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Circularly Polarized C-Band Lens-Horn Antenna for Radar Remote Sensing Calibration

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Abstract

In this paper the design and optimization process of a radar remote sensing calibration antenna is presented. The solution consists in a septum polarizer and a high gain Potter horn with exceptionally low axial ratio (0.2 dB) and low SLL at 5.3 GHz. To obtain a compact design, a dielectric lens has been designed to correct the horn phase error and reduce the final length. As the lens degrades the return loss, impedance matching transformers are designed and simulated in order to fulfill the system specifications. Finally measurements of the septum polarizer are shown and discussed.

1. Introduction

Radar satellite remote sensing is widely used to perform measurements of Earth parameters such as wind speed, and ocean currents. It usually operates by transmitting microwave pulses towards Earth's surface and measuring the reflected pulses. Geophysical inversion algorithms are used to derive measures from these radar backscattering cross-section measurements.

This type of measurements often requires high precision and gain stability (less than 0.15 dB variations), so periodic calibration [1] must be performed. A common way of performing this calibration is by means of an Earth transponder unit that relays the transmitted pulses back to the satellite in order to perform system gain measurements.

In this paper, the design of an antenna system for a radar remote sensing transponder is presented. The most relevant parameters and requirements of this antenna are listed below:

- Frequency band: 5.25 to 5.35 GHz.
- Antenna gain: 23 dBi.
- Polarization: Simultaneous RHC and LHC with axial ratio below 0.2 dB (two ports).
- Return loss < -20 dB.
- Isolation between ports > 25 dB.
- Side lobe level below ITU-R S.465-6.
- Cross polar polarization peaks below -25 dB.
- Outdoor conditions of operation: resilience to moisture and UV radiation.

The antenna will be implemented in waveguide technology. To obtain circular polarization, it consists of a polarizer and a horn antenna. A septum polarizer has been selected to feed the antenna, as it acts as a two port transducer and provides circular polarization.

For the radiating antenna, several types of horns have been considered. The gain requirement imposes an aperture diameter greater than 30 cm. With this size, a pure mode smooth walled horn gives a poor crosspolar response so multimode horns are needed to meet the specifications. Hybrid mode corrugated horns provide adequate crosspolar and SLL levels over wide bandwidths at the expense of higher manufacturing cost. Identical behavior can be obtained in narrowband by use of smooth walled multimode horns removing the mechanizations issues of the corrugated type. Therefore, a multimode TE11+TM11 horn will be used for the application, in particular a Potter horn.

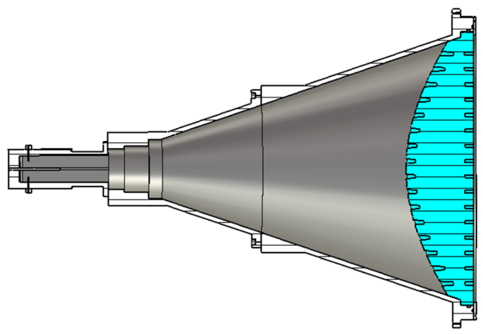

Figure 1. Complete antenna: septum polarizer and lens horn

Due to its high gain, a conventional Potter horn requires a low aperture phase error [2]. For example, a 23 dBi antenna meeting the mentioned ITU-R SLL recommendation needs an error phase below 0.15. This results in an antenna of 35 cm of diameter and around 1.5 m of length. This size is impractical for the application since the transponder will be placed in an el/az positioner to track the satellite. If the length is reduced while keeping the diameter, the horn phase error increases, thereby reducing the gain and increasing de SLL. However, the spherical phase front responsible of the phase error can be corrected using a dielectric lens in the aperture. This approach, which will be used in this paper, allows increasing the flare angle in order to reduce the axial length significantly.

In figure 1 the complete antenna system for the calibration transponder is shown. It consist of a square waveguide stepped septum polarizer with two SMA coaxial input ports, a square to circular waveguide, and the Potter horn loaded with the lens.

This paper is organized as follows. Section 2 deals with the design and optimization of the polarizer, section 3 shows the design of the Potter horn and guidelines regarding its lens design and adaptation, as well as the complete system integration. In section 4 measurements of the septum polarizer are shown and discussed, and in section 5 some conclusions are drawn.

2. Septum Polarizer

The septum polarizer has two coaxial inputs for each of the ports of the transponder. The design of this type of polarizers is dealt in the literature [3] and the required specifications are easily achieved in the simulation steps by optimization.

Due to the extremely low axial ratio specification, special attention has been paid to the posterior septum manufacturing process. For example, the step edges have been rounded to include in the simulation the effects of the mechanization by a 4 mm drill and a tolerance test has been carried out to obtain information about the mechanical precision required (lower than 50 µm).

The designed septum is depicted in figure 2. At the septum end, a single step circular quarter wavelength transformer will be attached to connect with the circular waveguide horn. The simulated reflection and isolation coefficients of the polarizer are below -25 dB in the whole bandwidth.

Figure 2. Unassembled septum polarizer and test horn

3. Lens and Potter Horn

Potter horns [4] have long been used due to its low cross polarization and side lobe level characteristics. For the current application, a compact design is needed, so the horn length has been reduced considerably using a dielectric lens to correct the high horn phase error.

The lens loaded Potter horn design includes the following steps:
-Design and optimization of the horn alone: using SABOR [5] analytical models, the horn diameter (33 cm) is selected to be the same of a zero phase error 23 dBi horn. Then, the desired length (43 cm) is imposed. This will produce a given phase error (0.52) to be corrected by the lens. Finally, and optimization process is performed to obtain a good matching and modal content.
-Lens design: a dielectric microwave lens is designed to correct the aperture phase error. This allows to increase the gain to the level of the zero error phase horn used as reference in the first step.
-Lens matching and optimization: As the lens itself degrades de return loss, impedance transformers must be added, as it will be explained in the following sections. Then, an optimization of some of the lens parameters is performed to improve the return loss and cross polarization characteristic of the complete antenna.

The design and optimization of a Potter horn is a simple process dealt in literature [4]. However, the lens design poses some difficulties. In the next sections, some guidelines are given on how to perform steps 3 and 4.

3.1 Lens Design

The lens shape is determined so that it produces a constant phase front over its aperture. Ray tracing techniques have been used to derive the equations that describe the lens surface. Figure 3 depicts the two most used types of lenses (Convex and meniscus). In the plane-convex lens, the refracting surface is a hyperbola while in the meniscus lens is an ellipse. Plane-convex lens tend to concentrate the rays at the aperture center, producing a more tapered field distribution while the meniscus lens causes the opposite effect [6].

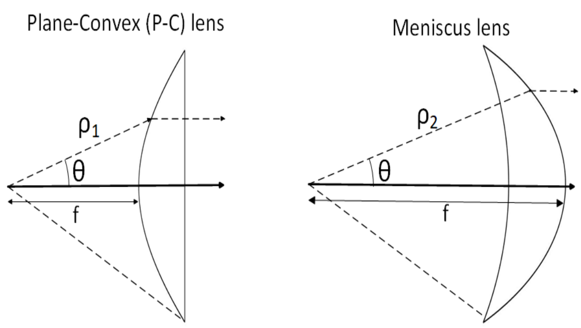

Figure 3. Geometry of the analyzed lenses

Any dielectric can be used to implement a lens. The higher the dielectric permittivity constant is, the thinner the lens will become. For this application, Teflon (ε_r=2.1) has been selected due to its good properties in terms of water absorption (hydrophobic material) and UV radiation resilience. In addition, it presents a very low dissipation factor (0.0002 loss tangent) at C-band frequencies.

The two types of lenses described have been designed and simulated with the Potter horn obtained in step 2.The aperture field distribution affects directly to the radiation patterns (see figure 4). Both lenses focus the radiation pattern narrowing the main lobe and increasing the gain. Due to the tapered aperture field, the plane-convex lens has a very low side lobe level, so it will the preferred type for this application, as this helps to mitigate multipath signals that can degrade stability. Regarding the cross-polar radiation, lenses have little effect on the CP/XP level, since they only affect the amplitude and phase of the fields, regardless of the polarization. Therefore, only XP pattern for the selected convex lens horn is depicted in figure 4.

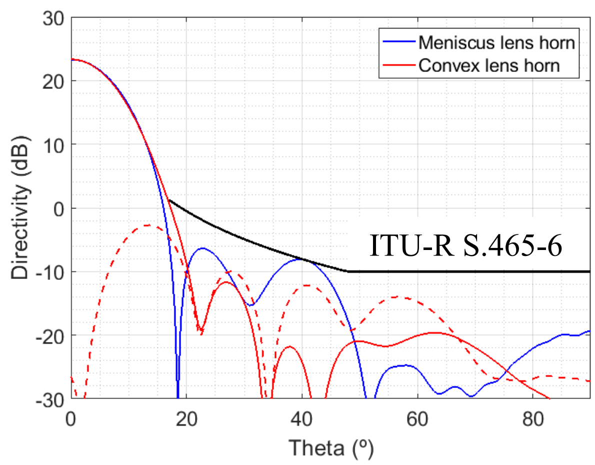

Figure 4. Simulated Phi=45º cut radiation pattern for the horn with and without lens

3.2 Lens Adaptation

The dielectric difference between the air and lens (ε_r=2.1) produces a discontinuity, which results in a high reflection coefficient, which degrades the total return loss. Therefore, matching techniques must be applied. The most common way is adding adaptation layers working as quarter wave impedance transformers at the desired frequency, placed in the inner and outer lens faces. Adaptation layers are usually implemented mechanizing cylindrical grooves or small holes [7] on the lens surfaces to obtain the desired effective dielectric constant.

Once the meniscus lens and its perforated adaptation layers have been designed, a final optimization is done to improve the return loss. This is done with small variations of the depth and size of the holes. In figure 1 a sectional view of the optimized lens can be seen. It presents 4 mm holes separated 10 mm of each other with a depth around 10 mm. The obtained return loss is depicted in figure 5, showing a return loss below -23 dB over the whole bandwidth.

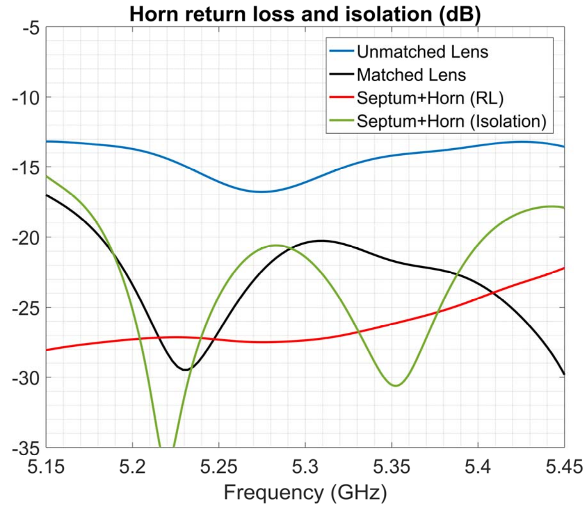

Figure 5. Simulated return loss and isolation for the convex lens horn and for the complete antenna

3.3. Combined Antenna: Septum+Horn

Once the septum and Potter horn have been designed, the last step is their assembly. Then, an optimization process has been performed of the waveguide section between the septum and horn in order to cancel the internal reflections of each component, thereby improving the RHC/LHC port isolation. As a circular polarization changes its rotation direction when reflected, the horn return loss does not contribute to the complete antenna reflection coefficient, but to the channel isolation. This means that the complete system return loss will be roughly the same as that of the septum, while the isolation will be a combination of the septum isolation and horn reflection coefficient, as it can be appreciated in figure 5.

4. Septum Measurements

The septum polarizer has been mechanized and dimensionally verified showing tolerance under 50 µm. The polarizer has been manufactured in three separated parts as shown in figure 1. This allows rapid disassembling to perform modifications to tune the final response if required. Since the lens horn antenna has not been manufactured yet, a small horn (see figure 1) has been designed to perform measurements in anechoic chamber. Scattering parameters as well as axial ratio measurements have been performed. The return loss and port isolation meet the specifications with good agreement with the simulation, as seen in figure 6.

In figure 7 the measured axial ratio for the two ports is depicted. Its value remains below 0.15 dB in the whole working bandwidth, meeting by far the specification. Even though the agreement with the simulation seems poor, the 50 µm mechanization tolerances must be taken into account. To do, the worst cases obtained during the aforementioned tolerance test have been superposed. In addition, some measurement error sources must be considered, such as the positioner rotary joint insertion loss variation of the measurement setup (0.05 dB typically) and the imperfect load in the opposite port. Taking in consideration these errors, the actual antenna axial ratio can be considered exceptionally good.

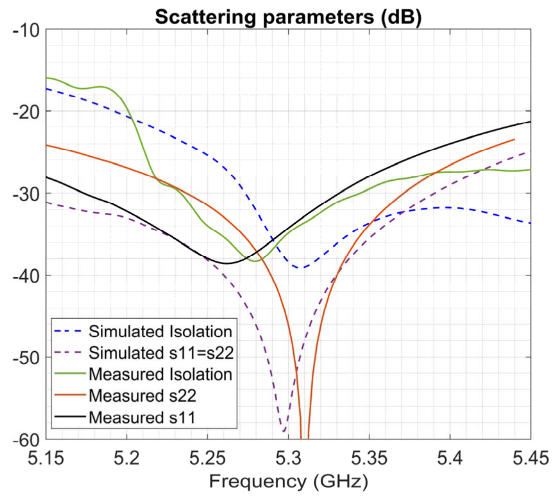

Figure 6. Septum measured and simulated matching parameters

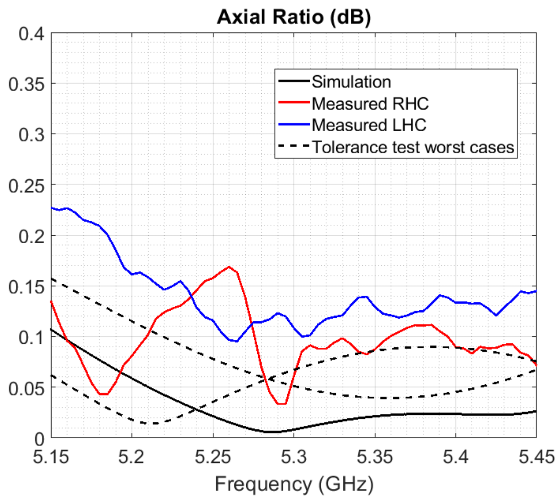

Figure 7. Axial ratio of the RHC port simulation and

5. Conclusions

A septum polarizer and a short Potter horn have been designed and simulated to be used in a radar remote sensing calibration transponder. The horn length has been reduced with the help of a Teflon plane-convex lens that produces a quasi-planar aperture phase and low SLL to meet the ITU-R S.465-6. The dielectric discontinuity produced by the lens is matched by means of an impedance transformer implemented performing holes in the both lens surfaces. Adaptation and radiation results are given for the proposed antenna. Finally measurements of the designed septum polarizer are presented and discussed.

6. Acknowledgements

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