Juno Project

Microwave Radiometer (MWR)
Instrument User Guide
(DRD SE-007)

Initial Release

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1. Introduction

1.1 Document Scope

The MWR Instrument User Guide is intended to provide a system level overview of MWR operation and to provide references to more detailed interface information, handling and storage requirements, command and telemetry specifications required for MWR operation.

1.2 Applicable Documents

The following documents contain information relevant to this MWR operation and this User Guide.

AD1	Juno MWR FSW User Guide	D-47902
AD2	MWR Electronics Unit to Temperature Sensor ICD	D-47909
AD3	Microwave Radiometer (MWR) Safe Handling Constraints	D-64807
AD4	Juno Flight Rules and Constraints	JUNO-ED-08-0162
AD5	Juno MWR Pre-Launch Calibration Report	D-62458
AD6	MWR to Juno S/C ICD	JUNO-RQ-06-0060
AD7	MWR EU to Receiver ICD	D-38974
AD8	Packaging, Handling, Storage and Transportation Requirements and Implementation Document (PHST)	JUNO-OT-09-0202
AD9	Juno Mission Plan	D-35556
AD10	MWR Telemetry Calibration Handbook	D-64256
AD11	Juno Command Dictionary	JUNO-ED-08-0158

1.3 Mission and Instrument Overview

The primary goal of the Juno Microwave Radiometer is to probe the deep atmosphere of Jupiter at radio wavelengths ranging from 1.3 cm to 50 cm using six separate radiometers to measure the planet's thermal emissions. The MWR experiment will provide answers to two key questions: How did Jupiter form? How deep is the atmospheric circulation that was measured from the Galileo Probe down to 22 bars of pressure, and at the cloud top level from imaging data returned by other missions?

The first question will be addressed by the determination of the water abundance in the deep atmosphere. The MWR will obtain measurements of ammonia and water in the Jupiter atmosphere, which are the principle absorbers in the microwave region, by scanning Jupiter along the orbital track as the spacecraft spins. These observations will allow scientists to determine whether the water abundance on Jupiter is three times that of the sun or nine times that of the sun in order to distinguish among two key models for Jupiter's formation, or if yet another model is needed in case a much different result is obtained. These observations will also address the second question by obtaining the latitudinal dependence of the emissions from the depths probed at each wavelength; namely, from the cloud-forming region around 1 bar pressure at 1.3-cm wavelength to as deep as 1000 bars at 50-cm wavelength.

1.4 MWR Performance Characteristics

Table 1.4-1 lists nominal MWR system characteristics. This information is provided for reference only. Detailed as-built system data is provided in various test reports and data packages. The Juno Pre-Launch Calibration Report (AD5) provides system radiometric performance data and antenna pattern correction (APC) analyses. Antenna test reports and range pattern data is provided in the antenna subsystem HRCR data packages. Receiver subsystem test data, including as-built channel bandpass characteristics, is provided in the Receiver subsystem HRCR packages.

Table 1.4-1 Nominal MWR System Characteristics (For Reference Only)

Parameter	Nominal Characteristic					
	C1	**C2**	**C3**	**C4**	**C5**	**C6**
Center Frequency (GHz)	0.6	1.25	2.6	5.2	10.0	22.0
3dB Bandwidth (MHz)	18	37.5	78	156	300	660
System noise figure (dB)	4.3	5.1	5.7	7.2	5.6	7.3
NEDT (Ta=300K, τ = 0.1s) (K)	0.6	0.5	0.4	0.4	0.2	0.2
Antenna Half Power Beamwidth (degrees)	20	20	12	12	12	11
Antenna Gain (dB)	19	19	24	24	24	25

1.5 MWR Functional Overview

1.5.1 Instrument Configuration

The MWR is a six channel microwave radiometer comprising antenna, receiver, and electronics subsystems. Figure 1.5.1-1 shows the MWR configuration on the Juno S/C and figure 1.5.1-2 shows an MWR functional block diagram. By convention, the six radiometer channel strings, including antenna, transmission line, and receiver, are designated as C1, C2, …, C6 from lowest to highest frequency channel. The corresponding antennas and receivers are designated as A1, A2, …, A6 and R1, R2, …, R6, respectively.

The antennas are mounted on two of the six S/C bays. Each antenna RF boresight extends out radially from the S/C spin axis and is parallel with the spin plane. Antenna technologies include planar patch arrays for A1-A2, slotted waveguide for A3-A5, and scalar horn for A6.

The receiver and electronics subsystems are located within a titanium spacecraft vault, shown as a bold, dashed line in Figure 1.5.1-2. The vault provides radiation shielding and thermal control for payload and flight system electronics. The antennas are connected to the receivers via coax (R1-R4) and waveguide transmission lines (R5 and R6). The R5 WG transitions to coax at the vault feedthrough to simplify routing within the vault.

The receiver subsystem comprises six, direct detection, Dicke switched radiometer receivers with integral noise diodes for short-term gain calibration.

The electronics subsystem comprises dual redundant Power Distribution Unit (PDU), single string Command and Data Unit (CDU), Housekeeping Data Unit (HKU), and associated internal cable harness.

Figure 1.5.1-1 MWR Spacecraft Configuration

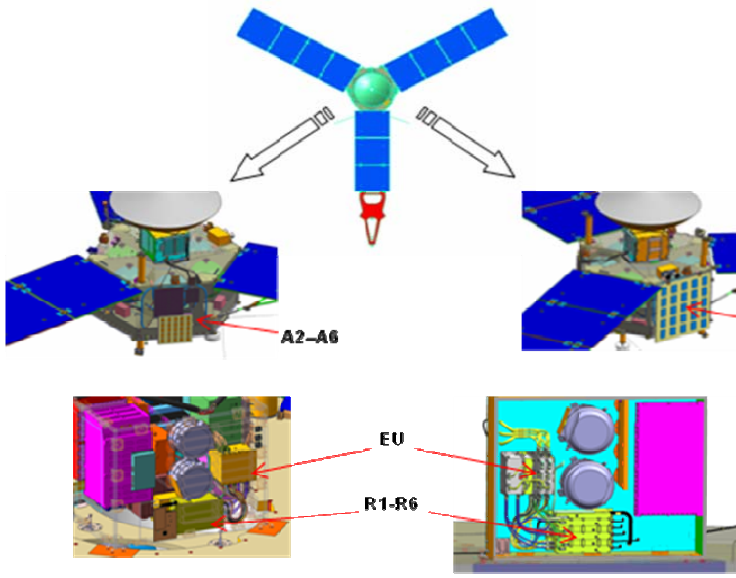
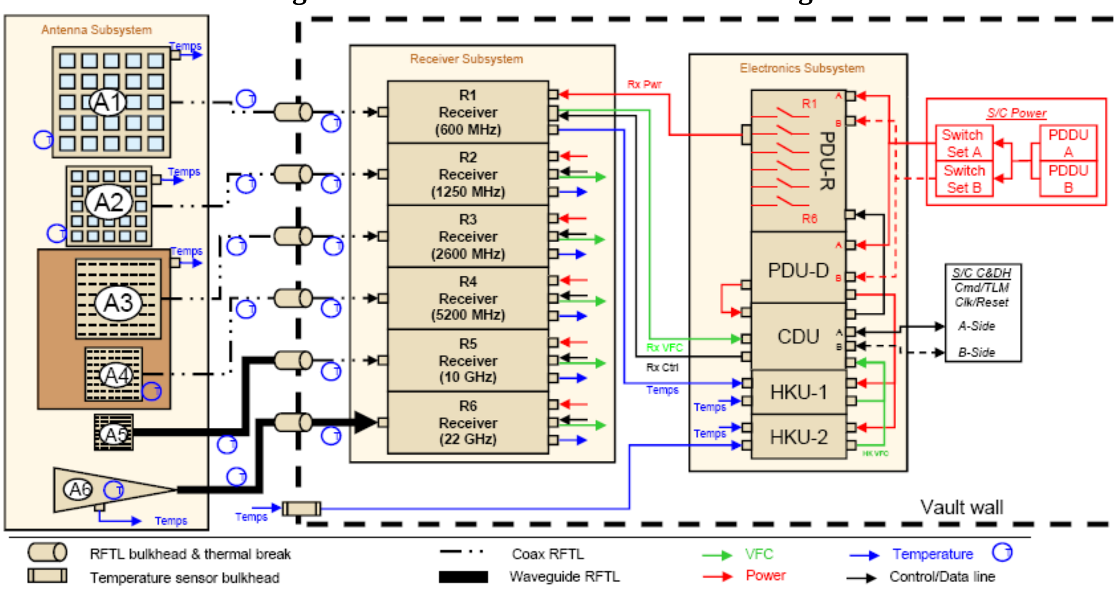


Figure 1.5.1-2 MWR Functional Block Diagram



1.5.2 Operational Concept

MWR is typically either powered off or is running in its nominal operational mode. The CDU executes a science measurement sequence defined by a table stored in ROM and copied to RAM at bootup. Each 100 ms science measurement comprises a 1 ms latency followed by a 99ms measurement integration period. During the 1ms latency between each measurement integration, the CDU outputs a configuration word from the configuration sequence, which configures the receiver for the subsequent 99 ms integration period. During the integration period, the CDU continuously integrates each receiver measurement.

The CDU also acquires engineering temperature and voltage measurements using a multiplexer (MUX) address sequence stored in ROM and copied to RAM at bootup. This housekeeping data acquisition is analogous to the science data acquisition, but with the MUX address in place of the configuration word and a 200ms measurement period in p-lace of the 100ms for science measurements.

MWR nominally transmits data packets to the S/C at a 1Hz rate. Each science packet contains 10, 100 ms radiometer measurements from each of the six receivers, sub-commutated engineering data, and status information. By default, the MWR also transmits a dedicated engineering packet every 20 seconds. Both science and engineering and science data packet rates can be changed via ground command.

A duplicate set of engineering data is also returned in the science packets, as engineering temperatures are used in the science data processing. The separate, engineering data packet is provided for ground data processing purposes.

The HKU acquires a full set of housekeeping measurements every 15 seconds. The default, 20 second HKU packet period is an artifact of a design change where the number of active housekeeping channels was reduced, but the default HK packet interval remained unchanged. A command may be sent on power up to change the HK packet interval to 15 seconds to keep the HK measurements synchronized on packet boundaries.

1.5.3 Redundancy and Fault Protection

MWR is a single string instrument with selected redundancy per Juno Project Implementation Plan. It also features functional redundancy in that MWR can meet its science objectives with any five of its six channels operating nominally.

The design includes a dual-redundant PDU and single string CDU. The CDU power supply is functionally independent from receiver supply to allow CDU operation in the event of a receiver load fault.

Any combination of one or more receivers may be isolated from the PDU in the event of a load fault so that the function of the other receivers will not be affected. Receiver to CDU and receiver to HKU electrical interfaces are current limited by series resistors, so a receiver load fault will not affect the function of the nominal channels. The PDUR provides short circuit protection on its secondaries and will not be permanently damaged by a receiver load fault, however it will not sustain normal receiver operation until and unless the faulted receiver is isolated by receiver load switches in the PDUR.

2. Instrument Operation Details

2.1 Instrument Power-On

2.1.1 Nominal Boot

On application of S/C bus power, the CDU and HKU are powered immediately, while the six receivers remain unpowered with their control lines states defined by configuration sequence #0 (Dicke switch fixed in reference load position). The side select logic (SSL) implemented in CDU hardware determines the active S/C communication interface (A/B) by the presence of a time tick within 2 seconds of power-on. Once the SSL determines the active S/C interface, the MWR telemetry drivers are enabled and the MWR begins transmitting science telemetry packets each second and engineering packets every 20 seconds.

Referring to Figure 2.1-1, after a 30 second wait period the FSW executes the autonomous receiver power-on sequence in which the FSW controls PDUR receiver power switches to power each receiver in sequence (R1 to R6) with a 1 second delay between each receiver. After the sixth receiver is powered on the FSW activates operational sequence #1 to place the MWR into its nominal science operational mode.

This default boot sequence allows the MWR to autonomously recover into a science data-taking mode in the event of an autonomous reset. This reduces the risk of loss of critical data during the MWR perijove science passes due to resets caused by single event upsets.

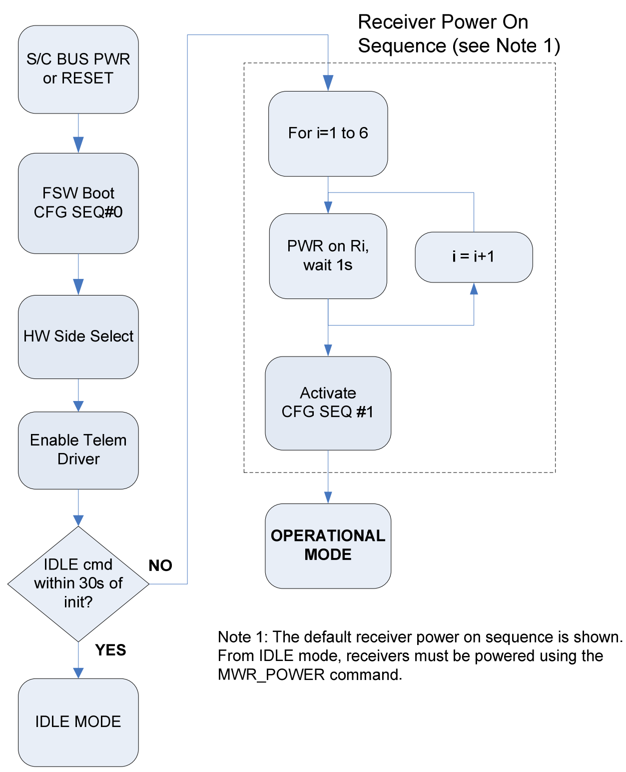
2.1.2 Optional Idle Mode Boot

The MWR is booted into idle mode if an idle mode command is received within 30 seconds of FSW initialization. With this idle mode boot, the FSW does not execute the autonomous receiver power-on sequence and the operational sequence #0 remains active. Otherwise, the FSW operation is identical to operational mode.

The idle mode boot is typically performed to prevent the autonomous receiver power on sequence. This may be used for communication tests in which the receivers are not to be powered, or to allow receiver power-on to be controlled by the MWR_POWER command, for example, to power a subset of the six receivers.

To return to nominal science operational mode from idle mode boot, the MWR receivers must be powered using a sequence of MWR_POWER commands, the MWR placed in its operational mode using the SET_MODE command, and receiver sequence #1 selected using the MWR_PARAM command.

Figure 2.1-1 MWR Nominal and Idle Mode Boot

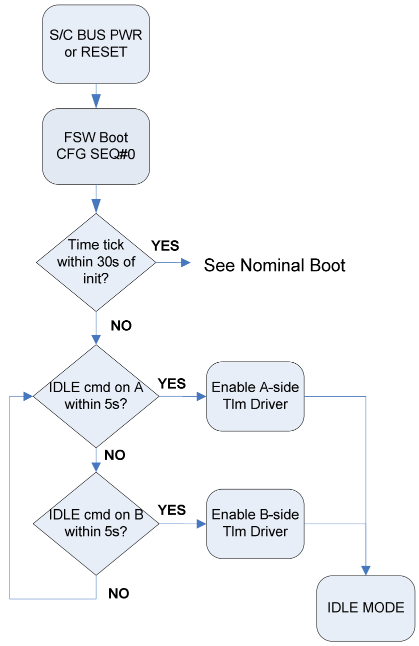


2.1.3 Missing Time Tick - Side Select Using Idle Command

Referring to Figure 2.1-2, if the hardware side select logic (SSL) fails to detect a S/C time tick within 30 seconds of initialization, the FSW will not enable the telemetry drivers until it has determined the active S/C side by receipt of an IDLE commend. The FSW will alternate listening on sides A and B, 5 second per side, until an IDLE mode command is received on one of the command interfaces. The FSW will then enable the corresponding telemetry drivers on that side and the MWR will wait in IDLE mode with receivers unpowered (same as idle mode boot) for additional commands.

To return to nominal science operational mode from idle mode boot, the MWR receivers must be powered using a sequence of MWR_POWER commands, the MWR placed in its operational mode using the SET_MODE command, and receiver sequence #1 selected using the MWR_PARAM command.

Figure 2.1-2 Missing Time Tick Case - Side Select Using Idle Command



2.2 Instrument State For Operational and Idle Modes

There are only two modes for MWR FSW, operational and idle mode. The only significant difference between the two is that idle mode forces both receiver and sensor sequence into sequence #0. This allows FSW replacement of receiver and sensor tables by upload. Telemetry rates and contents are independent of mode. Commandability is independent of mode with two exceptions: (1) in operational mode, MWR_UPLOAD commands are rejected and (2) in idle mode, if a MWR_PARAM command is received to change the receiver or sensor sequence, that new sequence will not become active until the MWR is commanded back into operational mode.

As discussed in Section 2.1, the FSW does not execute the autonomous receiver power-on sequence when MWR is *booted* into idle mode (i.e. idle command within 30 seconds of power-on). However the idle command only prevents the autonomous receiver power-on sequence from being executed, it does not change the existing receiver power switch state. That is, if an idle mode command is sent when MWR receivers are already powered, those receivers remain powered.

2.2 Instrument Commands

The MWR responds to six types of commands. Table 2.2-1 describes the six MWR instrument level command types. Refer to the MWR FSW User Guide, Appendix A, for details on MWR command function, parameters, and usage rules.

Table 2.2-1 MWR Instrument Level Command Types

Command Type	Description
MWR_UPLOAD	Uploads data to internal RAM, external RAM, and FPGA registers.
MWR_DOWNLOAD	Downloads data from PROM, internal and external RAM, and FPGA registers.
MWR_SETMODE	Selects and disables various off-nominal modes.
MWR_POWER	Controls receiver power switches in the PDUR.
MWR_PARAM	Specifies values for customizable parameters within the flight software.
MWR_TIME	Broadcast S/C time messages used to time stamp MWR packets.

Operationally, MWR is commanded via the Juno S/C using a S/C command format. The Juno Command Dictionary (AD11) is the official source for S/C command formats and provides links to the S/C command database.

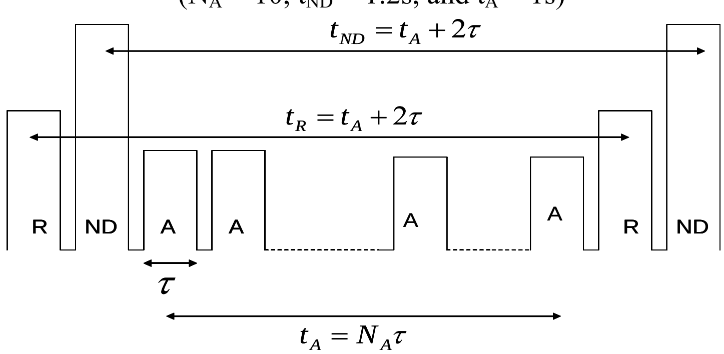
2.3 Science Measurement Acquisition

2.3.1 Receiver Sequences

The onboard ROM contains a number of receiver sequences, each containing one or more configuration word(s). Each sequence is identified by a sequence number. Sequence #0 is a special one word sequence, active by default during initialization and in idle mode. Sequence #1 is the default operational sequence. Any sequence can be selected by ground command from operational mode, however sequence #0 is always active in idle mode.

Figure 2.3.1-1 illustrates the typical operational MWR measurement sequence. The sequence seeks to maximize the antenna signal integration time while including periodic reference load and noise diode measurements for gain calibration. The noise diode measurements sequentially alternate between ND 1, 2 and 3 (not shown in the Figure). In ground science data processing, a running average is performed on noise diode and reference load measurements to reduce the noise on the measurements.

Figure 2.3.1-1 MWR Measurement Sequence
A= antenna, R= reference, ND= noise diode
(N_A = 10, t_{ND} = 1.2s, and t_A = 1s)



Alternate sequences in ROM, selected by ground command, are used for diagnostics or for operational workarounds for potential anomalies. Several, one word sequences are included that put the receiver into a fixed state, e.g. Dicke switch fixed in antenna or reference load position, various permutations of one or more noise diodes on with switch in the antenna or reference position, LNA bias off for postdetector DC offset measurement, etc.

Detailed descriptions of the receiver sequences included in onboard PROM are documented in the FSW User Guide, Section 2.3.

Alternate operational sequences are included in ROM that reduce the calibration interval (lower values of N_A in Figure 2.3.1-1), which might be needed if a receiver exhibits poorer than expected short term stability, or if it is desired to operate with fewer than three diodes.

Each word in a receiver sequence contains 8 control bits. Six control bits are distributed to each of six receivers and two are output to a CDU test port (GSE port) as illustrated in Figure 2.3.1-2. Each of the six receiver control bits are distributed in parallel to each of the six receivers via a dedicated buffer. Table 2.3.1-1 describes the control bit function and logic.

Figure 2.3.1-2 Receiver Control Bit Distribution

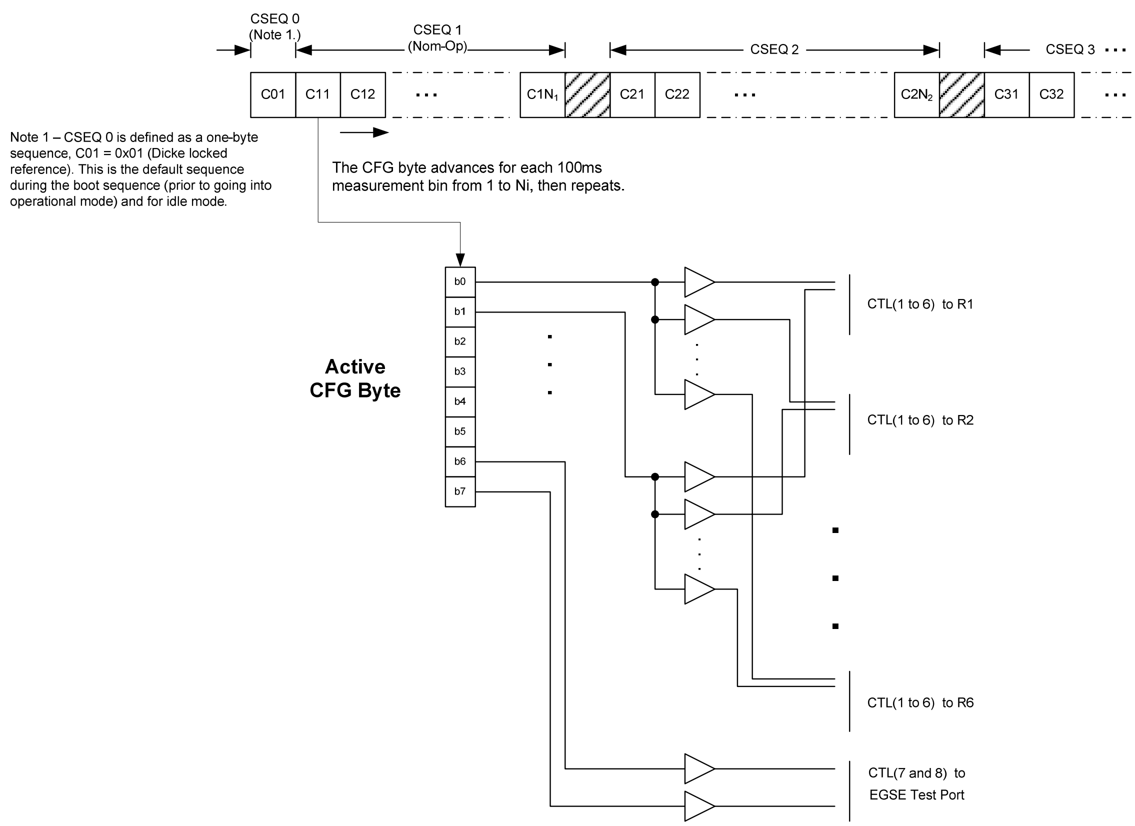


Table 2.3.1-1 Control Bit Definition

Bit	Function	Destination	Logic Definition	
			Logic Low	Logic High
0	Dicke CTL	R1 through R6	Antenna	Reference
1	ND1 CTL	R1 through R6	ND OFF	ND ON
2	ND2 CTL	R1 through R6	ND OFF	ND ON
3	ND3 CTL	R1 through R6	ND OFF	ND ON
4	RF Bias CTL	R1 through R6	LNA Bias ON	LNA Bias OFF
5	SPARE	R1 through R6	N/A	N/A
6	AUX CTL1	Test port	N/A	N/A
7	AUX CTL2	Test Port	N/A	N/A

Notes:

1. Bits 6 and 7 are used for ground test only and are ignored in the flight configuration. Their function and logic are application dependent and are not defined at this level.

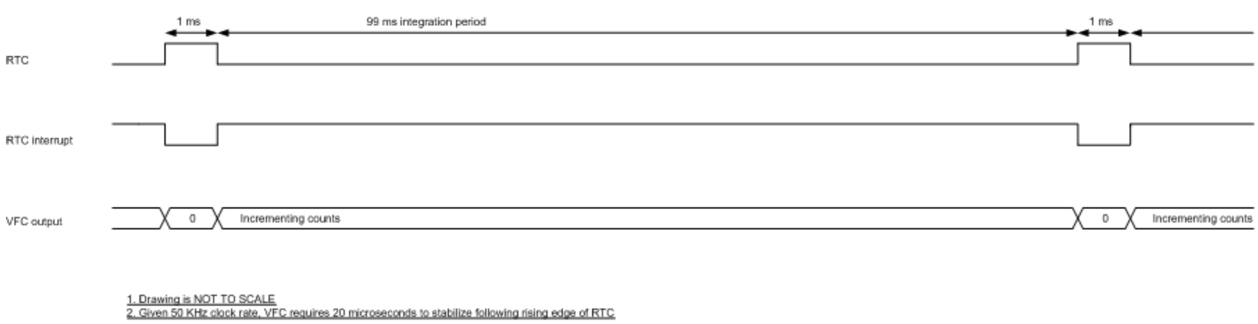
2.3.2 Measurement Timing

The science data measurement cycle timing is defined by a 10 Hz real time clock (RTC) generated by HW. A 1ms latency time is allocated at the start of each 100ms integration period.

Figure 2.3.2-1 shows the timing of the receiver measurement sequence. The RTC period is fixed at 100 msec. The first millisecond of the RTC period is used to set up the control word from the active receiver sequence for the next science measurement integration period. The receiver measurements are integrated over the remaining 99 ms.

During the 99ms period, the FSW transfers the previous science measurements to the telemetry packet and performs background tasks in the software (processing time commands, sampling temperature sensors, verifying memory contents, etc). Receiver measurements are double-buffered, so the values being read are not affected by the values being acquired.

Figure 2.3.2-1 Receiver Measurement Timing



2.3.3 VFC Simulator

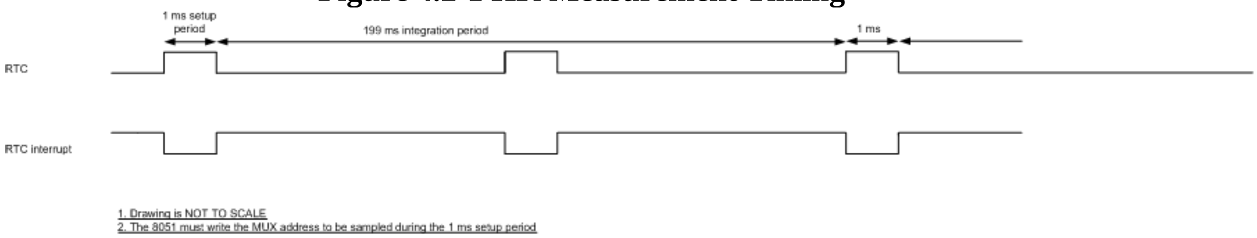
The MWR FPGA can be commanded to output simulated receiver voltage to frequency converter data. Enabling these signals disables normal data acquisition and substitute simulated data signals. This function is used for testing and diagnostics only.

2.4 Engineering Data Acquisition

2.4.1 Engineering Measurement Timing

Figure 2.6.1-1 illustrates the timing of the HK integration periods relative to the RTC period. The FSW sets up the HK MUX address by writing an address to the specified register during every other 1ms latency period and integrates the measurement over the subsequent two periods. The measurements are double buffered, so FSW may read the HK measurement during the subsequent integration period.

Figure 4.2-1 HK Measurement Timing



2.4.2 Engineering Sensor Address Sequence

The MWR HKU acquires engineering voltage and thermistor measurements and returns these in the science and engineering telemetry packets. The HKU has two channels, HKU-1 and HKU-2. Each MUX address maps to two measurements, one from each HKU-1 and HKU-2. The MWR Electronics Unit to Temperature Sensor ICD (AD2), Appendix A provides the sensor address mapping and Appendix B provides references to drawings showing the as-built location of the sensor on the flight hardware.

The onboard PROM contains two sensor address sequences. Sequence #0 is a special, one address sequence, automatically activated during commanded idle mode. Sequence #1 is the nominal operational sensor sequence.

The sensor sequences are documented in the FSW User Guide (AD1), Section 2.3. The nominal operational sequence comprises 75 addresses. The HKU acquires five sensor addresses (x 2 channels) per second, and measurements from a complete sensor sequence are subcommutated over fifteen, 1-second science packets. *The operational sensor address samples some sensors at a faster rate than others and skips spare addresses, so the sensor sequence does not increment monotonically.*

2.5 Telemetry Data Packets

Table 2.4-1 lists the MWR telemetry packet format types. Detailed telemetry packet formats and specifications are documented in the MWR FSW User Guide, Appendix B.

Table 2.4-1 Telemetry Data Packet Format Types

Packet Type	Description
Science	Science, engineering, and status.
Engineering	Engineering and status.
Diagnostic	Significant flight software variables values and status.
Memory Dump	Values from a command-specified section of processor memory and status.
Error Dump	The last 25 error messages issued by flight software and status.

2.5.1 Spacecraft Timestamps

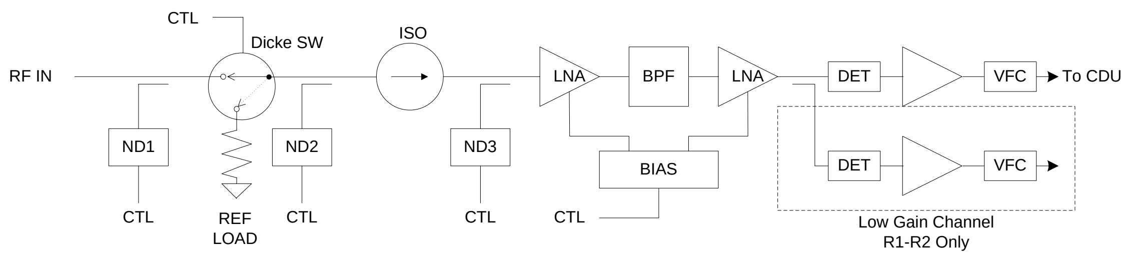
The MWR receives broadcast timestamps and a 0.5 Hz synchronization pulse (time tick) from the spacecraft. The timestamp is returned in the MWR telemetry as received along with an offset count, which is the number of 0.5 us internal clock periods between the receipt of the S/C time tick and the start of the MWR measurement sequence.

2.6 Vault Electronics Functional Overview

2.6.1 Receiver Unit

Figure 2.6.1-1 shows a functional block diagram of a typical MWR receiver. The control signals map to the receiver control bits as shown in Table 2.3.1-1. The noise diodes are controlled via their bias signals to provide gain calibration and diagnostics. The Dicke switch selects between the antenna signal and an internal reference load. The LNA bias control allows the RF amplifier bias to be controlled off for diagnostic measurement of the postdetector circuit DC offset.

Figure 2.6.1-1 MWR Receiver – Functional Block Diagram



The primary calibration diode is ND1 for channels for which the antenna signal is sufficiently stable to provide an accurate ND deflection. For R1 and R2, which will see a rapidly varying signal as the synchrotron rotates into and out of view, ND2, with switch in reference load position, provides the primary gain calibration. The other diodes provide various diagnostic information. For example, noise diode brightness ratios calculated between pairs of diodes help track stability of switch, isolator, and the diodes themselves.

A second, low gain channel is provided on R1 and R2 to allow measurement of the radiometric brightness of Jupiter's synchrotron, which is required to correct for synchrotron contamination of measurements via antenna sidelobe and backlobes. The coupler attenuates the RF signal to provide >10x increased dynamic range compared to the nominal channel. Table 2.6.1-1 shows the minimum receiver dynamic range (the design requirement is shown, however as built receivers typically function above these levels without saturation). Accuracy is less critical for synchrotron measurements, so linearity requirements are relaxed for low gain channels to account for the higher signal power in the LNA's.

The nominal channels on R1 and R2 may saturate when signal levels are in the extended range, however this will not damage the receivers.

Table 2.6.1-1 Receiver Minimum Dynamic Range (TA in Kelvin)

	R1	R2	R3	R4	R5	R6
Nominal Range (nominal channel)	1176	866	1850	695	695	695
Extended Range (low gain channel)	17850	5850	N/A	N/A	N/A	N/A

2.6.2 Electronics Unit (EU)

The MWR Electronics Unit (EU) comprises power distribution unit (PDU), Control and Data Unit (CDU), and Housekeeping Electronics Unit (HKU).

2.6.2.1 Power Distribution Unit (PDU)

The PDU receives nominal, unregulated +28V from the spacecraft and distributes regulated secondary power supplies to the MWR electronics unit and receivers. The dual redundant PDU provides FET switches on the supplies to each of the six receivers that allow a receiver to be isolated in the event of a fault condition.

MWR nominal and redundant (A/B) PDU are selected by S/C PDDU bus switch as shown in Figure 2.6.2-1. See the MWR Circuit Datasheets, an Appendix to the MWR to Juno S/C ICD (AD6) for electrical interface details.

The PDUR design includes short circuit protection on its secondaries. This ensures that the PDUR will not be damaged in the case of a load fault on one of the receivers, as the receivers must be powered to detect a load fault and it may take several hours to identify and isolate the offending receiver. PDU A and B secondaries are diode or'ed as shown in Figure 2.6.2-1.

Figure 2.6.2-1 MWR Bus Switch Configuration

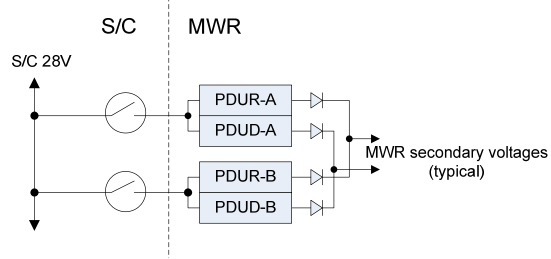
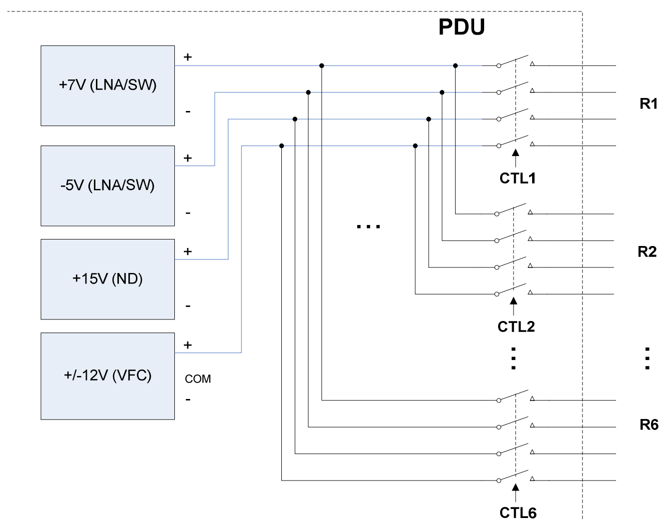


Figure 2.6.2-2 Receiver Load Switch Concept



Note: The PDUR overcurrent protection circuit design has several idiosyncrasies that can result in either false tripping due to receiver inrush current if multiple receivers are switched on simultaneously, or a failure to protect the PDUR from damage if a load fault occurs in certain secondaries when there is insufficient total load on the PDUR. Flight rules 1703-E-MWR and 1703-E-MWR in Appendix B of this document describe the workarounds required to avoid these issues.

2.6.2.2 Control and Data Unit (CDU)

The CDU is an 8051 microcontroller-based system that controls and acquires data from the receivers, addresses and acquires data from the HKU, receives commands, time tags, and time ticks from the spacecraft DHU and transmits science and housekeeping telemetry packets to the spacecraft DHU over a RS-422 interface. It includes both a watchdog timer implemented in hardware, which resets FSW and the FPGA if the FSW does not write to a specified register every 1.6 seconds, and a reset discrete, controlled by the S/C DHU.

2.6.2.3 Housekeeping Unit (HKU)

The HKU acquires temperature measurements from thermistors and platinum RTD's and acquires voltage monitor measurements from the PDU secondary supplies. The HKU outputs two VFC signals to the CDU where they are accumulated, converted to digital numbers, and returned via instrument telemetry. HKU measurements are converted into engineering units in ground processing algorithms.

3. MWR Checkout and Test

LMA ATLO plans and procedures describe the ATLO test activities. The Juno Mission Plan (AD9) describes test and operational activities for 21 days prior to launch to completion of the mission. MWR test and procedures are typically tailored to the specific objectives of those plans and procedures. This section gives a general overview of the type of testing performed in ATLO and after launch.

3.1 Functional Tests

3.1.1 Full Functional Test

The full verification test is typically only performed for instrument level acceptance and after FSW or other major changes. The full MWR functional verification test includes the following:

- Nominal boot
  - Verify nominal bus power draw
  - Verify nominal HW side select
  - Telemetry output (verify all packet types)
  - Commanding (test all command types)
  - Test alternate science and housekeeping packet rates
  - Memory read/write
  - Verify all alternate receiver PROM sequences
  - Secondary voltage monitor functional check and trending
  - Thermistor temperature functional check and trending
  - PRT temperature functional check and trending
  - RF chain test (using internal noise diodes)
    - Gain, noise figure
    - Dicke switch isolation
    - Internal noise diode ratios
- Idle Mode Boot
  - SW upload
  - Alternate receiver load switch configurations
  - Alternate configuration table upload
  - Alternate HK address sequence upload

3.1.2 Health Check Test

A subset of the functional tests listed above is adequate to verify MWR health and functional performance. The MWR health check test typically includes the following:

- Nominal Boot
  - Verify nominal bus power draw

  - Verify nominal HW side select
  - Telemetry output, verify nominal packet
  - Commanding (test one of each command type)
  - Memory read/write
  - Select alternate receiver PROM sequence
  - Voltage monitor functional check and trending
  - Thermistor and PRT temperature functional check and trending
  - RF trend test (using internal noise diodes)
    - Receiver gain
    - Noise figure
    - Noise diode ratios

3.1.3 Aliveness Test

In some cases, it is only desired to verify that MWR is responsive and communications are nominal. This test can be optionally performed after an idle mode boot with receivers unpowered. The MWR aliveness test typically includes the following:

- Idle Mode Boot (optional)
  - Verify nominal bus power draw
  - Verify nominal HW side select
  - Telemetry output, verify nominal packet
  - Memory read/write command

3.2 Radiometric Tests

3.2.1 Blackbody Test in Atmosphere

This test, performed at the S/C integration facility, uses a blackbody absorber in a special thermal atmosphere enclosure with a transparent radome cover. The MWR antennas are terminated with the target and the target temperature varied to get a two-point calibration. This allows tracking MWR performance against a radiometric baseline, with the instrument at ambient temperature.

3.2.2 Post-Launch Radiometric Tests

The major post-launch radiometric tests are the post launch initial checkout, periodic sky scans during cruise, periodic scans through same plane as MWR science orbit, MWR apojove calibration, Scan across Jovian disk during Jupiter approach and sky scan during an MWR orbit.

The objective of the post launch initial checkout is to verify nominal radiometer function and to acquire sky scan measurements to track the calibration from pre-launch to post-launch. The periodic sky scans during cruise will be used to track the system calibration using the sky background and galactic plane. During this test, the antenna temperatures and internal noise diode ratios will be used to track calibration from pre-launch to the science orbits. There will be at least three instances when the MWR spin plane is oriented as it will be for the science passes. In this case, we will take measurements into order to track the brightness temperature in this plane through cruise and through the science orbits.

The objective of the apojove calibration is to scan across Jovian disk to measure the beam pattern in one axis. The MWR will also take periodic data during the MWR orbits, outside of the nominal 2 hour science pass. Data will be taken approximately twice per day outside of 1 day from perijove and once every 2 hours inside of 1 day from perijove. These data will be used to track the system stability during the orbit and to sample the Jovian disk as it fills our antenna pattern. These measurements can be used for inter-comparisons between ground based full disk measurements and MWR measurements. It will also form a group of data points which can be tracked to assess stability over the full dynamic range of brightness temperatures that MWR will observe as well as providing an estimate of the MWR backlobes.

4. MWR Diagnostics

4.1 Engineering Telemetry

4.2 Voltage Monitors

The MWR voltage monitor measurements, described in Section 2.4, are not specified for high absolute accuracy over the instrument lifetime, and are only intended to allow trend tracking and to provide corroborating diagnostics information in the case of anomalous instrument behavior.

The voltage monitor telemetry, sensed within the PDU unit, is specified to provide a pre-launch absolute accuracy of +/-10% and a end-of-life accuracy of 50%, sufficient to detect a hard failure. The accuracy is limited by the tracking of the current transfer ratio (CTR) between analog optocouplers (OLS303) used to maintain ground isolation between secondary supplies.

The pre-launch accuracy is limited by thermal CTR tracking over the specified protoflight temperature range. Typical beginning-of-life accuracy is about 5% over the AFT range. The 50% end-of-life accuracy is specified very conservatively to account for pathological worst case CTR degradation due to total ionizing dose (TID) radiation. This specification was defined to avoid the need to perform radiation testing on the parts and does not represent the expected performance. OLS303's flown on OSTM/AMR in a similar functional application and similar total ionizing dose (TID) environment have not exhibited any observable performance degradation.

4.2.1 Alarm Limits

It is not recommended that the MWR secondary voltage sensor limits be used to trigger any automated safing response. It is unlikely that any such automated response would preclude hardware damage, and would risk loss of critical science data in the case of a housekeeping circuit malfunction or data corruption.

However voltage trends should be tracked and MWR engineers should be notified of any change exceeding 5% from the pre-launch baseline. Any significant degradation of receiver performance correlated with a change in a receiver secondary voltage could be evidence of a receiver load fault. Diagnosing such a condition would typically require assessment of data by MWR engineers.

If a receiver load fault is suspected, the typical diagnostic would be an instrument reset and analysis of data from the receiver power on sequence. If a receiver load fault affecting a common secondary supply were present on a receiver other than R1, the already powered receivers would be affected when the faulted receiver was switched on. If a load fault on R1 is suspected an alternate receiver power on sequence can be commanded to turn on R1 last. If a receiver load fault is detected, an idle mode boot can be performed and a commanded receiver power on sequence executed, isolating the faulted receiver.

The MWR design originally switched receiver on sequentially at 30 second intervals in the default power on sequence to allow detection of a load fault using voltage monitor telemetry, which updates every 15 seconds. However a PDU idiosyncrasy required that the design be changed to switch on receivers every second, limiting the usefulness of the engineering voltage telemetry as a primary means for diagnosing load faults (see flight rule #1703-E-MWR in Appendix B).

4.3 Temperature Monitors

The MWR temperature monitor measurements are primarily for radiometric calibration characterization and thermal model correlation. Thermistor temperatures within the receiver and EU provide some limited health monitoring capability, and help correlate packaging thermal analyses. The MWR telemetry calibration handbook (AD10) describes the conversion of raw telemetry counts to engineering units and the associated accuracy.

4.3.1 Alarm Limits

As with voltage sensors, it is not recommended that the MWR temperature sensor limits be used to trigger any automated safing response. It is unlikely that any such automated response would preclude hardware damage, and would risk loss of critical science data in the case of a housekeeping circuit malfunction or data corruption.

However temperatures should be monitored and MWR engineers notified if specified limits are exceeded. For sensors on passive components (i.e. any sensor other than the internal receiver and EU sensors), the limits are set at 5C within the corresponding AFT limits. For internal receiver and EU sensors, the limits are set at 5C above AFT cold and at 5C below the AFT hot temperature plus the typical temperature rise from the thermal control interface to the given sensor as measured in TVAC protoflight qualification. Appendix C lists the recommended alarm limits.

4.4 Science Telemetry

It is not recommended that the MWR radiometric data limits be used to trigger any automated safing response. It is unlikely that any such automated response would preclude hardware damage, and would risk loss of critical science data.

However routine trend monitoring against a baseline is recommended to track instrument health. Recommended parameters for trend monitoring are mean noise diode deflection ratios, receiver gain (calculated using noise diodes), and NEDT. These parameters are typically temperature dependent, so should be plotted alongside the relevant housekeeping temperatures.

Appendix A. Acronyms

AD	Applicable Document
APC	Antenna Pattern Correction
CDU	Command and Data Unit
CTR	Current Transfer Ratio
EU	Electronics Unit
FSW	Flight Software
GSE	Ground Support Equipment
HKU	Housekeeping Unit
HRCR	Hardware Review Certification Record
ICD	Interface Control Document
LNA	Low Noise Amplifier
MUX	Multiplexer
MWR	Microwave Radiometer

ND	Noise Diode
NEDT	Noise Equivalent Delta-T
PDU	Power Distribution Unit
PDUD	Power Distribution Unit (Digital)
PDUR	Power Distribution Unit (Receiver)
PHST	Packaging, Handling, Storage and Transportation Document
PROM	Programmable Read Only Memory
ROM	Read Only Memory (often used interchangeably with PROM)
RTC	Real Time Clock
S/C	Spacecraft
SSL	Side Select Logic
TBC	To Be Confirmed
TBD	To Be Determined
TID	Total Ionizing Dose
VFC	Voltage to Frequency Converter

Appendix B. Idiosyncrasies and Flight Rules

The LM document, *Juno Flight Rules and Constraints* (AD4), is the official source of Juno flight rules. Related guidelines on MWR command usage is provided in the *MWR FSW User Guide* (AD1), Appendices A and F. Two MWR flight rules, related to MWR idiosyncrasies, are described here. The rule number shown are referenced in AD4.

#1703-E-MWR MWR_POWER Command Constraint

Description:

The MWR_POWER command is for contingency use only. The only exception is the nominal use of the MWR_POWER (0x3F,0x0) command. This command removes power from all 6 receivers as part of instrument power down.

- When used in a contingency, the MWR_POWER command shall not be used to power on more than one receiver at a time.
- When the MWR_POWER command is used to power on receivers, at least 4 receivers must be powered on in sequence.
- Each MWR_POWER command must be sent in sequence with at least 1 second and no more than 3 seconds delay between commands.
- When MWR_POWER is used to power off receivers, at least 4 receivers shall remain powered or all must be turned off.

Rationale:

The MWR_POWER command parameters allow any combination of 1 to 6 receivers to be powered concurrently. However, due to an idiosyncrasy of the MWR PDUR, the PDUR OCP may trip when multiple receivers are powered concurrently, due to receiver current inrush.

When the MWR_POWER command is used to power on receivers, at least 4 receivers must be powered on before the PDUR overcurrent protection is fully functional.

The PDUR overcurrent protection on its +/-12V secondary is not functional if there is less than 10W total load on the PDUR. With 4 receivers powered, this condition is met and overcurrent protection (OCP) is fully functional.

The 1 to 3 second interval between power-on of each receiver, ensures that (1) the OCP is enabled soon enough to preclude PDUR damage in the presence of a short on an individual receiver +/-12V and (2) provides enough delay between receiver power on to preclude tripping the OCP due to nominal receiver inrush.

Impact:

An OCP trip will not result in damage to the hardware, but the condition would have to be detected on the ground and a reset and sequenced receiver power-on required to restore nominal receiver operation.

If there is no short on any receiver +/-12V secondary, a violation on the minimum 4 receivers on has no impact. In the presence of a short on a receiver +/-12V secondary (load fault condition), with lower than the minimum 4 receiver load, the PDUR switching FET may go into linear mode and overheat, potentially resulting in PDU failure within minutes.

If the delay between each receiver power-on is << 1 second, an anomalous OCP trip may occur on receiver power-up due to inrush current from multiple receivers. This would not damage the PDUR, but would require ground intervention to correct. If the power-on delay is >> 3 seconds, the PDUR may be damaged if there is a short on the +/-12V secondary.

1705-E-MWR MWR RF Bias Constraint

Description:

When the MWR_PARAM command is sent to turn off receiver RF bias for a diagnostic zero measurement (i.e. Parameter ID 2 and Receiver Sequence 19), the receivers must be powered off before the RF bias is re-enabled.

Return to nominal operations from receiver sequence 19 should typically be by a MWR Reset command. The reset will power off the receivers, initialize the receiver sequence, execute the receiver power-on, and switch to operational receiver sequence #1 autonomously.

Receivers may be powered off by alternate means other than a reset command prior to changing from receiver sequence 19. For example, this may be done by an MWR_POWER command to power-off the receivers, an MWR_PARAM command to change the receiver sequence from 19, followed by a receiver power-on using MWR_POWER command sequence. This alternate commanding method is viewed as a contingency due to MWR_POWER command restrictions in rule 1703-E-MWR.

Rationale:

The MWR receivers exhibit a current inrush when the RF bias regulator outputs are re-enabled after being disabled using Receiver Sequence 19. This inrush typically trips the PDUR overcurrent protection (OCP) circuit, resulting in shut down of all receivers.

If a receiver configuration other than the default is required, an Idle Mode command may be sent within 30 seconds of the Reset, and the required configuration commands sent.

Impact: An OCP trip does not result in damage to hardware, however ground intervention would be required to detect and correct the condition if this occurred in flight.

Appendix C. MWR Housekeeping Sensor Alarm Limits

The recommended response to tripping of MWR sensor alarm limits is discussed in Section 4. Temperature limits for passive components are 5□C inside their AFT limits. For receiver and EU sensors, the cold limit is 5□C inside the AFT limit, while the hot limit is 5□C inside the expected thermistor temperature when the unit to vault interface is at AFT hot. The expected thermistor temperature for receivers and EU is based on the typical temperature rise from the baseplate to the thermistor as measured during TVAC protoflight qualification. Voltage alarm limits are 5% outside their average values measured in TVAC protoflight qualification.

EDR slots 8 through 19 are internal calibration measurements that are not converted to engineering units. Alarm limits are not applicable to these measurements.

Relative EDR slot	MUX Address (hex)		Name	Limits	
	HKU1	HKU2		Low	High
0	60		CDU+5	4.7	5.5
1		60	LNA+7	6.7	7.4
2		62	LNA-5	-5.8	-5.2
3		61	ND+15	14.6	16.1
4		63	VFC+12	11.0	12.1
5		64	VFC-12	-12.1	-10.9
6	61		HKU+12	11.2	12.4
7	62		HKU-12	-12.8	-11.6
8	66		HKU1 VCAL A	N/A	N/A
9	67		HKU1 VCAL B	N/A	N/A
10		66	HKU2 VCAL A	N/A	N/A
11		67	HKU2 VCAL B	N/A	N/A
12	1E		HKU1 RTD CAL LO	N/A	N/A
13	1F		HKU1 RTD CAL HI	N/A	N/A
14	5E		HKU1 PRT CAL LO	N/A	N/A
15	5F		HKU1 PRT CAL HI	N/A	N/A
16		1E	HKU2 RTD CAL LO	N/A	N/A
17		5F	HKU2 PRT CAL HI	N/A	N/A
18		5E	HKU2 PRT CAL LO	N/A	N/A
19		5F	HKU2 PRT CAL HI	N/A	N/A
20	1B		PDUR-A	-10□C	+60□C
21		1B	PDUR-B	-10□C	+60□C
22	1C		HKU-1	-10□C	+45□C
23		1C	HKU-2	-10□C	+45□C
24	1D		CDU	-10□C	+45□C
25		1D	PDUD	-10□C	+55□C
26	00		R1T1	-10□C	+45□C
27	01		R1T2	-10□C	+45□C
28	02		R1T3	-10□C	+45□C
29	03		R1T4	-10□C	+45□C
30	12		INT_RFTL1T1	-10□C	+45□C
31		12	INT_RFTL1T2	-10□C	+45□C

32	4C		RFTL1T1	-130□C	+95□C
33		4D	RFTL1T2	-130□C	+95□C
34	4D		RFTL1T3	-130□C	+95□C
35	4E		A1T1	-115□C	+95□C
36		4E	A1T2	-115□C	+95□C
37	4F		A1T3	-115□C	+95□C
38		4F	A1T4	-115□C	+95□C
39	06		R2T1	-10□C	+45□C
40	07		R2T2	-10□C	+45□C
41	08		R2T3	-10□C	+45□C
42	09		R2T4	-10□C	+45□C
43		13	INT_RFTL2T1	-10□C	+45□C
44	13		INT_RFTL2T2	-10□C	+45□C
45	58		RFTL2T1	-115□C	+95□C
46		58	RFTL2T2	-115□C	+95□C
47	59		RFTL2T3	-115□C	+95□C
48		59	A2T1	-115□C	+95□C
49	5A		A2T2	-115□C	+95□C
50		5A	A2T3	-115□C	+95□C
51	0C		R3T1	-10□C	+45□C
52	0D		R3T2	-10□C	+45□C
53	0E		R3T3	-10□C	+45□C
54	0F		R3T4	-10□C	+45□C
55	14		INT_RFTL3T1	-10□C	+45□C
56		14	INT_RFTL3T2	-10□C	+45□C
57	5B		RFTL3T1	-130□C	+95□C
58		5B	RFTL3T2	-130□C	+95□C
59	5C		RFTL3T3	-130□C	+95□C
60		5C	A3T1	-130□C	+95□C
61	5D		A3T2	-130□C	+95□C
62		5D	A3T3	-130□C	+95□C
63		00	R4T1	-10□C	+45□C
64		01	R4T2	-10□C	+45□C
65		02	R4T3	-10□C	+45□C
66		03	R4T4	-10□C	+45□C
67		15	INT_RFTL4T1	-10□C	+45□C
68	15		INT_RFTL4T2	-10□C	+45□C
69	53		RFTL4T1	-130□C	+95□C
70		53	RFTL4T2	-130□C	+95□C
71	54		RFTL4T3	-130□C	+95□C
72		54	RFTL4T4	-130□C	+95□C
73	55		A4T1	-130□C	+95□C
74		55	A4T2	-130□C	+95□C
75	52		A4T3	-130□C	+95□C
76		06	R5T1	-10□C	+45□C
77		07	R5T2	-10□C	+45□C

78		08	R5T3	-10□C	+45□C
79		09	R5T4	-10□C	+45□C
80	16		INT_RFTL5T1	-10□C	+45□C
81		16	INT_RFTL5T2	-10□C	+45□C
82		50	RFTL5T1	-70□C	+95□C
83	50		RFTL5T2	-70□C	+95□C
84		51	RFTL5T3	-70□C	+95□C
85	51		A5T1	-130□C	+95□C
86		52	A5T2	-130□C	+95□C
87		0C	R6T1	-10□C	+45□C
88		0D	R6T2	-10□C	+45□C
89		0E	R6T3	-10□C	+45□C
90		0F	R6T4	-10□C	+45□C
91		17	INT_RFTL6T1	-10□C	+45□C
92	17		INT_RFTL6T2	-10□C	+45□C
93	56		RFTL6T1	-90□C	+95□C
94		56	RFTL6T2	-90□C	+95□C
95	57		RFTL6T3	-90□C	+95□C
96		57	A6T1	-130□C	+95□C