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Space systems — Calibration requirements for satellite-based passive microwave sensors

Systèmes spatiaux — Exigences d'étalonnage des capteurs passifs d'hyperfréquences satellitaires

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Water is one of the key elements for survival of all creatures on earth. Water brings us the blessings of food thanks to agriculture, but water is also responsible for providing forest products and fish, which are essential for our lives. However, too much or too little water can lead to environmental disasters such as hurricanes, heavy rains, floods, droughts and wild fires.

Many satellite sensors are launched through international cooperation ventures with the aim of monitoring the behaviour of the water cycle and estimating some of the parameters related to it, e.g. soil moisture, vegetation biomass, snow cover, sea ice, and so on. A systematic and timely monitoring of land surface parameters that affect the hydrological cycle at local and global scales are of primary importance in obtaining a better understanding of geophysical processes and in order to manage environmental resources and mitigate for natural disasters.

At present, some applications to assist our human activities are provided, such as weather forecasts and predictions of climate change. Nowadays, the observation data acquired by passive microwave sensors are used for weather forecasts, fishery services, drought monitoring on a daily basis, and for predicting climate change in the future. However, errors due to bias, gain, and sensitivity among passive microwave sensors can degrade accuracy of applications and users could waste effort and time for compensation by on-orbit operation.

This document standardizes calibration methods (requirements and verification methods) to minimize errors of observation data among passive microwave sensors. It is expected that this document can improve the accuracy of weather forecasts, sea surface temperatures for fishery services, soil moisture monitoring to decrease water waste for farmers, snow cover and depth for water storage. Moreover, these observations can provide useful information for climate change prediction that is relevant to our daily lives.

Space systems — Calibration requirements for satellite-based passive microwave sensors

1 Scope

This document defines the requirements and verification methods from design to on-orbit operation for Satellite Based Passive Microwave Sensors.

This document covers the requirements for, design, analysis, manufacturing, ground tests and on-orbit self-sensor calibration and validation. In addition, this document includes the conditions considered for on-orbit inter-comparison among sensors as preparation for cross-calibration. This document includes some examples on how to apply the development of passive microwave sensors as shown in Annex A through D.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10795:2011, *Space systems — Programme management and quality — Vocabulary*

ISO 14302, *Space systems — Electromagnetic compatibility requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10795:2011 and the following apply. ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
calibration
set of operations that establish, under specified conditions, the relationship between sets of values of quantities indicated by a measuring instrument or measuring system and the corresponding values realized by standards

3.2
validation
process of assessing by independent means the quality of the data products derived from the system outputs

3.3
level one processing
type of processing where the antenna brightness temperature of the sensor instrument is calculated and compensated radiometrically and geometrically based on evaluation results of ground test and on-orbit calibration

4 Abbreviated terms

ANT	Antenna sub-system
BTE	Bench Test Equipment
CCT	Cold Calibration Target
DT	Data Processor
EIA	Earth Incident Angle
FOV	Field Of View
GCP	Ground Control Point
GPS	Global Positioning System
ICS	Interface Control Specification
IF	Intermediate Frequency
LO	Local Oscillator
LCT	Low Calibration Target
MR	Main Reflector
NCS	Noise Calibration Source
RE	Radiated Emission
RF	Radio Frequency
RS	Radiated Susceptibility
RTT	Radiative Transfer Theory
Rx	Receiver
SRT	Standard Reference Target
VTS	Variable Temperature Source
WCT	Warm Calibration Target

5 Space based passive microwave sensor calibration overview

5.1 Mission and system overview

Satellite based passive microwave sensors observe weak microwave energy emitted from various components of the Earth's surface (rain, water vapour, clouds, snow, sea ice, soil, vegetation, etc.) using a variety of frequency bands from about 1 GHz to 200 GHz.

Each space-based passive microwave sensor design is tailored to meet its specific observation purpose. Observation data are collected at defined intervals and over defined integration periods. These data are downlinked through the spacecraft. Following Level One processing to perform radiometric and geometric compensation, the data are delivered to information providers.

Figure 1 shows the general operational concept view of space-based passive microwave sensor system integration. Space-based passive microwave sensors, to which this document applies, include the following components:

a) Cold Calibration Target (CCT) to determine deep-space limit or equivalent;

b) Warm Calibration Target (WCT) to monitor ambient temperature;

c) Main Reflector (MR) to capture the power of microwave emission from the earth; and

d) Receiver (Rx) sub-system to amplify the tiny power of the microwave emission.

Self-calibration is performed at specific time intervals using the WCT and the CCT.

Information providers process antenna brightness temperature to derive physical information and deliver that information to end users.

5.2 Types of passive microwave sensors

Satellite based passive microwave sensors are generally categorized as follows. This document covers the requirements for the following two types.

a) Microwave radiometer (or Microwave Imager)

   To mainly measure energy emitted from water related substances at sub-millimetre-to-centimetre wavelengths.

b) Microwave sounder

   To mainly measure the vertical profile of atmospheric temperature and moisture for operational weather and climate applications at sub-millimetre-to-centimetre wavelengths.

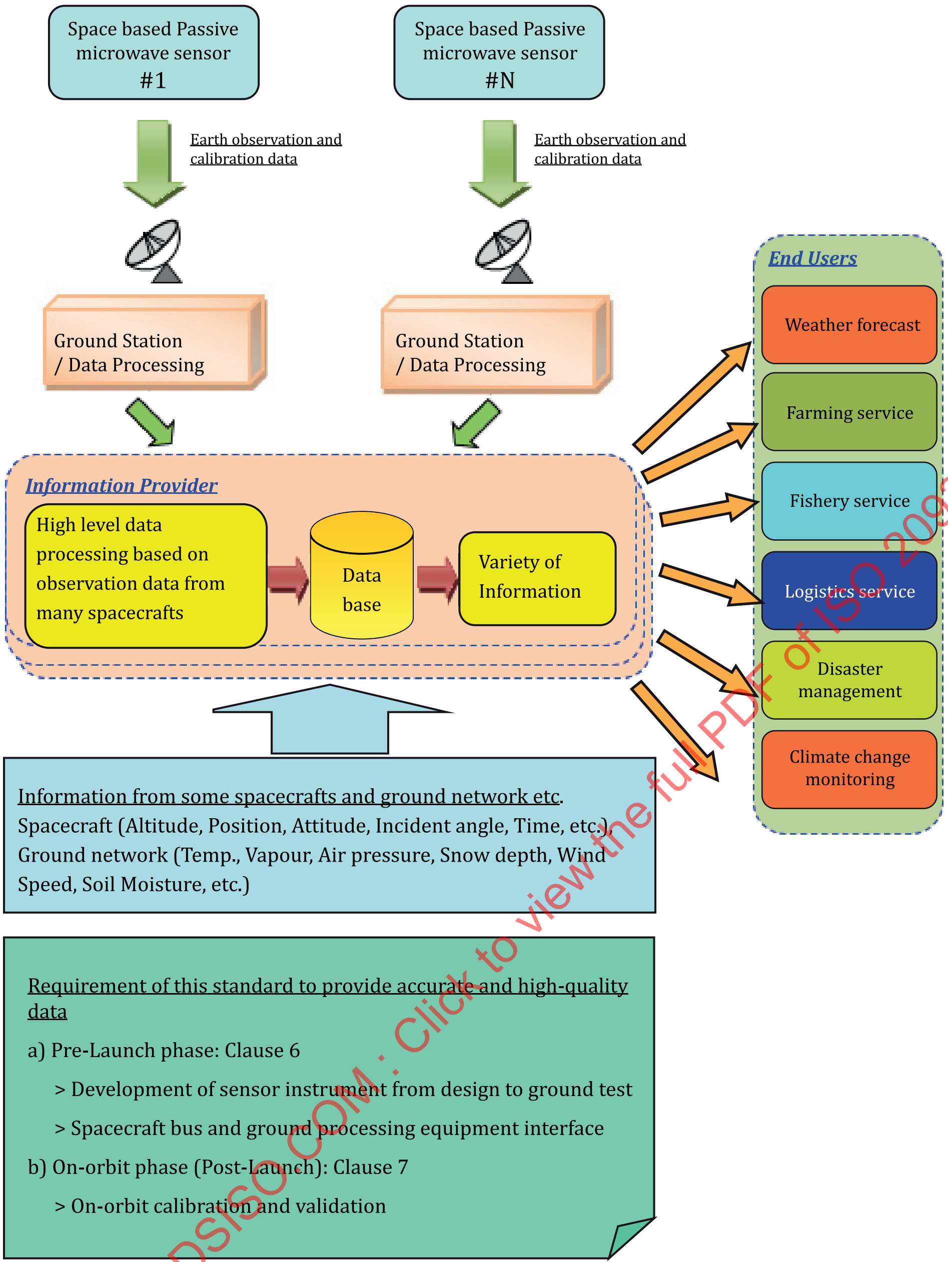


Figure 1 — Concept diagram of space based passive microwave sensor system

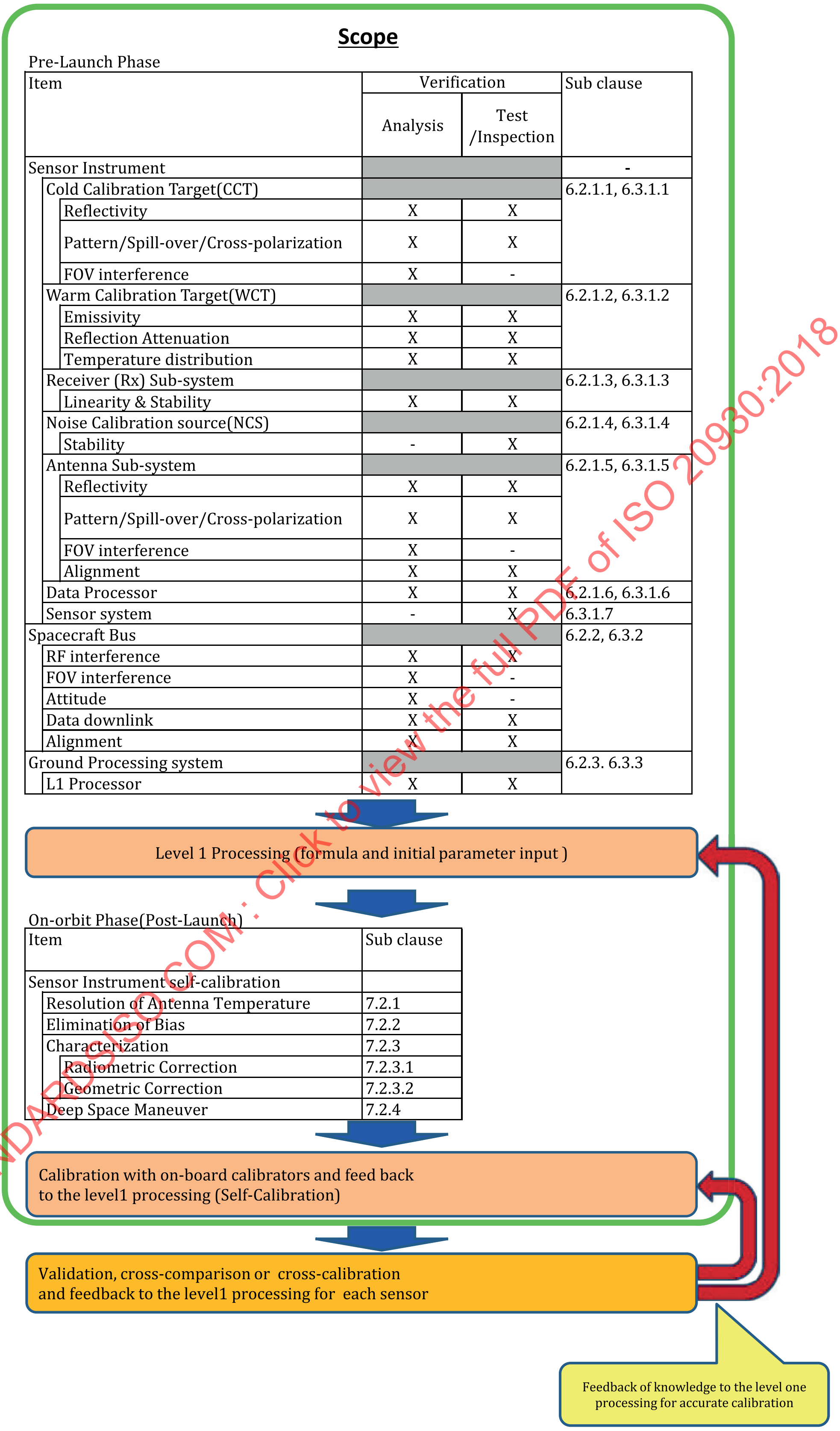
5.3 Concept of calibration and scope

Satellite based passive microwave sensors receive weak microwave emission from the earth. Errors among the sensors would cause or degradation of observation data quality (e.g. 0,1 K or around for sea surface temperature of climate change monitoring).

Therefore, it is necessary to understand the sensor characteristics in both pre-launch phase (design, manufacturing and ground test before launch campaign) and on-orbit phase (On-orbit activity for calibration).

This document covers not only requirements for the sensor itself but also those for the spacecraft bus and ground system because interfaces between the spacecraft bus and the ground system affect sensor performance.

Figure 2 shows the concept of calibration process and scope of this document.



Pre-Launch Phase

Item	Verification		Sub clause
	Analysis	Test /Inspection	
Sensor Instrument			-
Cold Calibration Target(CCT)			6.2.1.1, 6.3.1.1
Reflectivity	X	X	
Pattern/Spill-over/Cross-polarization	X	X	
FOV interference	X	-	
Warm Calibration Target(WCT)			6.2.1.2, 6.3.1.2
Emissivity	X	X	
Reflection Attenuation	X	X	
Temperature distribution	X	X	
Receiver (Rx) Sub-system			6.2.1.3, 6.3.1.3
Linearity & Stability	X	X	
Noise Calibration source(NCS)			6.2.1.4, 6.3.1.4
Stability	-	X	
Antenna Sub-system			6.2.1.5, 6.3.1.5
Reflectivity	X	X	
Pattern/Spill-over/Cross-polarization	X	X	
FOV interference	X	-	
Alignment	X	X	
Data Processor	X	X	6.2.1.6, 6.3.1.6
Sensor system	-	X	6.3.1.7
Spacecraft Bus			6.2.2, 6.3.2
RF interference	X	X	
FOV interference	X	-	
Attitude	X	-	
Data downlink	X	X	
Alignment	X	X	
Ground Processing system			6.2.3. 6.3.3
L1 Processor	X	X	

On-orbit Phase(Post-Launch)

Item	Sub clause
Sensor Instrument self-calibration	
Resolution of Antenna Temperature	7.2.1
Elimination of Bias	7.2.2
Characterization	7.2.3
Radiometric Correction	7.2.3.1
Geometric Correction	7.2.3.2
Deep Space Maneuver	7.2.4

Figure 2 — Concept of calibration process

6 Requirements for pre-launch phase

6.1 General

Before the launch campaign, the characteristics of sensor instruments shall be precisely specified and verified, and those characteristics should be registered in the ground processing system. This sub clause explains the requirements for designing, manufacturing and ground testing. The formula and their parameters prepared through the ground test and/or analysis shall be submitted to the ground processing system for accurate calibration and observation of data processing.

6.2 Requirements for design and manufacturing

This sub clause defines the requirements for the sensor instrument, the spacecraft bus and the ground systems.

To satisfy the on-orbit performance, the following requirements shall be considered through design, manufacturing and ground test phase.

6.2.1 Requirements for sensor instrument

The requirements for the sensor instrument, especially for the following equipment, are described in this sub clause:

a) Cold Calibration Target (CCT);

b) Warm Calibration Target (WCT);

c) Receiver (Rx) sub-system;

d) Noise Calibration Source (NCS);

e) Antenna sub-system (ANT); and

f) Data Processor (DP).

Engineering formulas and parameters obtained during the development stage shall be submitted to the ground processing system.

6.2.1.1 Cold Calibration Target (CCT)

The design of the Cold Calibration Target (CCT) shall meet the following requirements.

a) The CCT shall be designed (modelled or measured, or both) to meet the following:

   i) reflectivity of the CCT shall be specified; and

   ii) normal-incidence power reflection coefficient (Γ) shall be specified and included in the uncertainty calculation for the antenna brightness temperature (Tb).

b) At the position of beam centre of the Rx front-end antenna corresponding to that of the CCT, an analysis or measurement (or both) shall be conducted to obtain the distribution pattern of antenna spill-over and its weighting parameters in order to accurately calculate the antenna brightness temperature for CCT.

c) The specification of the CCT shall include either measuring or modelling the entire antenna power pattern to tune the instrument performance precisely on-orbit.

d) For precise calibration, analysis, or measurement, or both shall be made to obtain data of emissivity and antenna temperature of the interfered structure (or obstruction) out of −3 dB bore sight of the CCT, and engineering formula and parameters based on the above data shall be prepared.

6.2.1.2 Warm Calibration Target (WCT)

The design for the Warm Calibration Target (WCT) shall meet the following requirements.

a) The WCT shall be designed (modelled or measured, or both) to meet the following:

   i) reflectivity of the WCT shall be specified;

   ii) normal-incidence power reflection coefficient (Γ) shall be specified and included in the uncertainty calculation for the antenna brightness temperature (Tb).

b) At the position of Beam Centre of the Rx front-end antenna corresponding to that of the WCT, an analysis or measurement (or both) shall be conducted to obtain the distribution pattern of antenna spill-over and its weighting parameters.

c) Temperature sensors shall be mounted in (or on) the WCT to estimate temperature gradation of the effective area of the WCT. Temperature data measured by temperature sensors shall be delivered to ground processing system at a specific interval to calibrate and maintain sensor instrument performance.

   The standard uncertainty of monitored temperature shall be specified not to degrade the accuracy of measurement.

d) Analysis for temperature gradation of the effective area of the WCT shall be made to estimate temperature distribution of the WCT on-orbit.

   (The WCT should be designed to exclude (or minimize, at least) solar radiation intrusion, in order to maintain the quality of the estimation about the WCT temperature distribution. Analysis shall be performed to determine presence and extent of any solar radiation intrusion).

6.2.1.3 Receiver (Rx) sub-system

The design for Rx sub-system shall meet the following requirements.

a) Calibration targets, CCT and WCT, shall be mounted on the sensor instrument to minimize gain and offset changes in the Rx sub-system due to radiation-induced thermal variations on orbit. Observed data of the CCT and the WCT shall be delivered at specific intervals to calibrate and maintain sensor instrument performance.

   The Rx sub-system shall observe the CCT and the WCT in the specific interval that does not degrade the calibration accuracy.

b) Monitoring points to evaluate nonlinearity of the Rx Sub-system shall be equipped on a module, printed circuit, component, or the Rx sub-system shall be prepared to identify and evaluate nonlinearity, dynamic range and uncertainty of the Rx sub-system.

   In the design stage of the Rx sub-system, monitoring points on a module, printed circuit, component, or Rx sub-system shall be prepared to identify and evaluate nonlinearity, dynamic range and uncertainty of the Rx sub-system.

c) Electrical parts (e.g. MMIC, amplifier, diode, register capacitor) for the Rx sub-system shall be evaluated by testing (radiation, temperature) or analysis, prior to mounting them on the module, in order to guarantee the performance (including stability) of the Rx sub-system during on orbit operation throughout its life-time.

   The characteristics obtained by testing or analysis shall be input to level one processing to make formulas and parameters for nonlinearity compensation or uncertainty estimation due to the nonlinearity.

d) Temperature sensors shall be equipped inside or near receivers to monitor representative temperature in order to compensate receiver gain and offset.

e) In case that an observation channel needs a narrow band based on mission requirements, sensor instruments shall be designed to satisfy the stability requirements of the Local oscillator (LO) to down-convert from Radio frequency (RF) to Intermediate Frequency (IF frequency). A LO with minimum phase noise shall be selected and the total gain of the RX sub-system shall be adjusted to bring the power up to an optimal level from the S/N point of view.

6.2.1.4 Noise Calibration Source (NCS)

The design of the NCS shall meet the following requirements. These requirements shall be applied in cases where the NCS is an installed sensor instrument.

a) Stability of output power from the noise source (NCS) shall be specified based on an evaluation of the operating temperature range and specified electrical voltage and/or current, in cases where the NCS is required for three or four point self-calibration.

b) The temperature sensor shall be mounted in order to monitor the NCS temperature and accurately estimate output power of NCS. Electrical current shall also be monitored to take additional information, if required.

The monitored data shall be delivered to the ground processing system at a specific interval to calibrate and maintain sensor instrument performance.

6.2.1.5 Antenna sub-system

The design of the antenna sub-system shall meet the following requirements.

a) The Main Reflector (MR) shall be designed (modelled or measured, or both) to meet the following.

   i) Reflectivity of the MR shall be specified.

   ii) Γ shall be specified and included in the uncertainty calculation for the antenna brightness temperature (Tb).

   iii) The MR shall include temperature monitoring if $\Gamma < 0{,}999\ 9$ (e.g. exact number is open for discussion).

b) The specification of the antenna sub-system shall include either measuring or modelling the entire antenna power pattern to tune the instrument performance precisely on orbit.

c) Spill-over and cross-polarization of the MR shall be determined either by analysis or by measurements to calibrate unnecessary power.to calculate how much of the brightness temperature is reduced for the calculation of own calibration.

d) Antenna efficiency shall be specified. The physical temperature of the antenna shall be monitored over time to correct the added noise temperature of the antenna due to its loss.

6.2.1.6 Data processor

The data processor of the sensor instrument shall be designed to output its observation and calibration data with the information of the sensor instrument status and the data required for high level data processing.

The information shall be specified in accordance with the design of the ground processing system.

6.2.2 Requirements for spacecraft bus

In this sub clause, the interfaces between spacecraft bus and sensor instrument are specified. The spacecraft bus shall be designed and manufactured carefully, especially considering the following interface items with the sensor instrument:

a) RF Interface;

b) Field of view interference;

c) Spacecraft attitude; and

d) Observation and calibration data downlink.

6.2.2.1 RF Interference

The design for RF interface shall meet the following requirements.

a) RF Interface design specifications with the spacecraft bus (including active instruments mounted on the spacecraft bus) shall be specified in the ICS to avoid excessive RF radiative emission which interferes with sensor performance and damages the sensor instrument. ISO 14302, or its equivalent, shall be referred to in order to obtain the design criteria for interference and damage level.

b) Interface design requirements with the spacecraft bus shall be specified to avoid RF multi-path interference due to Tele-communication/tele-command devices and direct data transmission devices, in order to not degrade the performance of sensor instruments.

6.2.2.2 Field of View (FOV) Interference

The Field of View (FOV) interface design specification shall be specified in the ICS to eliminate unnecessary power input brought through the MR (or the CCT) by the spacecraft bus, specifically regarding the variation of spacecraft bus configurations on orbit, such as during the use of a solar paddle.

6.2.2.3 Spacecraft attitude

Interface design requirements with the spacecraft bus shall be specified to meet the following requirements.

a) Information of spacecraft attitude shall be delivered to sensor instruments to determine the Earth Incident Angle (EIA) when the sensor instrument observes the earth.

b) Errors of spacecraft attitude shall be specified in the ICS, considering EIA requirements for sensor instruments.

6.2.2.4 Observation and calibration data downlink

The observation and calibration data with the information specified in 6.2.1.6 shall be delivered to the ground processing system at the specific interval determined in the ICS between the spacecraft bus, the sensor instruments and the ground processing system.

6.2.3 Requirements for ground processing system

The design of the ground processing system to calculate antenna brightness temperature shall meet the following requirements.

a) Processing errors of the ground processing system shall be designed in a way that they do not to degrade the requirement for the antenna brightness temperature.

b) The ground processing system shall receive the observation and calibration data with the information specified in 6.2.1.6 at the specific interval determined in 6.2.2.4.

c) The ground processing system shall process both calibration and observation data to eliminate unnecessary power input from the structure (or obstruction) of the spacecraft bus such as, the structure of the solar paddle of the spacecraft bus.

In addition, the ground processing system shall eliminate the unnecessary bias or effect on RF interference, regarding the angle and direction of the solar cell panels, the elevation angle and trajectory of the sun, the location of radiation sources on earth, and the location (GPS) of spacecraft on orbit.

6.3 Ground test and requirements verification

6.3.1 Requirements for the sensor instrument

6.3.1.1 Cold Calibration Target (CCT)

The following requirements for the CCT shall be proved by analysis or test or both.

a) The CCT characteristics specified in 6.2.1.1 a) shall be verified by test and/or analysis.

NOTE 1 If measured for 6.2.1.1 a) i), monostatic normal reflectivity is considered a sufficient approximation of reflectivity at low magnitudes.

NOTE 2 It is preferable that CCT Γ be measured in the appropriate facility such as in the Antenna Compact Range.

b) The antenna pattern cross-polarization shall be measured under the configuration of the CCT with Rx front-end antennas in the appropriate facility, such as in the Antenna Compact Range.

c) The requirement of 6.2.1.1 c) shall be proved by analysis or test or both.

d) The requirement of 6.2.1.1 d) shall be proved by analysis or test or both.

e) The geometry between the CCT and the Rx front-end antenna shall be kept so that it subtends the main beam of the antenna to closely emulate the cold sky condition.

6.3.1.2 Warm Calibration Target (WCT)

The following requirements for the WCT shall be proved by analysis or test or both.

a) Emissivity or Γ, or both shall be measured or verified by analysis, or both, for all observation frequencies.

b) Material of microwave absorber for WCT shall be verified if it satisfies the above 6.2.1.2 a) by measurement or by analysis. The distance between the antenna and the WCT should be the same one as in the on-orbit configuration, when measuring.

c) Temperature distribution of WCT shall be measured in a thermal vacuum test to correlate its thermal math model.

This requirement can be excluded in the case of well-proved design heritage or similarity to other WCTs.

Temperature sensors mounted in (or on) the WCT shall be tested to prove design requirements in a ground test.

6.3.1.3 Receiver (Rx) sub-system

The following requirements for Rx sub-system shall be proved by analysis or test or both.

a) The data for dynamic range and stability for every component of Rx sub-system shall be measured prior to the Rx sub-system test, using various signal levels (e.g. from deep space to the highest input level of the Rx sub-system.)

b) The data for nonlinearity and standard deviation for the Rx sub-system within allowable operation temperature range shall be measured to characterize nonlinearity and observation stability of the Rx sub-system.

c) Stability of the local oscillator shall be measured to satisfy performance of the sensor instrument. This requirement (related to 6.2.1.3) is only applied for observation frequency channel with narrow band (e.g. 50 GHz to 70 GHz sounding channels) and the thermal vacuum test is required to simulate thermal condition on orbit.

d) Analysis or testing for the qualification against ion and radiation under the space environment on orbit shall be done to commit stable Rx sub-system performance.

6.3.1.4 Noise Calibration Source (NCS)

The following requirement for the NCS shall be proved by test. This requirement is only applied for sensor instrument with a NCS.

a) Output power of the NCS shall be measured within its allowable operation temperature range and under the condition of specific electrical current supplied to the NCS.

   NOTE Thermal vacuum test is preferable to estimate on-orbit status of NCS.

b) The long-term stability of NCS output power shall be measured to quantify the associated uncertainty.

6.3.1.5 Antenna sub-system

The following requirements for the antenna sub-system shall be proved by analysis or test or both.

a) Antenna characteristics specified in 6.2.1.5 a) shall be verified by test and/or analysis.

   In case the requirements of 6.2.1.5 are not met, a), the analysis shall be reported to the ground processing system.

   NOTE 1 If measured for 6.2.1.5 a) i), monostatic normal reflectivity is considered a sufficient approximation of reflectivity at low magnitudes.

   NOTE 2 It is preferable that the reflectivity of the MR be measured in the appropriate facility, such as a Compact Antenna Test Range (CATR).

b) Antenna pattern cross-polarization shall be measured under the configuration of the MR with the Rx front-end antennas in the appropriate facility, such as an Antenna Compact Range.

c) The misalignment between RF and mechanical axes of the antenna shall be delivered to the ground processing system.

6.3.1.6 Data processor

The observation and calibration data with the information specified in 6.2.1.6 shall be proved by analysis or test or both.

6.3.1.7 Sensor instrument

The following requirements for sensor instruments system shall be proved by both analysis and test.

a) Sensor instruments shall be tested with the configuration of the Rx sub-system with the three calibration sources or more to determine the characteristics of sensor instruments and nonlinearity.

   In ground tests, the following need to be considered.

   i) The WCT shall be used.

   ii) The Low-temperature Calibration Target (LCT), like LN2, shall be used instead of monitoring deep space.

   iii) The Variable Temperature Source (VTS) as scene-view target shall be prepared to check if the formula for nonlinearity compensation is appropriate.

NOTE Use of a thermal vacuum chamber is preferable in order to estimate temperature variation on orbit, if permitted by the ground test facility.

6.3.2 Requirements for spacecraft bus

The requirements specified in 6.2.2.1 through 6.2.2.4 shall be proved by analysis or test or both.

Sensor instruments shall verify if the following requirements for the spacecraft bus are also proved by analysis or test or both.

a) Radiative Emissivity (RE) and radiative susceptibility (RS) tests shall be done to confirm if the spacecraft bus satisfies the specified RE/RS interface requirements with the sensor instrument. RE/RS tests shall be conducted with the sensor instrument mounted on the spacecraft bus.

   It is preferable that the demonstration is done in a radio wave darkroom to prove if the spacecraft bus does not radiate unexpected microwave power through the Electromagnetic Compatibility (EMC) test. Configuration of spacecraft and sensor instrument shall be the same as, or equivalent to, the final one in orbit.

   ISO 14302, or its equivalent, shall be referred to in ground test to avoid unexpected interference and damage on sensor instrument.

b) The alignment matrix between the spacecraft bus reference axes and the instrument reference axes shall be measured and delivered to the sensor instrument and the ground processing system.

6.3.3 Requirements for ground processing system

The following requirement for the ground processing system shall be proved by analysis or test or both.

a) Performance specified in 6.2.3 shall be verified with the test data equivalent to real observation data output by sensor instrument.

7 Requirements for on-orbit phase

7.1 General

Prior to transferring to nominal operation, the sensor instrument should be calibrated to achieve its best performance on orbit, with respect to radiometry and geometry.

This sub clause explains the requirements for calibration during on-orbit operation.

7.2 Requirements for sensor instrument self-calibration

The requirements for sensor instrument self-calibration on orbit operation are described in this sub clause as follows.

Sensor instrument self-calibration shall be conducted while ensuring that the timing does not to contaminate calibration data due to RF interference by other satellites on orbit and ground stations.

7.2.1 Resolution of antenna temperature

The resolution of the antenna temperature shall be verified with its own specification, based on observation data of calibration sources such as the CCT, the WCT and the NCS.

Periodical calibration using the CCT and the WCT (NCS if possible) shall be made because the gain and added noise of the Rx sub-system may drift.

7.2.2 Elimination of bias

Bias of the antenna temperature, by the energy input from the earth surface captured due to spill-over of the MR and the CCT, shall be processed and eliminated in the ground processing system. The GPS time and location with calibration data shall be delivered to the ground processing system for processing, in order to determine the source and to quantify the bias for correction.

7.2.3 Characterization

The formula to convert observation and calibration data to brightness temperature shall be compensated and correlated for the ground processing system, evaluating the following:

a) nonlinearity of Rx sub-system;

b) FOV interference to the CCT and the MR due to structure (or obstruction) of the sensor instrument itself or the spacecraft bus;

c) temperature distribution of the WCT;

d) stability of NCS output (in case that sensor instrument is equipped with a NCS).

7.2.3.1 Radiometric correction

The antenna pattern shall be corrected by Ground Control Points (GCP) pre-determined prior to launch. The GCPs shall be chosen to verify the antenna beam pattern on orbit to compare with that in the ground test.

NOTE The locations where brightness temperature clearly changes, like islands and coasts, are preferable.

This activity is performed to correct alignment errors in the installation of a sensor with spacecraft correction for weighting parameters based on antenna pattern. This activity will result in minimization of mechanical errors in Level one processing of the ground system.

7.2.3.2 Geometric correction

The geometrical alignment of the instrument shall be realized. In case of discrepancy with the pre-flight alignment, a correction matrix shall be delivered to the ground processing system.

The Field of view (FOV) shall be validated and corrected, using GCPs, the antenna main beam incident angle and spacecraft attitude information.

Spacecraft attitude information shall be periodically down-linked with observation data to correct the antenna beam pattern to obtain appropriate data for geolocation.

7.2.4 Deep space manoeuver

Deep space calibration with cosmic microwave background radiation (isotropic non-polarized view) shall be done to precisely match up the antenna patterns of the MR with that of the CCT and to eliminate unexpected bias due to spacecraft observation, in case that spacecraft allows its manoeuvre operation.

Annex A
(informative)

Nonlinearity correction (example)

Nonlinearity of sensor instruments is due to the following characteristics.

a) Rx sub-system

  i) Amplifier (Low Noise Amplifier, DC-Amplifier)

  ii) Detector

b) Signal processor

  i) Analogue to Digital Converter (ADC)

The above characteristics are measured and evaluated in each test stage, such as the device test, module test before component assembly, component test, sensor instrument system test with Rx sub-system and Signal Processor. Here, two examples are introduced as follows.

A.1 Rx or Rx sub-system

In the phase of Rx test or Rx sub-system test, it is preferable that the evaluation with the reference target and the reference feed horns is done to trace and calibrate the receiver's characteristics as shown in Figure A.1.

Two-point calibration should be done prior to measuring a reference target for either nonlinearity or traceability calibration.

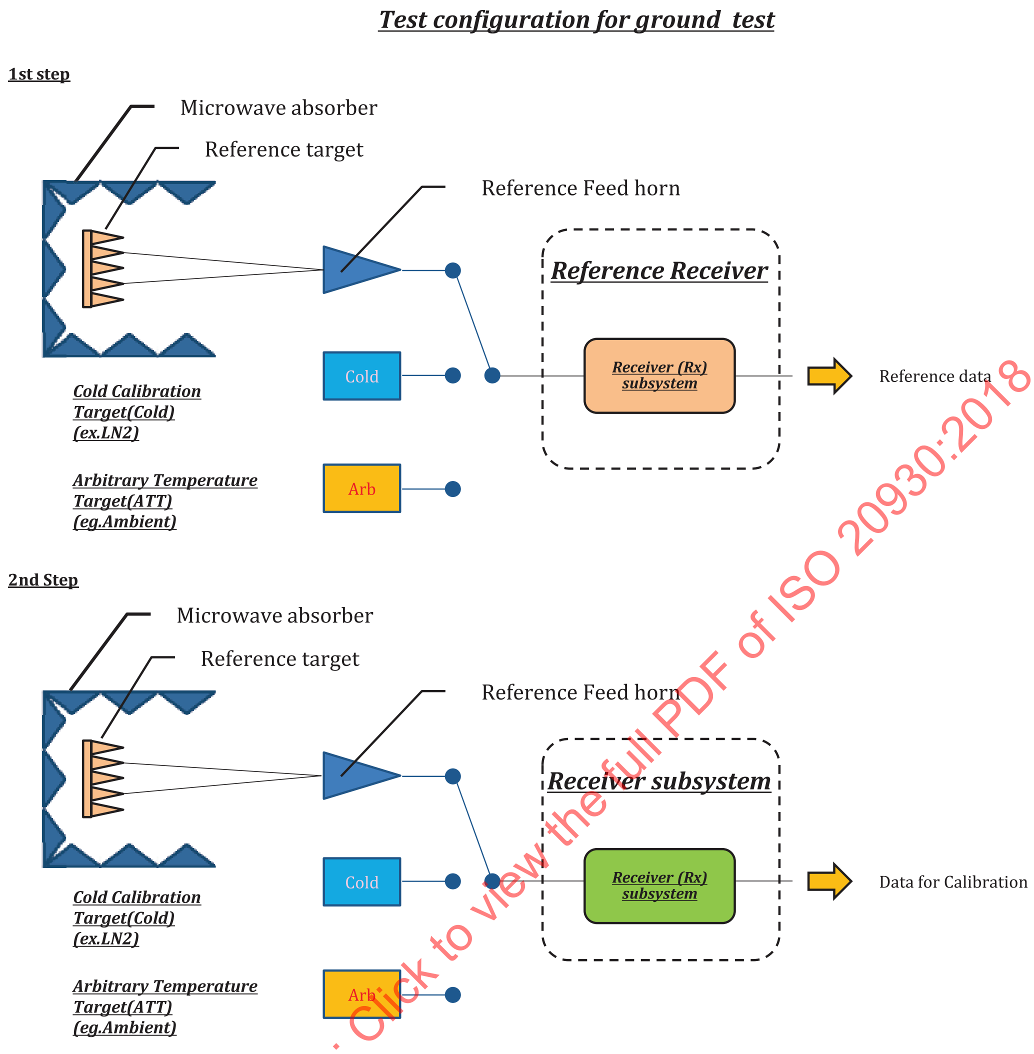


Figure A.1 — Ground test configuration image for Rx sub-system or receiver

A sensor instrument equipped with a Noise Calibration Source (NCS) is effective for the characterization of Rx nonlinearity on orbit. The sensor instrument should be designed to taken care of the following.

a) the stability of output power from a noise source (NCS) should be specified, based on an evaluation under operating temperature and specified electrical current, in case that the NCS is required for three or four point self-calibration.

b) The temperature sensor should be mounted for monitoring NCS temperature in order to accurately estimate the output power of the NCS. Electrical current should also be monitored to take additional information, if required.

The monitored data should be delivered to the ground processing system at a specific interval in order to calibrate and maintain sensor instrument performance.

In a ground test, output power of the NCS should be measured within its allowable operation temperature range and under the condition of specific electrical current supplied to the NCS.

A thermal vacuum test is preferable to estimate on-orbit status of the NCS.

A.2 Sensor instrument system test

In sensor instrument system test, the targets, WCT (around 300 K or higher) and cold target like LN2, should be monitored with the end-to-end test configuration at least. If it is difficult to measure those targets with a main reflector, it can be acceptable, because nonlinearity is determined by the characteristics of both the Rx sub-system and the Signal Processor.

An image of the test configuration is shown in Figure A.2.

An evaluation using these targets with three temperatures is desirable to specify the characteristics.

The VTS should have the characteristics of large heat capacity with less temperature gradient in the view of the feed horn.

In case an NSC is mounted, it is preferable to evaluate the nonlinearity.

The temperature of the standard calibrator should be adjusted in a flexible manner to specify the characteristics of nonlinearity.

If allowed, it is preferable that the test for the sensor instrument be executed in a thermal vacuum chamber, because the temperature condition of the Rx sub-system is evaluated under both higher and lower temperature conditions in Figure A.1 and Figure A.2.

A.3 On-orbit self-calibration

On orbit, the characteristics of nonlinearity are finally compensated because nonlinearity of Rx sub-system depends on its temperature.

Two (or three if an NSC is mounted) targets will be used for self-calibration of the sensor instrument. An image of the on-orbit configuration is shown in Figure A.3.

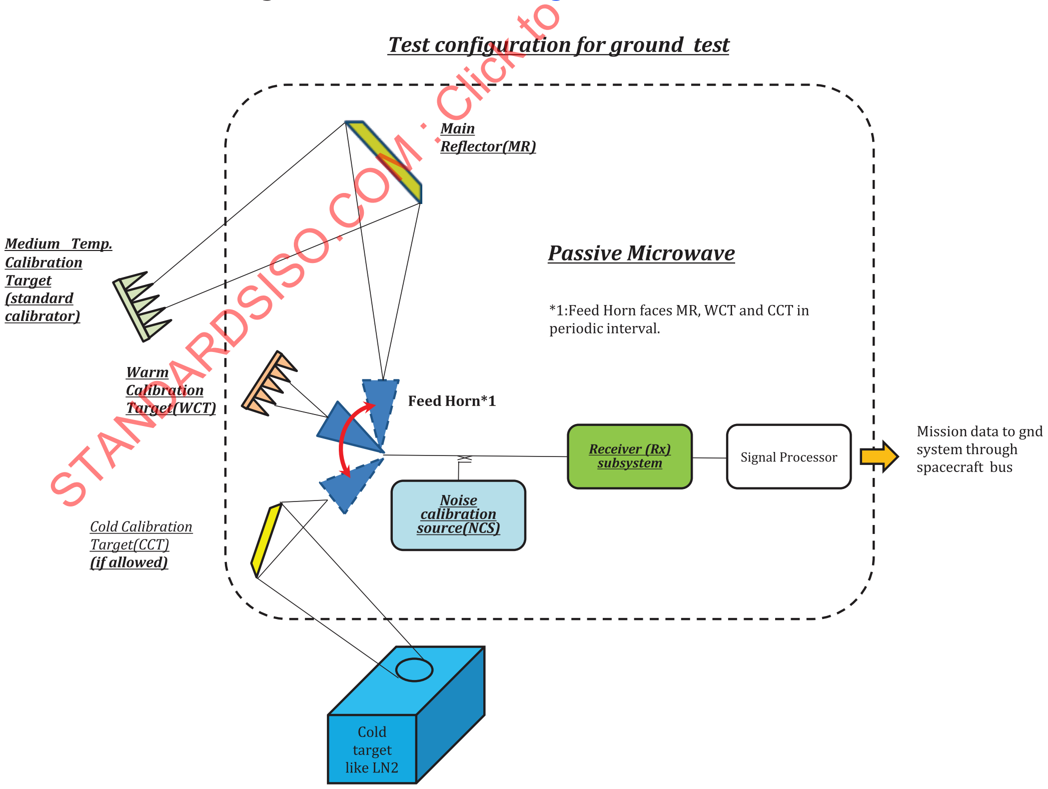


Figure A.2 — Ground test configuration in sensor instrument test

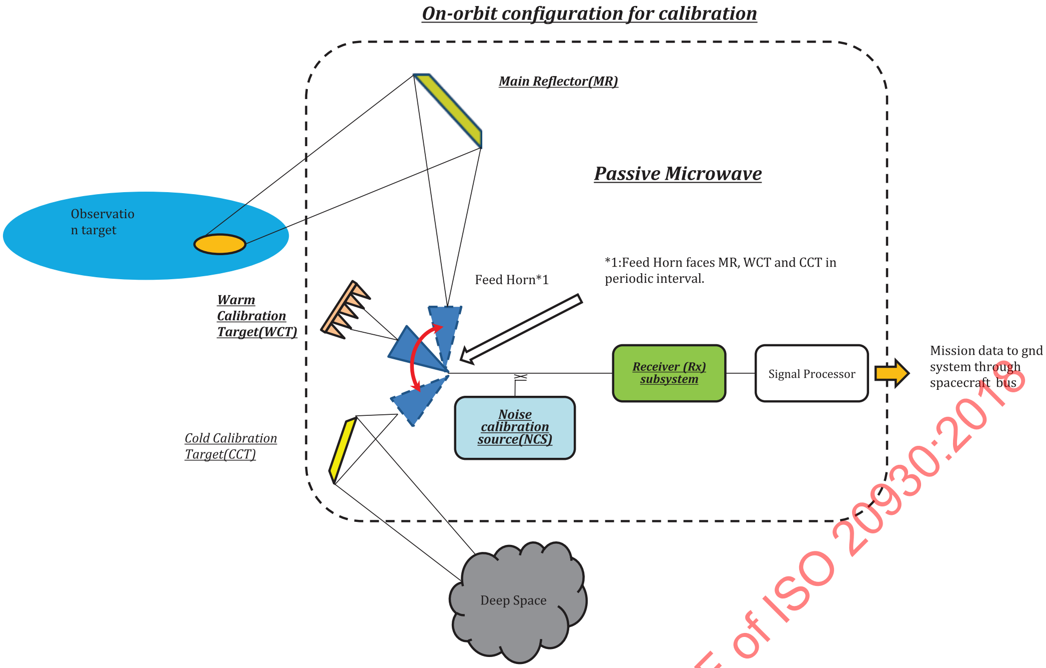


Figure A.3 — On-orbit configuration

Annex B
(informative)

Validation by SRT (Standard Reference Target)

The Standard Reference Target (SRT) is prepared as the target for the sensor instrument test. The SRT should be designed considering the following characteristics (same as the WCT).

a) The SRT has radio wave absorption characteristics with Γ of −40 dB or less under the following conditions:

   i) while covering all operational observation frequencies;

   ii) during calibration data acquisition.

b) Temperature sensors are mounted in (or on) the SRT to estimate temperature gradation of the effective area of the SRT. Temperature data measured by temperature sensors is delivered to the Bench Test Equipment (BTE) in a specific interval.

   The standard uncertainty of monitored temperature should be designed not to degrade the performance. For example, 1/5 or less of the uncertainty estimate is preferable in a ground test.

c) The temperature variation within 2,0 K peak-to-peak or less is preferable for the effective area of the SRT. The SRT should be designed to maintain the above performance (a) and (b) under ambient conditions in, a thermal vacuum chamber.

Annex C
(informative)

Ground-based information required for sensor calibration

For more precise observation after sensor instrument self-calibration, inter-comparison should be required prior to mutual data use among passive microwave sensors.

Some homogeneous extended target areas should be selected in order to inter-calibrate or inter-compare different sensors.

The common conditions for inter-comparison among sensors that should be considered are listed as follows.

a) Area

The area of the target is wider than that of the widest sensor FOV. The areas should be selected worldwide choosing surfaces with extreme characteristics in terms of microwave emission and with homogeneous conditions. In particular, deserts, equatorial forests, large ice/snow extensions, prairies, water bodies (salt and fresh water) should be included. Some of these areas can be selected among the ones already used for satellite microwave sensor calibration (e.g. SSMIS, TMI, SMOS, SMAP, AMSU, ATMS AMSR-E, AMSR2, GMI). *In situ* observation could be advisable in order to fully understand the exact local situation in terms of surface and air temperature, soil moisture, vegetation cover, meteorological parameters, etc.

b) Observation timing

It is preferable that sensor instruments observe the same targets within 1 h to minimize error by environmental change or fluctuation.

c) Number of targets

Multiple targets should be selected to minimize observation errors.

d) Orbit (ascending/descending)

Orbit to obtain observation data should be determined according to the surface property of the target, taking into consideration scattering characteristics (e.g. the surface roughness of the earth's surface).

Ascending and descending orbits should be considered separately during the phase of surface parameter estimate, since they correspond to different day periods, thus affecting the output of the algorithm based on RTT models (Radiative Transfer Theory).

e) Incident angle

Spacecraft attitude should be delivered with observation data of targets to specify the incident angle of the sensor's main beam.

f) Weather

Weather condition should be recorded during observation (e.g. rainfall, humidity, wind speed, air pressure etc.).

A sunny day with low humidity, clear skies, and little or no wind is preferable to minimize error due to rainfall, water vapour, cloud liquid, wind etc.

g) Season or period

A season or period to avoid sun glitter and reflection of sunlight from the earth's surface should be selected.

h) Restriction during observation data acquisition

i) Avoidance of RF interference

Time and location without RF interference by other satellites on orbit and ground stations should be selected to obtain observation data.

ii) Avoidance of interference by the moon

An orbit with the moon in sight of the CCT should not be selected, to avoid unexpected bias due to the reflection of sunlight from the moon surface.

Depending on the observation target, there are varieties of conditions that should considered in addition to the above common conditions.

The following are some examples of inter-comparison among sensors.

C.1 Sea surface temperature (Climate Change Monitoring)

Observation data of the sea surface temperature can be used for the climate change forecast.

On the view point of calibration (including cross-calibration), the following parameters in Table C.1 should be taken into account to match up observation data among sensors.

Table C.1 — Parameters to be accounted for in case of cross-calibration of microwave sensors

PARAMETER	INFLUENCE (1 min – 3 max)	NOTES
Water vapour in the air	1–2	Balloon
Cloud liquid	2	Balloon
Sea winds	2	Measured by buoys
Precipitation	3	Measured by buoys, Balloon
Salinity	2	Measured by buoys, Balloon
NOTE Scale of INFLUENCE: 1 = Low , 2 = Medium, 3 = High.		

It is preferable to choose some selected homogeneous areas in different climatic zones for better calibrating the sensors.

a) Homogeneous ocean areas such as the Pacific Ocean or the Atlantic Ocean, with low sea winds, low water vapour and low cloud cover.

b) Area with buoys delivering the following accurate data as periodical interval in order to compensate the observation data delivered by sensors:

i) wind speed/wind direction;

ii) air temperature;

iii) rainfall, relative humidity;

iv) sea surface and subsurface temperature;

v) salinity;

vi) bolometric pressure;

vii) current velocity

In general, it is preferable that the Tb accuracy be in the order of 0,02 K to 0,05 K, in order to have accuracy in sea surface temperature retrieval.

C.2 Precipitation

Observation data of precipitation can be used for the weather forecast.

On the view point of calibration (including cross-calibration), the following parameters in Table C.2 are taken into account to match up observation data among sensors.

Table C.2 — Parameters to be accounted for in case of cross-calibration of microwave sensors

PARAMETER	INFLUENCE (1 min – 3 max)	NOTES
Water vapour in the air	1–2	Measured by buoys, balloons, GPS etc.
Cloud liquid	2–3	Measured by ground-based microwave radiometers etc.
Sea surface temperature	1–2	Measured by buoys, etc.
3-dimensional precipitation patterns	3	Measured by ground-based or satellite radars etc.
NOTE Scale of INFLUENCE: 1 = Low, 2 = Medium, 3 = High.		

Since precipitation has large temporal and spatial variability, calibration of microwave sensors requires high-density, simultaneous precipitation observations by radars.

It is also preferable to have simultaneous observations for inter-comparison of different microwave sensors. Hence, non sun-synchronous satellite observations (GPM, Megha-Tropique, etc.) are used as the reference, and data sets between the reference and other satellite observations are matched-up.

In general, it is preferable that the Tb accuracy be in the order of 0,3 K, in order to have accuracy in precipitation retrieval.

C.3 Soil moisture

Observation data of soil moisture can be used for drought monitoring, fire prevention, flood forecasting, water waste detection and services for farmers.

On the view point of calibration (including cross-calibration), the following parameters in Table C.3 should be accounted for to match up observation data among sensors.

Table C.3 — Parameters to be accounted for in case of cross-calibration of microwave sensors

PARAMETER	INFLUENCE (1 min – 3 max)	NOTES
Water vapour in the air	1–2	Scarce influence for frequencies <10 GHz (it depends on frequency)
Cloud liquid	2	
Precipitation	3	Heavy rainfall can affect microwave Tb, especially at frequencies >10 GHz
Temperature of ground surface	3	Tb should be normalized to surface temperature (it can be done using Tb at 37 GHz as a proxy)
NOTE Scale of INFLUENCE: 1 = Low, 2 = Medium, 3 = High.		