Development of Calibration Targets for MetOp-SG Microwave Instruments

Arne Schröder[1]*, Axel Murk[1], Richard Wylde[2], Karl Jacob[1], Mike Winser[3], Marc Bergada Pujades[4], and Ville Kangas[5]

[1]*University of Bern, 3012, Bern, Switzerland*

[2]*Thomas Keating Ltd, RH14 9SH, Billingshurst, United Kingdom*

[3]*Airbus Space and Defence, PO3 5PU, Portsmouth, United Kingdom*

[4]*Airbus Space and Defence, 28022, Madrid, Spain*

[5]*European Space Agency, 2201 AZ, Noordwijk, Netherlands*

Contact: arne.schroeder@iap.unibe.ch, axel.murk@iap.unibe.ch

***Abstract*—This work presents the development of microwave calibration units for the second generation of meteorological operational satellites (MetOp-SG), developed by ESA and EUMETSAT. In particular, we focus on the design and manufacturing of on-board calibration targets (OBCT) for the microwave sounder (MWS) and the ice cloud imager (ICI), respectively. MWS operates in seven bands between 23 GHz and 230 GHz, while ICI covers five bands between 180 GHz and 670 GHz. As the OBCTs act as temperature reference for microwave radiometers, they are required to exhibit a low electromagnetic reflectivity and a uniform temperature distribution. This paper summarizes the electromagnetic and thermal design and analyses of the MWS and ICI OBCTs.**

I. Introduction

MetOp-SG is the second generation of European meteorological operational polar orbit satellites which are developed by ESA and EUMETSAT [1]. MetOp-SG will consist of two series of satellites, planned to be operational between 2021 and 2048. The Earth's observation data provided by various on-board remote sensing instruments will enhance future numerical weather prediction and monitoring. The microwave sounder (MWS) and the ice cloud imager (ICI) are two of the instruments on board the MetOp-SG satellites. MWS is a cross-track scanning radiometer observing temperature and humidity profiles as well as cloud water in 24 channels between 23 GHz and 230 GHz [2]. ICI is a conical scanning radiometer intended to measure the cloud ice water path, the cloud ice effective radius, and the cloud ice mean altitude 13 channels between 180 GHz and 670 GHz [3].

Both instruments, ICI and MWS, will be continuously calibrated during operation using a two-point hot-cold calibration. The cold reference point will be provided by cold space 2.7 K measurements. The hot reference point will be provided by an on-board calibration target (OBCT). Two common classes of calibration targets are usually applied in radiometers: Cavity absorbers and pyramid absorbers. Cavity absorbers, such as conical [4], [5] or wedge geometries [6] can exhibit excellent electromagnetic and thermal performance. But, the large dimensions of those cavities often restrains the application in compact instruments. Pyramid absorbers provide a good electromagnetic performance, but their thermal performance is inferior. Nevertheless, due to the compact dimensions, spaceborne radiometers are commonly equipped with pyramid calibration targets. Pyramid absorbers are therefore foreseen for the OBCTs of the MWS and ICI instrument.

The development of spaceborne calibration units raises a wide variety of engineering challenges: A high electromagnetic emissivity and a high temperature uniformity at the same time are required to guarantee an accurate calibration. Moreover, a low coherent backscattering is needed. In particular, the diffuse reflectivity for MWS shall be below -35 dB while the coherent backscatter shall be below -45 dB. For ICI, a diffuse reflectivity of at most -45 dB and a coherent backscatter of at most -50 dB is required. Beside these requirements, a mechanically robust design is needed to ensure mechanical shock and vibration resistivity. The target has to operate in a wide range of temperatures. Moreover, temperature sensors deployed in the target need to measure the physical OBCT temperature within an accuracy of a few mK.

During the design of OBCTs, we concentrated on design aspects which haven't been considered in previous works. In particular, we analyzed the impact of the metal backing geometry on the brightness temperature and electromagnetic properties of a target. Based on these studies, a novel pyramid layout was developed. We analyzed and applied multi-layer absorber coatings for broad band applications. As previous works neglected potential manufacturing artifacts, we studied the impact of most common artifacts on the reflectivity and remedies to the most critical manufacturing imperfections have been proposed. Prototypes of the numerically designed pyramid targets have been manufactured and examined experimentally. This abstract summarizes the OBCT development for MWS and ICI. Details on the development can be found in [7].

II. Numerical Design and Experimental Validation

A pyramid geometry has been chosen as absorbing structure for the MWS and ICI OBCTs. Both OBCTs consist of a metallic pyramid array coated with an absorbing medium. We use Stycast doped with carbonyl iron powder (CIP) as

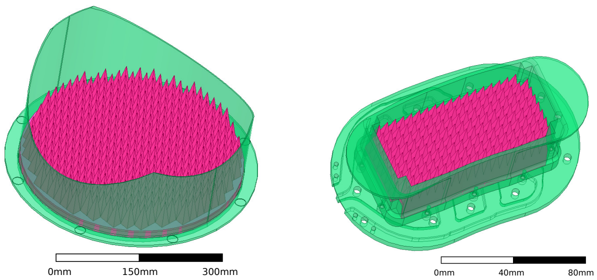

Fig. 1. Illustration of MWS and ICI pyramidal calibration targets. CAD model of MWS prototype (*left*) and ICI prototype (*right*).

absorber. Although other available absorbing materials exhibit superior electromagnetic properties, Stycast turned out to be more robust in terms of adhesion and cracking. The electromagnetic properties of different Stycast-CIP compositions were determined by measurements which have been carried out in a broad frequency range between 18 GHz and 620 GHz [8], [9]. The design of the OBCTs was performed by numerical simulations. We have employed the finite element method (FEM) and modeled the pyramid targets as infinite periodic array to reduce the computational effort. To study the reflectivity in the high frequency regime where the target is electrically very large, we have implemented a geometrical optics (GO) approach.

Using GO simulations, we chose a pyramid geometry with a width to high ration of 1:3.5 as starting point for the design process. A main challenge is to find a pyramid geometry which exhibits a good electromagnetic performance and a good thermal performance. In particular, temperature gradients in the absorber should be as small as possible in order to provide a defined brightness temperature for radiometric calibrations. We have developed a curved pyramid kernel geometry which, compared to conventionally used linear kernels, exhibits additional absorber volume at the bottom section of the pyramids. With that the electromagnetic performance is significantly improved while the temperature distribution is only slightly degraded. We worked on a numerical procedure to analyze the brightness temperature of pyramid targets [10]. Employing this approach, we have demonstrated that reducing temperature gradients results in an improvement of the brightness temperature and hence in a more accurate calibration.

For the ICI OBCT, a single absorber layer turned out to be sufficient. For the MWS OBCT, a two-layer absorber structure has been considered. In order to provide low reflectivity in the low frequency bands of MWS, we coat the metal backing structure with a highly absorbing Stycast-CIP composition. A less absorbing second layer is deposited on top. Numerical analyses predicted that this absorber composition exhibits a very good broad band performance and is hence superior to a single layer design. Figure 1 illustrates the designed MWS and ICI OBCTs.

After developing the pyramid absorbers, we have investigated the impact of potential manufacturing artifacts on the electromagnetic performance of the absorber. In particular, imperfect absorber and metal tips were studied. Moreover, radii at the pyramid notches and material property variations have been considered. While small variations in the material properties are negligible, imperfect pyramid tips decrease the absorptivity of the target. However, the studies revealed that round pyramid notches is the most severe artifact as radii downgrade the reflectivity significantly. We have developed a novel notch design which turned out to be insusceptible to manufacturing precision related issues.

Prototypes of the calibration targets were manufactured and we have conducted measurements in the selected frequency bands between 20 GHz and 670 GHz. It has been shown that the performance of both calibration targets fulfill the MetOp-SG specific radio frequency requirements.

III. Conclusion and Outlook

We have developed OBCT prototypes for the MWS and ICI instruments. The manufactured prototypes were analyzed experimentally and we have proven that the prototypes fulfill the electromagnetic specifications. The designed prototype geometries serve as starting point for the development of engineering qualification models (EQM) in the next stage of the project.

References

[1] EUMETSAT, "EUMETSAT Polar System - Second Generation," 2016, [Online; accessed 18-August-2016]. [Online]. Available: http://www.eumetsat.int/website/home/Satellites/-FutureSatellites/EUMETSATPolarSystemSecondGeneration/index.html

[2] V. Kangas, S. D'Addio, M. Loiselet, G. Mason, M. Buckley, G. Tennant, and P. Campbell, "Microwave sounder instrument for MetOp second generation," in *2014 13th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment (MicroRad)*, March 2014, pp. 232–235.

[3] V. Kangas, S. D'Addio, U. Klein, M. Loiselet, G. Mason, J. C. Orlhac, R. Gonzalez, M. Bergada, M. Brandt, and B. Thomas, "Ice cloud imager instrument for metop second generation," in *2014 13th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment (MicroRad)*, March 2014, pp. 228–231.

[4] A. Murk, P. Yagoubov, R. Wylde, G. Bell, and I. Zivkovic, "Development of conical calibration targets for ALMA," in *21st International Symposium on Space Terahertz Technology*, mar 2010.

[5] A. Schröder and A. Murk, "Numerical design and analysis of conical blackbody targets with advanced shape," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 5, pp. 1850–1858, May 2016.

[6] S. Fernandez, A. Murk, and N. Kämpfer, "Design and characterization of a Peltier-cold calibration target for a 110-GHz radiometer," *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 53, no. 1, pp. 344–351, Jan 2015.

[7] A. Schröder, A. Murk, R. Wylde, K. Jacob, M. Winser, M. B. Pujades, and V. Kangas, "Electromagnetic Design of Calibration Targets for MetOp-SG Microwave Instruments," *IEEE Transactions on Terahertz Science and Technology, in review.*

[8] D. A. Houtz et al., "Electromagnetic Design and Verification of the NIST Conical Microwave Blackbody Calibration Target," *submitted for publication.*

[9] K. Jacob, A. Schröder, and A. Murk, "Design, Manufacturing, and Characterization of Conical Calibration Targets with Optimized Profile," *submitted for publication.*

[10] A. Schröder, A. Murk, R. Wylde, D. Schobert, and M. Winser, "Brightness temperature computation of microwave calibration targets," *IEEE Transactions on Geoscience and Remote Sensing*, 2017, in review.