MHS Level 1 Product Generation Specification

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Document Change Record

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
Draft E	03/05/99		Based on the AMSU-A document
Draft F	23/07/99		Implemented CGSRR RIDs
			Updates for CGS KO
			1.3 Applicable documents list update
			2.2 Refinements
			2.3 refinements
			3.1 Refinements of configured data bases
			3.2 Refinements, introduction of quality control functions
Draft G			introduction of user configurability of calibration processing introduction of static parameter files remove relative azimuth angle (solar and satellite) introduced navigation tie points configurable, default every scan line and every sample
			4.4 introduction of quality control functions at product level and at scan line level
			4.6 removed encoding and formatting of products
			Annex B introduced Configurable Auxiliary Database
			Annex C introduced Sample Auxiliary Database with calibration parameters and secondary calibration coefficients
Issue 2 Draft A	15/06/2000		Implementation of Mini-RIDs to Draft G
			Produced for Kick-off. Several issues still open. Some sentences in red left as markers for further discussions The Operations Concept section has been introduced (still preliminary in this issue). The MHS Processor states have been identified: this is to be further refined. Explanatory text already in the document has been used to fill this section. Two new sections have been introduced to explicitly deal with Backlog Processing and Reprocessing (sections 3.2.2 and 3.2.3) Section 2 - Overview of the Processing Algorithms has been renamed Overview of the Instrument All SADT diagrams have been removed.

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			Requirements are all included in Section 4 and have been grouped according to applicability (e.g., all requirements applying to Level 1b processing are included in subsections of the same section). Many comments have been added to the requirements to clarify their scope: this is to be checked by the scientists Science has been moved to a new section (Section 5 - Supporting Science) A new set of traceability matrices has been introduced (sections 3.5 and 4.11).
			Wherever a TBD or TBC is encountered, have made an attempt to insert a note describing when and by whom the issue is expected to be resolved
			All requirements starting with “The function shall....” have been re-phrased since there are no SADT functions any more
			Completely altered to reflect restructuring: Included the Document Evolution and Document Status sections describing the document’s lifeline and status as well as the how TBCs and TBDs are to interpreted.
			1 Also the major issues still pending in Issue 3 Draft A are recorded, namely the full specification of the reprocessing and of the backlog processing as well as the algorithms in Section 5. Added a List of Acronyms (previously List of Abbreviations at the end of the document)
			2 Largely altered to reflect restructuring
			2.1 Removed
			2.2 Renumbered to 2.1
			2.2.1 Renumbered to 2.2
			2.2.2 Renumbered to 2.3
			2.3 Renumbered to 2.4
			2.3 Content moved to Sections 3.2.1 and 3.2.4
			2.4 Removed
			2.5 Removed
			3 Completely altered to reflect restructuring
			3.1 Restructured: SADT diagram removed; list of data flows converted to a table and moved to Section 3.3.

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			3.2 Removed
			3.2.1 Removed
			3.2.1.1 moved to Section 5.1.1 as to the Navigation Computation and to the Section 5.1.2 as to the Calibration Coefficients Calculation.
			3.2.1.2 Moved to Section 5.2.
			3.2.1.3 Moved to Section 3.4.
			3.2.2 Requirements re-numbered and moved to Section 4.1.
			3.2.3 Requirements re-numbered and moved to Section 4.2.
			3.2.4 Requirements re-numbered and moved to Section 4.3
			4 Completely altered to reflect restructuring
			4.1 SADT diagram removed; explanatory text moved to Section 4.4
			4.1.1 Requirements re-numbered and moved to Section 4.4.1.
			4.1.2 Requirements re-numbered and moved to Section 4.4.2.
			4.1.3 Requirements re-numbered and moved to Section 4.4.3.
			4.2 SADT diagram removed; explanatory text moved to Section 4.5
			4.2A requirements re-numbered and moved to Section 4.5.1
			4.2B requirements re-numbered and moved to Section 4.5.2
			4.2C requirements re-numbered and moved to Section 4.5.3
			4.2D requirements re-numbered and moved to Section 4.5.4
			4.2E requirements re-numbered and moved to Section 4.5.5
			4.2.1 SADT diagram removed; explanatory text moved to Section 4.5.6; requirements re-numbered and moved to Section 4.5.6
			4.2.1.1. SADT diagram removed; explanatory text removed. This section actually maps to Section 5.1.2.1

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			4.2.1.1.1.moved to Section 5.1.2.1.1
			4.2.1.1.2 moved to Section 5.1.2.1.2
			4.2.1.1.3 moved to Section 5.1.2.1.3
			4.2.1.1.4 moved to Section 5.1.2.1.4
			4.2.1.1.5 moved to Section 5.1.2.1.5
			4.2.1.1.6 moved to Section 5.1.2.1.6
			4.2.1.2 SADT diagram removed; explanatory text removed. This section actually maps to Section 5.1.2.2
			4.2.1.2.1 moved to Section 5.1.2.2.1
			4.2.1.2.2 moved to Section 5.1.2.2.2
			4.2.1.3 SADT diagram removed; explanatory text moved to moved to section to Section 5.1.2.3
			4.2.1.4 SADT diagram removed; explanatory text moved to section to Section 5.1.2.4
			4.2.1.5 SADT diagram removed; explanatory text moved to section to Section 5.1.2.5
			4.2.1.6 SADT diagram removed; explanatory text moved to Section 5.1.2.
			4.2.1.6.1 moved to Section 5.1.2.6.1
			4.2.1.6.2 moved to Section 5.1.2.6.2
			4.2.2 SADT diagram removed; explanatory text moved to Section 5.1.1; requirements re-numbered and moved to Section 4.5.3
			4.2.2.1 moved to Section 5.1.1.1
			4.2.2.2 moved to Section 5.1.1.2
			4.2.2.3 moved to Section 5.1.1.3
			4.2.2.4 moved to Section 5.1.1.4
			4.2.2.5 moved to Section 5.1.1.5
			4.3 SADT diagram removed; explanatory text moved to Section 4.6; requirements re-numbered and moved to Section 4.6
			4.3.1 SADT diagram removed; explanatory text moved to Section 5.2
			4.3.1.1 moved to Section 5.2.1
			4,4 SADT diagram removed; explanatory text moved to Section 4.7
			4.4.A requirements re-numbered and moved to Section 4.7.1

Issue / Revision	***Date***	***DCN. No***	***Changed Pages / Paragraphs***
			4.4B requirements re-numbered and moved to Section 4.7.2
			4.4C requirements re-numbered and moved to Section 4.7.3
			4.4D requirements re-numbered and moved to Section 4.7.4
			4.5 explanatory text moved to Section 4.8
			4.5A requirements re-numbered and moved to Section 4.8.1
			4.5B requirements re-numbered and moved to Section 4.8.2
			4.6 SADT diagram removed; explanatory text moved to Section 4.9
			4.6A requirement ALG.A6.10 removed: all incoming data is assumed to be in EPS format, thus there is no need for specifying such Requirement ALG.A6.20 re-numbered and moved to Section 4.9
			4.7 SADT diagram removed; explanatory text moved to Section 4.10 Requirements re-numbered and moved to Section 4.10
			New TBDs/TBCs have been added. Some were implicit in the previous issue of the document; some others have been added
			Appendix A The list of symbols has been checked: some mismatches have been identified but not yet corrected
Issue 3 Draft A Internal Draft	13/10/2000		Second iteration of the restructuring Process Change bars have not been used since this is still a draft document The wording “Side information” has been systematically replaced with “Auxiliary Data”. This is to be checked against the overall definition of Auxiliary Data.
			Added a remark on the scope of the acceptance, which is limited to the requirements in Section 4. Section 3 and 5 are provided as guidelines.
			1.3 Updated Document Status
			1.4 Updated List of Acronyms
			Updated Definitions
			3 Completely reviewed Added System Context figure Removed suspend/resume from the list of features the PGE is required to support

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			Included introductory foreword Added note on timeliness requirements for the MHS PGF, which are TBD by the Contractor Written the Backlog Processing Mode Completed the Reprocessing Mode Added the operational scenarios Added the Traceability Matrix
			4: Completely reviewed and re-numbered requirements. Most requirements did not appear in the previous issue
Issue 3 Draft A	15/11/2000	DCN. SYS DCN .021	Re-structuring of document
Issue 4 Revision 0	15/5/2001		Removed trace matrix. Removed Use Case diagram. Compacted description of state transitions to one location; added state transition diagram. Compacted all processing descriptions for separate modes to one location; partitioned by processing level. Removed references to split mission. Removed separate section on near real- time mode as it is redundant.
			Section 3.1, Section 3.2.1 Moved the section on product generation.
			Section 3.1.2 Moved major interface application closer to rest of system concept.
			Section 3.2 Changed title of section. Removed remark on operational situations.
			Section 3.2.1.1 Moved list of supporting functions to just after the single unified processing steps description.
	1/06/2001		Section 1 Added note on V1 in Document Evolution paragraph. Removed reference to GPP.
			Modified section 1.3 as appropriate for PDR. Removed landmark database reference- land marking not done by PGS. See MHS-PGF-4.2-0010 MMI” on page 20.
	29/10/2001		Modified Chapter 5 according to revised knowledge on the instrument calibration

Issue / Revision	***Date***	***DCN. No***	***Changed Pages / Paragraphs***
Issue 5 Revision 1	04/6/2002	EUM.EPS. SYS.DCR. 0 2.108	Comments included from Algorithm Panel 15/03/2002 (cf. Minutes of meeting) Comments from internal review included (cf. Comment forms) Comments from Nigel Atkinson (Met. Office; cf. Comment Forms) Removed all references to warm starting. Removed references to start/stop/abort/resume
			Introduced scan-line consistency check
			Introduced antenna position check for OBCT
			Added Moon glint correction to Chapter 5
			Updated List of symbols
			Removed reference to L1b products in MHS-PGF-4.1-0030 Clarified term in requirement MHS-PGF-4.1-0050Ensured consistent wording in requirement MHS-PGF-4.1-0070 Clarified text of requirement MHS-PGF-4.1-0080 "The MHS PGF shall beagle to process any Auxiliary Data identified in this document as being used by it." Removed reference to start, stop, and abort from MHS-PGF-4.1-0100MHS-PGF-4.1-0110, MHS-PGF-4.1-0120, MHS-PGF-4.1-0130 removed Removed reference to L1b reprocessing in MHS-PGF-4.2-0040MHS-PGF-4.4-0010 A product shall be considered complete if all the required data content as per AD39MHS Level 1 Product Format Specification (EPS/MIS/SPE/97229), was produced from the full set of data supplied and the complete product made available. Deleted MHS-PGF-4.4-0020 as it referred to warm start .Deleted MHS-PGF-4.4-0030as it referred to warm start. Removed reference to aux data inventory in MHS-PGF-4.5-0030.MHS-PGF-4.5-0060 removed MHS-PGF-4.7.1.1-0060 clarified and comment added. Removed reference to duplicated data in MHS-PGF-4.7.1.2-0030 Clarified MHS-PGF-4.7.1.2-0050Spelling checked.MHS-PGF-4.7.1.3-0010 Added the term ancillary data. Clarified MHS-PGF-4.7.2-0030 BY REMOVING "OTHER TBD" Inserted the term "ancillary" into MHS-PGF-4.7.1.2-0050 Clarified MHS-PGF-4.7.2-0010 by referencing CH 5 Added clarification on timeliness to MHS-PGF-4.7.2-0020Clarified by adding phrase "in accordance at least with the specifications in Chapter 5" to MHS-PGF-4.1-0010 Removed reference to parameter estimation function in 4.8.

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			Changed "file" to "dataset" to avoid the impression that we wish to constrain the design in such a way in MHS-PGF-4.8.1.1-0030 Added explanatory comment to MHS-PGF-4.8.1.3-0010 Removed "other TBD." in MHS-PGF-4.8.1.4-0020 Removed last 2 points in MHS-PGF-4.8.1.5-0010 Name of dataset corrected in comment to MHS-PGF-4.8.2.1-0050 MHS-PGF-4.8.1.5-0020 and MHS-PGF-4.8.1.5-0030: max scan lines used specified. Changed "specified" to user-configurable in MHS-PGF-4.8.2.1-0150 Changed meant to mean in MHS-PGF-4.8.2.1-0160.Changed "the" to "a" in comment to MHS-PGF-4.8.2.3-0040 Removed point 4 in MHS-PGF-4.9.2-0010 Section 4.10 removed.
			Removed MHS-PGF-4.6-0020
5.2	14/03/2003	EUM:EPS.SYS.DCR.03.070	Chapter 5, 5.1.1, 5.1.1.3, 5.1.2, 5.1.2.1 Added statement on flag setting. Minor updates for clarification, text and eq.40, 4, 5.
			5.1.2.2.1 Partly rephrased, introduced subchapters and modified eq. 22 and 24 for clarification; removed eq. 25 and 26.
			5.1.2.2.1 -5.2.1.1 Modified text and eq. 8, 9, 27, 28, 10,29, 11, 37, 13, 36, 17 for clarification; corrected eq. 31; removed eq. 2 (in 5.1.2.6)
Issue5, Revision 3	6 April2004	EUM.EPS.SYS.DCR.04.031	Moon contamination description according to PLP Updated calibration data content Removed misleading description of the calibration procedure (e.g. mean target temperatures, mean target radiances etc.)
Issue 5, Revision 4	4 June 2013	EPS Docet228	Added requirement section to document function HMHS-PGF-4.6.1.5-0050. Function specifies requirements for NEdT, the Noise-equivalent delta temperature. Added Section 5.1.2.9 to provide specifications of the algorithms for the NEdT calculation.
Version 6	17 Sep 2013		Document transcribed to Word format from Framemaker, retaining original Reference Number.

4.9.3 Accuracy Requirements

MHS-PGF-4.9.3-0010	**PERF**
The application of the calibration to the pixels shall be performed with an accuracy of better than 0.6 LSB (Least Significant Bit) maximum and 0.3 LSB RMS. ***Note*:** The LSB corresponds to the LSB of the final Level 1b binary representation. ***Note:*** It is expected that the transformation would be based on a LUT transformation mapping the Level 1a representation to the Level 1b representation. To achieve this accuracy, the derivation of the LUT would need to be performed with floating point accuracy, followed by the rounding to the final binary representation.	

4.10 Instrument Models Parameter Estimation

(Section Removed)

4.11 Reporting Statistics Requirements

All the reporting information produced by the PGF is gathered to generate the input data for the CGS reporting function. Both the reporting inputs and the full quality information are transferred to the G/S for centralised mission reporting and off-line analysis.

MHS-PGF-4.11-0010	**FUNCT, MMI**
The PGF shall support the generation of monitoring information reports on the observed MHS Instrument status and on the MHS PGF status via the PGE services. Such information reports shall be displayed on screen and printed out on user request.	

MHS-PGF-4.11-0020	**FUNCT, MMI**
The PGF shall monitor its internal status and shall include in its reports at least the following information: 1. Number of products generated since the last report 2. For each generated product, the time tags of first and last scan line 3. For each generated product, the date and time of the end of processing 4. For each generated product, an overall quality indicator 5. Number of received scan lines since the last report 6. Number of corrupted, missing and duplicated scan lines since the last report 7. Progress of any on-going processing. ***Note:*** “Progress” is intended as a percentage of completion: a linear interpolation is sufficient (number of scan lines processed / total number of scan lines).	

MHS-PGF-4.11-0030	**INT**
All reporting shall be performed in accordance with AD49 Core Ground Segment Requirements Documents (EPS/GGS/REQ/95327).	

MHS-PGF-4.11-0040	**FUNCT, INT, MMI**
The PGF shall have the capability to select any of the following parameters in a user-configurable way for forwarding to the CGS for routine monitoring: 1. Any parameter derived from the contents of the pixel data contained in the MHS level 0 data stream (raw counts for a given pixel, calibrated radiance for a given pixel, averaging counts over a target view, gain value, offset value) 2. Any parameter of the PGF software itself 3. Any generated report.	

4.12 Testing Requirements

MHS-PGF-4.12-0010	**TEST**
A complete and coherent set of simulated TEST data shall be developed to TEST the MHS PGF. ***Note:*** “Complete” means that all cases shall be simulated (missing, corrupted or duplicated scan lines; tuning of the quality control thresholds; manoeuvres; etc.). “Coherent” means that the appropriate auxiliary data shall also be produced.	

5 SUPPORTING SCIENCE

This section includes the description of the algorithms mentioned in Section 4.

The description of the algorithms was derived from the MHS on ground calibration activities at the manufacturer's site and leans heavily on the algorithm used for the AMSU-B instrument.

The summary and meaning of the symbols used in the equations is given in Annex A.

In the following it is assumed that the MHS information is made available per scan-line. In those sections where the information of more than one scan line is needed, it is assumed that the information is available in units of one scan line for those multiple scan-lines required. This is valid for both the Metop and NOAA satellites.

From the decommutation process, information shall be available for MHS:

- The instrument status for each instrument
- The space view position for the instrument

A flag shall contain the respective information for each scan line and indicate non-usable scan lines:

- In case the instrument is switched off and not scanning.
- In case the scan line is already flagged as bad.

A warning shall be issued in case a non recommended space view is selected.

There shall be a navigation status flag per scan line, which is to be initialised.

There shall be a calibration status flag per scan line which is to be initialised.

Except for the case of flags which are passed directly through from the level 0 data stream, where no other specification of the setting of a flag bit is identifiable from a combined reading and analysis of this document and the descriptions and/or names of the flag bits in its associated PFS, the flag bits shall not be set, and where no other specification of the setting of a flag bit with a name or description in the PFS including the word 'some,' is identifiable in this document or its associated PFS, then the word 'some' in the bit name or description is to be taken to mean 'more than zero,' and where bits are indicated as not used in the PFS, these bits are not to be set.

For MHS, the antenna pointing of the Earth views must be checked. The thresholds are given in the calibration parameter data set. The antenna pointing position P_{ant} is calculated using the pointing counts C_{ant} in the science data packets according to the following:

$$P_{ant}(i) = M_{ant}C_{ant}(i) + I_{ant}$$

Equation 1

for each antenna view i. M_{ant} and I_{ant} are user-configurable and it is $M_{ant} = 7.03125\ 10^{-3}$ and $I_{ant} = 0$ for MHS. Antenna pointing positions are defined relative to 0 degree (0 counts = 0 degrees) at the centre of the on-board calibration target (OBCT); nadir corresponds to an antenna position of 180°.

Then the ideal antenna pointing position η_{ant} has to be calculated, using the spacing between pixel midpoints $\alpha_{MHS} = 1.1111°$ for MHS:

$$\eta_{ant}(i) = \alpha_0 - (i-1) \cdot \alpha_{MHS}$$

Equation 2

where α_0 is the scan angle for Earth view 1 and $\eta_{ant}(i)$ is the nominal antenna pointing position (scan angle) for Earth view position i. This nominal position is then checked against the error tolerance value taken from the calibration parameter data set MHS_L1_PGS_COF_CAL. These are composed on pre-flight tabulated mispointing data, which are used to calculate the baseline pointing for each antenna view. If the difference from the ideal pointing exceeds a threshold $\varepsilon_{ANT,\ MHS}$, then a flag should be set to indicate the questionable pointing of the respective pixel.

5.1 Level 1a Processing

5.1.1 Navigation Processing

The purpose of this processing step is to compute the Earth location in geodetic co-ordinates (longitude, latitude) of each pixel which will be appended to the MHS Level 1a and 1b data.

The navigation function performs the creation of the Navigation data of each Earth observation pixel. A generic algorithm for the geolocation of pixels from scanning radiometers is specified in section 5.4.3.1 of the AVHRR Level 1 PGS.

Satellite azimuth and zenith angles with reference to north direction and local vertical at the ground measurement location are computed, as well as solar zenith and azimuth angles. In detail:

- Solar zenith angle,
- Satellite zenith angle
- Solar azimuth angle
- Satellite azimuth angle
- Average Terrain elevation in the pixel

The following functions are required:

1. a time handling and processing function which performs the dating of the data using the OBT/UTC correlation data;
2. an orbit propagator, initialised either with a predicted state vector or with the on-board provided state vector;
3. a satellite attitude model to provide the attitude of the platform;
4. an instrument viewing model to express the location of the intersection of each optical ray of the considered field of view with the Earth ellipsoid;
5. an Earth model for the computation of the navigation ;
6. a Digital Elevation Model to annotate pixels with surface altitude.

The respective reference frames of the Metop and NOAA S/C have to be used as per EPS Mission Conventions Document [AD 4].

5.1.1.1 Computation of the Clock Error

The satellite clock error estimate is required to correct the On-Board Time before converting it to UTC. With this the along track error of the sub satellite point is corrected. The clock error is specified in EPS Mission Conventions Document [AD 4].

5.1.1.2 Computation of the Satellite Orbit State and Position

From the flight dynamics function the satellite position, velocity and attitude is obtained and interpolated at the time resolution specified in MHS Level 1 Product Format Specification [AD 3]. In addition, the orbit state vector is provided for the start time of the dump. The flight dynamics information is specified in EPS Mission Conventions Document [AD 4].

5.1.1.3 Computation of the Position for Every Pixel

With the instrument scan characteristics and the satellite position (orbit information) the latitude and longitude of every pixel of every scan line is calculated.

5.1.1.4 Computation of the Satellite and Solar Zenith Angle and Azimuth

From astronomical information provided in MHS_L1_PGS_DAT_ASTRO and from the information obtained in Section 5.1.1.2 and Section 5.1.1.3 the satellite zenith angle, azimuth angle, the solar zenith angle and azimuth angle are calculated.

5.1.1.5 Computation of the Earth Parameters

From the Earth information data set specified in EPS Mission Conventions Document [AD 4] the average terrain elevation is calculated for the MHS Fields of View. Together with terrain type information this information is put into the appended part of the Level 1a and Level 1b Products.

5.1.2 Calibration Coefficients Calculation

The calibration coefficients to convert from Earth view counts to radiance for each of the MHS channels are determined in-flight by viewing the on-board black body target and cold space. A calibration is performed at each scan line (8/3 seconds).

Earth scene radiance R_s, depends on the Earth scene counts C_s through the non-linear relationship.

$$R_s = R_w + \frac{R_w - R_c}{\bar{C}_w - \bar{C}_c} \cdot (C_s - \bar{C}_w) + Q$$

Equation 3

The linear slope M_l (inverse of the linear gain term *G)* is given by:

$$G = \frac{\bar{C}_w - \bar{C}_c}{R_w - R_c}$$

Equation 4

where is *G* a function of the average warm target calibration measurement counts $\bar{C}_w$, the cold space calibration measurement counts $\bar{C}_c$, the warm target radiance R_w, and the radiance of cold space R_c. The warm target radiance is calculated from PRT measurements of the temperature of the warm target using the Planck function, and the cold space radiance is calculated from the temperature of cold space, using the Planck function.

The non-linear term *Q* is given by

$$\begin{aligned} Q &= u \cdot (R_w - R_c)^2 \cdot \frac{(C_s - \bar{C}_w) \cdot (C_s - \bar{C}_c)}{(\bar{C}_w - \bar{C}_c)^2} \\ &= u \cdot \frac{(C_s - \bar{C}_w) \cdot (C_s - \bar{C}_c)}{G^2} \end{aligned}$$

Equation 5

where *u* is an instrument channel dependent non-linearity coefficient. *u* also depends on the current instrument temperature and is calculated by a linear interpolation of pre-launch values measured for three different instrument temperatures. Each of these terms is described in more detail below in the following.

The following steps are to be performed, for both the primary and secondary set of calibration coefficients:

- **compute the internal warm target temperature** from several (the default is five) PRT output values, translated into temperature using the PRT Calibration Channels, if available. There is a primary and a secondary set of PRT temperatures used.
- **compute the effective internal warm target brightness temperature** for each channel, using supplied warm target corrections;
- **compute the effective cold space brightness temperature for each channel,** using the known temperature of cold space and supplied cold view corrections;
- **convert the mean warm target temperature and the cold space temperature into radiance**;
- **compute the linear slope from the warm target and cold space averaged counts and radiance;**
- **compute calibration coefficients** to convert counts into radiance including a quality control (variation of the coefficients with respect to the previous calibration);
- **optional corrections**: scan dependent corrections for cold scene temperatures, antenna corrections (side lobes).

5.1.2.1 Get Information From Calibration Data Set

The user-configurable data set MHS_L1_PGS_COF_CAL contains the required information for the calibration of the instrument. It is specific for each flight model and contains the following information:

MHS generic information:

- Brightness temperature of space at MHS frequencies in K.
- Five central wave numbers.
- Band correction coefficients *a, b* for each channel.
- Three nominal space and 1nominal internal target viewing angles in degrees.
- Flag for moon contamination detection on/off.
- Threshold for the difference between the lunar angle and the antenna space view position.

MHS flight model specific information:

- MHS instrument ID.
- Selected position (one out of three possible) of space view for calibration.
- Slope and offset for converting the antenna pointing counts to antenna positions in degrees, for MHS.
- Antenna position error allowed in degrees for calibration and Earth views.
- Misalignment for each channel in degree for tabulated bore sight angles.
- Three calibration resistor resistance values in for reference resistors (PIE-A).
- Three calibration resistor resistance values in for reference resistors (PIE-B).
- Five sets of four resistances to temperature conversion coefficients for PRT set A.
- Five sets of four resistances to temperature conversion coefficients for PRT set B.
- Weight coefficients for each of the five PRT, PRT set A.
- Weight coefficients for each of the five PRT, PRT set B.
- Reasonable PRT resistance count limits.
- Reasonable reference resistances count limits.
- Reasonable PRT resistance limits (minimum, maximum, in Ohms)
- Reasonable PRT temperature limits (minimum, maximum, in K)
- Maximum PRT temperature change (in K) allowed before rejecting
- Minimum number of PRT readings acceptable
- Number of scan lines to fill in bad PRT data
- Number of scan lines to use in consistency checks of calibration views
- Instrument temperature sensor ID (QBS5 or QBS1)
- Three instrument reference temperatures (QBS5)
- Three backup instrument reference temperatures (QBS1)
- Coefficients for converting counts of the 24 housekeeping thermistors into temperatures
- Warm load correction factors (each channel, each reference temperature)
- Cold space correction factors (each channel, each space view)
- Gross count limits (maximum and minimum) for the Earth view targets counts
- Gross count limits (maximum and minimum) for the internal target counts
- Gross count limits (maximum and minimum) for the space view counts
- Maximum change in mean counts from previous scan allowed before rejecting
- Non linearity correction coefficients, three reference temperatures, channels H1 - H5
- Non linearity correction coefficients, three backup reference temperatures, channels H1-H5
- Nominal space and internal target viewing angles
- Analogue conversion coefficients (slope and intercept)
- Survival thermistor coefficients

5.1.2.2 Computation of the Warm Target Radiance

The warm target is also denoted as the On Board Calibration Target (OBCT). The radiance measured from the OBCT provides one point in the calibration curve.

5.1.2.2.1 Computation of the Warm Target PRT Temperatures

The Planck function allows the calculation of the warm target radiance given estimates of their temperatures. The MHS warm target temperature is measured with five embedded Platinum Resistance Thermometers (PRTs) whereas the AMSU-B on NOAA KLM has seven PRTs. The PRT counts are contained in the CCSDS source packet along with other instrument monitoring temperatures.

The family of 5 PRT sensors provides an estimate of the mean temperature of the On Board Calibration Target (OBCT, warm target). There are two sets of PRT (see Figure 3), set A and set B. The default OBCT temperature will be derived from set A. The set B serves as a backup. There is no mixture possible of the temperatures of the two sets. There are four sensors positioned in a ring equally spaced and on the same pitch circle diameter and one central sensor per set. The sensors are read in a particular order (1,2,3,4,5).

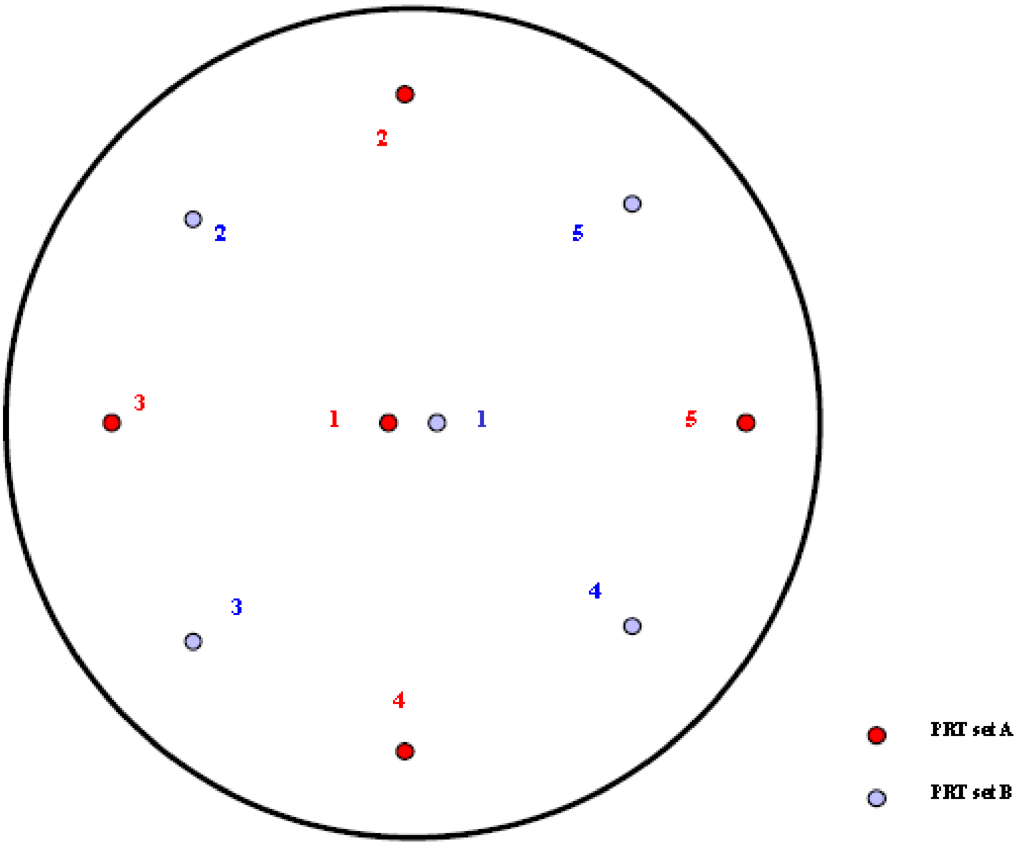

Figure 3: *Primary (set A, red) and secondary (set B, blue) set of PRT in the OBCT, as seen from the bottom of the instrument.*

The PRT set A is processed by the Process and Interface Electronics PIE-A, whereas the PRT set B is processed by PIE-B.

Additionally, there is a set of three precision resistors connected to each PIE. Their resistance values are constant over the expected temperature range and life time and are chosen to lie at the lower, middle and upper resistance values expected of the OBCT PRTs throughout mission life. These three resistors are fed by the same power supply as the five PRTs and their counts are generated by the same electronics. Their constant resistance values, which are measured pre-flight on ground, and their corresponding counts, which are generated for each scan line on board and which are contained in the CCSDS source packets, define three calibration points from which the offset R_{off} and slope m of the linear calibration function for the five PRTs are calculated by a least squares linear regression. This calibration of the PRTs eliminates the effect of slow variations in the values of the power supply, the PRTs and the electronics.

The PRT temperatures are derived in a two-step process:

1. The PRT counts are converted to PRT resistances by making use of the values of three precision calibration resistors.
2. The PRT resistances are converted to PRT temperatures using a polynomial function.

5.1.2.2.1.1 PRT count to PRT resistance conversion

Using the constant resistance values of the three calibration resistors in use (indicated by the PIE Identify Bit in the Mode and Subcommutation Code of the Full Housekeeping Telemetry Data Block of the CCSDS Source Packet) and the corresponding resistors counts the least squares linear regression mentioned above delivers for the slope *m.*

$$m = \frac{3 \cdot \sum_{i=1}^{3} C_R(i) \cdot R_0(i) - \sum_{i=1}^{3} C_R(i) \cdot \sum_{i=1}^{3} R_0(i)}{3 \cdot \sum_{i=1}^{3} (C_R(i))^2 - \left(\sum_{i=1}^{3} C_R(i) \right)^2}$$

Equation 6

and for the offset R_{off}

$$R_{off} = \frac{\sum_{i=1}^{3} R_0(i) \cdot \sum_{i=1}^{3} (C_R(i))^2 - \sum_{i=1}^{3} C_R(i) \cdot \sum_{i=1}^{3} C_R(i) \cdot R_0(i)}{3 \cdot \sum_{i=1}^{3} (C_R(i))^2 - \left(\sum_{i=1}^{3} C_R(i) \right)^2}$$

Equation 7

where

- $C_R(i)$ is the calibration resistor count value of resistor i, i = 1, 2, 3;
- $R_0(i)$ is the corresponding calibration resistor resistance value of resistor i, i = 1, 2, 3.

The slope m and the offset R_{off} applied to each of the OBCT PRT count samples gives the PRT resistance value R_k for each individual PRT number k:

$$R_k = m \cdot C_k + R_{off}$$

Equation 8

5.1.2.2.1.2 PRT resistance to PRT temperature conversion

Then, subsequently the PRT resistances R_k are converted to equivalent temperatures via a cubic polynomial with the pre-launch determined coefficients $f_{k,j}$. where k indicates the PRT number and j is the respective exponent.

$$T_k = \sum_{j=0}^{3} f_{k,j} \cdot R_k^j$$

Equation 9

There is a set of four polynomial coefficients $f_{k,j}$ for each PRT k of PIE-A and PIE-B. They are different for each flight model and are taken from the calibration data set (MHS_L1_PGS_COF_CAL).

5.1.2.2.1.3 Consistency check of the PRT temperatures

The PRT temperatures are then checked for consistency over a scan line before the mean temperature is computed. First "good" PRT values are selected:

- The PRT weight must be greater than 0;
- The PRT temperature must be within gross limits;
- The PRT used for the calculation of the average PRT temperature must be within a range from the median.

Hence, the check:

$$T_{k,\,min} \le T_k \le T_{k,\,max}$$

Equation 10

selects good points for all weights greater than zero. Then, there is a check of the good values against the median value:

$$\left| T_{k,\,good} - T_{median} \right| \le \delta T_{PRT}$$

Equation 11

where $T_{k,good}$ are the PRT temperatures selected through the check above, T_{median} is the median of the good temperatures and δT_{PRT} is a threshold taken from the calibration data set. The average PRT temperature is then computed using the "good" PRT temperatures, which passed the median test according to

$$T_{PRT,\,avg} = \frac{\sum_{n=1}^{good} w_n \cdot T_{n,\,good}}{\sum^{N_{good}} w_n}$$

Equation 12

where n is the index of the good PRT temperatures, which passed the median test, w_n is the weight of the good PRT, the temperature of which has passed the median test.

Finally, if the current average PRT temperature is of good quality so far, an interline consistency check of the PRT temperature is performed by comparing the PRT temperature of the current scan line with the most recent good one.

If the number of scan lines between the line of the most recent good PRT temperature and the current scan line is smaller than or equal to a threshold, the differences between the PRT temperatures and the instrument temperatures are calculated. If both differences are smaller than or equal to a threshold, the current PRT temperature is declared good. Otherwise the current PRT temperature is replaced with the previous good one if their difference is greater than the threshold. The same procedure is applied to the instrument temperature.

If the number of scan lines between the line of the most recent good PRT temperature and the current scan line exceeds the threshold of the maximum allowed gap then the current PRT temperature is declared good.

A flag is set for the PRT and instrument temperature status as well as for the scan-line quality.

5.1.2.2.2 Calculation of the Average Warm Target Temperature

All the PRT temperatures are averaged to estimate the corresponding warm target temperature:

$$T_{w,ch} = \frac{\sum_{k=1}^{m} w_k \cdot T_k}{\sum_{k=1}^{m} w_k} + \delta T_{w,ch}$$

Equation 13

where w_k is a weighting factor associated with each PRT k, and m is the number of PRTs for the target. $\delta T_{w,ch}$ is a warm target bias correction determined by linear interpolation from pre-launch values measured for each instrument channel at three instrument temperatures. Therefore, the average warm target temperature is channel dependent due to this bias correction. The bias correcting term reflects for each channel the contamination by radiation originating from the spacecraft and the Earth limb.

5.1.2.2.3 Computation Of The Warm Target Radiance

The radiance $R_{w,ch}$ emitted by the warm target with the temperature $T_{w,ch}$ in the instrument channel *ch* band is calculated applying Planck's law

$$R_{w,ch} = B(T_{w,ch}')$$

Equation 14

Planck's law is approximated by first band-correcting the temperature to get the effective channel temperature $T'_{w,ch}$ according to

$$T'_{w,ch} = a + b\bar{T}_{w,ch}$$

Equation 15

where *a* and *b* are the channel dependent band correction coefficients. The averaged mean warm target temperature $\bar{T}_{w,ch}$ is computed according to Equation 14 of Section 5.1.2.4.

Generally, the radiance in mW/(m^2 ster cm^{-1}) is expressed as a function of the channel's central wave number κ in cm^{-1} and the temperature T in K via

$$R_{w,ch} = \frac{c_1 \kappa^3}{\exp\left(c_2 \cdot \frac{\kappa}{T_{w,ch}'}\right) - 1}$$

Equation 16

where c_1 and c_2 are the first and second constant of the Planck function and are to be taken from the data set of physical constants. The band correction coefficients and the central wave numbers κ are determined before launch such that they implicitly reflect the filtering effect of the channels' spectral response functions.

It is possible to use a look up table approach (radiance, temperature) to transform temperatures into radiances via the Planck function.

5.1.2.3 Computation of the Cold Space Radiance

5.1.2.3.1 Estimation of the Cold Space Temperature

The space view provides the second point on the calibration curve. The cold space microwave background radiation has been measured several times, since its discovery by Penzias and Wilson. The temperature of cold space is 2.7 ± 0.2 K. The cold space temperature is hence directly estimated from:

$$T_{c,\,ch} = 2.7 + \delta T_{c,\,ch} \qquad \textit{Equation 17}$$

where $\delta T_{c,ch}$ is a cold space temperature bias correction determined by linear interpolation from values given for each instrument channel at three instrument temperatures. Therefore, the average cold space temperature is channel dependent due to the bias correction. The bias correcting term reflects for each channel the contamination by radiation originating from the spacecraft and the Earth limb. Three sets of bias correction values will be provided pre-launch, corresponding to the three possible space view settings. Which space view is in use is given by the Profile code in the Status Word of the Science Data Packet.

5.1.2.3.2 Moon Contamination Correction

It has turned out (Saunders et al., 2002) that the moon, if visible in the cold space view of the AMSU-A and MHS instruments, can cause considerable problems in the calibration, which may amount to several tens of K in brightness temperatures, in the case of MHS. Hence, there is a need to correct for this effect. The several steps required for this correction are described here.

5.1.2.3.2.1 Calculation of the moon angle

1. Calculate the geocentric right ascension $\alpha_{RA,moon}$ and declination δ_{moon} of the moon using standard astronomic formula or tables. This position needs to be accurate to 0.3 degrees or better (*http://www.xylem.f2s.com/kepler/moon.html*). It is acceptable to do the full calculation at the beginning and end of each dump, and interpolate for intermediate scan-lines to save computation time.
2. To establish whether the moon lies within any of the four instrument space field of views, the moon coordinates must be transformed from the space fixed reference frame, to the instrument field of view reference frame. This process involves several stages. Firstly, the moon co-ordinates are converted from a space fixed geocentric reference frame to an earth fixed geocentric reference frame (with the x-axis pointing to the Greenwich Meridian, z-axis to the North pole and the y-axis making up the right handed set). To transform to the Greenwich Meridian earth-fixed reference frame, the space fixed moon coordinates must be rotated about the z-axis by the hour angle α_h . In this case, the hour angle is simply the sidereal time at the Greenwich meridian expressed as an angle since the right ascension on the first point of Aries (the x-axis of the space-fixed coordinate system), is zero. The hour angle is simply how much sidereal time has passed since the first point of Aries was on the Greenwich meridian.

As a result, for each individual scan line *i*, we need to compute the local sidereal time t_{ist} according to:

$$t_{lst}(i) = 100.46 + 0.98564735 \cdot j_{day} + h \cdot 15° + \lambda$$

Equation 18

where j_{day} is the time in days since the epoch 12:00 at 1 January 2000, *h* is the hour of the day in GMT and is the longitude of the Greenwich meridian (zero degrees in this case). The earth-fixed coordinates of the moon for each scan line are then given by:

$$\begin{bmatrix} x^{earth}_{moon} \\ y^{earth}_{moon} \\ z^{earth}_{moon} \end{bmatrix} = \begin{bmatrix} \cos\alpha_h & \sin\alpha_h & 0 \\ -\sin\alpha_h & \cos\alpha_h & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} x^{space}_{moon} \\ y^{space}_{moon} \\ z^{space}_{moon} \end{bmatrix}$$

Equation 19

3. Given the position of the satellite in the same earth-fixed reference frame, the position of the moon, **$\underline{dr}$**, with respect to the satellite is:

$$\underline{dr} = \begin{bmatrix} dx \\ dy \\ dz \end{bmatrix} = \underline{r}_{moon} - \underline{r}_{sat}$$

Equation 20

This vector must be transformed to the satellite frame of reference and then to the actual field of view reference frame. The satellite reference frame [AD4] is defined by the right-hand geocentric axes with the z axis pointing away from the earth's centre, the y-axis points approximately in the direction of negative velocity and the x-axis making up the right hand set.

4. To transform to the satellite frame of reference, a rotation about the z-axis by the satellite longitude, λ is required, followed by a rotation about the new x-axis by 90° - latitude, ϕ. The x-y axes then need aligning such that the y-axis points in the direction of negative satellite velocity. The three transformations required to convert $\underline{dr}$ to the satellite reference frame of reference $\underline{dr}^{sat}$, are summarized below:

$$\begin{bmatrix} dx' \\ dy' \\ dz' \end{bmatrix} = \begin{bmatrix} \cos\lambda & \sin\lambda & 0 \\ -\sin\lambda & \cos\lambda & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} dx \\ dy \\ dz \end{bmatrix}$$

$$\begin{bmatrix} dx'' \\ dy'' \\ dz'' \end{bmatrix} = \begin{bmatrix} \cos\left(\frac{\pi}{2} - \phi\right) & 0 & -\sin\left(\frac{\pi}{2} - \phi\right) \\ 0 & 1 & 0 \\ \sin\left(\frac{\pi}{2} - \phi\right) & 0 & \cos\left(\frac{\pi}{2} - \phi\right) \end{bmatrix} \times \begin{bmatrix} dx' \\ dy' \\ dz' \end{bmatrix}$$

$$\begin{bmatrix} dx^{sat} \\ dy^{sat} \\ dz^{sat} \end{bmatrix} = \begin{bmatrix} \cos\left(\frac{\pi}{2} + \theta^{vel}\right) & \sin\left(\frac{\pi}{2} + \theta^{vel}\right) & 0 \\ -\sin\left(\frac{\pi}{2} + \theta^{vel}\right) & \cos\left(\frac{\pi}{2} + \theta^{vel}\right) & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} dx'' \\ dy'' \\ dz'' \end{bmatrix}$$

Equation 21

where Θ^{vel} is the angle subtended by the x-y component velocity and the x-axis in the x-y plane of the intermediate x'',y'',z'' frame (there should be no z component of velocity).

$$\theta^{vel} = \operatorname{atan}\left(\frac{v_y''}{v_x''}\right)$$

Equation 22

Note: The velocity vectors vx'' and vy'' must also be defined in the intermediate x'',y'',z'' frame. For example, if the satellite velocity is known in earth fixed geocentric co-ordinates, the velocity vectors must also be transformed in the same way that the moon position vector was transformed from (dx,dy,dz) to (dx'',dy'',dz'').

5. The satellite attitude must also be taken into account by transforming to the satellite actual frame of reference. This involves 3 rotations about the x,y,z axes by the roll, pitch and yaw angles as defined in [AD 4].

6. MHS has 4 space FOVs used for calibration purposes. The space field of views, δ^{FOV}, given here are measured anti-clockwise from the -x axis in the z-x plane of the satellite actual frame of reference.

   Note: Several settings for the 4 space FOVs may exist and so the actual positions of the space field of views must be obtained from the satellite data itself for each scan line.

   To establish whether the moon is within each field of view, the angular separation between moon and each space view is calculated using standard trigonometry. To achieve this, the coordinate system i s transformed such that the direction field of the view in question is coincident with the –xaxis and then the dot product of the new -x axis and the new moon position vector $\underline{dr}^{FOV}$ is calculated as follows:

$$\begin{bmatrix} dx_i^{FOV} \\ dy_i^{FOV} \\ dz_i^{FOV} \end{bmatrix} = \begin{bmatrix} \cos\delta_i^{FOV} & 0 & \sin\delta_i^{FOV} \\ 0 & 1 & 0 \\ -\sin\delta_i^{FOV} & 0 & \cos\delta_i^{FOV} \end{bmatrix} \times \begin{bmatrix} dx^{sat} \\ dy^{sat} \\ dz^{sat} \end{bmatrix}$$

Equation 23

where i ranges from 1 to 4 and denotes which field of view is being referred to. The angle subtended by the moon and the space field of view in question, $\theta\Delta_i^{moon}$, is given by

$$\Delta\theta_i^{moon} = \mathrm{acos}\left(\frac{-\hat{\underline{x}} \bullet \underline{dr}_i^{FOV}}{\left|-\hat{\underline{x}}\right| \left|\underline{dr}_i^{FOV}\right|} \right)$$

Equation 24

where $-\hat{\underline{x}}$ is a unit vector and i ranges from 1 to 4 (denotes to which field of view angle refers.)

7. Space view readings are considered contaminated if the moon is within a predefined angle of the space view. The condition for moon contamination is then:

$$\Delta\theta^{moon} > \left(\frac{1.1^{\circ}}{2} + 0.25^{\circ} + 0.3^{\circ} \right)$$

Equation 25

where:

i. the instrument field of view = 1.1 degrees

ii. the angle subtended by the moon = 0.25 degrees

iii. the error in the moon calculation is at worst 0.3 degrees.

These values must be user configurable and may be changed.

8. An alternative method would be to use the satellite attitude information and the earth located two mid-swath samples (45 and 46 for MHS) to calculate the angle subtended by the moon and the space field of views. However, care must be taken to allow for the forward motion of the spacecraft during the time elapsed between the acquisition of the mid-swath pixels and the space counts.

5.1.2.3.2.2 Correction of the data

For MHS, there will be normally be at least one remaining non-contaminated space-view sample. In this case the calibration proceeds as normal, except the contaminated samples are rejected and not used. In these circumstances, recovery from contamination is achieved. In the case there are no good space field of views, recovery is not achieved and the scan line must be flagged.

Lines which are moon-contaminated must be flagged as such by setting bit 18 in the SCAN_LINE_QUALITY flag. If the scan line recovered from contamination then bit 17 in the SCAN_LINE_QUALITY flag must also be set. In addition, the angles subtended by the moon position vector and the centre of the space field of views must be recorded using the lunar angles level 1 product.

5.1.2.3.3 Computation of the Cold Space Radiance

The radiance $R_{c,ch}$ emitted by the cold space target with the temperature $T_{c,ch}$ in the instrument channel *ch* band is calculated applying Planck's law:

$$R_{c,ch} = B(T_{c,ch}')$$

Equation 26

Planck's law is approximated by the band correction method as specified in section 5.1.2.2.3.

5.1.2.4 Averaging the Warm Target and Cold Space Counts and Temperatures

At each scan, four measurements of the internal black body (warm) target C_w and of the cold space C_c, are performed and averaged. If the maximum and the minimum of the four measurements differ by more than a pre-set limit of black body (respectively cold space) count variation, the data from that scan line is not used. The initial limit is calculated from the pre-launch calibration data and is set to 5σ of this data set.

As a first step, the antenna pointing to the internal warm target and the external cold space needs to be checked, in an analogue way to the check of the earth view antenna position. The thresholds are given in the calibration parameter data set MHS_L1_PGS_COF_CAL. The antenna pointing position is calculated using the antenna pointing counts $C_{x,ant}$ and the slope $M_{x,ant}$ and offset $I_{x,ant}$ for the counts to antenna position conversion. This is performed as follows:

$$P_{x,\,ant} = M_{x,\,ant} \cdot C_{x,\,ant} + I_{x,\,ant}$$

Equation 27

where x stands for c(old) and w(arm) target. Then the selected space view position is then checked against the error tolerance value taken from the calibration parameter data set MHS_L1_PGS_COF_CAL. If

$$\left|\eta_{c,\ ant} - P_{c,\ ant}\right| > \varepsilon_{c,\ ant}$$

Equation 28

then a warning flag should be set for the space view. The scan-line flag should indicate that the cold space view antenna pointing is bad.

The same check is done on the internal warm target. against the error tolerance value taken from the calibration parameter data set MHS_L1_PGS_COF_CAL. If

$$\left|\eta_{w,\ ant} - P_{w,\ ant}\right| > \varepsilon_{w,\ ant}$$

Equation 29

then a warning flag should be set for the internal target view. The scan-line flag should indicate that the internal warm target antenna pointing is bad.

To reduce the noise and provide calibration coefficients that vary smoothly with time, the instrument counts from *n* consecutive scan lines before and after the current scan line are used to compute the average counts, ($\bar{C}_w$ and $\bar{C}_c$). For $n = 3$, a triangular convolution function defined over the seven measurements is applied for each scan line:

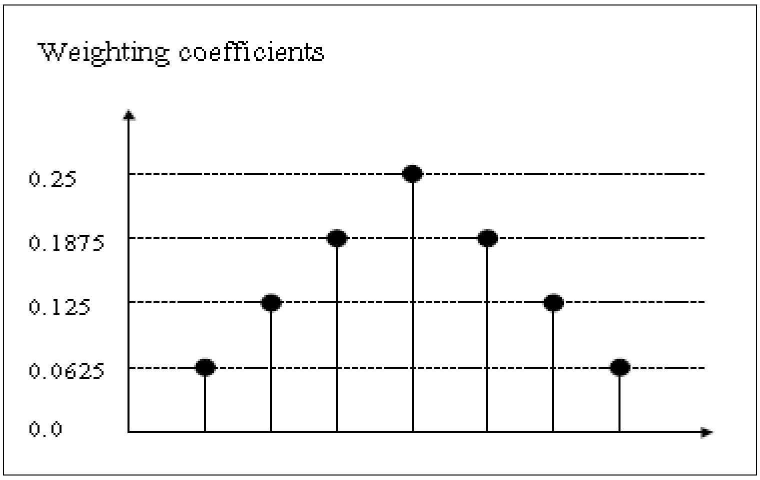

Figure 4: Weighting coefficients for the Warm Target/Cold Space Counts Convolution Function

The following equation determines the applied convolution:

$$\overline{C}_x = \frac{1}{n+1} \cdot \sum_{i=-n}^{+n} \left(1 - \frac{|i|}{n+1}\right) \cdot C_x(t_i)$$

Equation 30

where

- x stands for w (warm black body target) or c (cold space target),
- n is half of the number of the additional scan lines over which the averaging is done,
- t_i is the time of the scan lines before or after the current scan line, and
- $C_x(t_i)$ is the average of scan line's four black body views or four cold space views at time ti,

where:

$$C_x(t_i) = \frac{1}{N} \cdot \sum^{N} C_{x,\,i}$$

Equation 31

and N=4 if all OBCT and space views are usable per scan line. In case of failure, N denotes the number of working calibration target views. If t_0 is the time of the current scan line, one can write $t_i = t_0 + i \bullet \Delta t$, where $\Delta t = 8/3$ seconds for MHS. The $2n + 1$ values are equally distributed around the scan line to be calibrated ($n = 3$ for MHS). Around a scan line gap, the convolution is applied with a restricted number of scan lines.

In case a moon-glint correction needs to be made, **N** may be less than 4 (see above).

Likewise, the average calibration target temperature from the PRT measurements $\overline{T}_w$ is determined:

$$\overline{T}_{w,\,ch} = \frac{1}{n+1} \cdot \sum_{i=-n}^{+n} \left(1 - \frac{|i|}{n+1}\right) \cdot T_{w,\,ch}(t_i)$$

Equation 32

5.1.2.5 Interpolation Of The Non-Linearity Correction Coefficients

u is the non-linearity coefficient (see Equation 3) of the instrument channel count to radiance calibration equation. *u* is a function of the current instrument temperature, the instrument channel and the Local Oscillator in use.

Each channel can be individually switched per telecommand from the Local Oscillator–A to B and the reverse. H3 and H4 can only be switched together. The state of the channels is given by status bits in the Switch Status Telemetry. Non-linearity coefficients are given for each combination of instrument channel, Local Oscillator in use and at three instrument temperatures. *u* is determined for the current instrument temperature from those reference values by linear interpolation.

Tests of the MHS showed that the calibration is very close to linear on all channels and that operational processing of data where biases less than 0.3 K are acceptable can be done using a linear calibration law . However, a non-linearity correction in the medium temperature range is desirable for higher precision applications, such as climate studies.

5.1.2.6 Deduce the Slope

The next step in the calibration sequence is then to derive the slope (inverse gain) from the warm and cold target radiances and also the average cold and warm target counts:

$$\frac{1}{G} = \frac{R_w - R_c}{\bar{C}_w - \bar{C}_c}$$

Equation 33

5.1.2.7 Derive Zero Radiance Counts

Subsequently the zero radiance counts Co are calculated using the slope, the average warm target radiance and the average warm target counts. This is calculated for information only but not used in the subsequent processing.

$$C_0 = \bar{C}_w - (G \cdot R_w)$$

Equation 34

5.1.2.8 Calculation and Application of Calibration Coefficients

The non-linear calibration function:

$$R_s = R_w + \frac{1}{G} \cdot (C_s - \bar{C}_w) + Q$$

Equation 35

can also be written:

$$R_s = a_0 + a_1 \cdot C_s + a_2 \cdot C_s^2$$

Equation 36

where a_0, a_1 and a_2 are the calibration coefficients computed from G and u at each scan line:

$$\begin{cases} a_0 = R_w - \dfrac{\overline{C}_w}{G} + u \cdot \dfrac{\overline{C}_w \cdot \overline{C}_c}{G^2} \\ a_1 = \dfrac{1}{G} - u \cdot \dfrac{(\overline{C}_w + \overline{C}_c)}{G^2} \\ a_2 = \dfrac{u}{G^2} \end{cases}$$

Equation 37

5.1.2.9 The Algorithm to Calculate the Noise Equivalent Temperature

The value for NEdT is calculated for each channel and each scan line. It is driven by the variability of the warm target view counts generated during the blackbody view of the antenna. Like the previously described procedure of the operational instrument calibration, the counts for the blackbody views and the space views are averaged using a triangular-sliding window. For an arbitrary scan line f, these weights are given by:

$$w_{k,j} = \frac{1}{n+1}\left(1 - \frac{k-f}{n+1}\right)$$

Equation 38

The parameter n determines the width of the window, which is *(2n+1)*. In the current code, n is set to 3. Using this formula, the weights are normalized to 1 since:

$$\frac{1}{n+1} \sum_{k=j-n}^{k=j+n} \left(1 - \frac{|k-j|}{n+1}\right) = 1$$

Equation 39

The weighted standard deviation of the warm target counts of seven subsequent scan lines is therefore:

$$\sigma_{w,j} = \sqrt{\sum_{k=j-n}^{k=j+n} w_{k,j}\overline{C_{wk}^{2}} - \left\{ \sum_{k=j-n}^{k=j+n} w_{k,j}(\overline{C}_{w,k}) \right\}^{2}}$$

Equation 40

whereas:

$$\overline{C}_{wk} = \frac{1}{N}\sum_{i=1}^{N} C_{wi}\Bigg|_{k} \qquad \text{with N=4}$$

Equation 41

The latter equation represents the scan line average of the four individual warm target views C_{wi} and:

$$\overline{C^{2}{}_{wk}} = \frac{1}{N}\sum_{i=1}^{N} C_{wi}\Bigg|_{k} \qquad \text{with N=4}$$

Equation 42

Thus, in the first step, the warm target counts C_W are averaged per scan line and in the second step, a weighted mean of the averaged counts is calculated using seven subsequent scan lines and a triangular, sliding window.

The NEdT for an individual scan line f is given by the fraction of the weighted standard deviation and the gain of this scan line:

$$NEDT_j = \frac{\sigma_{w,j}}{\dfrac{\sum\limits_{k=j-n}^{k=j+n} w_{k,j}(\overline{C}_{wk}) - \sum\limits_{k=j-n}^{k=j+n} w_{k,j}(\overline{C}_{\dot{c},k})}{T_{PRTavgj} - 4}}$$

Equation 43

With the following parameters:

$\overline{C}_{c,k}$	Cold space view counts averaged over a scan line K.
$T_{PRT,avg,j}$	Temperature of the warm targets derived from the thermistor measurements.

The value of 4 is an approximation of the temperature of space plus an offset due to some background radiation. In practice, $NEDT_j$ is often averaged over a distinct number of subsequent scan lines (typically 100) in order to get a smoother estimate. The averaging procedure is not part of the operational procedure.

5.2 Level 1b Processing

The calibration coefficients are applied to the Earth view counts and thus the engineering information converted into physical parameters.

The MHS Level 1b processing includes the application of the calibration coefficients to the Earth view counts to retrieve the calibrated radiance for all the five channels.

5.2.1 Radiance Computation

Radiance is computed according to the calibration equation for the calibration parameters (see Equation 18).

5.2.1.1 Optional Level 1 B Processing Steps

It shall be possible to ***de***-activate the following optional additional correction by user-configurable configuration parameters:

- Scan Angle Dependent Antenna Corrections ΔR_A

The corrections are optionally added to the Earth scan radiance R_s:

$$R_s^{corr} = R_s + \Delta R_A$$

Equation 44

5.2.1.1.1 Scan Angle Dependent Antenna Corrections

These may include a scan-dependent correction for cold scene temperatures, which would be computed per channel and with a dependency on the scan position n.

$$\Delta R_A = f(n, \nu_i, R_s)$$

Equation 45

where *n* is the scan position and is the frequency of channel i.

5.3 Handling of Edge-of-Dump/Data-Gap Conditions

At the edge of dump as well as at possible data gaps the calibration procedure is applied as indicated in the previous sections above. In the case of data gaps the relative weights of Figure 4 are used, but any points that would fall in the gap are excluded, and the weights are re-normalised. The averaging of calibration counts and temperatures is then performed only for the remaining parts of the weighting triangle. (Hence: If x is the last line before the gap, for the (x-3)rd line the full averaging procedure can be applied, for the (x-2)nd line there is one weight less to apply, as follows. The exact opposite is true for the lines after the gap.

At the dump boundary, a buffer of 2n lines is kept, which have to be used for the calibration of the next dump, where the first line needs to be synchronised with the lines kept. The full averaging procedure is then to be applied. The first lines of the new dump have to be used to calibrate the last lines of the previous dump.

APPENDIX A: LIST OF EQUATIONS PARAMETERS

The following table presents the preliminary list of parameters, coefficients and intermediate values used to translate the Earth view counts into calibrated radiances for the MHS instrument.

The symbol and a short description are followed by the origin column, which provides the origin of the variable:

C	Computed
M	Earth view measurement data
Aux	Auxiliary data
Anc	Ancillary data

Variables are listed as follows:

1. Origin C, M, Aux and Anc in this order
2. Alphabetical order within an origin; first common symbol characters then Greek characters.

Symbol	***Description***	***Origin***
$\alpha_h(t)$	Moon hour angle	C
$\alpha_{RA,moon}$	Moon right ascension of the ascending node	C
δ_{moon}	Moon declination	C
δ^{FOV}	space field of view angle, as measured anti-clockwise from the -x axis in the z-x plane in the satellite frame of reference	C
$\Delta\theta_{moon}$	angle subtended by the moon and the space field of view	C
a_0	zeroth-order coefficient for the computation of the calibrated radiance	C
a_1	first-order coefficient for the computation of the calibrated radiance	C
a_2	second-order coefficient for the computation of the calibrated radiance	C
$C_c(t_i)$	cold space counts (averaged over two views at scan time t_i)	C
$\bar{C}_c$	averaged cold space counts (weighted average of 7 scans)	C
C_s^{int}	counts at zero radiance	C
$C_w(t_i)$	warm internal target counts (averaged over two views at scan time t_i)	C
dx, dy, dz	position vectors of the moon with respect to the satellite in earth fixed geocentric coordinates	C
dx', dy', dz'	position vectors of the moon with respect to the satellite – intermediate frame of reference	C
dx'', dy'', dz''	position vectors of the moon with respect to the satellite – intermediate frame of reference	C
$dx^{sat}, dy^{sat}, dz^{sat}$	position vectors of the moon with respect to the satellite in the satellite frame of reference	C
dx^{FOV}, dy^{FOV}, dz^{FOV}	position vectors of the moon with respect to the satellite as viewed by the space FOV (sometimes written drFOV)	C
$\bar{C}_w$	averaged warm internal target counts (weighted average of 7 scans)	C
G	gain of the linear calibration law	C

Symbol	Description	Origin
j_{day}	Days since epoch (for moon glint correction)	C
λ	Longitude	C
$Ngood$	Number of good PRT	C
$\eta_{ant}(i)$	nominal antenna position	C
φ_{loc}	local azimuth of the Moon	C
Φ	Latitude	C
$P_{x,ant}$	Antenna pointing to internal warm target or cold space (x stands for (c)old and (w)arm target)	C
Q	non-linear correction term	C
R_c	computed radiance of the cold space target	C
R_s	calibrated radiances	C
R_{sL}	calibrated radiances (linear calibration approximation)	C
R_w	computed radiance of the warm internal target	C
$t_{lst}(i)$	local siderial time	C
$T_b^{a,cor,j}$	Antenna-corrected Brightness temperature	C
$T_b^{limbcor,j}$	Limb-corrected Brightness temperature	C
T_c	estimated temperature of the cold space target	C
T_{inst}	instrument internal temperature	C
T_k	estimated temperature for PRT k	C
T_s	scene brightness temperature	C
T_s'	effective scene brightness temperature	C
T_s^{prt}	average PRT temperature of the calibration scene target	C
$T_{PRT,avg}$	average PRT temperature calculated from good PRT temperatures	C
T_w	estimated temperature of the internal warm target	C
T_w'	modified estimated temperature of the internal warm target	C
T_W^{rad}	radiometric temperature of the black body	C
$T_{k,good}$	good PRT temperature	C
T_{median}	median of good PRT temperature	C
θ^{vel}	angle subtended by the satellite velocity vector and x axis in the intermediate dx'',dy'',dz'' frame of reference	C
$\underline{r}_{moon}$	Cartesian position vector of the moon in geocentric earth fixed coordinates	C
$\underline{r}_{sat}$	Cartesian position vector of the satellite in geocentric earth-fixed coordinates	C
vx'',vy'',vz''	Cartesian velocity vectors in the intermediate dx'',dy'',dz'' frame of reference	C

Symbol	***Description***	***Origin***
x^{earth}_{moon}, y^{earth}_{moon}, z^{earth}_{moon}	Cartesian position vectors of the moon in earth fixed geocentric coordinates	C
x^{space}_{moon}, y^{space}_{moon}, z^{space}_{moon}	Cartesian position vectors of the moon in space fixed geocentric coordinates	C
u	nonlinearity coefficient (function of instrument temperature)	C
$\Delta R_{\Theta(\nu)}$	scan-dependent cold target temperature correction	C
$\Delta R_{\psi(\nu)}$	radiance antenna correction	C
$\psi(f)$	first antenna correction function	C
$\Gamma(f)$	second antenna correction function	C
C_c	cold space counts	M
C_s	earth view counts	M
C_w	warm internal target counts	M
$\tilde{C}_k$	PRT count of PRT k	M
$C_{ant}(i,k)$	Antenna position count of view i of instrument k	M
h	hour of the day in GMT	M
b, c	coefficients for the computation of the modified temperature of the warm target (band correction coefficients)	Aux
α_0	Scan angle for view 1	Aux
α_{MHS}	Scan step angle for MHS	Aux
C_1	first constant of the Planck function	Aux
C_2	second constant of the Planck function	Aux
d_j	conversion coefficients for instrument reference temperature	Aux
$\varepsilon_{ant}(k)$	Pointing error tolerance value	Aux
$\varepsilon_{c,ant}(k)$	Pointing error tolerance value for space view	Aux
$\varepsilon_{w,ant}(k)$	Pointing error tolerance value for warm target	Aux
$f_{k,j}$	polynomial coefficients for the computation of the PRT temperature	Aux
k	warm target PRT index	Aux
$I_{ant}(k)$	Antenna count intercept	Aux
$M_{ant}(k)$	Antenna count slope	Aux
D	Distance of the Moon from the centre of the Earth	Aux
d	line to line consistency threshold	Aux
u_i	nonlinearity coefficients characterised pre-flight at 3 temperatures	Aux
w_k	PRT weights for the computation of the warm target temperature	Aux

Symbol	Description	Origin
Re	Earth's radius	Aux
$T_{k,min}$	minimum meaningful PRT temperature	Aux
$T_{k,max}$	maximum meaningful PRT temperature	Aux
δT_{PRT}	PRT median check tolerance value	Aux
δT_{inst}	Instrument temperature threshold	Aux
$\delta T_{PRT,avg}$	PRT check tolerance value	Aux
$\gamma(\nu)$	empirical constant for scan dependent correction	Aux
α_1	first antenna correction constant	Aux
α_2	second antenna correction constant	Aux
α_3	third antenna correction constant	Aux
δT_w	internal warm target temperature correction factor	Aux
δT_c	cold space temperature correction factor	Aux
$\Delta(\nu)$	spectral discretisation for the radiance computation	Aux
$\Gamma(1)$	second antenna correction function constant	Aux
ν_c	central wave number of each channel	Aux
ν_1, ν_2	lower and upper spectral limits of the channels	Aux
$\Phi(LUT)$	instrument spectral response function (discretised)	Aux
$\tilde{C}_k$	warm target PRT counts for PRT k	Anc
H^j	instrument reference temperature counts	Anc
j	field of view position index	Anc
Θ	scan angle measured from nadir	Anc

APPENDIX B: CONFIGURABLE AUXILIARY DATA SETS

Identifier	*Contents of Data Set*
MHS_L1_PGS_COF_CAL	MHS calibration parameters file containing for all MHS instruments central wave numbers, band correction coefficients, nominal space and internal target viewing angles, position of space view for calibration, antenna position errors permitted for calibration and Earth views, slope and intercept for counts to antenna position, count to temperature conversion coefficients, weight coefficients for each PRT, PRT temperature limits, number of scan lines to fill in bad PRT data, number of scan lines to use in consistency checks, instrument RF shelf temperatures, correction factors for warm and space load, gross counts limits, non linearity correction coefficients, analogue conversion coefficients
MHS_L1_PGS_COF_CALSEC	Secondary calibration coefficients for three temperature ranges and all channels
MHS_L1_PGS_DAT_SFCTOP	Geographical land-surface topography distribution
MHS_L1_PGS_DAT_NAV	Configurable navigation parameters, interpolation width for pixel and lines tie points of navigation information
MHS_L1_PGS_DAT_ASTRO	Data Set with Astronomical information

APPENDIX C: SAMPLE AUXILIARY DATA SETS

The following pages provide an example (taken from the AMSU-B Instrument) of the possible format of the configurable data sets. The actual format is to be determined by the contractor.

Calibration Parameters

```
############################################################
### ###
### FILE OF AMSU-B CALIBRATION PARAMETERS ###
### ###
############################################################
05 ; version number (cal parameter id in 1B dataset)
1998 ; year of the version
350 ; day of year of the version
## Values for Fundamental Constants ##
## Speed of light m/s ##
299792458
## Planck constant J s ##
6.62606876e-34
## Boltzmann constant J/K ##
1.38065030e-23
## First & second radiation constants mW/(sqm.ster.cm^-4) & K/cm^-1 ##
1.191044e-05,1.438769
## Brightness temperature of space at AMSU frequencies degK ##
2.73
## AMSU-B PFM DATA ##
## ID of instrument
4#
5 Central wavenumbers #
2.9684
5.0032
6.1146
6.1146
6.1146
# Band Correction Coefficients a,b for each channel --
# used to modify TW to give an effective temperature T'W for use
# in the Planck function.
0,1
0,1
-0.0031,1.00027
-0.0167,1.00145
# Number of space and black body views #
4#
Selected position of space view for calibration 0->3#
2#
Conversion factor from counts in telemetry to antenna posn in deg #
7.03125E-3
# Antenna Positional error allowed in degrees for cal and Earth views #
0.5,0.11
# IWT PRT count to temperature in degK conversion coefficients #
262.047,7.650E-04,1.224E-09,2.56E-15
262.107,7.655E-04,1.219E-09,2.63E-15
262.087,7.654E-04,1.225E-09,2.55E-15
261.927,7.668E-04,1.172E-09,2.91E-15
261.947,7.648E-04,1.225E-09,2.55E-15
261.982,7.656E-04,1.226E-09,2.54E-15
261.999,7.652E-04,1.221E-09,2.57E-15
```

```
# Weight coefficients for each PRT #
1.,1.,1.,1.,1.,0.,1.
# Reasonable PRT temp limits in degK (min,max) #
270,310
# Max PRT temp change in degK allowed before rejecting#
0.2
# Minimum number of PRT readings acceptable#
2#
Number of scan lines to fill in bad PRT data
50
# 3 Instrument reference temperatures degK#
286.1,298.1,308.7
# Instrument temp A05 PRT count to temperature in degK conversion coeffs #
265.12,8.34E-4,1.74E-9,5.40E-16
# Warm load correction factor for each reference instrument temp #
0,0,0,0,0
0,0,0,0,0
0,0,0,0,0
# Cold space correction factors for each space view and channel#
1.16, 0.30, 0.43, 0.43, 0.43
0.85, 0.24, 0.38, 0.38, 0.38
0.77, 0.23, 0.37, 0.37, 0.37
0.85, 0.28, 0.39, 0.39, 0.39
# Gross count limits (maximum & minimum) for the internal target counts#
20000,21000,27000,24000,20000
31000,29000,35000,29000,25000
# Gross count limits (maximum & minimum) for the space view counts#
13000,17000,22000,19000,15000
22000,23000,30000,24000,23000
# Max change in mean counts from previous scan allowed before rejecting#
50,80,100,70,60
# Max number of scan lines before resetting last value
25
# Non-linearity corrn coefficients for 3 instrument ref temps & 5 chans#
-1.370E-1,-0.300E-1,0.,0.,0.
-1.390E-1,-0.246E-1,0.,0.,0.
-1.746E-1,-0.262E-1,0.,0.,0.
# Nominal space & internal target viewing angles
155.5,156.5,157.5,158.5,268.5,269.5,270.5,271.5
159.5,160.5,161.5,162.5,268.5,269.5,270.5,271.5
163.5,164.5,165.5,166.5,268.5,269.5,270.5,271.5
167.5,168.5,169.5,170.5,268.5,269.5,270.5,271.5
# Digital A conversion coefficients
2.6508E2, 8.33E-4 , 1.74E-9 , 5.47E-16
2.6519E2, 8.34E-4 , 1.74E-9 , 5.41E-16
2.6512E2, 8.34E-4 , 1.74E-9 , 5.40E-16
2.6506E2, 8.34E-4 , 1.74E-9 , 5.52E-16
2.6509E2, 8.33E-4 , 1.74E-9 , 5.54E-16
2.6519E2, 8.34E-4 , 1.74E-9 , 5.53E-16
2.6510E2, 8.33E-4 , 1.74E-9 , 5.59E-16
2.6510E2, 8.33E-4 , 1.74E-9 , 5.51E-16
2.62047E2 ,7.650E-4 ,1.224E-9 ,2.56E-15
2.62107E2 ,7.655E-4 ,1.219E-9 ,2.63E-15
2.62087E2 ,7.654E-4 ,1.225E-9 ,2.55E-15
2.61927E2 ,7.668E-4 ,1.172E-9 ,2.91E-15
2.61947E2 ,7.648E-4 ,1.225E-9 ,2.55E-15
2.61982E2 ,7.656E-4 ,1.226E-9 ,2.54E-15
2.61999E2 ,7.652E-4 ,1.221E-9 ,2.57E-15
2.4932E2,1.208E-3 ,4.13E-9 ,2.07E-15
-3.893 ,2.089E-2 , 0.0 , 0.0
-1.259 ,2.081E-2 , 0.0 , 0.0
-2.351 ,2.376E-2 , 0.0 , 0.0
2.6514E2, 8.34E-4 , 1.74E-9 ,5.47E-16
```

```
2.61999E2 ,7.652E-4 ,1.221E-9 ,2.57E-15
2.4932E2,1.208E-3 ,4.13E-9 ,2.07E-15
-3.893 ,2.089E-2 , 0.0 , 0.0
-1.259 ,2.081E-2 , 0.0 , 0.0
-2.351 ,2.376E-2 , 0.0 , 0.0
2.6514E2, 8.34E-4 , 1.74E-9 ,5.47E-16
2.6560E2, 8.34E-4 , 1.74E-9 ,5.61E-16
2.6517E2, 8.34E-4 , 1.74E-9 ,5.49E-16
0.0 , 6.866E-2 , 0.0 , 0.0
4.0234E2,-7.6984E-3 , 2.035E-7 ,-2.1637E-12
# Analogue conversion coefficients
0.1206 ,7.314E-2 , 0.0 , 0.0
-20.049 ,9.894E-2 , 0.0 , 0.0
1.569E-2 ,6.916E-2 , 0.0 , 0.0
-19.996 ,9.473E-2 , 0.0 , 0.0
4.0E-3 ,6.963E-2 , 0.0 , 0.0
-0.1321 ,7.317E-2 , 0.0 , 0.0
0.0 ,6.769E-2 , 0.0 , 0.0
-20.0 ,9.803E-2 , 0.0 , 0.0
0.0 ,7.042E-2 , 0.0 , 0.0
361.797 , -2.1068 , 2.1375E-2, -7.7657E-5
361.797 , -2.1068 , 2.1375E-2, -7.7657E-5
361.797 , -2.1068 , 2.1375E-2, -7.7657E-5
361.797 , -2.1068 , 2.1375E-2, -7.7657E-5
361.797 , -2.1068 , 2.1375E-2, -7.7657E-5
-305.24 , 18.83 , 0.0 , 0.0
0.43 , 1.805 , 0.0 , 0.0
0.43 , 1.805 , 0.0 , 0.0
0.43 , 1.805 , 0.0 , 0.0
## AMSU-B FM2 DATA ##
## ID of instrument
8#
5 Central wavenumbers #
2.9689
5.0037
6.1142
6.1142
6.1142
# Band Correction Coefficients a,b for each channel --
# used to modify TW to give an effective temperature T'W for use
# in the Planck function.
0,1
0,1
0,1
-0.0031,1.00027
-0.0167,1.00145
# Number of space and black body views #
4#
Selected position of space view for calibration 0->3#
2#
Conversion factor from counts in telemetry to antenna posn in deg #
7.03125E-3
# Antenna Positional error allowed in degrees for cal and Earth views #
0.5,0.11
# IWT PRT count to temperature in degK conversion coefficients #
2.62014E2 ,7.652E-4 ,1.223E-9 ,2.57E-15
2.61966E2 ,7.645E-4 ,1.224E-9 ,2.54E-15
2.61947E2 ,7.654E-4 ,1.230E-9 ,2.48E-15
2.4932E2,1.208E-3 ,4.13E-9 ,2.07E-15
-3.893 ,2.089E-2 , 0.0 , 0.0
-1.259 ,2.081E-2 , 0.0 , 0.0
-2.351 ,2.376E-2 , 0.0 , 0.0
2.6514E2, 8.34E-4 , 1.74E-9 ,5.47E-16
```

```
2.61911E2 ,7.647E-4 ,1.226E-9 ,2.52E-15
2.62032E2 ,7.654E-4 ,1.222E-9 ,2.59E-15
# Weight coefficients for each PRT #
1.,1.,1.,1.,1.,0.,1.
# Reasonable PRT temp limits in degK (min,max) #
270,310
# Max PRT temp change in degK allowed before rejecting#
0.2
# Minimum number of PRT readings acceptable#
2#
Number of scan lines to fill in bad PRT data
50
# 3 Instrument reference temperatures degK#
286.45,298.65,308.85
# Instrument temp A05 PRT count to temperature in degK conversion coeffs #
265.18,8.36E-4,1.72E-9,5.32E-16
# Warm load correction factor for each reference instrument temp #
0,0,0,0,-0.16
0,0,0,0,-0.16
0,0,0,0,-0.16
# Cold space correction factors for each space view and channel#
1.16, 0.30, 0.43, 0.43, 0.43
0.85, 0.24, 0.38, 0.38, 0.38
0.77, 0.23, 0.37, 0.37, 0.37
0.85, 0.28, 0.39, 0.39, 0.39
# Gross count limits (minimum & maximum) for the internal target counts#
23000,24000,30000,21000,20000
35000,35000,38000,29000,33000
# Gross count limits (maximum & minimum) for the space view counts#
17000,18000,25000,16000,16000
27000,28000,32000,23000,28000
# Max change in mean counts from previous scan allowed before rejecting#
33,39,63,42,30
# Max number of scan lines before resetting last value
25
# Non-linearity corrn coefficients for 3 instrument ref temps & 5 chans#
-0.885E-1,-0.277E-1,0.,0.,0.
-0.852E-1,-0.272E-1,0.,0.,0.
-1.079E-1,-0.287E-1,0.,0.,0.
# Nominal space & internal target viewing angles
155.5,156.5,157.5,158.5,268.5,269.5,270.5,271.5
159.5,160.5,161.5,162.5,268.5,269.5,270.5,271.5
163.5,164.5,165.5,166.5,268.5,269.5,270.5,271.5
167.5,168.5,169.5,170.5,268.5,269.5,270.5,271.5
# Digital A conversion coefficients
2.6553E2, 8.38E-4 , 1.72E-9 , 5.51E-16
2.6514E2, 8.36E-4 , 1.72E-9 , 5.42E-16
2.6518E2, 8.36E-4, 1.72E-9 , 5.32E-16
2.6520E2, 8.36E-4 , 1.72E-9 , 5.35E-16
2.6516E2, 8.36E-4 , 1.72E-9 , 5.38E-16
2.6516E2, 8.36E-4 , 1.71E-9 , 5.20E-16
2.6520E2, 8.36E-4 , 1.72E-9 , 5.41E-16
2.6513E2, 8.35E-4 , 1.72E-9 , 5.35E-16
2.62027E2 ,7.647E-4 ,1.222E-9 ,2.58E-15
2.62106E2 ,7.653E-4 ,1.220E-9 ,2.62E-15
2.61938E2 ,7.649E-4 ,1.224E-9 ,2.53E-15
2.61995E2 ,7.649E-4 ,1.225E-9 ,2.58E-15
2.62012E2 ,7.650E-4 ,1.229E-9 ,2.48E-15
2.61911E2 ,7.647E-4 ,1.226E-9 ,3.52E-15
2.62032E2 ,7.654E-4 ,1.222E-9 ,1.59E-15
2.4993E2,1.207E-3 , 4.230E-9 , 2.10E-15
-5.882 ,2.096E-2 , 0.0 , 0.0
-1.898 ,2.099E-2 , 0.0 , 0.0
-6.012 ,2.384E-2 , 0.0 , 0.0
2.6552E2, 8.37E-4 , 1.72E-9 ,5.47E-16
2.6516E2, 8.37E-4 , 1.72E-9 ,5.11E-16
```

```
2.61911E2 ,7.647E-4 ,1.226E-9 ,3.52E-15
2.62032E2 ,7.654E-4 ,1.222E-9 ,1.59E-15
2.4993E2,1.207E-3 , 4.230E-9 , 2.10E-15
-5.882 ,2.096E-2 , 0.0 , 0.0
-1.898 ,2.099E-2 , 0.0 , 0.0
-6.012 ,2.384E-2 , 0.0 , 0.0
2.6552E2, 8.37E-4 , 1.72E-9 ,5.47E-16
2.6516E2, 8.37E-4 , 1.72E-9 ,5.11E-16
2.6515E2, 8.35E-4 , 1.72E-9 ,5.46E-16
0.0 , 6.866E-2 , 0.0 , 0.0
4.0234E2,-7.6984E-3 , 2.035E-7 ,-2.1637E-12
# Analogue conversion coefficients
0.02458 ,6.971E-2 , 0.0 , 0.0
-20.004 ,9.869E-2 , 0.0 , 0.0
2.321E-2 ,6.916E-2 , 0.0 , 0.0
-20.003 ,9.960E-2 , 0.0 , 0.0
5.2E-4 ,6.987E-2 , 0.0 , 0.0
2.866E-2 ,7.097E-2 , 0.0 , 0.0
0.0 ,6.997E-2 , 0.0 , 0.0
-20.0 ,9.997E-2 , 0.0 , 0.0
0.0 ,7.141E-2 , 0.0 , 0.0
361.255 , -2.0882 , 2.1168E-2, -7.6949E-5
361.255 , -2.0882 , 2.1168E-2, -7.6949E-5
361.255 , -2.0882 , 2.1168E-2, -7.6949E-5
361.255 , -2.0882 , 2.1168E-2, -7.6949E-5
361.255 , -2.0882 , 2.1168E-2, -7.6949E-5
-334.75 , 18.91 , 0.0 , 0.0
0.53 , 1.806 , 0.0 , 0.0
0.53 , 1.806 , 0.0 , 0.0
0.53 , 1.806 , 0.0 , 0.0
## ID of instrument 99 terminator
99
```

```
##################################################################
### ###
### FILE OF SECONDARY AMSU-B CALIBRATION COEFFICIENTS ###
### ###
##################################################################
01 ; version number (cal parameter id in 1B dataset)
1996 ; year of the version
059 ; day of year of the version
## ID of instrument
4
## AMSU-B PFM DATA ##
## Ref temp 1
##zeroth order cal coeffs in units of mW/(sqm.ster.cm-1)
-53331E-6 -253257E-6 -452610E-6 -400126E-6 -380885E-6
##first order cal coeffs in units of mW/(sqm.ster.cm-1)/count
29349E-10 109690E-10 163567E-10 185147E-10 184598E-10
##second order cal coeffs in units of mW/(sqm.ster.cm-1)/count^2
-11555E-16 -28780E-16 0 0 0
## Ref temp 2
##zeroth order cal coeffs in units of mW/(sqm.ster.cm-1)
-53331E-6 -253257E-6 -452610E-6 -400126E-6 -380885E-6
##first order cal coeffs in units of mW/(sqm.ster.cm-1)/count
29349E-10 109690E-10 163567E-10 185147E-10 184598E-10
##second order cal coeffs in units of mW/(sqm.ster.cm-1)/count^2
-11555E-16 -28780E-16 0 0 0
## Ref temp 3
##zeroth order cal coeffs in units of mW/(sqm.ster.cm-1)
-53331E-6 -253257E-6 -452610E-6 -400126E-6 -380885E-6
##first order cal coeffs in units of mW/(sqm.ster.cm-1)/count
29349E-10 109690E-10 163567E-10 185147E-10 184598E-10
##second order cal coeffs in units of mW/(sqm.ster.cm-1)/count^2
-11555E-16 -28780E-16 0 0 0
## ID of instrument 99 terminator
99
```