HIFI ILT summary report

Version 1.0 of 2008-06-09, by Michael Olberg

Abstract

The report summarizes results from the HIFI ILT campaign which took place during the first half of 2007. The work was organized through a number of topical teams, and the main conclusions from each team are presented. For more detailed information the reader is referred to the individual reports, the respective references can be found in this document.

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Reference Documents

Doc. ref		Title
SRON-G/HIFI/TR/2008-003	RD01	HIFI FM vector scan measurements
JPL/HIFI/TN/2008-006	RD02	Detection Strategy for Spurious Response
SRON-G/HIFI/PR/2007-102	RD03	FM ILT Frequency Response Test Report
SRON-G/HIFI/TR/2008-002	RD04	HIFI FM gas cell measurements
SRON-G/HIFI/TR/2008-010	RD05	Standing wave analysis of HIFI ILT data
FPSS-01201	RD06	HIFI ILT Stability
SRON-G/HIFI/TR/2008-001	RD07	HIFI FM radiometry measurements
SRON-G/HIFI/PR/2008-015	RD08	FM ILT Linearity Test Report
ICC 2008-131	RD09	HIFI AOT Observing Mode Tests (FM-ILT)
–	RD10	Herschel Telescope Beam Patterns

Contents

1 Introduction

The HIFI ILT campaign took place during the first half of 2007. A number of test teams investigated instrument performance according to the following list:

- Functional tests
- Radiometry tests
- Stability tests
- Spectral tests
  - Spurious signals and responses
  - Frequency Response
  - Continuum Linearity
  - Line Linearity
  - Gas cell
  - Standing Wave
- AOT Tests

During the ILT campaign a number of hardware modifications were performed, most notably the installation of optical LO attenuators in order to improve on the poor instrument stability observed during the early phase of ILT. This means that data quality is typically non-uniform over the test series and that some conclusions will have to be based on results from tests with the final hardware configuration, leading at times to coarser frequency coverage than what would have been possible if the instrument had worked optimally over the whole period.

A number of ILT investigations address the determination of parameters that directly enter the calibration equation for the HIFI instrument:

$$J_{on} - J_{off} = \frac{1}{G_{ssb}\eta_l + \omega_{ssb}} \frac{\eta_{hot} + \eta_{cold} - 1}{\eta_{sf}} \times \ldots \quad (1)$$

where G_{ssb} is the side-band gain ratio, which is investigated by the gas cell tests (see Sec. 9) and η_{hot}, η_{cold} are the coupling coefficients for the hot and cold calibration loads, respectively, under study as part of the radiometry tests.

Most test teams have submitted there final reports and some of their conclusions are quoted below. However, the reader is referred to the respective document for the full picture and detail[1]. A few reports came in late due to issues raised during the HIFI ILT results review, which took place at SRON Groningen on April 25, 2008, making it necessary to repeat parts of the data analysis. Unfamiliarity with and shortcomings of the HCSS data analysis environment also has severely delayed the delivery of reports in a number of cases.

1.1 Acronyms

AD	Applicable Document
AOR	Astronomical Observation Request
AOT	Astronomical Observation Template
COP	Commissioning Phase
CUS	Common Uplink System
DP	Data Processing
DTCP	Daily Telecommunication Period
ESA	European Space Agency

[1] available via the HIFI-SRON KnowledgeTree document server at `https://kt.sron.nl/browse.php?fFolderId=2401`

FM	Flight Model
FP	Focal Plane
HIFI	Heterodyne Instrument for the Far-Infrared
HPBW	Half Power Beam Width
HRS	High resolution spectrometer
HSC	Herschel Science Centre
IA	Interactive Analysis
IF	Intermediate Frequency
ICC	Instrument Control Centre
ILT	Instrument Level Test
IST	Instrument System Test
LO	Local Oscillator
LOU	Local Oscillator Unit
OBS	On-Board Software
PV	Performance Verification
RD	Reference Document
SBR	Side-Band gain Ratio
SFT	Short Functional Test
WBS	Wide-Band Spectrometer

2 Conclusions

In this section the main conclusions are summarised in the form of a few figures and tables for the convenience of the reader. The focus is on system performance and the quality of those parameters measured during ILT, that enter Eq. 1 directly.

2.1 Performance

Figure 1 shows DSB noise temperatures as a function of frequency. These values have also been fed back into HSpot, where they are used for time/noise estimates.

Figure 2 shows Allan times for a reference bandwidth of 1 MHz. Total power stability times for the whole band are shown in red, spectroscopic stability over the whole band in blue and, finally, the spectroscopic stability time for the best subband in green. The displayed values are the ones used by HSpot for sequencer calculations. Subband 7b is characterised by more than one constant value, as stability is clearly improved near the band edges.

2.2 Calibration parameters

Figure 3 shows so-called box-plots for the coupling coefficients measured as part of the radiometry tests. Based on the observed values for each band, we can test the null hypothesis that these values could come from a distribution with mean value $\bar{\eta} = 1$. The results are summarised in table 1. Bands 1,2,3 and 5 show significant deviations from perfect coupling and the sample mean would be the most reasonable value to use for calibration purposes, taken to be constant across the band. For bands 4 (small sample sizes) and the HEB bands, 6 and 7, the measurements are compatible with perfect coupling because of the large scatter, consequently $\eta = 1$ should be used.

For the sideband gain ratios studied by the gas-cell team, the analysis is ongoing as more complicated molecules are being added. Thus, it appears premature to make quantitative assessments of any deviation from the theoretically expected gain values of 0.5, i.e. equal contribution from the two sidebands. At first glance, the data do not contradict this assumption, though.

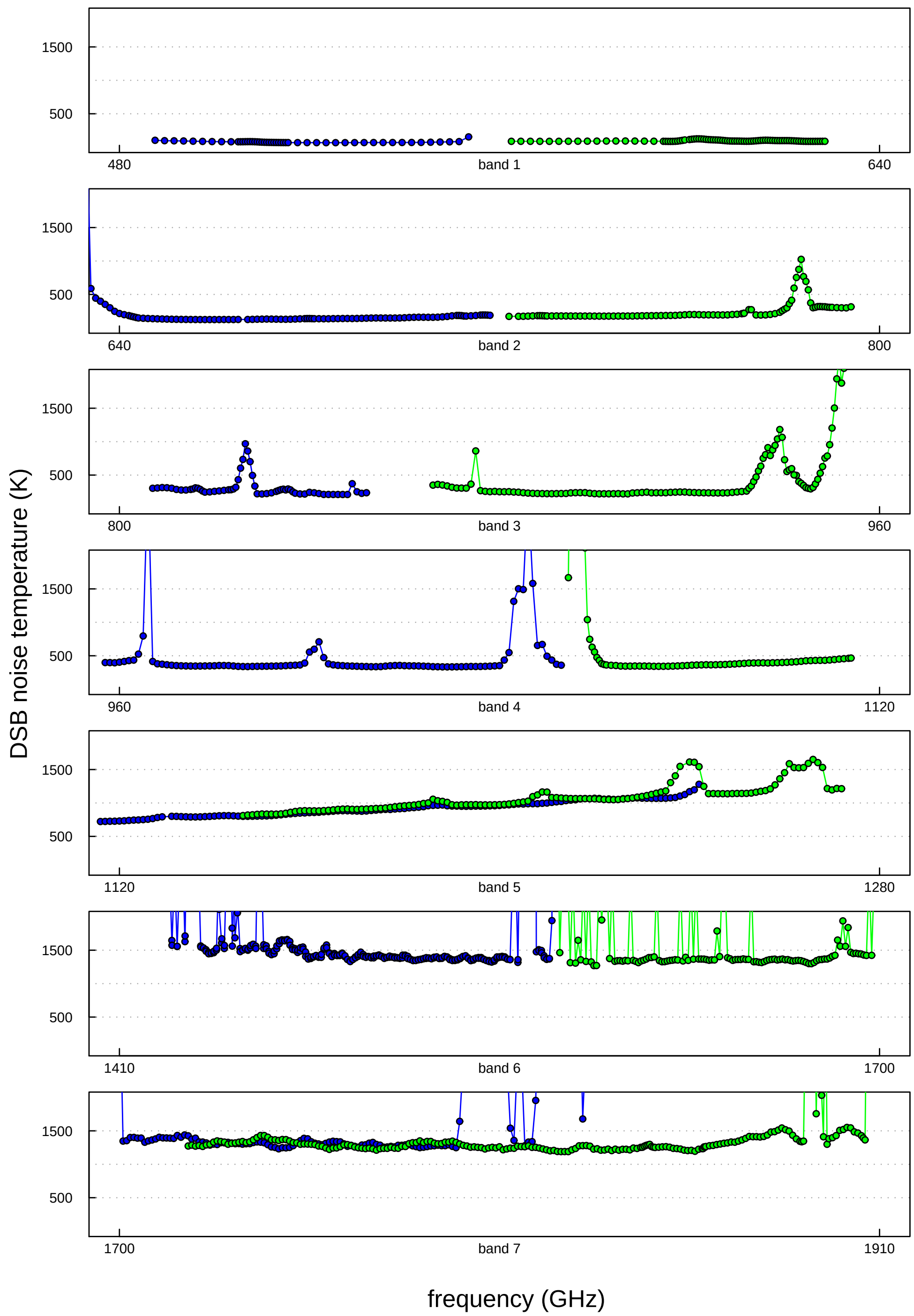

Figure 1: System performance in terms of noise temperature. Temperatures shown are weighted averages of horizontal and vertical polarization. The a LO-subband is shown in blue, b in green.

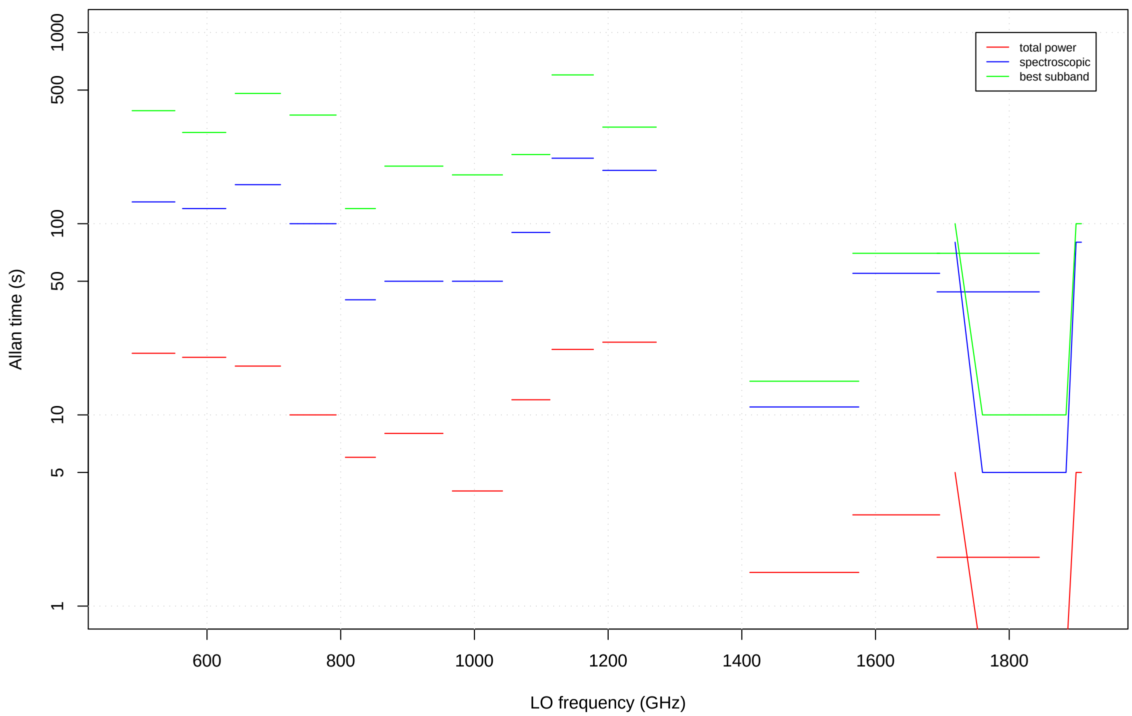

Figure 2: System stability in terms of Allan times as a function of LO frequency. Note, that most subbands are characterised by one constant value, except for band 7b. The latter shows poor stability except for the band edges and is therefor shown as a “trough”-like function.

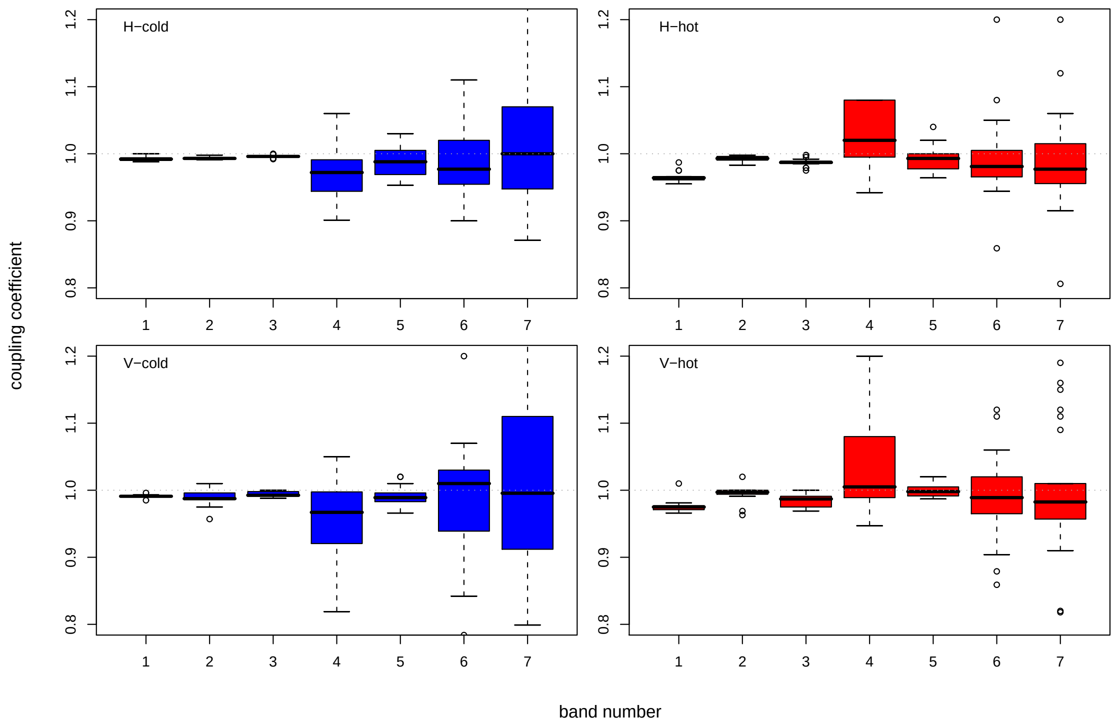

Figure 3: Boxplots for distributions of coupling coefficients as function of band.

Table 1: Results of one-sample *t*-tests for coupling coefficients

			hot load coupling			cold load coupling		
band	polari-	deg. of	sample	95% conf.limit		sample	95% conf.limit	
no.	zation	freedom	mean	lower	upper	mean	lower	upper
1	H	12	0.966	0.961	0.971	0.992	0.991	0.993
2	H	19	0.993	0.991	0.995	0.993	0.993	0.994
3	H	20	0.988	0.985	0.990	0.996	0.995	0.997
4	H	6	1.072	0.934	1.209	0.955	0.886	1.023
5	H	34	0.992	0.987	0.998	0.988	0.981	0.996
6	H	46	0.990	0.976	1.003	0.972	0.936	1.009
7	H	34	0.987	0.965	1.009	1.028	0.973	1.084
1	V	16	0.976	0.971	0.981	0.991	0.990	0.992
2	V	18	0.995	0.989	1.001	0.988	0.981	0.995
3	V	12	0.984	0.978	0.990	0.994	0.992	0.996
4	V	5	1.038	0.943	1.133	0.955	0.896	1.014
5	V	23	0.999	0.995	1.003	0.990	0.985	0.995
6	V	33	0.989	0.970	1.008	0.987	0.952	1.021
7	V	35	1.003	0.966	1.039	1.001	0.950	1.051

3 SFT, chopper performance, IF feedback

3.1 Short functional tests

During ILT short functional tests were covered by a collection of separate tests, which later became one SFT test during IST. Its goal is to

- test harness continuity
- test basic hardware functionality
- go-ahead for next level testing

For this particular area data are available either from dedicated ILT-databases or from the various subsystem teams. Also, the analysis of the resulting data took place mostly in the subsystem teams (LO, FP, HRS, WBS).

Some ILT results are test-configuration dependent, e.g. due to different harness resistance or thermal environment, and made a translation from ILT to IST necessary.

All ILT data have been analyzed for reference-purpose, in addition a substantial IST-database is now available for further analysis.

3.2 Chopper performance

The goal of the chopper performance was the additional validation of the chopper-system in terms of

- (re)positioning accuracy
- positioning speed (dead-time)

for a range of chopper positions/throws.

The ILT-data give us position calibration plus single step-performance: the chopper performs as per specification (FPSS-1046_03). During IST the validation was extended with step-response as a function of position.

3.3 Mixer performance

Another issue addressed by this part of ILT is mixer performance and the early/pre-Validation of FP-system performance in terms of:

- unpumped: device performance + IF-system performance
- pumped: heterodyne performance

In addition these results are usable for troubleshooting and trend analysis. The system performance is mostly determined via surveys of T_{sys} (Sec. 12), stability (Sec. 11).

The cold LO ILT-data will allow to generate a “picture-book” for reference before starting TB/TV.

3.4 IF feedback

It had been noticed during ILT, that the rotation of metal pieces inside the FM test cryostat (e.g. the chopper (M6) or the shutter) created some feedback at the IF level. This feedback modifies the IF response and the difference in the measurements show up as strong scatter in the receiver noise and source coupling spectra, especially at the band edges.

A IF-2 refurbishment has substantially decreased feedback ($\approx 20\,$dB), which was confirmed in stability measurements done by J. Kooi. However, not all resonant modes are suppressed equally and IST-results will be needed to asses severity of the problem in operation in the flight cryostat. The IF-feedback signal is very stable for a fixed chopper-position so if needed, calibration is possible. See also notes on IF feedback in Sec. 11.

4 LO vector scans

The goal of the so-called vector scans is primarily to characterize the mixer current response to the output power of the LO. The mixer current is then used as the criteria to assess the level of pumping of the mixer. Using this principle the on-board software automatically tunes the LO output power for an optimum pumping level, and therefore an optimum sensitivity and stability of the mixer.

As a second step, one uses the vector scans in order in interpolate the best guesses for the VD_2 to be applied for a given mixer current targets. These values populate uplink look-up tables used as starting point for the automatic tuning algorithm.

Finally, the vector scans provide an overview of the LO frequency coverage as they indicate areas where power shortage might be expected. Because they probe the two mixers simultaneously, they will reflect potential imbalance between the respective H- and V-mixer pumping level for a given shared LO power. This type of information has been of utmost importance in the design of the LO attenuators. The data can also be used to detect strong slopes of the I_{mix}/VD_2, which are indicative of instable functioning of the LO chain.

Section 7 of the stability report (parametric study), has up-to-date vector scans of B6, B7 with optical attenuation.

The Band 5 LO has no need for optical attenuation, being driven hard (beam splitter band) and having little variation across the LO pass band. This is not so for B6 and B7, where the use of optical attenuation is limited by the available LO power and dynamic range.

5 LO & diplexer calibration

5.1 Coarse diplexer optimisation

The LO & diplexer calibration was done in order to find the diplexer settings for best LO power coupling. For approximately 10 frequencies per mixer band the following steps were performed

- diplexer scan: I_{mix} vs $I_{diplexer}$
- find all minima (IA)
- feed into (diplexer specific) model (MathCad)
- optimum settings fed into new CUS LUT

Initially it was unknown what LO power to use, bootstrapping with 5 VD_2 values. The resulting best VD_2 is used for subsequent fine tune. Due to using a wrong bias the last ILT test with more frequencies failed. For band 6+7 the scan was done at $3\,$mV, there is no I_{mix} prediction for $0.6\,$mV.

The diplexer calibration performed ok for bands 3 and 4. It performed at a limited number of frequencies for bands 6 and 7. The look-up table is ok for ILT ($< 5\%$ coupling loss) and a report has been distributed with diplexer I_{mix} conversions.

5.2 Fine diplexer optimisation

In a subsequent step a fine diplexer optimization is done, in order to find the diplexer setting for the best signal coupling. For 5 frequencies per mixer band:

- a diplexer scan around found optimum:
  - measure IF total power HOT, then COLD
  - derive T_{sys}, calculate optimum

using the assumption that a slight change in LO power level is negligible.

For bands 6 and 7 the LO power needs to be close to optimum, as otherwise the HEB may start to oscillate while scanning the diplexer.

Again, the test succeeded for bands 3 and 4, but failed for bands 6 and 7. Results are not yet analyzed, a comparison with coarse has not yet been performed.

6 Spurious signals/responses

The HIFI ILT campaign demonstrated that HIFI has several problems with spurious responses, problems with spurs in the IF band and in some spots poor system stability. The origin of the spurious response in band 3b, 5 and 7 has been tracked down to issues with the local oscillator chains suffering from an oscillation in the bias circuit. Additionally there is a distinct possibility that a lower Q version of this is responsible for the situation in band 4a where the IF power is very high with a peak at the low frequency end. This IF power peak correlates well with the observed lack of stability in this band.

If housekeeping data can be successfully correlated with known bad and good behavior then it may be possible to avoid a number of expensive tests during the PV phase to diagnose and correct the known problem.

In summary, HIFI currently has significant spurious response problems in band 3b, 5 and 7b with band 6 and band 7a being unknown. Band 7a is strongly suspected to have difficulties.

It is suggested that proper data processing may provide a means to detect problems in the housekeeping data, making it possible to tag suspect observations in an automated way. Additionally, it should identify a number of regions where further examination of the affected band is likely to yield significant improvement or means of detection.

7 Frequency response

The goal here is to verify the frequency resolution of the instrument, its required line shape and the frequency accuracy. The instrument frequency line profile/shape is a combination of the sharpness and stability of the local oscillator(s), as well as the intrinsic line profile of the spectrometer in use.

In addition, the frequency accuracy and stability of IF up-converter used for the HEB bands needs to be characterised.

7.1 WBS

The frequency calibration of the WBS is internally done by measuring a comb and a zero spectra (comb generator in the WBE). Comb lines are regularly distributed exactly every 100 MHz (over all CCDs) each of them at a different distance from the center of the WBS channels (the width of a channel is 0.56 MHz, hence 100/0.56 is not an integer). It is thus possible to reconstruct an oversampled spectrum from the comb lines.

For the WBS the following is noted:

1. The index of refraction of air needs to be compensated, which has been done in Cologne by inserting a plane-parallel glass-plate of 2 mm thickness in the optical path after being perfectly aligned in air at the Herschel operating temperature. Therefore, the CCD was slightly out of focus in air and at the operating temperature used during ILT at SRON. As a result the observed lines are broadened and slightly asymmetric. This is expected and should appear in orbit.
2. Asymmetries are caused by imperfect focusing and, more important, also by imaging errors in the optics of the AOS. All lenses and other optical parts including the Bragg-crystal itself contribute to the imaging errors. With a total budget of $\lambda/10$ one can demonstrate that visible asymmetries are inevitable, and this accuracy is already more than one can ever expect. It should be noted that the asymmetries are changing at different frequencies, because the imaging errors contribute differently at different trajectories.

7.2 HRS

The frequency performance of the auto-correlators depend intimately on the performance of the LSU. As several bands share different parts of the signal chain, an out-of-spec condition of the LSU will affect several bands in the same way. During ILT it was found that band 2a, and consequently 4a are out specifications: 215 kHz observed versus 180 kHz spec. Conclusions for band 3b are indecisive. All other bands are within specification.

8 Line and continuum linearity

The purpose of the liearity tests was to verify instrument linearity, as specified in requirements IS-04.05.04-01 and IS-04.05.04-02 (see also calibration use case UC-1.4.7). The HIFI specification requires a non-linearity less than 1%. The level of instrument non-linearity was to be determined, using two methods:line and continuum linearity. The non-linearity is measured with both HRS and WBS, because the results could be different for the two spectrometers.

Main conclusions:

- Based on the analysis of all the continuum and line linearity data, we can conclude that there is no evidence of non-linearity within the measurements accuracy.
- For bands 1–4, the continuum and the line non-linearity is less than 1.6%, for bands 5–7 is less than 3% for the H polarization. The worst case is for the V polarization of bands 5–7 with a rms less than 8%. The WBS and HRS spectrometers have similar continuum non-linearity values.
- The results for continuum and line non-linearity of bands 1–4 are close to the non-linearity requirement of 1%.
- The continuum and line calibration are naturally limited by the non-linearity. The calibration is therefore better than 1.5–3% for the H polarization, and 1.5-8% for the V polarization.

9 Gas cell

The goal of these measurements is twofold:

1. using saturated isolated lines, it provides a measure of the mixer side-band gain ratio (SBR, G_{ssb} from equ. 1)

2. using un-biased surveys of rich spectra of molecular species, it offers a representative data-set for the development of de-convolution tools. As a side-product, it is a very useful source of information for standing wave, spurious signal and spurious response analysis.

Ideally, the SBR needs to be surveyed over the full HIFI frequency range. The granularity obtained is totally dependent on the availability of adequate molecular lines absorbing sufficiently at the frequencies of interest.

Test campaign	February 07	May 07	June 07
Bands covered	1, 2, 4, 5, 6	2b, 3, 4, 6, 7	2, 4, 5, 6, 7
Molecules	OCS, CH_3OH, CH_3CN, SO_2, ^{12}CO, ^{13}CO	CH_3OH, H_2S, toluene, ^{12}CO, ^{13}CO	CH_3OH, H_2O
H/W config	No LOU attenuators	LOU attenuators but not yet on LO baffle	LOU attenuators on LO baffle
Remarks	very poor stability in bands 2, 4, 6	still poor baselines in bands 6 and 7	all measurements in fast-chop

The simpler molecules (e.g. ^{12}CO and ^{13}CO) have been fully analysed. The much more complex molecules like CH_3OH are posing extra problems in terms of the physics underlying their sub-mm spectra and the accuracy with which these can be calculated and/or have been measured in the lab.

As a consequence, the analysis of the gas-cell data-set for side-band ratio determination is still on-going. A quick-look coarse analysis was performed over all available lines. It provides a first overview of the ratios. A more accurate analysis based on LTE line profile fitting is on-going. Results are still affected by poor baseline quality and un-corrected baseline distortion. Various groups work in parallel on this, but final results depend on progress.

10 Standing waves

Standing waves occur due to reflections from the sub-reflector in a Cassegrain telescope, from the calibration loads or from coupling of the signal to the cavity formed by the mixer and LO feed-horns.

The goal of this investigation was to derive the period and amplitude of the most prominent standing waves (ripples) found in each observation and to create an overview of these for all 14 LO-subbbands.

During ILT, four sources were observed: the external and internal hot and cold black bodies. Observations were conducted with the wide band spectrometer (WBS) in all 14 LO bands (RD03). Two widely different LO frequencies were observed in each band. For each of these sets of observations, a series of 21 (up to 41) LO frequencies, spaced by 27 MHz, was observed. This results in 4 41 14 2 observations for ILT-FM3 and ILT-FM4 and in 4 21 14 2 for ILT-FM5.

The main conclusions are the following:

- Ripples of less than 400 MHz period, hardly show systematic differences between data of different polarisations (V, H) of the WBS. However, those with longer periods do.
- We hardly find differences in ripple frequencies and amplitudes between the different loads, which indicates that the loads are not the main sources for any of the ripples.
- In general, bands 1a, 4a, and 7a show the largest amplitudes.
- The long standing waves ($>$ 400 MHz) are difficult to characterize accurately. However, they are often clearly visible in the overall spectral change with LO frequencies. We seem them changing smoothly from e.g. a convex to a concave shape, consistent with a standing wave of varying phase.

11 Stability

The stability investigation can be broken down into the following parts:

IF Stability	IF Amplifier Warm-up
	Total Power Stability WBS, HRS
	Spectroscopic Stability WBS, HRS
System Stability	LO Warm-up
	Total Power Stability
	Spectroscopic Stability
Differential Stability	LO Warm-up
	Load-Chop
	Internal Load
	Beam Switching
	Frequency switching
Parametric Stability	B6, B7 Stability as a function of Vbias
	B6, B7 Stability as a function of LO Pump current
	B5 Stability as a function of B-field.

Half way through the ILT stability tests it became evident that there was a serious instability problem in SIS bands 1, 2, 3, 4[2], and HEB bands 6, 7. Fundamentally, the problem was found to be related to the local oscillator (LO) power amplifiers and multiplier drive level.

As a consequence optical attenuators were added to the LO signal path. Apart from this issue, we have mapped regions of instability, obtained the relevant time constants needed to properly run the instrument, measured system and differential stability times, Not the least have we learned how to operate this complex instrument.

The information resulting from the stability investigation is now fed into HSpot and is being used in the thermal vacuum (TV) and performance verification (PV) stability tests plans. The addition of the optical attenuators has been found to resolve most of the instability problem for SIS bands 1, 2, 3, 4 and HEB band 6. However, due to the large dynamic range (up to 10 dB) of some of the LO output signals (notably B3a, B6, B7) it is not possible to optimize the amount of attenuation needed without loss in frequency coverage. Thus a compromise between frequency coverage and optical attenuation had to be made. The bands most adversely affected by this compromise are B3a and B7, as evidenced by the measured data.

Some general Stability observations:

- For beam splitter bands (B1, B2, B5) WBS sub-band 1–3 have similar stability, with sub-band4 being generally a bit worse (7–8 GHz channel). Thus observations should preferentially take place in WBS sub-bands 1–3.
- Diplexer SIS bands (B3, B4), are most stable in the center of the IF (WBS sub-band 2, 3), followed by WBS sub-band 1 (4–5 GHz) and WBS sub-band 4 (6–7 GHz).
- HEB bands are most stable in WBS sub-band1 (3.8–4.8 GHz) where T_{sys} is the highest! In the IF frequency range 2.4–2.8 GHz (WBS sub-band 3) T_{sys} is lowest (-3 dB mixer gain corner frequency) but the stability is also the worst. (Most sensitive to standing wave power fluctuations . . .).
- At frequencies where there is significant instability, the use of only the center WBS/HRS channel is still workable (galactic observations).
- Increasing the HEB mixer bias to 1 mV improves the stability, but degrades T_{sys} by $\approx 16\%$. Changing the mixer bias from 0.4 mV to 0.6 mV has no effect. (0.5 mV is nominal). This may be a useful trade-off when observational baselines are poor (Section 7).

[2] the band 5 LO, operating in the range 1100–1200 GHz utilizes a beam splitter to inject the local oscillator signal.

- Increasing the HEB LO pump drive level from nominal (40–50 μA) to 30 μA improves the system stability but also degrades T_{sys} ($\approx$ 30%.). (Section 7).
- For the HEB mixers, the LO power cutoff is $\approx$ 58 μA. Less then this results in unusable behavior. In addition at very low LO pump levels the mixer IF output impedance gets large and complex. This is likely to results in poor baseline subtraction.
- In case of the B5 mixer: When the B-field is properly set, a $\pm$6% deviation from nominal has a negligible effect on system stability. Conversely, increasing the B5 mixer bias by 0.1 mV from nominal has no effect, decreasing the bias by 0.1 mV degrades the system stability. (Section 7).

IF2 feedback was extensively investigated in March 2007 and compared to before the repair. The results are presented in Section 4.7. Frequency switch differential measurements were limited to 20 minutes and one frequency per LO band due to a lack of time. Results are promising for the SIS bands, and questionable for the HEB mixer bands. Further investigation is needed in TV and PV. Table in section 6.4.4.

There is a large spread in the Allan stability time per LO sub-band. This spread is real, and caution must be taken in interpreting these tables.

The B6, B7 HEB system stability results are very poor (notably band 7b). Some of this is likely due to modulation of the LO-mixer standing wave, due to microphonics, between the LOU and FPU cryostats.

In Jan 2007, ILT1 temperature investigations confirmed the need for very stringent temperature control.

In May 2007, several ground loops were removed from the ILT test setup, just prior to the (final) ILT-3 phase.

In general we find the system stability acceptable for the SIS bands and marginal for the HEB mixer bands.

Stability for all mixer bands is dominated by the individual LO sub-bands, and as such the HIFI instrument really ought to be thought of as 14 individual receiving units. This result has had a considerably impact on the required test time during ILT, and data reduction/analyses time. It will undoubtedly impact the thermal vacuum (TV) and performance verification (PV) planning as well.

Frequency switching is an important observing mode, however due to time pressure it has been for a large part omitted from the ILT. It is a questionable mode for the HEB bands where minute changes in LO power affect equilibrium and baseline subtraction.

Special attention was given to the performance and spectral purity at the 1898 GHz (USB) C^+ line in band 7b. Last minute tests with an external (VDI) signal source revealed that by biasing the first multiplier (M1) more negative resolved the issue.

12 Radiometry

The goal of the radiometry activity is twofold:

1. Measurement of the instrument sensitivity, as given by the receiver noise temperature.
2. Measurement of the mixer beam coupling onto the internal calibration sources (hot and cold sources, hereafter HBB and CBB respectively).

Each of the above quantities needs to be surveyed over the full HIFI frequency range, with a granularity of at least 4 GHz. The calibrated data are obtained following equation 1 where the contribution to the calibration error budget is:

- 1% error on η_{hot} corresponds to 1% error on the absolute calibration at any frequency
- 1% on η_{cold} corresponds to 0.2% error in the absolute calibration at 500 GHz, and 0.5% at 1900 GHz

Radiometry measurements were performed over 3 dedicated campaigns: February 2007, April 2007 and June 2007. In between these campaigns, several instrument configuration changes occurred, the main one being the insertion of attenuators between in the LOU and the FPU after the April campaign. Therefore, the full set of data has been unequally affected by the caveats of the test environment.

Because the source coupling determination makes use of measurements taken at different times, the final result is sensitive to gain drifts. These potential baseline distortions are mostly present in bands 2b, 4a, 4b, and all HEB bands. They are clearly affecting the data of the February and April campaigns. In June, measurements performed with the attenuators in place showed an improvement in the SIS bands, but HEB bands are still suffering from drifts. In addition the IF feedback effect reported in Sec. 3 had to be taken into account.

In summary we can state that the coupling coefficients are observed to be very close to 1, as is predicted by quasi-optical simulation. Departure from unity can be due to i) real optical mis-alignment, ii) un-stable measurements leading to non-physical results. The coupling to the cold load is basically unity everywhere. The coupling to the hot load experiences a slow rise in bands 1a and 1b, then settles around unity.

The June campaign shows a much reduced scatter due to the enhanced stability. On the other hand, here we suffer from a systematic offset apparent in the hot load coupling seen in a number of bands. This turned out to be due to a non-stable temperature of the external absolute hot black body, such that the reported temperature values from the house-keeping data did not properly reflect the true physical temperature of the load.

13 AOTs

The FM3 ILT phase high level schedule did not allow dedicated campaigns for Observing Mode tests. The testing was approached opportunistically to exploit available time slots of several to ≈ 48 hours at a time in night and weekend shifts. Three phases of test time occured during the period January to June 2007, where the major objectives of AOT code shake-out were achieved.

However, the planning/setup was sub-optimal. The schedule was sometimes too tight for adequate preparations, e.g. for a coordinated MIB, ILT and AOT CUS build and release because of configuration management difficulties. The test equipment configuration was usually left as is, the gas cell or RF line source with re-imager were not always available despite requested facilities for test modes using LoadChop or FSwitch.

These were the testing objectives:

- Set up and operate the instrument in configurations/timings determined by AOT Observing Mode logic.
- Verify that the command history matches the sequencing setup and predicted command time lines of the instrument and telescope.
- Obtain a unified operation scheme for ILT and AOT CUS, streamline procedures and uplink parameters
- Assess observing efficiencies, spectral properties and system noise performances for the validity of
  - Observing Mode design (noise model and calibration scheme assumptions and setups), and
  - Calibration parameter accuracy with respect to current (ILT) knowledge of the instrument.
- Verify consistent usage of interfaces from HSpot (AORs) down to the subsystem commanding.

The May–June campaign resulted in an overall much smoother testing, validating fixes/updates of previously identified issues. Few random command completion errors persisted. The tests provided a relatively reliable reference for data processing in the pipeline and further performance evaluations.

In summary:

- No ObsMode performance evaluations yet.
  - generally too many run time errors and command rejection/failures in the early runs.
  - the real Pipeline has been far from serviceable until lately
  - test modes run in the final phase may be suited to processing with latest pipeline scripts, this is an ongoing action.
- Structural evaluation of ObsMode code quite successful
  - there are no fundamental flaws in AOT design
  - many relatively small problems (in terms of effort) solved at the procedural level, and in the interfaces with ILT procedures and OBS
  - Input from other test teams systematically used
- Several key functionalities of the ObsModes are not yet validated:
  - frequency switching and spectral scans successful only in few LO bands
  - variable chop rates (fast chop is known to have problems)

14 Beam pattern

The Herschel telescope as built differs slightly form the design, and more importantly, the focus position is temperature dependent. The effects that these differences from the design will have on the beam patterns for HIFI has been considered, in terms of their effect on the aperture efficiency, main beam efficiency, half power beam width, pointing offset and the power distribution in the beam out to 180 arc seconds from the peak. The beam patterns are compared with those found for the "as designed" telescope for band 1 at 480GHz, band 4 at 1128GHz and band 7 at 1800GHz. It is found that the effects of the changed specification parameters (mirror curvature etc.) are negligible, but that reasonable focus should be maintained in order not to significantly effect the efficiency at the high frequency end of the HIFI operating range.

Conclusions:

- Overall the (quasi-)optical alignment is very good.
- Optical coupling losses will stay below 6%.
- Co-alignment is generally 20–30% of waist size or 10–15% of FWHM at sky.
- Losses per polarization channel when re-pointing to average position at sky typically 1–3%
- There is a large systematic measurement error (2–3 mm) in the absolute position of the beams in the focal-plane.
- Error analysis did not identify source of error. Edge scan did confirm that it is a systematic measurement error.
- Error only important for predicting nominal pointing at sky and will not affect conclusions about compliance or co-alignment.
- Within Herschel Pointing Calibration Working Group this error is taken into account, but not significantly larger than other sources of error (inter-alignment FPUs and STR alignment)

These calculations also form the basis for the SIAM entries for the HIFI instrument.