# METOP SEM-2

# F5 MEPED/SN 0015

# Calibration Report

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# 1.0 INTRODUCTION

This is the Calibration Report for the SEM-2 F5 MEPED SN 0015. It provides all the coefficients necessary to convert the MEPED outputs into appropriate internal voltages, temperature values, and particle fluxes. Section 2.0 contains the calibration data for the various monitor outputs, which provide information on internal voltages, operational status, and temperature. Particle flux calibration constants are given in Section 3.0, which contains a summary of the EM and PM MEPED accelerator calibration data. The absolute threshold calibration data for the F5 MEPED are given in Section 4.0. The thresholds are all sufficiently close to the nominal values that the particle channel responses are essentially the design values. Section 5.0 contains a description of the MEPED IFC operation and calibration constants. Appendix A contains a description of the compression counter algorithm used to convert the MEPED particle counts into the compressed counts used in telemetry, and the algorithm used to invert the compressed counts back into the full counts.

In normal operation most of the MEPED data is obtained through the DPU, which does all of the count compression and digital conversion of most of the MEPED analog monitors (Digital A MEPED analog monitor data). Thus some of the MEPED calibration constants are coupled to the DPU analog-to-digital converter calibration. These constants in Section 2.0 are provided for the SEM-2 DPU SN 0015, which is expected to be used with the MEPED SN 0015. Calibration constants are also provided for the direct MEPED analog outputs, and these data can be used to calculate the calibration constants for a different DPU.

# 2.0 MONITOR CALIBRATION

## 2.1 Analog Monitors

The MEPED has four (4) analog monitors which are provided directly to the spacecraft through the DPU connectors (all are on the DPU-J4 connector - see Ref. 3). Two (2) of these monitors are for voltages in the MEPED, and are also given in the Digital A output of the DPU. The remaining two (2) analog monitors are the isolated temperature monitors for the MEPED electronics (MEP ELEC THERM) and the 90° proton telescope (MEP P TEL THERM) which can be read by the spacecraft whenever the 28 V ATM bus to the SEM-2 is powered. There is also a temperature monitor which is used to control the MEPED heater, with connection directly to the MEPED through the heater control cable.

The calibrations for the two MEPED voltage monitors are given in Table 2.1. The calibrations are derived from data in TIR-RTP-112 (Ref. 4) and TIR-RTP-114 (Ref. 5), and are both linear with a zero point intercept. Two calibrations are given: one is for the direct MEPED output line, and the second is for the output to the spacecraft after the DPU buffer. The F5 DPU SN 0015 analog monitor output buffers have a 0.998 gain as measured in Ref. 13.

The calibration of the MEPED isolated temperature monitors (MEP ELEC THERM and MEP P TEL THERM) are given in Table 2.2. The polynomial fits are for the 28V ATM bus being precisely 28.0

V. For different 28V ATM bus voltages the telemetered monitor voltage values, $(\text{MEP ELEC THERM V})_{TM}$ and $(\text{MEP P TEL THERM V})_{TM}$ must first be corrected by

$$(\text{MEP ELEC THERM V})_{corr} = (\text{MEP ELEC THERM V})_{TM} \times 28.0/(\text{Actual 28V ATM V}) \quad (2.1)$$

and

$$(\text{MEP P TEL THERM V})_{corr} = (\text{MEP P TEL THERM V})_{TM} \times 28.0/(\text{Actual 28V ATM V}) \quad (2.2)$$

The corrected values $(\text{MEP ELEC THERM V})_{corr}$ and $(\text{MEP P TEL THERM V})_{corr}$ are then used in the Table 2.2 polynomial fit with

$$\text{MEP THERM Temp} = \sum_{i=0}^{8} A_i \times (\text{MEP THERM V})_{corr}^{\,i} \ (°\text{C}) \quad (2.3).$$

The two MEPED isolated temperature monitor circuits are calibrated for voltage output vs. resistance input in TIR-RTP-113 (Ref. 6). The test data show that the actual voltage outputs agree reasonably well with the nominal response. Using the fit based on the nominal response, given in Table 2.2, the calculated temperature differs from the true temperature by about ±0.6°C at +35°C, and by about ±1.5°C at -20°C. The test data also verify the +28V ATM bus voltage correction of eqs. (2.1) and (2.2). Only one calibration fit is given for both MEPED isolated temperature monitors, simplifying data reduction procedures.

Table 2.1 MEPED Analog Voltage Monitor Calibrations

| MEPED Monitor Description | Mnemonic | Actual Value (V) | Monitor Calibration (V/V) | | Source |
|---|---|---|---|---|---|
| | | | Direct | F5 DPU | |
| MEPED +5 Volt | MED +5V | 4.99 | 1.246 | 1.248 | Ref. 4 |
| MEPED Omni Bias Voltage | MED OMNI BV | 558. | 173.8 | 174.2 | Ref. 5 |

One of the MEPED heater thermistors is read by the spacecraft using its own conditioning circuitry. The NOAA heater thermistors were obtained from the spacecraft manufacturer; Table 2.3 gives the specification NOAA thermistor resistance for -55°C to 70°C. The NOAA MEPED heater thermistor is not read out over the spacecraft telemetry, so the resistance calibration in Table 2.3 is for reference only. The second MEPED heater thermistor was provided by METOP, and is used for heater control when the MEPED is on the METOP spacecraft. The METOP MEPED heater control thermistor is a METOP part number S311P18-07T-30R.

| Table 2.2 MEPED Isolated Temperature Monitor (MEP THERM) Fit | |
|---|---|
| Polynomial Term i (Power of (MEP THERM V)) | Eq. (2.2) $A_i$ Polynomial Coefficient |
| 0 | 86.043939 |
| 1 | -74.384817 |
| 2 | 26.691091 |
| 3 | 4.805859 |
| 4 | -10.648079 |
| 5 | 5.130014 |
| 6 | -1.236963 |
| 7 | 0.153214 |
| 8 | -0.007788 |

| Table 2.3 MEPED Heater Thermistor Resistance Calibration - NOAA Thermistor | | | |
|---|---|---|---|
| Temperature (°C) | Resistance (kΩ) | Temperature (°C) | Resistance (kΩ) |
| -55 | 1296.5 | 10 | 21.134 |
| -50 | 886.38 | 15 | 16.385 |
| -45 | 612.31 | 20 | 12.698 |
| -40 | 428.28 | 25 | 10.000 |
| -35 | 304.13 | 30 | 7.9075 |
| -30 | 217.89 | 35 | 6.264 |
| -25 | 157.73 | 40 | 4.986 |
| -20 | 115.37 | 45 | 4.039 |
| -15 | 83.094 | 50 | 3.253 |
| -10 | 63.329 | 55 | 2.641 |
| -5 | 47.746 | 60 | 2.1525 |
| 0 | 36.085 | 65 | 1.7631 |
| 5 | 27.572 | 70 | 1.4383 |

## 2.2 Digital A Analog Monitors

The MEPED has seventeen (17) analog monitors in Digital A, two (2) of which are also direct analog monitors to the spacecraft. The direct voltage outputs of these monitors are calibrated in V/V (Volts input/Volts output), but this is not directly used for the Digital A outputs, since the DPU digitizes the monitor data for telemetry. The monitor calibrations for the F5 MEPED SN 0015 have been converted to Digital A calibrations using the monitor digitizer calibration for the DPU SN 0015, which is 0.019950 (V input)/(count output) (the intercept is essentially 0.0V). The DPU calibration factor is not expected to vary significantly for different units, but if the MEPED SN 0015 should be used with a different DPU than SN 0015 the Digital A calibration factors can be corrected, if desired. The MEPED Digital A monitor calibration factors are given in Table 2.4. The direct monitor calibrations are derived from data in test procedures Refs. 6 to 8. The monitors are read once per major frame or are subcommutated as described in Ref. 1.

The four MEPED Temperature monitors in Digital A (MEP TEMPs) each provides a measured voltage from which the temperature is then calculated. The measured voltage depends on the MEPED -6.2 volt supply value, and the measured Digital A voltages must be corrected using the measured -6.2 volt supply value. The corrected $(\text{MEP TEMP V})_{corr}$ values are obtained from the Digital A voltages $(\text{MEP TEMP V})_{TM}$ by

$$(\text{MEP TEMP V})_{corr} = (\text{MEP TEMP V})_{TM} \times (-6.2/(\text{Actual } -6.2\text{V V})) \tag{2.4}$$

The MEPED -6.2 volt supply is regulated within the MEPED and is quite stable, so normally the correction of (2.4) will not be significant. The corrected values $(\text{MEP TEMP V})_{corr}$ are then used in the Table 2.5 polynomial fit with

$$\text{MEP TEMP Temp} = \sum_{i=0}^{8} A_i \times (\text{MEP TEMP V})_{corr}^{\,i} \ (°\text{C}) \tag{2.5}$$

The four MEPED commutated temperature monitor circuits are calibrated for voltage output vs. resistance input in TIR-RTP-113 (Ref. 6). The test data show that the actual voltage outputs agree closely with the nominal response calculated from the circuit resistances and the specification thermistor resistance. Using the fit based on the nominal response given in Table 2.5, the calculated temperatures from the Ref. 6 resistance measurements differ from the true temperatures by about ±0.6°C at -20°C and about ±2.7°C at +30°C. The test data also verify the -6.2 volt supply correction of eq. (2.4). Thus only one calibration fit is given for all four MEPED commutated temperature monitors, simplifying data reduction procedures.

| Table 2.4 Digital A Analog Monitor Calibration Constants | | | | | |
|---|---|---|---|---|---|
| MEPED Monitor Description | Ref. 1 Mnemonic | MEPED Analog Line Cal (V/V) | Digital A Cal (V/cnt) | Ref. 1 Analog Subcom | Source |
| MEPED Omni Bias V | MEP OMNI BV | 173.8 | 3.468 | - | Ref. 5 |
| MEPED IFC V | MEP IFC V | 1.000 | 0.01995 | - | Ref. 7 |
| MEPED +6.8 Volt | MEP +6.5V | 1.658 | 0.03307 | 2 | Ref. 4 |
| MEPED +7.8 Volt | MEP +7.8V | 1.871 | 0.03733 | 2 | “ |
| MEPED -7.8 Volt | MEP -7.8V | -1.877 | -0.03745 | 2 | “ |
| MEPED +5 Volt | MEP +5V | 1.246 | 0.02485 | 2 | “ |
| MEPED +6.2 Volt | MEP +6.2V | 1.494 | 0.02981 | 2 | “ |
| MEPED -6.2 Volt | MEP -6.2V | -1.500 | -0.02993 | 2 | “ |
| MEPED P Tel Bias V | MEP P TEL BV | 48.60 | 0.9696 | 2 | Ref. 5 |
| MEPED E Tel Bias V | MEP E TEL BV | 99.04 | 1.976 | 2 | “ |
| MEPED IFC Ref. V | MEP IFC REF | 1.000 | 0.01995 | 3 | Ref. 7 |
| MEP 0 Deg/D4/D5 Ref V | MEP 0 DEG REF | 1.000 | 0.01995 | 3 | Ref. 8 |
| MEP 90 Deg/D6/D7 Ref V | MEP 90 DEG REF | 1.000 | 0.01995 | 3 | “ |
| MEP P Tel Temperature | MEP P TEL TEMP | 1.000 | 0.01995 | 3 | Ref. 6 |
| MEP E Tel Temperature | MEP E TEL TEMP | 1.000 | 0.01995 | 3 | “ |
| MEP Omni Temperature | MEP OMNI TEMP | 1.000 | 0.01995 | 3 | “ |
| MEP Electronics Temp | MEP ELEC TEMP | 1.000 | 0.01995 | 3 | “ |

| Table 2.5 MEPED Digital A Temperature Monitor (MEP TEMP) Fits | |
|---|---|
| Polynomial Term i (Power of (TED THERM V)) | Eq. (2.4) $A_i$ Polynomial Coefficient |
| 0 | -61.941892 |
| 1 | 88.898524 |
| 2 | -95.433699 |
| 3 | 76.566451 |
| 4 | -39.448188 |
| 5 | 12.846635 |
| 6 | -2.540039 |
| 7 | 0.277591 |
| 8 | -0.0128 |

## 2.3 Bi-Level Monitors

The MEPED has two (2) bi-level monitor outputs which are given in Digital A, one (1) of which is also provided as a separate line for the Digital B output. All of the Digital A bi-level outputs are listed in Table 3.6 of Ref. 1; the MEPED bi-levels are summarized in Table 2.6 below.

| Table 2.6 MEPED Bi-Level Monitors | | |
|---|---|---|
| Monitor Description | Mnemonic | Status Indications |
| MEPED IFC Status | MEP IFC | 0 = IFC off; 1 = IFC on |
| MEPED IFC Phase | MEP IFC PH | 0 = IFC Phase 0; 1 = IFC Phase 1 |

The Digital B bi-level outputs are listed in Table 5.1 of Ref. 1; the only MEPED bi-level in Digital B is the MEPED IFC Status (MEP IFC).

# 3.0 PARTICLE RESPONSES

## 3.1 Electron Telescope Response

The electron telescope design is described in Ref. 2, and the nominal response is summarized in Table 3.1. Note that all electron channels have an upper limit (veto) threshold of 2500 keV which limits the response from higher energy protons and alpha particles. The electron telescope is designed with

entrance collimators that give a 0° (normal incidence) open area of 0.0856 $cm^2$ and a total geometric factor of 0.00961 $cm^2$ sr with a 30° full width detection cone. The PM MEPED was calibrated with electrons at the GSFC calibration facility, and with electrons at the PL calibration facility, with the results being summarized in Ref. 9.

Table 3.1 Electron Telescope Nominal Response

| Electron Channels | Threshold (keV) | Detected Energy Range )keV) | |
|---|---|---|---|
| | | Electrons | Protons |
| 0E1/9E1 | 25.6 | ≥30 | 210-2700 |
| 0E2/9E2 | 98.1 | ≥100 | 280-2700 |
| 0E3/9E3 | 299. | ≥300 | 440-2700 |

3.2 Proton Telescope Response

The proton telescope design is described in Ref. 2, and the nominal proton telescope response is summarized in Table 3.2. Note that most proton channels have a window set of thresholds on the front detector in anti-coincidence/coincidence with a threshold on the rear detector (see Ref. 2). The proton telescope is designed with entrance collimators that give a 0° (normal incidence) open area of 0.0856 $cm^2$ and a total geometric factor of 0.00961 $cm^2$ sr with a 30° full width detection cone. The PM MEPED was calibrated with protons at the GSFC calibration facility, with the results being summarized in Ref. 9.

Table 3.2 Proton Telescope Nominal Response

| Proton Channels | Threshold Energies (keV) | | Detected Proton Energy Range (keV) |
|---|---|---|---|
| | Front SSD | Rear SSD | |
| 0P1/9P1 | 21.4 | <50. (anti-coincidence) | 30. - 80. |
| 0P2/9P2 | 70.7 | <50. (anti-coincidence) | 80. - 250. |
| 0P3/9P3 | 243. | <50. (anti-coincidence) | 250. - 800. |
| 0P4/9P4 | 796. | <50. (anti-coincidence) | 800. - 2500. |
| 0P5/9P5 | 2498. | <50. (anti-coincidence) | 2500. - 6900. |
| 0P6/9P6 | 21.4 | 50. | >6900. |

## 3.3 Omni Sensor Responses

The Omni sensor designs which provide the P6, P7, P8 and P9 high energy proton channels are described in Ref. 2. The energy thresholds are determined by the moderator thicknesses, with the solid state detectors having an energy loss threshold of 2500 keV to reduce response to lower energy electrons. The nominal proton responses are summarized in Table 3.3, which list the primary energy range for the upper hemisphere response of Ref. 2. The detector area for normal incidence is 0.50 $cm^2$ and the upper hemisphere omnidirectional geometric factor is 0.125 $cm^2$, or 1.571 $cm^2$ sr (0° to 90°). The full-sphere omnidirectional geometric factor is 0.438 $cm^2$, or 5.50 $cm^2$ sr, but this is only applicable to fully isotropic proton fluxes. For polar cap measurements of solar protons the omni sensor upper hemisphere geometric factors are most appropriate, since atmospheric loss eliminates most of the back hemisphere protons. The PM omni sensors were calibrated with proton beams at the Harvard Cyclotron, with the results being summarized in Ref. 9.

Table 3.3 Omni Sensor Nominal Response to Protons

| Proton Channel | Threshold (keV) | Detected Proton Energy Range (MeV) (0°/60°) | Approximate G ($cm^2$ sr) |
|---|---|---|---|
| P6 | 2500. | 16. - 215./1100. | 1.57 |
| P7 | 2500. | 35. - 220./1100. | 1.57 |
| P8 | 2500. | 70. - 235./1110. | 5.50 |
| P9 | 2500. | 140. - 275./1130. | 5.50 |

## 3.4 Summary of Sensor Geometric Factors

The MEPED sensor accelerator calibrations of Ref. 9 verify that the measured particle responses are close to the calculated responses. The data in Ref. 9 are summarized in Table 3.4, which gives a summary of the MEPED channel particle responses.

| Table 3.4 Summary of MEPED Channel Particle Responses | | | |
|---|---|---|---|
| Channel | Particle Type | Detected Energy Range | Geometric Factor, G ($cm^2$ sr) |
| 0E1/9E1 | Electrons | >30 keV | 0.0100 |
| 0E2/9E2 | " | >100 keV | 0.0100 |
| 0E3/9E3 | " | >300 keV | 0.0100 |
| | | | |
| 0E1/9E1 | Protons | 210 - 2700 keV | 0.0100 |
| 0E2/9E2 | " | 280 - 2700 keV | 0.0100 |
| 0E3/9E3 | " | 440 - 2700 keV | 0.0100 |
| | | | |
| 0P1/9P1 | Protons | 30 - 80 keV | 0.0100 |
| 0P2/9P2 | " | 80 - 250 keV | 0.0100 |
| 0P3/9P3 | " | 250 - 800 keV | 0.0100 |
| 0P4/9P4 | " | 800 - 2500 keV | 0.0100 |
| 0P5/9P5 | " | 2500 - 6900 keV | 0.0100 |
| 0P6/9P6 | " | >6900 keV | 0.0100 |
| | | | |
| P6 | Protons | 16 - (500) MeV | 1.50[a] |
| P7 | " | 35 - (500) MeV | 1.50[a] |
| P8 | " | 70 - (500) MeV | 1.50[a] |
| P9 | " | 140 - (500) MeV | 1.50[a] |
| [a] These are for the angle range of 0° to 105°. | | | |

## 4.0 ABSOLUTE THRESHOLD CALIBRATION

The absolute values of the MEPED thresholds are obtained from data recorded in Test Procedure TIR-RTP-125, MEPED Calibration Procedure (Ref. 10). The necessary data are taken from Section 4.0 of Ref. 10, Adjustment Verification. The calibrations are made using a Research Pulse Generator (RPG) which is calibrated in absolute energy by using radioactive sources ($^{241}$Am for a 59.54 keV x-ray peak, and $^{137}$Cs for a 477.3 keV Compton edge). The thresholds are measured by determining the RPG dial settings

for 50% firing of the appropriate particle channel. The calibrated threshold values are calculated from the following set of numbers:

$C_o$ = MCA zero channel (this is not measured in TIR-RTP-125, but is measured later in TIR-RTP-139, MEPED CPT (Ref. 11)
$C_A$ = $^{241}$Am 59.54 keV x-ray peak channel, or the $^{137}$Cs 477.3 keV Compton edge channel
$C_P$ = RPG channel for 0.1987 setting ($^{241}$Am source), or for 1.5910 setting ($^{137}$Cs source)
$P_M$ = measured RPG dial reading for threshold

The calibrated threshold value is then given by

$$LS(actual) = (59.54\ keV/0.1987) \times P_M \times [(C_P - C_o)/(C_A - C_o)] \quad (4.1)$$

for the $^{241}$Am source use, and by

$$LS(actual) = (477.3\ keV/1.5910) \times P_M \times [(C_P - C_o)/(C_A - C_o)] \quad (4.2)$$

for the $^{137}$Cs source use. The absolute thresholds have been calculated from the November 11, 1998 CPT, using the RSE data to provide the absolute calibration. The thresholds are listed in Table 4.1.

## 5.0 IFC DATA PROCESSING

### 5.1 General Outline of MEPED IFC Operation

The basic outline of the MEPED IFC operation was described in Ref. 12. For normal (in-orbit) SEM-2 operation, the DPU accumulates and outputs the MEPED data synchronized to a Major Frame (MF) pulse which occurs every 32 seconds. A MF is divided into 320 0.1 s minor frames (mf's). A complete set of MEPED counts is output every 2 s, which is every 20 mf's, except for P8 and P9 which alternate in the output and are thus read out every 4 s (see Ref. 1 for a more complete description of the data stream). The MEPED IFC consists of two phases, Phase 0 and Phase 1, each lasting 192 seconds. During the IFC the pulser is off for two seconds and active for two seconds, allowing background measurements to be made during the IFC, except for P8 and P9 which have the 4 second accumulation periods. Each 192 second IFC phase thus provides a set of 48 IFC counts, which are numbered 0 to 47; for all counts except P8 and P9 there are also 48 background counts. Each IFC count includes four consecutive pulser ramp steps (amplitudes), with the nominal ramp steps ranging from 0 to 191. Information on the nominal IFC ramp end point energies and activity for the various SSD's are listed in Table 5.1. The energy of the ramp origin depends on the definition of IFC Count Number in terms of IFC ramp step. However, since the IFC circuits have an offset because of non-linearities at very low pulse amplitudes, there is an additional offset which must be calibrated out, and this is done as shown in Section 5.2. Table 5.2 shows the detector threshold and noise measurement plan. The IFC Count Number is based on a range of 0-47 for 48 pulser-on counts, and is adjusted so that a value of N.00 corresponds to count N (the N+1 count of the 48 count sequence) being exactly 50% of the full-on count.

| Table 4.1 F5 MEPED Absolute Threshold Values | | | | | |
|---|---|---|---|---|---|
| Solid State Detector (SSD) | Threshold | Channel Count | Threshold Values (keV) | | (Cal/Des) Threshold Ratio |
| | | | Design | Calibrated | |
| 0D1 | LS1 | 0P1 | 21.4 | 21.36 | 0.998 |
| “ | LS2 | 0P2 | 70.7 | 71.92 | 1.017 |
| “ | LS3 | 0P3 | 243. | 241.2 | 0.993 |
| “ | LS4 | 0P4 | 796. | 793.5 | 0.997 |
| “ | LS5 | 0P5 | 2498. | 2477. | 0.992 |
| 0D2 | LS6 | 0P6 | 50. | 54.54 | 1.091 |
| 9D1 | LS1 | 9P1 | 21.4 | 21.51 | 1.005 |
| “ | LS2 | 9P2 | 70.7 | 70.51 | 0.997 |
| “ | LS3 | 9P3 | 243. | 236.8 | 0.974 |
| “ | LS4 | 9P4 | 796. | 773.0 | 0.971 |
| “ | LS5 | 9P5 | 2498. | 2409. | 0.964 |
| 9D2 | LS6 | 9P6 | 50. | 47.19 | 0.944 |
| 0D3 | LS1 | 0E1 | 25.6 | 26.37 | 1.030 |
| “ | LS2 | 0E2 | 98.1 | 100.08 | 1.020 |
| “ | LS3 | 0E3 | 299. | 301.1 | 1.007 |
| “ | LS4 | 0E3 | 2500. | 2510. | 1.004 |
| 9D3 | LS1 | 9E1 | 25.6 | 25.17 | 0.983 |
| “ | LS2 | 9E2 | 98.1 | 99.18 | 1.011 |
| “ | LS3 | 9E3 | 299. | 302.6 | 1.012 |
| “ | LS4 | 9E3 | 2500. | 2528. | 1.011 |
| D4 | LS1 | P6 | 2500. | 2625. | 1.050 |
| D5 | LS2 | P7 | 2500. | 2537. | 1.015 |
| D6 | LS3 | P8 | 2500. | 2517. | 1.007 |
| D7 | LS4 | P9 | 2500. | 2553. | 1.021 |

Table 5.1 Nominal IFC Ramp Characteristics for Phase 0 and Phase 1

| IFC Phase | Interval Seconds of Readout Data[a] | Ramp End Points for Detectors (SSDs), in keV | | | |
|---|---|---|---|---|---|
| | | P-tel/FD (0D1/9D1) | P-tel/RD (0D2/9D2) | E-tel (0D3/9D3) | Omni SSDs |
| 0 | 1 - 192 | 120 | 60 | 120 | 2750 |
| 1 | 193 - 384 | 2750 | - | 2750 | 2750 |

[a] Interval seconds are for data accumulation from IFC start pulse, which occurs shortly after a Major Frame Synch pulse at T = 0.00 seconds. Counts in interval seconds 1-2 were accumulated in the period 0-2 second, and read out to telemetry in the period T = 2-4 second (there is actually a slight shift of about +0.2 second for the MEPED counts). IFC output data in the telemetry stream begins at 2 seconds after the Major Frame start.

| Ramp End Point Energy (keV) | Used in IFC Phase | Ramp Step Size (E.P./191) (keV) | Energy Increment per IFC Count Number (keV)[b] |
|---|---|---|---|
| 120 | 0 | 0.628 | 2.513 |
| 60 | 0 | 0.314 | 1.257 |
| 2750 | 0 and 1 | 14.40 | 57.59 |

[b] In the text this is referred to as (keV/IFC cnt no).

The MEPED IFC starts at a MF pulse, so the IFC pulse ramp becomes active at that time. The first 2 s (20 mf's) of the IFC are for background, with the pulser inactive, while the next 2 s have the pulser active with the four lowest ramp steps (0, 1, 2 and 3). The MEPED counts output during the first 2 s of the MF in which the IFC started were accumulated in the previous 2 s, and thus are not part of the IFC. The first set of IFC background (ambient particle) counts, BC(0), are output in the second 2 s period of the first IFC MF. The count sequence for the MF where the IFC starts is thus given by

NC, BC(0), IC(0), BC(1), IC(1), BC(2), IC(2), ...

where NC is a "normal" count (non-IFC, or pre-IFC background), and IC(0) is the first IFC pulser-on count. Note that for the 4 s accumulation counts P8 and P9 the output count sequence for the first IFC MF is

P8(NC), P9(NC), P8(IC(0)), P9(IC(0)), P8(IC(1)), ...

where the first count pair can be used as background measurements. Each IFC phase, 0 and 1, lasts for 6 MF's, for a total of 12 MF's, or 384 s. Note that the final IFC count of phase 1, IC(47), is the first count set in the MF after the IFC terminates, except that P8 is read out in the first 2 s, and P9 in the second 2 s. This offset of 1 count (2 s) in the telemetry stream must be taken into account to properly analyze the MEPED IFC data.

The counts to be used for IFC calculations are the net IFC count values (background corrected) calculated from

$$NTC(I) = IC(I) - (BC(I) + BC(I+1))/2 \tag{5.1}$$

and these are the count values used for calculating threshold and FWHM noise values. The subtraction in (5.1) is made with the decompressed counts, obtained from the telemetry data as shown in the Appendix. For the P8 and P9 counts the background subtraction can be made using pre- and post-IFC counts, or by using counts within the IFC that occur just before the threshold is activated by the IFC pulser and after the IFC has terminated. The latter is only needed if the P8 and P9 backgrounds (true detected particle counts) are varying significantly during the IFC.

## 5.2 Use of MEPED IFC

### 5.2.1 Calculation of Thresholds with FWHM Noise Measurements

Table 5.2 shows that there are ten (10) telescope thresholds which are measured along with the SSD FWHM noise, all in IFC Phase 0. If an OMNI SSD has a noise level >40 keV, then it can also be measured by the IFC in Phase 1. For each threshold the IFC count values are labeled by count numbers I of 0-47, and the calculations are made using the net IFC count (background subtracted) of (5.1). A set of net count values and the corresponding count numbers I around the region of threshold turn-on are fit to a Gaussian integral from

$$F(Z(I)) = NTC(I)/2080 \tag{5.2}$$

where 2080 is the full on count for the telescope channels in the IFC (2080 is replaced by 4160 if this method is used with the OMNI SSD's at >40 keV noise levels). The above can also be written as

$$F(Z(I)) = 0.5\ (1 + erf(Z(I)/sqrt(2))). \tag{5.3}$$

where erf(x) is the error function integral. Eqs. (5.2) and (5.3) can be inverted by either a table interpolation or a suitable computer subroutine to give

$$Z(I) = INVERSE(F(Z(I))) \tag{5.4}$$

Table 5.2 Detector Threshold and Noise Measurement Outline

| Sensor Type | SSD(s) | Level | Design Value (keV) | Counts Used | IFC Phase | IFC Count No.[a] | Count On or Off | IFC Ramp Step[b] | SSD Noise Meas. |
|---|---|---|---|---|---|---|---|---|---|
| P-tel | 0D1/9D1 | LS1 | 21.4 | 0P1/9P1 | 0 | 8.14 | on | 34.06 | yes |
| “ | “ | LS2 | 70.7 | 0P2/9P2 | 0 | 27.76 | on | 112.53 | yes |
| “ | “ | LS3 | 243. | 0P3/9P3 | 1 | 3.84 | on | 16.88 | - |
| “ | “ | LS4 | 796. | 0P4/9P4 | 1 | 13.45 | on | 55.29 | - |
| “ | “ | LS5 | 2498. | 0P5/9P5 | 1 | 43.00 | on | 173.50 | - |
| “ | 0D2/9D2 | LS6 | 50. | 0P6/9P6 | 0 | 39.42 | on | 159.17 | yes |
| | | | | | | | | | |
| E-tel | 0D3/9D3 | LS1 | 25.6 | 0E1/9E1 | 0 | 9.81 | on | 40.75 | yes |
| “ | “ | LS2 | 98.1 | 0E2/9E2 | 0 | 38.66 | on | 156.14 | yes |
| “ | “ | LS3 | 299. | 0E3/9E3 | 1 | 4.82 | on | 20.77 | - |
| “ | “ | LS4 | 2500. | 0E3/9E3 | 1 | 43.03 | off | 173.64 | - |
| | | | | | | | | | |
| Omni | D4 | LS1 | 2500. | P6 | 0, 1 | 43.03 | on | 173.64 | <40 keV[c] |
| “ | D5 | LS2 | 2500. | P7 | 0, 1 | 43.03 | on | 173.64 | <40 keV[c] |
| “ | D6 | LS3 | 2500. | P8 | 0, 1 | 43.03 | on | 173.64 | <40 keV[c] |
| “ | D7 | LS4 | 2500. | P9 | 0, 1 | 43.03 | on | 173.64 | <40 keV[c] |

[a] IFC count number (0-47) for nominal threshold value. Fraction shows the level position in that count number energy range. The IFC count number values have been adjusted so that if IFC count N has 50% of the full-on count, then the fractional value is .00, giving a count number value of N.00.

[b] IFC ramp step magnitude (0-191) for nominal threshold value. Note that IFC count number = (IFC ramp step + 0.5)/4 - 0.5.

[c] Noise can only be measured above 40 keV; normally it is only a limit.

The values of Z(I) from (5.4) and I are then fit with a straight line of the form

$$I = A + B \times Z. \tag{5.5}$$

The routine to do this should return the values of A(fit), B(fit), the correlation coefficient, and the number of points fit. The fit of (5.5) should use only counts which have $0.05 < F(Z(I)) < 0.95$. This is necessary to avoid problems from the compression counter resolution at high count values where the decompressed count can have a ± 3% uncertainty. This is especially important when there is a high background (ambient particle) count, since then the net counts of (5.1) are the difference of two large compressed counts.

The Gaussian fit outputs A(fit) and B(fit) of (5.5) give the measured threshold and noise values from

$$LS(measured) = A(fit) \times CSLOPE + COFFSET \tag{5.6}$$

and

$$FWHM(measured) = 2.35482 \times B(fit) \times CSLOPE. \tag{5.7}$$

The calibration factors CSLOPE and COFFSET to be used in (5.6) and (5.7), along with the NTC(I) count sets to be used to calculate the fit of (5.5), are given in Table 5.3. All telescope threshold/noise measurement counts come from IFC Phase 0, while the omni sensor counts come from IFC Phase 1. Note that the four omni sensor thresholds are to be used only if the noise level is sufficiently high to allow a fit of (5.5) with at least two (2) points satisfying the F(Z(I)) limits. It is expected that normally the omni sensors will have a noise < 40 keV, and will use the threshold calculation method of Section 5.2.2.

### 5.2.2 Calculation of Thresholds with No Noise Measurements

The higher level telescope thresholds and the omni sensor thresholds usually allow no noise measurement because there is only one IFC count value which is between 0 and the full on count (either 2080 for the telescopes, or 4160 for the omni's), and this only allows an upper limit calculation for the FWHM noise. The threshold values are calculated from

$$LS(measured) = COFFSET + CSLOPE \times CNTFRAC \tag{5.8}$$

where

$$CNTFRAC = (\Sigma\ NTC(I))/C3. \tag{5.9}$$

The calibration constants COFFSET and CSLOPE, and the range of NTC(I) counts to use are listed in Table 5.4. Note that all counts come from IFC Phase 1.

| Table 5.3 IFC Calibration Constants for Thresholds with Noise Measurement | | | |
|---|---|---|---|
| Threshold | Counts Used[a] (NTC(I) Range) | COFFSET (keV) | CSLOPE (keV/(IFC count)) |
| 0P/LS1 | I = 4 - 13 | 1.645 | 2.536 |
| 0P/LS2 | I = 21 - 30 | 1.760 | 2.714 |
| 0P/LS6 | I = 36 - 47 | 4.931 | 1.189 |
| 9P/LS1 | I = 4 - 13 | 1.480 | 2.662 |
| 9P/LS2 | I = 20 - 26 | 1.571 | 2.826 |
| 9P/LS6 | I = 28 - 41 | 0.436 | 1.364 |
| 0E/LS1 | I = 6 - 15 | 3.204 | 2.244 |
| 0E/LS2 | I = 35 - 44 | 3.517 | 2.463 |
| 9E/LS1 | I = 5 - 14 | 2.602 | 2.327 |
| 9E/LS2 | I = 32 - 41 | 2.930 | 2.619 |
| | | | |
| D4/LS1[b] | I = 35 - 47[c] | -14.55 | 61.58 |
| D5/LS2[b] | I = 30 - 43[c] | -17.70 | 67.51 |
| D6/LS3[b] | I = 38 - 47[c] | -19.05 | 55.25 |
| D7/LS4[b] | I = 31 - 44[c] | -14.62 | 65.57 |

[a] Range of I for NTC(I) to be used, with I ranging from 0 to 47. All telescope thresholds use the Phase 0 IFC counts, while the omni sensors use the Phase 1 IFC counts. The particle count to be used is given in Table 5.2.
[b] The four omni sensor thresholds are used for threshold + noise calculations only when the noise is > 40 keV and there are two (2) or more counts available for fitting.
[c] These counts are from IFC Phase 1, so the numbers referenced to the start of the IFC are larger by 48.

| Table 5.4 IFC Calibration Constants for Thresholds with No Noise Measurement | | | | |
|---|---|---|---|---|
| Threshold | Counts Used[a] (NTC(I) Range) | COFFSET (keV) | CSLOPE (keV/(IFC count)) | C3 |
| 0P/LS3 | I = 4 - 5 | 296.2 | -106.5 | 4160 |
| 0P/LS4 | I = 14 - 15 | 862.5 | -110.8 | 4160 |
| 0P/LS5 | I = 43 - 44 | 2533.3 | -113.7 | 4160 |
| 9P/LS3 | I = 4 - 5 | 304.6 | -107.3 | 4160 |
| 9P/LS4 | I = 13 - 14 | 820.0 | -111.7 | 4160 |
| 9P/LS5 | I = 41 - 42 | 2445.9 | -114.6 | 4160 |
| 0E/LS3 | I = 5 - 6 | 355.9 | -109.8 | 4160 |
| 0E/LS4 | I = 43 - 44 | 2443.7 | 115.0 | 4160 |
| 9E/LS3 | I = 5 - 6 | 376.9 | -116.8 | 4160 |
| 9E/LS4 | I = 41 - 42 | 2496.4 | 123.4 | 4160 |
| D4/LS1[b] | I = 42 - 43 | 2693.1 | -123.2 | 8320 |
| D5/LS2[b] | I = 37 - 38 | 2616.7 | -135.0 | 8320 |
| D6/LS3[b] | I = 45 - 46 | 2588.1 | -110.5 | 8320 |
| D7/LS4[b] | I = 38 - 39 | 2604.7 | -131.1 | 8320 |

[a] Range of I for NTC(I) to be used, with I ranging from 0 to 47. All thresholds use the Phase 1 IFC counts, so the numbers referenced to the start of the IFC are larger by 48. The particle count to be used is given in Table 5.2.

[b] This is expected to be the normal method of measuring the omni sensor thresholds. When the noise is > 40 keV and there are two (2) or more counts available for fitting, the corresponding omni sensor can be used for threshold + noise calculations.

## 5.3 Method of Calculating MEPED IFC Calibration Constants

The basic manner of calculating the MEPED thresholds and FWHM noise values from the in-orbit IFC data were presented in the previous Sections. The following discussion gives more detail on how the IFC calibration constants are calculated from the MEPED calibration data (Ref. 10 and Section 4.0) and the baseline MEPED CPT data (Ref. 11).

### 5.3.1 Measurement of IFC Ramp Offsets

The IFC ramps have slight non-linearities at the very lowest amplitudes because of transistor turn-on characteristics and low-level gate pulse feed-through. The higher level pulse amplitudes are linear against the ramp step number, but the linear relation has an offset, with the extrapolated zero amplitude pulse corresponding to an extrapolated ramp step number of $S_o$. This offset is important for proper calculation of the lower threshold levels. The IFC calibration factor can normalize the measured IFC threshold to the actual (source-calibrated) threshold at one point, but as the measured threshold shifts from this point (mostly through temperature variations) the ramp offset $S_o$ is needed to avoid increasing errors. The data needed to calculate $S_o$ are taken during the RSE part of the MEPED CPT. The test data are used to obtain the following numbers for each SSD in each IFC phase. In the following, MCA is a MultiChannel Analyzer used to measure the pulse height distribution from various MEPED and/or pulser outputs.

| | |
|---|---|
| (MCA zero channel) | = channel for 0.0V pulse into the MCA |
| (IFC zero channel) | = channel for IFC step 0 |
| (IFC ramp step) | = a selected IFC ramp step, usually 96 |
| (IFC ramp step channel) | = MCA channel for the selected IFC ramp step |

Using the data from the new MEPED Baseline CPT starting on 11/17/2008, the IFC ramp offsets are calculated from

$$S_o = \frac{(\text{IFC ramp step}) \times ((\text{MCA zero channel}) - (\text{IFC zero channel}))}{(\text{IFC ramp step channel}) - (\text{IFC zero channel})} \tag{5.10}$$

The effective (linear with zero intercept) IFC ramp step is given by

$$S_{eff} = S - S_o \tag{5.11}$$

where S is the nominal ramp amplitude (0-191). Note that the first IFC count (IFC count number 0) uses IFC ramp steps of 0, 1, 2 and 3, for an average value of 1.5, and similar increments of four IFC ramp steps for the higher IFC count numbers (1-47). If the fractional part of the "threshold" IFC count number is to be .00 when the count value is 50% of the full-on count, then the IFC count number must be given by

$$\text{IFC count number} = (\text{IFC ramp step} + 0.5)/4 - 0.5 \tag{5.12}$$

as shown in Table 5.2. The measured values of $S_o$ for the F5 MEPED are listed in Table 5.5. These IFC ramp step offsets are used in the calculation of the IFC calibration constants, as shown in the following two Sections.

Table 5.5 Measured Values of the IFC Ramp Offset for the F5 MEPED

| SSD | IFC Phase | Threshold Levels | $S_o$ |
|---|---|---|---|
| 0D1 | 0 | LS1, LS2 | -1.09 |
| “ | 1 | LS3, LS4, LS5 | 1.25 |
| 0D2 | 0 | LS6 | -15.09 |
| 9D1 | 0 | LS1, LS2 | -0.72 |
| “ | 1 | LS3, LS4, LS5 | 0.78 |
| 9D2 | 0 | LS6 | 0.22 |
| 0D3 | 0 | LS1, LS2 | -4.21 |
| “ | 1 | LS3, LS4 | 1.57 |
| 9D3 | 0 | LS1, LS2 | -2.97 |
| “ | 1 | LS3, LS4 | 1.68 |
| D4 | 1 | LS1 | 0.55 |
| D5 | 1 | LS2 | 0.45 |
| D6 | 1 | LS3 | 0.12 |
| D7 | 1 | LS4 | 0.61 |

### 5.3.2 Calibration Constants for Thresholds with FWHM Noise Measurements

Thresholds with FWHM noise measurements use the fitting method described in Section 5.2.1, with the calibration constants calculated as follows. Using the A(fit) and B(fit) values obtained from the fitting of eq. (5.5), the nominal threshold and FWHM noise values are calculated from

$$\text{LS(nominal)} = \text{A(fit)} \times (\text{keV/IFC cnt no}) \tag{5.13}$$

and

$$\text{FWHM(nominal)} = \text{B(fit)} \times (\text{kev/IFC cnt no}) \times 2.35482. \tag{5.14}$$

where (keV/IFC cnt no) = 2.513 for the telescope front SSD's, = 1.257 for the proton telescope rear SSD's, and = 57.59 for the OMNI SSD's (see the last column in Table 5.1). The IFC measured threshold and noise values are then calculated from the calibration constants for that threshold by

$$LS(measured) = LS(nominal) \times CL1 + CL2 \tag{5.15}$$

and

$$FWHM(measured) = FWHM(nominal) \times CL3. \tag{5.16}$$

The calibration constants CL1, CL2 and CL3 = CL1 are calculated as follows. The value of A(fit) from the Gaussian fitting is the value of I for Z = 0 (F(Z) = 0.5). If A = 0.00, then for a perfectly linear IFC ramp with a true 0 intercept the threshold would be at IFC ramp step 1.5. Allowing for the IFC ramp offset step measurement described in Section 5.3.1, the offset corrected IFC count number value is given by

$$A(offset\ corr) = A(fit) + (1.5 - S_o)/4. \tag{5.17}$$

This then gives an offset corrected nominal IFC value for the threshold of

$$LS(nom,\ offset\ corr) = LS(nominal) + (keV/IFC\ cnt\ no) \times (1.5 - S_o)/4 \tag{5.18}$$

where LS(nominal) is given by (5.13). The calibration constants are calculated from the calibrated LS values of Table 4.1 using

$$LS(actual) = LS(nom,\ offset\ corr) \times CL1 = LS(nominal) \times CL1 + CL2 \tag{5.19}$$

Using (5.18) and (5.19) the results for the calibration constants are

$$CL1 = LS(actual)/[LS(nominal) + (keV/IFC\ cnt\ no) \times (1.5 - S_o)/4] \tag{5.20}$$

and

$$CL2 = CL1 \times (kev/IFC\ cnt\ no) \times (1.5-S_o)/4. \tag{5.21}$$

The CL1 factor corrects the nominal IFC ramp slope (keV/IFC cnt no) to the true IFC ramp slope using the actual threshold value LS(actual), while CL2 corrects for the IFC ramp offset $S_o$. The FWHM calibration factor CL3 must be the true IFC ramp slope, and thus CL3 = CL1. The preceding equations can be used to derive expressions for the calibration constants used in Section 5.2.1 as

$$CSLOPE = CL1 \times (keV/IFC\ cnt\ no) \tag{5.22}$$

and

$$COFFSET = CL2. \tag{5.23}$$

The above method is used for all telescope thresholds. For the omni sensors the calibration constants CSLOPE and COFFSET are calculated as shown at the end of Section 5.3.3.

5.3.3 Calibration Constants for Thresholds with No Noise Measurements

Thresholds with no FWHM noise measurements use the fitting method described in Section 5.2.2, with the calibration constants calculated as follows. The nominal thresholds are calculated from the background corrected NTC(I) counts of (5.1) using

$$LS(nominal) = C1 + C2\ (1 - (\Sigma\ NTC(I))/C3) = (C1 + C2) - (C2 \times (\Sigma\ NTC(I))/C3) \tag{5.24}$$

and the measured thresholds are calculated from

$$LS(measured) = LS(nominal) \times CAL(LS) \tag{5.25}$$

The calibration constants C1, C2 and C3 are calculated as follows. The sum over IFC counts in (5.24) starts at IFC count $I_o$ (0-47 range) and includes a total of N counts. The full on IFC count is $C_f$ (= 2080 for the telescopes; =4160 for the OMNI SSD's). This gives

$$C3 = N \times C_f \tag{5.26}$$

$$C2(on) = N \times (keV/IFC\ cnt\ no) \tag{5.27}$$

and

$$C1(on) = [I_o - 0.5 + (1.5 - S_o)/4] \times (keV/IFC\ cnt\ no) \tag{5.28}$$

for a threshold which turns the output count on. For a threshold which turns the output count off (the electron telescope LS4 thresholds) the C2(off) constant is the negative of (5.27) (C2(off) = -C2(on) as given in (5.27)) while

$$C1(off) = [I_o + N - 0.5 + (1.5 - S_o)/4] \times (keV/IFC\ cnt\ no) \tag{5.29}$$

For processing of the MEPED IFC data the form of (5.24) and (5.25) are combined into one equation with two constants given by

$$COFFSET = (C1 + C2) \times CAL(LS) \tag{5.30}$$

and

$$CSLOPE = -C2 \times CAL(LS). \quad (5.31)$$

The calibration constant, CAL(LS), is calculated by using the values of LS(nominal) obtained from (5.22) for the baseline MEPED CPT and the calibrated LS values of Section 5.1 in

$$CAL(LS) = LS(actual)/LS(nominal). \quad (5.32)$$

The OMNI SSD FWHM noise can be measured if it is greater than about 40 keV, since then there will be two net IFC counts with values > 0 and < 4160, the full-on count. The procedure is given in Section 5.2.1, but the values for COFFSET(fit) and CSLOPE(fit) which are used in Section 5.2.1 are calculated from

$$COFFSET(fit) = COFFSET(OMNI) + CSLOPE(OMNI) \times (I_o + N)/N \quad (5.33)$$

and

$$CSLOPE(fit) = -CSLOPE(OMNI)/N \quad (5.34)$$

where COFFSET(OMNI) is the value from (5.30) and CSLOPE(OMNI) is the value from (5.31). Table 5.3 contains the necessary calibration constants for the omni sensor threshold and FWHM noise measurement, and Table 5.4 contains the calibration constants for only threshold measurements. The Table 5.3 omni calibration constants have been derived from the Table 5.4 calibration constants using eqs. (5.33) and (5.34). Thus by using eqs. (5.33) and (5.34) only the Table 5.4 calibration constants need be used for the OMNI SSD threshold calculation routine, whichever method is used. Note that since the OMNI SSD IFC ramp has a nominal step size of 14.40 keV and an IFC count number energy increment of 57.59 keV, the calculated FWHM noise will generally be larger than the true value. Detailed IFC calculations show that for a "true" FWHM noise of 60 keV, the routine of Section 5.2.1 will calculate a "measured" value of about 70 keV. Thus any OMNI SSD FWHM noise measurement which is < 60 keV is a conservative indication that the SSD meets the specification requirement.

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APPENDIX: COMPRESSION COUNTER ALGORITHM

The compression counter algorithm used by the DPU converts input counts in the range of 0 to ≥1998848 to a compressed range of 0 to 255 (8-bit compressed counts). The algorithm for compressing an input count $I_{in}$(24-bits) to the compressed output count $O_c$(8-bits) is as follows.

For $I_{in} \leq 32$, $O_c = I_{in}$(low 8 bits)

Otherwise, shift $I_{in}$(24-bits) left until the first "1" is shifted out. The number of shifts used is S. Define E = 24 - S. Take the next 5 bits of $I_{in}$ (excludes the "1" shifted out) as $M_1$. Calculate M as follows:

If $M_1 \leq 21$, then $M = M_1/2$ (truncated)
Otherwise, $M = (M_1 - 2)/3 + 4$

Calculate the output count as

$$O_c = M + (E - 5) \times 14 + 32$$
$$= M + (19 - S) \times 14 + 32$$

If an overflow occurs ($E \geq 21$) then set $O_c = 255$. This also occurs when $I_{in} \geq 1998848$.

The output count $O_c$(8-bits) can be converted to a minimum input count by the following algorithm.

For $O_c \leq 32$, $I_{in}(\min) = O_c$

Otherwise, calculate (use truncated integer division)

$$C_1 = O_c - 32$$

$$M_1 = C_1 - 14 \times (C_1/14)$$

$$Em = (C_1 - M_1)/14 = C_1/14$$

If $M_1 \leq 10$, then $M_2 = 2 \times M_1$
If $M_1 > 10$, then $M_2 = 3 \times M_1 - 10$

$$I_{in}(\min) = (M_2 + 32) \times 2^{Em}$$

The above gives the minimum input count, $I_{in}(\min)$, for the compressed output count $O_c$. The average input count corresponding to $O_c$ is given by

$$I_{in}(avg) = [I_{in}(\min,O_c) + I_{in}(\min,O_c+1)]/2$$