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PACE and WFIRST Spacecraft Traveling Wave Tube Amplifier (TWTA) Specification



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and
Space Administration

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PACE and WFIRST Spacecraft Traveling Wave Tube Amplifier (TWTA) Specification

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Preface

This document is under Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) Mission configuration control. Changes to this document require prior approval of the PACE Configuration Control Board (CCB) Chairperson or designee. Proposed changes **shall** be submitted to the PACE Configuration Management 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 GENERAL INFORMATION

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission is a strategic climate continuity mission that will extend the high quality ocean ecological, ocean biogeochemical, cloud, and aerosol particle data records begun by NASA in the 1990s. The mission will be capable of collecting radiometric and polarimetric measurements of the ocean and atmosphere, from which these biological, biogeochemical, and physical properties will be determined. PACE data products will not only add to existing critical climate and Earth system records, but also answer new and emerging advanced science questions related to Earth's changing climate.

WFIRST, the Wide Field InfraRed Survey Telescope, is a NASA observatory designed to settle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics. The telescope has a primary mirror that is 2.4 meters in diameter (7.9 feet), and is the same size as the Hubble Space Telescope's primary mirror. WFIRST will have two instruments, the Wide Field Instrument, and the Coronagraph Instrument.

WFIRST is designed for a 5 year mission, and will launch on a EELV. The targeted launch date is 2026. After transfer trajectory, the observatory will operate ~ 1.6 e6 km from the Earth, in an orbit around the L2 point of the Sun-Earth System.

1.2 SCOPE

This specification describes the electrical, mechanical, environmental, and verification testing requirements for a space-qualified Traveling Wave Tube Amplifier (TWTA), from this point on referred to as the TWTA, for the NASA Goddard Space Flight Center (GSFC) PACE and WFIRST Missions. Although this specification includes requirements for both the PACE and WFIRST missions, only PACE will be referenced from this point on for simplicity.

2.0 APPLICABLE DOCUMENTS

The following documents and drawings in effect on the day this specification was signed **shall** apply to the fabrication and to the electrical, mechanical, and environmental requirements of the TWTA 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 PACE TWTA Statement of Work (PACE-COMM-SOW-0021), in which case the Statement of Work takes precedence.

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

Table 2-1 Applicable Documents

Document Number	Title
PACE-COMM-SOW-0021	PACE TWTA Statement of Work
PACE-COMM-LIST-0008	PACE TWTA Deliverable Items List and Schedule (DILS)
NASA-STD-8719.24	NASA Expendable Launch Vehicle Payload Safety Requirements
NASA-HDBK-7005	Dynamic Environment Criteria
NASA-STD-7001	Payload Vibroacoustic Test Criteria
IEST-STD-CC-1246E	Product Cleanliness Levels And Contamination Control Program
ASTM E-595-07	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
MIL-DTL-5541	Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-A-8625F	Anodic Coatings for Aluminum and Aluminum Alloys
EEE-INST-002	Instructions for EEE Parts Selection, Screening, Qualification, and Derating
MIL-STD-461F	Military Standard, Electromagnetic Emission And Susceptibility Requirements For The Control Of Electromagnetic Interference (EMI)
GSFC-STD-7000A	General Environmental Verification Standard (GEVS)
NASA-STD-5019A	Fracture Control Requirements for Spaceflight Hardware
NASA-STD-5020	Requirements for Threaded Fastening Systems in Spaceflight Hardware
FAA AC 20-71	Federal Aviation Administration Advisory Circular (AC) 20-71, "Dual Locking Devices on Fasteners".
NASM 33540	Safety Wiring, Safety Cabling, Cotter Pinning, General Practices for
541-WI-5330.1.41	Fastener Locking Using Arathane 5753

Document Number	Title
MSFC-STD-3029A	Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments
MIL-STD-462, Notice 2	Electromagnetic Interference Characteristics, Measurement of, 1 May 1970
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft

3.0 CONTRACT DESCRIPTION

3.1 TRAVELING WAVE TUBE AMPLIFIER DESCRIPTION

The TWTA will function as the transmitting element in a Spacecraft communications system and will include a Traveling Wave Tube (TWT), Electronic Power Conditioner (EPC) and interconnecting umbilical wiring harness. A block diagram of the PACE Ka-Band TWTA is shown in Figure 3-1.

The EPC will contain a power supply that produces all required voltages from an unregulated source for operation of the TWTA including monitoring and control circuitry. The TWTA will amplify an input modulated signal to 70W minimum at the output. The TWTA will incorporate a timer, called the High Voltage Timer, to delay the application of high voltage to the TWT until a safe time interval has elapsed following the turn ON of filament heater power.

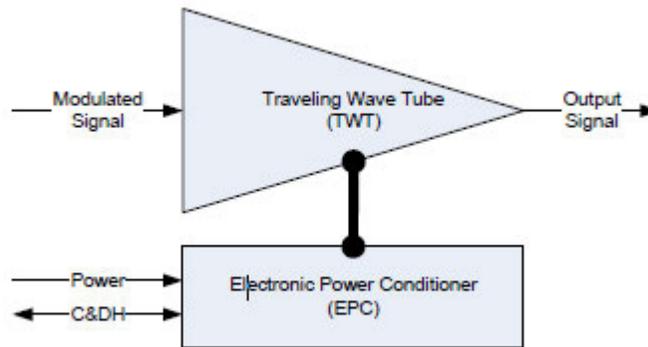


Figure 3-1: Ka-band TWTA Block Diagram

4.0 FUNCTIONAL/PERFORMANCE REQUIREMENTS

The TWTA **shall** be designed to withstand the operational and non-operational environments specified in the following section without degradation to mission goals and performance requirements.

All performance requirement in this document **shall** apply for the TWTA operating with an RF output power of 70W, minimum. Unless otherwise indicated, all specifications apply over the operating bandwidth.

4.1 TWTA FLIGHT UNIT FUNCTIONAL/PERFORMANCE REQUIREMENTS

4.1.1 Center Frequency

The nominal center frequency **shall** be between 26 and 27 GHz, to be specified at the time of contract.

4.1.2 Operating Band

The operating bandwidth **shall** be at least ± 700 MHz from the center frequency.

4.1.3 Saturated Output Power

The nominal and End-of-Life saturated output power **shall** be at least 70 Watts.

4.1.4 Stability

The saturation point shall not change by ± 0.25 dB across all temperatures, bus voltages, life, and frequency.

A Pout vs Pin curve from Psat to (Psat-10 dB) **shall** be provided in 1 dB increments.

The TWTA shall be unconditionally stable under the following conditions:

At all input drive levels from 0 to 9 dB above the saturation drive level, no permanent damage or performance degradation (after the input drive level is restored to nominal value) shall result from prolonged periods (30 minutes or greater) of overdrive.

When simultaneously terminated with input source and output load impedance having a maximum VSWR of 2.0:1 over the unity gain bandwidth, there shall be no damage or oscillation. The vendor shall provide the unity gain bandwidth.

This requirement shall be met without the use of isolators.

The TWTA shall meet the stability requirements, stated above, over the electrical and thermal operating ranges.

4.1.5 RF Interface

4.1.5.1 RF Input Interface

The type of RF input interface, coaxial or waveguide, **shall** be recommended by the supplier and approved by the Contracting Officer's Representative (COR).

If the recommended interface is waveguide, WR-34 **shall** be used.

If the recommended input interface is coaxial, the flange configuration **shall** be recommended by the supplier and approved by the COR.

The RF input signal **shall** be designated RF-IN.

4.1.5.2 RF Input Return Loss

The input return loss cold (non-operating) **shall** be ≥ 13 dB.

The input return loss hot (operating) **shall** be ≥ 9.5 dB.

4.1.5.3 RF Output Interface

The RF output interface **shall** be a WR-34 wave-guide interface.

The flange configuration **shall** be recommended by the supplier and approved by the COR.

The RF output signal **shall** be designated RF-OUT.

4.1.5.4 RF Output Return Loss

The output return loss cold (non-operating) **shall** be ≥ 14 dB.

The output return loss hot (operating) **shall** be ≥ 6 dB.

4.1.5.5 Load Return Loss

The operating load return loss will be ≥ 15 dB.

4.1.6 Input RF Power

Saturated input power is defined as the minimum input RF power level that produces a maximum TWTA RF output. The saturated power input signal level **shall** be between 0 and -10 dBm.

The saturated input power flatness over acceptance temperature levels **shall** be ≤ 2.5 dBpp.

The saturated input power flatness over any 15° C Range **shall** be ≤ 1.0 dBpp.

The saturated input power flatness versus frequency **shall** be ≤ 1.0 dBpp.

With a saturation level signal applied at the input, the specified saturation output power level **shall** be obtainable within 300 seconds after the filament power is turned ON, i.e. the High Voltage Timer has timed out and TWT high voltage has been enabled.

4.1.7 Over Drive Capability

The overdrive capability **shall** be \geq saturation point +6 dB.

4.1.8 Noise Figure

The Noise figure **shall** be ≤ 40 dB.

4.1.9 Carrier to Intermodulation Ratio

The carrier to intermodulation ratio **shall** be:

Drive*:

-3 dB ≥ 9 dB

-10 dB ≥ 15 dB

-17 dB ≥ 25 dB

*Drive relative to saturation.

4.1.10 Signal Phase Shift

The output signal phase shift **shall** be:

Drive*:

0 dB $\leq 47^\circ$

-3 dB $\leq 38^\circ$

-
- 6 dB \leq 30°
 - 10 dB \leq 25°
 - 15 dB \leq 5°
 - 20 dB \leq 0°

*Drive relative to saturation.

4.1.11 AM to PM Conversion

The AM to PM conversion **shall** be:

Drive*:

0 dB \leq 4.5° / dB

-3 dB \leq 3.5° / dB

-10 dB \leq 2.5° / dB

*Drive relative to saturation.

An AM to PM curve from Psat to (Psat-10 dB) **shall** be provided in 1 dB increments

4.1.12 Signal Gain

The gain compression at saturation **shall** be \leq 8.5 dB.

The gain flatness at saturation over the operating band **shall** be \leq 0.4 dBpp.

The gain slope at saturation **shall** be \leq 0.025 dB / MHz.

The group delay within the operating band **shall** be \leq 2 ns.

The group delay slope **shall** be \leq 0.03 ns / MHz.

4.1.13 Spurious

The in-band spurious over any 4 kHz band **shall** be at least -70 dBc.

The in-band spurious over any 1 MHz band **shall** be at least -60 dBc.

The out-of-band spurious **shall** be at least -70 dBc.

4.1.14 Harmonics

The second harmonic level at saturated drive, **shall** be \leq -25 dBc.

The third harmonic level at saturated drive **shall** be \leq -30 dBc.

4.1.15 Protection Circuits

4.1.15.1 Undervoltage Protection

If the spacecraft DC bus voltage drops below the unit's undervoltage trip-off level, the unit **shall** autonomously power itself OFF and remain in this state until restarted, by means of an ON command, sent by the ground station.

4.1.15.2 Overpower Protection and Auto Restart

If the unit's input power/current draw rise 130 to 200% of nominal power/current draw, the unit **shall** autonomously go on standby mode and initiate restart within 50 ms and if the overpower trip-off level is still present, then the unit **shall** autonomously power itself OFF and remain in this state until restarted, by means of an ON command, sent by the ground station.

4.1.16 Helix Overcurrent Protection

The unit **shall** be equipped with a helix overcurrent protection circuit, which, when enabled, will prevent continued unit operation under conditions of excessive helix current, which can damage the TWT. This feature prevents unit damage due to excessive helix current resulting from a fault within the unit or from extreme overdrive conditions because of operator error or test equipment failure.

It **shall** be possible to disable helix overcurrent protection by means described/provided (**TBD**) by the Vendor.

If a Helix Overcurrent Condition is triggered, it **shall** be possible to restart the unit by sending an ON command, when the condition has cleared.

4.2 RESOURCE ALLOCATIONS

4.2.1 Mass Allocation

Requirements in this section are for the assembly. Section 5.2.1 contains more requirements on mass properties and individual component mass.

The TWTA **shall** have a mass of less than or equal to 3.1 kg.

4.2.2 Nominal Power Allocation

The pre-heating (standby mode) prime power consumption **shall** be $\leq 15\text{W}$.

The DC (peak) power consumption at saturated input drive level **shall** be $\leq 165\text{W}$.

The DC power consumption with TWTA ON and input drive OFF **shall** be $\leq 95\text{W}$.

4.3 POWER

4.3.1 Primary (Unregulated) Power Input Requirements

The TWTA **shall** accept redundant prime power and prime power return lines. The two power inputs should be diode ORed inside the Transponder.

4.3.1.1 Operating Voltage Range

The TWTA **shall** be designed to operate over the bus voltage range of +24 to +35 VDC at their primary power inputs.

4.3.1.2 Abnormal Voltages

The TWTA **shall** survive without performance degradation after indefinite exposure to an anomalous voltage range of 0 to +40 VDC. This requirement is to be verified by analysis or test of a non-flight unit.

4.3.1.3 Voltage Ripple

The TWTA **shall** be designed to meet its performance requirements in the presence of ripple voltages specified in the CS101 and CS114 requirements in paragraphs 8.4.2.2 and 8.4.2.3, respectively.

4.3.1.4 Voltage Transients

The TWTA **shall** be designed to meet its performance requirements in the presence of transient voltages specified in the CS106 requirements in paragraph 8.4.2.4.

4.3.1.5 Sudden Removal of Power

The TWTA **shall** meet its performance requirements without degradation after exposure to an abrupt, unannounced removal of power.

4.3.1.6 Polarity Reversal Protection

The TWTA **shall** should have built-in protection to prevent damage due to polarity reversal at the power inputs (up to -35V), where feasible.

4.3.1.7 Over-Current Protection

The TWTA **shall** not use non-resetting over-current protection (i.e., fuses) internal to the unit, but if they are required by the contractor to isolate an internal fault, prior approval **shall** be obtained from the COR.

4.3.1.8 Primary Power Return Ground

TWTA **shall** provide a dedicated Primary Power return in the same connector as the primary power.

4.3.1.9 Power Wiring Redundancy

The TWTA **shall** utilize redundant power wiring.

4.3.2 Load Induced Noise Requirements

4.3.2.1 Turn-on Current Transients

The amplitude and duration of TWTA in-rush currents, at both initial application of prime power and subsequent component turn-on, **shall** be per the following:

- <10 microseconds: not to exceed 10 times max steady state or 10A, whichever is larger
- Between 10 microseconds and 10 milliseconds: not to exceed 3 times max steady state or 3A, whichever is larger
- >10 milliseconds: not to exceed max steady state.

4.3.2.2 Operational Current Transients

The TWTA operational current transients **shall** be less than or equal to 5A above the steady state current for a period of less than 1 millisecond.

The rate of change of the current **shall** be less than or equal to 20 milliamperes/microsecond.

4.3.2.3 Repetitive Transients

Any repetitive current transients, in the frequency range between 1 Hz to 200 Hz, **shall** not exceed 0.2 A peak-to-peak.

This measurement will be performed with an oscilloscope current probe in time domain.

4.4 ELECTRICAL GROUNDING

4.4.1 Primary Power DC Isolation

At the TWTA primary power interfaces, primary power and primary power returns **shall** be isolated from signal grounds and from the component chassis by a DC resistance of greater than or equal to 1 M Ω .

4.4.2 Internally Generated Secondary Returns

Secondary returns (power and signal grounds) **shall** be referenced to the component chassis ground by connecting them at one or more places.

4.4.3 Internally Generated Secondary to Primary DC Isolation

Secondary power (or signal) inputs **shall** be isolated from primary power by a DC resistance of greater than 1 M Ω .

4.4.4 Mechanical Contact Resistance

The DC resistance of the mechanical contact between two conductive mating surfaces (internal to the component, and at the spacecraft interface) **shall** be less than or equal to 2.5 m Ω DC resistance.

4.4.5 Mating Method

The primary mating method for a PACE component is metal-to-metal contact between component mounting feet (or base plate) and the spacecraft structure. When the use of this method is not possible, as determined by the Mechanical Interface Control Document (MICD), the use of a ground strap is necessary.

4.4.6 Ground Strap, Non-Conductive Surface

The TWTA **shall** contain provisions for a grounding strap to be attached from the component chassis for connection to the spacecraft conductive structure.

4.4.6.1 Ground Lug Contact Area

The grounding lug location on the TWTA chassis or the tie points in contact with the ground strap **shall** have a minimum contact area of 80 mm². The ground lug contact area must remain free of any material finish that may affect the reliability of the ground connection and be shown in the MICD.

4.4.7 Reserved

4.4.8 Connector DC Resistance

Component connectors **shall** be electrically connected to chassis with a DC resistance less than or equal to 2.5 m Ω .

4.5 SIGNAL AND DATA INTERFACES

The TWTA will have three types of telemetry interfaces: (1) active analog and (2) passive analog readings and (3) digital status indicators.

All telemetry interfaces **shall** be redundant to accommodate spacecraft redundancy

4.5.1 Active Analog Telemetry

4.5.1.1 Active Analog Telemetry

As a minimum, the following active analog telemetry lines **shall** be provided from the TWTA for assessing the "health" of the TWTA:

- Anode Voltage
- Helix Current
- DC Power Consumption

At least one dedicated Return Line, connected to the EPC chassis, **shall** be provided at the TWTA/SC interface for the Active Analog Telemetry.

4.5.1.2 Active Analog Telemetry Short Circuit Protected

The sources of active analog signals **shall** be short circuit protected.

4.5.1.3 Active Analog Telemetry Source and Load Resistance

The source and load resistances (at the source and destination, respectively) **shall** be documented in the component Electrical Interface Control Document (EICD) such that the overall system compatibility of the telemetry signal is reviewed and controlled.

4.5.1.4 Anode Voltage, Helix Current, and DC Power Telemetry Characteristics

The output range of anode voltage, helix current, and DC power consumption **shall** be nominally 0 to +5.0V full scale. The nominal calibration of the telemetry reading is:

Anode Voltage: 1Volt per 100-200 Volts (TBR)

Helix Current: 1Volt per milliAmp (V/mA)

DC Power Consumption: As agreed by vendor and COR

The accuracy of the analog telemetry **shall** be within $\pm 5\%$ of full scale at any temperature within the specified TWTA operating temperature range.

Each signal output **shall** have an output impedance of 5 ± 1 kilo ohms (kohms) resistive.

4.5.1.5 TWTA RF Power Output Telemetry

Calibration curves **shall** be provided such that RF output power level may be determined as a function of a measurable TWTA parameter, such as DC power consumption.

Calibration curves **shall** be generated for the temperatures -10°C, 25°C, and 50°C.

4.5.2 Passive Analog Telemetry

4.5.2.1 Passive Analog Telemetry Interface

If the TWTA is supplied with passive internal temperature sensors, they **shall** be #311P18-02A101 thermistor parts, with a resistance of 2252 ohms at 25 degrees C.

4.5.2.2 Passive Linearizing Resistor

The linearizing resistor for the thermistors will be located with the temperature sensor conditioning circuit in the Spacecraft Bus avionics.

4.5.2.3 Thermistor Resistor Conditioning

Temperature sensors will be conditioned to provide a voltage range which represents a temperature range that includes a margin of greater than or equal to 5 degrees C beyond the unit qualification or non-operational survival limit, whichever is worse.

4.5.3 Digital Telemetry

4.5.3.1 Digital Status Telemetry

At a minimum, the following digital status indicators **shall** be provided by the TWTA so that the TWTA state can be determined given that the state of the external relay that switches the SC bus voltage to the TWTA is known:

- a. TWTA ON/OFF: Indicates the ON/OFF state of the TWTA.
- b. High Voltage (HV) ON/OFF: Indicates the ON/OFF state of the HV from the EPC to the TWT.
- c. Spurious Shutoff (Auto Restart Event) ON/OFF: Indicates whether a spurious shutoff/auto restart event occurred.

4.5.3.2 Digital Telemetry Voltage Range

The digital telemetry voltage range **shall** be within 0 to +5 VDC.

4.5.3.3 Digital Telemetry Short Circuit Protected

The sources of digital telemetry signals **shall** be short circuit protected.

4.5.3.4 Digital Telemetry Source and Load Resistance

The source and load resistances (at the source and destination, respectively) for digital telemetry signals **shall** be such that the intended logic levels from the source are not violated.

4.5.3.5 Digital Status Max Voltage

The unit **shall** be able to withstand a 12 VDC on open contact on a fault condition where the maximum voltage is driven by the C&DH.

4.5.3.6 Digital Status Return Line

At least one dedicated Return Line, connected to the EPC chassis, **shall** be provided at the TWTA/SC interface for the Digital Status Telemetry.

4.5.4 Reserved

4.5.5 Pulse Commands

All TWTA command interfaces **shall** be redundant to accommodate spacecraft redundancy

The pulse applied to the TWTA command line **shall** have the following characteristics:

Pulse Amplitude: 24-35 Volts (31-32V nominal)

Pulse Duration: 20 milliseconds $\pm 10\%$; Pulse Current: <100 milliamps; Source Impedance: <1 Ohm

Each pulse input **shall** have a dedicated return wire.

The TWTA command line and command return line **shall** be DC isolated from the TWTA primary and secondary returns and TWTA chassis by 1 Mega ohm (Mohm) minimum.

4.5.6 RF Signals

4.5.6.1 Reserved

4.5.6.2 Multipaction

The TWTA **shall** not exhibit multipaction breakdown at any internal pressure from sea level to less than 10⁻⁵ Torr. A 6 dB margin above the maximum power specified in Section 4.1.3 shall be demonstrated by test, or alternatively, a 10 dB margin shall be verified by analysis.

If 10 dB of analytical margin can be demonstrated, vacuum testing shall be performed at 0 dB above the operating power for no less than 8 Hours at 25°C.

4.6 OPERATING MODES

4.6.1 TWTA States

The TWTA **shall** have four basic states:

- OFF: SC bus voltage is removed from the TWTA.
- IDLE: SC bus voltage is applied to TWTA but EPC and TWT are both in an OFF state.
- STANDBY: The EPC is ON but only filament power is supplied to the TWT (high voltages are OFF).
- ON: The TWTA is ON with high voltages applied to the TWT (i.e. Cathode Beam ON). In this state the TWTA is fully functional.

Note: SC bus voltage is applied to the TWTA by an external switch, which is not part of the TWTA. The SC controls this switch.

4.7 COMMAND AND DATA SERVICES

4.7.1 Commands and ON/OFF Sequences

To command the TWTA ON and OFF, the SC provides redundant sets of two command (CMD) lines and a command return to the TWTA. A voltage pulse (pulse command) is applied to these lines to transition the TWTA to the desired state. The pulse commands and a normal ON and OFF sequence **shall** be as follows:

A. TWTA ON Sequence: This sequence assumes that SC bus voltage has been applied to the TWTA through the external switch, resulting in the IDLE state.

CMD Line 1: TWTA ON: Causes the TWTA to turn ON from the IDLE or STANDBY state. If initially in the IDLE state, the command shall cause the EPC to turn ON and supply filament voltage to the TWT. The result is the STANDBY state. An internal timer controls when high voltages should be applied to the TWT, allowing sufficient warm-up time for proper operation of the TWT. The EPC then automatically supplies high voltages to the TWT, resulting in the ON state.

B. TWTA OFF Sequence: This sequence assumes that the TWTA is in the ON state defined above.

CMD Line 2: TWTA OFF: Causes the TWTA to turn itself OFF in the proper sequence and the result is the IDLE state.

The SC bus voltage is removed from the TWTA to complete the OFF sequence.

If the TWTA ON command is executed without the SC bus voltage applied to the EPC, the TWTA **shall** not be damaged or degraded.

The TWTA ON sequence **shall** only be executed when the TWTA ON command is generated with SC bus voltage applied. If the ON command is generated without spacecraft voltage, the TWTA **shall** remain in the OFF state.

The TWTA OFF state can be achieved in several ways but the preferred method is as listed above. Other sequences to the OFF state, (e.g. removing the SC bus voltage from the TWTA without first turning the TWT and EPC OFF when the TWTA is in the ON state), **shall** not be damaging to the TWTA.

If the input RF drive is turned off with the TWTA ON, the TWTA **shall** not be damaged or degraded.

5.0 PHYSICAL REQUIREMENTS

5.1 INTERFACE DOCUMENTATION

The contractor **shall** use metric units when interfacing with NASA GSFC including any drawings, documents, models, except for the following cases:

- Heritage Hardware: Hardware that has been previously qualified, or of similar design heritage, may be specified in English units where use of metric equivalents would lead to additional cost to the program.
- Fasteners: Although bolt circles will be defined using metric dimensioning, use of English fasteners is permitted.
- Angular Measurement: Angular measurement may be expressed in degree of arc or in an appropriate subdivision of degree of arc such as second of arc (arc-sec) when advantageous to application.

5.1.1 Mechanical Interface

The mounting interface **shall** be defined in the Mechanical Interface Control Document (MICD), which will be developed between the contractor and NASA GSFC.

5.1.2 Electrical Interface

The electrical interface **shall** be defined in the Electrical Interface Control Document (EICD), which will be developed between the contractor and NASA GSFC.

5.2 MASS PROPERTIES

5.2.1 Component Masses

The EPC mass **shall** be ≤ 1600 grams.

The TWT mass **shall** be ≤ 1400 grams.

5.2.2 Center of Mass Location

The contractor **shall** define the center of mass in the Mechanical ICD.

5.2.3 Center of Mass Accuracy

The center of mass **shall** be determined to within ± 6 mm relative to an external reference.

5.2.4 Determination of Moments and Products of Inertia

The final moments and products of inertia of the TWTA **shall** be calculated to within 10%.

5.3 PHYSICAL ENVELOPE

The EPC external dimensions, including mounting provisions, **shall** be less than the envelope of 25 cm x 10 cm x 15 cm (LWH) including connectors and mounting flanges, as defined in the Mechanical ICD.

The TWT external dimensions, including mounting provisions, **shall** be less than the envelope 40 cm x 15 cm x 10 cm (LWH), including connectors and mounting flanges, as defined in the Mechanical ICD.

High voltage interconnect cable **shall** be **TBD** cm, as defined in the Mechanical ICD.

5.4 MOUNTING

Mounting interface flatness, and co-planarity requirements for the component side of the interface (including brackets, if any, and shims) **shall** be as defined in the MICD.

The TWTA **shall** have a flatness of 0.25 mm from any 2 points on the mounting interface for a component $<0.3 \text{ m}^2$ and 0.50 mm from any 2 points on the mounting interface for a component $>0.3 \text{ m}^2$ and $<0.6 \text{ m}^2$.

Connector locations names, and orientations **shall** be defined in the mechanical drawings and MICD to be supplied.

6.0 ENVIRONMENTAL REQUIREMENTS

Environmental design requirements for the spacecraft components are specified in this section. The PACE spacecraft components will be capable of meeting their performance requirements after exposure to the environments specified in this section.

6.1 MECHANICAL FACTORS OF SAFETY

The TWTA **shall** demonstrate positive Margins of Safety under limit loads for all yield and ultimate failures using the Factors of Safety (FS) defined in Table 6-1. Margin of Safety (MS) is defined as follows:

$$MS = (\text{Allowable Stress (or Load)} / (\text{Applied Limit Stress (or Load)} \times FS)) - 1$$

Table 6-1 Factors of Safety

Type	Static	Sine	Random/Acoustic ^{4,5}
Metallic Yield	1.25 ³	1.25	1.6
Metallic Ultimate	1.4 ³	1.4	1.8
Stability Ultimate	1.4	1.4	1.8
Beryllium Yield	1.4	1.4	1.8
Beryllium Ultimate	1.6	1.6	2.0
Composite Ultimate	1.5	1.5	1.9
Bonded Inserts/Joints Ultimate	1.5	1.5	1.9
Glass/Ceramic Ultimate	3.0	3.0	3.8

(1) Factors of Safety for pressurized systems to be compliant with NASA-STD 8719.24 (with Annex) (NASA EXPENDABLE LAUNCH VEHICLE PAYLOAD SAFETY REQUIREMENTS).

(2) All composite structure must be tested to 1.25 x limit loads.

(3) If qualified by analysis only, positive margin must be shown for factors of safety of 2.0 on yield and 2.6 on ultimate. See section 2.4.1.1.1 of GEVS.

(4) Factors shown should be applied to statistically derived peak response based on RMS level. As a minimum, the peak response shall be calculated as a 3-sigma value.

(5) Factors shown assume that qualification/protoflight testing is performed at acceptance level plus 3dB. If difference between acceptance and qualification levels is less than 3dB, then above factors may be applied to qualification level minus 3dB.

Primary and secondary structure comprised of composite materials, Beryllium, bonded joints and/or bonded inserts **shall** be proof tested to 1.25 x Limit Load; qualification by analysis only is not acceptable. Actual flight component testing is preferred, but testing of representative sets of hardware with a similarity qualification argument can be used if approved by the COR.

6.2 QUASI-STATIC ACCELERATION

Quasi-static acceleration represents the combination of steady-state accelerations and the low frequency mechanically transmitted dynamic accelerations that occur during launch.

The TWTA **shall** be designed to withstand the quasi-static design limit loads defined in the mass-acceleration curve (MAC) shown in Table 6-2 without damage or degradation of performance. The design loads shown below will be updated based on the results of coupled loads analysis.

Linear interpolation should be used between breakpoints to determine the appropriate limit load as a function of TWTA weight. Note that these design limit loads are intended to cover only the low frequency launch environment and must be used in conjunction with the random vibration environments to assess structural margins.

Table 6-2 TWTA Design Limit Loads

Mass (kg)	Accel. (G)	Mass (kg)	Accel. (G)
1.0	67.9	168.6	12.8
11.5	38.0	179.1	12.5
21.9	30.2	189.5	12.2
32.4	25.9	200.0	11.9
42.9	23.2	225.0	11.3
53.4	21.2	250.0	10.7
63.8	19.6	275.0	10.3
74.3	18.4	300.0	10.0
84.8	17.4	325.0	9.6
95.3	16.5	350.0	9.3
105.7	15.8	375.0	9.0
116.2	15.2	400.0	8.7
126.7	14.6	425.0	8.5
137.2	14.1	450.0	8.2
147.6	13.6	475.0	8.0
158.1	13.2	500.0	7.8

6.3 FREQUENCY REQUIREMENT

6.3.1 Fundamental Launch Frequencies

The TWTA **shall** have a fundamental frequency greater than 100 Hz when hard mounted at its S/C interface. Any component, which fails to meet the specified fundamental frequency, must

supply a finite element model, correlated to modal survey test results up to 50 Hz, to be used in coupled loads analyses. Requirements for the submitted finite element model are in the SOW and discussed in Section 11.5.4.

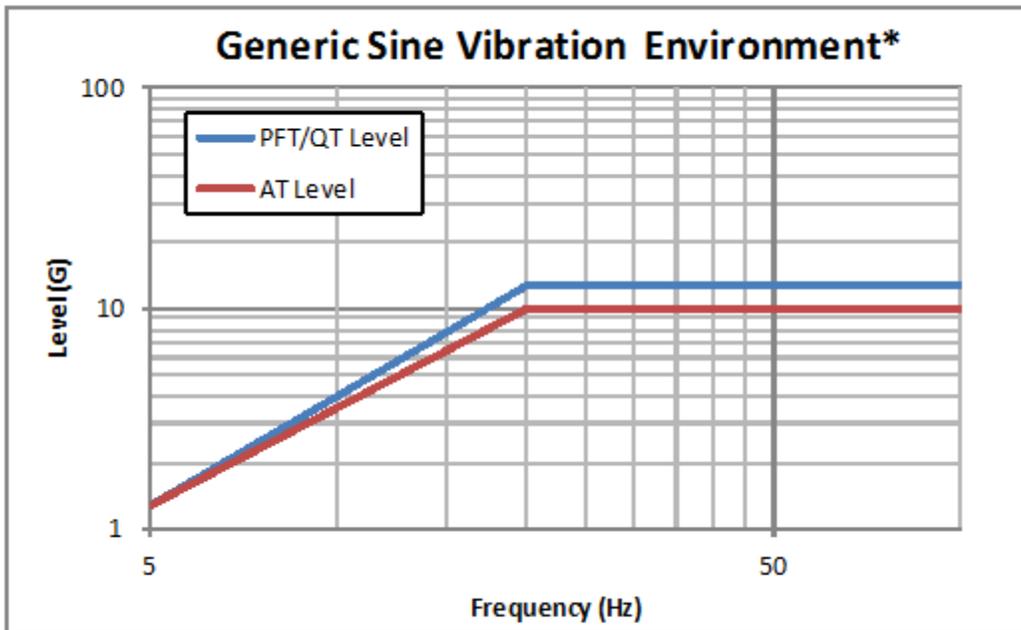
6.4 VIBRATION

6.4.1 Sinusoidal Vibration

The TWTA **shall** undergo qualification, protoflight or acceptance (level depends on qualification status of unit) sine vibration testing on all three axes at the levels shown in Table 6-3. Stiff components showing a first mode greater than 150Hz can be exempted from sine vibration testing upon approval by the COR. A generic sine vibration specification is provided for both Protoflight (PFT), Qualification (QT) and Acceptance (AT) levels applied at the PACE to TWTA interface. See Section 11.4.1 for definitions of Protoflight, Qualification, and Acceptance.

Table 6-3 TWTA Sine Vibration Environment

Frequency	Protoflight, Qual Level	Flight, Acceptance Level
5-20 Hz	0.63 in (double amplitude)	0.50 in (double amplitude)
20-100 Hz	12.5 G	10.0 G



* The equivalent 5 Hz level and slope will vary based on shaker hardware limitations

Figure 6-1 Sine Vibration Environment

Levels may be notched to not exceed 1.25 times the design limit load outlined in section 6.2. Peak levels at the low end of the frequency range (5 – 20 Hz typically) may be ramped up as needed to accommodate shaker table displacement limitations.

6.4.2 Random Vibration

The TWTA **shall** demonstrate its ability to meet its performance requirements after being subjected to the random vibration environment in Table 6-4.

Table 6-4 TWTA Random Vibration Environment

Frequency (Hz)	ASD Level (g^2/Hz)	
	Qualification	Acceptance
20	0.026	0.013
20-50	+6 dB/oct	+6 dB/oct
50-800	0.16	0.08
800-2000	-6 dB/oct	-6 dB/oct
2000	0.026	0.013
Overall	14.1 G_{rms}	10.0 G_{rms}

Table 6-5 Reserved

Figure 6-2 Reserved

The contractor **shall** perform random vibration analysis along with static loads analysis. Please see NASA-HDBK-7005 and NASA-STD-7001 for more information.

During the test, the test input level will be reduced (notched) at critical frequencies, if required, to limit the random vibration loads and/or acceleration responses to 3 dB above design limit levels.

Notching **shall** be limited to -12 dB of the original input and to a bandwidth of less than 100 Hz to limit the random vibration responses to 3dB above design limit levels. Notching beyond these limits will require PACE project approval.

6.5 SHOCK

The TWTA **shall** be designed to meet its performance requirements after being subjected to the shock environment in)

Table 6-6, applied at the TWTA interface to the PACE spacecraft structure.

(Note that the enveloped levels shown below are driven by WFIRST below 1000Hz and PACE above 1000 Hz.)

Table 6-6 Qualification Level Shock Response Spectrum

Freq (Hz)	SRS (G)
100	100
500	1300
1400	1600
10000	1600

A shock susceptibility and attenuation assessment **shall** be performed on all Spacecraft components. If the flight shock environment as shown on a Shock Response Spectra (SRS) plot (Q=10) is enveloped by the curve shown below (Figure 6-3), then the shock environment can be considered benign and there is low risk in deferring the shock test to the Observatory level.

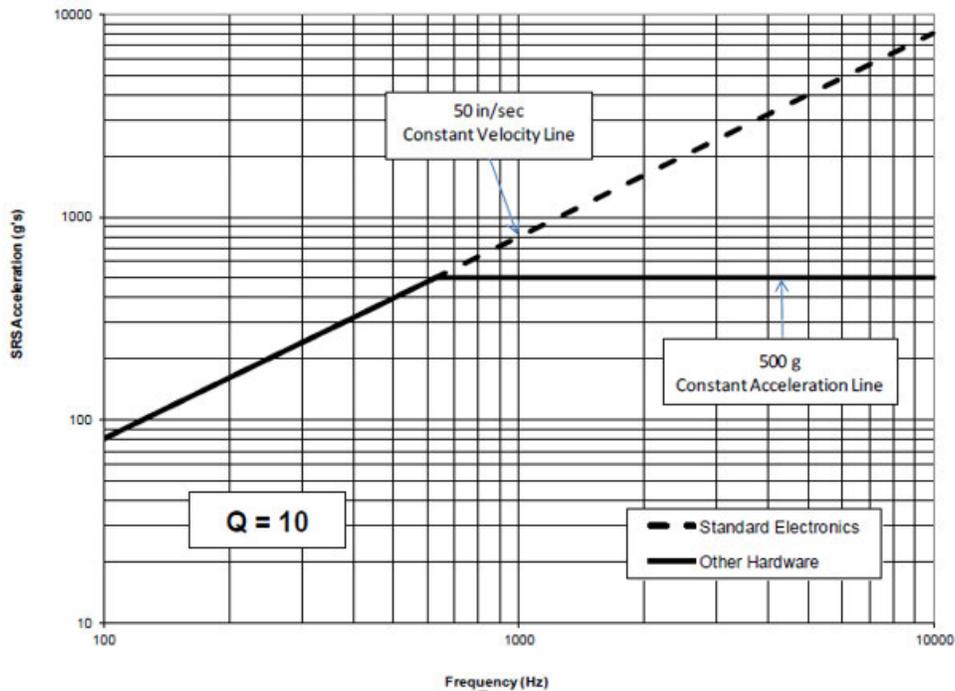


Figure 6-3 Shock Envelope

Analysis supporting this conclusion (i.e. deferral of shock testing) **shall** be provided to the PACE Project for review.

Any component determined to be susceptible to the shock environment (e.g., shock levels are above the curve) **shall** have shock testing performed at the component level (preferably on a qualification unit).

Component self-induced shock testing **shall** be accomplished by two actuations at the component level for each self-induced shock source (in order to account for the scatter associated with the actuation of the device) for the first flight unit, and a single actuation on subsequent units.

6.6 RESERVED

6.7 TRANSPORTATION

In addition to the launch loads shown above, the TWTA **shall** also be designed to withstand the maximum transportation loads shown in Table 6-7 without damage or degradation of performance.

Table 6-7 Transportation Loads

Method	Fore/Aft (G)		Lateral (G)		Vertical (G)	
	Air (C5)	-2.00	1.00	-1.00	1.00	-3.60
Road	-1.00	1.00	-0.75	0.75	-2.50	0.50

Notes:

- Minus sign denotes downward for vertical load. Vertical loads include gravity (-1 G)
- Vertical loads to be applied independently. In-plane loads to be combined with 1 G vertical loading

6.7.1 Transportation Cleanliness

Materials and enclosure used for transportation and storage **shall** not generate molecular or particle contaminants or degrade the surface cleanliness of the item or adjacent items

6.8 PRESSURE

6.8.1 Operating Pressure Range

The TWTA **shall** be designed to meet all performance requirements while operating over a pressure range of $1.08 \times 10^5 \text{ N/m}^2$ (813 Torr) to $1.3 \times 10^{-12} \text{ N/m}^2$ (1×10^{-14} Torr).

6.8.2 Maximum Depressurization Rate

The TWTA **shall** be designed to meet all performance requirements after exposure to a maximum depressurization rate of -50 mbar/sec (-0.72 psi/sec) experienced during launch and ascent.

The TWTA **shall** be vented such that internal pressure is equal to external pressure within 30 minutes after launch.

6.9 RESERVED

6.10 GROUND ENVIRONMENTS

The TWTA **shall** meet all of their performance requirements during exposure to air temperature between +5 and +30 degrees C and relative humidity between 30% and 70%.

After powered “OFF” and exposed to air temperatures of +5 to +30 degrees C and relative humidity of 0 to 70%, the TWTA **shall** meet all of their performance requirements.

6.11 THERMAL REQUIREMENTS

6.11.1 Flight Interface Design Temperature Limits

When powered “OFF”, the TWTA **shall** be capable of surviving indefinitely when its temperatures are within the survival limits shown in Table 6-8 without damage or permanent performance degradation.

The TWTA **shall** also survive indefinitely, without damage or permanent performance degradation, if powered “ON” anywhere within the Operational and Protoflight/Qualification limits shown in Table 6-8.

The TWTA **shall** demonstrate turn on at the Minimum and Maximum Protoflight/Qualification limits shown in Table 6-8.

Table 6-8 Temperature Limits at Box Mounting Interface

	Minimum Temperature (°C)	Maximum Temperature (°C)
Operational (In Spec)	-10	+50
Protoflight/Qualification (In Spec)	-20	+60
Survival (Unpowered)	-25	+65

Thermal dissipation at saturation over the operating band **shall** be:

- ≤ 80 W for TWT
- ≤ 15 W for EPC

The thermal dissipation mode **shall** be conduction only.

Thermal dissipation in no-drive mode **shall** be ≤ 95 W.

6.12 CHARGED PARTICLE RADIATION REQUIREMENTS

Components containing electronic parts will be exposed to a natural space radiation environment that consists of: (1) trapped particles which include electrons, protons, and heavier ions; (2) particles from solar events (coronal mass ejections and flares); and (3) galactic cosmic ray particles.

6.12.1 Definitions

Total Ionizing Dose (TID) - the mean energy deposited by ionizing radiation in a device region divided by the mass of the region. This is often given in units of rad(Si), where 1 rad(Si) = 100 erg deposited per gram of silicon.

Enhanced Low Dose Rate Sensitivity (ELDRS) - used to refer to a part that shows enhanced radiation-induced damage at dose rates below 50 rad(Si)/s. The enhancement is the result of true dose rate effects.

Displacement Damage Dose (DDD) - the mean energy deposited by ionizing radiation in a device region that goes into atomic displacements divided by the mass of the region. There is no official unit for DDD. One such unit is MeV/g.

Single Event Effect (SEE) - any measurable effect to a circuit due to an ion strike. This includes, but is not limited to, single event upsets (SEUs), single event transients (SETs), single hard errors (SHEs), single event latchups (SELs), single event functional interrupts (SEFIs), single event burnouts (SEBs), single event gate ruptures (SEGRs), and single event dielectric ruptures (SEDRs).

Single Event Upset (SEU) - a change of state or transient induced by an energetic particle such as a cosmic ray or proton in a device. This may occur in digital or analog, circuits and may have effects in surrounding interface circuitry (a subset known as SETs). These are “soft” errors in that a reset or rewriting of the device will usually return the device to normal behavior thereafter. The general goal for non-destructive events such as SEUs or SETs is not to avoid them completely, but to manage their impact through robust circuit design, automatic correction, and/or operational activities based on knowledge from ground radiation tests and circuit/system analysis.

Single Event Latchup (SEL) - a condition that may cause device failure due to a single event induced high current state. A SEL may or may not cause permanent device damage, but requires power cycling of the device to resume normal device operations. In addition, susceptible devices have the concern for latent damage (device does not fail from the immediate single particle event, but reliability is degraded and premature failure may occur).

Linear Energy Transfer (LET) - a measure of the energy deposited per unit length as an energetic particle travels through a material. The common LET unit is MeV*cm²/milligram (mg) of material.

Threshold LET (LET_{th}) - the maximum LET at which no SEE is observed at a particle fluence of 10⁷ ions/cm².

6.12.2 Total Ionizing Dose

6.12.2.1 Minimum TID Tolerance for EEE Parts and Materials

The top-level total ionizing dose requirement (“WFIRST”) is shown in Figure 6-4. The dose values are calculated as a function of aluminum shield thickness in units of krad in silicon. For a nominal 100 mils (2.54 mm) of equivalent aluminum shielding and a 6-year mission life, the expected dose is 25.5 krad-Si at the 95% confidence level.

EEE parts and materials shall be selected according to the level of shielding and 95% confidence level curve in Figure 6-4

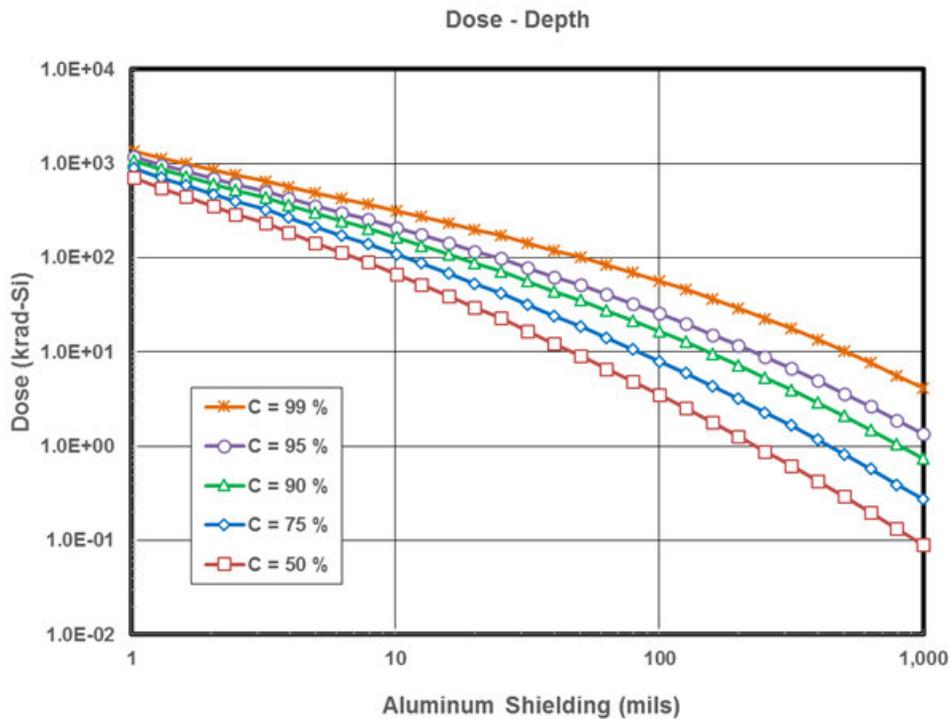


Figure 6-4 Total Ionizing Dose-Depth Curves (“WFIRST”)

6.12.2.2 ELDR Evaluation

Linear bipolar and BiCMOS device types that are known to be, or potentially susceptible to Enhanced Low Dose Rate Sensitivity (ELDRS) for TID, **shall** be evaluated using test data at a low dose rate not to exceed 0.01 rad(Si)/sec in accordance with the latest version of MIL-STD-883, Test Method 1019 for all bias cases to be used in the Spacecraft Observatory equipment (i.e., biased and unbiased), unless existing data shows that a lower dose rate is required to manifest the ELDRS effect.

6.12.3 Displacement Damage Dose

The displacement damage dose or non-ionizing dose is the mean energy deposited in a material that goes into atomic displacements divided by the mass of the material. It is analogous to the ionizing dose except that the energy considered produces displacements in a semiconductor lattice.

Parts sensitive to displacement damage degradation (e.g., optical detectors, precision bipolar integrated circuits, crystal oscillators, and power devices) **shall** be able to tolerate a minimum DDD of 6.67×10^8 MeV/g (or a 10 MeV equivalent proton fluence of 8.45×10^{10} cm⁻²) and 5.50×10^8 MeV/g (or a 10 MeV equivalent proton fluence of 8.35×10^{10} cm⁻²), respectively.

This meets the DDD exposure for a 6-year mission with orbit about the Sun-Earth second Lagrange point, L2, at the 95% confidence level and nominal 100 mils of aluminum shielding.

6.12.4 Single Event Effects

The TWTA **shall** be designed to avoid or tolerate errors due to non-destructive Single Event Upsets.

6.12.4.1 Destructive Events (SELs)

All devices **shall** have a single-event latchup (SEL) LET threshold greater than 37 MeV-cm²/mg.

Latch-up susceptibility will be evaluated using test data obtained on at least three samples at maximum specified device operating temperature and maximum specified device operating voltage(s) and using at least 10^7 ions/cm² with ions of sufficient energy to meet the linear energy transfer requirement throughout the active charge-collection depth of the device.

For devices with SEL LET thresholds between 37 and 75 MeV-cm²/mg, an evaluation of the probability and impact of destructive events **shall** be conducted to determine acceptability.

Circumvention techniques **shall** be evaluated to ensure that no latent damages are induced by an event in the devices prior to correction. This requires radiation test and failure analysis as per NASA Alert NA-GSFC-2005-05. This requires current density analysis and testing to verify devices are latent damage free.

Parts with an onset LET threshold > 75 MeV-cm²/mg are taken to be immune to SEL, and no additional analysis is necessary.

6.12.5 Charging Environment

The TWTA **shall** be designed to withstand the degradation of surface materials and associated surface charging effects due to the radiation environment for a mission with an orbit about the Sun-Earth second Lagrange point, L2.

7.0 CLEANLINESS

The requirements in this section ensure the cleanliness of TWTA at delivery so as not to adversely affect its own performance, as well as not be a source of contamination to other items, including not generating contaminants following delivery in excess of that permitted below by virtue of its design, materials of construction, or operation.

7.1 SURFACE CONTAMINATION

7.1.1 Surface Contamination Levels at Delivery

7.1.1.1 Particulate Contamination

The TWTA **shall** meet IEST-STD-CC-1246E VC-0.5-1000 + UV when inspected with both UV and white light in a darkened room.

7.1.2 Surface Contamination Generation

7.1.2.1 Particulate Generation

The TWTA contractor **shall** not employ any of the following particle generating materials or processes into the TWTA design or construction without prior approval from NASA/GSFC:

- Paints prone to shedding due to large paint pigment molecules, overspray, poor adhesion, etc.
- Dry lubricants (e.g. molybdenum disulfide).
- Surfaces prone to corrosion or oxides because of a lack of corrosion protection or dissimilar metals in close contact.
- Fabrics with brittle constituents (e.g., composites, graphite or glass).
- Perforated materials when material is highly susceptible to tear propagation (e.g., MLI).
- Metal oxides (bare [untreated] aluminum and magnesium, iron, non- corrosion resistant steel, etc.).
- Braided metallic or synthetic wires, ropes, slings, etc. unless measures have been taken to contain any broken filaments or fibers (sheathing, sealing with polymers, covering, etc.).
- Woven materials especially cut or unfinished ends (metal braid, EMI shielding, lacing cord, expando sleeving), unless measures have been taken to prevent fraying or generation of particles (cut with a hot knife, seal with polymer, bag, etc.).
- Materials with thin films known to erode or crack or flake when subjected to normal handling (e.g., indium tin oxide [ITO] or other rigid or brittle semiconductor or ceramic coating on flexible substrates, Teflon, multi-layered insulation [MLI], etc.).
- Foams, highly textured materials.
- Trapped debris in holes.

7.1.2.2 Molecular Generation

7.1.2.2.1 Material Selection

The TWTA materials **shall** have a total mass loss (TML) less than 1.00% and a collected volatile condensable mass (CVCM) less than 0.10%, when measured in accordance with ASTM E-595 unless a materials usage agreement has been generated and approved by NASA/GSFC.

7.1.2.2.2 Material Selection - Silicones

Silicones on external (to the spacecraft) surfaces **shall** not be exposed to the space environment unless approved by NASA/GSFC. Silicones should be avoided or minimized. It is highly recommended that silicones be baked out at a high temperature prior to integration into the system to prevent extended bakeouts of the entire assembly.

7.1.2.2.3 Assembly Outgassing

The TWTA's outgassing **shall** be measured in a vacuum of 1E-5 torr at the item under test's maximum hot survival temperature based on Table 6-8, The hot operating temperature plus 5 degrees may be used with the PACE Contamination Engineer's approval.

The TWTA's outgassing **shall** not exceed 2E-8 g/sec per kg of unit under test's mass that is condensable on a Quartz Crystal Monitor (QCM) that is operated at -20 degrees C. The measurement will be made in a chamber that has been certified clean (back ground outgassing rate and free of silicones and other high molecular weight contaminants) and has been modeled by the GSFC Contamination Analyst to account for mass sinks (cold fingers, pumps, cold surfaces, etc.) that could influence the source outgassing rate.

It is recommended that certification be conducted after thermal cycling to take advantage of heat exposure times. Items with significant quantities of organics are baked out at the hottest temperature that will not degrade the performance of the item. This is especially true of harnesses.

A cold finger and/or a scavenger plate **shall** be used unless approved otherwise by the Contamination Engineer.

7.1.2.3 Intentional and Unintentional Vents

When located external to the spacecraft, intentional vents (dedicated ascent vents or thermal blanket vents for example) and unintentional vents (through holes, gaps at seams and faying surfaces, thermal blanket openings and other openings) **shall** not impinge on the surface of instruments or other contamination sensitive surfaces (star trackers, calibration standards, contamination sensitive thermal surfaces like radiators, etc.).

7.1.2.4 Intentional and Unintentional Vents – Filters

Any vents **shall** have filters or other means of preventing the egress of particles larger than 35 microns.

7.1.2.5 Intentional Vents - Pressure Buildup Prevention

Intentional vents **shall** be sized to prevent a buildup pressure during ascent that may result in mechanical damage

Intentional vents **shall** be sized to prevent a buildup pressure during high vacuum due to outgassing that could result in discharges in higher voltage circuits.

7.1.3 Cleanability

7.1.3.1 Cleanability – Sensitive Surfaces

If any surfaces are not cleanable with Isopropyl alcohol and polyester wipes or light vacuuming, they **shall** be identified on the MICD.

7.1.3.2 Cleanability – Sensitive Surface Cleaning Methods

Alternate cleaning methods **shall** be identified and appropriate documentation provided for any surfaces that are not cleanable with Isopropyl alcohol.

7.2 ELECTROSTATIC CLEANLINESS

The following paragraphs provide requirements and guidelines for minimizing the magnitude and variations in the radiated electric field from the external surfaces of the TWTA when exposed to the space plasma. All external Observatory surfaces that are exposed to the space plasma will be sufficiently conductive and be connected to spacecraft ground through low impedance paths.

7.2.1 Conductive Surface Ground Path

All TWTA external conductive surfaces **shall** be connected to the spacecraft interface with a resistance less than 5 ohms, either through the use of ground wire(s) or through metal-to-metal mounting contact. All external conductive surfaces should have a minimum of two (2) connections to the nearest grounded spacecraft surface.

7.2.2 Reserved

7.2.3 Closeout of Gaps and Apertures

All gaps and apertures not required for component fields of view, deployments, or observatory venting **shall** be closed out with conductive tape or thermal blankets.

7.2.3.1 Conductive Tape Surface Resistivity

Conductive tapes used to closeout gaps or apertures **shall** be designed to meet the conductive surface resistivity requirements.

7.2.3.2 Conductive Tape, Grounding

The external surface of conductive tapes **shall** be connected to the spacecraft interface through the use of folded under tabs, or conductive adhesives.

7.2.4 Exposed Harness Specific Requirements

Harnesses that are exposed to sunlight or the ambient plasma **shall** be bundle shielded from source to destination.

8.0 DESIGN & CONSTRUCTION REQUIREMENTS

8.1 PARTS, MATERIALS & PROCESSES (PMP)

8.1.1 EEE Parts

The TWTA contractor’s Quality Assurance system for EEE parts **shall** be in accordance with the requirements in the SOW, PACE-COMM-SOW-0021.

8.1.2 Materials

The TWTA assembly **shall** be comprised of materials and processes in accordance with the requirements in the SOW, PACE-COMM-SOW-0021.

External mounting surfaces **shall** be coated with chromate conversion coating per MIL-DTL-5541.

External non-mounting surfaces **shall** be either coated with chromate conversion coating per MIL-DTL-5541 or coated with a high emissivity coating (>0.7) such as black anodize per MIL-A-8625F Type II, Class 2, to be specified at time of contract.

8.1.2.1 Material Conductivity

All parts should be passivated and mounting surfaces on the TWTA **shall** be conductive as defined in Section 4.4.

8.1.2.2 Material Limitations for Debris Casualty Area

The TWTA **shall** limit the use of materials shown in Table 8-1.

The TWTA **shall** report the mass, dimensions, and use of materials shown in Table 8-1.

The TWTA **shall** report assemblies comprised of multiple piece parts of Table 8-1 materials should be assessed using the total quantity within that assembly. Isolated pieces of material may weigh less than 50 grams; however, if attached to other parts of the same material it will stay together until demise or until reaching ground.

Table 8-1 Limited materials for debris casualty area

Material	Quantity
Titanium	Mass > 50g
Steel	Mass > 50g
Inconel	Mass > 50g
Invar	Mass > 50g

Materials with melting points above 1200° C (1473 K)	Mass > 50g
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8.2 ELECTRICAL

8.2.1 Test Sensors

Test sensors **shall** be designed for flight. Unless specified to be removed before flight, test sensors **shall** not be removed prior to flight.

8.2.2 Interface Requirements

8.2.2.1 Connector Selection

8.2.2.1.1 Connector Specifications

Selected connector types **shall** meet the Connector and Contact Requirements defined in Section C2 of EEE-INST-002.

Environmental seals **shall** not be used in connectors especially if made from silicone without the explicit approval of the GSFC PACE Contamination Control engineer.

8.2.2.1.2 Prohibited External Box Power Connector

The use of micro-miniature D connectors **shall** be prohibited to power interfaces between external box connections.

8.2.2.1.3 Contact Derating

The current carrying capacity of the contacts **shall** be derated for continuous operation at the required current levels in a vacuum, as defined in Section C2 of EEE-INST-002.

8.2.2.1.4 Redundant Contact Derating

When redundant contacts are used for a single power source, each contact **shall** meet the required derating criteria.

8.2.2.2 Signal Segregation

Wherever possible, different classes of signals (power, digital, analog, etc.) **shall** be separated by using separate connectors and separate harness bundles.

If separate connectors are not feasible, classes of signals within a common connector **shall** be isolated from one another. Connector pin assignments should be such that sensitive circuits are separated from potential interference sources.

8.2.2.3 Test and Flight Signal Isolation

Test signals and flight signals **shall** not be located in the same connector.

8.2.2.4 Test Interfaces

Component test signals that require access during observatory-level testing will be handled as follows:

8.2.2.4.1 Facility-Induced Noise

All test signals should be protected or isolated from facility-induced noise.

8.2.2.4.2 Facility-Induced ESD GSE Malfunction

All test signals **shall** be protected or isolated from facility-induced ESD GSE malfunction.

8.2.2.4.3 Facility-Induced GSE Malfunction

All test signals **shall** be protected or isolated from facility-induced GSE malfunction.

8.2.3 Mitigation of Internal Charging

Internal charging refers to the physical effect where high energy electrons deposit charge in a dielectric, if the charging rate is higher than the leakage rate eventually a point is reached where the dielectric discharges to the nearby structure.

8.2.3.1 Mitigation Strategies for Internal Charging

There are a number of mitigation strategies possible to prevent charge build-up and subsequent arcing within components. Designers **shall** implement one, or more, of the following strategies:

- (1) Provide sufficient AL shielding (2.5mm for bulk dielectric or 1 mm for Tefzel cable).
- (2) Use low pass filters at either end of the cable that absorb the energy from the discharge without creating dangerous voltages.
- (3) Provide circuits at either end that have sufficiently low impedance that they are not harmed by the discharges

Note, that if the contractor uses strategies (2) or (3), all affected circuit designs **shall** be analyzed to demonstrate compliance with the requirements, using a transient circuit analysis tool such as PSpice.

8.2.3.2 Floating Conductors

Floating conductors, if present, **shall** have a bleed path of less than 10 MΩ to the component structure. This requirement is not applicable to small floating conductors (1 inch² or less) or short (1 inch or less) unterminated traces or wires that are inside of the components.

8.2.3.3 Dielectric Structures

8.2.3.3.1 Bulk Resistivity

Dielectric structures **shall** have a bulk resistivity less than 10¹² ohm-cm.

8.2.3.3.2 Charge Bleed-Off

All dielectric structures **shall** have a charge bleed path to the spacecraft interface, designed to route the discharge into the spacecraft structure in a controlled fashion.

8.3 SAFETY

The TWTA **shall** meet the applicable sections of NASA-STD-8719.24 ELV Safety Requirements.

8.4 ELECTROMAGNETIC COMPATIBILITY

The TWTA design will be such that they are electromagnetically compatible with each other and with all the external environments in which they are expected to operate. Specifically, the components will not: (a) generate electromagnetic interference that could adversely affect the operation and safety of each other, the launch vehicle, and other equipment present during ground operations; and (b) be susceptible to emissions that could adversely affect their operation and safety. These emissions may originate from each other, from the launch vehicle, or from other equipment present during ground operations.

The mode of transmission of electromagnetic interference may be conduction through wires or radiation through space. Electromagnetic compatibility requirements are designed to limit both conducted and radiated emissions and to minimize susceptibility to both types of emissions. These requirements can be grouped into four types:

- (1) Conducted emission requirements are designed to prevent excessive noise from being induced on the spacecraft power bus by components, subsystems, and instruments that are connected to the bus.
- (2) Conducted susceptibility requirements are designed to insure that any component, subsystem, or instrument connected to the spacecraft power bus is not unduly susceptible to noise expected to be present on the power bus.
- (3) Radiated emission requirements are designed to prevent excessive noise from being radiated by the observatory and its components.

- (4) Radiated susceptibility requirements are designed to ensure that spacecraft components, subsystems, or instruments are not unduly susceptible to radiated noise emanating from the observatory and other sources.

The following table summarizes the emission and susceptibility requirements.

Table 8-2 Emission and Susceptibility Requirements

Category	Description	MIL-STD-461F Identification	GEVS Paragraph Reference	Applicability
Conducted Emissions (CE)	Power Leads, 30 Hz to 150 kHz	CE101	2.5.2.1.1	Applicable for the primary power and return leads that supply power to a component. Not applicable for secondary power wires or signal wires except where noted in each test requirement section.
	Power Leads, 150 kHz to 50 MHz	CE102	2.5.2.1.1	
	Power & Signal Cables, 150 kHz to 200 MHz	CMBCE (GEVS)	2.5.2.1.2	
Conducted Susceptibility (CS)	Power Leads, 30 Hz to 150 kHz	CS101	2.5.2.2.1	Applicable for the primary power and return leads that supply power to a component. Not applicable for primary power returns, secondary power wires, or signal wires.
	Power Leads, 150 kHz to 50 MHz	CS114 (Ripple)	2.5.2.2.4.2	
	Power Lead Transients	CS106	2.5.2.2.3	
	Power & Signal Cables, 10 kHz to 200 MHz	CS114 (Common Mode)	2.5.2.2.4.1	
Radiated Emissions (RE)	Electric Field, 200 MHz to 18 GHz	RE102	2.5.2.3.2	Applicable to all components.
Radiated Susceptibility (RS)	Electric Field, 2 MHz to 18 GHz	RS103	2.5.2.4.2	Applicable to all components.
RF Component Unique Tests	Antenna Terminals, above 200 MHz	CE106	2.5.2.1.4	Only Applicable to RF Transmitters and Receivers
	Antenna Terminal (intermodulation)	CS103	2.5.2.2.2	
	Antenna Terminal (rejection of undesired signals)	CS104	2.5.2.2.2	

8.4.1 Conducted Emissions

Conducted emission requirements are designed to prevent excessive noise from being induced on the spacecraft power bus by components that are connected to the bus.

8.4.1.1 Applicability of Conducted Emissions

The conducted emissions requirements are applicable for the primary power (+32V bus) and return leads that supply power to the TWTA. The requirements do not apply to secondary power wires or signal wires.

8.4.1.2 CE101 – Differential Mode Current Emission Limits

The TWTA **shall** not produce reflected ripple greater than the CE101 limits from 30 Hz to 150 KHz shown in Figure 8-1, when power leads are tested to a modified MIL-STD-461F CE101 (extended frequency range) test method as described in GSFC-STD-7000A, Section 2.5.2.1.1.

8.4.1.3 CE102 – Differential Mode Current Emission Limits

The TWTA **shall** not produce reflected ripple greater than the limits from 150 KHz to 50 MHz shown in Figure 8-1, when power leads are tested to the MIL-STD-462C CE03 test method as described in GSFC-STD-7000A, Section 2.5.2.1.1.

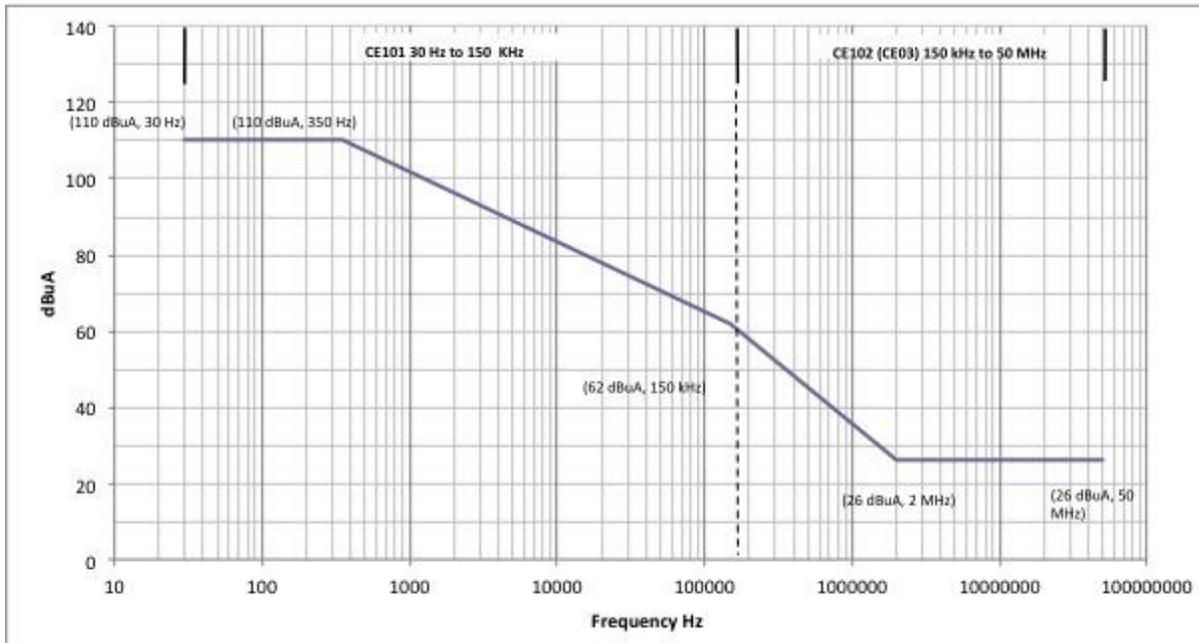


Figure 8-1 CE101/CE102 Differential Mode Current Emission Limits

8.4.1.4 Common Mode Bulk Current Emissions Limits

Common Mode Current Emissions (CMCE) from the TWTA power and return leads **shall** not exceed the limits from 150 kHz to 200 MHz, shown in Figure 8-2, referenced to chassis, when tested using an absorbing clamp per GSFC-STD-7000A, Section 2.5.2.1.2.

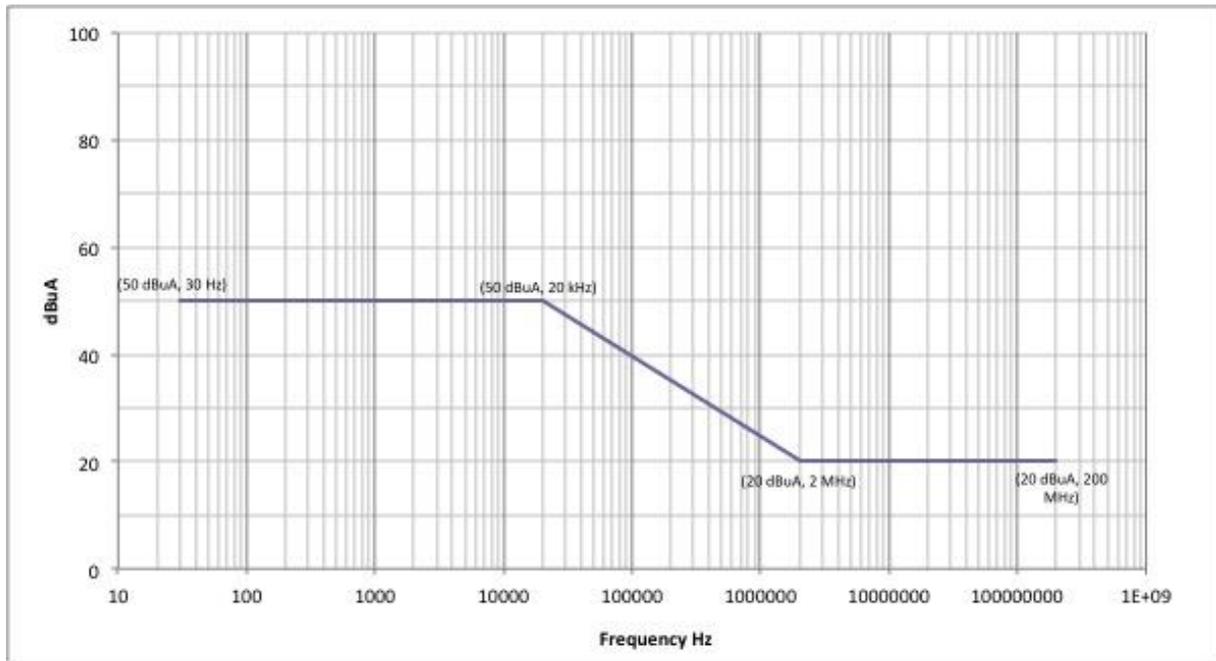


Figure 8-2 Common Mode Current Emission Limits

8.4.2 Conducted Susceptibility

Conducted susceptibility requirements are designed to ensure that any component connected to the spacecraft power bus is not unduly susceptible to noise expected to be present on the power bus.

8.4.2.1 Applicability of Conducted Susceptibility

The conducted susceptibility requirements are applicable for the primary power wires that supply power to a component. Conducted susceptibility requirements do not apply to the power return wires, secondary power wires or signal wires.

8.4.2.2 CS101 – Low Frequency Ripple

The TWTA **shall** meet performance requirements in the presence of a ripple voltage of 1 Vrms (2.8 V peak-to-peak) from 30 Hz to 150 kHz on the power bus.

The preferred method of verification is using the MIL-STD-461F CS101 test method as described in GSFC-STD-7000A, Section 2.5.2.2.1.

8.4.2.3 CS114 – Radio Frequency Ripple

The TWTA **shall** meet performance requirements in the presence of a ripple voltage of 0.5 Vrms (1.4V peak-to-peak) from 150 kHz to 400 MHz on the power bus.

MIL-STD-461F, CS114 “CS Power Lead” test, or MIL-STD-461C CS02 test could be used. If the CS114 method is chosen, the equivalent current limit is 15 mA (83.5 dB μ A) with 3 dB test margin. It should also be noted that the upper frequency limit for the CS114 test method is 50 MHz, therefore CS02 is required for frequencies above 50 MHz.

8.4.2.4 CS106 – Power Transients

The TWTA **shall** meet performance requirements when subjected to positive and negative 10 volt spikes injected on the positive power lead with the wave shape in Figure 8-3, applied per the MIL-STD-462 CS06 test method as defined in GSFC-STD-7000A, section 2.5.2.2.3.

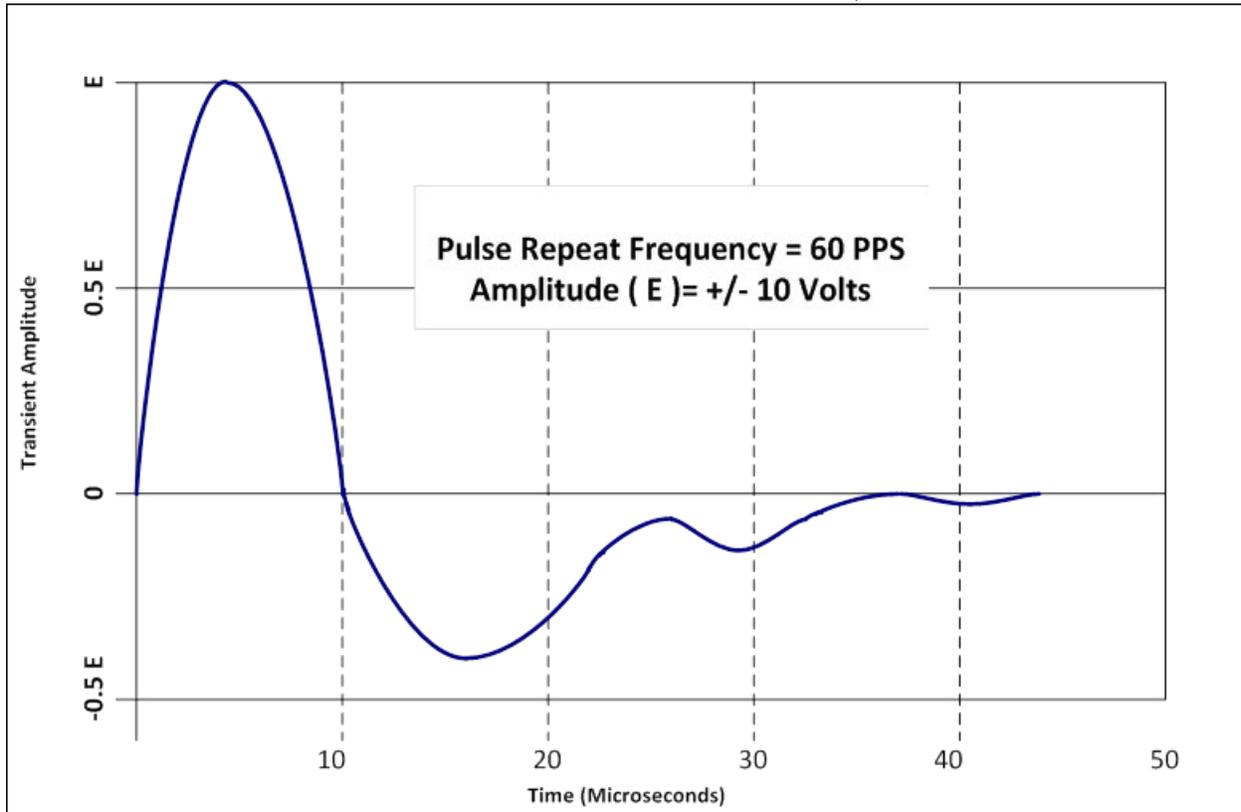


Figure 8-3 CS106 Transient Waveform

8.4.2.5 CS114 – Power and Signal Cables, Common Mode

The TWTA **shall** meet performance requirements when power cables are subjected to the limits shown in Figure 8-4 from 10 kHz to 200 MHz per the MIL-STD-461F CS114 test method (Common Mode) as defined in GSFC-STD-7000A, section 2.5.2.2.4.1.

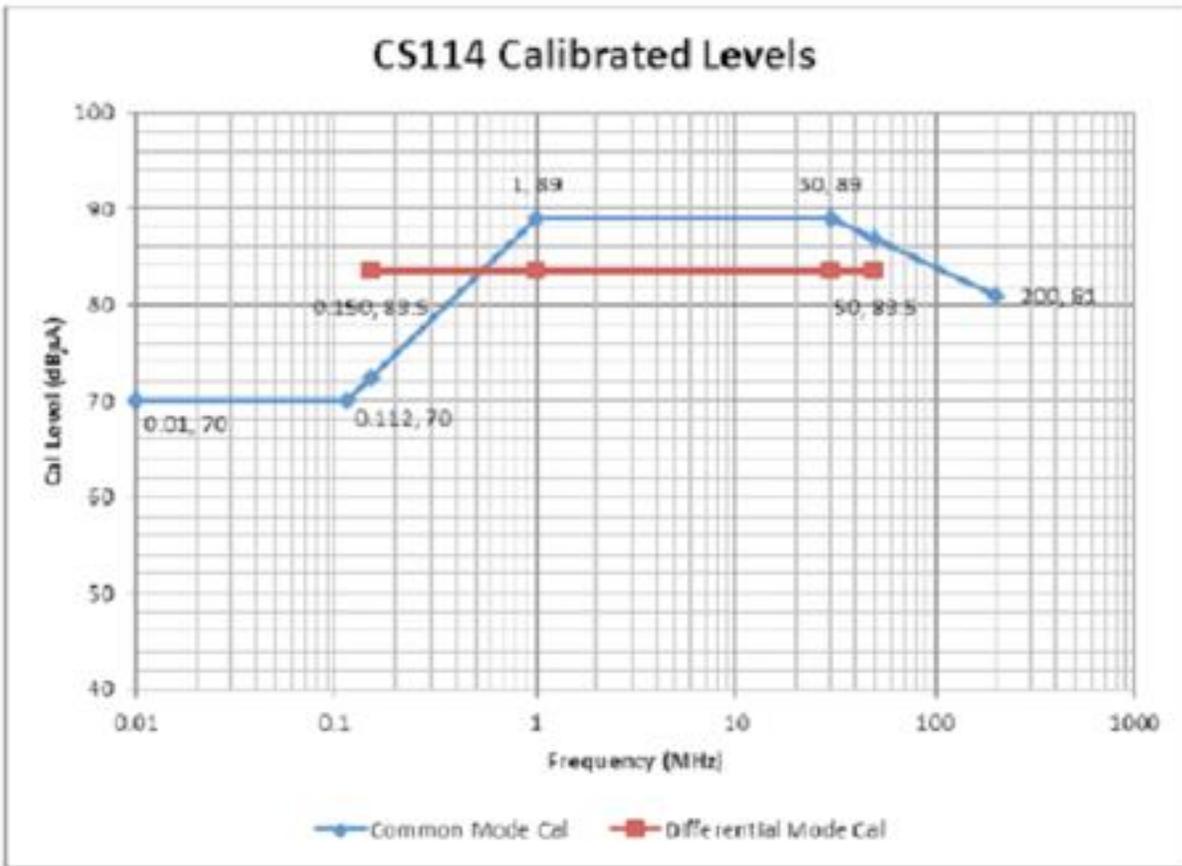


Figure 8-4 Bulk Cable Injection (CS114) Calibrated Test Levels

8.4.3 Radiated Emissions

Radiated emission requirements are designed to prevent excessive noise from being radiated by the spacecraft components.

8.4.3.1 RE102 - Electric Field Emissions

The TWTA electric field emissions **shall** not exceed the limits of Figure 8-5 and Table 8-3 when tested per the MIL-STD-461F RE102 test method as defined in GSFC-STD-7000A, section 2.5.2.3.2.

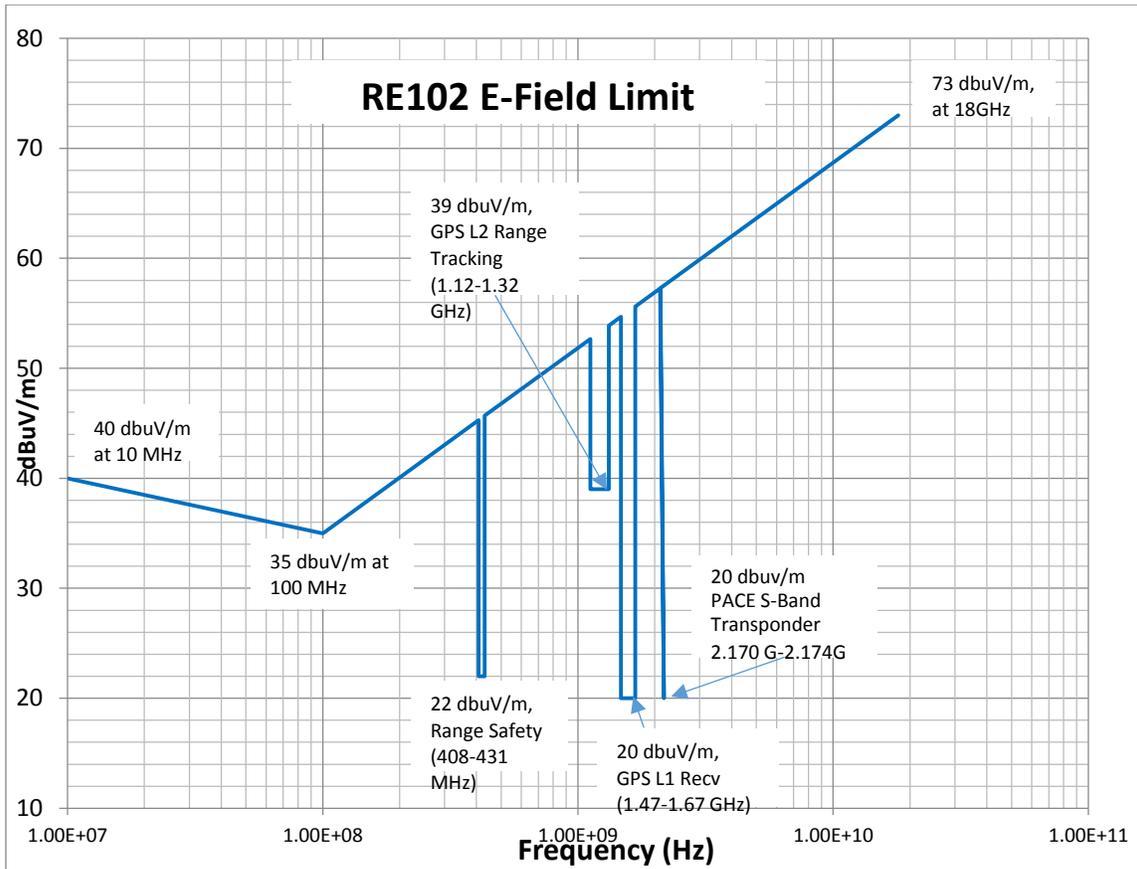


Figure 8-5 Component Level RE102 Radiated Electric Field Emission Limits

Table 8-3 Receiver Notch RE102 Test Limit Levels (TBR)

Frequency (MHz)	Limit Level (dB μ V/m)	6dB Resolution Bandwidth (Hz)	Receiver Protected
408 to 431	22	100K	LV-FTS
1127 to 1327	39	1000	LV-GPS L2
1475 to 1675	20	1000	SC-GPS-L1; LV-GPS-L1
2170 to 2174 (TBR)	20	1000	SC-CMD

8.4.4 Radiated Susceptibility

Radiated susceptibility requirements are designed to ensure that spacecraft components are not unduly susceptible to radiated noise emanating from the observatory and other sources.

8.4.4.1 RS103 - Electric Field

The TWTA **shall** not exhibit any malfunction, degradation of performance, or deviation from the specified indications, beyond the tolerances indicated in their individual specifications, as a result of being irradiated with electric field levels specified in Table 8-4 when tested per the MIL-STD-461F RS103 test method as defined in GSFC-STD-7000A, section 2.5.2.4.2.

Table 8-4 RS103 Radiated Susceptibility Levels

Frequency	E-Field V/m
14 KHz to 1.0 GHz	20
1.0 GHz to 18.0 GHz	20
2.2 GHz to 2.3 GHz	40 (Antares)*
2.211 GHz (LV S-Band)	66 (Atlas V)*
5.4 GHz to 5.9 GHz	50 (Antares)*
5.755 GHz to 5.775 GHz (LV C-Band)	101 (F9)*
26.045 GHz to 26.645 GHz (PACE Ka-band)	14
	*LV levels with TWTA powered off. Verification by analysis acceptable

8.4.5 RF Component Unique Tests

8.4.5.1 CE106 – Conducted Emissions, Antenna Terminals

Conducted emissions appearing at antenna terminals (CE106) **shall** not exceed 34 dB μ V for receivers, transmitters in standby mode, or amplifiers in standby mode, from 200 MHz to 10 GHz.

Conducted emissions appearing at antenna terminals (CE106) for transmitters and amplifiers in transmit mode **shall** not exceed these values: Harmonics, except the second and third, and all other spurious emissions are to be at least 80 dB down from the level at the fundamental. The second and third harmonics are to be suppressed to a level of -20 dBm or 80 dB below the fundamental, whichever requires less suppression.

Conducted emissions at antenna terminals (CE106) **shall** be conducted per GSFC-STD-7000A, section 2.5.2.1.4.

8.5 IDENTIFICATION AND MARKING

Each TWTA **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 COR.

All markings **shall** use alcohol proof ink, engraving, or laser etching.

8.6 WORKMANSHIP

8.6.1 Workmanship Standards

The workmanship standards and processes outlined in the SOW **shall** be used.

8.6.2 Connector

8.6.2.1 Reserved

8.6.2.2 Prevention of Connector Mismatching

Connector mismatching prevention requirements are identified in this section.

8.6.2.2.1 Connector Uniqueness

Physically adjacent connectors **shall** be of different sizes or of different sexes or uniquely keyed to facilitate proper mating.

8.6.2.2.2 Connector Facing

Physically adjacent Rectangular “D” connectors should not face the same way.

8.6.2.2.3 Connector Keying

Circular connectors **shall** be positively keyed.

8.6.2.2.4 Accessibility

The TWTA Spacecraft interface connectors **shall** be spaced far enough apart to allow the mate and demate operations to be performed without a special tool.

8.6.2.2.5 Connector Gender

The connector half that sources power to another TWTA **shall** be female (socketed) to protect against inadvertent grounding prior to mating.

8.6.2.3 Test Connectors

Wherever possible, TWTA power **shall** not be applied or accessed at or through a test connector.

8.6.2.4 Connector Identification

Each connector **shall** be labeled and clearly visible to facilitate proper mating.

8.6.2.5 Protection of Unused Test Connectors

Test connectors **shall** be capped with flight-approved RF and static control covers when not in use.

8.6.2.6 Connector Savers

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

8.7 RELIABILITY AND MISSION LIFETIME

8.7.1 Mission Life

The TWTA shall meet the design specification through two (2) years of ground testing and six (6) years of operation in space, following a two (2) month commissioning period.

The TWTA shall meet the on-orbit lifetime after a ground storage phase lasting up to 5 years.

8.7.2 Operating Time

8.7.2.1 Total Time

The TWTA **shall** accumulate a minimum of 400 hours of operating time prior to delivery to NASA GSFC.

8.7.2.2 Failure Free Time

The TWTA **shall** demonstrate failure-free performance for the last 200 hours of operation prior to delivery to NASA GSFC.

The TWTA **shall** receive at least 32 hours of failure free operating time in vacuum at the hot dwell temperature and 32 hours of failure free operating time at the cold dwell temperature prior to delivery to NASA GSFC.

8.7.3 Mean Time to Failure

The TWT shall have a Mean Time To Failure (MTTF) of greater than 20,000,000 hours (50 Failure In Time (FITs)) at an average interface temperature of +30°C.

The EPC shall have MTTF of greater than 2,267,000 hours (~441 FITs) at an average interface temperature of +30°C.

8.7.4 Operating Times

The TWTA **shall** operate in a non-continuous mode. For PACE, during each orbital period (approximately 98 minutes) the TWTA is enabled 1-2 times for 9 minutes during each period. This operation continues during the entire mission lifetime. This operation results in a duty cycle of approximately 8-25%. For WFIRST, the TWTA will be ON for up to 16 hours per day continuously.

8.7.5 On/Off Cycles

The TWTA **shall** meet performance requirements through at least 64,000 power cycles throughout its lifetime.

9.0 MECHANICAL DESIGN REQUIREMENTS

For additional guidance on the design and analysis of threaded fastening systems in NASA spaceflight hardware, consult NASA-STD-5020, Requirements for Threaded Fastening Systems In Spaceflight Hardware.

9.1 STRUCTURAL REQUIREMENTS

The TWTA **shall** be capable of withstanding all worst-case load conditions to which it may be exposed, without requiring additional recalibration or realignment and by maintaining structural integrity (i.e., positive structural margins). This includes handling and transportation, test, pre-launch operations, launch, and on-orbit operations.

Structural margins **shall** be expressed using the following formula:

$$MS = \frac{(Allowable\ Load\ or\ Stress)}{(Factor\ of\ Safety) \times (Limit\ Load\ or\ Stress)} - 1$$

9.1.1 Component Fatigue

Thin-walled, highly loaded metallic TWTA components serving as springs, flexures and other compliance devices under cyclic loading **shall** show sufficient fatigue strength for 4 times the number of mission cycles (including ground testing, launch and on-orbit loading).

9.1.2 Fracture Control Requirements

The use of materials that are susceptible to brittle fracture or stress-corrosion cracking require development of, and strict adherence to, special procedures to prevent problems.

If materials are used for structural applications that are not listed in Table 1 of MSFC-STD-3029, a Materials Usage Agreement (MUA) **shall** be approved by the COR.

Fracture control requirements (per NASA-STD-5019) **shall** apply to the following elements only:

- (1) Pressure vessels, dewars, lines, and fittings (per NASA-STD 8719.24)
- (2) Castings (unless hot isostatically pressed and the flight article is proof tested to 1.25 times limit load)
- (3) Weldments
- (4) Parts made of materials on Tables II or III of MSFC-STD-3029 if under sustained tensile stress
- (5) Parts made of materials susceptible to cracking during quenching
- (6) Nonredundant, mission-critical preloaded springs loaded to greater than 25 percent of ultimate strength

All glass elements that are stressed above 10% of their ultimate tensile strength **shall** also be shown by fracture analysis to satisfy "Safe-life" or "Fail-safe" conditions or be subjected to a proof loads test at 1.0 times limit level.

9.2 FASTENING SYSTEMS

9.2.1 Fastener Performance Analysis

9.2.1.1 Factors of Safety

Factors of safety for fastener strength analysis **shall** be as specified in Table 6-1.

9.2.1.2 Supplemental Factor

A supplemental factor, referred to as a fitting factor (greater than or equal to 1.0), **shall** be applied. See NASA-STD-5020, section 4.1(b) as a reference.

9.2.1.3 Ultimate Design Loads

All threaded fastening systems **shall** withstand ultimate design loads in conjunction with the applicable maximum expected range of environmental conditions without rupture.

9.2.1.4 Yield Design Loads

All threaded fastening systems **shall** withstand yield design loads in conjunction with the applicable maximum expected range of environmental conditions without detrimental yielding. Detrimental yielding is yielding that affects the fit, form, function, or integrity of the structure. See NASA-STD-5020, section 6.3 as reference.

9.2.1.5 Design Separation Load

Mechanical joints using threaded fastening system hardware **shall** withstand the design separation load in conjunction with applicable maximum or minimum temperatures without separation, using a separation factor of safety (FS_{sep}) of 1.0 for non-separation critical joints, $FS_{sep}=1.25$ for non-catastrophic separation critical joints, and $FS_{sep}=1.4$ for catastrophic separation critical joints. See NASA-STD-5020, section 4.3 for reference.

NOTE: A separation critical joint is one that would not function properly if separated; e.g., a fluid or gas would penetrate a seal at an unacceptable rate, or an instrument would fail to perform properly due to misalignment. Further, 'catastrophic' here refers to risk/loss of human life, such as could occur if a pressurized component failed or released a toxic substance due to joint separation.

NASA-STD-5020 Section 6.5 provides criteria for separation analysis and guidance for fitting factor application.

9.2.2 Fastener Locking and Retention

9.2.2.1 Locking Features

9.2.2.1.1 Locking Feature Minimum

Regardless of the magnitude of preload, each threaded fastening system in spaceflight hardware **shall** incorporate a minimum of one locking feature that does not depend upon preload to function.

Devices such as jam nuts may not be suitable locking features to satisfy this requirement if they require preload to function effectively, or if a change in preload could compromise the locking performance. A redundant locking feature may be advisable for some joints as described in FAA AC 20-71, "Dual Locking Devices on Fasteners".

9.2.2.1.2 Locking Feature Verification

Locking features **shall** be verifiable per Section 7.6 of NASA-STD-5020.

9.2.2.1.3 Locking Feature Installation

Mechanical locking features such as cotter pins, safety wire, and safety cable, **shall** be installed per National Aerospace Standard NASM 33540, "Safety Wiring, Safety Cabling, Cotter Pinning, General Practices for", and Society of Automotive Engineers International SAE AS567, "Safety Cable, Safety Wire, Key Washers, and Cotter Pins for Propulsion Systems, General Practices for Use of".

9.2.2.1.4 Snap Ring & Cotter Pin Use Limitation

Snap rings and cotter pins **shall** not be used where other acceptable retention methods are possible.

9.2.2.1.5 Snap Ring & Cotter Pin Use

Where use of snap rings or cotter pins cannot be avoided, new snap rings or cotter pins **shall** be used once the previous snap ring or cotter pin is removed.

9.2.2.1.6 Liquid Locking Compounds

When a liquid locking compound is used, it should be applied using a formal, validated process that addresses, where appropriate, the following link layer component (LLC) sensitivities: (1) quantity and coverage of LLC, (2) fastener and joint material, (3) thread size, (4) fastener preload, (5) all environmental conditions, (6) specified process for cleaning threads, (7) specified process for application of primer to threads, (8) specified process for applying LLC to threads, and (9) break-torque strength in comparison with LLC's manufacturer-stated capability.

9.2.2.2 Verification

9.2.2.2.1 Torque Measurement

Prevailing torque features, such as deformed thread features, pellets, strips, or patches, **shall** be verified by torque measurement during the installation process.

9.2.2.2.2 Witness Coupons

Adhesive locking features dependent upon substrate and/or configuration for cure, such as anaerobic liquid locking compounds, **shall** be verified by torque measurements on witness coupons that are representative of and processed with the hardware being verified.

9.2.2.2.3 Cure Samples

All other adhesive locking features **shall** be verified using cure samples processed at the time of application/processing.

9.2.2.3 Locking Features

9.2.2.3.1 Specification

Locking features and their installation processes, including verification methods, **shall** be specified in the engineering documentation.

9.2.2.3.2 Validation

When using locking adhesives, whether as thread-locking compounds or staking materials, installation processes **shall** be developed and validated prior to implementation to ensure adhesives cure, adhere, and function as expected; see 541-WI-5330.1.41 for specific instructions

It should be recognized that some locking features are not a means of maintaining preload, but rather are safety devices principally intended to resist rotational loosening and prevent loss of fasteners. Examples of the selection of locking features are provided in Appendix B of NASA-STD-5020.

9.2.2.4 Installation Torque Specification and Control

9.2.2.4.1 Installation Torque Range

The engineering documentation **shall** specify the installation torque range or specify an applicable standard that defines the installation torque range

9.2.2.4.2 Running Torque Identification

The engineering documentation **shall** clearly identify when the installation torque is the torque above running torque

9.2.3 Fastened Joints Criteria

9.2.3.1 Minimum and Maximum Preload

Analysis of threaded fastening systems **shall** address maximum and minimum preloads per NASA-STD-5020 Section 6.1.

9.2.3.2 Analysis Addressing Potential Rupture

Analysis for ultimate design loads **shall** address potential rupture in all elements of the threaded fastening system, including the fastener, the internally threaded part, such as a nut or an insert, and the clamped parts. Additional explanation can be found in NASA-STD-5020, Section 6.2.

9.2.3.3 Ultimate Strength Analysis

Ultimate strength analysis of a fastening system under applied tensile loading **shall** be performed per NASA-STD-5020, Section 6.2.1.

9.2.3.4 Applied Shear Loading

Ultimate strength analysis of a fastening system under applied shear loading **shall** be performed per NASA-STD-5020, section 6.2.2.

9.2.3.5 Shear Loading

Ultimate strength analysis of bolts under shear loading **shall** be based on the assumption that no shear load is carried by friction between the faying surfaces.

9.2.3.6 Simultaneous Applied Tensile and Shear Loads

For fasteners under simultaneous applied tensile and shear loads, along with any applicable bending, analysis **shall** account for interaction of the combined loading. See the equations contained in NASA-STD-5020, section 6.2.3 for reference.

9.2.3.7 Allowable Yield Tensile Load

If one or more of the following applies:

- a. Fastener yielding causes the joint to separate under an applied tensile load that is less than the design separation load
- b. Fastener yielding causes the joint to suffer detrimental slip under an applied shear load that is less than the applicable design shear load
- c. Some other design-specific reason exists for why fastener yielding is detrimental (e.g., any fastener yielding that adversely affects the form, fit, or function of the design)

then fastener yielding is detrimental and analysis **shall** be performed per NASA-STD-5020, Section 6.3, to show the fastener's total tensile load, when accounting for maximum preload and the yield design tensile load, does not exceed the allowable yield tensile load.

9.2.3.8 Separation Analysis

Analysis **shall** be performed per NASA-STD-5020, Section 6.5 showing no separation for each threaded fastening system that is subject to applied tensile loading, with the assumption of minimum preload.

9.2.3.9 Seal Analysis

For a joint that maintains a seal (e.g., to maintain pressure or contain a fluid), analysis **shall** show that the seal meets its requirements at the design separation load when assuming minimum preload for all fasteners in the joint.

10.0 RESERVED

11.0 VERIFICATION REQUIREMENTS

The contractor **shall** conduct a verification program that demonstrates the hardware design is qualified and meets all requirements contained in this document. Per the SOW (PACE-COMM-SOW-0021), the contractor will provide a verification matrix defining the method of verification for each specific requirement of this document.

11.1 VERIFICATION METHODS

Verification methods include inspection, analysis, as well as environmental, functional, and performance testing, or a combination of these techniques.

11.1.1 Inspection

Verification by inspection includes (but is not limited to) visual inspection, simple physical manipulation, gauging, measurement, and documentation examination.

11.1.2 Analysis

Verification by analysis will be used to show design margins. Also, when the particular tests required for verification are impractical, risky, unacceptably long, or prohibitively expensive, analysis may be used instead of testing, as noted in the verification matrices.

Analysis, including simulations where applicable, will also be used to guarantee that the TWTA and its components will perform as expected under worst-case conditions.

11.1.3 Test

Verification by test includes, but is not limited to, the evaluation of performance by use of special equipment or instrumentation, simulation techniques, and the application of established principles and procedures to determine compliance with requirements.

11.2 INSPECTION REQUIREMENTS

Verification by inspection **shall** be by one of these three methods: 1) visual inspection of the physical hardware; 2) a physical measurement of a property of the hardware, or; 3) a documentation search demonstrating hardware of an identical design has demonstrated fulfillment of a requirement.

11.2.1 Visual Inspection

Visual inspection of the physical hardware **shall** be performed by a customer appointed qualified inspector certifying that the hardware has the properties/configuration specified in the requirement.

11.2.2 Physical Measurement

Physical measurement of hardware property (i.e. mass, dimensions, etc.) **shall** be performed by a customer appointed qualified inspector demonstrating the hardware meets specific requirement.

11.2.3 Documentation Search

Verification of requirements based on similarity **shall** include supporting rationale and documentation and **shall** be approved by the COR

11.3 ANALYSIS REQUIREMENTS

Verification of performance or function through detailed analysis, using all applicable tools and techniques, is acceptable with COR approval. Detailed descriptions of the minimum required analyses, as well as analysis requirements, are provided in the SOW.

11.4 TEST REQUIREMENTS

This section provides general test requirements on how testing is to be performed in the process of verifying that the deliverable item meets its requirements. 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 degradation of performance trend within specification limits that could result in unacceptable performance in flight.

Any requirement that exceeds previous qualification test data **shall** be presented to the PACE project as part of the verification planning process described in the SOW, for evaluation and a possible delta qualification test.

11.4.1 Definitions

The hardware definitions are reproduced here from Section 1.8 of GEVS (GSFC-STD-7000A).

Protoflight Hardware: “Flight hardware of a new design; it is subject to a qualification 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.” The purpose of the test on this hardware is to prove that a new design meets one or more of its design requirements. Protoflight testing is performed at maximum expected flight levels plus a margin. Test durations are typically the same as for acceptance tests.

Follow-On (Acceptance) Hardware: “Flight hardware built in accordance with a design that has been qualified either as prototype or as protoflight hardware; follow-on hardware is subject to a flight acceptance test program.” The purpose of the test on this hardware is to prove that a particular flight unit has been manufactured properly. The design has already been proven during a qualification or protoflight test program. Acceptance testing is performed at maximum expected flight levels.

11.4.2 Test Factors

The following test factors and durations, shown in Table 11-1, **shall** be used for prototype, protoflight, and follow-on flight hardware.

Table 11-1 Test Factors and Durations

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

- (1) Sine burst testing **shall** be done a frequency sufficiently below primary resonance as to ensure rigid body motion.
- (2) If qualified by analysis only, positive margins must be shown for factors of safety of 2.0 on yield and 2.6 on ultimate. Beryllium and composite materials cannot be qualified by analysis alone. Test levels for beryllium and composite structure, including metal matrix, are 1.25 x Limit Level for both qualification and acceptance testing.
- (3) Unless otherwise specified these sine sweep rates **shall** apply.

11.4.3 Test Tolerances

Tolerances for the various mechanical test parameters are given in Table 11-2.

Table 11-2 Test Tolerances

Test	Test Parameter	Tolerance
Temperature		± 2 °C
Humidity		± 5% RH
Loads	Steady-State (Acceleration):	± 5%
	Static:	± 5%
Mass Properties	Weight:	± 25g
	Center of Gravity:	± 6 mm
	Moments of Inertia	± 10 %
	Products of Inertia	± 10 %

Mechanical	Response Spectrum: Simulated ($f \leq 3\text{kHz}$) Simulated ($f \geq 3\text{kHz}$) Shaker	$\pm 6\text{ dB}$ $+9/-6\text{ dB}$ $\pm 3\text{ dB}$
Shock	Time History:	$\pm 10\%$
Pressure	$>1.3 \times 10^4\text{ Pa}$ ($> 100\text{ mm Hg}$): 1.3×10^4 to $1.3 \times 10^2\text{ Pa}$ (100 mm Hg to 1 mm Hg): 1.3×10^2 to $1.3 \times 10^1\text{ Pa}$ (1 mm Hg to 1 micron): $< 1.3 \times 10^1\text{ Pa}$ ($< 1\text{ micron}$):	$\pm 5\%$ $\pm 10\%$ $\pm 25\%$ $\pm 80\%$
Vibration	Sinusoidal: Amplitude Frequency Random: RMS Level Accel. Spectral Density	$\pm 10\%$ $\pm 2\%$ $\pm 10\%$ $\pm 3\text{ dB}$

11.4.4 Test Restrictions

11.4.4.1 Failure During Tests

When a failure (non-conformance or trend indicating that an out-of-spec condition will result) occurs, determination will be made as to the feasibility and value of continuing the test to its specified conclusion. 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. If corrective action is taken, the test will be repeated to the extent necessary to demonstrate that the test item’s performance is satisfactory. If corrective action taken as a result of failure affects the validity of previously completed tests (e.g., redesign of a component), prior tests will be repeated.

If during a test sequence, a test item is operated in excess of design life and wears out or becomes unsuitable for further testing from causes other than deficiencies, a spare will be substituted, and previously completed tests will be repeated to the extent necessary.

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 necessary to assure its proper operation. A complete record of any exceptions taken to this requirement **shall** be included in the test report.

11.4.4.2 Modification of Hardware

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

11.4.4.3 External Adjustment

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

11.4.4.4 Re-Test Requirements

If any event, including test failure, requires that the TWTA 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.

11.5 REQUIRED TESTS

The following tests are required for each TWTA to provide assurance that the TWTA meets all of its requirements. Each test or demonstration is described below:

- Performance Testing
- Mass Properties
- Static Load/Strength
- Sine Sweep Survey
- Sine Vibration
- Random Vibration
- Shock (if analysis shows it is required)
- Electromagnetic Compatibility
- Thermal Vacuum Bake-Out
- Thermal Vacuum

11.5.1 Performance Tests

11.5.1.1 Comprehensive Performance Test

The Comprehensive Performance Test (CPT) will be used to verify full compliance of each flight unit to all of its performance requirements, within the limitations of the environment and facilities. The CPT will be designed to verify unit performance in all modes and configurations and under varying input/output conditions.

11.5.1.2 Limited Performance Test

The Limited Performance Test (LPT) is a subset of the CPT and is designed to verify functionality of the flight unit under nominal input/output conditions. The LPT will be used to verify unit operation when it is not practical to use the CPT. Typically, it is used during and after certain environmental tests to demonstrate that the functional capability of the component has not been degraded due to environmental exposure, handling, and transportation. It is also commonly used during some of the hot and cold plateaus during thermal vacuum testing.

11.5.1.3 Abbreviated Functional Test

An Abbreviated Functional Test (AFT) may be used when it is necessary to monitor the performance of the flight unit over a very short period of time. The AFT is typically used when a unit is being subjected to vibration testing.

11.5.2 Mass Properties Measurement

Measurement of the weight and center of gravity of each flight hardware component will be made to show compliance with requirements and to provide accurate data for the observatory mass properties control program. Center of gravity at the component level will be referenced to the component to spacecraft mounting interface.

11.5.3 Static Loads/Strength Test

Strength testing is used to verify the component strength and structural integrity (beryllium and composite materials cannot be qualified by analysis alone), and it can be done using a variety of techniques, such as sine burst, static pull, or centrifuge testing.

Structural design loads **shall** be applied to 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).

No permanent deformation may occur as a result of the loads test, and all applicable alignment requirements must be met following the test. Units that require alignment will have an alignment check following loads testing.

The TWTA **shall** be powered during static loads tests if the item will be powered during launch.

A performance test **shall** be conducted after the static loads test to verify that no damage occurred due to the loads test.

A functional test **shall** be performed before the start of testing and after a test in each axis if sine burst is used.

11.5.3.1 Sine Burst

If sine burst test is selected, the test will be performed in each of three orthogonal component axes. A simple Sine Burst test following the random vibration test in each axis is a convenient method to conduct a structural loads test. Test frequency will be less than one-third of the resonant frequency of the component to avoid dynamic amplification during test. This test applies a ramped sine input at a sufficiently low frequency such that the test item moves as a rigid body. The test will be conducted in a stepwise manner starting with lower level sine-bursts that are fractions of the full load. 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. The number of cycles at maximum level will be at least 5.

11.5.3.2 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 the TWTA 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. The Test Duration **shall** be at least 30 seconds.

11.5.4 Sine Sweep Survey

The Sine Sweep **shall** be conducted on the TWTA before and after vibration testing in each axis. A low-level sine sweep is used to determine the modal signature of the flight item to verify compliance with fundamental frequency requirements, and to verify no change in structural integrity from testing. Test parameters will be as follows:

- Frequency: 5 - 2000 Hz
- Acceleration: 0.25 g
- Sweep Rate: 2 octaves/minute

This test will be performed immediately preceding the sine/random vibration tests and will be repeated after the sine/random vibration tests to verify that the modal signature of the unit under test (first resonant frequency) is within 5% of the pre-test frequency. In this case, the unit has passed and the test can continue. If the post-test frequencies are between 5% and 10% of the pre-test frequencies, the cause of the shift should be investigated (test bolt torques, etc.) before determining whether failure has occurred or success has been achieved and whether the test can continue. A shift of greater than 10% indicates failure, and the test should be terminated, and the failure documented. In either case when the shift is greater than 5%, NASA/GSFC **shall** be notified.

Frequencies **shall** be verified and reported up to 200 Hz. Any component that fails to meet the fundamental frequency requirements specified in Section 6.3.1 is required to submit a test-correlated model. If a test-correlated model is required, all significant modes up to the required frequency must be determined both in terms of frequency and mode shape. A mode is considered significant if it has modal effect mass $\geq 5\%$ of the total mass of the hardware at the level of assembly for which the modal survey is being considered. Modes that drive high responses of critical components from a coupled loads analysis should also be considered as target modes for a modal survey. Cross-orthogonality checks of the test and analytical mode shapes, with respect to the analytical mass matrix, shall be performed with the goal of obtaining at least 0.9 on the diagonal and no greater than 0.1 off-diagonal for acceptable model correlation. Frequencies between the corresponding test and analytical modes shall also match within 5%.

11.5.5 Sine Vibration

The TWTA **shall** be subjected to swept sine vibration testing to the appropriate levels and durations shown in the mechanical requirements section.

Sine vibration test is intended to verify workmanship quality and to simulate launch vehicle loading conditions. The test will consist of a low frequency sine transient or sustained sine environment that would be present in launch by minimum modal frequency in each of three mutually perpendicular axes, one of which is normal to the mounting surface.

For the sine vibration tests, the unit under test will be attached to the vibration table using the same configuration, attachment points, preloads, and attachment hardware that will be used during launch and flight. Cross-axis responses of the fixture will be monitored to preclude unrealistic levels. During the test, the test input level will be reduced (notched) at critical frequencies, if required, to limit the vibration loads and/or acceleration responses to 1.25 times design limit levels. During the vibration test, the flight unit will be powered and critical signals monitored and recorded using recording instruments that have a response equal to or greater than the highest frequency of vibration (this requirement applies only to those units that are expected to be powered during launch). A functional test **shall** be performed before the start of testing and after a test in each axis.

11.5.6 Random Vibration

The TWTA **shall** be subjected to a random vibration test in each of three orthogonal axes of the unit under test, one axis being perpendicular to the mounting surface to the appropriate levels and durations shown in the environmental requirements section. Random vibration test is intended to demonstrate workmanship quality and to simulate launch vehicle aerodynamic environmental levels. During the test, the test input level will be reduced (notched) at critical frequencies, if required, to limit the random vibration loads and/or acceleration responses to 1.25 times design limit levels. Notching will be limited to -12 dB of the original input and to a bandwidth of less than 100 Hz to limit hardware responses to 3dB above design limit loads. Notching beyond these limits will require PACE project approval.

For the random vibration test, the unit under test will be attached to the vibration table using the same configuration, attachment points, preloads, and attachment hardware that will be used during launch and flight. 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. Cross-axis responses of the fixture will be monitored during the test to preclude unrealistic levels.

During the vibration test, the flight unit will be powered and critical signals monitored and recorded using recording instruments that have a response equal to or greater than the highest frequency of vibration (this requirement applies only to those units that are expected to be powered during launch). A functional test **shall** be performed before the start of testing and after a test in each axis.

11.5.7 Reserved

11.5.8 Reserved

11.5.9 Shock

Shock test is designed to verify that flight hardware will survive expected shock events such as observatory separation, solar array deployment, etc.

The shock test at the component level is not required if previous qualification data showing adequate margin exists or it can be shown by analysis that expected (attenuated) shock levels are enveloped by the curve presented in Figure 6-3. Items that are more likely to be shock sensitive include very brittle materials (e.g., glass, ceramics), wire bonds, sensors, transducers, and filters.

If the TWTA is deemed shock sensitive by the COR and margin (per Table 11-1) cannot be demonstrated based on prior testing, then a component level shock test **shall** be performed. Shock testing may be performed at the sub-component or part level so as to limit the test risk to the flight hardware. The component shock testing approach should be coordinated with the project and consistent with the approach described in Section 2.4.4.1 of GSFC-STD-7000A.

If the TWTA is not deemed shock sensitive by the COR, then qualification for the shock environment is not required, and the shock testing can be deferred to the level of assembly that allows for actuation of the actual shock-producing device.

11.5.10 Thermal Vacuum Bake-out

The TWTA **shall** be baked-out prior to delivery to NASA GSFC to reduce outgassing of contaminants to meet the requirements in Section 7.1.2.2.3 of this document and SOW Section 7.9.4.

The rate measured at the QCM **shall** be adjusted to account for chamber geometry, presence of cold sinks, chamber pumping speed, view factors of the QCM, and any other factors necessary to assure an accurate measurement of the total outgassing per unit time per Kg mass of the unit under test.

11.5.11 Thermal Vacuum Test

11.5.11.1 Thermal Vacuum Test Parameters

Thermal vacuum testing **shall** be conducted in accordance with the requirements of Table 11-3.

Table 11-3 Thermal Vacuum Test Parameters

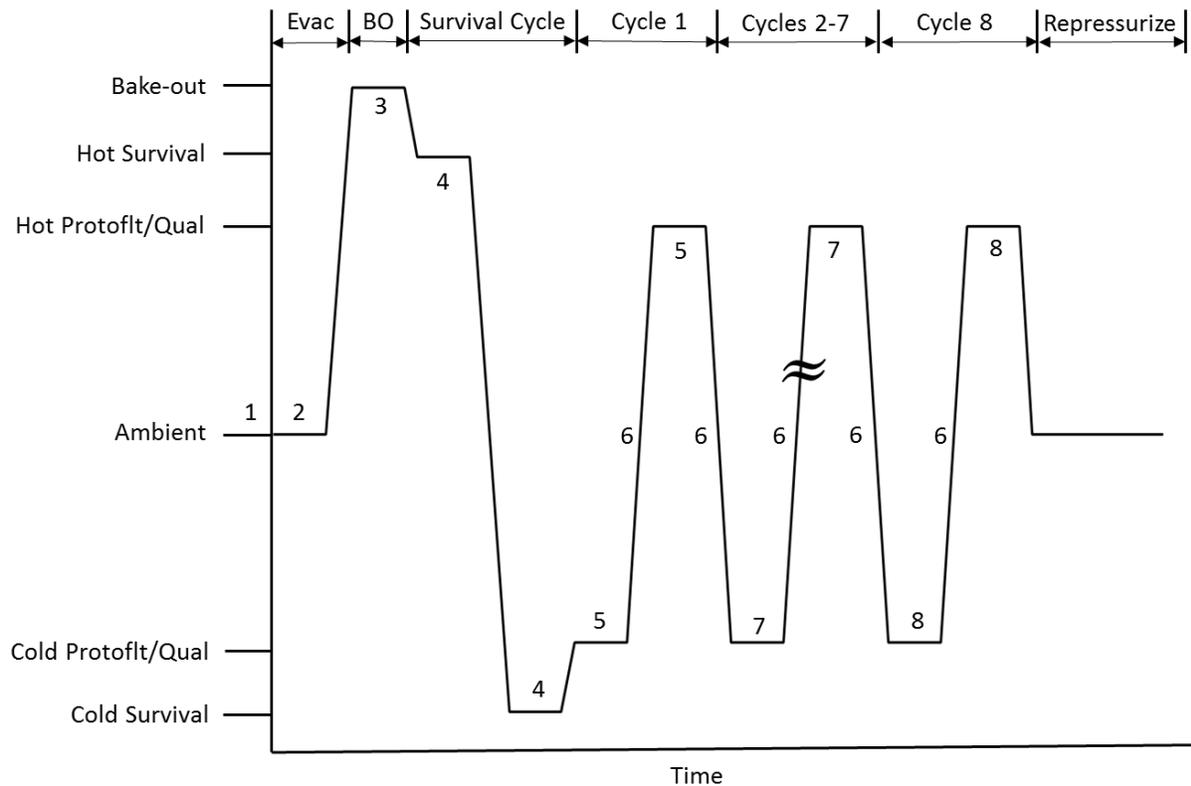
Parameter	Component Level
Chamber Pressure After Evacuation	< 1 x 10 ⁻⁵ Torr

Number of Cycles	8
Acceptance Temperature Limits (beyond operational limits)	5 °C
Proto-flight Temperature Limits (beyond operational limits)	10 °C
Temperature Rate of Change	2 – 4 °C per minute
Minimum Dwell Time (at cold and hot plateaus)	4 hrs
Cold/Hot Turn On of Components (at cold and hot plateaus)	Yes
Total Number of Comprehensive Performance Tests (at least one each at cold and hot plateaus)	≥ 2

11.5.11.2 Thermal Vacuum Test Profile

During Thermal Vacuum testing, the TWTA **shall** be in flight configuration, with the possible exception that items that do not involve mechanisms may remove their thermal blankets to speed the transition times between temperature extremes.

The TWTA **shall** apply the Thermal Vacuum Test profile shown in Figure 11-1.



- (1) A CPT will be performed prior to the start of chamber evacuation at nominal voltage of +32Volts.
- (2) The component will be powered and critical parameters monitored using the AFT during chamber evacuation. For RF components that are expected to be powered during launch, the absence of corona or multipaction effects will be verified.
- (3) Bake-out will be performed.
- (4) Unpowered survival soak will be performed.
- (5) Cold-start and hot-start capability will be demonstrated by performing CPTs at first cold and hot plateaus.
- (6) During the transition between temperature extremes, the component will remain powered and its performance will be monitored and recorded using the AFT.
- (7) LPTs will be performed after a soak period at the high/low temperature plateaus during Cycles 2-7. At least 1 LPT will be performed at minimum voltage at both hot and cold plateaus. At least 1 LPT will be performed at maximum voltage at both hot and cold plateaus.
- (8) Cold-start and hot-start capability will be demonstrated again at the eighth cold and hot plateaus using the redundant power input.

Figure 11-1 Thermal Vacuum Profile

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- 11.5.12 **Reserved**
 - 11.5.13 **Reserved**
 - 11.5.14 **Reserved**
 - 11.5.15 **EMI/EMC Tests**

EMC tests comprise emissions and susceptibility tests. Emissions tests are intended to verify that the flight unit does not generate either conducted or radiated interference that could hinder the operation of other components, and susceptibility tests are intended to verify that the flight unit will operate properly when subjected to conducted or radiated interference from other sources. It is encouraged to perform these EMI tests as early as possible in the development.

All tests **shall** be performed with the TWTA in its most sensitive mode for susceptibility testing and in its most noisy mode as appropriate for the EMI emission test.

11.5.15.1 Conducted Emissions Tests

The conducted emissions tests **shall** be performed on the primary (+32V) power and return leads that supply power to the TWTA (these tests do not need to be performed on secondary power wires or signal wires).

The conducted emissions tests **shall** be performed on all flight units.

11.5.15.2 Conducted Susceptibility Tests

The conducted susceptibility tests **shall** be performed on the primary power (+32V bus) wires that supply power to the TWTA (these tests do not need to be performed on the power return wires or secondary power wires or signal wires).

The conducted susceptibility tests **shall** be performed on all flight units.

11.5.15.3 Radiated Emissions Tests

The radiated emissions tests **shall** be performed on all flight units.

11.5.15.4 Radiated Susceptibility Tests

The radiated susceptibility tests **shall** be performed on all flight units.

APPENDIX A ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	Definition
AC	Alternating Current
AFT	Abbreviated Functional Test
Al	Aluminum
CCB	Configuration Control Board
CCR	Configuration Change Request
CE	Conducted Emissions
CG	Center of Gravity
CM	Configuration Management
CMO	Configuration Management Office
CMOS	Complementary Metal Oxide Semiconductor
COR	Contracting Officer's Representative
CPT	Comprehensive Performance Test
CS	Conducted Susceptibility
CVCM	Collected Volatile Condensable Mass
DA	Double Amplitude
DC	Direct Current
DDD	Displacement Damage Dose
DILS	Deliverable Items List and Schedule
EED	ElectroExplosive Actuators
EEE	Electrical, Electronic, and Electromechanical
ELDR	Enhanced Low Dose Rate
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EOL	End of Life
EPC	Electronic Power Conditioner
ESD	Electrostatic Discharge
FS	Factor of Safety
GeBK	Germanium Black Kapton
GSFC	Goddard Space Flight Center
HV	High Voltage
ICD	Interface Control Document
I&T	Integration and Test
ITO	Indium Tin Oxide
LET	Linear Energy Transfer
LPT	Limited Performance Test
LVDS	Low Voltage Differential Signal
MBU	Multi Bit Upset
MICD	Mechanical Interface Control Document

MLI	Multi-Layer Insulation
Mohms	Megaohms
MOP	Maximum Operating Pressure
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
MS	Margin of Safety
NASA	National Aeronautics and Space Administration
NEA	Non-Explosive Actuators
NIEL	Non-Ionizing Energy Loss
OSR	Optical Solar Reflector
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PDL	Product Design Lead
QCM	Quartz Crystal Monitor
RE	Radiated Emissions
RF	Radio Frequency
RS	Radiated Susceptibility
S/C	Spacecraft
SCoRe	Signature Controlled Request
SEB	Single Event Burnout
SEGR	Single Event Gate Rupture
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEL	Single Event Latchup
SEM	Scanning Electron Microscope
SERDES	Serializer/Deserializer
SEU	Single Event Upset
SHE	Single Hard Error
SOW	Statement of Work
SPL	Sound Pressure Level
TBD	To Be Defined
TBR	To Be Reviewed
TID	Total Ionizing Dose
TML	Total Mass Loss
TWT	Traveling Wave Tube
TWTA	Traveling Wave Tube Amplifier
UUT	Unit Under Test
VDA	Vapor Deposited Aluminum
VDC	Voltage, Direct Current