

NIRCam Integration and Test

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ABSTRACT

The Near Infrared Camera (NIRCam) instrument for NASA's James Webb Space Telescope (JWST) is one of the four science instruments installed into the Integrated Science Instrument Module (ISIM) on JWST intended to conduct scientific observations over a five year mission lifetime. NIRCam's requirements include operation at 37 kelvins (K) to produce high resolution images in two wave bands encompassing the range from 0.6 microns to 5 microns. In addition NIRCam is used as a metrology instrument during the JWST observatory commissioning on orbit, during the initial and subsequent precision alignments of the observatory's multiple-segment 6.3 meter primary mirror. This paper describes the integration and test (I&T) processes used to verify the Imaging Optical Assembly (IOA) to the defined requirements.

Keywords: NIRCam, James Webb, JWST, ISIM

1. INSTRUMENT OVERVIEW

The NIRCam IOA consists of two mirror image modules mounted back-to-back. Figure 1.0 illustrates the two modules mounted atop the Goddard Space Flight Center (GSFC) Kinematic Mounts ready for installation onto the ISIM structure. The NIRCam spectral waveband is divided into two optical channels on each of the two modules to provide a short wavelength channel from 0.6 to 2.3 microns, and a long wavelength channel covering 2.4 to 5.0 microns. Figure 2.0 illustrates the division of the spectral range into the two channels. The left side illustrates each module with stray light baffles installed, while the right side module has the optical beam path exposed.

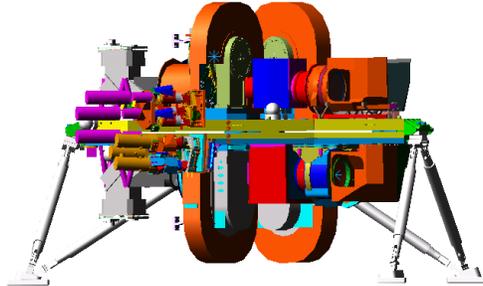


Figure 1.0 NIRCam Instrument consisting of two modules on ISIM Kinematic Mounts

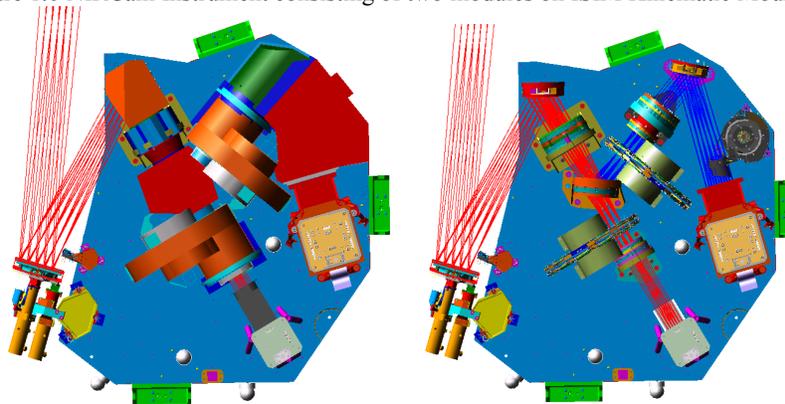


Figure 2.0 NIRCam Optical Ray trace with and without stray light baffles installed

2. INSTRUMENT BLOCK DIAGRAM

Figure 3.0 illustrates the NIRCam block diagram. This illustration shows the IOA mounted on the ISIM inside the 32K to 37K region 1 enclosure. The Instrument Control Electronics (ICE) and Focal Plane Electronics (FPE) are located in the region 2 thermal zone at 293K. The NIRCam flight software (FSW) resides within the JWST Integrated Command and Data Handling (ICDH) computer.

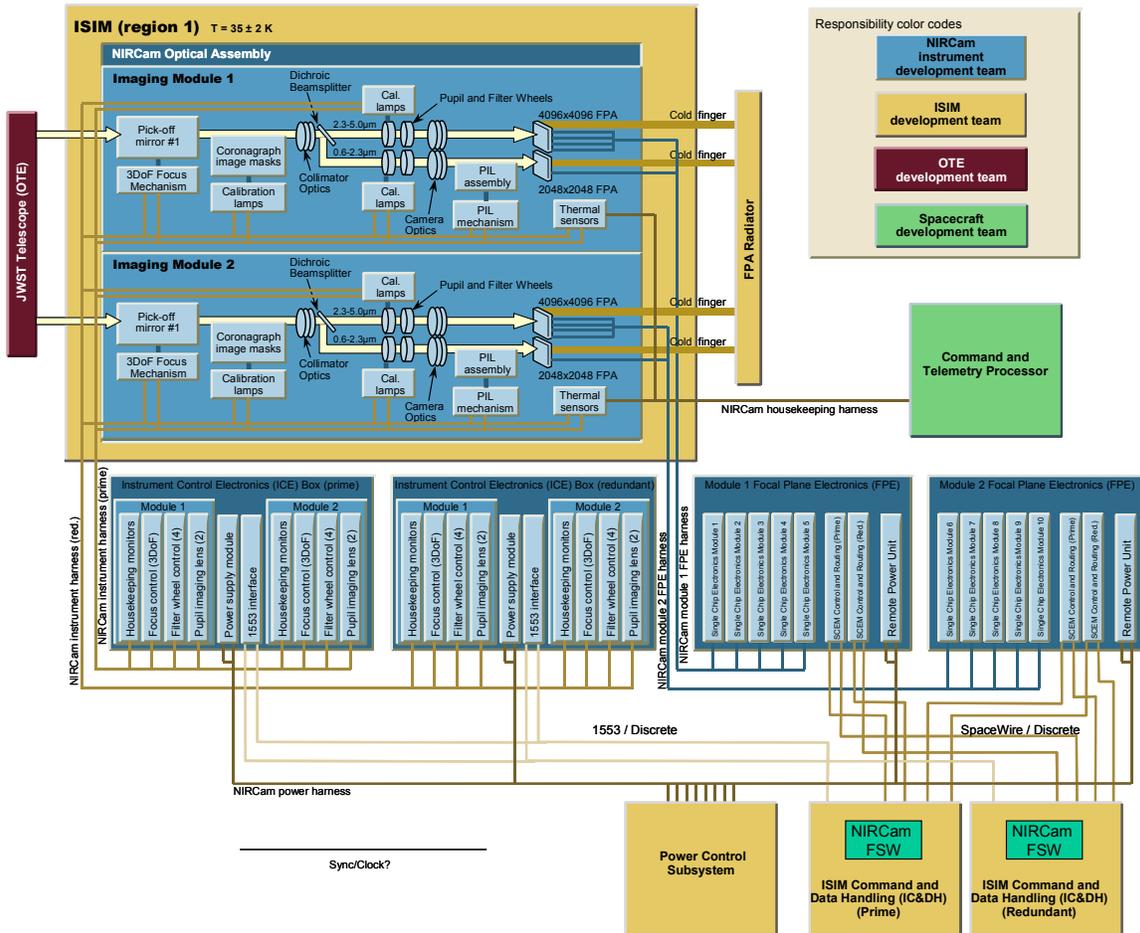


Figure 3.0 NIRCam Instrument block diagram

3. DRIVING PERFORMANCE REQUIREMENTS

NIRCam serves the dual roles as a metrology instrument during JWST commissioning, and a science imager during science operations. Two driving performance requirements for NIRCam are its wavefront error (WFE) and optical alignment. The total wavefront error budget is illustrated in Figure 4.0 which is divided into the low spatial frequency (<5 cycles/aperture), mid spatial frequency (5 cycles/aperture to <35 cycles/aperture), and high spatial frequency (> 35 cycles/aperture). The optical alignment requirement at the module level is to obtain a 95% overlap between the short and long wavelength channels with a goal of 99% overlap. This will enable each module to view the area in the sky while the second module views the adjacent area of the universe for a total FOV of $2x (2.2 \text{ arcminutes})^2$. A third driving requirement is the knowledge of the IOA boresight referenced to the ISIM coordinate plane.

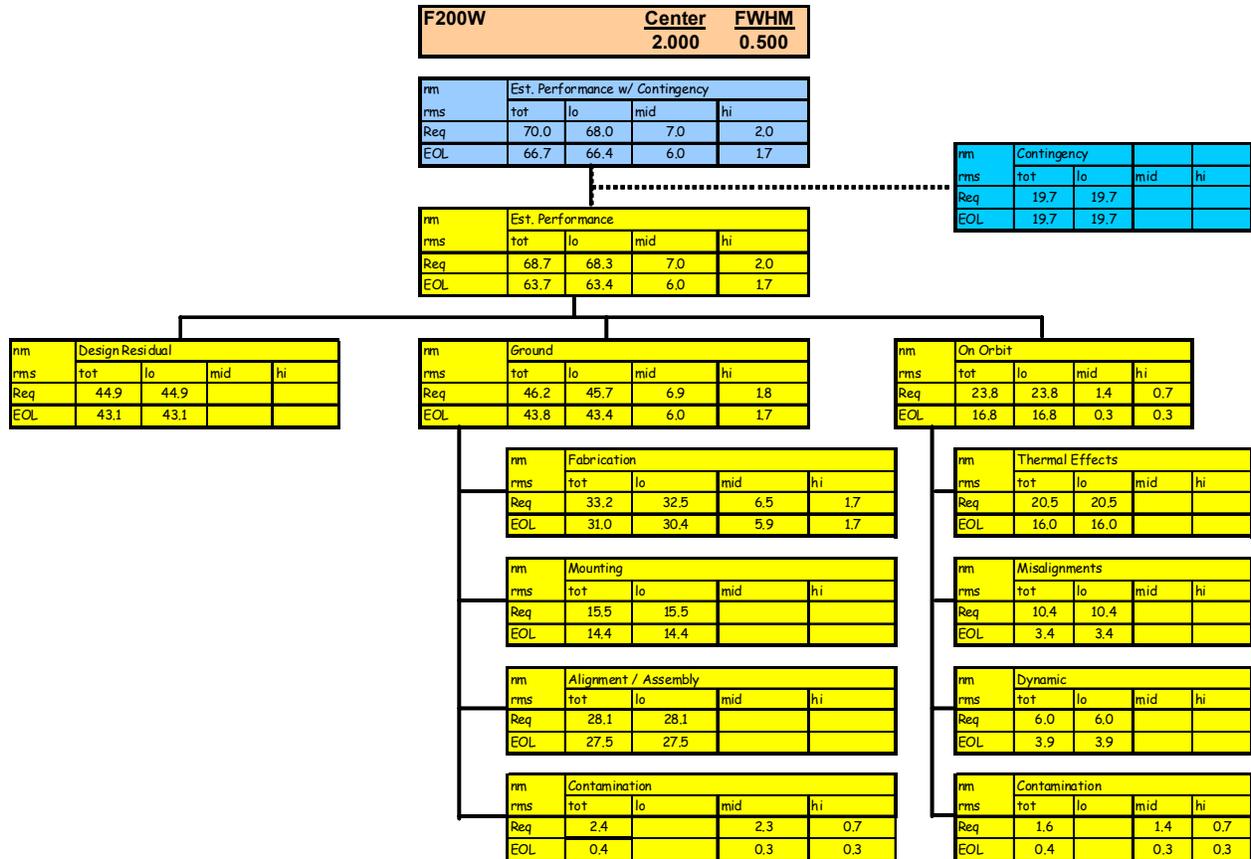


Figure 4.0 NIRCam Wavefront Error Budget

4. INTEGRATION PROCESS FLOW

The NIRCam program is developing two instruments: an Engineering Test Unit (ETU), and a Flight Model (FM). The ETU is a pathfinder used to validate the assembly processes, functional verifications, flight and ground support software, and the performance requirements. The NIRCam ETU is to be used during the ISIM and Observatory ETU testing. The ETU contains a single fully functional, flight equivalent short wave channel with the mosaic FPA consisting of four 2k x 2k detectors. The remaining subsystems are replaced with flight equivalent thermal mass simulators with the exception of the beryllium (Be) optical bench assembly (OBA) being flight equivalent for both ETU modules. The FM will be fully populated with flight hardware. Figure 5.0 illustrates the entire I&T process beginning with the assembly, module cold alignment testing, FPA integration, IOA assembly, IOA Comprehensive Performance Test 1 (CPT1), environmental testing, and CPT2 performance test. The NIRCam Optical Telescope Element Simulator (NOTES) testing immediately follows CPT2 to verify the NIRCam focus requirements, WFE, and IOA throughput. The secondary role of NIRCam as a metrology instrument will be characterized during Wave Front Sensing and Control (WFS&C) testing following NOTES testing.

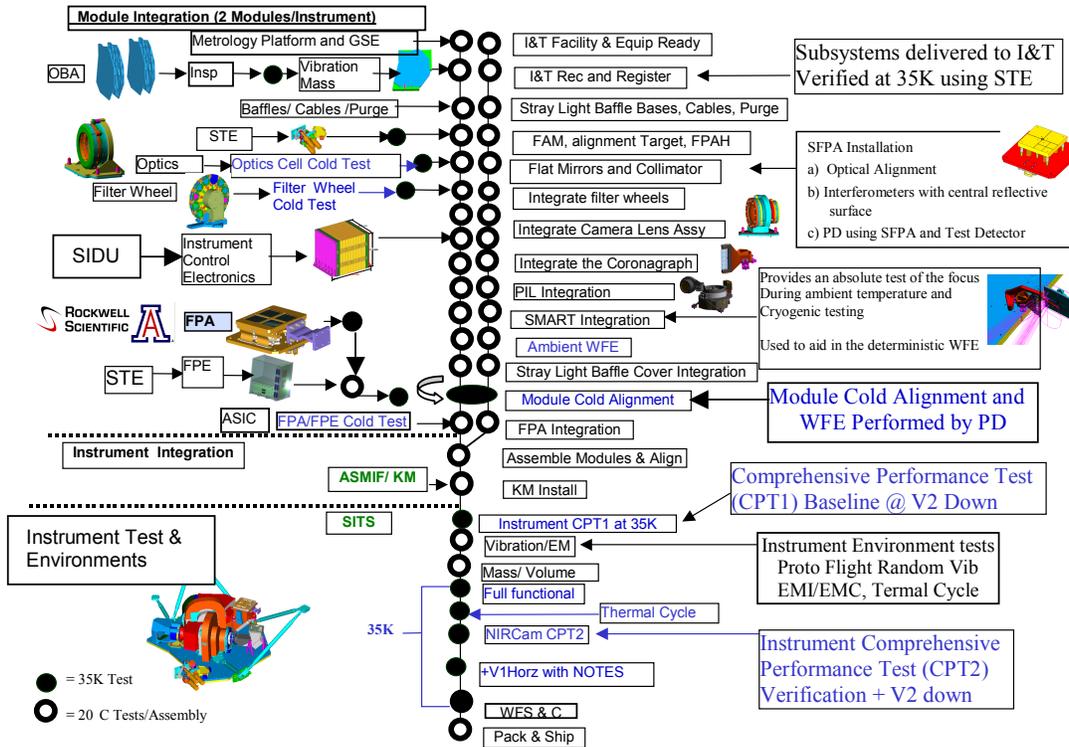


Figure 5.0 NIRCam Integration and Test Flow

4.1. Module Assembly

The I&T activities begin with the delivery of each NIRCam subsystem which have been verified to the unique requirements at operating temperature. The integration of the subsystems onto the optical bench is performed at ambient environment in a class 100 cleanroom to support the level 350A at delivery requirement. The subsystem tests include functional, environmental, and optical tests performed at the operating temperature using the ICE and FSW. The prescription, position, and performance math models used in the NIRCam design at operating temperature are converted to ambient temperature prescription, position, and performance to place each subsystem correctly onto the OBA. This converted data establishes the requirements for the assortment of mechanical and optical metrology aids required to complete the alignment and functional testing prior to cold alignment testing.

4.2. Cold Alignment Testing

The NIRCam cold alignment tests are performed at the module level while at the operating temperature of 35K. The cold alignment test is designed to verify the FSW, IOA telemetry, ICE operation and subsystem functionality as an integrated assembly, the module optical alignment, and to characterize the WFE prior to assembly into the IOA. The cold alignment test is performed in a ‘staggered’ sequence to characterize the long and short wavelength channel performance from both modules in one cold cycle.

The optical alignment is characterized with a series of on-board optical sources and external optical metrology tools. A Surrogate Focal Plane Assembly (SFPA) projects a point source from the image plane to a test detector located externally to the thermal vacuum chamber. Image data collected at the test detector is used to verify the optical alignment. The module WFE is characterized using phase diversity (PD).

A final step in the cold testing is to quantify the alignment of the NIRCam boresight to the Instrument alignment cube at operating temperature. This is accomplished using optical metrology tooling viewing the optical cube from two orthogonal axes through chamber windows, and referenced to the optical axes of the external optical system. Figure 6.0 illustrates the NIRCam module level cold test configuration.

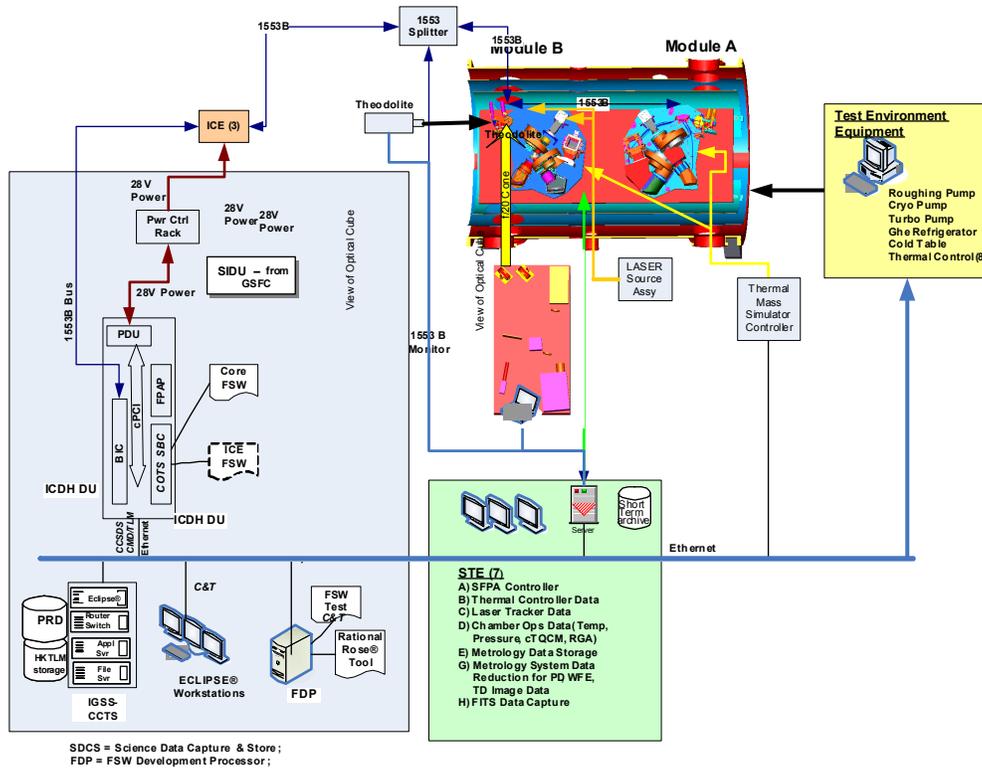


Figure 6.0 NIRCcam Module Cold Alignment Test Configuration

4.3. Image Optical Assembly development

The development of the IOA addresses three major activities:

1. Installing the associated FPAs.
2. Assembling the two modules together.
3. Installing the GSFC provided ISIM kinematic mounts

At the conclusion of the Cold Alignment testing the modules are returned to the class 100 cleanroom for installation of the FPAs. Knowledge of the SFPA though the use of metrology tooling will be used to align the FPA to the module image plane. The joining of the two modules will be performed in a rotational fixture specially designed to rotate each module and the IOA between the horizontal and vertical orientations. Once the modules are assembled, the IOA will be installed atop the kinematic mounts and referenced to the ISIM coordinates using the GSFC provided Ambient Science Master Interface Fixture (ASMIF) as the optical reference.

4.4. Comprehensive Performance Testing

The Comprehensive Performance Tests (CPT1 and CPT2) are designed to replicate the test procedures and execution between CPT1 and CPT2. CPT1 will establish the performance baseline while CPT2 will duplicate the test procedures, validate NIRCcam FSW and operations, and verify NIRCcam operational requirements. This will ensure any functional or performance variation created during environmental testing will be noted during CPT2. Figure 7.0 illustrates the IOA test configuration using the GSFC provided Science Instrument Test Station (SITS). The SITS represents the onboard IC&DH for verification instrument operation and protocols.

Each CPT will evaluate:

- Flight Software initialization and ICDH simulator
- System initialization to include health and safety checks, telemetry, ICE and FPE ‘built in test’, and the configuration of all commanded subsystems
- Ambient environment readout of the reference pixels on each of the 10 detectors to establish communication links
- Telemetry data acquisition and validation

- Thermal control and maintenance
- IOA initialization
- FSW command and IOA functional audits
- FPE thermal control and stability
- Simultaneous image data collected
- Performance measures for IOA dark current and flat fielding using on-board calibration sources
- Performance measurements for alignment, FOV, and short and long wavelength channel magnification
- FPE image data for full frame, subarrays, and alterations of integration time
- Functional Audits of the focus adjust mechanism for full range of motion, resolution, repeatability, tilt, and thermal performance when compared to math models
- Filter wheel operations to include pupil wheel insertion and repeatability, positional stability, alignment of WFS elements, and thermal performance
- Validation of the Ground Support Software
- Validation of the NIRCam Test Controller operations, data collections and analysis, thermal vacuum control functions, and thermal GSE control

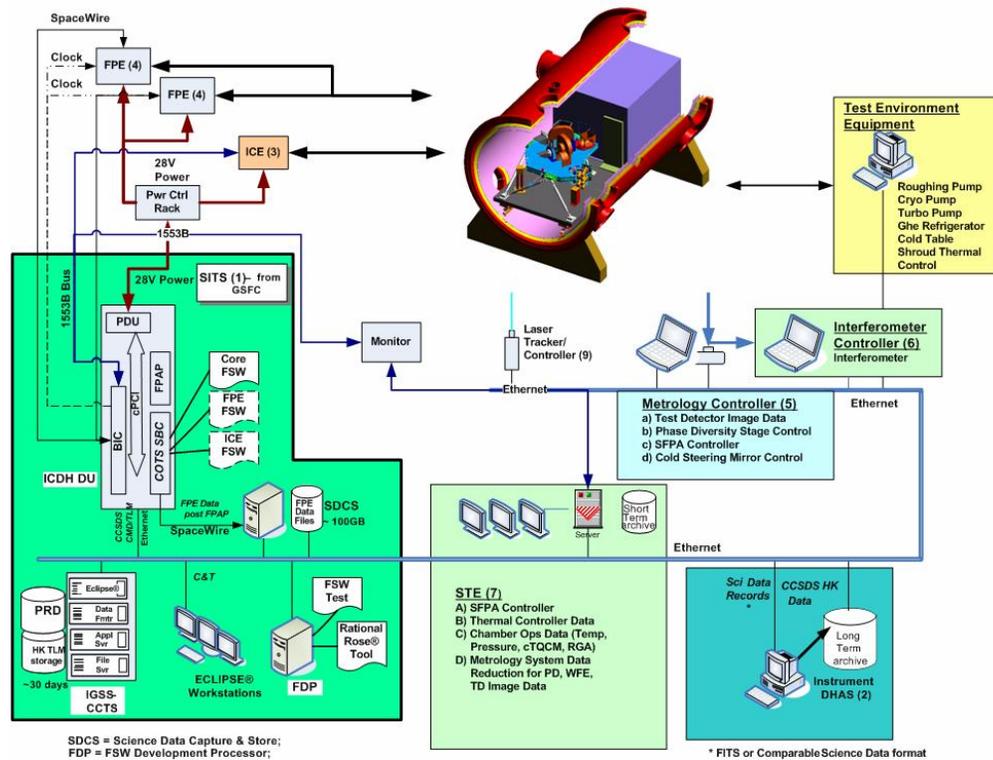


Figure 7.0 NIRCam Testing in Thermal Vacuum Chamber

4.5. Vibration Environmental testing

The NIRCam IOA will undergo flight prototype levels in the ambient environment. The testing will be performed with the IOA in the horizontal configuration on the GSFC Kinematic Mounts. Low signature sine sweep data will be collected at the beginning of the test to demonstrate that the control signals are operating correctly and reporting the expected data range and resolution. The 159 Kg NIRCam instrument will be tested using the profile illustrated in figure 8.0. All three axes will be tested to the required value and duration with a low level sine sweep performed at the conclusion of the test to verify there are no changes in the hardware due to the test environment.

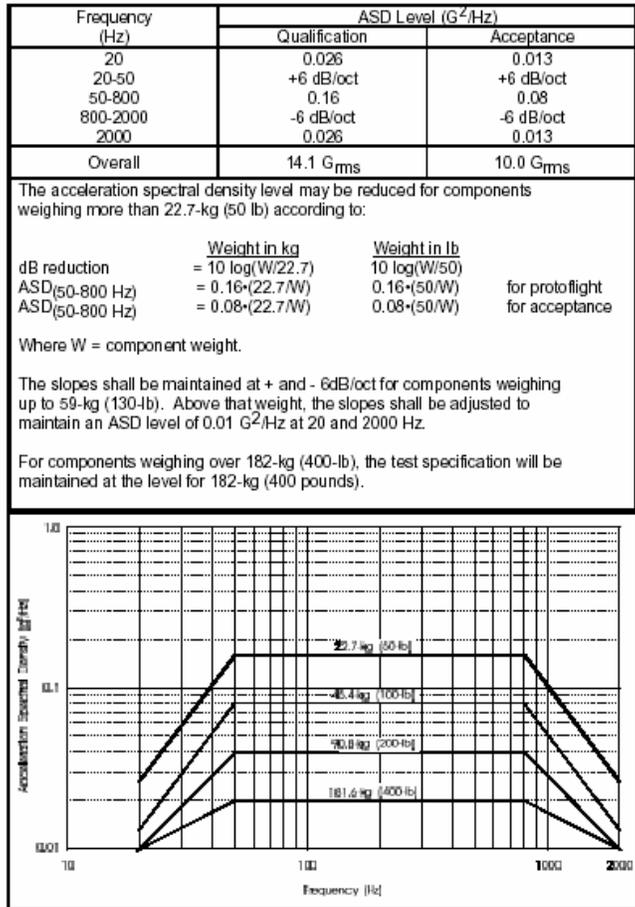


Figure 8.0 NIRCam Proto Flight Random Vibration test profile

4.6. Electromagnetic Testing

NIRCam will undergo electromagnetic susceptibility and compatibility in a RFI screen room at an ambient environment. The IOA will be installed in this room along with the ICE and FPE with interconnections performed using flight like cables. The ICE will be connected through bulkhead flanges to the SITS for data collection and instrument configuration commands. Testing will monitor the data return on the FPA reference pixels, and telemetry data as reported from ICE to the SITS. A sample of the test parameters is noted in Figure 9. The IOA support fixture will provide electrical isolation of the IOA from the conductive frame while rotated through 90 degree to provide direct access to the edges and the normal direction of the IOA. At the conclusion of EMI/EMC testing, NIRCam and all its support equipment will be returned to the Thermal Vacuum test facility for CPT2.

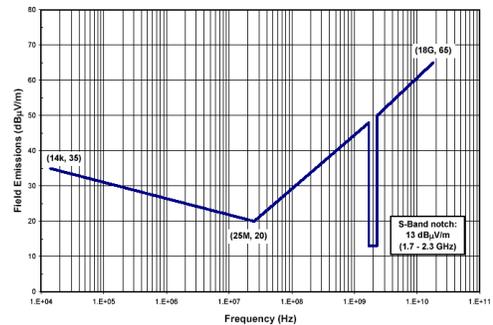


Figure 9 NIRCam EMI/EMC Test

4.7 Comprehensive Performance Test 2

NIRCam will be integrated into the same thermal vacuum test chamber used for CPT1 in preparation for CPT2. CPT2 will be preceded with a thermal cycle test to ± 3 degrees of the operating temperature between 32K and 37K.

Performance data will be collected at these temperatures. The test series will be performed as follows:

- Validation of Flight Software initialization on the ICDH simulator
- Ambient environment readout of the reference pixels on each of the 10 detectors to establish communication links
- System initialization to include health and safety checks, telemetry validation, ICE and FPE ‘built in test’, and the configuration of all commanded subsystems
- Positional and telemetry data acquisition and validation
- Thermal control during cool down
- IOA initialization with focus on current demand, parasitic heat loads, and telemetry data
- FSW command and IOA functional audits
- FPE thermal control and stability
- Simultaneous image data collected from all ten detectors for health and status operations
- Performance measures for IOA dark current and flat fielding using on-board calibration sources
- Quantify the test environment background flux levels
- Performance measurements for focus, alignment, FOV, and short and long wavelength channel magnification factors using sources projected to the focal surface using the star mask and registration tool (SMART)
- Instrument thermal cycling with abbreviated performance testing at 40K, 37K, 35K, 32K, 29K
 - Functional Audits of the focus & alignment mechanism for range of motion, resolution, repeatability, tilt, and thermal performance when compared to math models
 - FPE image data for full frame, subarrays, and changes in programmable integration time
 - Filter wheel operations to include pupil wheel insertion and repeatability, positional stability, alignment of WFS elements, insertion time, and thermal performance
 - On Board characterization using flat fields and point sources image data

5. NOTES TESTING

NOTES is a GSFC-provided simulator to verify the focus, WFE, and throughput of NIRCam. This equipment will be integrated into the LMATC thermal vacuum chamber for operation at <100K. This instrument design includes an elliptical mirror to obtain the proper $f/20$ outgoing optical beam and it also includes the associated steering mirrors. The 3018mm effective focal length is packaged into a working volume of approximately 1.2m x 1.2m x 1m. NOTES includes an in-situ calibration source and an adjustable diffraction-limited point source at the back focal point of the elliptical mirror.

The final steering mirror enables an external view of the instrument boresight through a chamber optical port. NOTES will include an operations console and dedicated electrical equipment required for operations and testing.

6. WAVEFRONT SENSING AND CONTROL TESTING

As mentioned earlier NIRCam is a metrology instrument during the commissioning phase of JWST to aid in the alignment of the segmented 6.3 meter primary mirror. During this phase NIRCam image data and weak lenses will enable PD to be performed in-flight. The test configuration will use NOTES as the stimulus to evaluate the JWST developed WFS&C

algorithms. NOTES will insert phase shifts into its optical path to alter the optical beam quality to demonstrate detection using the NIRCam images. This testing is being performed at the LM ATC facility as the first opportunity to validate PD and WFS&C to further reduce risk for the JWST program.

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