MEDIA CALIBRATION SYSTEM FOR DEEP SPACE MISSIONS: PRELIMINARY DESIGN AND TECHNICAL ASPECTS

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ABSTRACT

Media Calibration Systems (MCS) are intended as a group of one or more meteorological instruments, to be used to estimate the troposphere path delay at a Deep Space Station (DSS) to calibrate the RF-links of deep space probes. The most accurate MCS are capable of estimating the path delay along the Line-of-Sight between the probe and the ground station. Some critical aspects have been highlighted which lead to the definition of an accurate MCS based on a combination of: steerable microwave radiometers (Troposphere Calibration Radiometers – TCR), meteorological stations, atmosphere profilers, GNSS receivers and data acquisition and processing systems. This work shows the layout of a preliminary design of a MCS to be installed at the ESA tracking station of Cebreros (Spain) and the estimated error budget.

Troposphere Calibration Radiometer

The TCR represents the most crucial component of the MCS. In this study the design of the instrument is based on the RPG-ATPROP (Radiometric Physics GmbH, Atmospheric Profiler) MWR.

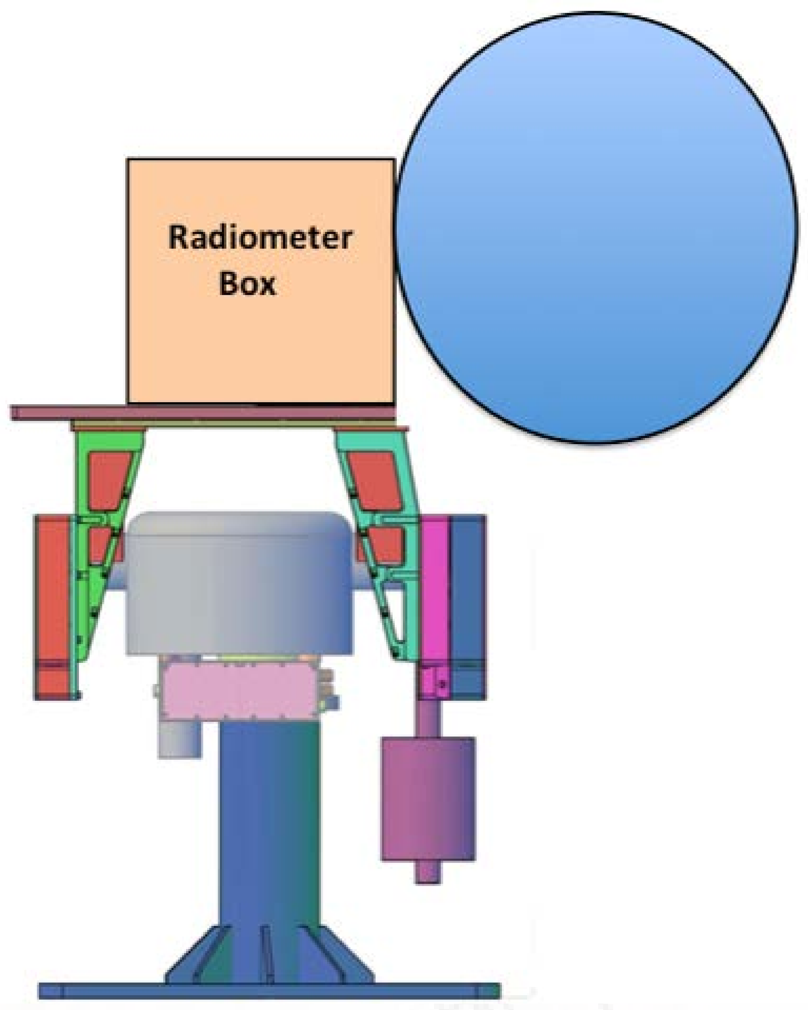
The instrument is equipped with a K-band receiver with noise level of about 0.5 K, in order to provide estimates of the SWD accurate to about 10 mm for all elevations equal or higher than 20 deg.

The use of the 7 frequencies of ATPROP (22.235 to 31.4 GHz) is required. This approach provides information on the vertical distribution of water vapor, the reduction of the risk of radio frequency interference and slightly improves the SWD accuracy. The results of a trade-off analysis drives the need for two notable changes:

1) The need for a larger antenna beamwidth about 1° Full Width Half Maximum with high side lobe suppression to achieve the requirements for atmospheric beam matching and avoid Sun contamination.

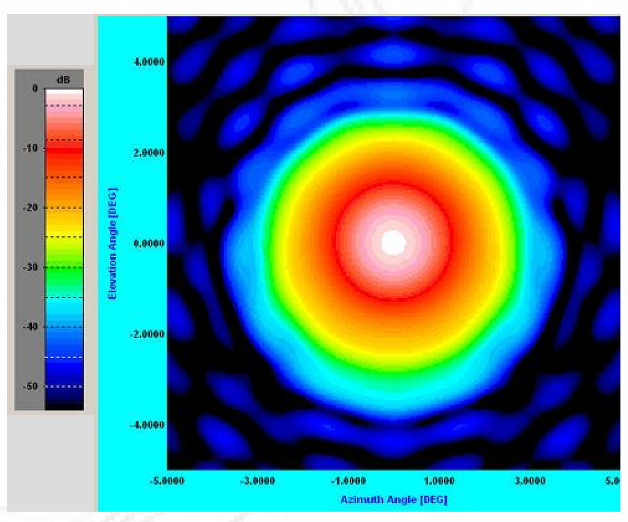
2) The inclusion of a total power receiver in addition to the Dicke switch noise injection receiver in order to achieve the Allan Standard Deviation (ASD) requirements for both short and long integration times.

A crucial aspect is that the TCR will be installed on a tracking system which allows synchronized pointing of the instrument to the spacecraft (S/C).



TCR ANTENNA DESIGN

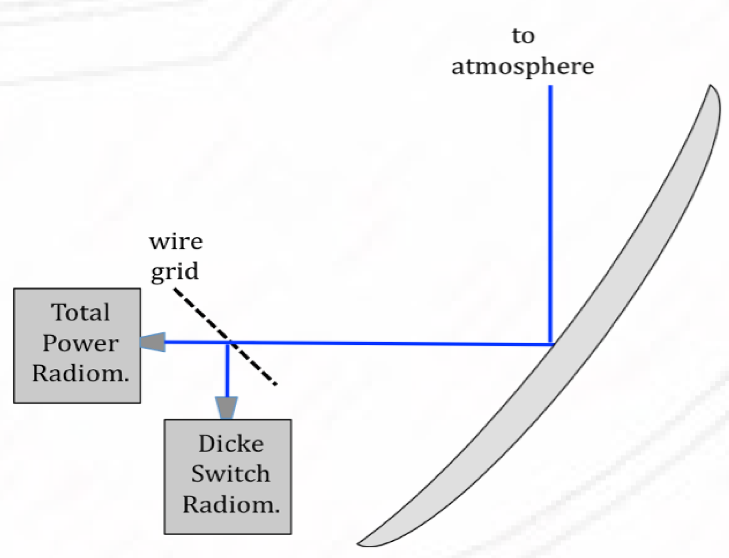
A 80 cm off-axis parabolic antenna will be milled in one piece to guarantee highest stability and high surface accuracy up to 40 GHz. The resulting beamwidth is 1.334 deg at 23 GHz and the gain is 42.5 dB. The antenna beam patter shows a side lobe suppression of -45 dB compared to -32dB for ATPROP that is well suited to avoid sun contamination via the side lobes.



TCR RECEIVER DESIGN

At short integration times an ASD increase is expected due to mismatching of the MWR and the DSA beams. For this reason, the TCR would be equipped with a double radiometric unit incorporating a total power radiometer and a Dicke-Switch radiometer. A wire grid would split the incoming signal from the atmosphere into its two linear components so that the same antenna viewing the same part of the atmosphere can be used. The receiver units contain the same low noise amplifier and filterbank system used in RPG-ATPROP. Each unit has seven channels that are individually amplified and bandpass filtered.

The receiver noise temperature of the channels will be lower than 400 K.



Meteorological Station

This instrument is crucial to measure the main meteorological parameters in order to monitor the weather conditions around the MCS (e.g. the turbulence level) and to better define the retrieval algorithm for the TCR. The sensors included in the meteorological station have to measure: surface temperature, surface humidity, surface pressure, wind direction and strength, height of the cloud base and rain rate.

At the ESA DSA sites a meteorological station is currently available and it should be used and included in the next generation MCS.

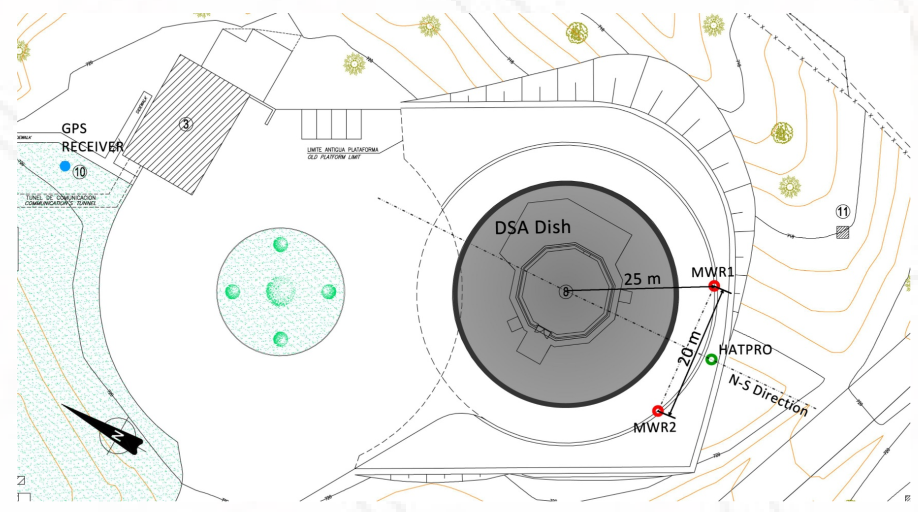
Atmosphere Profiler

A dedicated instrument should be included in the MCS for profiling assessment (humidity and temperature) and capable to perform autonomously its scan pattern. This solution does not limit the TCR's tracking activity. While the TCR will be synchronized to track in parallel with the DSA, the profiler can continuously perform boundary layer scan and provide information on high accurate Atmospheric profiles. A possible instrument is the RPG-HATPRO capable of humidity and temperature profiling and equipped with a total power receiver in order to have a more accurate estimation.

GNSS Receiver

A GNSS receiver is an optional, but recommended, component of the MCS. It can serve as a backup instrument for different applications: estimation of atmosphere turbulence, time reference and comparison of Zenith Total Delay. Since accurate observations of the ground pressure are provided by meteorological stations, the equivalent ZWD can be inferred as a reference in order to validate the performance of the TCRs.

MCS Configurations and Deplyment Aspects



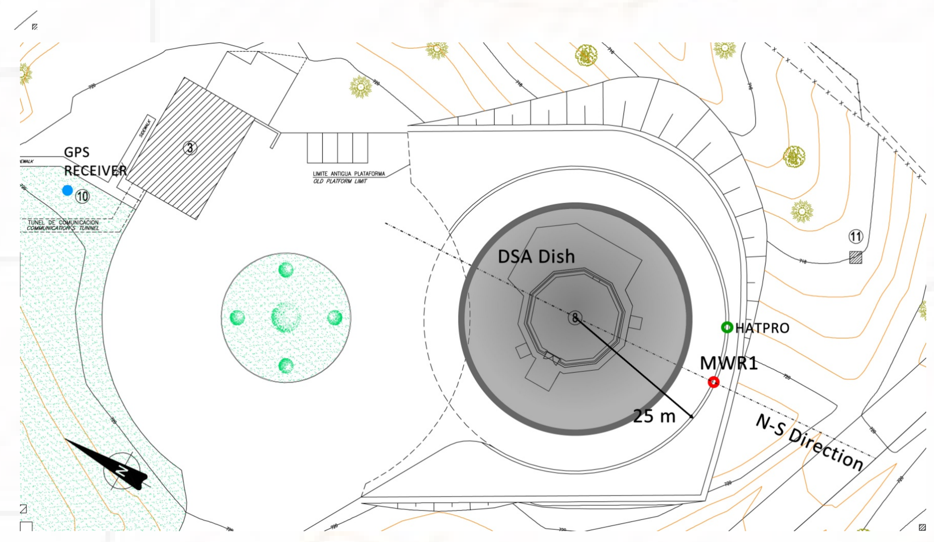
TWIN TCR CONFIGURATION

This is the most accurate and reliable and includes: two TCR, one RPG-HATPRO, one Meteorological Station one GNSS receiver and the data acquisition and processing system.

The two TCRs have been installed southward of the DSA antenna dish at a distance of about 25m from the center of the DSA basement in order to have a free of obstacle view of the sky.

SINGLE TCR CONFIGURATION

It is a backup solution. The equipments considered are: one TCR, one RPG-HATPRO, one Meteorological Station one GNSS receiver and the data acquisition and processing system. The expected performance of the MCS would be less reliable than the twin TCR configuration and no redundancy is guaranteed.



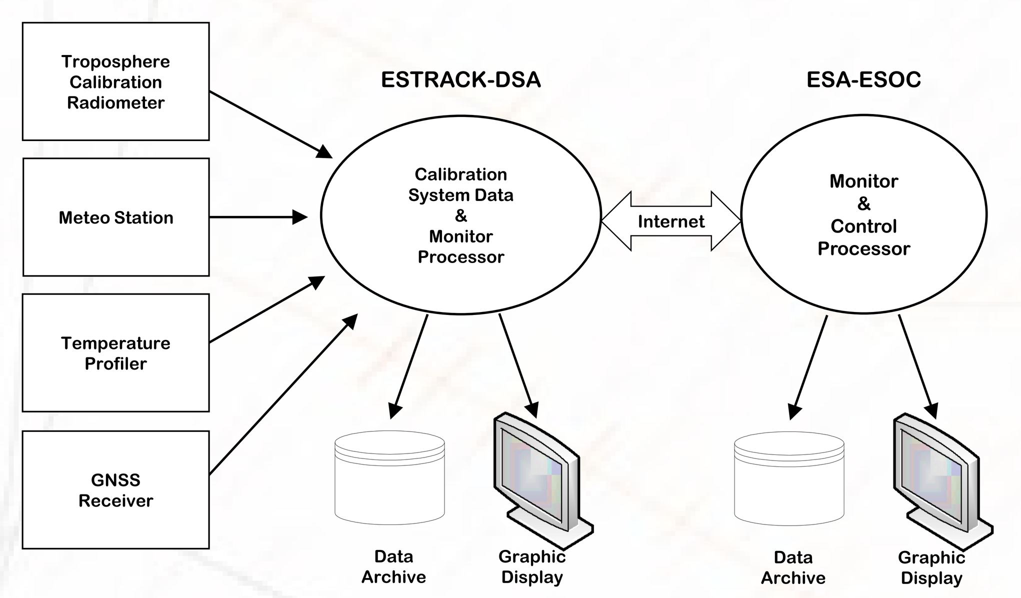
Data Acquisition and Processing System

This system is crucial to control the activity and to collect data from all instruments of the MCS and to process them in order to obtain the most accurate calibration.

Some MCS instrument (e.g. TCRs) are able to operate independently using their embedded computer. Thanks to an external connection, The collected data are sent to an external computer which interfaces with all other MCS instruments and processes all data in order to provide troposphere calibration.

Concerning the TCRs the software has to manage automatic tipping curve procedure.

At the same time the SW has to manage the scanning activity of the profiler as well as to monitor the acquisition activity of the other instruments.



Error Budget Computation

ALLAN STANDARD DEVIATION

The radio science requirements are defined in terms of a two-way tracking Allan Standard Deviation (ADEV) at different observation times, for this reason the MCS error budget terms have to be defined with the same parameter.

$$\sigma_x(\tau) = \left(\left\langle \frac{\left(x(t_k + 2\tau) - 2x(t_k + \tau) + x(t_k) \right)^2}{2\tau^2} \right\rangle \right)^{1/2}$$

ERROR BUDGET

Instrumental Stability: it represents the electronic and thermal internal noise of the instrument. This term dominates the entire budget.

Pointing Uncertainty: this term refers to the real and different pointing of the MWR and DSA beams.

Beam Offset: this error occurs when the MWR is not mounted on the axis of the DSA.

Beam Mismatch: this effect occurs since the MWR beam is a conic and senses a different volume of troposphere from the DSA cylindrical volume sampled.

Water Vapour Emission Model: it represents the uncertainty in the water vapor emission model.

Retrieval Algorithm: the use of different retrieval algorithms may induce a ADEV contribution.

Hydrostatic Fluctuations: it is a small contribution to the error budget due to the stable nature of the hydrostatic component of the atmosphere.

Hydrostatic Mapping Function: this error scales the path delay at higher magnitude than the wet one.

Error Budget Term	Observation time [s]		
	20	1000	10000
H/W Stability	2.22e-14	6.48e-16	7.11e-17
Feedhorn Spillover	1.12e-16	5.00e-17	5.00e-17
Pointing Uncertainty	6.18e-17	1.24e-18	1.24e-19
Beam Offset	4.27e-14	9.11e-16	9.11e-17
Beam Mismatch	9.23e-15	7.70e-17	7.70e-18
Emission Model	7.00e-16	3.00e-16	1.30e-16
Retrieval Algorithm	1.39e-14	8.00e-16	2.00e-16
Dry Fluctuations	4.47e-15	2.00e-16	2.00e-17
Dry Mapping Function	1.34e-16	2.60e-16	3.80e-16
Total	5.21e-14	1.29e-15	4.61e-16
MORE Requirements	3.00e-14	3.00e-14	3.00e-14

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Results of the ESA Study:
AWARDS – Advanced Microwave Radiometer in Deep Space Station (Contract 23127/10)