VERIFICATION OF L-BAND FULLY POLARIMETRIC NOISE INJECTION RADIOMETER MEASUREMENT CAPABILITY

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Abstract

A functional test to verify the proper and accurate measurement capability of an L-band fully polarimetric noise injection radiometer is presented. The test is designed specifically for the MDPP-2 (MIRAS Demonstrator Pilot Project 2) NIR (Noise Injection Radiometer), which has two functions: (1) to calibrate the MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) instrument by measuring a noise source and (2) to measure the brightness temperature of the target scene with fully polarimetric capability i.e. to measure the modified Stokes parameters. The second one is discussed in this paper. The calibration procedure using the sky as the reference source is briefly described and a measurement simulating the actual brightness temperature scene measurement is introduced and the uncertainties involved are discussed.

1 INTRODUCTION

The MDPP-2 NIR is a demonstrating model of the L-band (1.4 GHz) noise injection radiometer of the SMOS (Soil Moisture and Ocean Salinity) satellite. The SMOS mission is one of the Earth Observation Opportunity missions of ESA (European Space Agency) and HUT is working in MDPP-2 under subcontract for EADS-CASA, the prime contractor of the project.

The purpose of the spaceborne NIR is to calibrate the MIRAS instrument on board the SMOS satellite and to measure the fully polarimetric brightness temperature of the earth surface. Calibrating the MIRAS is done by measuring the power of a centralised noise source, which in turn is used for calibration of the MIRAS receivers. The NIR itself can be calibrated by measuring the cosmic background radiation by turning the satellite and pointing the instrument to the sky (the final calibration method is still to be confirmed). Testing the overall performance of the polarimetric NIR with an adequate accuracy is complicated. In this paper first the calibration procedure is briefly described, then the polarimetric measurement is introduced and finally its uncertainties are addressed.

2 CALIBRATION

The calibration using the sky from the surface of the earth is difficult due to the uncertainty caused by the atmospheric radiation and effect of cosmic sources. Additionally, the NIR antenna lobe is very wide making the instrument pointing highly critical. The sky measurement calibrates the NIR brightness temperature detection but the digital correlator used for the Stokes parameter retrieval requires also a calibration. This is done with a matched termination and a noise source, but the procedure is out of the scope of this paper.

The NIR should be pointed up to the sky so that there is a minimum amount of disturbing sources in the field of view. These include the Sun and the Moon as well as high buildings and towers, because of the wide antenna lobe. In effect this means that the measurement is done in the zenith direction at a high place after the sunset during the time when the Moon is near the horizon. The NIR is shielded with a round metal piece so that the disturbing sources from horizontal direction are eliminated. The piece may extend to the edges of the antenna lobe (about 80 degrees from zenith direction), but not further in order to avoid additional uncertainties. The brightness temperature of the sky is 6.4 K $\pm$ 0.3 K [2].

3 BRIGHTNESS TEMPERATURE SCENE MEASUREMENT

Simulating the earth with an adjustable and well-defined fully polarimetric measurement target is a challenging task due to the fact that changing the polarimetric state of electromagnetic radiation with sufficient accuracy requires special equipment and special facilities. Radiation from a fully polarised transmitting antenna will be measured in an anechoic chamber (Figure 1). However, the target cannot cover the whole NIR field of view and the transmitted and received electromagnetic fields have to be related with somewhat complex mathematics producing extra uncertainty.

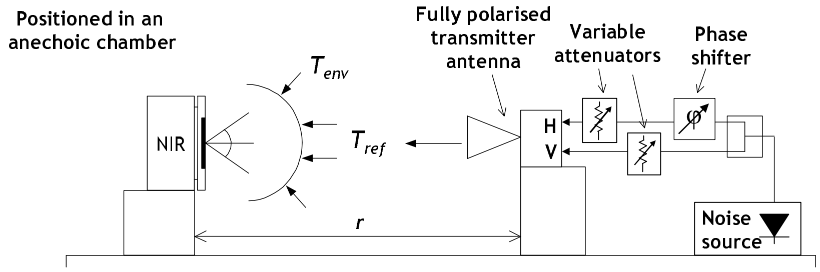

Figure 1. The measurement configuration for the fully polarimetric measurement. The transmitted polarimetric radiation is adjusted with attenuators and a phase shifter. The received radiation consists of the transmitted radiation, T_{ref}, and the radiation emitted by the absorbers of the anechoic chamber, T_{env}.

The measurement setup, positioned inside an anechoic chamber, consists of a noise source, transmitter antenna and a transmission chain connecting the two. The transmission chain is composed of a power divider, variable attenuators and an adjustable phase shifter, with which the polarisation state of the transmitted radiation is adjusted. The measured modified Stokes parameters are defined as [1]

$$T_B = \begin{bmatrix} T_V \\ T_H \\ T_3 \\ T_4 \end{bmatrix} = \begin{bmatrix} T_V \\ T_H \\ 2\sqrt{T_V T_H}\cos\varphi \\ 2\sqrt{T_V T_H}\sin\varphi \end{bmatrix}. \tag{1}$$

The noise temperature going through the transmission chain into the input of the transmitter antenna is determined as follows [3]

$$T_V' = \left(1 - \frac{1}{L_V}\right) T_{phys} + \frac{T_N}{L_V}, \tag{2}$$

where T_N is the noise temperature of the noise source; T_{phys} is the physical temperature of the connecting chain and L_V is the attenuation of the connecting chain going to the vertical input of the reference antenna. For the horizontal polarisation an analogous equation may be written. The received vertical polarisation is calculated by integrating over the whole NIR field of view as follows [1]

$$T_V = T_{env} e_{env} \frac{\int_0^{\theta_1}\int_0^{\phi_1} P_n(\theta,\phi)\sin\theta d\theta d\phi + \int_{\theta_2}^{\pi}\int_{\phi_2}^{2\pi} P_n(\theta,\phi)\sin\theta d\theta d\phi}{\int_0^{\pi}\int_0^{2\pi} P_n(\theta,\phi)\sin\theta d\theta d\phi} + T_V' D_{ref}\eta_{ref} \frac{\int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2} P_n(\theta,\phi)\sin\theta d\theta d\phi}{\int_0^{\pi}\int_0^{2\pi} P_n(\theta,\phi)\sin\theta d\theta d\phi}, \tag{3}$$

where P_n is the normalised antenna pattern of the NIR antenna; T_{env} is the mean physical temperature of the absorbers in the anechoic chamber; e_{env} is the mean emissivity of the absorbers; θ_1, ϕ_1, θ_2 and ϕ_2 are the angles in which the NIR sees the reference antenna (Figure 2); η_{ref} is the radiation efficiency of the reference antenna and

$$D_{ref} = \int_{\theta_1'}^{\theta_2'}\int_{\phi_1'}^{\phi_2'} D(\theta,\phi)\sin\theta d\theta d\phi, \tag{4}$$

in which D is the directivity function of the reference antenna and θ_1', ϕ_1', θ_2' and ϕ_2' are the angles in which the reference antenna sees the NIR antenna cross-section (Figure 2).

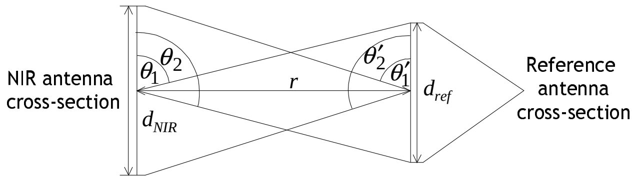

Figure 2. The angles of the measurement situation in the vertical plane.
The situation is analogous for the horizontal plane.

Now Equation (3) can be written as

$$T_V = T_{env} e_{env} A + T_V' D_{ref} \eta_{ref} B = T_{env} e_{env} (1 - B) + T_V' D_{ref} \eta_{ref} B \,, \qquad (5)$$

where *A* and *B* are the integrals of the Equation (3). The received H polarisation is determined analogously. Now by changing the attenuation and phase of the signals in the transmitter, the desired modified Stokes parameters can be produced and the proper operation of the NIR can be verified.

3.1 Uncertainty of the measurement

The uncertainty of the determined modified Stokes parameters consists of the uncertainty of the following items: (1) the physical temperature of the chamber absorbers, (2) the emissivity of the chamber absorbers, (3) the pointing of the antennas, (4) the power level at the transmitter antenna input, (5) the phase difference of the transmitted polarisations and (6) the reference antenna parameters.

The first three items depend on the properties of the anechoic chamber used and can be reduced with fairly simple measurements characterizing the chamber (e.g. [4] and [5]). Item 4 can be dealt with a set of vector network analyser (VNA) measurements with every possible attenuation state of the transmission chain and careful measurements of the noise source with power meter and spectrum analyser. Item 5 can also be measured with a VNA. From items 4 and 5 it follows that the accuracy of the VNA used is highly critical. Item 6 depends on the accuracy of the characterisation of the reference antenna.

As an example the following values can be used: T_{env} = 290 ± 0.5 *K*, e_{env} = 0.9 ± 0.005, *B* = 0.0044, T_V' = 500 ± 10 *K*, D_{ref} = 10, η_{ref} = 0.9 yielding for T_V = 280 *K*. Uncertainty can be calculated using the standard propagation of error method [6] yielding ΔT_V = 1.4 *K*, which is adequate since the required accuracy for the NIR brightness temperature measurement is 1.5 *K*.

4 CONCLUSIONS

In order to assure proper and accurate NIR operation and to demonstrate the measurement capability extensive and complicated testing is needed. In this paper the test verifying the polarimetric brightness temperature scene measurement with high enough accuracy was described and its uncertainties were addressed. Lower brightness temperature can be achieved by utilising a more laborious method, in which the sky works as the background and the reference source is positioned over the NIR. The theory presented in this paper applies also for that method.

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