Infrared Spectrograph
Technical Report Series

IRS-TR 05001: Detector Substrate Voltage and Focal Plane Temperature of the LH module

Daniel Devost (1), Jeff van Cleve (2), G. C. Sloan (1),
Lee Armus (3), Jim Ingalls (3), Phil Appleton (3) *

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Abstract

We present the results for campaigns IRS-N2, IRS-12 and IRS-18 of the detector properties analysis procedure for the Long-High module. From campaign IRS-N2 to campaign IRS-18, the figure of merit of the current voltage and temperature settings has dropped from 8% below the maximum figure of merit to 58% below the maximum. Also, the number of bad pixels in the LH module has quadrupled. The probability of having a bad pixel in any 6-pixel window is now greater than 50%. We recommend to change the detector substrate voltage from 3.0 V to 3.4 V and to leave the focal plane temperature to 4.4 K. This change will lower the bad pixel count but a loss in sensitivity per pixel especially at $\lambda > 35$ μm will also occur. A minimum of 10 hours of telescope time and 5-7 weeks of analysis are required to bring the system to the same level of calibration that we have now.

*(1) Infrared Spectrograph Science Center, Cornell University; (2) Ball Aerospace, Boulder, CO; (3) *Spitzer* Science Center, Caltech

1 Introduction

After the initial suite of diagnostics performed on the Infrared Spectrograph (IRS) on the *Spitzer Space Telescope* done during In-Orbit Checkout (IOC), the operating parameters for all four modules were changed prior to campaign IRS-K2. These changes were done based on a Figure Of Merit (FOM) calculated for each module using data that were gathered during Campaigns IRS-E, IRS-F, and IRS-H. The FOM was calculated by taking into consideration the sensitivity, noise, and number of bad pixels at a number of predefined Voltages and Temperature Settings (VTS).

As a result of this analysis, the detector substrate voltage (V_{det}) and the focal plane temperature were adjusted to get optimal performance from the detectors. Table 1 lists those values for each module. Throughout this document, we will use V_{det} as the reference to the voltage measurements. This quantity is related to the bias voltage (V_{bias}) by:

$$V_{det} + V_{bias} = 5.0 \text{ Volts} \quad (1)$$

During Campaign IRS-N of IOC, the Sun produced one of the most powerful solar flares ever measured. It was then decided to create a special campaign, IRS-N2, to probe the extent of the damage from this event. The same FOM analysis done earlier during IOC was performed once again on all the modules. One of the main conclusions of the analysis was that the sensitivity of the detectors had dropped by about 20% and that the number of bad pixels had increased significantly on all modules. At this time, though, the total merit of the operating VTS was only 8% below the maximum merit (see Table 4)[1]. Even with the increased number of bad pixels, the improvement introduced by changing the operating voltages and temperatures was deemed insignificant compared to the complications it would produce in the calibration pipeline for the IRS. As a result, it was decided to continue operating all the modules at the voltages and temperatures set before Campaign IRS-K2 (Table 1).

The data necessary to perform the FOM analysis were obtained once again during Campaign IRS-12 as part of the mandatory periodic detector health assessment. It was found that the Long-High (LH) detector had degraded. The probability of having a bad pixel in any 6-pixel window was now around 40% compared to 25% during Campaign IRS-N2. We also found that the LH VTS

[1]The Tables giving the figure-of-merit results for the different VTS values list the settings in order of figure of merit.

TABLE 1
VOLTAGE AND TEMPERATURE SETTINGS, 2003 NOVEMBER

Module	V_{det} (V)	T (K)
Short-Low	3.0	6.2
Short-High	3.0	6.2
Long-Low	3.2	4.4
Long-High	3.0	4.4

merit was 32% below the maximum merit function (see Table 3). After discussions on these numbers and their impact on the instrument performance and on the data reduction process, the instrument team decided to leave the bias voltage and focal plane temperature of the LH array unchanged.

Another powerful Solar storm hit *Spitzer* just after Campaign IRS-17. It was decided to perform the FOM analysis again during the course of Campaign IRS-18 to see how the detectors were affected by this storm. This paper presents the analysis of the LH dataset and compares it with the datasets from Campaigns IRS-N2 and IRS-12. The calculation of the FOM has been done using the same analysis plan and software used during Campaigns IRS-E, IRS-F, IRS-H, IRS-N2 and IRS-12.

2 Analysis

The calculation of the FOM for each module is done on datasets collected with the detector responsivity Astronomical Observing Request (AOR). The same AORs were run during Campaigns IRS-N2, IRS-12 and IRS-18.

The detector responsivity AOR gathers data that we use to examine the variation of detector noise as a function of detector voltage, focal plane temperature, and ramp time. There are 3 values of V_{sub} (+ one repeat of the default voltage, which is discarded), 3 temperatures, and 4 ramp times, for a total of 40 exposures. The detector responsivity AOR collects data to examine the variation of the photoresponse (ηG), the gain dispersion product (βG) and the detector noise as a function of voltage, temperature and ramp time. There are 5 STIM settings, 3 voltages, and 3 temperature for a total of 45 exposures. All the data is acquired in the Sample Up the Ramp (SUR) acquisition mode and the Sample Reset Sample (SRS) acquisition mode.

The data collected during the performance and responsivity AORs are used to derive the number of bad pixels, the Bright source FOM (BFOM), the Faint source FOM (FFOM) and the Total FOM (TFOM) for each combination of bias voltages and focal plane temperatures. The BFOM is given by:

$$\mathrm{BFOM} = \mathrm{n}_{good}^{6} \frac{\eta \mathrm{G}}{\beta \mathrm{G}} \tag{2}$$

while the FFOM is:

$$\mathrm{FFOM} = \mathrm{n}_{good}^{6} \frac{\eta \mathrm{G}}{\mathrm{N_d}}. \tag{3}$$

The TFOM is given by:

$$\mathrm{TFOM} = \mathrm{BFOM} \times \mathrm{FFOM} \tag{4}$$

In these equations, n_{good} is the fraction of pixels which are good and N_d is the dark noise for the second longest ramp time permitted by science Astronomical Observing Templates (AOT). The calculations of pixel badness criteria are outlined in detail in the data analysis procedure for these activities, which may be downloaded from the IRS IOC Web site http://isc.astro.cornell.edu/tech/ioc/. The 6th power of the fraction of good pixels gives the probability that there are no bad pixels in an extracted point source comprised of 6 pixels.

3 Results

3.1 FOM analysis

Tables 2, 3, and 4 give summaries of the LH results obtained from the analysis of the data from Campaigns IRS-18, IRS-12, and IRS-N2, respectively. Figure 1 shows how the number of bad pixels increases with detector voltage. These images are darks taken during the IRS long-wavelength detector responsivity AOR.

3.2 Sensitivity per wavelength element

A change to the voltage has repercussions on the number of bad pixels and the sensitivity. The FOM analysis results presented here incorporate the detector photoresponse (ηG), but not the sensitivity as a function of wavelength.

TABLE 2
CAMPAIGN IRS-18

V_{det} (V)	T (K)	n^6_{good}	BFOM	FFOM	TFOM ($\times 10^6$)
3.4	4.4	0.734	23413	371.2	8.7
3.4	5.0	0.733	23100	374.4	8.6
3.4	3.8	0.734	20419	360.8	7.4
3.8	5.0	0.906	9558	504.8	4.8
3.8	4.4	0.906	8676	504.8	4.4
3.0	5.0	0.464	14298	254.2	3.6
3.0	4.4	0.464	14703	246.1	3.6
3.0	3.8	0.464	14783	237.3	3.5
3.8	3.8	0.907	5417	485.9	2.6

TABLE 3
CAMPAIGN IRS-12

V_{det} (V)	T (K)	n^6_{good}	BFOM	FFOM	TFOM ($\times 10^6$)
3.4	4.4	0.822	26597	285.3	7.6
3.4	5.0	0.822	26139	287.9	7.5
3.4	3.8	0.822	22948	277.4	6.4
3.0	4.4	0.600	19058	265.5	5.1
3.0	5.0	0.600	18407	274.7	5.1
3.0	3.8	0.600	19472	256.0	5.0
3.8	5.0	0.929	10137	360.0	3.6
3.8	4.4	0.929	9323	360.3	3.4
3.8	3.8	0.930	6033	347.4	2.1

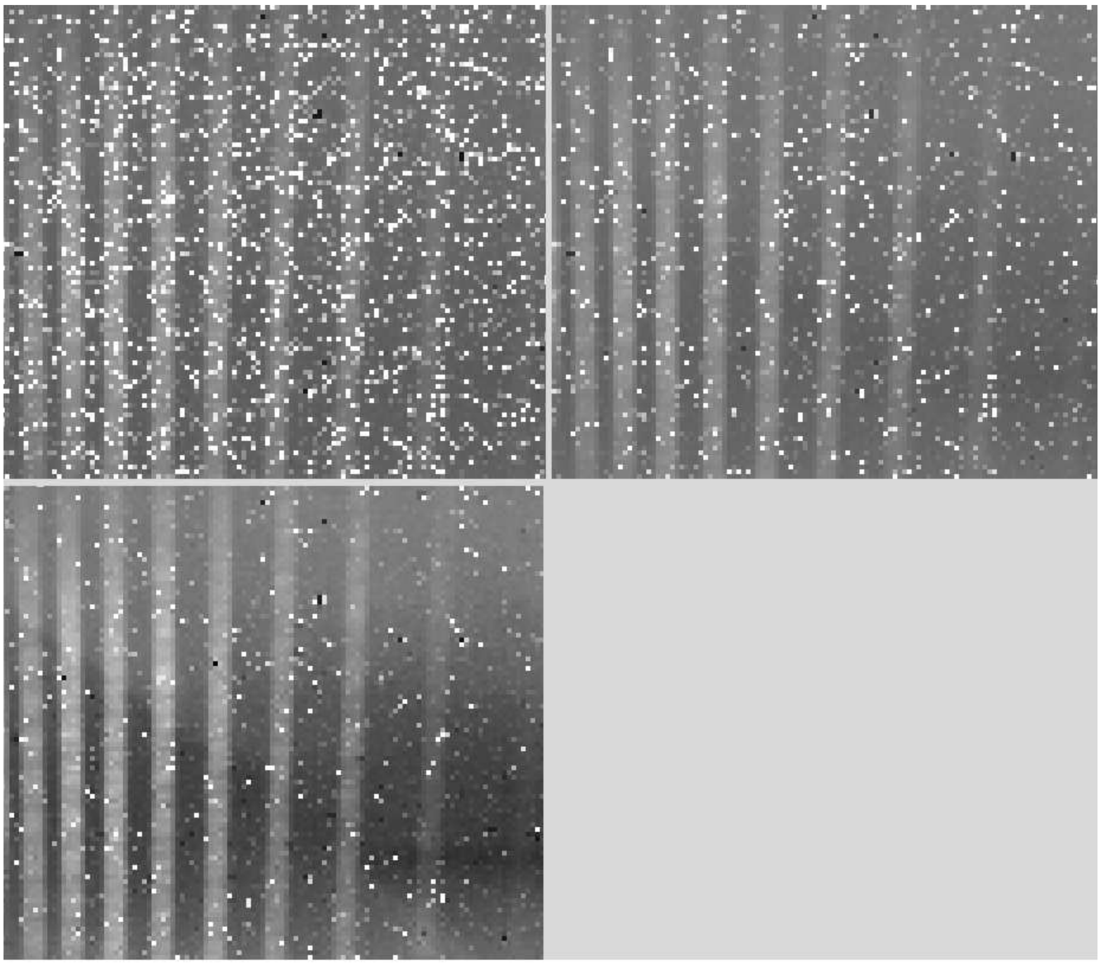

Figure 1 —Comparison of LH darks at different voltages. *Upper left*: V_{det} =3.0 V. *Upper right*: V_{det} =3.4 V. *Lower left*: V_{det} =3.8 V. The temperature for all the slope images presented here is 4.4 K. These images have been cleaned from cosmic ray signatures and all have the same ramp times.

TABLE 4
CAMPAIGN IRS-N2

V_{det} (V)	T (K)	n^6_{good}	BFOM	FFOM	TFOM ($\times 10^6$)
3.4	5.0	0.879	24543	471.0	11.6
3.4	4.4	0.879	24583	466.2	11.5
3.0	4.4	0.748	22190	480.5	10.7
3.0	5.0	0.747	20684	497.9	10.3
3.0	3.8	0.748	22043	461.4	10.2
3.4	3.8	0.879	20995	451.1	9.5
3.8	5.0	0.941	6857	415.0	2.8
3.8	4.4	0.942	6166	415.7	2.6
3.8	3.8	0.942	3863	397.7	1.5

In order to have a better understanding of the impact of a voltage change on sensitivity, we used the test results from the University of Rochester Group (URG) on antimony-doped silicon (Si:Sb) flight detectors. The report shows that the detector quantum effi ciency (DQE) of Si:Sb detectors decreases when V_{det} is raised.

Figure 2 shows the relative signal-to-noise ratio (RSNR) as a function of V_{det} and wavelength for the LH detector. We can see that the RSNR drops rapidly after 30 μm and that it goes below 3 at 36 μm when V_{det} is 3.0 V, at 33.5 μm for a V_{det} of 3.4 V and at 31.5 μm at V_{det} of 3.8 V.

Also, the photoresponse degrades signifi cantly at wavelengths greater than 35 μm. This issue was addressed by the URG's analysis. They found that sensitivity decreases roughly linearly with wavelength between 30 μm and a cut-off wavelength, defi ned by some minimum DQE (5% or 10% are typical). The URG concluded that $V_{det} < 3.0$ V is required to give 10% DQE at 36 μm. Table 5 shows how the cut-off values vary as a function of V_{det}.

The current VTS for LH is 3.0V/4.4K (Table 1). For this particular setting, the Campaign IRS-N2 data (Table 4) gave a TFOM close to the maximum TFOM. The Campaign IRS-12 analysis (Table 3) indicates that the current VTS is lower than the maximum TFOM by about 32%. At the time, the LH detector was judged healthy and the decision was taken to leave its voltage and temperature unchanged. Also, the results from Campaign IRS-N2 and IRS-12 showed that it took nearly

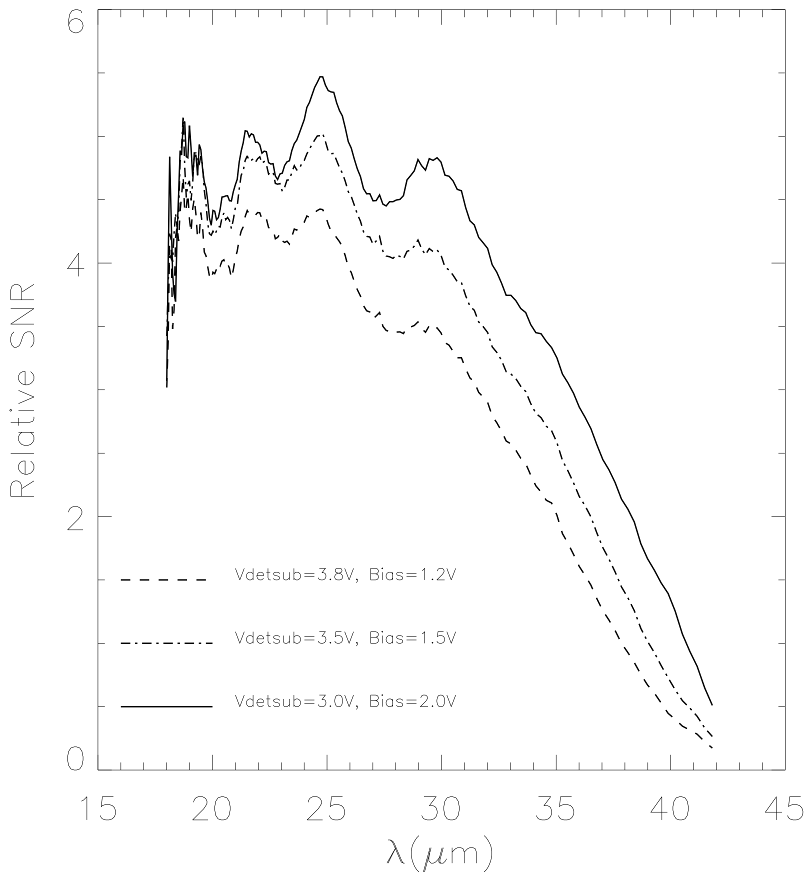

Figure 2 —Relative SNR for different voltages as reported by the URG.

TABLE 5
CUT-OFF WAVELENGTHS

V_{det} (V)	10% DQE λ (μm)	5% DQE λ (μm)
3.0	35.1	37.6
3.4	33.5	36.3
3.8	31.5	34.1

a year to degrade the LH detector and letting the detector degrade at this rate for another year seemed reasonable.

4 Discussion

From Campaign IRS-12 to Campaign IRS-18, the VTS TFOM has degraded from 32% to 58% below maximum. Also, the number of bad pixels has nearly doubled (Tables 2 and 3). This degradation is similar to what was observed from Campaigns IRS-N2 to IRS-12. However, 11 months separated Campaign IRS-N2 from Campaign IRS-12 while only 4 months separated Campaign IRS-12 from Campaign IRS-18. The Solar storm that happened after Campaign IRS-17 seems to have done as much damage as 11 months of exposure to low-level Solar activity. It is also important to notice that the probability of having a bad pixel in any 6-pixel window ($1-n_{good}^6$) has become greater than 50% for the first time in Campaign IRS-18. Increasing the value of V_{det} to 3.4 V would maximize the operating VTS (Table 2). The operating temperature has little effect on the TFOM. Also, an operating value of 3.4 V would bring the probability of finding a bad pixel in a 6-pixel window back to $\sim$27%.

Nevertheless, a change of voltages impacts the sensitivity of the detector. If we assume that a SNR of 3 represents a detection limit, then a source of constant f_λ estimated to have a SNR of 4.5 at 28.15 μm will be undetected at wavelengths greater than 36 μm at the present voltage settings (V_{det} =3.0 V; Figure 2). If V_{det} is raised to 3.4 volts, then the same source will have a SNR of 4.1 (at 28.15 μm) and will be undetected at wavelengths longer than 33.5 μm. At 3.8 V, the source SNR will be 3.4 and it will be undetected at 31.5 μm and after.

5 Required Calibration and Analysis

A change in operating parameters will require new calibration observations in order to characterize the behavior of the LH detector. These observations include, but may not be limited to:

1. SUR and SRS Stim data to characterize the droop and linearity coefficients at the new bias setting. We estimate that 1–2 hrs are required to collect these data.

2. Bright star spectral maps and deep zodiacal spectra to characterize the flat field at the new bias settings. Two super-sampled (1/3-pixel steps) spectral mapping observations of standard stars are required to produce slit-filling spectrophotometric observations. The stars ξ Dra (HR 6688) and 35 Dra (HR 6705) are used for this. One star provides good coverage of the blue responsivity, and the other is optimized for the red. Deep zodiacal observations are used to correct for uneven illumination along the slit. We estimate that 7–8 hrs are required to collect these data.

In addition, we will need to build up a set of darks and standard star (photometric) observations to fully calibrate the LH module at the new bias setting. The standard star observations will need to be obtained over a number of IRS campaigns. It is expected that the wavelength solution will not be affected by the bias change.

It will be necessary to either suspend science operations with the LH module, or embargo science data taken with the LH module, while these calibration observations, and the subsequent analysis and derivation of coefficients for the pipeline, are performed. We estimate that this process (inclusive of the observations and assuming a two-week IRS campaign) will take approximately 5–7 weeks, excluding the time for observations of multiple (photometric) standard stars for which we have accurate models. Once the pipeline has been validated with the new coefficients, science observations can begin in parallel with ongoing photometric calibration.

6 Recommendation

The FOM analysis of Campaign IRS-18 data shows that raising V_{det} would bring the operating VTS to the maximum TFOM. It would also cut the number of bad pixels by a factor of approximately two. Tables 2, 3 and 4 show that the merit for the 3.0 V (V_{det}) voltage has degraded since Campaign IRS-N2. Based on that, we recommend that the operating parameters for the Long-High module on the Infrared Spectrograph aboard *Spitzer* be modified as a compromise between per-pixel sensitivity and bad-pixel count. Our estimate for best performance shows that the detector substrate voltage (V_{det}) should be changed from 3.0 V to 3.4 V, and the focal plane temperature should be left at 4.4 K.

A Appendix—Voltage change procedure

V_{bias} is set by setting V_{det}; the two quantities are related by $V_{bias} + V_{det}$ = 5.0 V . The seting is accomplished by changing the patchable constant CD DAC_SUB_DAC when a CESISETVLT command is issued. (The detector substrate voltage is referred to in some documentation as V_{detsub}.)

The focal plane temperature is changed by modifying the CESITRMON variable in the READY to OBSERVE block, not by changing a patchable constant.