DESIGN AND VERIFICATION OF GALILEOSAT GROUND STATION P-BAND ANTENNA

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ABSTRACT

A ground station antenna for Galileosat application operating in right hand circular polarization at P-band has been designed, manufactured, and tested.

Other than stringent environmental requirements for typical ground station antennas the specification call for an antenna with very stringent requirements on pattern shape and symmetry and a very severe control on side and back lobes. In order to ease the requirement on the antenna positioner the antenna should have very compact size and low weight. The final antenna consists of an array of 7 medium gain, dual linear polarized yagi elements as shown in Figure 1.

This paper describes the antenna design trade-off activity including the selection of the most suited antenna technology and manufacturing details. It also reports on the testing in the SATIMO SG-64 multiprobe spherical near field test range with considerations on the associated measurement uncertainty. The final acceptance of the antenna was based on measurements performed in CNES and SATIMO.

Keywords: Galileosat, ground station, array antenna, radiation pattern optimization, measurement campaign, spherical near field test range.

INTRODUCTION

This paper describes the design and testing activities in the realization of the P-band antenna shown in Figure 1. This antenna is used as uplink UHF antenna for the In-Orbit payload testing of the Galileo satellites (Search and Rescue transponder). The antenna was designed, manufactured and installed by SATIMO under a contract with Inmarsat, responsible for the Galileo payload IOT services to DLR, main contractor to ESA for the Galileo operation in the Initial Operational Validation phase of Galileo.

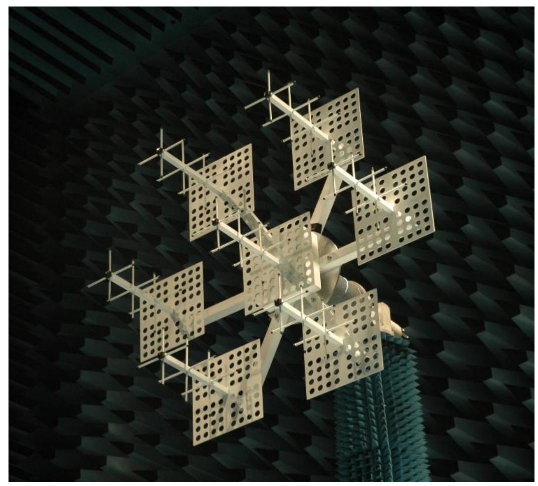

Figure 1: Galileosat ground station antenna

The following phases will be described in details:

- due to stringent radiation pattern requirements, a detailed modeling of the possible antenna configurations has been developed and subject to optimization, taking into account both the element configuration and the array geometry;
- after the trade-off, the defined configurations have been designed exploiting all the geometrical and electrical degree of freedom;
- all the other aspects of the antenna have been evaluated: the environmental aspects (phase stability, ground impact, etc.), the mechanical definitions (interface impact, modeling of the supporting arms, etc.);
- manufacturing and integration steps, intermediate verifications, prototype testing, etc.
- different antenna measurements phases: preliminary testing for antenna fine tuning, SATIMO SG-64 for performance verification and final acceptance test in CNES test range facility.

REQUIREMENTS SUMMARY

Many environmental and electrical requirements are defined for the antenna. The most important requirements related to the radiating pattern definition, are hereafter summarized to understand the complexity of the design.

- The radiation pattern of the antenna shall be such that, with reference to the maximum radiation level and its direction, the radiation (both co-polar and cross-polar) shall be less than -13dB in the sectors 25º to 50º and less than -23dB in the sectors from 50º to 180º. The limits shall be met in all plane-cuts containing the direction of the maximum radiation. The first value is related to the main beam width, while the second value is applicable to the antenna side lobes.
- The antenna system shall operate in the frequency band between 406.0 MHz and 406.1 MHz radiating in the right-hand circular polarization (RHCP).
- The axial ratio shall not exceed 2.0 dB within the 1 dB beam contour;

Details of the RF system are shown in Figure 2.

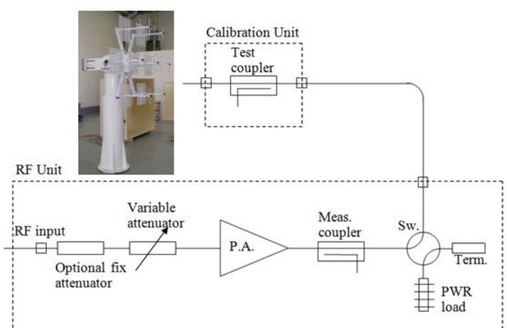

Figure 2: Galileosat ground station RF system

The antenna will be mounted on a Elevation over Azimuth positioner supporting the antenna load under all environmental conditions as shown in Figure 3. It will allow all the movements of the antenna between -10°/100° (Elevation) and -190°/+190° (Azimuth) with pointing accuracy better than 0.1°. The movement can be performed at any speed between 0.001°/s and 1.5°/s.

Figure 3: Galileosat ground station antenna on the dedicated positioner

ARRAY TOPOLOGY TRADE-OFF STUDY

The beam shape constraint implies an antenna directivity around 17 dBi. The most complex requirement is the side lobe mask: it is required a constant very low side lobe level. The low frequency and the limited number of elements than can be designed implies a low number of degree of freedom for the optimization procedure.

The first step of the trade-off study is the evaluation of the optimum number of elements. Lattices too far from the rotational symmetry have been not considered

- The single antenna is not practical due to its physical length necessary to reach the required directivity.

- 4 elements array: the array factor has only the spacing among the elements as unique degree of freedom. High gain elements are needed. The side lobes of the overall array are due to the single element because the array factor has not side lobes. Then, the optimization process should need to combine the interference of all the side lobes to the required limited level exploiting only the single available degree of freedom. It should be necessary to optimize the single elements geometry and structure also, but this implies immediately a degradation of the absolute gain and main beam shape because the phasing among contributes results modified (e.g. the phasing among the directors of a yagi antenna).

- 7 element array. The array factor is quite rotationally symmetric. The degrees of freedom are the spacing among the elements and the relative feeding among the central element and the external ones. Medium gain elements are needed: these kinds of elements have the useful advantage to exhibit relatively narrow beam but without side lobes in the front of the array, so this configuration has these important aspects: 1) the element beam has a low level at 90° off-axis, helping to reduce the side lobe level; 2) the optimizer needs only to reduce the array factor side lobes and not element side lobes.

- 9 elements. In this case the array factor has many degrees of freedom. Low gain elements are needed: these elements have large beam width which doesn't contribute to the side lobe reduction. All the side lobe control needs to be performed by the array factor, with suitable optimization procedure.

More number of elements is not a practical configuration because 9 elements is already a very close sampling of the available aperture.

In order to confirm the preliminary design considerations above, various arrays with different number of elements and radiating elements have been modeled and optimized. This analysis confirmed the 7 element array topology as baseline configuration.

ANTENNA TRADE-OFF STUDY

Many different antennas have been considered as radiating element for the different array configurations. Such as patches, helices, lop periodic and other simple antennas. For the 7 element array configuration the final selection was between the monofilar axial mode helix and log-periodic antenna as radiating element.

The monofilar axial mode helix has been widely used for spatial and ground application in VHF and UHF bands, but in the present application it is not adequate due to both the high sidelobe level of the single element itself and the poor axial ratio. Therefore, the log-periodic have been selected because element radiation pattern can be shaped and modified easily at the individual element level. Nevertheless the poor number of degree of freedom and the large coupling of the elements implies a limited capability of array pattern control.

High gain yagi with many wire elements can be used for arrays with a limited number of antennas but as discussed previously, the candidate array element cannot have significant sidelobe levels for the present application. Sidelobes arising from the radiating element alone cannot be completely reduced by array topology optimization due to the limited degree of freedom.

The radiation patterns of basic 10, 4 and 3 wire element yagi antennas are compared in Figure 4. The 10 element yagi is preferable from the overall gain performance point of view but has significant sidelobes in the forward hemisphere pattern. The lowest gain yagi with 3 elements is very suited for arrays with a large number of elements. The radiation pattern has relatively high levels in at 90° from boresight, similar to a patch antenna, so this element does not significantly contribute to the sidelobe mitigation in this direction as required by the specification.

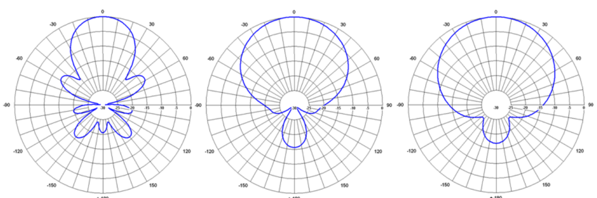

Figure 4: Patterns of potential array elements 10, 4 and 3 elements yagi.

A 7 element array topology designed to meet the -13dB sidelobe constraint in the 25º to 50º direction from boresight cannot meet the side lobe constraint in the 50°-90° direction without some contribution from the single element. The 4 wire element yagi has the benefit of reduced radiation in this direction without adding other sidelobes. Therefore the 4 wire yagi antenna was selected as baseline radiating element.

ARRAY OPTIMISATION / REFINEMENT

The four wire yagi elements have been optimized in the complete array configuration of seven elements. Further important details have been defined.

- The reflector element of the yagi has been transformed into a wire grid flat reflector. This was necessary to improve the front/back ratio in order to reach the lobe requirement in the back hemisphere region.

- Sequential rotation has been considered to improve the axial ratio performance of the overall antenna. Since this approach is an effective redistribution of radiated power rather than a reduction of the cross-polar. This implies an unacceptable increase of the cross-polar side lobes.

- Polarization purity depends mainly on the beam forming network. Suitable components have been selected.

The baseline array configuration has been completed in all the details, including the antenna boom and the actual beam forming network performance. The full EM model of the antenna is shown in Figure 5. The performance has been optimized taking into account also margins in main beam shape and side lobe levels to allow for manufacturing and integrations imperfections.

The predicted array pattern is shown in Figure 6. The expected radiation pattern indicates the complete matching of the requirements.

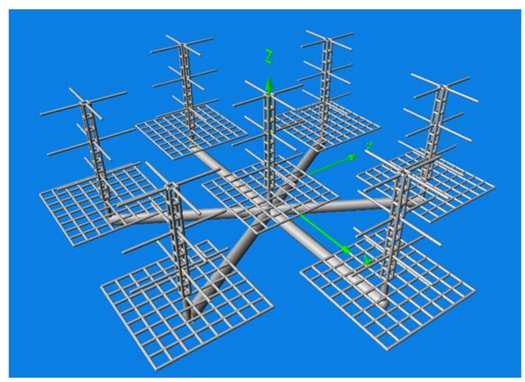

Figure 5: EM model of the complete array antenna.

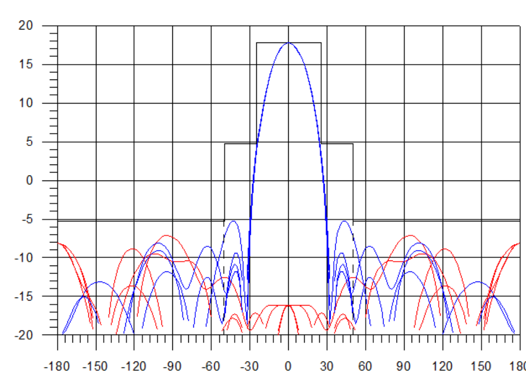

Figure 6: Predicted performance of final antenna.

MEASUREMENTS

The final antenna was measured in the SATIMO SG-64 multiprobe spherical near field range in Paris as shown in Figure 7.

To further improve the quality of the measurements two sets of measurements at λ/4 distance in the boresight direction where performed and the results averaged taking into account the proper phasing of the patterns. Additional absorbers where added below the antenna to reduce the impact of the positioner on the actual antenna performance.

Figure 7: Measurement of final antenna in SATIMO SG-64 multiprobe spherical near field range.

As a reference measurement the final antenna was also measured in the CNES compact test range (CATR) in Toulouse as shown in Figure 8.

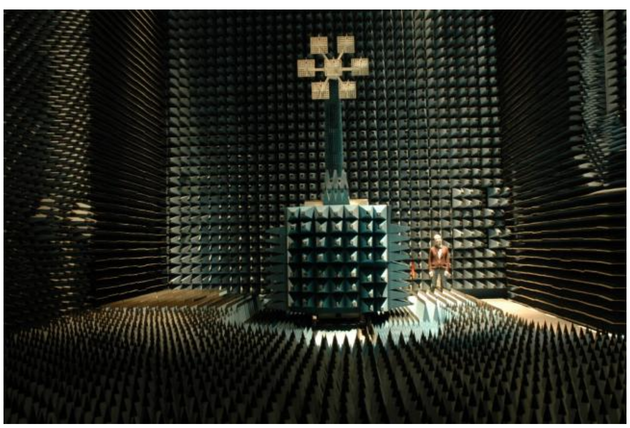

Figure 8: Measurement of final antenna in CNES compact test range in Toulouse.

COMPARISON OF RESULTS

The normalized pattern measurement and the requirements from the SATIMO SG-64 and CNES CATR ranges are shown in Figure 9 and 10 respectively. Both measurements are of high quality considering the low frequency.

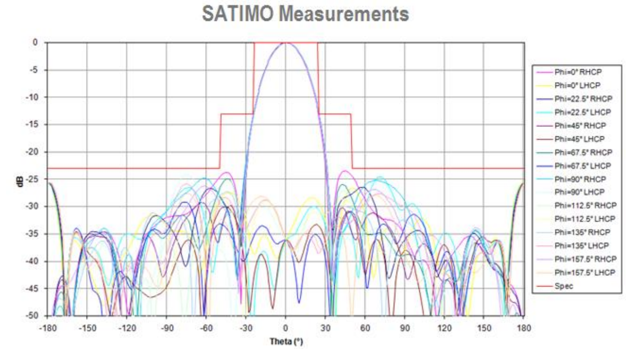

Figure 9: Measured pattern SATIMO Normalised pattern and requirements.

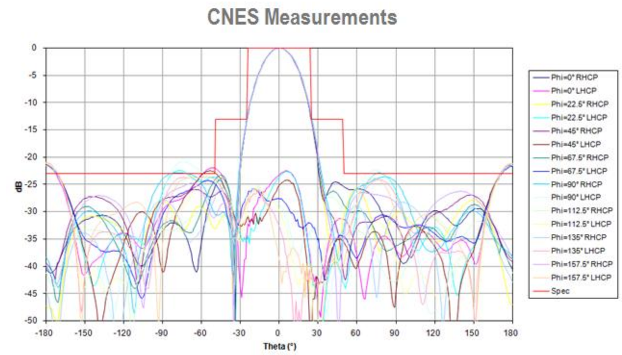

Figure 10: Measured pattern CNES Normalised pattern and requirements

The SG-64 measurements show that the antenna performance is fully within specification for gain, main lobe, cross polar levels and all sidelobes within +/-180°. The SG-64 measurement show a very pure circular polarization with cross polar levels almost 30dB below peak level. This level of accuracy has been achieved by very careful positioning and alignment of the antenna and by averaging two measurements at λ/4 distance in the boresight direction to mitigate reflections from the chamber and measurement structure.

The CATR measurements confirm the main lobe shape but with slightly higher sidelobe levels probably due to reflections in the range. The back lobe level is slightly higher than expected which is probably due to the presence of the positioner in the CATR. The measured cross polar levels are also higher than expected and the levels measured in the SG-64. This is probably due to phase errors in the acquisition and recombination of the dual linear components for measuring circular polarization.

CONCLUSIONS

A ground station antenna for Galileosat application operating in right hand circular polarization at P-band has been designed, manufactured, and tested to very stringent specifications.

The measurements show that the antenna performance is fully within specification for gain, main lobe, cross polar levels and all sidelobes within +/-180°.

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