Report 10356
Final
September 1994

Earth Observing System (EOS)/ Advanced Microwave Sounding Unit-A (AMSU-A) Calibration Management Plan

Contract No: NAS 5-32314
CDRL: 018

Submitted to:

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Goddard Space Flight Center
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SCOPE

This is the Calibration Management Plan for the Earth Observing System/ Advanced Microwave Sounding Unit-A (EOS/AMSU-A). It is provided in accordance with the EOS Instrument Calibration Management Plan, GSFC 420-03-01, paragraphs 3.1 and 3.2. The Calibration Management Plan establishes a definition of calibration requirements, calibration equipment, and calibration methods.

This Calibration Management Plan is submitted in response to Contract NAS 5-32314, CDRL No. 018. This is the final issue of this plan.

Section 2

APPLICABLE DOCUMENTS

2.1 **Government Documents**.- The following documents are referenced in or are applicable to this report. Unless otherwise specified, the latest issue is in effect.

GSFC 422-12-12-01 March 1993	Performance and Operation Specification for the Advanced Microwave Sounding Unit-A (AMSU-A) - EOS PM Project
GSFC 420-03-01 January 1990	Earth Observing System Calibration Management Plan

Section 3

INTRODUCTION

3.1 AMSU-A System Overview

The Advanced Microwave Sounding Unit-A (AMSU-A) is a 15-channel passive microwave radiometer that will be used for measuring global atmospheric temperature profiles from the EOS polar orbiting observatory. The EOS observatory will have an orbital altitude of 705 Kilometers (km) and an inclination of 98.2 degrees. The AMSU-A system will also provide data to verify and augment that of the Atmospheric Infrared Sounder (AIRS).

The AMSU-A instrument was originally built by Aerojet for NASA for use by the National Oceanographic and Atmospheric Administration (NOAA) on Meteorological Satellite (Metsat) flights. The EOS/AMSU-A is scientifically identical and almost physically identical to the NOAA/AMSU-A instrument.

The AMSU-A system passively monitors radiation from the Earth's surface and atmosphere in the microwave portion of the spectrum. It consists of cross-track, line scanned instruments designed to measure scene radiances in fifteen discrete frequency channels. At each frequency, the half-power antenna beamwidth is a constant 3.33°. Thirty contiguous scene resolution cells spaced 3.33° along the scan line are sampled in a stepped-scan fashion every eight seconds as shown in Figure 1. A scan covers 50° on each side of the subsatellite path.

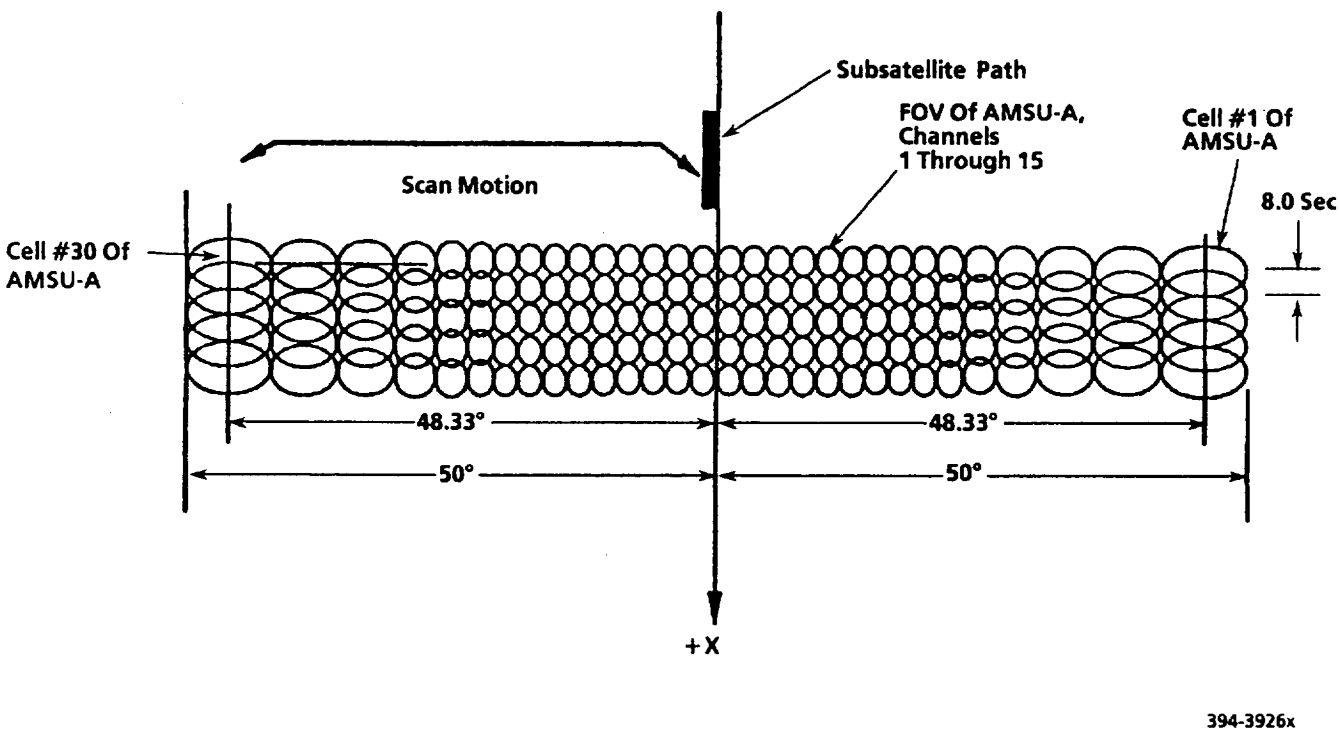

Figure 1 Scan Patterns of AMSU-A and Resolution Cell

AMSU-A sensors incorporate 15 total-power superheterodyne type radiometers. The AMSU-A system is composed of two modules, as illustrated in the photographs of Figures 2 and 3. The two lowest-frequency channels (Ch 1 at 23.8 GHz and Ch 2 at 31.4 GHz) are contained in one module designated AMSU-A2. The thirteen remaining channels (Ch 3 through 15, from 50.3 GHz to 89 GHz) are contained in a second module designated AMSU-A1. Block diagrams of the modules are provided in Figures 4 and 5. Periodic, on-board calibration is accomplished by using an inflight blackbody calibration target and cold space as energy reference sources. During each scan, the shrouded reflector observes 30 Earth scene cells with one sample period each, and two calibration target cells with two sample periods each. Complete end-to-end inflight calibration from the antenna to the AMSU-A output is provided for each channel, yielding maximum inflight calibration accuracy.

3.2 Requirements Overview

Details of AMSU-A calibration requirements have been extracted from the AMSU-A Performance and Operation Specification, GSFC 422-12-12-01, and are presented in the AMSU-A Calibration Verification Matrix of Section 5, Table V, along with verification methods and applicable test procedures and analysis reports. Tables I and II identify key radiometric and calibration requirements. A summary of AMSU-A calibration test parameters is provided in Tables III and IV.

Generally, AMSU-A calibration will provide, 1) demonstration of system and subsystem performance, 2) provision of data from which the instrument spectral radiance to digital output transfer function can be determined, and 3) provision of data from which the foresight (relative to the spacecraft reference frame) and antenna patterns can be determined.

The results of component tests, subsystem tests, and calibrations will be summarized in calibration log books. The following information will be derived from the calibration data: 1) temperature sensitivity (NEΔT) of each channel, 2) standard deviation of individual calibration points from the best-fit calibration curves for each channel and each calibration, 3) calibration of in-flight blackbodies (targets) in terms of effective brightness temperature versus temperature monitor bit outputs, 4) calibration curves of all thermistors, 5) calibration curves of all platinum temperature sensors, 6) temperature stability data for the instrument, and, 7) beam profile in the far field for each channel.

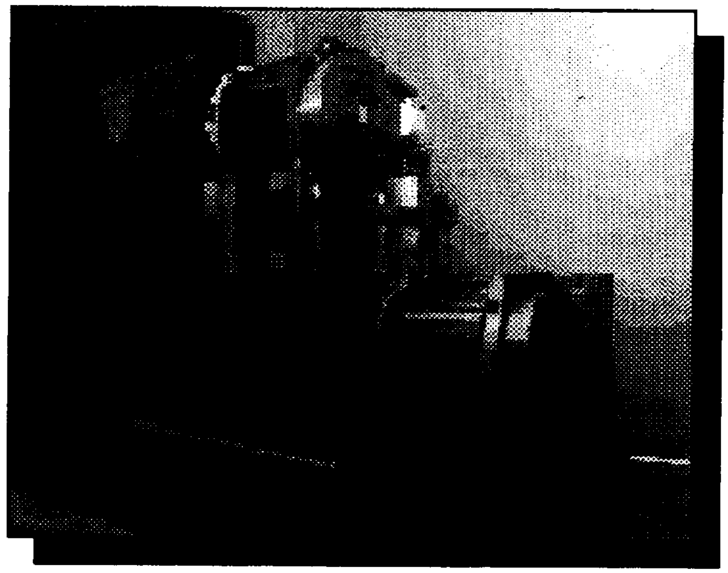

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Figure 2 AMSU-A1 Module

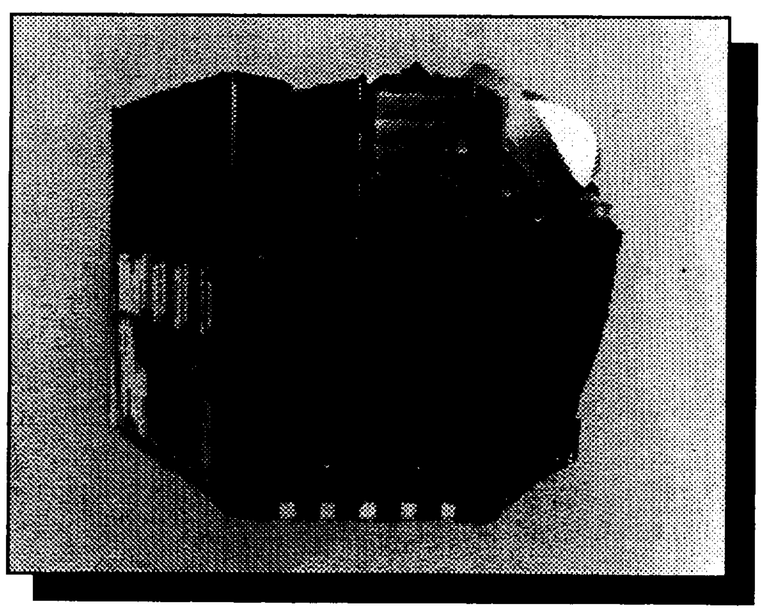

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Figure 3 AMSU-A1 Module

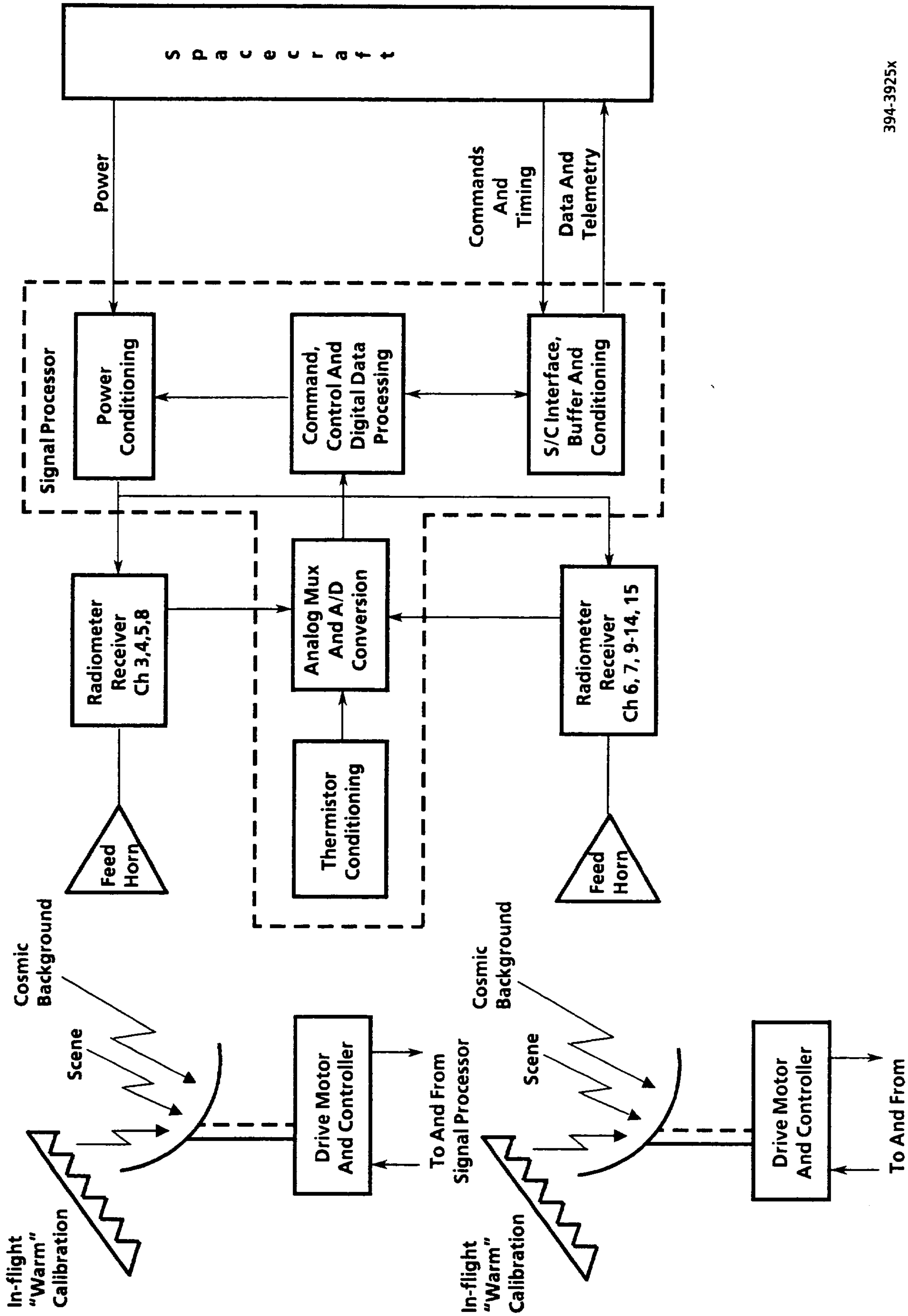

Figure 4 AMSU-A1 Block Diagram

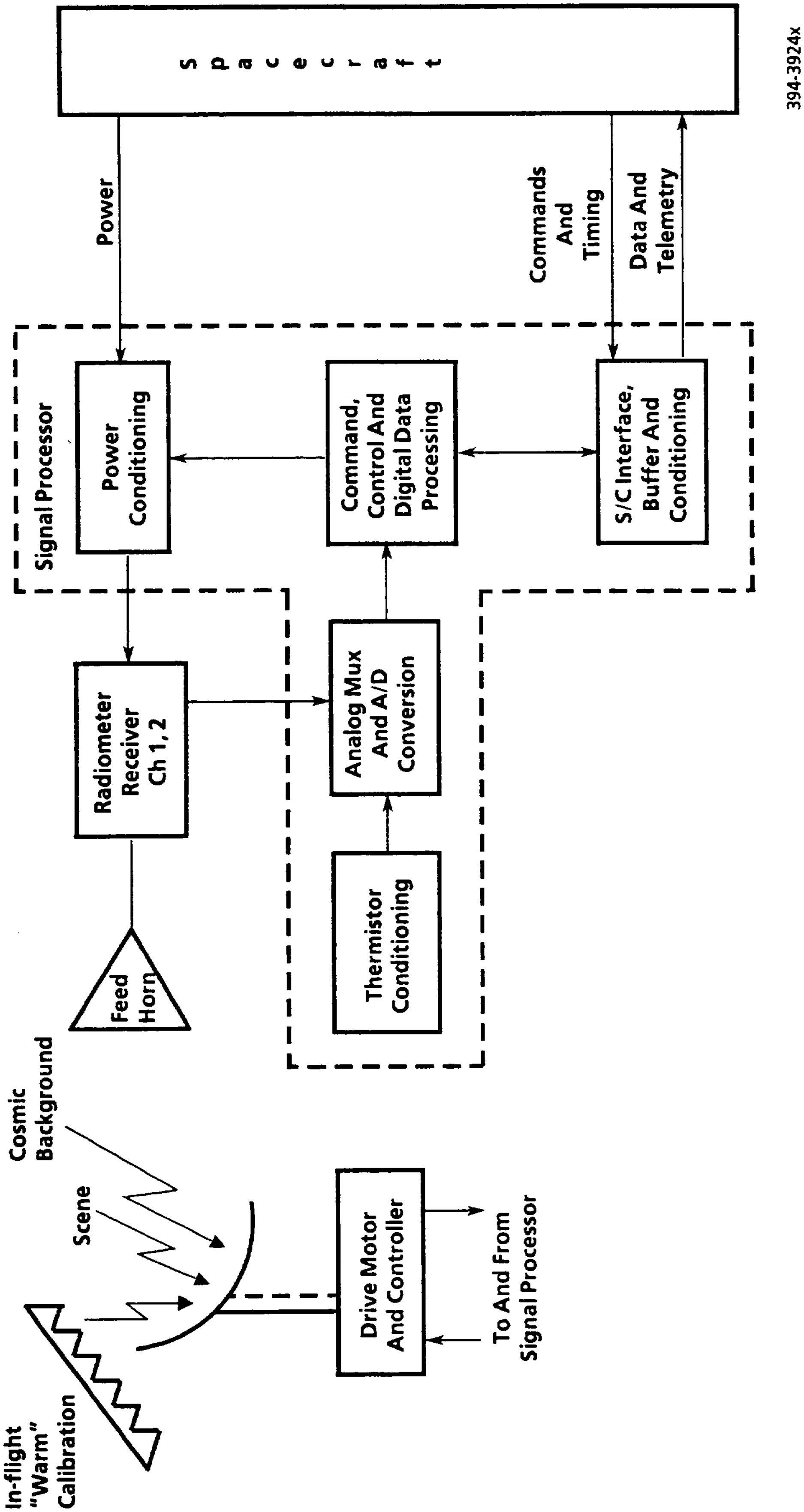

Figure 5 AMSU-A2 Block Diagram

Table I AMSU-A Key Radiometric and Calibration Requiremnts

Chan No.	Center Frequency (MHz)	No. of Pass-band	Max Band-width (MHz)	Center Freq. Stab. (± MHz)	NEΔT (K)	Calib Acc (K)	Beam Diam (deg)	Polari-zation Angle (deg)	Polari-zation Ref
1	23800	1	270	10	0.30	2.0	3.33	90-Θ**	V
2	31400	1	180	10	0.30	2.0	3.33	90-Θ	V
3	50300	1	180	10	0.40	1.5	3.33	90-Θ	V
4	52800	1	400	5	0.25	1.5	3.33	90-Θ	V
5	53596±115	2	170	5	0.25	1.5	3.33	*	H
6	54400	1	400	5	0.25	1.5	3.33	*	H
7	54940	1	400	5	0.25	1.5	3.33	*	V
8	55500	1	330	10	0.25	1.5	3.33	*	H
9	57290.344 = f_{LO}	1	330	0.5	0.25	1.5	3.33	*	H
10	f_{LO}±217	2	78	0.5	0.40	1.5	3.33	*	H
11	f_{LO}±322.4±48	4	36	1.2	0.40	1.5	3.33	*	H
12	f_{LO}±322.4±22	4	16	1.2	0.60	1.5	3.33	*	H
13	f_{LO}±322.4±10	4	8	0.5	0.80	1.5	3.33	*	H
14	f_{LO}±322.4±4.5	4	3	0.5	1.20	1.5	3.33	*	H
15	89000	1	3000	50	0.50	2.0	3.33	90-Θ	V

* Unspecified, single polarization **Θ = Scan angle

Table II AMSU-A Radiometric and Calibration Requirements

- Through-the-Antenna Calibration
- Minimum of two measurements per scan "Warm" and "Cold" calibration
- "Warm" Calibration Target
  - Minimum of 5 each platinum wire thermistors for A1 and 7 for A2 with accuracy better than ±0.05 K
  - Knowledge of brightness temperature ≤ ±0.2 K
- "Cold" target is cosmic background
- Calibration repeatability ≤0.3 K for all channels
- Total power radiometer system
- Dynamic range: 3 to 330 K
- Residual Nonlinearity ≤0.5 K channels 1, 2, 15
  ≤0.375 K channels 3-14
- Variation of nonlinearity over operating temperature range ≤ NEΔT
- Beam efficiency: ≥95%
- Beam pointing accuracy with respect to mean of window channel
  - | Intended-Actual | ≤0.2°
  - Knowledge better than ±0.1°
  - Maximum change W.R.T. alignment cube ±0.05°

Table III Calibration Test Parameters – Instrument/Interface Temperature Combinations

Combination	Instrument Internal Temperature	Interface Temperature
1	Projected High	Projected Nominal
2	Projected Midpoint Between High and Nominal	Projected Nominal
3	Projected Nominal	Projected High
4	Projected Nominal	Projected Nominal
5	Projected Nominal	Projected Low
6	Projected Midpoint Between Nominal and Low	Projected Nominal
7	Projected Low	Projected Nominal

Table IV Calibration Test Parameters Test Matrix

Target Temp.	Protoflight Model							Flight Model							Special Tests
	Temp. Combination*							Temp. Combination*							
Cycle #1	1	2	3	4	5	6	7	1	2	3	4	5	6	7	
84	X	X		X		X	X	X			X			X	Primary oscillator
105	X	X		X		X	X								
130	X	X		X		X	X	X			X			X	
155	X	X		X		X	X								
180	X	X		X		X	X	X			X			X	
205	X	X		X		X	X								
230	X	X		X		X	X	X			X			X	
255	X	X		X		X	X								
280	X	X		X		X	X	X			X			X	
305	X	X		X		X	X								
330	X	X		X		X	X	X			X			X	
84	X	X		X		X	X	X			X			X	Ant. on orbit scan target
Vary				X											Hysteresis
330				X											Short term gain
305			X	X	X										Thermal decoupling
Cycle #2															
84	X	X		X		X	X	X			X			X	Secondary oscillator
130	X	X		X		X	X	X			X			X	
180	X	X		X		X	X	X			X			X	
230	X	X		X		X	X	X			X			X	
280	X	X		X		X	X	X			X			X	
330	X	X		X		X	X	X			X			X	
Cycle #3															
84	X	X		X		X	X	X			X			X	Primary oscillator
130	X	X		X		X	X	X			X			X	
180	X	X		X		X	X	X			X			X	
230	X	X		X		X	X	X			X			X	
280	X	X		X		X	X	X			X			X	
330	X	X		X		X	X	X			X			X	

* As specified in Table III.

Section 4
AMSU-A SYSTEM CALIBRATION PLAN

The retrieval of accurate atmospheric temperature profile information from multifrequency radiometric measurements depends on accurate and stable in-orbit calibration of the sensing radiometers. The AMSU-A performance specification requires the long-term calibration accuracy (time scale longer than 24 hours) to be better than 1.5 K for channels 3 through 14 and 2.0 K for Channels 1, 2, and 15. Short-term stability of the system is defined in terms of repeatability of 16-second continuous calibration averages. Calibration repeatability errors of less than 0.3 K are specified for all channels. In addition, the specification of the effective temperature sensitivity of calibration data points (standard deviation of the measured mean from the true mean) is to be less than 0.03 K.

A comprehensive plan of measurement and analysis, compliant with all AMSU-A calibration requirements, with emphasis on the requirements above, is described herein.

4.1 System Calibration Flow

The interaction of various measurements, analyses, and the instrument performance in producing a final calibration algorithm is indicated in the flow diagram of Figure 6. The calibration process begins at component and subsystem levels. It then progresses through the system integration level. At the system level comprehensive thermal vacuum calibration measurements will be conducted to characterize the system radiometer transfer function, calibrate the inflight warm calibration target, and determine the in-orbit calibration algorithm. In addition, thermal vacuum measurements will be conducted to demonstrate compliance with key radiometric system performance requirements. Each of the Aerojet activities identified in the AMSU-A system calibration flow diagram of Figure 6 is described in the following subsections. Subsystem test details and formal subsystem test procedures will be contained in the EOS/AMSU-A Verification Procedures.

4.1.1 Channel Frequency and Bandwidth

Channel frequency and bandwidth are measured at both the receiver component and the receiver subsystem levels. Center frequency for each channel is measured at nominal, high, and low operating temperatures. The bandwidth/bandpass data are characterized for each channel. At each frequency band the bandpass characteristic is measured at the component (IF Filter) level in both a swept response test and at twenty discrete and uniformly spaced frequencies. Ten of these points are within the passband and the remaining ten points outside the passband (5 above and 5 below) as specified in the Performance and Operations Specification, paragraph 7.2.3. These data will be utilized by NASA in computations of atmospheric temperature profiles.

4.1.2 Antenna Patterns

Antenna patterns satisfy two major calibration requirements: a) accurate in-flight cosmic background calibration reference and b) antenna pattern correction for energy received from sidelobes during scene sector sampling. The antenna (radiation) pattern characteristics are measured as specified in the

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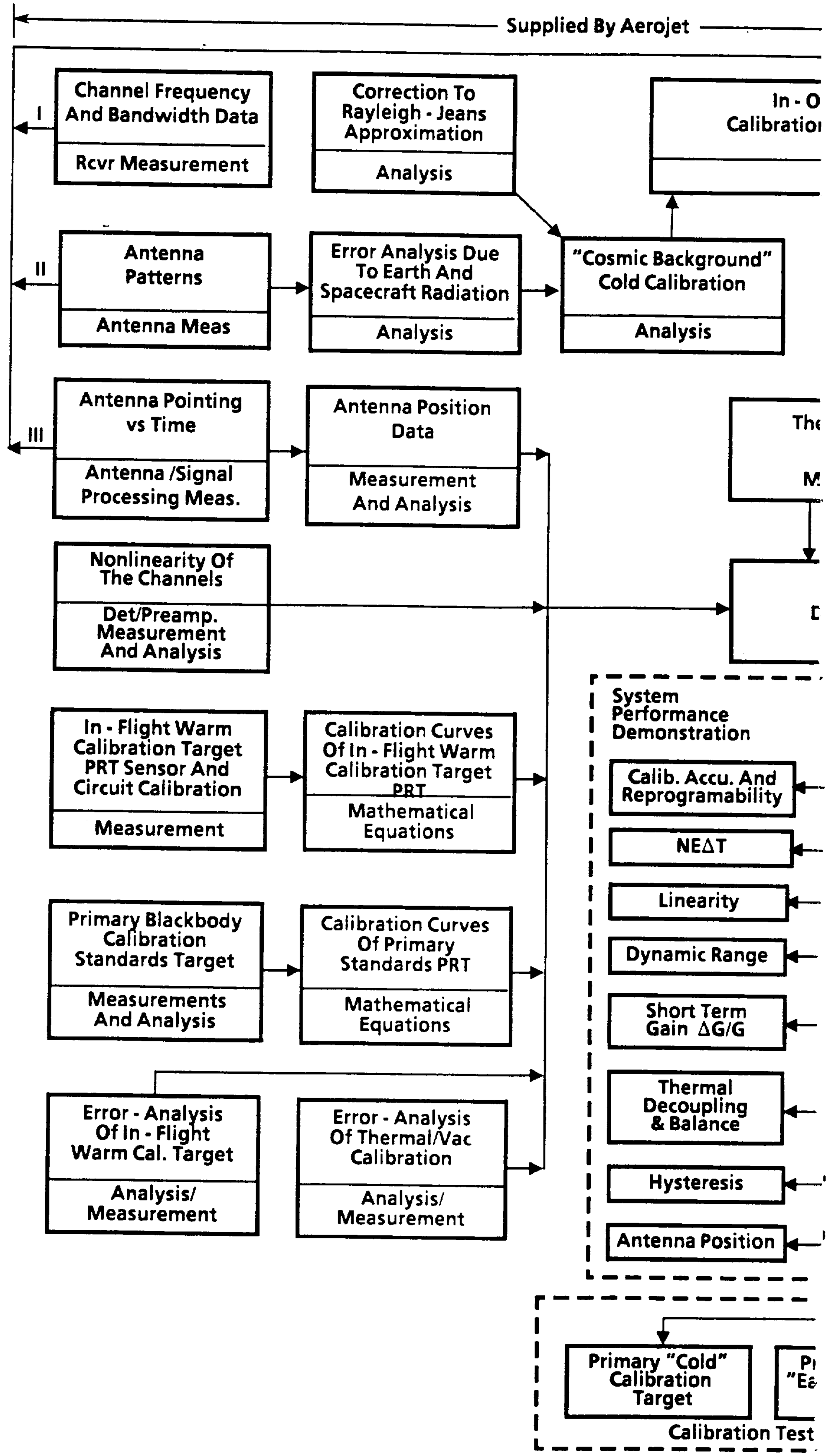

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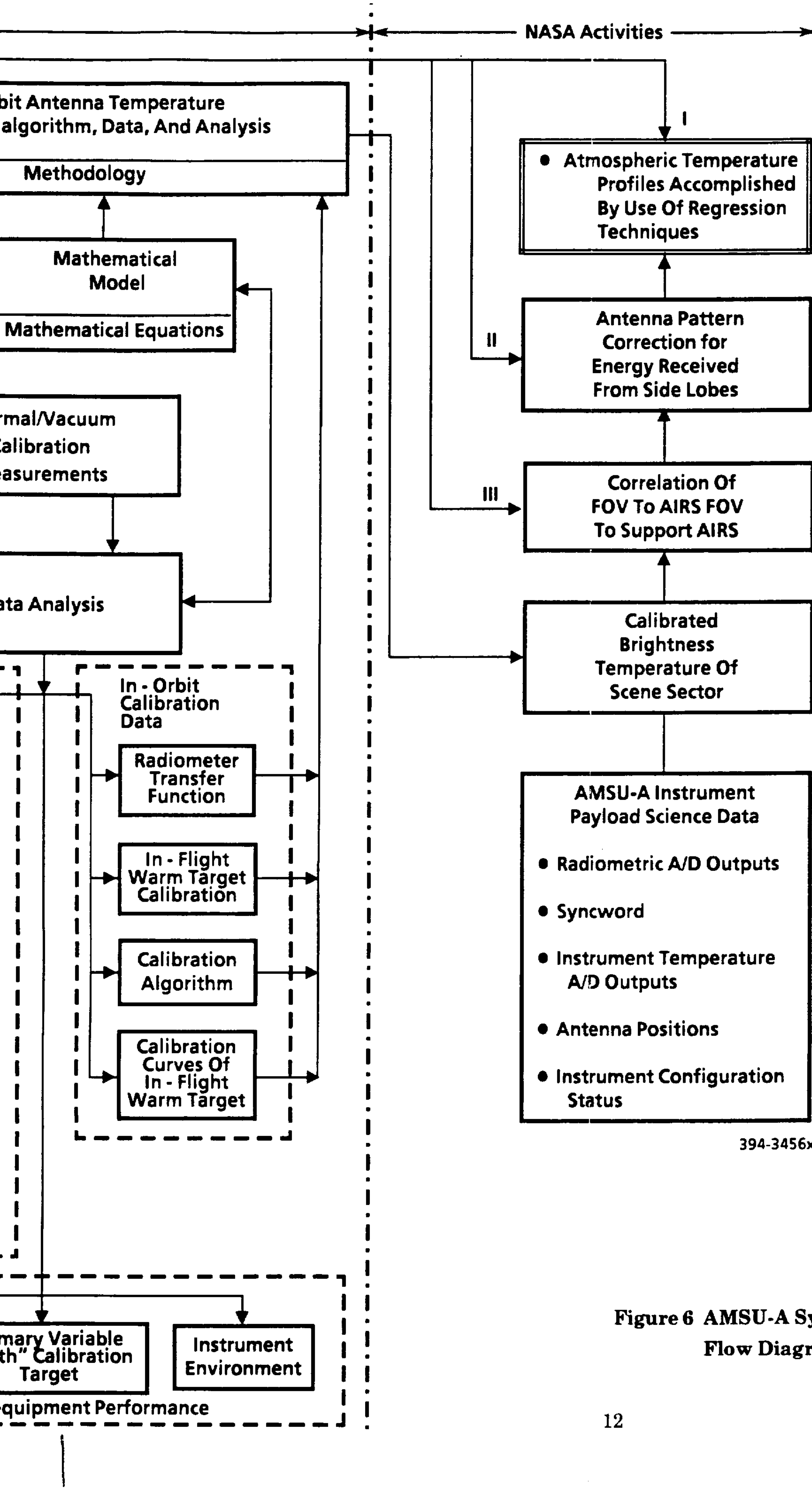


Figure 6 AMSU-A System Calibration Flow Diagram

Performance and Operations Specification, paragraph 7.2.6. Antenna pattern measurements are made at beam positions 1, 15, and 30. In addition to these three positions, antenna pattern measurements are planned for the primary cold calibration beam position (nominally at 6.67° declination to the orbit plane). Antenna patterns are measured at each center frequency of the passbands of Channels 1 through 8 and 15, and at 56968 MHz, 57290 MHz and 57613 MHz for channels 9 through 14. Patterns are measured in the principle plane of the antenna and at 45°, 90°, and 135° from the principal plane at 0° and 90° polarizations for all channels, in addition to 45° for channels 1 through 4 and 15. Each pattern will cover an angular range of 360° at maximum angular intervals of 0.22°. The minimum dynamic range of antenna pattern measurements will be 50 dB.

Antenna (radiation) pattern data will be utilized by NASA to make adjustments to brightness temperatures of each of the 30 scene cells of the scene sector in order to compensate for energy received from sidelobes. Aerojet will provide NASA the cosmic background calibration data. In the following section the process/plan is described in detail for cosmic background calibration.

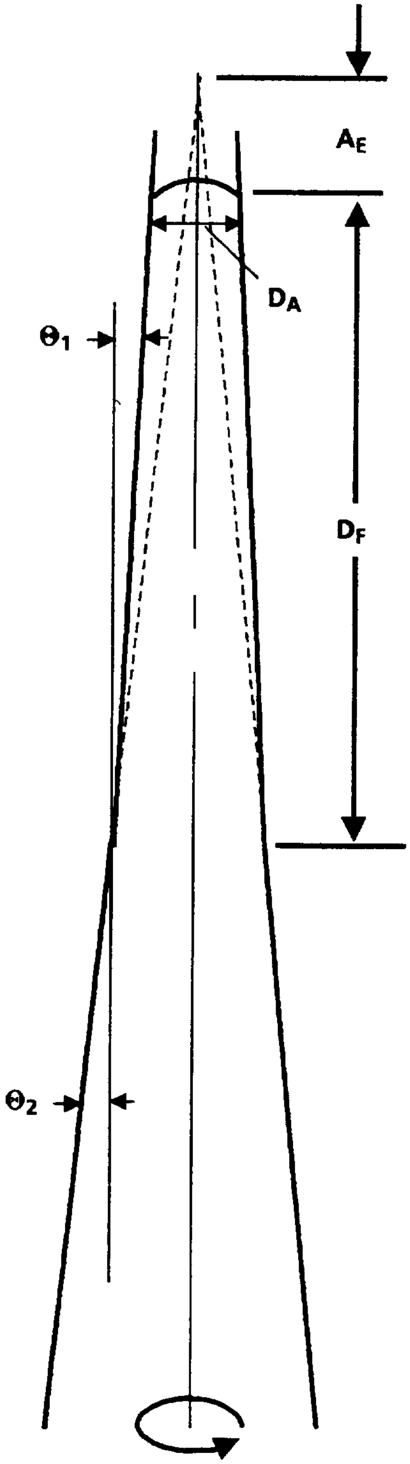
4.1.3 Cold "Cosmic Background" Calibration

Determination of the actual in-flight cold "cosmic background" calibration temperature requires consideration of two parameters: a) sidelobe contamination and b) absolute background temperature. The first parameter is obtained from antenna pattern measurements. It is the primary source of in-orbit cold calibration error arising from reception of extraneous radiation through antenna side lobes from the Earth and from the spacecraft. Both fixed bias and random errors are calculated from antenna pattern measurements. A first-order correction for bias calibration errors is made to the cosmic background antenna brightness temperature. The cold background temperature error resulting from the reception of extraneous radiation through the antenna sidelobes during the cosmic background calibration will be determined from an integration of the far-field antenna patterns over the angular region subtended by the Earth, to include the energy received from the Earth, and an integration of near-field energy density of the antenna over regions of the spacecraft structures to include the energy received from spacecraft reflections of Earth radiation. Antenna beam efficiency is specified as 95 percent minimum for all beam positions.

The second parameter to be considered is the actual cosmic background temperature and correction to the Rayleigh-Jeans approximation. The Rayleigh-Jeans correction, which is nearly quadratic at the AMSU-A frequencies, will be determined for each AMSU-A center frequency. An error analysis of cold "cosmic background" calibration will be performed to ensure satisfaction of the absolute in-flight calibration accuracy requirement.

4.1.4 Antenna Pointing and Position

Precise antenna pointing and positional information of each AMSU-A resolution cell is required for (a) geophysical location of AMSU-A pixels and (b) correlation of the AMSU-A field of view (FOV) to the Atmospheric Infrared Sounder (AIRS) field of view.



D_A – Antenna Aperture Diameter in Inches

A_E – Distance To Arc Of Rotation in Inches

D_F – Distance To Full Cone Angle FOV in Inches

Θ_1 – 1/2 • Full Half Cone Angle FOV

Θ_2 – Full Half-Cone Angle FOV

	AMSU	
	A1	A2
D_A	6	12
A_E	4	8

$$\Theta_2 = 2\,\Theta_1$$

$$\Theta_1 = 3.5°$$

$$D_F = \frac{D_A/2 - A_E \tan\Theta_2}{\tan\Theta_2 - \tan\Theta_1}$$

= 42 (For A1)

= 82 (For A2)

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Figure 7 AMSU-A2 Field-of-View Requirement For Both Dimensions (Crosstrack And Down-Track) For All Beam Positions (1 Through 30) And Cold Calibration

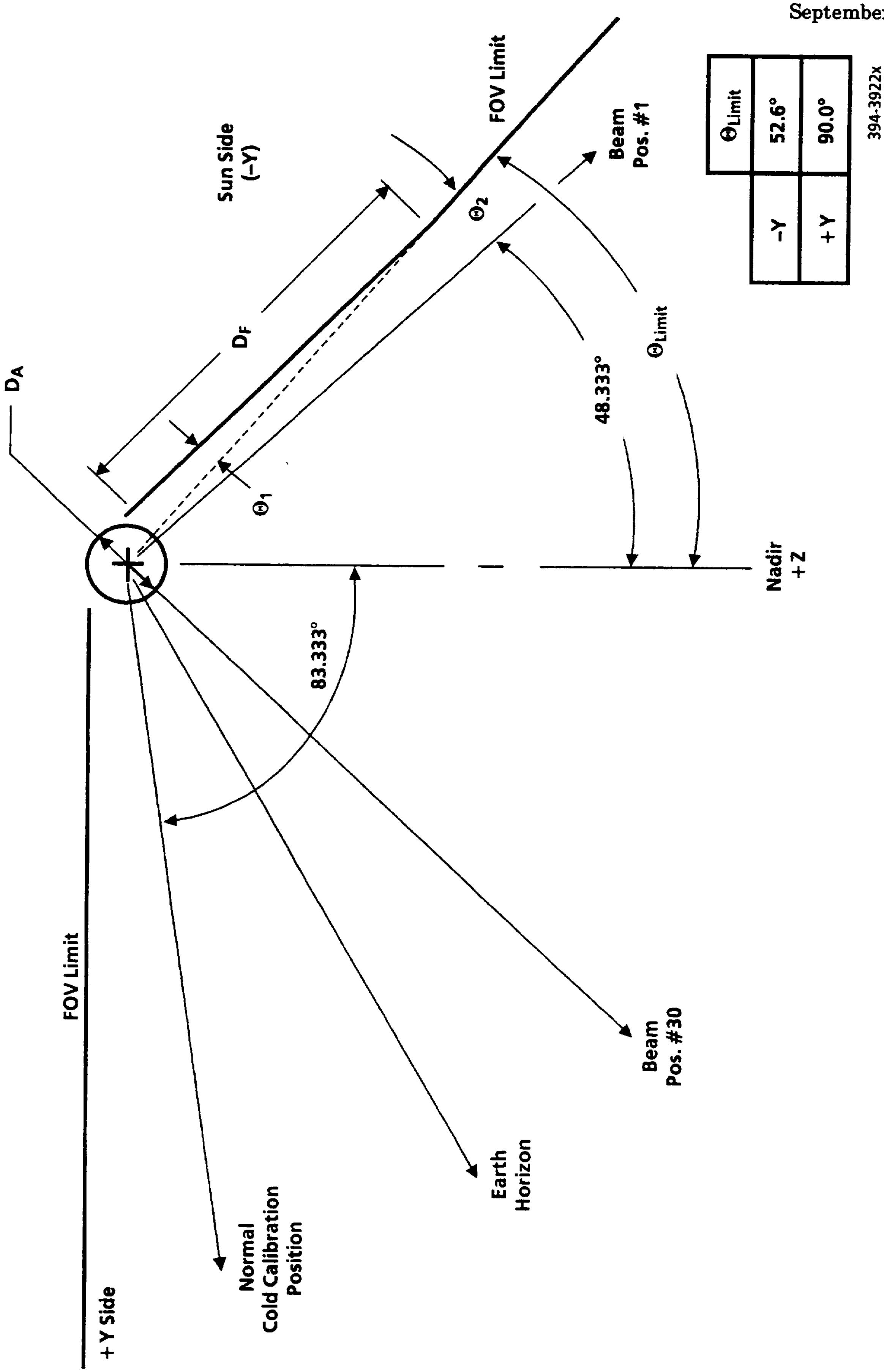


Figure 8 FOV Crosstrack Scan Profile

The AMSU-A antenna alignment and pointing accuracy is defined with respect to an alignment cube and is achieved at the system level. Antenna beam pointing accuracy is measured using the instrument alignment cube as a reference at the Aerojet antenna range. The beam positions and beamwidth (FOV) at each AMSU-A frequency is determined by RF pattern measurements conducted at the antenna range. For each of the 30 Earth viewing positions and the cold calibration position, RF pattern measurements of the antenna provide data from which actual beam electrical boresite directions are obtained. Also, the alignment cube is optically measured with respect to the spacecraft mounting surface such that AMSU-A instruments can be aligned accurately to the spacecraft coordinate system and, thereby, to the AIRS instrument.

The angle of each antenna beam position is encoded and multiplexed with the corresponding radiometric value. The antenna positional information is contained within AMSU-A instrument payload data for each 8-second scan. Measurements are performed at the antenna subsystem level, at the system integration level, and at the system level to obtain accurate temporal correlation between the EOS time code data (provided by the EOS PM spacecraft command and data handling system) and AMSU-A beam positions.

The encoded antenna position data will be trended and checked against the baseline data throughout integration and test of the system (including vibration, thermal cycling, and thermal-vacuum calibration over the operating temperature range). The antenna pointing versus time and antenna positional data will be provided to NASA to correlate the field-of-view data to the AIRS instrument and to geolocate AMSU-A pixels.

4.1.5 Nonlinearity of AMSU-A Channels

An ideal linear radiometer yields a straight line when radiometric temperature is plotted versus input brightness temperature. Nonlinearity of AMSU-A channels is largely determined by departure from perfect square-law operation of the diode detectors. Nonlinear effects of IF Amplifiers are secondary since they are typically operated -20 to -30 dB below output compression. AMSU-A uses germanium tunnel diodes operating in the current mode. This, combined with minimal operating power levels (near -27 dBm) yields a high degree of linearity. Linearity of each AMSU-A channel is measured at the detector/video amplifier subsystem level. Linearity of each AMSU-A channel is measured at both the subsystem level and the system level. The subsystem measurement is conducted on the detector/video preamplifier subassembly in a laboratory environment. The test measures the change in slope of the amplifier output voltage versus input power that occurs when the same attenuator change is used at several detector operating points. The change in slope is then used to determine the departure of the unit under test from linear operation. The accuracy of the measurement is determined by the repeatability of the attenuator and has been shown to have negligible effect on the measurement of the transfer function slope for electrically activated attenuators. Measurements are conducted at the nominal detector input power level, and at power levels 3 dB above and 3 dB below nominal. At each level, the nonlinearity measurements span a range of detector input power that simulates the projected operational detector power resulting from a) the full dynamic range of radiometer input brightness temperatures; 3 K to 330 K, b) gain variations arising from projected receiver shelf temperature variations, and c) aging. These subsystem measurements bound the maximum expected nonlinearity as a function of input brightness temperature. They are coarse three-point measurements, however, and do not characterize the instrument transfer function from 3 K to 330 K with useful resolution.

System nonlinearity measurements are conducted in the thermal-vacuum chamber. Here, the antenna brightness temperature as determined by the AMSU-A instrument is compared to the physical temperature of the primary standard (blackbody) the instrument is observing. These measurements yield a high degree of resolution of system nonlinearity (resolution greater than 0.1 K) for input brightness temperature between 84 K and 330 K. They do not, however, characterize the instrument transfer function below 84 K, because of thermal limitations of the calibration loads. System nonlinearity measurements are conducted at the projected nominal operational instrument temperature, 10°C above the projected maximum operational temperature and 10°C below the projected minimum operational temperature.

4.1.6 Inflight Warm Calibration Target

Knowledge of the radiometric temperature of inflight warm calibration targets is dependent on (1) emissivity, (2) physical temperature, (3) external effects, and (4) reflectivity. Emissivity of inflight warm calibration targets will be measured at AMSU-A frequencies using a reflectometer test setup at the antenna subsystem level, as indicated in Figure 28. The physical temperature of inflight warm calibration targets is determined by means of platinum resistance transducers (PRT) located in the base of the target. The PRT are calibrated to an accuracy of ±0.01°C and traceable to NIST (National Institute of Standards and Technology). The resistance of each PRT is conditioned and digitized by means of an A/D converter within the AMSU-A instrument. During AMSU-A integration and test, each PRT conditioning circuit is calibrated by replacing the PRT with various discrete resistances from a very precise variable-resistance decade box. From these measurements and the initial PRT calibration measurement, polynomial coefficients are developed for AMSU-A ground and inflight calibration. External effects are analyzed to determine the uncertainties in the knowledge of radiometric temperature of inflight warm calibration targets. Reflection of local oscillator (LO) leakage is measured by performing a tunable short test (as required by the Performance and Operations Specification, paragraph 7.2.7) to assure performance of the absolute calibration requirement. From tunable short test data, the error in calibration accuracy due to the LO leakage will be determined for each AMSU-A channel. Additionally, thermal analysis will be performed to assure that the thermal design of the inflight warm calibration target in a space environment will provide high temperature stability and negligible target gradients.

4.1.7 Primary Standard Calibration Target

The primary calibration targets are near blackbody sources providing known and highly accurate radiometric temperatures for the purpose of primary instrument calibration. Two targets are utilized for calibration of the AMSU-A system. One target operates at a fixed temperature of 84 K and the other varies from 84 K to 330 K. Knowledge of the brightness temperature of primary calibration targets is dependent on 1) surface emissivity, 2) temperature measurement accuracy, 3) target temperature gradients, 4) rate of change of target temperature, 5) reflection of AMSU-A local oscillators, and 6) RF coupling to AMSU-A reflectors.

The emissivity of primary calibration targets is measured at each AMSU-A center frequency using a reflectometer test setup. Target temperature measurements are provided with four-wire, 1000 ohm, PRT calibrated to an accuracy of 0.01 K, and traceable to the NIST. Individual calibration coefficients are used for the resistance-to-temperature conversion of each PRT in order to ensure a high degree of measurement accuracy. Attaining the required target temperature gradients and the required rate of change of target temperature is achieved by the appropriate target thermal mass and appropriate target cooling/heating techniques. The temperature gradient across the base of the target and the rate of change of the target temperature will each be measured at every calibration step of the thermal vacuum calibration test. Vertical target gradients will be analyzed to assure that overall target performance requirements are met. Reflectometer measurements of the target, in conjunction with sliding-short measurements of AMSU-A channels, will provide the data necessary to calculate the effect of the local oscillator leakage component on absolute calibration accuracy. External coupling of energy through the gap between the AMSU-A reflector and the calibration target is minimized by means of the interface shape and the small gap dimension. The AMSU-A reflector and calibration target are adjusted to minimize the interface gap prior to calibration.

4.1.8 Error Analysis of Inflight Warm Calibration Target

A comprehensive error analysis of the inflight warm calibration target will be performed to demonstrate satisfaction of target calibration requirements. The analysis will include components of emissivity, rate of target temperature change, temperature gradients, temperature measurement accuracy, reflection of spurious signals, and RF coupling to the AMSU reflector.

4.1.9 Error Analysis of Thermal/Vacuum Calibration

Error analysis of the AMSU-A radiometer will be performed to demonstrate satisfaction of calibration requirements at the instrument level. The contributors to radiometer calibration error at the thermal/vacuum level are presented in Figure 9.

4.1.10 Mathematical Model

An AMSU-A Radiometric Math Model, Report No. 10371, has been developed, updated, and will be refined and utilized during the AMSU-A calibration phase. The model will be related to actual test and calibration data. It contains both sensitivity and in-orbit calibration models. Within the models, each component and parameter affecting radiometric performance is defined, quantified, and structured in sensitivity and calibration accuracy budgets demonstrating instruments performance under worst-case conditions (all components at specification limits, in worst-case directions). In-orbit calibration algorithms are presented to partially correct major bias errors of warm and cold calibration reference temperatures, significant channel nonlinearities, and dynamic transfer function errors on a multi-scan basis. Comparisons of measured NOAA/AMSU-A performance and predicted worst-case EOS/AMSU-A performance are presented.

4.1.11 Thermal/Vacuum Measurements and Data Analysis

Description

The thermal vacuum calibration measurements are conducted to characterize the system radiometer transfer function, calibrate the in-orbit warm calibration target, and determine the in-orbit calibration algorithm. In addition, the measurements demonstrate compliance with the required system performance and provide information necessary to determine the stability and accuracy of calibration test equipments.

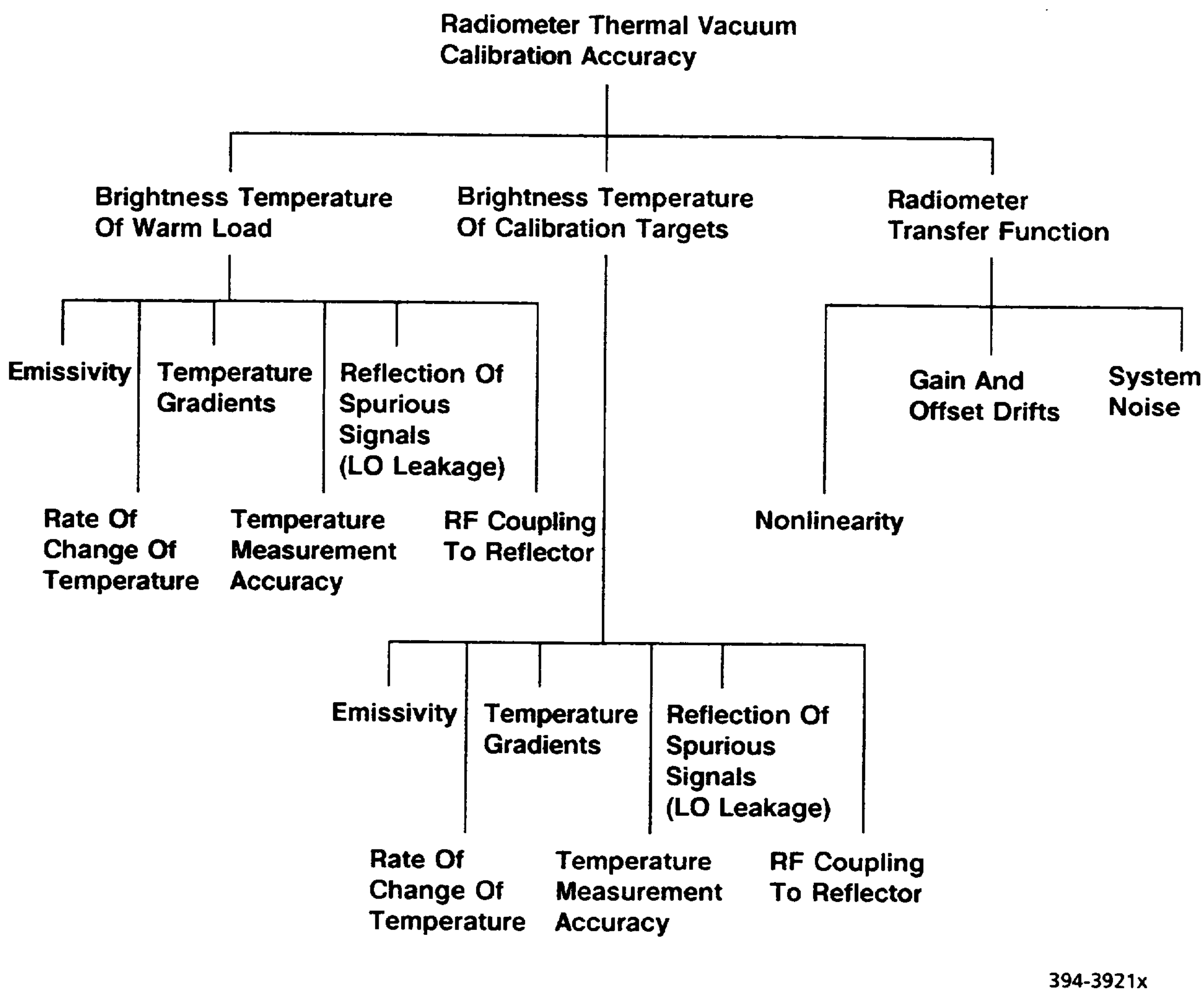


Figure 9 Contributions to Radiometer Calibration Accuracy

During these measurements, space environmental conditions will be realistically simulated maintaining the radiometer at selected temperatures, within limits of less than ± 1 K. In addition to the expected in-orbit nominal instrument temperature, the maximum (predicted in-orbit high temperature plus 10°C) and minimum (predicted in-orbit low temperature minus 10°C) temperatures, as well as intermediate values of operating temperature, will be employed.

At each of the required values of radiometer operating temperature, the radiometer output is recorded in response to a sequence of precisely known values of antenna temperature. The antenna temperatures are supplied by the variable-temperature primary calibration target which is configured to simulate free-space conditions. The target is sequenced in 25 K increments from 84 to 330 K. All test temperatures will be maintained within 1.0 K of the value selected during the test. The target thermal control system will limit target temperature excursions to within 0.1 K during radiometer measurements.

The data acquisition time required at any given target temperature is dictated by the number of samples required to achieve the specified thermal noise NEΔT of less than 0.03 K (for all frequency channels).

Thermal vacuum measurements provide data to determine the following:

a. **In-Orbit Calibration Data**

- Calibration of the inflight 'warm' targets
- AMSU-A calibration algorithm

b. **System Performance Demonstration**

- Calibration accuracy and repeatability
- NEΔT
- Linearity
- Short-term gain fluctuation (ΔG/G) (PFM only)
- Calibration hysteresis (PFM only)
- Thermal decoupling and balance (PFM only)
- Instrument temperature stability

c. **Calibration Test Equipment Performance**

- Primary calibration target temperature stability and gradient

- Spacecraft interface (baseplate) stability
- Environmental conditions
  - Vacuum
  - Thermal
  - Contamination control and monitoring

Thermal Vacuum Measurement Plan

AMSU-A thermal vacuum calibration measurements will be performed using special test equipment (STE) and calibration test equipment (CTE). The thermal vacuum calibration instrumentation test setup is presented in Figure 10. The STE consists of a minicomputer, magnetic tape system, line printer, and video terminal expansion chassis. This equipment provides a simulated spacecraft interface and records, displays, monitors, and computes thermometric temperature data from highly accurate platinum sensors embedded at various locations within the AMSU-A modules and the primary blackbody calibration targets, and it utilizes these data, along with the AMSU-A radiometric data, to calibrate and evaluate the sensor performance. The STE software characteristics and functions are presented in Figure 11. The CTE consists of thermally controlled primary blackbody calibration targets, a controlled instrument mounting platform, and cooled radiating panels (adjunct radiators) for instrument temperature control. Contamination control and monitoring equipment consists of a cold plate, RGA, and contamination test plates. The thermal vacuum chamber and its support equipment will provide a vacuum test level of less than 10^{-5} torr. It will be continuously monitored. Failsafe devices and equipment will provide automatic/safe shut down to protect the AMSU-A instrument.

Thermal vacuum calibration cycles will be performed as indicated in Figures 12, 13, and 14 for AMSU-A1, and Figures 15, 16, and 17 for AMSU-A2. The test sequence (as shown in Figures 12 through 17) provides an optimum calibration test scenario in satisfaction of specified Performance and Operations Specification instrument calibration requirements. At each calibration step, data will be processed in the sequence indicated in Figure 18. From the processed data and from the thermal-vacuum chamber support equipment data, both the AMSU-A system performance and the calibration test equipment performance will be demonstrated. In addition, in-orbit calibration will be determined. Also, first-order corrections to the in-orbit warm calibration reference and system nonlinearity, as they pertain to the radiometric math model, will be determined, refined, and updated utilizing the thermal vacuum measurements and data analysis process.

4.1.12 In-orbit Antenna Temperature Calibration Algorithm, Data and Analysis

Once thermal-vacuum measurements and thermal-vacuum data analysis is complete, a methodology describing the calibration process flow to compute in-orbit antenna temperature for the AMSU-A instrument will be generated. The process flow will provide all necessary data, analysis, algorithms, mathematical equations and calibration coefficients to produce calibrated brightness temperatures of the scene sector from AMSU-A instrument payload science data. As shown in Figure 6, this information is the input required to derive: (1) antenna pattern correction algorithm coefficients for each resolution cell in the scene sector, (2) correlation techniques to the AIRS field of view, and (3) atmospheric temperature profile algorithms or regression techniques, items generated by NASA.

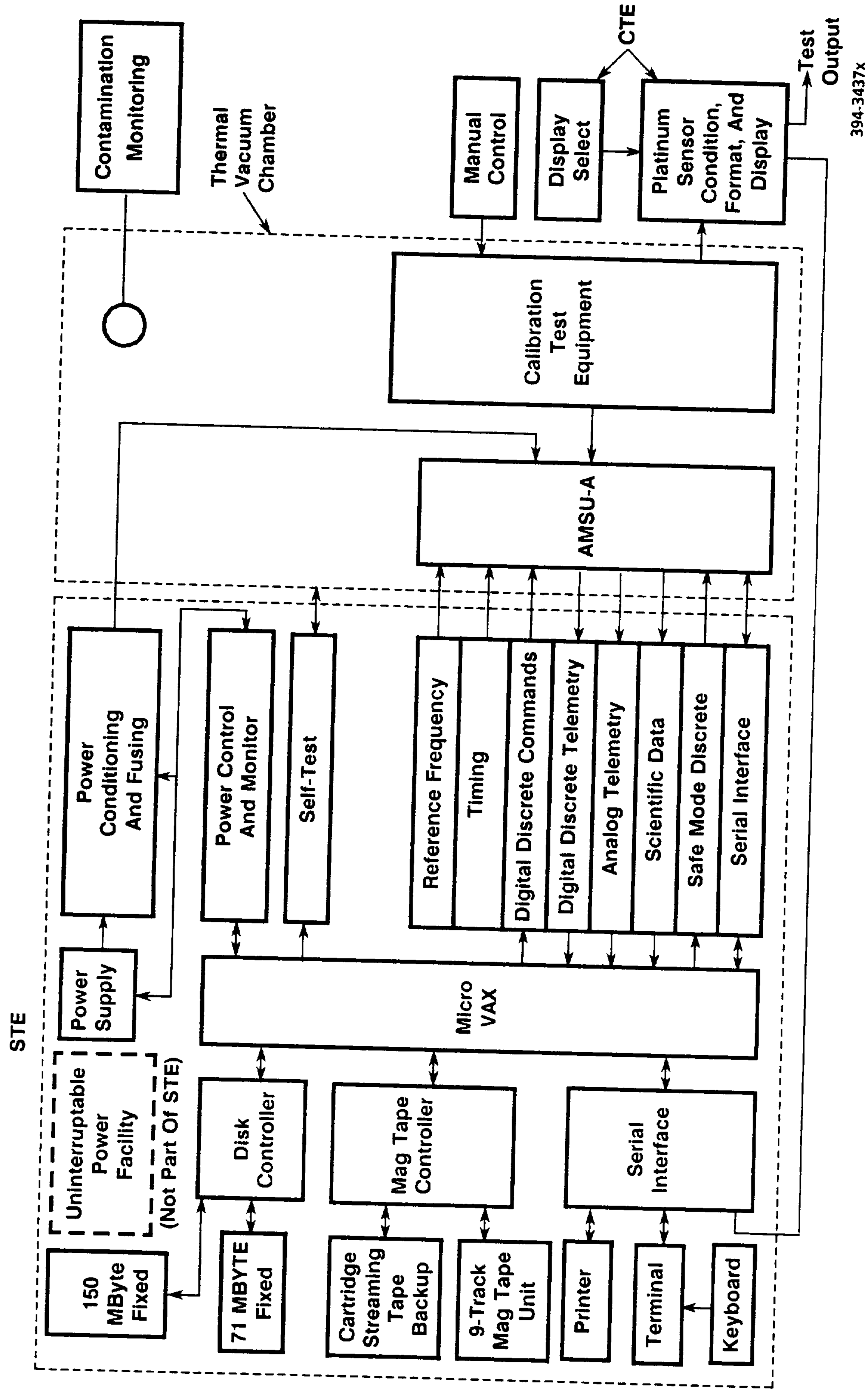


Figure 10 AMSU-A Thermal Vacuum Calibration Instrumentation

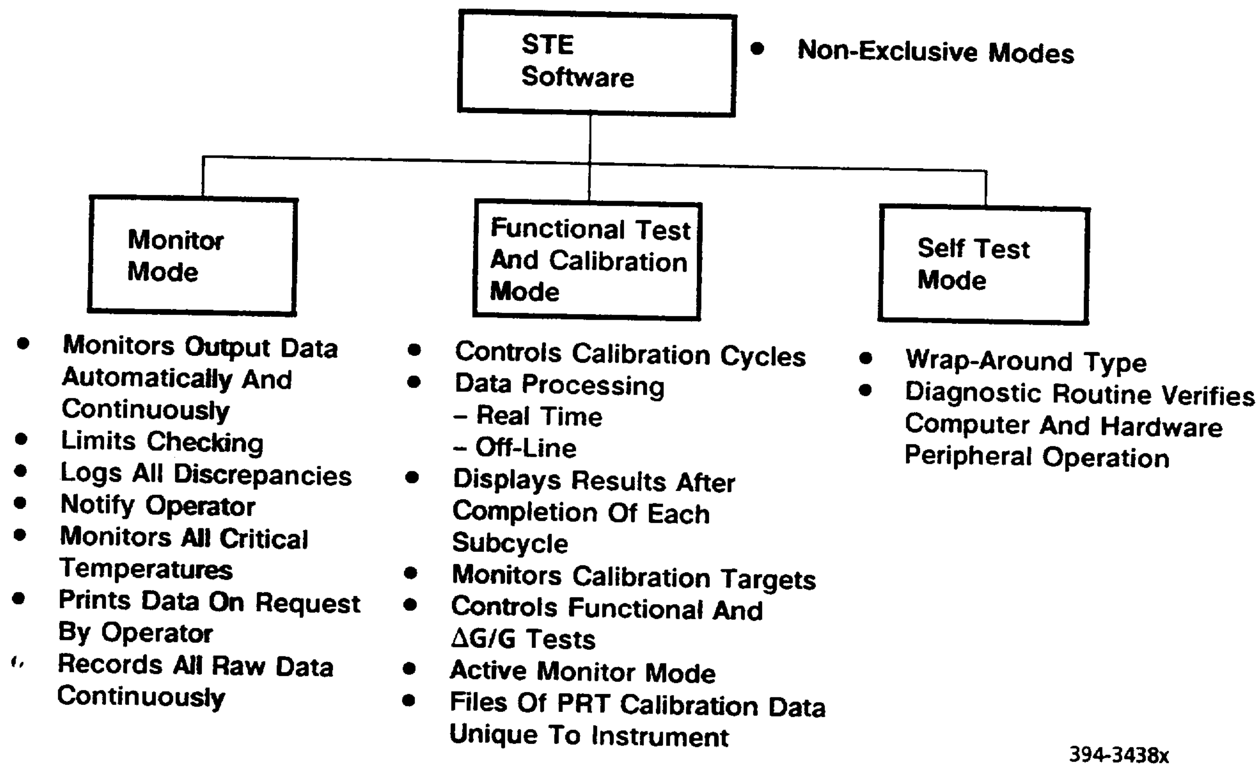


Figure 11 The Special Test Equipment Software Characteristics and Functions

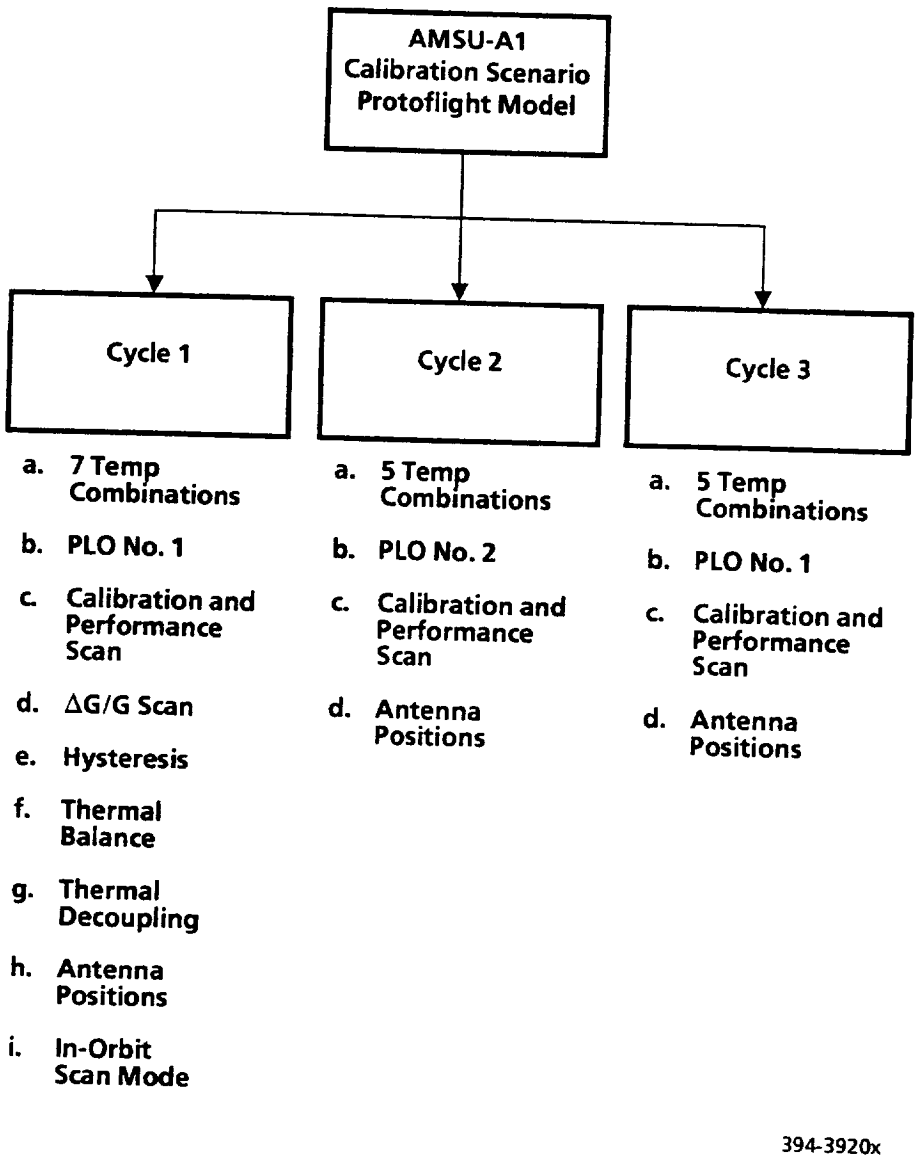
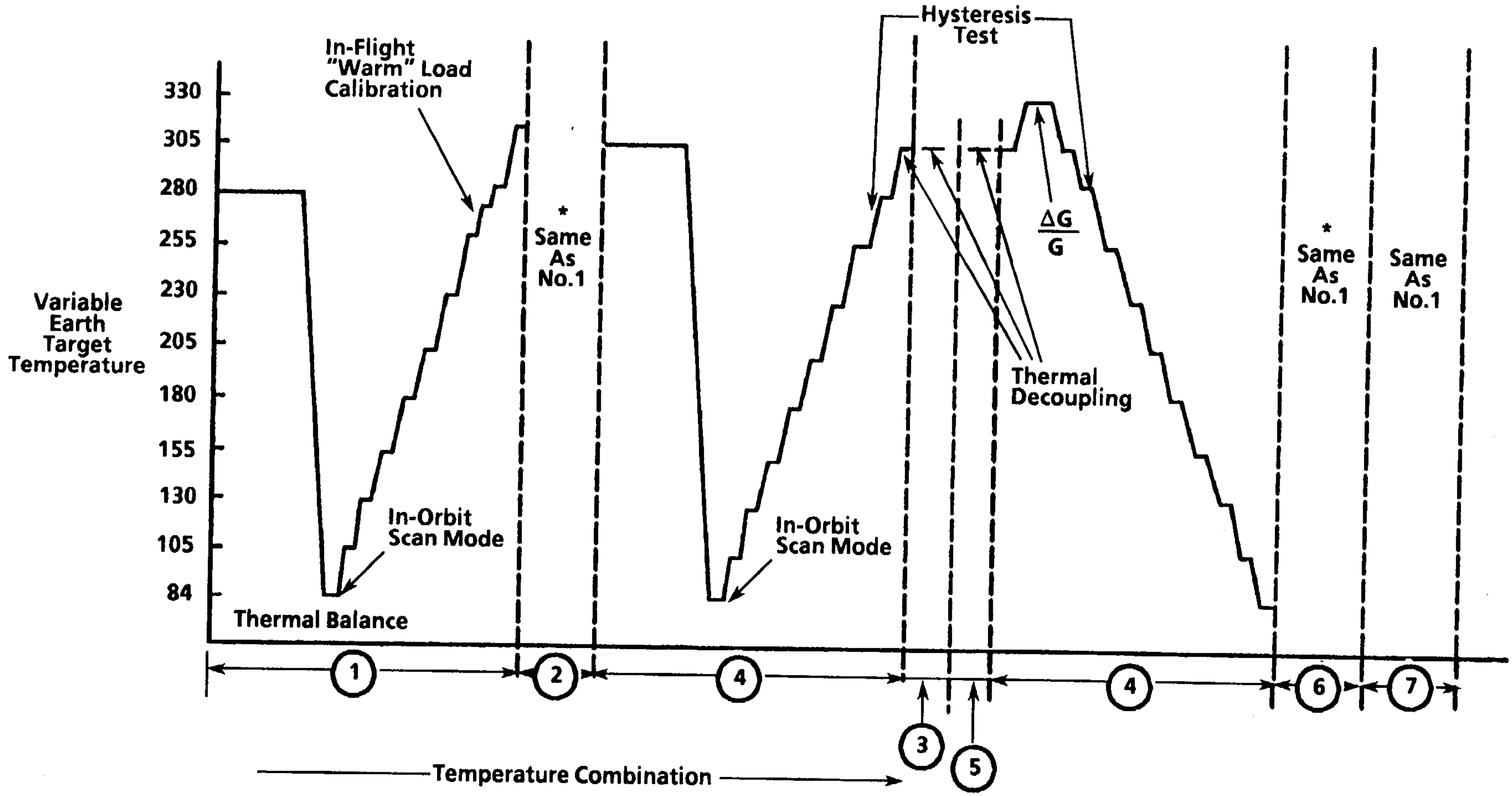


Figure 12 AMSU-A1 Calibration Test Scenario



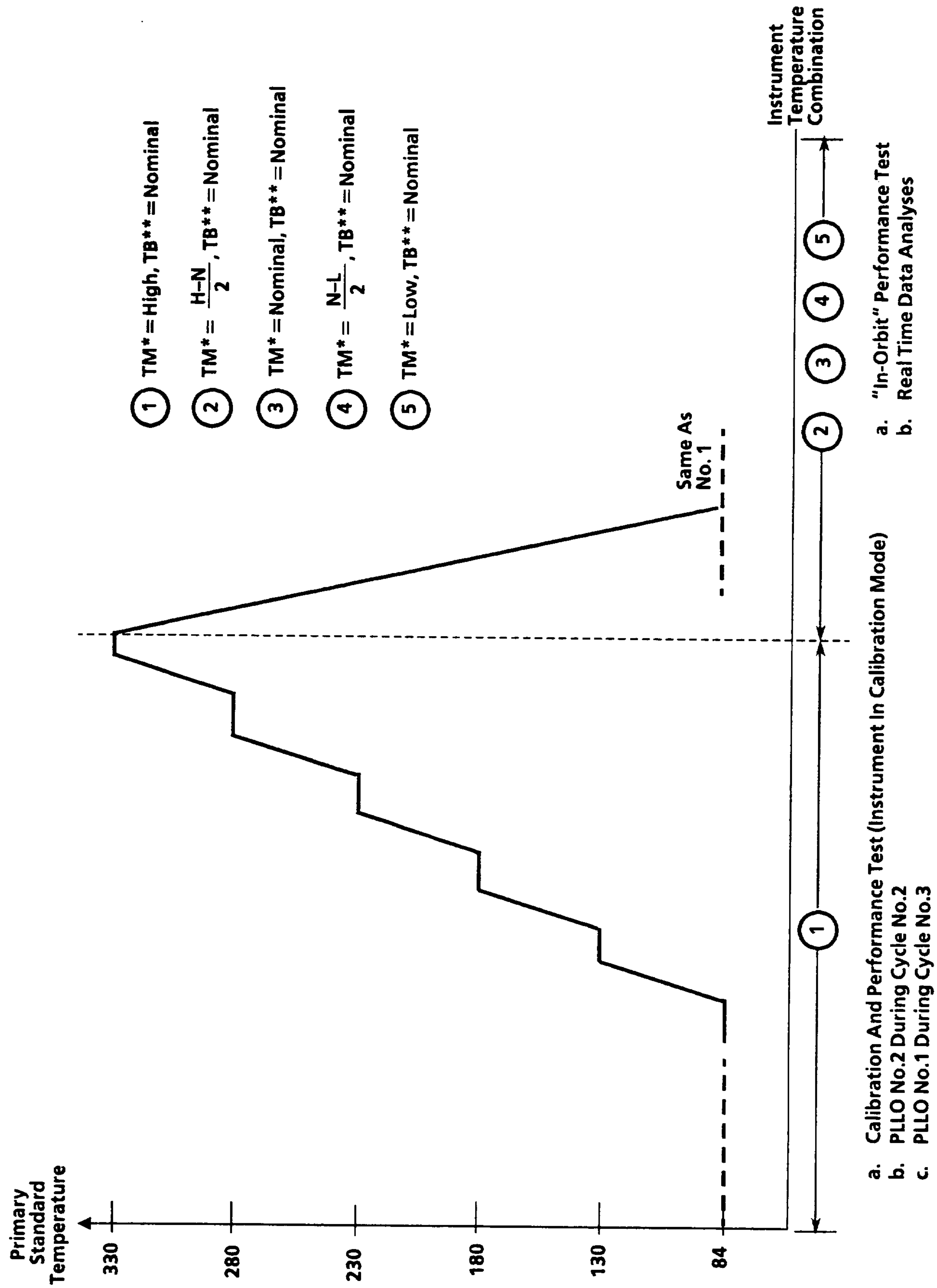
Note: Calibration And Performance Test (Instrument In Calibration Mode)– All Temperature Combinations

Temperature Combination	1	2	3	4	5	6	7
Instrument Temperature	High (H)**	H–N/2	Nominal	Nominal	Nominal	N–L/2	Low**
Projected Interface Temperature	Nominal (N)	Nominal	High	Nominal	Low (L)	Nominal	Nominal

*No thermal balance **10°C beyond the predicted mission extremes

Figure 13 AMSU-A1 Protoflight Model Cycle 1

394-3919x



*TM is instrument temperature
**TB is interface temperature

Figure 14 AMSU-A1 Protoflight Model Cycle 2 and 3

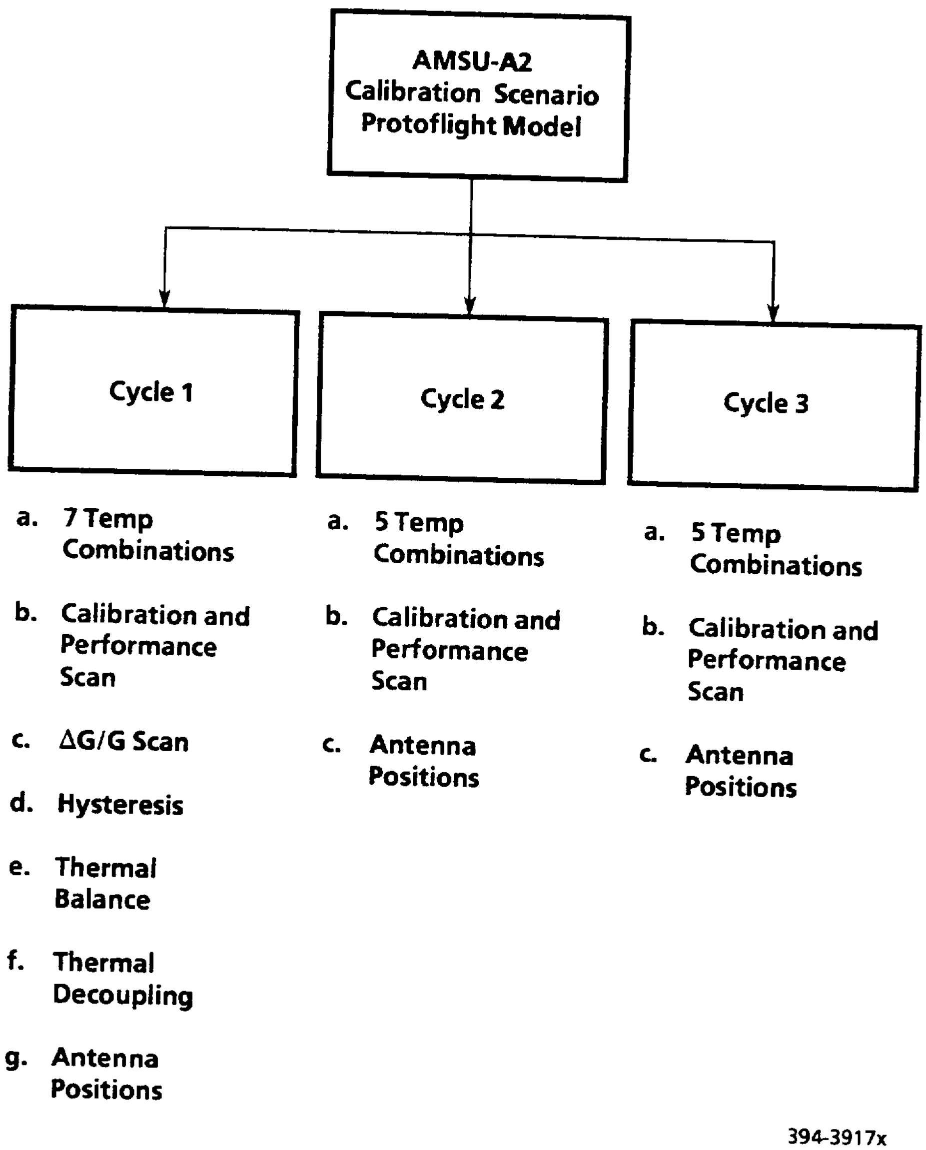
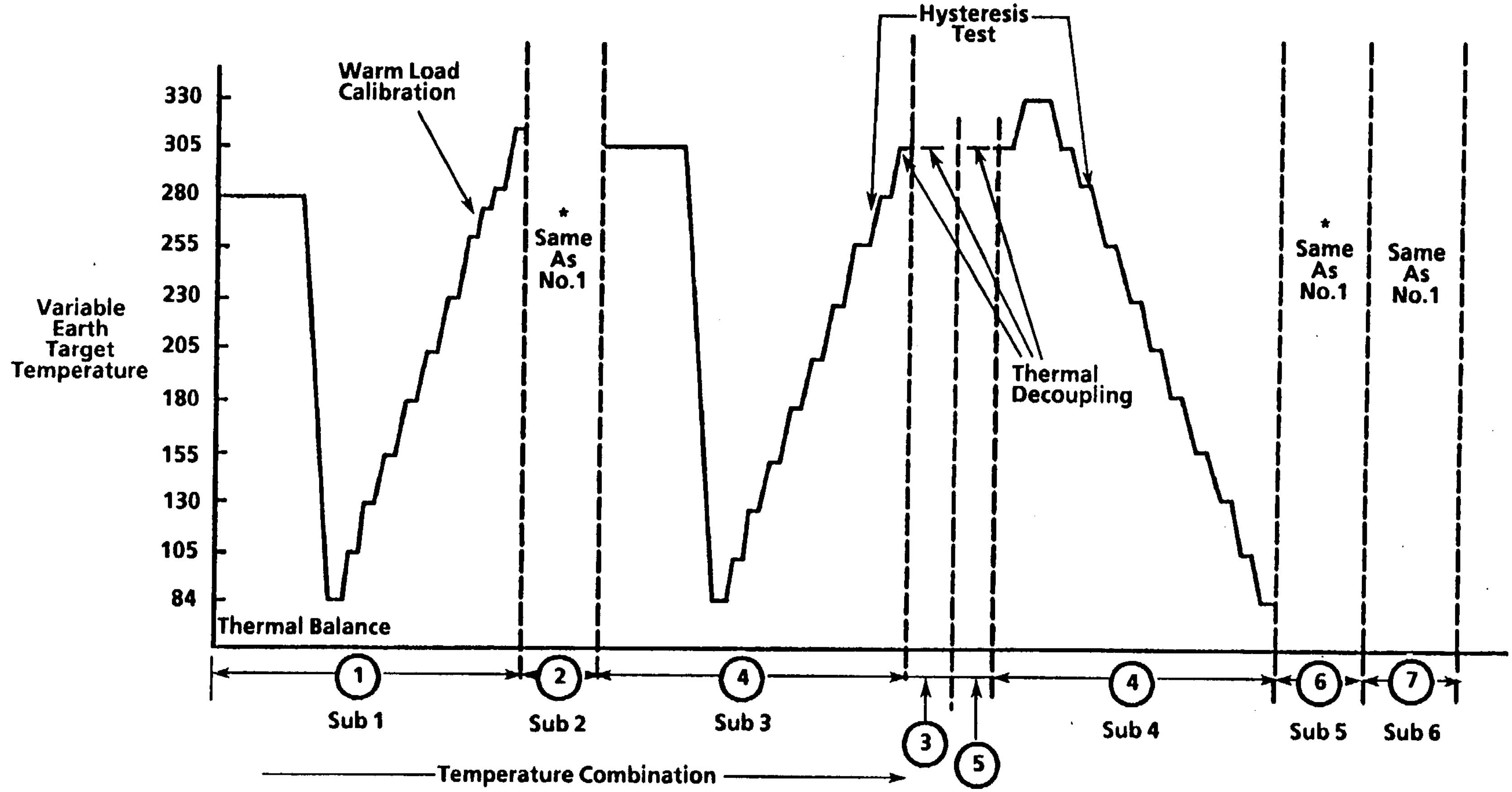


Figure 15 AMSU-A2 Calibration Test Scenario



Note: Calibration And Performance Test – All Temperature Combination

Temperature Combination	1	2	3	4	5	6	7
Projected Instrument Temperature	High (H)	H–N/2	Nominal	Nominal	Nominal	N–L/2	Low
Projected Interface Temperature	Nominal (N)	Nominal	High	Nominal	Low (L)	Nominal	Nominal

*No thermal balance **10°C beyond the predicted mission extremes

394-3916x

Figure 16 AMSU-A2 Protoflight Model Cycle 1

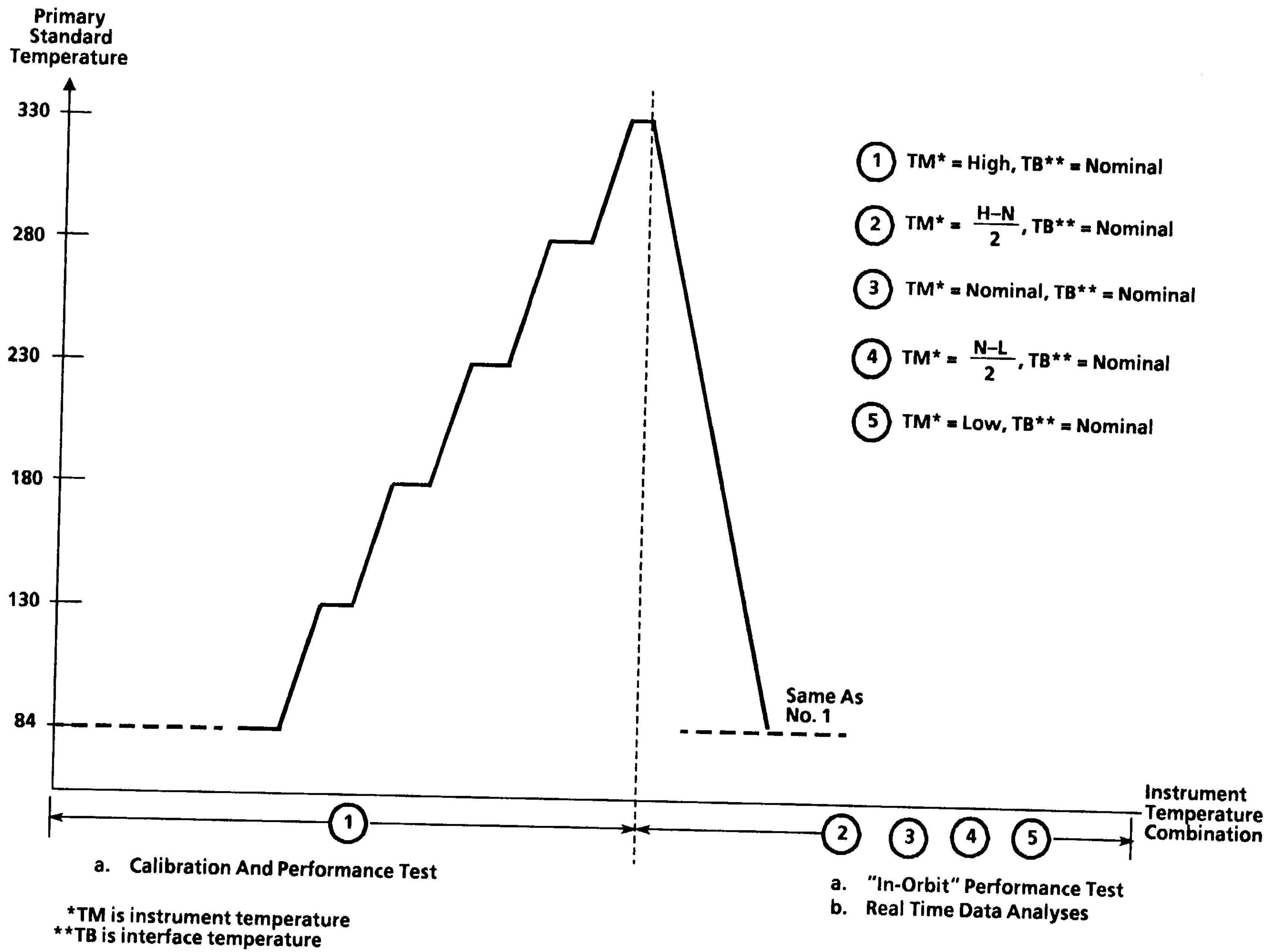


Figure 17 AMSU-A2 Protoflight Model Cycle 2 and 3

394-3915x

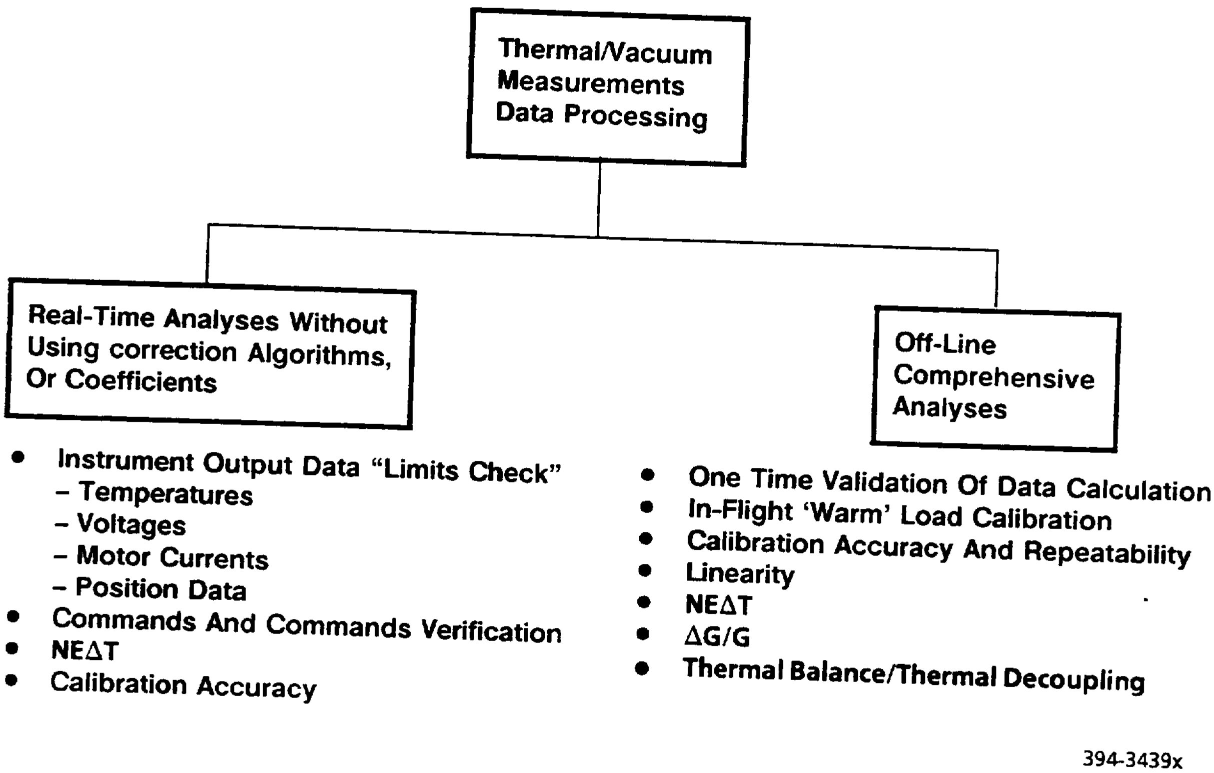


Figure 18 Thermal Vacuum Measurements Data Processing

Section 5

AMSU-A SYSTEM CALIBRATION MANAGEMENT PLAN

Since calibration of the AMSU-A instrument is of the highest priority, managing and maintining calibration of the instrument requires a detailed system Calibration Management Plan. The Calibration Management Plan presented in this section addresses:

1) Implementation of calibration

2) Logistic aspects of calibration

3) Facility and equipment descriptions

4) Test and calibration time

5) Test and calibration configurations

6) Calibration verification matris

In addition, it discusses the following:

a. Calibration in terms of physical standards, physical standard processes, or NIST maintained services and materials.

b. Use of more than one calibration technique whenever possible to verify instrument calibration accuracy.

c. Calibration approaches which can be easily related to other instruments as far as possible, and comparisons and calibrations between the AMSU-A instrument and other instruments before launch.

d. The feasibility of determining post-launch calibration using a surface calibration network, and a method to integrate results derived from such a data validation effort into the performance records.

e. Instrument sensitivity analysis in terms of mathematical models of the instrument.

The first section of the Calibration Management Plan provides a calibration verification matrix. Then the subjects of (1) implementation, (2) logistics, (3) facilities and equipment, (4) test time, and (5) configuration are presented in an order consistent with the AMSU-A system calibration flow diagram of Figure 4. NIST related issues of the in-flight warm calibration and primary blackbody calibration target subsections are then discussed.

5.1 Calibration Verification Matrix

The AMSU-A calibration verification matrix of Table V is generated from EOS/AMSU-A project specifications and project requirement documents. The matrix provides a cross reference of calibration procedures to be developed from existing NOAA/AMSU-A procedures and EOS/AMSU-A Performance and Operations Specification requirements. Calibration procedures are generated from the matrix, and after execution the calibration results will be reported to NASA via reports and log books, as indicated in Figure 19. This process provides traceability and verification of all calibration performance requirements.

5.2 Channel Frequency and Bandwidth Measurements

AMSU-A channel center frequencies will be measured at the subassembly level (local oscillator) over the operating temperature range of the instrument. The measurement test setup and measuring test equipment list are provided in Figure 20 and Table VI, respectively. Measurements will be compliant with Section 3.2 of GSFC 422-12-12-01, and conducted in accordance with applicable test procedures.

The bandpass characteristic of each channel selection filter will be measured in accordance with test procedures and will be compliant with the Performance and Operations Specification, paragraphs 7.2.3, 3.2.2, 3.2.3, and 3.2.4. The measurement test setup and measuring test equipment list are provided in Figure 21. Bandpass characteristic will be measured at the subassembly level.

The test time required to measure center frequency and bandpass characteristics is estimated to be 100 hours.

5.3 Antenna Pattern, Alignment, and Pointing Measurements

Antenna pattern measurements, beam alignment, and beam pointing tests are performed at the Aerojet antenna range facility, in compliance with sections 3.7 and 7.2.6 of GSFC 422-12-12-01 and in accordance with applicable test procedures. Figure 22 is a photograph of the Aerojet compact range to be used. The test setup and block diagram of the compact range to be used. The test setup and block diagram of the compact range is presented in Figure 23. A list of the necessary test equipment is provided in Table VII. The compact range performance verification and boresighting techniques are depicted in Figure 24. A laser alignment system will be used in conjunction with the compact range, as indicated in Figure 25.

Antenna pattern measurements, beam alignment, and beam pointing measurements will be performed at the antenna subassembly level with the complete instrument structure.

Test time to perform antenna pattern measurements, alignment, and pointing measurements is estimated to be 1100 hours total. During test, the drive motor bearing will be purged with dry nitrogen to prevent contamination.

Table V AMSU-A Calibration Verification Matrix

Requirement Parameter	TYPE	Specification Paragraph GSFC 422-12-12-01	Verification Method: TEST	Verification Method: ANALYSIS	Verification Method: INSPECTION	Verification Method: DESIGN	Level: INSTRUMENT	Level: INTEGRATION	Level: SUBSYSTEM	Level: ASSEMBLY	EOS/AMSU-A Test Procedure/ Analysis Report
Channel Frequency and Bandwidth	S	3.2	√	√	√				√	√	Receiver Subsystem
Antenna Pattern	S	7.2.6	√						√		Antenna Subsystem
"Cosmic Backgrount" Cold Calibration	S	3.5.1	√			√	√				System
• Correction To Rayleigh-Jeans Approximation	D	N/A		√			√				Radiometric Math Model Report 10371
• Beam Efficiency	S	3.7.3.5	√	√					√		Antenna Subsystem
• Field Of View	D	N/A		√		√	√				Need to Verify at Spacecraft
• Error Analysis Due To Earth And Spacecraft Radiation	D	N/A		√			√				Radiometric Math Model Report 10371
Antenna Position, Pointing Alignment Synchronization											
• Synchronization	S	3.7.3.3.	√				√			√	System & Antenna Drive Assembly
• Beam Pointing And Alighment	S	3.7.3.4	√						√		Antenna Subsystem

S = Specified D = Derived

(Continued)

Table V AMSU-A Calibration Verification Matrix (Continued)

Requirement Parameter	TYPE	Specification Paragraph GSFC 422-12-12-01	Verification Method: TEST	ANALYSIS	INSPECTION	DESIGN	Level: INSTRUMENT	INTEGRATION	SUBSYSTEM	ASSEMBLY	EOS/AMSU-A Test Procedure/ Analysis Report
Antenna Position, Pointing Alignment, Synchronization (continue)											
• Antenna Position	S	3.7.3.2.	√				√	√			System
Nonlinearity	S	3.6	√	√			√			√	System & Detector/ Preamp Assembly
In-Flight Warm Calibration Target											
• Brightness Temp. Accuracy	S	3.5.1		√			√				Worst-case Analysis - Calibration Error
– Thermal Temp. Accuracy	S	3.5.1	√	√			√	√		√	Target Assembly
– Emissivity	D	N/A	√							√	Target Assembly
– Tunable Short (LO Leakage)	S	7.2.7	√	√					√		Antenna, Receiver Subassemblies
– Temperature Gradient & Stability	D	N/A		√		√	√				Worst-Case Analysis - Calibration Error

S = Specified D = Derived

(Continued)

Table V AMSU-A Calibration Verification Matrix (Continued)

Requirement Parameter	TYPE	Specification Paragraph GSFC 422-12-12-01	Verification Method				Level				EOS/AMSU-A Test Procedure/ Analysis Report
			TEST	ANALYSIS	INSPECTION	DESIGN	INSTRUMENT	INTEGRATION	SUBSYSTEM	ASSEMBLY	
• Error Analysis	D	N/A		√			√				Worst-Case Analysis - Calibration Error
Primary Blackbody Calibration Target	S	9.3.1			√						
• Location & Mounting	S	9.3.2.2 (1)			√		√				System
• Emissivity	S	9.3.2.2 (2)	√							√	GSE
• Temp Accuracy	S	9.3.2.2 (3)	√	√						√	GSE
• Gradients	S	9.3.2.2 (4)	√	√			√				GSE
• Temp Range	S	9.3.2.2 (5)	√				√				GSE
• Stability	S	9.3.2.2 (6)	√				√				GSE
• Amplitude Of Controller Cycling	S	9.3.2.2 (7)	√				√				GSE
• Cooling	S	9.3.2.2 (8)	√				√				GSE
• Step Change	S	9.3.2.2 (9)	√				√				GSE
• Thermal Off-Loading	S	9.3.2.2 (10)	√				√				GSE
• Temp Sensor Requirements	S	9.3.2.2 (11)	√	√						√	GSE

S = Specified D = Derived

(Continued)

Table V AMSU-A Calibration Verification Matrix (Continued)

Requirement Parameter	TYPE	Specification Paragraph GSFC 422-12-12-01	Verification Method: TEST	Verification Method: ANALYSIS	Verification Method: INSPECTION	Verification Method: DESIGN	Level: INSTRUMENT	Level: INTEGRATION	Level: SUBSYSTEM	Level: ASSEMBLY	EOS/AMSU-A Test Procedure/ Analysis Report
Error-Analysis	D			√			√				Analysis Report
Calibration Curves Of In-Flight Warm Cal Target PRT	S	5.3.2 (5)	√					√		√	Calibration Log Book
Calibration Curves Of Primary Calibration Target PRT	D	N/A	√							√	Analysis Report
System Calibration											
• Calibration Test Requirements	S	5.3.3	√	√			√				System
• Calibration Results	S	5.3.2		√			√				Calibration Log Book
• Calibration Accuracy And Repeatability	S	3.5.2.1	√				√				System
• Calibration Algorithm	S	3.5.2.3		√			√				Calibration Log Book
• Calibration Algorithm	S	3.5.2.3		√			√				Calibration Log Book

S = Specified D = Derived

(Continued)

Table V AMSU-A Calibration Verification Matrix (Continued)

Requirement Parameter	TYPE	Specification Paragraph GSFC 422-12-12-01	Verification Method				Level				EOS/AMSU-A Test Procedure/ Analysis Report
			TEST	ANALYSIS	INSPECTION	DESIGN	INSTRUMENT	INTEGRATION	SUBSYSTEM	ASSEMBLY	
Mathematical Model, Radiometric	S	3.10.1		√			√				Report 10371
In-Orbit Antenna Temperature Calibration Algorithm, Data And Analysis, Methodology	D	N/A		√			√				Calibration Log Book
Calibration Plans And Procedures	S	5.1.2									Report 10356 Test & Procedures
Documentation	S	5.1.3									Refer To Figure 16

S = Specified D = Derived

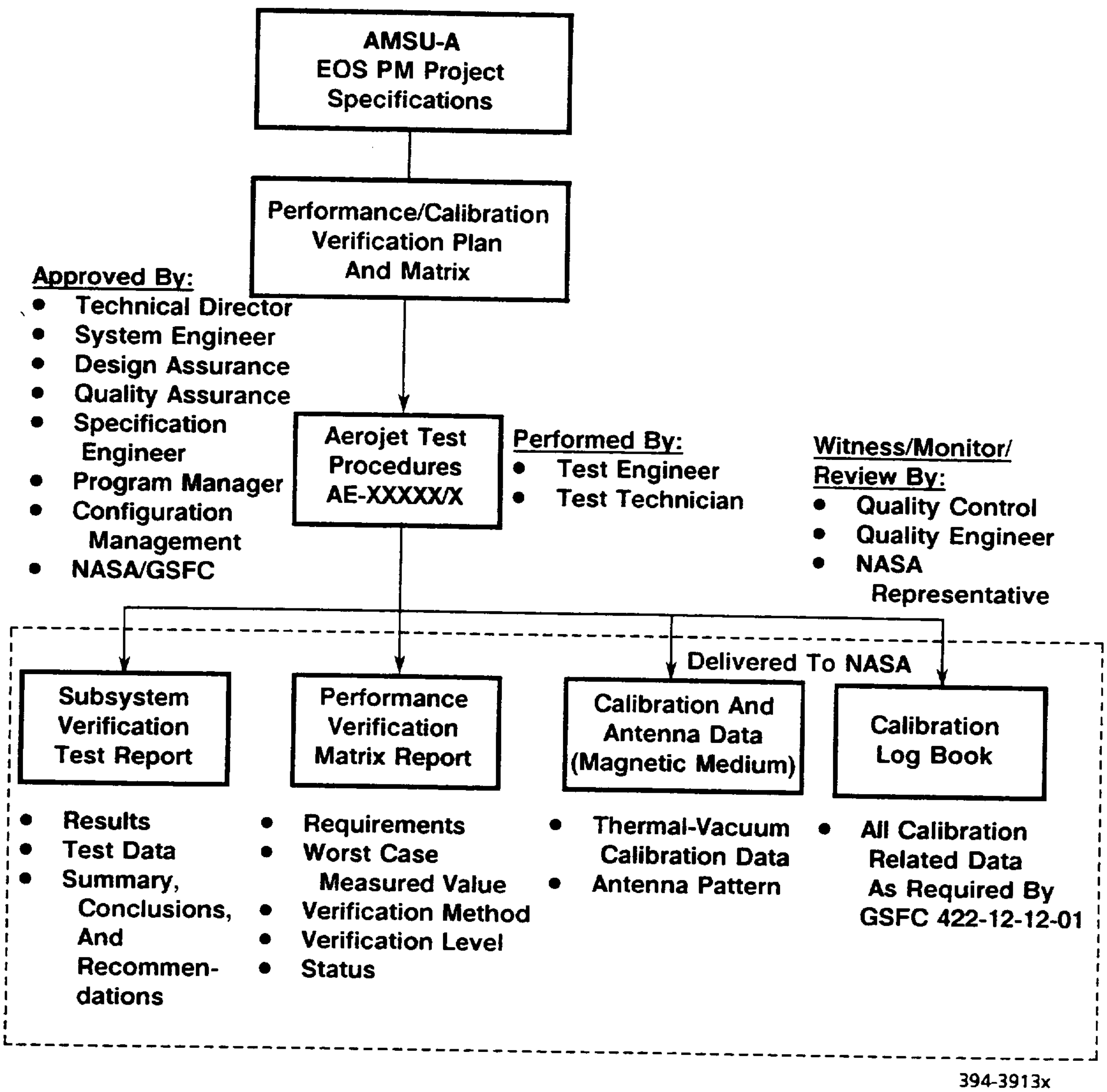
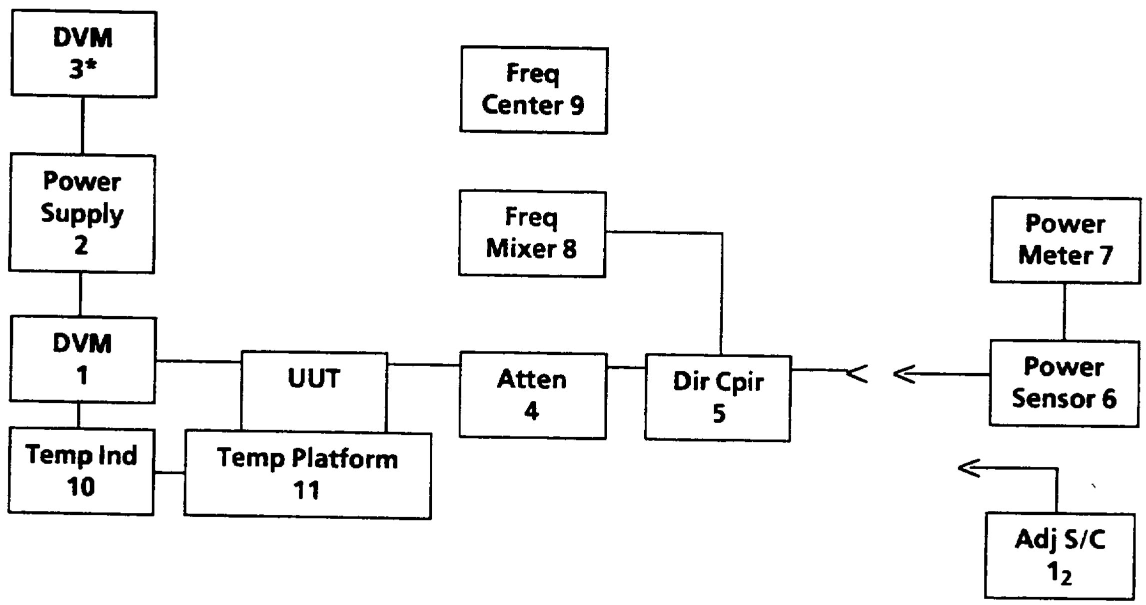


Figure 19 AMSU-A Calibration Test Procedures and Reports



*See Table VI for Description/Item Number

Figure 20 Test Setup for Local Oscillator Center Frequency Measurement

Table VI Test Equipment List for the Local Oscillator Center Frequency Measurements

Item	Description	Manufacturer	Model No.
1	Digital Voltmeter	Hewlett Packard	3478A
2	Power Supply	Hewlett Packard	6101A
3	Digital Voltmeter	Hewlett Packard	3478A
4	Attenuator	TRG	V510
5	Directional Coupler	TRG	V599-10
6	Thermistor	Hughes	45774H
7	Power Meter	Hewlett Packard	432 Series
8	V-Band Mixer	Tektronix	W490W
9	Frequency Counter	EIP	588
10	Temperature Indicator	Doric	400 J/C
11	Temperature Platform	Sigma	TP781
12	Adjustable Short Circuit	Baytron	3-15-295

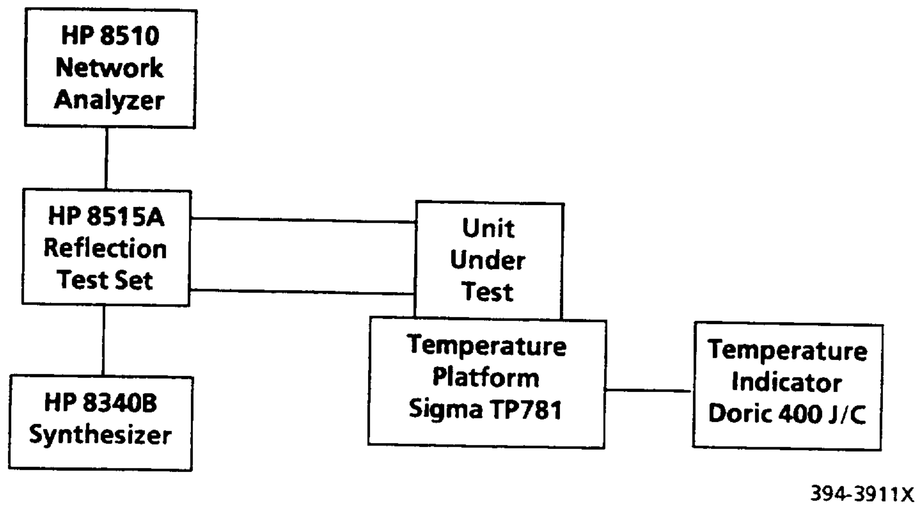


Figure 21 Test Setup and Equipment for Bandpass Characteristic Measurement

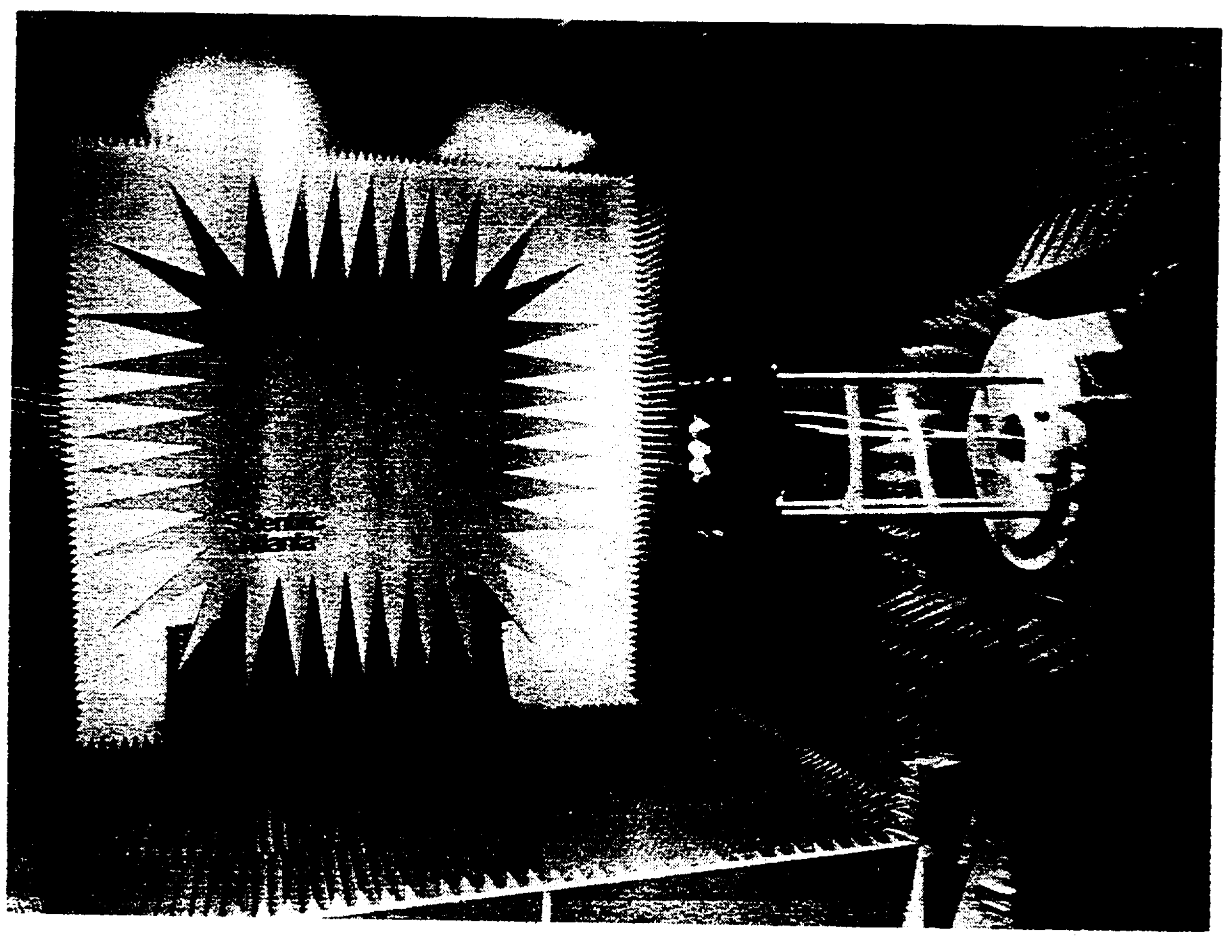


Figure 22 Antenna Compact Range Used for Pattern Measurement and Alignment

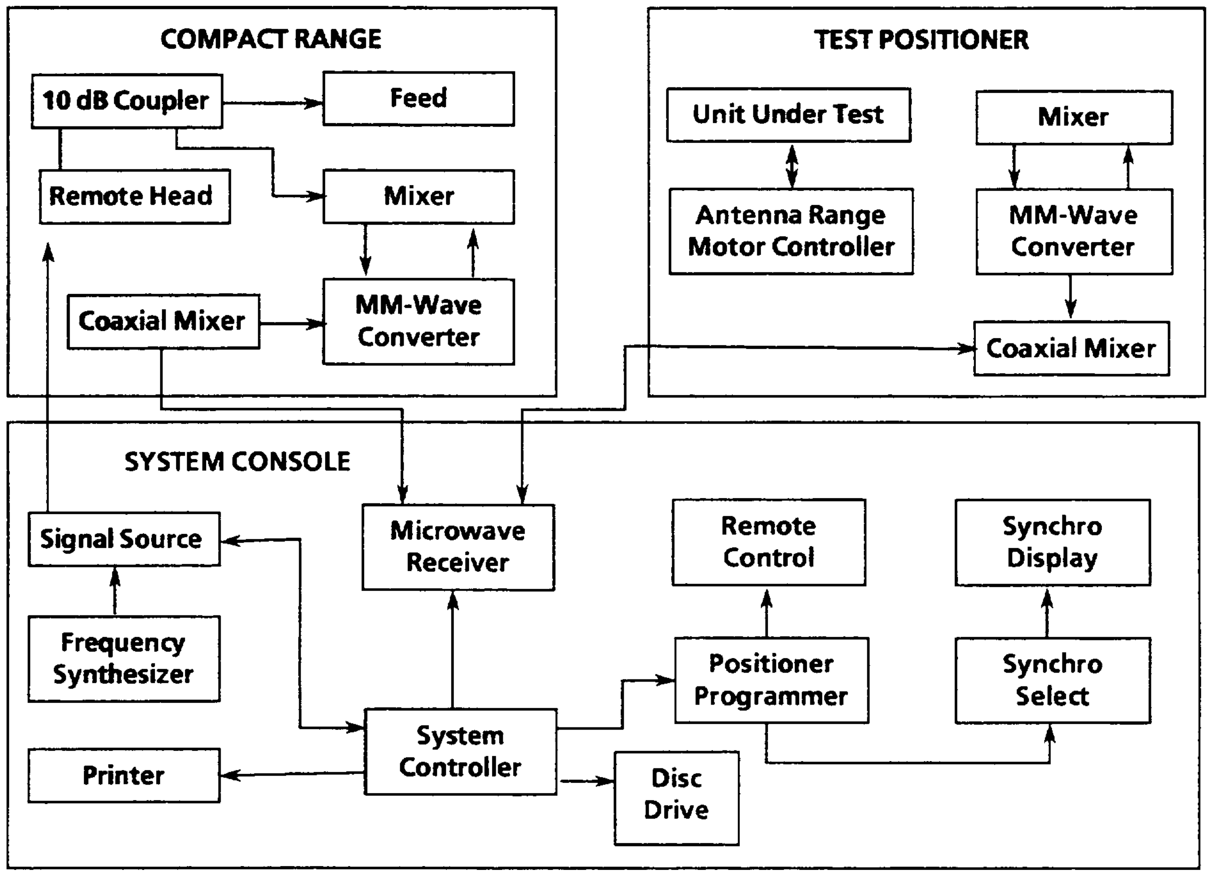


Figure 23 Antenna Pattern Test Setup

Table VII Test Equipment for Antenna Pattern, Alignment, and Pointing

Equipment	Manufacturer	Model
Compact Range	Scientific Atlantic	5703
Test Positioner	Scientific Atlantic	328573
Microwave Receiver	Scientific Atlantic	1780
Signal Source Remote Head	Scientific Atlantic	2180-40
Frequency Synthesizer	Scientific Atlantic	2186
Millimeter Wave Converter	Scientific Atlanta	1784
Millimeter Wave Converter	Scientific Atlanta	1785
Mixer (V-band) (2)	Hughes	47444H-1002A
Mixer (W-band) (2)	Hughes	47446H-1002A
Mixer (Coaxial) (2)	Scientific Atlanta	14-5
Positioner Programmer	Scientific Atlanta	2012A
Remote Control Unit	Scientific Atlanta	4180A
Digital Syncro Display	Scientific Atlanta	1885
Synchro Select Unit	Scientific Atlanta	2013
Compact Range (CR)Feed (V-Band)	Scientific Atlanta	253342
CR Feed (W-band)	Aerojet	1337764
System Controller	Hewlett-Packard	9836
Hard Disc Drive	Hewlett-Packard	9134
Printer	Hewlett-Packard	ThinkJet
Microwave Amplifier	Hewlett-Packard	8349B
Precision Attenuator (V-band)	Alpha	520V
Precision Attenuator (W-band)	Alpha	510W
10 dB Coupler (V-band)	Baytron	3-15-400/10
10 dB Coupler (Ka-band)	Baytron	3-10-400/10
Sweep Oscillator Main Frame	Hewlett-Packard	8350B
Antenna Range Motor Controller	Aerojet	E-1293778
CR Feed (K-band)	Aerojet	1337765
CR Feed (Ka-band)	Aerojet	1337766
Precision Attenuator (K-band)	Hewlett-Packard	K382A
Precision Attenuator (Ka-band)	Hewlett-Packard	R382A

(Continued)

Table VII Test Equipment for Antenna Pattern, Alignment, and Pointing (Cont)

Equipment	Manufacturer	Model
10 dB Coupler (K-band)	Hewlett-Packard	K752C
10 dB Coupler (Ka-band)	Hewlett-Packard	R752C
RF Plug-in (K-band)	Hewlett-Packard	8357A
RF Plug-in (Ka-Band	Hewlett-Packard	8357A
A1 Boresight Fixture	Aerojet	1337767
A1 Beam Position 1 Fixture	Aerojet	1337768
Source Module (V-band)	Hewlett-Packard	83557A
Source Module (W-band)	Hewlett-Packard	83558A
Scalar Network Analyzer	Hewlett-Packard	8757
Detector Adapter (2)	Hewlett-Packard	85025C
Detector (K-band) (2)	Hewlett-Packard	K422A
Detector (Ka-band) (2)	Hewlett-Packard	R422A
Detector (V-band) (2)	M/A-Com	4-15-720-01
Detector (W-band) (2)	Hughes	47326H-1211
Mixer (K-band) (2)	Tektronix	WM 490K
Mixer (Ka-band) (2)	Tektronix	WM 490A
CR Feed (V-band)	Scientific Atlanta	253342
Mixer (V-band)	M/A-Com	5-15-740
A1 Beam Position 15 Fixture	Aerojet	1337769
A1 Beam Position 30 Fixture	Aerojet	1337770
A1 Cold Calibrate Fixture	Aerojet	1337771
A2 Boresight Fixture	Aerojet	1337772
A2 Beam Position 1/30 Fixture	Aerojet	1337773
A2 Beam Position 15 Fixture	Aerojet	1337774
A2 Cold Claibrate Fixture	Aerojet	1337775
HeNe Laser	Uniphase	U-1307P
Quadrature Detector	K&E	71-2627
Digital Readout	K&E	71-2623
Beamsplitter Cube	Newport	10FC16
Quarter Wave Plate	Newport	10RP24

(Continued)

Table VII Test Equipment for Antenna Pattern, Alignment, and Pointing (Cont)

Equipment	Manufacturer	Model
A-1 Multiplexer*	Aerojet	1331546
A-2 Multiplexer **	Aerojet	1331507

* AMSU A-1 Feedhorn Adapter, T-1339006, may be substituted for the A-1 Multiplexer.

** AMSU A-2 Feedhorn Adapter, T-1339007, may be substituted for the A-2 Multiplexer.

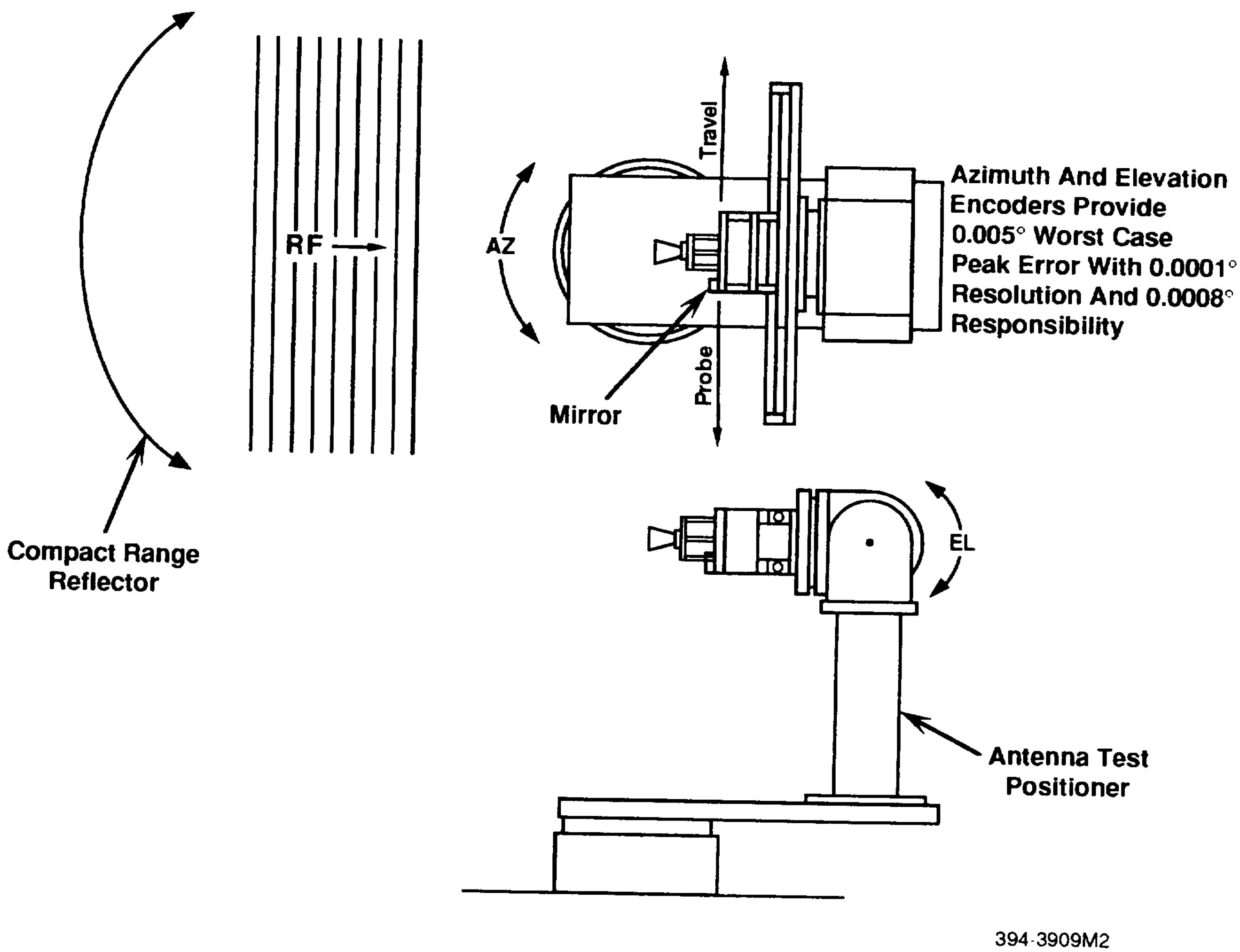


Figure 24 Compact Range Verification and Boresight Techniques

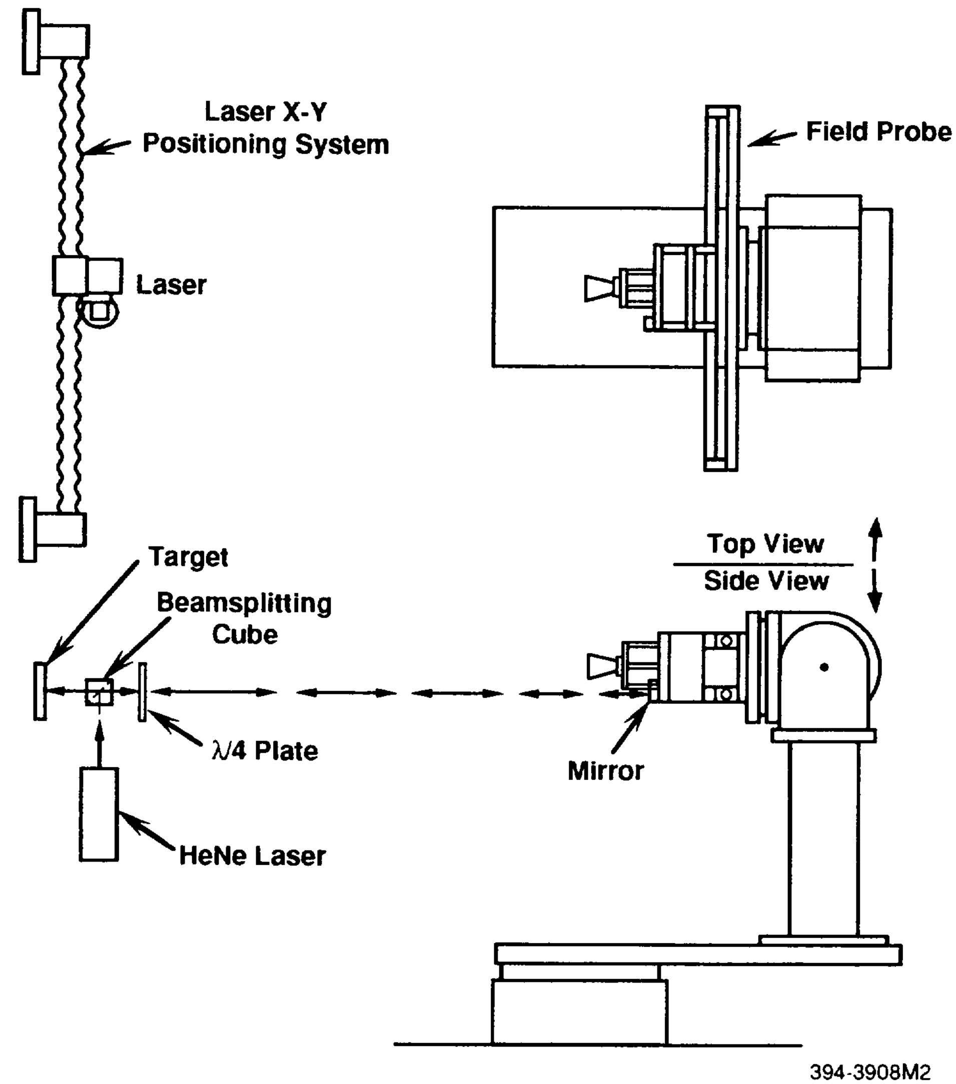


Figure 25 Compact Range Laser Alignment System

5.4 Antenna Beam Position Data

Antenna beam position and synchronization data are obtained using the test setup depicted in Figure 26. The required test equipmenbt is listed in Table VIII. This test will be performed at the instrument integration level, with the AMSU-A instrument in its final configuration except that one side panel and thermal blankets will be removed. The total antenna position test time for AMSU-A1 is estimated to be TBS. Total test time for AMSUS-A2 is estimated as TBS.

5.5 Channel Nonlinearity

Nonlinearity of AMSU-A channels will be measureed in conformance with 3.5.2.2, 3.6, and 7.2.4 of GSFC 422-12-12-01 at both the system and detector preamplifier assembly levels. Performance at the system level will be conducted for antenna brightness temperatures between 84 K and 330 K. Verification of performance down to 3 K will be provided through detector preamp assembly measurements and analysis. The detector preamp assembly nonlinearity test is performed with a sliding "differentially switched" annenuator test sytem, as shown in Figure 27. Nonlinearity test equipment is indicated in the block diagram of Figure 27.

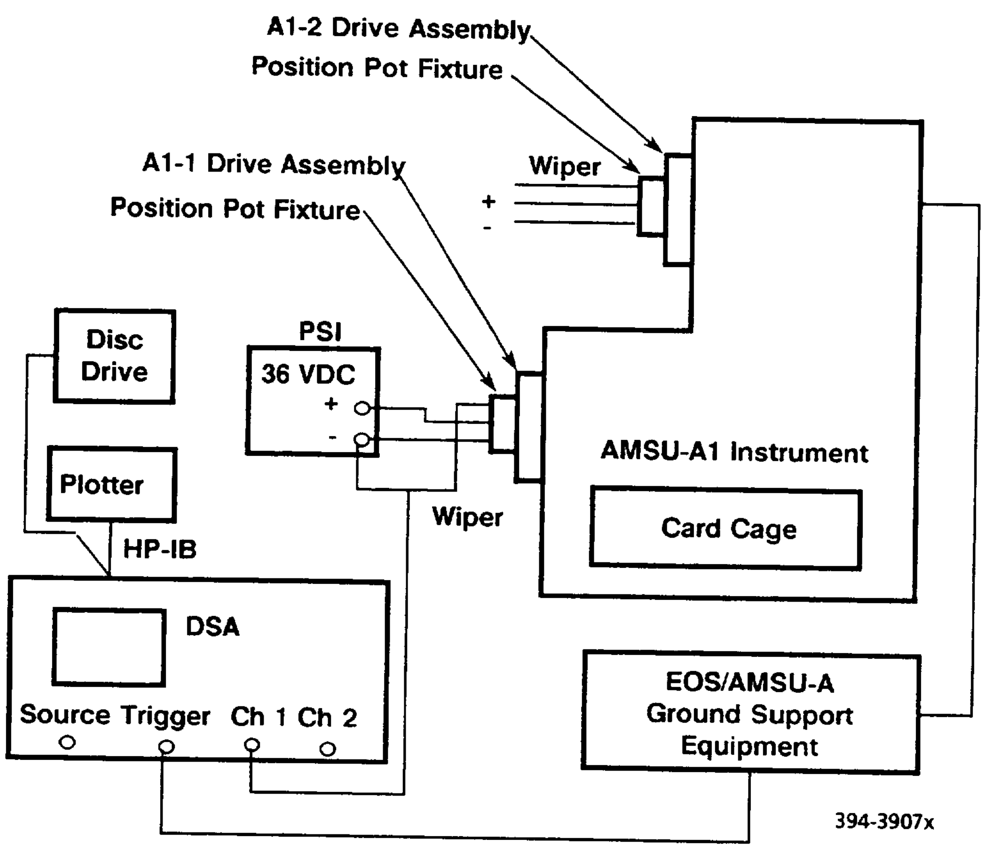


Figure 26 Test Setup for Antenna Position Measurement

Table VIII Test Equipment List for the Local Oscillator Center Frequency Measurements

Test Equipment	Manufacturer	Designation
Dynamic Signal Analyzer (DSA)	Hewlett Packard	3562A or 3563A
Plotter	Hewlett Packard	7470A
Position Pot Fixture	Aerojet	T-1289366
Power Supply	Power Design	5015T
Test Potentiometer	--	---
3.5" Floppy Disc Drive	Hewlett Packard	9122C

5.6 Inflight Warm Calibration Target PRT Sensor and Conditioning Circuit Calibration

Inflight warm calibration target PRT sensors are vendor calibrated and traceable to NIST standards. AMSU-A PRT conditioning circuits will be calibrated in accordance with test specifications by substituting precision resistors (measured to a resolution of 0.01 ohm) in place of the PRT and measuring the resultant A/D converter output count using the AMSU-A ground support equipment. A total of 40 resistors (with a nominal 2.5 ohm increment) are used to obtain the conditioning readout circuit calibration curve, in conjunction with the best polynominal curve fit to the measured data. Conditioning circuit calibration is accomplished at the integration level with the AMSU-A instrument operating in the in-orbit scenario. Total test time for AMSU-A1 and A2 conditioning circuit calibration is estimated to be TBS and TBS respectively.

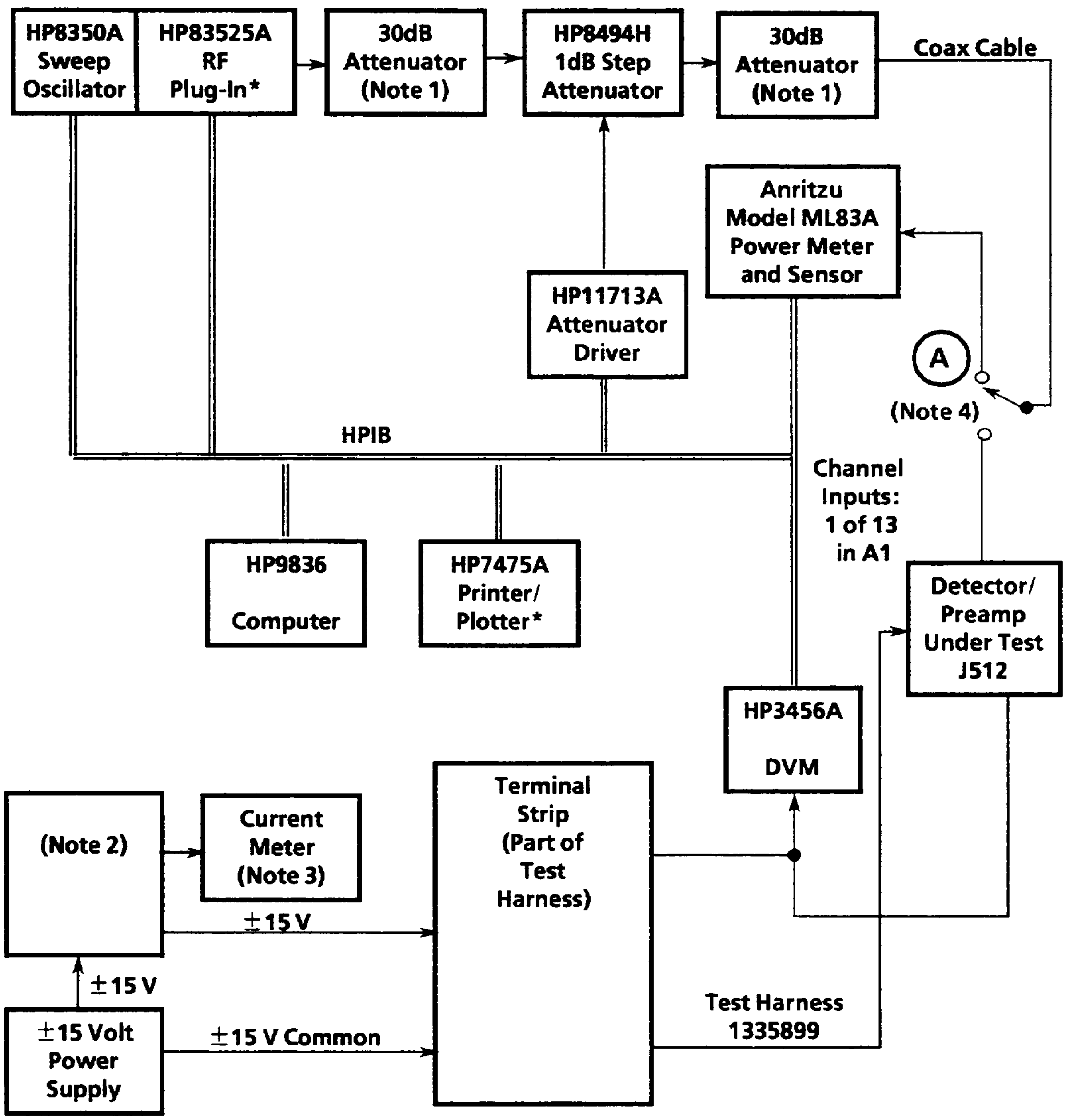
Emissivities of AMSU-A inflight calibration targets are measured by means of a reflectometer. The test setup is presented in Figure 28. This test is performed at the assembly level in accordance with the target assembly test specification. The estimated test time is 40 hours for each inflight warm calibration target. Emissivity Test Equipment requirements are presented in Figure 28.

5.7 Primary Calibration Standards PRT Sensor Calibration and Test

Primary calibration target PRT sensors utilize a 4-wire interface configuration. They are calibrated in an extremely stable, well controlled laboratory environment (as are the inflight 'warm' calibration PRT) using standards that are traceable to NIST. A detailed plan of target calibration in terms of physical standards, physical standard processes, or NIST-maintained services and materials is in the test specification. Emissivity of the primary calibration targets will be measured using the reflectometer test setup of Figure 28 in accordance with the test specification.

5.8 Thermal-Vacuum Calibration Measurements

Implementation of calibration and test measurements in the thermal-vacuum chamber requires extensive planning and preparation of test equipment, the test facility, and the necessary manpower. Logistics of the test are controlled by means of a comprehensive test readiness review (TRR) before the test is conducted. The TRR is presented to senior management for approval. A typical TRR check list is provided in Table IX. The TRR includes data requirements, test article information (unit under test: AMSU-A), test equipment information, test support information, test plans, test procuderes (including emergency procedures), test facility information, and an on-site review. Measurements to be conducted during Thermal-Vacuum Calibraiton are described in 4.1.11, and will be conducted in accordance with the test specification.



NOTES;

1. M/A COM 2082-61XX-XX Series (Typical), equivalents may be used.
2. Supply Current Switch Assembly
3. HP3465A or equivalent
4. Not an actual switch. Cable must be manually connected to proper place.
5. * indicates that equivalents may be substituted for items in box. TE and QC signoff required.

394-3906x

Figure 27 Detector/Preamplifier Non-Linearity Test Setup (A1) Functional Block Diagram

Table IX TRR Checklist

CATEGORY	OK	REMEDY
DATA REQUIREMENTS		
Complete defn. of test data reqmts - include pass/fail criteria.		
Clear traceability of data reqmts. to test objectives.		
Sufficient data reduction plan - assures utility of proposed data products.		
TEST ARTICLE		
As built and as tested documentation.		
All test objectives met by as tested config.		
Test article instrumentation adequate to collect reqd. data.		
Test article sensitivity to test environments known and documented.		
Test article handling/operation procedure for routine and emergency conditions.		
History of significant failure and risk mitigation action.		
Test article handling equip. is in safe operating order/satisfactory environmental reqmts.		
TEST EQUIPMENT		
Standard test support is calibrated and in good working condition - operation document available.		
STE is adequate to collect data meeting test reqmts.		
FMEA of test set-up is current and adequate.		
STE has adequate as-built/operation documentation.		

(Continued)

Table IX TRR Checklist (Cont.)

CATEGORY	OK	REMEDY
STE is calibrated and tolerance bands for data products has been characterized.		
History of significiant failures/risk mitigation action.		
Summary of preventive maintenance sched., overdue items, and action/no action rationale.		
Proof of proper operation of test equipment safety shutoffs, fail safe equip.		
Review impacts of recent test equipment changes of success of testing.		
TEST SUPPORT		
Verify qualified test team: test conductor, test tech., test engineer, QE, QA, and other support personnel are available and have been trained in all aspects of test operation including:		
Test article config.		
Test equip. operation		
Test plan and procedure		
Anomaly and emergency procedures Test responsibility and authority		
List of assigned personnel identified/posted.		
TEST READINESS (ON-SITE)		
Review test dry run results - need for corrective action		
Review test schedule for conflicts with utilities, facilities or support interruptions.		
Verify LN2 systems readiness to support testing (if req'd.)		
Review test article pretest inspection and test data for effects on test start.		
All test documentation available at test location?		

(Continued)

Table IX TRR Checklist (Cont.)

CATEGORY	OK	REMEDY
TEST READINESS (ON SITE) (Continued)		
All functional support identified/available for duration of test (tech, QA, inspection, maintenance).		
Review test S/W readiness - adequacy/proper config.		
Review of post test summary from most recent test.		
Crew briefing complete.		
TEST PLAN & PROCEDURE		
Written test plan - shows how collected data products used to meet test objectives.		
Test set-up definition - shows detailed test equip./interfaces		
Pre & post test inspection reqmts are defined.		
Test conditions with tolerances/not-to-exceed limits specified.		
Test data sheets sufficient to accurately and completely record data/observations.		
TEST FACILITY		
Review of proper operation of facility safety shut-offs, safety equip. and fail safe procedures.		
Review facility set-up reqmts/limitations including electrical power.		
Verify facility calibration, maint., repair, proper operation.		
Review impacts of recent facility changes on ability to conduct successful test.		
FMEA of test facility is current/adequate.		
History of significant failures and risk mitigation action.		
Summary of preventative maintenance schedule, over due items, and action/no action rationale.		

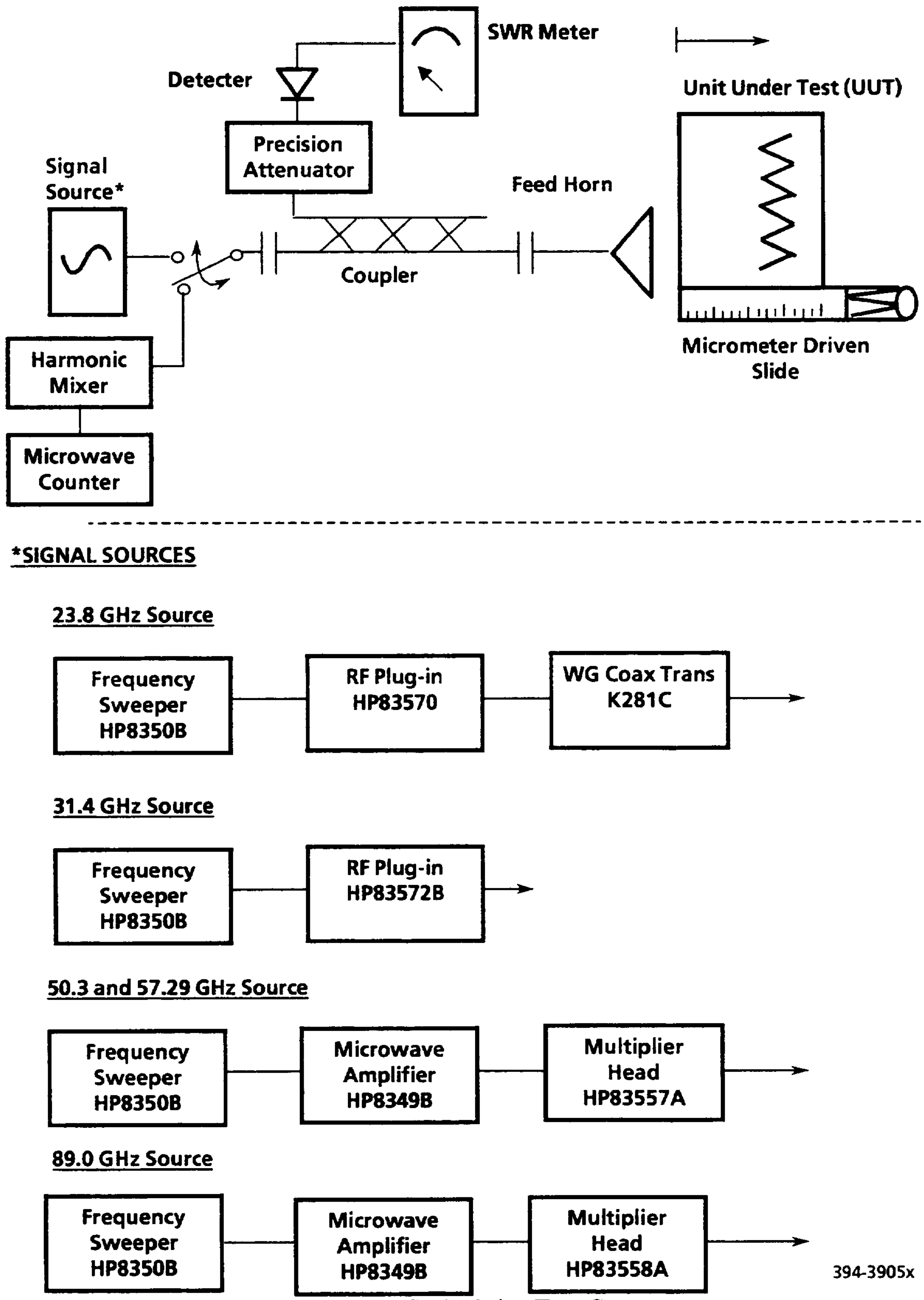


Figure 28 Emissivity Test Setup

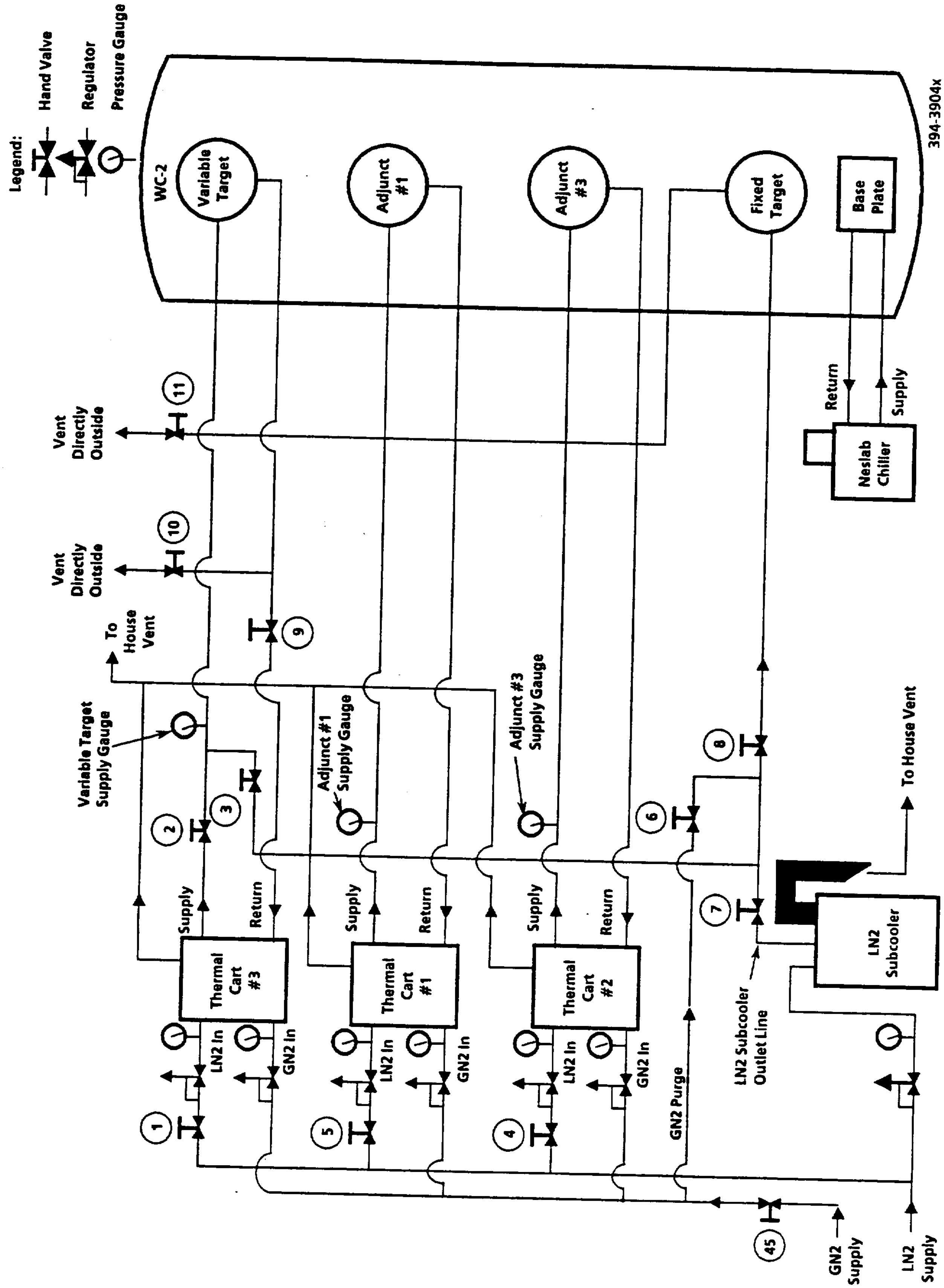


Figure 29 Block Diagram of AMSU-A2 Thermal Vacuum Facility Setup.

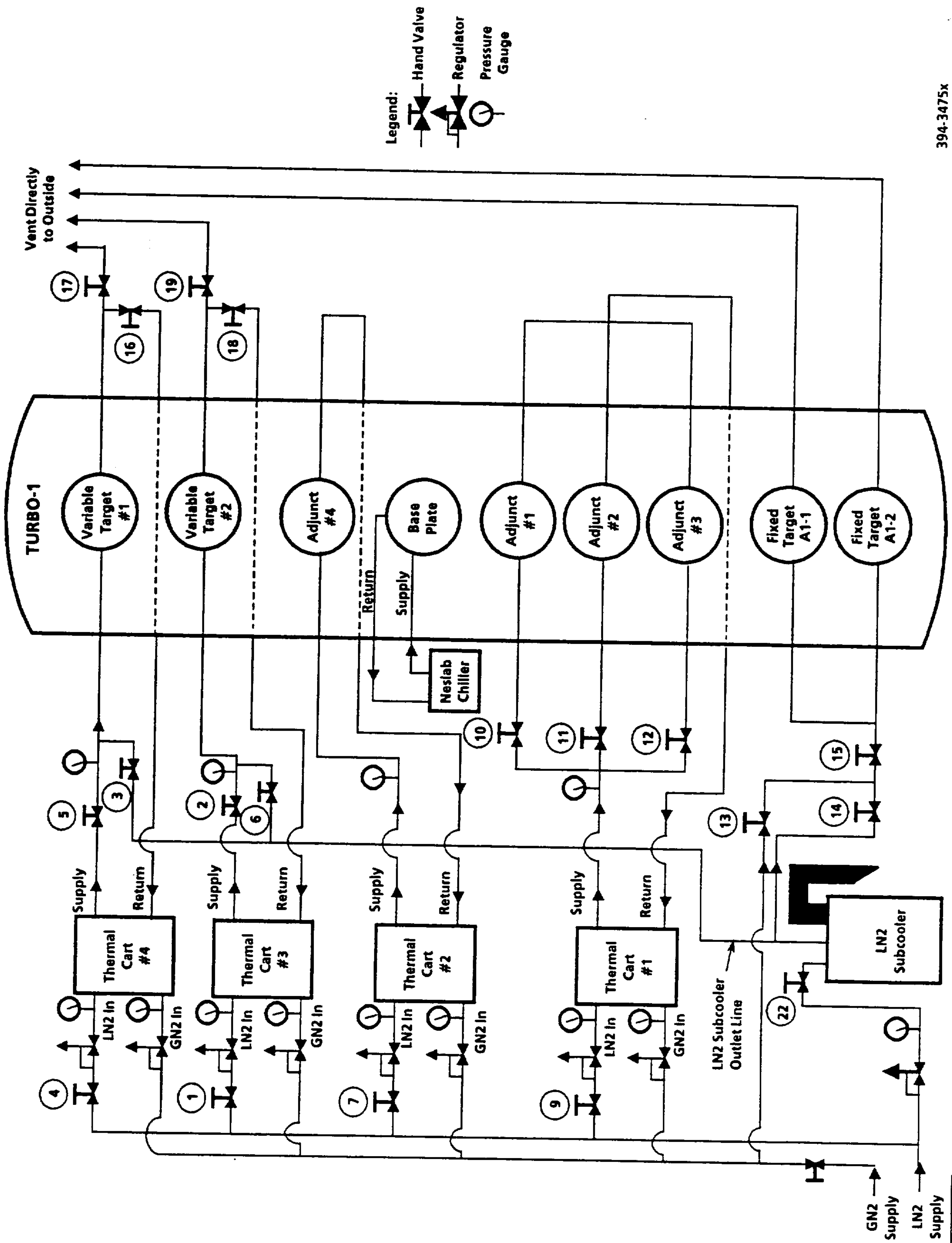


Figure 30 Block Diagram of AMSU-A1 Thermal Vacuum Facility Setup.

Table X AMSU-A2 Thermal Vacuum Test Equipment List

Item	Description	Model No.
1	Vacuum Chamber, Xiron	WC-2
2	Gauge Controller, Granville-Phillips	280
3	RGA	
4	Temperature Data Record	
5	Shroud Controller, Watlow	Series 922
6	Dual Gas Cart, Thermodynamic	12-157
7	Gas Cart No. 2, Thermodynamic	12-157
8	Refrigerated Bath/Circulator, NESLAB	RTE 110
9	LN2 Subcooler, CVI	61-2537-05001
10	Shroud Failsafe, Newport	INFT-0-01-2-TC
11	GN2 Failsafe, Newport	INFT-0-01-2-TC
12	Dual Gas Cart Failsafes, Eurotherm	92, 94C (2 ea.)
13	Gas Cart No. 2 Failsafe, Eurotherm	92, 94C (1 ea.)
14	Humidity Meter	TBS
15	TQCM	TBS

Table XI AMSU-A1 Thermal Vacuum Test Equipment List

Item	Description	Model No.
1	Vacuum Chamber	Turbo-1
2	Ion Gauge Controller	Type 290
3	Thermocouple Controller	Type 286
4	RGA, Hiden	TBS
5	Temerature Data Recorder, Fluke	Series 922
6	Gas Cart No. 1, Thermodynamic Eng.	12-157
7	Gas Cart No. 2, Thermodynamic Eng.	12-157
8	Gas Cart No. 3, Thermodynamic Eng.	12-157
9	Gas Cart No. 4, Thermodynamic Eng.	12-157
10	Refrigerated Bath/Circulator, NESLAB	RTE 110
11	LN2 Subcooler, CVI	TBS
12	Shroud Failsafe	TBS
13	GN2 Failsafe	TBS
14	Gas Cart No. 1 Failsafe	92, 94C (1 ea.)
15	Gas Cart No. 2 Failsafe	92, 94C (1 ea.)
16	Gas Cart No. 3 Failsafe	92, 94C (1 ea.)
17	Gas Cart No. 4 Failsafe	92, 94C (1 ea.)
18	Humidity Meter	TBS
19	TQCM	TBS

5.9 Other Calibration Techniques

Aerojet is not aware of calibration techniques, other than those described in this calibration plan, that will yield high-accuracy absolute-temperature measurements from the AMSU-A instrument. As a qualitative back-up, however, tipping calibration may be considered. Tipping calibration verifies the linear relationship between relative atmospheric absorption and cosec θ (θ = antenna elevation angle). Tipping calibration may be accomplished in a relatively straightforward manner by acquiring upward-looking brightness temperature measurements at various elevation angles. During the measurements, instrument stability and linearity are necessary. However, absolute calibration is not required. Tipping calibration is limited to the 23 GHz, 31 GHz, and 89 GHz window channels (and possibly 50.3 GHz) and requires clear weather conditions.

While making tipping measurements, a qualiitative test of channel 14 may also be conducted. As a consequence of high atmospheric absorption at channel 14 frequencies, channel 14 brightness temperature measurements should correspond very well with surface and near surface air temperatures.

5.10 Cross-Calibration

No cross-calibration activity is required for the AMSU-A instruments to be used on EOS.

5.11 Feasibility of Post-Launch Calibration

Post-Launch calibration validation of the AMSU-A system may be feasible in a manner similar to that conducted by the Naval Research Laboratory on the Special Sensor Microwave Imager (SSM/I)*, i.e., by comparing simultaneous radiometric measurements made by the AMSU-A system from the EOS spacecraft, and those made by aircraft underflights. Validation may be restricted to 23 GHz, 31 GHz, 50.3 GHz, and 89 GHz window channels, however, because of the impracticality of aircraft flights above 100,000 feet. At 30,000 feet, aircraft measurements may be conducted above nearly all atmospheric water vapor. These measurements should correspond to simultaneous overhead AMSU-A brightness temperature measurements providing a means of validating post-launch calibration of the AMSU-A window channels.

For temperature sounding channels, there are (from channel to channel) varying degrees of atmospheric attenuation between 30,000 feet and 100,000 feet. To obtain reasonable correspondence between aircraft and spacecraft brightness temperatures at these frequencies will require expremely high altitude flights. Post-launch instrument sensitivity (NEΔT) is easily determined from in-flight samples of internal warm blackbody and cosmic background calibration sources.

It is unlikely that a surface calibration network, i.e., temperature references restricted to the surface of the Earth, could provide meaningful validation of post-launch calibration. Surface features, such as land-water boundaries, can be utilized for validation of, and possibly improvement of, AMSU-A pixel geolocation. Geolocation measurements are restricted to window channels, and therefore, apply directly to the large reflector of the AMSU-A2 unit and the small reflector of the AMSU-A1 unit supporting 89 GHz. Geolocation of the second AMSU-A1 reflector must be referenced to the 89 GHz reflector through antenna range measurements.

* "DMSP Special Sensor Microwave/Imager Calibration/Validation" Final Report (Volume I), J. Hollinger, Naval Research Laboratory, 20 July 1989.

5.12 Instrument Sensitivity Analysis With Respect to Mathematical Models of the Instrument

Temperature sensitivity of the EOS/AMSU-A instrument is modeled in the Radiometric Math Model, Aerojet Report No. 10371. All factors affecting temperature sensitivity are discussed, quantified, and structured in a system NEΔT budget. The budget represents worst-case conditions in which all components and factors affecting NEΔT are at specification limits in worst-case directions. Margins are presented between worst-case predicted NEΔT and the specified NEΔT requirement, and between predicted and actual NOAA/AMSU-A NEΔT measurements.

In addition to the scan-by-scan NEΔT predictions above, an in-orbit algorithm is presented which, over the period of several antenna scans, will provide first-order correction of system nonlinearities, calibration bias errors, and an improvement of NEΔT through reduction of calibration amplification and correction of transfer function errors.

Section 6

NOTES

Abbreviations, acronyms and symbols

AIRS	Atmospheric Infrared Sounder
AMSU-A	Advanced Microwave Sounding Unit
CDRL	Contractual Data Requirement List
dB	decibel
EOS	Earth Observing System
FOV	Field of View
GHz	Gigahertz
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
IF	Intermediate Frequency
K	Kelvin
Km	Kilometer
LO	Local Oscillator
MHz	Megahertz
NASA	National Aronautics and Space Adminstration
NEΔT	Noise Equivalent Temperature
NIST	National Institute of Standards and Technology
PRT	Platinum Resistance Transducer
RGA	Residual Gas Analyzer
STE	Special Test Equipment
TBS	To be supplied
TQCM	Temperature Compensated Quartz Crystal Microbalance
TRR	Test Readiness Review
UUT	Unit under test
$\Delta G/G$	Short term gain fluctuation

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No. 10356	2. Government Accession No. ---	3. Recipient's Catalog No. ---
4. Title and Subtitle Earth Observing System (EOS)/Advanced Microwave Sounding Unit-A (AMSU-A) Calibration Management Plan		5. Report Date September 1994 6. Performing Organization Code ---
7. Author(s) Weldon Chapman		8. Performing Organization Report no. 10356 September 1994 10. Work Unit No. ---
9. Performing Organization Name and Address Aerojet 100 Hollyvale Avenue Azusa, California 91702		11. Contract or Grant. No. NAS 5-32314
12. Sponsoring Agency Name and Address NASA Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Final 14. Sponsoring Agency Code ---

15. Supplementary Notes

---

13. ABSTRACT *(Maximum 200 words)*

This is the Calibration Management Plan for the Earth Observing System/Advanced Microwave Sounding Unit-A (EOS/AMSU-A). It is provided in accordance with the EOS Instrument Calibration Management Plan, GSFC 420-03-01, paragraphs 3.1 and 3.2. The Calibration Management Plan establishes a definition of calibration requirements, calibration equipment, and calibration methods.

17. Key Words (Suggested by Author(s)) EOS Microwave System	18. Distribution Statement Unclassified - - Unlimited

19. Security Classif.(of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	61	---

NASA FORM 1626 OCT 86

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OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1994

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Earth Observing System (EOS)/Advanced Microwave Sounding Unit-A (AMSU-A) Calibration Management Plan

5. FUNDING NUMBERS
NAS 5-32314

6. AUTHOR(S)
Weldon Chapman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Aerojet
1100 Hollyvale Avenue
Azusa, California 91702

8. PERFORMING ORGANIZATION REPORT NUMBER
CDRL 018
10356
September 1994

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NASA
Goddard Space Flight Center
Greenbelt, Maryland 20771

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
---

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE
---

13. ABSTRACT *(Maximum 200 words)*

This is the Calibration Management Plan for the Earth Observing System/Advanced Microwave Sounding Unit-A (EOS/AMSU-A). It is provided in accordance with the EOS Instrument Calibration Management Plan, GSFC 420-03-01, paragraphs 3.1 and 3.2. The Calibration Management Plan establishes a definition of calibration requirements, calibration equipment, and calibration methods.

14. SUBJECT TERMS
EOS
Microwave System

15. NUMBER OF PAGES
61

16. PRICE CODE
---

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

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Form Approved
OMB No. 0704-0188

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	September 1994	Contractor Report

4. TITLE AND SUBTITLE
Earth Observing System (EOS)/Advanced Microwave Sounding Unit-A (AMSU-A)
Calibration Management Plan

5. FUNDING NUMBERS
422

6. AUTHOR(S)
Weldon Chapman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Aerojet
1100 W. Hollyvale
Azusa, CA 91702

8. PERFORMING ORGANIZATION REPORT NUMBER
Report 10356

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D. C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
CR-189376

11. SUPPLEMENTARY NOTES
Technical Monitor: M. Domen, Code 422

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category 61

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This is the Calibration Management Plan for the Earth Observing System/Advanced Microwave Sounding Unit-A. It is provided in accordance with the EOS Instrument Calibration Management Plan, GSFC 420-03-01, paragraphs 3.1 and 3.2. The Calibration Management Plan establishes a definition of calibration requirements, calibration equipment, and calibration methods.

14. SUBJECT TERMS
Earth Observing System (EOS), Advanced Microwave Sounding Unit (AMSU)

15. NUMBER OF PAGES
61

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited