SUBJECT: **SPIRE Channel Gain calibration product technical note**

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1	29th April 2009	First issue – incorporates reference to JFET gain tables

1. INTRODUCTION

1.1 Scope of the document

This Technical Note describes the content of the SPIRE Channel Gain calibration product for both the Photometer and the Spectrometer, written for the delivery of calibration products. This note deals with the DC signal part of the gain only. Other notes and calibration products address the correct of the electronics to time varying signals (see AD-1 and RD-.

1.2 Documents

1.2.1 Applicable Documents

AD-1 The SPIRE Analogue Signal Chain and Photometer Detector Data Processing Pipeline (SPIRE-UCF-DOC-002890), Issue 6, 21/11/2008

AD-2 Karki, James, "*Analysis of the Sallen-Key Architecture*", Application Report, Texas Instruments, rev. September 2002. (http://focus.ti.com/lit/an/sloa024b/sloa024b.pdf)

1.2.2 Reference Documents

RD-1 HERSCHEL/SPIRE Detector Control Unit Design Document (SPIRE-SAP-PRJ-001243), Issue 1.0, 11/07/2005

RD-2 SPIRE Low-pass filter calibration file description (SPIRE-BSS-DOC-003188 draft 0.2 April 2009)

RD-3 Warm Photometer JFET Gain Verification (SPIRE-RAL-NOT-002872 issue 2.0 23 March 2009)

RD-4 Warm Spectrometer JFET Gain Verification (SPIRE-RAL-NOT-00xxxx issue 1.0 24th Feb 2009)

2. SPIRE CHANNEL GAINS

The readout electronics for SPIRE detectors is composed by the JFET unit and the Detector Control Unit (DCU). The DCU is composed by a Lock-In Amplifier and an Analogue to Digital Converter (ADC) – see RD-1 for a full description.

2.1 JFET Gain

There is one JFET based per-amplifier per detector. The nominal gain for these amplifiers is 0.96, however there is some small variation from device to device and their gains were measured using SPIRE flight model electronics by feeding the bias supply directly into the input of the units – see RD-3 and RD-4. We will use the gain per channel measured at RAL as the best value of the system level variation in gain for the spectrometer and photometer and, because we did not measure the PTC channels, we will use fixed nominal values for the PTC channels.

2.2 Lock-In Amplifier

The signal from the JFETs is demodulated by the Lock-In Amplifier (LIA), which has three stages:

1. a pre-amplifier band-pass filter to remove the DC component and amplify the signal;
2. a square-wave synchronous demodulator which rectifies the signal;
3. a low-pass filter.

The pre-amplifier band-pass filter has the following transfer function:

$$H_{BPF}(\omega_b) = G\left[\frac{R_B C_B j\omega_b}{1+(R_B C_B)j\omega_b + \left(\frac{G}{S}+R_I\right)C_H R_B C_B (j\omega_b)^2}\right] \text{ where } G = \left(1+\frac{R_1}{R_2}+\frac{2R_1}{R}\right)$$

and $\omega_b = 2\pi f_b$ is the bias angular frequency.

The parameters in the above formula are resistances and capacities that compose the circuit. The table 1 reports the values of parameters for the pre-amplifier band-pass filter extracted from RD-1 together with the maximum gain values for reference.

Band-pass filter parameters	Photometer	TC	Spectrometer
R_1	15 kΩ	15 kΩ	15 kΩ
R_2	15 kΩ	15 kΩ	15 kΩ
R	115 Ω	316 Ω	267 Ω
R_B	100 kΩ	100 kΩ	100 kΩ
C_B	47 nF	47 nF	47 nF
C_H	1.5 nF	1.5 nF	1.5 nF
S	3.868e-3	3.868e-3	3.868e-3
G	262.8	96.9	114.4

Table 1: Pre-amplifier band-pass filter parameters from RD-1 (pages 36 and 49)

After the pre-amplifier band-pass filter, the signal is rectified with a square-wave synchronous demodulator. The demodulator is assumed to have gain:

$$H_{demod}(\Delta\varphi) = \frac{2 \cdot \sqrt{2}}{\pi} \cdot \cos(\Delta\varphi)$$

when RMS voltage is used as input (see AD-1). When the phase is correctly set – $\Delta\varphi = 0$ – then $H_{demod}(0) = 0.900316$.

The low-pass filters are implemented, for the photometer, as 4-pole Bessel filters, or 2 Low-Pass Sallen-Key Circuit (AD-2) plus a final RC filter. For the spectrometer, 6-pole Bessel filters are used, or 3 Low-Pass Sallen-Key Circuit plus a final RC filter. The transfer function for the low pass filters is described in RD-2 and the values of the various components used in the transfer function are given in the *SCalSpecLpfPar* and *SCalPhotLpfPar* products described in RD-2. We are only concerned in this document with the DC (0 Hz signal frequency) gain of the low pass filters:

$H_{LPF}(0, \text{Phot}) = 1.93$
$H_{LPF}(0, \text{Spec}) = 2.86$

2.3 Digitalization

The output signal of the LIA is multiplexed, then a offset is subtracted, then the signal is amplified by a factor 12 and finally digitalized with a 16 bit ADC. The ADC range is 5 volts which are divided in 65535 values. The digitalization formula is:

$$V_{JFET-RMS}(\omega_b, DATA, OFFSET) = \left[\frac{5}{G_{tot}(\omega_b)}\right]\left[\frac{DATA - 2^{14} + 52428.8 OFFSET}{2^{16} - 1}\right] \text{ where}$$

$G_{tot}(\omega_b) = 12 \cdot H_{LPF}(0) \cdot H_{BPF}(\omega_b) \cdot H_{demod}(0)$ is the DCU end to end gain. The value of G_{tot} for various frequencies extracted from RD-1 are reported in table 3.

Modulation frequency [Hz]	**Photometer DCU gain**	**TC DCU gain**	**Spectrometer DCU gain**
50	4620.49	1688.22	2954.24
60	4868.03	1777.23	3110.28
70	5037.18	1838.16	3217.09
80	5155.97	1881.15	3292.43
90	5241.45	1912.34	3347.07
100	5304.24	1935.55	3387.69
110	5351.09	1953.18	3418.51
120	5386.45	1966.83	3442.32
130	**5413.32**	**1977.55**	3460.99
140	5433.75	1986.09	3475.81
150	5449.22	1992.96	3487.69
160	5460.77	1998.53	**3497.29**
170	5469.18	2003.09	3505.08
180	5475.03	2006.82	3511.42
190	5478.77	2009.90	3516.59
200	5480.72	2012.43	3520.79
210	5481.16	2014.50	3524.19
220	5480.28	2016.20	3526.91
230	5478.27	2017.58	3529.06
240	5475.25	2018.69	3530.71
250	5471.33	2019.56	3531.94
260	5466.61	2020.22	3532.80
270	5461.17	2020.70	3533.32
280	5455.05	2021.02	3533.56
290	5448.33	2021.21	3533.53
300	5441.04	2021.26	3533.27

Table 2: DCU end to end gains (G_{tot}) from RD-1 (p. 77)

3. CONTENT OF THE CHANNEL GAIN CALIBRATION PRODUCT

The Channel Gain calibration product contain the gains for the JFET module and the DPU end to end gain. The DCU end to end gain is written as:

$$G_{tot}(\omega_b) = G_{tot}(\omega_{b-Ref}) \cdot \left| \frac{f(\omega_b)}{f(\omega_{b-Ref})} \right| \text{ where } f(\omega_b) = \left[\frac{4.7\text{e-}3 \cdot j\omega_b}{1 + 4.7\text{e-}3 \cdot j\omega_b + A \cdot (j\omega_b)^2} \right].$$

The channel gain calibration product will contain the value of the reference frequency, the G_{tot} at the reference frequency and the value of the parameter A. It will contain also the value of the JFET gain for each channel as given in the tables 5a-c and 6a and b.

Parameter	**Photometer**	**TC**	**Spectrometer**
G_{tot}	**5413.32**	**1977.55**	**3497.29**
Ref. Frequency [Hz]	**130**	**130**	**160**
A	**5.85e-7**	**5.85e-7**	**3.14e-7**
JFET gain	**Per channel values at 130 Hz**	**Fixed values of 0.96**	**Per channel values at 160 Hz**

Table 3: Values contained in the channel gain calibration product

Table 5a: PLW JFET Gains

PLW	**130 Hz**
R1	0.957106
A8	0.960047
A7	0.957997
A6	0.958440
A9	0.959980
C9	0.958503
B8	0.958498
B7	0.958060
C7	0.960193
B5	0.957715
B6	0.958001
A5	0.958164
T1	0.959566
B4	0.959
C4	0.959429
B3	0.955295
C2	0.957327
B2	0.959841
B1	0.957756
A3	0.957813
A4	0.959106
A1	0.957416
DK1	0.957271
A2	0.957
E1	0.951848
E2	0.948545
E3	0.954380
E4	0.952660
D1	0.955422
D2	0.955152
D3	0.955765
D4	0.954043
C1	0.952056
C3	0.954281
C5	0.954570
T2	0.952455
E5	0.951372
C6	0.954405
C8	0.954552
D5	0.954515
D6	0.955806

D7	0.954827
D8	0.952599
E7	0.952083
E6	0.955214
E8	0.954008
DK2	0.952812
E9	0.953570

Table 5b: PMW JFET Gains

PMW	130 Hz
A13	0.959312
T1	0.958653
B12	0.959719
C13	0.959155
A12	0.959800
D12	0.959032
C12	0.959065
B11	0.960635
A11	0.960113
E13	0.958658
D11	0.935952
C11	0.959014
B10	0.959815
A10	0.960169
D10	0.958358
B9	0.958471
C10	0.923259
C9	0.960467
A9	0.958738
B8	0.960290
A8	0.961028
D8	0.958985
C8	0.960123
B7	0.955390
R1	0.963378
G1	0.963
T2	0.963
E1	0.963
D1	0.952747
F1	0.957646
E2	0.960770
G2	0.962419
F2	0.962200
G3	0.962895
E3	0.962927
D3	0.963219
F3	0.962830
G4	0.963
E4	0.962274
F4	0.959305
E5	0.957817
D5	0.935477
F5	0.963684
G5	0.963453
E6	0.963535
G6	0.963790
F6	0.963389
G7	0.963165
F10	0.962879
E11	0.940895
G11	0.948264
F11	0.963897
E12	0.963580

G12	0.908713
F12	0.958148
G13	0.961567
DK2	0.954784
E7	0.953855
D7	0.962870
F7	0.963
E8	0.887566
G8	0.935504
F8	0.962154
E9	0.963672
G9	0.963
D9	0.930394
F9	0.919380
E10	0.960846
G10	0.915897
C4	0.959681
B3	0.960157
C3	0.959923
B2	0.960628
D2	0.959630
A3	0.960733
A2	0.961553
C2	0.959865
B1	0.959434
A1	0.958762
DK1	0.962022
C1	0.956521
A7	0.956375
A6	0.960537
B6	0.961
C7	0.961246
A5	0.956571
B5	0.961354
C6	0.957907
D6	0.962528
B4	0.955976
C5	0.960699
D4	0.961239
A4	0.962066

Table 5c: PSW JFET Gains

PSW	130Hz
R1	0.966282
D16	0.963690
T1	0.964498
B16	0.966660
C15	0.962253
A15	0.960371
D15	0.967118
B15	0.967274
C14	0.966411
D14	0.965871
A14	0.964845
A13	0.966750
B14	0.966427
C13	0.966850
B13	0.966596
D13	0.966442
A12	0.934758
C12	0.967357
D12	0.963662
B12	0.967316

E11	0.966949
A11	0.964608
C11	0.964238
B11	0.965460
E1	0.967308
F1	0.967092
T2	0.964764
H1	0.967130
G1	0.961825
J1	0.966447
H2	0.961926
F2	0.960495
J2	0.949619
G2	0.963251
H3	0.966015
J3	0.962901
E2	0.966492
F3	0.966205
G3	0.963637
H4	0.965388
J4	0.966560
E3	0.967000
F4	0.965943
G4	0.966855
H5	0.949380
E4	0.964401
J5	0.964463
F5	0.966488
D6	0.954837
B6	0.961222
C5	0.963405
A5	0.960513
E5	0.959908
B5	0.964048
D5	0.961343
C4	0.955080
A4	0.962594
D4	0.962601
B4	0.950481
C3	0.961260
B3	0.958796
A3	0.964565
A2	0.962048
D3	0.960185
C2	0.961831
B2	0.961897
D2	0.963165
A1	0.963284
C1	0.964527
B1	0.962917
DK1	0.962680
D1	0.957341
F12	0.965305
J11	0.964859
E12	0.963848
H12	0.923918
G12	0.925365
F13	0.942459
E13	0.966694
J12	0.957869
H13	0.965629
G13	0.963774
F14	0.967404

E14	0.963835
J13	0.962730
H14	0.964618
G14	0.965074
J14	0.963599
F15	0.964884
H15	0.962971
J15	0.964035
G15	0.966059
H16	0.965488
DK2	0.965265
F16	0.967681
E15	0.964040
D11	0.968669
A10	0.968
E10	0.969119
C10	0.964888
B10	0.968212
D10	0.966671
A9	0.969313
E9	0.968903
C9	0.968877
B9	0.969016
D9	0.968969
A8	0.969121
C8	0.969411
E8	0.968961
D8	0.967653
B8	0.969067
C7	0.967998
E7	0.966006
A7	0.967921
D7	0.969398
B7	0.968309
C6	0.968811
E6	0.969090
A6	0.967868
G5	0.969004
H6	0.967557
J6	0.967
F6	0.968108
G6	0.967987
H7	0.969709
F7	0.970866
J7	0.968603
G7	0.968646
H8	0.968817
F8	0.969
G8	0.970782
J8	0.966063
F9	0.967556
H9	0.967773
G9	0.969592
J9	0.971710
F10	0.969841
H10	0.972085
G10	0.969793
F11	0.969007
J10	0.967716
H11	0.971478
G11	0.971370

Table 6a: SLW JFET Gain

SLW	160 Hz
R1	0.969421
T1	0.968814
C1	0.968967
DK1	0.967182
B1	0.968715
D1	0.967019
E1	0.967029
A1	0.969438
C2	0.968
D2	0.968810
B2	0.965399
E2	0.969509
A2	0.967010
C3	0.969452
D3	0.966752
B3	0.967136
E3	0.967049
C4	0.968994
DK2	0.969287
D4	0.969575
C5	0.966935
B4	0.969595
A3	0.969589
T2	0.967410

Table 6b: SSW JFET Gain

SSW	160 Hz
R1	0.966656
A4	0.967052
A3	0.960958
A2	0.966977
A1	0.966246
DK1	0.966134
B3	0.960801
B2	0.965727
B1	0.966622
C3	0.966589
C2	0.966611
C1	0.966588
D3	0.966960
D2	0.966187
D1	0.964819
E3	0.966087
E2	0.966252
E1	0.966553
F3	0.966163
F2	0.956321
F1	0.966000
G1	0.966227
T1	0.944595
G2	0.939484
E5	0.965506
E4	0.961355
D7	0.960
D6	0.960370
D5	0.962957
D4	0.961996
C6	0.965616
C5	0.964981
C4	0.965040

B5	0.964331
B4	0.964868
T2	0.965190
G3	0.965484
G4	0.932831
DK2	0.964353
F5	0.965167
F4	0.962758
E6	0.965049