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Global Precipitation Measurement (GPM) Project

Navigator GPS Front-End Electronics Performance Specification

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

CM FOREWORD

This document is Global Precipitation Measurement (GPM) Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the GPM CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

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1.0 INTRODUCTION

1.1 Mission Background

The overarching Earth science mission objective of GPM is to develop a scientific understanding of the earth system and its response to natural and human-induced changes. This will enable improved prediction of climate, weather, and natural hazards for present and future generations.

1.2 Orbit

The GPM gets its heritage from the Tropical Rainfall Measuring Mission (TRMM) and will provide more accurate, frequent (3-hourly), global, high spatial resolution, and micro-physically detailed measurements of precipitation. The orbital information is specified in table 1-1.

Table 1-1GPM Orbit Summary

Orbit Type	Circular
Altitude	400 km
Inclination	65º
Period	92.56 min
Repeat Cycle	Changes 24 hours of local time in 46-day precession cycle

2.0 DOCUMENT DESCRIPTION

2.1 PURPOSE

The intent of this performance specification is to list the required minimum performance requirements for the Flight Front-End Electronics unit.

2.2 SCOPE

This specification is limited to defining the functional, performance, and environmental requirements for the Flight Front-End Electronics unit. Design implementation is not specified.

The FEE is defined as one combined electronics unit consisting of component stages (Band Pass Filter, DC Block, and Low Noise Amplifier) as illustrated in figure 2-2.

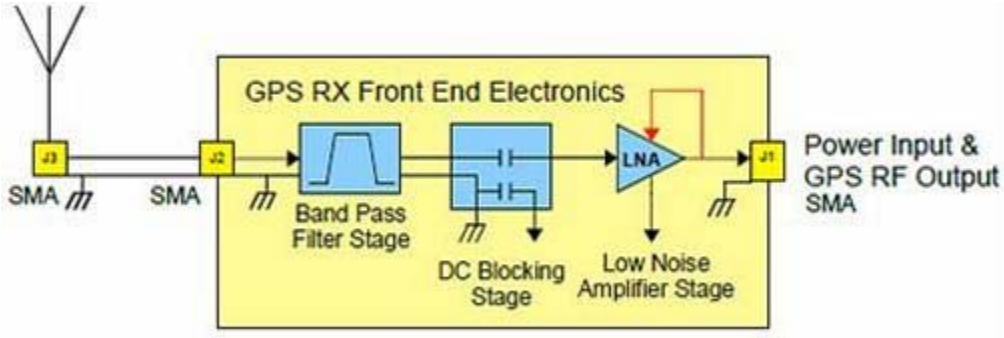


Figure 2-1 GPS Antenna and Front End Electronics Configuration

2.3 DOCUMENTS AND DEFINITIONS

2.3.1 Applicable Documents

The following documents and drawings *shall* apply to the fabrication and to the electrical, mechanical, and environmental requirements of the GPS Front-End Electronics (FEE) to the extent specified herein. In the event of conflict between this specification and any referenced document, this specification will govern, with the exception of the Statement of Work, *GPM-GN&C-SOW-0042*, in which case the SOW takes precedence.

The following is a list of the applicable specifications and publications.

Table 2-1 List of Reference Documents

DOCUMENT NUMBER	TITLE
GPM-GN&C-SOW-0042	GPM Navigator GPS Front-End Electronics Statement of Work
GPM-GN&C-DILS-0142	GPM Navigator GPS Front-End Electronics Deliverable Items List and Schedule
422-40-01-004	GPM Mission Assurance Requirements
422-40-03-001	GPM Core Spacecraft Performance Requirements
GPM-ESE-REQ-006	CORE Observatory Electrical Systems Requirements
JSC-SN-C-005	Contamination Control Requirements for the Space Shuttle Program
MIL-C-5541	Military Specification, Chemical Conversion Coatings on Aluminum and Aluminum Alloys
GSFC-STD-7000	General Environmental Verification Standards (GEVS) for GSFC Flight Programs and Projects
NASA-STD-7001	Payload Vibroacoustic Test Criteria
NASA-HDBK-7005	Dynamic Environmental Criteria

MIL-STD-1246C	Product Cleanliness Levels and Contamination Control

2.3.2 Definitions

Flight Unit: A Flight Unit is hardware that will be used operationally in space. A Protoflight Unit, described below, is considered a Flight Unit.

Protoflight Unit: A Protoflight Unit is Flight hardware of a new design. It is subject to a test program that combines elements of prototype and flight acceptance verification; that is, the application of design qualification test levels and flight acceptance test durations.

3.0 REQUIREMENTS

In this document, a requirement is identified by "*shall*", a good practice by "*should*", permission by "*may*", or "*can*", expectation by "*will*" and descriptive material by "*is*". All of the written requirements in this document must apply at the end of spacecraft (SC) life (EOL), as defined in Section 3.4.20.

3.1 Description

The Front-End Electronics (FEE) shall provide filtering, a DC block, and low-noise amplification for an L1 GPS system as a key part of the GPM attitude control system.

3.2 Component-Specific Functional/Performance Requirements

The FEE *shall* operate and perform within the following limits.

3.2.1 Lifetime

The FEE *shall* operate within specification during the component mission life as defined in Section 3.5.1.

3.2.2 Operating Frequency Range

The front-end electronics (FEE) *shall* meet or exceed all performance requirements in the operating frequency range (OFR) from 1574.32 MHz to 1576.52 MHz, unless otherwise noted.

3.2.3 Characteristic Impedance (Z0)

The FEE *shall* have a characteristic impedance of 50 Ohms in the OFR (Operational Frequency Range).

3.2.4 Gain

The FEE *shall* have a minimum gain of 40 dB in the OFR.

3.2.5 Gain Flatness

The FEE *shall* have a variation in gain of less than 0.2 dB over the OFR.

3.2.6 Dynamic Range

The FEE *shall* have a 1-*dB* (P1dB) compression point > 12 dBm at the output.

3.2.7 Group Delay

The FEE shall have a group delay of ≤ 1.5 µs with a ripple of less than 200 ns peak-to-peak and a linear phase deviation of less that +/- 2º in the OFR.

3.2.8 Noise Figure

The FEE *shall* have an overall noise figure of less than 3 dB in the OFR, with a targeted noise figure of ≤ 1.8 dB.

3.2.9 Return Loss/VSWR

The FEE *shall* have an input and output return loss of < -20 dB (VSWR ≤ 1.2:1) in the OFR, with reference to a 50 Ohm characteristic impedance.

3.2.10 Reverse Isolation

The FEE *shall* have a port-to-port isolation of greater than 25 dB in the OFR.

3.2.11 Out of Band Signal Rejection

The FEE *shall* reject input signals according to the following table:

Table 3-1: FEE Out of Band Rejection

Frequency (MHz)	|S21| (dB)
<1000	-70
1000-1300	-50
1300-1500	-30
1600-2100	-30
>2100	-70

3.2.12 Input RF Power

The FEE *shall* survive without damage or performance degradation at maximum RF input power level of greater than 0 dBm.

3.2.13 RF Connection

The FEE *shall* receive and transmit RF energy via gold-plated non-magnetic SMA-Female connectors at the input and output, respectively. [M39012/59 or equivalent.]

3.3 Physical Characteristics

3.3.1 RESERVED

3.3.2 Mass

The total, as delivered, mass of the FEE *shall not* exceed 1.0 kg each.

3.3.3 Dimensions

The physical dimensions of the FEE *shall not* exceed the following:

Table 3-2 FEE Physical Dimensions

Length (mm)	Width (mm)	Height (mm)
190	100	50

3.3.4 Material

The material of the FEE enclosure *shall* be a MSFC-STD-3029, Table 3 material.

The use of pure tin, cadmium, and zinc plating in flight electrical hardware *shall* be prohibited.

3.3.5 Mounting

The package will be hard-mounted on a mechanical surface of the spacecraft structure. Proper fit/alignment of the FEE to the structure *shall* be inherent in its design, fabrication, and assembly to the structure, through the use of close dimensional control in the location of mounting holes and the use of correct mounting hardware. The mounting interface *shall* be defined in the Interface Control Document (ICD).

3.3.6 Minimum Resonant Frequency

The GPM FEE shall have a minimum resonant frequency greater than 100 Hz when hard mounted at their spacecraft interface.

3.3.7 External Adjustment

The FEE *shall* be designed so that no external physical adjustments are required after start of acceptance or qualification testing.

3.3.8 Finish

All parts *should* be passivated and external mounting surfaces *shall* be conductive as defined in Section 3.4.16.1 (Surface Conductivity). Aluminum parts shall be finished with iridite per MIL-C-5541, Class 3.

3.3.9 Identification and Marking

Each unit *shall* be permanently marked with the part number and a unique sequential serial number in the area designated on the Interface Control Drawing in a manner to be approved by the GSFC Contracting Officer's Technical Representative (COTR).

3.3.10 Fastener Locking

All threaded fasteners used shall employ a locking feature.

3.4 Electrical Characteristics

The electrical interface configuration *shall* meet the overall requirements of this specification.

3.4.1 Power Input Configuration

Power to the FEE will be remotely switched using properly derated lines. The DC power is delivered on the center conductor of the output port SMA connector.

3.4.2 DC Power Supply Architecture

The FEE *shall* receive DC bias via the RF output connector.

3.4.3 DC Ground

The DC circuitry for the FEE *shall* utilize a Negative Ground

3.4.4 DC Bias Voltage

The FEE *shall* operate within all specifications using a nominal supplied DC voltage of 5.0Volts.

3.4.5 DC Bias Tolerance

The FEE *shall* operate within all specifications with a DC voltage tolerance of up to +/- 0.2 V

3.4.6 DC Power Dissipation

The nominal FEE operational DC power dissipation *should* be ≤ 330mW.

3.4.7 Maximum Operational DC Power Dissipation

The maximum FEE operational DC power dissipation *shall never* exceed 350mW.

3.4.8 Survival of Anomalous Voltage

The FEE *shall* be designed to not be damaged by any voltage in the range of 0 to +5.5 V_{DC} for an indefinite time period applied to the power input during anomalistic operations.

3.4.9 Voltage Ripple

The FEE *shall* meet its performance requirements in the presence of a 75 mV peak-to-peak ripple over the frequency range of 20kHz to 10 MHz at the power input.

3.4.10 Operational Transients

Operational transients *shall not* exceed 125% of the maximum current drawn during peak power operation (25% higher than peak operational current) with the maximum duration not to exceed 1-ms and the rate of change of current during the transients not to exceed 5 mA/µs.

3.4.11 Turn-Off Protection

The FEE *shall not* be damaged by the unannounced removal of power.

3.4.12 Internal Fusing/Over-Current Protection

The FEE *shall not* use non-resetting over-current protection (i.e., fuses) internal to the FEE.

3.4.13 Connectors

External box connectors *shall* be space flight quality SMA connectors in accordance with EEE-INST-0002.

Connector savers shall be used during integration and test to minimize wear on connector contacts.

Connector mate/demate logs shall be used to record mates and demates on flight connectors.

All component input/output (I/O) connector interfaces shall be designed to accommodate EMI backshells.

3.4.14 Reserved

3.4.15 Bonding or Mating Surfaces

The primary mating surface for the FEE shall be the metal-to-metal contact between component base plate(or mounting feet) and the GPM structure. Mating (electrically bonding) surfaces should be free from nonconductive finishes and should establish sufficient conductive contact surface area such that the electrical direct current (DC) resistance between the mating surface of the FEE and the mating structure shall not exceed 2.5 mΩ DC. This requirement assumes that isolation from the FEE body to the spacecraft is not required. If proper operation of the device requires isolation from the mating structure then the vendor shall specify the level of isolation required.

The FEE component will meet all ESD requirements especially while ESD sensitive electronics are being carried from one location to another. Proper ESD containers shall be used and proper container removal processes shall also be followed. The person removing the device from a container shall be grounded and an ESD station shall be used when the device is to be worked on.

3.4.16 Surface/Dielectric Charging Protection

The FEE *shall* meet the following requirements in order to survive the LEO charging environment.

3.4.16.1 Surface Conductivity/External Discharge Protection

External surfaces on externally mounted components *shall* be conductive with a resistivity of less than 10^9 ohms/sq. and grounded to the NAVIGATOR structure, so that charge can bleed from that surface faster than the charge can build up on that surface.

The component *shall* be designed to prevent discharges on the external surfaces from permanently damaging components or upsetting data collection.

The component's electrical system *shall* be designed to carry discharge currents and to shield from the electric field from the discharge without any permanent damage to the NAVIGATOR.

3.4.16.2 Internal Charging

The FEE design *shall* prevent internal charging/discharging effects that can damage the internal components or disrupt operations. Internal charging effects shall be controlled by shielding all electronics elements with at least 0.1 inches of Aluminum so that the internal charging rate is benign.

Internal dielectrics materials with bulk resistivity of $>10^{12}$ ohm-cm (such as the connectors, thermal isolators, thermistor mounting, and other materials such as Kapton and Teflon insulators) that do not meet the shielding requirement shall be controlled via one of the methods described in the following paragraphs below.

a) Limit the electron flux to insulators by shielding to 10^{10} electrons/cm^2 in 10 hours.
b) Filter nearby circuitry to withstand a 5,000-Volt, 20-pf, 10-ohm discharge. Detailed analysis of discharge could result in smaller or larger discharge source than above.
c) Coat the exterior surface of the dielectric with a grounded layer with a resistivity of $<10^9$ ohm/sq.
d) Prevent the discharge from reaching a victim circuit by EMI shielding and or grounded conductive barrier that will safely absorb and dissipate the discharge.

If none of above control techniques can be applied, the impacts of the discharge from the dielectric material shall be assessed for an approval.

Ungrounded (floating) conductors *shall not* be allowed in the component. This includes unused wires in harnesses; ground test sensors; unused or unpopulated circuit board traces; ungrounded IC, relay, transistor, or capacitor cases; spare pins in connectors; aluminum or copper tape; ungrounded brackets for harness or connectors; TC105 harness tie-down clips; harness P-clamps; conductive epoxy; thermostat cases; screws; or nut plates.

Leakage impedance of conductive internal parts shall be less than 10,000 ohms. This requirement applies to conductive fittings on dielectric structural parts. Further investigation into these effects and mitigations of internal charging can be found in the NASA document, Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects, NASA-HDBK-4002.

3.4.17 Dielectric Strength

Dielectric material between mutually isolated electrical circuits shall withstand a test voltage of at least 100 V_{AC} for 60 seconds without exceeding a current of 1.0 mA.

3.4.18 Insulation Resistance

Insulation resistance between mutually isolated electrical circuits shall be at least 100 MΩ at a test voltage of at least 50 V_{DC} for 60 seconds minimum.

3.4.19 Electromagnetic Interference and Electromagnetic Compatibility (EMI/EMC)

All FEE units shall be subjected to EMI/EMC testing as described in this section.

The EMI/EMC test methods *shall* be per the requirements of MIL-STD-462 (Notice 1) unless noted in this document.

All tests *shall* be performed in ambient with the FEE in its most sensitive mode for susceptibility testing.

3.4.19.1 Reserved

3.4.19.2 Reserved

3.4.19.3 Radiated Susceptibility (RS03)

No undesirable response, malfunction, or degradation of performance shall be produced in the FEE when subjected to the transmitted frequencies and E-Field levels defined Table 3-3 and Table 3-4, and are illustrated in Figure 3-4.

Note: As a minimum, the GEVS (GSFC-STD-7000) levels apply.

Table 3-3 GPM Radiated Sources and Levels

Frequency Range	Test Level (Source)
14 KHz-2GHz	2 V/m (GEVS)
2GHz-10GHz	5 V/m (GEVS)
2287.5 MHz	5 V/m (TBR) GPM S-B Transmitter
13.6 GHz	1 V/m GPM DPR-Ku radar
35.5 GHz	2 V/m GPM DPR-Ka radar

Table 3-4 Launch Vehicle – H2-A Transmitter Emission Levels

Frequency Range	Test Level
14 KHz – 30 GHz	0.1 V/m
294 MHz – 297 MHz	0.5 V/m
400 MHz – 500 MHz	1.41 V/m
2.200 GHz – 2.290 GHz	1.26 V/m
2.205 GHz – 2.215 GHz	4.47 V/m
5.23 GHz – 5.786 GHz	33.9 V/m
14.855 GHz- 14.865GHz	0.354 V/m

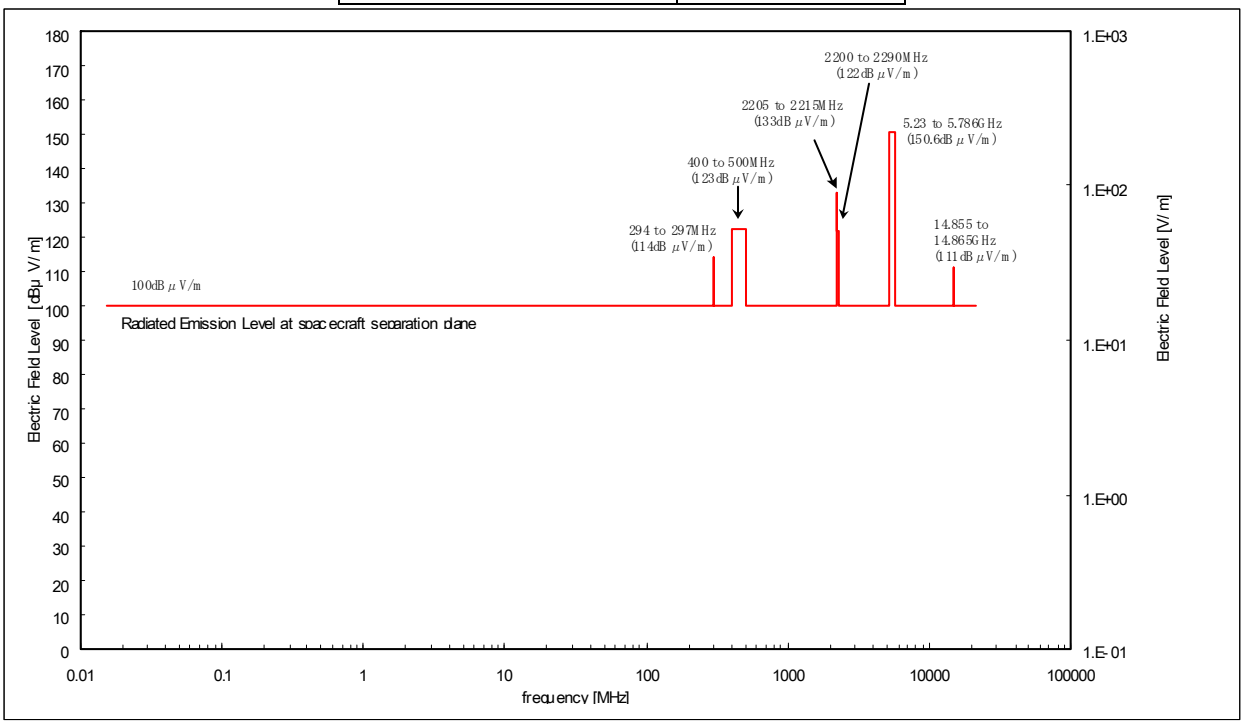


Figure 3-1 Launch Vehicle Transmitter Emission Levels (GPM RS03)

3.4.19.4 Reserved

3.4.20 <u>EEE Parts Program</u>

A EEE parts program *shall* be planned for and implemented for the FEE flight hardware for the purpose of part selection, de-rating, screening, and overall qualifications.

3.5 LIFE REQUIREMENTS

3.5.1 <u>Mission Life</u>

Component orbit life *shall* be 2 years ground testing and 38 months on-orbit.

3.5.2 Shelf Life

The component *shall not* suffer any degradation in performance when stored for five (5) years when packaged using agreed-to procedures.

3.6 ENVIRONMENTAL REQUIREMENTS

The FEE *shall* be designed to withstand (without degradation of specified performance) the operational and non-operational environments specified in the following section.

3.6.1 Static Loads

The static design load is 36g. The FEE shall demonstrate its ability to meet its performance requirements after being subjected to the appropriate net center of gravity (CG) limit load. This design load is intended to cover low-frequency dynamic inputs less than 100Hz, as well as static inputs on components and subsystems typically less than 100 kg. Loads are to be applied independently in each axis. High-frequency dynamic inputs up to 2000Hz shall be addressed using random vibration loads.

3.6.2 Vibroacoustic Loads

The FEE shall be capable of withstanding the random vibration levels shown in Table 3-2 and the sine vibration levels of Table 3-3, individually applied to three mutually orthogonal axes.

Table 3-5 Random Vibration

FREQUENCY (HZ)	Acceptance (Flight) LEVELS (g2/Hz)	Qualification (PROTOFLIGHT and PROTOTYPE) LEVELS (g^2/Hz)
20	0.013	0.026
20-50	+6 dB/oct	+6 dB/oct
50-800	0.080	0.160
800-2000	-6 dB/oct	-6 dB/oct
2000	0.013	0.026
Overall Grms	10.0 Grms	14.1 Grms

The above random environment is appropriate for components weighing 22.7 kilograms (kg) (50 pounds [lbs]) or less. Note for lightweight components, the highest design loads may be from this random vibration environment. The contractor shall perform random vibration analysis along with static loads analysis. Please see NASA-HDBK-7005 and NASA-STD-7001 for more information.

Table 3-6 Sine Vibration Test Levels

	Acceptance		Qualification/Protoflight	
Axis	**Frequency (Hz)**	**Level (g)**	**Frequency (Hz)**	**Level (g)**
Axial	5-100	6.4	5-100	8.0
Lateral	5-100	6.4	5-100	8.0

Sine vibration levels may be notched to not exceed 1.25 times the design limit load taken from the curve in Section 3.6.1. The FEE shall test for this environment up to 70 Hz and analyze from 70 to 100 Hz.

3.6.3 Shock

The maximum expected shock environment at the FEE interface is shown below. The component *shall* be assessed for damage due to shock based on shock sensitivity or proximity to shock sources. If the component is not considered susceptible to the shock environment, shock testing can be deferred to the level of assembly that allows for actuation of the actual shock-producing device.

If the FEE is considered to be susceptible to the shock environment, the contractor may need to perform a shock test to demonstrate that the item can survive the predicted shock environment. The GPM Project will assess the final shock environment based on specific component location.

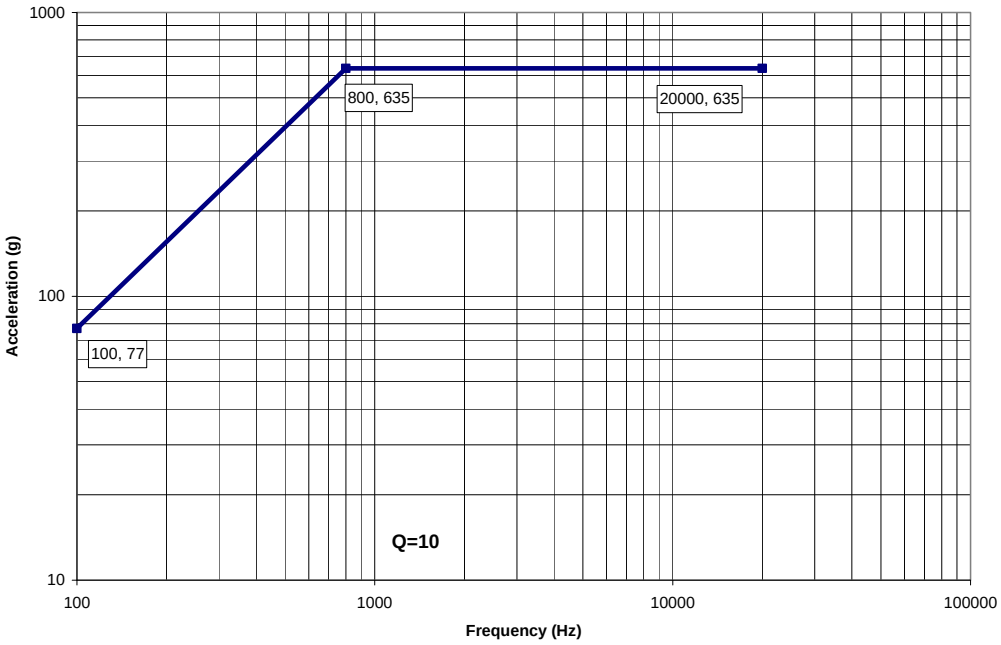


Figure 3-2 Component Shock Specification

3.6.4 Thermal

The FEE shall be capable of operation with interface temperatures defined in Table 3-7. Unless specifically approved by the COTR, the thermal design shall dissipate heat conductively through the mounting interface, which should be assumed to be at the qualification temperatures.

Table 3-7 Temperature Limits at Mounting Interface

Condition	Cold Limit (degrees C)	Hot Limit (degrees C)
Operational Temp (nominal expected orbital range)	-15	+50
Acceptance Temp	-20	+55
Qualification Temp	-25	+60
Survival Temp (each unit must turn on at these extremes but does not have to meet performance requirements)	-30	+75

3.6.5 Vacuum

The FEE shall be capable of meeting all performance requirements of Section 4.3 at ambient as well as when exposed to a vacuum environment of 1×10^{-5} Torr, or less.

3.6.6 Atomic Oxygen

Materials used in the construction of the FEE assembly shall not generate contamination products resulting from the interaction with an atomic oxygen environment. The atomic oxygen (AO) fluence for GPM Core Observatory surfaces in the velocity vector as a monthly basis is depicted in Figure 6-11. The total AO fluence for the mission lifetime of 3 years plus 2 months is 9.76×10^{21} atoms/cm^2 with no design margin. A minimum design margin of 1.5x shall be applied to account for analysis uncertainties. Applying the 1.5x design margin results in the total AO fluence of 1.464×10^{22} atoms/cm^2 for the mission.

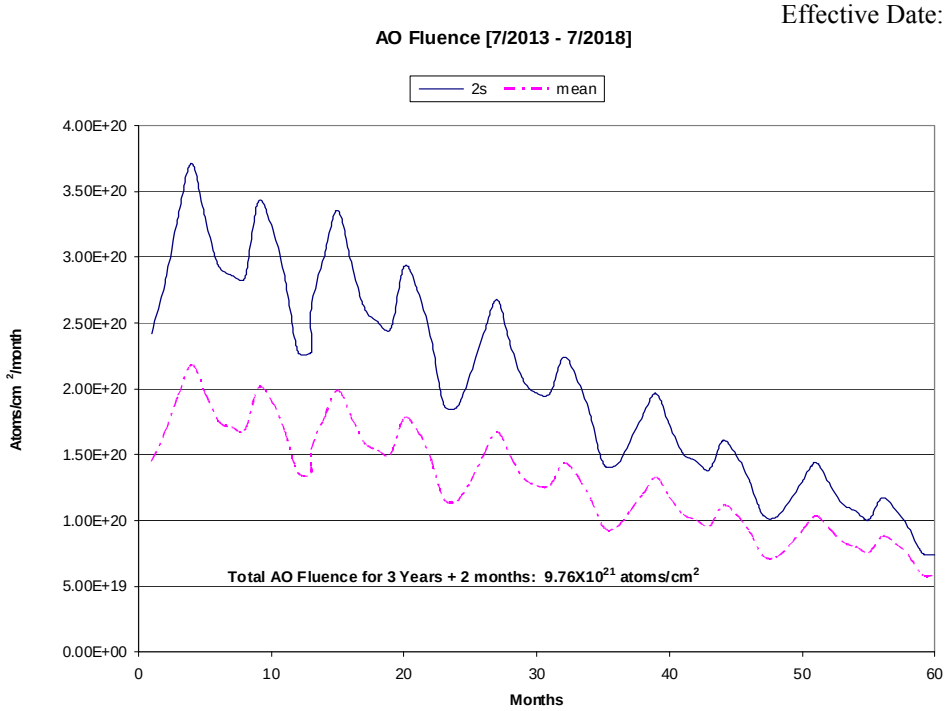


Figure 3-3 Atomic Oxygen Fluence for GPM Mission

3.6.7 Radiation

The FEE design shall protect against the radiation environment as shown in Figure 3-4 through Figure 3-11.

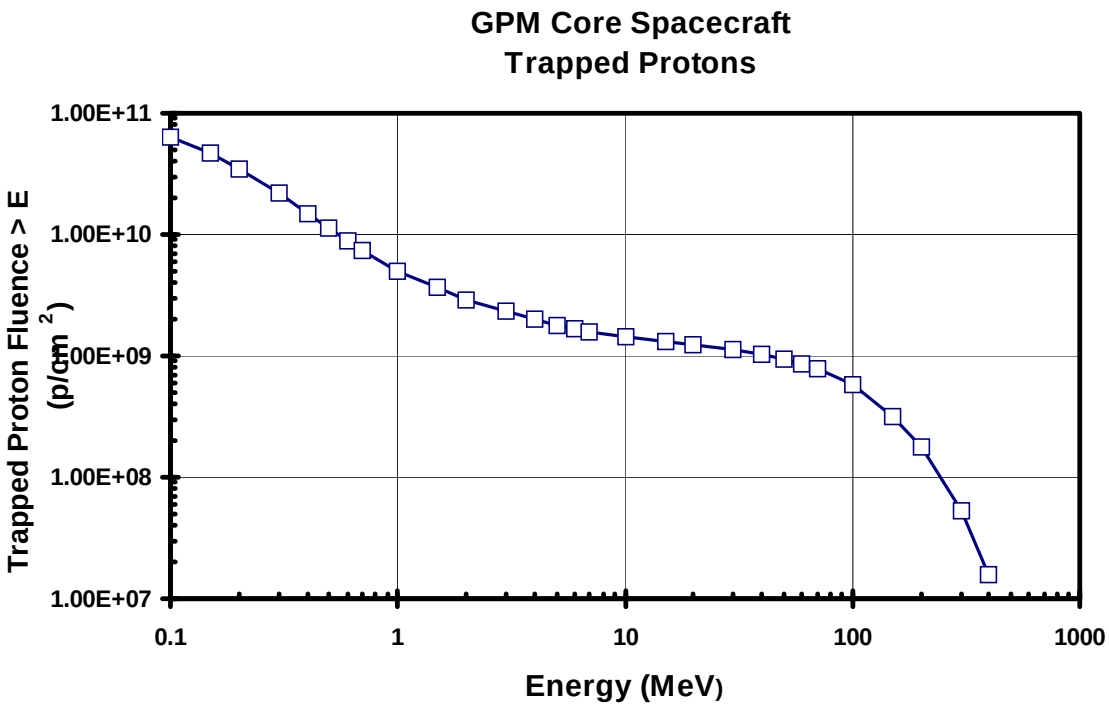


Figure 3-4 Surface Incident Integral Trapped Proton Fluence for 5-year Mission

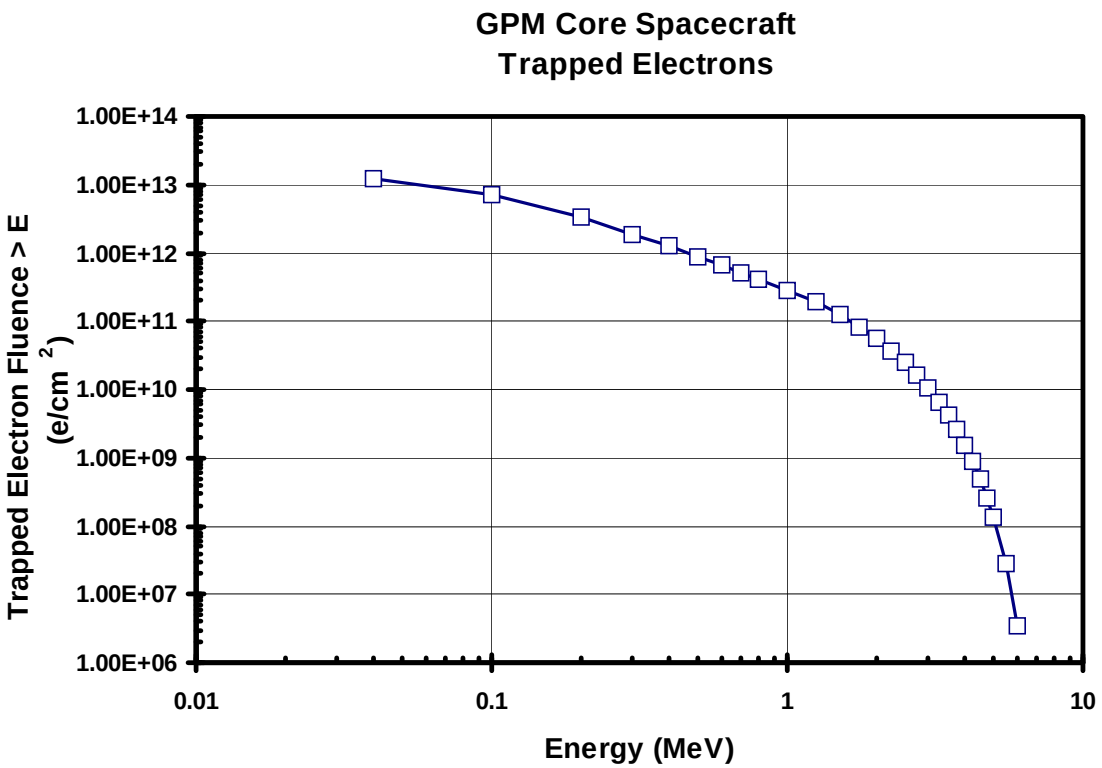


Figure 3-5 Surface Incident Integral Trapped Electron Fluence for 5-year Mission

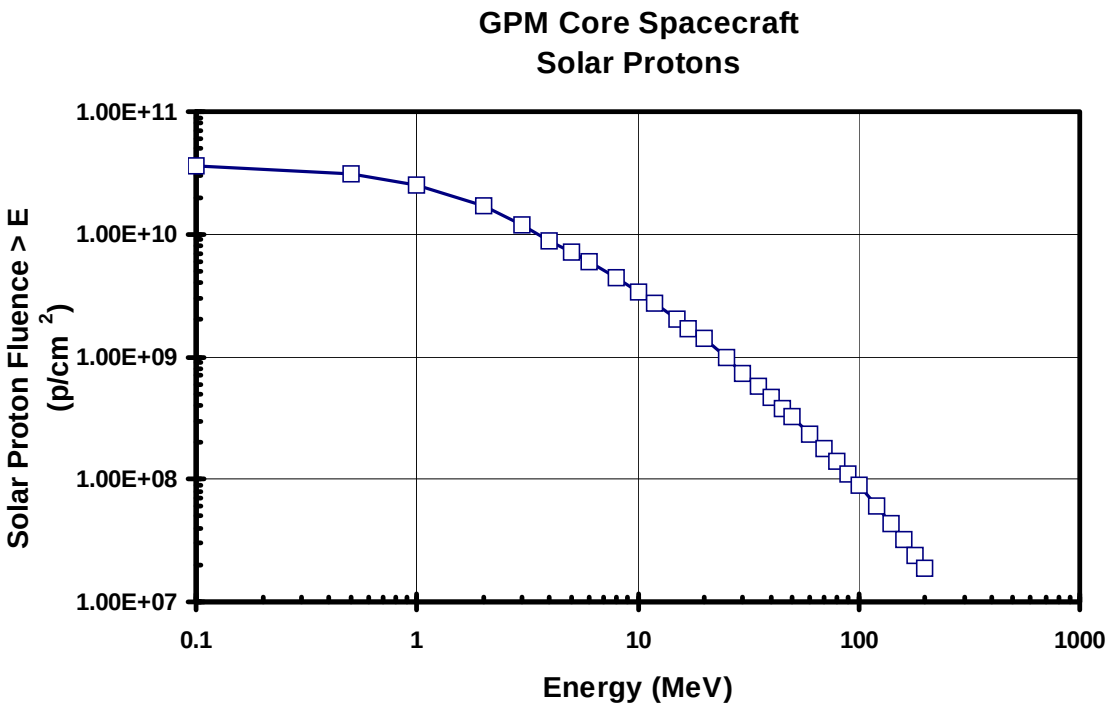


Figure 3-6 Surface Incident Integral Solar Proton Fluences for 5-year GPM Core Mission

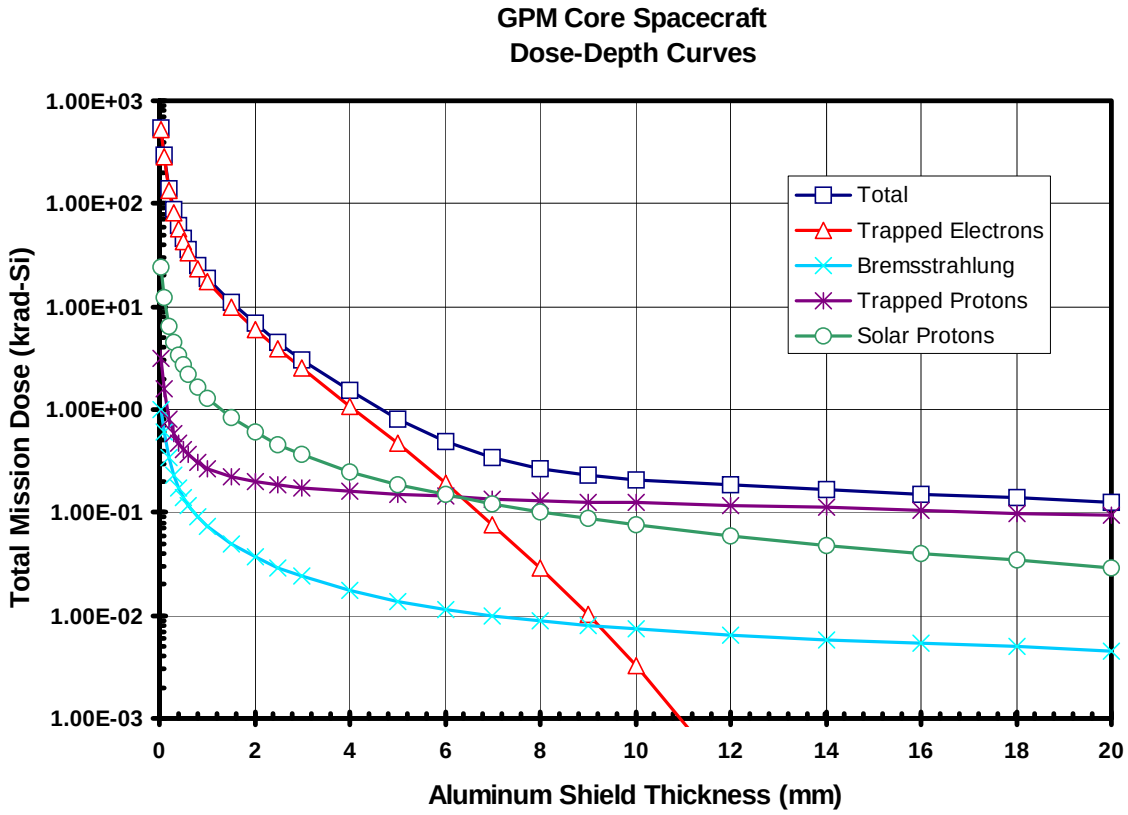


Figure 3-7 Total Ionizing Dose Curves for Dose at the Center of Solid Aluminum Spheres

*Values do not include design margins

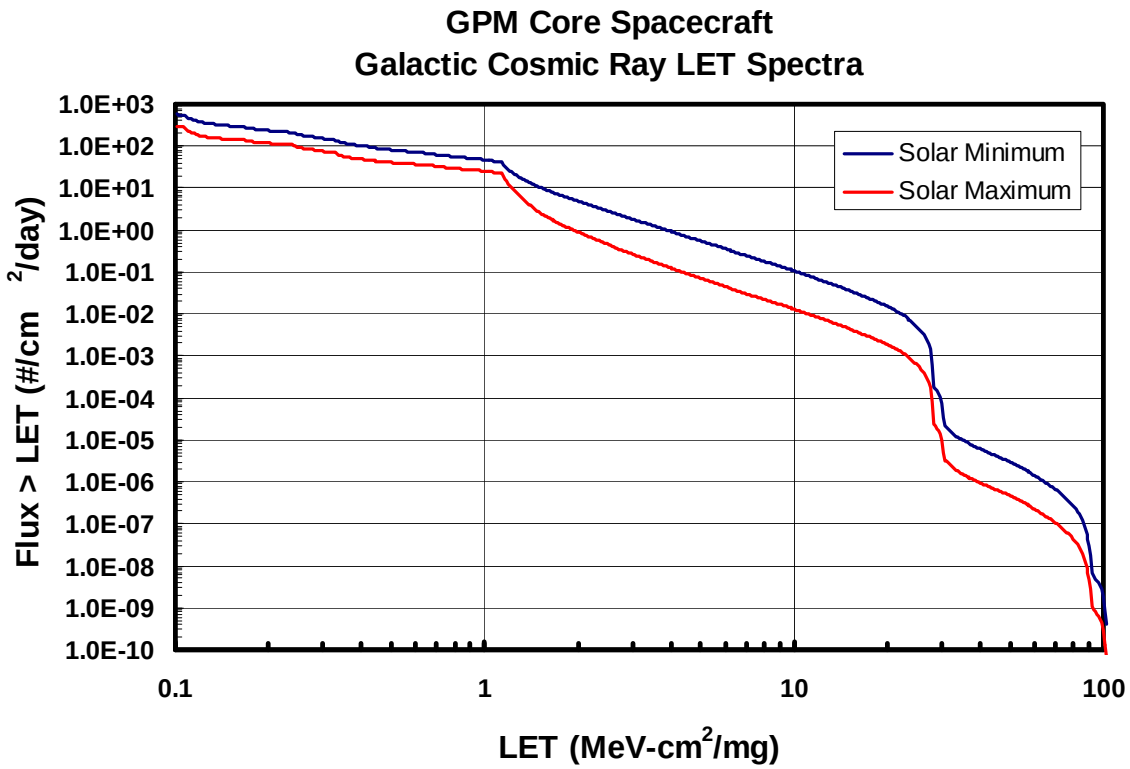


Figure 3-8 Integral LET Spectra for Galactic Cosmic Ray Ions Hydrogen Through Uranium

*Assumes 100 mils of aluminum shielding

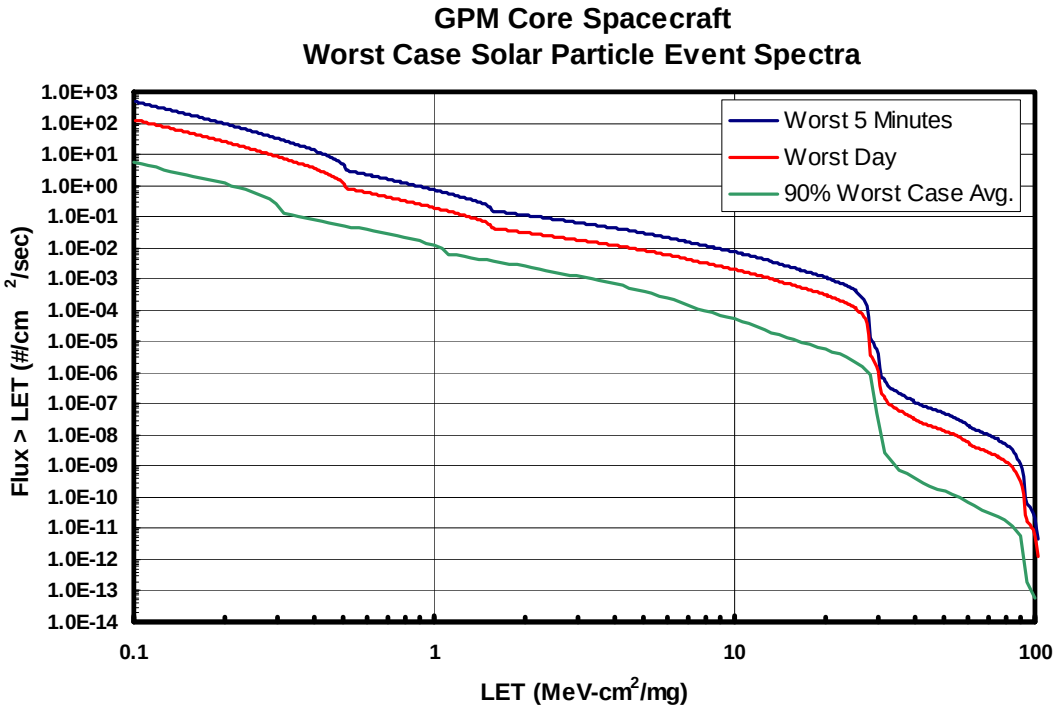


Figure 3-9 Integral LET Spectra for Hydrogen Through Uranium

*For 3 worst case situations:
(1) Average over the peak 5 minutes of the October 1989 event
(2) Average over the worst day during the October 1989 event
(3) 90% worst case average over the solar maximum period

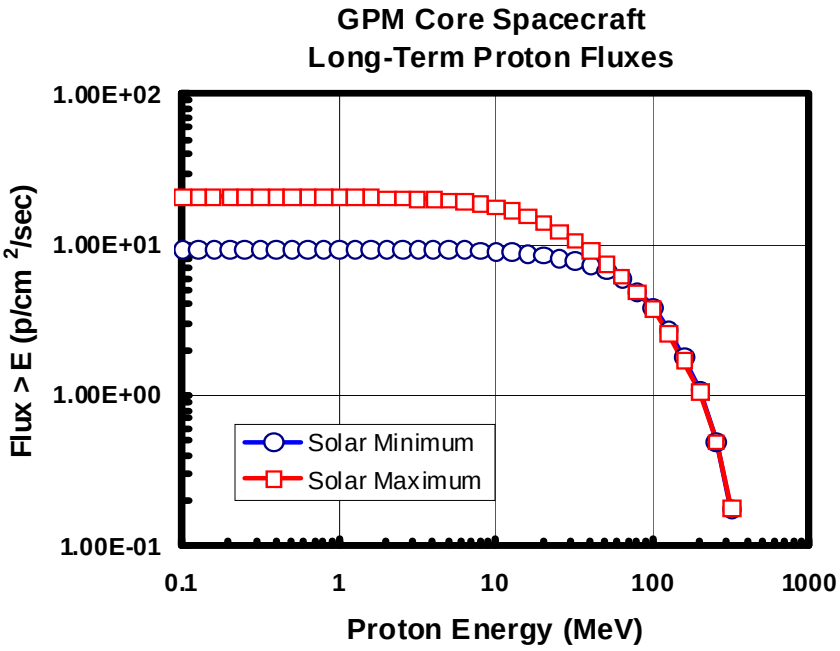


Figure 3-10 Long-Term Integral Proton Fluxes for Single Event Effects Evaluation

Included are the trapped proton and solar proton fluxes behind 100 mils of aluminum shielding.

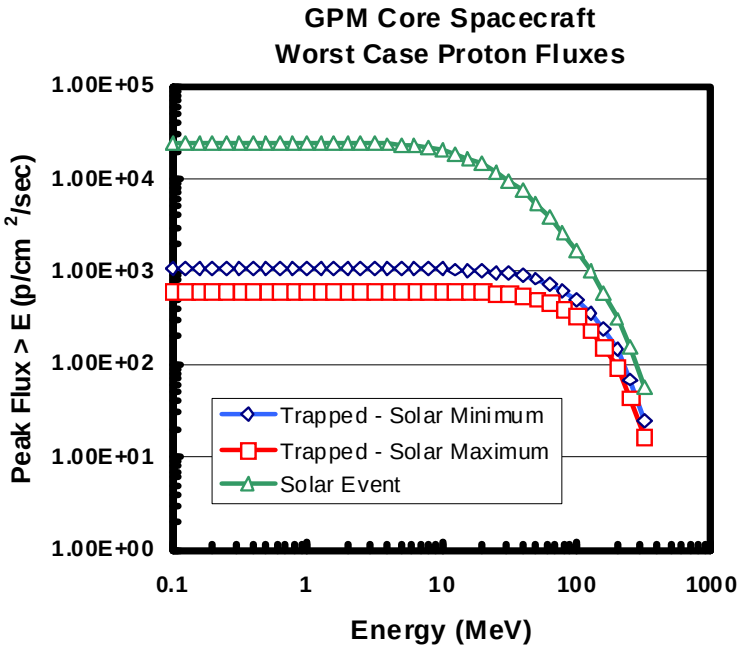


Figure 3-11 Worst Case Integral Proton Fluxes for Single Event Effects Evaluation

Included are the peak trapped proton fluxes averaged over a 1-minute interval during solar maximum and solar minimum. Also shown is the worst-case solar proton flux averaged over a 5-minute interval at the 90% confidence level. Calculations are done for 100 mils of aluminum shielding.

3.6.8 Radiation Survivability

No radiation-induced failure, anomaly or error shall result in the permanent loss of FEE capability for the mission duration and environments specified in Section 3.6.7.

3.6.9 Solar Event Survivability

The FEE shall be capable of surviving the worst-case solar particle event profiles (time, LET spectrum and particle fluxes and □luencies) specified in Figure 3-4 through Figure 3-9.

3.6.10 Single-Point Failure Prevention

No radiation induced single part failure shall cause permanent loss of a function, or prevent access to extant redundant functionality.

3.6.11 Operability

The FEE shall operate through the worst-case flare environment as defined by Figure 3-9 and Figure 3-11.

3.6.12 Radiation Design and Verification Requirements

The following requirements delineate the analysis, test, and documentation requirements for the three major design areas of radiation environment mitigation; Single Event Effects (SEE), Total Ionizing Dose (TID), and Displacement Damage (DD).

3.6.12.1 Single Event Effects (SEE) Design and Verification Requirements

All SEE induced errors, failure modes and possible consequences (especially potentially destructive failures and operational anomalies) shall be documented.

3.6.12.1.1 Destructive Single-Event Effects

The FEE shall not use parts susceptible to destructive single-event effects. Any part with potential susceptibility to destructive SEE shall be characterized according to a test plan consistent with EIA/JESD57 "Test Procedures for the Measurement of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation" prior to its use. Any device that exhibits a high-current, nondestructive error mechanism giving rise to a current exceeding device specifications or a current density within the device greater than 106 A/cm^2 to 10^6 A/cm^2 shall be analyzed subsequent to SEE testing.

3.6.12.1.1.1 Single Event Latch-Up (SEL)

Parts susceptible to single-event latchup shall not be used without thorough characterization of all SEL modes to which the part is susceptible.

3.6.12.1.1.2 Single-Event Burnout (SEB) and Single-Event Gate Rupture (SEGR)

The FEE design team shall verify that all power MOSFETs, discrete bipolar junction transistors, FETs and other devices susceptible to SEB and/or SEGR are operating with all applied voltages in their safe operating regions (as determined by test or approved analysis).

3.6.12.1.1.3 Other Destructive Single-Event Modes

The FEE design team shall identify critical functions of all devices susceptible to single-event induced hard failure modes, as well as SEE modes that may result in latent damage, and supply sufficient information about these functions and their implementation to estimate failure rates. For the purposes of analysis, stuck bits shall be considered as destructive failures. However, annealing characteristics may be considered as mitigating factors in categorizing the resulting errors.

3.6.12.1.1.4 Mitigation of Destructive SEE

Where necessary and appropriate, the FEE design team shall implement and verify measures to mitigate unacceptable effects of SEE induced destructive failures. Any adverse consequences of the mitigation (i.e. diminished speed or performance, interruption of operations by spurious SEL indications, etc.) shall be documented.

3.6.12.1.2 Nondestructive Single-Event Effects

All non-destructive SEE modes shall be classified with respect to their duration, DT (time from incidence to full recovery of operations) and consequences (or criticality). The rates for non-destructive SEE shall not cause the FEE to violate the mission availability requirements.

3.6.12.1.3 Propagation of Single-Event Effects

No error caused by an SEE occurring in the FEE shall cause permanent loss of functionality to another subsystem outside of the FEE.

3.6.12.2 Total Ionizing Dose (TID) Design and Verification Requirements

The FEE design team shall perform an analysis documenting the effects of twice (2x) the expected mission total ionizing dose (TID) requirements. All TID effects shall be mitigated when they compromise mission objectives. The TID for GPM is 10.0 krads (Si) when behind 100 mils of aluminum equivalent shielding

3.6.12.3 Displacement Damage (DD) Design and Verification Requirements

The FEE design team shall demonstrate that the FEE performs its intended function with no system-level degradation after being exposed to a fluence of protons or neutrons causing an equivalent or greater amount of displacement damage than twice (2x) the mission dose predicted for the under worst case application conditions (including dose rate, applied voltages, temperatures, etc.). In the event that mitigation (shielding, etc.) of displacement damage effects is needed to ensure adequate performance, the effects of this mitigation on mission goals shall be analyzed prior to implementation. No mitigation of displacement effects shall be implemented that compromises the achievement of mission goals. If displacement damage mitigation is necessary, these measures and any potential effects on system performance and achievement of mission goals should be addressed in the displacement damage analysis report.

3.6.12.3.1 Use of Non-Ionizing Energy Loss (NIEL) and Equivalent Fluence

For the purposes of testing, Non-Ionizing Energy Loss (NIEL) may be used to determine an equivalent fluence of particles (protons or neutrons) at a single or a few energies to bound the mission fluence only if it is known that damage is proportional to NIEL for all particle energies. If application of NIEL leads to inconsistent equivalent □luencies at different energies, then the fluence producing the highest displacement damage dose shall be used to bound the on-orbit degradation.

3.6.13 <u>Humidity</u>

The FEE *shall* be capable of meeting the requirements herein during and after exposure to 30 to 70% relative humidity for 2 years.

3.6.14 <u>Venting</u>

The FEE *shall* be vented to prevent pressure buildup during the ascent phase of launch. The FEE shall survive external depressurization from one atmosphere (atm) to 10^{-5} Torr in 60 seconds.

GPM components not having a minimum of 0.25 square inches of vent area for each cubic foot volume, shall demonstrate the ability to survive the venting rate. If analysis is required, the venting analysis must indicate a positive structural margin at loads equal to the maximum expected pressure differential during launch, with a Factor of Safety of 2.0 applied to the loads.

3.6.15 Contamination Control

The contractor shall establish cleanliness requirements to minimize performance degradation and delineate the approaches to meet the GPM Project requirements.

3.6.16 Cleanliness

All hardware shall be verified to be visibly clean, upon delivery to GSFC. The FEE components shall be cleaned to 450A per MIL-STD-1246C (Product Cleanliness Levels and Contamination Control).

3.6.17 Magnetic Cleanliness

The magnetic flux density of the FEE shall be no more than 100 nanoTesla (6 milligauss) when measured 1 meter from the item.

4.0 VERIFICATION REQUIREMENTS

The contractor shall conduct a verification program that demonstrates the hardware design is qualified and meets all requirements contained in this document. The contractor shall provide a verification matrix defining the method of verification for each specific requirement of this document. Verification methods include inspection, analysis, test or a combination of these techniques.

4.1 INSPECTION

Verification by inspection includes visual inspection of the physical hardware, a physical measurement of a property of the hardware, or the documentation search demonstrating hardware of an identical design has demonstrated fulfillment of a requirement.

4.1.1 Visual Inspection

Visual inspection of the physical hardware by a customer appointed qualified inspector.

4.1.2 Physical Measurement

Physical measurement of hardware property (i.e. mass, dimensions, etc.) demonstrating the hardware meets specific requirement.

4.1.3 Documentation Search

Verification of requirements based on similarity shall include supporting rationale and documentation and shall be approved by the GSFC COTR.

4.2 ANALYSIS

Verification of performance or function through detailed analysis, using all applicable tools and techniques, is acceptable with GSFC COTR approval.

4.2.1 Factors of Safety

Structural analyses shall be performed to show positive margins of safety based on the factors of safety show in Table 4-1. Margins shall be calculated using limit (acceptance) loads.

Table 4-1 Factors of Safety

Type of Hardware	Design Factors of Safety	
	Yield	Ultimate
Tested Flight Structure – metallic	1.25	1.4
Tested Flight Structure – beryllium	1.4	1.6
Tested Flight Structure – composite(1)	N/A	1.5
Tested Flight Structure – pressurized glass(2)	N/A	3.0
Tested Flight Structure – unpressurized glass	N/A	3.0
Untested Flight Structure – unpressurized glass	N/A	5.0
Untested Flight Structure – metallic only	2.0	2.6

(1) All composite structures must be tested to 1.25 x limit loads
(2) Pressurized glass structures must be tested to 2.0 x limit loads

4.3 Test

Verify by test represents a detailed test of performance and/or functionality throughout a properly configured test setup where all critical data taken during the test period is captured for review.

Performance parameter measurements shall be taken to establish a baseline that can be used to assure that there are no data trends established in successive tests that indicate a constant degradation of performance within specification limits that could result in unacceptable performance in flight.

4.4 Test Factors

The following test factors and durations, shown in Table 4-2, shall be used for prototype, protoflight, and flight hardware. The hardware definitions are included in the General Environmental Verification Standards (GEVS) for Flight Programs and Projects (GSFC-STD-7000).

Table 4-2 Test Factors and Durations

Test	Prototype	Protoflight	Acceptance
Structural Loads			
Level	1.25 X Limit Load	1.25 X Limit Load	Limit Load(2)
Duration			
Centrifuge	1 Minute	30 Seconds	30 Seconds
Sine Burst(1)	5 Cycles Full Level	5 Cycles Full Level	5 Cycles Full Level
Acoustic			
Level	Limit Level +3dB	Limit Level +3dB	Limit Level
Duration	2 Minutes	1 Minute	1 Minute
Random Vibration			
Level	Limit Level +3dB	Limit Level +3dB	Limit Level
Duration	2 Minutes/Axis	1 Minute/Axis	1 Minute/Axis
Sine Vibration			
Level	1.25 X Limit Level	1.25 X Limit Level	Limit Level
Sweep Rate(3)	2 Octaves/Minute/Axis	4 Octaves/Minute/Axis	4 Octaves/Minute/Axis
Shock			
Actual Device	2 Actuations	2 Actuations	1 Actuations
Simulated	1.4 X Limit level 2 X Each Axis	1.4 X Limit Level 1 X Each Axis	Limit Level 1 X Each Axis

(1) Sine burst testing shall be done at a frequency sufficiently below primary resonance as to ensure rigid body motion.
(2) All composite structures must be tested to 1.25 x limit loads.
(3) Unless otherwise specified these sine sweep rates shall apply.

4.5 TEST RESTRICTIONS

4.5.1 Failure During Tests

The test shall be stopped if equipment fails during testing in cases where this failure will result in damage to the equipment. Otherwise, the test shall be completed to obtain as much information as possible. No replacement, adjustment, maintenance, or repairs are authorized during testing. This requirement does not prevent the replacement or adjustment of equipment that has exceeded its design operating life during tests, provided that after such replacement, the equipment is tested as are necessary to assure its proper operation. A complete record of any exceptions taken to this requirement shall be included in the test report.

4.5.2 Modification of Hardware

Once the formal acceptance test has started, cleaning, adjustment, or modification of test hardware shall not be permitted.

4.5.3 Re-Test Requirements

If any event, including test failure, requires that a component be disassembled and reassembled, then all tests performed prior to the event must be considered for repeat. If the unit has multiple copies of the same build, then all units must be examined to determine if the problem is common. If all copies require disassembly for repair, then each must receive the same test sequence.

4.6 REQUIRED VERIFICATION METHODS

The following measurements, tests, environments, and inspections are required for each FEE to provide assurance that the FEE meets specified performance, functional, environmental, and design requirements. Each test or demonstration is described below.

a. Weight and Envelope Measurements
b. Initial Performance and Functional Tests
c. Shock Test (if necessary)
d. Loads Test (Prototype/Protoflight only)
e. Sine Vibration
f. Random Vibration
g. Thermal Vacuum
h. Final Performance and Functional Tests

4.6.1 Weight and Envelope Measurement

Measurement of the weight and envelope of the FEE shall be made to show compliance with specified requirements and provide accurate data for the mass properties control program.

4.6.2 Performance Tests

The FEE shall be tested to demonstrate compliance with performance requirements, including alignment if necessary. Performance Tests are detailed functional tests conducted under conditions of varying internal and external parameters with emphasis on all possible modes of operation for the component. A Performance Test shall be conducted at the beginning and end

of each acceptance test. Functional Tests are abbreviated Performance Tests done periodically during or following the component environmental testing in order to show that changes or degradation to the component have not resulted from environmental exposure, handling, transporting, or faulty installation.

4.6.3 Load Tests

Structural design loads per the levels in Table 3-1 shall be applied to prototype or protoflight hardware. There is no requirement to strength test flight hardware that has already been strength tested through a prototype or protoflight program (i.e., there is no "acceptance level" strength test requirement for flight hardware).

Structural Loads testing can be verified by performing either a fixed frequency Sine Burst test, or a series of static loads pull tests.

No permanent deformation may occur as a result of the loads test, and all applicable alignment requirements must be met following the test. Components that require alignment will have an alignment check following loads testing. A performance test will be conducted to verify that no damage occurred due to the loads test.

4.6.3.1 Sine Burst

A simple Sine Burst test following the random vibration test in each axis is a convenient method to conduct a structural loads test. This test applies a ramped sine input at a sufficiently low frequency such that the test item moves as a rigid body. An analysis is required to show that a base drive Sine Burst test will not cause over-test or under-test in some areas of the structure.

Test Duration: 5 cycles of full level amplitude.

4.6.3.2 Static Pull

Static pull tests are another method to perform loads testing and can be applied at flight interfaces in a static test facility. The loads can be applied either as component loads applied simultaneously, or the single resultant vector load can be applied to the test point. Strain gages are generally positioned around the test point to verify deflection predictions from the analytical model.

Test Duration: 30 seconds

4.6.4 Random Vibration

The FEE shall be subjected to a random vibration test along each axis to the appropriate levels shown in Section 3.6.2. The test item shall be mounted to the test fixture as it would be mounted to the spacecraft. A functional test shall be performed before the start of testing and after a test in each axis.

Prior to the test, a survey of the test fixture/exciter combination will be performed to evaluate the fixture dynamics and the proposed choice of control accelerometers.

The Test Duration shall be 1 minute per axis for Flight Hardware and 2 minutes per axis for Prototype Hardware.

A 0.25 g Signature Sine sweep between 5 and 2000 Hz at a sweep rate of 4 oct/min will be conducted on each component before and after vibration testing in each axis. This test is a tool to verify no change in structural integrity from testing and to verify the primary resonant frequency meets requirements of Section 3.3.3.

4.6.5 Sine Vibration

The FEE shall be subjected to swept sine vibration testing to the appropriate levels in Section 3.6.2. The sweep rate shall be 4 octaves/minute for Flight Hardware and 2 octaves/minute for Prototype Tests.

A 0.25 g Signature Sine sweep between 5 and 2000 Hz at a sweep rate of 4 oct/min will be conducted on each component before and after vibration testing in each axis. This test is a tool to verify no change in structural integrity from testing and to verify the primary resonant frequency meets requirements of Section 3.3.3.

4.6.6 Thermal Vacuum Test

Each component shall be cycled a total of eight (8) times at the component level. During these tests, chamber pressure shall be less than 1.33 X 10-3 Pa. (1 X 10-5 torr).

4.6.6.1 Temperature Transitions

Transitions from cold to hot conditions increase contamination hazards because material that has accreted on the chamber walls may evaporate and deposit on the relatively cool test item. Transitions will be conducted at rates sufficiently slow to prevent that from occurring. Testing *shall* start with a hot soak and end with a hot soak to minimize this risk.

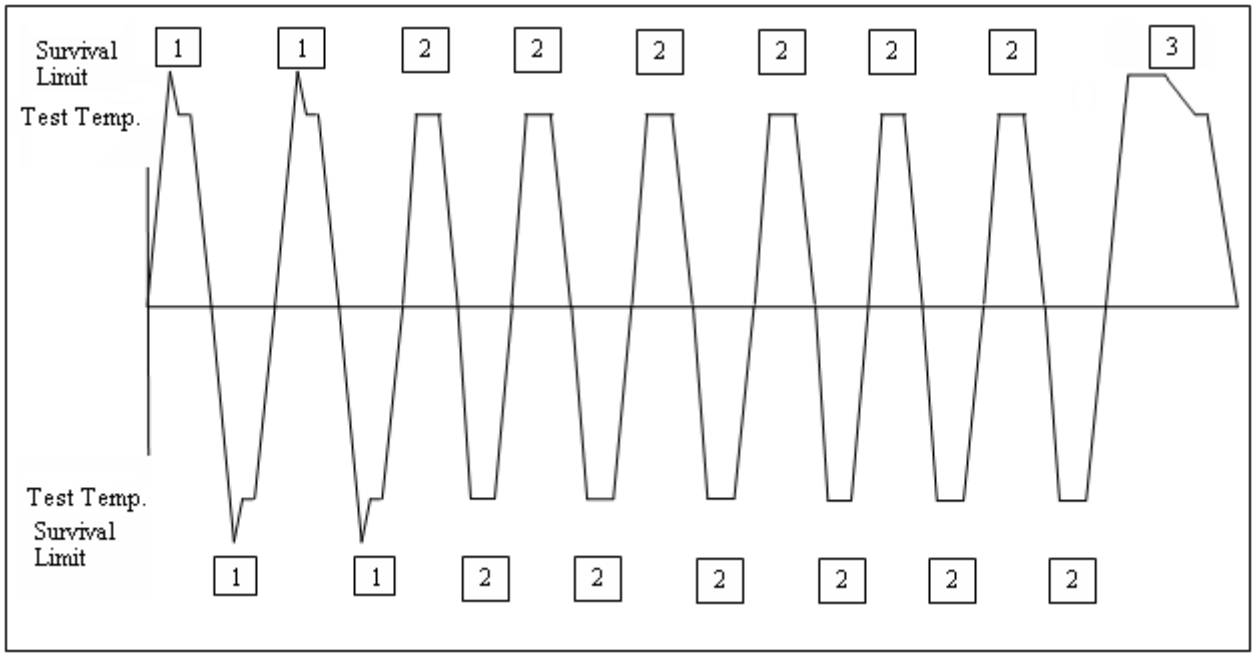
4.6.6.2 Hot/Cold Turn-On Demonstration

Components or subsystems *shall* be turned on twice after exposure to hot and cold survival temperatures.

4.6.6.3 Thermal Vacuum Test Profile

Number of complete cycles:

Prototype Unit:	8 full cycles, start and end on hot cycle. Use Qualification Temperatures per Table 3-7 as the “test temperature” in Figure 4-1. Soak at test temperature 4 hours.
Protoflight Unit:	8 full cycles, start and end on hot cycle. Use Qualification Temperatures per Table 3-7 as the “test temperature” in Figure 4-1. Soak at test temperature 4 hours.
Flight / Copy / Spare Unit:	8 full cycles, start and end on hot cycle. Use Acceptance Temperatures per Table 3-7 as the “test temperature” in Figure 4-1. Soak at test temperature 4 hours.



1 =	Achieve survival temp, stabilize 1 hour, return to test temperature, turn on, soak at test temperature 4 hours, run performance test.
2 =	Soak at test temperature 4 hours, run performance test
3 =	Bakeout phase

Figure 4-1. Thermal Vacuum Profile 8 Hot/Cold Cycles with Bakeout

4.6.6.4 Bakeout

The FEE shall be baked-out prior to delivery to GSFC (see Figure 4-1). The bake-out performance shall be measured using a temperature-controlled Quartz Crystal Microbalance (TQCM) at chamber pressures below 1.0E-5 torr. The bake-out shall be performed at the hardware's maximum hardware survival temperature, unpowered, for 48 hours followed by a 12 hour period, powered, at the maximum operational temperature as defined in Table 3-7. The TQCM shall be maintained at -20C throughout the test to measure total outgassing of volatile outgassed condensables without the influence of water vapor. The TQCM must have a representative view of the hardware, preferably a vent.

The following test data shall be collected and delivered to GSFC: Chamber configuration (ie. Chamber size, use of shrouds, TQCM location, cold finger/scavenger plate locations (if used), and general test setup), TQCM readings (taken as a minimum every 0.5 hours), hardware temperature, chamber/shroud temperature, TQCM temperature, and pressure

If the Contractor's vacuum chamber uses a shroud to elevate and sustain an item's temperature for bake-out, background TQCM measurements must be conducted before the bake-out with chamber in bake-out configuration in order to determine flight hardware contribution. Provision must be made to measure effectiveness of pump system. The value of a chamber's exit conductance is generally much lower than the rating of its pump alone. This is necessary to relate TQCM deposition rates to source outgassing rates

If the Contractor uses a bake-out box, the chamber should feature a shroud held at temperatures below the TQCM reading so as not to interfere with it, otherwise the bake-out box should feature a coldplate near the bake-out box vent to collect contaminants that would otherwise interfere with the TQCM readings. In such cases, knowledge of the chamber pump effectiveness is not necessary.

4.6.6.5 Outgassing Certification Requirements

Each flight item shall meet an outgassing certification requirement of no greater than 1.3E-10 g/cm2/sec to be verified during thermal vacuum bakeout or thermal vacuum testing. The outgassing certification requirement shall be measured with a TQCM. The results of the test shall be submitted to the GPM Project for approval. The data set shall be recorded at least once every 30 minutes, for a minimum of 5 hours, during testing and shall contain, as a minimum, QCM data, temperature of hardware, QCM temperature, and chamber pressure. In addition, the chamber configuration and cold finger data shall be delivered with the results.

APPENDIX A. ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	DEFINITION
AMS	Aerospace Material Specification
ANSI	American National Standards Institute
AO	Atomic Oxygen
atm	atmosphere
CLA	Coupled-Loads Analysis
C	Centigrade
CCB	Configuration Control Board
CCR	Configuration Change Request
CG	Center of Gravity
CM	Configuration Management
cm^2	Centimeters squared
CMO	Configuration Management Office
COTR	Contracting Officer Technical Representative
DA	Displacement Amplitude
dB	Decibel
dB/oct.	Decibel per octave
DC	Direct Current
ESD	Electrostatic Discharge
FEE	Front-End Electronics
FOV	Field of View
g	grams
GEVS	General Environmental Verification Standards
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HDBK	Handbook
Hz	Hertz
kg	kilogram
km	kilometer
Lbs	pounds
mm	millimeter
MIL	Military
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
OFR	Operational Frequency Range
Ohms/sq.	Ohms per square
SMA	SubMiniature, version A
SOW	Statement of Work
STD	Standard
TID	Total Ionizing Dose

TIM	Technical Interchange Meeting
TQCM	Thermoelectric Quartz Crystal Microbalance
VDA	Vapor Deposit Aluminum
W/m^2	Watts per meter squared