REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
1	Various changes since SRR	8/25/09	
2	Initial CDRL release	Oct 2009	
3	Release for Discovery 12 AO	May 2010	

1 SCOPE

This User Interface Control Document (ICD) defines the electrical, mechanical, thermal, and environmental interfaces for the Advanced Stirling Radioisotope Generator (ASRG) for deep space and planetary surface missions.

As of this release, no specific missions have been assigned. Thus, this ICD has been structured to define the characteristics of the ASRG, rather than a specific ASRG-User Interface. Mission requirements and environments have been defined for the ASRG, as specified in the DOE Performance Specification. This User ICD will be updated as the ASRG detailed design progresses and for specific ASRG User interface definition when User mission details become available.

SIGNATURES	DAY	MO	YR	LOCKHEED MARTIN ENERGY SYSTEMS, P.O.BOX 8555, PHILADELPHIA, PA 19101		
DRAWN				ASRG User ICD		
ISSUED						
QA						
Generator						
Controller				CONTRACT NO. DE-AC07-00SF22191		
Thermal						
System				SIZE A	CODE IDENT. NO. 04236	**912IC002085**
PMO						
						SHEET 1 OF 52

To Be Determined (TBD) Log

TBD	SECTION	TITLE
TBD-03	Table 9.1-1, Table 9.1-2	MIL STD 1553B Transmit and Receive Commands Definition
TBD-04	5.1.2.2	ACU Mass Properties
TBD-05	9.3	Telemetry Packet Definition
TBD-07	5.1.2.2	ACU Moments and Products of Inertia

To Be Revised (TBR) Log

TBR	SECTION	TITLE
TBR-03	4.3. 2.1	Telemetry word size
TBR-06	Table 9.2-1	MIL STD 1553B Mode Code Support

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2 APPLICABLE DOCUMENTS

The following documents contributed to the development of this ICD. For Lockheed Martin documents, the issue used shall be the latest version that is controlled by the Document Control Specialist in accordance with ASRG Configuration Management Plan, LMSP-7292. When the interface requirements of this ICD and other documents are in conflict, the following precedence shall apply in the following order:

a) ASRG System Specification (912SS002086)
b) This User ICD (912IC002085)
c) Other documents referenced in this document
d) Other documents which are subsidiary to those referenced in this document

2.1 Government Documents

2.1.1 Military Specifications

MIL-STD-461F	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystem and Equipment, 10 December 2007
AFSPCMAN 91-710	Air Force Space Command Manual, Range Safety User Requirements, 1 July 2004
MIL-STD-1553B	DOD Interface Standard for Digital Time Division Command/Response Multiplex Data Bus, per Notice 4, 15 January 1996.

2.1.2 National Aeronautics and Space Administration

SC-C-0005	Space Shuttle Contamination Control Requirements, Rev. D, 20/7/90
NPR 8020.12C	Planetary Protection Provisions for Robotic Extraterrestrial Missions

2.2 Non-Government Documents

2.2.1 Specifications - Lockheed Martin

912SS002086	ASRG System Specification
912PS002094	ASRG Pressure Relief Device Product Specification

2.2.2 Drawings - Lockheed Martin

912AD002010	ASRG Assembly
AACUMA00001F-501	Controller Assembly
912AD002050	Gas Management Valve
LMSP-7292	ASRG Configuration Management Plan
LM PIR U ASRG-88	ASRG to SV Electrical Integration

3 ORGANIZATION AND INTRODUCTION

3.1 Document Organization

Section 3 provides a brief introduction to the ASRG. This introduction is not intended to provide a detailed design description or show operation of the ASRG. That detail is part of other specifications as defined in the applicable documents section. This introduction is here for completeness of the interface description and for the reader to reference the ASRG components as they relate to the external interfaces.

Section 4 provides the electrical interface information used to connect the ASRG to a Space Vehicle (SV) Electrical Power System (EPS) bus. This includes the power interface to the SV bus, and the command and telemetry interfaces to the Command and Data Handling (C&DH) system for control and monitoring purposes.

Section 5 provides the mechanical interface information for ASRG mass, structural integrity, housing pressurization and venting.

Section 6 provides the thermal interfaces needed for the ASRG to maintain temperature control for continuous operation.

Section 7 provides the interface information needed during environmental testing prior to mission use.

Section 8 provides electrical connector definition.

Section 9 provides command and telemetry definitions.

Section 10 lists acronyms used herein.

3.2 Introduction - ASRG Components

The ASRG is comprised of four major components:

General-Purpose Heat Source (GPHS)
Advanced Stirling Convertor (ASC)
Generator Housing Assembly (GHA)
ASC Controller Unit (ACU)

The ASRG block diagram is shown in Figure 3.2-1. The complete ASRG assembly is defined in 912AD002010. The ASRG is designed in accordance with AFSPCMAN 91-710 with respect to active power sources, pressure vessels, and materials.

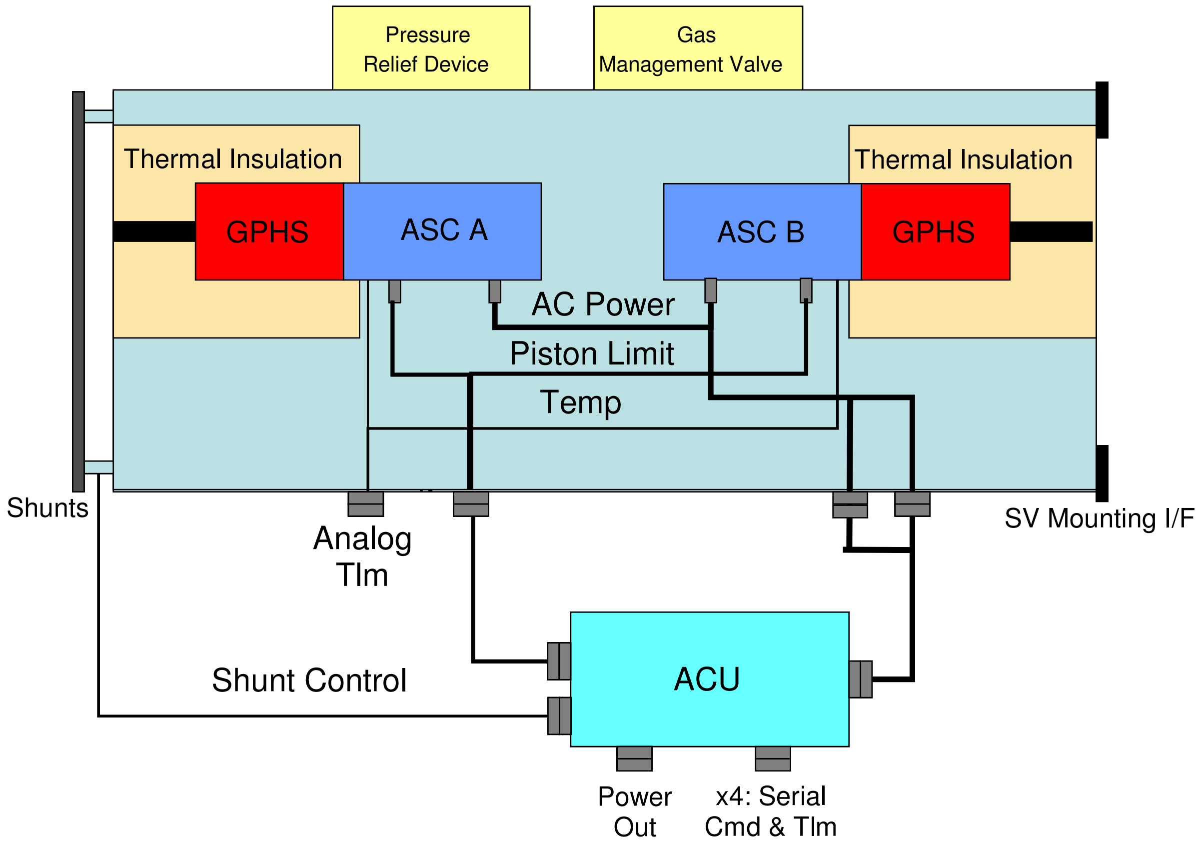


Figure 3.2-1. ASRG Block Diagram.

3.2.1 The General Purpose Heat Source

The GPHS implemented in the ASRG is a Step 2 design and contains the plutonium oxide fuel pellets. The GPHS is Government Furnished Equipment, and is assumed to meet all necessary safety and handling requirements. Two GPHS modules are required, each providing heat to one ASC.

3.2.2 Advanced Stirling Convertor

The ASC converts heat from the GPHS to Alternating Current (AC) electrical power. An ASRG contains two ASCs, designated herein as ASC A and ASC B.

Changes in the pressures and volumes of the ASC working spaces drive a power piston that reciprocates to produce electrical power via an attached permanent magnet linear alternator. Electrical power and telemetry are provided to the ACU and transmitted to the SV.

3.2.3 Generator Housing Assembly

The housing assembly is the main support and attachment structure for the ASRG. It contains a pair of ASCs, a pair of GPHS modules, thermal insulation and end closures, and provides mounting for a shunt dissipater and electrical interfaces to/from the ACU.

A gas management subsystem, consisting of a Gas Management Valve (GMV) as defined in 912AD002050 and a Pressure Relief Device (PRD) as defined in 912PS002094, is mounted externally. The GMV is used to provide pressurized inert gas and gas exchanges during storage, transportation and pre-launch operation of the fueled ASRG to protect the GPHS from oxidation. The barometrically-operated PRD is used to vent the inert atmosphere from the housing during launch ascent to reduce the insulation thermal loss. The components of the ASRG inside the housing but outside the hermetically sealed ASCs will be in the same atmospheric environment as the SV during the mission.

A shunt dissipater is mounted on the outboard end of the ASRG housing. The shunt dissipater is an ASRG-controlled load that allows for the shunting of ASRG produced power in the event of an out-of-range bus voltage condition at the SV power interface. This dissipater may not be used by the spacecraft for routine load management. The shunt dissipater can provide loading during ground operations, such as storage, transportation, and space vehicle integration at the launch site. A separate non-flight shunt can be used to support these ground operations.

3.2.4 ACU Assembly

The ACU is attached to the ASRG housing by a cable that may be up to six feet between the ACU and the ASRG/SV mounting interface. The ACU provides electrical power rectification for two independent ASC alternators, delivers constant power to the SV while tracking the SV power bus voltage, and monitors and regulates each ASC to remain within its safe operating ranges. The ACU synchronizes the two ASC operating frequencies and phasing, which minimizes the dynamic vibration imposed onto the SV. The ACU provides ASRG health and status telemetry to the SV and receives commands to alter the ASC operating conditions, as needed, to vary the output power. Except for these optional commands, the ACU functions autonomously, requiring no intervention from the SV.

The ACU is designed to be single-fault tolerant, having an N+1 redundancy configuration: one Controller Card Assembly (CCA) for each ASC and a third card on hot standby (Figure 3.2-2). Switching to the redundant CCA is autonomous, and is reported in telemetry.

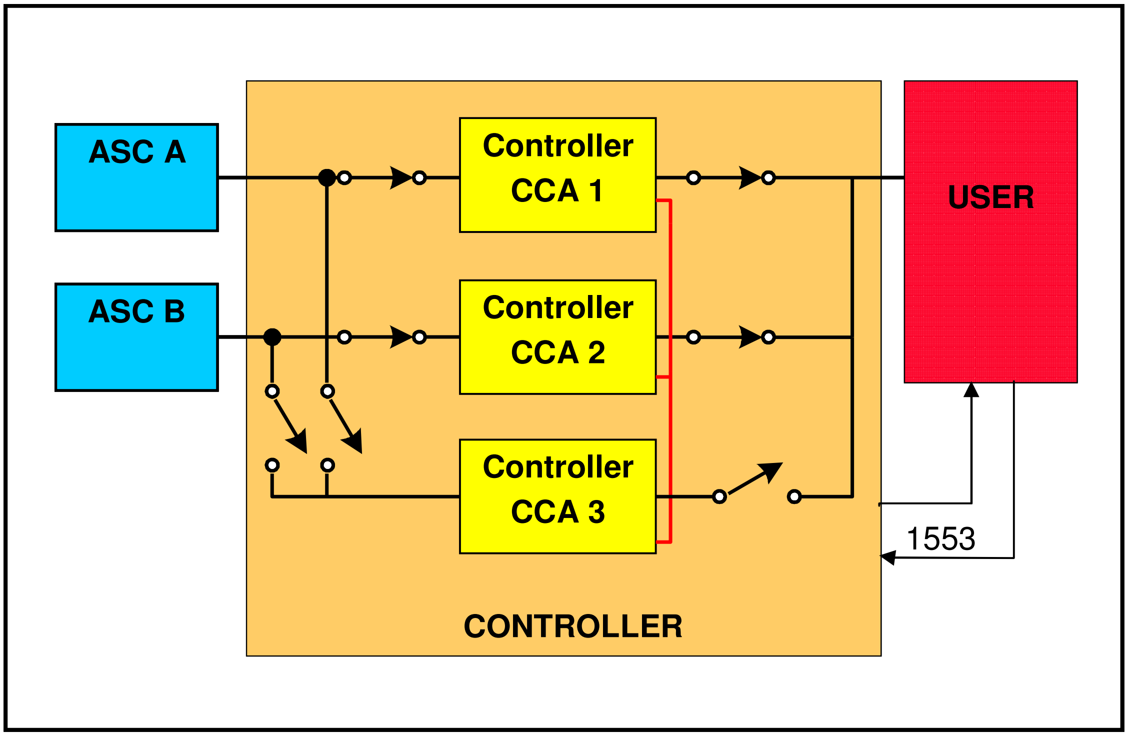


Figure 3.2-2. Single-Fault Tolerant Controller Block Diagram.

4 ELECTRICAL INTERFACES

4.1 Introduction

This section defines the electrical interfaces between the ASRG and the SV EPS, and between the ASRG and the SV C&DH. The ASRG is considered to be part of the SV EPS, which may be defined as either a battery energy storage bus or a DC capacitive energy storage bus.

The electrical interfaces between the SV and the ASRG include the following:

- Power: As provided by the ASRG to the SV.
- Command: Commands from the SV to the ASRG for operational control.
- Telemetry: Health and status provided from the ASRG to the SV.

4.1.1 Battery Energy Storage EPS Bus

When the SV EPS is configured as a battery energy storage bus, the output of the ASRG is nominally connected to the battery terminals by the SV battery charger (Figure 4.1-1). The ASRG supplies constant power to the SV at a voltage determined by the SV. The ASRG requires a minimum bus capacitance of 1500 µF. The SV power bus ranges and limits to which the ASRG interfaces are defined in Section 4.2.

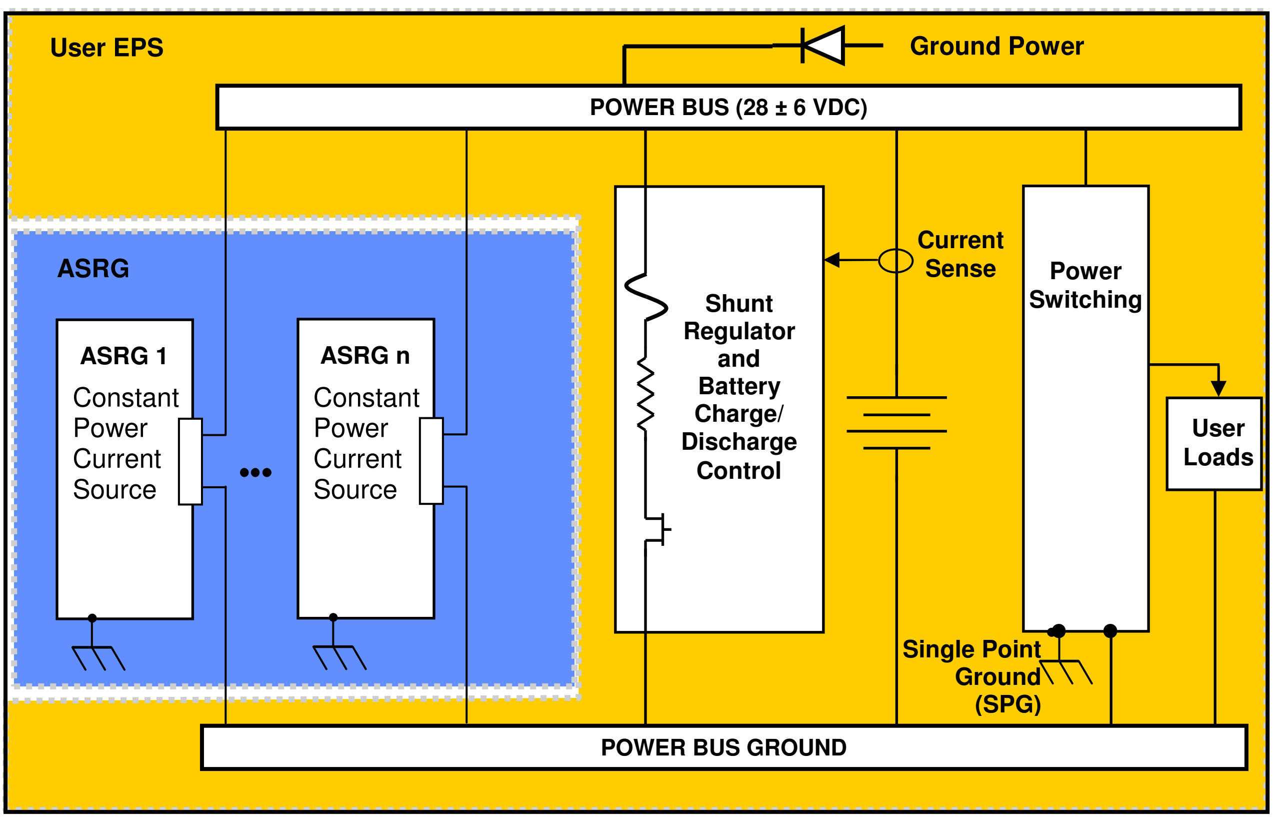


Figure 4.1-1. Conceptual System – Battery Energy Storage Bus.

4.1.2 DC Capacitive Energy Storage EPS Bus

When the SV EPS is configured as a DC capacitive energy storage bus (Figure 4.1-2), the output of the ASRG will be connected to the SV capacitor for transient energy storage and an SV voltage regulator to provide the DC bus voltage regulation. The ASRG can interface to a capacitance range of 10,000 µF to 100,000 µF.

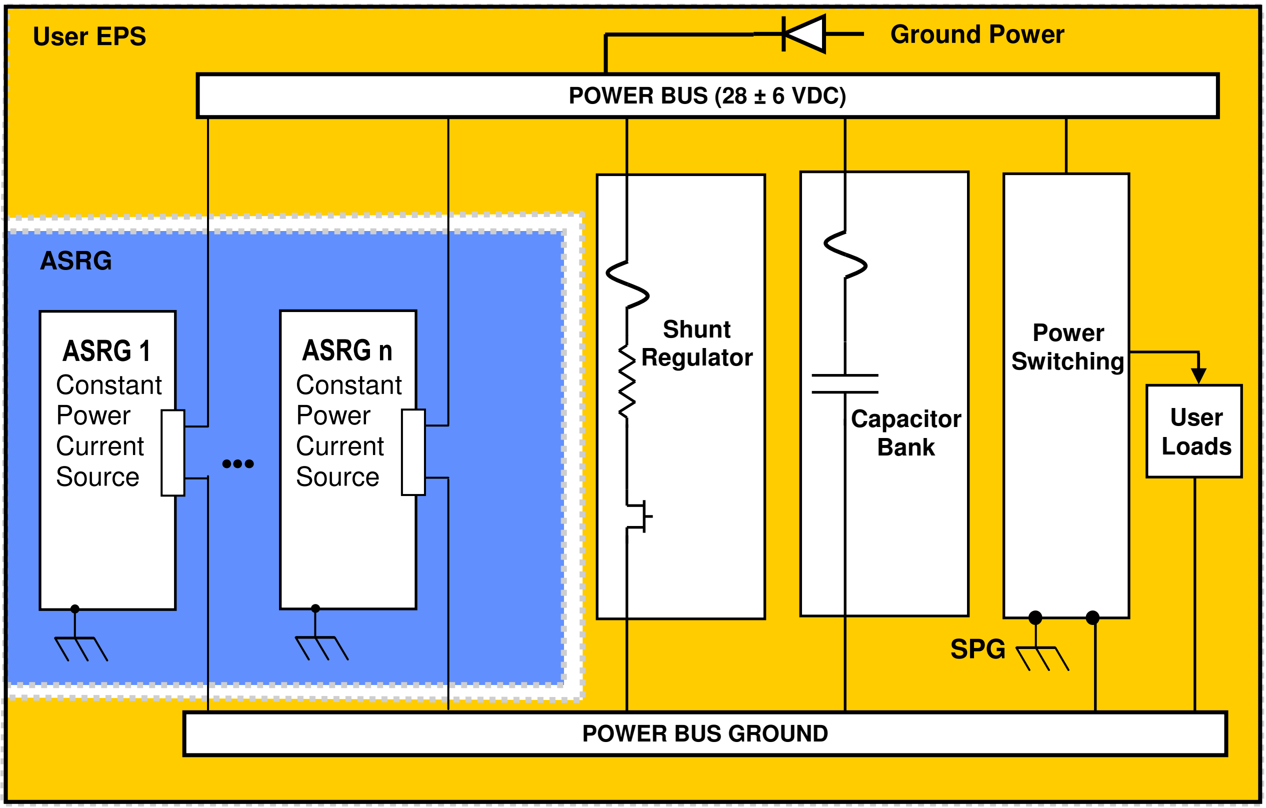


Figure 4.1-2. Conceptual System – Capacitive Energy Storage Bus.

4.1.3 Multiple ASRG Operation

Multiple ASRGs can operate in a single DC bus system, provided that the EPS Bus Impedance requirement of 4.2.5.5 is met for each ASRG. Each ASRG operates independently of any other ASRG on the SV.

4.2 DC Output Power Interface

4.2.1 Mission Power

The ASRG output provides steady-state electrical power at the ACU power output connector. The output voltage is maintained by the SV EPS. The ASRG delivers constant power to the SV within the nominal bus voltage range of 28 ± 6 Vdc maintained by the bus, and internally dissipates its generated power when the bus voltage is outside the nominal range, as described in 4.2.5.

The ASRG Performance Specification cannot define the output power requirement under every condition in which the generator may be used. As such, it defines specific points at which the power will be verified. The ASRG Performance Specification requires a power output of 140 W_e under Beginning of Mission (BOM) environmental conditions, for a GPHS module fuel loading of 244 W_t. Environmental BOM, for the purposes of the specification, is defined as the point when the ASRG reaches equilibrium just after launch, in deep space with a 4K sink temperature and no solar flux. It also requires that the ASRG produce at least 85% of its BOM power 14 years later, under the same environmental conditions.

ASRG output power will actually vary with time, sink temperature, initial thermal power of the radioisotope fuel, mechanism of heat rejection (ASRG fins only or with user-provided cooling loops) and existence of an atmosphere, such as on Mars. Estimates of ASRG output power variation with these conditions are provided in the remainder of this section. For the purposes of selecting additional margins to apply, users should note that all following power estimates are derived from the ASRG current best estimate for stated conditions, not the specified requirement.

The estimated ASRG power output versus time is provided in Figure 4.2-1. Three power curves included in the figure are provided to bound the allowable variation in initial fuel loading. The three cases vary the GPHS modules from their lowest (244 W_t per module), nominal (250 W_t) and highest (258 W_t) specified thermal power as of an estimated module production date of June 2012. These power curves are for vacuum environment with the ASRG rejecting heat to a 4 K deep space sink. Figure 4.2-2 shows the estimated power output as a function of sink temperature at the BOM. To estimate the power output for a given sink temperature with mission year, Figure 4.2-2 can be scaled linearly based on the power output/time profile shown in Figure 4.2-1.

For Mars surface missions, the ASRG power output will be reduced due to the CO_2 environment and consequently the limitation on ASC operating temperature. Figure 4.2-3 shows the estimated power output with mission year with three cases of GPHS thermal power as of an estimated module production date of June 2012. An average fixed ASRG temperature is assumed in the power output estimate, since the thermal integration with a rover/lander to account for the variation in a diurnal cycle is yet to be determined by the user.

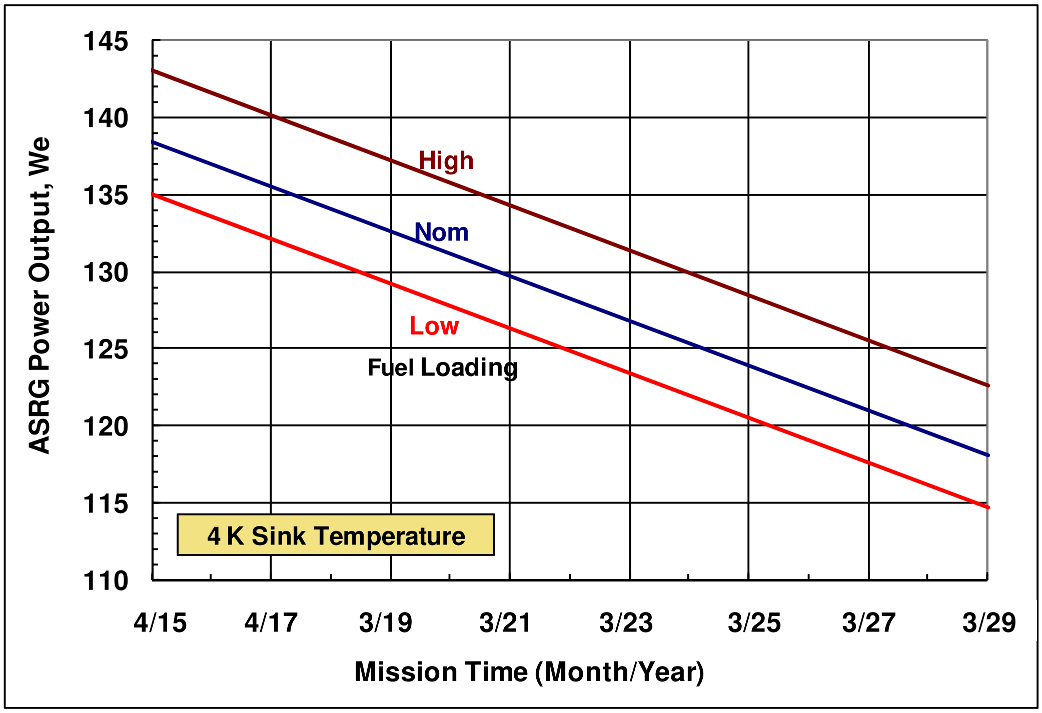


Figure 4.2-1. ASRG Power Output versus Mission Year.

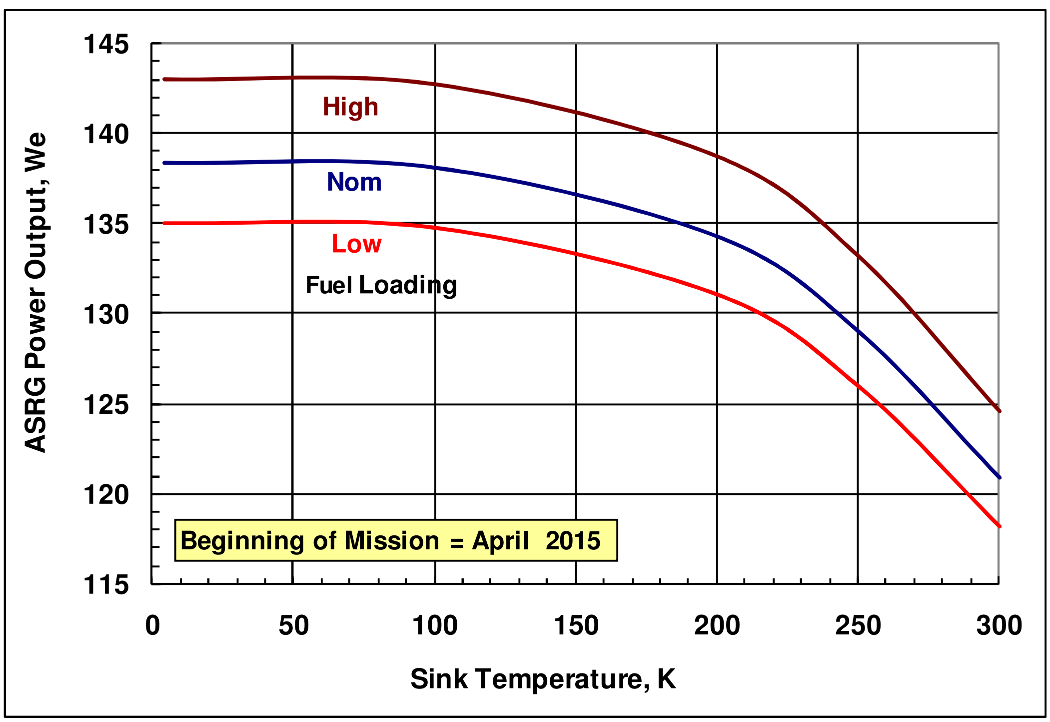


Figure 4.2-2. ASRG Power Output versus Sink Temperature.

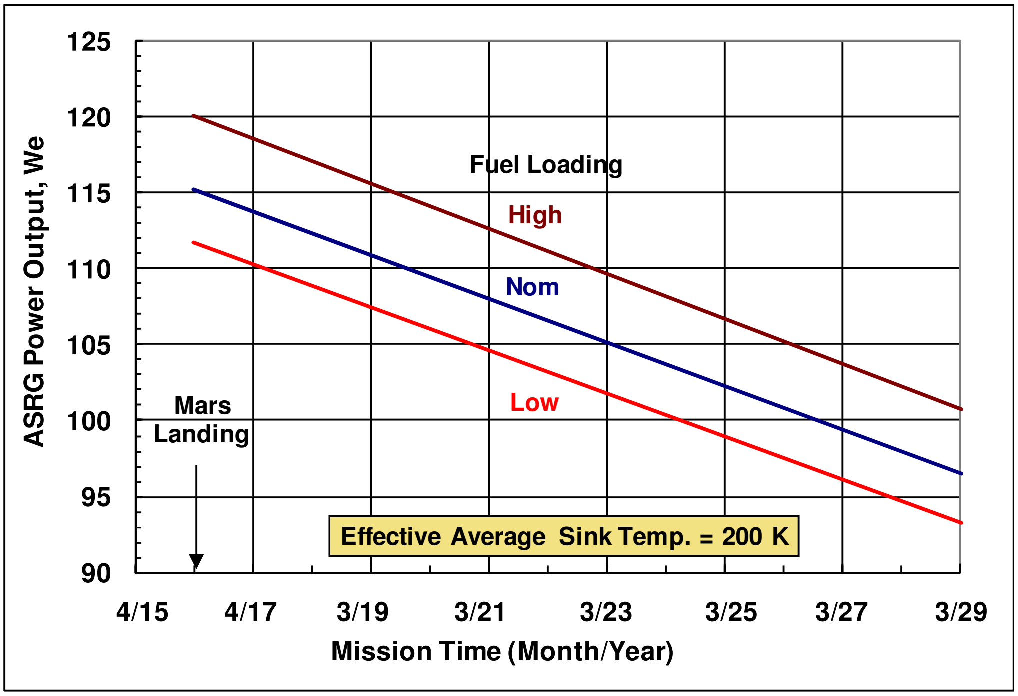


Figure 4.2-3. ASRG Power Output for Mars Surface Missions.

4.2.2 Pre-launch Power

With the inert cover gas that increases thermal loss, the ASRG supplies a minimum of 80% of the BOM power output shown in Figure 4.2-1 during launch site integration.

4.2.3 Launch Power

Due to launch dynamic loading, the ASRG will experience sub-second transient power reductions down to approximately 30% of the pre-launch power. The average ASRG power output under these conditions will be a minimum of 80% of the pre-launch power. The ASRG returns to 100% of the pre-launch power within 30 seconds after separation of the space vehicle from the last stage of the launch vehicle. The dynamic environments to which this requirement is applicable are defined in Section 7.1. These power transients could also apply to other dynamic loading events, such as atmospheric entry.

ASRG power output transient reductions during dynamic loading will be characterized as part of the final design and testing. SVs employing a capacitive bus should consider sizing a primary battery in their EPS architecture sufficient to support these transient reductions, as well as other high current pulse loads (e.g. pyro firings).

4.2.4 Unused Power

The SV manages unused power delivered by the ASRG under nominal bus voltage conditions. The ASRG dissipates self-generated power only under off-nominal conditions. Off-nominal conditions are specified as a bus voltage greater than 34 Vdc or a bus voltage less than 22 Vdc.

4.2.5 ASRG Power Output

4.2.5.1 Switching

It is recommended that the SV EPS provide switching provisions to connect/disconnect the ASRG to/from the SV power bus. This feature is intended to assist with SV-provided failure corrective actions, such as isolating a possible ASRG output short in a multiple ASRG application, and to facilitate initial electrical integration with the SV.

4.2.5.2 Over-Voltage / Open Circuit Condition

The ASRG can operate indefinitely without damage during an open-circuit condition at the output power connector.

The ASRG senses the bus voltage. The over-voltage threshold is set in the ACU at 35 ± 1.0 Vdc. The ASRG provides constant power until the bus voltage exceeds the threshold, then the ASRG internally proportionally shunts self-generated power to limit the output voltage to 35 ± 1.0 Vdc. The ASRG ceases shunting when the SV bus voltage drops to less than 34 Vdc.

During an over-voltage condition, the ASRG remains electrically connected to the bus. To prevent over-stressing the ASRG ACU, the maximum bus voltage presented to the ASRG may not exceed 40 Vdc.

4.2.5.3 Under-Voltage / Short Circuit Condition

The ASRG can withstand a short circuit condition at the SV interface for an indefinite period of time without damage.

The ASRG senses the bus voltage. The under voltage threshold is set in the ACU at less than 22 Vdc. The ASRG provides constant power until the bus voltage drops below the threshold, where the ASRG will operate in an under-voltage mode. The ASRG ceases shunting and resumes supplying full power, when the SV bus rises to above 22 Vdc.

While in the under-voltage mode, the ASRG will supply some power to assist the SV power bus recovery. The final concept is still being developed, but it is anticipated that the ASRG will pulse-width modulate the disconnect switch on/off time, controlling the peak current. Its behavior in the under-voltage mode is expected to approximate a current limited buck-type switching power converter. ASRG internal control is maintained by sharing/trimming between the ASRG internal shunts and the current limited output.

The recovery average RMS current will be 1.75 amps, which represents approximately 40% of the equivalent 28V bus current capacity at EOM. It is assumed that the SV will autonomously reduce its power load during its bus under voltage, such that less than full ASRG power output could assist in recovering the SV bus voltage to within the operational range. Note that power output quality will depend on the bus actual low-voltage condition, and can represent increased voltage and current ripple, and increased conducted and radiated emissions, compared to nominal operating conditions. All ASRG requirements will be met after the SV bus voltage recovers to the nominal operating range (22 to 34V).

4.2.5.4 Power Quality

4.2.5.4.1 Conducted Emissions

The ASRG will comply with the conducted emissions requirements specified in MIL-STD-461F tailored for space applications, as specified in Figure 4.2-4, when connected to a bus interface as described in Paragraphs 4.1.1 and 4.1.2.

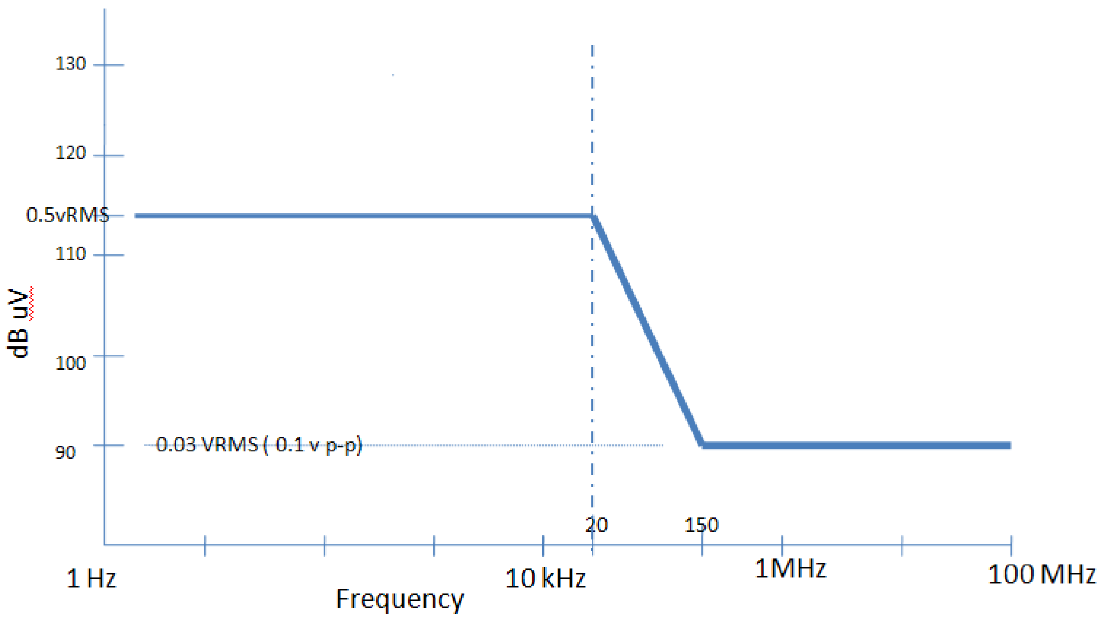


Figure 4.2-4. ASRG Conducted Emissions.

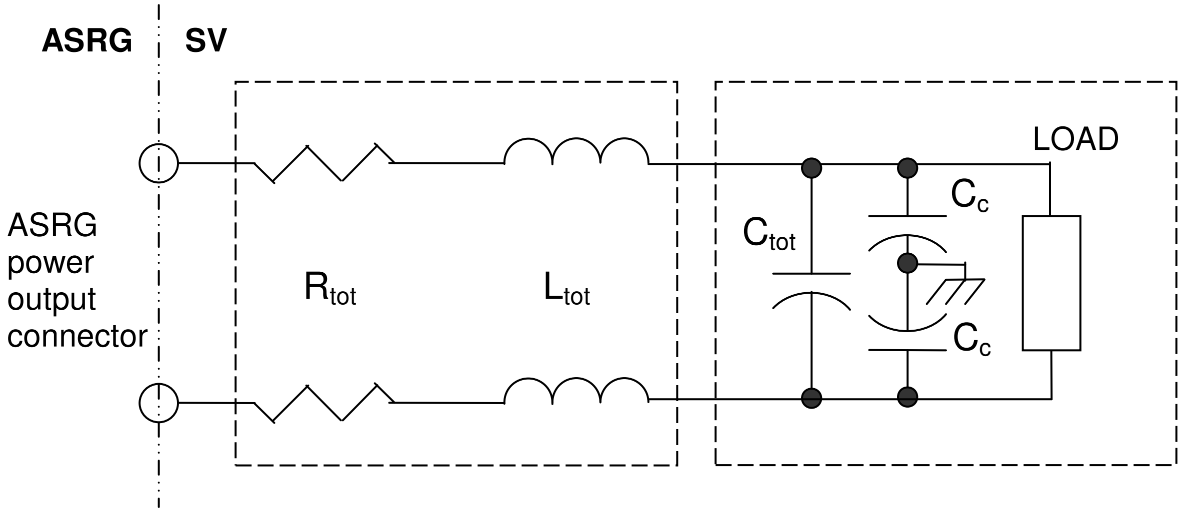
4.2.5.4.2 Voltage Transient Spikes

The ASRG generated output voltage transient spikes, independent of SV bus capacitance or batteries, will be less than 1.0 V peak-to-peak, over a measurement bandwidth of DC to 100 MHz, when connected to a bus interface as described in Paragraphs 4.1.1 and 4.1.2 and supplying a load current transient of less than or equal to 2.0 amp-msec.

4.2.5.5 ASRG Output Impedance at Bus Interface

4.2.5.5.1 Interconnect Impedance

The ASRG to SV power interconnection must be low impedance with twisted pair positive and negative conductors. The SV EPS bus interface with the ASRG must be within the impedance limits shown in Figure 4.2-5.



1. Total Round Trip Line Resistance, $R_{total} \leq 0.2\ \Omega$
2. Total Round Trip Line Inductance, $L_{total} \leq 200\ \mu H$
3. Stray/chassis capacitance $\mathbf{C}_c \leq 0.01\ \mu F$
4. Total Load Capacitance, $C_{total} \geq 1500\ \mu F$ (battery bus) 10,000 µF to 100,000 µF (capacitance bus)

Figure 4.2-5. SV EPS Bus Equivalent Interconnect Impedance.

4.2.5.5.2 Multiple ASRG Interconnection

In a system configuration utilizing multiple ASRGs, the ASRG to SV power interconnection impedance of each ASRG must adhere to Section 4.2.5.5.1.

4.2.6 Failure Mode Operation

4.2.6.1 ASC Fault-Mode Operation

In the event of an ASC failure, the ASRG is capable of providing output power from the remaining non-failed ASC to the EPS bus. The failed ASC is electrically isolated from the EPS bus. The DC power output of a single ASC is a minimum of 45 percent of the output values shown in Figure 4.2-1 and Figure 4.2-2.

4.2.6.2 ACU Fault-Mode Operation

In the event of a failure within the ASRG attached to a capacitive bus with 10,000 µF bus impedance, internal fault recovery reduces a nominal 28 V bus by a maximum of 2.8 V for a maximum of 10 msec in duration.

4.3 Serial Command and Telemetry Interface

The ASRG accepts commands and sends telemetry via a dual-redundant bus, per MIL-STD-1553B. This interface supports transformer-coupled connectivity to a standard A and B bus network as shown in Figure 4.3-1.

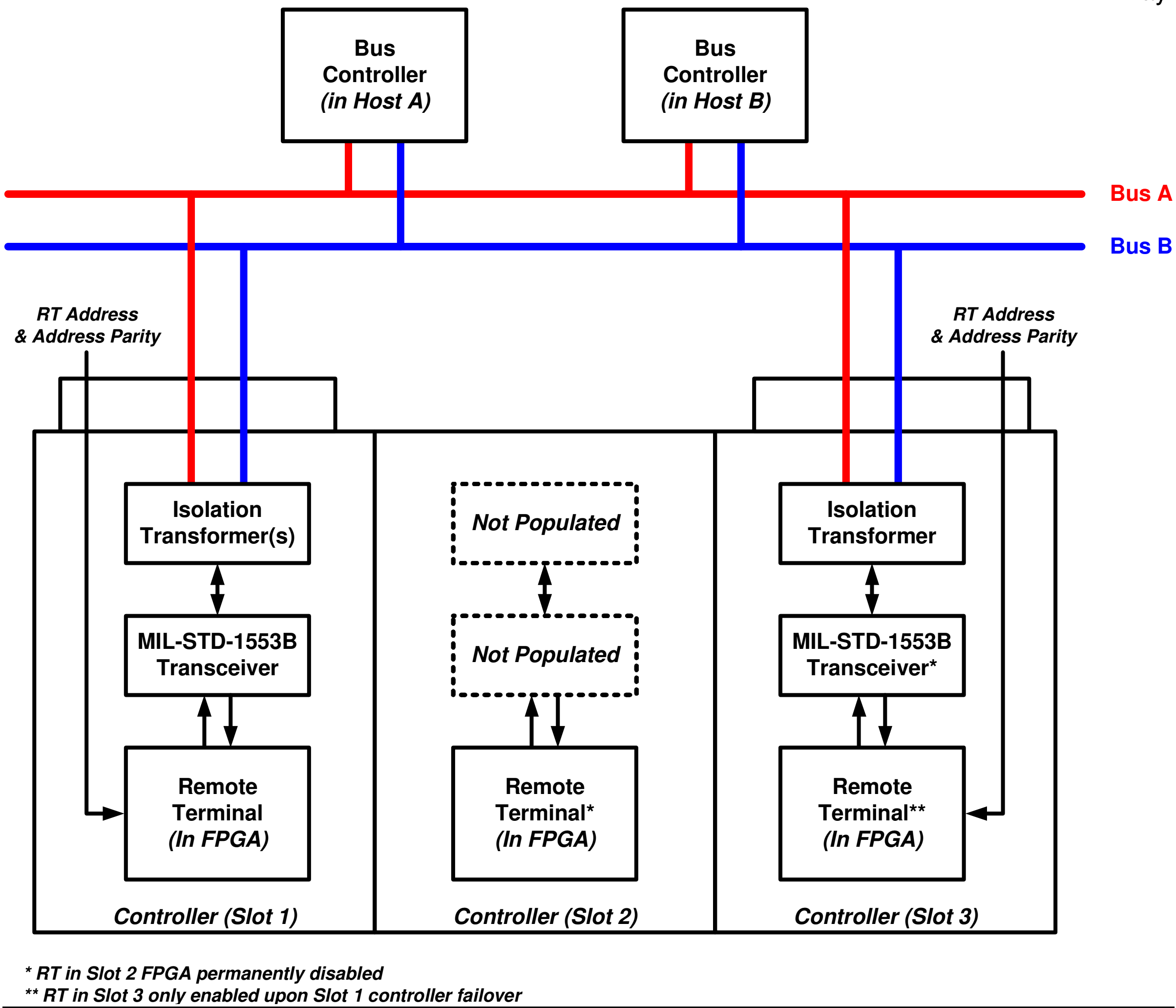


Figure 4.3-1. ASRG 1553B Command and Telemetry Interface Block Diagram.

4.3.1 ASRG Commanding

ASRG commanding consists of a command word followed by a command confirmation word. Necessary command functions will be developed as part of the flight design process, and are not expected to be part of nominal SV mission commanding. However, the following two command functions are available for control of ASRG operation:

- Piston amplitude reduction for ASC A, ASC B or both ASCs
- Modify the ASC voltage set-point

4.3.1.1 Reduced ASC Amplitude Commands

This command provides a means to manage the ASRG fault mode due to an ASC failure.

In the event of a single ASC failure, the resulting dynamic disturbance shown in Figure 5.2-2 can be temporarily decreased by reducing the piston amplitude of the functioning ASC for no longer than 60 seconds. Operation in the reduced-amplitude mode for a period of greater than 60 seconds could permanently damage the ASC.

The resulting disturbance force imparted onto the space vehicle with this command is shown in Figure 4.3-2, as compared to Figure 5.2-2 without this reduced-amplitude command as a function of ASRG structure mount natural frequency. During this period, no power output from this ASC should be expected. Power required during this period shall be met by another ASRG or battery power supply.

At the end of this 60-second operating mode, an ASC set point command described in 4.3.1.2 can be issued to bring the ASC back to nominal operation.

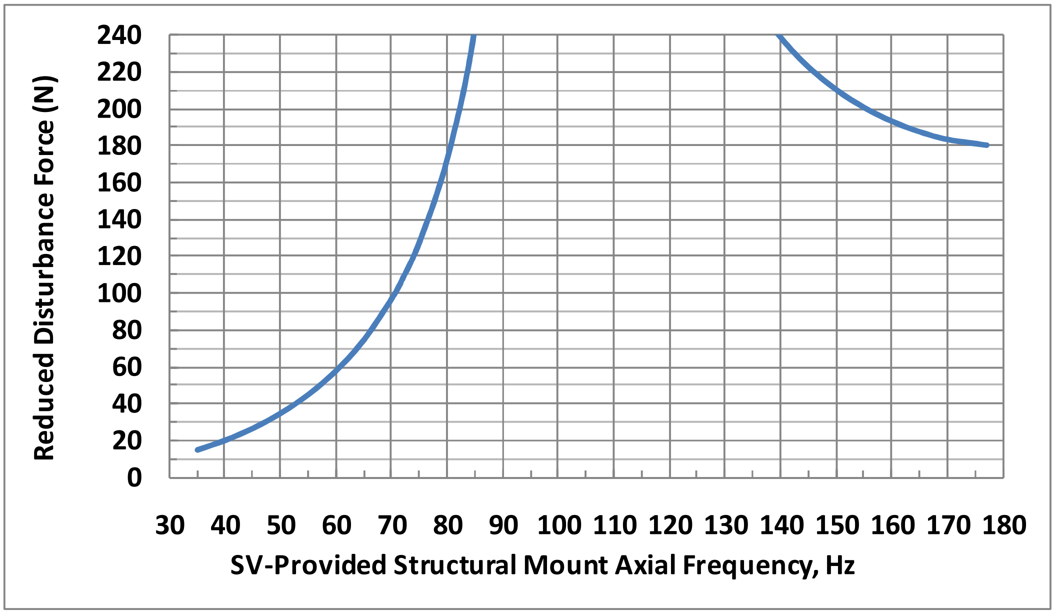


Figure 4.3-2. Dynamic Disturbance to Space Vehicle with Reduced-Amplitude Command

4.3.1.2 ASC Set Point Adjustment

The ASRG accepts an SV command to effectively provide adjustment in the ASC operation in order to optimize power output. When commanded, the ASC transitions from the previous power output to a new power output condition within 120 minutes. This adjustment normally causes a power output variation of no more than 4 We.

4.3.1.3 Serial Command Inputs

The command word is stored but not implemented until the confirmation word is sent on the very next command transmission. The confirmation word can be sent in the same transmission event or later in a second consecutive transmission. Upon receipt of a valid command word and a valid confirmation word, the ACU executes the command immediately and clears the command buffer.

4.3.1.3.1 Incorrect Command Implementation

If a second command word is sent without a confirmation word being sent for the first one, the ACU will replace the first command word with the second command word and then wait for the confirmation word.

4.3.2 ASRG Telemetry

Telemetry is provided to the SV for monitoring ASRG performance and to provide diagnostic data in the event of an anomaly. The ASRG provides the telemetry to the SV as defined below.

4.3.2.1 Serial Telemetry

Options are being considered for the ASRG to make specific ASRG health and status telemetry available to support SV failure detection and correction. The need for and utility of this capability are likely to be mission-specific, and can be worked as part of the User/ASRG interface integration activity.

The telemetry packet consists of eight-bit words (TBR-03) and contains the following categories of information:

- ASC temperatures
- ACU card temperatures
- ASC alternator current
- Internal and external bus voltages
- Command and execution status
- ACU internal voltage
- ACU card redundant status
- ASC voltage set points
- ASC piston position status

4.3.2.2 ASRG Analog Telemetry

Analog telemetry is provided to the SV in order to monitor ASRG performance and provide diagnostic data in the event of an anomaly. Implementation and usage of the available telemetry can be at the option of the user. The user provides stimulation and digitization. The ASRG analog is defined below.

4.3.2.2.1 ASC Hot-End Temperature Telemetry

The ASRG provides two intermediate hot-end telemetry points to the SV, one from each ASC. These sensors are not used in the control function, but provide representative temperature reading for reference. This telemetry is provided as a direct interface between the SV and precision RTDs. The user provides bias current, amplification, and digitization. The interface circuit is shown in Figure 4.3-3. Because of the required calibration accuracy, a Kelvin four-wire, measurement scheme is recommended.

However, if the SV uncalibratable wiring resistance uncertainty can be maintained below 0.1 ohm, a two wire scheme is acceptable.

Reference characteristics of the RTD interface are defined as follows:

- Resistance range of interest: 280 Ω to 345 Ω (approx. 500℃ to 700℃)
- Applied Voltage: 1.3 V_{DC} (max)
- Applied Current: 4 mA (max)
- Thermal Coefficient of Resistance: 0.003919 Ω/Ω/℃
- Element Bias: 100 Ω at 0.0℃
- Telemetry sample rate: at least once per 30 seconds
- Scale Factor (reference only): $R_T = 100.0 \times (1 + 3.9083E\text{-}3 \times T - 5.775E\text{-}7 \times T^2)$, for 0℃ < T < 850℃, where R_T = resistance (Ω) at temperature T in ℃.

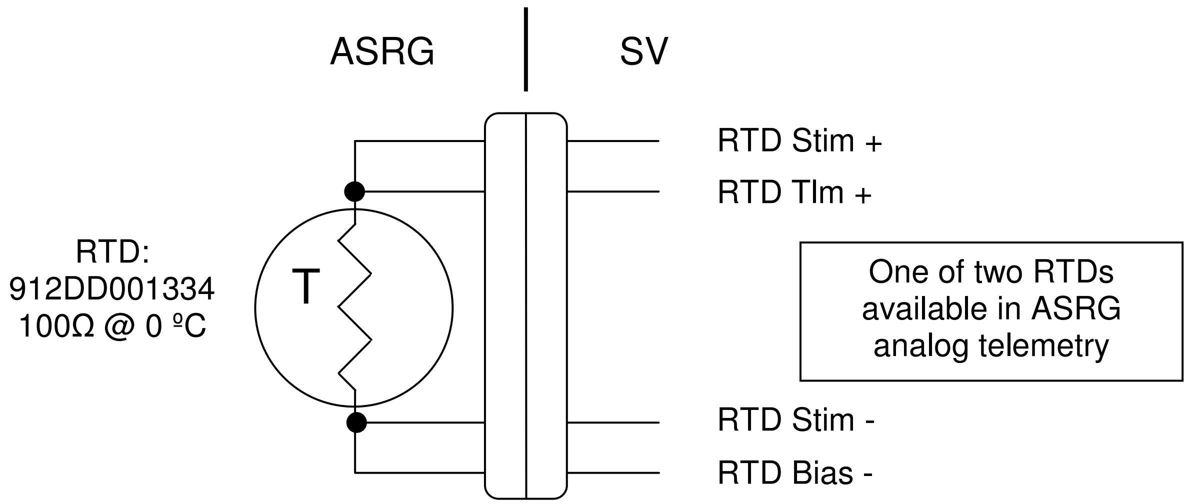


Figure 4.3-3. ASC Hot-end Temperature Telemetry Interface Circuit.

4.3.2.2.2 ASC Cold-End and Alternator Temperature Telemetry

The ASRG provides four thermistor interfaces, two for each ASC, directly to the SV. One is used to monitor each ASC cold-end temperature and one is used for each ASC alternator temperature. The interface circuit for a thermistor is shown in Figure 4.3-4.

Reference characteristics of the thermistor interface are as follows:

- Resistance range of interest: 10 kΩ to 0.4 kΩ (approx. 25℃ to 125℃)
- Applied Voltage: 5.0 V_{DC} (max)
- Applied Current: 1 mA (max)
- Element Bias: 10 kΩ at 25.0℃
- Telemetry sample rate: at least once per 30 seconds

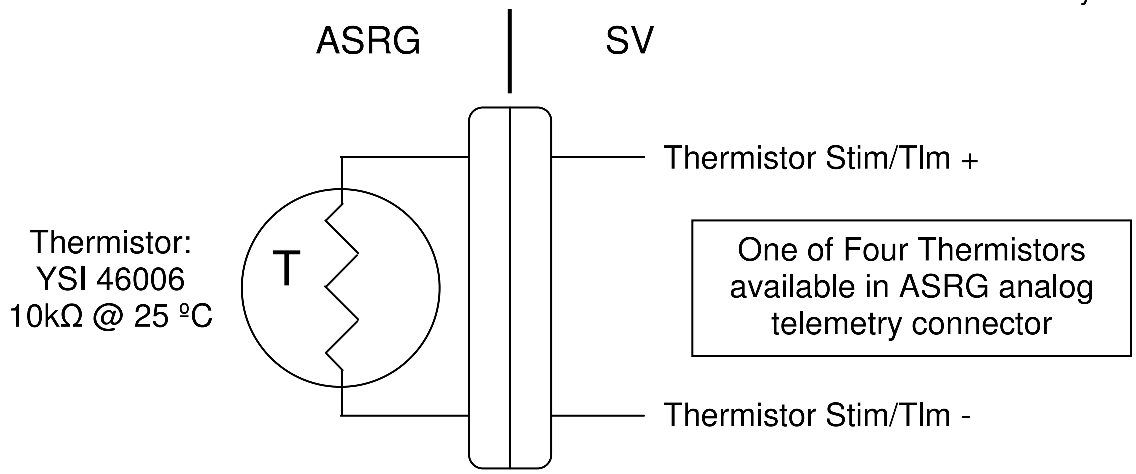


Figure 4.3-4. Thermistor Interface Circuit.

4.3.3 Grounding

The ASRG contains two unique internal electrically isolated grounds: Generator Housing (Chassis Ground) and Output Power Return (Power Ground). The internal isolation of these grounds will allow the user to configure the ASRG in accordance with the SV grounding scheme.

4.3.3.1 Chassis Ground

The generator housing is electrically referenced to the SV mounting surface via the mounting interface or ground straps, at the discretion of the user. The bonding resistance between SV chassis ground and ASRG chassis ground must not exceed 2.5 mΩ.

4.3.3.2 Power Ground

Power ground is defined by the power output return lines of the ASRG. Power ground is isolated from chassis ground within the ASRG by greater than 1.0 MΩ and less than 1.0 µF.

4.3.3.3 Signal Ground

The ASRG contains internal signal and power converter grounds. These internal grounds are isolated from chassis ground within the ASRG by greater than 1.0 MΩ and less than 1.0 µF. Signal ground is reference to the EPS power ground within the ASRG.

4.3.4 Bonding Resistance

The DC bonding resistance between each mated surface that form a part of the electromagnetic interference shielded boundary will be less than 2.5 mΩ throughout the lifetime of the ASRG.

4.4 Electromagnetic Compatibility and Interference

The ASRG is compliant with MIL-STD-461F for space power applications.

4.4.1 Magnetic Field Emissions

ASRG magnetic field emissions are not controlled by requirements. The values described in this section are characteristics derived from development test results.

4.4.1.1 DC Magnetic Field Emissions

The total ASRG dipolar magnetic field vector will not exceed 90 nT, when measured at 1 m from the geometric center of the ASRG when operating at maximum BOM power, at 28 volts output.

4.4.1.2 AC Magnetic Field Emissions

With the ASRG operating at nominal condition, the H-field emissions will not exceed 120 dBpT when measured at 1 m from the geometric center of the ASRG.

4.4.2 Radiated Emission, E-Fields

The ASRG will not radiate narrowband electric fields in excess of those described in Figure 4.4-1. The ASRG does not yet meet the Electra communications system emission limits for Mars applications. Testing and design efforts are in process to improve emissions in this band, with the ultimate intent to meet the requirement. It is not yet clear how effective these efforts will be, and some spacecraft design accommodations may also be required for use of the ASRG with Electra. The specific emission levels that the ASRG is designed to meet are provided in Table 4.4-1.

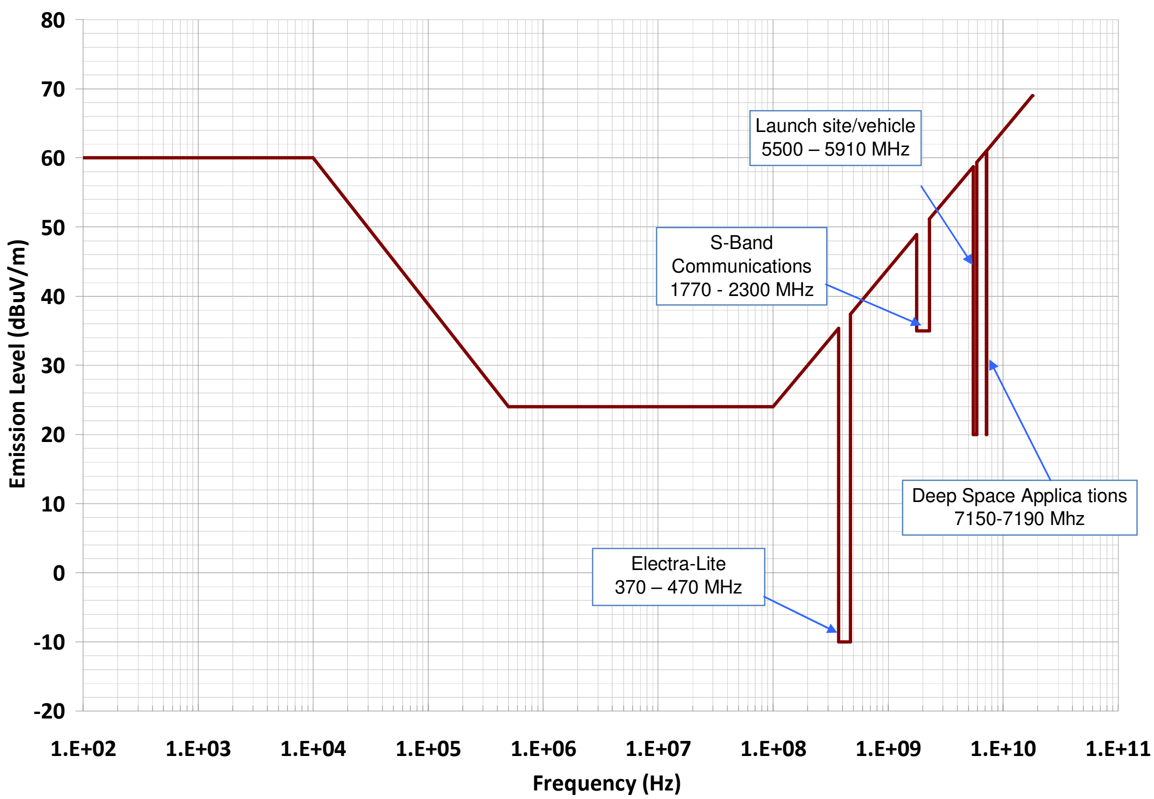


Figure 4.4-1. Limit for Narrowband Electric Fields Radiated Emissions

Table 4.4-1. Electra Emission Limits.

Frequency Range	Electric Field Level
350 - 490 MHz	< 10 dBuV/m
390 - 405 MHz and 435 - 450 MHz	< 0 dBuV/m
401.585626 ± 2 MHz	< -5 dBuV/m
401.585626 ± 0.1 MHz	< -10 dBuV/m

4.4.3 Conducted Susceptibility

The ASRG performs as specified while subjected to a narrowband bus voltage ripple of 1 V_{RMS} from 30 Hz to 100 MHz.

4.4.4 Radiated Susceptibility, E-Fields

The ASRG performs as specified when subjected to the electric (E) fields defined in Figure 4.4-2, when tested in accordance with Mil-Std-461F.

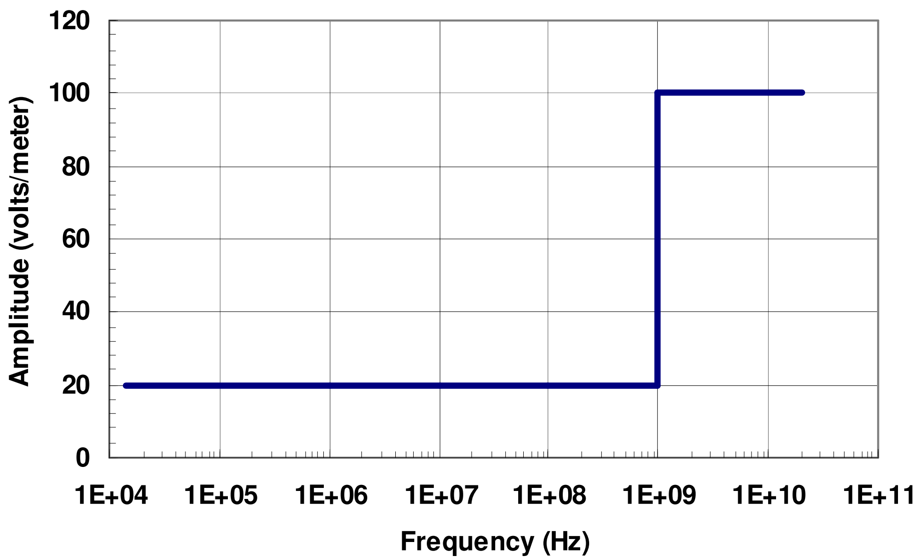


Figure 4.4-2. Radiated Susceptibility, E-Field.

4.4.5 Corona

The ASRG design prevents corona or other forms of electrical breakdown at internal cover gas pressures between 67 and 6.7 x 10^{-4} mbar (50 and 5 x 10^{-4} torr).

4.4.6 Electrostatic Discharge Tolerance

The ASRG is required to tolerate triboelectric charging for Mars re-entry and landing. The specified ESD tolerance level is 3 mJ at 13 kV at the ASRG case.

5 MECHANICAL INTERFACES

5.1 Physical Characteristics

5.1.1 Coordinate System

The ASRG coordinate system is defined in Figure 5.1-1. The four inboard mounting surfaces lie on the X-Y plane at Z = 0.

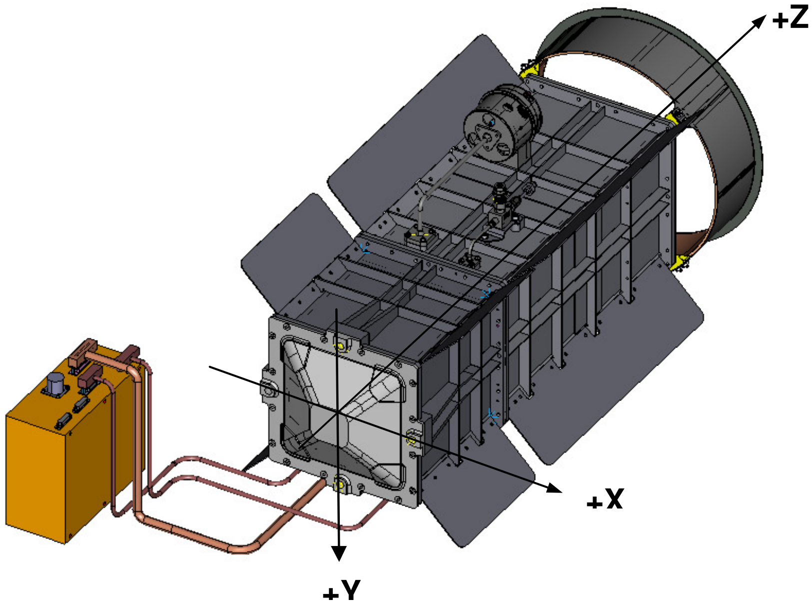


Figure 5.1-1. ASRG Coordinate System Definition.

5.1.2 Mass Properties

5.1.2.1 Generator Housing Assembly Mass Properties

The mass of a flight ASRG Generator Housing assembly is less than 23 kg, excluding any interface hardware such as mounting rings or optional cooling tubes.

The ASRG Generator Housing center of mass is located within a 5 mm sphere with its center located at coordinates X = -0.46 mm, Y = 5.28 mm, Z = 340.97 mm. The ASC moving components do not affect the center of mass within the 5 mm sphere.

The ASRG Generator Housing moments and products of inertia at its center of mass with respect to the three orthogonal axes are as follows, including the ASRG to SV interface cables, but excluding the ACU:

	Moments of Inertia (± 0.05 kg-m^2)
Ixx	3.960
Iyy	3.926
Izz	0.215

	Products of Inertia (± 0.012 kg-m^2)
Ixy	0.004
Iyz	-0.016
Izx	-0.010

The overall ASRG Generator Housing dimensions are 76.2 cm length (Z axis) by 45.7 cm height (Y axis) by 39.4 cm width (X axis).

5.1.2.2 ACU Mass Properties

The mass of a flight ASRG ACU is less than 5.0 kg, excluding cabling from the ACU to the SV interface.

The ASRG ACU center of mass is located within a 5 mm sphere with its center located at coordinates X = TBD-04 mm, Y = TBD-04 mm, Z = TBD-04 mm.

The ASRG ACU moments and products of inertia at its center of mass with respect to the three orthogonal axes are as follows, excluding the ACU to SV interface cables:

	Moments of Inertia (± 0.05 $kg\text{-}m^2$)
Ixx	TBD-07
Iyy	TBD-07
Izz	TBD-07

	Products of Inertia (± 0.012 $kg\text{-}m^2$)
Ixy	TBD-07
Iyz	TBD-07
Izx	TBD-07

The overall dimensions of the ASRG ACU are 20.4 cm length by 15.3 cm height by 11.5 cm width.

5.1.2.3 ASRG Cabling Mass Properties

The ASRG cables connecting between the ASRG housing and the ACU consist of the AC power cable, the shunt cable, and command and serial telemetry cable. The total mass of these cables up to the ASRG housing to SV interface is 2.6 kg, including mating connectors. Beyond the SV interface, the total cable mass is estimated at 1.8 kg per meter separation length between the ACU and the ASRG housing interface, not including mating connectors.

The mass of the analog telemetry cable going directly from the ASRG housing to the SV is not included in the mass estimate.

5.1.3 ASRG to SV Mounting Interface

The interface of the ASRG to the SV is via a four bolt cantilever mount at the ASRG inboard dome as shown in Figure 5.1-2. The ACU is mounted to the housing X-Z face. The SV mounting structure interfacing with the ASRG shall have a natural frequency between 35 and 45 Hz in the X and Y axes (see Figure 5.1-1) and between 35 and 72 Hz or between 144 and 180 Hz in the Z axis.

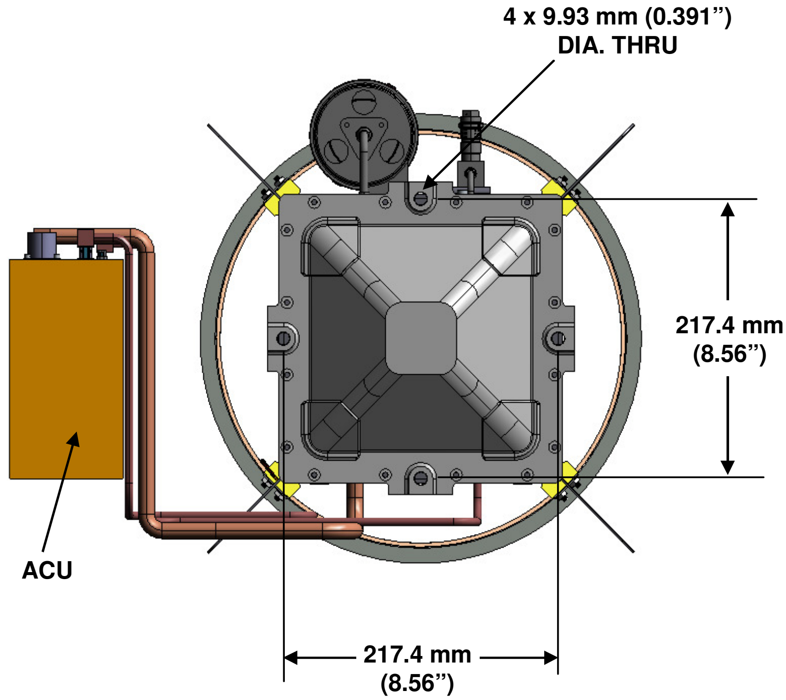


Figure 5.1-2. ASRG to SV Mounting Interface.

5.1.4 Pressurization

For ground operation, the ASRG provides a minimum positive inert gas pressure of 0.105 MPa (15.3 psia) in the housing assembly after a 30-day in-air operation period. Beyond the 30-day period, a re-pressurization to the design pressure of 0.137 MPa (20 psia) could be required (via the ASRG provided gas service cart).

5.1.5 Venting

5.1.5.1 Ground Venting Operation

The GMV, 912AD001338, is used for gas venting and exchange during ground operations. The GMV provides a visible indication of the open position.

5.1.5.2 Flight Venting Operation

After launch, the housing assembly is automatically vented via the PRD. This occurs by a decrease in the barometric pressure during launch. A safety pin that precludes inadvertent operation during ground operations is included. The PRD safety pin is a 'red tag kit' item that must be removed (armed) and accounted for prior to launch.

5.1.6 Handling and Lifting

In addition to the mounting holes allocated for SV integration shown in Section 5.1.3, eight additional 5.18-mm diameter holes, four each on the mid flange and outboard flange of the housing assembly are provided for handling and lifting during ground operation.

5.1.7 General Design and Construction

5.1.7.1 Cleanliness

The ASRG will be delivered for flight integration at the launch site in accordance with the Visibly Clean requirement of NASA Standard SC-C-0005.

5.1.7.2 Planetary Protection

The ASRG is designed and assembled in accordance with the NASA planetary protection requirements for Mission Category IVc of NPR 8020.12C. As part of the integrated SV on the launch pad, the ASRG is being evaluated for compatibility using vaporized hydrogen peroxide (VHP) as the final method to meet exterior surface microbial spore burden requirement. The fueled ASRG cannot be subjected to a heat treatment process to meet this requirement.

5.2 Dynamic Disturbance

5.2.1 Disturbance from Nominal Operation

The ASC pair under normal operating conditions provides a peak disturbance force to the SV that will be dependent on the axial frequency of the SV-provided mounting structure, as shown in Figure 5.2-1. The force has a frequency of 102.2 Hz, the operating frequency of the ASCs.

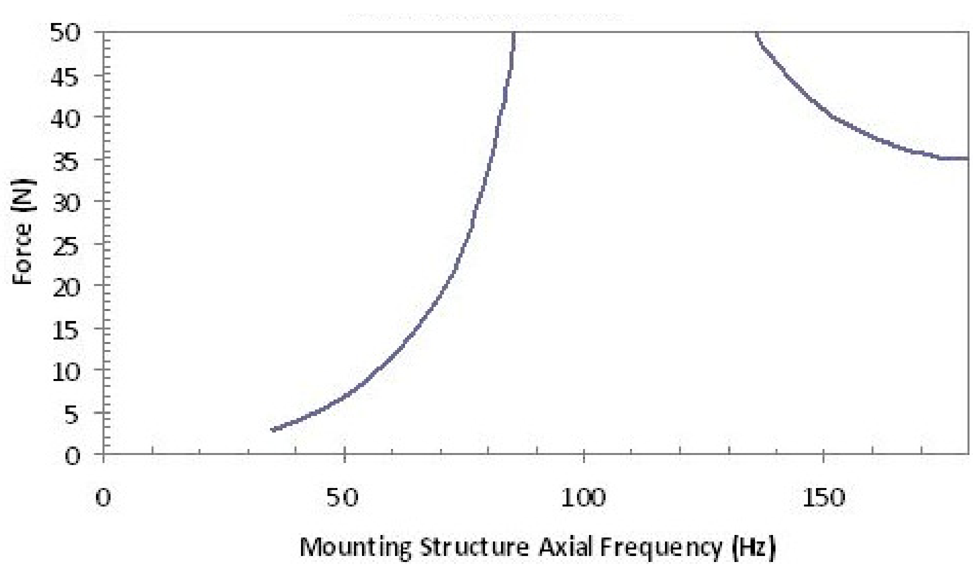


Figure 5.2-1. Disturbance Force to the SV During Normal Operation.

5.2.2 Disturbance from Single ASC Operation

Following an ASC failure, the ASRG produces a disturbance force to the SV that will be dependent on the axial frequency of the mounting structure as shown in Figure 5.2-2 at the ASRG nominal operating frequency of 102.2 ± 0.2 Hz.

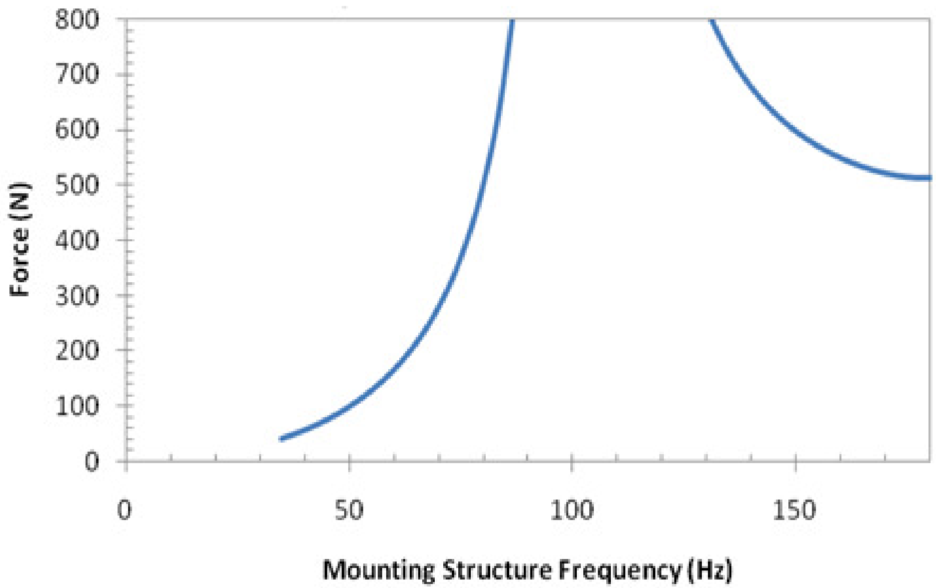


Figure 5.2-2. Disturbance Force to the SV During Single-ASC Operation.

5.2.3 Optional Active Cooling System (ACS) Attachment

For planetary surface missions where active cooling of ASRG is required for thermal control during various mission phases, the ASRG can accommodate a user-supplied cooling loop, either heat pipe or pumped loop types, to be mounted on two sides of the inboard and outboard housing cross ribs where ASC waste heat is conducted to the housing, as shown in Figure 5.2-3.

The generator is designed to carry a user-supplied ACS having a maximum mass of 2.5 kg. This mass includes the heat pipe or pumped loop tubing, working fluid, and mounting brackets. A concept of the pumped cooling loop integrated on the ASRG housing is illustrated in Figure 5.2-3.

Currently, removal of the radiator fins is prohibited with the use of the ACS for the mission. Consideration has not been given for a concept of operations required to maintain the ASRG within allowable temperature limit without the radiator fins attached during ground operation, launch integration, and launch ascent. Approximately two times the waste heat recovery shown in Figure 6.6-1 can be realized without the radiator fins attached.

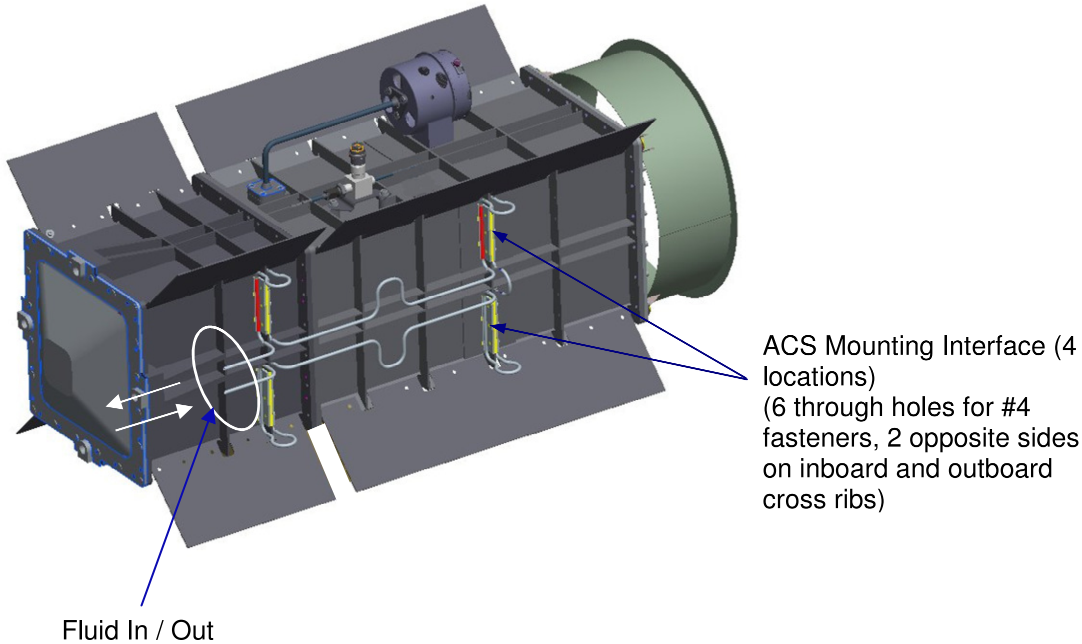


Figure 5.2-3. A Conceptual User-Provided Active Cooling Loop Approach and Mounting Interfaces.

6 THERMAL INTERFACE

This section describes the typical thermal interfaces and temperature conditions between a cantilever-mounted ASRG and a generic SV. The power output of ASRG is a function of its heat rejection from a relatively low housing surface temperature. As a result, the performance of ASRG will be sensitive to its thermal interaction with the SV and the space sink environment, and therefore must be included as part of the integrated thermal analysis and SV design. This section provides the general thermal information that a typical SV can expect from the ASRG. An equivalent thermal analysis must be performed for the mission-specific application.

The maximum temperature limit of the ASRG is defined only by an internal component temperature limit. The allowable flight temperature of the ASC alternator housing, which is available in telemetry to the SV, must not exceed 115℃ to ensure that no performance degradation will occur.

6.1 ASRG Housing Surface Temperature

This section describes the typical interface temperatures between the ASRG and the SV during the various mission phases.

6.1.1 Launch Integration

During typical integration of the ASRG using passive fins with the launch vehicle within the payload fairing, the average ASRG housing surface temperature will be less than 80℃, assuming EELV-supplied cooling dry air or N_2 at <20℃ and 3 m/sec.

6.1.2 Ascent

Typical launch transients for an EELV-class launch vehicle will cause the average ASRG housing surface temperature to rise approximately 10℃ from the launch integration temperatures depending on ascent profile and launch vehicle.

6.1.3 Mission Operation

For deep space operations, the average ASRG housing surface temperature will typically vary between 0 to 90℃ depending on mission phase and environmental conditions. The typical ASRG temperature profiles for the extreme hot case, which occurs during near-earth after launch, and for the extreme cold case, which occurs at end of mission with lowest GPHS fuel loading and deep space sink, are illustrated in Figure 6.2-1.

6.2 Inboard End Dome Temperature

6.2.1 Launch Integration

During typical integration of the ASRG with the launch vehicle within the payload fairing, the ASRG inboard end dome average temperature will be less than 60℃, assuming EELV-supplied cooling at 20℃ dry air or N_2.

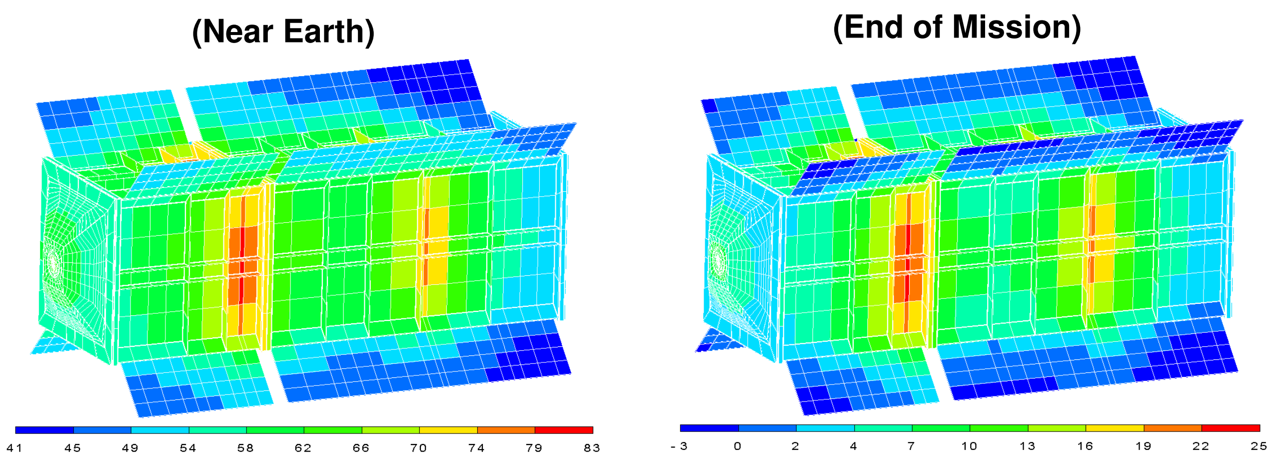


Figure 6.2-1. Typical Housing Surface Temperature Profiles (°C).

6.2.2 Ascent

Typical launch transients for an Evolved Expendable Launch Vehicle-class (EELV) launch vehicle will cause the ASRG inboard end dome to rise approximately 10°C from the launch integration temperatures depending on ascent profile and launch vehicle.

6.2.3 Deep Space Operation

During deep space operations, the ASRG inboard end dome average temperature will typically vary between 5 to 60°C depending on mission phase and environmental conditions, as shown in Figure 6.1-1.

6.3 Environmental Temperature Limits

6.3.1 Deep Space

To maintain the ASRG within temperature limit describe in Section 6.0, the effective sink temperature, defined as the temperature that combines the effects of solar radiation and planetary albedo, if any, space temperature, and SV surface temperatures, must not exceed -23°C (250 K) for ASRG heat rejection.

6.3.2 Martial Surface

To maintain the ASRG within temperature limit describe in Section 6.0, the effective sink temperature, defined as the temperature that combines the effects of solar radiation and planetary albedo, if any, space and Martial surface temperatures, and SV surface temperatures, must not exceed -13°C (240 K) for ASRG heat rejection.

6.4 Contact to ASRG Surfaces

No part of the SV may come in contact with any surface of the ASRG with the exception of the electrical and mechanical interfaces described in Section 4.0 and 5.0.

6.5 ASRG Surface Coating

Heat will be radiated from all exposed surfaces of the ASRG. The external surfaces of the ASRG are coated with a low absorptivity / high emissivity white paint. The properties of the coating at beginning of mission and end of mission (14 years from launch) are shown in Table 6.5-1.

Table 6.5-1. Thermal Coating Reference Properties.

	BOM	EOM
Emissivity	0.90	0.90
Absorptivity	0.13	0.30

6.6 Optional Active Cooling System Waste Heat Recovery

The preliminary estimate of the amount of waste heat and corresponding DC power output that can be recovered from the ACS described in Section 5.2.3 is shown in Figure 6.6-1 as functions of radiative sink temperature and average cooling loop temperature. The ACS temperature affects the ASRG reject temperature, and as a result will provide a slightly higher DC power output than in the radiation-only configuration at the same sink environment (see Figure 4.2-2). Figure 6.6-1 is based on the nominal GPHS fuel loading as of March 2014 launch date. For predictions at different mission year and fuel loading, the waste heat and power values from Figure 6.6-1 can be scaled proportionally based on the DC power values provided in Figure 4.2-1.

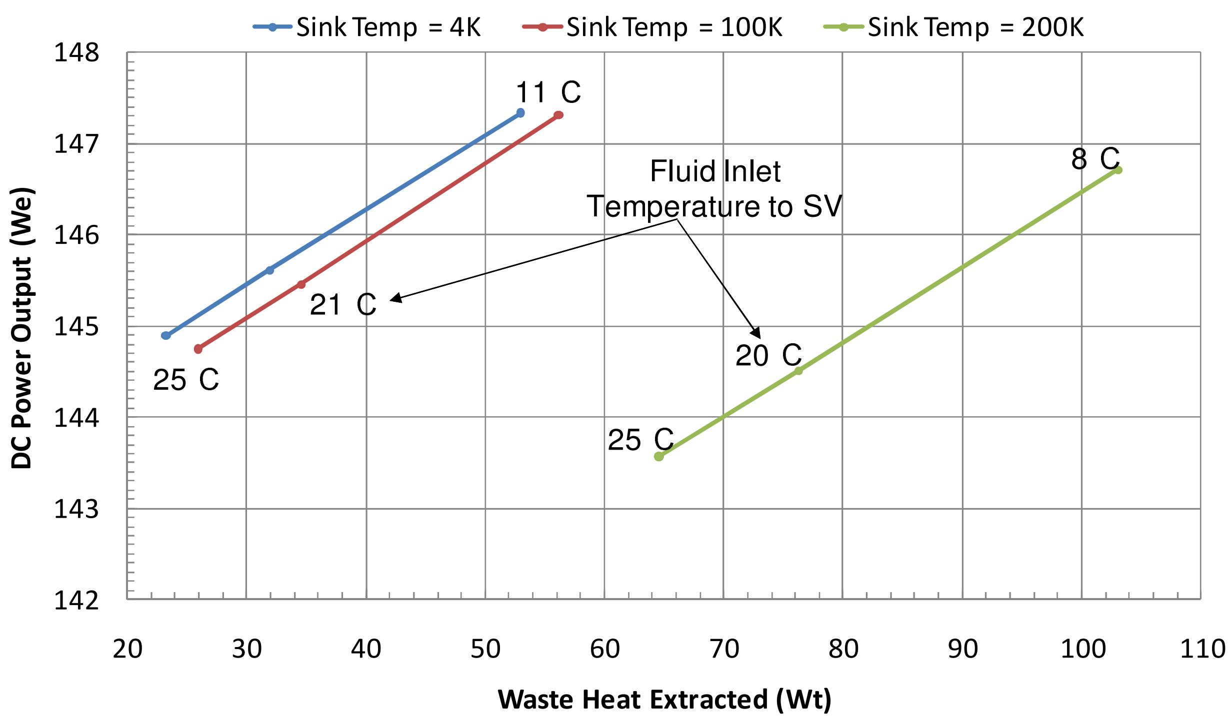


Figure 6.6-1. DC Power Output and Waste Heat Recovery with Active Cooling System.

6.7 ACU Thermal Interface

If the ACU is located inside the SV payload bay, thermal control approach from the user will be required to ensure that 19 Wt of waste heat from the ACU can be rejected at the ACU base plate temperatures between 0° and 50°C.

7 ENVIRONMENTAL INTERFACES

7.1 Dynamic Capability

The ASRG performs as specified subsequent to the vibration, acoustic noise, acceleration, and shock environments that it will experience during launch and subsequent mission maneuvers as defined below.

7.1.1 Random Vibration

The ASRG is designed to meet the random vibration test levels as defined in Table 7.1-1. The upper-bound force spectra used to limit the input acceleration are listed in Table 7.1-2. The ASRG is qualified to a higher vibration level than Table 7.1-1, in accordance with NASA-STD-7001.

Table 7.1-1. Random Vibration Environment.

Frequency, Hz	Flight Acceptance (FA)
20 - 50	+ 3 dB/Oct.
50 - 250	0.10 g^2/Hz
250 - 350	- 6.0 dB/Oct.
350 - 1000	0.05 g^2/Hz
1000 - 2000	- 12 dB/Oct.
Overall	8.7 g_{rms}

Flight Acceptance Duration: 1 minute in each of three orthogonal axes

Table 7.1-2. Force Limit Specification.

Frequency, Hz	Force Spectral Density Level
20 - f_0	77 M^2, N^2/Hz
f_0 - 1000	- 6.0 dB/Octave

f_0 = fundamental frequency of the ASRG in the axis of test
M = ASRG weight in kg.

7.1.2 Quasi-Steady Acceleration

The ASRG is capable of withstanding EELV-class quasi-steady acceleration in the thrust axis and the quasi-steady acceleration and spin from a solid upper stage burn (18-g peak).

7.1.3 Pyrotechnic Shock

The ASRG Generator Housing withstands pyrotechnic shock environments, defined in terms of shock response spectrum for a frequency range of 100-10,000 Hz as shown in Table 7.1-3. These values are derived from, and intended to envelop, representative mission values.

Table 7.1-3. Generator Housing Shock Environment.

Frequency (Hz)	Peak SRS Response (Q=10)
100 100 – 2,000 2,000 – 10,000	20 g + 10.0 dB/Oct. 3000 g

The ASRG ACU withstands pyrotechnic shock environments, defined in terms of shock response spectrum for a frequency range of 100-10,000 Hz as shown in Table 7.1-4. Depending on the mounting location of the ACU within the SV, user provided shock isolation may be required.

Table 7.1-4. ACU Shock Environment.

Frequency (Hz)	Peak SRS Response (Q=10)
100 100 – 1,000 1,000 – 10,000	14 g +9.3 dB/Oct. 500 g

7.1.4 Acoustic

The ASRG withstands the acoustic noise environment as shown in Table 7.1-5. These values are derived from, and intended to envelope, representative launch vehicle values.

Table 7.1-5. Acoustic Environment.

1/3 Octave Band Center Frequency, Hz	Flight Acceptance Level, dB
50	128.0
63	130.0
80	130.5
100	130.5
125	130.5
160	130.5
200	130.5
250	130.5
315	130.2
400	128.0
500	125.5
630	123.0
800	121.0
1000	119.5
1250	118.0
1600	116.5
2000	115.0
2500	113.5

1/3 Octave Band Center Frequency, Hz	Flight Acceptance Level, dB
3150	112.0
4000	110.0
5000	108.5
Overall SPL (dB)	140.6

dB reference: 2×10^{-5} Pascal. Flight Acceptance Duration: 1 minute

7.1.5 Planetary Surface Mission Landing Loads

The ASRG can withstand a maximum landing load equivalent to a 30 g static load, applied independently to each of the three ASRG orthogonal axes.

7.2 Natural Radiation Environment

7.2.1 Total Ionizing Dose Radiation Environment

The ASRG performs as specified following exposure to a total ionizing dose (TID) natural radiation environment of 50 krads (Si) behind 60-mil aluminum shield, in addition to exposure to its self-generated ionizing radiation.

7.2.2 Low Energy Plasma Environment

The ASRG performs as specified in a low energy plasma environment of 6×10^5 /cm^3 with an energy level of 25 keV.

7.2.3 Single Event Effects

The ASRG has no permanent performance degradation due to single event effects (SEE) in semiconductor devices as a result of exposure to heavy ion environment, shown in Figure 7.2-1, and solar flare (SF) proton environment, shown in Table 7.2-1. The transient effects are expected to be within the performance requirements and will be determined as part of final design and analysis.

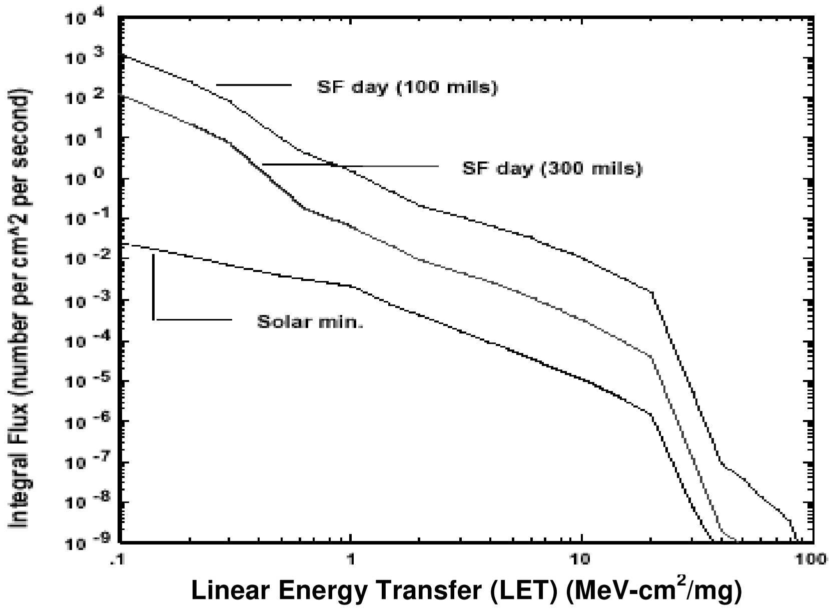


Figure 7.2-1. Heavy Ion Flux Environment.

Table 7.2-1. Solar Flare Fluence Proton Environment.

Energy >MeV	Fluence, particles/cm2
1	1.03×10^{12}
5	3.89×10^{11}
10	1.93×10^{11}
30	4.26×10^{10}
50	1.79×10^{10}
60	1.23×10^{10}
100	4.65×10^{9}

7.3 General Purpose Heat Source Radiation Environment

The estimated radiation environments generated by the ASRG are provided as contour plots in Figure 7.3-1 for gamma ray dosage and Figure 7.3-2 for neutron flux at distance from the inboard mounting interface.

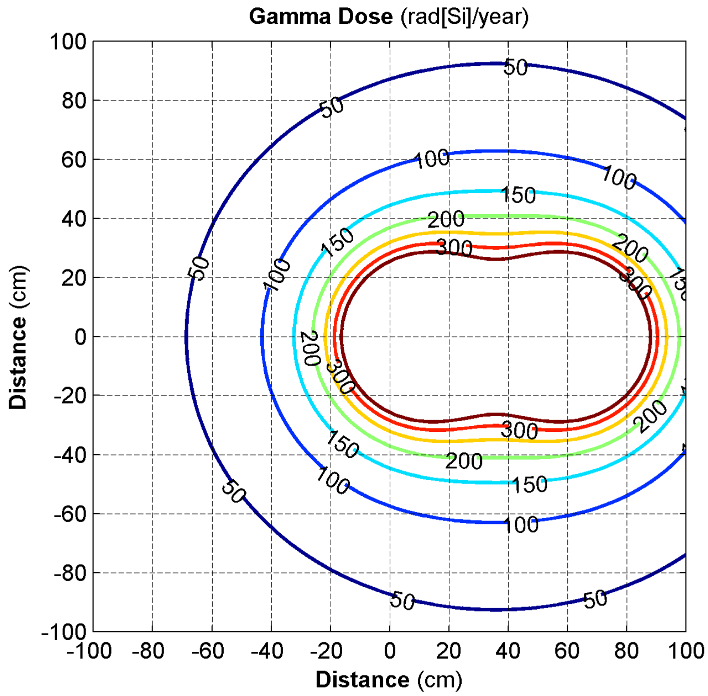


Figure 7.3-1. ASRG Gamma Ray Dosage Contours.

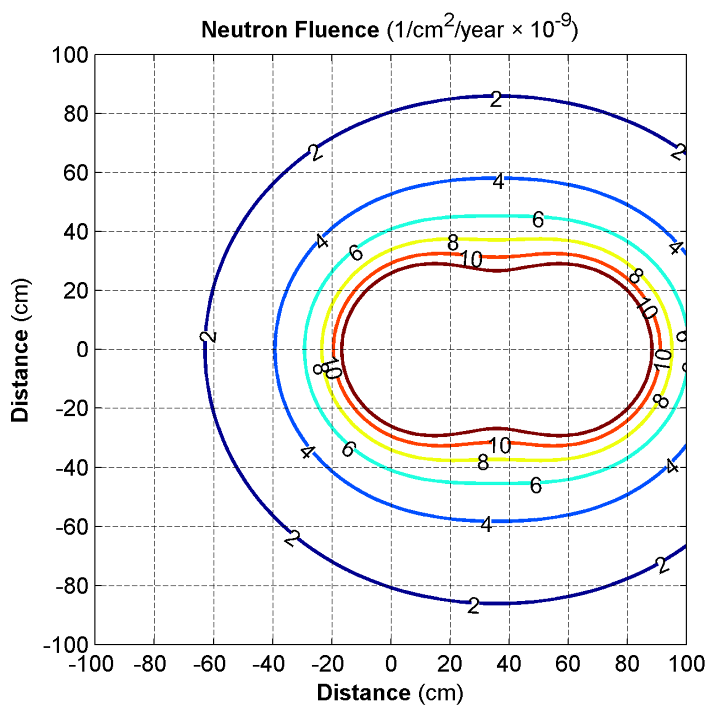


Figure 7.3-2. ASRG Neutron Flux Contours.

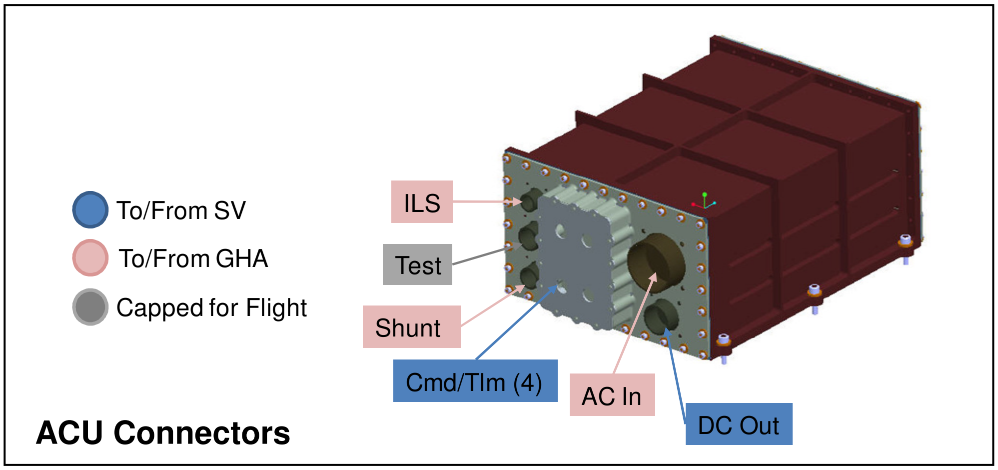
7.4 Gaseous Environments

The ASRG is designed to operate to specified performance in earth-ambient atmosphere, space vacuum, and Mars-ambient atmosphere. Other gaseous environments can adversely affect the ASRG's General Purpose Heat Sources, performance and life, and must be specifically analyzed for compatibility.

8 ELECTRICAL CONNECTOR DEFINITION

8.1 Connector Interfaces

The electrical interfaces with the ASRG are denoted in Figure 8-1. Three connectors are defined: DC power and primary and redundant command and telemetry.



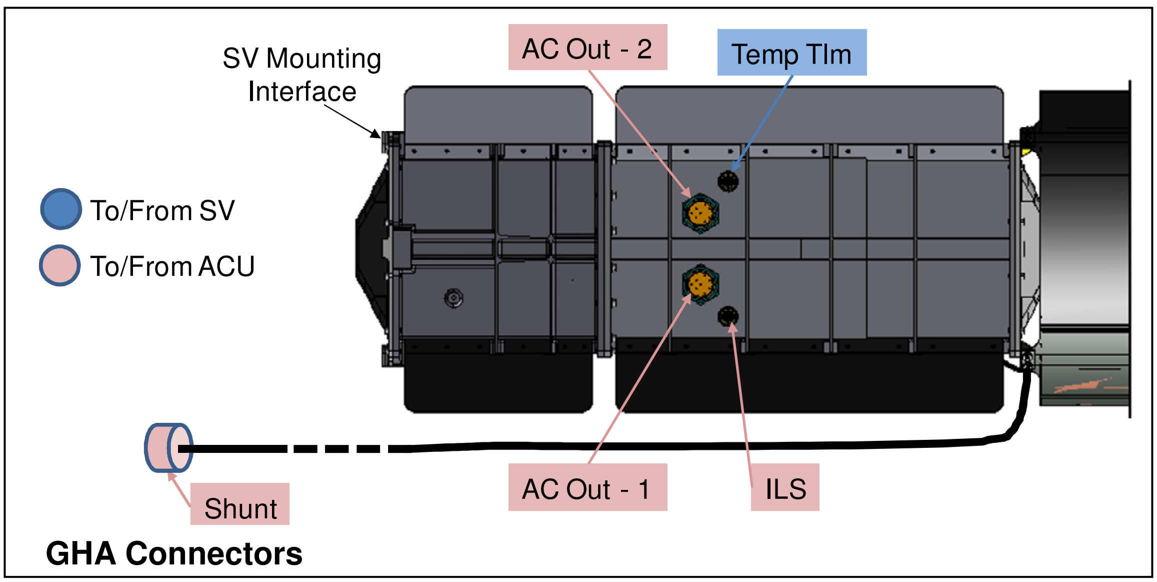


Figure 8.1-1. Electrical Connector Interfaces.

8.2 Connector Types

Table 8.2-1. ASRG to SV Connectors.

Location	Designator	Part Number	Function
ACU	J3	805-006-07-Z111-210PA	Power, 10 contacts, circular, keyed, “scoop proof”
ACU	J4	BJ3150	1553 Cmd/Tlm, Twin-Axial, A Side Primary

ACU	J5	BJ3150	1553 Cmd/Tlm, Twin-Axial, A Side Redundant
ACU	J6	BJ3150	1553 Cmd/Tlm, Twin-Axial, B Side Primary
ACU	J7	BJ3150	1553 Cmd/Tlm, Twin-Axial, B Side Redundant
Generator Housing	J1	805-012-07Z112-26PA	Analog Temperature Telemetry, 26 contacts, circular, keyed, “scoop proof”

8.3 Power Interface

Table 8.3-8.3-1. ASRG Power Interface Connector J3.

Pin Number	Name
1	DC Bus Positive
2	DC Bus Positive
6	DC Bus Return
7	DC Bus Return
8	DC Bus Return
3	DC Bus Positive
4	DC Bus Positive
5	DC Bus Positive
9	DC Bus Return
10	DC Bus Return

8.4 Command and Telemetry

Table 8.4-1. ASRG Primary Command and Telemetry

(ACU J4, J5, J6 J7)

Pin Number	Name
O	Differential line
C	Differential line

Table 8.4-2. ASRG Analog Telemetry Connector.

(Generator Housing J1)

Pin Number	Name
1	spare
2	spare
3	spare
4	spare

5	ASC_B_ALT_TEMP_SIGNAL
6	spare
7	ASC_B_ALT_TEMP_SIGNAL_RTN
8	ASC_B_COLD_END_TEMP_SIGNAL
9	ASC_B_RTD2_BIAS
10	ASC_A_COLD_END_TEMP_SIGNAL
11	ASC_B_COLD_END_TEMP_SIGNAL_RTN
12	spare
13	ASC_A_RTD1_SIGNAL
14	ASC_A_COLD_END_TEMP_SIGNAL_RTN
15	spare
16	ASC_B_RTD2_SIGNAL_RTN
17	ASC_A_RTD1_BIAS
18	ASC_A_ALT_TEMP_SIGNAL
19	ASC_A_RTD1_SIGNAL_RTN
20	ASC_A_ALT_TEMP_SIGNAL_RTN
21	ASC_B_RTD2_BIAS
22	ASC_A_RTD1_BIAS_RTN
23	spare
24	ASC_B_RTD2_BIAS_RTN
25	spare
26	spare

9 APPENDICES

9.1 MIL-STD-1553B Command Sub-address Definition

9.1.1 Receive Commands

MIL-STD-1553B receive commands (T/R bit = 0) are defined in Table 9.1-1.

Table 9.1-1. MIL-STD-1553B Receive Commands Definition.

(TBD-03)

9.1.2 Transmit Commands

MIL-STD-1553B transmit commands (T/R bit = 1) are defined in Table 9.1-2.

Table 9.1-2. MIL-STD-1553B Transmit Commands Definition.

(TBD-03)

9.2 MIL-STD-1553B Mode Codes

Table 9.2-1 defines the mode codes supported by the ASRG. Refer to section 4.3.3.5.1.7 of MIL-STD-1553B for more detail on each mode code.

Table 9.2-1. ASRG MIL-STD-1553B Mode Code Support.

(TBR-06)

Mode Code	T/R Bit	Mode Code Description	Data Word	Supported by ASRG
00000	1	Dynamic bus control	No	No
00001	1	Synchronize (w/o data word)	No	Yes
00010	1	Transmit status word	No	Yes
00011	1	Initiate self-test	No	Yes
00100	1	Transmitter shutdown	No	Yes
00101	1	Override transmitter shutdown	No	Yes
00110	1	Inhibit terminal flag (T/F) bit	No	Yes
00111	1	Override inhibit terminal flag (T/F) bit	No	Yes
01000	1	Reset remote terminal	No	Yes
01001 - 01111	1	Reserved	N/A	N/A
10000	1	Transmit vector word	Yes	Yes
10001	0	Synchronize (w/ data word)	Yes	Yes
10010	1	Transmit last command	Yes	Yes
10011	1	Transmit built-in-test (BIT) word	Yes	Yes
10100	0	Selected transmitter shutdown	Yes	No
10101	0	Override selected transmitter shutdown	Yes	No
10110 - 11111	1 or 0	Reserved	N/A	N/A

9.3 Telemetry Packet Definition

(TBD-05)

9.4 Concept of Operations

Based on recent Pluto New Horizons mission, Table 9.4-1 provides a hypothetical step-by-step concept of operations (ConOps) for the ASRG upon arrival at the KSC launch site for SV integration and testing; transport within the launch site; ASRG cover gas exchange maintenance; installation of PRD and removal of its safety pin; and final mechanical and electrical mating to the SV at the payload fairing. ID #1 through #129 are omitted from Table 9.4-1 as they define the ConOps during ASRG fueling, testing and shipment prior to arrival at KSC.

In addition to Table 9.4-1, three separate ConOps descriptions below are being prepared and will be made available upon completion to define in more detail the interface requirements.

Electrical Integration and De-integration with SV (LM ASRG PIR #088)
This document defines the safe electrical mating and demating of ASRG to the SV electrical power subsystem with constraints and characteristics assumed on both sides of the interface.

ASRG Active ACU and Cabling Replacement (LM ASRG PIR #099)
This document defines the method by which the active ACU and associated power cable can be safely replaced during emergency without causing damage to the balance of ASRG.

ASRG Mission Operation (LM ASRG PIR #100)
This document provides the necessary command guidance and telemetry description for ASRG operation after launch and throughout the mission duration.

Table 9.4-1. ASRG Concept of Operations at Launch Site.

ID	Activity	Electrical Load	Load Voltage	ConOps Phase	GMV Status	PRD Bellow Installed	PRD Safety Pin Installed	ASRG Cover Gas	ASRG Environment	Estimated Hours
130	Receipt at KSC	PLU	28 V	Receipt	C	N	N	Y	Helium	1
131	Off load KSC	PLU	28 V	Receipt	C	N	N	Y	Helium	2
132	Unpackage at KSC	PLU	28 V	Receipt	C	N	N	Y	Air	4
133	Transfer ASRG to Onsite transfer base	PLU	28 V	Storage	C	N	N	Y	Air	2
134	Transfer load to EGSE	EGSE	28 V	Interim Processing	C	N	N	Y	Air	1
135	Perform functional test	EGSE	28 V	Interim Processing	C	N	N	Y	Forced Air	4
136	Connect to gas service cart and verify ASRG receipt pressure. Disconnect gas service cart.	EGSE	28 V	Interim Processing	O	N	N	Y	Air	2
137	Perform receipt inspection	EGSE	28 V	Interim Processing	C	N	N	Y	Air	8
138	Storage, monitor with EGSE	EGSE	28 V	Interim Processing	O/C	N	N	Y	Forced Air	TBD
139	Transfer electrical load to PLU (Disconnect from EGSE Bus Sim)	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	1
140	Secure in on site shipping container	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	2
141	Release for shipment	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	1
142	SC loading to air ride trailer	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	2
143	SC Tie Down	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	2
144	Transfer to SV processing facility - KSC	PLU	28 V	Shipping	C	N	N	Y	Air	1
145	Receipt at SV processing facility	PLU	28 V	Receipt	C	N	N	Y	Air	1
146	Off load SV processing facility	PLU	28 V	Receipt	C	N	N	Y	Air	2
147	Unpackage at SV processing facility	PLU	28 V	Receipt	C	N	N	Y	Air	2
148	Transfer ASRG to SV interface cart	PLU	28 V	SV Integration	C	N	N	Y	Air	2
149	Cleaning as required / Planetary Protection method and Criteria TBD	PLU	28 V	SV Integration	C	N	N	Y	Air	2

ID	Activity	Electrical Load	Load Voltage	ConOps Phase	GMV Status	PRD Bellow Installed	PRD Safety Pin Installed	ASRG Cover Gas	ASRG Environment	Estimated Hours
150	Mechanical integration with SV	PLU	28 V	SV Integration	C	N	N	Y	Air	4
151	Electrical integration with SV	SV	TBD	SV Integration	C	N	N	Y	Air	4
152	Verify SV mechanical and electrical interfaces	SV	TBD	SV Integration	C	N	N	Y	Air	8
153	Support SV integration/testing	SV	TBD	SV Integration	C	N	N	Y	Air	24
154	Transfer electrical load to PLU (Disconnect from SV)	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	1
155	Electrical de-integration with SV	PLU	28 V	SV Integration	C	N	N	Y	Air	4
156	Mechanical de-integration with SV	PLU	28 V	SV Integration	C	N	N	Y	Air	4
157	Transfer ASRG to SV interface cart	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	4
158	Transfer to on site shipping base	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	2
159	Secure in on site shipping container	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	2
160	Release for shipment	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	1
161	SC loading to air ride trailer	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	2
162	SC Tie Down	PLU	28 V	Shipping Preparation	C	N	N	Y	Air	2
163	Transfer to storage facility - KSC	PLU	28 V	Shipping	C	N	N	Y	Air	1
164	Receipt at storage facility	PLU	28 V	Receipt	C	N	N	Y	Air	1
165	Off load storage facility	PLU	28 V	Receipt	C	N	N	Y	Air	2
166	Unpackage at storage facility	PLU	28 V	Receipt	C	N	N	Y	Air	2
167	Transfer load to EGSE	EGSE	28 V	Interim Processing	C	N	N	Y	Air	1
168	Perform Functional test	EGSE	28 V	Interim Processing	C	N	N	Y	Forced Air	4
169	Perform Inspection	EGSE	28 V	Interim Processing	C	N	N	Y	Air	2
170	Storage, monitor with EGSE	EGSE	28 V	Interim Processing	O/C	N	N	Y	Forced Air	TBD
171	Set inert cover gas pressure for launch	EGSE	28 V	Interim Processing	O	N	N	Y	Air	2

ID	Activity	Electrical Load	Load Voltage	ConOps Phase	GMV Status	PRD Bellow Installed	PRD Safety Pin Installed	ASRG Cover Gas	ASRG Environment	Estimated Hours
172	Install PRD bellows and safety pin	EGSE	28 V	Interim Processing	C	Y	Y	Y	Air	4
173	Transfer electrical load to PLU (Disconnect from EGSE Bus Sim)	PLU	28 V	Shipping Preparation	C	Y	Y	Y	Air	1
174	Secure in on site shipping container	PLU	28 V	Shipping Preparation	C	Y	Y	Y	Air	2
175	Release for shipment	PLU	28 V	Shipping Preparation	C	Y	Y	Y	Air	1
176	SC loading to air ride trailer	PLU	28 V	Shipping Preparation	C	Y	Y	Y	Air	2
177	SC Tie Down	PLU	28 V	Shipping Preparation	C	Y	Y	Y	Air	2
178	Transfer to SV processing facility - KSC	PLU	28 V	Shipping	C	Y	Y	Y	Air	1
179	Receipt at SV processing facility	PLU	28 V	Receipt	C	Y	Y	Y	Air	1
180	Off load SV processing facility	PLU	28 V	Receipt	C	Y	Y	Y	Air	2
181	Unpackage at SV processing facility	PLU	28 V	Receipt	C	Y	Y	Y	Air	2
182	Transfer ASRG to SV interface cart	PLU	28 V	SV Integration	C	Y	Y	Y	Air	2
183	Cleaning as required / Planetary Protection method and criteria TBD, assume VHP	PLU	28 V	SV Integration	C	Y	Y	Y	Air	2
184	Mechanical integration with SV	PLU	28 V	SV Integration	C	Y	Y	Y	Air	4
185	Electrical integration with SV	SV	TBD	SV Integration	C	Y	Y	Y	Air	4
186	Verify SV mechanical and electrical interfaces	SV	TBD	SV Integration	C	Y	Y	Y	Air	8
187	Remove PRD safety pin	SV	TBD	SV Integration	C	Y	N	Y	Fairing Cooled Air	1
188	Exit	SV	TBD	SV Integration	C	Y	N	Y	Fairing Cooled Air	1
189	Final SV preparations	SV	TBD	SV Integration	C	Y	N	Y	Fairing Cooled Air	TBD
190	Fairing Closure	SV	TBD	SV Integration	C	Y	N	Y	Fairing Cooled Air	TBD
191	Roll out to launch pad	SV	TBD	SV Integration	C	Y	N	Y	Fairing Cooled Air	TBD

ID	Activity	Electrical Load	Load Voltage	ConOps Phase	GMV Status	PRD Bellow Installed	PRD Safety Pin Installed	ASRG Cover Gas	ASRG Environment	Estimated Hours
192	Launch	SV	TBD	SV Integration	C	Y	N	Y	Air	TBD
193	PRD activation due to decreasing atmospheric pressure	SV	TBD	SV Integration	C	Y	N	Y	Partial Vacuum	1
194	ASRG housing evacuated	SV	TBD	SV Integration	C	Y	N	N	Vacuum	1
195	Stable ASRG operation	SV	TBD	SV Integration	C	Y	N	N	Vacuum	4

10 ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
ACS	Active Cooling System
ASC	Advanced Stirling Convertor
ACU	ASC Control Unit
ASRG	Advanced Stirling Radioisotope Generator
BOM	Beginning of Mission
CCA	Controller Card Assembly
C&DH	Command and Data Handling
dc/DC	Direct Current
EELV	Evolved Expendable Launch Vehicle
EOM	End of Mission
EPS	Electrical Power System
ESD	Electrostatic Discharge
GHA	Generator Housing Assembly
GMV	Gas Management Valve
GPHS	General Purpose Heat Source
KSC	Kennedy Space Center
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
GHA	Generator Housing Assembly
PLU	Portable Load Unit
PRD	Pressure Relief Device
rms	Root Mean Square
RTD	Resistance Temperature Device
SEE	Single Event Effects
SF	Solar Flare
SPG	Single Point Ground
SV	Space Vehicle
TBD/R	To Be Determined/Resolved
TID	Total Ionizing Dose