected wave to the incident wave.

Figure 11 shows the front-end transmission coefficient and return loss for each GNSS band. High gain values higher than 30dB in the main operating bands and good out of band rejection are achieved.

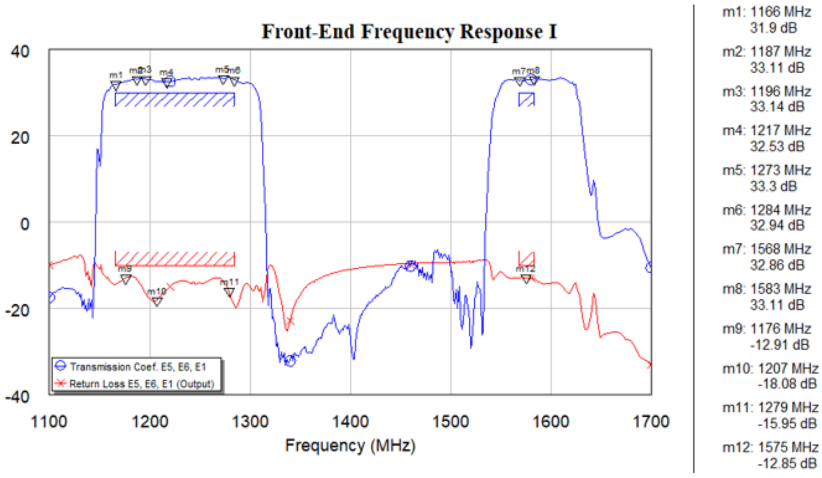


Figure 11. Front-end frequency response.

Noise figure is a parameter used in the RF circuit design of radio receivers to understand the noise performance of any active circuit, or the performance of a component that may need to be selected for this system.

Noise figure in the intended GNSS frequency bands shows good performance with values inside the specification (NF $\leq$ 3.0dB).

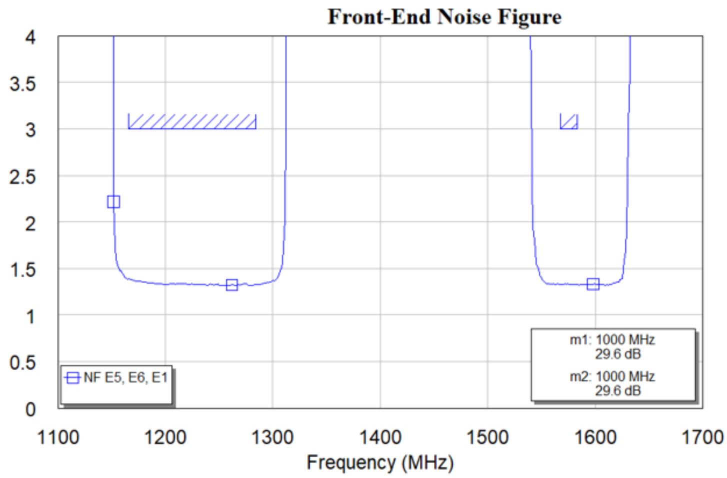


Figure 12. Front-end Noise Figure

Group delay is a measurement of the time taken by the modulated signal to get through the system. Group Delay is measured in seconds. For an ideal RF system, the phase will be linear and the group delay would be constant. However, in the reality group delay distortions occur, as signals at different frequencies take different amounts of time to pass through a filter, adding small errors in the calculated position.

Figure 13 depicts the group delay, with values being stable in the bands of operation.

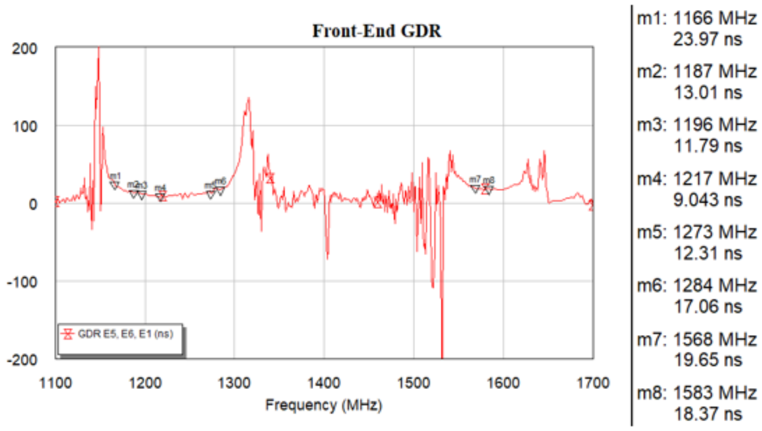


Figure 13. Front-end Group Delay

The preliminary simulation results of the radiating element and the front-end confirm the feasibility of obtaining a multi-frequency and multi-constellation GNSS antenna with the specified dimensions and meeting the typical automotive antenna requirements. Further active antenna simulations and measurements will finally prove it.

6. Conclusions & Future work

In the present paper an overview of the MAGICA project, as well as, the first simulation results obtained during the first months of the project are described.

As it can be seen, the obtained preliminary simulation results fulfil the requirements for the multiband multi-constellation GNSS antenna under development. These initial results show that with the proposed topologies it is feasible to achieve a low cost and high performance antenna, with a small form factor and ready for the automotive market. Furthermore, it is important to highlight that the designed antenna is ready for the new Galileo E6 band, which was one of the main goals of the research work and non-existing on the automotive market in-production nowadays.

The future work will be focused on the deeper analysis of the best antenna design with mechanical engineers to simplify the structure for the prototyping, further manufacturing and proper integration in the vehicle.

The best prototyped antenna solution will be fully measured and characterized in free space to provide the input data for Rohde & Schwarz testbench adjustment and further antenna characterization in different scenarios.

In the latest stages of the project SEAT will provide a vehicle and guidelines for proper antenna integration. Measurements in a 3D anechoic chamber of the antenna integrated in the vehicle and subjective field tests in different urban and rural areas will be performed.

Progress of the project can be followed up in the project website: www.gnss-magica.eu.

7. Acknowledgements

This work is supported by the GSA under the European Union’s Fundamental Elements research and development program under grant agreement No. GSA/GRANT/01/2018.

8. References

[1] Leica AR25 GNSS Antenna. URL: https://leica-geosystems.com/products/gnss-reference-networks/antennas/leica-ar25

[2] Trimble GNSS Ti-V2 Choke Ring Geodetic Antenna. URL: https://www.trimble.com/Real-Time-Networks/Trimble-Choke-Ring-Antenna.aspx
[3] InPAQ Technologies GPS Antenna Manufacturer.URL: https://www.inpaqgp.com/index.php
[4] Amotech Antenna Solution. URL: http://global.amotech.co.kr/wp/antenna-solution_2/
[5] Deutsches Zentrum für Luft- und Raumfahrt e.V., 51147 Köln, DE, DE 20 2018 002 095 U1 “Controlled Radiation Pattern Antenne”, 2019.04.11