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| Publication Year | 2009 |
| Acceptance in OA @INAF | 2023-02-08T10:51:56Z |
| Title | Planck LFI CPV: TSA Failure and Thermal Dynamic Response |
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| Handle | http://hdl.handle.net/20.500.12386/33272 |
| Number | PL-LFI-PST-RP-078 |



Planck LFI CPV: TSA Failure and Thermal Dynamic Response (ref: P_PVP_LFI_0023_01)

TITLE:

DOC. TYPE:

Test Report

PROJECT REF.:

PL-LFI-PST-RP-078

PAGE: I of IV, 12

ISSUE/REV.:

1.1

DATE: **09 Oct, 2009**

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CHANGE RECORD

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1 ACRONYMS

| | |
|--------|---|
| AIV | Assembly, Integration, Verification |
| ASW | Application Software |
| BEM | Back End Module |
| BEU | Back End Unit |
| CCS | Central Check-out System |
| CDMU | Central Data Management Unit |
| DAE | Data Acquisition Electronics |
| DPU | Digital Processing Unit |
| EGSE | Electrical ground Support Equipment |
| FEM | Front End Module |
| FPU | Focal Plane Unit |
| I-EGSE | Instrument EGSE |
| IST | Integrated Satellite Test |
| OBC | On Board Clock |
| RAA | Radiometer Array Assembly |
| REBA | Radiometric Electronic Box Assembly |
| S/C | Spacecraft |
| SCOE | Spacecraft Control and Operation System |
| SPU | Signal Processing Unit |
| SUSW | Start- Up Software |
| SVM | Service Module |
| TBC | To Be Checked |
| TBW | To Be Written |
| TC | Telecommand |
| TM | Telemetry |
| UFT | Unit Functional Test |



2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

- [AD1] Herschel/Planck Instrument Interface document Part A, SCI-PT-IIDA-04624 Issue 3.3
- [AD2] Herschel/Planck Instrument Interface document Part B, SCI-PT-IIDB-04142 Issue 3.1
- [AD3] Herschel/Planck Instrument Interface document Part B, SCI-PT-IIDB-04142 Issue 3.1, Annex 3, ICD 750800115
- [AD4] Herschel/Planck Instrument Interface document Part A, SCI-PT-IIDA-04624 Issue 3.3 Annex 10
- [AD5] Data analysis and scientific performance of the LFI FM instrument, PL-LFI-PST-AN-006 3.0
- [AD6] Planck-LFI TV-TB test report: executive summary, PL-LFI-PST-RP-040 1.1

2.2 Reference Documents

- [RD1] Planck Instrument Testing at PFM S/C levels, H-P-3-ASP-TN-0676, Issue 1.0
- [RD2] Planck LFI User Manual, PL-LFI-PST-MA-001 Issue 2.1
- [RD3] M.Tomasi et al., Dynamic Validation of the Planck/LFI Thermal Model, 2009, submitted to JINST



3 INTRODUCTION

3.1 Purpose and Scope

Characterize the dynamic behaviour of the LFI Focal Plane with no active control of the TSA temperature, evaluate transfer functions between FPU sensors and compare results with previous tests and thermal model predictions.

3.2 Test configuration

The test configuration is the following

SCOS 2 K HPCCS Version 2.0.787
LFI Gateway Version V0R9P1
TQL 3.1.2
LIFE Machine version OM 3.00

Personnel involved during the test is:

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| Industry support | |



4 Test Execution

4.1 Pass-fail criteria, verification matrix

CPV P_PVP_LFI_0023_01
July, 29 2009 OD 77
Duration 24 hours
Test name: TSA failure and thermal dynamic response
Test objectives: Characterise the dynamic behaviour of Thermal Model and susceptibility.

| Verification matrix | | | | | |
|---|---------|----|---|------------|----|
| Check | Passed? | | | Recovered? | |
| | Yes | No | Notes | Yes | No |
| No unexpected events packets | Yes | | | | |
| Housekeeping and Science production telemetry as expected | Yes | | | | |
| Test sequence successfully run | | No | Duration was agreed to be reduced to 4 hours. Data are enough for the analysis to be run. | Yes | |
| Real time data available | Yes | | | | |
| Data saved and stored at DPC | Yes | | | | |

The test was run successfully. A reduced duration of the TSA switch off time was agreed before the test started.

4.2 Procedure/ Test sequence

The test started on July 29th at 6:00 UTC when the sorption cooler TSA was switched off. The test was run after a steady period of 12 hours when the instruments were working in nominal conditions, so that the comparison between the TSA on nominal setup and the TSA off is also possible as an additional information for the thermal susceptibility test. The duration of 4 hours was agreed in order to have a sufficient number of cooler cycle monitored and at the same time to minimize the time the system is kept out of the nominal state, so to avoid other cryochain parts than LFI FPU interface to be affected. On July 29th at 10:00 UTC the TSA was activated back. An overview of relevant temperature data are given in Fig. 2, where also the FPU temperature steady state period before the test is visible. An overview of the FPU sensors is given in Fig. 1. The Sorption Cooler nominal unit cold end is located on the bottom right of the figure. After switching off the TSA fluctuation propagates from the TSA to the other sensors location following the direction upwards left.

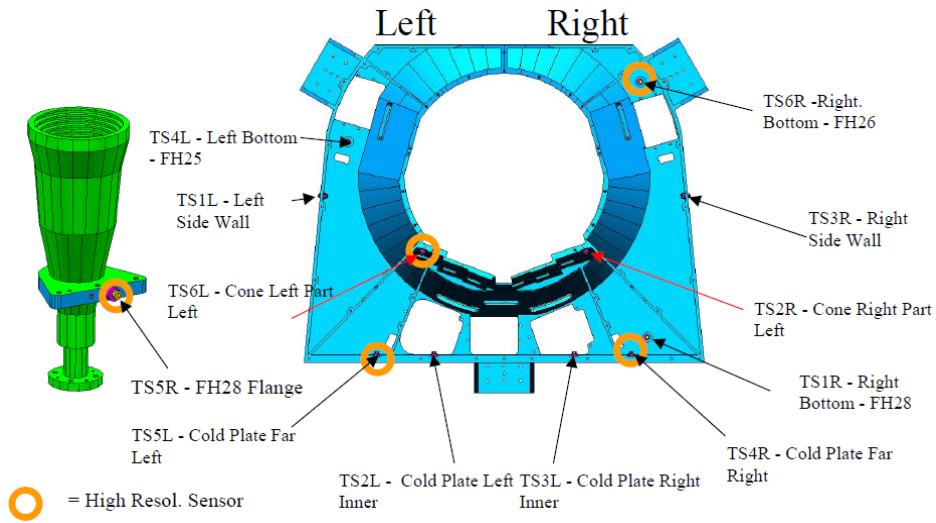


Fig. 1 Temperature sensors location on the LFI focal plane. The cold end interface is in the corner on the bottom right of the figure

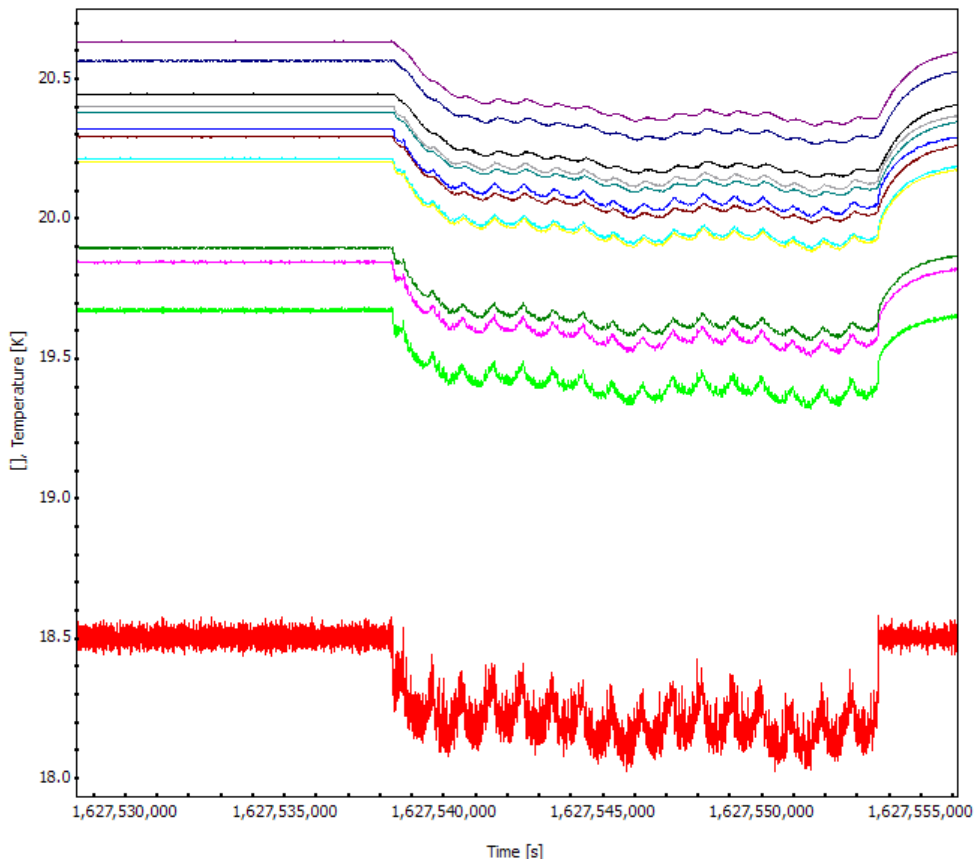


Fig. 2 Temperature sensor curves during the thermal dynamic response test. The red curve is the sorption cooler TSA sensor.

5 Data Analysis

The source of fluctuations is characterized by two main periods which are the sorption cooler typical periods:

1. the bed cycle time, which is set to 940 sec during the test
2. the complete cooler period which is six times larger: 5640 sec in our case.

The first analysis to run is to evaluate the transfer functions of the fluctuation in the TSA temperature to the 12 FPU temperature sensors at the two main frequencies.

Two methods for evaluating the transfer functions were used, as described also in [RD3].

The first method consists on performing a DFT of the sensor timestreams and then evaluating the ratio of the amplitude and the difference of the phases found at the relevant frequencies of interest.

The second method consists in fitting the sensor timestreams with a double sin function:

$$T(t) = T_0 + A_1 \sin(\omega_1 t + \phi_1) + A_2 \sin(\omega_2 t + \phi_2)$$

where $\omega_1 = 1/940$ Hz and $\omega_2 = 1/5640$ Hz: and then transfer functions are evaluated by the ratio of the amplitudes and phases found.

5.1 Transfer functions from DFT

The total time with steady conditions we can exploit for analysis makes us have a clear DFT for the peak around 1 mHz only, as evident, from the Fig. 3.

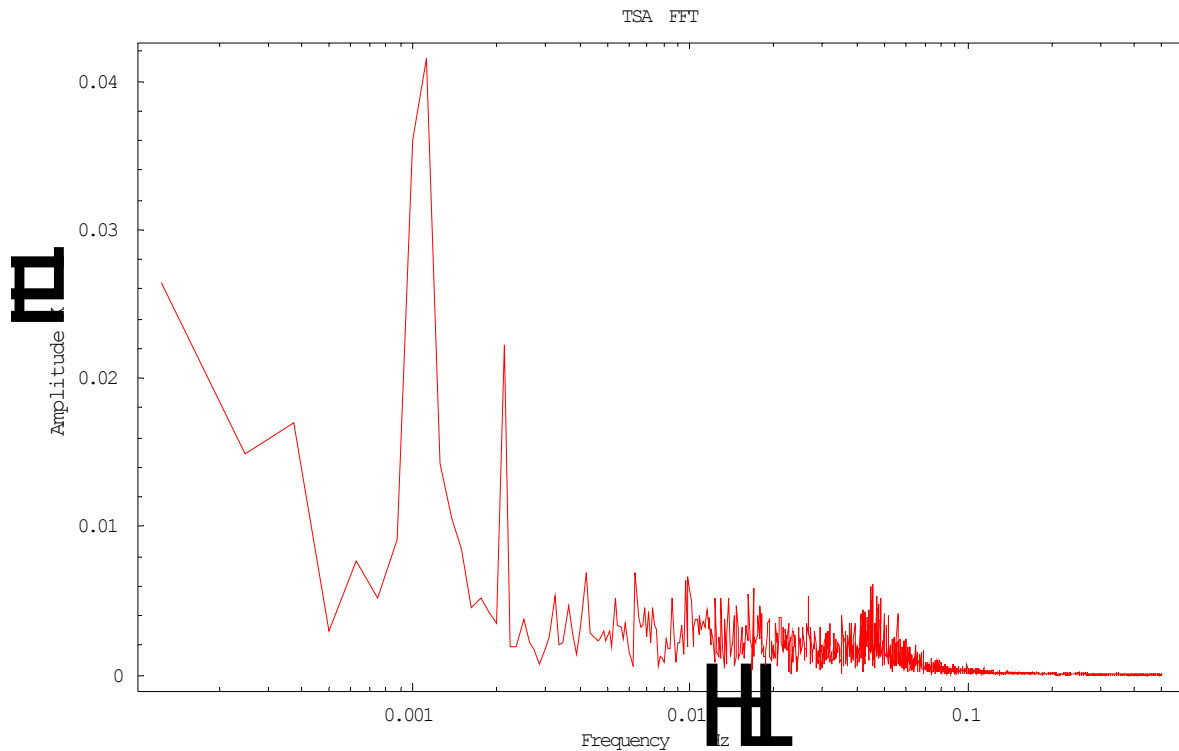


Fig. 3 TSA temperature DFT during latest test phase (about 8000 sec) before switching it on again. Peak at 1mHz is evident, while lowerfrequencies are poorly scanned.

So the final results were obtained from points at 0.998 mHz and 1.12 mHz, which are the frequencies closest to the 940sec period fluctuation, which was not resolved exactly by the transform as evident also from Fig. 4.

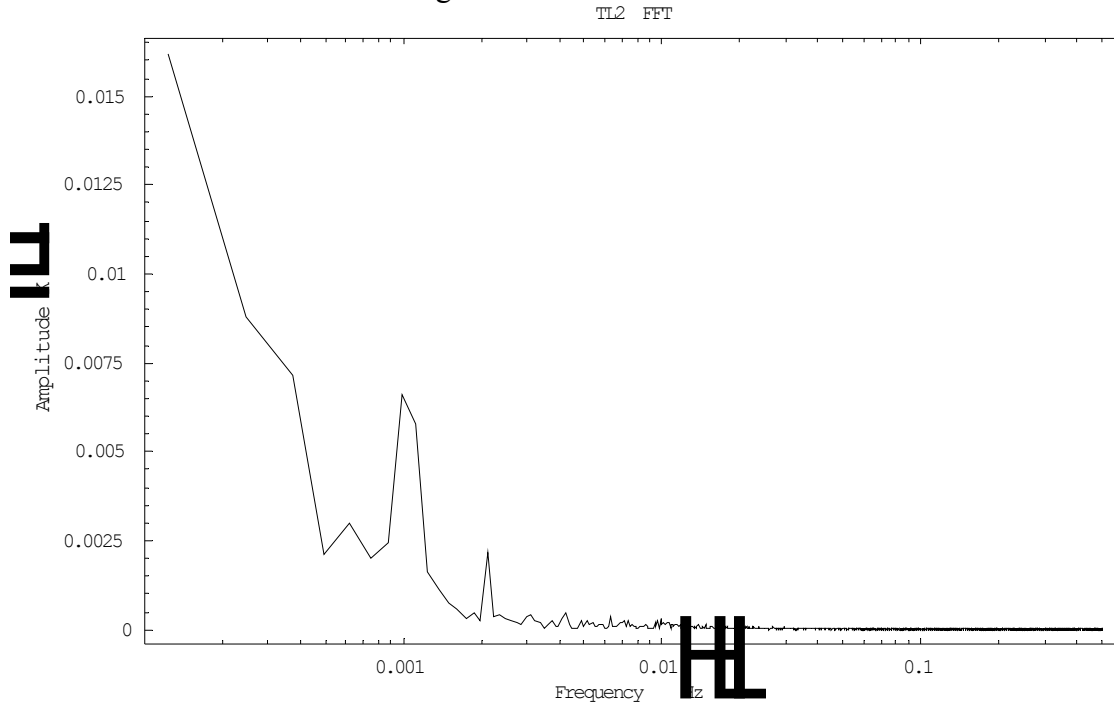


Fig. 4 Discrete fourier transform for the sensor TSL2. the distance between the two points at about 1mHz shows the frequency resolution close to the peak.

The transfer function amplitude is evaluated by the ratio of the amplitudes of the FPU sensors to the TSA one (see Fig. 5).

The phase is given by the difference between the FPU sensors phase and the TSA sensor phase.

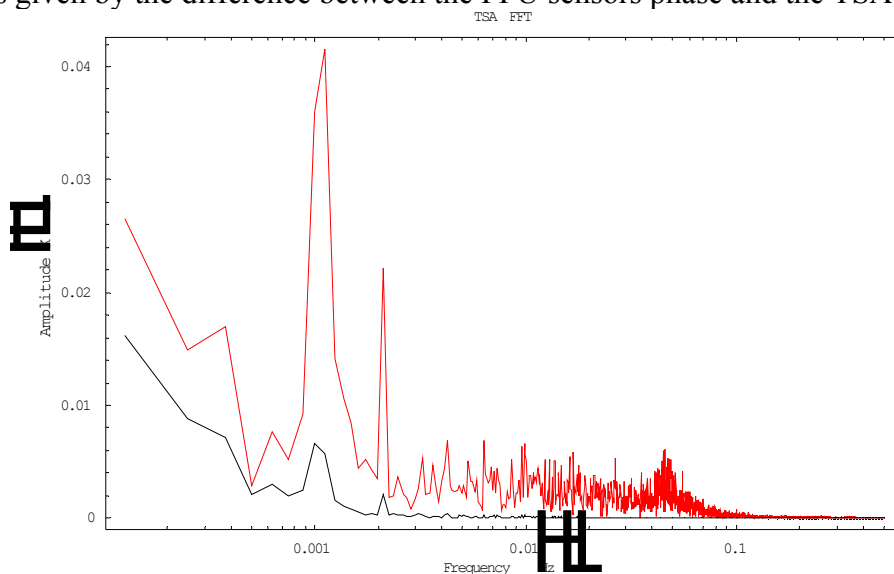


Fig. 5 The TSA Fourier transform amplitude (red) plotted with the TSL2 one (black). The transfer function amplitude is evaluates from the ratio of the two.

Results are shown in Table 1.

| Sensor ID | 0.998 mHz | | 1.12 mHz | |
|-----------|-----------|-------------|----------|-------------|
| | TF Amp | Phase (rad) | TF Amp | Phase (rad) |
| TSL1 | 0.132 | 1.58 | 0.113 | 1.99 |
| TSL2 | 0.184 | 1.09 | 0.139 | 1.21 |
| TSL3 | 0.289 | 0.64 | 0.253 | 0.60 |
| TSL4 | 0.130 | 1.60 | 0.113 | 2.04 |
| TSL5 | 0.164 | 1.27 | 0.125 | 1.50 |
| TSL6 | 0.136 | 1.51 | 0.112 | 1.91 |
| TSR1 | 0.417 | 0.36 | 0.393 | 0.32 |
| TSR2 | 0.244 | 0.88 | 0.205 | 0.88 |
| TSR3 | 0.250 | 0.86 | 0.209 | 0.85 |
| TSR4 | 0.333 | 0.53 | 0.302 | 0.48 |
| TSR5 | 0.253 | 0.86 | 0.210 | 0.85 |
| TSR6 | 0.184 | 1.17 | 0.146 | 1.32 |

Table 1 Results from DFT analysis for transfer functions of FPU temperature sensors

5.2 Transfer functions from sinusoidal function fitting

The second method is implemented in the time domain. It consists in fitting as mentioned above each sensor curve with a double sinusoidal function.

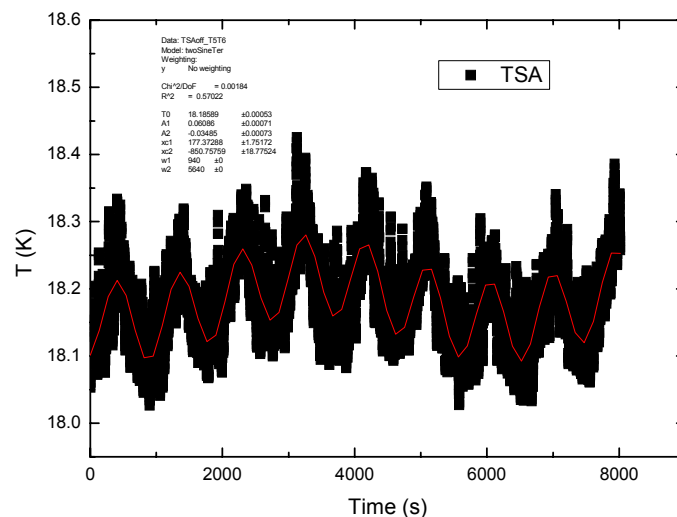


Fig. 6 TSA sensor temperature curve (black points) fitted by a double sinusoidal function (red line).

In Fig. 6, the temperature curve of the TSA sensor is shown together with its fitting curve. The fit is very good also because the TSA sensor is the most variable and it is rapidly decreasing its temperature to the minimum steady state. When fitting the FPU sensors, we realized that a slow drift was occurring again for some of them, in particular the farthest from the cold end temperature sink, so that the simple fit used before was not sufficient to have a detailed data analysis result.

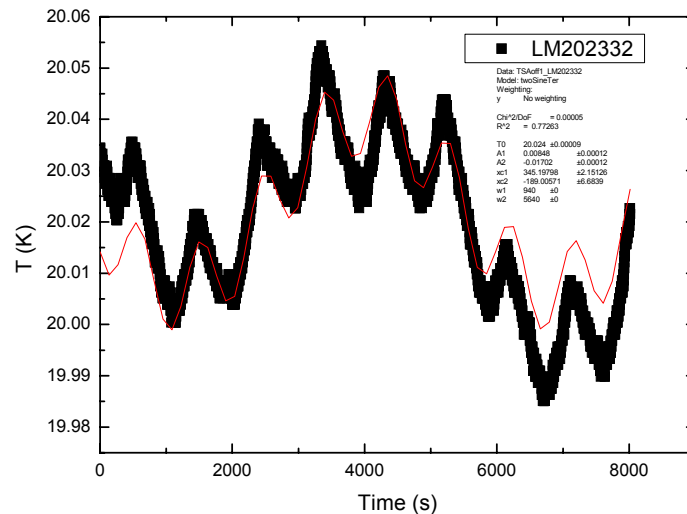


Fig. 7 Temperature curve of the TS2L sensor (black points), plotted together with the double sinusoidal fitting function (red line). A drift is still present in the data and it could affect the quality of the results.

So a further additional exponential decay was added to the fitting function in order to take into account the residual drift and have a compliant fit result (see)

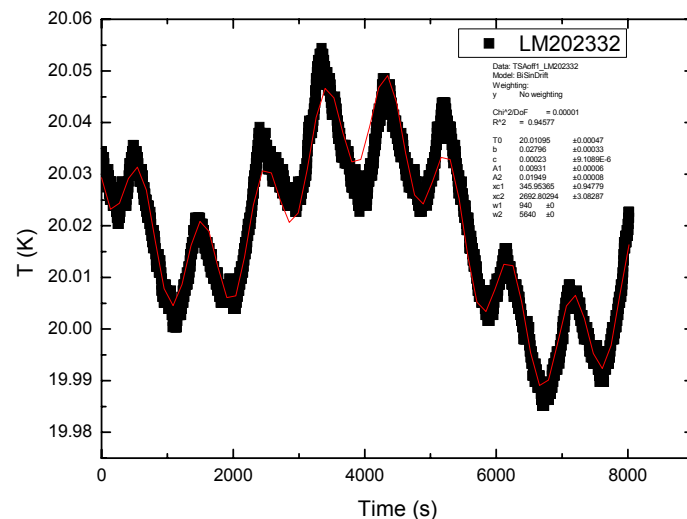


Fig. 8 Temperature curve of the TS2L sensor (black points), plotted together with the new double sinusoidal fitting function with exponential decay (red line).



The final function was defined as:

$$T(t) = T_0 + Be^{-Ct} A_1 \sin(\omega_1 t + \phi_1) + A_2 \sin(\omega_2 t + \phi_2)$$

Also in this case the transfer function amplitude is defined by the ratio of the amplitudes of the fit and phases are defined by the differences.

In this last case also the long period component at 5640 sec is monitored in the analysis.

Results are given in Table 2.

| <i>Sensor ID</i> | 1.064 mHz | | 0.177 mHz | |
|------------------|------------------|--------------------|------------------|--------------------|
| | <i>TF Amp</i> | <i>Phase (rad)</i> | <i>TF Amp</i> | <i>Phase (rad)</i> |
| TSL1 | 0.113 | 1.79 | 0.520 | 0.95 |
| TSL2 | 0.153 | 1.13 | 0.560 | 0.81 |
| TSL3 | 0.266 | 0.60 | 0.600 | 0.60 |
| TSL4 | 0.112 | 1.83 | 0.522 | 0.96 |
| TSL5 | 0.136 | 1.37 | 0.554 | 0.87 |
| TSL6 | 0.110 | 1.70 | 0.483 | 0.98 |
| TSR1 | 0.402 | 0.33 | 0.660 | 0.41 |
| TSR2 | 0.218 | 0.86 | 0.583 | 0.68 |
| TSR3 | 0.222 | 0.84 | 0.589 | 0.68 |
| TSR4 | 0.313 | 0.49 | 0.616 | 0.52 |
| TSR5 | 0.224 | 0.84 | 0.586 | 0.68 |
| TSR6 | 0.158 | 1.23 | 0.545 | 0.81 |

Table 2 Results for transfer functions evaluated from the double sinusoidal function fitting with exponential decay.

6 Steady state temperature distribution

A dedicated time, with all temperatures in the focal plane were in a steady condition was allocated since August 2nd 12:00z to August 3rd 12:00z. The corresponding temperature curves of the TSA and FPU sensors are reported in Fig. 9.

In the Table below main statistics (average temperature, standard deviation and peak-to-peak amplitude) for the sensors temperature curve during the 24 hours duration of the test are reported. The TSA was controlled at 18.5 K. The mean value of the peak-to-peak amplitude of the high resolution sensors is of about 4 mK, while the sensor closest to the source of fluctuations and fixed directly on the RCA28 feed horn flange has a p-p amplitude of 4.7 mK, with a reduction of the TSA fluctuations of a factor 45.

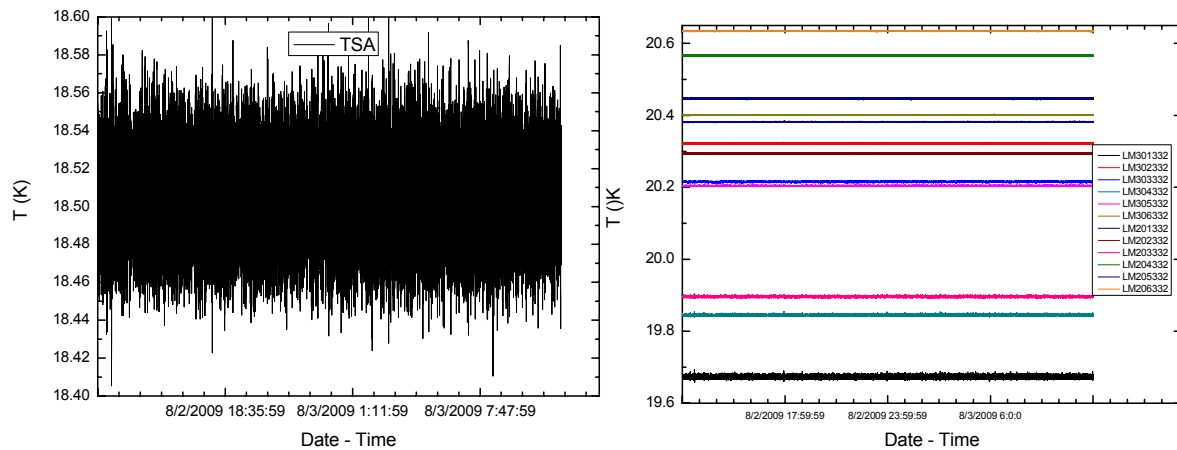


Fig. 9 Steady state temperature curves of the TSA (left panel) and FPU (right panel) sensors

| Sensor Id | Mean T (K) | ΔT rms (K) | ΔT p-p (K) |
|-----------|------------|--------------------|--------------------|
| TSA | 18.50059 | 0.02311 | 0.21227 |
| TSL1 | 20.44637 | 7.04331E-4 | 0.00669 |
| TSL2 | 20.29393 | 8.10118E-4 | 0.00667 |
| TSL3 | 19.89597 | 0.00128 | 0.01176 |
| TSL4 | 20.56603 | 7.73461E-4 | 0.00554 |
| TSL5 | 20.38185 | 5.00818E-4 | 0.004 |
| TSL6 | 20.63433 | 5.03124E-4 | 0.00401 |
| TSR1 | 19.67198 | 0.00344 | 0.03553 |
| TSR2 | 20.32162 | 8.91561E-4 | 0.00667 |
| TSR3 | 20.21499 | 8.63764E-4 | 0.00777 |
| TSR4 | 19.84482 | 0.00145 | 0.0154 |
| TSR5 | 20.20399 | 5.85881E-4 | 0.00467 |
| TSR6 | 20.40109 | 5.14072E-4 | 0.004 |



7 Conclusions and recommendations

The analysis carried out provides the reference values of in flight transfer functions. The two methods give a good agreement when comparing the 1.12 mHz results in Table 1 to the 1.064 mHz results in Table 2.

As expected also the temperatures of the FPU sensors are sorted with ascending values in the direction from the bottom right of the FPU to the upper left side, in a coherent way with fluctuation decrease.

These results then also give a clear view of the heat flux lines through the whole front end unit and main frame.