

SMOS L1 Processor L0 to L1a Data Processing Model

Code : SO-DS-DME-L1OP-0007
Issue : 2.24
Date : 12/07/18

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Document Information

Contract Data	Classification
Contract Number: 4000101241/10/I-AM	Internal <input checked="" type="checkbox"/>
	Public <input type="checkbox"/>
Contract Issuer: ESA (ESRIN)	Industry <input type="checkbox"/>
	Confidential <input type="checkbox"/>

Internal Distribution		
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Archiving	
Word Processor:	MS Word 2000
File Name:	<u>SO-DS-DME-L1OP-0007_DPML1a-Data-Processing-Models_E2_R24.doc</u>
Archive Code:	SO-DS-DME-L1OP-0007-DPM

Document Status Log

Issue	Change description	Date	Approved
	L1PP document		
0.1	Table of Contents	2004-06-26	
0.2	First document version	2004-09-29	
0.3	First review of the document	2004-10-13	
0.4	Second internal review of document	2004-10-29	
0.5	Review after Progress Meeting	2004-11-22	
1.0	ADR Delivery	2004-12-20	
1.1	Review after ADR	2005-01-05	
1.2	Further reviews after ADR. Consistency between product definition and DPM	2005-02-15	
1.3	Internal review version, <i>not delivered</i>	2005-02-23	
1.4	Changes to document format, <i>not delivered</i>	2005-04-20	
1.5	Complete re-formatting of doc according to new requirements	2005-05-27	
1.6	Changes to NIR calibration and LICEF-NIR baselines	2005-06-30	
1.7	Full re-write before FAT	2006-03-03	
1.8	Review after FAT	2006-04-06	
1.9	Review for Final Delivery	2006-06-07	
2.0	V2R delivery	2006-11-17	
2.1	Reviewed by CASA and ESA	2006-11-24	
2.2	V3R delivery	2007-04-09	
2.3	V3.5 delivery	2007-07-16	
2.4	Updates for V4R delivery: - Clarifications on NIR-LICEF elements (system temperatures, T3, T4 and correlations) - Clarification on XBAND data processing - Clarification on short-extended sequence and its additional calibration steps and identifications	2007-11-16	

Issue	Change description	Date	Approved
2.5	Updates for V5R delivery: <ul style="list-style-type: none"> - Clarification on T receiver computations - Correction of XBAND formulations - Update on time_id default initialisation values 	2008-03-31	
2.6	<ul style="list-style-type: none"> - Updated Fig. 21 with missing calibration steps 5 & 6 - Added clarification on the usage of NIR Switch S-Parameters in Section 5.8 - Corrected Eq. references in Section 5.9 - Clarified how Switch S-parameter phases are computed for usage in FWF calibration (Eq. 19) 	2008-07-31	
2.7	Updates for L1PP v2.0 Delivery: <ul style="list-style-type: none"> - Improved Calibration and Consolidation section by pruning unused sequences and combining redundant ones - Corrected Section 3.3 with residual truncation correction before performing 1-0 correction - Added LICEF-NIR distributed calibration in section 3.8.1.3 - Corrected LICEF-NIR equations in section 3.5.3 according to errata in NIR calibration note - Added clarification on data usage for full pol mixed epochs in section 5.7.4.2 - changed units of angular velocity to rad/s in section 5.1.10 	2008-12-12	
2.8	<ul style="list-style-type: none"> - Corrected L_FE definition in section 3.5.3.3 - Updated text about NIR-R data usage (ADF data should only be used if no ANIR product is found) in section 3.8.1.1 	2009-05-19	
2.9	Updates for L1PP v2.2 Delivery; <ul style="list-style-type: none"> - Added protection against non realistic normalised NIR pulse length in section 5.1.8.2 - Added computation of Receiver Noise Temperature during PMS Cold Sky calibration in section 3.10.1 	2009-07-24	
2.10	Updates for L1PP v3.2 Delivery; <ul style="list-style-type: none"> - Modified Visibilities Offset formulation and usage in sections 3.6 and 3.7 - Clarified NIR-LICEF Receiver Noise Temperature computation in sections 3.8.1.2 and 3.9 - Added PMS External data consolidation strategy in section 7.4 	2009-09-24	

Issue	Change description	Date	Approved
2.11	<p>Updates for L1PP v3.3 Delivery;</p> <ul style="list-style-type: none"> - Modified PMS linearity correction to use Deflection method in sections 3.4.1 and 3.5 - Added PMS Heater correction in section 5.1.5.2 - Added consolidation strategy clarification in section 7 	2010-03-26	
2.12	<p>Updates for L1PP v3.4 Delivery;</p> <ul style="list-style-type: none"> - Clarified Noise Source association with Arm CMN to select Spar Path, and use of new CAS path correction factors in section 5.8.4 - Introduced Trec CIP Sensitivity correction for Tsys computation in NIR-LICEF elements in section 3.8.1.2 - Introduced latest calibration parameters baseline agreed at KP3 in section 3.11 	2010-05-31	
2.13	<p>Update for the beginning of the SMOS operations phase:</p> <ul style="list-style-type: none"> - Introduced clarifications required by new ESA maintenance contract PA manager (Jean Claude Debrun) - Introduced clarification on NIR-A and NIR-R calibration for the expected Sky BT computation in section 5.9.3.2 - Introduced new NIR antenna model for L1 parameter that includes error component and long/short term drift coefficients with Tp7 temperature in sections 3.5.3.1.1, 5.6.3 and 5.9.3 - Introduced new LO unlock consolidation in Correlated Noise Injection products and their use in the FWF phase interpolation approach in section 7.5 - Introduced new NIR averaged datasets in sections 8.3.13 and 8.3.14 - Added annotation of LO_Locking and LO_Output_Power into HKTM L1a products in section 8.3.10 	2010-10-29	
2.14	<p>Updates for L1PP v5.0.0 Delivery;</p> <ul style="list-style-type: none"> - Added range check on antenna physical temperatures in section 5.1.7.2 - Introduced new LICEF antenna model for L1 parameter that includes error component and long/short term drift coefficients with Tp7 temperature in section 3.5.1 - Introduced new PMS Offset consolidation in Correlated Noise Injection products and their use in the PMS interpolation approach in section 7.4 	2011-05-05	
2.15	<p>Updates for L1PP v5.5.0 Delivery;</p> <ul style="list-style-type: none"> - Updated Leakage and Cross-coupling equations in section 3.8.2.3 	2011-11-29	

Issue	Change description	Date	Approved
2.16	Updates for L1PP v6.0.0 Delivery; - Updated section 7.5 and 5.1.14 to reflect actual flags used in LO unlock sequence detection - Updated section 5.1.14 to correct treatment of CCU_Error_Flag - Updated sections 3.10 and 5.10 to reflect changes from PMS Cold Sky Calibration to L1 Calibration technique - Added sections 3.11 and 5.6.5 to introduce new RFI flagging technique - Added description of RFI flag in Section 8.3.1	2012-11-29	
L1OP document			
2.17	Updates for L1OP v6.0.0 Delivery; - Removed Orchestration Section - Removed Data Structures Section	2013-05-02	
2.18	Updates for L1OP v6.2.0 Delivery; - Updated RFI flagging threshold - Updated L1 and L2 usage for NIR	2014-03-25	
2.19	Updates for L1OP v7.0.0 Delivery - New ALL-LICEF mode description - Addition of Gkj correction factor - Clarification on Processing of NIR-A and AR modes	2015-07-09	
2.20	Updates for L1OP v7.1.0 Delivery - Detailed new PMS Heater Correction with the Double Exponential Method (Section 5.1.5.2)	2016-12-01	
2.21	Updated after L1OP v711 FAT	2017-01-31	
2.22	Updates for L1OP v7.2.0 Delivery - New Fixed TNa mode (Sections 3.5.5, 3.8.1, 5.4.3, 5.6.3 and 6.5.3) - New Tp7 latency correction (Section 5.1.7) - New RFI filtering for correlated noise injection calibration data (Sections 6.3 and 6.4)	2017-11-28	

Issue	Change description	Date	Approved
<u>2.23</u>	<u>Updates for L1OP v7.2.0 Delivery</u> - Explicitly mention that LFE is always used for plane translations (Section 3.5.4) - Explicitly mention that Fixed Tna0 mode is now the baseline for L1a processing (Section 3.5.5.1) - Update Visibilities plane translation to use Front-End Losses (Section 3.7.1) - Explicitly mention that Fixed Tnr0 mode is now the baseline for L1a processing (Section 3.8.1) - Updated implementation steps of System Temperatures to reflect new 1p/4p calibration flag - Changed Section names to better reflect how the gains are computed: 1-point, 4-point instead of NIR/ALL-LICEF modes (Sections 3.5.1, 3.5.2, 3.5.3, 5.4.5, 5.5.4)	<u>2018-05-25</u>	
<u>2.24</u>	<u>Renamed System Temperatures Plane Translation section (3.5.4.2)</u>	<u>2018-07-12</u>	

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1. INTRODUCTION

1.1. Purpose

The main purpose of this document is to provide a detailed definition of the processes and algorithms contained in the Error Correction Module within the SMOS Level 1 Processor. This module is the first entry point to the processor, and is tasked with applying all the calibration procedures to the measured data (using ground and in-flight calibration).

The document begins with a general overview of algorithms to be used in the Error Correction Module, its main tasks and its role in the Level 1 Processor. Following the identification of a high-level architecture, a further top-down decomposition is presented to cover the whole set of algorithms involved in the calibration process which, in turn, will be described in detail.

1.2. Scope

The scope of this document is to describe the algorithms involved in the processing of the Error Correction Module, providing both architectural and functional definitions of the main features identified.

This document should be read together with the SMOS Product Specification document [AD.4], in order to get a complete view of the facility.

1.3. Acronyms and Abbreviations

For the list of acronyms, please refer to the “Directory of Acronyms and abbreviations” [RD.3].

Some of the abbreviations specific to this document are presented below:

ASIC	Application Specific Integrated Circuit
CIP	Calibration Input Plane
CMN	Command and Monitoring Node
NDN	Noise Distribution Network
NS	Noise Source
OBET	On Board Estimated Time
OS	Optical Splitter
PD	Power Divider
PVT	Position, Velocity and Time
RSC	Redundant Space Calibration

1.4. Applicable and Reference Documents

1.4.1. Applicable Documents

Ref.	Code	Title	Issue & Date
AD.1	SO-SOW-CASA-PLM-0855	Level 1 Processor Prototype Development Phase 3 and Support and Analysis Activities. Statement of Work	1.0
AD.2	SO-RS-ESA-PLM-0003	SMOS System Requirements Document	3.0 19/01/2004
AD.3	SO-IS-DME-L1PP-0014	SMOS L1 Processor Input Output Data Definition (obsolete)	2.3
AD.4	SMOS-TN-IDR-GS-0005	SMOS L1 and ADF Product Specification	6.7 (preliminary version)
AD.5	SO-IS-DME-L1PP-0003	SMOS L1 Auxiliary Product Format (obsolete)	2.4
AD.6	SO-TN-UPC-PLM-0001	IN-ORBIT CALIBRATION PLAN	3.3 30/01/2004
AD.7	SO-TN-UPC-PLM-0019	SMOS In Orbit Calibration Plan Phase C-D	1.5 17/01/07
AD.8	ECSS-E-40B	ECSS E-40 Software Engineering Standards	
AD.9	SO-PL-CASA-PLM-0022	Definition of coordinate system / reference frame & units nomenclature	2.0
AD.10	EE-MA-DMS-GS-000x	Earth Explorer CFI Manuals	3.7.3 07/05/10

Table 1 - Applicable Documents

1.4.2. Reference Documents

Ref.	Code	Title	Issue & Date
RD.1	SPA-CAS-20200-TNO-001	System Performance Modelling	1.2
RD.2	Radio Science Vol. 38 No. 2 p. 1032	R. Butora, et al, "Fringe-Washing Function Calibration in Aperture Synthesis Microwave Radiometry"	2003

Ref.	Code	Title	Issue & Date
RD.3	SO-LI-CASA-PLM-0094	Directory of Acronyms and abbreviations	
RD.4	SO-RS-CASA-PLM-0050	CCU requirements specification	3.3
RD.5	SO-TN-DME-L1PP-0024	SMOS L1 Full Polarisation Data Processing	1.6 16/07/07
RD.6	SO-TS-HUT-NIR-0005	NIR Calibration and Characterisation Plan	5F 08/10/08
RD.7	SO-TN-CASA-PLM-0279	SMOS PLM Command and Control	2.5 12/02/07
RD.8	SO-TN-CASA-PLM-0594	Ancillary Packet Description	3.2 18/02/08
RD.9	SO-TN-YLIN-NIR-0006	SMOS Phase C/D NIR Subsystem, NIR Technical Description	05A
RD.10	SO-DS-DME-L1PP-0006	SMOS L1 System Concept	2.9 29/10/10
RD.11	SO-DS-DME-L1PP-0012	SMOS L1 Processor Prototype Architecture (obsolete, included in DPMs)	1.3
RD.12	SPS-TN-GMV-PLM-0003	SMOS End-to-End Performance Simulator (SEPS v4.0) Architectural and Detailed Design Document	5
RD.13	SO-TN-UPC-PLM-0020	Technical Note on the Calibration by Moon Pointing	1.1
RD.14	SO-TN-UPC-PLM-0010	Distributed Amplitude Calibration by the Two-Level Approach	1.4
RD.15	SO-TN-CASA-PLM-0625	CAS Characterization From a Set Of 4 S-Matrices	1.0 26/07/05
RD.16	SO-DS-DME-L1OP-0008	SMOS L1 Processor L1a to L1b Data Processing Model and ATBD	2.25 12/07/18
RD.17	SO-TN-CASA-PLM-1075	Usage of Calibration Data in Measurement Processing	2.0 20/04/07
RD.18	SO-TN-UPC-PLM-0054	In-orbit CAS and LICEF receiver temperature validation	2.1
RD.19	SO-TN-UPC-PLM-0048	MIRAS EM tests at INTA facilities	2.6 16/12/05

Ref.	Code	Title	Issue & Date
RD.20	SO-TN-HUT-NIR-0102	Calibration of mixed baselines	02B 22/05/08
RD.21	SO-TN-DME-L1PP-0167	SMOS DPGS V3 Calibration Baseline	1.0 16/04/08
RD.22	SO-DS-DME-L1OP-0009	SMOS L1 Processor L1b to L1c Data Processing Model and ATBD	2.17 28/11/17
RD.23	N/A	RFI Detection in NIR signals	31/12/12 (received on 30/10/12)
RD.24	SO-DDD-DME-L1OP-0277	L1OP V600 Detailed Design Document	1.0 13/04/13
RD.25	SO-TN-UPC-PLM- 0163	Front-end loss and CAS factors	1.0 20/02/14
RD.26	SO-TN-UPC-PLM-0167	All LICEF mode implementation	1.1 15/04/15
RD.27	SO-IOP-ECE-TN-1368	Receiver and LFE Selection for ALL-LICEF Testing	1.0 05/05/15
RD.28	SO-IOP-ECE-TN-1370	Heater Correction with Double Exponential	0.2 05/07/16
RD.29	NIR-TN-HARP-029	Thermal Latency Correction Algorithm Theoretical Baseline Description	1.1 28/09/17
RD.30	UPC Presentation at SPCM31	Improvements in Calibration	1.0 27/09/17

Table 2 - Reference Documents

2. ERROR CORRECTION MODULE IN THE SMOS L1 PROCESSOR

The proposed data processing model for the L1 processor prototype Error Correction Module is defined in the following chapters. The Error Correction Module is responsible for computing the calibration data (calibration parameters) necessary to correct the measured visibilities and to apply it to all incoming nominal measurement data.

The location of the Error Correction Module in the general L1 Processor data flow is shown below:

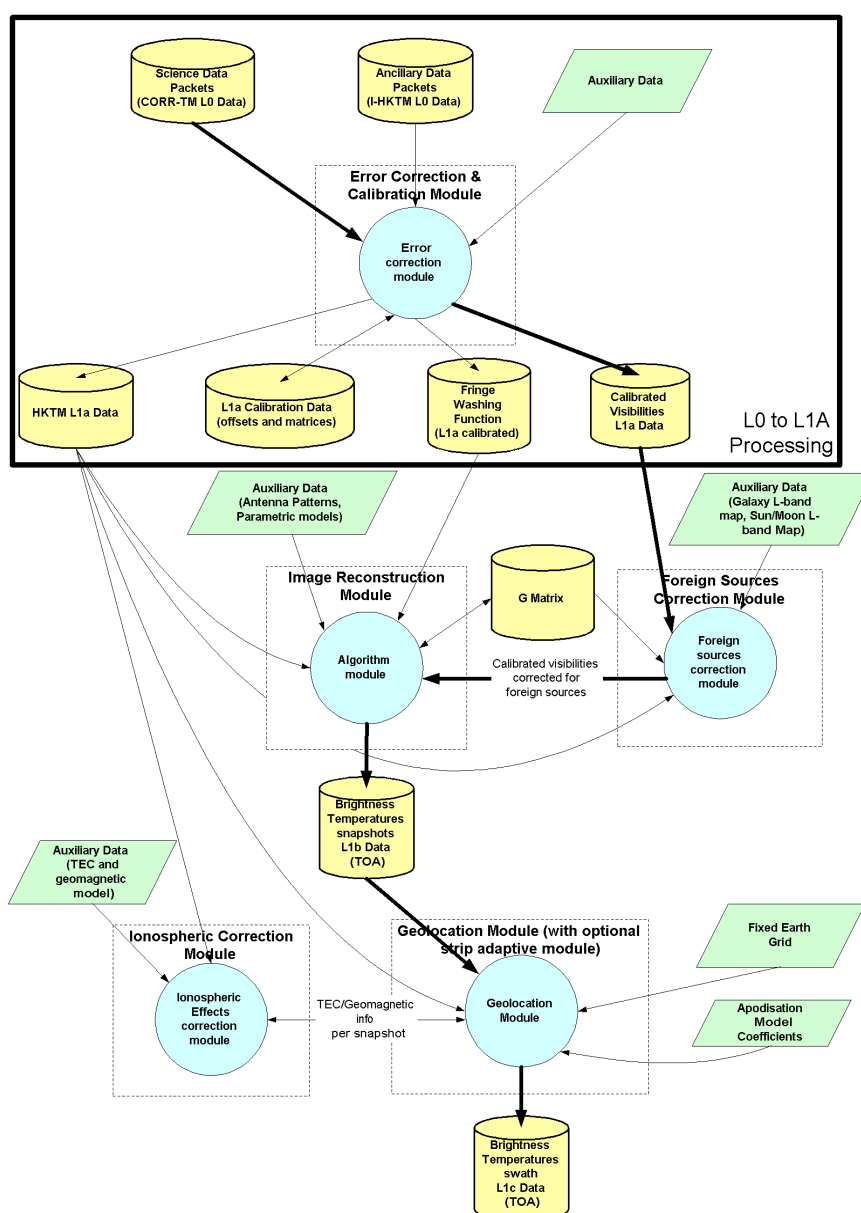


Figure 1 - L1 Processor complete data flow

The Error Correction Module processes the Level 0 data coming from the L0 Processor. MIRAS L0 data comprises the raw correlation data, plus voltage measurements from the PMS and NIR system as well as the instrument physical temperatures. Additional L0 data shall be obtained from the status of the spacecraft (state vector and attitude) and the status of the MIRAS instrument health. L0 data simply contains data packets, each integration time providing one Ancillary Data Packet and 24 Science Data Packets in dual polarisation mode. In full polarisation mode, every alternate integration time generates one Ancillary Data Packet and three sets of 24 Science Data Packets.

All the HKTM shall be converted into appropriate units by means of manufacturer tables and diagrams, or known formulae, and it shall be stored into an appropriate L1a product for easy reference in later modules, and to avoid extracting the data from L0 packets every time it is needed. This produces as output what has been called the HKTM L1a data (S/C and Instrument). The MIRAS instrument has several modes of operation, for calibration and measurement procedures, distinguished by different APID codes in the Level 0 packets' headers. The instrument modes, together with APID codes retrieved, are:

- ☐ Full polarisation mode (APID_FULL)
- ☐ External Calibration in full polarisation mode (APID_EXC_FULL)
- ☐ Dual polarisation mode (APID_DUAL)
- ☐ External Calibration in dual polarisation mode (APID_EXC_DUAL)
- ☐ Internal Calibration with uncorrelated noise injection (APID_U)
- ☐ External Calibration with uncorrelated noise injection (APID_EXC_U)
- ☐ Internal Calibration with correlated noise injection (APID_C)
- ☐ External Calibration with correlated noise injection (APID_EXC_C)
- ☐ Test (APID_TEST)

There is one more APID code, to distinguish ancillary from science data processing, although it does not correspond to a separate instrument mode:

- ☐ Ancillary Data (APID_A)

The relationship between APID of the instrument source packets as presented above, and the L0 product types as defined in [AD.4] is the following:

APID	Product Type	Packet_ID (Version+Type+ Header+APID)
APID_DUAL	MIR_SC_D0_	0x8832 (Hex)
APID_FULL	MIR_SC_F0_	0x8834 (Hex)
APID_EXC_DUAL	MIR_TARD0_	0x8833 (Hex)
APID_EXC_FULL	MIR_TARF0_	0x8835 (Hex)
APID_U	MIR_UNCN0_	0x8836 (Hex)

APID	Product Type	Packet_ID (Version+Type+Header+APID)
APID_C	MIR_CORN0_	0x8837 (Hex)
APID_EXC_U	MIR_UNCU0_	0x8839 (Hex)
APID_EXC_C	MIR_CORU0_	0x883A (Hex)
APID_TEST	MIR_TEST0_	0x8838 (Hex)
APID_A	TLM_MIRA0_	0x8803 (Hex)

Table 3 - APID correlation to L0 Product Type

All ancillary packets, for all instrument modes, are included in the same L0 file and the processed L1a HKTM data will also be stored in a single product file (not separated by instrument mode). When processing a specific instrument mode data (e.g. correlated noise injection data), the corresponding HKTM data will be accessed directly from the HKTM L1a data using the timestamp as a reference.

The Science Data Packets produced while in Noise Injection modes shall be processed by dedicated subparts of the module, and will produce the calibration data required to calibrate the nominal observation measurements. This calibration sub-processes shall generate specialised L1a data required for the calibration of raw correlations. It shall also be possible to generate as part of the process an estimation of three points of the Fringe Washing Function (FWF)¹ that are only used in the L1b module.

This process for generating the calibration coefficients requires Auxiliary Data Files (ADF), comprising reflection coefficients, S-parameters in all reference planes, ohmic efficiency, characterisation of the PMS detectors and antenna phases at reference planes. Further information on these ADF shall be provided in the ADF format definition [AD.4].

Science Data Packets generated while in nominal mode (dual or full polarisation) shall be calibrated with the previously created calibration L1a products, and be consolidated in time ordered scenes. The contents shall be an array of ordered Calibrated Visibilities per each scene. The information on which baseline (u, v pair) corresponds to each visibility shall be defined within the product format. Additional information on receiver and correlator failures shall be contained within the HKTM L1a product referencing the scene or integration time where it happened. There will also be a provision to read from a user configurable file a component fail list, enabling transmission of failures, detected while examining the data, to the L1 processor and avoid unnecessary processing of corrupted data. Finally, the set of calibration procedures is user configurable, i.e., the user will be able to disable some of the calibration sequences in order to speed up or study the full calibration processes.

NIR Calibration, or processing of Science Data Packets while in external target observation (Sky or Moon) shall be carried out as nominal processing, with the objective of passing the calibrated visibilities to the Image Reconstruction algorithm and extract the reconstructed image for comparison with the reference image. This process shall perform the in-orbit calibration of the NIR model that is used in this

¹ The Fringe Wash Function is an envelope function, present in all interferometers and is dependent on the bandwidth of the instrument. It does not carry any information about the object being measured, it is only an effect of the system response.

module and, although it is clear that it should be part of the L1 processing, it might be performed at a calibration facility external to the Error Calibration Module and passed as Auxiliary Data.

3. DESCRIPTION OF ALGORITHMS

3.1. L0 data structure

Input Data at this level is the Digital Correlator System (DICOS) output, the PMS's¹ output voltages and the NIR pulse length outputs and number of averaged samples as well as the instrument physical temperatures, attitude and orientation. All these quantities are directly retrieved from the L0 product, with each correlation encoded in 16bit.

PMS output voltage has to be transformed into system temperatures by means of manufacturer tables that specify the conversion formulae and characterisation approaches. These tables will have measurements throughout the temperature range. The in-flight measured temperatures will then be used to retrieve the correct parameters. The PMS parameters shall also be calibrated in-flight through correlated noise injection, to correct for changes in the response and allow for correct values of those parameters to be used.

The NIR pulse length output is transformed into the L-band antennae temperatures, using an algorithm provided by the NIR manufacturer. Final antenna temperature shall be the average temperature of the three NIR receivers.

The DICOS output consists of correlator counts, N_C , for each pair of receiver outputs in addition to correlator counts between each receiver outputs (quadrature and in-phase) and one of two constant channels (with “1” and “0” values respectively).

¹ Power Measuring System, it will measure the power of the signal received by each antenna.

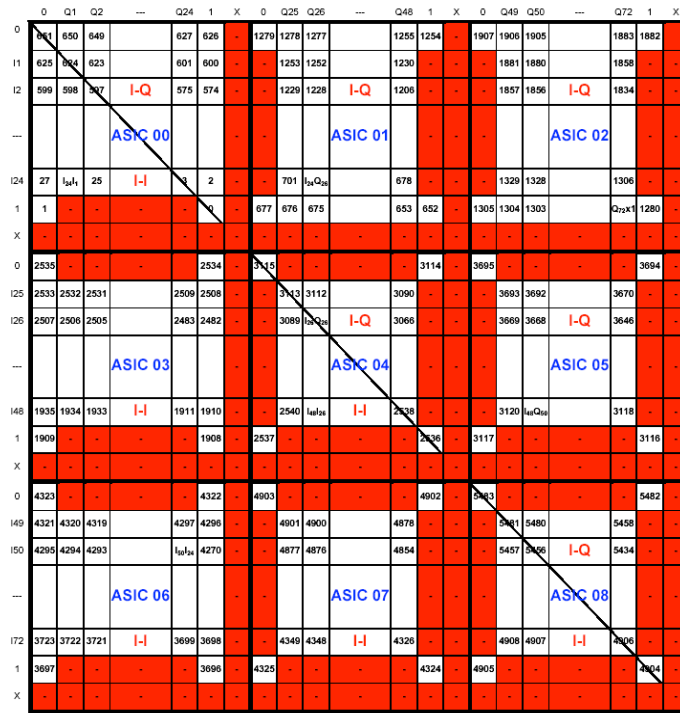


Figure 2 - Logical organization of L0 data, nominal layer

$N_{C_{max}}$ is the maximum number of counts, which is a function of the sliding window of the DICOS and the integration time used. By construction (duration of the integration time), for dual polarisation mode the value of $N_{C_{max}}$ is 65437 while for full polarisation mode it is 43625. In Fig.3, there is only the representation for the L0 nominal layer. In fact, there is a redundant layer of L0 data, which contains the Q-I correlations instead of I-Q correlations (and QQ instead of II). In the remainder of this document we will only address the processing of the nominal layer data, being the redundant layer processing essentially the same. Whenever there are differences in the equations for each layer, they will be explicitly presented.

In the following figure is the counting schema of the LICEF and LICEF-NIR receivers for each arm. As can be seen, the elements in the hub can be assigned to each arm by extending the arm direction into the hub as far as the hub centre. For those elements in the hub in a region between arms, the arm naming convention [AD.9] incorporates the labelling for the two adjacent arms. For example, the elements between arms A and B are labelled AB.

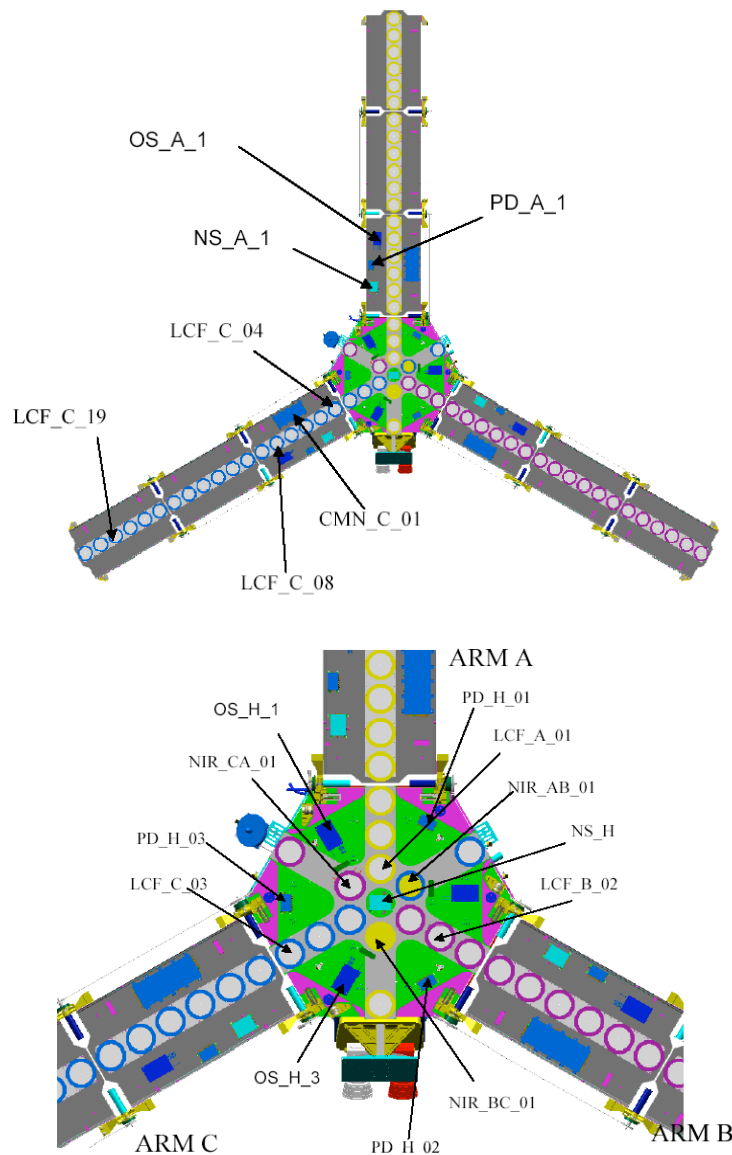


Figure 3 - Antenna indexing in the SMOS instrument

Using this nomenclature, it is possible to clarify the data organization in the L0 format (Fig. 5). Note that the output starts with elements in the hub – LCF_AB_03 in the case of arm A- followed by the two separate outputs from the LICEF-NIR, in horizontal and vertical mode - NIR_AB_01_H and NIR_AB_01_V, in the case of arm A – and only then we have the arm receivers outputs’ – LCF_A_01 to LCF_A_21.

The L0 data also contains correlation data between each antenna and a stable signal of “0” or “1”. In Fig. 5, these correlations are colour coded in red, and are stored in between the cross-correlations data. Finally, the diagonal of the logical data matrix contains the autocorrelations between the quadrature and in-phase outputs for each antenna. Above the diagonal, for nominal layer L0 data, the cross-correlations are between in-phase (I) and quadrature (Q) outputs for each of the antennas, while below the diagonal the cross-correlations are the between the in-phase outputs of each of the antennas. For more information on the L0 data structure, refer to documents [RD 4] and [AD.4].

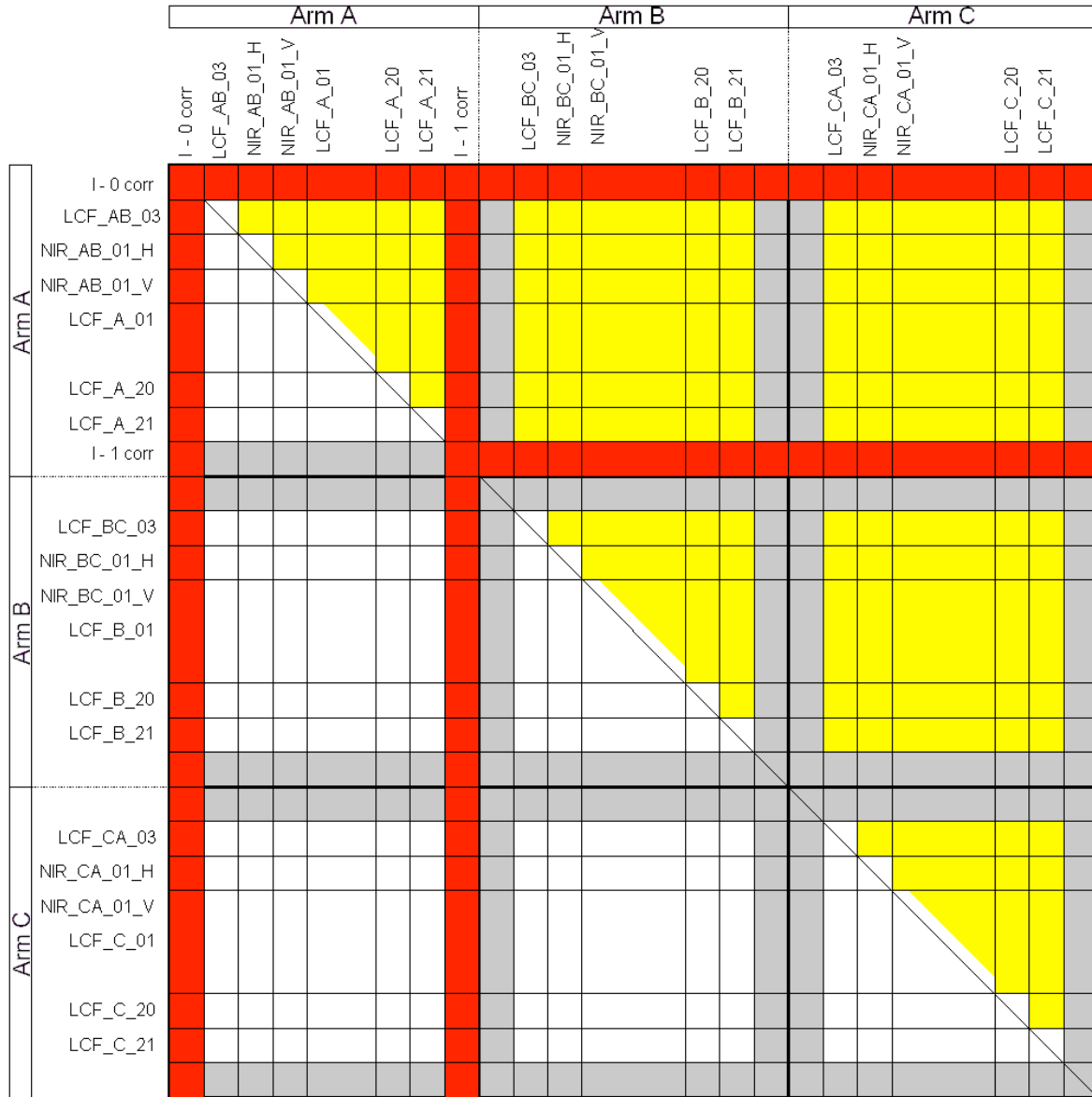


Figure 4 - Correlations ordering in L0 nominal data packets

Therefore, the data accessible on the nominal correlations layer consists of:

- ❑ 2556 correlations between I channels of different receivers ($N_C = (I_k, I_j)$)
- ❑ 2556 correlations between I and Q channels of different receivers ($N_C = (I_k, Q_j)$)
- ❑ 72 correlations between I and Q channels of same receiver ($N_C = (I_k, Q_k)$)
- ❑ 72 correlations between I and 0 channels ($N_C = (I_k, 0)$)
- ❑ 72 correlations between Q and 0 channels ($N_C = (Q_k, 0)$)

- ❑ 72 correlations between I and 1 channels ($N_C = (I_k, 1)$)
- ❑ 48 correlations between Q and 1 channels ($N_C = (Q_k, 1)$)
- ❑ 36 control correlations between 1 and 0 channels (4 for each ASIC)

Since each LICEF-NIR has two separate output channels, one for each polarisation mode, only 69 signals from the receivers will be used at a time when doing the image reconstruction of the scene. In H-polarisation measurement mode, for example, the horizontal outputs of the LICEF-NIR will be used and the vertical polarisation outputs will be discarded. However, the data calibrated from L0 to L1a shall be the complete 72 signals from all receivers.

For correlations between antennae and stable signal, it should be noted that the total information for correlations between the Q channels and the “1” channel is missing. Their values, however, are easily retrieved from the I-0 and Q-0 correlations due to the fact that I-0 and I-1 values, as well as Q-0 and Q-1 values, are complementary ($N_C(I_k, 0) + N_C(I_k, 1) = N_{C_{\max}}$, for example).

So, for image reconstruction of a unique polarisation (H or V), in dual polarisation mode, only the following data shall be used by the Image Reconstruction module:

- ❑ 2346 correlations between I channels of different receivers ($N_C = (I_k, I_j)$)
- ❑ 2346 correlations between I and Q channels of different receivers ($N_C = (I_k, Q_j)$)
- ❑ 69 correlations between I and Q channels of same receiver ($N_C = (I_k, Q_k)$)
- ❑ 69 correlations between I and 0 channels ($N_C = (I_k, 0)$)
- ❑ 69 correlations between Q and 0 channels ($N_C = (Q_k, 0)$)

The Error Correction module will process all L0 data in the same processing step, using the 72 signals for each antenna (66 LICEF + 2*3 LICEF-NIR). An even more simplified logical organization of the useful data in a scene is depicted in the following diagram:

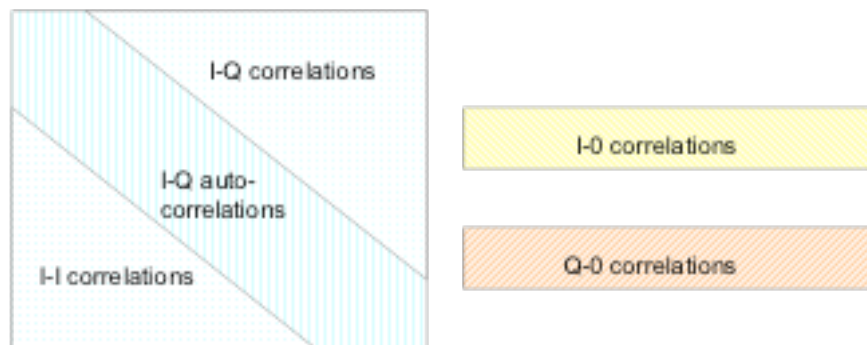


Figure 5 - Simplified organization of L0 nominal layer science data

The XML schemas in the Data Handling Library shall transparently handle the access to each element of the correlations matrix and vectors. The composite matrix will be used to define two symmetric matrices, the μ_{kj}^{ii} correlations full matrix containing the real components, and the μ_{kj}^{iq} correlations full

matrix containing the imaginary components. For the dual-pol case, after the raw normalized correlations are computed (Eq. 2), the full μ_{kj}^{ii} correlations matrix can be simply built by transposing the elements measured below the diagonal, and the full μ_{kj}^{iq} correlations matrix must be built using the complex conjugate when transposing elements. For full-pol mode, the L0 data must be previously re-arranged, as described in Section 3.2.1.2.

The main diagonal values are only used for the quadrature correction since they do not define any baseline (each element corresponds to an auto-correlation).

3.2. Instrument Modes

This chapter links the instrument modes as taken from decoding of the APID value from the L0 packets, and section 6 of the [AD.6] where the in-orbit modes are also described.

3.2.1. Measurement modes

There are two instrument polarisation modes, dual and full. In dual polarisation, all arms are in the same polarisation mode. In full polarisation, one arm is in a cross-polarisation mode for 1/3 of the integration time. The cross-polarized arm is rotated in a clockwise fashion. Schematically:

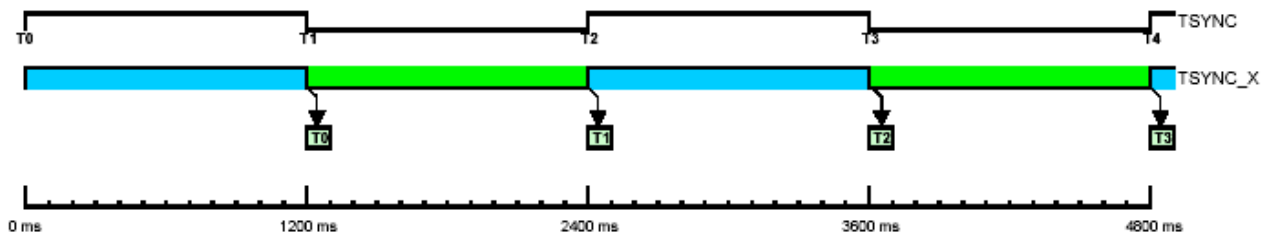


Figure 6 - Time sequence for dual polarisation mode

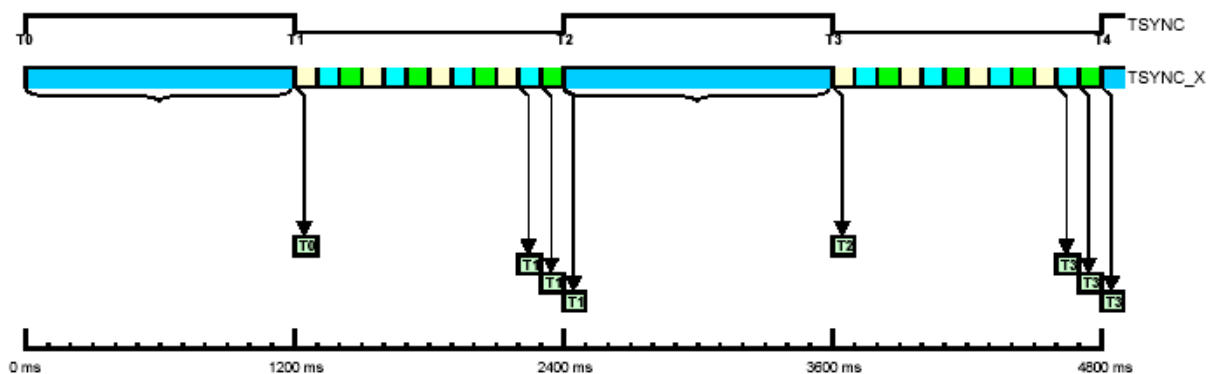


Figure 7 - Time sequence for full polarisation mode

This means that, in four consecutive integration intervals, the instrument will measure two dual polarisation brightness temperature, HH and VV, and two cross-polarized brightness temperatures, VH

and HV. In fact, as can be seen from Fig. 8, the arms in full-polarisation mode rotate polarisations four times, each mode producing one set of visibilities corresponding to a third of the integration time.

3.2.1.1. Dual Polarisation Mode (APID_DUAL)

In dual polarisation mode, each scene will be a complete HH or VV mode measurement, with the upper triangle of the matrix containing the iq raw correlations and the lower triangle containing the ii raw correlations. Therefore, each scene can be calibrated and processed individually. The complete array of visibilities in the star domain can be obtained by taking the complex conjugates of the opposite elements in the correlations matrix.

3.2.1.2. Full Polarisation Mode (APID_FULL)

In the case of full polarisation mode, however, data within each scene will contain information about different cross-polarisation measurements, since the arms polarizations will go through three possible combinations. This is depicted in the following picture:

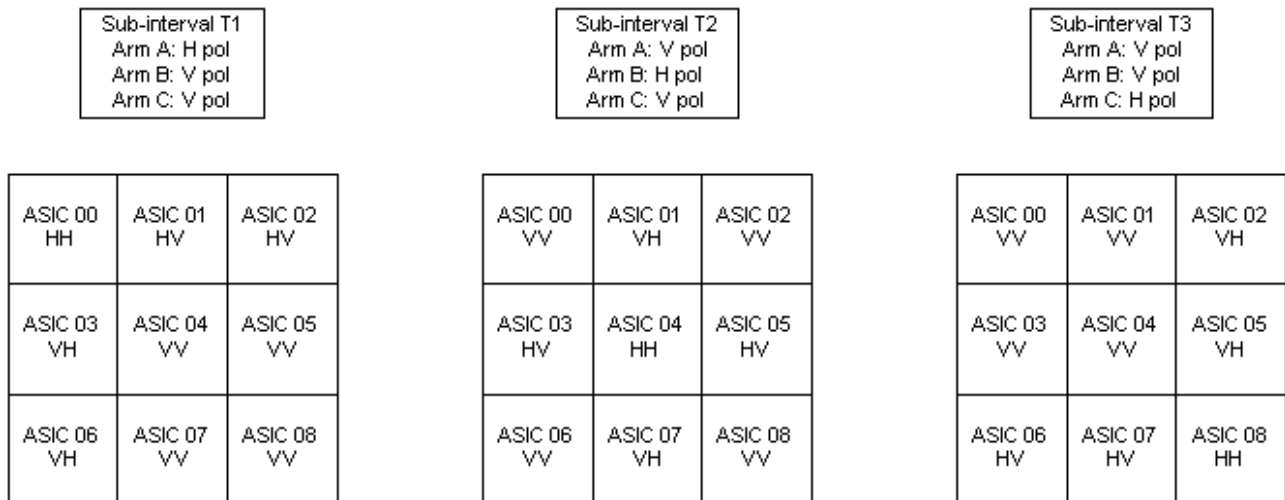


Figure 8 - Full polarisation scene output

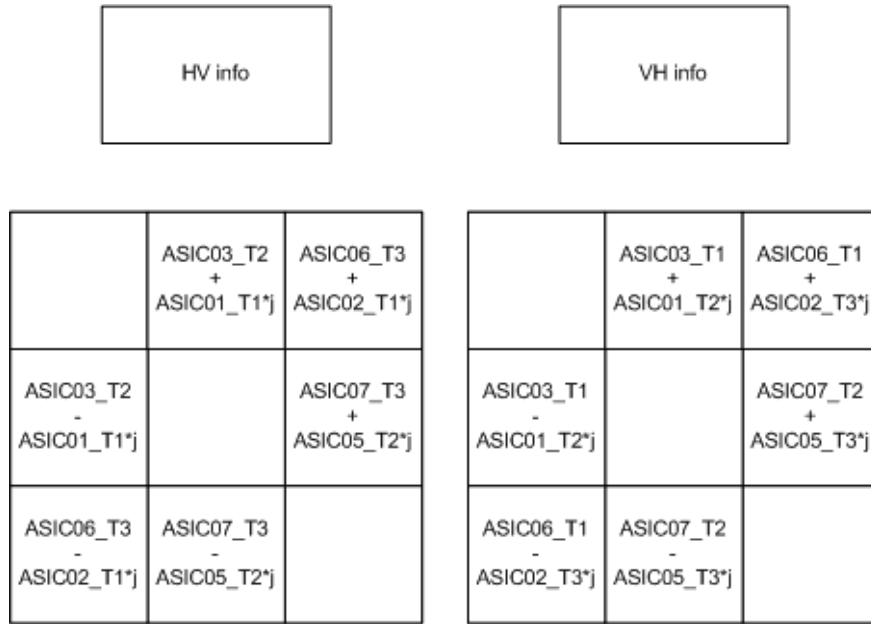


Figure 9 - Full polarisation L0 data reordering

In order to process the full polarisation data, the ASIC data in the three top scenes (as they are received in L0), must be rearranged in order to retrieve same cross-polarisation brightness temperatures. For example: In the top left image of Fig. 9, the ASIC01 contains the μ_{kj}^{ii} for in-phase signals with receiver k in H-pol, and receiver j in V-pol, whereas ASIC03 has μ_{kj}^{qi} for quadrature signals with receiver k in V-pol, and receiver j in H-pol. Thus, in order to build the complex correlations, the signals from the receivers must be in the correct polarization, e.g, receiver k always in H and receiver j always in V. So, in this example, the corresponding μ_{kj}^{qi} can only be found in ASIC03 from the middle top image.

It has been decided that this reorganization will only be done after L1a data has been produced, namely in the Image Reconstruction module. In fact, each scene for full polarisation measurements is self-contained calibration wise. What this means is that each scene, even if it has information about different cross-polarized modes, has all the necessary information to be amplitude and phase calibrated. For more information, please refer to [RD 5].

3.2.2. Internal Calibration modes

These operation modes are switched on demand in order to inject noise in the radiometers and measure calibration coefficients for several elements. The procedures are described in detail in [AD.6] and [AD.7].

3.2.2.1. Uncorrelated Noise Injection (APID_U)

Uncorrelated Noise is generated locally at each LICEF, with the purpose of detecting any offset that may happen in the correlators.

3.2.2.2. Correlated Noise Injection (APID_C)

Correlated Noise is injected through the Noise Sources following a certain strategy described in the [AD.7]. Additionally, attenuators may be activated on the PMS elements and delays introduced in the path of the correlated signals.

Not only the APID shall be used to determine the processing strategy, but also additional parameters in the ancillary packet, like the CMN Last Executed Command and FWF delay, will be needed to properly identify and process the calibration data.

3.2.2.3. External Calibration modes

These operation modes are switched on demand in order to calibrate the NIR elements, PMS gains and offsets and also to image sky or moon scenes that may be used for the Flat Target Transformation or G-Matrix calibration in orbit. The APID is commanded to change to APID_EXC_DUAL, APID_EXC_FULL, depending on the polarisation mode, or APID_EXC_C and APID_EXC_U for noise injection calibration while measuring external targets.

However, not all packets with the previous APIDs shall be used for NIR calibration; it shall also depend on the status of other processing flags. The procedures are also described in detail in [AD.6].

3.2.2.4. Test modes

This operation mode is not described in [AD.6], as it is a built-in test mode with a fixed output in all correlators. The APID APID_TEST shall identify it.

3.3. L0 decoding and fundamental calibration equations

To obtain the digital correlations, $c_{kj}^{ii,iq}$, from the correlator counts, the following transformation is used:

$$c_{kj}^{ii,iq} = \frac{N_C}{N_{C_{\max}}} \quad \text{Eq. 1}$$

where $N_{C_{\max}}$ is the maximum number of counts. N_C is an integer from 0 to $N_{C_{\max}}$, the digital correlations (or raw normalised correlations), $c_{kj}^{ii,iq}$, range from 0 to 1.

The raw normalised correlations between antennas k and j and, for each polarisation and cross-polarisations, the in-phase and quadrature values (ii and iq)¹ are converted into normalised correlations $\mu_{kj}^{ii,iq}$ by solving the non-linear equation proposed in [RD.1]:

¹ Note that in [AD.7] the equations are written based on II and QI correlations. This document approach is not inconsistent with that formulation (see Section 9 of [AD.7]), only the equations are based on the nominal layer data (II and IQ correlations).

$$c_{kj}^{ii,iq} - \Delta c_k^i = \frac{1}{2} + \frac{1}{\pi} \sin^{-1} \mu_{kj}^{ii,iq} - \frac{1}{\sqrt{1 - (\mu_{kj}^{ii,iq})^2}} \left(\mu_{kj}^{ii,iq} (X_k^i)^2 + \mu_{kj}^{ii,iq} (X_j^{i,q})^2 - 2X_k^i X_j^{i,q} \right)$$

with

$$\frac{\partial c_{kj}^{ii,iq}}{\partial \mu_{kj}^{ii,iq}} = -\frac{1}{\pi} \frac{1}{\sqrt{1 - (\mu_{kj}^{ii,iq})^2}} + \left(\frac{(X_k^i)^2 + (X_j^{i,q})^2}{\sqrt{1 - (\mu_{kj}^{ii,iq})^2}} + \frac{(\mu_{kj}^{ii,iq})^2 (X_k^i)^2 + (\mu_{kj}^{ii,iq})^2 (X_j^{i,q})^2 - 2X_k^i X_j^{i,q} \mu_{kj}^{ii,iq}}{(\sqrt{1 - (\mu_{kj}^{ii,iq})^2})^3} \right) \quad \text{Eq. 2}$$

Where the values of $X_{k,j}^{i,q}$ and Δc_k^i are built using the correlations of I and Q channels with constant 1 and 0 channels, using the following expressions, in which x_{k0}^i is the correlation of I channels to all zeros (first vertical red line in Fig. 5) and x_{k1}^q is the correlation of the I or Q channels to all ones:

$$X_k^i = \frac{1}{2}(x_{k0}^i - x_{k1}^i), X_k^q = \frac{1}{2}(x_{k0}^q - x_{k1}^q), X_j^i = \frac{1}{2}(x_{j0}^i - x_{j1}^i), X_j^q = \frac{1}{2}(x_{j0}^q - x_{j1}^q), \Delta c_k^i = \frac{1}{2}(x_{k0}^i + x_{k1}^i - 1)$$

Equation 2 has to be solved iteratively, using as first solution $\mu_{kj}^{ii,iq} = \sin\left(\frac{\pi}{2}(2(c_{kj}^{ii,iq} - \Delta c_k^i) - 1)\right)$.

After computing the digital correlations, complex normalised correlation of baseline kj can be written, for the L0 nominal layer and any time delay, as:

$$\begin{aligned} \mu_{kj}^N &\equiv \mu_{kj}^{ii} + j\mu_{jk}^{qi} = \mu_{kj}^{ii} - j\mu_{kj}^{iq} \\ \mu_{kj}^N(\tau) &= \mu_{jk}^{ii}(-\tau) - j\mu_{kj}^{iq}(\tau) \end{aligned} \quad \text{Eq. 3}$$

and, for the redundant layer, as:

$$\begin{aligned} \mu_{kj}^R &\equiv \mu_{kj}^{qq} - j\mu_{jk}^{iq} = \mu_{kj}^{qq} + j\mu_{kj}^{qi} \\ \mu_{kj}^R(\tau) &= \mu_{jk}^{qq}(-\tau) + j\mu_{kj}^{qi}(\tau) \end{aligned} \quad \text{Eq. 4}$$

The redundant data will only be used in the case of failure of the nominal layer. Please note that Eqs. 3 and 4 account for the only difference in the processing of nominal or redundant data. The processing of time delays is only relevant for FWF shape calibration, but it is interesting to notice that the real parts must be interchanged between time delays to build the complex correlations.

After computing μ_{kj} all the subsequent processing is unchanged. The complex correlations are theoretically related to the calibrated visibilities through the equation:

$$\mu_{kj} = \frac{1}{\sqrt{T_{sys_k} T_{sys_j}}} \left(\text{Re}[\tilde{r}_{kj}^{ii}(0)\hat{V}_{kj}] + j \text{Im}[\tilde{r}_{kj}^{qi}(0)\hat{V}_{kj}] \right) \quad \text{Eq. 5}$$

where $\tilde{r}_{kj}^{ii,qi}$ is the fringe washing function at the origin for the corresponding pair of filters indicated by the sub and superscripts and \hat{V}_{kj} are the calibrated visibilities. The system temperatures are the sum of the antenna temperature and the receiver noise temperature referred to the theoretical antenna phase centre and including antenna ohmic losses. The objective of the calibration procedures is to compute the system temperatures and the FWF values at the origin to recover the calibrated visibilities.

The final calibrated visibilities are computed as [AD.7]:

$$\begin{aligned}\hat{V}_{kj}^{V,H} &= \frac{V_{kj}^{VV,HH} - V_{kj}^{UV,UH}}{c \cdot g_{kj}^{V,H}} \\ V_{kj}^{VV,HH} &= \sqrt{T_{sys_k}^{VV,HH} T_{sys_j}^{VV,HH}} M_{kj}^{V,H} \\ V_{kj}^{UV,UH} &= \sqrt{T_{sys_k}^{UV,UH} T_{sys_j}^{UV,UH}} M_{kj}^U\end{aligned}\tag{Eq. 6}$$

where c is a configurable correction complex number (implemented since L1OP v700 to account for correlation losses) and M_{kj} is defined as:

$$\begin{aligned}M_{kj}^q &= \frac{1}{\cos \theta_{qj}} \left(\text{Re} \left[M_{1kj} \mu_{kj}^N \right] + j \text{Im} \left[M_{2kj}^* \mu_{kj}^N \right] \right) \text{ (for Nominal layer)} \\ M_{kj}^q &= \frac{1}{\cos \theta_{qj}} \left(\text{Re} \left[M_{1kj}^* \mu_{kj}^R \right] + j \text{Im} \left[M_{2kj} \mu_{kj}^R \right] \right) \text{ (for Redundant layer)}\end{aligned}\tag{Eq. 7}$$

with index $q=H, V$ or U , and T_{sys} are the system temperatures during measurement. The parameter g_{kj} , in Eq. 6, is the value of the fringe washing function at the origin. M_{kj} is the quadrature-corrected normalised correlation and in turn has the following parameters:

$$\begin{aligned}M_{1kj} &= \cos \left(\frac{\theta_{qj}}{2} + \frac{\theta_{qk}}{2} \right) + j \sin \left(\frac{\theta_{qj}}{2} - \frac{\theta_{qk}}{2} \right) \\ M_{2kj} &= \cos \left(\frac{\theta_{qj}}{2} - \frac{\theta_{qk}}{2} \right) + j \sin \left(\frac{\theta_{qj}}{2} + \frac{\theta_{qk}}{2} \right)\end{aligned}\tag{Eq. 8}$$

The terms in these equations, other than the complex correlations, are computed during three calibration procedures - quadrature, phase/amplitude and offset.

3.3.1. Quadrature Error Correction

The quadrature correction is computed for all instrument modes' outputs and applied before any other processing is done. This approach obtains the θ_{qk} term known as the quadrature error of receiver k in the previous equations. It is directly estimated from the measured normalised auto-correlation between an antenna in-phase and quadrature outputs [AD.7]:

$$\theta_{qk} = -\arcsin(\mu_{kk}^{qi}) \quad \text{Eq. 9}$$

After knowing θ_{qk} , and defining

$$\begin{aligned} Q_{kj} &= \frac{\theta_{qj}}{2} - \frac{\theta_{qk}}{2} \\ Q'_{kj} &= \frac{\theta_{qj}}{2} + \frac{\theta_{qk}}{2} \end{aligned} \quad \text{Eq. 10}$$

Eq. 8 transforms into

$$\begin{aligned} M_{1kj} &= \cos Q'_{kj} + j \sin Q_{kj} \\ M_{2kj} &= \cos Q_{kj} + j \sin Q'_{kj} \end{aligned} \quad \text{Eq. 11}$$

M_{1kj} and M_{2kj} are easily computed and M_{kj} , the quadrature corrected correlations, are computed through Eq. 7. Since it is obtained directly from the instrument's own output, the quadrature-corrected correlation M_{kj} can be considered as instrument output.

3.4. Amplitude and In-Phase Error Correction

The correction parameters for amplitude and in-phase errors is computed from MIRAS output while in correlated noise injection mode. The outputs of these computations are then used in conjunction with the system temperatures measured in observation mode to calibrate the visibilities.

3.4.1. Power Measurement System calibration

The four-point measurement technique is based on a linear model of the PMS. A measured PMS voltage v depends on the system temperature T_{sys} as [AD.7]:

$$\begin{aligned} T_{sysk} &= T_{extk} + T_{rk} \\ v_k &= v_{offk} + G_k T_{sysk} + a_k T_{sysk}^2 \end{aligned} \quad \text{Eq. 12}$$

where T_r is the system noise temperature, T_{ext} is the external temperature, v_{offk} is the PMS offset, G_k is the PMS gain and a_k is the PMS 2nd order linearity correction term (although this parameter is not used, and instead the deflection C_k from Eq.36 is used instead).

It should be noted that in case the linearity correction is enabled, Eq.36 should be applied to all input PMS voltages before using them in the remaining equations.

If two external noise temperatures are used, T_{C1} (WARM) and T_{C2} (HOT), and if an attenuator is used to switch the system gain between two values, G and G/L , we have four possible PMS measurements, neglecting the 2nd order term:

$$\begin{aligned} v_{1k} &= v_{offk} + G_k(T_{C1k} + T_r) \\ v_{2k} &= v_{offk} + G_k(T_{C2k} + T_r) \\ v_{3k} &= v_{offk} + \frac{G_k}{L}(T_{C1k} + T_r) \\ v_{4k} &= v_{offk} + \frac{G_k}{L}(T_{C2k} + T_r) \end{aligned} \quad \text{Eq. 13}$$

The estimated calibration parameters are obtained as

$$\begin{aligned} v_{offk} &= \frac{v_{2k}v_{3k} - v_{1k}v_{4k}}{(v_{2k} - v_{4k}) - (v_{1k} - v_{3k})} \\ G_k &= \frac{v_{2k} - v_{1k}}{T_{C2k} - T_{C1k}} \end{aligned} \quad \text{Eq. 14}$$

and the estimated system temperatures, with the calibrated PMS data, will then be

$$T_{sysk} = \frac{v_k - v_{offk}}{G_k} = \frac{v_k - v_{offk}}{v_{2k} - v_{1k}}(T_{C2k} - T_{C1k}) \quad \text{Eq. 15}$$

As can be seen from Eq. 14, only a differential knowledge of the calibration temperatures is needed. The attenuator value is not needed.

In the case of relative amplitude calibration, a single noise source is used, delivering two calibration temperatures, T_{S1} (WARM) and T_{S2} (HOT), to port 0 of the NDN. The NIR will measure two temperatures, T_{NS1} and T_{NS2} at the port 1 of the NDN – the calibration external temperatures. As there are three NIRs in the MIRAS instrument, the values T_{NS1} and T_{NS2} will be the average of the noise temperatures measured by each NIR. Each NIR has two outputs, H and V and will in fact provide two measurement of the noise temperature, in NIR-R mode (see Section 3.8.1.1), which will also be averaged, after compensation with the S-Parameters for each polarization path¹. This averaging of the NIR signals reduces the noise and possible systematic errors.

The equivalent system temperatures at the LICEF receivers (port k and j) of the NDN are T_{CS2k} , T_{CS2j} , T_{CS1k} and T_{CS1j} . For example [AD.7]:

$$\begin{aligned} T_{CS2k} &= T_{S2} |S_{ks}|^2 + \Delta T_{[S], T_{ph}} \\ T_{NS2} &= T_{S2} |S_{Ns}|^2 + \Delta T'_{[S], T_{ph}} \end{aligned} \quad \text{Eq. 16}$$

where ΔT and $\Delta T'$ are the noise contributions from the NDN due to its physical temperature. Rearranging Eq. 16 and inserting into Eq. 15, the system temperature can be written as

¹ Computed as $T_{NS1} = \frac{1}{3} \sum_{i=1}^3 \frac{1}{2} \left(\frac{T_{NS1,h}}{|S_{Ni,h}|^2} + \frac{T_{NS1,v}}{|S_{Ni,v}|^2} \right)$ and $T_{NS2} = \frac{1}{3} \sum_{i=1}^3 \frac{1}{2} \left(\frac{T_{NS2,h}}{|S_{Ni,h}|^2} + \frac{T_{NS2,v}}{|S_{Ni,v}|^2} \right)$

$$T_{sysk} = \frac{v_k - v_{offk}}{v_{2k} - v_{1k}} (T_{C2k} - T_{C1k}) = \frac{v_k - v_{offk}}{v_{2k} - v_{1k}} \frac{|S_{ks}|^2}{|S_{Ns}|^2} (T_{NS2} - T_{NS1}) \quad \text{Eq. 17}$$

3.4.2. Fringe Washing Function Estimation

The estimated values of the fringe washing function at the origin shall be used as a parameter to correct amplitude and in-phase errors. Together with the values at two different time delays it will also be used later during the image reconstruction process, by approximating the FWF with a sinc function. Details on the computation of this approximation and associated coefficients can be found in [RD.16]. The fringe washing function needs to be estimated for all possible pairs of receivers, without repetition. This gives a total of $N_{Receivers} (N_{Receivers} - 1) / 2$ pairs to be computed.

The amplitude of the FWF is computed using data from the relative amplitude calibration approach, using the system temperatures computed during calibration with correlated noise injection. Three different measurements are made at the three different time delays needed.

Special care has to be taken in the computation of the M_{kj} terms for the two time delays ($-t_s$ and $+t_s$). The baseline for the time delay is given from a Local Oscillator at 55.84MHz, and the value shall be retrieved from the PLM ADF. As mentioned in [RD.19], Equations 3, 4 and 7 must be adjusted for the effect of the time delay. The net effect is that the real part of $\mu_{kj}(-t_s)$ has to be computed from the correlations at time delay $+t_s$ and viceversa.

Additionally, the quadrature error correction computed in Eq.9 θ_{qk} has to be taken from the zero delay self-correlations, as otherwise the quadrature error is badly estimated.

The resulting equations for the fringe wash amplitude term g_{kj} at the hub, at time delays

$\tau = -t_s, 0, +t_s$ are [AD.7]:

$$g_{kj}^C(\tau) = \frac{M_{kj}^{C2}(\tau) \sqrt{(v_{2k} - v_{offk})(v_{2j} - v_{offj})} - M_{kj}^{C1}(\tau) \sqrt{(v_{1k} - v_{offk})(v_{1j} - v_{offj})}}{\sqrt{(v_{2k} - v_{1k})} \sqrt{(v_{2j} - v_{1j})}} \frac{|S_{k0}| |S_{j0}|}{S_{k0}^* S_{j0}^*}$$

$$\left. \begin{aligned} \bar{g}_{kj}^C(-\tau) &= \frac{g_{kj}^C(-\tau)}{g_{kj}^C(0)} e^{j2\pi f_{IF}\tau} \\ \bar{g}_{kj}^C(0) &= 1 \\ \bar{g}_{kj}^C(\tau) &= \frac{g_{kj}^C(\tau)}{g_{kj}^C(0)} e^{-j2\pi f_{IF}\tau} \end{aligned} \right\} \quad \text{Eq. 18}$$

where $|S_{k,j0}|$ are the modulus of the S-parameters relating the k receiver with the noise source (dependent on physical temperature). The term M_{kj}^{C2} will be measured with HOT noise temperature

while the term M_{kj}^{C1} is measured with WARM noise temperature. The normalised values at time delays shall be used to estimate the FWF shape coefficients, as it is described in [RD.16] The value of f_{IF} is the intermediate frequency computed as the central frequency minus the local oscillator frequency (both values are contained in the PLM ADF)

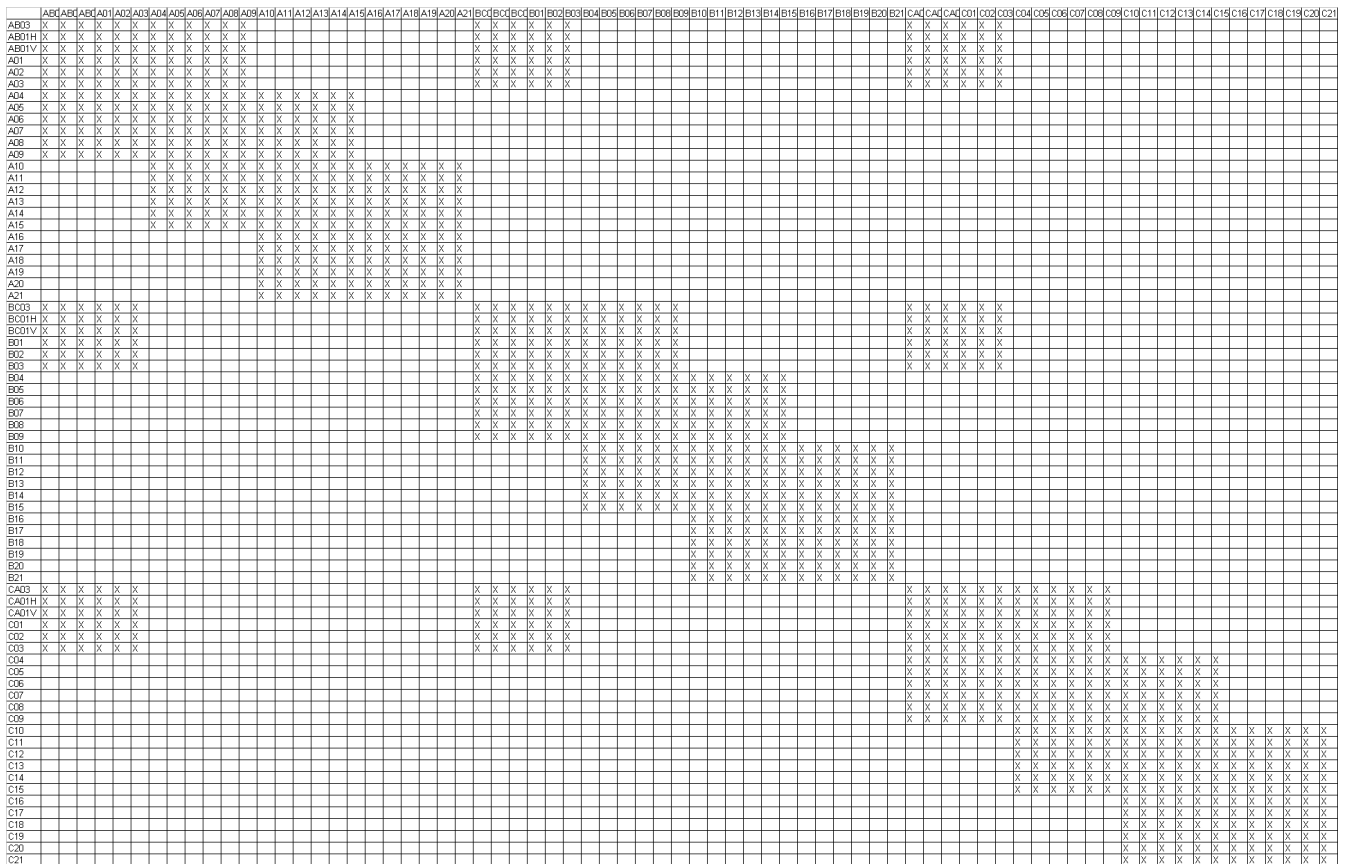
The FWF estimated values at the origin are then computed in the antenna polarisation reference planes by:

$$g_{kj}^{H,V}(0) = g_{kj}^C(0) \frac{\bar{S}_{LH,Vk} \bar{S}_{LH,Vj}^*}{\bar{S}_{LCk} \bar{S}_{LCj}^*} e^{j(\phi_{H,Vk} - \phi_{H,Vj})} \quad \text{Eq. 19}$$

Where \bar{S}_{LCk} and $\bar{S}_{LH,Vk}$ are the phases of the switch S-parameters¹ relating port C and H (or V) with port L in the k receiver (dependent on physical temperature) and $\phi_{H,Vk}$ are the antenna patterns absolute phases. Only the FWF at the origin needs to be translated to the antenna plane, the shape values (FWF at time delays) will be a function of $g_{kj}(0)$. The g_{kj} values are complex and will be used to correct amplitude and in-phase errors.

The values shown in Eq. 19 can only be computed for pairs of receivers that share the same Noise Source, as correlated noise can only be injected through the same Noise source. This means that the total number of elements that can be measured is 612 (see next figure and consider only the elements in the upper triangular matrix), and for the rest of the pairs, the values should be estimated based on these measurements.

¹ Computed as the Switch S-Parameter divided by its modulus $\bar{S}_{LH,Vk} = \frac{S_{LH,Vk}}{|S_{LH,Vk}|}$



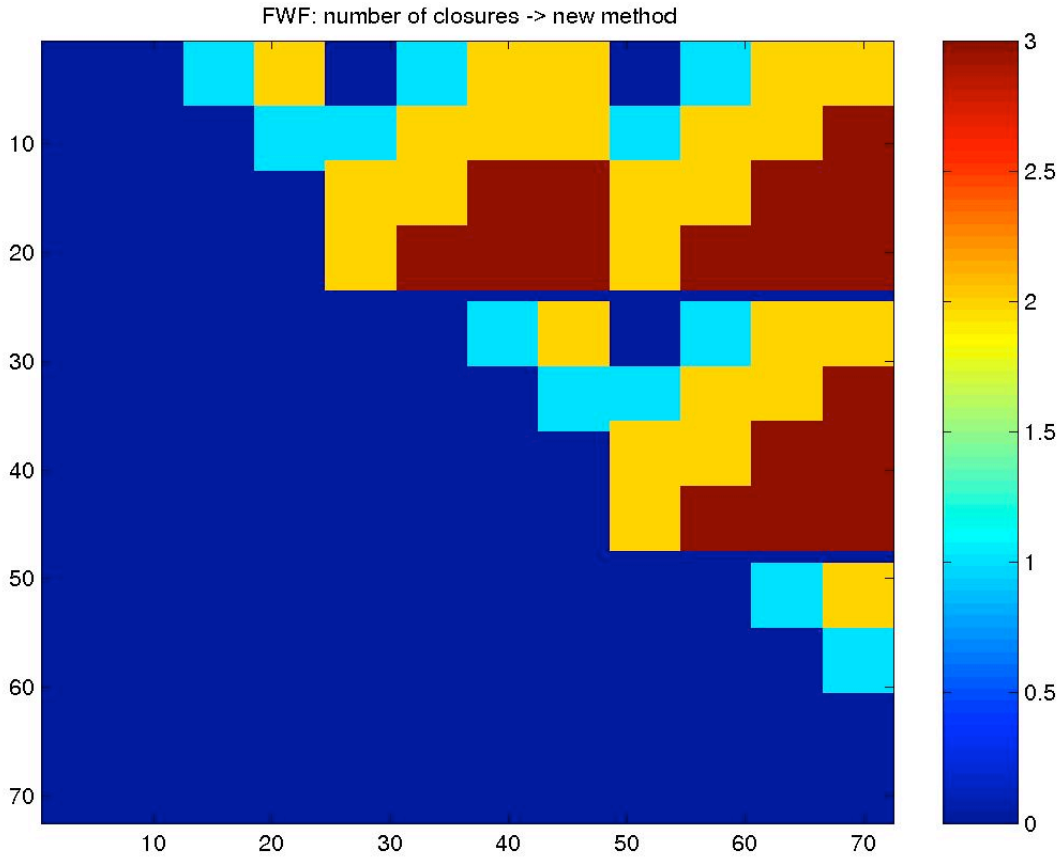


Figure 11 - Number of closures needed to compute the FWF for each pair of receivers

There are, however, a number of baselines that do not have any possible closure for the estimation of the FWF, namely the ones between receiver LICEF_A21 and all the receivers in arms B and C and the ones between the receiver LICEF_B21 and all the receivers in arm C, amounting to a total of 72 baselines. For these remaining pairs of receivers, the FWF will have to be estimated by solving a system of equations on phase and amplitude.

Phase and amplitude estimation for these remaining pairs of receivers is achieved by first solving the systems of equations determined by:

$$\alpha_{kj} = \theta_j - \theta_k - \theta_{kj}$$

$$\log(g_{kj}) = \log(g_j) + \log(g_k)$$

Eq. 21

Where α_{kj} is the FWF phase of the baseline k-j at CIP plane, θ_j , θ_k are the phase of receivers j and k, respectively, θ_{kj} is the non-separable error, g_{kj} is the FWF amplitude and g_k and g_j are the individual amplitude of receivers.

The system is solved initially by assuming that the non-separable errors are negligible. The system is over-determined, as there are 612 equations and only 72 unknowns in total, independently for amplitude and phase. As a reference phase is required, the phase of receiver LICEF A01 shall be taken as 0°. No reference is required for the amplitude system.

Once the best solution is found for each receiver phase, the non-separable error can be estimated for those baselines that are not covered by any closure, by computing the average value of the error between the measured FWF phase and the solutions of the receivers' phases, as per the next equation:

$$\bar{\theta} = \text{mean}(\theta_j - \theta_k - \alpha_{kj}) \quad \text{Eq. 22}$$

The FWF phase is then estimated by using a modified version of equation 21:

$$\alpha_{kj} = \theta_j - \theta_k - \bar{\theta} \quad \text{Eq. 23}$$

The amplitude for the same baselines not covered by any closure is simply computed multiplying the output of the system of equations g_k and g_j .

For a detailed description of the processing of Eqs. 20-23, please refer to Section 5.4.4.2.

3.5. System Temperatures Computation

In measurement mode, the visibilities must be amplitude and phase corrected with the parameters computed in calibration mode. While the quadrature, offset and in-phase corrections are straightforward to apply, since the coefficients have been computed during the noise injection modes, the denormalisation of the calibrated visibilities will rely on the computation of the system temperatures in the reference planes at the time of each measurement.

Firstly, the correct PMS parameters must be retrieved from auxiliary or previous calibration data, by choosing the values measured at the closest physical temperature. The correct parameters will be the ones computed at the closest physical temperature to the one at measurement time. If the temperature change between calibration and observation times is

$$\Delta T_{phy} = T_{phyL1k} - T_{phyL0k} \quad \text{Eq. 24}$$

the gain and offset of the PMSs during observation is computed using ΔT_{phy} and the PMS sensitivity to physical temperature:

$$\begin{aligned} G_k^C &= G_k (1 + S_{T_{phy}}^G \Delta T_{phy}) \\ v_{offk}^C &= v_{offk} + S_{T_{phy}}^{v_{off}} \Delta T_{phy} \end{aligned} \quad \text{Eq. 25}$$

The sensitivity terms, $S_{T_{phy}}^G$ and $S_{T_{phy}}^{v_{off}}$, will be characterized on ground as well as in-orbit during the calibration orbit.

3.5.1. Hub system temperatures in NIR-4-point calibration mode

Using Eq. 15, one can express the calibration temperature at the receiver k and the system temperature at the antenna plane as

$$T_{sys_k}^{HC,VC} = \frac{v_k - v_{off}}{G_k}$$

$$\eta_{H,Vk} = \frac{1}{L_{2H,Vk}^0 \left(L_{1H,Vk}^0 + B_{H,Vk}^{short} (T_{p7} - T_{p7,0}) + B_{H,Vk}^{long} (T_{p7,0} - T_{p7,ref}) \right)}$$

$$T_{sys_k}^{HH,VV} = T_{sys_k}^{HC,VC} \frac{|S_{LCk}|^2}{|S_{LH,LVk}|^2 \eta_{H,Vk}}$$

Eq. 26

where $|S_{LCk}|$ and $|S_{LH,LVk}|$ are the modulus of the switch S-parameters relating port C and H (or V) with port L in the k receiver (dependent on physical temperature), $\eta_{H,Vk}$ is the ohmic efficiency of the antenna k in H (or V) mode, v_k are the PMS voltages for the antenna k measured while the visibilities are retrieved, v_{offk} are the PMS calibrated offsets, G_k are the PMS calibrated gains(also dependent on physical temperature).

With the new LICEF antenna model introduced in 2011, $\eta_{H,Vk}$ ohmic efficiency is computed using the following parameters:

- $L_{1H,Vk}^0$ and $L_{2H,Vk}^0$ are the L1 and L2 attenuator values measured on-ground
- $B_{H,Vk}^{long}$ is the long term drift component of the L1 attenuator in-orbit using data from the first year
- $B_{H,Vk}^{short}$ is the short term drift component of the L1 attenuator in-orbit using data from the first year
- $T_{p7,ref}$ is the reference Tp7 at which the previous 3 coefficients were obtained
- T_{p7} is the physical temperature of the radiator of the antenna (antenna patch) during the current measurement
- $T_{p7,0}$ is the physical temperature of the radiator of the antenna (antenna patch) during the NIR calibration sequence, as defined in section 3.5.3.1

A further correction to PMS 2nd order linearity needs to be applied before the plane transition, as is explained in Eq. 36 in the next section.

3.5.2. Arm system temperatures in ~~NIR~~ 4-point Calibration mode

The MIRAS/SMOS configuration uses a distributed approach to inject noise in the three arms of the instrument. Each arm is divided in three segments, with 6 receivers each, denominated quite simply segments 1, 2 and 3. The following assumptions were made:

- 2 EVEN noise sources: 0 and β placed at ports 0 and β of the NDN
- 2 ODD noise sources: α and γ placed at ports α and γ of the NDN
- 18 PMS k placed at the HUB
- 3 NIR placed at port 1 of the HUB

- ❑ 6 PMS l placed at first segment of each arm
- ❑ 6 PMS m placed at second segment of each arm
- ❑ 6 PMS n placed at third segment of each arm

The hub PMS calibration method of Section 3.4.1 can be extended and applied to the PMS in the arms. Two sets of PMS voltage readings can be obtained, from EVEN and ODD noise sources. In the first segment, the PMS can be calibrated using the NIR at port 1 of the HUB when driven by the common ODD noise source α . Due to the symmetry of the temperature at port C of each of the 6 PMS l receivers, we can calculate [RD.14]:

$$T_{sys_l}^C = \frac{1}{4} \sum_{h=1}^4 \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} \frac{v_l - v_{offl}}{v_{2l}^{\alpha} - v_{1l}^{\alpha}} \frac{|S_{l0}|^2}{|S_{h0}|^2} \frac{v_{2h}^{\alpha} - v_{1h}^{\alpha}}{v_{2h}^0 - v_{1h}^0} (T_{NS2}^0 - T_{NS1}^0) \quad \text{Eq. 27}$$

where the noise source temperatures are averaged from the measurements of the receivers in the hub, excluding the NIR channels. Since the offset term can be calculated from both sources, EVEN and ODD, it can be written as

$$v_{offl} = \frac{1}{2} (v_{offl}^0 + v_{offl}^{\alpha}) \quad \text{Eq. 28}$$

where

$$\begin{aligned} v_{offl}^0 &= \frac{v_{2l}^0 v_{3l}^0 - v_{1l}^0 v_{4l}^0}{v_{2l}^0 - v_{4l}^0 - v_{1l}^0 + v_{3l}^0} \\ v_{offl}^{\alpha} &= \frac{v_{2l}^{\alpha} v_{3l}^{\alpha} - v_{1l}^{\alpha} v_{4l}^{\alpha}}{v_{2l}^{\alpha} - v_{4l}^{\alpha} - v_{1l}^{\alpha} + v_{3l}^{\alpha}} \end{aligned} \quad \text{Eq. 29}$$

Please note that for the last segment in each arm, Eq. 27 is not used, since there is only one noise source available.

While this averaging can be done for the offsets, the same can not be done for the gains, since these depend on the S-Parameters of the paths connecting the LICEFS with each Noise Source. Making use of the same symmetry, the calibration temperature for receivers m in the second segment can be calibrated with

$$T_{sys_m}^C = \frac{v_m - v_{offm}}{v_{2m}^{\beta} - v_{1m}^{\beta}} \frac{|S_{m\beta}|^2}{|S_{l\beta}|^2} (T_{sys_l}^{\beta C2} - T_{sys_l}^{\beta C1}) \quad \text{Eq. 30}$$

since any PMS l in the first segment can play the role of NIR when both segments are driven by the common noise source β . As the PMS l have been calibrated already, we have

$$T_{sys_l}^{\beta C2} = \frac{1}{4} \sum_{h=1}^4 \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} \frac{v_{2l} - v_{offl}}{v_{2l}^\alpha - v_{1l}^\alpha} \frac{|S_{l0}|^2}{|S_{h0}|^2} \frac{v_{2h}^\alpha - v_{1h}^\alpha}{v_{2h}^0 - v_{1h}^0} (T_{NS2}^0 - T_{NS1}^0) = \frac{v_{2l} - v_{offl}}{v_{2l}^\alpha - v_{1l}^\alpha} \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} (T_{NS2}^\alpha - T_{NS1}^\alpha)$$

$$T_{sys_l}^{\beta C1} = \frac{1}{4} \sum_{h=1}^4 \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} \frac{v_{1l} - v_{offl}}{v_{2l}^\alpha - v_{1l}^\alpha} \frac{|S_{l0}|^2}{|S_{h0}|^2} \frac{v_{2h}^\alpha - v_{1h}^\alpha}{v_{2h}^0 - v_{1h}^0} (T_{NS2}^0 - T_{NS1}^0) = \frac{v_{1l} - v_{offl}}{v_{2l}^\alpha - v_{1l}^\alpha} \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} (T_{NS2}^\alpha - T_{NS1}^\alpha)$$

Eq. 31

Arranging the last two equations we have

$$T_{sys_m}^C = \frac{v_m - v_{offm}}{v_{2m}^\beta - v_{1m}^\beta} \frac{|S_{m\beta}|^2}{|S_{l\beta}|^2} \frac{v_{2l}^\beta - v_{1l}^\beta}{v_{2l}^\alpha - v_{1l}^\alpha} \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} (T_{NS2}^\alpha - T_{NS1}^\alpha)$$

Eq. 32

Moreover, the taking into account that each noise source drives 12 receivers, 6 PMS in each segment can be used as NIR and the results averaged in order to improve the results. The previous will then transform into:

$$T_{sys_m}^C = \frac{1}{6} \sum_{l=1}^6 \frac{v_m - v_{offm}}{v_{2m}^\beta - v_{1m}^\beta} \frac{|S_{m\beta}|^2}{|S_{l\beta}|^2} \frac{v_{2l}^\beta - v_{1l}^\beta}{v_{2l}^\alpha - v_{1l}^\alpha} \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} (T_{NS2}^\alpha - T_{NS1}^\alpha)$$

Eq. 33

Finally, the same procedure can be applied to the third segment, for the PMS n :

$$T_{sys_n}^C = \frac{v_n - v_{offn}}{v_{2n}^\gamma - v_{1n}^\gamma} \frac{|S_{n\gamma}|^2}{|S_{m\gamma}|^2} (T_{sysm}^{\gamma C2} - T_{sysl}^{\gamma C1})$$

Eq. 34

and again using the fact that the PMS m have already been calibrated and can be averaged, we have

$$T_{sys_n}^C = \frac{1}{36} \sum_{m=1}^6 \sum_{l=1}^6 \frac{v_n - v_{offn}}{v_{2n}^\gamma - v_{1n}^\gamma} \frac{|S_{n\gamma}|^2}{|S_{m\gamma}|^2} \frac{v_{2m}^\gamma - v_{1m}^\gamma}{v_{2m}^\beta - v_{1m}^\beta} \frac{|S_{m\beta}|^2}{|S_{l\beta}|^2} \frac{v_{2l}^\beta - v_{1l}^\beta}{v_{2l}^\alpha - v_{1l}^\alpha} \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} (T_{NS2}^\alpha - T_{NS1}^\alpha)$$

Eq. 35

After computing the system temperatures at CIP for all receivers $T_{sys_k}^{SC(1)}$, a further 2nd order linearity correction must be performed using the deflection parameter measured on ground C_k .

$$v_{ik}^{(2)} - v_{off_k} = C_k \sqrt{1 + \frac{2}{C_k} (v_{ik}^{(1)} - v_{off_k})} - C_k$$

Eq. 36

The objective is to apply again the previous equations, but using these new voltages $v_{ik}^{(2)}$ as a starting point, in order to obtain a final system temperature $T_{sys_k}^{SC(2)}$ (i.e. computing again new offsets and gains with Eq. 27-35).

3.5.3. System Temperatures in ~~ALL-LICEF-mode~~ 1-point Calibration mode

Since L1OP v700 (June 2015) a new mode of PMS Gain calibration was implemented [RD.26]. This mode makes use of the Uncorrelated Noise epochs to calibrate the PMS gains, bypassing the NIR measurements and therefore avoiding the propagation of the NIR calibration errors to the System Temperatures computation.

The computation is done by using the voltages measured in each Uncorrelated Noise epoch and calculating:

$$G_k^C = \frac{v_{u_k} - v_{off_k}}{T_{u_k} - T_{R_k}} \quad \text{Eq. 37}$$

where

- v_{u_k} is the PMS voltage at the Uncorrelated Noise epoch
- v_{off_k} is the consolidated PMS offset computed in the same long calibration event using the four point technique (Eq. 29). The usual second order, temperature sensitivity and heater corrections should be applied (Eq. 36).
- T_{u_k} is the physical temperature of the U-load at the Uncorrelated Noise epoch, in Kelvin
- $T_{R_k} = T_{R_k}^{21^\circ C} + STR \cdot (T_{u_k} - 21^\circ C)$ is the receiver noise temperature at CIP in K. Its value at 21°C and the corresponding sensitivity STR are read from the MIRAS database.

The L1OP will also compute the Gain Sensitivity with temperature (SG), by doing a linear fit to all the PMS gains computed in the Uncorrelated Noise mode, and store it for use during measurement System Temperatures computation.

3.5.4. System Temperatures at the Antenna Plane

3.5.4.1. Plane translation in NIR mode

To extract the system temperature at the antenna phase centre in NIR mode, the following plane translation, between calibration and antenna planes, is made (H mode exemplified):

$$T_{sys_{l,m,n}}^H = \frac{|S_{LCl,m,n}|^2}{|S_{LHL,m,n}|^2 \eta_{HL,m,n}} T_{sys_{l,m,n}}^{C(2)} \quad \text{Eq. 38}$$

where $|S_{LCl,m,n}|$ and $|S_{LHL,m,n}|$ are the modulus of the switch S-parameters relating port C and H with port L for PMS l,m,n (dependent on physical temperature) and $\eta_{l,m,n}$ is the antenna efficiency in horizontal mode. The same procedure must be applied for the vertical measurement modes.

So, introducing the definition of PMS gain from Eq. 12, for each segment we have the values of system temperature in terms of PMS output $v_{l,m,n}$, gain $G_{l,m,n}^{\alpha,\beta,\gamma}$ and offset $v_{off_{l,m,n}}$:

$$\begin{aligned}
 T_{sys_l}^{H,V} &= \frac{|S_{LCI}|^2}{|S_{LH,Vl}|^2} \frac{v_l^{(2)} - v_{offl}^{(2)}}{G_l^{\alpha(2)}} \\
 T_{sys_m}^{H,V} &= \frac{|S_{LCm}|^2}{|S_{LH,Vm}|^2} \frac{v_m^{(2)} - v_{offm}^{(2)}}{G_m^{\beta(2)}} \\
 T_{sys_n}^{H,V} &= \frac{|S_{LCn}|^2}{|S_{LH,Vn}|^2} \frac{v_n^{(2)} - v_{offn}^{(2)}}{G_n^{\gamma(2)}}
 \end{aligned}
 \tag{Eq. 39}$$

Since L1OP v720 (end of 2017) all system temperatures, either in NIR mode or ALL-LICEF mode, will be plane translated as in the following section (Eq. 39 is no longer applicable).

3.5.4.2. **System Temperatures Plane translation in ALL-LICEF mode**

When the PMS gains where computed in ALL-LICEF mode, the LICEF system temperatures are computed during measurement. First at the calibration plane through:

$$T_{sys_k}^C = \frac{v_k - v_{offk}}{G_k^C} \tag{Eq. 40}$$

with the PMS Gain translated to the measurement temperature as usual $G_k = G_k^{Cal} + SG \cdot (T_{u_k} - T_{u_k}^{Cal})$, with G_k^{Cal} , SG and $T_{u_k}^{Cal}$ read from the nearest calibration file (see Section 3.5.3) and T_{u_k} the physical temperature of the U-load in the science epoch. The PMS offset used must have the second order, temperature sensitivity and heater corrections applied.

The final plane translation between Calibration Plane (CIP) and Antenna plane (HAP/VAP) is simply done as:

$$T_{sys_k}^{H,V} = T_{sys_k}^C LFE^{H,V} \tag{Eq. 41}$$

with LFE as the new Front-End Losses computed by CASA and shown in [RD.27]. **Since L1OP v720 (end of 2017) all system temperatures, either in NIR mode or ALL-LICEF mode, will be plane translated as in Eq. 41.**

3.5.5. **NIR Antenna Temperatures**

This section was based on the description of NIR calibration procedures in [RD 6] and on the latest In Orbit Calibration Plan [AD 7]. For more information, please refer to that document.

3.5.5.1. **NIR brightness temperatures**

3.5.5.1.1. **Dual polarisation temperatures**

In dual polarisation mode, the NIR brightness temperatures are computed from data retrieved in NIR-A mode, namely the NIR pulse length and the measured noise temperature:

$$\begin{aligned}
 T'_{A,v} &= (A_{A,v} + \Delta A_{A,v}) \eta_v + (B_{A,v} + \Delta B_{A,v}) \\
 T'_{A,h} &= (A_{A,h} + \Delta A_{A,h}) \eta_h + (B_{A,h} + \Delta B_{A,h}) \\
 &\text{with} \\
 \Delta A_{A,v} &= a_v (T_{p7} - T_{p7,0}) \\
 \Delta A_{A,h} &= a_h (T_{p7} - T_{p7,0}) \\
 \Delta B_{A,v} &= b_v (T_{p7} - T_{p7,0}) \\
 \Delta B_{A,h} &= b_h (T_{p7} - T_{p7,0})
 \end{aligned}
 \tag{Eq. 42}$$

where $\eta_{v,h}$ are the NIR pulse lengths in H and V polarisations, T_{p7} is the physical temperature of the antenna patch (subscript 0 indicates the temperature during calibration) and A_A and B_A are coefficients computed as is explained in the following paragraphs.

The coefficient A_A can be computed simply from

$$\begin{aligned}
 A_{A,v} &= -L_{1v} L_{2v} T_{NA,v} \\
 A_{A,h} &= -L_{1h} L_{2h} T_{NA,h}
 \end{aligned}
 \tag{Eq. 43}$$

where T_{NA}^{\dagger} is the corrected noise injection temperature, computed from the noise injection level measured during calibration, T_{NA0} (see Section 3.8.2.1), by

$$\begin{aligned}
 T_{NA,v} &= T_{NA0,v} + u_{Av} (T_{p1v} - T_{p1v,0}) \\
 T_{NA,h} &= T_{NA0,h} + u_{Ah} (T_{p1h} - T_{p1h,0})
 \end{aligned}
 \tag{Eq. 44}$$

with the parameters defined as:

- ❑ $u_{Av,h}$ - Sensitivity to physical temperature gradient (please check [RD 6] - Section 5.3.3)
- ❑ T_{p1} - Is the physical temperature of the noise source
- ❑ $T_{p1h,v0}$ - Is the physical temperature of the noise source during calibration (see Section 3.8.2.1)
- ❑ L_1 - Attenuator between antenna plane and antenna intermediate layer computed as $L_{1h,v} = L_{1h,v}^0 + \delta L_{1h,v} + \alpha_{h,v} (T_{p7,0} - T_{p7,ref}) + \beta_{h,v} (T_{p7} - T_{p7,ref})$ in which
 - $L_{1h,v}^0$ is the L1 attenuator value measured on-ground
 - $\delta L_{1h,v}$ is a fixed L1 attenuator error characterised in-orbit using data from the first year

[†]~~Since L1OP v720 (end of 2017), is fixed ([RD.30]). It is still computed during External Mode (see Section 3.8.2.1 is unchanged) but a single fixed value is retrieved from the NIR ADF and used to compute the NIR BTs during measurements. To ensure the exact value is used, the propagation parameters - and - have been set to 0.~~

- $\alpha_{h,v}$ is the long term drift component of the L1 attenuator in-orbit using data from the first year
- $\beta_{h,v}$ is the short term drift component of the L1 attenuator in-orbit using data from the first year
- $T_{p7,ref}$ is the reference Tp7 at which the previous 3 coefficients were obtained
- T_{p7} is the physical temperature of the radiator of the antenna (antenna patch) during the current measurement
- $T_{p7,0}$ is the physical temperature of the radiator of the antenna (antenna patch) during the NIR calibration sequence

□ L_2 - Attenuator between antenna intermediate layer and antenna input plane

Since L1OP v720 (end of 2017), T_{NA} is fixed ([RD.30]) in the baseline processing. It is still computed during External Mode (see Section 3.8.2.1, which is unchanged) but a single fixed value is now retrieved from the NIR ADF and used to compute the NIR BTs during measurements. To ensure the exact value is used, the propagation parameters c_A , d_A and $u_{Av,h}$ have been set to 0. However, the computation in Eq. 44 can still be activated through a configuration flag (“Fixed Tna0 mode” set to *false*).

As for the coefficient B_A , several intermediate temperatures must be computed. First, the thermal noise contributions are computed from

$$\begin{aligned}
 T_{t1v} &= \left(1 - \frac{1}{L_{1v}}\right) \frac{T_{p7}}{L_{2v}} + \left(1 - \frac{1}{L_{2v}}\right) T_{p6v} \\
 T_{t1h} &= \left(1 - \frac{1}{L_{1h}}\right) \frac{T_{p7}}{L_{2h}} + \left(1 - \frac{1}{L_{2h}}\right) T_{p6h} \\
 T_{t2v} &= \left(1 - \frac{1}{L_{NCv}}\right) \frac{T_{p3v}}{L_{Av} L_{DAv}} + \left(1 - \frac{1}{L_{Av}}\right) \frac{T_{Cabv}}{L_{DAv}} + \left(1 - \frac{1}{L_{DAv}}\right) T_{pUv} \\
 T_{t2h} &= \left(1 - \frac{1}{L_{NCh}}\right) \frac{T_{p3h}}{L_{Ah} L_{DAh}} + \left(1 - \frac{1}{L_{Ah}}\right) \frac{T_{Cabh}}{L_{DAh}} + \left(1 - \frac{1}{L_{DAh}}\right) T_{pUh}
 \end{aligned}
 \tag{Eq. 45}$$

where

- T_{p7} - Physical temperature of the radiator of the antenna (antenna patch)
- T_{p6} - Physical temperature of the intermediate layer of the antenna
- T_{p3} - Physical temperature of the attenuator in reference noise injection channel
- L_{NC} - Attenuator between antenna input plane and antenna output plane
- L_A - Attenuator between antenna output plane and LICEF input plane
- L_{DA} - Attenuator between antenna LICEF input plane in H or V port and LICEF output plane

- T_U - Physical temperature measured inside the LICEF (between U-Load and isolator)
- T_{pU} - U-load. Approximated by T_U
- T_{Cab} - Physical temperature between radiator output plane and LICEF input plane. Shall be approximated from T_{p3} and T_U as

$$\begin{aligned} T_{Cabv} &= \frac{T_{p3v} + T_{Uv}}{2} \\ T_{Cabh} &= \frac{T_{p3h} + T_{Uh}}{2} \end{aligned} \quad \text{Eq. 46}$$

Finally, the coefficient B_A is computed as

$$\begin{aligned} B_{Av} &= L_{1v} L_{2v} [L_{NCv} L_{Av} L_{DAv} (T_{Uv} - T_{t2v}) - T_{t1v}] \\ B_{Ah} &= L_{1h} L_{2h} [L_{NC h} L_{Ah} L_{DAh} (T_{Uh} - T_{t2h}) - T_{t1h}] \end{aligned} \quad \text{Eq. 47}$$

and Eq. 42 is applied. The resulting brightness temperature is further corrected by

$$\begin{aligned} \hat{T}_{A,v} &= T'_{A,v} + c_{Av} (T'''_{A,v} - T'''_{A0,v}) + d_{Av} (T'''_{A,v} - T'''_{A0,v})^2 \\ \hat{T}_{A,h} &= T'_{A,h} + c_{Ah} (T'''_{A,h} - T'''_{A0,h}) + d_{Ah} (T'''_{A,h} - T'''_{A0,h})^2 \end{aligned} \quad \text{Eq. 48}$$

where the parameters c_A and d_A are parameters measured on-ground and used to compensate the uncertainty in the front-end characterization (first and second order). $T'''_{A,v}$ and $T'''_{A0,v}$ are computed by:

$$\begin{aligned} T'''_{A,v} &= \frac{T'_{A,v}}{L_{1,v} L_{2,v}} + T_{t1,v} \\ T'''_{A,h} &= \frac{T'_{A,h}}{L_{1,h} L_{2,h}} + T_{t1,h} \end{aligned} \quad \text{Eq. 49}$$

and T'''_{A0} is the antenna temperature during calibration (see Section 3.8.2), and stored with the NIR-A data (i.e. with physical temperatures measured at the time of calibration).

3.5.5.1.2. Full polarisation temperatures

In the case of the processing of full polarisation scenes, the NIR brightness temperatures are computed as in the dual polarisation case but the 3rd and 4th Stokes parameters, T_3 and T_4 , have to be computed from NIR pulse lengths, the FWF(0) values and the phase corrected correlations.

The 3rd and 4th Stokes parameters are retrieved by using

$$\begin{bmatrix} T_3 \\ T_4 \end{bmatrix} = \begin{bmatrix} g'_s & 0 \\ 0 & g'_s \end{bmatrix} \begin{bmatrix} r_3 \\ r_4 \end{bmatrix} + \begin{bmatrix} f_{ii} \\ f_{qi} \end{bmatrix} \quad \text{Eq. 50}$$

The factors in the previous computation must be retrieved from a set of measurement and calibration data. The steps to obtain these are shown below. First, the correlations are used to compute the factor

$$\begin{bmatrix} r_3 \\ r_4 \end{bmatrix} = \begin{bmatrix} \arcsin(\mu_{ii}^{CIP}) \\ \arcsin(\mu_{qi}^{CIP}) \end{bmatrix} \quad \text{Eq. 51}$$

And the g'_s are gain parameters computed as

$$g'_s = \frac{2}{g_{kjNIR}} \Lambda_{kj} \sqrt{T_{sys}^{HA} T_{sys}^{VA}} \quad \text{Eq. 52}$$

where g_{kjNIR} is the Fringe Wash Function at the origin applicable to the two LICEF correlation within a NIR, T_{sys}^{AA} are the system temperatures computed through Eq. 63 and $T_{NA,hv}''$ is the noise injection temperature from Eq. 44, converted to the antenna plane by

$$T_{NA,vh}'' = L_{1,vh} L_{2,vh} T_{NA,vh} \quad \text{Eq. 53}$$

Additionally, parameter Λ_{kj} from Eq. 52 is dependant on the condition $\eta_h > \eta_v$, as shown in the following equation.

$$\begin{aligned} \eta_v > \eta_h : \\ \Lambda_{kj} &= \left(n_1 \sqrt{\frac{T_{sys}^{HA} T_{sys}^{VA}}{(T_{sys}^{HA} + T_{NA,h}'')(T_{sys}^{VA} + T_{NA,v}'')}} + n_2 \sqrt{\frac{T_{sys}^{VA}}{(T_{sys}^{VA} + T_{NA,v}'')}} + n_3 \right)^{-1} \\ \eta_v < \eta_h : \\ \Lambda_{kj} &= \left(n_1 \sqrt{\frac{T_{sys}^{HA} T_{sys}^{VA}}{(T_{sys}^{HA} + T_{NA,h}'')(T_{sys}^{VA} + T_{NA,v}'')}} + n_2 \sqrt{\frac{T_{sys}^{HA}}{(T_{sys}^{HA} + T_{NA,h}'')}} + n_3 \right)^{-1} \end{aligned} \quad \text{Eq. 54}$$

Finally, the coefficients n_i are computed from the NIR pulse lengths by the following rules

$$\begin{aligned} n_1 &= \frac{1}{2} \min(\eta_v, \eta_h) \\ n_2 &= \frac{1}{2} \max(\eta_v, \eta_h) - \frac{1}{2} \min(\eta_v, \eta_h) \\ n_3 &= \frac{1}{2} - \frac{1}{2} \max(\eta_v, \eta_h) \end{aligned} \quad \text{Eq. 55}$$

By expanding all the coefficients of Eq. 50, the full equation for T_3 and T_4 is obtained:

$$\begin{aligned} T_3^V &= \text{Re} \left\{ 2 \frac{\Lambda_{kj} \sqrt{T_{sys}^{HA} T_{sys}^{VA}} M_{kjNIR} - V_{kjNIR}^{UV}}{\mathcal{G}_{kjNIR}} \right\} + f_{ii} = 2\hat{V}_{kj}|_{ii} + f_{ii} \\ T_4^V &= \text{Im} \left\{ 2 \frac{\Lambda_{kj} \sqrt{T_{sys}^{HA} T_{sys}^{VA}} M_{kjNIR} - V_{kjNIR}^{UV}}{\mathcal{G}_{kjNIR}} \right\} + f_{qi} = 2\hat{V}_{kj}|_{qi} + f_{qi} \end{aligned} \quad \text{Eq. 56}$$

The terms f_{ii} and f_{qi} are the corrections for cross-coupling and leakage, computed during the NIR calibration process (Section 3.8.2.3). Moreover, Eq.56 has been further expanded from Eq.50 by using the definition of calibrated visibilities (Eq. 72).

The values are computed in VIP, since both NIR-LICEF are switched to the NIC (and subsequently to the antenna) using the VIP port. The procedure to transform the FWF(0) to the antenna plane is the same as described in Eq.19, but taking care to use the combination of H and V polarisation needed in this case, and noting that the final plane is still VIP for both polarisations.

3.5.5.2. NIR receiver noise temperatures

The receiver noise temperatures measured in LICEF-LC and -LC2 modes ($T_{rec}^{LV-CIP, LH-CIP}$, see Section 3.8.1.2) are converted from the calibration plane to the H and V Input planes through:

$$\begin{aligned} T_{rec}^{LV-VIP} &= \frac{L_{DAV}}{L_{DCV}} T_{rec}^{LV-CIP} + \left(\frac{L_{DAV}}{L_{DCV}} - 1 \right) T_{pUv} \\ T_{rec}^{LH-HIP} &= \frac{L_{DAh}}{L_{DCh}} T_{rec}^{LH-CIP} + \left(\frac{L_{DAh}}{L_{DCh}} - 1 \right) T_{pUh} \end{aligned} \quad \text{Eq. 57}$$

and then, into the antenna planes by:

$$\begin{aligned} T_{rec}^{VAP} &= T_{L1v} + L_{1v} T_{L2v} + L_{1v} L_{2v} T_{LNCv} + L_{1v} L_{2v} L_{LNCv} T_{LAh} + L_{1v} L_{2v} L_{LNCv} L_{Av} T_{rec}^{LV-VIP} \\ T_{rec}^{HAP} &= T_{L1h} + L_{1h} T_{L2h} + L_{1h} L_{2h} T_{LNC h} + L_{1h} L_{2h} L_{LNC h} T_{LAh} + L_{1h} L_{2h} L_{LNC h} L_{Ah} T_{rec}^{LH-HIP} \end{aligned} \quad \text{Eq. 58}$$

Where $T_{rec}^{HAP, VAP}$ is the total receiver noise temperature at the antenna plane.

The coefficients present in the previous computation are found using the following relations. The receiver temperature between antenna patch input plane and antenna intermediate plane (H or V) is

$$T_{L1v,h} = (L_{1v,h} - 1)T_{p7v,h} \quad \text{Eq. 59}$$

The receiver temperature between the antenna intermediate plane and the input connector plane (H or V) is

$$T_{L2v,h} = (L_{2v,h} - 1)T_{p6v,h} \quad \text{Eq. 60}$$

The receiver temperature between the input connector plane and output connector plane is

$$T_{LNCv,h} = (L_{LNCv,h} - 1)T_{p3v,h} \quad \text{Eq. 61}$$

The receiver temperature between the output connector plane and LICEF input connector plane is

$$T_{LA v,h} = (L_{Av,h} - 1)T_{Cabv,h} \quad \text{Eq. 62}$$

The parameters used in the previous equations, measured on-ground, are

- T_{L1} - Receiver temperature between antenna plane and antenna intermediate layer
- T_{L2} - Receiver temperature between antenna intermediate layer and antenna input plane
- T_{LNC} - Receiver temperature between antenna input plane and antenna output plane
- T_{LA} - Receiver temperature between antenna output plane and LICEF input plane
- L_{DC} - Attenuator between antenna LICEF input plane in C port and LICEF output plane

3.5.5.3. LICEF-NIR baselines system temperatures

For LICEF-NIR baselines, while the LICEF system temperature can be computed in the usual way (Sections 3.5.1 and 3.5.2), the NIR system temperature needs to be computed in a different way, making use of the antenna temperature, the receiver temperature described above, the noise temperature in the antenna plane and a the NIR pulse length information.

The noise injection level $T''_{NA,hv}$, is translated to the antenna plane, through Eq. 53, and the NIR equivalent system temperature T_{sys}^{VV,HH_b} , is defined as

$$T_{sys}^{VV_b} = T_{sys}^{VA} \left[\frac{1}{2} \left(\eta_v \sqrt{\frac{T_{sys}^{VA}}{T_{sys}^{VA} + T''_{NA,v}}} + 1 - \eta_v + \frac{S_{LV}^{U-V}}{\sqrt{L_{FE,v}}} \sqrt{\frac{T_{sys}^{VA}}{T_{sys,v}^{UU}}} \right) \right]^{-2}$$

$$T_{sys}^{HH_b} = T_{sys}^{HA} \left[\frac{1}{2} \left(\eta_h \sqrt{\frac{T_{sys}^{HA}}{T_{sys}^{HA} + T''_{NA,h}}} + 1 - \eta_h + \frac{S_{LH}^{U-V}}{\sqrt{L_{FE,h}}} \sqrt{\frac{T_{sys}^{HA}}{T_{sys,h}^{UU}}} \right) \right]^{-2} \quad \text{Eq. 63}$$

where

$$\begin{aligned}
 T_{sys}^{VA} &= \hat{T}_{A,v} + T_{rec}^{VAP} \\
 T_{sys}^{HA} &= \hat{T}_{A,h} + T_{rec}^{HAP} \\
 T_{sys,v}^{UU} &\approx T_{rec}^{LV-CIP} + T_{ph,v} \\
 T_{sys,h}^{UU} &\approx T_{rec}^{LH-CIP} + T_{ph,h}
 \end{aligned}
 \tag{Eq. 64}$$

with $S_{LH,V}^{U-V}$ as the complex Dicke Switch isolation, and $L_{FE} = \frac{L_1 L_2 L_{NC} L_A L_{DA}}{L_{DC}}$, where the attenuator parameters have been used in Eqs. 59-62. It has to be remarked, that the Dicke Switch Isolation is provided in the NIR ADF, and that it must be interpolated to the corresponding temperature of the NIR unit $T_{ph,h-v}$

3.5.6. Applying system temperatures to PMS calibration in NIR mode

After measuring the 4 voltages from each PMS, the calibration parameters for the hub are obtained through (Eq. 14) [RD.14]:

$$\begin{aligned}
 V_{off_k} &= \frac{v_{2k} v_{3k} - v_{1k} v_{4k}}{(v_{2k} - v_{4k}) - (v_{1k} - v_{3k})} \\
 G_k &= \frac{v_{2k} - v_{1k}}{\frac{|S_{k0}|^2}{|S_{N0}|^2} (T_{NS2} - T_{NS1})}
 \end{aligned}
 \tag{Eq. 65}$$

and for the PMS l,m,n in each of the three arms, A, B and C through¹:

$$\begin{aligned}
 v_{off_{l,m,n}} &= \frac{v_{2l,m,n} v_{3l,m,n} - v_{1l,m,n} v_{4l,m,n}}{(v_{2l,m,n} - v_{4l,m,n}) - (v_{1l,m,n} - v_{3l,m,n})} \\
 v_{off_{l,m}} &= \frac{1}{2} (v_{off_{l,m}}^{odd} + v_{off_{l,m}}^{even}) \\
 G_{l,m,n}^s &= \frac{v_{2l,m,n} - v_{1l,m,n}}{(T_{C2} - T_{C1})_{l,m,n}}
 \end{aligned}
 \tag{Eq. 66}$$

Where the system temperatures differential for each segment can be related to the measured one at the hub by:

¹ please note that, for the last segment on each arm, the offset is computed with the only noise source available and that there is no averaging

$$\begin{aligned}
 (T_{C2} - T_{C1})_l &= \frac{1}{4} \sum_{h=1}^4 \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} \frac{v_{2h}^\alpha - v_{1h}^\alpha}{v_{2h}^0 - v_{1h}^0} \frac{|S_{l0}|^2}{|S_{h0}|^2} (T_{NS2}^0 - T_{NS1}^0) \\
 (T_{C2} - T_{C1})_m &= \frac{1}{24} \sum_{l=1}^6 \frac{|S_{m\beta}|^2}{|S_{l\beta}|^2} \frac{v_{2l}^\beta - v_{1l}^\beta}{v_{2l}^\alpha - v_{1l}^\alpha} \frac{|S_{l\alpha}|^2}{|S_{N\alpha}|^2} \sum_{h=1}^4 \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} \frac{v_{2h}^\alpha - v_{1h}^\alpha}{v_{2h}^0 - v_{1h}^0} \frac{|S_{l0}|^2}{|S_{h0}|^2} (T_{NS2}^0 - T_{NS1}^0) \\
 (T_{C2} - T_{C1})_n &= \frac{1}{144} \sum_{m=1}^6 \sum_{l=1}^6 \frac{|S_{n\gamma}|^2}{|S_{m\gamma}|^2} \frac{v_{2m}^\gamma - v_{1m}^\gamma}{v_{2m}^\beta - v_{1m}^\beta} \frac{|S_{m\beta}|^2}{|S_{l\beta}|^2} \frac{v_{2l}^\beta - v_{1l}^\beta}{v_{2l}^\alpha - v_{1l}^\alpha} \sum_{h=1}^4 \frac{|S_{l\alpha}|^2}{|S_{h\alpha}|^2} \frac{v_{2h}^\alpha - v_{1h}^\alpha}{v_{2h}^0 - v_{1h}^0} \frac{|S_{l0}|^2}{|S_{h0}|^2} (T_{NS2}^0 - T_{NS1}^0)
 \end{aligned} \tag{Eq. 67}$$

It has to be taken into account, that in order to correct the PMS linearity term, this process must be done in two iterations, as indicated in Eq. 36, and only the second iteration PMS voltage $v_{ik}^{(2)}$ is used to compute the final PMS gain/offset and the System Temperatures.

3.5.7. LICEF Antenna Temperatures

When the gains are computed in ALL-LICEF mode, also the computation of the NIR Brightness Temperatures can be bypassed. The antenna temperature for each LICEF can be computed (in science mode) from the system temperature at antenna plane and the receiver noise temperature:

$$T_{A_k}^{H,V} = T_{sys_k}^{H,V} - \left(T_{u_k} (LFE^{H,V} - 1) + T_{R_k} LFE^{H,V} \right) \tag{Eq. 68}$$

where T_{R_k} is computed as described in Section 3.5.3.

3.6. Offset correction

All receivers from the same segment should have zero cross-correlation when connected to separate uncorrelated noise sources. In order to have this behaviour, the residual offset must be calibrated through periodic injection of uncorrelated noise in the receivers. The cross-correlations are quadrature corrected and de-normalised, yielding a set of visibilities. The measured visibilities are then stored in memory and subtracted from all subsequent visibilities measured in normal observation mode or during calibration.

Uncorrelated noise injection will be done at various points of the orbit and at various temperatures. More than one offset per visibility will be stored, as a function of the temperatures of the LICEFs involved in the generation of the visibility.

The subtractions are performed at the level of de-normalised visibilities, so the U-load temperatures during uncorrelated noise injection will be computed as Eq. 26.

$$T_{sys_k}^{UC} = \frac{v_k - v_{offk}}{G_k^U} \tag{Eq. 69}$$

The U-load system temperatures and Fringe Washing Function at the origin are then used together with the quadrature corrected correlations to compute the visibilities offset:

$$\hat{V}_{kj}^{UC} = \frac{\sqrt{T_{sys_k}^{UC} T_{sys_j}^{UC}} M_{kj}^{UC}}{c \cdot g_{kj}^C} \quad \text{Eq. 70}$$

where c is a configurable correction complex number (implemented since L1OP v700 to account for correlation losses).

3.7. Error Compensation

3.7.1. Visibilities Calibration

The final step for calibrating visibilities is to de-normalise them, with the system temperatures computed in the measurement mode calibration

$$V_{kj}^{H,V} = \sqrt{T_{sys_k}^{H,V} T_{sys_j}^{H,V}} M_{kj}^{H,V} \quad \text{Eq. 71}$$

and apply the in-phase and amplitude error corrections as well as removing the offsets computed previously.

The visibilities offsets amplitudes are corrected with the ~~switch S-parameters~~ static Front-End Losses, ~~retrieved using the physical temperature at calibration time~~:

$$\hat{V}_{kj}^{UH,V} = \hat{V}_{kj}^{UC} \sqrt{LFE_{H,Yk} LFE_{H,Yj}} \quad \text{Eq. 72}$$

and the phases corrected through Eq. 19. The final equation will thus be:

$$\hat{V}_{kj}^{H,V} = \frac{V_{kj}^{H,V}}{c \cdot g_{kj}^{H,V}} - a_{kj} \hat{V}_{kj}^{UH,V} \quad \text{Eq. 73}$$

where c is a configurable correction complex number (implemented since L1OP v700 to account for correlation losses) and a_{kj} is a coefficient to adjust the influence of the visibilities offsets in the final calibrated visibility. This coefficient is defined as an integer number (0, 1 or 2) indicating if offset correction is needed for baseline kj .

Additionally, as discovered by ESTEC during November 2007, the offset correction for baselines involving NIR-LICEF needs to be corrected with a factor 2, due to the different integration time in which the NIR-LICEF are providing correlations (the rest of the time it operates as a NIR).

During IVT campaign, it was seen that offset correction is only required for baselines sharing the same Local Oscillator, so for the current time there shall be three configurable processing options:

- ☐ No offset correction ($a_{kj} = 0$ for all baselines)
- ☐ Offset correction ($a_{kj} = 1$ for all LICEF baselines, and $a_{kj} = 2$ for all NIR-LICEF baselines)

- Local Oscillator Offset Correction ($a_{kj} = 1$ only for LICEF baselines sharing the same Local Oscillator, i.e. the LICEF for those baselines are linked to the same CMN, and $a_{kj} = 2$ only for NIR-LICEF baselines sharing the same Local Oscillator)

3.7.2. Redundant Space Calibration

This method is based on the fact that there are redundant baselines measured that should be measuring the same value, in case this is not true, it can be attributed to separable amplitude and phase errors associated to each receiving chain.

As this method is very sensitive to non-separable errors, in SEPS it has only been applied to calibrate non-normalised visibilities to correct for error terms associated to the path between the antenna and the input switch, that is, for all the antennae along the arms.

The set of equations for this purpose is expressed in phase and amplitude as [RD.12]:

$$\begin{aligned}\phi_{k-1,k}^{raw} &= f_{k-1} - f_k + \phi_{k-1,k} \\ |V_{k-1,k}^{raw}| &= g_{k-1} g_k V_{k-1,k} \approx \ln(|V_{k-1,k}^{raw}|) = \ln(g_{k-1}) + \ln(g_k) + \ln(|V_{k-1,k}|)\end{aligned}\tag{Eq. 74}$$

Where k and $k-1$ are the indexes of adjacent antennae in the same direction along the arms (spaced the minimum distance d). These baselines should measure the same correlations and any difference between measurements is attributed to the separable phase and amplitude errors. As a starting assumption, the phase of the first element in the first arm is set to 0, and its amplitude is set to unity. The set of equations is solved for $f_{k,1}$ and $g_{k,1}$.

This method amplifies the amplitude errors, so UPC recommends that it be used only for phase calibration, and only after having made Noise Injection Calibration for calibrating the path after the switch, so that only the path antenna to switch is covered by RSC.

This method is not part of the SMOS In-Orbit Calibration baseline and is shown here for reference.

3.8. NIR calibration

By NIR calibration, two sets of different sets of measurements are defined. While in NIR-A mode, the NIR measures the brightness temperatures and acts in parallel as a LICEF, forming mixed baselines, in NIR-R mode, the NIR is measuring the CAS noise level, and the gain, offset and receiver temperature of the NIR channels. Therefore, the description of NIR-R measurements is included in this chapter since it is a NIR calibration procedure.

On the other hand, the NIR-A and NIR-R modes themselves must be calibrated. The NIR requires two targets as calibration standards. The first one is an internal reference load at the inner instrument's temperature. The second target is the cold sky. Additionally, a third mode, NIR-AR mode, will be necessary to calibrate NIR-R mode.

The following description is based on the documents [RD6] and [AD7].

3.8.1. NIR-R mode measurements

3.8.1.1. Reference CAS noise temperature

The CAS noise temperature, used in the System Temperatures Computation (Sections 3.4.1 and 3.5), can be computed through Eq. 42, reproduced here with the correct coefficients:

$$\begin{aligned} T'_{NS,v} &= A_{R,v} \eta_v + B_{R,v} \\ T'_{NS,h} &= A_{R,h} \eta_h + B_{R,h} \end{aligned} \quad \text{Eq. 75}$$

With A_R defined as

$$\begin{aligned} A_{R,v} &= \frac{T_{NR0,v} + u_{Rv} (T_{p1v} - T_{p1v,0})}{L_{Rv}} \frac{L_{DCv}}{L_{DRv}} \\ A_{R,h} &= \frac{T_{NR0,h} + u_{Rh} (T_{p1h} - T_{p1h,0})}{L_{Rh}} \frac{L_{DCh}}{L_{DRh}} \end{aligned} \quad \text{Eq. 76}$$

where all the coefficients have the same meaning as in Section 3.5.5 but are reference values (hence the subscript R). Since L1OP v720 (end of 2017), T_{NR0} is fixed ([RD.30]). It is still computed in External Calibration Mode but it is used in Eq. 76 as retrieved from the NIR ADF, with a single constant value. To ensure the exact value is used, the propagation parameters c_R , d_R and $u_{Rv,h}$ have been set to 0.

~~is computed in External Calibration Mode[†] and T_{NR0} is the value of T_{NR0} during calibration (if using on-ground calibration it is stored in NIR ADF file, if using in-flight calibration it is stored in the NIR calibration product, ANIR).~~

As for the coefficient B_R it is computed through

$$\begin{aligned} B_{R,v} &= \frac{T_{p3,v}}{L_{Rv}} \frac{L_{DCv}}{L_{DRv}} + T_{t3v} \\ B_{R,h} &= \frac{T_{p3,h}}{L_{Rh}} \frac{L_{DCh}}{L_{DRh}} + T_{t3h} \end{aligned} \quad \text{Eq. 77}$$

with

[†]~~Since L1OP v720 (end of 2017), T_{NR0} is fixed ([RD.30]). It is still computed in External Calibration Mode but it is used in Eq. 76 as retrieved from the NIR ADF, with a single constant value. To ensure the exact value is used, the propagation parameters c_R , d_R and $u_{Rv,h}$ have been set to 0.~~

$$\begin{aligned} T_{t3v} &= \left(1 - \frac{1}{L_{Rv}}\right) T_{Cabv} \frac{L_{DCv}}{L_{DRv}} + \left(1 - \frac{L_{DCv}}{L_{DRv}}\right) T_{pUv} \\ T_{t3h} &= \left(1 - \frac{1}{L_{Rh}}\right) T_{Cabh} \frac{L_{DCh}}{L_{DRh}} + \left(1 - \frac{L_{DCh}}{L_{DRh}}\right) T_{pUh} \end{aligned} \quad \text{Eq. 78}$$

After applying Eq. 75, the CAS noise temperature is further corrected through the equivalent of Eq. 45:

$$\begin{aligned} T_{NS,v}^{LV-CIP} &= T'_{NS,v} + c_{Rv} (T'_{NS,v} - T_{A_ON0,v}^{CIP}) + d_{Rv} (T'_{NS,v} - T_{A_ON0,v}^{CIP})^2 \\ T_{NS,h}^{LH-CIP} &= T'_{NS,h} + c_{Rh} (T'_{NS,h} - T_{A_ON0,h}^{CIP}) + d_{Rh} (T'_{NS,h} - T_{A_ON0,h}^{CIP})^2 \end{aligned} \quad \text{Eq. 79}$$

with $T_{A_ON0,v,h}^{CIP}$ measured in NIR-A mode during NIR calibration with an external target (see Section 3.8.2.1).

3.8.1.2. Reference receiver noise temperatures

The receiver noise temperatures at CIP planes for the NIR-LICEF units are computed through the PMS measurements obtained when the instrument is in LICEF-LC mode inside the PMS calibration sequence, by using the following equation:

$$\left. \begin{aligned} T_{rec_k}^{LV-CIP} &= \frac{(v_{1_k} - v_{off_k}) T_{NS2,v}^{LV-CIP} - (v_{2_k} - v_{off_k}) T_{NS1,v}^{LV-CIP}}{(v_{2_k} - v_{1_k})} \\ T_{rec_k}^{LH-CIP} &= \frac{(v_{1_k} - v_{off_k}) T_{NS2,v}^{LH-CIP} - (v_{2_k} - v_{off_k}) T_{NS1,v}^{LH-CIP}}{(v_{2_k} - v_{1_k})} \end{aligned} \right\} \begin{array}{l} \text{where indices 1 and 2 indicate WARM} \\ \text{and HOT Noise Injection Temperatures} \end{array} \quad \text{Eq. 80}$$

where v_{1_k}, v_{2_k} are the PMS voltages when the instrument is in Hot and Warm noise injection mode, but taking care to use the voltage offsets from the appropriate NIR-LICEF unit, with the Noise injection temperatures taken from the Eq. 79.

The explanation for this receiver noise temperature estimation can be found in more detail in section 3.9.

It should be noted that these $T_{rec}^{LV-CIP, LH-CIP}$ temperatures are calibrated during the PMS calibration sequence and annotated to a physical temperature; so whenever they are used in Eq. 57 or 64 during science processing, they will need first to be propagated with the sensitivity to temperature available in the PMS ADF (as done in Eq. 101).

3.8.1.3. NIR-LICEF Receiver gains and offsets

The NIR-LICEF receiver gain and offsets are also found through the 4-point method. Measurements from NIR modes LICEF-LC and LICEF-LC2 are used in the equivalent of Eq. 14 and Eq. 27, after the PMS gain of all LICEF has been computed as shown in sections 3.5.1 and 3.5.2.

This time, however, the distributed calibration is performed over the first odd section in each arm, thus calibrating each NIR-LICEF with 10 adjacent receivers (4 on the Hub and 6 in the first arm section):

$$T_{sys_k}^C = \frac{1}{10} |S_{k\alpha}|^2 \frac{v_k - v_{off_k}}{v_{2k}^\alpha - v_{1k}^\alpha} \left(\sum_{h=1}^4 \frac{v_{2h}^\alpha - v_{1h}^\alpha}{|S_{h\alpha}|^2 G_{PMS_h}} + \sum_{l=1}^6 \frac{v_{2l}^\alpha - v_{1l}^\alpha}{|S_{l\alpha}|^2 G_{PMS_l}} \right) \quad Eq. 81$$

$$v_{off_k} = \frac{v_{2k} v_{3k} - v_{1k} v_{4k}}{(v_{2k} - v_{4k}) - (v_{1k} - v_{3k})}$$

The voltage offsets are computed from noise injection from the ODD Noise Sources configuration.

3.8.2. NIR absolute calibration through external sources

In order to calibrate the remaining parameters of the NIR, the next measurement steps must be made

- ☐ Look at a cold scene in NIR-A mode
- ☐ Look at a cold scene in NIR-AR mode
- ☐ Look at a cold scene in NIR-LA mode

3.8.2.1. NIR-A Calibration

The parameters T'_{A0} and T_{NA0} are calibrated periodically in flight, by measuring a “known” scene. The values $T'_{A0,h}$ and $T'_{A0,v}$ represent the expected NIR measurement from that scene. It must be computed combining the Sky observed Brightness Temperature distribution with the NIR antenna patterns. The observed Sky distribution is computed using PVT and AOCS to obtain the instrument pointing direction, and the Galaxy Map layer with the averaged NIR values.

$$T'_{A0} = \int_{(\xi, \eta) \in UnitCircle} \frac{T^{Galaxy}(\xi, \eta) |F_{NIR}(\xi, \eta)|^2}{\sqrt{1 - \xi^2 - \eta^2}} d\xi d\eta \quad Eq. 82$$

The antenna noise injection temperature is computed as:

$$T_{NA0} = \left[L_{NC} L_A L_{DA} (T_U - T_{t2}) - \frac{T'_{A0}}{L_1 L_2} - T_{t1} \right] \frac{1}{\eta} \quad Eq. 83$$

where the attenuation coefficients and physical temperatures are defined as in Section 3.5.5.

Additionally, two parameters are computed, to be used in NIR-AR mode. First

$$T_{A0}''' = \frac{T'_{A0}}{L_1 L_2} + \left(1 - \frac{1}{L_1} \right) \frac{T_{p7,0}}{L_2} + \left(1 - \frac{1}{L_2} \right) T_{p6,0} \quad Eq. 84$$

which is the reference input power from the antenna and stored as Observed_Antenna_TB in the NIR-A data set. This value is then used to compute

$$T_{A_ON0}^{(6)} = \left(T_{pU} - \frac{T_{A0}'''}{L_{NC}L_AL_{DA}} - T_{t2} \right) \frac{1}{\eta_A} + \frac{T_{A0}'''}{L_{NC}L_AL_{DA}} + T_{t2}$$

and also

Eq. 85

$$T_{A_ON0,v}^{CIP} = T_{A_ON0,v}^{(6)} L_{DC,v} - (L_{DC,v} - 1) T_{pU}$$

$$T_{A_ON0,h}^{CIP} = T_{A_ON0,h}^{(6)} L_{DC,h} - (L_{DC,h} - 1) T_{pU}$$

$T_{A_ON0}^{CIP}$ is the input power of the antenna branch at C-port and is stored in the NIR calibration product in the NIR-R Data Set also as Observed_Antenna_TB. All the parameters in the previous two Eqs. have the same meaning as in Section 3.5.5.1.

3.8.2.2. NIR-AR Calibration

The NIR-AR mode is used to calibrate the NIR-R mode, by computing the noise injection temperature in the reference branch T_{NR0} . This is done by applying

$$T_{NR0} = \frac{L_R L_{DR}}{\eta_R} \left(T_{A_ON0}^{(6)} - \frac{T_{p3}}{L_R L_{DR}} - T_{t3} \right) \quad \text{Eq. 86}$$

where T_{p3} is used instead of T_{ref} (the noise coming to the V,H-OPR planes), since there is no noise injection ([RD.6], Section 4.3). T_{t3} is defined as

$$T_{t3} = \left(1 - \frac{1}{L_R} \right) \frac{T_{Cab}}{L_{DR}} + \left(1 - \frac{1}{L_{DR}} \right) T_{pU} \quad \text{Eq. 87}$$

where all the coefficients have the same meaning as in Section 3.5.5 but are reference values (hence the subscript R).

3.8.2.3. Leakage and cross-coupling calibration

To account for cross-coupling between the different channels of the NIR and leakage from the noise injection channels to the remaining ones, the factors χ (cross-coupling) and ϑ (leakage) must be extracted and used to compute the correction functions f_{ii} and f_{qi} that calibrate the values of the third and fourth Stokes parameters (Section 3.5.5.1.2).

Several modes of the instrument are needed to collect all the data necessary for this computation. The denormalised correlations extracted in each mode are listed here:

- ❑ \hat{V}_{LA} are measured in LICEF-LA mode when looking at the cold sky
- ❑ \hat{V}_{NA} are measured in NIR-A mode when looking at the cold sky

\hat{V}_{NA} is denormalised as shown in Section 3.5.5.1.2. while \hat{V}_{LA} is denormalized as the LICEFs visibilities. The equation to compute both these quantities is Eq.73, using the corresponding system temperatures, FWF at the origin calibration and offset correction. Special care must be taken in the

noise offset correction for LICEF-LA visibilities, as the factor 2 does not need to be applied because the NIR does not operate in NIR-A mode in those epochs.

Then, when the instrument is in LICEF-LA mode, looking at cold sky, this value is used, together with the antenna temperatures, $T'_{A,v}$ (Eq. 42), and \hat{V}_{LA} , to compute

$$\begin{aligned}\chi_{ii} &= \frac{1}{T_{A,v}^c + T_{A,h}^c} \left(\hat{V}_{LA} \Big|_{ii} \right) \\ \chi_{qi} &= \frac{1}{T_{A,v}^c + T_{A,h}^c} \left(\hat{V}_{LA} \Big|_{qi} \right)\end{aligned}\tag{Eq. 88}$$

where $T_{A,v}^c$ is computed directly from the antenna temperature by

$$T_{A,v}^c = T'_{A0,v}\tag{Eq. 89}$$

and

$$T_{A,h}^c = T'_{A0,h}\tag{Eq. 90}$$

Using χ during measurement in NIR-A mode, assuming that the cross-coupling between channels is equal, the value \hat{V}_{UT}^{blind} (denormalised correlation induced by cross-coupling) is computed by

$$\hat{V}_{UT}^{blind} = (T_{A,v}^c + T_{A,h}^c) \chi\tag{Eq. 91}$$

where T_A^c is now computed from T_{pU} and \hat{T}_A . As for the leakage factor, ϑ , it is computed in NIR-A mode, when looking at the cold sky, by

$$\mathcal{G}_{ii} = \frac{1}{(\eta_v T_{NA0,v}'' + \eta_h T_{NA0,h}'')} \left(\hat{V}_{NA} \Big|_{ii} - \hat{V}_{LA} \Big|_{ii} \right)\tag{Eq. 92}$$

and

$$\mathcal{G}_{qi} = \frac{1}{(\eta_v T_{NA0,v}'' + \eta_h T_{NA0,h}'')} \left(\hat{V}_{NA} \Big|_{qi} - \hat{V}_{LA} \Big|_{qi} \right)\tag{Eq. 93}$$

where η is the NIR pulse length, both in NIR-A, when looking at cold sky. T_{NA0}'' is the corrected noise injection temperature transferred to the VAP plane through Eq. 53, but using T_{NA0} as it is measured during cold sky calibration.

Using ϑ during measurement in NIR-A mode, the denormalisation factor due to noise leakage is computed by

$$\hat{V}_{UT}^{noise} = [\eta_v T_{NA,v}'' + \eta_h T_{NA,h}''] \mathcal{G}\tag{Eq. 94}$$

In conclusion, the correction functions f_{ii} and f_{qi} are computed during measurement by solving \hat{V}_{UT}^{blind} and \hat{V}_{UT}^{noise} and then using

$$\begin{aligned} f_{ii} &= -2 \operatorname{Re} \left\{ \hat{V}_{UT}^{noise} + \hat{V}_{UT}^{blind} \right\} \\ f_{qi} &= -2 \operatorname{Im} \left\{ \hat{V}_{UT}^{noise} + \hat{V}_{UT}^{blind} \right\} \end{aligned} \quad \text{Eq. 95}$$

3.9. Receiver Noise Temperature Monitoring

As of September 2006, a new step has been introduced in the PMS calibration sequences. In this step, the instrument is in Uncorrelated Noise Injection configuration, with the NIR-LICEF also in LICEF-LU configuration.

The purpose of this step is to measure the System Temperatures with the switch in U position, at the same time (and temperature) as the rest of PMS calibration is performed, and use it to derive the Receiver Noise Temperature. This way, the Receiver Noise Temperature can be characterised in the same way as the PMS gain and offset are, and be computed during nominal science observations. The objective is to have an independent source for the antenna temperature not related to the NIR measurements.

The basic principle behind this formulation is presented in [RD.18], and is repeated here below.

The System temperature at LIP plane when the switch is in U position is given by the following equation:

$$T_{sysk}^{UL} = (T_{phUk} + T_{rec}) \quad \text{Eq. 96}$$

Where T_{rec} is receiver temperature at LIP plane and T_{phUk} is the physical temperature of the U-Load (LICEF isolator). However, since the PMS is calibrated at CIP plane, we must write system temperature at this plane:

$$T_{sysk}^{UC} = \frac{1}{|S_{Lck}|^2} (T_{phUk} + T_{rec}) \quad \text{Eq. 97}$$

And now, taking into account that this system temperature can be retrieved by the PMS as per Eq. 69, the receiver temperature at LIP plane can be recovered from PMS measurement as

$$T_{rec} = |S_{Lck}|^2 T_{sysk}^{UC} - T_{phUk} \quad \text{Eq. 98}$$

Note that PMS gain at CIP plane must be temperature corrected to have $G_k^C(T_{phUk})$. This is directly achieved, as the U-load is incorporated to the short calibration sequences, where PMS gain is calibrated simultaneously. Now, the magnitude we want to retrieve is receiver temperature at VAP (HAP) plane, when the switch is in A=V,H position. This can be written as:

$$T_{Rk}^A = \frac{1}{\eta_{Ak} |S_{LAk}|^2} \left[T_{rec} + T_{phUk} \left(1 - \eta_{Ak} |S_{LAk}|^2 \right) \right] \quad \text{Eq. 99}$$

If we insert the expression of T_{rec} in the equation above, it yields

$$T_{Rk}^A = \frac{|S_{LCK}|^2}{\eta_{Ak} |S_{LAk}|^2} T_{sysk}^{UC} - T_{phUk} \quad \text{Eq. 100}$$

Note that we are retrieving receiver temperature at VAP/HAP plane at the temperature that the short calibration has been performed, $T_{Rk}^A(T_{phUk})$, in spite of the fact that the switch has not been connected either to H or V.

It should be remarked that the equation above is valid only for LICEF units. For NIR-LICEF units, the equation to be applied for obtaining the Receiver Noise Temperature at the antenna plane is still Eq. 55.

During the orbit in calibration mode, long calibration, LICEF_k receiver temperature can be retrieved as a function of temperature. This must be performed at VAP/HAP plane. This allows to compute receiver temperature sensitivity to physical temperature by linear fit, in the same way as performed for PMS gain and offset (A=H,V), using a sensitivity value $S_{\Delta T_{phk}}^{T_{RA}} \text{ K/}^\circ\text{C}$

Now, the receiver noise temperature at any orbit position in measurement mode can be computed by applying

$$T_R^A = T_{Rcal}^A + S_{T_{phk}}^{T_R} (T_{phk} - T_{phcal k}) \quad \text{Eq. 101}$$

Where $T_{phcal k}$ is the temperature of the latest Averaged PMS Dataset Record, which is combined with the Receiver Noise Temperature Sensitivities from the PMS ADF. It must be pointed out that once receiver temperature is known at T_{phk} , this gives an estimate of the antenna temperature seen by the LICEF in measurement mode:

$$T_{Ak}(T_{phk}) = T_{sysk}^A(T_{phk}) - T_{Rk}^A(T_{phk}) \quad \text{Eq. 102}$$

Where $T_{sysk}^A(T_{phk})$ is the system temperature used to denormalize the correlations. Finally, a weighted average is applied taking into account the estimations from the two adjacent calibration point in the orbit.

3.10. L1 calibration

3.10.1. PMS characterisation

The CAS calibration procedure can be validated when the instrument is in deep sky measurement, by calibrating the PMS in the same way as the NIR is calibrated, and then comparing both calibration sets of parameters. A calibration sequence has been designed for this process and it will be recognised by the Proptotype Processor (but not by the Operational Processor).

First, we define a method to calibrate the PMS gain in orbit, G_k^{AA} , by using the U-load as WARM noise, v_{U_k} , and the receiver output when looking at cold sky, v_{SKY_k} as COLD noise:

$$G_k^{AA} = \frac{v_{U_k} - v_{SKY_k}}{T_{U_k} - T_{SKY_k}^A} \quad \text{Eq. 103}$$

$$A = H, V$$

where T_{U_k} are the physical temperatures of the receivers when in Uncorrelated noise injection and $T_{SKY_k}^A$ are retrieved from the cold sky map as in Section 3.8.2. The PMS offset and attenuator ratios can also be computed if the PMS 4-point voltages are redefined as

- v_{1_k} - PMS output voltage for deep sky mode with attenuator off (L_{0k})
- v_{2_k} - PMS output voltage for uncorrelated noise injection mode with attenuator off (L_{0k})
- v_{3_k} - PMS output voltage for deep sky mode with attenuator on (L_{1k})
- v_{4_k} - PMS output voltage for uncorrelated noise injection mode with attenuator on (L_{1k})

and by using

$$v_{offk} = \frac{v_{2_k} v_{3_k} - v_{1_k} v_{4_k}}{(v_{2_k} - v_{4_k}) - (v_{1_k} - v_{3_k})} \quad \text{Eq. 104}$$

$$\Delta L_k = \frac{L_{1k}}{L_{0k}} = \frac{v_{2_k} - v_{1_k}}{v_{4_k} - v_{3_k}}$$

It should be noted that for NIR-LICEF elements, the above equation cannot be applied as the NIR modes do not account for U-noise injection with attenuator.

The PMS gains can be compared to the ones computed in Section 3.5.6, G_k^{CC} , by translating the deep-sky calibrated gains to the CIP plane

$$G_k^{AC} = G_k^{AA} \frac{|S_{LC_k}|^2}{\eta_{Ak} |S_{LA_k}|^2} \quad \text{Eq. 105}$$

$$A = H, V$$

where η_{Ak} are the antenna ohmic efficiencies and the switch S-Parameters are the ones defined in the previous sections. An average shall be performed between the values obtained from HIP or VIP planes, in order to obtain a unique CIP value. A measure of the relative error is computed as

$$e_G = \frac{G_k^{AC} - G_k^{CC}}{G_k^{AC}} 100$$

Eq. 106

$$A = average(H, V)$$

In addition, the Receiver Noise Temperature can be computed during Cold Sky calibration, in replacement of the one used in Eq.100, using the following equation:

$$T_{Rk}^A = \frac{(v_{SKY_k} - v_{off_k})T_{U_k} - (v_{U_k} - v_{off_k})T_{SKY_k}^A}{v_{U_k} - v_{SKY_k}}$$

Eq. 107

$$A = H, V$$

3.10.2. Front-End Loss computation

Since L1OP v700 and the application of the ALL-LICEF mode, it was suggested by UPC that a better and more useful attenuation factor is the LFE as defined in [RD.26]. Although this parameter is computed in ground and used in an Auxiliary Data File, the L1OP is required to compute it for monitoring.

The computation uses the 1-point calibration in Eq. 103 to compute the external PMS Gain and then explicitly computes the PMS Gain at CIP from Uncorrelated Noise by:

$$G_k^C = \frac{v_{U_k} - v_{off_k}}{T_{U_k} - T_{Rk}}$$

Eq. 108

in order to compute LFE as the ratio of both:

$$LFE^{AA} = \frac{G_k^C}{G_k^{AA}}$$

Eq. 109

$$A = H, V$$

3.10.3. CAS and receiver temperature validation

The cold sky measurements can also be used to validate the CAS plane translation coefficients computed from ground data. The coefficients used for comparison are defined as

$$C_{Nk}^{gnd} = \frac{|S_{LA_k}|^2 |S_{N0}|^2}{|S_{LC_k}|^2 |S_{k0}|^2} \eta_{Ak} \quad \text{Eq. 110}$$

$A = H, V$

The equivalent coefficients can be computed from deep sky measurements when, during short calibration, the following values are collected:

- v_{1_k} - PMS voltages for WARM noise injection (even and odd)
- v_{2_k} - PMS voltages for HOT noise injection (even and odd)
- T_{NS1} - WARM temperature measured in NIR-R
- T_{NS2} - HOT temperature measured in NIR-R

After these values are stored, the coefficients must be computed for the hub, in the first place:

$$C_{Nk}^{hub} = \frac{T_{NS2} - T_{NS1}}{v_{2k}^{hub} - v_{1k}^{hub}} G_k^{AA} \quad \text{Eq. 111}$$

where N are the 6 paths from the hub Noise Source to the NIRs and there are 12 values for k representing the LICEF elements in the Hub. It shall be noted that there will be different coefficients depending on the polarisation (H or V)

For the odd noise sources we have two options depending of NIR-R is active during ODD noise injection or not,

$$C_{Nk}^{odd} = \frac{T_{NS2} - T_{NS1}}{v_{2k}^{odd} - v_{1k}^{odd}} G_k^{AA} \quad \text{Eq. 112}$$

$$C_{Nk}^{odd} = \frac{v_{2N}^{odd} - v_{1N}^{odd}}{v_{2k}^{odd} - v_{1k}^{odd}} \frac{G_k^{AA}}{G_N^{CC}}$$

where N are the 6 paths from the odd Noise Sources to the NIRs and there are 10 values for k representing the other 10 LICEFS sharing the same NS. Again, it shall be noted that there will be different coefficients depending on the polarisation (H or V)

The CAS differences plane translation coefficients are then compared by

$$eC_{Nk}^{hub} = 20 \log_{10} \left[\frac{C_{Nk}^{hub}}{C_{Nk}^{gnd}} \right] dB \quad \text{Eq. 113}$$

$$eC_{Nk}^{odd} = 20 \log_{10} \left[\frac{C_{Nk}^{odd}}{C_{Nk}^{gnd}} \right] dB$$

As for the case of the receivers that are driven by a Noise Source without a direct path to the NIRs, the coefficients must be computed using as reference the gain of the receiver closest to the hub in each

group sharing the same Noise Source. The gain used as reference is the one computed through the 4-point method, G_r^{CC} . The equivalent to the previous equations in this case is

$$C_{rk}^{odd} = \frac{v_{2r}^{odd} - v_{1r}^{odd}}{v_{2k}^{odd} - v_{1k}^{odd}} \frac{G_k^{AA}}{G_r^{CC}}$$

$$C_{rk}^{even} = \frac{v_{2r}^{even} - v_{1r}^{even}}{v_{2k}^{even} - v_{1k}^{even}} \frac{G_k^{AA}}{G_r^{CC}}$$

Eq. 114

There will be 3 sets of coefficients C_{rk}^{odd} and 3 sets of C_{rk}^{even} , each with 11 values for k . The comparison between ground and sky coefficients is done again as

$$eC_{rk}^{odd} = 20 \log_{10} \left[\frac{C_{rk}^{odd}}{C_{rk}^{gnd}} \right] dB$$

$$eC_{rk}^{even} = 20 \log_{10} \left[\frac{C_{rk}^{even}}{C_{rk}^{gnd}} \right] dB$$

Eq. 115

During the commissioning phase, it has been established that as long as the internal PMS calibration is performed over one complete orbit to reduce the noise levels there is no need for the PMS Cold Sky Calibration in the operational baseline. Thus, it is still described in the DPM, but it is not applicable to the L1 Operational Processor.

3.10.4. L1 attenuation calibration

During the commissioning phase a variation of the front end losses (namely L1 and L2) was detected through the NIR calibration. The initial correction was performed by fitting a model of the L1 losses of the NIR antenna patch with the physical temperature given by the thermistor located in the screw. However, after one year of operations it was detected that the evolution of the L1 losses did not perfectly correlate with the temperature given by the NIRs. Hence it has been decided to use the individual measurements of the L1 losses instead of modelling it with temperature. This section provides the equations needed for the computation of the L1 parameter and its use when denormalizing the visibilities.

For each PMS Cold Sky calibration together with the part of the NIR calibration in which the NIRs are set to LICEF-LA mode one value of the patch antenna attenuation L1 can be computed. The L1 value can be derived as

$$L_1 = \frac{T_s - T_{p7}}{T_s' - T_{p7}}$$

Eq. 116

Where T_s is the antenna temperature computed from the convolution of the galactic map and the corresponding antenna pattern, T_{p7} is the average of the temperatures of the 3 NIR measurements of the antenna patches temperatures (T_{p7}) and

$$T'_S = L_X \left(\frac{v_S - v_U}{G_C} + T_U \right) - T_X \quad \text{Eq. 117}$$

where v_s is the average of the PMS voltages for each receiver for each of the two polarizations (instrument is in DUAL POL and NIR in LICEF-LA mode), v_u the average of the PMS voltages when the switch is pointing to the internal load (U noise), T_U the average physical temperature of the receiver and

$$G_C = \frac{v_U - v_{off}}{T_U + T_R} \quad \text{Eq. 118}$$

Being v_{off} the offsets derived from the closest IC4EC sequence, v_u the average of the PMS values when the switch is in U and T_R the receiver noise temperature measured at MIER adjusted in temperature with the use of the receiver noise temperature sensitivity (i.e.)

$$T_R = T_R(MIER) + S_{T_R}(T_U - 21^\circ) \quad \text{Eq. 119}$$

where S_{T_R} is the temperature sensitivity of the receiver noise temperature. The values of L_x and T_x depend on whether the receiver is a NIR-LICEF or a LICEF. For the LICEFs:

$$LICEF \left\{ \begin{array}{l} L_X = L_2 |S_{LC}|^2 / |S_{LA}|^2 \\ T_X = T_U (L_X - 1) \end{array} \right\} \quad \text{Eq. 120}$$

where S_{LC} and S_{LA} are the switch S-parameters, for the calibration and antenna plane respectively. L_x depends on the selected polarization of the antenna through the switch port.

And for the NIRs:

$$NIR - LICEF \left\{ \begin{array}{l} L_X = L_2 L_{NC} L_A L_{DA} / L_{DC} \\ T_X = T_{p6} (L_2 - 1) + L_2 T_{p3} (L_{NC} - 1) + L_2 L_{NC} T_{cab} (L_A - 1) + L_2 L_{NC} L_A T_U (L_{DA} / L_{DC} - 1) \end{array} \right\} \quad \text{Eq. 121}$$

Where all the parameters are extracted from the NIR on-ground characterization and the physical temperatures retrieved from the NIR thermistors (see Section 3.5.4).

In 2014 the values of the L1 and L2 parameters for the NIR receivers were optimized to reduce land-sea contamination and increase instrument stability.

In the NIR units, an attenuator of L1=0.15 dB has demonstrated to provide better long term stability and reduced difference between ascending and descending orbits. The values of L2 for NIR were then adjusted in order to have L1+L2, that is, equal to the average of the calibrated L1 results plus the original L2 NIR values ([RD.25])

3.11. RFI Detection and Flagging

Since the beginning of the mission, SMOS data have been plagued by RFI sources emitting in the protected L-Band frequency range where MIRAS operates. Despite institutional efforts made to track and shut down these sources, RFI contamination continues to be a significant issue 3 years into the mission.

Due to the effect that RFI sources have on the calibrated SMOS data, already at this processing level it is possible to do a first detection layer on a snapshot basis by analysing NIR Brightness Temperatures and LICEF System Temperatures.

The detection is based on [RD.23], where a two-step approach is used to approximate the NIR or LICEF temperatures to a cubic spline and flag the outliers in the distribution. The two steps involved are the following:

- ❑ *Median filtering of Temperatures in a sliding window* surrounding each snapshot, in order to select the most suitable value for a non-RFI contaminated scene, taking into account the dwell time of an RFI source in the SMOS FOV. The median is used because it is well known that it is a more robust filter in the presence of outliers than the arithmetic mean.
- ❑ *Iterative re-weighted splines approximation*, where weights are computed on each snapshot based on the difference between the approximation and the most suitable value (given initially by step one), using a configurable threshold to define the 3sigma expected noise. The spline coefficients are computed by a minimization process of the residuals between the approximated curve and the weighted real distribution. After each minimisation step, the weights are recomputed and the spline coefficients as well, until this iterative process converges by producing the same weights.

The choice of values to fit to the weighted splines, as mentioned before, is the NIR Brightness Temperatures and the LICEF System Temperatures, as each value is sensitive to a different type of RFI source. NIR BT are more sensitive to continuous RFI sources that are picked up by the -3dB NIR antenna pattern, and which are continuously integrated in the 1.2s integration time of each snapshot. LICEF System Temperatures, on the other hand, are integrated sequentially in smaller sampling times, as designed in the MIRAS CCU, and so are more sensitive to pulsed RFI sources which operate below the 1.2s integration time and would be too faint to be captured in the NIR response. This pulsed effect can be captured by analysing the standard deviation of the 69 LICEF System Temperatures, since in nominal conditions they should be very close, but when a set of LICEF is affected by a pulsed RFI and the rest are not, the standard deviation will spike significantly.

This method is based on the following parameters, as defined in [RD.23]:

- ❑ Length of the sliding window for initial median computation: 60s before and after each snapshot
- ❑ Separation of the spline control nodes: 50s in order to characterise the variation of significant changes in Tx/Ty, which is approximately 150s.
- ❑ 3sigma threshold for characterisation of expected noise distribution in measurements vs approximating spline: 0.75K for NIR Brightness Temperatures, and 0.06K for LICEF System Temperatures standard deviation

In addition, the re-weighted spline approximation will only work for time series that fulfil the following conditions:

- ❑ Time series longer than 10 minutes and containing more than 500 snapshots

- ❑ Time series have to be continuous without any gap that exceeds 2 minutes (separation from one snapshot to the following one)
- ❑ Time series cannot contain more than 10 continuous snapshots in saturation (considered as 294K for NIR BT) and should also exclude an interval of 3 minutes before and after such saturation interval

This means that products need to be analysed to fulfil these conditions above before applying the RFI detection method. For additional information please refer to [RD.23].

3.12. Calibration Processing and Consolidation

All calibration procedures shall be composed of a sequence of processing steps, from which the different data used in the equations shall be retrieved. Each step may be composed of one epoch (1.2s) or more, whose measurements shall be averaged in order to reduce noise. The step is described as a unique PLM configuration, and a sequence is a unique combination of steps.

All steps, identified so far, are presented in the table below:

Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del
1	C	NIR-R	WARM	OFF	L1	0
2	C	NIR-R	HOT	OFF	L1	0
3	C	NIR-R	WARM	OFF	L0	0
4	C	NIR-R	HOT	OFF	L0	0
5	C	LICEF-LC	HOT	OFF	L0	0
6	C	LICEF-LC	WARM	OFF	L0	0
7	U	LICEF-LU	OFF	OFF	L0	0
8	C	LICEF-LC	OFF	HOT	L0	0
9	C	LICEF-LC	OFF	WARM	L0	0
10	C	LICEF-LC2	OFF	HOT	L1	0
11	C	LICEF-LC2	OFF	WARM	L1	0
12	C	LICEF-LC2	WARM	OFF	L1	0
13	C	LICEF-LC2	HOT	OFF	L1	0
14	C	NIR-R	OFF	WARM	L1	0
15	C	NIR-R	OFF	HOT	L1	0
16	C	NIR-R	OFF	WARM	L0	0
17	C	NIR-R	OFF	HOT	L0	0

Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del
18	C	LICEF-LC	OFF	HOT	L0	-T
19	C	LICEF-LC	OFF	WARM	L0	-T
20	C	LICEF-LC	WARM	OFF	L0	-T
21	C	LICEF-LC	HOT	OFF	L0	-T
22	C	LICEF-LC	OFF	HOT	L0	+T
23	C	LICEF-LC	OFF	WARM	L0	+T
24	C	LICEF-LC	WARM	OFF	L0	+T
25	C	LICEF-LC	HOT	OFF	L0	+T
26	C	LICEF-LC2	OFF	HOT	L1	-T
27	C	LICEF-LC2	OFF	WARM	L1	-T
28	C	LICEF-LC2	WARM	OFF	L1	-T
29	C	LICEF-LC2	HOT	OFF	L1	-T
30	C	NIR-A	OFF	OFF	L0	0
31	Dual	NIR-A	OFF	OFF	L0	0
32	Dual	LICEF-LA	OFF	OFF	L0	0
33	Dual	NIR-AR	OFF	OFF	L0	0
34	Dual	LICEF-LA2	OFF	OFF	L1	0

Table 4 -Calibration Steps

The main calibration sequences are shown in the next tables, together with their steps. It is important to mention that the order of the steps is agreed, although it may change in the future, so the processing shall be independent of it.

As shown above, each step is identified by a combination of LICEF mode, NIR mode, NS mode, Attenuator mode and correlator delay mode.

In the tables below, the rightmost columns indicate which type of data may be extracted from each step, and if there is any epoch of the step that will be marked as corrupted (which means it shall be discarded during processing).

SHORT FLIGHT CALIBRATION SEQUENCE															
	Step	Epochs		LICEF	NIR	NS EVEN	NS ODD	Att	PMS (V)	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
		CMD	Valid												
PMS, FWF(0) & Trec	1	3	2	C	NIR-R	WARM	OFF	L1	-1,71	0	$(*)M_{kj}^{C1e}$	η_1^e	-	v_3^e	3rd
	2	3	2	C	NIR-R	HOT	OFF	L1	-1,51	0	$(*)M_{kj}^{C2e}$	η_2^e	-	v_4^e	3rd
	3	3	2	C	NIR-R	WARM	OFF	L0	-1,23	0	$(*)M_{kj}^{C1e}$	η_1^e	-	v_1^e	3rd
	4	3	2	C	NIR-R	HOT	OFF	L0	0,1	0	$(*)M_{kj}^{C2e}$	η_2^e	-	v_2^e	3rd
	5	2	1	C	LICEF-LC	HOT	OFF	L0	0,1	0	M_{kj}^{C1e}	-	v_2^e	v_2^e	2nd
	6	2	1	C	LICEF-LC	WARM	OFF	L0	-1,23	0	M_{kj}^{C2e}	-	v_1^e	v_1^e	2nd
	7	2	1	U	LICEF-LU	OFF	OFF	L0	-1,27	0	M_{kj}^U	-	v_U	v_U	2nd
	8	2	1	C	LICEF-LC	OFF	HOT	L0	0,1	0	M_{kj}^{C2o}	-	v_2^o	v_2^o	2nd
	9	2	1	C	LICEF-LC	OFF	WARM	L0	-1,23	0	M_{kj}^{C1o}	-	v_1^o	v_1^o	2nd
	10	2	1	C	LICEF-LC2	OFF	HOT	L1	-1,51	0	M_{kj}^{C2o}	-	v_4^o	v_4^o	2nd
	11	2	1	C	LICEF-LC2	OFF	WARM	L1	-1,71	0	M_{kj}^{C1o}	-	v_3^o	v_3^o	2nd
	30	1	0	C	NIR-A	OFF	OFF	L0	-	0	-	-	-	-	1st

Table 5 - Short Calibration Sequence

NIR-A Individual Sequence

NIR-A INDIVIDUAL SEQUENCE												
	Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
NIR-A	32	Dual	LICEF-LA	OFF	OFF	L0	0	M_{kj}^{LA}	-	v_{SKY}	-	26th
	31	Dual	NIR-A	OFF	OFF	L0	0	M_{kj}^A	η_2^e	-	-	26th

NIR-R Individual Sequence

NIR-R INDIVIDUAL SEQUENCE												
	Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
NIR-R	33	Dual	NIR-AR	OFF	OFF	L0	0	-	η_1^e	-	-	26th
	31	Dual	NIR-A	OFF	OFF	L0	0	-	η_2^e	-	-	26th

Table 6 - NIR Calibration Sequences

In the next table, notice that the first 4 steps are also included in the PMS calibration (Table 5), as they are simply repetitions of some steps already present before, whereas the steps with the time delay are different, so they have a different step number.

The reason for the identifier jump between Step 11 and 18 is that the steps 12-17 are now considered as redundant, but they shall still be tested during IVT. Thus, their identifiers are still maintained, just in case they would need to be processed in nominal conditions.

LONG_FLIGHT CALIBRATION SUB-SEGMENT SEQUENCE															
	Step	Epochs		LICEF	NIR	NS	NS	Att	PMS	Corr	FWF(0)	NIR	NIR	LICEF	DATA
		CMD	Valid			EVEN	ODD		(V)	Del	Mkj	Dicke	PMS	PMS	
PMS, FWF(0) & Trec	1	3	2	C	NIR-R	WARM	OFF	L1	-1,71	0	$(^*)M_{kj}^{C1e}$	η_1^e	-	v_3^e	2nd
	2	3	2	C	NIR-R	HOT	OFF	L1	-1,51	0	$(^*)M_{kj}^{C2e}$	η_2^e	-	v_4^e	2nd
	3	3	2	C	NIR-R	WARM	OFF	L0	-1,23	0	$(^*)M_{kj}^{C1e}$	η_1^e	-	v_1^e	2nd
	4	3	2	C	NIR-R	HOT	OFF	L0	0,1	0	$(^*)M_{kj}^{C2e}$	η_2^e	-	v_2^e	2nd
	5	2	1	C	LICEF-LC	HOT	OFF	L0	0,1	0	M_{kj}^{C1e}	-	v_2^e	v_2^e	2nd
	6	2	1	C	LICEF-LC	WARM	OFF	L0	-1,23	0	M_{kj}^{C2e}	-	v_1^e	v_1^e	2nd
	7	2	1	U	LICEF-LU	OFF	OFF	L0	-1,27	0	M_{kj}^U	-	v_U	v_U	2nd
	8	2	1	C	LICEF-LC	OFF	HOT	L0	0,1	0	M_{kj}^{C2o}	-	v_2^o	v_2^o	2nd
	9	2	1	C	LICEF-LC	OFF	WARM	L0	-1,23	0	M_{kj}^{C1o}	-	v_1^o	v_1^o	2nd
	10	2	1	C	LICEF-LC2	OFF	HOT	L1	-1,51	0	M_{kj}^{C2o}	-	v_4^o	v_4^o	2nd
	11	2	1	C	LICEF-LC2	OFF	WARM	L1	-1,71	0	M_{kj}^{C1o}	-	v_3^o	v_3^o	2nd
FWF Shape	9	5	4	C	LICEF-LC	OFF	WARM	L0	-1,23	0	M_{kj}^{C1o}	-	v_1^o	v_1^o	5th
	6	5	4	C	LICEF-LC	WARM	OFF	L0	-1,23	0	M_{kj}^{C2e}	-	v_1^e	v_1^e	5th
	5	5	4	C	LICEF-LC	HOT	OFF	L0	0,1	0	M_{kj}^{C1e}	-	v_2^e	v_2^e	5th
	8	5	4	C	LICEF-LC	OFF	HOT	L0	0,1	0	M_{kj}^{C2o}	-	v_2^o	v_2^o	5th
	18	6	5	C	LICEF-LC	OFF	HOT	L0	0,1	-T	M_{kj}^{C2o}	-	v_2^o	v_2^o	6th
	19	6	5	C	LICEF-LC	OFF	WARM	L0	-1,23	-T	M_{kj}^{C1o}	-	v_1^o	v_1^o	6th
	20	6	5	C	LICEF-LC	WARM	OFF	L0	-1,23	-T	M_{kj}^{C2e}	-	v_1^e	v_1^e	6th
	21	6	5	C	LICEF-LC	HOT	OFF	L0	0,1	-T	M_{kj}^{C1e}	-	v_2^e	v_2^e	6th
	22	6	5	C	LICEF-LC	OFF	HOT	L0	0,1	+T	M_{kj}^{C2o}	-	v_2^o	v_2^o	6th
	23	6	5	C	LICEF-LC	OFF	WARM	L0	-1,23	+T	M_{kj}^{C1o}	-	v_1^o	v_1^o	6th
	24	6	5	C	LICEF-LC	WARM	OFF	L0	-1,23	+T	M_{kj}^{C2e}	-	v_1^e	v_1^e	6th
	25	6	5	C	LICEF-LC	HOT	OFF	L0	0,1	+T	M_{kj}^{C1e}	-	v_2^e	v_2^e	6th

Table 7 - Long calibration sequence

SHORT_EXTENDED CALIBRATION SEQUENCE															
	Step	Epochs		LICEF	NIR	NS EVEN	NS ODD	Att	PMS (V)	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
		CMD	Valid												
	1	4	2	C	NIR-R	WARM	OFF	L1	-1.71	0	^(*) M_{kj}^{C1e}	η_1^e	-	v_3^e	1st & 4th
	2	4	2	C	NIR-R	HOT	OFF	L1	-1.51	0	^(*) M_{kj}^{C2e}	η_2^e	-	v_4^e	1st & 4th
	3	4	2	C	NIR-R	WARM	OFF	L0	-1.23	0	^(*) M_{kj}^{C1e}	η_1^e	-	v_1^e	1st & 4th
	4	4	2	C	NIR-R	HOT	OFF	L0	0.1	0	^(*) M_{kj}^{C2e}	η_2^e	-	v_2^e	1st & 4th
	5	4	3	C	LICEF-LC	HOT	OFF	L0	0.1	0	M_{kj}^{C1e}	-	v_2^e	v_2^e	4th
	6	4	3	C	LICEF-LC	WARM	OFF	L0	-1.23	0	M_{kj}^{C2e}	-	v_1^e	v_1^e	4th
	7	4	3	U	LICEF-LU	OFF	OFF	L0	-1.27	0	M_{kj}^U	-	v_U	v_U	4th
	8	4	3	C	LICEF-LC	OFF	HOT	L0	0.1	0	M_{kj}^{C2o}	-	v_2^o	v_2^o	4th
	9	4	3	C	LICEF-LC	OFF	WARM	L0	-1.23	0	M_{kj}^{C1o}	-	v_1^o	v_1^o	4th
	10	4	3	C	LICEF-LC2	OFF	HOT	L1	-1.51	0	M_{kj}^{C2o}	-	v_4^o	v_4^o	4th
	11	4	3	C	LICEF-LC2	OFF	WARM	L1	-1.71	0	M_{kj}^{C1o}	-	v_3^o	v_3^o	4th
	12	4	3	C	LICEF-LC2	WARM	OFF	L1	-1.71	0	M_{kj}^{C1e}	-	v_3^e	v_3^e	4th
	13	4	3	C	LICEF-LC2	HOT	OFF	L1	-1.51	0	M_{kj}^{C2e}	-	v_4^e	v_4^e	4th
	14	4	2	C	NIR-R	OFF	WARM	L1	-1.71	0	^(*) M_{kj}^{C1o}	η_1^o	-	v_1^o	1st & 4th
	15	4	2	C	NIR-R	OFF	HOT	L1	-1.51	0	^(*) M_{kj}^{C2o}	η_2^o	-	v_4^o	1st & 4th
	16	4	2	C	NIR-R	OFF	WARM	L0	-1.23	0	^(*) M_{kj}^{C1o}	η_1^o	-	v_1^o	1st & 4th
	17	4	2	C	NIR-R	OFF	HOT	L0	0.1	0	^(*) M_{kj}^{C2o}	η_2^o	-	v_2^o	1st & 4th
	30	1	0	C	NIR-A	OFF	OFF	L0	-	0	-	-	-	-	-

Table 8 - Short-extended calibration sequence

From these tables, individual sequences may be separated for each calibration purpose (PMS, FWF...), and these shall be described in the corresponding chapters along section 5.

The L1a Processor must be able to identify unambiguously each sequence based on its steps and epochs. This makes it necessary to define a series of configuration parameters, so that the epochs, steps and sequences may be automatically detected and processed by the calibration processes. Additionally, the calibrated data shall be consolidated into products usable during nominal processing. This consolidation data shall replace older/obsolete data by newer data, and recompute additional values.

The configuration parameters are the same as described in [RD.17], they are repeated here for consistency:

- Minimum epochs per step (MES): smallest number of valid data in a given PLM configuration (step, as described above) that is necessary in order to obtain calibration data of sufficient quality. If within a calibration sequence any of the steps does not reach the value specified in this parameter, the calibration data is discarded in most cases. It will be tagged as “degraded” only for the case of FWF Shape computation or NIR calibration.

- ❑ Maximum separation within step (MSS): maximum time allowed for all the data gathered in the same PLM configuration that is to be used in a given calibration event. Normally, several epochs are assigned to each step and are averaged, and this parameter ensures that they are not gathered under very different conditions.
- ❑ Maximum gap (MG): maximum time allowed for the separation between two consecutive steps of a sequence. It is used to split a sequence in two if there is a gap in the data. For example, if within a sequence there is a set of missing data, or data that does not belong to the sequence, the maximum gap parameter would determine how long the set should be for the sequence to be processed as two events instead of one.
- ❑ Maximum sequence duration (MSD): largest amount of time that a calibration sequence can last. Starting from the first epoch of the first calibration step, when the max sequence duration has elapsed, no more data is gathered for that sequence. If there is sufficient data to proceed with the calibration computation, processing should start. If not enough data has been gathered, the data shall be discarded.
- ❑ Period of Validity (PV): validity for the data. Each type of calibration data will be considered valid (or not degraded) for a given amount of time. This parameter may be specified in time, and not in epochs, given that for some of them the validity will be in the order of several orbits or even days, and for those durations epochs are not intuitive units
- ❑ Minimum number of sub-events: when a given event is defined by the occurrence of a series of other sub-events, this parameter sets the minimum number of those sub-events that must be detected in order for the event to be triggered.

As mentioned before, out of the previous tables, it shall be possible to derive different sequences, according to the type of calibration data that is desired. The types of sequences that can be computed with the current baseline presented in the tables above, and their configuration parameters are shown in the table below. It should be noted that there are two distinct event types: “nominal” ones and “consolidation” ones.

“Nominal” events are used to compute a single calibration event out of the full calibration sequence as described in [RD.17]. This way, complex sequences are identified and its data used to obtain the corresponding calibration parameters.

“Consolidation” events are used to group previously computed “nominal” calibration events and treat them as sub-components of a bigger meta-sequence (for example averaging FWF Shape calibration data over a period of several orbits).

Recognition Parameter	Type of Event												
	Short PMS	PMS Consolidation	PMS Offsets	PMS Offsets Consolidation	PMS External	Short FWF(0)	FWF(0) Consolidation	FWF Shape	FWF Shape Consolidation	Correlator Offset	NIR Calibration	NIR Cal Consolidation	FTT Calibration
Minimum Epochs per Step	1	3	1	1	1	1	3	1	3	60	20	20	100
Maximum Separation within Step	35	N/A			200	2	N/A	35	N/A	50000	30	N/A	800
Maximum Gap	40	50000			50	2	50000	100	50000	50000	30	3000	200
Maximum Sequence Duration	250	50000			350	7	50000	250	50000	50000	100	5000	800
Period of Validity	5 orbits	8 weeks	5 orbits	8 weeks	1 orbit	5 orbits	8 weeks	8 weeks	8 weeks	8 weeks	8 weeks	8 weeks	8 weeks
Minimum Number of Sub-events	N/A	40	N/A	3	N/A	N/A	40	N/A	40	N/A	N/A	4	N/A

Table 9 - Possible calibration sequences

Nominally, the processing to derive a calibration sequence out of the complete data in the L0 products shall be the following:

- ☐ Locate the first epoch in which calibration is starting
- ☐ Search for the minimum number of epochs of the same PLM configuration within the maximum step separation.
- ☐ Average all values from all epochs found into a unique step
- ☐ Continue searching for different PLM configurations up to the maximum gap or maximum sequence duration (whichever is more limiting), or until the sequence is closed
- ☐ If all steps for a calibration sequence have been gathered, proceed with processing.
- ☐ If not all steps are available, discard them and log a warning.
- ☐ Restart whole search process at the point of closing

Details on each calibration sequence shall be presented in their detailed description.

Regarding the consolidation procedure, which involves the gathering of all calibration data into a single product to be used for calibrating nominal data, further information is presented in Section 7.

4. ERROR CORRECTION MODULE HIGH LEVEL DESCRIPTION

4.1. Error Correction Module Data Flow

The Error Correction module shall compute the calibrated visibilities from the Level 0 data coming from the Level 0 Processor. MIRAS Level 0 data comprises the raw correlation data, plus voltage measurements from the PMS and NIR system, additional L0 data shall be obtained from the status of the spacecraft (state vector and attitude) and the status of the MIRAS instrument health as well as the physical temperatures of the PLM.

The following figure shows the intended data flow. It is repeated at the end of the document in Annex 2 at a much bigger size, in order to improve clarity.

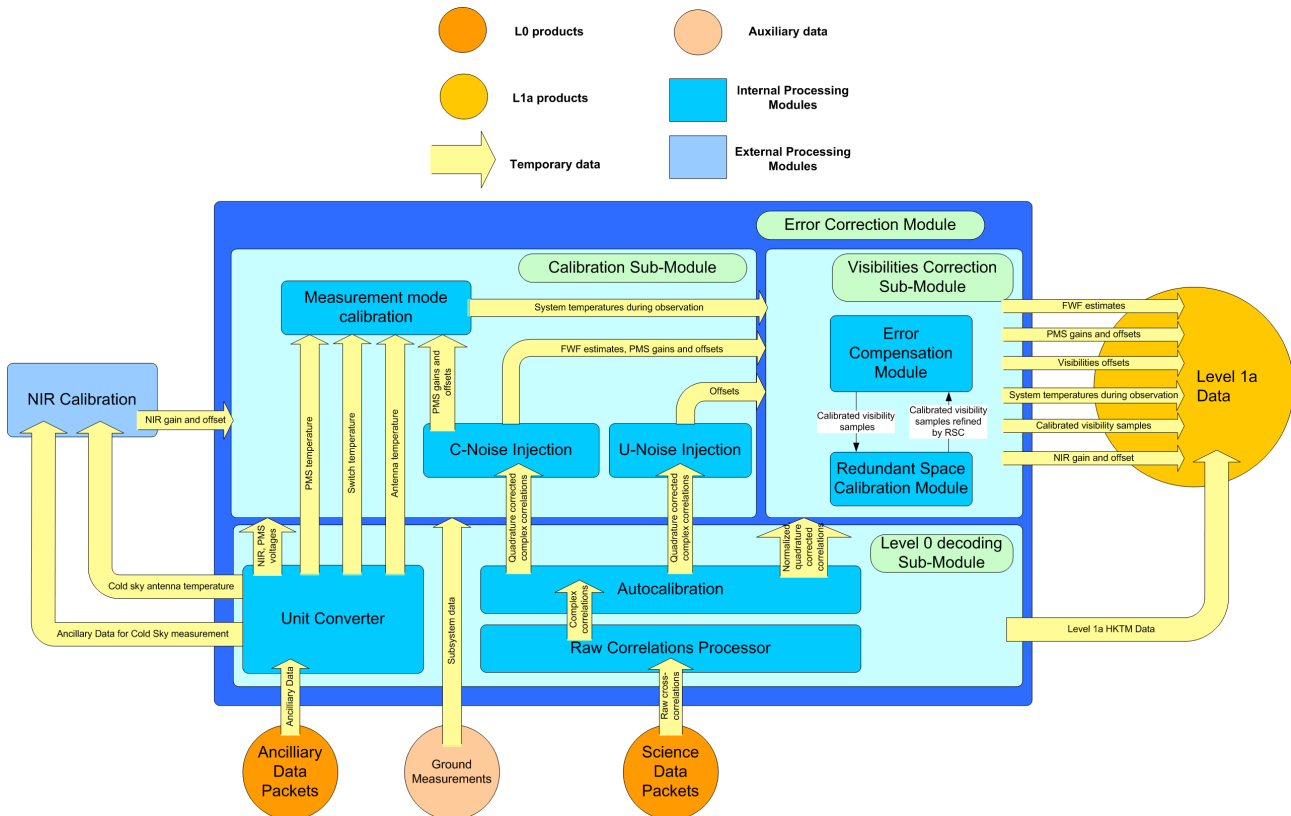


Figure 12 - Calibration Module Data Flow

The processing sequence is sequential, correlated noise injection data is processed first to retrieve the PMS calibration data and FWF estimated values, then uncorrelated noise injection is processed to retrieve the correlation offsets, and only then is the measurement mode data processed in order to produce the corrected visibilities.

It is assumed that the data entering the Level 1 Processor shall be only Level 0 data products, formed by source packets of the same APID, ordered by time stamp, with a XML ASCII header according to the L0 product format [AD.4].

All Level 0 ancillary packets will be pre-processed by the Unit Converter in order to produce consolidated data, converted to engineering units, used by all subsequent sub-modules of the Level 1 Processor. The Calibration sub-module will update and consolidate the calibration data with the appropriate recalibrated quantity (PMS parameters, FWF estimates or offsets) each time that Internal Calibration mode is detected. The external NIR calibration module will also update the NIR calibration parameters, used in other calibration modes and for the visibilities correction.

The calibrated parameters (PMS, FWF, offsets), HKTM data and corrected visibilities will be stored as Level 1a products, in static files, indexed by time stamp, type and physical temperature. In this way, reprocessing of the data becomes transparent. It will be enough to choose the time stamp for the Level 0 data and the appropriate calibration and auxiliary data will be automatically available.

For the calibration of the visibilities, the calibration parameters and offsets are retrieved using a set of rules for applicability:

1. Nearest time stamp for all consolidated L1a calibration products
2. Extrapolation of the last L1a calibration product until its validity stop
3. Static calibration parameters measured on-ground

The L1 processor will incorporate the option to use these rules in a predefined order, ensuring that in case of data loss it will still find an appropriate calibration scheme. The calibrated data, depending on the origin of the calibration parameters can be flagged as less significant (if, for example, data is calibrated with a very old calibration matrix or a static or theoretical one).

There will be an option to disable each calibration module individually, or any combination of modules, in order to access the impact of each calibration or to test the performance of individual modules. . It has been found that the most straightforward way to implement this feature is to control the data input to each module, instead of implementing a switch inside each module. The modules and processing units themselves won't need to know their status (on or off), simplifying the coding and substructure in each one, and will process all input data in the same way. For example, if the user decides to disable the offset correction, the data fed to the offset correction module will be dummy data, containing only zeros for all correlations.

As for element failures detected during the instrument operation (either by the instrument itself or by the operational team), they will be processed by the Unit Converter and used by the processing units to tag corrupted data. Per processing unit, the behaviour will be as follows:

Processing Unit	Element in failure	Behaviour
Raw Correlations Processor	LICEF	Continue processing, corrupted data will not affect valid data.
	NIR	N/A
	NOISE SOURCE	N/A
Autocalibration	LICEF	Continue processing, corrupted data will not affect valid data.
	NIR	N/A
	NOISE SOURCE	N/A

Processing Unit	Element in failure	Behaviour
Correlated Noise Injection	LICEF	PMS calibration – Voltages from faulty LICEFs will not be used for the averaging of calibrated quantities FWF estimation – Data from faulty LICEFs will not be used for the estimation of FWF values of antennas that do not share the same NS
	NIR	N/A – failure is already taken into account during System Temperatures Computation
	NOISE SOURCE	PMS calibration – Data from LICEFs driven by the faulty NS will not be used, calibrated quantities will be estimates FWF estimation – Data from LICEFs driven by the faulty NS will not be used, calibrated quantities will be estimates
Uncorrelated Noise Injection	LICEF	Continue processing, corrupted data will not affect valid data.
	NIR	N/A – failure is already taken into account during System Temperatures Computation
	NOISE SOURCE	N/A – failure is already taken into account during System Temperatures Computation
System Temperatures Computation	LICEF	Voltages from faulty LICEFs will not be used for the averaging of calibrated quantities
	NIR	Faulty NIR measurements will be discarded during the averaging
	NOISE SOURCE	Data from LICEFs driven by the faulty NS will not be used. Sys Temps will be estimates.
Error Compensation	LICEF	Continue processing, corrupted data will not affect valid data.
	NIR	N/A – failure is already taken into account during System Temperatures Computation

Processing Unit	Element in failure	Behaviour
	NOISE SOURCE	N/A – failure is already taken into account during System Temperatures Computation
Redundant Space Calibration	LICEF	Voltages from faulty LICEFs will not be used for the averaging of calibrated quantities
	NIR	N/A
	NOISE SOURCE	N/A
NIR Calibration	LICEF	N/A
	NIR	Faulty NIRs will not generate calibration data
	NOISE SOURCE	Data from defective NS will not be used

Table 10 - Element failure treatment

5. DETAILED PROCESSING MODEL

The following sections will detail the implementation of each processing unit, with processing diagrams and variable lists. The diagrams make use of some representations that are explained in the following table:




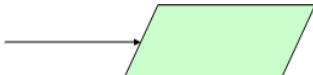
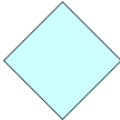

Element	Description
	Processing step, described in the same chapter – This diagram element will be used to represent processing steps that are being defined within that chapter. A typical processing unit will have several of these.
	Processing step, described somewhere else – This diagram element will be used to represent processing steps that are already described elsewhere or to represent calls to other processing units.
	Input data – This diagram element represents input data retrieved from auxiliary data files, L1a HKTM or as processing results of external processing units. The processing unit then uses the input data represented, in some or all of its processing steps.
	Output data – This diagram element represents output data generated by the processing unit, to be used as input for other processing units or to be written in a product file.
	Decision – This diagram element represents a decision statement. It will represent conditional decisions, typically with only two possible outcomes, or classification decisions, where there are more than two processing chains for each type of argument (file type, calibration method, etc.).
	Endpoint - This diagram element is used to represent the beginning/ending of the processing. It is also used, when there is no possible ambiguity, to represent the beginning/ending of loops.

Table 11 - Element Interpretation

The “List of Variables” tables describe the variables used in the subsequent implementation section. Variables are listed as input, local and output (I, L, O). The *Size* column indicates the number of elements constituting that variable, and NOT the size of the variable in bytes (this information can be taken from the *Type* column).

Where applicable, a table with the data retrieval strategy will detail how data computed in other processing units, or accessed from auxiliary files, is selected.

Finally, a table will list the behaviour of the processing units for each of the errors possible.

5.1. Unit Converter

This processing unit is part of the Level0 decoding sub-module. The Unit Converter will use manufacturer tables and conversion tables to translate the binary data from the ancillary packets into ready-to-use data in standard engineering units.

The main Unit Converter processing consists on the reading of L0 data, invocation of processing functions, filling of the L1a HKTM structure and writing of the binary file with the resulting quantities.

The main processing also prepares the variables related to the physical temperatures computation since only two out of fourteen possible thermistor channels per CMN are read in each packet. A rolling matrix with the latest physical temperatures for all components has two channels updated for every packet processed. This matrix is initialized with the values retrieved from the latest L1a HKTM packet available. The L1a HKTM data will have all the temperatures in this matrix for each packet, making some entries up to 7 packets old (~8 seconds). The reference voltages needed to compute the physical temperatures are also updated every 7 packets and are kept up to date in a variable named `ref_temps`.

After initialization, the processing unit performs all computations for each individual packet.

Finally, the processed data is saved in a binary file and the processing unit will then return all the output variables necessary for the product writing.

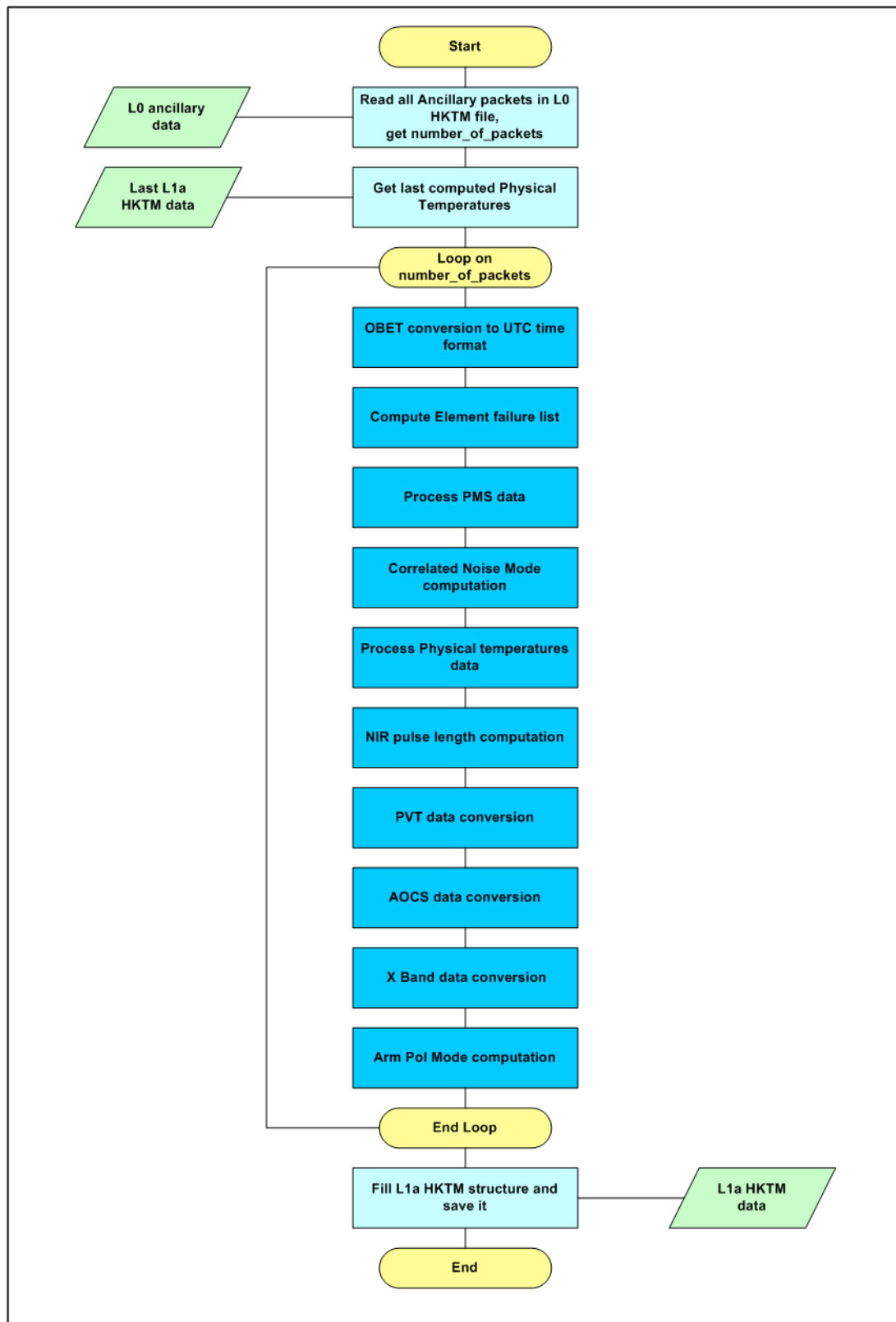


Figure 13 - Unit Converter Processing Steps

5.1.1. Inputs

- ❑ Ancillary Data Packets in L0 Ancillary Product
- ❑ Auxiliary Data
 - Manufacturer tables for PLM elements unit conversion (SM_xxxx_AUX_PLM__<ID>)
 - NIR auxiliary data (SM_xxxx_AUX_NIR__<ID>)
 - Orbit Scenario File (SM_xxxx_MPL_ORBSCT<ID>)
 - Bulletin B File (SM_xxxx_AUX_BULL_B_<ID>)
 - Failure lists (SM_xxxx_AUX_FAIL__<ID>)

5.1.2. Outputs

- ❑ L1a HKTM data (SM_xxxx_TLM_MIRA1A_<ID>)
 - NIR pulse length
 - PMS output voltage
 - CAS and NIR physical temperature
 - Components physical temperatures
 - X-Band Data
 - OBET in UTC format
 - Correlated Noise Injection mode
 - Arms Polarisation Mode
 - LICEF failures
 - Local oscillator failures
 - S/C PVT and AOCS (propagated to snapshot time)

The unit converter is a complex processing unit with separate functions for the processing of different physical quantities from the ancillary packets data. It is therefore simpler to describe each processing step in a dedicated sub-section with its own list of processing steps.

5.1.3. OBET conversion to UTC format

5.1.3.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
obet	Timestamp	N/A	long long	I	N/A	1
pps_obet	Instrument timestamp at PPS	N/A	long long	I	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
converted.UTC	Converted UTC in string representation	N/A	char	L	N/A	XL_TIME_ASCII_DIM_MAX
utc_time_processing_format	EE CFI time processing format	N/A	double	L	N/A	1
sat_id	Mission Identifier (EE CFI variable)	N/A	long	L	N/A	1
cfi_error	CFI list of errors (EE CFI variable)	N/A	long	L	N/A	XL_NUM_ERR_OBT_TIME
xl_ierr	Error codes (EE CFI variable)	N/A	long	L	N/A	XL_ERROR_VECTOR_MAX_LENGTH
processing_format	Time processing format (EE CFI variable)	N/A	long	L	N/A	1
time_reference	UTC time reference (EE CFI variable)	N/A	long	L	N/A	1
transport_format	Transport format (EE CFI variable)	N/A	long	L	N/A	1
ascii_id_out	Time processing format (EE CFI variable)	N/A	long	L	N/A	1
cfi_status	CFI status codes (EE CFI variable)	N/A	long	L	N/A	1
smos_obet_param	OBET parameters for SMOS mission (EE CFI variable)	N/A	xl_smos_obt_param	L	N/A	1
smos_obet_value	OBET values for SMOS mission (EE CFI variable)	N/A	xl_smos_obt_value	L	N/A	1
time_id	Time initialization (EE CFI variable)	N/A	xl_time_id	L	N/A	1
pps_utc	Platform timestamp in UTC time format	N/A	t_utc_time	L	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
obet_in_utc	Instrument timestamp in UTC time format	N/A	t_utc_time	O	N/A	1

Table 12 - OBET to UTC variable list

5.1.3.2. Implementation

- This function will use a set of EE CFI functions to convert OBET to UTC. First, the following variables have to be set:
 - sat_id = XL_SAT_SMOS
 - processing_format = XL_PROC
 - time_reference = XL_TIME_UTC
 - transport_format = XL_TRANS_STD (although a format XL_TRANS_SMOS_TM exists, it should only be used to simulate time data as produced by the MIRAS on-board SW. In the whole SMOS L1 Processing chain, only the XL_TRANS_STD is used)
 - ascii_id_out = XL_ASCII_CCSDSA_COMPACT
- The structures smos_obet_param and smos_obet_value are filled with the available data:
 - smos_obet_param.sat_id = sat_id
 - smos_obet_param.obet0_c = (pps_obet & MASK_OBET_COARSE_TIME) >> FINE_TIME_N_BITS
 - smos_obet_param.obet0_f = pps_obet & MASK_OBET_FINE_TIME
 - smos_obet_param.utc0_week, smos_obet_param.utc0_seconds and smos_obet_param.utc0_fraction are updated with the correspondent quantities in pps_utc structure
 - the previous steps are also applied to the structure smos_obet_value
- The OBET timestamp is used to initialise the time reference:
 - cfi_status = xl_time_obt_to_time(&sat_id, &processing_format, &smos_obet_param, &smos_obet_value, utc_time_processing_format, cfi_error)
 - time_id structure can be left initialised to NULL, as the following conversions are all between UTC time
- Finally, the OBET is converted to UTC time format as
 - cfi_status = xl_time_processing_to_ascii(&time_id, &processing_format, &time_reference, utc_time_processing_format, &ascii_id_out, &time_reference, converted_UTC, xl_ierr)
 - cfi_status = xl_time_processing_to_transport(&time_id, &processing_format, &time_reference,

```
utc_time_processing_format, &transport_format,  
&time_reference, obet_in_utc->utc_std.time_array, xl_ierr)
```

5. The results of the computation are the values stored in the structure `obet_in_utc`.
6. In case the `PPS_ERROR_FLAG` ancillary data is set to 1, the PPS data for that specific integration time shall not be used, and the most recent valid one shall be used. This implies the need to keep stored at least the latest valid PPS data during processing.

5.1.4. Element Failures computation

5.1.4.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
obet	Timestamp	N/A	long long	I	N/A	1
obet_in_utc	Instrument timestamp in UTC time format	RD.24	t_utc_time	I	N/A	1
cmn_errors	CMN failure flags	RD.8	t_bool	I	N/A	CMN_NUMBER
lcl_flag	LICEF failure flags	RD.8	t_bool	I	N/A	[CMN_NUMBER]x7
nir_error_flag	NIR failure flags	N/A	t_bool	I	N/A	[NIR_NUMBER]
lice_f_failure_flag	Failure flags, one for each LICEF and polarization mode (1 if failure)	N/A	t_bool	O	N/A	[ARM_NUMBER] x [LICEFS_PER_ARM] x [POL_MODE]
nir_failure_flag	Failure flags, one for each NIR and polarization mode (1 if failure)	N/A	t_bool	O	N/A	[NIR_NUMBER] x [POL_MODE]
ns_failure_flag	Failure flags, one for each noise source (1 if failure)	N/A	t_bool	O	N/A	[NOISE_SOURCE_NUMBER]

Table 13 - Failure list computation variable list

5.1.4.2. Implementation

1. The LICEF and NIR status list are updated from the information contained in the following flags, retrieved from the ancillary data packet:
 - a. LCL flag – this flag will indicate status for each LICEF. However, some of these flags will be shared with other instrument data and their output will be interlaced. All elements (LICEF, NIRs and Noise sources) identified as in failure will be added to the failure list, updating variables *lice_f_failure_flag*, *nir_failure_flag* and *ns_failure_flag*.
 - b. Local Oscillator flags – these flags (output power and lock status), when indicating a failure, will affect a whole segment of arm. All LICEFs belonging to the CMN segment with lock status failure will be processed as degraded data. The output power flag shall not be used since it can be activated and not indicate a failure.
 - c. Synchronisation Health (Tsync) flag - this flag, when indicating a failure, will affect a whole segment of arm. Epoch will be discarded.
 - d. NIR error flag - a group of three flags, one for each NIR. Any flag indicating a failure will mean that that NIR is added to the failure list, updating variables *nir_failure_flag*.
2. The processing unit will also load a user-defined failure list from the ADF file AUX_FAIL. If any failure is configured by the user as existing, it will be marked as such in the L1a HKTM file.
3. The implementation of this module is straightforward in the sense that the structures in charge of storing the failure lists (LICEF, NIR and noise source) will be updated each time a packet is received, using the rule list above.

5.1.4.3. Data Retrieval

Contents	Size	File type	Method
LICEF failure list	[ARM_NUMBER]x[LICE FS PER ARM] t_bool	*AUX_FAIL*	Constant value (user defined)
NIR failure list	[NIR_NUMBER] t_bool	*AUX_FAIL*	Constant value (user defined)
Noise sources failure list	[NOISE_SOURCE_NUMBER] t_bool	*AUX_FAIL*	Constant value (user defined)

Table 14 - Data retrieval strategy for user configurable failure lists

5.1.5. PMS data processing

5.1.5.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
l0_pms_voltages	Matrix to hold computed PMS voltage values	N/A	unsigned short	I	V	[ARM_NUMBER]x[LICE

Variable name	Description	Definition	Type	Class	Unit	Size
						FS_PER_ARM]
pms_heater_cm_n_index	Relationship between PMS unit index and CMN unit index that affects that PMS when the heater is activated	N/A	char	I	V	[LICEF_NUMBE R]
pms_scale	Range of the PMS voltage values	[RD8], Section 2.2.3	float	L	N/A	1
pms_alpha_on	Double Exponential parameter	Section 5.1.5.2	float	I	N/A	[LICEF_NUMBE R]
pms_tau_1_on	Double Exponential parameter	Section 5.1.5.2	float	I	epochs	[LICEF_NUMBE R]
pms_beta_on	Double Exponential parameter	Section 5.1.5.2	float	I	N/A	[LICEF_NUMBE R]
pms_tau_2_on	Double Exponential parameter	Section 5.1.5.2	float	I	epochs	[LICEF_NUMBE R]
pms_alpha_off	Double Exponential parameter	Section 5.1.5.2	float	I	N/A	[LICEF_NUMBE R]
pms_tau_1_off	Double Exponential parameter	Section 5.1.5.2	float	I	epochs	[LICEF_NUMBE R]
pms_beta_off	Double Exponential parameter	Section 5.1.5.2	float	I	N/A	[LICEF_NUMBE R]
pms_tau_2_off	Double Exponential parameter	Section 5.1.5.2	float	I	epochs	[LICEF_NUMBE R]
pms_voltages	Matrix to hold computed PMS voltage values	Eq. 12	float	O	V	[ARM_N UMBER] x [LICEFS _PER_A RM]

Table 15 - PMS data processing variable list

5.1.5.2. Implementation

1. The PMS data processing first uses a 16 bit 2-complement to decode the L0 ancillary data.
2. Then it applies the conversion to engineering units found in [RD 8]:
 - a. It converts the format to float.
 - b. It normalizes the L0 value to 2^{18} . In reality, the value has to be normalized with 2^{16} , but an extra gain of 4 is added by the CMN, which has to be taken out as well, hence the 2^{18} normalisation. The default output of the LICEF is $\pm 2.5V$, whereas the default output of the CMN is $\pm 10V$.
 - c. It multiplies the result by `pms_scale` (baseline is 20 volts, but should be read from configuration).
3. Finally, a correction must be applied to the PMS voltage measured. First a check is performed on the heater flag of the CMN unit to which that PMS is allocated (using variable `pms_heater_cmn_index`). Then, depending on the value of the flag (ON or OFF), a double exponential correction is computed as follows:

$$\Delta v_{ON} = \alpha_{ONI}(v_i - v_{MAX}) \left(1 - e^{-t/\tau_{ON,1}}\right) + \beta_{ONI}(v_i + v_{MAX}) \left(1 - e^{-t/\tau_{ON,2}}\right) \quad \text{Eq. 122}$$

$$\Delta v_{OFF} = \alpha_{OFFi}(v_i - v_{MAX})e^{-t/\tau_{OFF,1}} + \beta_{OFFi}(v_i + v_{MAX})e^{-t/\tau_{OFF,2}}$$

where v_i is the current PMS values without correction for each of the 72 receivers, expressed in V, v_{MAX} is the maximum measurable PMS which has a value of 2.5V, α and β are fixed constants and τ is the number of epochs since the heater was turned on in the case of the ON function and the number of epochs since the heater was turned off in the case of the OFF function. Each receiver is assigned to a heater.

The values of the α_{ON} α_{OFF} , β_{ON} β_{OFF} and τ_{ON} and τ_{OFF} are taken from the PMS ADF.

4. The correction is applied as:

$$v_{corrected} = v_{uncorrected} - \Delta v \quad \text{Eq. 123}$$

Note that due to the smooth variations exhibited by some of the receivers, the time that the function takes to get to its asymptotic value is larger than the current overlap for TLM in the L0 processor. This way, it could happen that the initial time when the heater changes from OFF to ON or vice versa is not available in the data. For such cases, where the initial change of the heater is not found within the overlap of the L0 data, it is proposed to use those asymptotic values:

$$\begin{aligned} \Delta v_{ON} &= \alpha_{ONI}(v_i - v_{MAX}) + \beta_{ONI}(v_i + v_{MAX}) \\ \Delta v_{OFF} &= \alpha_{OFFi}(v_i - v_{MAX}) + \beta_{OFFi}(v_i + v_{MAX}) \end{aligned} \quad \text{Eq. 124}$$

5.1.6. Correlated Noise Injection Mode computation

5.1.6.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
last_cmn_issued_comm and	Last command value, for each CMN	N/A	short	I	N/A	CMN_NUMBER
cnoise_mode	Correlated Noise Injection Mode	RD.24	t_cnoise_mode	O	N/A	1

Table 16 - Correlated Noise Injection Mode variable list

5.1.6.2. Implementation

1. This function will check each ancillary packet last issued commands for each CMN.
2. If this complete sequence of commands corresponds to one of the instrument modes needed for correlated noise injection calibration procedure, the variable `cnoise_mode` will be updated accordingly.
3. Using the steps listed in Section 3.9 and the last command codes in [RD 8], we can build a table with a correspondence of modes and steps:

cnoise_mode value	Last command for EVEN noise sources	Last command for ODD noise sources	Value for NIR Op_Mode	Value for FWF delay	Description
CAL_STEP1	0x180C	0x180E	0x01	0	Warm, even correlated noise (attenuator on), NIR-R
CAL_STEP2	0x180A	0x180E	0x01	0	Hot, even correlated noise (attenuator on), NIR-R
CAL_STEP3	0x1804	0x1806	0x01	0	Warm, even correlated noise (attenuator off), NIR-R
CAL_STEP4	0x1802	0x1806	0x01	0	Hot, even correlated noise (attenuator off), NIR-R
CAL_STEP5	0x1802	0x1806	0x04	0	Hot, even correlated noise (attenuator off), LICEF-LC
CAL_STEP6	0x1804	0x1806	0x04	0	Warm, even correlated noise (attenuator off), LICEF-LC
CAL_STEP7	0x1836	0x1836	0x06	0	No NS, uncorrelated noise (attenuator off), LICEF-LU

cnoise_mode value	Last command for EVEN noise sources	Last command for ODD noise sources	Value for NIR Op_Mode	Value for FWF delay	Description
CAL_STEP8	0x1806	0x1802	0x04	0	Hot, odd correlated noise (attenuator off), LICEF-LC
CAL_STEP9	0x1806	0x1804	0x04	0	Warm, odd correlated noise (attenuator off), LICEF-LC
CAL_STEP10	0x180E	0x180A	0x05	0	Hot, odd correlated noise (attenuator on), LICEF-LC2
CAL_STEP11	0x180E	0x180C	0x05	0	Warm, odd correlated noise (attenuator on), LICEF-LC2
CAL_STEP12	0x180C	0x180E	0x05	0	Warm, even correlated noise (attenuator on), LICEF-LC2
CAL_STEP13	0x180A	0x180E	0x05	0	Hot, even correlated noise (attenuator on), LICEF-LC2
CAL_STEP14	0x180E	0x180C	0x01	0	Warm, odd correlated noise (attenuator on), NIR-R
CAL_STEP15	0x180E	0x180A	0x01	0	Hot, odd correlated noise (attenuator on), NIR-R
CAL_STEP16	0x1806	0x1804	0x01	0	Warm, odd correlated noise (attenuator off), NIR-R
CAL_STEP17	0x1806	0x1802	0x01	0	Hot, odd correlated noise (attenuator off), NIR-R
CAL_STEP18	0x1806	0x1802	0x04	1	Hot, odd correlated noise (attenuator off), LICEF-LC, time lag -Ts
CAL_STEP19	0x1806	0x1804	0x04	1	Warm, odd correlated noise (attenuator off), LICEF-LC, time lag -Ts
CAL_STEP20	0x1804	0x1806	0x04	1	Warm, even correlated noise (attenuator off), LICEF-LC, time lag -Ts
CAL_STEP21	0x1802	0x1806	0x04	1	Hot, even correlated noise (attenuator off), LICEF-LC, time lag -Ts
CAL_STEP22	0x1806	0x1802	0x04	2	Hot, odd correlated noise (attenuator off), LICEF-LC, time lag +Ts

cnoise_mode value	Last command for EVEN noise sources	Last command for ODD noise sources	Value for NIR Op_Mode	Value for FWF delay	Description
CAL_STEP23	0x1806	0x1804	0x04	2	Warm, odd correlated noise (attenuator off), LICEF-LC, time lag +Ts
CAL_STEP24	0x1804	0x1806	0x04	2	Warm, even correlated noise (attenuator off), LICEF-LC, time lag +Ts
CAL_STEP25	0x1802	0x1806	0x04	2	Hot, even correlated noise (attenuator off), LICEF-LC, time lag +Ts
CAL_STEP26	0x180E	0x180A	0x05	1	Hot, odd correlated noise (attenuator on), LICEF-LC2, time lag -Ts
CAL_STEP27	0x180E	0x180C	0x05	1	Warm, odd correlated noise (attenuator on), LICEF-LC2, time lag -Ts
CAL_STEP28	0x180C	0x180E	0x05	1	Warm, even correlated noise (attenuator on), LICEF-LC2, time lag -Ts
CAL_STEP29	0x180A	0x180E	0x05	1	Hot, even correlated noise (attenuator on), LICEF-LC2, time lag -Ts
CAL_STEP30	0x1806	0x1806	0x00	0	No NS, correlated noise (attenuator off), NIR-A
CAL_STEP31	0x60XX	0x60XX	0x00	0	No NS, nominal science (attenuator off), NIR-A
CAL_STEP32	0x60XX	0x60XX	0x03	0	No NS, nominal science (attenuator off), LICEF-LA
CAL_STEP33	0x60XX	0x60XX	0x02	0	No NS, nominal science (attenuator off), NIR-AR
CAL_STEP34	0x60XX	0x60XX	0x0F	0	No NS, nominal science (attenuator off), LICEF-LA2
CAL_STEP35	0x183E	0x183E	0x06	0	No NS, uncorrelated noise (attenuator on), LICEF-LU

Table 17 - Correlated Noise Injection mode rule table

4. EVEN noise sources are those located in CMNs H1, H2, H3, A2, B2 and C2. ODD noise sources are located in CMNs A1, A3, B1, B3, C1 and C3.
5. If the sequence does not correspond to one of the instrument modes, the variable will be updated as CNOISE_OFF.

Note: The above table can be interpreted by seeing, for example, that the cnoise_mode value of CAL_STEP1 can only be obtained if ALL CMNs containing EVEN noise sources have received the last command 0x180C, and ALL CMNs containing ODD noise sources have received the last command 0x180E.

5.1.7. Physical Temperatures computation

5.1.7.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
last_phys_temps	The rolling matrix with the most up to date physical temperatures	N/A	float	I	K	[CMN_NUMBER] x [THERMISTOR_CHANNELS]
10_temps	Thermistor data	N/A	unsigned short	I	N/A	[POL_MODE] x [CMN_NUMBER]
10_temps_channel_id	Channel ID of the thermistor data	N/A	t_thermist or_channel	I	N/A	[POL_MODE] x [CMN_NUMBER]
ref_temps	Matrix with the latest reference voltages provided by the instrument. Used in physical temperatures computation.	[RD8], Section 2.2.4	long double	I	V	[CMN_NUMBER] x [2]
t_high	Reference temperature (high value)	[RD8], Section 2.2.4	double	I	°C	1
t_low	Reference temperature (low value)	[RD8], Section 2.2.4	double	I	°C	1

Variable name	Description	Definition	Type	Class	Unit	Size
temperatures	Thermistor data after 2's complement decoding	N/A	int	L	N/A	[2] x [CMN_NUMBER]
g2_x_vc	Coefficients of the thermistor response function	[RD8], Section 2.2.4	double	L	N/A	1
g1	Coefficients of the thermistor response function	[RD8], Section 2.2.4	double	L	N/A	1
r1	Coefficients of the thermistor response function	[RD8], Section 2.2.4	int	L	N/A	1
rth	Coefficients of the thermistor response function	[RD8], Section 2.2.4	double	L	N/A	1
v0	Nominal voltage delivered by the thermistor	[RD8], Section 2.2.4	double	L	V	1
temp_regression_a	Coefficients for Steinhart & Hart eq., used in physical temperature computation	[RD8], Section 2.2.4	double	L	N/A	1
temp_regression_b	Coefficients for Steinhart & Hart eq., used in physical temperature computation	[RD8], Section 2.2.4	double	L	N/A	1
temp_regression_c	Coefficients for Steinhart & Hart eq., used in physical temperature computation	[RD8], Section 2.2.4	double	L	N/A	1
mcal	Temperature computation parameter, updated with ancillary data	[RD8], Section 2.2.4	double	I/L	N/A	1
qcal	Temperature computation parameter, updated with ancillary data	[RD8], Section 2.2.4	double	I/L	N/A	1
qfly	Calibrated qcal	[RD8], Section 2.2.4	long double	L	N/A	[CMN_NUMBER]

Variable name	Description	Definition	Type	Class	Unit	Size
mfly	Calibrated mcal	[RD8], Section 2.2.4	long double	L	N/A	[CMN_N UMBER]
thermistor_temp	Computed thermistor temperature	[RD8], Section 2.2.4	float	L	°C	1
last_phys_temps_data_ pointer	Structure with all necessary data for physical temperatures computation	N/A	t_last_phy s_temps_i nput_data	I/O	N/A	pointer

Table 18 - Physical temperatures computation variable list

5.1.7.2. Implementation

This function converts voltage outputs to physical temperatures in Kelvin, by using the characterisation of the thermistors, and the calibration parameters computed from two reference loads on each CMN unit (`ref_temps`).

1. The rolling mechanism that was referred previously (section 5.1) is applied to the physical temperatures matrix. The matrix is indexed by CMN and thermistor channel and values in each cell are listed in the following table:

	CMN H1	CMN H2	CMN H3	CMN X 1/2/3 (X=A,B or C)
Ch. 1	LICEF_AB_03	LICEF_BC_03	LICEF_CA_03	LICEF_X_04/10/16
Ch. 2	LICEF_NIR_AB_01_H	LICEF_NIR_BC_01_H	LICEF_NIR_CA_01_H	LICEF_X_05/11/17
Ch. 3	LICEF_NIR_AB_01_V	LICEF_NIR_BC_01_V	LICEF_NIR_CA_01_V	LICEF_X_06/12/18
Ch. 4	LICEF_A_01	LICEF_B_01	LICEF_C_01	LICEF_X_07/13/19
Ch. 5	LICEF_A_02	LICEF_B_02	LICEF_C_02	LICEF_X_08/14/20
Ch. 6	LICEF_A_03	LICEF_B_03	LICEF_C_03	LICEF_X_09/15/21
Ch. 7	NIR_A_T3 (NS_1H)	NIR_A_T3 (NS_2H)	NIR_A_T3 (NS_3H)	NS_X_1/2/3
Ch. 8	NIR_A_T5 (Lref_1H)	NIR_A_T5 (Lref_2H)	NIR_A_T5 (Lref_3H)	Hinge_n
Ch. 9	NIR_A_T7 (AntennaPatch_1H)	NIR_A_T7 (AntennaPatch_2H)	NIR_A_T7 (AntennaPatch_3H)	Not used
Ch. 10	NIR_A_T11 (NS_1V)	NIR_A_T11 (NS_2V)	NIR_A_T11 (NS_3V)	Not used
Ch. 11	NIR_A_T13 (Lref_1V)	NIR_A_T13 (Lref_2V)	NIR_A_T13 (Lref_3V)	Not used
Ch. 12	NIR_A_T15 (AntennaInterm_1H)	NIR_A_T15 (AntennaInterm_2H)	NIR_A_T15 (AntennaInterm_3H)	Not used
Ch. 13	NS_H_Internal	Not used	Not used	Not used
Ch. 14	PD_H1_n	PD_H2_n	PD_H3_n	PD_X_1/2/3

Table 19 - Physical temperatures matrix

- The hub CMNs are H1, H2 and H3, while the arms CMNs are indexed per arm (A, B or C) and segment (1, 2 or 3). The power dividers temperatures have the code “PD_X1/2/3”, where X can be hub (H) or arms (A, B or C). The LICEF temperatures begin with the code “LICEF_”.
- With respect to the hub channels, the quantities measured by the thermistors, apart from those of the LICEFs that are clearly identified, are:
 - Channels 2 and 3 are the NIR temperatures for uncorrelated noise injection
 - Channels 7 and 10 are connected to thermistor outputs from the NIR noise sources, H and V-pol
 - Channels 8 and 11 are the thermistor outputs for the reference channels attenuators
 - Channel 9 is the thermistor output for the NIR antenna patch
 - Channel 12 is the thermistor output for the intermediate layer, located between the NIR controller box and the NIR antenna patch
 - Channel 13 of CMN H1 is the thermistor output for the hub noise source
- The function will start by retrieving the last computed values of the physical and reference temperatures, by accessing the previously processed L1a HKTM product. If those are not available it will use 0°C as default values for the temperatures and the following ones for other quantities (for details on the physical temperatures computation refer to [RD.8]):

- a. $g2_x_vc = -15.15748031496063$
 - b. $g1 = 1.29870129870129$
 - c. $temp_regression_a = 0.001400531$ (Coefficients for Steinhart & Hart eq.)
 - d. $temp_regression_b = 0.000237737$ (Coefficients for Steinhart & Hart eq.)
 - e. $temp_regression_c = 0.000000098$ (Coefficients for Steinhart & Hart eq.)
 - f. $r1 = 3010$
5. The following values shall be retrieved from the PLM ADF for each CMN, although the following default values may be used:
- a. $mcal = 0.1978$
 - b. $qcal = 0.0892$
 - c. $t_high = 49.5476$
 - d. $t_low = 0.5473$
6. Then, the update of the physical temperatures will be computed. Cycling through CMN and thermistor channel values, the 16 bit 2's complement is computed for $l0_temps$ (T_{L0}).
7. According to the temperature channel ID the correct quantities are updated. If the thermistor outputs are the reference voltages, $ref_temps(v_{ref1,2})$, as well as m_{fly} (m_{fly}) and q_{fly} (q_{fly}), are updated for each CMN by:

$$\begin{aligned}
 v_{ref1,2} &= \frac{20}{2^{16}} v_{ref1,2} \\
 m_{fly} &= \frac{v_{ref2} - v_{ref1}}{T_{high} - T_{low}} \\
 q_{fly} &= \frac{v_{ref1} T_{high} - v_{ref2} T_{low}}{T_{high} - T_{low}}
 \end{aligned}
 \tag{Eq. 125}$$

8. If the thermistor outputs are from a component measurement, the temperature is computed by (Steinhart & Hart eq.):

$$\begin{aligned}
 v_0 &= \frac{20}{2^{16}} T_{L0} \\
 v_0 &= \left(v_0 - q_{fly} \right) \frac{m_{cal}}{m_{fly}} + q_{cal} \\
 R_{th} &= - \frac{(v_0 + V_C G_2) R}{v_0 + V_C G_2 (1 - G_1)} \\
 T_{L1a} &= \frac{1}{a + b \ln(R_{th}) + c [\ln(R_{th})]^3}
 \end{aligned}
 \tag{Eq. 126}$$

9. And the cycle over CMNs is ended. Finally, the physical temperatures matrix is updated according to thermistor channel ID.
10. Optionally, the Tp7 temperatures (channel 9 for the Hub CMNs) can be corrected for latency, with a simple correction proposed by HUT in 2017 ([RD.29]):

$$\begin{aligned}
 \hat{T}_{p7} &= T_{p7} - \frac{1}{LP} \cdot \frac{dT_{p7}}{dt} \\
 \left. \frac{dT_{p7}}{dt} \right|_{\text{epoch N}} &= \frac{T_{p7}|_{\text{epoch N}} - T_{p7}|_{\text{epoch N-8}}}{1.2s \cdot 8}
 \end{aligned}
 \tag{Eq. 127}$$

this correction is OFF by default and is set by the L1OP configuration file.

11. An additional check has been added as of 2011, by which the physical temperatures of the LICEF (and NIR-LICEF) shall be contained within the range [15, 29] °C. If any of the LICEF temperatures is outside this range, this check shall raise the instrument error flag for that snapshot.

5.1.7.3. Data Retrieval

Contents	Size	File type	Method
Last Physical Temps.	[CMN_NUMBER]x[THERMISTOR_CHANNELS] float	L1a HKTM	Use data from last OBET
mcal	1 double	*AUX_PLM*	Constant value
qcal	1 double	*AUX_PLM*	Constant value
Thigh	1 double	*AUX_PLM*	Constant value
Tlow	1 double	*AUX_PLM*	Constant value

Table 20 - Data retrieval strategy for Physical Temperatures Computation

5.1.8. NIR Pulse Length computation

5.1.8.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
nir_samples	Average number of NIR samples per pulse length	N/A	short	I	N/A	1
l0_nir_temp	NIR counts	N/A	unsigned short	I	N/A	[POL_M ODE]x[NIR_NUMBER]
pulse_length	NIR pulse length ($\eta_{v,h}$)	Eq. 39	double	O	V	[POL_M ODE]x[NIR_NUMBER]

Table 21 - NIR Pulse Length computation variable list

5.1.8.2. Implementation

1. The function will de-normalise the NIR pulse length. The L0 data it is coded in the interval [0,1] in 24 bits and normalised with `nir_samples` and the maximum value of the NIR pulse ($10^{16}-1$). The quantity `nir_samples` is a L0 ancillary data element
2. The function shall be protected against normalised values greater than 1.0. In case a higher value is detected, it indicates a problem in the instrument, so the value should be set to zero and the epoch flagged as degraded by instrument error.

5.1.9. PVT Data processing

5.1.9.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
obet_in_utc	Instrument timestamp in UTC time format	RD.24	t_utc_time	I	N/A	1
l0_pvt_data	L0 PVT data	RD.24	t_pvt	I	N/A	1
sat_id	Mission Identifier (EE CFI variable)	N/A	long	L	N/A	1
orbit_id	Orbit Identifier (EE CFI variable)	N/A	xo_orbit_id	L	N/A	1
propag_id	Propagator Identifier (EE CFI variable)	N/A	xo_propag_id	L	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
tai	Orbit Reference Times (EE CFI variable)	N/A	double	L	N/A	1
utc	Orbit Reference Times (EE CFI variable)	N/A	double	L	N/A	1
utl	Orbit Reference Times (EE CFI variable)	N/A	double	L	N/A	1
gps	Orbit Reference Times (EE CFI variable)	N/A	double	L	N/A	1
time_id	Time initialization (EE CFI variable)	N/A	xl_time_id	L	N/A	1
pos_EF	Satellite position, Earth Fixed coordinates	N/A	double	L	meters	3
vel_EF	Satellite velocity, Earth Fixed coordinates	N/A	double	L	m/s	3
acc_EF	Satellite acceleration, Earth Fixed coordinates	N/A	double	L	m/s ²	3
acc_GM	Satellite acceleration, Geocentric Mean coordinates	N/A	double	L	m/s ²	3
tri_time	Time correlation structure	N/A	double	L	N/A	XL_TIME_TRANS_DIM_MAX
cfi_error	CFI list of errors (EE CFI variable)	N/A	long	L	N/A	XL_NUM_ERR_OBT_TIME
xl_ierr	Error codes (EE CFI variable)	N/A	long	L	N/A	XL_ERROR_VECTOR_MAX_LENGTH
processing_format	Time processing format (EE CFI variable)	N/A	long	L	N/A	1
time_reference	UTC time reference (EE CFI variable)	N/A	long	L	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
transport_format	Transport format (EE CFI variable)	N/A	long	L	N/A	1
orbit_duration	Orbit Duration (EE CFI variable)	N/A	double	L	N/A	1
orbit_number	Orbit number (EE CFI variable)	N/A	long	L	N/A	1
anx_time	Time parameter (EE CFI variable)	N/A	double	L	N/A	1
lla_pvt_data	Processed PVT data	RD.24	t_lla_pvt	O	N/A	1

Table 22 - PVT data variable list

5.1.9.2. Implementation

- The orbital elements (PVT) and platform attitude (AOCS) will often have different time stamps than the one for the science data packets. In that case, the satellite position and attitude must be propagated from the last measurement up until the time when the measurement was produced, ensuring data coherence.
- The first thing the function does is initialise the time correlation data using the Bulletin B ADF
- If no Bulletin B is available, the function will load the time correlation data (constant values) from the ORBSCT ADF file:
 - `tri_time[0] = tai`
 - `tri_time[1] = utc`
 - `tri_time[2] = ut1`
 - `tri_time[3] = gps (tai-19.0s)`
- If this reference is not available, default data will be loaded
 - `tri_time[0] = 2610.2504237268290 (TAI time [days])`
 - `tri_time[1] = 2610.2500186342363 (UTC time [days] (= TAI - 35.0 s))`
 - `tri_time[2] = 2610.2500147268288 (UT1 time [days] (= TAI - 35.6 s))`
 - `tri_time[3] = 2610.2502038194216 (GPS time [days] (= TAI - 19.0 s))`
- And the time reference is initialized as
 - `orbit_number = 1`
 - `anx_time = 0.0`
 - `orbit_duration = 6004.4776119402986`

-
- d. `cfi_status = xl_time_ref_init(tri_time, &orbit_number, &anx_time, &orbit_duration, time_id, xlerr)`
6. The velocity and position fields from L0 data are decoded by a 2's complement of 32 bit. The position has to be converted from cm to meters and velocity also is converted to m/s.
7. The EECFI settings are defined and the time stamp is converted, in order to enable a coordinate transformation from Geocentric Mean of 2000 to Earth Fixed:
- a. `calc_mode=XL_CALC_POS_VEL`
 - b. `time_ref = XO_TIME_UTC`
 - c. `cs_in = XL_GM2000` (Initial coordinate system = Geocentric Mean of 2000)
 - d. `cs_out = XL_EF` (Final coordinate system = Earth Fixed)
 - e. `status=xl_time_transport_to_processing(&time_id, &transport_format, &time_ref, l0_pvt_data.pvt_utc.utc_std.time_array, &processing_format, &time_ref, &time, xl_ierr)`
8. The orbit is initialized
- a. `abs_orbit=1` (Dummy data)
 - b. `status=xo_orbit_cart_init(&sat_id, &time_id, &time_ref, &time, pos_EF, vel_EF, &abs_orbit, &val_time0, &val_time1, &orbit_id, xo_ierr)`
9. The propagation functions are initialized:
- a. `status = xo_propag_init(&orbit_id, &propag_model, &time_mode, &time_ref, &time, &abs_orbit, &val_time0, &val_time1, &propag_id, xo_ierr)`
 - b. `status = xl_time_transport_to_processing(&time_id, &transport_format, &time_ref, obet_in_utc.utc_std.time_array, &processing_format, &time_ref, &time, xl_ierr)`
10. and the propagation function is applied:
- a. `status = xo_propag(&propag_id, &propag_model, &time_ref, &time, (double*)l1a_pvt_data->position, (double*)l1a_pvt_data->velocity, acc_EF, xo_ierr)`
11. and `l1a_pvt_data->position` and `l1a_pvt_data->velocity` are the converted quantities.
12. Finally, `l1a_pvt_data->pvt_utc` is assigned the value `obet_in_utc`
13. In case the G1 bit from the UTC time of the PVT ancillary data structure is set to 1, see [RD.7], the PVT data for that specific integration time shall not be used, and the most recent valid one shall be used. This implies the need to keep stored at least the latest valid PVT data during processing.
-

5.1.9.3. Data Retrieval

Contents	Size	File type	Method
Time constants to initialise date	4 doubles	*AUX_TIME*	Constant value

Table 23 - Data retrieval strategy for PVT data extrapolation

5.1.10. AOCS Data Processing

5.1.10.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
q	AOCS quaternion (q)	Eq. 125	double	I/O	N/A	4
qdot	AOCS quaternion derivative (\dot{q})	Eq. 125	double	L	N/A	4
angular_velocity	Angular velocity of the satellite (ω)	Eq. 124	double	I/O	rad/s	3
omega	Antisymmetric matrix for quaternion propagation (Ω)	Eq. 126	double	L	rad/s	4 x 4
delta_t	Difference of times between AOCS.UTC and OBET.UTC, Δt (the interval in which we wish to propagate the quaternion)	Eq. 127	double	L	N/A	1
lla_aocs_data	Structure with processed AOCS data	RD.24	t_lla_aocs	O	N/A	1

Table 24 - AOCS data processing variable list

5.1.10.2. Implementation

1. The function will start by doing the L0 data conversion, using a 32 bit 2's complement and converting the angular velocity to rad/s by:

$$\omega = \frac{2}{2^{31}-1} \omega \frac{\pi}{180} \quad \text{Eq. 128}$$

2. After that, there are two procedures that can be followed: using spherical harmonics (SLERP) to interpolate in time between two available quaternions, or an extrapolation with time using the information from a unique quaternion:

3. With the SLERP interpolation, the two quaternions (q_0 and q_1) to be used in the interpolation process need to define an interval that contains the new quaternion (q) to be computed (i.e. to perform an interpolation and not an extrapolation: $t_0 < t < t_1$)

- a. The angle between quaternions is computed using the scalar product $\cos \omega = q_0 \cdot q_1$
- b. The time for the quaternion interpolation is normalised to the difference between the interpolating quaternions $h = \frac{t - t_0}{t_1 - t_0}$

- c. The quaternion is computed using the following equation

$$q = q_0 \frac{\sin[(1-h)\omega]}{\sin \omega} + q_1 \frac{\sin[h\omega]}{\sin \omega} \quad \text{Eq. 129}$$

- d. In case ω is zero or close to zero, then the interpolation should not be performed and the alternative extrapolation using only one quaternion should be performed.

4. With the extrapolation using only one quaternion, first the quaternion is normalized, and the anti-symmetric Ω matrix is built as

$$\Omega = \begin{bmatrix} 0 & \omega_x & \omega_y & \omega_z \\ -\omega_x & 0 & -\omega_z & \omega_y \\ -\omega_y & \omega_z & 0 & -\omega_x \\ -\omega_z & -\omega_y & \omega_x & 0 \end{bmatrix} \quad \text{Eq. 130}$$

5. Δt is computed using subtractTime
6. Then the quaternion values are propagated through the rule (M. Sidi, *Spacecraft Dynamics and Control*, Appendix A):

$$\dot{q} = \frac{1}{2} q_i \Omega$$

$$q_f = \dot{q} \cdot \Delta t \quad \text{Eq. 131}$$

7. Finally, the function re-normalizes the quaternion and `lla_aocs_data->q[i]` is the propagated quaternion. The UTC time and angular velocity are saved as constants (angular velocity having been converted to radians/second).

5.1.11. X-band Data processing

5.1.11.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
x_band_data	Ancillary packet data for X-Band processing	RD.24	t_x_band	I	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
rf_level	Power RF signal Level	RD.8	t_raw_data	I	mV	1
temp	Temperature telemetry	RD.8	t_raw_data	I	K	1
sspa_alim	Voltage of the the solid state RF power amplifier	RD.8	t_raw_data	I	mV	1
num_alim	Voltage of the digital parts supply	RD.8	t_raw_data	I	mV	1
vco	DC level of the PLL VCO	RD.8	t_raw_data	I	mV	1
Tn	Temperature telemetry value calculation coefficients (Steinhart & Hart)	N/A	float	L	K	1
Rn	Temperature telemetry value calculation coefficients (Steinhart & Hart)	N/A	float	L	KΩ	1
B	Temperature telemetry value calculation coefficients (Steinhart & Hart)	N/A	float	L	K	1
lla_x_band_data	Structure with processed X-Band data	RD.24	t_lla_x_band	O	N/A	1

Table 25 - X-Band data processing variable list

5.1.11.2. Implementation

1. Details on the expected values for X-Band data can be found in [RD8]. The X-Band data is coded as 8-bit 2's complement in the ancillary source packets, so it must be transformed into engineering units by this function.
2. The process to be followed, for example for the Power RF signal level, is to decode the 2's complement and de-normalise the value by the increment in mV (default is 39.0625mV as in [RD8])
3. The rest of the variables are decoded in exactly the same way (vco, num_alim and sspa_alim), except for the temperature telemetry value (temp), which is measured directly in kOhms (V_x) does not need 2's complement correction, and instead uses the following equation. All coefficients (T_n , B and R_n) shall be obtained from the PLM ADF file.

$$\frac{1}{T(K)} = \frac{1}{T_n} + \frac{1}{B} \times \ln \frac{R(T)}{R_n}$$

$$R(T) = V_x$$

Eq. 132

4. Additionally, a flag detailing if the XBand transmission is ON or OFF will be computed and updated here. The name of the flag will be simply XBand_flag.

5.1.12. Arms Polarization Modes computation

5.1.12.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
tsync_status	T_sync data from ancillary packet	RD.24	t_lla_tsync	I	N/A	1
arm_pol_mode	Polarization mode for each arm	RD.24	t_polarization_mode	O	N/A	[ARM_NUMBER]

Table 26 - Arm Polarization Modes processing variable list

5.1.12.2. Implementation

- This function will process the Tsync shape data and return each arm polarization mode. A table can be built with the values of Tsync data and the arms polarisation mode (for more details, refer to [RD8]).
- The use of three characters to represent the polarisation mode is not related to the number of arms, it is instead related to the three integration sub-intervals within the integration time. This means that the value HVV for arm A represents arm A in H polarisation for the first interlaced scene of each 0.4s interval:

Tsync code, arm A	Tsync code, arm B	Tsync code, arm C	Arm polarisation T ₁ T ₂ T ₃ (Arm)
0xFFFF	0xFFFF	0xFFFF	HHH (A, B and C)
0x0000	0x0000	0x0000	VVV (A, B and C)
0x0924	-	-	HVV (A)
0x06DB	-	-	VHH (A)
-	0x0492	-	VHV (B)
-	0x0B6D	-	HVH (B)
-	-	0x0249	VVH (C)
-	-	0x0DB6	HHV (C)

Table 27 - Possible polarization modes

5.1.13. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	File accessor unable to read the L0 file	DATA_CORRUPTED	Processing unit returns with no data processed.	No
2	Unable to retrieve last computed temperatures	None	Output error to log and continue with temperatures initialized to 0	No
3	File accessor unable to write L1a HKTM	None	Output error to log. Unit converter processing is finished when writing L1a HKTM	No
4	Reference voltages are zero	DIVISION_BY_ZERO	Default values mcal and qcal are used	Yes
5	Mfly is zero	DIVISION_BY_ZERO	Thermistor voltage is zero	Yes
6	Division by zero in thermistor response function computation	DIVISION_BY_ZERO	Rth is set to 1	Yes
6b	Thermistor resistance is zero or negative	DIVISION_BY_ZERO	Thermistor temperature is set to 1K	Yes
7	Division by zero in Steinhart & Hart equation solution	DIVISION_BY_ZERO	Thermistor temperature is set to 1K	Yes
8	Unknown polarization mode	DATA_CORRUPTED	Pol mode returned as POL_UNKNOWN	Yes

Table 28 - Unit Converter error handling

5.1.14. List of flags and additional converted data

Ancillary Packet Flags	Description	Allowed values	Processing Action
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Ancillary Packet Flags	Description	Allowed values	Processing Action
PPS_ERROR_FLAG	Flag describing if last PPS value was received within last second.	0=No error 1=Error (more than one second passed since PPS)	Process as nominal. OBT and UTC have not been updated but are still useful
ARM_RED_CONF	Information regarding branch (nominal/ redundant) detected after CCU switch on.	Bit2=1 Arm C RED Bit3=1 Arm C NOM Bit4=1 Arm B RED Bit5=1 Arm B NOM Bit6=1 Arm A RED Bit7=1 Arm A NOM	Select nominal or redundant values from CMNs as applicable for arms (e.g. thermistors, NS, S parameters, etc)
CMN_ERROR_FLAG	Validity of CCU-CMN communications. One value per CMN unit.	0=No error Any value=Error in ancillary packet (analysis codes available in [RD.8])	Discard epoch.
TSYNC_HEALTH	Status of Tsync signal at integration time. One value per CMN unit. It indicates that Tsync has been received properly at this CMN	0=No error 1=Error (Tsync did not change in last second)	Possibly LICEFs don't have the right polarization. If the problem persists might indicate hardware problems and needs switching to redundant and detailed investigation. Discard epoch.
LCL_STATUS	Status of CMN current limiters at integration time. One set of 7 values per CMN unit.	0=No error 1=Error (overcurrent in element, and associated Latch Current Limiter has opened)	Mark element as failure for this integration time. Disregard any affected measurement including correlations or Noise sources.
LO_OUTPUT_POWER	Local Oscillator Power Level at integration time. One value per CMN unit	0=No error 1=Output power exceeds requirements	Possible hardware problem but data could still be valid. Process and flag as corrupted data. Annotate flag which will be used later on during LO unlock event detection

Ancillary Packet Flags	Description	Allowed values	Processing Action
LO_LOCKING	Phase lock status of Local Oscillator at integration time. One value per CMN unit	0=Error. LO is not phase-locked 1=No error. LO is phase- locked.	Process and flag as corrupted data. Annotate flag which will be used later on during LO unlock event detection.
LAST_CMD_OK	Status of last command received in the CMN. One value per CMN unit	0=No error 1=Parity error in the fields ADDRESS, COMMAND TYPE or DATA	Process as nominal. If last command was not executed the CMN configuration is not changed but will be reflected in LAST_EXECUTED_CMD
HEATER_SWITCH	Heater status at integration time. One value per CMN unit	0=Heater OFF 1=Heater ON	Process as nominal.
NIR_ERROR_FLAG	NIR composite status	0=No error Any value=NIR data is invalid	Discard NIR information (pulse length, correlations, Av samples, op mode) for this NIR. Flag NIR as failing. Science Data has to be reconstructed using information from the other NIRs.
TSYNC_ERROR_FLAG	Error status of the Tsync signal	0=No error 1=Error	Discard epoch.
X_B_ERROR_FLAG	Error status of X-band telemetry	0=No error 1=Error	Process as nominal
XBND_STATUS	Component status of X-band system	Bit0=1 Xband NOM Bit1=1 Xband RED	Process as nominal
CCU_ERROR_FLAG	Error status of CCU telemetries	0=No error 1=Error	Process as nominal.
MODE	Operation mode of ALL correlators at integration time	0=STOP 1=DUAL 2=FULL	If STOP no science packets available. Ancillary packets information is still valid.

Ancillary Packet Flags	Description	Allowed values	Processing Action
FWF	ASIC delayers configuration at integration time	0=STEP_1 (no delay) 1=STEP_2 (delay +t) 2=STEP_3 (delay -t)	Use in FWF computation during correlated noise injection
ASIC#	Operation mode of ASIC number # at integration time	0x00=IDLE 0x0C=READOUT 0x0D=MAXCOUNT 0x0E=OCTG 0x0F=LFSR	IDLE= Correlator data not useful READOUT= Nominal Rest: Correlator test modes
PM_STATUS	Processing Module status (CCU)		Process as nominal
CORR_NOM_RED	Correlator layers status (powered/unpowered)	0=No power 1=Nominal layer powered 2=Redundant layer powered 3=Both layers powered	Select equations to be applied in raw correlations processing. Verify against ASIC info bytes in science ASICs.
MMU_NOM_RED	Mass Memory Units status (powered/unpowered)	0=Nominal layer powered 2=Redundant layer powered	Process as nominal
DATA_CORRUPTED	Validity indicator of correlators and NIR data for integration period	0=OK 1=Error. Instrument performed operation which affects accumulated values in ASICs or NIR	Science packet for this integration time not available. NIR data is corrupted in most cases. Discard NIR data.

Table 29 - Ancillary data flags processed

The remaining quantities in the ancillary data packet will be converted as follows:

Original Data	Contents	Converted Data	Contents
OBET	8 bytes	OBET	8 bytes

Original Data	Contents	Converted Data	Contents
		UTC at OBET	8 bytes
OBET at PPS	8 bytes	OBET at PPS	8 bytes
UTC at PPS	8 bytes	UTC default structure for L1OP	8 bytes
Operational mode	1 bytes	Operational mode (Enumerated value)	2 bytes
Last APID	2 bytes	Last APID (Enumerated value)	2 bytes
Instrument mode	1 byte	Instrument mode (Enumerated value)	2 bytes
Tsync	1 bit per CMN	LICEF failure list	N/A
XBand_flag	1 bit	XBand flag, computed value detailing if XBand is ON or OFF	2 bytes
CORR_NOM_RED	1 byte	Correlator mode (<i>iq</i> or <i>qi</i>)	2 bytes

Table 30 - Additional ancillary data processing

5.2. Raw Correlations Processor

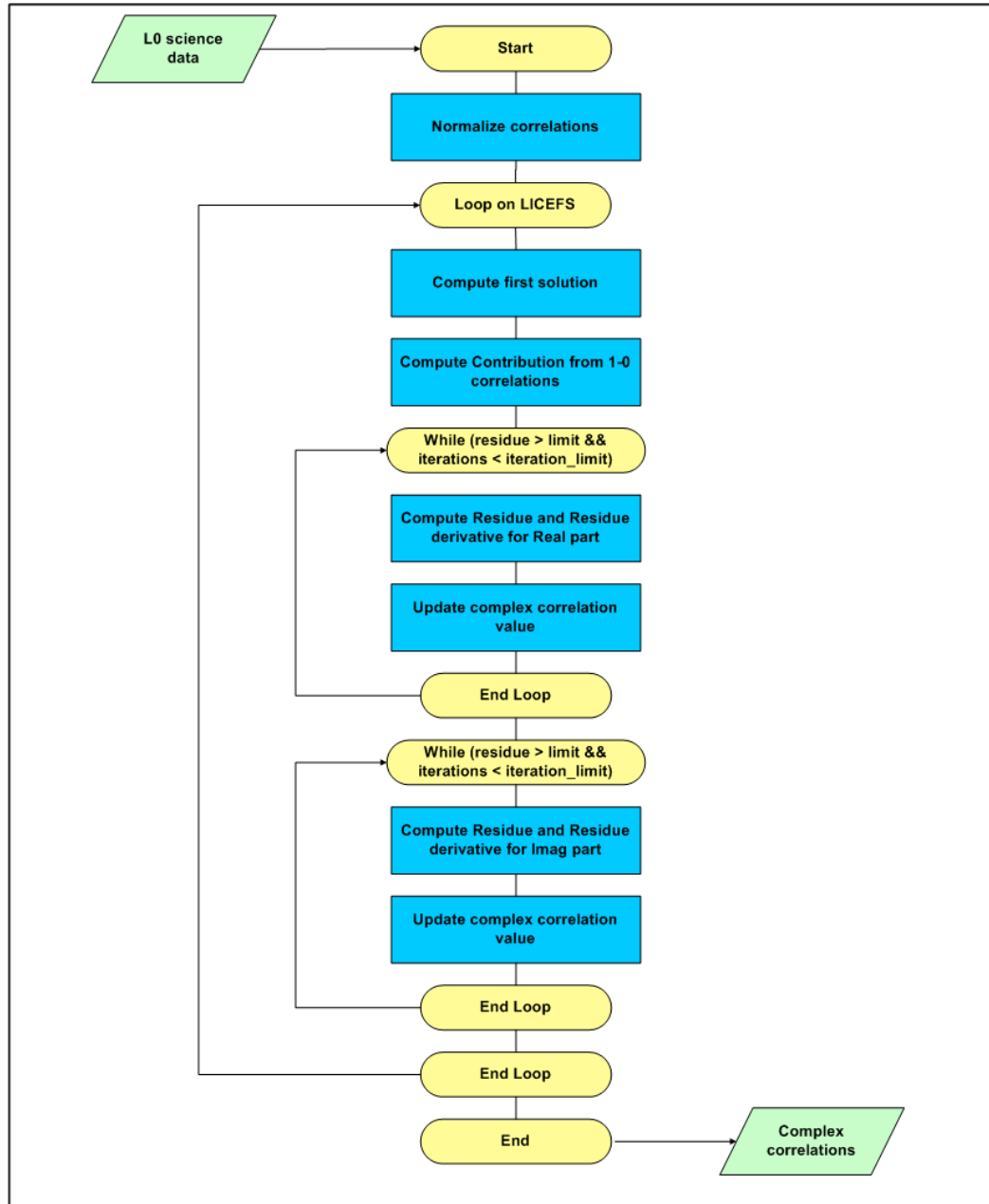


Figure 14 - Conversion from raw counts to complex correlations

This processing unit is part of the Level0 decoding sub-module. Its purpose is to act as a pre-processor of the measured correlations in all modes of the instrument.

5.2.1. Inputs

- ❑ All raw non-normalised correlations, N_c (SM_xxxx_MIR_xxxx0_<ID>)
- ❑ The maximum number of counts, $N_{c\max}$ (SM_xxxx_MIR_xxxx0_<ID>)

❑ Correlators' mode (SM_xxxx_TLM_MIRA1A_<ID>)

5.2.2. Outputs

❑ Complex normalised correlations, μ_{kj}

❑ Autocorrelations, μ_{kk}^{iq}

5.2.3. List of Variables

Variable name	Description	Definition	Type	Class	Unit	Size
science_data	Structure with all the science data extracted from the L0 file	N/A	t_science_data	I	N/A	The number of scenes in the L0 file
normalized_correlations	Digital receiver correlations ($c_{kj}^{ii,iq}$)	Eq. 2	float	L	N/A	[LICEF_NUMBER] x [LICEF_NUMBER]
normalized_i_zero_corr	Digital correlations between receiver in-phase channels and 0 signal channel (c_{k0}^i)	Section 3.1	float	L	N/A	[LICEF_NUMBER]
normalized_i_one_corr	Digital correlations between receiver in-phase channels and 1 signal channel (c_{k1}^i)	Section 3.1	float	L	N/A	[LICEF_NUMBER]
normalized_q_zero_corr	Digital correlations between receiver quadrature channels and 0 signal channel (c_{k0}^q)	Section 3.1	float	L	N/A	[LICEF_NUMBER]
normalized_q_one_corr	Digital correlations between receiver quadrature channels and 1 signal channel (c_{k1}^q)	Section 3.1	float	L	N/A	[LICEF_NUMBER]
miu_imag	Imaginary part of the complex correlations (μ_{kj}^{qi})	Eq. 2	float	L	N/A	[LICEF_NUMBER] x

Variable name	Description	Definition	Type	Class	Unit	Size
						[LICEF_NUMBE R]
miu_real	Real part of the complex correlations (μ_{kj}^{ii})	Eq. 2	float	L	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R]
x_real	Real part of the contribution from correlations between receivers and reference channels ($X_k^{i,q}$)	Eq. 2	float	L	N/A	[LICEF_NUMBE R]
x_imag	Real part of the contribution from correlations between receivers and reference channels ($X_k^{i,q}$)	Eq. 2	float	L	N/A	[LICEF_NUMBE R]
y_real	Real part of the contribution from correlations between receivers and reference channels ($X_j^{i,q}$)	Eq. 2	float	L	N/A	[LICEF_NUMBE R]
y_imag	Real part of the contribution from correlations between receivers and reference channels ($X_j^{i,q}$)	Eq. 2	float	L	N/A	[LICEF_NUMBE R]
limit	Precision limit for accepted convergence status (value is 10^{-7})	N/A	double	L	N/A	1
iteration_limit	Maximum number of iterations (value is 1000)	N/A	float	L	N/A	1
residue	Error of the approximation	N/A	double	L	N/A	1
residue_deriv	Derivative of the approximation error	N/A	double	L	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
complex_correlations	Complex correlations between receivers, except auto correlations (μ_{kj})	Eq. 3	Double complex	O	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R]
normalized_auto_correlations	Auto correlations between receivers (μ_{kk}^{iq})	Eq. 2	double	O	N/A	[LICEF_NUMBE R]

Table 31 - Raw Correlations variable list

5.2.4. Implementation

1. The processing unit starts by normalising the correlator counts, using Eq. 1.
2. Then Eq. 2 is solved for real (μ_{kj}^{ii}) and imaginary (μ_{kj}^{qi}) parts separately (autocorrelations do not need to be computed here), using the Newton-Raphson method, with the first guess as indicated above. This method is very suited to this case because of its fast rate of convergence (quadratic). The shortfalls of the method do not apply in this case, since the initial guess for the value of the complex correlations is already very near to the correct one (no local maxima between initial guess and solution). The threshold residue limit for the solution shall be set to 10^{-15} and the maximum number of iterations to 1000, to ensure convergence.
3. Finally, the complex correlations (μ_{kj}) are computed using Eq. 3 or Eq. 4, depending on the correlator mode (obtained from L1a HKTm product with the same timestamp as the science packet being processed).

5.2.5. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	Maximum number of correlations is 0	DIVISION_BY_ZERO	Correlations are not normalized	Yes
2	Residue derivative is 0	DIVISION_BY_ZERO	Cycle is broken since approximation error is constant	Yes
3	Denominator in non-linear equation is 0	DIVISION_BY_ZERO	Impossible to compute, complex correlation is equalled to 0	Yes
4	Number of iterations exceeded maximum value	NO_CONVERGENCE	Use last computed value for the real part of the complex correlation	Yes

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
5	Number of iterations exceeded maximum value	NO_CONVERGENCE	Use last computed value for the imaginary part of the complex correlation	Yes

Table 32 - Raw correlations processor error handling

5.3. Autocalibration

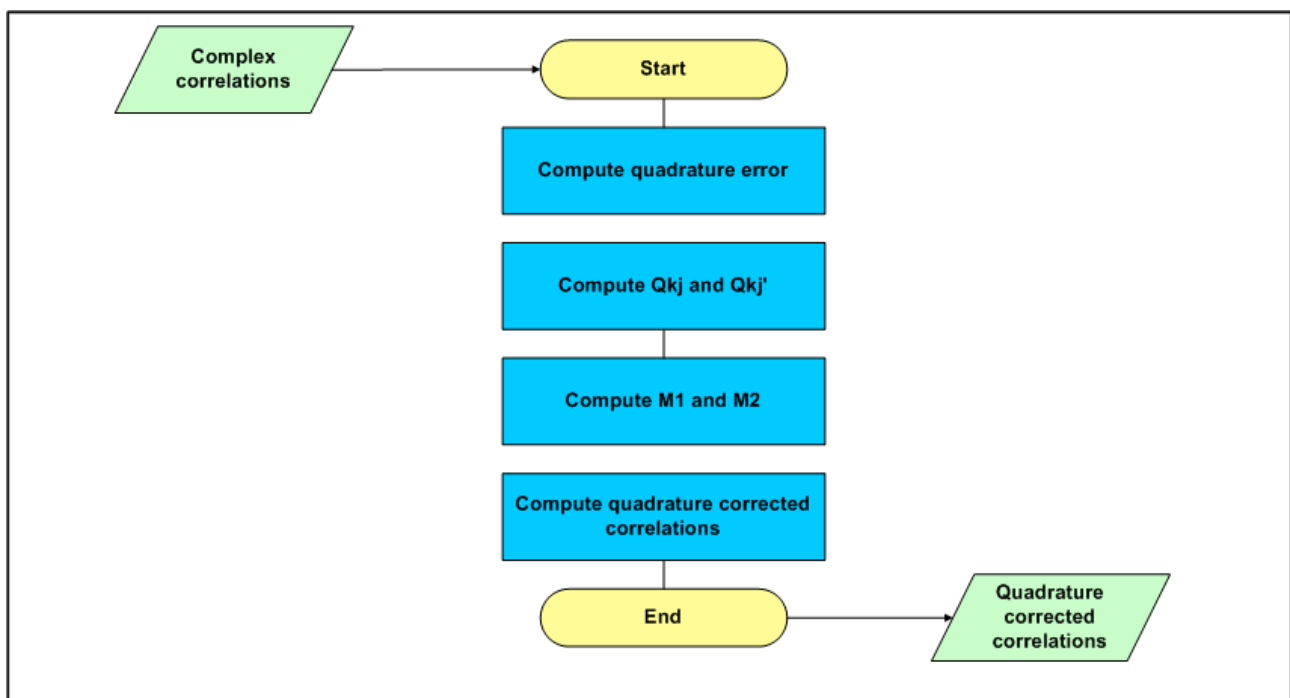


Figure 15 - Quadrature correction of raw correlations.

The quadrature correction is made continuously for all cross-correlations, before any further processing. This processing unit shall be invoked for all Level 0 data.

5.3.1. Inputs

- ☐ Complex normalized correlations, μ_{kj}
- ☐ Autocorrelations, μ_{kk}^{iq}

5.3.2. Outputs

- ☐ Quadrature corrected correlations, M_{kj}

5.3.3. List of Variables

Normalised quadrature corrected correlations, M_{kj} , will be stored in a matrix with all possible correlations (hub and arms). The size of this matrix will be $72 * 72$, where 72 is the total number of antennas in the instrument (in the current baseline, 72 considers the two outputs from each of the NIR-LICEF receivers).

Variable name	Description	Definition	Type	Class	Unit	Size
complex_correlations	Complex correlations between receivers, except auto correlations (μ_{kj}^{qi})	Eq. 5	Double Complex	I	N/A	[LICEF_NUMBER] x [LICEF_NUMBER]
auto_correlations	Auto correlations between receivers (μ_{kk}^{qi})	Eq. 9	double	I	N/A	[LICEF_NUMBER]
quadrature_error	Quadrature error, θ_{qk}	Eq. 9	double	L	N/A	[LICEF_NUMBER]
qkj	Intermediate computation value, Q_{kj}	Eq. 10	double	L	N/A	[LICEF_NUMBER] x [LICEF_NUMBER]
qkjcomma	Intermediate computation value, Q'_{kj}	Eq. 10	double	L	N/A	[LICEF_NUMBER] x [LICEF_NUMBER]
m1	Intermediate computation value, M_1	Eq. 11	Double Complex	L	N/A	[LICEF_NUMBER] x [LICEF_NUMBER]
m2	Intermediate computation value, M_2	Eq. 11	Double Complex	L	N/A	[LICEF_NUMBER] x [LICEF_NUMBER]
mkj	Quadrature corrected complex correlations (M_{kj})	Eq. 7	Double Complex	O	N/A	[LICEF_NUMBER] x [LICEF_NUMBER]

Table 33 - Autocalibration variable list

5.3.4. Implementation

1. First, the quadrature error, θ_{qk} , is computed through Eq. 9.
2. Then, for every antenna correlation:
 - a. Q_{kj} and Q'_{kj} are computed by Eq. 10.
 - b. M_1 and M_2 are computed by Eq. 11.
 - c. M_{kj} is obtained from Eq. 7, computed with all the quantities computed in the previous step.

5.3.5. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	Cosine of quadrature error is 0	DIVISION_BY_ZERO	Quadrature corrected correlations are returned as zero	Yes

Table 34 - Autocalibration error handling

5.4. Correlated Noise Injection

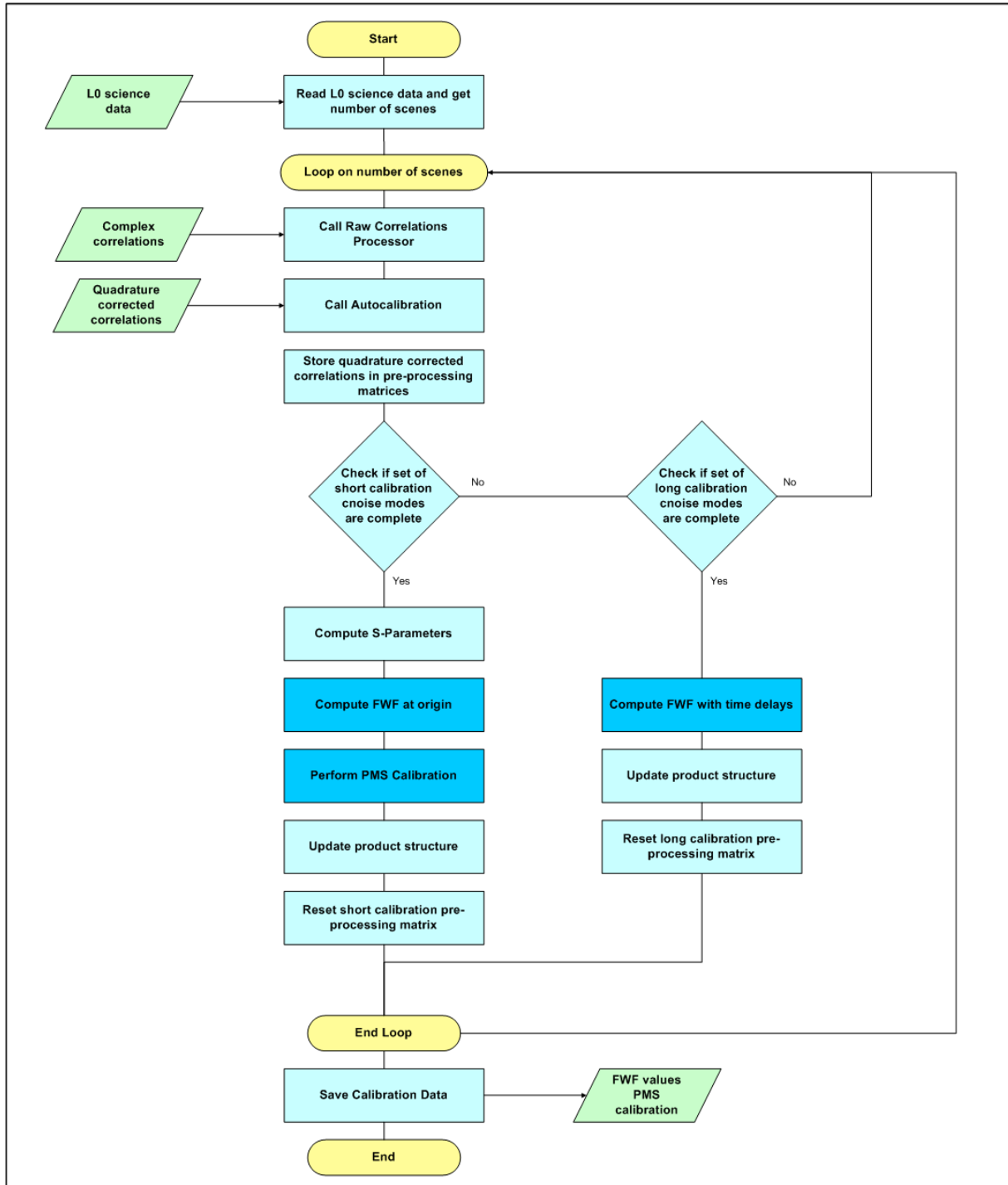


Figure 16 - Determination of calibration parameters and FWF estimation.

The calibration procedure for correlated noise injection is one of the most important. In fact, three crucial types of parameters are calibrated in this mode: PMS gains and offsets, the value of the FWF at the origin and the values of the FWF at time delays (used to compute the FWF shape). This processing

unit will be invoked each time the instrument is in internal calibration with correlated noise injection mode.

The PMS parameters and the FWF at the origin will be computed through the use of the 4-point calibration method, for the arms and the hub, while the FWF shape estimation will make use of correlated noise injection at different time delays. The outputs of the processing unit are the PMS parameters and the FWF estimation at all time points (origin and delayed).

The processing unit will need 4 different calibration steps, each with a different type of correlated noise injection mode [AD.7] for the FWF estimation at the origin, 8 steps for PMS calibration and 12 steps for FWF shape estimation. The processing unit will poll the L1a HKTM files for sets of correlated noise injection steps, needed to identify which set of calibration procedures can be executed.

Although the estimation of the FWF at the origin can be estimated with a subset of the packets needed for PMS calibration, the procedure for both calibrations, at instrument level, is done at the same time. As such, both calibrations are triggered only when all the 8 packets are present.

5.4.1. Inputs

- ❑ C-Noise Injection normalised, quadrature corrected, correlations, $M_{kj}^{C1,2}$ (from Autocalibration)
- ❑ Subsystem data required for instrumental error correction and antenna error correction, from ground calibration
 - S-parameters (SM_XXXX_AUX_SPAR__<ID>)
 - NIR auxiliary data (SM_XXXX_AUX_NIR__<ID>)
- ❑ Levell1a HKTM Data. (PMS and PHYSICAL_TEMPERATURES of HKTM data set from SM_XXXX_TLM_MIRA1A_<ID>)
 - NIR measured noise temperature (NIR measuring CAS temperature)
 - PMS output voltages for HOT and WARM noise injection temperatures:
 - PMS output voltage (Switch in C-even position, ATT=0)
 - PMS output voltage (Switch in C-even position, ATT=L)
 - PMS output voltage (Switch in C-odd position, ATT=0)
 - PMS output voltage (Switch in C-odd position, ATT=L)
 - PMS output voltage (Switch in C position, ATT=0, LAG -1)
 - PMS output voltage (Switch in C position, ATT=0, LAG 0)
 - PMS output voltage (Switch in C position, ATT=0, LAG +1)
 - PMS output voltage (Switch in U position, ATT=0)
 - PMS physical temperature
 - NDN physical temperature

where C/U position is the Noise Injection setting on the switch, ATT is the attenuation of the signal and LAG is the time lag in the noise injection signal.

5.4.2. Outputs

- ❑ Calibrated NIR PMS gain and offset, V_{off_k} and G_k (GAIN and OFFSET fields from PMS_COEFFICIENTS data set of SM_xxxx_CRSt1A<ID>)
- ❑ Receiver Temperature for NIR and LICEF (T_Rec_Ref_H, T_Rec_Ref_V and T_Rec_Ref_LICEF fields from PMS_COEFFICIENTS data set of SM_xxxx_CRSt1A<ID>)
- ❑ Reference CAS noise temperature (T_Noise_Ref_H and T_Noise_Ref_V fields from NIR_REFERENCE data set of SM_xxxx_CRSt1A<ID>)
- ❑ Dependent on calibration type (long or short), one delay or three delays:
 - One estimated point of the FWF, for amplitude calibration, $g_{kj}^C(0)$ (for use in amplitude calibration) (FWF_Origin field from AMPL_PHASE_CORRECTION data set from SM_xxxx_MIR_CRSt1A<ID>)
 - Three points of the FWF, for image reconstruction, $g_{kj}^C(-t_s), g_{kj}^C(0), g_{kj}^C(t_s)$ (FWF_MEASUREMENTS field from FWF_COEFFICIENTS data set from SM_xxxx_MIR_AFWx1A<ID>)
 - 5 coefficients of the FWF Shape, for image reconstruction, (A, B, C, D and E fields from FWF_COEFFICIENTS data set from SM_xxxx_MIR_AFWx1A<ID>)

5.4.3. NIR-R mode

NIR-R calibration will measure the Noise Source injection temperature valid for the whole sequence. The processing unit will implement the steps defined in Eqs 75-79.

5.4.3.1. List of Variables

Variable name	Description	Definition	Type	Class	Unit	Size
obet	Timestamp	N/A	long long	I	N/A	1
nir_temps	Components physical temperatures ($T_{p1}, T_{p3}, T_{p6}, T_{p7}, T_{pUh}, T_{pUv}$)	Section 3.5.5	float	I	K	[NIR_NUMBER][6]
nir_pulse_length	NIR normalised pulse length (η)	Eq. 75	double	I	N/A	[POL_MODE][NIR_NUMBER]
t_nr_0	Reference noise injection temperature (T_{NR0})	Eq. 86	double	I	K	[POL_MODE][NIR_NUMBER]

Variable name	Description	Definition	Type	Class	Unit	Size
t_a_on0	Correction parameter from external target calibration ($T_{A_ON0}^{CIP}$)	Eq. 85	double	I	K	[POL_M ODE][NI R_NUM BER]
l_r	NIR parameters (L_R)	Section 3.5.5	double	I	N/A	1
l_dr	NIR parameters (L_{DR})	Section 3.5.5	double	I	N/A	1
l_dc	Attenuator between LICEF input plane in C port and LICEF output plane (L_{DC})	Section 3.5.5	double	I	N/A	1
u_r	Noise temperature correction factor, measured on ground (u_R)	Eq. 76	double	I	N/A	1
c_r	Front-end characterization coefficient, measured on ground (c_R)	Eq. 79	double	I	N/A	1
d_r	Front-end characterization coefficient, measured on ground (d_R)	Eq. 79	double	I	N/A	1
a_r	NIR computation factor, (A_R)	Eq. 76	double	L	N/A	1
b_r	NIR computation factor, (B_R)	Eq. 77	double	L	N/A	1
t_t3	NIR computation factor (T_{t3})	Eq. 78	double	L	K	1
t_cab	NIR parameters (T_{Cab})	Eq. 46	double	L	K	1
ndn_temp	NDN temperature (T'_{NS})	Eq. 75	double	L	K	[POL_M ODE][NI R_NUM BER]

Variable name	Description	Definition	Type	Class	Unit	Size
ndn_temp_Cport	NDN temperature at C port of the switches $(T_{NS}^{LV,H-CIP})$	Eq. 79	double	O	K	[POL_M ODE][NIR_NUM BÉR]

Table 35 - NIR-R mode calibration variable list

5.4.3.2. Implementation

1. This function will start when the following sequence is found complete, according to the configuration parameters defined in section 3.9:

Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
1	C	NIR-R	WARM	OFF	L1	0	$(*)M_{kj}^{C1e}$	η_1^e	-	v_3^e	3rd
2	C	NIR-R	HOT	OFF	L1	0	$(*)M_{kj}^{C2e}$	η_2^e	-	v_4^e	3rd
3	C	NIR-R	WARM	OFF	L0	0	$(*)M_{kj}^{C1e}$	η_1^e	-	v_1^e	3rd
4	C	NIR-R	HOT	OFF	L0	0	$(*)M_{kj}^{C2e}$	η_2^e	-	v_2^e	3rd

Figure 17 - Correlated noise injection modes for NIR-R computation

2. In this mode the processing unit will start by getting all the ground measured NIR parameters, as well as the ones stored after External Calibration mode. The values used are the latest ones; they are not interpolated over temperature.
3. For each NIR, and for each polarisation, the steps outlined in Section 3.8.1 are taken.
 - 3.1. T_{Cab} is computed through Eq. 46.
 - 3.2. T_{t3} is computed through Eq. 78.
 - 3.3. A_R and B_R are computed through Eqs. 76 and 77, but retrieving T_{NR} from the NIR ADF.
 - 3.4. T_{NS}' is computed through Eq. 75.
 - 3.5. $T_{NS}^{LV,H-CIP}$ is computed through Eq. 79.
4. The processing unit stores $T_{NS}^{LV,H-CIP}$ values in the SM_xxxx_MIR_CRSx1A<ID> file.

5.4.3.3. Data Retrieval

Contents	Size	File type	Method
NIR parameters	32 doubles	*AUX_NIR*	l_xxx and t_rec_x by temperature c_xxx, d_xxx and

Contents	Size	File type	Method
			u_XXX are constant values
NIR temperatures	[NIR_NUMBER][6] doubles	L1a HKTM	Get them from thermistor table data
Antenna noise injection temperature during calibration	6 doubles	* NIR_1A*	Retrieve the last one computed

Table 36- Data retrieval strategy for NIR-R mode computation

5.4.4. Fringe Wash Function at the origin

5.4.4.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
obet	Time stamp	N/A	long long	I	N/A	[CNOIS E_PACK ETS]
mkj	Quadrature corrected correlations. This matrix will hold 4 steps. (M_{kj}^q)	Eq. 7	Double Complex	I	N/A	[LICEF_ NUMBE R] x [LICEF_ NUMBE R] x [CNOIS E_PACK ETS]
pms_offset	PMS calibrated offset (V_{off_k})	Eq. 14	double	I	mV	[LICEF_ NUMBE R]
pms_four_point	Four point PMS voltages LICEF index, last index is 0-V1, 1-V2, used in FWF computation ($v_{1k}, v_{2k}, v_{3k}, v_{4k}$)	Eq. 13	double	I	mV	[LICEF_ NUMBE R] x [2]
sparameters	Paths S-Parameters ($S_{LH,V,C,Uk}$)	Eqs. 17 and 19	t_11a_spar_paths	I	N/A	pointer
tns_warm	WARM noise injection temperature (T_{NS1}^α)	Eq. 75	double	I	N/A	[2] x [2]

Variable name	Description	Definition	Type	Class	Unit	Size
tns_hot	Hot noise injection temperature (T_{NS2}^{α})	Eq. 75	double	I	N/A	[2] x [2]
fwf_odd	Fringe Wash Function data, for ODD noise sources	N/A	Double Complex	L	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R] x [2]
fwf_even	Fringe Wash Function data, for EVEN noise sources	N/A	Double Complex	L	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R] x [2]
receiver_fwf_phases	Individual phase of each receiver, used in the estimation of the FWF for antenna pairs not sharing the same noise source (θ_k)	Eq. 21	double	L	Radian s	[LICEF_NUMBE R]
receiver_fwf_amplitude s	Individual amplitude of each receiver, used in the estimation of the FWF for antenna pairs not sharing the same noise source (g_k)	Eq. 21	double	L	N/A	[LICEF_NUMBE R]
fwf_shape	Fringe Wash Function shape coefficients (g_{kj}^C)	RD.16	double	O	N/A	6 x [LICEF_NUMBE R] x [LICEF_NUMBE R]
fwf_c	Fringe Wash Function data (g_{kj}^C)	Eq. 18	Double Complex	O	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R]

Table 37 - FWF(0) data processing variable list

5.4.4.2. Implementation

1. This function will start when the following sequence is found complete, according to the configuration parameters defined in section 3.9:

FWF(0) INDIVIDUAL SEQUENCE												
	Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
FWF(0)	12	C	LICEF-LC2	WARM	OFF	L1	0	M_{kj}^{C2e}	-	v_3^e	v_3^e	2nd
	13	C	LICEF-LC2	HOT	OFF	L1	0	M_{kj}^{C1e}	-	v_4^e	v_4^e	2nd
	6	C	LICEF-LC	WARM	OFF	L0	0	M_{kj}^{C2e}	-	v_1^e	v_1^e	2nd
	5	C	LICEF-LC	HOT	OFF	L0	0	M_{kj}^{C1e}	-	v_2^e	v_2^e	2nd
	8	C	LICEF-LC	OFF	HOT	L0	0	M_{kj}^{C2o}	-	v_2^o	v_2^o	2nd
	9	C	LICEF-LC	OFF	WARM	L0	0	M_{kj}^{C1o}	-	v_1^o	v_1^o	2nd
	10	C	LICEF-LC2	OFF	HOT	L1	0	M_{kj}^{C2o}	-	v_4^o	v_4^o	2nd
	11	C	LICEF-LC2	OFF	WARM	L1	0	M_{kj}^{C1o}	-	v_3^o	v_3^o	2nd
	30	C	NIR-A	OFF	OFF	L0	0	-	-	-	-	1st

Figure 18 - Correlated noise injection modes for FWF at the origin computation

2. Steps 12 and 13 are part of the short-extended sequence, which is not the operational baseline. The processing below does not need explicitly data in those configurations.
3. The data for EVEN and ODD noise injection modes is separated into two sets of matrices.
4. The fringe wash function estimation function will loop over all possible LICEF combinations
 - 4.1. Check if each antenna pair shares a noise source (see Figure 10).
 - 4.2. Compute the FWF value at the calibration plane (fwf_odd or fwf_even), through Eq. 18 with values of the corresponding noise source (ODD or EVEN)¹.
 - 4.3. If the antenna pair shares two noise sources, the value of the FWF at the calibration plane is stored as the average of both FWF estimates.
 - 4.4. At the end of the computation for each antenna pair, the value of $modulus_avg$ is updated.
5. After the cycle is completed, the FWF estimate for the remaining antenna pairs, the ones that do not share the same noise source, must be computed. There are two alternatives for this, using the FWF closures method described in Eq.20, or doing solving a system of equations for the receivers phase and amplitudes as in Eq.21
6. The FWF closures method is based on Eq.20, where for the FWF at the origin there is no need to perform Fast Fourier Transforms, and the g_{kj} values themselves can be used directly:

¹ – The S-Parameters used for ODD or EVEN noise source paths are, of course, different

6.1. Using the FWF measurements sharing the same NS for odd and even sources at C port, we can fill a 72x72 matrix with 1 where there is a measurement and 0 where there is not

6.2. The following matlab code plots how to close all relationships in just three iterations, showing the baselines closed and the ones used in the closure:

```
% R is the Matrix of baselines with measured fringe-washing function
R = zeros(Nant, Nant);
for arm=1:3
    for n=1:(NEL+NRED)/6-1
        R((arm-1)*(NEL+NRED) + (n-1)*6 +1:(arm-1)*(NEL+NRED) + (n-1)*6 +12, (arm-1)*(NEL+NRED) + (n-1)*6 +1:(arm-1)*(NEL+NRED) + (n-1)*6 +12) = ones(12,12);
    end
end

R(1:6, NEL+NRED+1:NEL+NRED+6) = ones(6,6);
R(1:6, 2*(NEL+NRED)+1:2*(NEL+NRED)+6) = ones(6,6);
R(NEL+NRED+1:NEL+NRED+6, 2*(NEL+NRED)+1:2*(NEL+NRED)+6) = ones(6,6);
R(NEL+NRED+1:NEL+NRED+6, 1:6) = ones(6,6);
R(2*(NEL+NRED)+1:2*(NEL+NRED)+6, 1:6) = ones(6,6);
R(2*(NEL+NRED)+1:2*(NEL+NRED)+6, NEL+NRED+1:NEL+NRED+6) = ones(6,6);

figure(10), clf; imagesc(R); axis 'xy'; axis equal; hold on
AA=R;

color = ['c'; 'y'; 'm'; 'w'];
found = 0;

for i=1:3 % three steps are enough to fill all
    for k=1:71
        for j=k+1:72
            if (R(k,j)==1)
                %do nothing, baseline is already measured
            elseif (R(k,j)==0)
                found = 0;
                for p=72:-1:k+1
                    if (R(k,p)==1) %check column has value from bottom to top
                        for m=1:p-1
                            if (R(m,j)==1) %check row has value from left to right
                                if (R(m,p)==1) %check column and row selected have
                                    correlation among themselves
                                        figure(10); hold on;
                                        plot(k,j, strcat(color(i), 'x'));
                                        plot(k,p, 'g. '); plot(m,j, 'g. '); plot(m,p, 'g. ');
                                        found = 1;
                                    end
                                end
                            end
                        end
                    end
                end
            end
            if (found == 1)
                break;
            end
        end
    end
    if (found == 1)
        break;
    end
end
end
```

```

        if (found == 1)
            AA(k,j) = 1;
        end
    end
end
R=AA;
end

```

6.3. The closure has to be done with the FWF value at the C port g_{kj}^C . This means that the system above has to be performed only once on the 72x72 correlation matrix.

6.4. Finally, some of the correlations cannot be closed with the available relationships (columns of A_21 and B_21 with the rest of receivers). For these correlations, the method based on the modulus estimation and phase difference shall be applied:

6.4.1. A first solution for the FWF phase is obtained by

- ⇒ Setting the phase of the first LICEF in each arm to 0
- ⇒ Using the phase of the first LICEF in each section driven by the same noise source as a reference (θ_j) and the phase of the compute FWF values (α_{kj}) to compute the individual phases of each of the other receivers in the same section (θ_k) by

$$\theta_k = \theta_j + \alpha_{kj} \quad \text{Eq. 133}$$

- ⇒ A final correction to the first estimate is applied when the difference between the individual phases of an antenna pair is $|2\pi|$ greater than the FWF value for that same receiver (phase unwrapping)

6.4.2. The linear system of Eq. 117 is then solved, by the Singular Value Decomposition method, using all the available values of α_{kj} and setting the non-separable errors to 0. The final solution for θ_k is obtained.

6.4.3. The non-separable errors are computed using Eq. 22

6.4.4. The FWF phase for each antenna pair not sharing the same noise source is computed using Eq. 23

6.4.5. The FWF modulus for each antenna pair not sharing the same noise source is computed using a similar system of equations derived from the FWF modulus for receivers sharing the same noise source (as in Eq. 21)

7. The function returns `fwf_c`, the averaged physical temperature during the sequence, number of epochs averaged and the R matrix representing FWF values measured and estimated.
8. The FWF coefficients, `fwf_shape`, are computed as described in [RD6].

5.4.4.3. Data Retrieval

Contents	Size	File type	Method
Instrument mode	1 t_cnoise_mode	L1a HKTM (cnoise_mode)	Return t_cnoise_mode value of L1a packet with same OBET
PMS voltages, v1 and v2	[LICEF_NUMBER]x2 double	L1a HKTM	Search for PMS voltages, in the preceding packets, with cnoise_mode set to “Step 1” (v1) and “Step 3” (v2)
CAS S-parameters	[LICEF_NUMBER]x3 doublecomplex	*AUX_SPAR*	By temperature

Table 38 - Data retrieval strategy for FWF at the origin computation

5.4.5. PMS calibration ~~through the 4 measurement technique~~ in the 4-point Calibration mode

This process will compute the PMS gain and offset for all LICEFs (not LICEF-NIR). The computation for LICEF-NIR is described in the next section, as it requires further computations.

5.4.5.1. List of Variables

Variable name	Description	Definition	Type	Class	Unit	Size
pms_four_point	Four point PMS voltages LICEF index, last index is 0-V1, 1-V2, used in FWF computation ($v_{1k}, v_{2k}, v_{3k}, v_{4k}$)	Eq. 13	double	I	mV	[LICEF_ NUMBER] x [POL_N UMER] x [4]
sparameters	Paths S-Parameters (S_{ks} and $S_{LH,V,C,Uk}$)	Eqs. 17 and 19	t_ll_a_spar _paths	I	N/A	pointer
tns_warm	WARM noise injection temperature (T_{NS1}^{α})	Eq. 65	double	I	N/A	[2] x [2]
tns_hot	Hot noise injection temperature (T_{NS2}^{α})	Eq. 65	double	I	N/A	[2] x [2]

Variable name	Description	Definition	Type	Class	Unit	Size
receiver_temp	LICEF receiver temperatures $T_{Rk}^{H,V}$	Eq. 100	double	O	K	[LICEF_NUMBER]
delta_l	Attenuator level (ΔL_k)	Eq. 104	double	O	N/A	[LICEF_NUMBER]
pms_gain	PMS calibrated gains (G_k)	Eq. 14	double	O	mV/K	[LICEF_NUMBER]
pms_offset	PMS calibrated offset (V_{off_k})	Eq. 14	double	O	mV	[LICEF_NUMBER]

Table 39- PMS calibration variable list

5.4.5.2. Implementation

1. This function will start when the following sequence is found complete, according to the configuration parameters defined in section 3.9. It will also retrieve the NIR-measured temperatures of the noise sources as explained in section 5.4.3.

PMS CALIBRATION SEQUENCE														
	Step	Epochs		LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
		CMD	Valid											
PMS	1	3	1	C	NIR-R	WARM	OFF	L1	0	$(*)M_{kj}^{C1e}$	η_1^e	-	v_3^e	1st & 3rd
	2	3	1	C	NIR-R	HOT	OFF	L1	0	$(*)M_{kj}^{C2e}$	η_2^e	-	v_4^e	1st & 3rd
	3	3	1	C	NIR-R	WARM	OFF	L0	0	$(*)M_{kj}^{C1e}$	η_1^e	-	v_1^e	1st & 3rd
	4	3	1	C	NIR-R	HOT	OFF	L0	0	$(*)M_{kj}^{C2e}$	η_2^e	-	v_2^e	1st & 3rd
	5	2	1	C	LICEF-LC	HOT	OFF	L0	0	M_{kj}^{C1e}	-	v_2^e	v_2^e	2nd
	6	2	1	C	LICEF-LC	WARM	OFF	L0	0	M_{kj}^{C2e}	-	v_1^e	v_1^e	2nd
	7	2	1	U	LICEF-LU	OFF	OFF	L0	0	M_{kj}^U	-	v_U	v_U	2nd
	8	2	1	C	LICEF-LC	OFF	HOT	L0	0	M_{kj}^{C2o}	-	v_2^o	v_2^o	2nd
	9	2	1	C	LICEF-LC	OFF	WARM	L0	0	M_{kj}^{C1o}	-	v_1^o	v_1^o	2nd
	10	2	1	C	LICEF-LC2	OFF	HOT	L1	0	M_{kj}^{C2o}	-	v_4^o	v_4^o	2nd
	11	2	1	C	LICEF-LC2	OFF	WARM	L1	0	M_{kj}^{C1o}	-	v_3^o	v_3^o	2nd
	30	1	0	C	NIR-A	OFF	OFF	L0	0	-	-	-	-	1st

Figure 19 - Correlated noise injection modes for PMS calibration

2. For each PMS there will be one gain and two offsets (except in the case of the third segment of each arm, where only one offset is available). However, only the mean value for each offset is stored.

3. The function will cycle through all LICEFS and compute the calibrated gain and offset. From Eqs. 62-64 it is easy to see that these computations will be different for the hub and arms, as well as different for each segment in a given arm.
 - 3.1. Hub computations for offset calibration are made using Eq. 65
 - 3.2. Hub computations for gain calibration are made using Eq. 65
 - 3.3. The arms computations are made using Eqs. 66 and 67:
 - 3.3.1. The computation for the PMS gain in the first segment, l , of the arms is the same as for the hub. For segment m , the computation for the offset is the same as for segment l . The PMS gain computation, however, must take into account the PMS gains from the previous segments.
 - 3.3.2. The implementation for the last segment, segment n , follows the same operations as in the hub for the offsets computation, since there is only one noise source for PMS data. The remaining PMS gains are computed as for segment m but taking into account both the averages of segment l and segment m gains.
4. The attenuator level, ΔL_k , is computed through Eq. 104.
5. The processing unit will also compute the receiver temperature, $T_{Rk}^{H,V}$, by using the data from step 7 in the previous figure, Eq. 69 and Eq. 100.
6. The output of the function is $T_{Rk}^{H,V}$, ΔL_k , G_k and V_{off_k} .

5.4.5.3. Data Retrieval

Contents	Size	File type	Method
Instrument mode	1 t_cnoise_mode	L1a HKTM (cnoise_mode)	Return t_cnoise_mode value of L1a packet with same OBET
PMS voltages, v1, v2, v3 and v4. EVEN and ODD	[ARM_NUMBER]x[LICEFS_PER_ARM]x4x2 double	L1a HKTM	Search for pms_voltages, in the preceding packets, with cnoise_mode set to “Step 1” (v2, EVEN), “Step 2” (v4, EVEN), “Step 3” (v1, EVEN), “Step 4” (v3, EVEN), “Step 8” (v2, ODD), “Step 9” (v1, ODD), “Step 10” (v4, ODD), “Step 11” (v3, ODD)

Table 40 - Data retrieval strategy for PMS calibration

5.4.6. LICEF-LC/LC2 mode

5.4.6.1. List of Variables

Variable name	Description	Definition	Type	Class	Unit	Size
ndn_temp_Cport	NDN temperature at C port of the switches $(T_{NS}^{LV,H-CIP})$	Eq. 79	double	I	K	[POL_MODE][NIR_NUMBER]
nir_four_point	Four point NIR PMS voltages $(v_{1k}, v_{2k}, v_{3k}, v_{4k})$	Eq. 13	double	I	mV	[NIR_NUMBER] x [POL_NUMBER] x [4]
noise_pms_voltages	LICEF unnoise injection PMS voltages (v_k^U)	Eq. 80	double	I	N/A	[LICEF_NUMBER]x[POL_NUMBER]
sparameters	Switch S-Parameters $(S_{LH,V,C,Uk})$	Eqs. 80	t_l1a_spar_paths	I	N/A	pointer
ohmic_efficiency	Antenna ohmic efficiencies $(\eta_{Hk,Vk})$	Eq. 80	double	I	N/A	[LICEF_NUMBER]x[POL_NUMBER]
receiver_temp	Receiver noise temperatures at CIP plane $(T_{rec}^{LV,H-CIP})$	Eq. 80	double	O	K	[POL_MODE][NIR_NUMBER]
nir_gain	NIR calibrated gain $(G_{PMS}^{LV,H-CIP})$	Eq. 81	double	O	mV/K	[POL_MODE][NIR_NUMBER]
nir_offset	NIR calibrated offset (v_{off})	Eq. 81	double	O	mV	[POL_MODE][NIR_NUMBER]

Table 41 - LICEF LC/LC2 mode list of variables

5.4.6.2. Implementation

1. The required steps for this processing are already included in the calibration configuration presented in section 5.4.5.2.
2. The function will start when all the information has been collected:
 - 2.1. CAS noise temperatures in HOT and WARM mode ($T_{NS}^{LV,H-CIP}$), from NIR-R mode
 - 2.2. NIR PMS voltages in the 4 modes, from LICEF-LC and LICEF-LC2 modes
 - 2.3. LICEF PMS voltages from LICEF-LU mode
3. The function computes $T_{rec}^{LV,H-CIP}$ using Eq. 80.
4. The function computes $G_{PMS}^{LV,H-CIP}$ and v_{off} using Eq. 81.
5. The processing unit stores $T_{rec}^{LV,H-CIP}$, $G_{PMS}^{LV,H-CIP}$ and v_{off} values in the SM_XXXX_MIR_CRSx1A<ID> file.

5.4.7. Fringe Wash Function with time delays

5.4.7.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
obet	Time stamp	N/A	long long	I	N/A	[6]
mkj	Quadrature corrected correlations. This matrix will hold 6 scenes. (M_{kj}^q)	Eq. 7	Double Complex	I	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R] x [6]
fwf_origin_hv	Fringe Wash Function at origin data (g_{kj})	Eq. 19	Double Complex	I	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R] x [2]
fwf_hv	Fringe Wash Function with time delays data (g_{kj})	Eq. 18	Double Complex	O	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R] x [2] x [2]

Table 42 - FWF at time delays variable list

5.4.7.2. Implementation

1. This function will start when the quadrature corrected correlations for the following noise injection modes are collected [AD.7]:

FWF SHAPE INDIVIDUAL SEQUENCE												
	Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
FWF Shape	10	C	LICEF-LC2	OFF	HOT	L1	0	M_{kj}^{C2o}	-	v_4^o	v_4^o	2nd
	13	C	LICEF-LC2	HOT	OFF	L1	0	M_{kj}^{C1e}	-	v_4^e	v_4^e	2nd
	12	C	LICEF-LC2	WARM	OFF	L1	0	M_{kj}^{C2e}	-	v_3^e	v_3^e	2nd
	11	C	LICEF-LC2	OFF	WARM	L1	0	M_{kj}^{C1o}	-	v_3^o	v_3^o	2nd
	9	C	LICEF-LC	OFF	WARM	L0	0	M_{kj}^{C1o}	-	v_1^o	v_1^o	6th
	6	C	LICEF-LC	WARM	OFF	L0	0	M_{kj}^{C2e}	-	v_1^e	v_1^e	6th
	5	C	LICEF-LC	HOT	OFF	L0	0	M_{kj}^{C1e}	-	v_2^e	v_2^e	6th
	8	C	LICEF-LC	OFF	HOT	L0	0	M_{kj}^{C2o}	-	v_2^o	v_2^o	6th
	18	C	LICEF-LC	OFF	HOT	L0	-T	M_{kj}^{C2o}	-	v_2^o	v_2^o	6th
	19	C	LICEF-LC	OFF	WARM	L0	-T	M_{kj}^{C1o}	-	v_1^o	v_1^o	6th
	20	C	LICEF-LC	WARM	OFF	L0	-T	M_{kj}^{C2e}	-	v_1^e	v_1^e	6th
	21	C	LICEF-LC	HOT	OFF	L0	-T	M_{kj}^{C1e}	-	v_2^e	v_2^e	6th
	22	C	LICEF-LC	OFF	HOT	L0	+T	M_{kj}^{C2o}	-	-	-	6th
	23	C	LICEF-LC	OFF	WARM	L0	+T	M_{kj}^{C1o}	-	-	-	6th
	24	C	LICEF-LC	WARM	OFF	L0	+T	M_{kj}^{C2e}	-	-	-	6th
	25	C	LICEF-LC	HOT	OFF	L0	+T	M_{kj}^{C1e}	-	-	-	6th
	30	C	NIR-A	OFF	OFF	L0	0	-	-	-	-	1st

Figure 20 - Correlated noise injection modes for FWF with time delays computation

2. Steps 12 and 13 are part of the short-extended sequence, which is not the operational baseline. The processing below does not need explicitly data in those configurations.
3. The data for EVEN and ODD noise injection modes is separated into two sets of matrices.
4. The fringe wash function estimation function will loop over all possible LICEF combinations
 - a. Check if each antenna pair shares a noise source (see Figure 10).
 - b. Compute the FWF value at time delays, through Eq. 18 (second set of equations)

- c. If the antenna pair shares two noise sources, the value of the FWF at the calibration plane is stored as the average of both FWF estimates.
 - d. At the end of the computation for each antenna pair, the value of `modulus_avg` is updated.
5. Step 5 of Section 5.4.4.2 is repeated for the antennas not sharing the same noise source. In this case, the closures method needs a discrete number of points for the FWF shape and the Fast Fourier Transform involved in it (see Eq. 20). The FWF shape is composed of a sinc function for the amplitude and a quadratic function for the phase (see RD.16). The discretisation is performed for a time range of $[-60, 60]$ nanoseconds using a total of 4096 samples to speed up the Fourier Transforms.
6. The function returns `fwf_hv`, with the values of the FWF at time delays +1 and -1.

5.4.8. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	File accessor unable to read the L0 file	DATA_CORRUPTED	Processing unit returns with no data processed.	No
2	Number of scenes is insufficient	DATA_CORRUPTED	Processing unit returns with no data processed.	No
3	File accessor unable to write calibration products	None	Output error to log. Processing unit is finished at the time of writing the product.	No
4	Unable to compute S-Parameter term	DIVISION_BY_ZERO	S-Parameter term used in computations is 1	Yes
6	Unable to compute PMS offset	DIVISION_BY_ZERO	PMS Offset computed and returned is 0	Yes
7	Unable to compute denominator of gain equation	DIVISION_BY_ZERO	Denominator used in computations is 1	Yes
8	Unable to compute PMS gain	DIVISION_BY_ZERO	PMS gain returned is the one measured on-ground	Yes
9	Unable to compute average of PMS gains of previous segment	DIVISION_BY_ZERO	Averaged PMS gain computed returned is the one measured on-ground	Yes

Table 43 - Correlated Noise Injection error handling

5.5. Uncorrelated Noise Injection

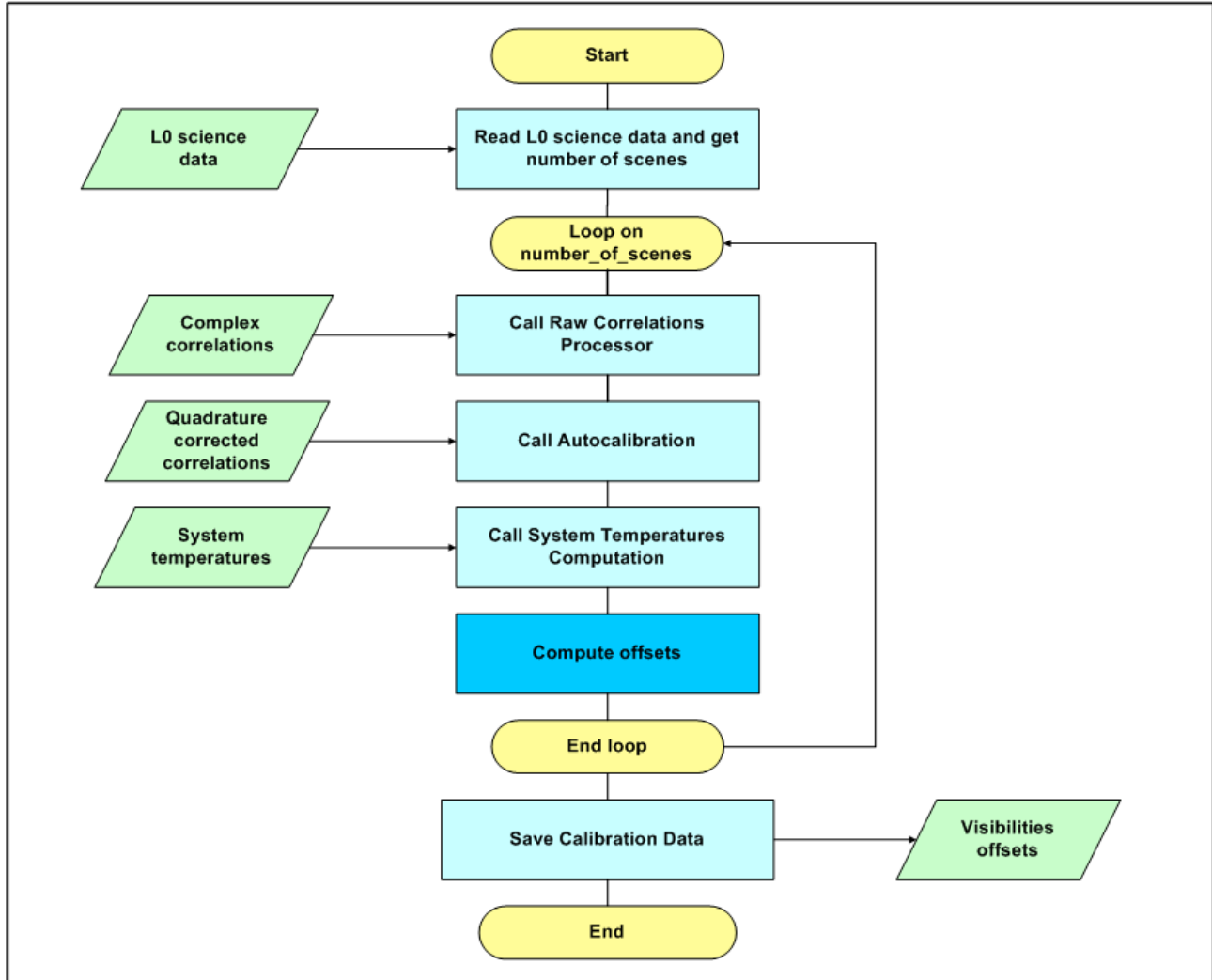


Figure 21 - Computation of visibilities offsets.

The uncorrelated noise injection procedure aims at the calibration of the residual offset of the visibilities for any pair of receivers. Every time that the instrument mode is recognized as internal calibration with uncorrelated noise injection, this processing unit will be used. It will compute an offset for each visibility sample and update a Level 1a product with these values. During error compensation, these offsets are subtracted from all visibilities measured in any instrument mode.

5.5.1. Inputs

- ❑ Normalised quadrature corrected correlations, M_{kj}^U (from Autocalibration)
- ❑ System Temperatures at reference planes, T_{sys}^q (from System Temperatures Computation)
- ❑ PMS Offsets, v_{off_k} , (from Correlated Noise Injection)

- ❑ Receiver Noise Temperature at CIP, $T_{R_k}^{21^\circ C}$, and its sensitivity (from LCF_ADF)

5.5.2. Outputs

- ❑ Correlations Offsets, V^{UH} , (OFFSET field from UNC_OFFSET_CORRECTION data set of SM_xxxx_MIR_UNCN1A<ID>)

5.5.3. Visibilities Offsets Computation

5.5.3.1. List of Variables

The offsets will be stored in a vector with $72 \times 71/2$ positions, corresponding to the total number of non-redundant visibilities ($N_{\text{signals}} \times (N_{\text{signals}} - 1) / 2$).

Variable name	Description	Definition	Type	Class	Unit	Size
filename	Name of L0 science data file to be processed	N/A	char	I	N/A	pointer
mkj	Quadrature corrected correlations (M_{kj}^q)	Eq. 7	Double Complex	I	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R]
system_temperatures	System temperatures ($T_{\text{sys}_k}^{UC}$)	Eq. 69	double	I	K	[LICEF_NUMBE R]
visibilities_offsets	The computed visibilities offsets (V_{kj}^{UC})	Eq. 70	Double Complex	O	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R]

Table 44 - Raw Correlations variable list

5.5.3.2. Implementation

1. The processing unit, retrieves the quadrature corrected visibilities
2. Executes the system temperatures processing unit to compute Eq. 69
3. Applies Eq. 66 to compute the visibilities offsets
4. And `visibilities_offsets` is the output of the processing unit.

5.5.4. PMS Gain Computation in ALL-LICEF1-point Calibration mode

5.5.4.1. List of Variables

The offsets will be stored in a vector with $72 \times 71/2$ positions, corresponding to the total number of non-redundant visibilities ($N_{\text{signals}} \times (N_{\text{signals}} - 1)/2$).

Variable name	Description	Definition	Type	Class	Unit	Size
filename	Name of L0 science data file to be processed	N/A	char	I	N/A	pointer
v_u	v_{u_k} is the PMS voltage at the Uncorrelated Noise epoch	Eq. 37	double	I	mv/K	[LICEF_NUMBER]
v_off	v_{off_k} is the consolidated PMS offset	Eq. 37	double	I	mv	[LICEF_NUMBER]
lice_f_temperatures	T_{u_k} is the physical temperature of the U-load	Eq. 37	double	I	K	[LICEF_NUMBER]
receiver_noise_temperature	$T_{R_k}^{21^\circ C}$ receiver noise temperature at CIP	Eq. 37	double	I	K	[LICEF_NUMBER]
STR	receiver noise temperature sensitivity	Eq. 37	double	I	K	[LICEF_NUMBER]
gain	The computed PMS Gains (G_k^C)	Eq. 37	Double Complex	O	N/A	[LICEF_NUMBER] x [LICEF_NUMBER]

Table 45 - Raw Correlations variable list

5.5.4.2. Implementation

1. The processing unit, retrieves the PMS voltages and the physical temperatures for each epoch
2. It then retrieves the receiver noise temperature from the ADF, along with the sensitivity and translates it to the epoch physical temperature
3. It then applies Eq. 37 to compute the PMS Gains

5.5.5. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	File accessor unable to read the L0 file	DATA_CORRUPTED	Processing unit returns with no data processed.	No
2	File accessor unable to write calibration products	None	Output error to log. Processing unit is finished at the time of writing the output product.	No

Table 46 - Uncorrelated Noise Injection error handling

5.6. System temperatures computation

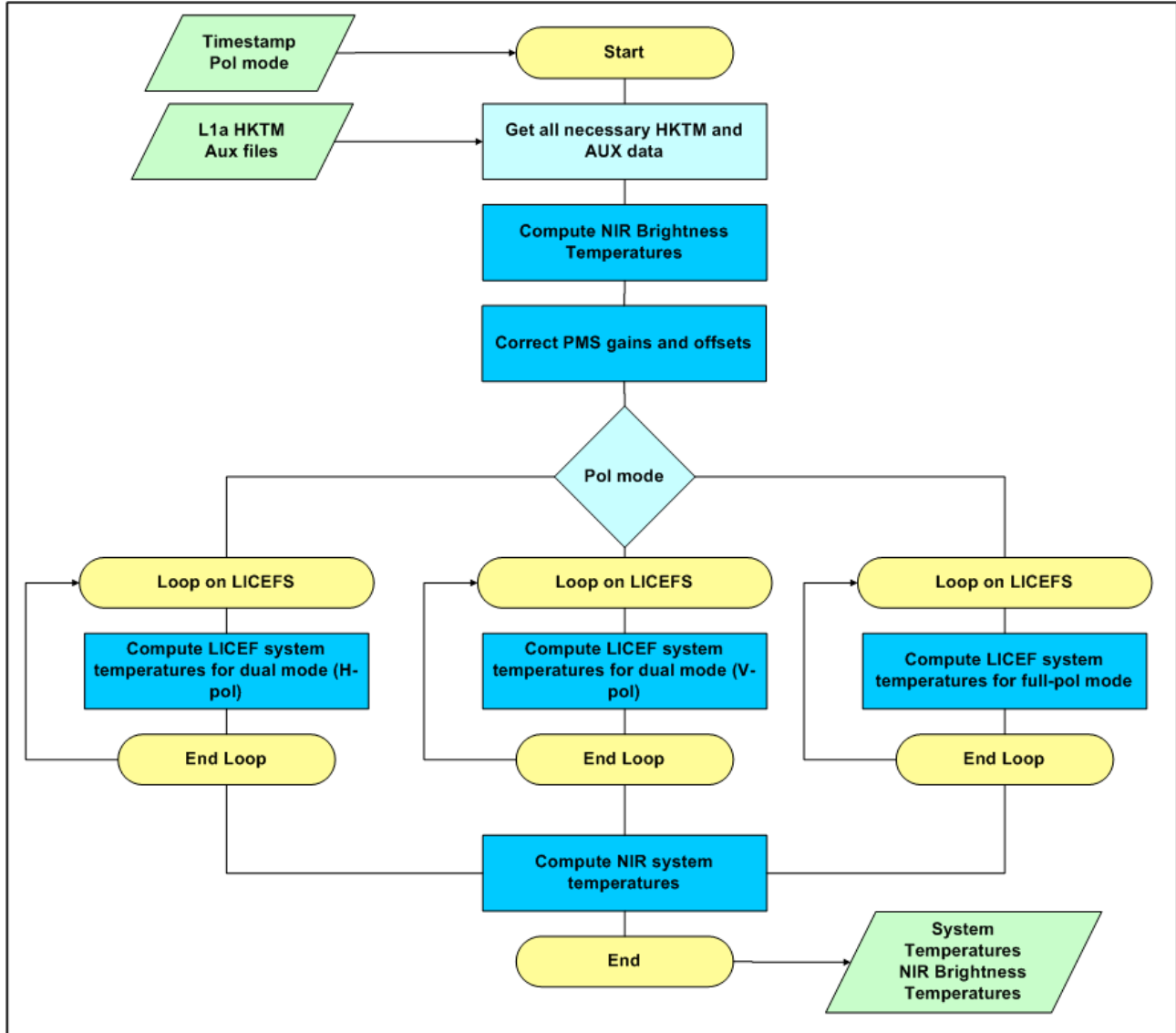


Figure 22 - Computation of system temperatures.

This processing unit will receive the ancillary data from all instrument modes. The system temperatures measured will then be stored as L1a products and used to denormalise the calibrated visibilities prior to image reconstruction.

The NIR brightness temperatures are computed separately and used in the system temperatures computation, as well as being returned directly, for use in the Error Correction processing unit.

5.6.1. Inputs

- ❑ Calibrated PMS gain and offset, V_{off_k} and G_k (GAIN and OFFSET fields from PMS_COEFFICIENTS data set of SM_xxxx_CRs1A<ID>), at given physical temperatures
- ❑ NIR auxiliary data (SM_xxxx_AUX_NIR__<ID>)

- ☐ NIR calibration data (SM_XXXX_MIR_NIR_1A<ID>)
 - NIR PMS gains and offsets
 - CAS noise temperature
 - Receiver temperatures
 - Cross-coupling and leakage parameters
 - NIR brightness temperature during calibration
- ☐ Fringe Wash Function values for NIR, $g_{NIR}^V(0)$ (SM_XXXX_MIR_CRSt1A<ID>)
- ☐ Quadrature corrected correlations for NIR, M_{NIR}
- ☐ NIR correlations Offsets, V_{UL}
- ☐ Subsystem data required for instrumental error correction and antenna error correction
 - Antenna ohmic losses relative to reference planes (SM_XXXX_LCF___<ID>)
 - PMS gain and offset sensitivity to physical temperature (SM_XXXX_AUX_PMS___<ID>)
- ☐ Level 1a Ancillary data, I-HKTM. (PMS and PHYSICAL_TEMPERATURES fields of HKTM data set from SM_XXXX_TLM_MIRA1A_<ID>)
 - PMS output voltage
 - PMS physical temperature
 - Switch physical temperature
 - Antenna physical temperature
 - NIR pulse length
 - NIR brightness temperatures
 - CAS and NIR physical temperature
 - Antenna physical temperature
 - NDN temperature distribution

5.6.2. Outputs

- ☐ System temperature at the antenna phase centre plane, T_{sys}^q , and receivers temperatures, T_{rec} , in observation mode for
 - Science Data, Dual Polarisation (SYS_TEMP field from CALIBRATED_VISIB_DUAL data set from SM_XXXX_MIR_SC_D1A<ID>)
 - Science Data, Full Polarisation (SYS_TEMP field from CALIBRATED_VISIB_FULL data set from SM_XXXX_MIR_SC_F1A<ID>)
 - External Target Data, Dual Polarisation (SYS_TEMP field from CALIBRATED_VISIB_DUAL data set from SM_XXXX_MIR_TARD1A<ID>)

- External Target Data, Full Polarisation (SYS_TEMP field from CALIBRATED_VISIB_FULL data set from SM_xxxx_MIR_TARF1A<ID>)

❑ NIR temperatures

- NIR brightness temperatures in observation mode $\hat{T}_{A,v}$, for Error Correction Processing Unit
- 3rd and 4th Stokes parameters for L1b processing, T_3 and T_4
- NIR receiver temperatures, $T_{rec}^{LV-CIP,LH-CIP}$

❑ LICEF Antenna Temperatures ~~computed in ALL LICEF mode~~

5.6.3. NIR Brightness Temperatures Computation

5.6.3.1. List of Variables

Variable name	Description	Definition	Type	Class	Unit	Size
obet	Timestamp	N/A	long long	I	N/A	1
nir_temps	Components physical temperatures ($T_{p1}, T_{p3}, T_{p6}, T_{p7}, T_{pUh}, T_{pUv}$)	Section 3.5.5	float	I	K	[NIR_NUMBER][6]
nir_pulse_length	NIR normalised pulse length ($\eta_{v,h}$)	Eq. 39	double	I	N/A	[POL_MODE][NIR_NUMBER]
t_rec	Receiver temperature ($T_{rec}^{LV-CIP,LH-CIP}$)	Eq. 76	double	I	K	6
l_1	Attenuator between antenna plane and antenna intermediate layer (L_1)	Section 3.5.5	double	I	N/A	1
dl_1	Attenuator error between antenna plane and antenna intermediate layer (δL_1)	Section 3.5.5	double	I	N/A	1
l_1_alpha	Attenuator long term drift component between antenna plane and antenna intermediate layer (α)	Section 3.5.5	double	I	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
l_1_beta	Attenuator short term drift component between antenna plane and antenna intermediate layer (β)	Section 3.5.5	double	I	N/A	1
l_1_tp7_ref	L1 attenuator reference temperature for drift coefficients ($T_{p7,ref}$)	Section 3.5.5	double	I	N/A	1
l_2	Attenuator between antenna intermediate layer and antenna input plane (L_2)	Section 3.5.5	double	I	N/A	1
l_nc	Attenuator between antenna input plane and antenna output plane (L_{NC})	Section 3.5.5	double	I	N/A	1
l_a	Attenuator between antenna output plane and LICEF input plane (L_A)	Section 3.5.5	double	I	N/A	1
l_da	Attenuator between antenna LICEF input plane in H or V port and LICEF output plane (L_{DA})	Section 3.5.5	double	I	N/A	1
l_dc	Attenuator between LICEF input plane in C port and LICEF output plane (L_{DC})	Section 3.5.5	double	I	N/A	1
c_a	Front-end characterization coefficient (c_A)	Eq. 47	double	I	N/A	1
d_a	Front-end characterization coefficient (d_A)	Eq. 47	double	I	N/A	1
t_a_0	NIR antenna temperature during calibration (T'_{A0})	Eq. 82	double	I	K	2 x [NIR_NUMBER]

Variable name	Description	Definition	Type	Class	Unit	Size
t_noise_0	Antenna noise injection temperature during calibration (T_{NA0})	Eq. 82	double	I	K	2 x [NIR_NUMBER]
g_nir	Fringe Wash Function values for NIR, ($g_{NIR}^V(0)$)	Eq. 52	Double Complex	I	N/A	[NIR_NUMBER]
m_nir	Quadrature corrected correlations for NIR, (M_{NIR})	Eq. 56	Double Complex	I	N/A	[NIR_NUMBER]
v_ul	NIR correlations Offsets, (V_{UL})	Eq. 88	Double Complex	I	N/A	[NIR_NUMBER]
coupling	Cross-coupling coefficients (χ)	Eq. 89	Double Complex	I	N/A	[NIR_NUMBER]
leakage	Leakage coefficients (ϑ)	Eq. 92	Double Complex	I	N/A	[NIR_NUMBER]
t_noise	Antenna noise injection temperature during calibration (T_{NA})	ADF	double	I	N/A	1
a_a	NIR computation factor, defined in [RD 6], Eq. 4-8 (A_A)	Eq. 43	double	L	N/A	1
b_a	NIR computation factor, defined in [RD 6], Eq. 4-8 (B_A)	Eq. 43	double	L	N/A	1
t_cab	Physical temperature between radiator output plane and LICEF input plane (T_{Cab})	Eq. 46	double	L	K	1
t_t1	Thermal Noise contribution (T_{t1})	Eq. 45	double	L	K	1
t_t2	Thermal Noise contribution (T_{t2})	Eq. 45	double	L	K	1

Variable name	Description	Definition	Type	Class	Unit	Size
nir_temp	Brightness temperature of the NIR ($T'_{A,v}$)	Eq. 42	double	L	K	[POL_MODE] x [NIR_NUMBER]
t_l1	Receiver temperature between antenna patch input plane and antenna intermediate plane (T_{L1})	Eq. 59	double	L	K	1
t_l2	Temperatures between antenna intermediate plane and input connector plane (T_{L2})	Eq. 60	double	L	K	1
t_lnc	The receiver temperature between the input connector plane and output connector plane (T_{LNC})	Eq. 61	double	L	K	1
t_la	The receiver temperature between the output connector plane and LICEF input connector plane (T_{LA})	Eq. 62	double	L	K	1
noise_temp_input	Noise temperature at input plane ($T_{rec}^{LV-HIP,LV-VIP}$)	Eq. 57	double	L	K	1
ta_c	Corrected antenna temperature (T_A^c)	Eq. 89	double	L	K	[POL_MODE] x [NIR_NUMBER]
noise_level_prima2	The noise injection level at the VAP plane (T''_{NA})	Eq. 93	double	L	K	[POL_MODE] x [NIR_NUMBER]
g_s	Gain factor for Stokes parameters (g'_s)	Eq. 52	double	L	N/A	2 x [NIR_NUMBER]

Variable name	Description	Definition	Type	Class	Unit	Size
n_n	Pulse length coefficients (n_1, n_2, n_3)	Eq. 55	double	L	N/A	3 x [NIR_N UMBER]
f	Cross-coupling and leakage corrections (f_{ii}, f_{qi})	Eq. 55	double	L	N/A	2 x [NIR_N UMBER]
noise_level_prima3	The noise injection level at the antenna plane (T_{NA}''')	Eq. 53	double	O	K	[POL_M ODE] x [NIR_N UMBER]
nir_antenna_temp	Corrected brightness temperature of the NIR (\hat{T}_A)	Eq. 48	double	O	K	[POL_M ODE] x [NIR_N UMBER]
noise_temp_antenna	Noise temperature measured at the antenna plane ($T_{rec}^{HAP,VAP}$)	Eq. 58	double	O	K	[POL_M ODE] x [NIR_N UMBER]
stokes_temps	3 rd and 4 th Stokes Parameters (T_3 and T_4)	Eq. 50	double	O	K	2 x [NIR_N UMBER]

5.6.3.2. Implementation

1. The function will compute the NIR brightness temperature for all 3 NIRS, in both polarizations. Please check Section 5.1.7 for physical temperatures indexing.
 - a. The function first computes the value of T_{Cab} , using the average of thermistor outputs for Nir U-load and attenuator temperature (Eq. 46).
 - b. It then computes T_{t1} , which is defined as noise equivalent temperature between VIP and LV-VIP (Eq. 45). It uses the antenna patch thermistor output as antenna radiator physical temperature and the intermediate layer thermistor output as physical temperature of intermediate layer.
 - c. Then follows the computation of T_{t2} , which is defined as noise equivalent temperature between VIP and LV-VIP. Using Lref thermistor output as attenuator physical temperature and T_{Cab} as previously defined.

- d. T_{NA} is retrieved from the NIR ADF
 - e. A_A and B_A are found through Eqs. 43 and 47.
 - f. The NIR BT, T'_A , is computed through Eq. 42.
 - g. Finally, a final correction is made to the brightness temperature, using Eq. 48 and yielding $T_{rec}^{HAP,VAP}$.
2. For the full-pol case, also the values of T_3 and T_4 are computed:
- a. The noise injection level at the antenna plane, T_{NA}'' , is computed through Eq. 53
 - b. The coefficients n_1, n_2, n_3 are computed through Eq. 55
 - c. The gain parameters, g'_s , are computed through Eq. 52, using Λ_{kj} from Eq. 54
 - d. The cross-coupling and leakage correction terms (f_{ii}, f_{qi}) are computed by
 - i. T_A^c is computed by Eq. 89-90
 - ii. \hat{V}_{UT}^{blind} is computed by Eq. 91
 - iii. T_{NA}'' is computed by Eq. 53
 - iv. \hat{V}_{UT}^{noise} is computed by Eq. 94
 - v. Finally, f_{ii}, f_{qi} are computed by Eq. 95
 - e. The Stokes parameters, T_3 and T_4 , are then computed by Eq. 56
3. The function will then compute the receiver noise temperatures, using Eq. 57.
- a. First, the receiver temperature between antenna patch input plane and antenna intermediate plane, T_{L1} , are computed through Eq. 59.
 - b. The temperatures between antenna intermediate plane and input connector plane, T_{L2} , are computed via Eq. 60.
 - c. Then, T_{LNC} is computed from Eq. 61.
 - d. The last coefficient, T_{LA} , is obtained from Eq. 62.
 - e. Eq. 57 is computed to get the values of $T_{rec}^{LV-HIP,LV-VIP}$
 - f. Which are then used in Eq. 58 to get $T_{rec}^{HAP,VAP}$.
4. The function returns the values for $\hat{T}_{A,v}$, T_3, T_4, T_{NA}''' and $T_{rec}^{HAP,VAP}$.

5.6.3.3. Data Retrieval

Contents	Size	File type	Method
NIR parameters	32 doubles	*AUX_NIR*	l_XXX and t_rec_x by temperature c_XXX, d_XXX and u_XXX are constant values
NIR temperatures	[NIR_NUMBER][6] doubles	L1a HKTM	Get them from thermistor table data
Antenna noise injection temperature during calibration	6 doubles	*NIR_1A*	Retrieve the last one computed

Table 47- Data retrieval strategy for NIR BT computation

5.6.4. System Temperatures Computation

5.6.4.1. List of variables

Receivers' temperatures at the reference planes will all be stored in vectors with 72 positions, one for each antenna.

Variable name	Description	Definition	Type	Class	Unit	Size
obet	Timestamp	N/A	long long	I	N/A	1
pol_mode	Polarization mode	N/A	t_sys_tem p_mode	I	N/A	1
nir_pulse_length	NIR normalised pulse length ($\eta_{v,h}$)	Eq. 42	double	I	N/A	[POL_MODE][NIR_NUMBER]
sparameters	Paths S-Parameters (S_{ks} and $S_{LHV,C,Uk}$)	Eqs. 17 and 19	t_l1a_spar_paths	I	N/A	pointer
corrected_gain	Corrected gains, after taking into account the temperature delta (G_k^C)	Eq. 25	double	I	N/A	[LICEF_NUMBER]
corrected_offsets	Corrected offsets, after taking into account the temperature delta (V_{offk}^C)	Eq. 25	double	I	N/A	[LICEF_NUMBER]

Variable name	Description	Definition	Type	Class	Unit	Size
ohmic_efficiency	Antenna ohmic efficiencies ($\eta_{Hk,Vk}$)	Eq. 26	double	I	N/A	[LICEF_NUMBER]x[POL_NUMBER]
LFE	Antenna Front End Losses	Eq. 41	double	I	N/A	[LICEF_NUMBER]x[POL_NUMBER]
i_dsw	Dicke switch isolation factor (I_{DSW})	Eq. 61	double	I	K	1
noise_temp_antenna	Noise temperature measured at the antenna plane ($T_{rec}^{HAP,VAP}$)	Eq. 57	double	I	K	[POL_MODE] x [NIR_NUMBER]
noise_level	The noise injection level at the antenna plane (T_{NA}''')	Eq. 53	double	I	K	[POL_MODE] x [NIR_NUMBER]
nir_sys_temperatures	Computed NIR system temperatures ($T_{sys}^{HH,VVb}$)	Eq. 63	double	L	N/A	[NIR_NUMBER]x[POL_NUMBER]
rec_temps	Computed LICEF receiver temperatures ($T_{sys}^{HH,VVb}$)	Eq. 102	double	O	N/A	[LICEF_NUMBER]
system_temperatures	Computed system temperatures ($T_{sys}^{H,V}$)	Eq. 36	double	O	N/A	[LICEF_NUMBER]
antenna_temperatures	Computed system temperatures ($T_A^{H,V}$)	Eq. 68	double	O	N/A	[LICEF_NUMBER]

Table 48 - System temperatures computation variable list

5.6.4.2. Implementation

1. The function starts by fetching the corrected PMS parameters. These are computed through interpolation and not through Eqs. 24 and 25.
2. If the 4-point calibration Processing is in NIR mode is selected
 - 2.1. The system temperature computation performed in this processing unit is based on the two level (HOT and WARM) calibration scheme. The PMS calibration has already taken into account the different contributions from each noise source.
 - 2.2. For H-pol, V-pol and Full-pol, the same computation is done. The processing unit will calculate the system temperature for the LICEF receivers using Eq. 26., taking care to use the appropriate S-parameters and ohmic efficiency values.
 - 2.3. The plane translation is done according to Eq. 41
3. If the Processing is in ALL LICEF mode 1-point calibration is selected
 - 3.1. The system temperature computation performed in this processing unit is done by Eqs. 40 and 41
- 3.2.4. The LICEF Antenna Temperature is also computed, through Eq. 68.
- 4.5. For the LICEF-NIR system temperatures, when the NIR are in NIR-A mode
 - a. $T_{sys, \nu h}^{AA}$, and $T_{sys}^{UH, UV}$ are computed through Eq. 65.
 - b. The LICEF-NIR system temperatures, $T_{sys}^{HH, VVb}$ are obtained through Eq. 63.
- 5.6. If the NIR elements are in LICEF-LA mode, the computation of LICEF-NIR system temperatures is performed as if they were a simple LICEF (i.e. Eq. 26)
- 6.7. The function will also compute the receiver temperatures, T_{rec} , using Eq. 101 and 102, or the equivalent Eq. 80
- 7.8. The function returns the complete matrix $T_{sys}^{H, V}$, that contains LICEF and LICEF-NIR system temperatures.

5.6.4.3. Data Retrieval

Contents	Size	File type	Method
PMS offsets	[LICEF_NUMBER] double	*MIR_CRSD1A* / *MIR_UAV_1A* / *AUX_PMS*	By temperature
PMS gains	[LICEF_NUMBER] double	*MIR_CRSD1A* / *MIR_UAV_1A* / *AUX_PMS*	By temperature
Gain Sensitivity	[LICEF_NUMBER] double	*MIR_CRSD1A* / *MIR_UAV_1A* / *AUX_PMS*	Constant value

Contents	Size	File type	Method
Offset Sensitivity	[LICEF_NUMBER] double	*MIR_CRSD1A* / *MIR_UAV_1A* / *AUX_PMS*	Constant value
Ohmic Efficiency	[LICEF_NUMBER][2] double	*AUX_LCF*	Constant value
PMS voltages	[LICEF_NUMBER] double	L1a HKTM	Search for PMS voltages, in the L1a packet with the same OBET
Δ Phys Temps	[LICEF_NUMBER] double	L1a HKTM /AUX files	Compute the difference between the current temperature of each PMS and the temperature for which the necessary data (gains and offsets) was gotten
LICEF physical temps	[LICEF_NUMBER] double	L1a HKTM	Get them from thermistor table data

Table 49 - Data retrieval strategy for System Temperatures Computation

5.6.5. RFI Flagging

5.6.5.1. List of variables

Variable name	Description	Definition	Type	Class	Unit	Size
nir_antenna_temp	Corrected brightness temperature of the NIR (\hat{T}_A)	Eq. 48	double	I	K	[POL_MODE] x [NIR_NUMBER] x [NUM_SNAPSHOTS]
system_temperatures	Computed system temperatures ($T_{sys}^{H,V}$)	Eq. 36	double	I	K	[LICEF_NUMBER] x [NUM_SNAPSHOTS]
obet_in_utc	Instrument timestamp in UTC time format	N/A	t_utc_time	I	N/A	NUM_SNAPSHOTS

Variable name	Description	Definition	Type	Class	Unit	Size
rfi_flag	Flag indicating if measurement exceeds the approximated spline	N/A	boolean	O	N/A	NUM_SN APSHOTS
rfi_saturation_flag	Flag indicating if measurement exceeds the saturation limit	N/A	boolean	O	N/A	NUM_SN APSHOTS
rfi_saturation_gap_flag	Flag indicating if measurement is within a 3 minute interval of a saturation event	N/A	boolean	O	N/A	NUM_SN APSHOTS

Table 50 - RFI Flagging computation variable list

5.6.5.2. Implementation

~~8-9~~ The function starts by analysing the time series in the product, and ensuring that it fulfils the 3 requirements set forth in section 3.11.

~~9-10~~ In case a saturation event is detected, it is flagged, and the time series is split in two by taking into consideration the 3 minute margin. The same applies if a gap greater than 2 minutes is detected in the time series

~~10-11~~ For each individual time series (continuous and without saturation events), the two-step method is applied:

- Computation of the median at each snapshot using the sliding window period.
- Iterative re-weighted splines approximation using the median as an initial weight estimate

~~11-12~~ Once the spline approximation is computed and has converged, the snapshots whose difference to the spline is greater than the configurable 3sigma threshold are flagged as RFI contaminated

~~12-13~~ The process is repeated for each NIR measurement channel (3 in X pol and another 3 in Y pol) and for each LICEF polarisation (one in X pol and another in Y pol).

~~13-14~~ In total, 6 flags can be computed: RFI_DETECTED, RFI_SATURATED and RFI_SATURATED_GAP for both X pol and Y pol, which will then be stored in the L1a product.

5.6.6. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	Unable to compute LICEF system temperatures	DIVISION_BY_ZERO	System temperature is 0	Yes
2	No valid polarisation mode requested	DATA_CORRUPTED	Processing unit returns	Yes

Table 51 - System temperatures computation error handling

5.7. Error Compensation

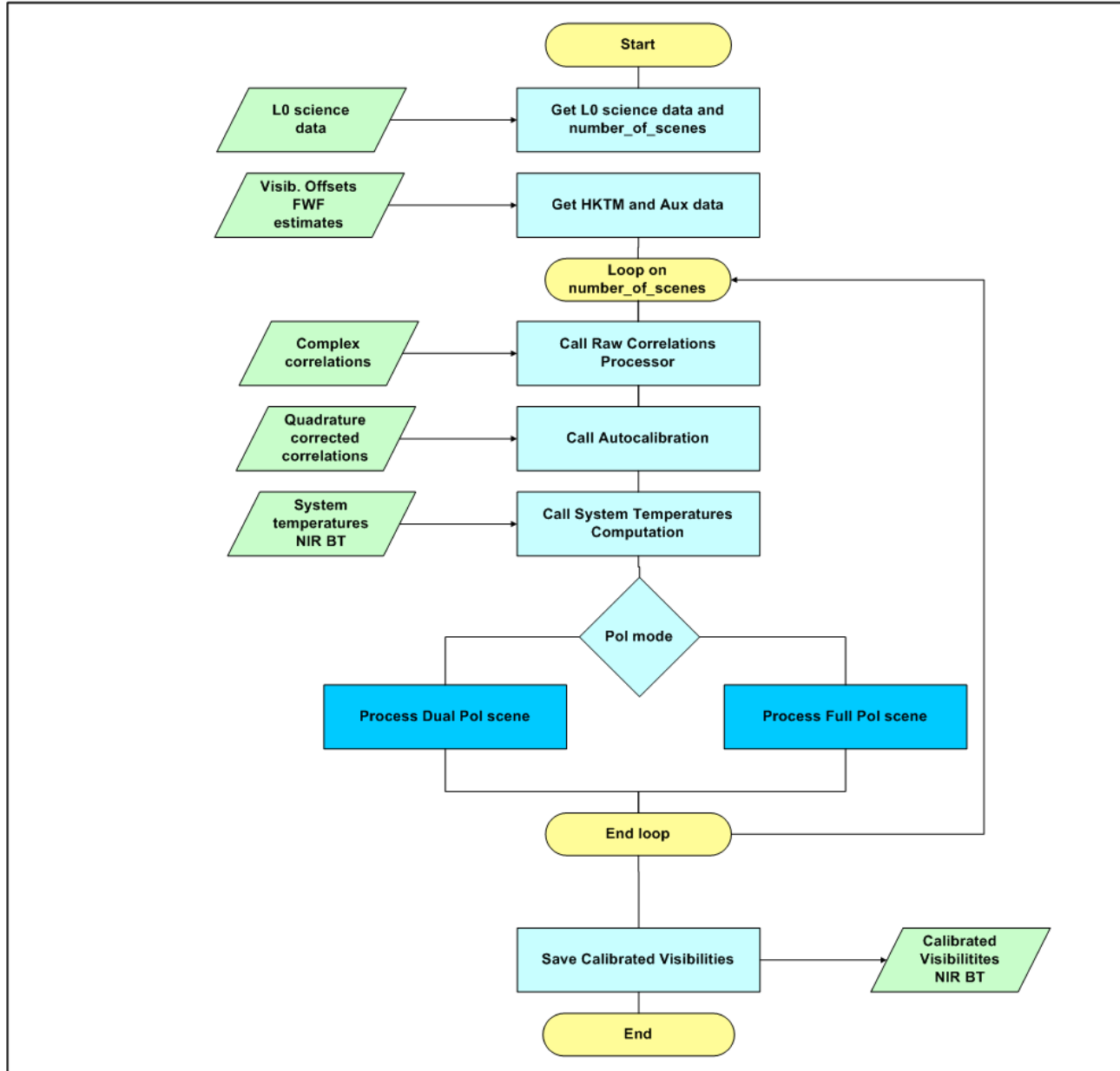


Figure 23 - Visibilities final calibration.

This processing unit will calibrate the instrument output in measurement mode with the most up to date calibration parameters and add the zero baseline NIR measurements to the L1a products. These parameters are loaded from Level 1a products updated by the different calibration procedures.

5.7.1. Inputs

- ❑ FWF values at the origin, $g_{kj}^C(0)$ (CALIBRATION field from AMPL_PHASE_CORRECTION data set from SM_xxxx_MIR_CRSx1A<ID>)

- ❑ Visibilities Offsets, V^U , (OFFSET field from MEAN_OFFSETS data set from SM_xxxx_MIR_UNCN1A<ID>)
- ❑ System Temperatures at reference planes, T_{sys}^q (from System Temperatures Computation)
- ❑ Normalised quadrature corrected correlations, M_{kj}^q (from Autocalibration)
- ❑ Subsystem data required for instrumental error correction and antenna error correction, from ground calibration
 - S-parameters (SM_xxxx_AUX_SPAR__<ID>)
 - Antenna phases relative to reference planes (SM_xxxx_AUX_LCF__<ID>)
 - Gkj correction factor (SM_xxxx_AUX_LCF__<ID>)

5.7.2. Outputs

- ❑ Calibrated visibilities in observation mode, $\hat{V}_{kj}^{H,V}$, for
 - Science Data, Dual Polarisation (CALIB_VISIB field from CALIBRATED_VISIB_DUAL data set from SM_xxxx_MIR_SC_D1A<ID>)
 - Science Data, Full Polarisation (CALIB_VISIB# fields from CALIBRATED_VISIB_FULL data set from SM_xxxx_MIR_SC_F1A<ID>)
 - External Target Data, Dual Polarisation (CALIB_VISIB field from CALIBRATED_VISIB_DUAL data set from SM_xxxx_MIR_TARD1A<ID>)
 - External Target Data, Full Polarisation (CALIB_VISIB# fields from CALIBRATED_VISIB_FULL data set from SM_xxxx_MIR_TARF1A<ID>)

5.7.3. List of Variables

The calibrated visibilities, $\hat{V}_{kj}^{H,V}$, will be stored in a matrix with 2556 positions, corresponding to the total number of correlations (Nsignals*(Nsignals-1)/2).

Variable name	Description	Definition	Type	Class	Unit	Size
filename	Name of L0 science data file to be processed	N/A	char	I	N/A	pointer
mkj	Quadrature corrected correlations (M_{kj}^q)	Eq. 7	Double Complex	I	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R]

Variable name	Description	Definition	Type	Class	Unit	Size
pol_mode	Polarization mode if the arms in full pol mode	N/A	t_sys_tem p_mode	I	N/A	1
system_temperatures	System temperatures at the time measuring, ($T_{sys}^{H,V}$)	Eq. 39	double	I	K	[LICEF_ NUMBE R]
visibilities_offsets	The computed visibilities offsets (V_{kj}^{UC})	Eq. 70	Double Complex	I	N/A	[LICEF_ NUMBE R] x [LICEF_ NUMBE R]
sparameters	Paths S-Parameters (S_{ks} and $S_{LH,V,C,Uk}$)	Eqs. 17 and 19	t_l1a_spar _paths	I	N/A	pointer
antenna_phases	Antenna Phases, last index is 0-H, 1-V ($\phi_{H,Vk}$)	Eq. 19	double	I	N/A	[LICEF_ NUMBE R] x [2]
ohmic_efficiency	Antenna ohmic efficiencies ($\eta_{Hk,Vk}$)	Eq. 26	double	I	N/A	[LICEF_ NUMBE R]x[POL _NUMB ER]
c	Gkj correction factor	Eq. 73	Double Complex	I	N/A	[1]
fwf_estimates	Fringe Wash Function at origin (g_{kj})	Eq. 18	Double Complex	I	N/A	[LICEF_ NUMBE R] x [LICEF_ NUMBE R] x [2]
visibilities_offsets_coef fs	Visibilities offsets coefficients(a_{kj})	Eq. 73	int	I	N/A	[LICEF_ NUMBE R] x [LICEF_ NUMBE R]
visibilities_offsets_ante nna	Visibilities offsets at antenna plane ($V_{kj}^{UH,V}$)	Eq. 72	Double Complex	L	N/A	[LICEF_ NUMBE R] x [LICEF_ NUMBE R]

Variable name	Description	Definition	Type	Class	Unit	Size
						R]
denorm_visibilities	Denormalized visibilities ($V_{kj}^{H,V}$)	Eq. 71	Double Complex	L	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R] x [2]
calibrated_visibilities	Calibrated Visibilities ($\hat{V}_{kj}^{H,V}$)	Eq. 73	Double Complex	O	N/A	[LICEF_NUMBE R] x [LICEF_NUMBE R/2]

Table 52 - Error compensation list of variables

5.7.4. Implementation

5.7.4.1. Dual pol mode processing

- In the case of dual mode processing, the processing unit will simply apply Eqs. 59-61 in the following order:
 - $V_{kj}^{H,V}$ is obtained through Eq. 71
 - $V_{kj}^{UH,V}$ is found by using Eq. 72
 - a_{kj} is retrieved from the active option regarding offset correction (only Local Oscillator, no Offset correction...) as described in section 3.7.1
 - $\hat{V}_{kj}^{H,V}$ are finally computed through Eq. 73
 - $g_{kj}^{H,V}$ in Eq.73 is computed through Eq. 19 using g_{kj}^C and the appropriate switch S parameters and relative antenna phases to the polarisation being computed. The physical temperature used to compute the switch S parameters shall be the one stored at calibration time with the g_{kj}^C values.

5.7.4.2. Full pol mode processing

- In the case of full polarisation mode, the processing is exactly the same as for dual mode except that care must be taken in the computation of the system temperatures. The de-normalisation of a visibility produced by receiver k in H polarisation and receiver j in V polarisation must use the System Temperature in H polarisation for receiver k and the System Temperature in V polarisation

for receiver j , measured in dual-pol mode, since the PMS output in full-pol is corrupted. This difference in System Temperature values is due to the application of different Switch S-parameters, as it has been shown before.

2. Using the `pol_mode` variable, the system temperatures computation will be invoked with the correct polarization for each element, ensuring a correct de-normalisation.
3. The same behaviour must be taken for the computation of elements, as for each cross-polar visibility there shall be one switch for H pol and another for V pol.
4. Also, for those scenes measured during the same integration time, it shall be required to identify them with a unique counter to specify in which sub-interval they were taken. First sub-interval corresponds to the receivers in arm A being in opposite polarisation to those in arms B and C; second sub-interval corresponds to the receivers in arm B being in opposite polarisation to those in arms A and C; and finally the third sub-interval corresponds to the receivers in arm C being in opposite polarisation to those in arms A and B.

In the following table, a summary of the data used and computed for each snapshot is shown:

PARAMETER	DUAL POL (all epochs)	FULL POL (pure pol epochs)	FULL POL (mixed pol epochs)
Physical Temperature to be used for all calibration parameters computation	From current dual pol epoch. Used to interpolate all temperature sensible parameters (S parameters)	From current pure pol epoch. Used to interpolate all temperature sensible parameters (S parameters)	From current mixed pol epoch. Used to interpolate all temperature sensible parameters (S parameters)
PMS Gain	From long calibration and propagated with temperature and sensitivity	From long calibration and propagated with temperature and sensitivity	From long calibration and propagated with temperature and sensitivity
PMS offset	From long calibration and propagated with temperature and sensitivity	From long calibration and propagated with temperature and sensitivity	From long calibration and propagated with temperature and sensitivity
PMS gain sensitivity with temperature	From characterization parameters	From characterization parameters	From characterization parameters
PMS offset sensitivity with temperature	From characterization parameters	From characterization parameters	From characterization parameters
LICEF System temperature	From current dual pol pms voltages and PMS gain and offset derived from long calibration, sensitivity from characterization and current physical temperature	From current pure pol pms voltages and PMS gain and offset derived from long calibration, sensitivity from characterization and current physical temperature	From previous / next pure pol pms voltages and PMS gain and offset derived from long calibration, sensitivity from characterization and current physical temperature
NIR LICEF Receiver noise temperature for NIR system temperature computation for mixed baselines denormalization	From long calibration and propagated with temperature sensitivity using temperature of current dual pol epoch	From long calibration and propagated with temperature sensitivity using temperature of current pure pol epoch	From long calibration and propagated with temperature sensitivity using temperature of current mixed pol epoch

PARAMETER	DUAL POL (all epochs)	FULL POL (pure pol epochs)	FULL POL (mixed pol epochs)
Receiver noise sensitivity with temperature	From characterization parameters	From characterization parameters	From characterization parameters
NIR antenna temperature	From current dual pol nir pulse length	From current pure pol epoch pulse length	From current mixed pol epoch pulse length to compute all four Stokes parameters
Lambda factor for mixed baseline denormalization	From current dual pol NIR antenna temperature and NIR LICEF receiver noise temperature (from long cal and propagated using current physical temperature)	From current pure pol NIR antenna temperature and NIR LICEF receiver noise temperature (propagated using long cal and current physical temperature)	From current mixed pol NIR antenna temperature and NIR LICEF receiver noise temperature (propagated using long cal and current physical temperature)
Gkj amplitude	From long calibration data	From long calibration data	From long calibration data
Gkj phase	Interpolation using all phase instances from LO cal, short and long calibration sequences	Interpolation using all phase instances from LO cal, short and long calibration sequences	Interpolation using all phase instances from LO cal, short and long calibration sequences
Correlator offset	From long calibration compatible with the minimum number of epochs	From long calibration compatible with the minimum number of epochs	From long calibration compatible with the minimum number of epochs

Table 53 - Dual-Full pol data usage according to epochs

5.7.5. Data Retrieval

Contents	Size	File type	Method
FWF estimates	[LICEF_NUMBER]x[LICEF_NUMBER] doublecomplex	*MIR_CRSD1A*	By temperature
Visibilities offsets	[LICEF_NUMBER]x[LICEF_NUMBER] doublecomplex	*MIR_UAV_1A*	By temperature
Polarization mode	[ARM_NUMBER] t_polarization_mode	L1a HKTM	Get arm_pol_mode from L1a packet with same OBET

Table 54 - Data Retrieval strategy for Error Compensation

5.7.6. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	File accessor unable to read the L0 file	DATA_CORRUPTED	Processing unit returns with no data processed.	No
2	File accessor unable to write calibrated visibilities	None	Output error to log. Processing unit is finished at the time of writing the output product	No
3	Unable to compute calibrated visibilities	DIVISION_BY_ZERO	Calibrated visibility computed and returned is 0	Yes

Table 55 - Error Compensation error handling

5.8. Path S-Parameters Computation

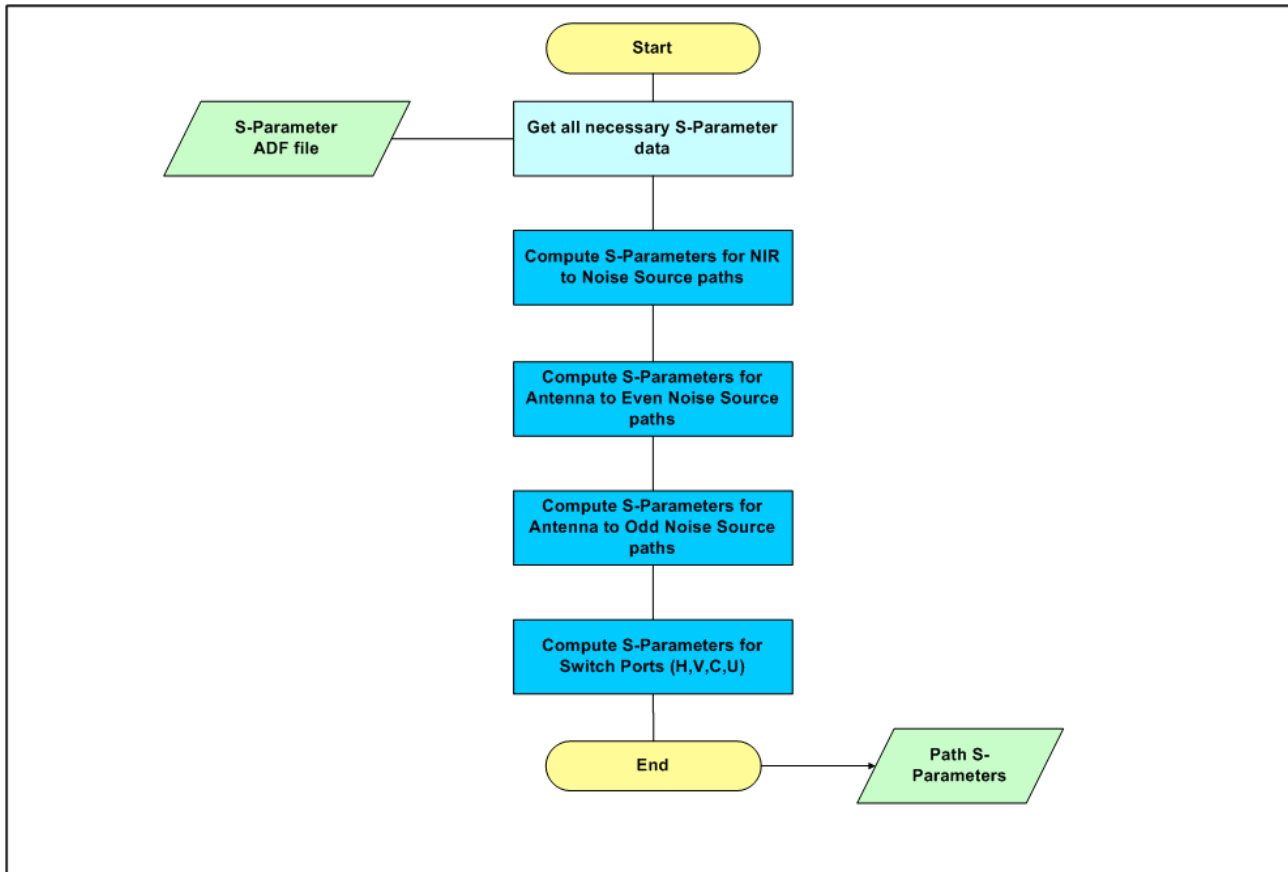


Figure 24 - The S-Parameters Processing Unit will compute the S-Parameters associated to each signal path

This processing unit will be invoked every time that the NDN S-Parameters are needed for the correction of instrument data. It will use HKTM data to get the reference physical temperatures at which the individual S-Parameter for each component will be used, as well as the Arm Redundancy configuration. It will then compute all S-Parameters associated to all signal paths. It returns a table with the parameters for individual paths between receiver-receiver connections and switch positions.

5.8.1. Inputs

☐ Level 1a Ancillary data, I-HKTM (from SM_XXXX_TLM_MIRA1A_<ID>)

- Reference timestamp
- PMS physical temperature
- Switch physical temperature
- Antenna physical temperature
- Arm Redundancy Configuration

☐ Subsystem data

- S-parameters (SM_XXXX_AUX_SPAR__<ID>)

5.8.2. Outputs

□ Instrument paths S-Parameters

- NIR to Noise Source Paths
- Antenna to Even Noise Sources Paths
- Antenna to Even Noise Sources Paths
- Switch S-Parameters

5.8.3. List of Variables

Variable name	Description	Definition	Type	Class	Unit	Size
obet	Timestamp	N/A	long long	I	N/A	1
t_l1a_spar_data_scene	Auxiliary file data with individual components' S-Parameters	N/A	t_l1a_spar_data_scene	I	N/A	pointer
sparameters	Paths S-Parameters (S_{ks} and $S_{LHV,C,Uk}$)	Eqs. 17 and 19	t_l1a_spar_paths	O	N/A	pointer

5.8.4. Implementation

1. The processing unit will retrieve the individual components S-Parameters from the ADF file. It uses the timestamp provided to find the physical temperature of each component and then find the correct S-Parameter by interpolation. It also finds the Arm Redundancy Configuration in L1a HKTM at the timestamp, as it is needed to select the Nominal or Redundant Noise Source
2. First it computes the S-Parameters for the paths between each NIR and the even Noise Sources at the hub.
3. The S-Parameter for the paths between each antenna and the arms Noise Sources are then computed. Paths for even and odd noise sources are computed independently, as follows.
 - a. To compute the S-Parameter for the path between a receiver in the first section of arm C and the first noise source in that arm (C1), the processing unit will have to sum the S-Parameters for each component in the path.
 - i. Cable between antenna and Power Divider
 - ii. Power Divider path between input and output
 - iii. Cable between Power Divider and Noise Source
 - iv. Noise Source path between input and output
 - v. CAS correction factor between NS and antenna element

- b. In the following Figure, as an example, the paths for all antennas in the first section, in relation to Noise Source C1 are highlighted [RD.15]. Please refer to this document for more detailed information.

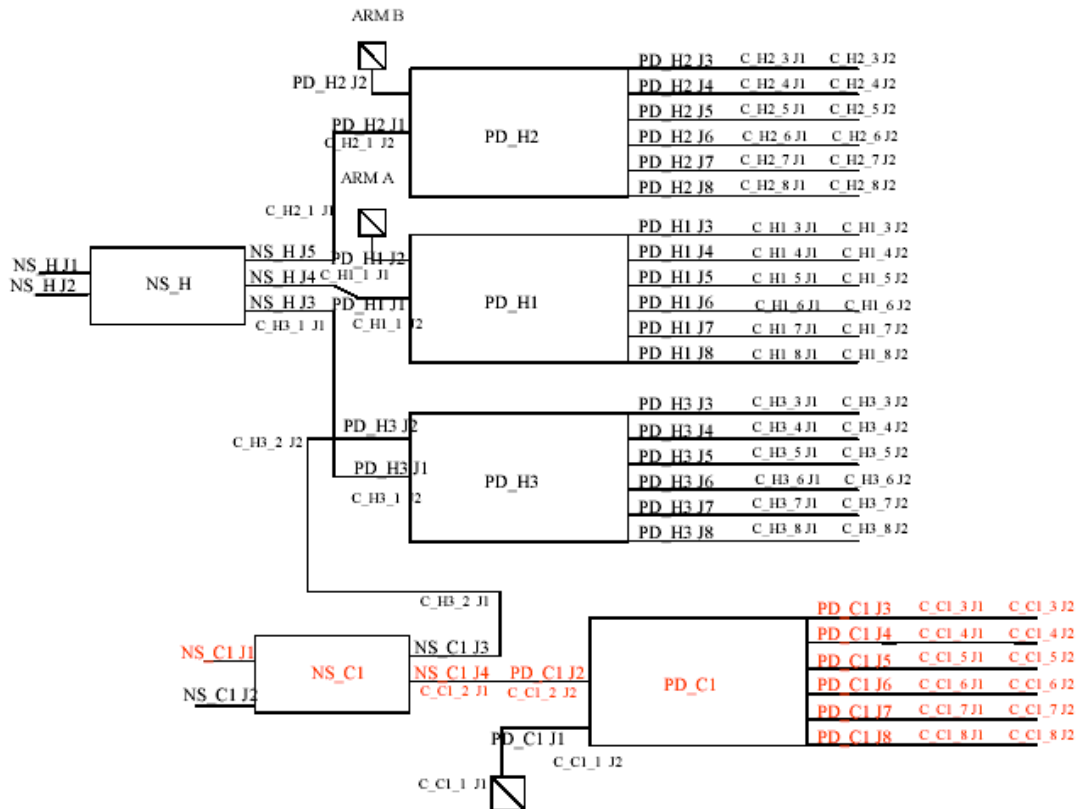


Figure 25 - Signal paths between for antennas in the first section of arm C

- c. According to the Arm Redundancy configuration detected in L1a HKTM at the corresponding timestamp, the path to the Nominal or Redundant Noise Source must be selected. In the Figure above, the input port for the Nominal Noise Source is represented as NS_X_J1, and the input port for the Redundant Noise Source is represented as NS_X_J2. If an arm is in Nominal configuration, then all the NS associated to that arm are in Nominal input, and the same happens for Redundant. Noise sources associated with arm A are NS_H, NS_A1, NS_A2 and NS_A3; Noise sources associated with arm B are NS_B1, NS_B2 and NS_B3; and Noise sources associated with arm C are NS_C1, NS_C2 and NS_C3
4. Finally, the S-Parameters for each switch (4 for each one, according to output – H,V,C and U) are also stored in the `sparameters` structure.

Note: The usage of the NIR switch S-Parameters has to take into account that both NIR-LICEF are switched to the NIC (and subsequently to the antenna) using the VIP port. So, the NIR plane is always VIP, independently of the polarization channel of the NIR being used. This note is not applicable to path S-Parameters, only to Switch S-Parameters.

5.8.5. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	Processing Unit unable to retrieve values from ADF file	DATA_CORRUPTED	Processing unit returns with no data processed.	Yes

Table 56 - S-Parameter computation error handling

5.9. Noise Injection Radiometer Calibration

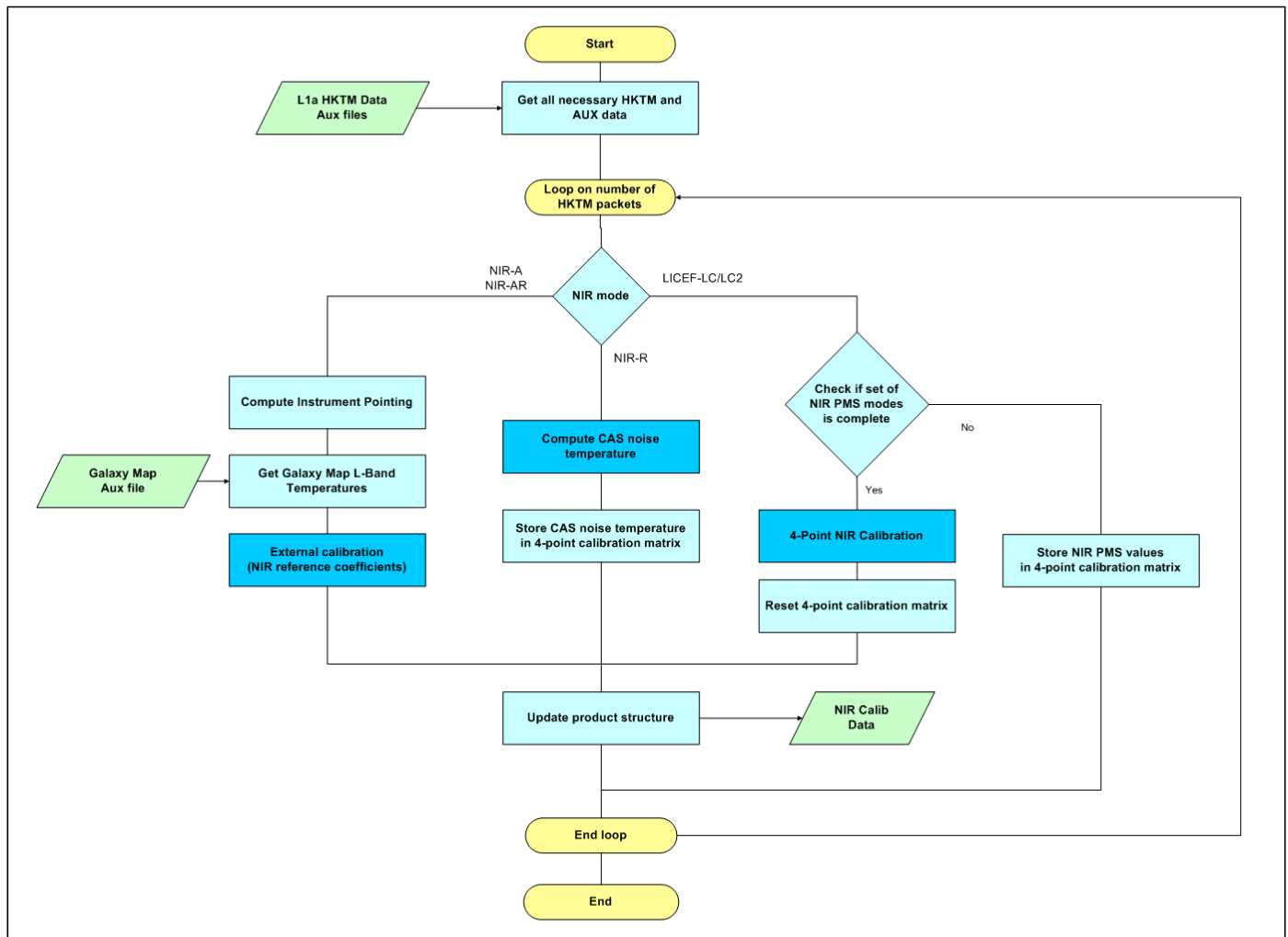


Figure 26 - Determination of the NIR gain and offset to relate NIR pulse length outputs with antenna temperature.

In order to calibrate the NIR parameters for all its different purposes, there are different modes of measurement that must be used:

- ❑ NIR-R – The NIR will measure the reference amplitude of the noise injection temperature to be used in conjunction with the calibration noise temperature in the calculations of the NIR brightness temperature in observation mode.
- ❑ NIR-A/AR/ and LICEF-LA, imaging an external target - The instrument will image an external target, the baseline is the deep sky, and the temperature measured by the NIR is compared with the estimated scene temperature. This estimation will be based on L-band galaxy maps, as well as models of the Earth, Sun and Moon emissions at L-band and the position and attitude of the PLM. An internal load, with a known temperature, is also measured by NIR. With the two known temperatures (internal and external) and their measurements, it is possible to calibrate the NIR measurement of the noise injection temperature and its brightness temperature measurement.
- ❑ LICEF-LC/LC2 – In this mode, the NIR PMS will act as a regular LICEF antenna and its measurements will be used to calibrate the gain and offset of the NIR PMS, as well as the receiver temperature.

5.9.1. Inputs

- ❑ L1a I-HKTM
 - Antenna physical temperature while pointing at cold sky (PHYSICAL_TEMPERATURES field from HKTM data set on SM_xxxx_TLM_MIRA1A_<ID>)
 - Attitude and position information (orbit position, velocity and quaternion fields from HKTM data set on SM_xxxx_TLM_MIRA1A_<ID>)
 - NIR pulse length while imaging external target (NIR_PULSE_LENGTH field from HKTM data set on SM_xxxx_TLM_MIRA1A_<ID>)
 - Past NIR calibration results (to extrapolate parameters evolution)
- ❑ NIR correlations Offsets, (SM_xxxx_MIR_UNCN1A_<ID>)
- ❑ Subsystem data required for instrumental error correction and antenna error correction
 - Galaxy L-band Map (SM_xxxx_AUX_GLXY_<ID>)
 - NIR Auxiliary parameters (SM_xxxx_AUX_NIR_<ID>)
 - NIR Antenna Patterns (SM_xxxx_AUX_PATT_<ID>)

5.9.2. Outputs

- ❑ NIR update to original MIRAS defaults (SM_xxxx_MIR_NIR_1A<ID>)
 - Calibration CAS noise temperature (NIR-A, NIR-AR mode)
 - NIR brightness temperature during calibration
 - Cross-coupling and leakage correction factors

5.9.3. External Target Calibration mode

5.9.3.1. List of Variables

Variable name	Description	Definition	Type	Class	Unit	Size
packet	HKTM packet to be processed	N/A	t_lla_hkt m_data_s cene	I	N/A	1
lla_pvt_data	Processed PVT data	RD.24	t_lla_pvt	I	N/A	1
lla_aocs_data	Structure with processed AOCs data	RD.24	t_lla_aoc s	I	N/A	1
nir_temps	Components physical temperatures ($T_{p1}, T_{p3}, T_{p6}, T_{p7}, T_{pUh}, T_{pUv}$)	Section 3.5.5	float	I	K	[NIR_NUMBER][6]
nir_pulse_length	NIR normalised pulse length (η)	Eq. 83	double	I	N/A	[POL_MODE][NIR_NUMBER]
nir_antenna_patterns	NIR antenna patterns (F_{NIR})	Eq. 82	double	I	N/A	[POL_MODE][NIR_NUMBER]
galaxy_temps	Galaxy temperatures in the unit circle (T^{Galaxy})	Eq. 82	double	I	K	Number of points in unit circle (variable)
l_1	Attenuator between antenna plane and antenna intermediate layer (L_1)	Section 3.5.5	double	I	N/A	1
dl_1	Attenuator error between antenna plane and antenna intermediate layer (δL_1)	Section 3.5.5	double	I	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
l_1_alpha	Attenuator long term drift component between antenna plane and antenna intermediate layer (α)	Section 3.5.5	double	I	N/A	1
l_1_beta	Attenuator short term drift component between antenna plane and antenna intermediate layer (β)	Section 3.5.5	double	I	N/A	1
l_1_tp7_ref	L1 attenuator reference temperature for drift coefficients ($T_{p7,ref}$)	Section 3.5.5	double	I	N/A	1
l_2	Attenuator between antenna intermediate layer and antenna input plane (L_2)	Section 3.5.5	double	I	N/A	1
l_nc	Attenuator between antenna input plane and antenna output plane (L_{NC})	Section 3.5.5	double	I	N/A	1
l_a	Attenuator between antenna output plane and LICEF input plane (L_A)	Section 3.5.5	double	I	N/A	1
l_da	Attenuator between antenna LICEF input plane in H or V port and LICEF output plane (L_{DA})	Section 3.5.5	double	I	N/A	1
l_dc	Attenuator between antenna LICEF input plane in C and LICEF output plane	Section 3.5.5	double	I	N/A	1
l_r	NIR parameters (L_R)	Section 3.5.5	double	I	N/A	1
l_dr	NIR parameters (L_{DR})	Section 3.5.5	double	I	N/A	1

Variable name	Description	Definition	Type	Class	Unit	Size
v_ul	NIR correlations Offsets, (V_{UL})	Eq. 88	Double Complex	I	N/A	[NIR_NUMBER]
t_cab	NIR parameters (T_{Cab})	Eq. 46	double	L	K	1
t_t1	Thermal Noise contribution (T_{t1})	Eq. 44	double	L	K	1
t_t2	NIR computation factor (T_{t2})	Eq. 44	double	L	K	1
t_t3	NIR computation factor (T_{t3})	Eq. 80	double	L	K	1
t_a_prima3	The noise injection level at the antenna plane (T_A''')	Eq. 49	double	L	K	[POL_MODE] x [NIR_NUMBER]
t_2prima_na_0	Corrected Noise Injection temperature during calibration (T_{NA0}'')	Eq. 53	double	I	K	[POL_MODE] x [NIR_NUMBER]
t_c_a	Antenna temperature for leakage (T_A^c)	Eq. 89	double	I	K	[POL_MODE] x [NIR_NUMBER]
coupling	Cross-coupling coefficients (χ)	Eq. 88	Double Complex	O	N/A	[NIR_NUMBER]
leakage	Leakage coefficients (ϑ)	Eq. 92, 93	Double Complex	O	N/A	[NIR_NUMBER]
t_a_0	NIR antenna temperature during calibration (T_{A0}')	Eq. 82	double	O	K	[POL_MODE] x [NIR_NUMBER]

Variable name	Description	Definition	Type	Class	Unit	Size
t_a_prima3_0	NIR antenna temperature during calibration (T_{A0}''')	Eq. 84	double	L	K	[POL_M ODE] x [NIR_NUMBER]
t_noise_0	Antenna noise injection temperature during calibration (T_{NA0})	Eq. 83	double	O	K	[POL_M ODE] x [NIR_NUMBER]
t_a_on0	Correction parameter from external target calibration ($T_{A_ON0}^{CIP}$)	Eq. 85	double	O	K	[POL_M ODE][NIR_NUMBER]
t_nr_0	Reference noise injection temperature (T_{NR0})	Eq. 86	double	O	K	[POL_M ODE][NIR_NUMBER]

Table 57 - NIR External Target mode calibration variable list

5.9.3.2. Implementation

The processing flow for external target calibration will use the NIR data in modes NIR-A, NIR-LA and NIR-AR while looking at an external target.

1. The function will start when the instrument orientation is found to be pointing to an external target.
 - a. The HKTM data is polled to get AOCS and PVT data
 - i. The instrument is can be in three positions:
 - ii. Nominal pointing (this is considered to be in the range [27.5°, 37.5°])
 - iii. External target pointing (this is considered to be in the range [153.5°, 206.5°])
 - iv. Manoeuvring, if the pointing is not in any of the previous ranges
 - b. If the instrument is in External target pointing, it proceeds with the computations
2. If the NIR-R sequence is detected:

NIR-R INDIVIDUAL SEQUENCE												
	Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUPT
NIR-R	33	Dual	NIR-AR	OFF	OFF	L0	0	-	η_1^e	-	-	26th
	31	Dual	NIR-A	OFF	OFF	L0	0	-	η_2^e	-	-	26th

Table 58 – NIR-R individual calibration Sequences

- a. In NIR-A mode
 - i. Calibration consists first in computing the expected NIR Brightness Temperature by combining the instrument's position and attitude with the Galaxy Map and the NIR antenna patterns.
 - ii. The precise instrument position is used to retrieve the visible part of the cold sky observed from the Galaxy Map AUX file (SM_XXXX_AUX_GLXY__<ID>). See [RD.16] section 2.2.2.1.1 for further details on how to compute the observed Galaxy BT.
 - iii. The expected brightness temperature, T'_{A0} , is computed through Eq. 82, by convoluting the observed Galaxy BT with the NIR antenna patterns..
 - iv. The antenna noise injection temperature is, T_{NA0} , computed from Eq. 83.
 - v. The antenna BT looking at cold sky is, T'''_{A0} , computed from Eq. 84.
 - vi. The coefficients $T_{A_ON0}^{(6)}$ and $T_{A_ON0}^{CIP}$ is computed using Eq. 85.
- b. In NIR-AR mode
 - i. T_{Cab} is computed through Eq. 46.
 - ii. T_{i3} is computed through Eq. 87.
 - iii. The noise injection temperature in the reference branch, T_{NR0} , is computed through Eq. 86.
- c. The processing unit stores $T_{A_ON0}^{CIP}$ and T_{NR0} values in the SM_XXXX_MIR_NIR_1A<ID> file.

3. If the NIR-A sequence is detected:

NIR-A INDIVIDUAL SEQUENCE												
	Step	LICEF	NIR	NS EVEN	NS ODD	Att	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
NIR-A	32	Dual	LICEF-LA	OFF	OFF	L0	0	$(*)M_{kj}^{C1e}$	η_1^e	v_{SKY}	-	26th
	31	Dual	NIR-A	OFF	OFF	L0	0	$(*)M_{kj}^{C2e}$	η_2^e	v_A	-	26th

Table 59 – NIR-A individual calibration Sequence

- a. In LICEF-LA mode:
 - i. \hat{V}_{LA} is computed using the NIR system temperatures (computed as in Section 5.6.4.2), and using Eq. 73 to calibrate the visibilities
 - ii. T_A^c is computed by Eq. 89
 - iii. χ is computed by Eq. 88 using the previously computed values

b. In NIR-A mode:

- i. \hat{V}_{NA} is computed using the NIR system temperatures (computed as in Section 5.6.4.2), and using Eq. 73 to calibrate the visibilities
- ii. T_A^c is computed by Eq. 89 and 90
- iii. \hat{V}_{UT}^{blind} is computed by applying cEq. 91
- iv. T_{NA0}'' is computed by Eq. 53, but using the values during calibration (i.e. T_{NA0})
- v. ϑ is computed by Eq. 92 and 93 using the previously computed values
- vi. The expected brightness temperature, T_{A0}' , is computed by convoluting the observed Galaxy BT with the NIR antenna patterns (identical to the NIR-R calibration process).
- vii. The antenna noise injection temperature is T_{NA0} , computed from Eq. 83.
- viii. The antenna BT looking at cold sky is T_{A0}''' , computed from Eq. 84.

c. The processing unit stores the T_{A0}' , T_{A0}''' , T_{NA0} , plus χ and ϑ values in the SM_xxxx_MIR_NIR_1A<ID> file.

5.9.3.3. Data Retrieval

Contents	Size	File type	Method
NIR parameters	32 doubles	*AUX_NIR*	l_xxx and t_rec_x by temperature c_xxx, d_xxx and u_xxx are constant values
NIR temperatures	[NIR_NUMBER][6] doubles	L1a HKTM	Get them from thermistor table data
Visibilities offsets	[NIR_NUMBER][2] doubles	*UAV_1A*	Retrieve the last one computed
Antenna noise injection temperature during calibration	6 doubles	*NIR_1A*	Retrieve the last one computed

Table 60- Data retrieval strategy for NIR-LA/AR mode computation

5.10. LFE Calibration

The sequence previously used for Cold Sky calibration has been updated in 2012 to allow the computation of the L1 attenuation factor in flight. Since L1OP v7.0.0 (2015), this calibration sequence is used only to compute the value of the Front End Loss, for monitoring purposes.

5.10.1. Inputs

- ❑ Level1a Correlated Noise Injection Data (SM_XXXX_CRsx1A<ID>)
 - Calibrated PMS gain and offset, V_{off_k} and G_k^{CC} (GAIN and OFFSET fields from PMS_COEFFICIENTS data set), at given physical temperatures
 - NIR measured noise temperature, T_{NS1}^α , T_{NS2}^α , (NIR measuring CAS temperature, NIR REFERENCE data set)
- ❑ Subsystem data required for instrumental error correction and antenna error correction, from ground calibration
 - S-parameters (SM_XXXX_AUX_SPAR__<ID>)
 - Antenna ohmic losses relative to reference planes (SM_XXXX_LCF__<ID>)
- ❑ Level1a HKTM Data. (PMS and PHYSICAL_TEMPERATURES of HKTM data set from SM_XXXX_TLM_MIRA1A_<ID>)
 - PMS output voltages for WARM and COLD temperatures:
 - PMS output voltage (Switch in U position, ATT=0)
 - PMS output voltage (Switch in U position, ATT=L)
 - PMS output voltage (Switch in H position, ATT=0)
 - PMS output voltage (Switch in H position, ATT=L)
 - PMS output voltage (Switch in V position, ATT=0)
 - PMS output voltage (Switch in V position, ATT=L)
 - PMS physical temperature
 - NDN physical temperature
 - PMS output voltages for HOT and WARM noise injection temperatures:
 - PMS output voltage (Switch in C-even position, ATT=0)
 - PMS output voltage (Switch in C-odd position, ATT=0)

where U/H/V position is the setting on the switch and ATT is the attenuation of the signal.

5.10.2. Outputs

- ❑ Deep sky calibration data (SM_XXXX_CRsx1A<ID>)
 - Sky temperatures
 - Computed Sky temperature, T_{Sky}
 - Expected Sky temperature, $T_{Sky}^{expected}$
 - Calibrated L1 attenuation factor, L_1

- Physical temperature of the antenna patch during L1 manouever, T_{p7}

5.10.3. List of Variables

Variable name	Description	Definition	Type	Class	Unit	Size
pms_two_point	Two point PMS voltages (v_{1k}, v_{2k})	Section 3.10.2	double	I	mV	[LICEF_NUMBE R] x [2] x [2]
receiver_temp	Receiver Noise Temperature (T_{Rk}^A)	Eq. 107	double	O	K	[LICEF_NUMBE R]
t_p7	Antenna Patch physical temperature, T_{p7}	Section 3.5.5	double	I	K	[NIR_NUMBE R] x [2]
l_x	Attenuation coefficient, L_x	Eq.120/121	double	L	N/A	[LICEF_NUMBE R] x [2]
t_x	Temperature coefficient, T_x	Eq. 120/121	double	L	N/A	[LICEF_NUMBE R] x [2]
g_c	Gain at CIP during manouever, G_C	Eq. 118	double	L	mv/k	[LICEF_NUMBE R] x [2]
t_sky	Sky temperature computed from NIR pattern and Galaxy Map, T_{Sky}	Eq. 84	double	O	K	[LICEF_NUMBE R] x [2]
t_sky_expected	Expected sky temperature computed from calibration data, $T_{Sky}^{expected}$	Eq. 117	double	O	K	[LICEF_NUMBE R] x [2]
lfe	Front End Loss	Eq. 109	double	O	N/A	[LICEF_NUMBE R] x [2]

Table 61- PMS deep sky calibration variable list

5.10.4. Implementation

- This function will start when the following sequence is found complete:

Cold Sky PMS Validation SEQUENCE															
	Step	Epochs		LICEF	NIR	NS EVEN	NS ODD	Att	PMS (V)	Corr Del	FWF(0) Mkj	NIR Dicke	NIR PMS	LICEF PMS	DATA CORRUP
		CMD	Valid												
PMS Cold Sky	1	21	20	U	LICEF-LU	OFF	OFF	L0	-	0	-	-	v_U	v_U	21st
	2	5	4	U	LICEF-LU	OFF	OFF	L1	-	0	-	-	v_4	v_4	5th
	3	10	8	Dual	LICEF-LA2	OFF	OFF	L1	-	0	-	-	v_3	v_3	1st & 10th
	4	1	0	C	NIR-A	OFF	OFF	L0	-	0	-	-	-	-	1st

Figure 27 - Correlated noise injection modes for PMS Cold Sky calibration

2. The receiver noise temperature, T_R , is computed using Eq. 119
 3. The gains, G_C , are computed using Eq. 108 and the T_R computed in step 2
 4. The expected sky temperature, $T_{Sky}^{expected}$, is computed using Eq. 117,
 5. The gains at antenna, G^{AA} , are computed using Eq. 103
 6. LFE is computed using Eq. 109,
- The processing unit returns LFE , T_{p7} , $T_{Sky}^{expected}$ and the T_{Sky} computed by convolving the Galaxy Map with the NIR antenna patterns

5.10.5. Data Retrieval

Contents	Size	File type	Method
Instrument mode	1 t_cnoise_mode	L1a HKTM (cnoise_mode)	Return t_cnoise_mode value of L1a packet with same OBET
PMS voltages, v1, v2, v3 and v4. EVEN and ODD	[ARM_NUMBER]x[LICEFS_PER_ARM]x4x2 double	L1a HKTM	Search for pms_voltages, in the preceding packets, with cnoise_mode set to “Step 3” “Step 4” “Step 7” “Step 16” “Step 17” “Step 31” “Step 34”

Table 62 - Data retrieval strategy for PMS cold sky calibration

5.10.6. Error Handling

Error Nr	Error Description	Error Code Returned	Program behaviour	Quality flag raised
1	File accessor unable to read the L0 file	DATA_CORRUPTED	Processing unit returns with no data processed.	No

Table 63 - PMS cold sky calibration error handling

6. CONSOLIDATION STRATEGY

This section details the strategies to compute and consolidate the L1a calibration data sequences for use in L1a computations during nominal operations. These strategies were built concurrently with the detailed calibration sequences explained in [RD.17], and were agreed between DME, EADS CASA Espacio and ESA over a series of meetings.

6.1. Visibility offsets

The visibilities offsets will be computed during the Uncorrelated Noise Injection mode of the instrument, during the Long Calibration period. During this period, that in the current baseline takes place during one orbit per month, there will be intervals in which uncorrelated noise is injected.

Each epoch spent in Uncorrelated Noise Injection will generate a complete set of correlators' offsets. The consolidation process shall use the parameters defined in section 3.9 for Correlator Offset and group all measurements into a single average, computing the time duration of the sequence, the number of samples and the validity.

The resulting averaged product shall be used during L1a nominal processing to remove the correlator offsets from the measurements. Each averaged offset shall be used on its corresponding baseline as such, with no interpolation in temperature or time needed.

6.1.1. Computation

6.1.1.1. Input data

- ❑ Uncorrelated Noise Injection L1a product, containing N epochs
- ❑ Previously available Consolidated Uncorrelated Noise Injection L1a product (if available)

6.1.1.2. Output data

- ❑ One visibility offset for each baseline, all of them time tagged with the start time and stop time of the consolidation period (first epoch and last epoch averaged)
- ❑ Averaged physical temperatures of the receivers for the averaged epochs
- ❑ Statistical parameters on the visibility offsets:
 - Number of samples averaged

6.1.1.3. Processing and storage

- ❑ Retrieve the N epochs of the Uncorrelated Noise Injection L1a product
- ❑ Retrieve the averaged values from the Consolidated Uncorrelated Noise Injection L1a product (if available)
- ❑ Perform a running average on the values by adding the new N epochs to the averaged correlator offsets
- ❑ Compute the new time interval combining the previous interval with the last of the new N epochs

- ❑ Store averages into a new Consolidated Uncorrelated Noise Injection L1a product, replacing the old averaged DSR.

6.1.2. Retrieval and Use

In the processing of the visibilities, each one will be corrected by the visibility offset stored that is applicable to the time of measurement. Extrapolation from the last value computed in case there is no applicable data will be possible.

6.2. FWF shape

The FWF shape Measurement data points will be computed during the Correlated Noise Injection mode of the instrument, during the Long Calibration period. For each set of correlated noise measurements (including $-\tau$, 0 and $+\tau$ correlations), the FWF shape Measurements points (M_{kj}) for each baseline are computed and averaged.

During FWF shape consolidation, the FWF shape measurements produced in the nominal FWF shape products are retrieved and used to compute a set of FWF Shape Coefficients per each FWF Shape sequence. These FWF Shape Coefficients are then averaged using the parameters in section 3.9 to select the group of measurements to be averaged.

6.2.1. Computation

6.2.1.1. Input data

- ❑ M_{kj} sets of correlations for the $-\tau$, 0 and $+\tau$ delays for each of the calibration sequences in the FWF shape L1a product
- ❑ Time span of each calibration sequence, and averaged number of epochs used in each of the steps for all calibration sequences in the FWF shape L1a product
- ❑ M_{kj} sets of correlations for the $-\tau$, 0 and $+\tau$ delays, time span and number of epochs averaged, which were previously available in the Consolidated FWF shape L1a product (if available)

6.2.1.2. Output data

- ❑ M_{kj} sets of correlations for the $-\tau$, 0 and $+\tau$ delays, time span and number of samples. These M_{kj} sets shall only contain FWF Shape sequences within the validity period defined in section 3.9 (previous FWF shape sequences available as input are discarded)
- ❑ Set of FWF shape coefficients extracted from the averaged FWF shape coefficients in each sequence

6.2.1.3. Processing and storage:

- ❑ Retrieve the N sequences of the M_{kj} sets of correlations for the $-\tau$, 0 and $+\tau$ delays from the FWF shape L1a product
- ❑ Retrieve the averaged values from the Consolidated FWF shape L1a product (if available)
- ❑ Compute the FWF shape coefficients for each of the calibration sequences, each one having one instance of $-\tau$, 0 and $+\tau$ correlations
- ❑ Perform a running average of the FWF Shape coefficients

- ❑ Store M_{kj} used and FWF shape coefficients into a new Consolidated FWF shape L1a product

6.2.2. Retrieval and Use

All averaged correlations and coefficients are stored in the Consolidated FWF shape L1a product. This allows more flexibility in the use of the data, as another method for extracting the coefficients may be tested. No thermal tagging is needed for the shape.

G matrix computation will start as soon as the 5 FWF shape parameters are produced (L1b processing). This G-matrix will be used for all subsequent measurements, until a new G-matrix is generated. Extrapolation using past G-matrices will be optional.

6.3. FWF at the origin

The FWF values at the origin will be computed during the Correlated Noise Injection mode of the instrument, during both the Short, Long Calibration and Local Oscillator Phase Tracking periods.

A first pass is done on the available sequences to identify and filter out RFI disturbances during correlated noise injection. This is done by computing the STD of each measurement within a sequence with respect to its average along the maneuver. If the STD of any of the following measurements is above 3sigma, the sequence is discarded and not used for consolidation:

- ❑ PMS gains
- ❑ Receiver Noise Temperatures
- ❑ FWF(0)

Only the Long FWF(0) Amplitude and LO FWF(0) Phase shall be consolidated, other events shall only be reported in the Correlated Noise Injection L1a products. The resulting data points will be tagged with the time frame of the sequence, and the averaged value of the physical temperature of each receiver.

During consolidation, two main activities shall be performed. The first one is to consolidate the Long FWF(0) Amplitude and LO FWF(0) Phase sequences into a time ordered list (Long FWF(0) sequences are those FWF(0) Sequences that fulfil the minimum number of epochs in the FWF(0) Consolidation event type). In addition to this, an averaging shall be performed using all the consolidated Long FWF(0) Amplitude sequences in order to generate only one record containing the FWF(0) Amplitude valid for calibrating the science data. No sensitivities shall be computed.

6.3.1. Computation

6.3.1.1. Input

- ❑ Correlated Noise Injection L1a product, containing N sequences of FWF(0) Amplitude and M sequences of LO FWF(0) Phase
- ❑ Previously available Consolidated Correlated Noise Injection L1a product (if available)

6.3.1.2. Output

- ❑ List of Long FWF(0) Amplitude sequences, along with their time start-stop, averaged physical temperatures and number of averaged epochs. This list shall contain all Long FWF(0) Amplitude sequences used to compute the Averaged FWF(0) Amplitude sequence, plus any sequence that is incorporated up to the current processing time

- ❑ List of LO FWF(0) Phase sequences, along with their time start-stop, averaged physical temperatures and number of averaged epochs. This list shall contain all FWF(0) Phase sequences within the validity period defined in section 3.9 (previous FWF(0) Phase sequences available as input are discarded)
- ❑ Averaged FWF(0) Amplitude sequence, along with its time start-stop, averaged physical temperatures and number of averaged epochs

6.3.1.3. Processing and storage:

- ❑ Retrieve the N sequences of the FWF(0) from the Correlated Noise Injection L1a product
- ❑ Retrieve the values from the Consolidated Correlated Noise Injection L1a product (if available)
- ❑ Discard or increment FWF(0) Amplitude and Phase values in the lists by using the new values available in the Correlated Noise Injection L1a product
- ❑ Recompute Averaged FWF(0) Amplitude value if new Long FWF(0) Amplitude sequences have been consolidated
- ❑ For the FWF(0) Phase storage, select the best sequences applicable, this is due to the fact that for a short FWF(0) sequence two phases can be measured, one from the short FWF(0) Sequence and another from the LO Sequence. In this case, the best phase value comes from the FWF(0) Sequence.
- ❑ Store new lists in a new Consolidated Correlated Noise Injection L1a product

6.3.2. *Retrieval and Use*

Whenever the FWF(0) is needed to perform calibration of L1a data, the Averaged FWF(0) Amplitude and the list of FWF(0) Phases stored in the Consolidated Correlated Noise Injection L1a product shall be used.

The Averaged FWF(0) Amplitude shall be used as is, that is without temperature interpolation of any kind.

The list LO FWF(0) Phase shall be used to fit a cubic spline and obtain the FWF(0) Phase at measurement time as indicated in [RD.21].

No FWF Sensitivities are used in the processing.

6.4. PMS gains and offsets

The PMS gains and offsets will be computed during the Correlated Noise Injection mode of the instrument, during the Short and Long Calibration periods. Thus, PMS Sequences may be described as Short or Long sequences. The user can also obtain these values through PMS Cold Sky calibration, by selecting the option in the configuration file. Each PMS sequence will contain gain and offsets, time start and stop of sequence, averaged physical temperatures, calibration type (nominal or cold sky calibration) and number of epochs used in the sequence. This last value shall distinguish Short and Long sequences. Additional values shall be the Receiver Noise Temperature computed for the LICEF-NIR and also for the LICEF (using U-noise injection).

As of 2011, the calibration baseline has been updated to include a faster calibration of PMS offsets by computing them on a weekly basis during specific PMS offset calibration campaigns (groups of 3 consecutive Short PMS sequences).

A first pass is done on the available sequences to identify and filter out RFI disturbances during correlated noise injection. This is done by computing the STD of each measurement within a sequence with respect to its average along the maneuver. If the STD of any of the following measurements is above 3sigma, the sequence is discarded and not used for consolidation:

- ❑ PMS gains
- ❑ Receiver Noise Temperatures
- ❑ FWF(0)

During consolidation and prior to product generation, two main activities shall be performed. The first one is to consolidate the Long PMS and PMS Offsets sequences into separate lists (e.g. Long PMS sequences are those PMS Sequences that fulfil the minimum number of epochs in the PMS Consolidation event type, and the same applies for PMS Offsets sequences and the PMS Offset Consolidation event type). In addition to this, an averaging shall be performed using all the consolidated Long PMS sequences and PMS Offset sequences and separating them according to the calibration type (there shall be two averaged sequences in case both internal and external sequences are found in the same Long PMS sequence). The averaged Long PMS sequences (one or two) shall be consolidated in a new product containing the PMS gain/s and offset/s valid for calibrating the science data, according to the calibration mode selected by the user. The averaged PMS Offset sequences (one) shall be consolidated also in the same product containing just the intended PMS offsets. No sensitivities shall be computed.

Long PMS calibration sequences and PMS Offset sequences shall be consolidated in the new product, taking care to discard the already existing ones, which have become obsolete (its validity has expired). The newly generated average PMS shall also be consolidated, discarding the previous average if it existed.

External PMS calibration sequences shall not be processed nor consolidated in the operational baseline. Their usefulness in operations has not yet been established.

6.4.1. Computation

6.4.1.1. Input

- ❑ Correlated Noise Injection L1a product, containing N new sequences of PMS Calibration
- ❑ Correlated Noise Injection L1a product, containing M new sequences of PMS Offset Calibration
- ❑ Previously available Consolidated Correlated Noise Injection L1a product (if available)

6.4.1.2. Output

- ❑ PMS gain and offset coefficients and Receiver Noise Temperatures per Long PMS Sequence, along with its time start-stop, averaged physical temperatures, calibration type and number of averaged epochs. This list shall contain all PMS sequences used to compute the Averaged PMS sequence, plus any sequence that is incorporated up to the current processing time
- ❑ Total Averaged PMS gain and offset coefficients and Receiver Noise Temperatures, along with its time start-stop, averaged physical temperatures, calibration type and number of averaged epochs.

- ❑ PMS offset coefficients per PMS Offset Sequence, along with its time start-stop, averaged physical temperatures and number of averaged epochs. This list shall contain all PMS Offset sequences used to compute the Averaged PMS Offset sequence, plus any sequence that is incorporated up to the current processing time
- ❑ Total Averaged PMS offset coefficients, along with its time start-stop, averaged physical temperatures and number of averaged epochs.

6.4.1.3. Processing and storage:

- ❑ Retrieve the N sequences of the PMS calibration from the Correlated Noise Injection L1a product
- ❑ Consolidate all new Long PMS sequences in the Consolidated Correlated Noise Injection L1a product, according to the calibration type, and discard those older than the Averaged PMS DSR.
- ❑ If new Long PMS sequences have been consolidated, recompute PMS gain and offset averages, otherwise leave them unchanged.
- ❑ Store all valid Long PMS sequences and PMS Averages in a new Consolidated Correlated Noise Injection L1a product
- ❑ Retrieve the M sequences of the PMS Offset calibration from the Correlated Noise Injection L1a product
- ❑ Consolidate all new PMS Offset sequences in the Consolidated Correlated Noise Injection L1a product and discard those older than the Averaged PMS Offset DSR.
- ❑ If new PMS Offset sequences have been consolidated, recompute PMS offset averages, otherwise leave them unchanged.
- ❑ Store all valid PMS Offset sequences and PMS Offset Averages in a new Consolidated Correlated Noise Injection L1a product

6.4.2. *Retrieval and Use*

Whenever the PMS coefficients are needed to perform calibration of L1a data, the Averaged PMS sequence/s stored in the Consolidated Correlated Noise Injection L1a product shall be used. If the PMS Cold Sky flag is on, Gain and Receiver noise temperatures shall be read from the external averaged sequence and if no external sequence is consolidated, the respective default ADF values shall be used.

The NIR noise temperatures shall always be read from the nominal averaged sequence, independently of the Calibration mode and in case there are no nominal sequences in the consolidated product, the ADF values shall also be used.

The PMS Offsets shall always be read from the Averaged PMS Offsets sequence, superseding those values that exist in the Averaged PMS sequence.

The averaged PMS gains and offsets shall be used in conjunction with the PMS sensitivity from the PMS ADF to be interpolated to the same physical temperature as the epoch to be calibrated.

These values, together with the physical temperature of the receiver at the time of measurement are the only magnitudes needed, as shown in Eq.25.

6.5. Local Oscillator Unlock Events

The LO Unlock event shall be computed during the Correlated Noise Injection mode of the instrument, using the associated HKTM products.

Within the HKTM product, it is only needed to check the LO_Locking and LO_Power flags, and annotate the time intervals in which they are activated and for what CMN it is happening.

During the use of the FWF Phase at the origin, the unlock information shall be used to split the interpolation splines of the baselines affected by the unlocking event.

6.5.1. Computation

6.5.1.1. Input

- ❑ HKTM product covering the Correlated Noise Injection L1a product

6.5.1.2. Output

- ❑ LO unlock time intervals (start/stop) with the CMN id of the unit in which the unlock event was detected.

6.5.1.3. Processing and storage:

- ❑ Process all LO_Locking and LO_Power flag arrays (one flag per CMN) over the complete number of epochs from the HKTM product
- ❑ In case either the LO_Locking or LO_Power flag are set, annotate start time, stop time and CMN id.

6.5.2. Retrieval and Use

Whenever the FWF phase at the origin is needed at measurement time, as per section 7.3.2, a spline must be initialised per baseline using all the available FWF phase measurements in the Correlated Noise Injection product.

For baselines affected by a LO unlock event, the spline must be cut to encompass only groups of FWF phase measurements separated by the LO unlock event (start/stop time). The identification of baselines affected is simply derived from the CMN unit on which the LO unlock event occurred (e.g. an unlock event on CMN H1 affects all baselines formed between LICEF in section H1 to all other LICEF in the remaining sections)

The spline curves, once created, are used in the same way as described in section 7.3.2.

7. PRODUCT GENERATION

L1a products shall be generated in accordance to the format described in [AD.4]. In this section it is described how to fill each substructure within each product type. MPH and SPH structures are common to all types of L1a products, so they shall only be described once.

7.1. MPH

See section 4.1.1 of [RD.5] for the generic description. All fields in the MPH are applicable to all L1a products and are filled according to the following rules:

- ☐ Product: Filename of the physical file generated according to the rules in section 3.1
- ☐ Proc_Stage_Code: Taken from the configuration mode in which the L1OP is operating
- ☐ Ref_Doc: Hardcoded in the L1OP software to reflect which reference document is applicable
- ☐ Header_Size: Set to the corresponding value according to each product header
- ☐ Validation_Schema: Set by the Header template function of the BinXML function
- ☐ Acquisition_Station: Taken from the configuration file of L1OP
- ☐ Proc_Centre: Hardcoded to “L1OP”
- ☐ Proc_Time: Set to the UTC time of product generation
- ☐ Proc_Version: Harcoded in the L1OP software to reflect processor version
- ☐ Sensing_Start: UTC time of the first snapshot inside the Measurement Data Set
- ☐ Sensing_Stop: UTC time of the last snaphsot inside the Measurement Data Set
- ☐ Abs_Orbit: Absolute orbit at Sensing_Start, extracted from EE CFI function xo_time_to_orbit
- ☐ Phase, Cycle, Rel_Orbit: Values taken from EE CFI function xo_orbit_rel_from_abs
- ☐ X_Position, Y_Position, Z_Position, X_Velocity, Y_Velocity, Z_Velocity: Values taken from EE CFI function xo_propag
- ☐ Vector_Source: Depending on the data used for initialising the propagators it may be IG (propagation initialised with GPS data in ancillary packet), SP (propagation initialised with SOGS Predicted data) or SR (propagation initialised with SOGS Restituted data)
- ☐ Leap_UTC: Value retrieved from the EE CFI function xl_time_get_leap_second_info
- ☐ Product_Confidence: Set to NOMINAL if no errors occur during processing. Set to DEGRADED if some errors occurred in one or more snapshots but their output data was written anyway. Set to ERROR if some errors occurred in one or more snapshots and their output data was not written.
- ☐ Total_Size: Set to the binary product size plus the Header size

7.2. SPH

The generic format of L1b products SPH is defined in section 4.12 and 4.4.1.2 of [RD.5].

The SPH is the same for all types of L1a product. All fields in the SPH are applicable to all L1a, except for the RSC_Flag that is only applicable to calibrated visibilities products and shall be set to zero on the rest of products.

Products are filled according to the following rules:

- ☐ Abs_Orbit_Start, Start_Time_ANX_T: Values extracted from EE CFI function xo_time_to_orbit using MPH Sensing_Start as input
- ☐ Abs_Orbit_Stop, Stop_Time_ANX_T: Values extracted from EE CFI function xo_time_to_orbit using MPH Sensing_Stop as input
- ☐ UTC_at_ANX: Value extracted from EE CFI function xo_orbit_to_time using Abs_Orbit_Start and zero seconds as input
- ☐ Long_at_ANX: Value extracted from EE CFI function xo_propag_extra using Abs_Orbit_Start and zero seconds as input
- ☐ Ascending_Flag: Set to A (Ascending) if Abs_Orbit_Stop > Abs_Orbit_Start, or D (Descending) if Abs_Orbit_Stop = Abs_Orbit_Start
- ☐ Mode: Adopts different values depending on the file type.
 - (APID_DUAL) MIR_SC_D1A
 - (APID_FULL) MIR_SC_F1A
 - (APID_EXC_DUAL) MIR_TARD1A
 - (APID_EXC_FULL) MIR_TARF1A
 - (APID_U_CAL) MIR_UAVx1A
 - (APID_C_CAL) MIR_CRSx1A, MIR_AFWx1A
 - (APID_A) TLM_MIRA1A
- ☐ L1A_Err_Flag: Value set to 1 if L1A_Quality > L1A_Err_Threshold. Set to 0 otherwise
- ☐ L1A_Quality: Cumulative quality check set through the processing of the product.
- ☐ L1A_Err_Threshold: Value taken from L1a configuration file
- ☐ RSC_Flag: Flag taken from L1a configuration file. If active, it is set only for product types MIR_SC_D1A, MIR_SC_F1A, MIR_TARD1A and MIR_TARF1A.

7.3. Data Set

The product format variables are filled according to the list of variables presented in the previous chapters. The following sections detail which are the elements that shall be set as output.

7.3.1. Calibrated_Visib_Dual

- ☐ Snapshot_Time, Snapshot_ID: Values taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input

- ☐ Snapshot_OBET: Value read from L0 data
- ☐ Correlator_Layer: Value taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ Snapshot_Order: Value set in full pol mode processing for each sub-scene processed. In dual pol mode, shall be always set to zero
- ☐ Receiver_Temp: Values taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ Sys_Temp: Values taken from system_temperatures structure
- ☐ NIR_Brightness_Temp: Values taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ Pol_Mode: Values taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ RFI_Flag: Values taken from the RFI flagging function
- ☐ Calib_Visib: Values taken from calibrated_visibilities structure

7.3.2. Calibrated_Visib_Full

Same as the previous dual polarisation case.

7.3.3. Offset_Correction

- ☐ Snapshot_Time: Values taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input
- ☐ Snapshot_OBET: Value read from L0 data
- ☐ Correlator_Layer: Value taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ Offset: Values taken from visibilities_offsets structure
- ☐ Receiver_Temp: Values taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.

7.3.4. Mean_Offset_Correction

- ☐ Start_Time: Set using the Snapshot_Time of the first scene in the block being averaged
- ☐ Stop_Time: Set using the Snapshot_Time of the last scene in the block being averaged
- ☐ Correlator_Layer: Value taken from l1a_hktm_data retrieved from data provider using all snapshot OBET in the block being averaged as input.
- ☐ Samples: Number of samples taken during the averaging process
- ☐ Offset: Values taken from averaging the block of visibilities_offsets structures
- ☐ Receiver_Temp: Values taken from l1a_hktm_data retrieved from data provider using all snapshot OBET in the block being averaged as input.

7.3.5. *Ampl_Phase_Correction*

- ☐ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the calibration sequence
- ☐ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the calibration sequence
- ☐ Correlator_Layer: Value taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ Samples: Average number of epochs processed in all steps
- ☐ FWF_Origin: Values taken from fwf_c structure
- ☐ FWF_Origin_Quality: Values taken from fwf_hv structure
- ☐ Receiver_Temp: Values taken from l1a_hktm_data retrieved from data provider using all snapshot OBET from all epochs involved in the calibration sequence as input.

7.3.6. *PMS_Coefficients*

- ☐ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the calibration sequence
- ☐ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the calibration sequence
- ☐ Calibration_Type: Set according to the data type – is 0 for internal and 1 for external calibration sequences
- ☐ Samples: Average number of epochs processed in all steps
- ☐ PMS_ID: Value read from L0 data
- ☐ Temperature: Values taken from l1a_hktm_data retrieved from data provider using all snapshot OBET from all epochs involved in the calibration sequence as input.
- ☐ Gain: Value taken from pms_gain structure.
- ☐ Offset: Values taken from pms_offset structure
- ☐ T_rec: Values taken from receiver_temp structure.
- ☐ T_rec_licef: Values taken from receiver_noise_temp structure

7.3.7. *NIR_Reference*

- ☐ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the calibration sequence
- ☐ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the calibration sequence
- ☐ Samples: Average number of epochs processed in all steps
- ☐ T_noise_ref: Values taken from ndn_temp_Cport structure.
- ☐ Temperature: Values taken from l1a_hktm_data retrieved from data provider using all snapshot OBET from all epochs involved in the calibration sequence as input.

7.3.8. FWF_Measurements

- ☐ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the calibration sequence
- ☐ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the calibration sequence
- ☐ Correlator_Layer: Value taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ Samples: Average number of epochs processed in each step
- ☐ Time_Delay: Value taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ FWF_Measurements: Values taken from fwf_c structure.

7.3.9. FWF_Coefficients

- ☐ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the calibration sequence
- ☐ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the calibration sequence
- ☐ Correlator_Layer: Value taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ Samples: Average number of epochs processed in each step
- ☐ Time_Delay: Value taken from l1a_hktm_data retrieved from data provider using snapshot OBET as input.
- ☐ A: Values taken from fwf_shape_coeff structure.
- ☐ B: Values taken from fwf_shape_coeff structure.
- ☐ C: Values taken from fwf_shape_coeff structure.
- ☐ D: Values taken from fwf_shape_coeff structure.
- ☐ E: Values taken from fwf_shape_coeff structure.

7.3.10. HKTM_Data

All the data represented below is taken from the list of variables presented in section 5.1

- ☐ Snapshot_Time: Values taken from obet_in_utc structure
- ☐ Snapshot_OBET: Value read from L0 data
- ☐ OBET_PPS, UTC_PPS: Values read from L0 data
- ☐ X_Position, Y_Position, Z_Position, X_Velocity, Y_Velocity, Z_Velocity, Vector_Source: Values taken from l1a_pvt_data structure.
- ☐ Q0, Q1, Q2, Q3, X_Ang_Velocity, Y_Ang_Velocity, Z_Ang_Velocity: Values taken from l1a_aocs_data structure
- ☐ PMS_Voltages: Values taken from pms_voltages structure

- ☐ NIR_Mode: Values read from L0 data
- ☐ NIR_Avg_Samples: Values taken from L0 data
- ☐ NIR_Error: Values taken from L0 data
- ☐ NIR_Pulse_Length: Values taken from L0 data
- ☐ NIR_Brightness_Temp: Values taken from nir_antenna_temp structure
- ☐ Physical_Temperatures: Values taken from last_phys_temp structure
- ☐ M_Fly: Values taken from m_fly structure
- ☐ Q_Fly: Values taken from q_fly structure
- ☐ LICEF_Status, CMN_NIR_Status, NS_Status: Values taken from Elements Failure computation
- ☐ TSYNC_Error: Values taken from L0 data
- ☐ Arm_Pol_Mode: Values taken from Arm Polarisation computation
- ☐ Arm_Redundancy_Config: Values taken from L0 data
- ☐ ASIC_Mode: Values taken from L0 data
- ☐ CCU_Error: Values taken from L0 data
- ☐ PPS_Error: Values taken from L0 data
- ☐ XBAND_Error: Values taken from L0 data
- ☐ Correlators_Op_Mode: Values taken from L0 data
- ☐ Correlators_Redundancy_Config: Values taken from L0 data
- ☐ Memory_Redundancy_Config: Values taken from L0 data
- ☐ Instrument_Mode: Values taken from L0 data
- ☐ Correlated_Noise_Mode: Values taken from Correlated Noise Mode computation
- ☐ FWF_Step: Values taken from L0 data
- ☐ Corrupted_Data: Values taken from L0 data
- ☐ TSYNC_CMN_Error: Values taken from L0 data
- ☐ Heater_Status: Values taken from L0 data
- ☐ Last_Executed_Command: Values taken from L0 data
- ☐ Last_Executed_Command_Error: Values taken from L0 data
- ☐ Last_APIID: Values taken from L0 data
- ☐ LO_Locking: Values taken from L0 data
- ☐ LO_Output_Power: Values taken from L0 data
- ☐ XBAND_Status: Values taken from L0 data
- ☐ RF_Level, VCO_TM, Num_Alim_TM, SSPA_Alim_TM, Temp_TM: Values taken from l1a_x_band_data structure
- ☐ PM_Nominal: Values taken from L0 data

- ☐ EEPROM_Selected: Values taken from L0 data
- ☐ Reset_Source: Values taken from L0 data
- ☐ EEPROM_Write: Values taken from L0 data

7.3.11. NIR_A_External

- ☐ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the calibration sequence
- ☐ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the calibration sequence
- ☐ NIR_Expected_BT: Values taken from t_a_0 structure
- ☐ NIR_Observed_BT: Values taken from t_a_prima3_0 structure.
- ☐ T_noise_cal: Values taken from t_noise_0 structure
- ☐ Cross-coupling and leakage factors from leakage and coupling structures
- ☐ Temperature: Values taken from l1a_hktm_data retrieved from data provider using all snapshot OBET from all epochs involved in the calibration sequence as input.
- ☐ All calibration parameters for the NIRs are an average of the values found for each of the three NIRs.

7.3.12. NIR_R_External

- ☐ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the calibration sequence
- ☐ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the calibration sequence
- ☐ NIR_Observed_BT: Values taken from t_a_on0 structure.
- ☐ T_noise_cal_ref: Values taken from t_nr_0 structure.
- ☐ Temperature: Values taken from l1a_hktm_data retrieved from data provider using all snapshot OBET from all epochs involved in the calibration sequence as input.
- ☐ All calibration parameters for the NIRs are an average of the values found for each of the three NIRs.

7.3.13. Avg_NIR_A_External

- ☐ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the first calibration sequence averaged
- ☐ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the last calibration sequence averaged
- ☐ NIR_Expected_BT: Values taken from the average of t_a_0 structure across all averaged calibration sequences
- ☐ NIR_Observed_BT: Values taken from the average of t_a_prima3_0 structure across all averaged calibration sequences.

- ❑ T_noise_cal: Values taken from the average of t_noise_0 structure across all averaged calibration sequences
- ❑ Cross-coupling and leakage factors from the average of leakage and coupling structures across all averaged calibration sequences
- ❑ Temperature: Values taken from the average of physical temperatures from all the calibration sequences averaged.
- ❑ All calibration parameters for the NIRs are an average of the values found for each of the three NIRs.

7.3.14. Avg_NIR_R_External

- ❑ Sequence_Start_Time: Set using the Snapshot_Time of the first epoch of the first step in the first calibration sequence averaged
- ❑ Sequence_Stop_Time: Set using the Snapshot_Time of the last epoch of the last step in the last calibration sequence averaged
- ❑ NIR_Observed_BT: Values taken from the average of t_a_on0 structure across all averaged calibration sequences.
- ❑ T_noise_cal_ref: Values taken from the average of t_nr_0 structure across all averaged calibration sequences.
- ❑ Temperature: Values taken from the average of physical temperatures from all the calibration sequences averaged.
- ❑ All calibration parameters for the NIRs are an average of the values found for each of the three NIRs.

8. ANNEX 1: L1A DATA FLOW DIAGRAM

