European Master of Research on Information and Communication Technologies

(MERIT) Master Thesis

External calibration of MIRAS/SMOS Instrument Drift and SuperMIRAS Error Budget

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ABSTRACT

This Master Thesis is a collection of all research activities developed to analyze the temperature drift of MIRAS instrument and perform amplitude calibration during the operational SMOS mission. Moreover, some preliminary results from SuperMIRAS instrument have been obtained related to baseline instrument calibration definition and Error Budget.

The articles published in magazines, congresses or workshops are included but not the technical notes due to the wide extension of them.
## SUMMARY OF RESEARCH ACTIVITIES

### ARTICLE IGARSS 2012 (GEOSCIENCE AND REMOTE SENSING SYMPOSIUM, Munich, Germany, 22-27 July 2012)

- **Title:** "Enhanced SMOS Amplitude calibration using external target"
  Authors: I. Corbella; F. Torres; N. Duffo; I. Durán; M. Pablos; M. Martín-Neira.
  [Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International]
  Publication Year: 2012; Page(s): 2868 - 2871

### ARTICLE MAGAZINE IEEE

- **Title:** “MIRAS Calibration and Performance. Results From the SMOS In-Orbit Commissioning Phase”
  Authors: I. Corbella; F. Torres; N. Duffo; V. González-Gambau; M. Pablos; I. Durán; M. Martín-Neira
  Volume: 49; Issue: 9; Publication Year: 2011; Page(s): 3147 – 3155

### ARTICLE SMOS-BEC WORKSHOP (Barcelona, Spain, 15 December 2010)

- **Title:** “Analysis of amplitude calibration drift in SMOS”
  Authors: M. Pablos; I. Durán.
  [http://www.smos-bec.icm.csic.es/one_year_of_smos_data_workshop]

- **Title:** “Assessment of antenna temperature drift over the ocean”
  Authors: I. Durán; M. Pablos; L. Rehn-Molin.
  [http://www.smos-bec.icm.csic.es/one_year_of_smos_data_workshop]

### ARTICLE IGARSS 2010 (GEOSCIENCE AND REMOTE SENSING SYMPOSIUM, Honolulu, Hawaii, USA, 25-30 July 2010)

- **Title:** “Some results on SMOS-MIRAS calibration and Imaging’
  Authors: I. Corbella; F. Torres; N. Duffo; V. González-Gambau; I. Durán; M. Pablos; M. Martín-Neira.
  Publication Year: 2010; Page(s): 3768 – 3771

### ARTICLE ESA’S LIVING PLANET (Symposium, Bergen, Norway, 20 June- 2 July 2010)

- **Title:** “SMOS-MIRAS calibration and performance”
  Author: I. Corbella; F. Torres; N. Duffo; V. González-Gambau; M. Pablos; I. Durán; J. Closa; M. Martín-Neira.
ARTICLE MICRORAD 2010 (GEOSCIENCE AND REMOTE SENSING SYMPOSIUM, Washington DC, USA, 1-4 March 2010)

- Title: "First results on MIRAS calibration and overall SMOS performance"
  Authors: I. Corbella; F. Torres; N. Duffo; V. González-Gambau; M. Pablos; I. Durán; M. Martín-Neira.
  *Microwave Radiometry and Remote Sensing of the Environment (MicroRad), 2010 11th Specialist Meeting*
  Publication Year: 2010; Page(s): 1 – 4

- Title: "One point calibration in interferometric radiometers: MIRAS/SMOS preliminary results"  
  Authors: F. Torres; I. Corbella; N. Duffo; V. González-Gambau; I. Durán; M. Pablos; M. Martín-Neira
  *Microwave Radiometry and Remote Sensing of the Environment (MicroRad), 2010 11th Specialist Meeting*
  Publication Year: 2010; Page(s): 243 – 246

TECHNICAL NOTES

- Title: "Simulation of antenna pattern differences impact on SMOS spatial bias"
  Authors: I. Durán; L. Wu; F. Torres; I. Corbella; N. Duffo

- Title: “Multiplicative mask performance assessment”
  Authors: L. Wu; F. Torres; I. Corbella; N. Duffo; I. Durán

- Title: “SuperMIRAS:Baseline Instrument Calibration definition and Error Budget”
  Authors: I. Durán; F. Torres; I. Corbella; N. Duffo
  Ref: XMIR-UPC-DD-5 v1.0. 10th February 2012. Universitat Politècnica de Catalunya.

- Title: “Summary of LICEF antenna models”
  Authors: F. Torres; I. Corbella; N. Duffo; I. Durán; M. Pablos

- Title: “CAS factors independent of antenna efficiency”
  Authors: F. Torres; I. Corbella; N. Duffo; I. Durán; M. Pablos

- Title: “All-LICEF Performance Assessment”
  Authors: M. Pablos; I. Durán; F. Torres; I. Corbella; N. Duffo

- Title: “Error budget First Preliminary results”
  Authors: I. Durán; F. Torres; I. Corbella; N. Duffo
• Title: “LICEF front-end enhance model”
  Authors: F. Torres; N. Duffo; I. Corbella; I. Durán; M. Pablos
  Ref: SO-TN-UPC-PLM-0113 v1.9. 5th October 2010.
  Universitat Politècnica de Catalunya.

• Title: “Review of PMS offset in-flight error”
  Authors: M. Pablos; I. Durán; F. Torres; N. Duffo; I. Corbella
  Universitat Politècnica de Catalunya.

• Title: “Impact of temperature drift on antenna patch attenuation L1”
  Authors: M. Pablos; I. Durán; F. Torres; N. Duffo; I. Corbella
  Ref: SO-TN-UPC-PLM-0117 v2.2. 15th November 2010.
  Universitat Politècnica de Catalunya.

• Title: “Comprehensive analysis of short terms LICEF front-end”
  Authors: M. Pablos; I. Durán; F. Torres; N. Duffo; I. Corbella
  Universitat Politècnica de Catalunya.

• Title: “CAS factors in arm B in nominal configuration”
  Authors: I. Durán; M. Pablos; F. Torres; N. Duffo; I. Corbella
  Universitat Politècnica de Catalunya.

• Title: “PMS gain drift 2010”
  Authors: M. Pablos; I. Durán; F. Torres; N. Duffo; I. Corbella
  Universitat Politècnica de Catalunya.

• Title: “Definition of a metric for instrument drift analysis”
  Authors: I. Corbella; F. Torres; N. Duffo; I. Durán; M. Pablos
  Universitat Politècnica de Catalunya.

• Title: “LICEF double slope coefficients”
  Authors: M. Pablos; I. Durán; F. Torres; N. Duffo; I. Corbella
  Universitat Politècnica de Catalunya.

• Title: “LICEF new antenna model: multivariable regression coefficients”
  Authors: M. Pablos; I. Durán; F. Torres; I. Corbella; N. Duffo;
  Ref: SO-TN-UPC-PLM-0137 v1.0. 8th July 2011.
  Universitat Politècnica de Catalunya.

• Title: “Summary of LICEF antenna models”
  Authors: I. Corbella; F. Torres; N. Duffo; I. Durán; M. Pablos
  Universitat Politècnica de Catalunya.
SMOS-MIRAS CALIBRATION AND PERFORMANCE

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ABSTRACT
An intense activity has been carried out during the in-orbit commissioning phase of the SMOS (Soil Moisture and Ocean Salinity) mission. Concerning the payload MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) it has been fully characterized using specific orbits dedicated to check all instrument modes. The procedures, already defined during the on-ground characterization, have been repeated so as to obtain realistic temperature characterization and updated internal calibration parameters. External calibration maneuvers have been tested for the first time and have provided absolute instrument calibration, as well as corrections to improve the internal calibration data.

Key words: SMOS; MIRAS; Interferometric Radiometers; Calibration; Imaging.

1. INTRODUCTION
The ESA SMOS satellite was successfully launched on the 2nd November 2009. The six-month long in-orbit commissioning phase started just after launch and included a complete and systematic check of the payload MIRAS, the retrieval of all calibration parameters and a thorough thermal characterization. The mission is now in the operational phase and data products are continuously being generated by the data processing ground segment using the selected algorithms and payload modes of operation.

This paper is focused on the work performed during the payload commissioning. It describes some tests carried out during this phase and the results obtained. All results have been obtained using the MIRAS-Testing Software (MTS) [1], an independent processing tool able to ingest SMOS raw data and produce calibration parameters, calibrated visibility (compatible with level 1A SMOS data) and geolocated brightness temperature (equivalent to the SMOS level 1C).

2. MIRAS CALIBRATION OVERVIEW
A complete description of the MIRAS calibration system can be found in [2]. In general, calibration of an interferometric radiometer such as MIRAS is needed to provide accurate values of visibility for all receiver pairs and antenna temperature (zero baseline visibility) for at least one element. Besides, image reconstruction algorithms [3, 4] need additional calibration parameters, such as the fringe washing function shape and the flat target response [5]. MIRAS uses a combination of both external and internal calibration procedures to estimate all the time varying parameters. On the other hand, stable parameters such as antenna patterns, S-parameters of noise distribution network and others, are directly used from on-ground characterization.

The visibility is derived by the level 1 processor using the following equation

\[ V_{kj} = \frac{M_{kj} \sqrt{T_{sys}T_{nm}}} {G_{kj}} \]  \hspace{1cm} \text{where} \hspace{1cm} T_{sys} = \frac{v_k - v_{off}} {G_k} \quad (1) \]

where \( v_k \) is the measured voltage of the PMS (power measurement system) and \( M_{kj} \) the normalized correlation measured by the on-board digital correlator. On the other hand, antenna temperature is measured by three noise-injection radiometers (NIR’s) [6] located near the center of the array using

\[ T_A = T_U - \eta T_{NA} \]  \hspace{1cm} (2) \]

where \( T_U \) is the physical temperature in kelvin measured by a sensor placed in a reference resistor near the antenna, \( \eta \) is the measured Dicke pulse fraction (raw NIR measurement) and \( T_{NA} \) the noise equivalent temperature of the internal noise source.

The brightness temperature is computed out of the calibrated visibility (1) by inverting the visibility equation [7].

\[ V_{kj} = \iint_{\xi^2 + \eta^2 \leq 1} T_{kj}(\xi, \eta) \overline{f}_{kj}(-\frac{4\pi a}{io}) e^{-j2\pi(ua+vo)} d\xi d\eta \] \hspace{1cm} (3)
where \( \tilde{r}_{kj}(\ ) \) is the fringe washing function normalized to its value at the origin and \( T_{kj} \) the modified brightness temperature:

\[
T_{kj}(\xi, \eta) = \frac{\sqrt{D_k D_j}}{4\pi} \frac{T_B(\xi, \eta) - T_r}{\sqrt{1 - \xi^2 - \eta^2}} F_{nk}(\xi, \eta) F_{nk}^*(\xi, \eta)
\]

(4)

where \( T_B \) is the brightness temperature to be retrieved. In this equation, the only parameter that has eventually to be updated is the normalized fringe washing function, which is approximated by the following analytical expression.

\[
\tilde{r}_{kj} \approx A \sin(B(\tau - C)) e^{i(Dr^2 + Er)}
\]

(5)

In summary, the outcome of the MIRAS calibration procedure is made of the following parameters: the PMS gain \( G_k \) and offset \( v_{off} \), the correlation complex gain \( G_{kj} \) in amplitude and phase, the NIR source noise temperature \( T_{NK} \) and the five parameters \( A \) to \( E \) of the fringe washing function. All calibration parameters are planned to be periodically updated during the mission to account for possible instrumental drifts. Additionally, the Flat Target Response, which is essentially the calibrated visibility measured when the instrument is pointing to the cold sky, is also considered a calibration parameter.

3. INTERNAL AND EXTERNAL CALIBRATION

External calibration is performed by commanding the platform to go into inertial attitude. In this case, the instrument starts to rotate with respect to the earth-fixed coordinate system until the earth disappears from the field of view of the antenna. At this point, the radiometer is measuring the brightness temperature of a fixed point of the sky, which is chosen to be near the galactic pole to avoid influence from the Galactic emission. Since the sky brightness temperature at L-band is known [8], the calibration parameters of the instrument are adjusted so as to match the measurements to this absolute reference.

External calibration provides the best quality of calibration and it is the only way to obtain the absolute accuracy of the instrument. However, the pointing maneuvers cannot be performed too often and the impact in terms of percentage of time dedicated to calibration is high.

Internal calibration, on the other hand, is carried out by periodically injecting noise to all receivers using an internal source and a distribution network [9]. It tracks fast variations of parameters, but for those requiring a known calibration standard, it cannot provide their absolute values. In this case, the accuracy of the internal calibration relies on the quality of a secondary standard, which has to be previously calibrated using the external view. On the other hand, noise injection is very fast and is easily interspersed between normal measurement operation.

The calibration method utilized for each of the parameters is the following:

- PMS gain: External calibration with periodic tracking by internal calibration
- PMS offset: Internal calibration.
- Correlator gain (amplitude and phase): Internal calibration.
- NIR internal noise temperature: External calibration
- Fringe washing function parameters: Internal calibration

4. CALIBRATION RATE

Most of the calibration procedures and measurement sequences were precisely defined during the on-ground characterization of the instrument [10]. The in-orbit commissioning phase has been essential to adjust the timing of calibration events in accordance with the real instrument operation. Particularly, the following general trends have been observed:

- Flat Target Response: Stable, to be corrected only twice a year.
- Fringe washing function shape: The same stability as the Flat Target Response
- Visibility amplitude: To be updated once every 8 weeks
- Antenna temperature: Needs to be calibrated every 2 weeks
- Visibility phase. A calibration is needed every 10 minutes.

Some parameters, as the PMS gain and offsets have been accurately characterized in terms of temperature variation though the computation of sensitivity parameters. This, in combination with a very low physical temperature drift of the whole instrument, has allowed to reduce the need for their frequent calibration updates. New sensitivity parameters have been derived during the in-orbit commissioning phase and they are very well in agreement with the ones obtained during the ground characterization.

As a general rule, the percentage of total time devoted to calibration must be the minimum, just to ensure that the quality of the measurements is according to the requirements. In SMOS, about one percent of the time is used in calibration. This has been achieved by minimizing the number of external calibration maneuvers, using accurate thermal characterization and agreeing a compromise value for the parameters changing the fastest (phase of visibility)

5. CORRELATOR CALIBRATION

Calibrating the correlator gain means measuring the complex parameter \( G_{kj} \) and its evolution with time and
temperature. This is achieved by processing the internal calibration data using a straightforward method described in [9, 11]. The absolute value of $G_{kj}$ is nearly one by definition and it has been observed having negligible variation from one calibration event to the other. However, the phase of $G_{kj}$ for some baselines shows large and relatively fast variations with time that must be tracked by frequent calibration events. The reason is that the $G_{kj}$ phase for two receivers not sharing a common local oscillator is roughly equal to the phase difference between the signals generated by the oscillators, which vary independently as a function of their local temperature variation. This effect is the main driver for the intercalibration period: every ten minutes a short burst of correlated noise is injected during 1.2 seconds to all receivers just to compute this phase. Figure 1 shows a plot of the amplitude stability of $G_{kj}$ and the large phase variation in a baseline having two different local oscillators.

![Figure 1. Left: Stability of the amplitude of $G_{kj}$ along time. Right: phase of $G_{kj}$ variation due to local oscillator phase drift](image1)

### 6. PMS CALIBRATION

According to (1), the PMS parameters (gain and offset) are directly responsible of the amplitude of the calibrated visibility. For this reason, accurate PMS calibration has a strong impact on the quality of the final brightness temperature image. In general, errors in the PMS gains and offsets increase the pixel bias, defined as the spatial standard deviation of an image in the director cosines coordinates [12, 13].

The measurements carried out during the commissioning phase have shown that the PMS offset has a periodic variation linked to a control signal used to drive the heaters of the instrument thermal control system. This effect is general but particularly noticeable in some receivers, and has been solved by applying a software correction based on a meticulous process of characterization. The results are given in figure (2) where plots of the offset and the heater signal are drawn superimposed to demonstrate this effect. At the right the same plot after applying the software correction is given. The effect of the correction is apparent.

On the other hand, the PMS gain is extremely stable and very well characterized in temperature. In fact, several retrievals made in different calibration events show high consistency among them. It is calibrated by external calibration using the sky as cold standard and an internal resistor at known physical temperature as hot standard [11]. Independently, their values are monitored by internal calibration using the method described in [9, 11, 14], based on using the NIR, working in a specific mode of operation, to measure the noise power injected to the receivers. This implies that the NIR has to be previously calibrated during the cold sky views. One key result of the in-orbit payload characterization is the computation of correction factors to be applied to internal noise distribution network parameters and antenna efficiencies so as to make these two PMS gain measurements consistent with each other.

![Figure 2. Effect of heater signal in the PMS offset and its correction](image2)

Figure 3 shows the difference in percentage between gain retrievals from both external and internal calibration, once the correction factors have been applied. The different traces correspond to six calibration events carried out respectively on 12th January, 2nd February, 2nd, 16th and 23rd March, and 6th April 2010, that is spanning about three months. The peak to peak differences in individual gains is always lower than $\pm 1\%$ and the drift of the average values is as low as 0.2%.

The PMS gain variation between calibration events is very well tracked by means of the measured physical temperature and the sensitivity parameter derived during the in-orbit commissioning phase. Figure 4 shows the measurements of gain during a specific test carried out to

![Figure 3. PMS gain calibration. Difference between external and internal calibrations once correction factors applied. The results are for H-pol and for six calibration events spanning three months](image3)
derive this sensitivity. During this test, several orbits of continuous gain retrievals using internal calibration were commanded. The gain sensitivity parameter to temperature was computed by using linear regression of the data acquired. The figure shows a comparison between the measured gain and the one derived using the sensitivity parameter and the physical temperature, so demonstrating that the gain can be accurately tracked just by measuring the temperature sensors, and there is no need for frequent calibration updates.

Finally, figure 5 shows the long-term stability of both PMS gain and offset. It shows the difference of the averaged values retrieved during ten calibration events distributed regularly between 12th January to 11th May 2010. It turns out that the long-term drift is lower than 0.5 mV for the offset and 0.2% for the gain, which has led to the proposal of a PMS intercalibration period of eight weeks to be conservative.

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REFERENCES


MIRAS Calibration and Performance. Results From the SMOS In-Orbit Commissioning Phase

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Abstract

After the successful launching of the SMOS satellite in November 2009, continuous streams of data started to be regularly downloaded and made available to be processed. The first six months of operation were fully dedicated to the In Orbit Commissioning Phase, with an intense activity aimed at bringing the satellite and instrument into a fully operational condition. Concerning the payload MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) it was fully characterized using specific orbits dedicated to check all instrument modes. The procedures, already defined during the on-ground characterization, were repeated so as to obtain realistic temperature characterization and updated internal calibration parameters. External calibration maneuvers were tested for the first time and provided absolute instrument calibration, as well as corrections to internal calibration data. Overall performance parameters, such as stability, radiometric sensitivity and radiometric accuracy were evaluated. The main results of this activity are presented in this paper, showing that the instrument delivers stable and well calibrated data thanks to the combination of external and internal calibration and to an accurate thermal characterization. Finally, the quality of the visibility calibration is demonstrated by producing brightness temperature images in

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the alias-free field of view using standard inversion techniques. Images of ocean, ice and land are given as examples.

**Index Terms**

SMOS, interferometric synthetic aperture radiometry, calibration, imaging

**I. INTRODUCTION**

SMOS (acronym of Soil Moisture and Ocean Salinity) is a European Space Agency (ESA) mission designed to provide global maps of soil moisture over land and sea surface salinity over oceans [1]. It consists of a satellite in a sun-synchronous orbit at about 770 km height carrying a passive L-band sensor called MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) [2], [3]. The satellite was successfully launched the 2nd November 2009 from the Plesetz cosmodrome in northern Russia and the payload was switched on on 17th November 2009. Since then, continuous data is regularly received by the ground segment data acquisition station located in Villafranca del Castillo, near Madrid (E).

The SMOS In-Orbit Commissioning Phase (IOCP) started just after the 3-week long Switch-On and Data Acquisition Phase (SODAP), which was mainly focused at testing low level processes for data acquisition and handling. The IOCP had an overall duration of 6 months and the first half part comprised the characterization, calibration, validation and verification of the instrument. The main goal was to provide a fine tune of MIRAS by means of: Systematic check of all instrument modes, retrieval of internal and external calibration parameters, computation of temperature sensitivity coefficients, assessment on imaging capability, assessment on calibration rate requirements, and instrument overall performance evaluation: Stability, Radiometric sensitivity, Radiometric accuracy and Absolute accuracy.

Most of the goals were successfully achieved on time thanks to the combined effort of a team formed by EADS-CASA Espacio (E) as instrument manufacturer; Deimos Enginheria (P) developer of the Level 1 Prototype Processor (L1PP); the ESA Calibration Expert Center (CEC) dedicated to analyze the quality of the calibration data; and the Universitat Politecnica de Catalunya (UPC) responsible of the definition and implementation of calibration and processing algorithms. All of them were efficiently led by the ESA’s principal engineer of the instrument.
The following sections provide a brief description of the activities carried out by UPC in the frame of the SMOS IOCP and shows the main results achieved, including determination of calibration parameters and their stability, as well as retrieval of brightness temperature images of ocean, ice and land. Everything has been processed using the MIRAS Testing Software, an independent software tool developed by UPC, capable of producing geolocated brightness temperature out of the raw data downloaded from the payload [4].

II. MIRAS CALIBRATION

A complete description of the MIRAS calibration system can be found in [5]. In general, calibration of an interferometric radiometer such as MIRAS is needed to provide accurate values of visibility for all receiver pairs and antenna temperature (zero baseline visibility) for at least one element. Besides, image reconstruction algorithms [6], [7] need additional calibration parameters, such as the fringe washing function shape and the flat target response [8]. MIRAS uses a combination of both external and internal calibration to estimate all the time varying parameters. On the other hand, stable parameters such as antenna patterns, S-parameters of noise distribution network and others, are directly used from on-ground characterization.

The visibility is derived by the level 1 processor using the following equation

\[ V_{kj} = \frac{M_{kj} \sqrt{T_{sys_k} T_{sys_j}}}{G_{kj}} \]  

where \( T_{sys_k} = \frac{v_k - v_{off_k}}{G_k} \)  

(1)

where \( v_k \) is the measured voltage of the PMS (power measurement system) and \( M_{kj} \) the normalized correlation measured by the on-board digital correlator. On the other hand, antenna temperature is measured by three noise-injection radiometers (NIR’s) [9] located near the center of the array using

\[ T_A = T_U - \eta T_{NA} \]  

(2)

where \( T_U \) is the physical temperature in kelvin measured by a sensor placed in a reference resistor near the antenna, \( \eta \) is the measured Dicke pulse fraction (raw NIR measurement) and \( T_{NA} \) the noise equivalent temperature of the internal noise source.

The brightness temperature is computed out of the calibrated visibility (1) by inverting the visibility equation [10].

\[ V_{kj} = \oint T'_{kj}(\xi, \eta) \bar{T}_{kj}(\frac{-\nu \xi + v \eta}{f_0}) e^{-j2\pi(\nu \xi + v \eta)} d\xi d\eta \]  

(3)
where \( \tilde{r}_{kj}(\cdot) \) is the fringe washing function normalized to its value at the origin and \( T'_{kj} \) the modified brightness temperature:

\[
T'_{kj}(\xi, \eta) = \sqrt{\frac{D_k D_j}{4\pi}} \left( T_B(\xi, \eta) - T_r \right) \sqrt{1 - \xi^2 - \eta^2} F_{nk}(\xi, \eta) F^*_{n_j}(\xi, \eta)
\]

with \( T_B \) is the brightness temperature to be retrieved. In this equation, the only parameter that needs eventually to be updated is the normalized fringe washing function, which is approximated by the following analytical expression.

\[
\tilde{r}_{kj} \approx A \sin(B(\tau - C)) e^{j(D\tau^2 + E\tau)}
\]

In summary, the outcome of the MIRAS calibration procedure is made of the following parameters: the PMS gain \( G_k \) and offset \( v_{off} \), the correlation complex gain \( G_{kj} \) in amplitude and phase, the NIR source noise temperature \( T_{NA} \), and the five parameters \( A \) to \( E \) of the fringe washing function. All calibration parameters are planned to be periodically updated during the mission to account for possible instrumental drifts. Additionally, the Flat Target Response, which is essentially the calibrated visibility measured when the instrument is pointing to the cold sky, is also considered a calibration parameter.

### III. INTERNAL CALIBRATION

Internal calibration is carried out by periodically injecting noise to all receivers using an internal source and a power distribution network. Two-levels of power are injected so as to cancel the internal noise coming from the distribution network [11], [12]. Also, in order to simplify this network, a distributed approach is used [13].

Internal calibration is used to monitor the power measurement system (PMS) (gain \( G_k \) and offset \( v_{off} \)), the correlator complex gain \( G_{kj} \), both in amplitude and phase and the fringe washing function parameters. It is also used to measure the residual visibility offset by switching all receivers’ inputs to internal resistors, so producing uncorrelated noise injection. This offset is very small and was very well characterized on ground [14].

#### A. PMS gain

Figure 1 shows the relative PMS gain variation in percentage with respect to the average value for all 72 receivers. Both the standard deviation and the peak to peak deviation are shown. It
is computed after analyzing a total of 2499 samples measured during more than 24 hours with the instrument continuously in internal calibration mode. Most of the receivers have PMS gain variations below 0.5% rms and all of them are well below the specified 1%. These variations are dominated by the thermal noise inherent to the measurements due to the limited integration time.

Nevertheless, there is still a small dependence of the PMS gain with temperature. To characterize this behavior, plots of PMS gains as a function of temperature have been produced and sensitivity coefficients have been computed from linear regression. An example of such plots is given in figure 2 along with a comparison between the measured gain and the one predicted from the temperature measurement. Two values of sensitivity are shown, one in blue corresponding to on ground measurement [14] and other in red obtained from flight data in the frame of the In Orbit Commissioning Phase.

Figure 3 shows the long-term stability of the gain. It represents the difference in the measured gain at six different calibration events spanning more than three months. At each event, the gain is computed by averaging 45 individual retrievals, saving the result as a calibration product to be used during the measurement mode (see section III-D). To make the plot of figure 3 all

Fig. 1. Relative PMS gain variation in 24 hours of continuous measurements

...
gains were corrected in temperature as described above. The main result is that the overall PMS gain is stable within 0.4% peak to peak in a period of three months, provided the temperature correction is applied.

**B. PMS offset**

The PMS offset voltages showed small jumps linked to the signal controlling the heaters in the payload temperature stabilization circuitry. Some receivers are more affected than others, but the effect is general. Plots of the offset voltage and the heater signal are drawn superimposed in figure 4 (left) to demonstrate this effect. To cancel this variation, a software correction was implemented based on an accurate characterization carried out with the data acquired during a test sequence specifically designed for it. It consisted of continuously driving the voltage detectors at four levels, so as to make continuous measurements of PMS offsets using the four-point technique [15]. The result is seen in the plot at the right of figure 4, showing the offset once the correction is applied. There are still some points where it is not perfect, but in general most of the points show only the random fluctuation due to thermal noise. A better insight on the quality of this correction is given in figure 5 where for all the receivers, the standard deviation of the measured offset is plot as a function of the receiver number. Three traces are given: without heater correction and with two different retrievals of the correction parameters measured at two different operations of the special sequence of calibration. The correction clearly reduces the
rms values of the offset and the results are very consistent with each other for both retrievals. The residual offset rms error is well below the 1 mV specification.

C. Correlator complex gain

The correlator gain $G_{kj}$ is a complex valued parameter. Its amplitude is always around unity and very stable: only a negligible variation with time has been detected (see the plot at the left of figure 6). On the other hand, in baselines formed by two receivers not sharing a common local oscillator, the phase of $G_{kj}$ has a significant variation. This phase is roughly equal to the phase difference between the signals generated by the oscillators, which vary independently as a function of their local temperature variation [16]. To account for this dependance, frequent phase calibration events must be carried out interspersed with the normal measurement operation. Several strategies were studied within the commissioning phase in order to decide the best phase calibration rate. To this end the payload was programmed to acquire data with different LO
calibration rates, ranging from 2 minutes to 14 minutes. The final value was fixed after a complete analysis of the data acquired, bearing in mind that the final goal is to provide the maximum quality of the geophysical parameters retrievals. It was finally established in ten minutes to keep residual rms phase error below the 1 deg requirement. Figure 6 shows an example of the phase of $G_{kj}$ along with its estimation based on a spline interpolation.

D. Internal calibration strategy

Two different sequences are used for internal calibration purposes. The so-called “LOcal” consists of injecting a short burst of noise (1.2s duration) just to record the phase of the correlation, which is equal to the phase of $G_{kj}$. Due to the distributed approach of the network [13], this is actually done twice, one with the “even” sources and other with the “odd” sources. For baselines not sharing noise source, their phases are estimated by solving a system of equations. The LOcal sequence is repeated once every ten minutes and has a total duration of 6 seconds to allow for signals to stabilize after changing the input power so drastically. This is the main contribution to an overall ratio of calibration to measurement slightly above 1%.

The second internal calibration sequence is the “Long-cal”. As described in [17] it uses a whole orbit (actually two half-orbits) continuously dedicated to internal calibration alternating between
two-level correlated noise and uncorrelated noise injection. Figure 7 shows the schematic time line of this sequence. The whole orbit of 5000 seconds is divided into 15 segments of about 400 seconds each. Each one includes three subsegments of correlated noise injection and a longer one of uncorrelated noise injection (abbreviated “U-noise”). This provides a total of 45 individual measurements of PMS gain, offset and amplitude of $G_{kj}$ (its phase is ignored). All of them are averaged to obtain a calibration product that is saved and used later for correcting the science measurements as explained below. All the U-noise measurements are averaged together to estimate the visibility offset to be subtracted to all the subsequent measurements. Finally, using part of the correlated noise injection with time delays, the parameters of the fringe washing function are estimated. The long calibration sequence is performed once every eight weeks, which is enough to track the small variation of the retrieved parameters.

During science measurement operation, the PMS gain is estimated from the calibration product just described but corrected in temperature using the temperature sensitivity coefficients derived during the commissioning phase (see figure 2). The offset is estimated from the calibration product and the correction of the heater signal. The amplitude of the correlator gain is just the
Fig. 6. Correlator complex gain $G_{kj}$: left: Stability of amplitude along time showing high stability in four-month span. Right: Fast phase variation due to local oscillator phase drift

one measured and its phase is estimated by spline interpolation between measurements of the LOcal sequence.

IV. EXTERNAL CALIBRATION

External calibration is performed by commanding the platform to go into inertial attitude. When this command is received, the instrument starts to rotate with respect to the earth-fixed coordinate system until the earth disappears from the field of view of the antenna. At this point, the radiometer is measuring the brightness temperature of a fixed point of the sky, which is chosen to be near the galactic pole to avoid influence from the Galactic emission. Since the sky brightness temperature at L-band is known [18], the calibration parameters of the instrument are adjusted so as to match the measurements to this absolute reference.

External calibration is used to calibrate the Noise Injection Radiometers (NIRs), which means computing the equivalent noise temperature of their internal source [9]. For each NIR, two parameters are obtained ($T_{NA}$ and $T_{NR}$), the first one used in equation (2) to measure the antenna temperature and the second one as a secondary standard for the PMS gain calibration in the internal calibration procedure [12].
External calibration is also used to correct for the term of the PMS gain not included in the internal calibration, namely the overall loss between the antenna plane and the noise input port. This is achieved by comparing the PMS gain derived from internal calibration with the one obtained using the one-point approach described in [12], [19] and using the sky as cold standard and an internal resistor at known physical temperature as hot standard. Figure 8 shows the measured difference in percentage between both PMS gains. The comparison is made by translating the internal gain to the antenna reference plane using the S-parameters of the switches measured on ground and a rough estimation of the antenna ohmic efficiencies. The plot shows that the gains have a discrepancy of about 4%, which is completely out of requirements.

Correction factors were computed during the in-orbit payload characterization to be applied to internal noise distribution network parameters, switches and antenna efficiencies so as to make these two PMS gain measurements consistent with each other. The correction factors were computed once for a particular external calibration data set and saved as fixed parameters to use in subsequent calibrations. Eventually, during the mission lifetime these parameters could be updated. Figure 9 shows the difference in percentage between gain retrievals from both
Fig. 8. Comparison between PMS gain retrieved with internal calibration and with external calibration.

external and internal calibration, once the correction factors have been applied. The different traces correspond to eight calibration events carried out at the dates specified in the figure, that is spanning about five months. The peak to peak differences in individual gains is always lower than ±1% and the drift of the average values is as low as 0.6%.

The gain derived from external calibration is more accurate than the one from internal calibration since it uses directly well known standards. The gain from internal calibration is based on using the NIR working in a specific mode of operation to measure the noise power injected to the receivers, which is then used as a secondary standard. This implies that the NIR has to be previously calibrated during the cold sky views. Figure 14 shows the long term stability of the PMS gain derived from external calibration using the one-point approach.

V. SYSTEM PERFORMANCE

Two parameters have been used to define the overall system performance of the instrument [20]. The first is the radiometric sensitivity, defined as the temporal standard deviation of the brightness temperature, a function of the spatial direction. The second is the pixel bias, defined as the spatial standard deviation across the image in the director cosines coordinates. Both of them have been obtained after analyzing in detail the data retrieved from ocean scenes. Figure
Fig. 9. PMS gain calibration. Difference between external and internal calibrations once correction factors applied. The results are for H-pol and for six calibration events spanning three months.

(11) at the left shows an image of the radiometric sensitivity as a function of the director cosines coordinates. At the right of the figure there is a plot of a cut for $\xi = 0$ and a comparison between the measured values and those predicted by the following theoretical formula derived in [21]:

$$\Delta T_B(\xi, \eta) = \frac{\sqrt{3}d^2}{2} T_A + T_R \frac{\Omega_a}{\sqrt{B\tau_{\text{eff}}}} \frac{1}{t(\xi, \eta)} \sqrt{1 - \xi^2 - \eta^2} \alpha_w \sqrt{N}$$  

where $T_A$ is the antenna temperature measured by the NIRs, $T_R$ is the average receiver noise temperature measured while in external calibration, $B$ is the noise equivalent bandwidth measured through the $B$ parameter of the fringe washing function, $\tau_{\text{eff}}$ is the effective integration time taking into account the one-bit correlator [20], $\alpha_w$ is a coefficient that depends on the window used in the inversion process (0.45 for Blackmann window), $\Omega_a$ is the antenna equivalent solid angle and $t(\xi, \eta)$ is the normalized antenna power pattern, these last two obtained from the accurate antenna measurements carried out on ground. The plot shows an excellent agreement between
the measurement results and the theoretical predictions.

Figure 12 gives the same results but for the measurement of the cold sky during an external calibration maneuver. The agreement is also good, although not as perfect as for the ocean scenes. One of the reasons for this discrepancy might be associated to the back lobes of the antennas that when the instrument is looking upwards are collecting the power emitted by the Earth and are thus contaminating the measurements.

Figure (13) shows an image corresponding to the average of about 60 consecutive snapshots of pure ocean after compensating for the incidence angle dependence. The pixel bias is estimated by the spatial standard deviation of this image in a circle of radius 0.3 inside the alias-free field of view. According to the labels of the images, this turns out to be 1.2 K and 1.35 K respectively.
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Fig. 11. Radiometric sensitivity in ocean scenes. Left: as a function of pixel position for H-pol. Right: comparison with theoretical formula.

Fig. 12. Radiometric sensitivity during sky looks. Left: as a function of pixel position for H-pol. Right: comparison with theoretical formula.

for horizontal and vertical polarization. It should be noted that the predicted value given in [20] was of 1.8K in the worst case, well in line with the values obtained with the real instrument, and it is a good indicator of the quality of the calibration and the inversion. The structure of the image and thus the corresponding standard deviation, is highly increased if the extended alias-free region is considered, although it is not shown here.
VI. BRIGHTNESS TEMPERATURE IMAGES

Brightness temperature images are obtained by inverting the calibrated visibility using equation (5). Examples are presented here for ocean, land and ice using the inversion approach number 3 defined in [6] and implemented in the MIRAS Testing software [4]. The images correspond to maps of half the first Stokes parameter, that is \((T_H + T_V)/2\) to make them independent of the rotation angles between the instrument frame at each pixel and the ground frame. In the case of ocean images, the theoretical variation due to specular reflection, directly computed from the fresnel reflection coefficients, has been compensated so as to obtain fairly constant images in all the field of view. Only the data in the true alias-free zone is considered since it is the one of which its quality depends only on the quality of the visibility calibration.

Figure (14) shows a four-days cumulated image over ocean corresponding to data from 6th to 9th June 2010 using both ascending and descending orbits. The image shows low brightness temperature values on the Atlantic compatible with a known increase of salinity in this area. Other stable spatial structures are observed at certain locations over the globe, particularly at high latitudes, although no scientific assessment has been made about them in the frame of this work. They could be caused by RFI sources, particularly in Southern Greenland and North of Canada. What is apparent from this figure is the increase of brightness temperature at the Amazon river plume, which is due to the mixing of fresh water. This is confirmed by a zoom
Fig. 14. Cumulated brightness temperature in ocean from 6th to 9th May 2010 for both ascending and descending orbits of the image shown in figure 15. There is a clear negative gradient of brightness temperature that enters to the ocean just at the point where the river Amazon flows into the Atlantic ocean.

Fig. 15. Zoom of the Amazon river plume showing the influence of higher brightness temperature of fresh water entering into the ocean.

Figure 16 shows the retrieved brightness temperature over Antarctica. A fairly constant value of about 200K is seen at the right of the image and in particular at the Dome-C area, but higher
values are measured in other zones.

![Brightness temperature image over the Antarctica in 9th May 2010](image)

Fig. 16. Brightness temperature image over the Antarctica in 9th May 2010

Brightness temperature over land is expected to be more variable in time since it depends on the amount of water in the soil, which can have important variations when strong rain events are present. Also, differences from ascending to descending orbits are expected since they correspond respectively to the dawn and dusk times of the day. In any case, in order to have a global view of the L-band brightness temperature of the land areas, Figure 17 shows the cumulated brightness temperature for the same four days (6th to 9th May 2010), but separating ascending and descending orbits. Clear features are observed, which in general coincide with the zones of the planet where there are changes in soil moisture. However, there are zones of the planet, particularly in Europe and Asia, that are highly contaminated by RFI, making the brightness temperature images to saturate.

VII. CONCLUSIONS

MIRAS provides accurately calibrated visibility as a result of using a combination of internal and external calibration. During the in-orbit commissioning phase, all calibration parameters were measured and found consistent with the ones obtained during the on-ground characterization of the instrument. The visibility amplitude shows a high degree of stability both in short- and long terms, which allows to space apart the external calibration events. On the other hand, the
phase has significant variations, requiring to perform updates every ten minutes using internal calibration. The main overall system performance parameters, such as radiometric accuracy and pixel bias have been found well in accordance with the expected values. Brightness Temperature images of good quality in the alias-free field of view have been demonstrated using the UPC’s MIRAS testing software, an independent processing tool able to ingest SMOS raw data and provide calibrated visibility and geo-located brightness temperature. Examples over sea, ice and land are given. As a general conclusion: SMOS mission is a success and good global maps of Soil Moisture and Ocean Salinity are expected to be produced in the years to come.

REFERENCES


SOME RESULTS ON SMOS-MIRAS CALIBRATION AND IMAGING

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ABSTRACT

After the six-month long In-Orbit Commissioning Phase (IOCP) the SMOS satellite started to work in its fully operational mode. During the IOCP, the payload MIRAS was completely characterized, both in short- and long-term, and the optimum calibration rate for in-flight operation was established. The results show that the amplitude of the visibility is very stable, thus allowing a very low calibration rate, and that the phase has a systematic and periodic variation, easily tracked with short but frequent internal calibration sequences. Absolute calibration for antenna temperature is carried out by external maneuvers to account for drift in the reference Noise Injection Radiometer. Brightness temperature images of good quality are obtained by inverting the calibrated visibility. The images show features compatible with ocean salinity over ocean and soil moisture over land.

1. INTRODUCTION

SMOS (acronym of Soil Moisture and Ocean Salinity) is an European Space Agency (ESA) mission aimed at providing global maps of soil moisture over land and sea surface salinity over oceans [1]. The mission payload is the Microwave Imaging Radiometer with Aperture Synthesis (MIRAS) [2, 3], an L-band, Y-shape 2D interferometric radiometer manufactured by EADS-CASA Espacio (ES) and integrated to a generic PROTEUS platform manufactured by Thales Alenia Space. SMOS was successfully launched on 2nd November 2009 from the Plesestz cosmodrome by a launcher from Eurokot. The payload was switched on on 17th November and since then raw data measurements are being received regularly by the ground segment data acquisition station, located near Madrid (ES). After due processing, they provide the first-ever global brightness temperature maps at L-band.

The first six months of operation were dedicated to make a complete and systematic check of the payload, including the retrieval of all calibration parameters and their temperature dependence [4]. Good brightness temperature images can be produced by inverting the calibrated visibility, which is a good indicator of the quality of the calibration. This paper shows some of the results, especially those dealing with the main calibration parameters and their stability; and the brightness temperature imaging. All the results have been obtained using the MIRAS testing software [5], developed by the UPC team.

2. CALIBRATION

Calibration is needed to provide accurate values of visibility for all receiver pairs and antenna temperature for at least one element. Besides, image reconstruction algorithms [6, 7] need the fringe washing function shape and the flat target response [8]. MIRAS uses a combination of both external and internal calibration to estimate all the time varying parameters [9]. Stable parameters such as antenna patterns, $S$-parameters of noise distribution network and others, are directly used from on-ground characterization [10].

The outcome of the MIRAS calibration system consists of the following parameters: the PMS (power monitoring system) gain $G_k$ and offset $v_{off}$, the correlation complex gain $G_{kj}$ in amplitude and phase, the NIR source noise temperature $T_{NA}$ and the the normalized fringe washing function $v_{fr}$ [11]. All of them are periodically updated during the mission to account for instrumental drifts. Additionally, the Flat Target Response [8] is also considered a calibration parameter.

2.1. Internal and External calibration

External calibration is performed by commanding the platform to go into inertial attitude. In this case, the instrument starts to rotate with respect to the earth-fixed coordinate system until the earth disappears from the field of view of the antenna. At this point, the radiometer is measuring the brightness temperature of a fixed point of the sky, which is chosen...
to be near the galactic pole to avoid influence from the Galactic emission. Since the sky brightness temperature at L-band is known [12], the calibration parameters of the instrument are adjusted so as to match the measurements to this absolute reference. External calibration provides the best quality of calibration and it is the only way to obtain the absolute accuracy of the instrument. However, the pointing maneuvers cannot be performed too often and the impact in terms of percentage of time dedicated to calibration is high.

Internal calibration is carried out by periodically injecting noise to all receivers using an internal source and a distribution network [11]. It tracks fast variations of parameters, but for those requiring a known calibration standard, it cannot provide their absolute values. In this case, the accuracy of the internal calibration relies on the quality of a secondary standard, which has to be previously calibrated using the external view. On the other hand, noise injection is very fast and is easily interspersed between normal measurement operation.

The calibration method utilized for each of the parameters is the following:

- **PMS gain**: External calibration with periodic tracking by internal calibration
- **PMS offset**: Internal calibration
- **Correlator gain (amplitude and phase)**: Internal calibration
- **NIR internal noise temperature**: External calibration
- **Fringe washing function parameters**: Internal calibration

### 2.2. Calibration rate

Most of the calibration procedures and measurement sequences were precisely defined during the on-ground characterization of the instrument [10]. Then, the in-orbit commissioning phase has been essential to adjust the timing of calibration events in accordance with the real in-flight instrument operation [4]. Particularly, the following general trends have been observed:

- **Flat Target Response**: Stable, to be corrected only twice a year.
- **Fringe washing function shape**: The same stability as the Flat Target Response
- **Visibility amplitude**: To be updated once every 8 weeks
- **Antenna temperature**: Needs to be calibrated every 2 weeks
- **Visibility phase**: A calibration is needed every 10 minutes.

Some parameters, as the PMS gain and offsets have been accurately characterized in terms of temperature variation though the computation of sensitivity parameters. This, in combination with a very low physical temperature drift of the whole instrument, has allowed to reduce the need for their frequent calibration updates. New sensitivity parameters have been derived during the in-orbit commissioning phase and they are very well in agreement with the ones obtained during the ground characterization.

As a general rule, the percentage of total time devoted to calibration must be the minimum, just to ensure that the quality of the measurements is according to the requirements. In SMOS, about one percent of the time is used in calibration. This has been achieved by minimizing the number of external calibration maneuvers, using accurate thermal characterization and agreeing a compromise value for the parameters changing the fastest (phase of visibility).

### 2.3. Calibration parameters trend

Figure 1 shows a plot of the long-term stability of the amplitude of correlator gain ($G_{kj}$), along with the short-term variation of its phase for a baseline having two different local oscillators. As seen, the amplitude has negligible variation from one calibration event to another. On the other hand, the phase variation is large, but can be easily tracked by frequent internal calibration sequences: every ten minutes a short burst of correlated noise is injected during 1.2 seconds to all receivers to measure this phase.

Fig. 1. Left: Stability of the amplitude of $G_{kj}$ along time. Right: phase of $G_{kj}$ variation due to local oscillator phase drift

Figure 2 shows the measurements of PMS gain during a specific test carried out to derive its thermal sensitivity. The figure shows a comparison between the measured gain and the one derived from the physical temperature and the sensitivity, demonstrating that the gain can be accurately tracked just by measuring the temperature sensors.

Figure 3 shows the long-term stability of both PMS gain and offset. It shows the difference of the averaged values retrieved during ten calibration events distributed regularly between 12th January to 11th May 2010. It turns out that the long-term drift is lower than 0.5 mV for the offset and 0.2% for the gain, which has led the the proposal of a PMS inter-calibration period of eight weeks to be conservative.
3. IMAGING

Figure 4 shows an example of several snapshots in a pass over Australia in dual polarization mode. Since the polarization is mixed in the field of view, the definitions Horizontal and Vertical refer to the sub-satellite track. These images were obtained just two weeks after the payload switch-on with still uncomplete calibration. Nevertheless, they already show that the instrument is capable of producing good brightness temperature images. Improved images were obtained after the instrument was fully characterized and calibrated. Figure 5 shows two images corresponding to four-day cumulated data over Australia acquired in January 2010 and in February 2010. Between both dates there were strong rain events in the eastern part of Australia due to the pass of the tropical storm “Olga”. This is clearly visible in the images, where lower brightness temperatures are measured after the pass of the storms.

Over the ocean the brightness temperature is lower than in land and has also a much smaller dynamic range than in land. On the other hand its spatial variation is much smoother, allowing to perform spatial averages. Figure 6 shows the averages of 150 consecutive snapshots over the ocean both for horizontal and vertical channel. The strong dependance with the incidence angle, characteristic of the ocean brightness temperature is clearly visible in these images. Also, some artifacts can be seen in the extended alias-free zone, in which a model is used to estimate the brightness temperature of the sky alias zone and the result subtracted to the images. This procedure is not eliminating all the errors in the sky alias zone. To assess the instrument capability of making brightness temperature images, only the strict alias-free zone has been considered in subsequent processing.

As an example, figure 7 shows the image of four-day cumulated first Stokes parameter over the Atlantic. As expected, it has lower values in those regions where the salinity is known to be larger according to the NOAA climatological data.
4. CONCLUSIONS

SMOS is producing high quality brightness temperature images thanks to the accurate characterization and calibration of the instrument MIRAS, which was performed first on ground and later in flight conditions during the In-Orbit Commissioning phase. Most of the calibration parameters have very small drift with time and temperature, while the others are accurately tracked using sensitivity coefficients or specially designed internal calibration sequences. The overall time dedicated to calibration is slightly larger than 1% of the measurement time, in agreement with the mission requirements. Images of first Stokes parameter over land and ocean show geophysical features compatible with soil moisture and salinity respectively.

5. REFERENCES


FIRST RESULTS ON MIRAS CALIBRATION AND OVERALL SMOS PERFORMANCE

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ABSTRACT
After the successful launching of the SMOS satellite, the first continuous streams of data are being processed and carefully analyzed in the frame of the SMOS In-Orbit Commissioning phase. Results regarding instrument calibration parameters retrieval, both internal and external, and brightness temperature imaging are presented. Images of ocean, ice and land are given as examples.

Index Terms— SMOS, interferometric synthetic aperture radiometry

1. INTRODUCTION
SMOS (acronym of Soil Moisture and Ocean Salinity) is a European Space Agency (ESA) mission designed to provide global maps of soil moisture over land and sea surface salinity over oceans [1]. It consists of a satellite in a sun-synchronous orbit at about 770 km height carrying a passive L-band sensor called MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) [2]. The satellite was successfully launched the 2nd November 2009 from the Plesetz cosmodrome in northern Russia and the payload was switched on on 17th November 2009. Since then, continuous data is regularly received by the ground segment data acquisition station located in Villafranca del Castillo, near Madrid (E).

The SMOS In-Orbit Commissioning Phase (IOCP) started just after the 3-week long Switch-On and Data Acquisition Phase (SODAP), which was mainly focused at testing low level processes for data acquisition and handling. The IOCP has an overall duration of 6 months and the first half part comprises the characterization, calibration, validation and verification of the instrument [3]. The main goal is to provide a “fine tune” of MIRAS by means of: - Systematic check of all instrument modes - Retrieval of internal and external calibration parameters - Computation of temperature sensitivity coefficients - Assessment on imaging capability - Assessment on calibration rate requirement and - Instrument overall performance evaluation: Stability, Radiometric sensitivity, Radiometric accuracy and Absolute accuracy.

Most of the goals are being successfully achieved on time thanks to the combined effort of a team formed by EADS-CASA Espacio (E) as instrument manufacturer; Deimos Ingeniería (P) developer of the Level 1 Prototype Processor (L1PP); the ESA Calibration Expert Center (CEC) dedicated to analyze the quality of the calibration data; and the Universitat Politècnica de Catalunya (UPC) responsible of the definition and implementation of calibration and processing algorithms. All of them are efficiently led by the ESA’s principal engineer of the instrument.

The following sections provide a brief description of the activities carried out by UPC in the frame of the SMOS IOCP and shows the main results achieved, including determination of calibration parameters and their stability, as well as retrieval of brightness temperature images of ocean, ice and land. Everything has been processed using the MIRAS Testing Software, an independent software tool developed by UPC, capable of producing geolocated brightness temperature out of the raw data downloaded from the payload [4].

2. INTERNAL CALIBRATION
The procedures for MIRAS internal calibration are fully described in [5]. Essentially, calibration is carried out by injecting two-levels of correlated noise into all receivers [6] using a distributed approach to simplify the internal noise distribution network. The outcomes of the calibration procedure are three parameters: the power measurement system (PMS) gain ($G_k$) and offset ($v_{off}$) and the correlation complex gain ($G_{kj}$). Once these parameters are known, the calibrated visibility during scene observation is computed as

$$V_{kj} = \frac{M_{kj} \sqrt{T_{sys_k} T_{sys_j}}}{G_{kj}}$$

where

$$T_{sys} = \frac{v_k - v_{off}}{G_k}$$

(1)
where $v_k$ is the measured PMS voltage and $M_{kj}$ the normalized correlation. Calibration parameters are measured at different times than when used during target observation. In order to accurately predict their values at measurement times, it is important to carefully assess their stability and temperature dependance. The following subsections show the main results obtained in specific tests carried out during the IOCP in order to measure the calibration parameters and their stability [3].

2.1. PMS gain

Figure 1 shows the relative PMS gain variation in percentage with respect to the average value. It has been computed after analyzing a total of 2499 samples measured during more than 24 hours with the instrument continuously in calibration mode. As seen, most of the receivers have PMS gain variations below 0.5% rms and all of them are well below the specified 1%. The plot at the right shows the long-term stability of the gain. It represents the difference in measured gain for 6 different calibration events separated more than one month. The result is that the PMS mean gain is stable within 1.2% peak to peak in a period of one month, and about 0.6% mean drift.

Nevertheless, there is still a small dependance of the PMS gain with temperature. To characterize this behavior, plots of PMS voltages as a function of temperature have been produced and sensitivity coefficients computed from linear regression. An example of such plots is given in figure 2 along with a comparison between the measured gain and the one predicted from the temperature measurement. Two values of sensitivity are shown, one in blue corresponding to on ground measurement [7] and other in red obtained from flight data in the frame of the IOCP.

Fig. 1. Relative PMS gain variation in 24 hours continuous measurements (left) and between separated calibration events.

2.2. PMS offset

The PMS offset voltages showed unexpected jumps linked to the signal controlling the heaters in the temperature stabilization circuitry. Some receivers are more affected than others, but the effect is general. A correction has been implemented so as to estimate the offset using its mean value, the physical temperature and the heater signals. Figure 3 shows the comparison between the estimated offset and the measured one for two particular receivers. The periodical variation corresponds to the heater signal frequency. It is apparent that the procedure devised is able to follow the actual value of the offset.

Fig. 3. PMS offset compared with its estimation using the temperature and the heater signal. Plots correspond to two sample receivers.

2.3. Correlator gain

The correlator gain $G_{kj}$ is a complex valued parameter. Its amplitude is always around unity and has small variation with time. On the other hand its phase depends on the local oscillator phases which in turn depend on the physical temperature variation with time. To account for this dependance, frequent phase calibration events are carried out interspersed with the normal measurement operation. Several strategies are being studied within the commissioning phase in order to decide the best phase calibration rate. To this end the payload has been programmed to acquire data with different LO calibration rates, ranging from 2 minutes to 14 minutes. The final value will be fixed after a complete analysis of the data acquired, bearing in mind that the final goal is to provide the maximum quality of the geophysical parameters retrievals. Figure 4 shows examples of amplitude and phase of $G_{kj}$. In this last case, the estimation based on a spline interpolation is also shown. As for the amplitude, in this particular case the variation is as small as 0.05% and in general most baselines present a ripple below 0.3% rms.

Fig. 2. PMS Gain sensitivity and estimation from physical temperature.

2.4. Internal calibration strategy

Once in a month a whole orbit is dedicated to internal calibration. Then, all measurements of PMS gain and offset as
well as amplitude of correlator gain are averaged and saved as reference. During science measurement operation, the PMS gain is estimated from this reference corrected using the temperature sensitivity coefficients. The offset is estimated using both the temperature sensitivity coefficient and the correction linked to the heater signal. The amplitude of the correlator gain is used just as measured and finally, the phase of this parameter is estimated by spline interpolation between interspersed measurements.

3. EXTERNAL CALIBRATION

Also once every month the platform rotates in order to point to the cold sky and acquire data for external calibration. The most important effect that must be corrected is the term of the PMS gain not included in the internal calibration procedure, namely the overall loss between the antenna plane and the switch, including the antenna ohmic efficiency. Figure 5 shows the difference in percentage between the PMS gain retrieved using internal calibration and by an independent procedure using the cold sky and the internal resistor [8]. At left, the original results are shown, which have been used to devise a procedure to correct for this inconsistency. At right the gain difference is shown after applying the correction factor. All differences remain below than $\pm 0.035$ dB.

4. BRIGHTNESS TEMPERATURE IMAGES

Once the instrument is fully calibrated, the visibility is injected into the inversion algorithms in order to retrieve brightness temperature images. Examples have been produced for ocean, land and ice using the inversion approach number 3 defined in [9]. Figure 6 shows the average of horizontal and vertical brightness temperature for incidence angles below 30° for a region of the south pacific overlaying a map of salinity available from NOAA climatological data. According to the expected results the brightness temperature decreases for regions with higher salinity. At the right of the figure, the horizontal and vertical brightness temperature for the stable region of lower latitudes is shown. The consistency with the theoretical values computed using the Fresnel reflection coefficient, plot as solid lines, is remarkable, especially in vertical polarization.

Finally, figure 8 shows again the average of horizontal and vertical brightness temperature for incidence angle lower than
30° in an overpass over South America. The image is superimposed to a map downloaded from Google Earth in order to show the extent of the Amazonian forest matching very well with the area of higher brightness temperature due to the shielding effect of the dense vegetation. The Amazon river itself is perfectly visualized in the image as a zone with lower brightness temperature. Other structures are seen corresponding to different terrains and humidities.

![Fig. 8. Map of $(T_H + T_V)/2$ over South America and the Amazonian forest](image)

5. CONCLUSIONS

MIRAS is already providing accurately calibrated visibility measurements as a result of using internal calibration corrected with external calibration. All parameters have been measured and found consistent with the on-ground characterization, showing high stability both in short- and long terms. Quality Brightness Temperature images are then ready to be retrieved, especially in the alias-free field of view and also in the extended part, although with some already expected degradation. Examples over sea, ice and land are given after processing data using the UPC’s MIRAS testing software, an independent processing chain from raw data to geo-located brightness temperature. As a general conclusion: SMOS mission is a success and good global maps of Soil Moisture and Ocean Salinity are expected to be produced in the years to come.

6. REFERENCES


ABSTRACT

After the successful launch of the SMOS satellite, on November 2009 at 02:50 CET (01:50 UT) from the Plesetsk Cosmodrome in northern Russia, a preliminary evaluation of the payload calibration strategy has been undertaken in order to assess the instrument performance and establish the operational measurement and calibration configuration. With this objective in mind, this work presents a preliminary study on the performance of the amplitude calibration strategy, a key issue in achieving a stable and accurate operation of the sensor.

Index Terms — radiometer, interferometer, aperture synthesis, amplitude calibration, error assessment.

1. INTRODUCTION

This work has been conducted in the framework of a project devoted to assess the performance of the MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) instrument [1], the single payload of the ESA-SMOS mission [2]. The MIRAS consists of a Y-shape interferometric radiometer basically formed by 72 receivers called LICEF (Lightweight Cost Effective Front End) placed along the three arms. Cross-correlations of the signals collected by each receiver pairs “k,j” give the samples of the so-called visibility function, $V_{kj}$, which develops into a brightness temperature map by means of a Fourier synthesis process. Amplitude calibration has a major impact in the final performance since amplitude errors in the visibility samples are directly translated into image distortion (the so-called pixel bias) through this Fourier synthesis process.

MIRAS measures normalized correlations $M_{kj}$ by means of 1-bit digital correlators. As detailed in [3], these measurements are denormalized according to

$$V_{kj} = \sqrt{\frac{T_{sys,ak} T_{sys,jk}}{G_{kj}}} M_{kj}$$

The orbital temperature drift of the 72 receivers is well constrained by the thermal control. However, this small temperature swing produces a non-negligible PMS gain drift that must be corrected for. In this sense, PMS gain in measurement mode at a physical temperature $T_{ph}$ is estimated as

$$G_k^A(T_{ph}) = G_k^A(T_{ph}) \left(1 + S_{ph}^G (T_{ph} - T_{ph}) \right)$$

Figure 1. The physical temperature of the 72 LICEF/PMS receivers is well constrained by means of the thermal control.

2. IN-FLIGHT AMPLITUDE CALIBRATION PERFORMANCE

The orbital temperature drift of the 72 receivers is well constrained by the thermal control (fig. 1). However, this small temperature swing produces a non-negligible PMS gain drift that must be corrected for. In this sense, PMS gain in measurement mode at a physical temperature $T_{ph}$ is estimated as

$$G_k^A(T_{ph}) = G_k^A(T_{ph}) \left(1 + S_{ph}^G (T_{ph} - T_{ph}) \right)$$

(2)
PMS gain at the calibration temperature $G_k^4(T_{ph})$ is estimated by means of the 4P method during an orbit in calibration mode to be performed, tentatively, every month. PMS gain sensitivity to temperature drift has been measured on-ground and in-flight showing good agreement (fig. 2).

PMS gain is foreseen to be calibrated periodically, with an estimated intercalibration period of about two weeks to be frozen by the end of the commissioning phase. Currently, more frequent calibration events during commissioning phase are showing PMS gain pk-to-pk residual drift constrained to $\pm 0.6\%$ with relation to the mean value of each PMS in an one month period, well within mission requirements (fig. 3).

3. ONE POINT CALIBRATION

The so-called “one-point calibration” [4][5] is an alternative PMS calibration method that has been developed, as a risk mitigation approach, with two objectives:

- Evaluate (and correct if required) CAS S-parameter residual errors during deep sky calibration.
- Alternative method to track PMS orbital gain drift by means of periodic U-noise injection

![Figure 3. Mean gain drift for each of the 72 PMS gains with relation to their mean value along the one month intercalibration period. Pk-to-pk residual drift below $\pm 0.6\%$, well within mission requirements.](image)

![Figure 4. LICEF/PMS front-end scheme to illustrate the one-point calibration scheme.](image)

3.1 Validation of CAS coefficients

Figure 4 gives the block diagram of the PMS front end, showing the main “1P calibration” magnitudes. During periodic (one month) deep sky views, the PMS is simultaneously calibrated by means of the internal 4P CAS system at the calibration plane CIP and by means of the external 1P calibration at the antenna plane. This last is given by

$$G_k^4, T_{phk}^4$$

On the other hand, when translated to the antenna plane, the internal PMS 4P gain is given by [3]:

$$G_k^{4P} = \frac{v_{2k} - v_{lk}}{T_{CASN}^4 - T_{CASN}^L}$$

As these two gains are computed at the same plane and at the same temperature, they must be equal:

$$G_k^4 = G_k^{4P}$$
In order to evaluate the error and compute a correction coefficient, the magnitudes are rearranged in the so-called $C_{NK}$ coefficients. One is computed from the on-ground parameters. The other uses the flight measurements and can be computed during each external calibration (deep sky views) if required:

$$C_{nk}^{pol} = \frac{|S_{Lk}|^2}{|S_{L0}|^2} \eta_{jk}$$  \hspace{0.5cm} (6)

$$C_{nk}^A = \frac{T_{CASN}^2 - T_{CASN}^1}{v_{2k} - v_{1k}} \frac{v_{UK} - v_{SKYk}}{T_{UK} - T_{SKYk}}$$  \hspace{0.5cm} (7)

The error in the $C_{nk}$ coefficients can be assigned to a CAS correction factor to force $G_{nk}^A = G_{nk}^{4P}$. In order to check the consistency of this correction, some analysis has been undertaken. First, it has been shown that the CAS correction factor presents low dependency on the polarization configuration of the receiver (horizontal or vertical), proving that the dominant error mainly comes from the noise distribution network (fig. 5, top). In second place, the CAS correction factor shows a good repeatability between one-month external calibration events (fig. 5, bottom). After applying the external CAS correction factors the internal 4P PMS gain and the external 1P PMS gain match to 0.023 dB rms error (fig. 6).

$$G_{k}^A(T_{ph}) = \frac{v_{UK} - v_{SKYk}}{T_{Rk}^1(T_{ph}) + T_{Rk}^0}$$  \hspace{0.5cm} (8)

Where, receiver temperature at $T_{ph}$ is estimated by

$$T_{Rk}^A(T_{ph}) = T_{Rk}^A(T_{pho}) \left(1 + S_{ph}^{TR} \left(T_{ph} - T_{pho}\right) \right)$$  \hspace{0.5cm} (9)

The reference receiver temperature $T_{Rk}(T_{pho})$ is estimated by means of the 4P method during external calibration (deep sky views) at physical temperature $T_{pho}$. Their sensitivity to temperature (about 0.75 K/ºC) was measured during the on-ground characterization when the instrument was tested at the Large Space Simulator (LSS) in Nordwijk, Holand (ESA) [5].

Figure 7 (top), shows an example of this calibration approach applied to unit 30 (LCF-B-03), which is one of the
four outlier units presenting larger temperature swing (fig. 1). The instrument was in calibration mode during a few orbits to assess the behaviour in temperature of several calibration parameters. The black line gives PMS gain calibrations performed every 30 s. The blue line shows the estimation of PMS gain by means of (2). The reference gain has been computed as the mean value for all the orbits, whereas the orbital drift is tracked by using the temperature measurements from a thermistor placed in the front end of each unit, and the sensitivity measured in flight (fig. 2). The effect of hysteresis is clearly seen in the comparison of the two plots (black and blue lines).

On the other hand, the red line presents spline interpolation of hysteresis, receiver noise temperature is well correlated to temperature drift. This allows a very good track of PMS gain by means of periodic (6 min) U-noise injection, aligned to the LO phase track measurements of the matched load (U-noise injection).

Although method c) is the more accurate, method b) has been selected since gives an error well below the 1% PMS system gain error requirement and minimizes the loss of snap shots (maximum observation mode configuration)

4. CONCLUSIONS

In-orbit MIRAS/SMOS amplitude calibration performs well within expectations. Preliminary results during the commissioning phase show that low orbital temperature swing, very good stability and careful temperature compensations keeps PMS gain estimation well below the 1% system error requirement.

5. ACKNOWLEDGMENT

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6. REFERENCES

ONE POINT CALIBRATION IN INTERFEROMETRIC RADIOMETERS: MIRAS/SMOS PRELIMINARY RESULTS

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ABSTRACT

After the successful SMOS launch on November 2009 a comprehensive evaluation of the payload calibration strategy has been undertaken during a six months commissioning phase. In the frame of the activities devoted to assess the instrument performance and to establish the operational measurement and calibration configuration, this work presents a study on the performance of the so called “one-point” method, an alternative calibration scheme developed as a risk mitigation approach.

1. INTRODUCTION

This work has been conducted in the framework of a project devoted to assess the performance of the MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) instrument [1], the single payload of the ESA-SMOS mission [2]. The MIRAS consists of a Y-shape interferometric radiometer basically formed by 72 receivers called LICEF (Lightweight Cost Effective Front End) placed along the three arms. Cross-correlations of the signals collected by each receiver pairs “k,j” give the samples of the so-called visibility function, \( V_{kj} \), which develops into a brightness temperature map by means of a Fourier synthesis technique. Amplitude calibration has a major impact in the final instrument performance since amplitude errors in the visibility samples are directly translated into image distortion (the so-called pixel bias) through this Fourier synthesis process.

MIRAS measures normalized correlations \( M_{kj} \) by means of 1-bit/2-level digital correlators. As detailed in [3], these measurements are denormalized according to

\[
V_{kj} = \frac{T_{syst.k}^T T_{syst.j}}{G_{kj}^A} M_{kj}, \quad T_{syst} = \frac{V_{dk} - V_{offk}}{G_k^A} \quad (1)
\]

A PMS (Power Measuring System) in each LICEF is used to measure the equivalent system temperature \( T_{syst.k} \) \((A=V,H)\) at each antenna plane. The fringe-wash term \( G_{kj}^A \), PMS gain at the calibration temperature \( k_{ph}T \) which is estimated by means of the so-called two-level four-point (4P) method [3]. This calibration procedure makes use of the CAS (CAlibration System) based on two-level noise sources (hot and warm) that inject the signals to the LICEF calibration port C by means of a noise distribution network. A highly stable radiometer called NIR (Noise Injection Radiometer) measures the hot and warm signals at the CAS output port N, to be used as references to calibrate the PMS units. A switch placed at the LICEF front end is used to select the instrument operating configuration: measurement mode (V/H) or calibration mode (CU).

![Physical temperature variation pk-to-pk and std](image)

Figure 1. The physical temperature of the 72 LICEF units is well constrained by means of thermal control.

The orbital temperature drift of the 72 receivers is well constrained by the thermal control (fig. 1). However, this small temperature swing produces a non-negligible orbital PMS gain drift that must be corrected for. At each snapshot, PMS\(_k\) gain in measurement mode is estimated as

\[
G_k^A(T_{ph_{ki}}) = G_k^A(T_{ph_{0k}})[1 + S_{Tph}(T_{ph_{ki}} - T_{ph_{0k}})] \quad (2)
\]

Where \( T_{ph_{ki}} \) is the measurement physical temperature, \( G_k^A(T_{ph_{0k}}) \) is PMS gain at the calibration temperature \( T_{ph_{0k}} \) which is estimated by means of the two-level four-point method during an orbit in calibration mode to
be performed every two months. Finally, $S_{2ph}^{G}$ is PMS gain sensitivity to temperature drift, which has been measured both on-ground and in-flight for each LICEF, showing good agreement.

$G_{pk}^{A}, T_{pk}^{A}$

$T_{sky}^{A}$

$T_{phb}$

$T_{sky}^{A}$

$T_{sky}^{A}$

$\eta_{pk}$

$V_{sky}, V_{ck}$

Figure 2. LICEF/PMS front-end scheme to illustrate the one-point calibration scheme.

2. ONE POINT AMPLITUDE CALIBRATION

The so-called one-point (1P) calibration [4],[5] is an alternative PMS calibration method that has been developed, as a risk mitigation approach, with two main objectives:

- Evaluate (and correct if required) ground CAS S-parameter residual errors, during deep sky calibration.
- Alternative method to track PMS orbital gain drift by means of periodic U-noise injection

As an exploratory option, the instrument has also been tested to operate in the so-called “all-LICEF” mode. In this mode, the one-point method is used to estimate the antenna temperature (zero baseline visibility) as the mean value given by the 72 LICEF units.

2.1. Validation of CAS coefficients

Fig. 2 gives the block diagram of the PMS front end, showing the main 1P calibration magnitudes. During periodic (e.g. one month) deep sky views, the PMS is simultaneously calibrated by means of the internal 4P CAS system at the calibration plane CIP and by means of the external 1P calibration at the antenna planes (VAP/HAP). For a perfectly matched passive front end at a constant temperature $T_{phb}$, [4] shows that switching the instrument to the internal matched load (U port) is equivalent to place an absorber at the same physical temperature in front of the antenna. In this way, 1P PMS gain at the antenna plane is given by

$$G_{1pk}^{A} = \frac{v_{Ik} - V_{sky}}{T_{pk} - T_{sky}}$$ (3)

On the other hand, when translated to the antenna plane, the internal PMS 4P gain is given by [3]:

$$G_{4pk}^{A} = \frac{v_{Ik} - V_{sky}}{T_{CAS,N}^{2} - T_{CAS,S}^{2}} \frac{S_{Lk}^{2}}{S_{Nk}^{2}} \eta_{A}$$ (4)

Where $T_{CAS,N}^{2}$, are the CAS hot and warm temperatures as measured by the reference radiometer (NIR) at CAS port N, $S_{Nk}, S_{ik}$ are the CAS S-parameters from the noise source to the reference radiometer and PMSk calibration ports, respectively, $\eta_{A}$ is the antenna efficiency (A=V/H) and, finally, $S_{Lk}, S_{LC}$ are the switch s-parameters. As the 1P and 4P gains are computed at the same plane and at the same temperature, an error free instrument would yield:

$$G_{1pk}^{A} = G_{4pk}^{A}$$ (5)

Figure 3. Comparison of CAS correction factors computed from horizontal and vertical amplitude calibrations by using ground antenna efficiencies (top) and flight antenna efficiencies (bottom).
In order to evaluate the error and compute a correction coefficient, the parameters in (5) are rearranged in the so-called $C_{Nk}$ coefficients. One of them is computed from the on-ground parameters.

$$C_{Nk}^{\text{gd}} = \frac{S_{La}}{|S_{La}|^2} \frac{S_{N0}}{|S_{N0}|^2} \eta_k$$

The other one uses the flight measurements and is computed during each external calibration (deep sky views):

$$C_{Nk}^{A} = \frac{T_{CASN}^{2} - T_{CASN}^{1}}{v_{2k} - v_{1k}} \frac{\gamma_{UK} - \gamma_{SKYk}}{T_{PHik} - T_{SKYk}}$$

The error in the $C_{Nk}$ coefficients can be assigned to a CAS correction factor to be applied to the CAS ground coefficients. In order to check the consistency of this correction, some analysis has been undertaken and presented hereafter.

The $C_{Nk}$ coefficients can be computed from horizontal and vertical PMS gains. Both magnitudes should be equal, since each LICEF has a single CAS coefficient related to its calibration port CIP. Fig. 3 (top) shows that the ground characterization of the PMS front end is quite good since vertical and horizontal CAS coefficients match to $\pm 0.14$ dB. However, when using antenna efficiencies computed from the external deep sky views, the match is almost perfect (fig. 3, bottom). That is, external calibration decouples the ground characterization errors in antenna efficiency (two values per PMS) from the CAS ground errors (one value per PMS). The good consistency of CAS coefficients computed from horizontal and vertical calibration reveals both the good quality of the measurements and the front-end model.

In second place, the CAS correction factors have shown very good repeatability in a three months period. In Fig. 4 the external antenna efficiency and external CAS factors have been computed from the calibration event on 02/02/2010 (reference calibration). These coefficients have then been used to calibrate the internal 4P gain in different calibration events from 12/01/2010 to 06/04/2010 to be compared with new 1P external calibrations. In this period, the match between internal and external gains remains within $\pm 1\%$ pk-to-pk, well below the system requirement of 1% RMS error. There is a small 0.2% bias in the error that requires further assessment. In any case, this bias is corrected by the periodic external calibration events.

### 2.2. PMS gain correction by periodic U-noise injection

This method has been devised as an alternative PMS gain estimation to be used in the case that periodic inter-orbit amplitude calibration was required. On-ground tests revealed some degree of hysteresis in the behaviour of PMS gain under fast and/or large temperature swings [5]. Since receiver noise temperature showed a better behaviour, in-orbit internal calibration was foreseen by periodically switching the receiver to the internal matched load (U-noise). In this case, PMS gain at the calibration physical temperature $T_{phi}$ is given by

$$G_{k}^{A}(T_{phi}) = \frac{\gamma_{UK} - \gamma_{SKY}}{T_{Rk}(T_{phi}) + T_{SKY}}$$

Where, receiver temperature at $T_{phi}$ is estimated as
The reference receiver temperature $T_{phot}^R(T_{ph0})$ is estimated by means of the 1P method [5] during external calibration (deep sky views) at the calibration physical temperature $T_{phot}$. $T_{ph0}$ sensitivity to temperature (about 0.75 K/°C) was measured during the on-ground characterization when the instrument was tested at the Large Space Simulator (LSS) in Nordwijk, Holland (ESA) [5].

Figure 5 (top), shows an example of the 1P calibration approach applied to unit 30 (LCF-B-03), which is one of the four outlier units presenting the largest temperature swing (fig. 1). The instrument was in calibration mode during a few orbits to assess the behaviour in temperature of several calibration parameters. The black line gives PMS gain calibrations performed every 30 s. The blue line shows the estimation of PMS gain by means of (2). The reference gain has been computed as the mean value for all the orbits, whereas the orbital drift is tracked by using the temperature measurements from a thermistor placed at the front end in each unit. The effect of a certain amount of hysteresis is clearly seen in the comparison of the two plots (black and blue lines), yielding a moderate rms error (red circle in fig. 5, bottom).

On the other hand, the red line presents spline interpolation from 1P calibration PMS gain estimations every 6 min (red dots). In this case, since receiver temperature shows lower hysteresis [5], PMS gain can be tracked by periodic measures of the internal matched load (U-noise injection). Figure 5, bottom, shows the PMS rms gain error for the three methods analyzed from flight data during the first months of the commissioning phase:

a) PMS gain constant as the mean value computed from several orbits in calibration mode (black stars). In this case, the error is caused by orbital temperature swing.

b) PMS gain estimation using the last calibration (more than one orbit apart) and temperature swing compensation by means of the PMS sensitivity to temperature (blue stars).

c) Inter-orbit PMS estimation by means of periodic (e.g. 6 min) measurements of the matched load (U-noise injection).

Although method c) is the most accurate, method b) has been selected since gives an error well below the 1% RMS system gain error requirement and minimizes the loss of snapshot (maximum observation mode configuration).

2.3. All-LICEF antenna temperature

Fig. 6 shows SMOS antenna temperature -V(0,0)-computed as the mean antenna temperature estimated by the 66 LICEF units. For each LICEF, antenna temperature at the antenna plane is computed as

$$T_{phk} = \frac{T_{phk}^A - v_{offk}}{G_{phk}^A} - \hat{T}_{rk}^A$$

Where PMS gain $G_{phk}^A$, offset $v_{offk}$ and receiver temperature $\hat{T}_{rk}^A$ are computed by means of the external PMS cold sky calibration directly at VAP/HAP, and corrected in physical temperature $T_{phot}$ for each snapshot, as given in (9).

All-LICEF antenna temperature is compared in H/V to the mean antenna temperature measured by the three NIR units. The plots show antenna temperature evolution (horizontal and vertical polarizations) within
an orbit on 02/02/2010. As shown in fig. 6, the coarse behaviour given by the NIR units and the All-LICEF mode is very similar. Some additional analysis reveals that the performance of each single LICEF unit yields a moderate error in the estimation of antenna temperature, however, the average of the 66 LICEF estimations gives a performance similar to the NIR units. Fig. 6 shows the capability of both, the NIR and the all-LICEF mode to track antenna temperature orbital evolution. However, further analysis is still required to fully assess the absolute accuracy of the measurements.

Figure 6. Comparison of antenna temperature (horizontal and vertical polarizations) measured by the all-LICEF mode and by the NIR units on 02/02/2010, showing similar performance.

In order to illustrate the capability of the one-point calibration method in retrieving V(0,0), fig. 7 presents the brightness temperature retrieval from data collected on January 2010 within the “all-LICEF” test.

3. CONCLUSIONS

In-orbit MIRAS/SMOS amplitude calibration performs well within expectations. First analysis performed during the commissioning phase show that low orbital temperature swing, very good stability and careful temperature compensations keep PMS gain estimation well below the 1% rms system error requirement.

The one point method has proved to work properly both to check (and fine tune) the performance of the current four point two level amplitude calibration method and as a risk mitigation alternative to be used, if required, to retrieve the antenna temperature (all-LICEF mode) or to track orbital PMS gain drift.

4. ACKNOWLEDGMENT

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6. REFERENCES

**One point calibration in interferometric radiometers: MIRAS/SMOS preliminary results**

F. Torres(1), L. Corbella(1), N. Dufoo(1), V. González-Gambau(1), I. Durán(1), M. Pablos(1) and M. Martín-Neira(2)

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**INTRODUCTION.** After the successful launch of the SMOS satellite, on November 2009 at 02:50 CET (01:50 UT) from the Plesetsk Cosmodrome in northern Russia, a preliminary evaluation of the payload calibration strategy has been undertaken in order to assess the instrument performance and fix the operational measurement and calibration configuration. This work presents the performance of the amplitude calibration strategy, a key issue in achieving a stable and accurate operation of the sensor.

**ONE POINT CALIBRATION:**

1) Used to correct CAS S-parameter residual errors during deep sky calibration.


**CONCLUSIONS**

- In-orbit MIRAS/SMOS amplitude calibration performs well within expectations. Low temperature swing, very good stability and careful temperature compensation keeps PMS gain estimation well below the 1% RMS system error requirement.

*Acknowledgments.* This work was supported by the European Space Agency and EADS-CASA Space Division in the frame of the SMOS project. This work has been partially funded by the Spanish Ministry of Science and Innovation and FEDER under project TEC2008-06764-C02-01.
ENHANCED SMOS AMPLITUDE CALIBRATION USING EXTERNAL TARGET

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1. INTRODUCTION

With almost three years of continuous operation, the instrument MIRAS (Microwave Interferometric Radiometer using Aperture Synthesis) on board the SMOS (Soil Moisture and Ocean Salinity) satellite is successfully providing calibrated level 1 data, which is automatically ingested into the higher level processors in order to produce Soil Moisture and Ocean Salinity data for the end users. The instrument calibration is based on a combination of internal and external procedures defined well before the launching of the satellite in November 2009 [1, 2, 3]. They were later refined during the six-months long in-orbit commissioning phase [4, 5] with the main objective of improving some of the parameters characterized on ground and also to decide on the most appropriate rate of calibration events according to the actual in orbit performance of the radiometer. The visibility phase calibration was early spotted as needing frequent refreshment, so an inter-calibration period of 10 minutes was set at the conclusion of the commissioning phase. Concerning amplitude calibration, the most critical elements were the noise-injection radiometers (NIR) used to measure the average antenna temperature of the target. The present periodicity of 2 weeks between NIR calibration events was also established in the commissioning phase. On the other hand, the visibility amplitude calibration relies on a quite standard two-level approach and it is carried out internally every 2 months.

Careful analysis of the calibration data gathered so far has shown that the nominal amplitude internal calibration is not accurate enough. It is mainly influenced by the antenna loss, which is outside the loop of thermal control and, due to the stringent conditions of the space environment, experiences continuous drifts and seasonal variations that can only be tracked using external calibrations.

Fortunately, an external procedure for amplitude calibration was already predicted before launching and it was included in the nominal calibration sequences of the on-board processor. At present, the outcome of these sequences is not used by the official SMOS level 1 processor. However, they have been used here in order to implement a new strategy for amplitude calibration that intends to minimize the drifts in the calibrated visibilities.

This paper focuses on the theoretical basis and general procedures for the characterization of antenna loss using the cold sky calibration sequences. The main objective is to find an improved procedure to compensate for the long- and short-term drifts observed in SMOS data. Future versions of the SMOS level 1 processor will include the procedures detailed here.

2. THE FRONT-END MODEL

Internal calibration is carried out by injecting noise power to the input of all receivers using dedicated switches. Conversion from antenna plane to calibration plane is then based on a circuit model of the front-end consisting of several attenuators at different physical temperatures. For the standard receivers (called LICEF), this model consists of an attenuator \( L_1 \) at temperature \( T_{p7} \) corresponding to outer part of the antenna, another attenuator \( L_2 \) at a different temperature \( T_{p6} \) for all microwave circuitry within the antenna enclosure and the switch itself, modeled also as an attenuator at \( T_u \). For the case of the NIR units there are extra attenuators to take into account the additional subsystems used to implement the NIR operation. Before the SMOS launch the antenna efficiency was set to a fixed value of 0.3dB for all antennas, corresponding to \( L_1 = 0.05dB \) and \( L_2 = 0.25dB \). The switch losses were accurately characterized on ground at different temperatures. It has been observed that these fixed values, especially for antenna losses, are not consistent with the observations.

When using the front-end model the different contributors to the measured noise temperature become function of antenna loss when this is considered as a parameter. If this is combined with the measurement of known targets, as the cold sky and a matched resistor, an estimation of the antenna loss can be carried out.
3. ANTENNA LOSS CHARACTERIZATION USING SKY LOOKS

When the instrument is pointing to the sky, the expected antenna noise temperature can be computed by integrating the galaxy map weighted by the antenna power pattern, which was accurately measured on ground for all antennas. By switching the receivers’ input from antenna to a matched load and recording the corresponding PMS (power measurement system) voltages, values of $L_1$ for all LICEF and NIR can be obtained at each cold sky calibration sequence.

Figure 1 shows the retrieved $L_1$ values corresponding to the maneuver of 14th March 2012 for both H- and V- polarization and for all antennas. The average value is shown in a thick black line in both cases (about 0.35 dB). There are some receivers that exhibit larger variation than others, but in general all antennas have similar behavior.

![Fig. 1. Retrieved $L_1$ values of LICEF and NIR in the external maneuver of 14th March 2012. Left: H-pol Right: V-pol.](image)

The retrieved values of $L_1$ vary in long-term periods, as found when computed from different external maneuvers. The plot at the left of figure 2 shows the average $L_1$ retrieved in each of the external maneuvers carried out since almost the beginning of the mission up to March 2012. There is a clear trend compatible with the strong variation of the physical temperature $T_{p7}$ shown in the plot at the right in the same figure for the three NIR units.

![Fig. 2. Left: Average $L_1$ values in all external maneuvers from January 2010 to 14th March 2012. Right: Antenna patch physical temperatures $T_{p7}$ for the three NIR units in the same period.](image)

4. IMPACT IN NIR CALIBRATION

A noise injection radiometer (NIR) is a Dicke radiometer that measures the antenna temperature by monitoring the width of a pulse during which noise is injected near the antenna in order to continuously provide balanced operation [6]. The basic equation for the antenna temperature is:

$$T_A = T_U - \eta T_{NA}$$  

(1)

where $T_U$ is the physical temperature of the internal resistor of the Dicke switch, $\eta$ is the pulse width and $T_{NA}$ is the equivalent noise temperature of the noise injection source. In SMOS this parameter is currently calibrated by periodic pointing of the instrument to the cold sky [3, 1].

The attenuation $L_1$ is used in the NIR calibration equations to subtract the noise generated by this component and also to make plane translations [3]. The original approach was to use the nominal values specified on ground. Later, a correction was applied by using a model for $L_1$ based on $T_{p7}$ to account for variation with respect to the nominal value [5]. This model did not completely mitigate the drifts due mainly to the progressive lack of correlation between the $L_1$ drift and the physical temperature.

On the other hand, if the values of $L_1$ computed from cold sky PMS calibration correctly account for antenna losses, they should also be used in the NIR calibration procedures and in the NIR antenna temperature retrieval during processing of science data. This section presents the results obtained when using the calibrated $L_1$ values into the NIR calibration equations.

4.1. Long term drift

Figure 3 shows the percentual drift of $T_{NA}$ for the three SMOS NIR units retrieved from all calibration events from the beginning of the mission. At left, the result obtained using the nominal $L_1$ values and at right the result when the calibrated $L_1$ values are used. In this last case, they become highly constant for all units. In the whole mission, all NIR units have a drift bounded within about ±0.5% and in most of the time, especially after the commissioning phase, substantially lower.

![Fig. 3. Relative long term TNA drift. Left: Using the nominal $L_1$ attenuator. Right: Using the calibrated $L_1$ values.](image)
This result is even more apparent when the average drift along all NIR units is considered, as shown in figure 4. The plot at the left corresponds to the average noise injection NIR temperature when using nominal $L_1$ while the one at the right is for the calibrated $L_1$. When using the calibrated $L_1$, the different drifts in different NIR units are uncorrelated among them (as seen in figure 3) and when averaging, the error reduces to about 0.2% in most of the period. However, when the nominal values are used the estimated drift in all NIR units become more correlated and their average roughly follows the $T_{p7}$ variation, as seen in the plot at the left of figure 4. The plots in figure 4 also show the drift in the TNR parameter, used to calibrate the PMS gains during internal calibration [3].

4.2. Short term drift

One of the features found while computing the NIR calibration parameters using the nominal $L_1$ value is that, within a given calibration event the different TNA retrievals do not remain constant but show instead a clear drift correlated to the instantaneous $T_{p7}$ variation in the maneuver. This drift is inconsistent with the result of figure 1, which shows that $L_1$ does not vary in the short term, even though $T_{p7}$ is continuously decreasing during the external maneuver.

To assess on this incongruence, the NIR TNA has been computed for a specific external maneuver (1st November 2011) using the nominal value of $L_1$ and also using the average value retrieved from cold sky PMS calibration. In both cases $L_1$ is assumed constant in the whole maneuver, but only with a different value. The result is shown in figure 5. The relative drift of TNA with respect to its mean value along the maneuver is plotted as a function of time for NIR units BC and CA (NIR AB shows a quite erratic behavior due to a known malfunction). The plot at the left corresponds to using the nominal attenuator value while the one at the right uses the attenuator computed using the PMS cold sky calibration sequences. Clearly, in this second case the slope is much lower, demonstrating that the negative trend of TNA observed in the left plot is only a calibration artifact due to using an erroneous value of $L_1$.

To confirm that this is general and not only a result of this particular maneuver, the slope of TNA with respect to time in a calibration event has been computed for all the external maneuvers from January 2010 to November 2011. It corresponds to the slope of the plots of figure 5 in K/min. The result is shown in figure 6 for both nominal $L_1$ at left and calibrated $L_1$ at right. As expected, there is a clear negative value of slope for most of the cases when the nominal $L_1$ is used. However, when using the calibrated value, the slopes are greatly reduced, as observed by the zero mean plot, demonstrating that the short term drift is either non existent or at least much less important than predicted.

5. CONCLUSIONS

The single element antenna patch loss, characterized by an attenuation $L_1$, is a key parameter in SMOS data processing. It is used to compute the system temperature for visibility de-normalization and the average antenna temperature from the raw NIR measurements. A theoretical estimation of this attenuation was carried out before launch in order to provide a default value, which was set equal to 0.05dB for all antennas. However, from the beginning of the mission it was soon observed that keeping a constant value for $L_1$ resulted in unexpected and un-natural drifts in the processed data. The conclusion is that $L_1$ does not remain constant and must be
periodically estimated in order to introduce refreshed values into the processing.

Accurate on-flight characterization of the antenna loss is performed using the PMS cold sky sequences programmed in each external maneuver. The results show that this parameter is about 0.32 dB larger than expected and experienced an important drift around April-June 2010 followed by a relatively small seasonal behavior. Within a given external maneuver it remains quite constant with no clear relation to any physical temperature.

6. REFERENCES


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Analysis of amplitude calibration drift in SMOS

Miriam Pablos, Israel Durán
SMOS-BEC / UPC / Remote Sensing Laboratory
NIR and PMS units have revealed an unexpected drift, that has become more apparent since March 2010.

Mean PMS cold sky gain drift (CIP)

Antenna patch mean temperature drift

NIR and PMS drift seems to be correlated to antenna patch temperature swing ($T_{p7}$ in NIR nomenclature)
Estimation of real LICEF PMS gain drift at CIP

\[ v_k = v_{off_k} + G_k \cdot T_{sys_k} \]

**PMS Internal 1P Gain:**

\[ G_{1P}^{CIP} (T_u) = \frac{v_u}{T_u + T_{rA} (T_u)} \cdot \frac{|S_{LC}|^2}{\eta_{ext} \cdot |S_{LA}|^2} \]

**PMS Internal 4P Gain:**

\[ G_{4P}^{CIP} (T_u) = \frac{v_{2k} - v_{1k}}{T_{NR} (\eta_2 - \eta_1)} \cdot \frac{|S_{N0}|^2}{|S_{k0}|^2} \]

**PMS External 1P Gain:**

\[ G_{ext}^{CIP} (T_u) = \frac{v_{u(external)}}{T_{u(external)} + T_{CIP}^{RMIER} (T_u)} \]
A systematic analysis has been assessed with 3 cases (fixing different calibration parameters)
Analysis of PMS real drift at CIP (absolute value)

A systematic analysis has been assessed with 3 cases (fixing different calibration parameters)

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The NIR front end has been successfully modeled by means of the antenna patch attenuation $L_1$ linearly drifting with its physical temperature $T_{p7}$ [1].

By using the NIR new model TNR values, internal 4P PMS mean gain drift is highly compensated (drift <0.2% January to June 2010)

Considerations: Receiver noise temperature at CIP is constant (no drift)
The front end is perfectly matched
Front-end error and drift exclusively assigned to $L_1$

$$T_R^A = \frac{v_{SKY} T_{Ueq} - v_U T_{SKY}}{v_U - v_{SKY}}$$
$$G^A = \frac{v_U - v_{SKY}}{T_{Ueq} - T_{SKY}}$$

Equivalent physical temperature $T_{Ueq}$ at VAP/HAP

$$T_{Ueq} = L_1 L_2 T_U - T_{p7} (L_1 - 1) - T_{p6} L_1 (L_2 - 1)$$

Antenna path attenuation $L_1$

$$L_1 = \frac{T_{p7} - T_{sky}}{T_{p7} + T_{p6} (L_2 - 1) - \frac{L_2 K}{v_U}}$$

$$K = v_A T_U - (v_U - v_A) \left[ \frac{|S_{LC}|^2}{|S_{LA}|^2} T_{RCC}^C + \frac{|S_{LC}|^2}{|S_{LA}|^2} - 1 \right] T_U$$

$$T_{RCC}^C = T_{RCC}^C (\text{Mier}) \text{ at calibration } T_U$$

$$L_2 = 1.0593 (+0.25 \text{ dB}). \text{ Nominal value}$$
NIR new front-end model applied to the LICEF units

Long term drift:

\[ L_1 = L_{10} + b_L \left( \bar{T}_{p7} - T_{p70} \right) \]

- reference temperature (mean \( T_{p7} \) for all calibration events Jan-Oct)
- mean \( T_{p7} \) during each PMS cold sky calibration (2, 4 or 8 calibrations)
- long term sensitivity
- antenna patch attenuation at \( T_{p70} \)

Short term drift:

\[ L_1 = \bar{L}_{10} + b_S \left( T_{p7} - \bar{T}_{p7} \right) \]

- mean \( T_{p7} \) during each PMS cold sky calibration event (8 calibrations)
- "instantaneous" temperature for each of the 8 calibrations
- short term sensitivity
- antenna patch attenuation at \( \bar{T}_{p7} \)

Long term and short term parameters are estimated independently. However, the equations are merged in calibration according to:

\[
L_1 = L_{10} + b_L \left( \bar{T}_{p7} - T_{p70} \right) + b_S \left( T_{p7} - \bar{T}_{p7} \right) = L_{10} + \left( b_L - b_S \right) \left( \bar{T}_{p7} - T_{p70} \right) + b_S \left( T_{p7} - T_{p70} \right)
\]
Estimation of long term coefficients

Linear regression of L1 values respect Tp7 (averaging before the calibrations of one day)

23 tests (Jan-Oct)
Estimation of short term coefficients

Linear regression of L1 values respect Tp7 (computing separately each day)

PMS gain error does not show a clear correlation either with $T_p7$ or with $T_u$.
Application of long and short term drift correction

- Long term coefficients correct LICEF front-end drift to a large extend.
- Short term regression yields a large regression error due to several causes: small set of points, low level of averaging in single calibrations, non-negligible residual $T_U$ correction error.

**With correction**

**Without correction**

![Graph showing Tp7 mean evolution during external calibrations]

External PMS calibrations from 27-04-2010 to 12-10-2010

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Conclusions

• LICEF new front-end model assessed by means of PMS cold sky calibration and new PMS cold sky calibration equations have been developed to take into account the new front-end model.

• LICEF long term model well behaved.

• LICEF short term behavior not well modeled by linear drift of L1 with Tp7.

On-going activities

• Computation of all-LICEF antenna temperature for ascending and descending orbits over the Pacific Ocean, in selected days, to assess the performance of the new LICEF front-end models.

• Further investigation of LICEF short term model. Assessment of the impact of residual Tu gain correction error.
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Assessment of antenna temperature drift over the Ocean

Israel Durán, Miriam Pablos, Lotta Rehn-Molin
SMOS-BEC / UPC / Remote Sensing Laboratory
Introduction

A new tool is being developed to provide a preliminary analysis of the impact of orbital temperature swing on SMOS data.

**OBJECTIVE**

Assess the differences between ascending and descending orbits of certain parameters

The main temperature impact is expected to come from:

- The antenna patch temperature (Tp7 in NIR nomenclature)
- The LICEF temperature $T_U$ as given by the LICEF front-end thermistor.

These preliminary results are based on UPC software MTS version 9. This version uses a LICEF front-end at a constant temperature.
Processing description

Organize L0/L1 data of the selected orbits for automatic analysis with different LICEF front-end models.

Assess the effect of short-term temperature swing on LICEF gain representing several variables (allLICEF mode) respect to the selected pacific latitudes:

- Antenna temperature (Ta)
- Antenna patch temperature (Tp7)
- Physical temperature (Tu)

Analyze the impact of the long-term PMS gain drift in the NIR/LICEF representing along the time (from January to November 2010):

- Antenna temperature (Ta)
Short-term tool scheme (1)(i)

Obtain L0/L1 data from SMOS

Select two Pacific half-orbits (one ascending and one descending)

Load necessary data
• Antenna temperature
• Antenna patch temperature Tp7
• LICEF temperature TU
• Latitude/Longitude (Boresight)
Short-term tool scheme (1)(ii)

Filter H/V polarization

Calculate mean of H/V

\[ T_a = \frac{1}{2} \left( T_{aH} + T_{aV} \right) \]

\[ T_{p7} = \frac{1}{2} \left( T_{p7H} + T_{p7V} \right) \]

\[ T_U = \frac{1}{2} \left( T_{UH} + T_{UV} \right) \]

Represent results

Differences between Ascending & Descending

Ascending vs Descending

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Preliminary results: Antenna temperature

Ascending

Descending
Preliminary results: Difference Ascending vs Descending

Ta difference Ascending vs Descending MEAN

Tp7 difference Ascending vs Descending MEAN

Ta difference Asc vs Desc < 1 K
**Long term tool scheme (2)(i)**

Chose an area that radiates uniformly

Area of Study in the Pacific Ocean

Select orbits from 5 days per month crossing the area of study

Crossing Orbits March

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Long term tool scheme (2)(ii)

Separate Ascending and Descending Orbits

Compute mean antenna temperature:
1) Mean of all measurements during one orbit for each receiver
2) Mean of all LICEFs & all NIRs in the same orbit
3) Weighted mean for each orbit depending on the number of measurements
4) Mean antenna temperature of all orbits in each month

Separate H & V polarization for both LICEFs and NIRs

Represent results
Preliminary results: **Long-term Stability of Antenna Temperature**

**Long-term Stability of Mean Antenna Temperature**

![Graphs showing long-term stability of mean antenna temperature](image)

1P Approach

4P Approach

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Preliminary results: Long-term Stability of Antenna Temperature

ZOOM: Long-term Stability of Mean Antenna Temperature

V-pol

H-pol

1P Approach

4P Approach

Mean Ta_H as
Mean Ta_V as
Mean Talicef_H as
Mean Talicef_V as
Mean Ta_H des
Mean Ta_V des
Mean Talicef_H des
Mean Talicef_V des

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Preliminary results: Long-term Stability of Antenna Temperature
Summary

The new tools provide:

- **Short-term** tool provides a large number of results in different kinds of representations (latitude, time, arm section)
- **Long-term** tool provides an stability analysis of antenna temperature where ascending and descending orbits are separated as well as H and V polarization for LICEF and NIR antennas.

On-going activities

- Representing antenna temperature with the new front-end model in order to compare ascending and descending half-orbits over the Pacific ocean.
- Investigating the Long-term stability of antenna temperature with different inversion and calibration options