Characterization of Materials in the 50-750 GHz Range Using a Scatterometer

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***Abstract*—In this work we describe the design and operation of a scatterometer to be used at the European Space Agency. The instrument has the purpose to characterize smooth as well as rough materials, in transmission and reflection in the 50-750 GHz frequency range. We first discuss some of the design challenges encountered during the design, and later show some of the initial measured results.**

I. INTRODUCTION

ACCURATE characterization of the electromagnetic properties of gold-plated metallic surfaces, composites, and ceramics in the mm-wave and lower THz region is becoming more and more important, driven by advances in telecommunications and science systems operating in these frequency bands. Such systems include high data-rate satellite communications [1] and scientific Earth observation missions [2]. In order to properly design components for such systems, the electromagnetic properties of the materials must be taken into account in the RF design phase. For an accurate design, the electromagnetic properties must be known in the frequency band of interest and for various incidence angles.

Typically, materials are characterized by their transmission, reflection, and absorption coefficients, which are measured for normal incidence by well-known procedures and instruments, when dealing with homogeneous materials with smooth surfaces, see for example [3]. However, when the frequency increases, the surface roughness of the materials scatterers some of the incident field away. For more advanced materials, such as composites, the traditional parameters might also not be sufficient due to the penetration of the field into the materials. In such cases, the angular-dependent scattering radiation from the material shall be measured as well, in order to correct reflectivity and transmission measurements, and avoid the scattered energy being interpreted as absorbed by the material [4]. Measuring scattering radiation requires a system in which the properties of the materials can be investigated over a wide range of incidence and scattering angles. This calls for a free space system in which these angles can be adjusted.

In the ESA/ESTEC project "Accurate RF Material Characterisation using Scattering Measurements from Quasi-Optical Bench" (ESA contract 4000116424/16), a scatterometer for material characterization in the 50-750 GHz frequency range, for smooth and rough samples, was designed according to the needs described above, and manufactured. In this work, we present the system and show some of the initial measured data.

II. DESIGN OF THE SCATTEROMETER

The scatterometer is shown in Fig. 1. It consists of a dual-level quasi-optical bench with standard ellipsoidal mirrors with a focal length of 250 mm in a compensated Z configuration, connected by a periscope. The two levels are separated by a distance of two times the focal length of the ellipsoids. The periscope, (marked "PER" in Fig. 1) is made by two paraboloidal reflectors in a compensated configuration and rotates around a vertical axis passing through the sample, allowing the collection of the scattered radiation from the sample over a wide angular region. The sample under test (SUT in Fig. 1) rotates around the same vertical axis allowing varying incidence angles of the incoming beam.

The frequency band from 50 GHz to 750 GHz is divided in 7 sub-bands. For each sub-band, a different set of transmit and receive horns (marked "TX" and "RX" in Fig. 1) and Vector Network Analyser (VNA) extenders is used. The horns are single linearly polarized and tilted 45°, in order to, together with four polarization grids (two on the top deck and two on the bottom deck, marked "POL" in Fig. 1), transmit and receive both linear polarizations. The signal rejected by the grid in the polarizers is absorbed by loads on the sides of the polarizers.

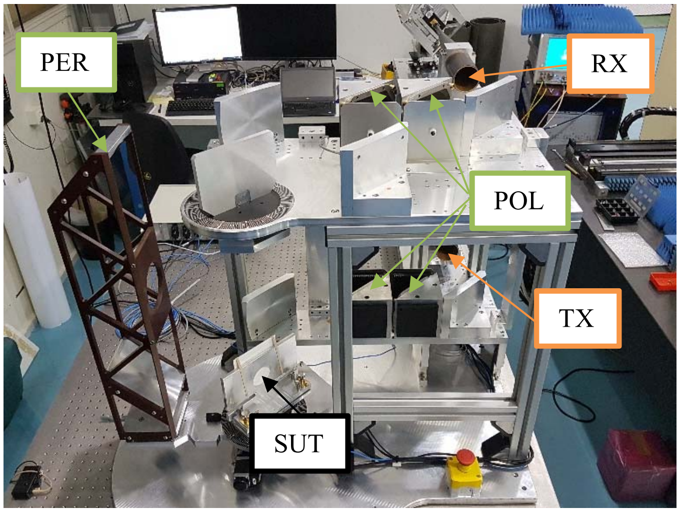

Fig. 1. Scatterometer; the transmit horn is marked "TX", the receive horn "RX", and the polarizers "POL".

III. COMPUTED AND MEASURED DATA FOR ROUGH SAMPLE

The scatterometer was modelled in the GRASP software [5] during the full design phase, see Fig. 2, in order to accurately compute the beam's quality, the cross-polar performance and the power received by the receiving horn, over the full frequency band and a wide range of incidence and scattering angles. Physical Optics (PO) is used on all mirrors and the sample. For samples with roughness correlation lengths smaller than a wavelength, a full wave solution on the sample is necessary, as provided by the MoM add-on to GRASP. The GRASP analysis provides the exact RF scattering from the mirrors and sample, including the higher order Gaussian modes generated by the offset ellipsoids, and a value of the spill-over losses through the system. The power received by the horn is extracted using the Coupling add-on to GRASP. Identical corrugated horns, described by spherical wave expansion coefficients provided by Thomas Keating Limited, are used to model the horns in GRASP.

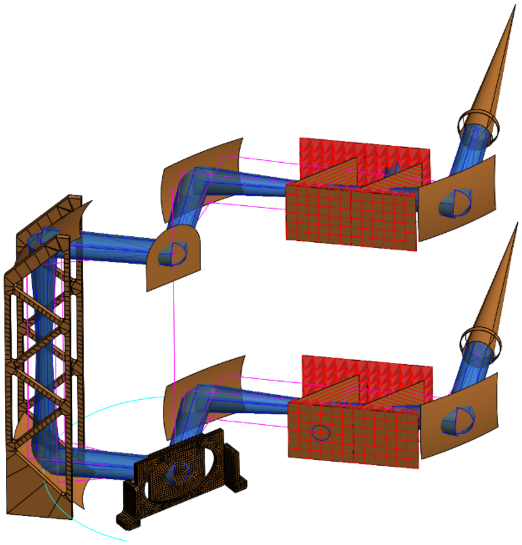

Fig. 2. GRASP model of the scatterometer of Fig. 1.

After a through RF design of the system, which is described in [6], the scatterometer was built and installed at ESA, see the details in [7]. A smooth metallic sample was used as reference during the initial test phase, confirming the correct alignment of the system. Especially designed rough samples were used as well, see [7], in order to test the instrument and compare the measured results with the expected ones. Here we show the results obtained for a rough aluminium sample of 120 mm X 120 mm, as shown in Fig. 3.

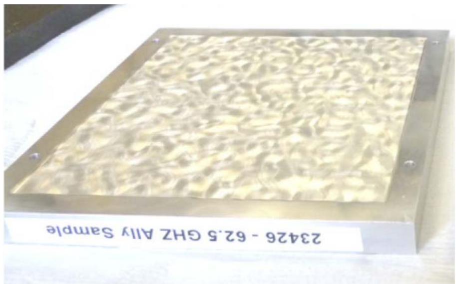

Fig. 3. Manufactured rough aluminum sample: roughness of Gaussian distribution with correlation length of 3.86 mm and rms of 0.1 mm.

The sample is fixed at 45° rotation angle and the polarization grids are placed in horizontal position providing a vertically polarised incident field, with respect to the baseplates. The scattering from the sample is measured at 62.5 GHz for varying periscope rotation angles. The same computation is made in GRASP, by generating a model with the same correlation length and rms, to be analysed with the MoM add-on. The comparison of the measured and computed power received by the horn is shown in Fig. 4, in function of the periscope orientation. The results are in excellent agreement and show that the scatterometer works as expected also for rough samples. Additional measurements are currently ongoing and will be presented at the conference.

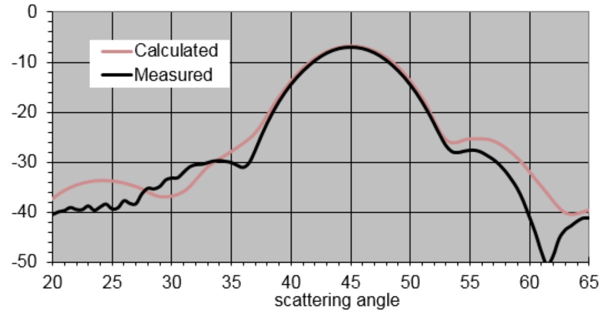

Fig. 4. Measured and calculated received power versus periscope rotation for the sample of Fig. 3 and vertically polarised incident field.

IV. CONCLUSIONS

The design and fabrication of a scatterometer for characterization of smooth and rough materials in reflection and transmission, and in the millimetre and sub-millimetre wave region of the spectrum, has been described. The instrument was designed and modelled in the GRASP software, using Physical Optics on all mirrors and the sample, to accurately compute the beam's quality and cross-polar performance over the full frequency band and a wide range of incidence and scattering angles. For samples with roughness correlation lengths smaller than a wavelength, the Method of Moments add-on to GRASP is used. The GRASP analysis allowed to greatly improve the system performances in the design phase and has shown that the scattering of rough samples can be predicted numerically. Measured results at 62.5 GHz for a rough metallic sample demonstrate that the installed scatterometer works as expected.

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