

SHAPE MEMORY ACTUATION AND RELEASE DEVICES

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Final Report

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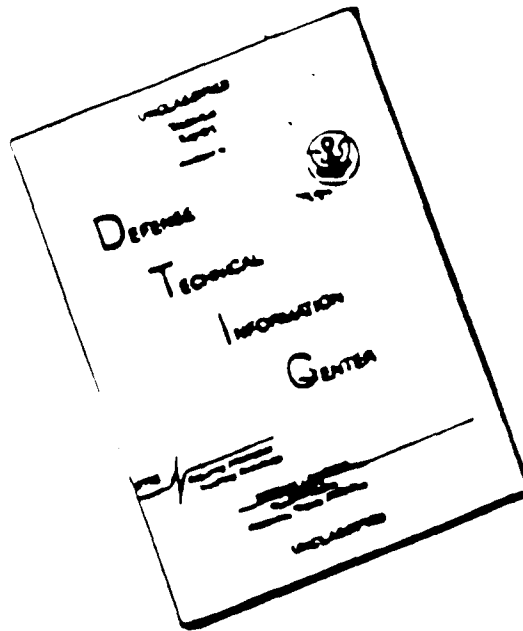
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EXECUTIVE SUMMARY

Spacecraft require a variety of separation and release devices to accomplish mission related functions. Current off-the-shelf devices such as pyrotechnics, gas-discharge systems, paraffin wax actuators, and other electro-mechanical devices may not be able to meet future design needs. The use of pyrotechnics on advanced lightweight spacecraft, for example, will expose fragile sensors and electronics to high shock levels and sensitive optics might be subject to contamination. Other areas of consideration include reliability, safety, and cost reduction. Shape memory alloys (SMA) are one class of actuator material that provides a solution to these design problems.

SMA's utilize a thermally active reversible phase transformation to recover their original heat treated shape (up to 8% strain) or to generate high recovery stresses (>700 Mpa) when heated above a critical transition temperature. NiTiCu alloy actuators have been fabricated to provide synchronized, shockless separation within release mechanisms. In addition, a shape memory damper has been incorporated to absorb the elastic energy of the preload bolt and to electrically reset the device during ground testing. Direct resistive heating of the SMA actuators was accomplished using a programmable electric control system. Release times less than 40msec have been determined using 90 watt-sec of power. Accelerometer data indicate less than 500 g's of shock were generated using a bolt preload of 1250 kgs.

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1.0 INTRODUCTION

Spacecraft require a variety of separation and release devices to accomplish mission related functions such as separation from the launch vehicle, deployment of solar arrays and other appendages. Existing technologies may not be able to meet mechanism requirements for future lightweight satellite programs. The use of pyrotechnics, for example, will expose fragile sensors and electronics to high shock levels and sensitive optics might be subject to contamination. A survey of pyroshock flight failures (Ref. 1) revealed 83 shock related anomalies out of 600 launches with over 50% of these resulting in catastrophic failure. More recently, NASA published a series of lessons learned (Ref. 2) and raised concern, for fracture of pyrotechnic components. In addition, pyrotechnics require special handling and storage procedures significantly increasing integration cost. The technologies described in this paper have broad applicability to Air Force, DoD, and NASA spacecraft.

Next generation release devices will be expected to provide near shockless separation while maintaining synchronization (short release time) with neighboring separation nuts. Also, these devices must act as direct replacements for existing technology to maintain "bolt on" compatibility with existing mechanical and electrical systems. Table 1-1 outlines the properties of common pyrotechnic, paraffin, and non-pyrotechnic releases along with a commercially available shape memory device and Lockheed Martin Corporation's Low Force Nut (LFN) and Two Stage Nuts (TSN). In general, each of these nuts have been based on 0.1 cm dia. (1/4 inch) bolts and operates using standard spacecraft power. The shape memory nut, which employs a shape memory actuator to fracture a structural element and consumes 2400 watt seconds, is acceptable for some spacecraft power systems. This particular device is lightweight and mechanically simple.

Table 1-1. Typical Release Mechanism Properties.

	LFN	TSN	Shape Memory	Pyro-technic	Non-Pyro-technic	Paraffin
Working Load (kg)	1300	2500	700	4000	2000	450
Voltage Range (volts)	24 to 36	24 to 36	24 to 36	5	22 to 31	24 to 36
Energy Requirements (watt sec)	90	90	2400	0.05	15	3000
Shock Output (g's)	<500	<200	2000	7000	5000	<200
Survival Temperature (°C)	50 to -40	50 to -40	TBD	71 to -73	121 to -150	115 to -180
Operational Temperature (°C)	40 to -20	40 to -20	50 to -50	71 to -73	121 to -150	115 to -180
Synchronization	Y	Y	N	Y	Y	N
Unit Weight (grams)	250	300	60	120	175	25 to 250
Separation Time (msec)	50	40	30 sec	2	20	20 to 300 sec
Redundancies	Y	Y	Y	Y	Y	Y
Resettable w/o Disassembly	Y	Y	N	N	N	Y

The pyrotechnic nut, the industry standard, consumes minimal power and has significant flight heritage. It produces high shock output and has special handling and storage requirements -- the principle reasons for developing the other devices in Table 1-1.

The non-pyrotechnic separation nut eliminates ordnance safety concerns, but generates significant shock. The mechanisms is environmentally insensitive operating over a broad temperature range.

Paraffin based actuators are in a different class compared to the other devices which are primarily used as shroud mounts. They do have wide utility as pin-pullers and single point release devices for a variety of spacecraft appendages. Paraffin based mechanisms have low force capability but produce low shock and are resettable without disassembly or removal from the spacecraft.

2.0 SEPARATION DEVICE DESIGN

2.1 SHAPE MEMORY ACTUATED LOW FORCE NUT

The low force nut (LFN) is a fully redundant shape memory (SM) actuated release device which produces negligible shock while maintaining a "synchronizable" actuation time. The existing (1/4 inch bolt) prototype can release a zero to 1300 kg preload within 40 msec. A standard mounting interface, with similar spatial, weight, and electrical features as "state of the practice devices" (e.g., pyrotechnic separation nuts), ensures easy integration into existing and future spacecraft systems. This mechanism also employs a SM reset spring which enables the device to be reset using electrical current. This feature allows ease of testing, no disassembly or need to remove it from the spacecraft, no debris and the ability to fly the device tested.

The design of the LFN uses mechanical advantages to reduce the required SMA initiation force. As shown in Figure 2-1, a redundant SM initiator spring strokes a plunger to unlock a ball and adjacent sleeve. A steel compression spring strokes the sleeve to unlock nut segments and the mating bolt. The SM reset spring dampens the impact shock of the sleeve, and is used to reset the device for multiple "firings".

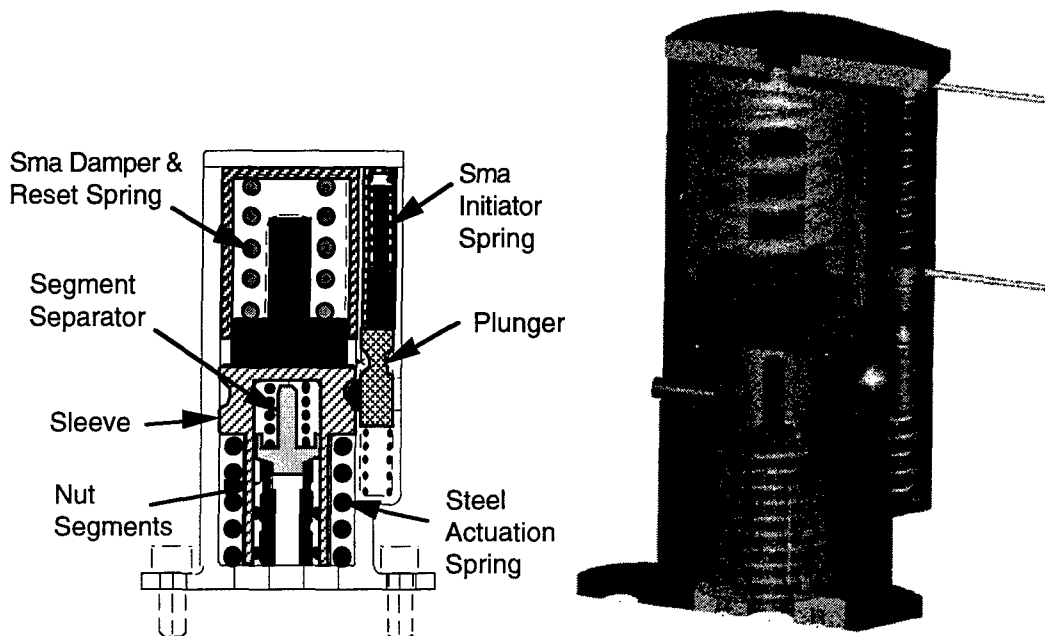


Figure 2-1. Shape Memory Actuated Low Force Nut.

The release time for the LFN may be tailored according to data provided in Figure 2-2. Release times of 50 msec may be obtained with 1200 watts. Power consumption is higher than either the pyrotechnic or non-pyrotechnic devices, however most spacecraft designs are able to accommodate the electrical load for the separation event.

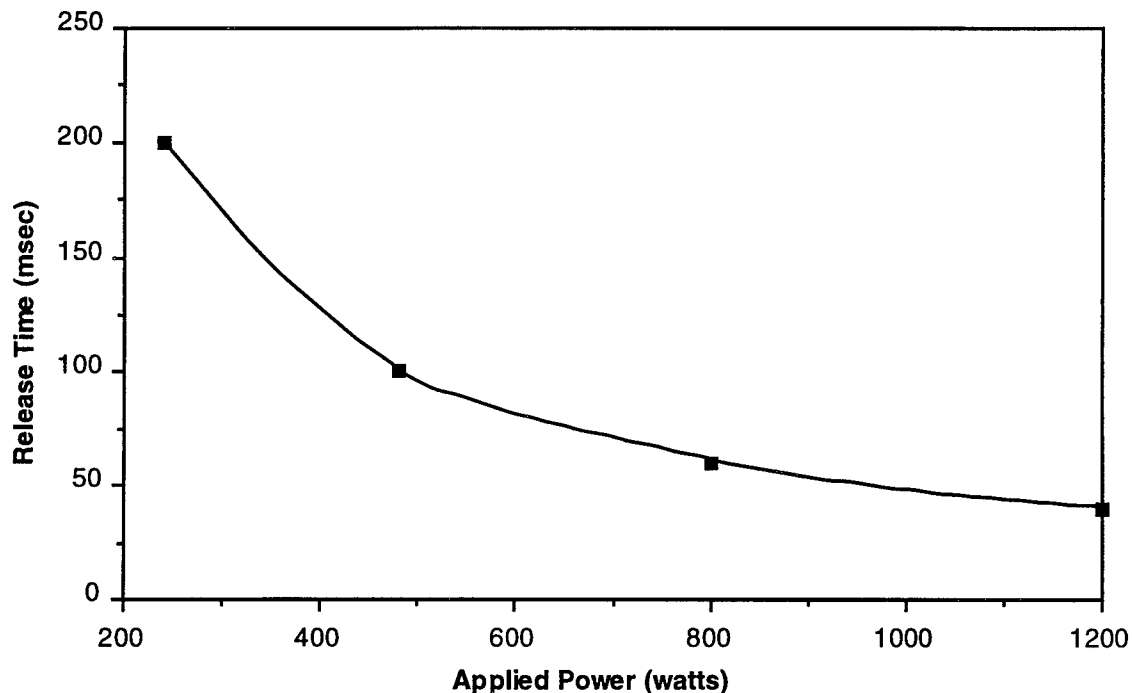


Figure 2-2. Release Time as a Function of Applied Power.

Shock generated by the bolt's retaining sleeve and the elastic energy stored in the bolt is dissipated by deformation of the martensitic shape memory damper and reset spring located in the top of the LFN housing. The LFN may be simply reset by resistively heating the reset spring causing it to recover to its elongated austenitic state. The both retaining nut segments, ball lock and plunger are automatically reset. Electrical reset features are expected to become increasingly important on future spacecraft as they allow the device that was tested to be the device flown and eliminate the need to remove the nut housing from spacecraft for refurbishment.

Comparative shock spectra (all data was acquired on the same test fixture) have been measured for two typical separation devices. These results are provided in Figure 2-3 along with the response spectra for the LFN. Shock output for the LFN falls below that of both pyrotechnic and non-pyrotechnic devices and is less than the shock design limit of 500g's. These results demonstrate the exceptional damping capability of shape memory springs and the ability to maintain release times of 50 msec.

2.2 SHAPE MEMORY ACTUATED TWO STAGE NUT

The Two Stage Nut (TSN) provides a zero shock method of releasing a bolt preloaded up to 2500 kgs without sacrificing simultaneity, in a package similar in size to a current state-of-the-art release devices.

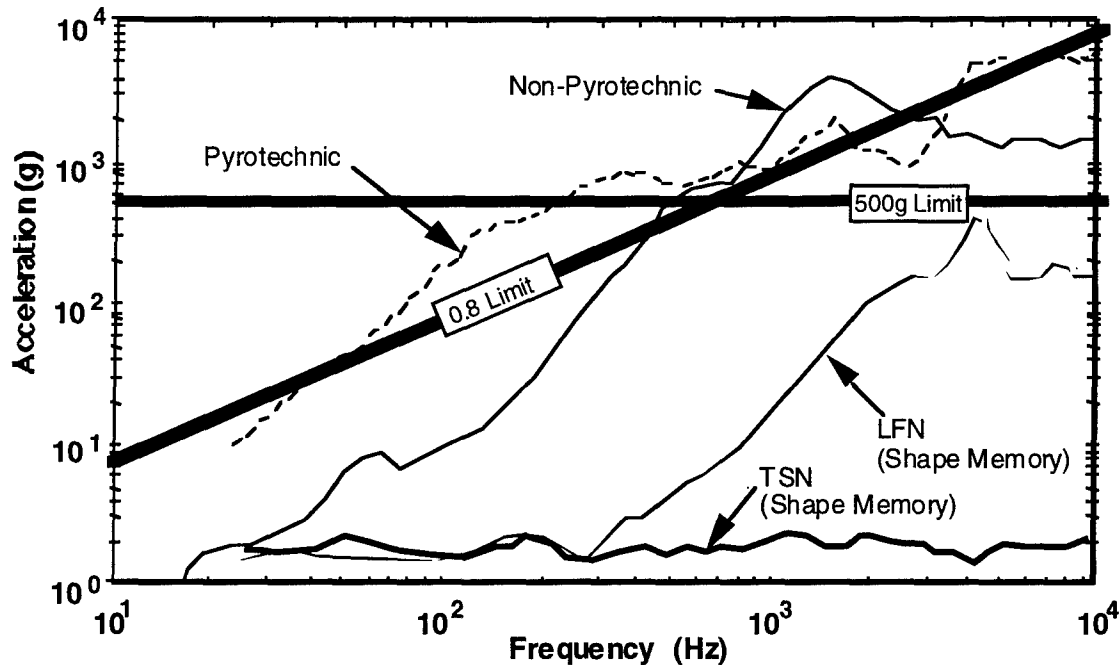


Figure 2-3. Typical Shock Response Spectra for Two Conventional Release Devices, the Shape Memory Actuation LFN, and the Shape Memory Actuated TSN.

As shown in Figure 2-4, the TSN operates by first removing the preload in the bolt, and then releasing the bolt that is retained by the segmented nut which rides in a collet that is free to travel axially. The collet is supported by a belleville washer which deforms under the preload of the bolt. By heating the SMA cylinder, the collet/segmented nut is translated, further deforming the belleville washer, and thus removing the preload from the bolt. At this point, the SMA initiation springs, positioned tangentially between the nut segments, are actuated, separating the segments, and releasing the bolt. The small force required for this final separation allows for the use of very small springs which reach full displacement, i.e., release, within 30 msec.

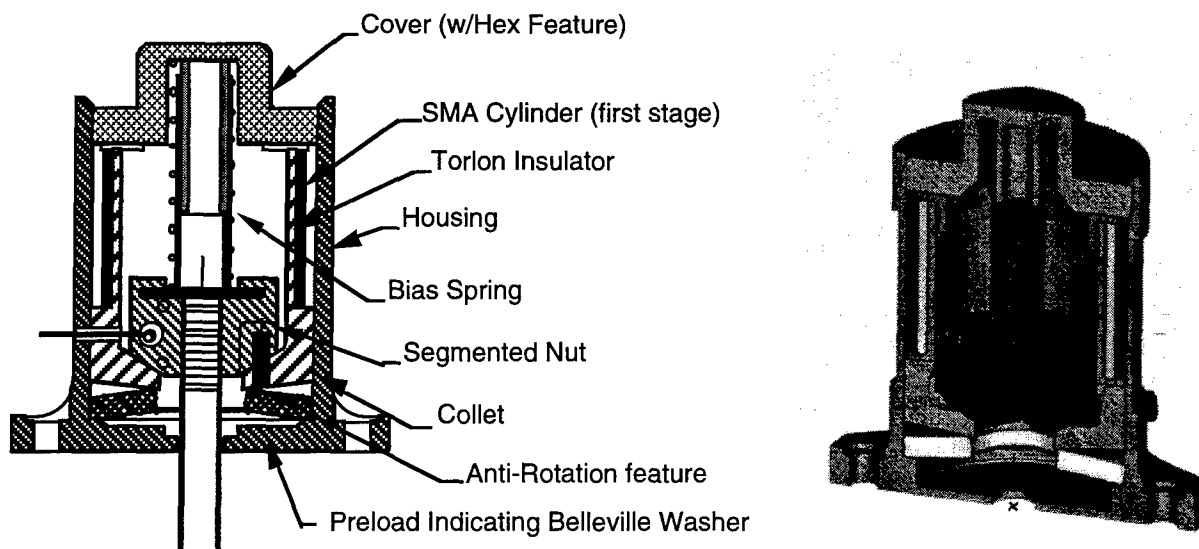


Figure 2-4. Shape Memory Actuated Two Stage Nut.

Redundancy in the mechanism consists of multitude heater circuits on the first stage cylinder, and actuation capability where any two of the three initiation springs are capable of displacing the segmented nut, and completing the release sequence.

Shock spectra for this device have also been acquired and are presented in Figure 2-3. Since actuation of the TSN involves the removal of stored energy prior to separation minimal shock is produced. Controlled dissipation of this energy is accomplished after release of the bolt by allowing the shape memory actuators to cool, without applied power. This action also resets the TSN allowing the bolt to be reinstated and torqued to the appropriate value.

2.3 G&H LINKWIRE RELEASE DEVICE

The G&H linkwire "low shock" device provides redundant spools that resist two plungers holding a nut locking sleeve in place (Figure 2-5). The sleeve retains split nut segments to maintain bolt preload. A compression spring provides the force against the sleeve reacted by the plungers. Upon command, the linkwire is heated and fractures, allowing a spool to separate, freeing the plungers. This movement releases enough spring force to push the nut locking sleeve out of position. The internal nut threads pull away, releasing their grip on the bolt. The device reacts within the specified 40 millisecond range, however the resultant mechanical shock from the nut locking sleeve impact is high.

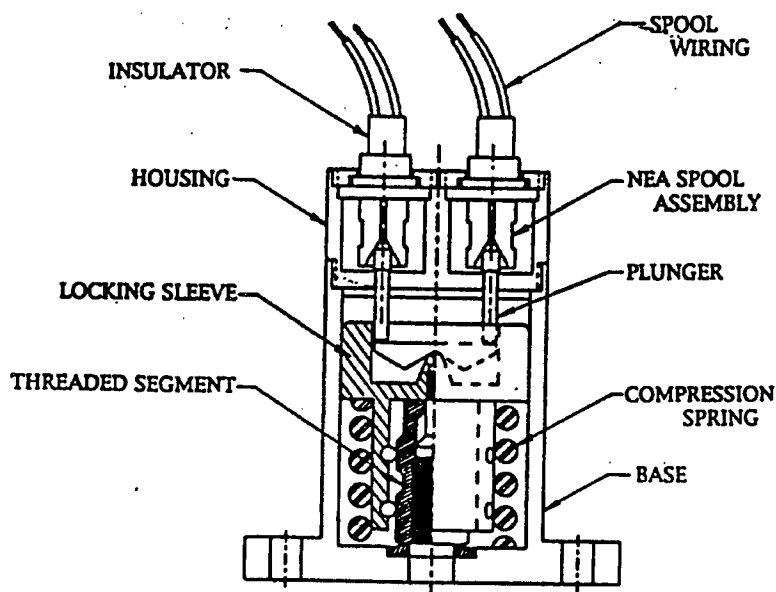


Figure 2-5. Linkwire Spool Separation Device.

2.4 HIGH SHEAR PYRO DEVICE

The hi-shear "low shock" device operates in the same fashion as the OEA device, except the pyrotechnic gases are channeled underneath the nut locking sleeve (Figure 2-6). When fired this causes the sleeve to move away from the spacecraft interface surface and impact the top of the housing. The philosophy is that this will reduce shock to the spacecraft by using the housing to dissipate the energy. In addition, crushable honeycomb is placed between the sleeve and housing to reduce impact shock. Since higher energy initiators are required to cover the losses of gases traveling through the channels underneath the locking sleeve, the shock response is over the limit specified.

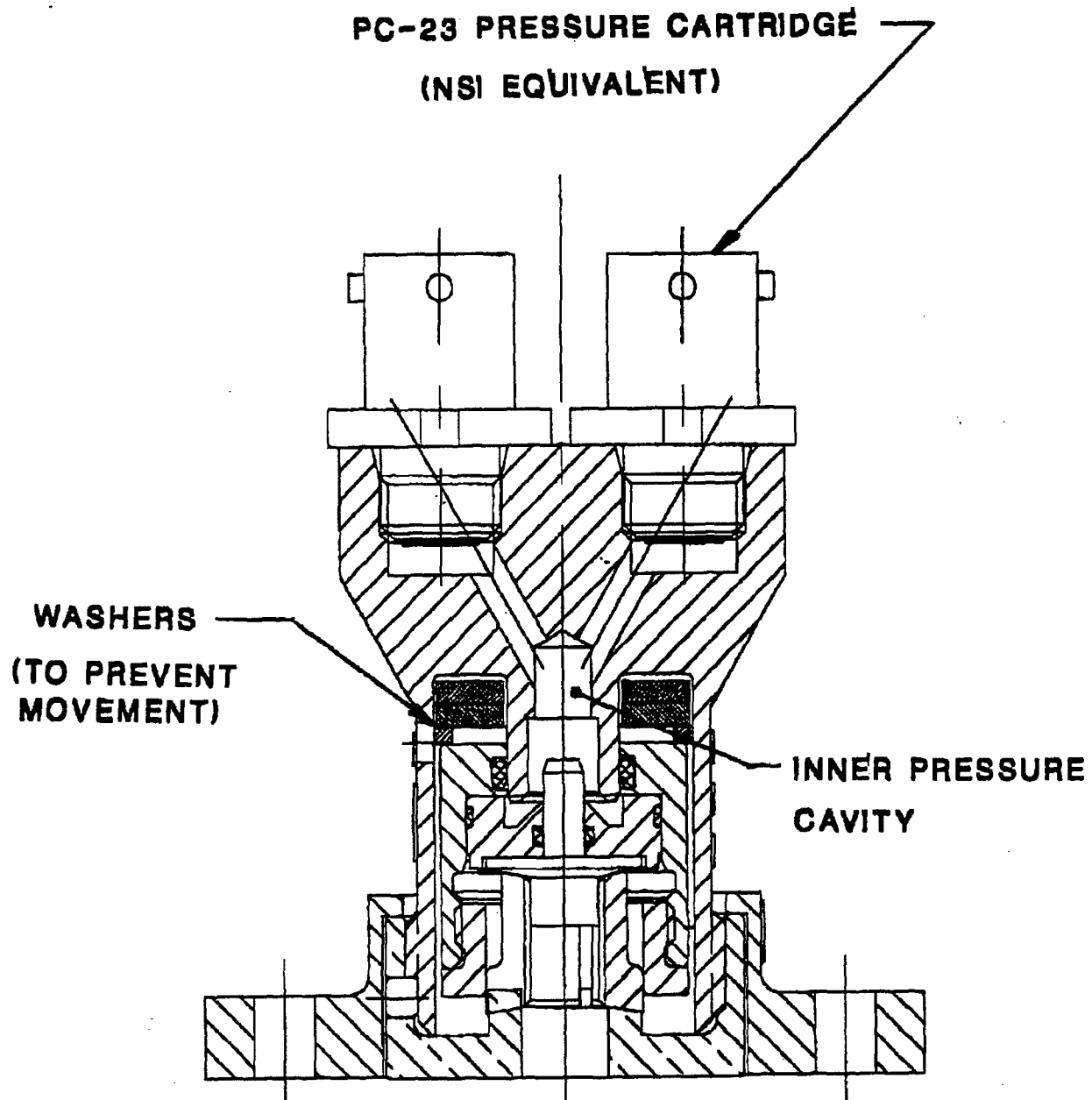


Figure 2-6. Pyrotechnic Separation Device.

3.0 ELECTRICAL SYSTEM DEVELOPMENT

The LFN and TSN control electronics is based on the Intel 80C51 8-bit microcontroller as shown in Figure 3-1. The 80C51 is a ROMless version and requires an external EEPROM for program memory. A MAX154 4-channel A/D converter is used to convert all analog feedback measurements and is connected to the controller via the I/O lines on Port 2. Three sense lines measure the voltage and current applied to the SMA device during operation. Two more control lines from the microcontroller are used for heating the SMA cylinder and subsequently firing the TSN device.

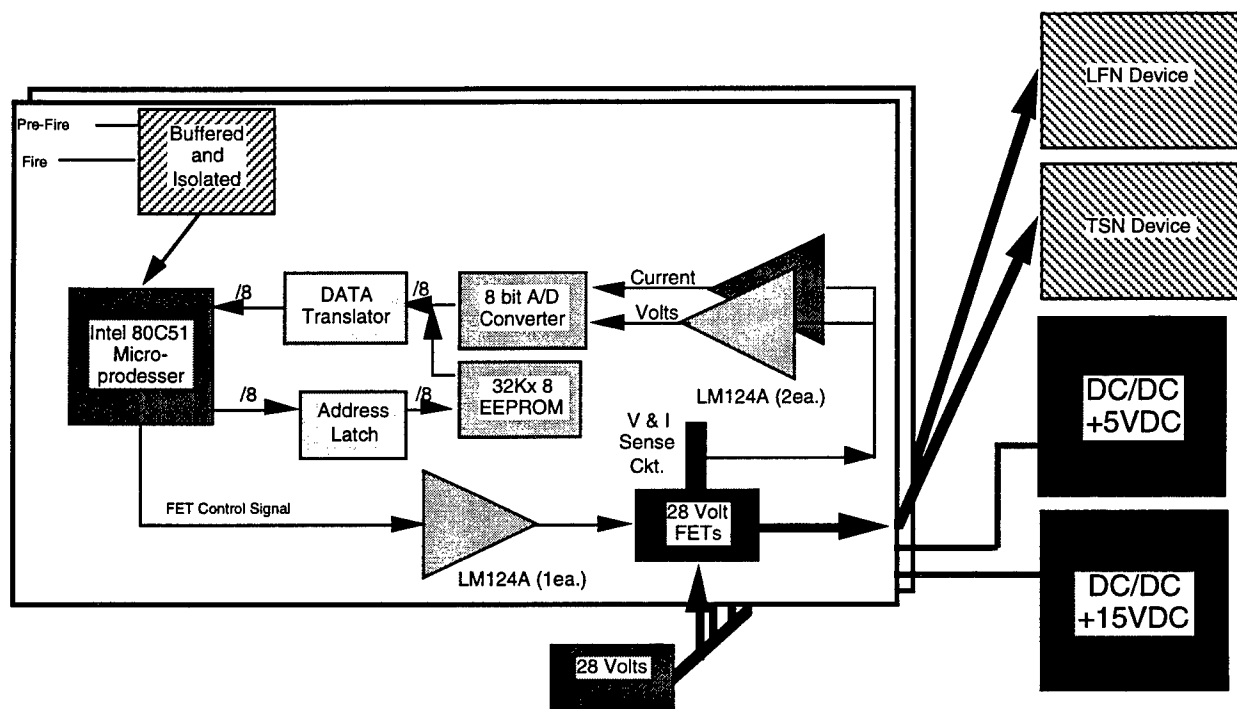


Figure 3-1. Block Diagram of LFN and TSN Control Electronics.

Each line to and from the SMA device is buffered through an LN124 operational amplifier to ensure adequate drive level. A detailed electrical schematic is provided in Appendix A.

The microcontroller is programmed to deliver a set amount of energy in watt-seconds to the SMA device. When the microcontroller detects a Pre-Fire signal in the pre-fire input line, power is turned on to a heating element for approximately 60 seconds. The microcontroller then waits for the Fire signal. Once detected, the microcontroller switches power to the SMA device and enters a control loop that measures the current and voltage being delivered to the SMA device every millisecond. The current and voltage measurements are then converted into watt-seconds and subtracted from the preprogrammed watt-second value. The microcontroller switches off the power to the device when the preprogrammed watt-seconds of energy has been delivered.

4.0 MIGHTY SAT EXPERIMENT

4.1 SCOPE

This section describes handling, mechanical interfacing and electrical interfacing of the SMARD experiment to the Mighty Sat 1 spacecraft bus.

4.2 SMARD EXPERIMENT DEFINITION

The SMARD experiment consists of four release devices and support electronics suitable for obtaining acceleration, preload, separation time, and temperature data for a shape memory actuated low force nut (LFN), a shape memory actuated two stage nut (TSN), a G&H link wire device, and a Hi-Shear separation nut which uses a NSI squib. Actuation power, duration and magnitude are controlled via the electronics box and the 28 VDC unregulated spacecraft power system.

4.3 OBJECTIVE OF SMARD SCIENCE MISSION

The objective of the SMARD science mission is to acquire comparative performance data from each release device within the Mighty Sat environment. This data includes shock response, load, release time, and temperature provided as analog signals to the spacecraft data acquisition system. Post-analysis of this data will be used to evaluate the feasibility of using shape memory alloys as low shock, low contamination release device actuators.

4.4 GENERAL PROCEDURES

4.4.1 SHIPPING

The SMARD experiment has been provided to the Phillips Lab in two reusable shipping containers. The first of these (labeled ESD Sensitive) contains the electronics box and two electrical cables. The second contains the nut housing and associated release devices. The NASA standard initiators (NSIs) have been provided to the Phillips Lab ordnance control in a separate shipment.

4.4.2 HANDLING

The SMARD experiment shall be removed from its shipping cartons within a clean (class 100 or better) laboratory environment. The electronics box contains sensitive components requiring nominal ESD precautions be observed. An ESD procedure is outlined in Section 4.6.1. The SMARD experiment should remain covered, except when undergoing active testing or integration, to avoid contamination. The SMARD experiment external surfaces shall be maintained visibly free of particulates, films and other deposits.

4.4.2.1 Establish ESD Work area and remove electronics box from shipping container.

TC _____ QC _____

4.4.2.2 Visually inspect for visible damage to outside surfaces.

TC _____ QC _____

4.4.2.3 Visually inspect the electronic box external surfaces for evidence of contamination. Any contamination may be removed with alcohol wipes to maintain the surface free of particulates.

TC _____ QC _____

4.4.2.4 Remove the two electrical cables from the shipping carton and verify that there is no obvious damage such as bent pins, frayed sheathing, or bent backshells.

TC _____ QC _____

- 4.4.2.5 Remove the cylindrical nut housing from the second shipping container and visually inspect for damage to outside surfaces.

TC _____ QC _____

- 4.4.2.6 Visually inspect the external surfaces of the nut housing for damage.

TC _____ QC _____

- 4.4.2.7 Visually inspect the external surfaces of the nut housing for evidence of contamination. Any contamination may be removed with alcohol wipes to maintain the surface free of particulate.

TC _____ QC _____

4.5 MECHANICAL INTERFACE

4.5.1 GENERAL

Attachment of the SMARD experiment to the spacecraft is accomplished according to the reference coordinate system provided in Figure 4-1. The SMARD mounting location on the spacecraft mid-deck is provided in Figure 4-2. Electrical connectors are oriented such that they face the -X direction.

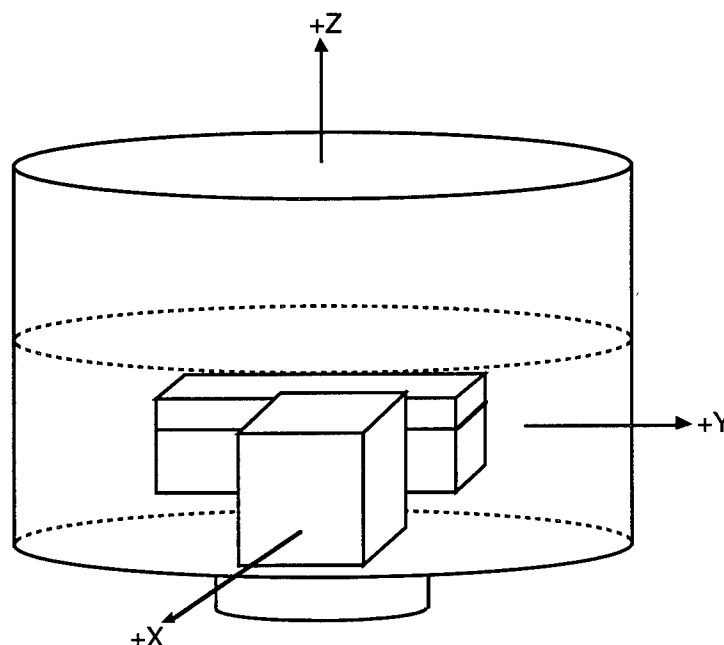


Figure 4-1. Reference Coordinate System.

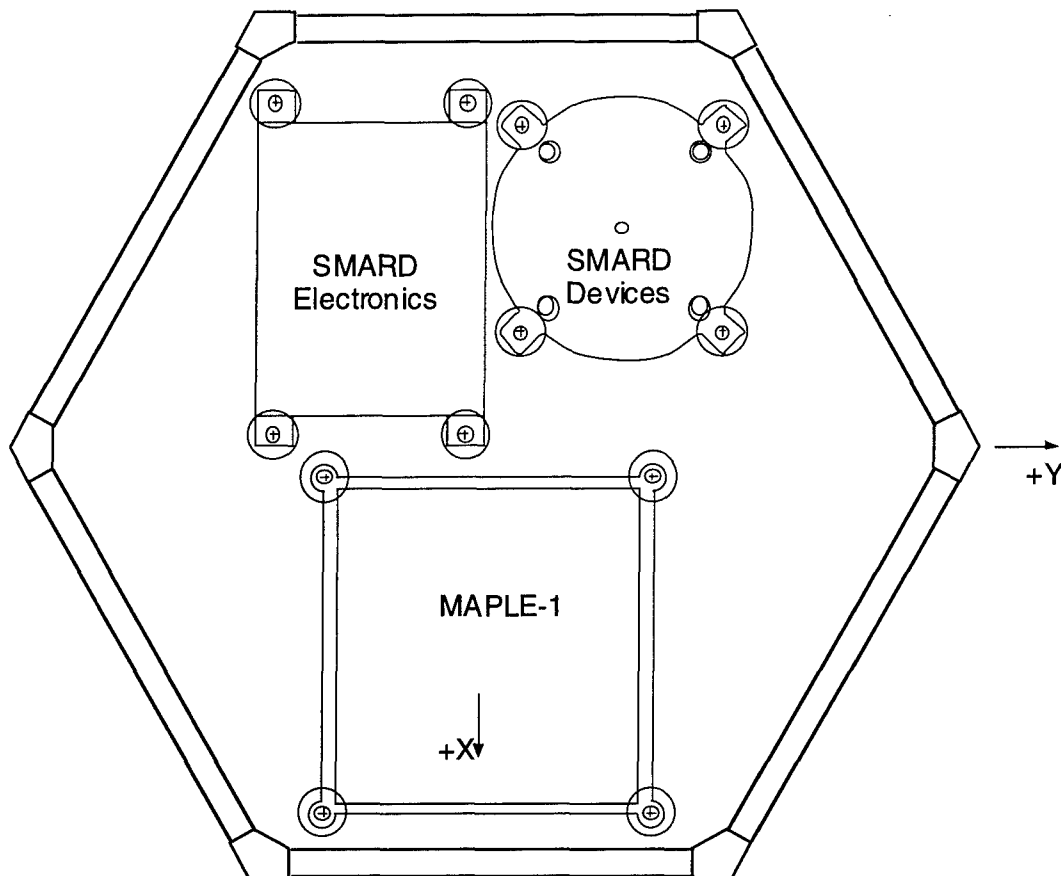


Figure 4-2. SMARD Experiment Mounting Location.

Attachment of the electronics box is accomplished using the four mounting feet and fasteners supplied by CTA. The bolts should be tightened evenly across the box diagonals to avoid distortion.

- 4.5.1.1** Position electronics box according to Figure 4-2 and verify that through mounting holes line up with the threaded inserts in spacecraft deck. Verify that electronics box sits flat with no more than 0.005 inch variation across diagonally opposed mounting feet. Install shims as required to satisfy 0.005-in. flatness criteria.

TC _____

QC _____

- 4.5.1.2** Install and hand tighten four CTA supplied (1/4-28) fasteners. Incrementally tighten diagonally opposed fasteners such that each fastener gradually approaches the specified torque of 75 in-lbs. Verify that the torque of each fastener is 75 in-lb $\pm$ 6 in-lb.

TC _____

QC _____

4.5.2 ATTACHMENT OF SMARD DEVICES

Attachment of the nut housing (SMARD devices) is accomplished using the four diametrically oriented mounts provided on the cylindrical base of the housing. Three of these are positioned next to the three tapped holes that retain the nut house cover. The CTA-supplied fasteners should be evenly tightened across the nut house diagonals to avoid distortion.

- 4.5.2.1** Position nut housing (SMARD Devices) according to Figure 4-2 and verify that through mounting holes line up with the threaded inserts in the spacecraft deck. Note the location of three 1/4-28 fasteners that retain the nut house cover as these will be removed in a subsequent procedure. Verify that the nut housing sits flat against the deck surface with no more than 0.005-in. variation across diagonally opposed mounting feet. Install shims as required to satisfy 0.005-in. flatness criteria.

TC _____ QC _____

- 4.5.2.2** Install and hand tighten four CTA supplied 1/4-28 fasteners. Incrementally tighten diagonally opposed fastener such that each fastener gradually approaches the specified torque of 75 in-lb. Verify that the torque of each fastener is 75 in-lb $\pm$ 6 in-lb..

TC _____ QC _____

Mass properties for the electronics box, nut house, and cables are provided in Table 4-1

Table 4-1. SMARD Experiment Mass Properties.

Electronics Box:	2117 g
Nut House:	2162 g
Cables (2 x 302 g):	604 g
Total:	4883 g
	(10.74 lbs)

4.5.3 ELECTRONICS BOX

Access to the electronics box is provided through removal of the top cover. Figure 4-3 shows the general layout of the four control boards and the I/O board. The three safe relays mounted in different orientations are also visible. Power requirements for the SMARD experiment are provided in Table 4-2 and Table 4-3.

4.5.4 NUT HOUSING (SMARD DEVICES)

Access to the nut housing is accomplished by removing the three housing fasteners (Figure 4-4) and lifting the cover upward clearing the tops of the four release devices, as shown in Figure 4-5. However, it will be necessary to install a single NSI in the threaded receptacle for the pyrotechnic separation nut and attach its mating electrical connector. Following this, the cover may be reinstalled and the fasteners evenly torqued to 75 in-lb $\pm$ 6 in-lb.

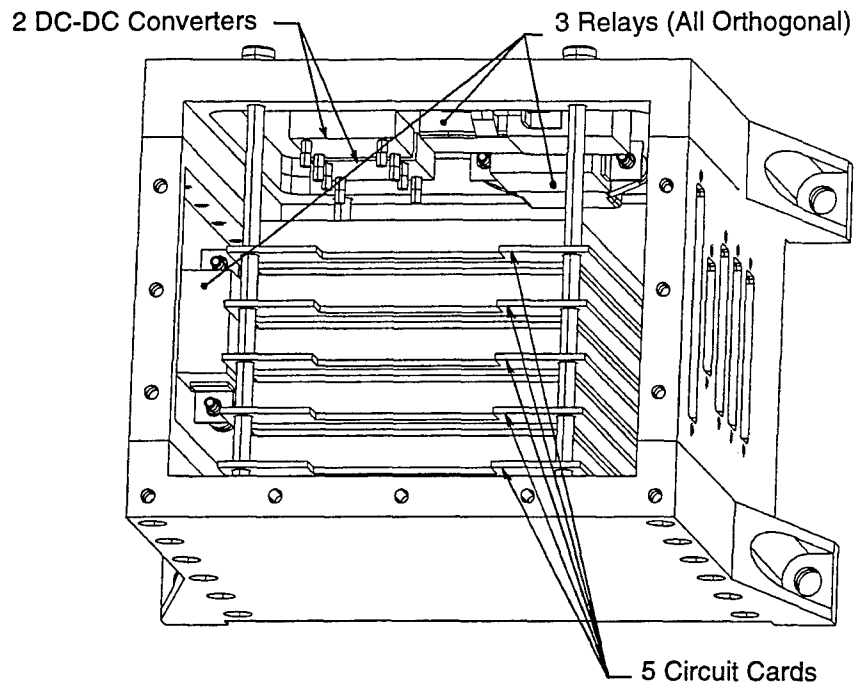


Figure 4-3. SMARD Electronics Box.

Table 4-2. SMARD Control Electronics Power Measurements.

Measured Voltage	Measured Current	Comment
+28 V	444 mA	Total Supply
+15 V	11 mA	Total Supply
+5 V	156 mA	Total Supply
+28 V	5.6 A	Heater TSN
+28 V	5.6 A	Heater LFN

Table 4-3. SMARD Actuation Power Requirements.

	Resistance (ohm)	Energy (Watt sec)	Time (msec)
SMA LFN	0.25	48	40
SMA TSN	0.25	48	40
G&H Linkwire	1	12	30
Hi Shear Pyrotechnic	1	8	20

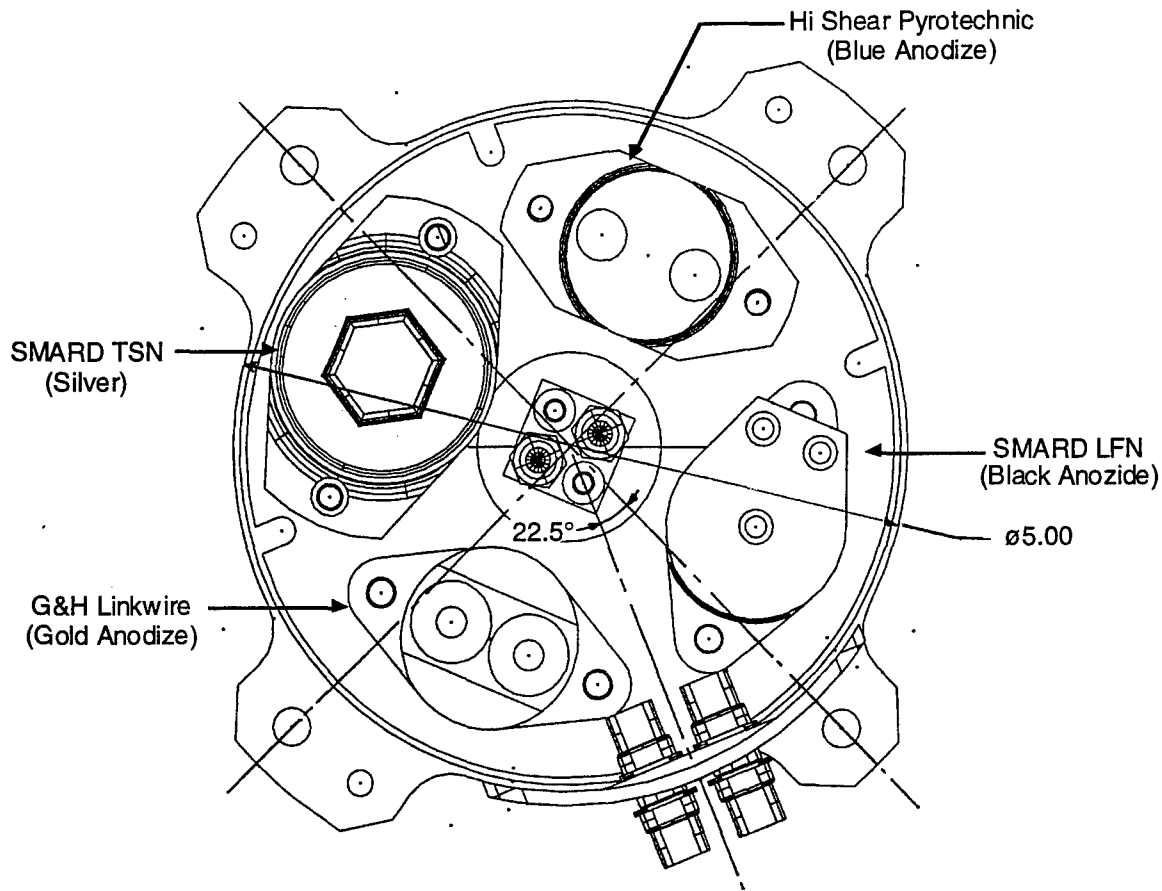


Figure 4-4. SMARD Nut Housing.

4.5.5 INSTALLATION OF NSI

A single NSI will be used to actuate the pyrotechnic device. As such, it is necessary to seal the unused port. This has been accomplished using a sealed NSI without ordnance. This NSI has been identified as non-operative using a green colored stain.

- 4.5.5.1** The following pertains to installation of the NASA Standard Initiator (NSI). Handling the NSI requires special precautions and procedures. It is therefore recommended that section 4.5.5.1 through 4.5.5.5 be conducted last. Verify pyrotechnic installation and handling procedure.

TC _____ QC _____ Ord _____

- 4.5.5.2** Remove the three nut housing cover fasteners. These are positioned adjacent to the four fasteners used to attach the nut housing to the spacecraft deck.

Lift the nut housing cover upwards, taking care not to damage sensor and actuation wires. Support nut housing cover above nut housing base to provide unobstructed access to blue pyrotechnic device.

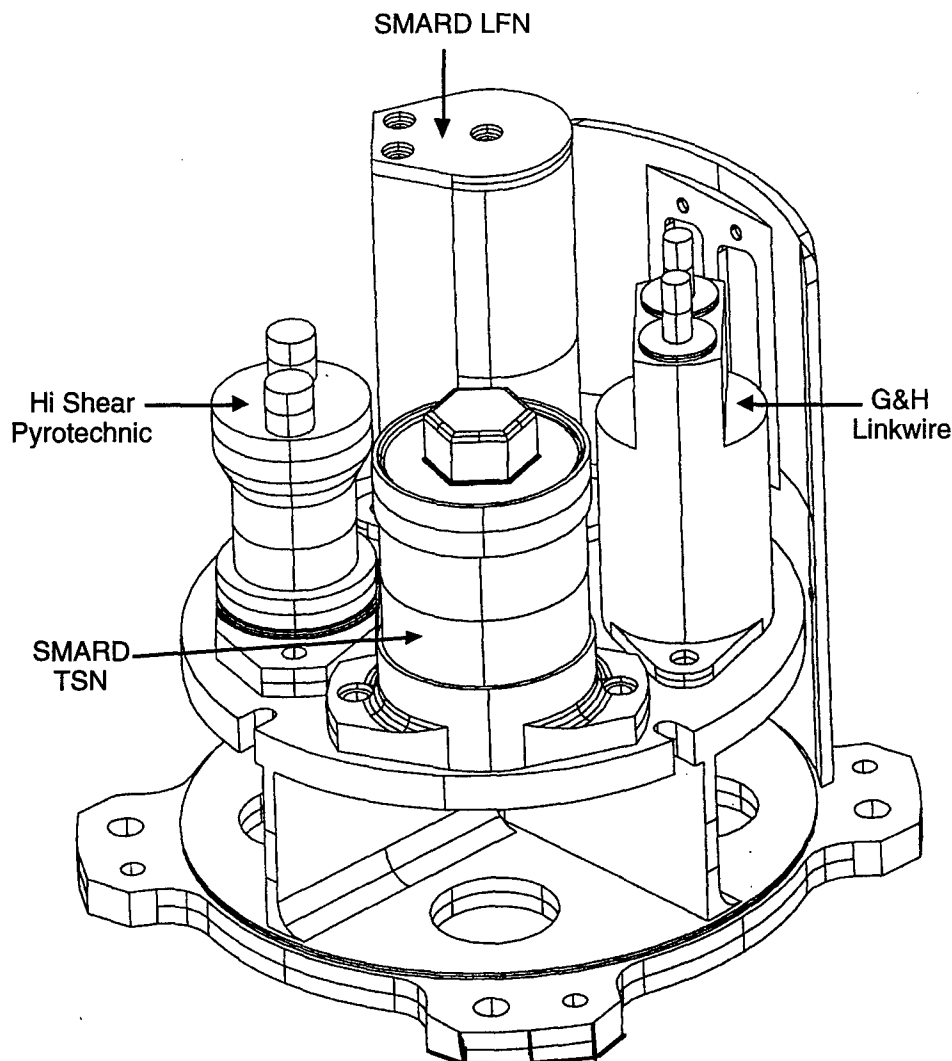


Figure 4-5. Isometric View of SMARD Nut Housing with Cover Removed.

Verify the presence of a non-operative NSI installed in one of the two threaded pyrotechnic pressure parts. Verify that the non-operative NSI has been torqued to 105 in-lb $\pm$ 5 in-lb using NSI spanner wrench. Verify that the non-operative NSI has been colored green to indicated it as being non-operative.

TC _____ QC _____ Ord _____

- 4.5.5.3** To install the active NSI, remove the red dust cap in the pyrotechnics pressure port. Verify that the 3/8-24 UNJF thread matches that of the NSI. Verify that the electrical connector within the device housing matches the mating connector on the NSI. Incompatibility between either the threads or electrical connectors would require procurement of a different NSI. Notify Lockheed Martin if this condition exists.

TC _____ QC _____ Ord _____

- 4.5.5.4** Install NSI and torque to specified value of 105 in-lb $\pm$ 5 in-lb using NSI spanner wrench. Attach electrical connector to active NSI and verify that mating halves are locked into connector detents. Note that the non-operative NSI is electrically equivalent to the active NSI. It is important that the electrical connection to the SMARD electronics **not be made to the non-operative NSI** which has **been color coded green**.

TC _____ QC _____ Ord _____

- 4.5.5.5** Reinstall the nut housing cover taking care not to damage electrical wiring. Position nut housing to line up with threaded holes in nut housing base. Install fasteners and incrementally torque to 75 in-lb. Verify torque of 75 in-lb $\pm$ 6 in-lb.

TC _____ QC _____ Ord _____

4.6 ELECTRICAL INTERFACE

4.6.1 EDS CONTROL PROCEDURE FOR CONNECTING SMARD ELECTRONICS BOX TO THE SMARD SPACECRAFT SIMULATOR

The SMARD electronics box contains four buffers that are ESD sensitive and subject to damage when connecting the SMARD interface cable to either the spacecraft or spacecraft simulator. The intent of this procedure is to eliminate any voltage potential that might exist between electrical cables, and the devices they are connected to.

- 4.6.1.1** Using an ESD wrist band and pad, remove the SMARD electronics box from the ESD bag and place it on the pad. Attach one end of a jumper wire to one of the circuit board retention bolts on the outside of SMARD electronics box. It is best to select one of the bolts located closest to the side of the box electrical connectors. Attach the opposite end of the jumper wire to the piece of block conductive foam supplied with the jumper wire. Using the foam, wipe each of the pins on connectors J1 through J5. Once complete, remove the foam and replace it with the pin connector. Using the pin connector, touch each socket on electrical connector J1 through J5.

TC _____ QC _____

- 4.6.1.2** Using the conductive foam and pin connector, wipe each end of the SMARD test cables and SMARD simulators.

TC _____ QC _____

- 4.6.1.3** Place the SMARD simulator box on the ESD pad. Unlike the SMARD electronics box, the SMARD simulator box is not electrically connected to the internal ground. As such, it is necessary to attach the conductive foam and pin connector used previously directly to the conductive ESD pad using a jumper wire of suitable length. Following the procedure described previously, wipe each pin and socket of connectors J1 through J3 on the SMARD simulator box.

TC _____ QC _____

- 4.6.1.4** Attach the electrical cables and SMARD simulators to their respective connectors on the SMARD electronics box and the SMARD simulator box. Tighten these to the specified torque. Attach the SMARD simulators to their respective locations and tighten to the specified torque.

TC _____ QC _____

The SMARD experiment may now be tested using the procedures described in this document. During spacecraft integration the ESD procedure must be employed using the spacecraft cables.

4.6.2 ELECTRICAL INTERFACE TO SPACECRAFT

The electrical connections between the SMARD experiment and the spacecraft are accomplished using three D-style connectors — a 37-pin command and telemetry, a 15-pin regulated power, and a 25-pin 28 VDC unregulated power. These are labeled J1 through J3, respectively. J1 and J2 are socket connectors on the electronics box, and J3 is a pin connector on the electronics box, as shown in Figure 4-6. Connection of the electronics box to the nut housing (SMARD devices) is accomplished using J4 and J5 D-style socket connectors. The electrical pin outs for each of these connectors is provided in Tables 4-4 through 4-8, respectively.

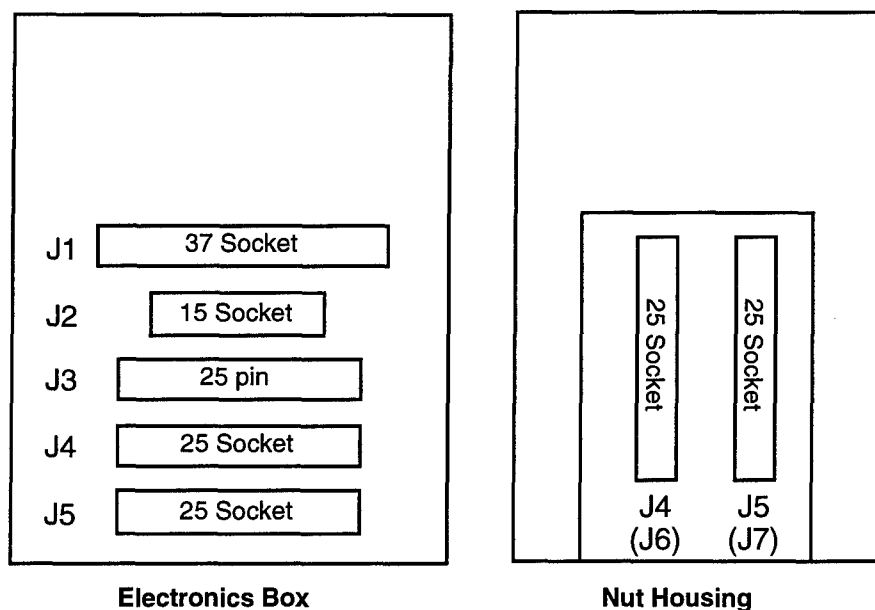


Figure 4-6. Electrical Connector Positions.

Table 4-4. SMARD Command and Telemetry Connector , A703J1.

Pin #	Gauge	I/O	Name	Description
1	24	I	TSN PREFIRE - 60 seconds	Active High CMOS Pulse
2	24	O	IGND	Isolated Ground
3	24	I	ARM Input 1	Active High CMOS Bilevel
4	24	O	IGND	Isolated Ground
5	24	O	IGND	Isolated Ground
6	24	O	Accel #1	Analog Telemetry TSP +
7	24	O	IGND	Isolated Ground
8	24	O	Accel #2	Analog Telemetry TSP +
9	24	O	IGND	Isolated Ground
10	24	O	SERIAL 1	EGSE Serial Test Line 1
11	24	O	IGND	Isolated Ground
12	24	O	Load Washer #1	Analog Telemetry TSP +
13	24	O	IGND	Isolated Ground
14	24	O	Load Washer #2	Analog Telemetry TSP +
15	24	O	IGND	Isolated Ground
16	24	O	Load Washer#3	Analog Telemetry TSP +
17	24	O	IGND	Isolated Ground
18	24	O	Load Washer #4	Analog Telemetry TSP +
19	24	I	TSN FIRE Pulse - 40 msec	Active High CMOS Pulse
20	24	O	IGND	Isolated Ground
21	24	I	LFN FIRE Pulse - 40 Msec	Active High CMOS Pulse
22	24	O	IGND	Isolated Ground
23	24	I	ARM Input 2	Active High CMOS Bilevel
24	24	O	IGND	Isolated Ground
25	24	O	Accel #1 Ret	Analog Telemetry TSP -
26	24	I	G&H FIRE Pulse - 40 msec	Active High CMOS Pulse
27	24	O	Accel #2 Ret	Analog Telemetry TSP -
28	24	I	NSI Pyrotechnic FIRE Pulse - 40 msec	Active High CMOS Pulse
29	24	O	BASE PLATE TEMP	Analog Temperature
30	24	I	ARM Input 3	Active High CMOS Bilevel
31	24	O	Load Washer #1 Ret	Analog Telemetry TSP -
32	24	I	LFN PREFIRE - 60 seconds	Active High CMOS Bilevel
33	24	O	Load Washer #2 Ret	Analog Telemetry TSP -
34	24	O	SERIAL 2	EGSE Serial Test Line 2
35	24	O	Load Washer #3 Ret	Analog Telemetry TSP -
36	24	O	SERIAL 3	EGSE Serial Test Line 3
37	24	O	Load Washer #4 Ret	Analog Telemetry TSP -

Table 4-5. SMARD Regulated Power Connector, A703J2.

Pin #	Gauge	I/O	Name	Description
1	20	I	+5 VDC PWR1	+5 VDC PWR1
2	20	I	+5 VDC PWR2	+5 VDC PWR2
3	20	O	K1 INPUT	Monitor Line for 1st Relay
4	20	I	+15 VDC PWR	+15 VDC PWR
5				UNUSED/SPARE
6	20	O	K1 OUTPUT	Monitor Line for 1st Relay
7	20	I	-15 VDC PWR	-15 VDC PWR
8				UNUSED/SPARE
9	20	O	+5 VDC RET1	+5 VDC RET1
10	20	O	+5 VDC RET2	+5 VDC RET2
11	20	O	+15 VDC RET	+15 VDC RET
12	20	O	K2 OUTPUT	Monitor Line for 2nd Relay
13	20	O	K3 OUTPUT	Monitor Line for 3rd Relay
14	20	O	-15 VDC RET	-15 VDC RET
15	20	O	FET OUTPUT	Monitor Line for FET

Connection of spacecraft and SMARD experiment cables is accomplished as follows:

- 4.6.2.1** Establish a chassis ground between the electronics box, SMARD nut housing and spacecraft. Establish an ESD protected work zone and remove the conductive shipping tape from the electronics box connectors. Remove the plastic protection caps from the SMARD nut housing and the two electrical cables (these have 25 pin connectors on each end and are labeled "Interconnect Cable #1" and "Interconnect Cable #2").

TC _____ QC _____

- 4.6.2.2** Visually inspect J5 on the electronics box and J7 on the nut housing for evidence of damage and obstructions in the connector sockets. Visually inspect "Interconnect Cable #2" for evidence of damage and bent pins. Align and seat each end of "Interconnect Cable #2" from J5, Electronics Enclosure to J7, Nut House Enclosure. Note the M/W ("Mates With") tags on each end of interconnect cable. Hand tighten connector retaining screws. Torque retaining screws to 15 in-lb. Verify that connector is retaining screw torque is 15 in-lb $\pm$ 5 in-lb.

TC (J5) _____ QC (J5) _____

Repeat procedure for "Interconnect Cable #1" from J4, Electronics Enclosure to J6, Nut House Enclosure. Note the M/W ("Mates With") tags on each end of Interconnect cable.

TC (J4) _____ QC (J4) _____

Table 4-6. SMARD Unregulated Power Connector, A703J3.

Pin #	Gauge	I/O	Name	Description
1	20	I	+28 VR	28 VDC Unregulated Supply
2	20	I	+28 VR	28 VDC Unregulated Supply
3	20	I	+28 VR	28 VDC Unregulated Supply
4	20	I	+28 VR	28 VDC Unregulated Supply
5	20	I	+28 VR	28 VDC Unregulated Supply
6	20	I	+28 VR	28 VDC Unregulated Supply
7	20	I	+28 VR	28 VDC Unregulated Supply
8	20	I	+28 VR	28 VDC Unregulated Supply
9	20	I	+28 VR	28 VDC Unregulated Supply
10	20	I	+28 VR	28 VDC Unregulated Supply
11	20	I	+28 VR	28 VDC Unregulated Supply
12	20	I	+28 VR	28 VDC Unregulated Supply
13	20	I	NC	NC
14	20	I	GNDR	28 VDC Unregulated RTN
15	20	I	GNDR	28 VDC Unregulated RTN
16	20	I	GNDR	28 VDC Unregulated RTN
7	20	I	GNDR	28 VDC Unregulated RTN
18	20	I	GNDR	28 VDC Unregulated RTN
19	20	I	GNDR	28 VDC Unregulated RTN
20	20	I	GNDR	28 VDC Unregulated RTN
21	20	I	GNDR	28 VDC Unregulated RTN
22	20	I	GNDR	28 VDC Unregulated RTN
23	20	I	GNDR	28 VDC Unregulated RTN
24	20	I	GNDR	28 VDC Unregulated RTN
25	20	I	GNDR	28 VDC Unregulated RTN

Table 4-7. SMARD Electronic Box to Nut House (Devices) Power Cable, A703J4.

+28VDC Power				
(17 inches tip to tip)				
M/W	P4		P4	M/W
A703J4	1	+28VDC LFN FIRE	1	A703J6
(Electronics)	2	+28VDC LFN FIRE	2	(DEVICES)
	3	+28VDC LFN FIRE	3	
	4	+28VDC LFN FIRE	4	
	5	+28VDC LFN FIRE	5	
	6	+28VDC LFN FIRE	6	
	7	+28VDC TSN FIRE	7	
	8	+28VDC TSN FIRE	8	
	9	+28VDC TSN FIRE	9	
	10	+28VDC TSN FIRE	10	
	11	+28VDC TSN FIRE	11	
	12	+28VDC TSN FIRE	12	
	13	NC	13	
	14	28VDC LFN FIRE RET	14	
	15	28VDC LFN FIRE RET	15	
	16	28VDC LFN FIRE RET	16	
	17	28VDC LFN FIRE RET	17	
	18	28VDC LFN FIRE RET	18	
	19	28VDC LFN FIRE RET	19	
	20	28VDC TSN FIRE RET	20	
	21	28VDC TSN FIRE RET	21	
	22	28VDC TSN FIRE RET	22	
	23	28VDC TSN FIRE RET	23	
	24	28VDC TSN FIRE RET	24	
	25	28VDC TSN FIRE RET	25	

* Use 20AWG MS22759/32 wire.
EMI/EMC backshells are required.
Alpha P/N 2174 or equivalent shielding required.

Table 4-8. SMARD Electronic Box to Nut House Signal (Devices) Cable, A703J5.

SMARD Signal Cable				
(17 inches tip to tip)				
M/W	J5		J5	M/W
A703J5				A703J7
(Electronics)				(DEVICES)
	1	20 AWG	+28VDC LFN PREFIRE	1
	2	20 AWG	+28VDC TSN PREFIRE	2
	3	20 AWG	+28VDC G&H	3
	4	20 AWG	+28VDC PYRO	4
	5	20 AWG	+5VE	5
	6	20 AWG	+5VE	6
	7	24 AWG	Accel #1 (TSP+)	7
	8	24 AWG	Accel #2 (TSP+)	8
	9	24 AWG	Base Plate Temp (TSP+)	9
	10	24 AWG	Load Washer #1 (TSP+)	10
	11	24 AWG	Load Washer #2 (TSP+)	11
	12	24 AWG	Load Washer #3 (TSP+)	12
	13	24 AWG	Load Washer #4 (TSP+)	13
	14	20 AWG	+28VDC LFN PREFIRE RET	14
	15	20 AWG	+28VDC TSN PREFIRE RET	15
	16	20 AWG	+28VDC G&H RET	16
	17	20 AWG	+28VDC PYRO RET	17
	18	20 AWG	+5VE RET	18
	19	20 AWG	+5VE RET	19
	20	24 AWG	Accel #1&2 RET (TSP-)	20
	21	24 AWG	Base Plate Temp (TSP-)	21
	22	24 AWG	Load Washer #1 RET (TSP-)	22
	23	24 AWG	Load Washer #2 RET (TSP-)	23
	24	24 AWG	Load Washer #3 RET (TSP-)	24
	25	24 AWG	Load Washer #4 RET (TSP-)	25

* Use 24AWG & 20AWG MS22759/32 wire per Drawing.
EMI/EMC backshells are required.
Alpha P/N 2174 or equivalent shielding required.

- 4.6.2.3** Visually inspect J3 on the electronics box and the associated 25 pin mighty sat spacecraft power cable (DB-25 S/C) for damage such as bent pins or socket obstructions.

Align and seat the connector into the electronics box. Hand tighten connector retaining screws. Torque retaining screws to 15 in-lb. Verify that connector retaining screw torque is 15 in-lb $\pm$ 5 in-lb.

TC (J3) _____ QC (J3) _____

Repeat procedure for J2 and J1.

TC (J2) _____ QC (J2) _____

TC (J1) _____ QC (J1) _____

4.7 SMARD EXPERIMENT ELECTRONICS TEST PROCEDURES

The SMARD experiment may be tested according to the following procedures. Sensor verification is performed first, followed by actuation testing using a nut house simulator.

4.7.1 SENSOR VERIFICATION

The following procedure demonstrates SMARD Sensor outputs for the two accelerometers, four load washers and the temperature sensor. This procedure requires the use of the SMARD spacecraft simulator shown in Figure 4-7 and associated test cables. The three test cables are identified as SMARD 15 pin test cable, SMARD 25 pin test cable, and SMARD 37 pin test cable. Note that the flight end of the connector has been identified as "flight" on each cable and is protected with a red plastic cap. Do not insert flight connectors into non-flight rated receptacles.

- 4.7.1.1** Visually inspect J1 (37 pin) of the SMARD electronic box for evidence of damage. Visually inspect the flight connector end of the 37 pin test cable after removing its red protective cap. seat the 37 pin connector into its receptacle. Visually inspect and insert the non-flight rated end of the 37 pin test cable into J1 of the SMARD spacecraft simulation box

TC (J1 Test) _____

Repeat the above steps for the 15 pin test cable (J2) and the 25 pin test cable (J3).

TC (J2 Test) _____

TC (J3 Test) _____

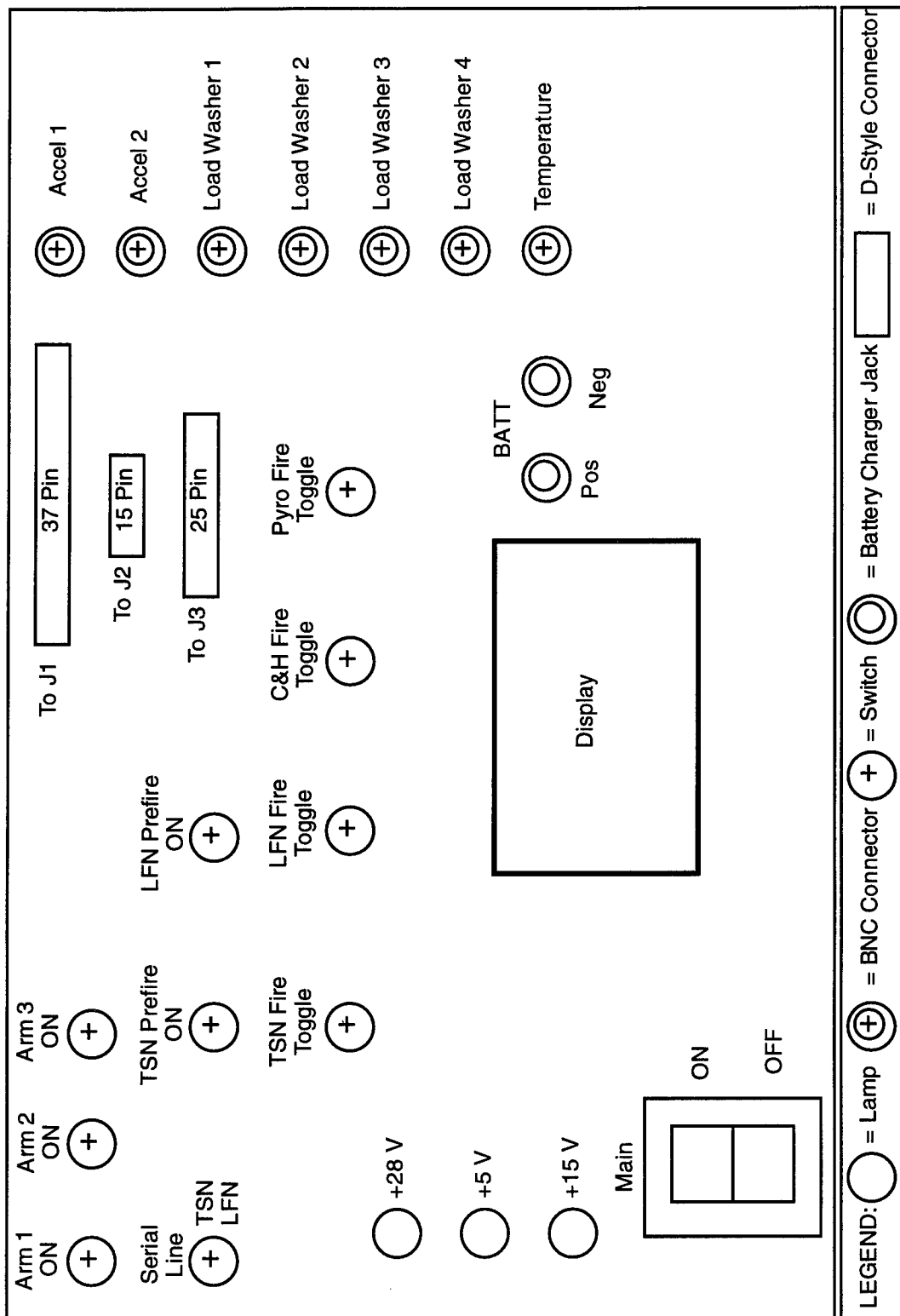


Figure 4-7. SMARD Experiment Spacecraft Simulation Box.

- 4.7.1.2** Visually inspect and install the 25 pin SMARD signal cable from J5 on the electronics box J7 on the nut housing. Hand tighten the connector retaining screws. It is not necessary to install the 25 pin SMARD power cable from J4 on the electronic box to J6 on the nut housing for sensor verification.

TC (J5) _____

- 4.7.1.3** Attach a digital multimeter (DMM) to the BNC connector identified as Accel #1 on the SMARD spacecraft simulator box.

Turn on the main power switch of the simulator box and observe that +28 VDC, +15 VDC and +5 VDC LED indicator lights are ON. If these do not illuminate the battery inside the simulator box needs to be recharged using the enclosed power supply.

Observe the digital multimeter readout and verify that the 2.5 VDC accelerometer #1 bias voltage is present.

Measure the remaining sensor output voltages at each of the BNC terminals on the spacecraft simulator and verify that these voltages conform to the following:

Accel #1	2 to 3 VDC	TC _____
Accel #2	2 to 3 VDC	TC _____
Load Washer #1 (LFN)	1.5 to 2.0 VDC	TC _____
Load Washer #2 (TSN)	1.5 to 2.0 VDC	TC _____
Load Washer #3 (G&H)	1.5 to 2.0 VDC	TC _____
Load Washer #4 (Pyrotechnic)	1.5 to 2.0 VDC	TC _____
Temperature at 22°C	5.5 to 6.5 VDC	TC _____

- 4.7.1.4** Following sensor verification, switch OFF the main power to the spacecraft simulator, disconnect the four cables and reinstall the protective caps on the flight connectors.

TC _____ QC _____

4.7.2 ACTUATION TEST PROCEDURE

This procedure demonstrates actuation of the separation devices using nut house simulators and the spacecraft simulation box.

- 4.7.2.1** Connection of the spacecraft simulator to the SMARD electronics box is accomplished using the procedure described in 4.7.1.1.

TC (J1 Test) _____

TC (J2 Test) _____

TC (J3 Test) _____

- 4.7.2.2** Visually inspect the 25 pin SMARD power test cable (Figure 4-8) for evidence of mechanical damage. Connect the power test cable to "INTERCONNECT CABLE #1" and connect "INTERCONNECT CABLE #1" to J4 of the electronics box to simulate the shape memory actuated Low Force Nut (LFN) and Two Stage Nut (TSN).

TC (J4 Simulator) _____

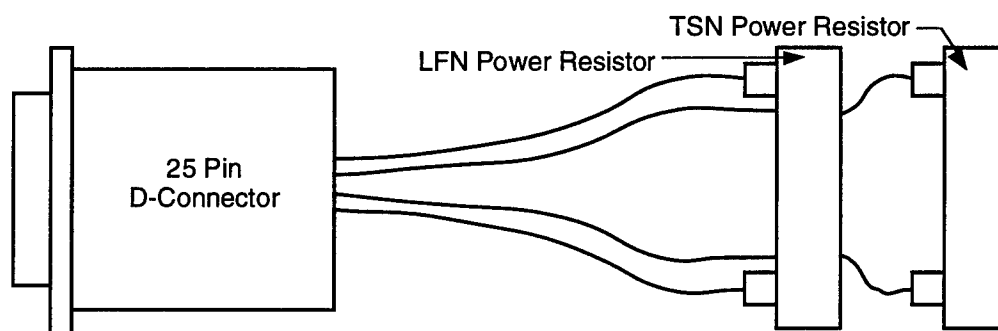


Figure 4-8. SMARD Power Test Cable (LFN, TSN, and Load Simulator).

- 4.7.2.3** Visually inspect the 25 pin SMARD Load Simulator Cable (Figure 4-9) for evidence of mechanical damage. Connect the Load Simulator Cable to "INTERCONNECT CABLE #2" and connect "INTERCONNECT CABLE #2" to J5 of the electronics box. This cable simulates operation of the LFN heater, TSN heater, G&H Separation Nut and the Pyrotechnic Separation Nut.

TC (J4 Simulator) _____

- 4.7.2.4** Following connection of the SMARD simulators, the operational capability of the electronics box to actuate the four separation devices may be confirmed using the following procedures:

Turn ON the main power switch located on the spacecraft simulator and observe that the +28 VDC, +15 VDC, and +5 VDC LED indicator lights are illuminated. If these lights are not visible, the battery inside the spacecraft simulator needs to be recharged.

To recharge the battery, inset the red jack of the SMARD battery charger into the positive (yellow) recepticle of the spacecraft simulator. Insert the black jack of the

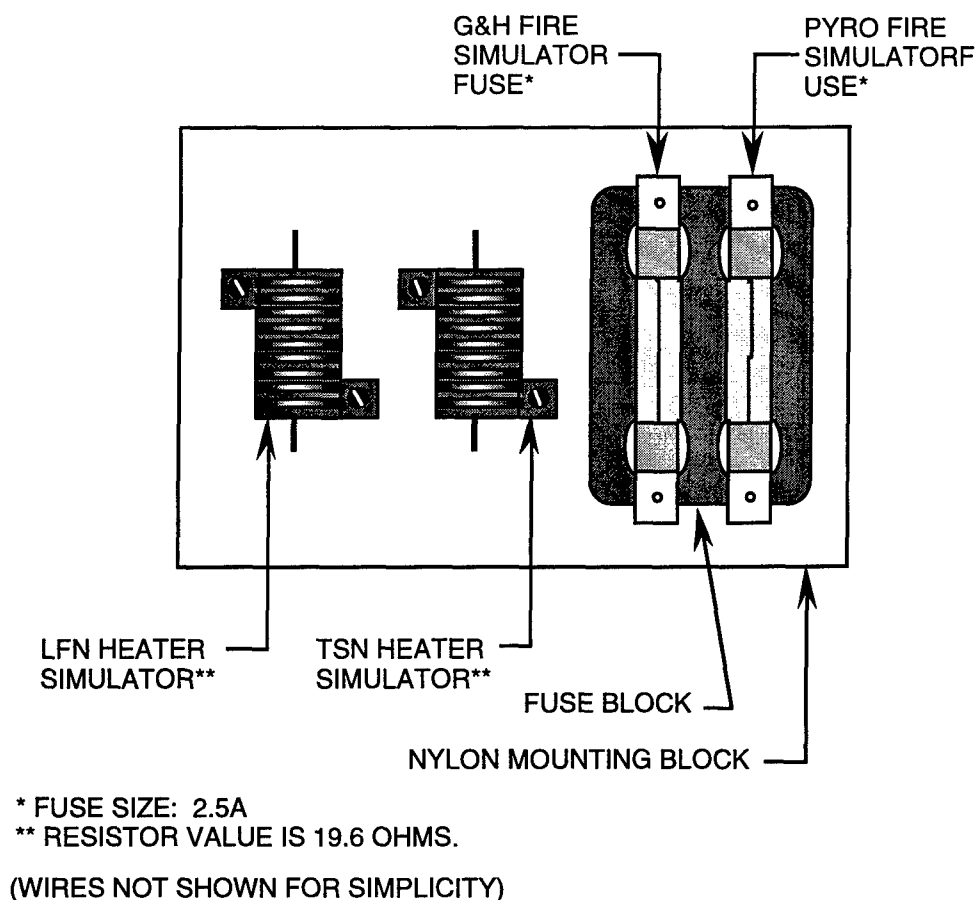


Figure 4-9. SMARD Load Simulator.

battery charger into the negative (black) receptacle of the spacecraft simulator. Plug the battery charge into the 110 VAC line. It takes approximately 3 to 4 hours to fully charge the spacecraft simulator battery. It is advisable to periodically charge the spacecraft simulator battery.

Turn ON the ARM 1, ARM 2, and ARM 3 switches to engage the SMARD safeing relays.

4.7.2.5 TSN Test Procedure

- Connect a digital multimeter (DMM) across the heater load simulator of the TSN shown in Figure 4-9.
- Select the TSN position on the serial line to toggle switch located on the spacecraft simulator box.
- Turn the TSN Prefire heater switch to the ON position and verify that the DMM reads $24 \text{ VDC} \pm 2 \text{ VDC}$.

TC _____

QC _____

- Turn OFF the TSN Prefire switch.
- Toggle the TSN fire switch ON then OFF and check the LCD display on the spacecraft simulator (the LCD displays supplied voltage, current, and watt/seconds in that order). Verify that 30 ± 10 Watt/second was delivered to the TSN simulator.

TC _____ QC _____

4.7.2.6 LFN Test Procedure

- Connect a DMM across the heater load simulator of the LFN as shown in Figure 4-9.
- Select the LFN position on the serial line toggle switch located on the spacecraft simulator box.
- Turn the LFN Prefire switch to the ON position and verify that the DMM reads $24 \text{ VDC} \pm 2 \text{ VDC}$.

TC _____ QC _____

- Turn OFF the LFN Prefire switch.
- Toggle the LFN fire switch ON then OFF and check the LCD display (The LCD display outputs the supplied voltage, current, and watt/seconds in that order). Verify that 100 ± 10 watt/second was delivered to the LFN simulator.

TC _____ QC _____

4.7.2.7 G&H Linkwire Test Procedure

- Place a 2-1/2 amp BUSS fuse or equivalent into the G&H load simulator shown in Figure 4-9. The fuse is a commercial grade part and may be replaced with any fuse having a similar ampere rating.
- Turn the G&H switch ON and observe the fuse blow. Turn OFF the G&H switch.
- Verify that 30 ± 10 watt/second was delivered to the G&H simulator using the LCD display.

TC _____ QC _____

4.7.2.8 Pyrotechnic Test Procedure

- Place a 2-1/2 amp BUSS fuse or equivalent into the pyrotechnic load simulator shown in Figure 4-9. The fuse is a commercial grade part and may be replaced with any fuse having a similar ampere rating.
- Turn the pyrotechnic switch ON and observe the fuse blow. Turn OFF the pyrotechnic switch.
- Verify that 30 ± 10 watt/second was delivered to the pyrotechnic simulator using the LCD display.

TC _____

QC _____

- 4.7.2.9 Following testing, turn OFF the ARM 3, ARM 2, and ARM 1 switches. Turn OFF the main power switch to the spacecraft simulator box. Disconnect the test cables and load simulators.

5.0 SMARD QUALIFICATION TEST RESULTS

The SMARD LFN, TSN and associated electronics have been subject to the tests described in Table 5-1. The qualification vibration spectra is provided in Figure 5-1. In addition, the pyrotechnic device has been exposed to proof pressure and lock-shut testing also described in this section.

Table 5-1. Qualification Test Results.

Test Title	Test Parameters	Comments
Performance	Actuation of LFN and TSN devices. Devices are electrically reset.	Has been repeated before and after each environmental test using spacecraft simulator box and SMARD electronics box.
Random Vibration	Conducted according to spectra shown in Figure 5-1.	SMARD electronics box, TSN, and LFN passed in x, y, and z axes.
Thermal Cycling	-20°C to +50°C 5 Cycles.	SMARD electronics box pass without component failure. LFN, TSN passed without loss of preload.
Max thermal Exposure for Actuation	Temperature increased at 10°C/hour until bolt preload released as indicated by load washer.	TSN: 57°C max temperature LFN: 75°C max temperature

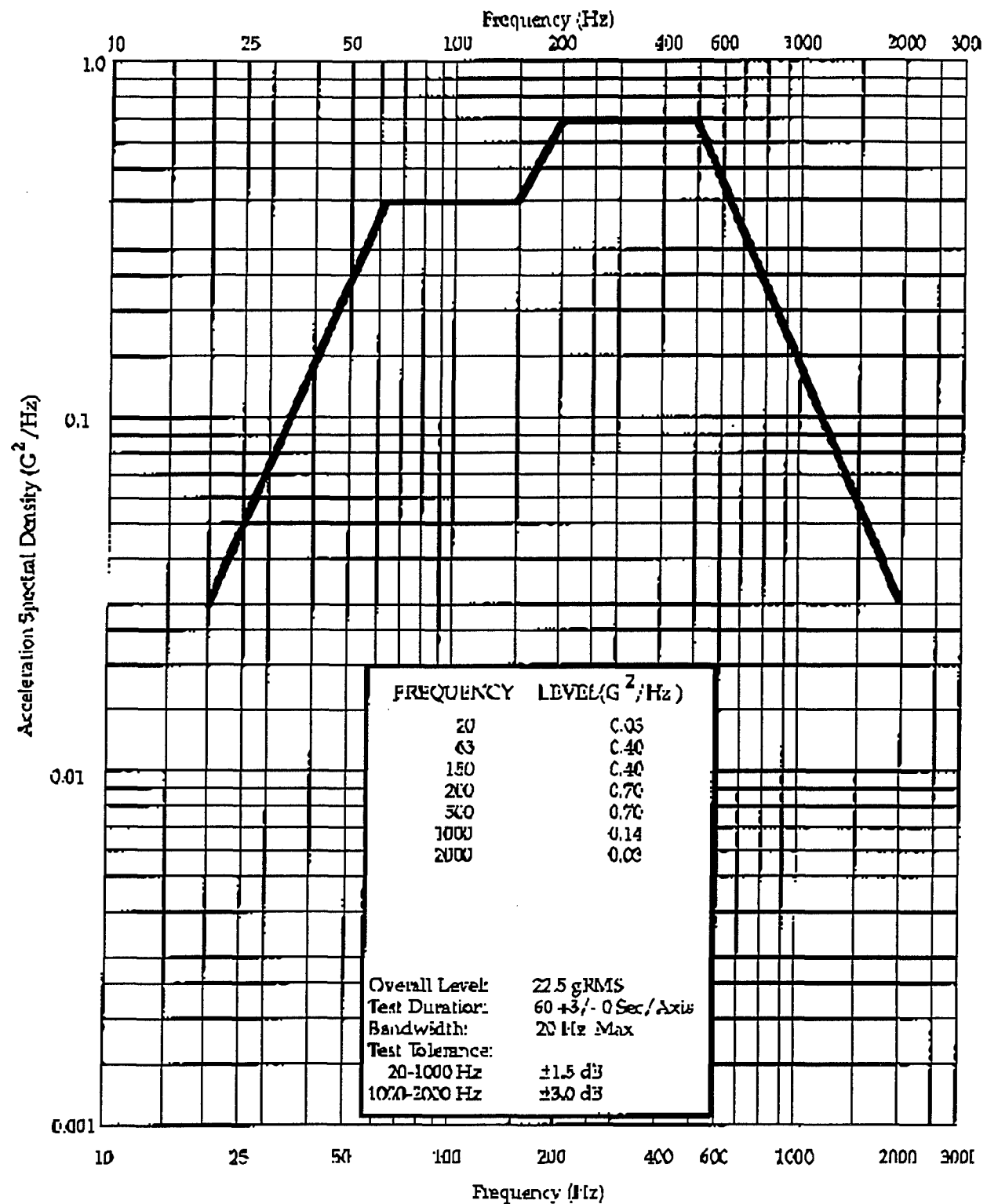


Figure 5-1. Protoflight Level Vibration Spectrum.

5.1 PYROTECHNIC TEST RESULTS

5.1.1 PROOF PRESSURE TESTING

Actuation of the Hi-shear pyrotechnics device was accomplished using the test setup shown in Figure 5-2. For the 1/4 separation device S/N 95009 pressures as a function of actuation cycle were acquired as shown in Table 5-2.

From these data the flight unit has been subject to pressures as high as 2080 psi with a nominal in-flight actuation pressure requirement of 900 psi. In order to qualify the flight unit, it is necessary to proof the device at 1.2 times the maximum design pressure of 7800 psi, which is significantly greater than the 2000 psi actuation pressure. The situation is currently being investigated analytically based on a failure mode associated with the NSI pressure port.

5.1.2 LOCK-SHUT TEST RESULTS

Lock-shut testing was conducted on a device similar to S/N 95009. This test was conducted to demonstrate the ability of the 1/4 inch separation devices to withstand a dual cartridge firing without rupture failure or release of combustion products.

The separation nut was assembled using washers within the inner cavity to prevent motion of the cylinder/ring assembly. The unit was then assembled onto a test plate and NSI cartridges installed with five 565 Viton O-rings.

The entire assembly was placed in a safety chamber and both NSI's fired using a 5 amp 10 msec pulse supplied to both NSI's.

When the 1-in. initiator was removed, a "pop" and distinct hiss of escaping gas was noted. Both initiators were removed and examined to verify that they had both fired. The unit was disassembled from the test plate and the base/keyseat removed. Disassembly and removal of the internal component showed no evidence of rupture or leakage. The products of combustion were completely contained within the inner pressure chamber. Dual 100% initiator "lock shut" firing of the SN 9422-2 Separation Nut was accomplished with no evidence of rupture leakage or yielding of any critical components.

6.0 CONCLUSIONS/RECOMMENDATIONS

The primary goal of this research was to develop a separation device that is functionally equivalent to standard pyrotechnic separation nuts. The two devices fabricated and tested under this program employed shape memory actuators and dampers to release a preloaded bolt under 50 msec and produce less than 500 g's shock. In addition, reset features have been added to allow the device to recapture the bolt without removing the release device from the spacecraft. In-situ reset capability is expected to reduce the labor required to qualify these devices and allows the end user to fly the device that was tested. To demonstrate these devices under on-orbit conditions, the two shape memory devices, a non-pyrotechnic link wire device and a NSI actuated pyrotechnic device, have been mounted to an instrumented plate. This experiment will fly on Mighty Sat 1, scheduled for STS-88 in December 1997. The experiment will record comparative separation time, power, shock output, and temperature data for each of the four separation devices.

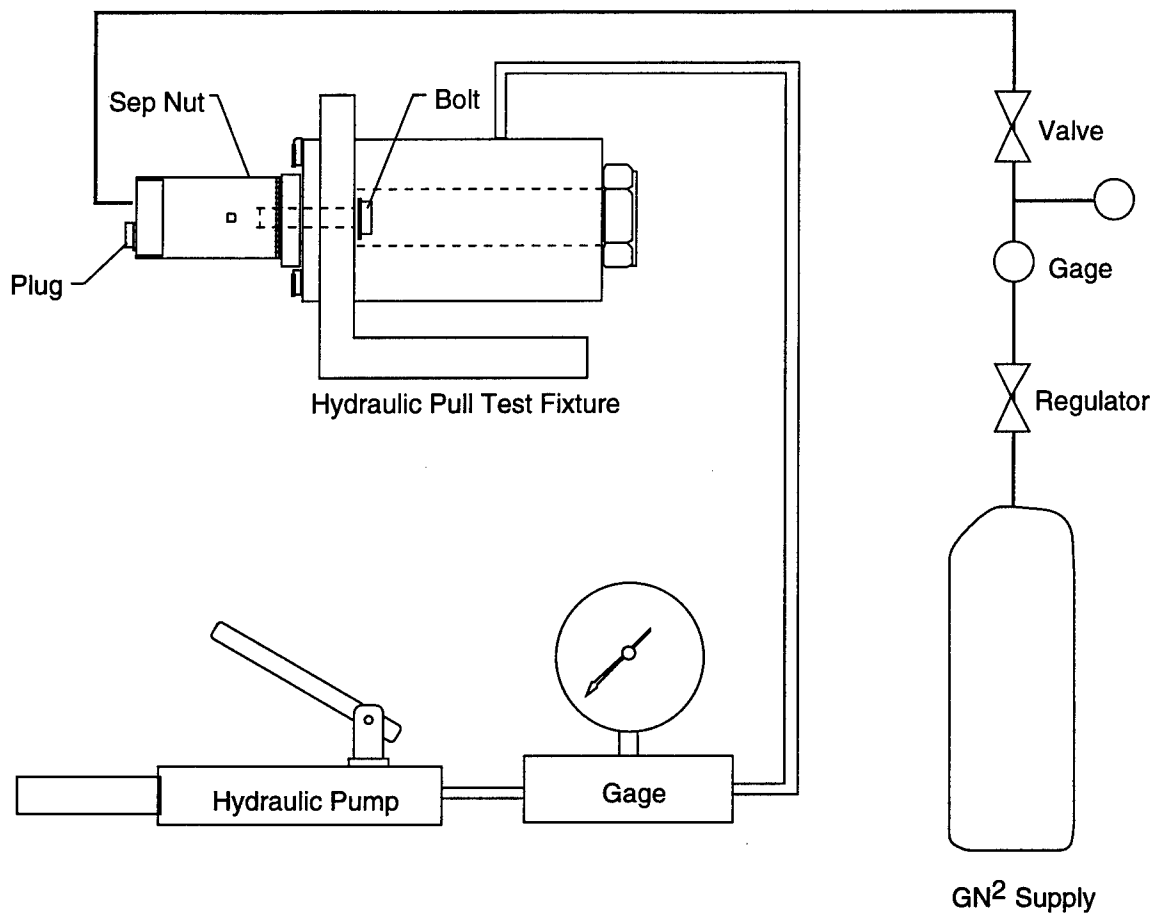


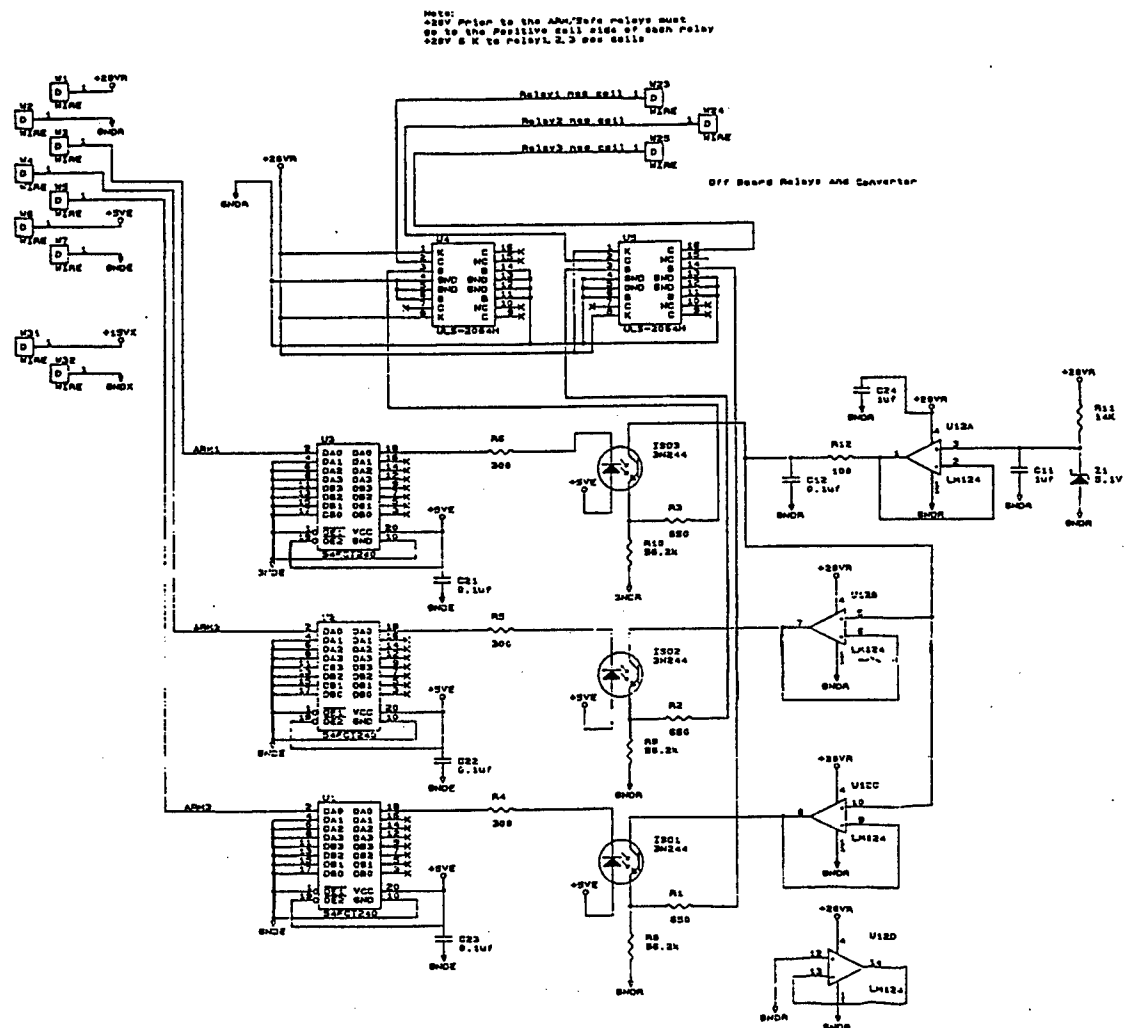
Figure 5-2. Pneumatic Actuation Test Set-Up.

Table 5-2. Cold Gas Actuation Pressure

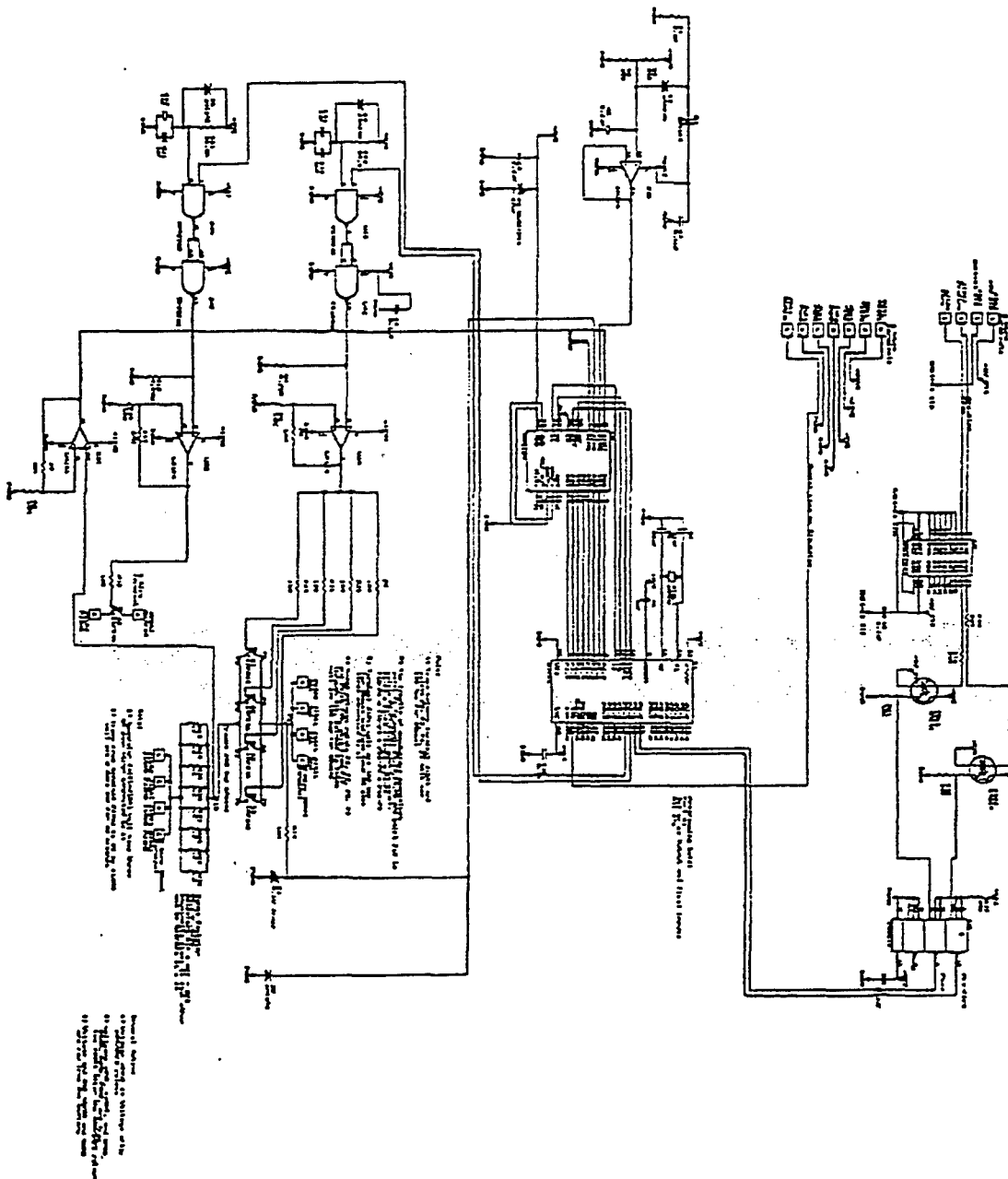
Actuation Cycle	Pressure (psi)
1	2080
2	960
3	900

7.0 APPENDIX A: SMARD ELECTRICAL DRAWINGS

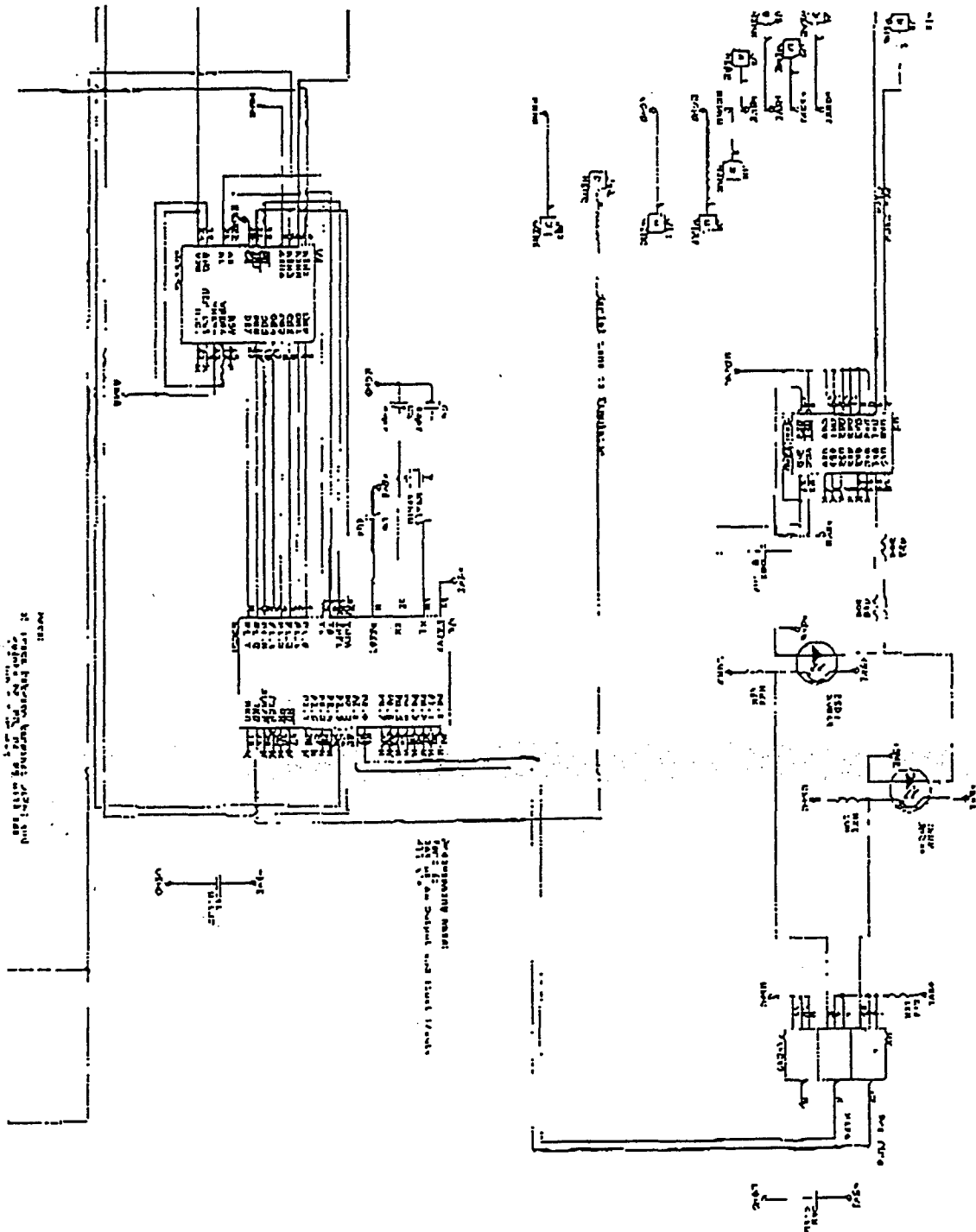
Full size drawings of SMARD Electronics (I/O Board, Instrumentation and Control Boards) can be obtained from Lockheed Martin Astronautics, Research and Technology Group. 12257 State Highway 121, Littleton, CO 80127, Attn: Bernie Carpenter, Mail Stop DC3085, (303) 971-9128. E-Mail address Bernie.F.Carpenter@den.mmc.com



SMARD Electrical Schematic.

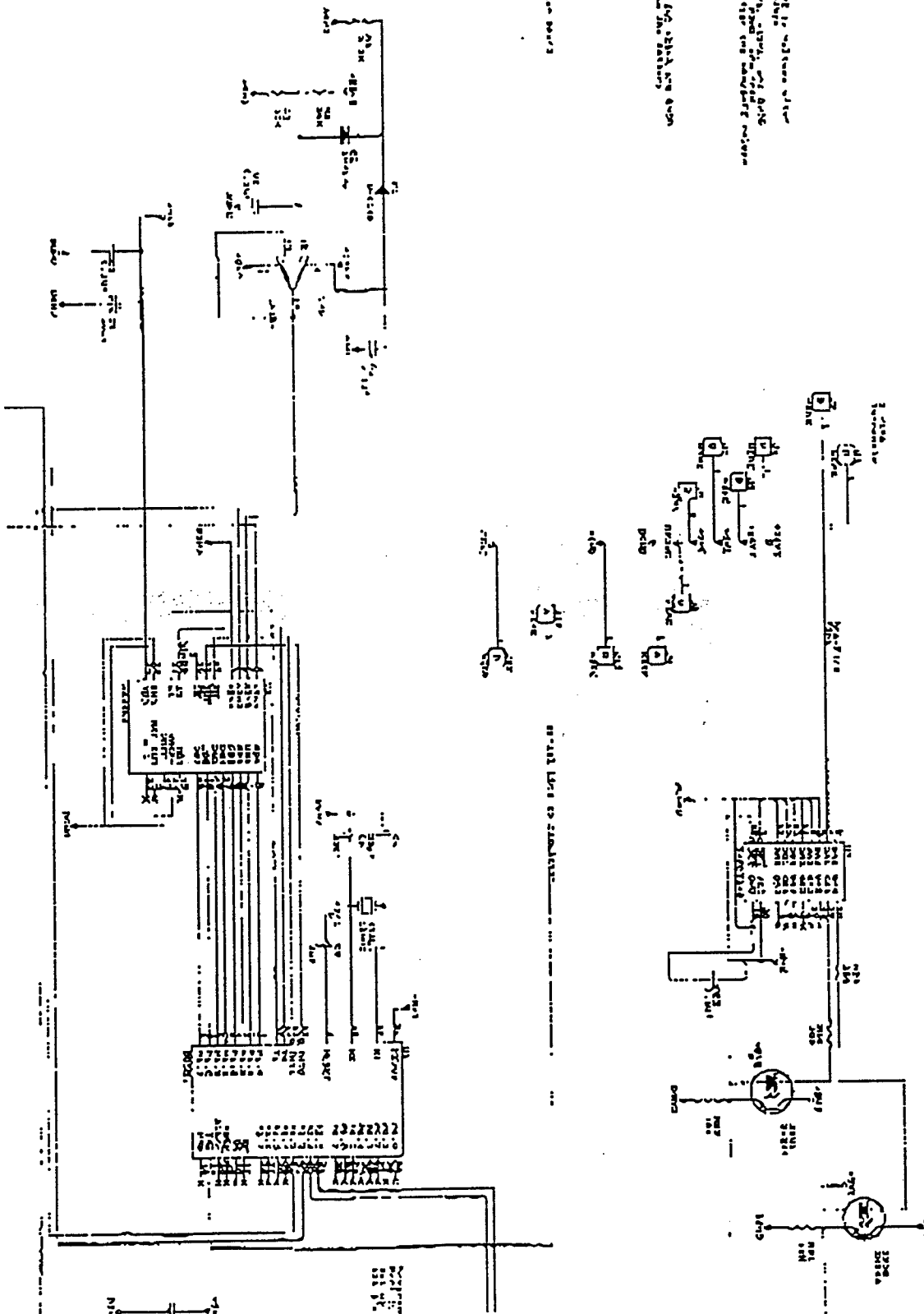






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