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Topography Experiment (TOPEX) Software Document Series

Volume 1

TOPEX Radar Altimeter Development Requirements and Specifications Version 6.0, August 1988

Laurence C. Rossi

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May 2003

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May 2003

About the Series

The TOPEX Radar Altimeter Technical Memorandum Series is a collection of performance assessment documents produced by the NASA Goddard Space Flight Center Wallops Flight Facility over a period starting before the TOPEX launch in 1992 and continuing over greater than the 10 year TOPEX lifetime. Because of the mission's success over this long period and because the data are being used internationally to redefine many aspects of ocean knowledge, it is important to make a permanent record of the TOPEX radar altimeter performance assessments which were originally provided to the TOPEX project in a series of internal reports over the life of the mission. The original reports are being printed in this series without change in order to make the information more publicly available as the original investigators become less available to explain the altimeter operation and details of the various data anomalies that have been resolved.

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TOPEX Project

Radar Altimeter Development Requirements and Specifications

January 4, 1984 Original

January 25, 1984 Revision 1

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1.0 SCOPE

This document provides the guidelines by which the TOPEX Radar Altimeter hardware development effort for the TOPEX flight project shall be implemented and conducted. The conduct of this activity shall take maximum advantage of the efforts expended during the TOPEX Radar Altimeter Advanced Technology Model development program and other related Radar Altimeter development efforts. This document complies with the TOPEX Project Office document 633-420 (D-2218), entitled, "TOPEX Project Requirements and Constraints for the NASA Radar Altimeter" dated December 1987.

2.0 BACKGROUND

The Ocean Topography Experiment (TOPEX) is a NASA program designed to define the surface topography of the world's oceans with accuracy and precision useful for studies of the ocean circulation, the variability of this circulation, and tides. The primary instrument that will be used in the TOPEX Project to measure topography will be the Radar Altimeter. For the TOPEX Mission, the Radar Altimeter technology used will be improved to obtain an overall instrument precision of ≈2 centimeters for 3-second data averages with ionospheric correction. To achieve this level of precision the main enhancements that will be incorporated into the TOPEX Radar Altimeter will be: the addition of a second frequency to allow operation at 5.3 GHz, in addition to the primary channel of 13.6 GHz; the provision to operate the 13.6 GHz channel at a pulse repetition frequency (prf) of at least 4000 pulses per second; and an operating bandwidths for each channel of 320 megahertz. This two-frequency design will allow the removal of the significant range delays/errors resulting from ionospheric electron content, while the higher prf will improve the precision of height information over higher sea states.

TOPEX Radar Altimeter development activities have been on-going since 1980. Various system concepts have been studied and some breadboard hardware has been developed. In January 1983 the TOPEX Development Model Radar Altimeter activity was initiated. This effort was established to demonstrate the performance potential of a two-frequency (13.6 GHz and 5.3 GHz) Radar Altimeter design to achieve better than 2 centimeters precision on-the-bench, with suitable test equipment. This Development Model Radar Altimeter effort was completed in fiscal year 1986. The TOPEX Flight Project began in FY 1987, and the planned launch date of the TOPEX Mission is December 1991. A design mission lifetime of 3 years is planned. Two additional years of operations will be conducted if systems and resources permit.

The TOPEX Project will be conducted as a joint mission with the French Centre National D'Etudes Spatiales (CNES). This joint mission is entitled TOPEX/Poseidon. A CNES Radar Altimeter will be part of the TOPEX/Poseidon spacecraft sensor complement. The NASA and CNES Radar Altimeters will share a common antenna sub-system provided by NASA and will operate on a time-sharing basis during the mission. The joint NASA/CNES venture will utilize the ESA Ariane 42P launch vehicle system launched from French Guinea.

3.0 ASSOCIATED DOCUMENTATION

The following documents form a part of this specification to the extent specified herein. In case of a conflict between the requirements of this specification and any of the Controlling Documents (Section 3.1), the requirements of this specification shall govern. Conflicts shall be identified to GSFC who will resolve them with the JPL TOPEX Project Office.

3.1 Controlling Documents

"Ocean Topography Experiment (TOPEX) Requirements and Constraints for the Radar Altimeter," December 1987, JPL Document 633-420," D-2218.

"TOPEX Project Product Assurance Policies and Requirements," January 1988, JPL Document 633-106; D-2118, Rev. A.

TOPEX Project Environmental Design Requirements for Sensors," January 1988, JPL Document 633-405; D-5177.

"TOPEX Radar Altimeter Performance Assurance Requirements," April 1988, GSFC 672-30-001-PAR, Rev. B.

"TOPEX Specific Sensor Interface Specification for the NASA Radar Altimeter," FSC-968-GR1008.

"TOPEX General Instrument Interface Specification," FSC 968-GR1007.

"TOPEX Project Orbit Radiation Environment Requirements," JPL Document 633-290, D-2116, Rev. A, February 1, 1988.

3.2 Supporting Documentation

"Satellite Altimeter Measurements of the Ocean," Report of

the TOPEX Science Working Group, March 1981, JPL Document 400-111.

"TOPEX JPL Study Team Phase A Report," September 1981, JPL Document 1633-1.

"TOPEX Mission Description," July 1983, JPL Document D-601A.

"CNES Altimeter Interface Definition," August 9, 1983, Preliminary.

"CNES 5% Operations Plan," September 1983.

"TOPEX Measurement Analysis," James C. Frautnick, JPL, June 1, 1984.

"TOPEX/Poseidon Joint Working Group Final Report," December 1984, JPL Document D-2035.

"TOPEX Project Cost Guidelines," TPO 82-107 dated May 5, 1982.

"TOPEX Project Cost Guidelines," TPO 83-033 dated March 17, 1983.

"TOPEX Project Cost Guidelines," TPO 85-064 dated April 12, 1985.

"TOPEX Project Resources Guidelines," TPO 86-298 dated November 26, 1986.

"Conceptual Design Review Material for TOPEX Radar Altimeter Development Model," May 1983, APL Document SDO-6833.

"Critical Design Review Material for TOPEX Radar Altimeter Development Model," October 25, 1983, APL Document SDO-7063.

"Status Review Information for the TOPEX Radar Altimeter," Applied Physics Laboratory, November 15, 1984.

"TOPEX Radar Altimeter Interface Description Information," August 1, 1984, WFF-971.1-84-008.

"Preliminary Design Review Material for TOPEX Radar Altimeter," February 3-4, 1988, APL.

"TOPEX Project NASA Altimeter Interface Description," August 1985, JPL Document D-1807.

"Assessment of Atmospheric Height Uncertainties for High Precision Satellite Altimeter Missions to Monitor Ocean Currents," June 1980, APL Document SIR-8OU-018, NASA CR-156868.

"TOPEX Mission Total Dose Radiation Study," APL Internal Memo SOR-83024, March 3, 1983.

"The Influence of Rain and Clouds on a Satellite Dual Frequency Radar Altimeter System Operating at 13 and 35 GHz," May 20, 1983, APL Document SIR 83J-020.

"A Laboratory Study of Normal Incidence Microwave Backscattering at 5.625 and 13.5 GHz," C. L. Parsons, and L. S. Miller, in preparation.

"Ariane 40 Users Manual."

"Guidelines for Spaceborne Microwave Remote Sensors," NASA Reference Publication 1086, March 1982.

"Drawings, Engineering and Associated Lists" Category A, Form 3, DoD-D-1008.

"Contractor Prepared Monthly, Periodic, and Final Reports," S-250-P-1C.

"Handbook for Preparation of Work Breakdown Structures," NHB 5610.1.

3.3 Other

"Radar Altimeter Waveform Modeled Parameter Recovery," G. S. Hayne, August 1981, NASA Technical Memorandum 63294.

"Pulse-to-Pulse Correlation in Satellite Radar Altimeters," E.J. Walsh, Radio Science, Vol. 17, July-August 1982.

"A Tutorial Assessment of Atmospheric Height Uncertainties for High-Precision Satellite Altimeter Missions to Monitor Ocean Currents," October 1982, IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-20, No. 4.

4.0 SUPPORT PHASES

4.1 Development Phase

This phase extends from the initiation of the Radar Altimeter development activity through delivery of the Radar Altimeter and its associated ground support equipment (RASE, etc.) to the spacecraft integration contractor. Ground baseline testing and calibration shall be an integral portion of this phase.

4.2 Spacecraft Integration and Prelaunch Support Phase

This phase extends from the delivery of the Radar Altimeter and RASE to the spacecraft integration contractor and includes activity such as spacecraft/Radar Altimeter integration and systems level testing, then launch range processing support. Participation in the training of operations control center personnel shall also be included. Ground baseline testing in the integrated spacecraft environment shall be an integral portion of this phase.

4.3 Launch and Post-Launch Engineering Performance Assessment Phase

This phase extends from the initiation of the launch countdown to T+30 days. During this period those activities necessary to safely insure the survival of the Radar Altimeter through the launch phase shall be accomplished. Participation at the operations control center and elsewhere to ascertain the performance achieved in orbit, against the specified performance requirements stipulated herein, shall be accomplished. APL shall participate with GSFC in the on-orbit engineering assessment activities associated with the Radar Altimeter .

4.4 On-Call Mission Support Phase

Subsequent to the first 60 days, mission support will be requested on an as-needed basis. (For estimating purposes consider four 5-day trips per year, over a 3 year period to the operations control center at JPL, by 1-2 individuals with a subsequent 10 day associated documentation period to prepare and submit written memoranda/reports.)

5.0 TECHNICAL CHARACTERISTICS

5.1 Mission Profile

The final orbital parameters for the mission have not been selected, but it is assumed that they will differ little from the baseline orbit defined thus far. The baseline orbit parameters of significance to the altimeter are listed below:

(1) Altitude = 1334 ± 60 km

(2) Inclination = 62 to 66 deg (63.1 deg for reference orbit)

(3) Eccentricity $\leq$ 0.001

The design of the altimeter shall not preclude operation over the altitude range of 1000 to 1500 km. If necessary, on-orbit software reprogramming is acceptable to meet this requirement outside the design altitude range of 1334 ± 60 km.

5.2 Environments

The Radar Altimeter shall be capable of accomplishing the performance specified herein when exposed to the following:

5.2.1 Ionospheric Electrons

The Radar Altimeter shall operate over the TEC range of 0-200 x 10^{16} e/m^2.[1,2]

5.2.2 Radiation

The radiation environment shall be assumed to be that described in the "TOPEX Project Orbit Radiation Environment Requirements," JPL Document 633-290, D-2116, Rev. B, June 1988.

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[1]"Assessment of Atmospheric Height Uncertainties for High Precision Satellite Altimeter Missions to Monitor Ocean Currents," June 1980, APL Document SIR 80U-018, NASA CR-15686.

[2]"A Tutorial Assessment of Atmospheric Height Uncertainties for High Precision Satellite Altimeter Missions to Monitor Ocean Currents," October 1982, IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-20, No. 4.

5.2.3 Rainfall

The Radar Altimeter shall operate up to and including rainfall rates of 2 mm/hour.

5.2.4 Spacecraft Attitude

The spacecraft attitude control system will maintain the Radar Altimeter electrical boresight axis to within 0.42° of nadir, with a 99% probability when the requirements of Section 5.9.4 are met.

5.3 Ocean Surface Conditions

The ocean surface conditions shall be assumed to be characterized by the following:

$H_{1/3}$	1-20 Meters, See Figure 1.
Backscatter ($\sigma°$)[3]. . . .	Ku-band nominally 6-20 dB; C-band 4-20 dB (See Figure 2), and "A Laboratory Study of Normal Incidence Microwave Backscattering at 5.625 and 13.5 GHz" of Section 3.2.
Skewness	.1 ± 0.1.
Ocean Return Model . . .	See Appendix A.

[3]All performance calculations and tests shall account for discrete values of s° versus $H_{1/3}$ or wind speed.

5.4 Performance Requirements

5.4.1 Overall Mission Science Objectives

The TOPEX Mission has been established to determine the following geophysical parameters to the indicated levels:

Sea Surface Height	±13 cm for a 3 second average for dual-frequency operation
Surface Wind	±2 meters/sec
Ocean Waveheight	±10% or 0.5 m whichever is greater,
Ionospheric Total Electron Content.	$\pm 4 \times 10^{16} e/m^2$
Time Tag Error	100 μsec overall
Height Measurement Drift Error.	$\leq$ 2 centimeters.

5.4.2 On-Orbit Instrument Precision

The on-orbit instrument precision of the TOPEX Radar Altimeter under the conditions specified in paragraphs 5.2 and 5.3 shall be as follows. (Note: Unless otherwise specified, the following are based on both the Ku-Band and C-Band channels operating at 320 MHz bandwidth, 3-second averaged data, and correlated returns.[4])

[4]As defined in "Assessment of Atmospheric Height Uncertainties for High Precision Satellite Altimeter Missions to Monitor Ocean Currents," June 1980, APL Document SIR 80U-018, NASA CR-156868.

5.4.2.1 Height Measurement Uncertainty

At an averaged output rate of one height measurement per 3 seconds, over a minimum duration of 1 minute, the combined noise level[5] of the Ku and C-band data shall be that 68% of the Radar Altimeter height data shall be within

$$\pm 2.4 \text{ cm for } 2 \text{ M } H_{1/3}$$

$$\pm 2.7 \text{ cm for } 4 \text{ M } H_{1/3}$$

$$\pm 3.2 \text{ cm for } 8 \text{ M } H_{1/3}$$

of a fitted mean derived as follows: A raw surface height will be computed (by subtracting the full rate Radar Altimeter data from the ephemerides estimates and averaged) over 3 second periods. Geoid effects will be removed. The standard deviation of the residual height measurements based on 3 second data averaging will be computed in areas of interest.

Single channel height measurement uncertainty at Ku- and C-band shall be within

	Ku-Band[6]	C-Band[7]
2 M H1/3	± 2.0 cm	± 3.1 cm/± 6.3 cm
4 M H1/3	± 2.2 cm	± 3.5 cm/± 8.0 cm
8 M H1/3	± 2.6 cm	± 4.3 cm/± 8.4 cm

using the same fit process defined above.

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[5]As defined in "Assessment of Atmospheric Height Uncertainties for High Precision Satellite Altimeter Missions to Monitor Ocean Currents," June 1980, APL Document SIR 80J-018, NASA CR-156868.

[6]at 320 MHz bandwidth.

[7]at 320 MHz and 100 MHz bandwidth.

5.4.2.2 Sea State ($H_{1/3}$)

Provide at Ku-band and C-band at a 1 per second rate a measurement of $H_{1/3}$ to within 10% or 50 cm (accuracy), whichever is larger, of the true sea state over the $H_{1/3}$ range of 1 to 20 meters.

5.4.2.3 Radar Reflectivity (Backscatter Coefficient)

The backscatter coefficient will be determined primarily from the receiver automatic gain control (AGC).

The precision of the AGC measurement shall be ± 0.25 dB.

The AGC measurement in conjunction with the calibration mode data and appropriate ground processing shall allow for determination of radar backscatter coefficient to an accuracy of within ± 1.0 dB, and to a precision of ± 0.25 dB.

5.4.2.4 Ionospheric Content

Provide a measurement of total electron content to within $\pm 4 \times 10^6$ e/m^2.

5.4.2.5 Velocity

Provide a measurement of altitude rate of change ($\dot{h}$) for combined or single channel operation to within 1 centimeter/sec of the fit determined h over the range of 0 to ± 50 meters/sec using a first order fit to 3 second averaged altitude data.

5.4.2.6 Acceleration

Provide a height correction for acceleration-induced lag for combined or single channel operation under acceleration ($\ddot{h}$) conditions of < 1 meter/sec^2 for use in ground processing. This correction shall be good to within 0.2 centimeters or less.

5.4.2.7 Acquisition and Data Quality Settling Time

Provide data of the specified quality within 5 seconds of the initiation of acquisition over the ocean for either combined or single channel operation.

5.4.2.8 Time-Tag Error

The time-tag error within the Radar Altimeter shall be $\leq$ 10 usec. Time-Tag Error is defined as the difference between the time the altitude measurement is performed by the Radar Altimeter and the time which is inserted in the TM data within the Radar Altimeter. This shall be the maximum allowable time-tag error at the Radar Altimeter interface to the spacecraft. It does not include any clock errors which may exist in the spacecraft timing system.

5.4.2.9 Absolute Internal Calibration

An internal absolute calibration ability for both the Ku-band and C-band channels shall be provided which:

a) monitors changes in height bias due to internal hardware aging, etc., to within 1.5 centimeters;

b) monitors gate bias and gain to within 1% of maximum average value at nadir and 0 $H_{1/3}$;

c) monitors transmit power to ± 1 dB;

d) monitors changes in AGC values indicative of RF path loss, RF output power, receiver gain, and processor performance with a precision of ± 0.25 dB and an accuracy of ± 0.25 dB.

5.4.2.10 Height Measurement Drift Rate

The maximum residual height drift rate shall be less than 2 centimeters per 10 days during combined or single channel operation, after appropriate calibration and processing via temperature correction lookup tables, etc.

5.4.3 Laboratory Instrument Precision

Unless otherwise specified the following are based on both the Ku-Band and C-Band channels operating at 320 MHz bandwidth, 3-second averaged data, and correlated returns.[8] Each side (A&B) of the altimeter shall meet the following requirements:

5.4.3.1 Height Measurement Uncertainty

At an averaged output rate of one height measurement per 3 seconds, over a minimum duration of 3 minutes, the combined noise level of the Ku- and C-band data when subjected to the model

[8]"Pulse-to-Pulse Correlations in Satellite Radar Altimeters," E. J. Walsh, Radio Science, Vol. 17, July-August 1982.

defined in Appendix A shall be such that 68% of the Radar Altimeter height data shall be within

± 1.7 cm for 2 M $H_{1/3}$

± 2.1 cm for 4 M $H_{1/3}$

± 3.0 cm for 8 M $H_{1/3}$

of a least-squares fit to a linear trend. In the zero-rate-case the precision shall be taken as the standard deviation from a straight mean.

Single channel height measurement uncertainty at Ku-band and C-band shall be within

	Ku-Band[9]	C-Band[10]
2 M $H_{1/3}$ (simulated)	± 1.4 cm	± 2.3/± 4.1 cm
4 M $H_{1/3}$ (simulated)	± 1.7 cm	± 2.8/± 5.5 cm
8 M $H_{1/3}$ (simulated)	± 2.5 cm	± 4.1/± 7.4 cm

using the same <u>fit process</u> defined above.

5.4.3.2 <u>Sea State $H_{1/3}$</u>

Provide at Ku-band and C-band at a 1 per second rate a measurement of $H_{1/3}$ to within 10% or 50 cm (accuracy), whichever is larger, of the simulated sea surface over the $H_{1/3}$ range of 1 to 20 meters.

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[9]at 320 MHz bandwidth

[10]at 320 MHz and 100 MHz bandwidth, respectively

5.4.3.3 Ionospheric Content

Same as paragraph 5.4.2.4.

5.4.3.4 Velocity

Same as paragraph 5.4.2.5.

5.4.3.5 Acceleration

The Radar Altimeter shall remain locked-up through simulated accelerations within the range of -1 to +1 meter/sec^2, and be able to determine the induced lag to within ± 0.2 cm.

5.4.3.6 Acquisition and Data Quality Settling Time

Same as paragraph 5.4.2.7 over simulated ocean surfaces.

5.4.3.7 Time Tag Error

Same as paragraph 5.4.2.8.

5.4.3.8 Absolute Internal Calibration

An internal absolute calibration capability for each channel shall be provided which:

a) monitors changes in height bias on a point source return to within 1.5 centimeters,

b) monitors gate bias and gain to within 1% of maximum average value at 0° off-boresight and simulated 0 $H_{1/3}$,

c) monitors transmit power with a repeatability of ± 1 dB with respect to actual transmit power and approximately a square law power response,

d) same as paragraph 5.4.2.9d.

These performance parameters will be verified during the ground test program.

5.4.3.9 Height Measurement Drift Rate

Same as paragraph 5.4.2.10.

5.4.3.10 Initial Absolute Height Bias

The initial absolute height bias of the Radar Altimeter shall be measured to within 0 ± 10 centimeters with a goal of ±1.5 centimeters for combined or single channel operation. This includes path delays, timing, and internal signal shape effects.

5.4.3.11 Initial AGC Calibration

The initial calibration of the AGC relative to known input signal levels shall be $\leq$ ± 0.1 dB.

5.4.3.12 Point Target Response

Knowledge of each channel's point target response via a calibration shall be within 1% of the peak mean amplitude response.

5.4.3.13 Functionality

The Radar Altimeter shall be functionally tested at a simulated altitude of 1000 km. Performance testing is not required at this altitude. Reprogramming of the onboard microprocessor is an acceptable way to accomplish this.

5.5 System Characteristics

In addition to the performance requirements stipulated in paragraph 5.4, the Radar Altimeter shall encompass the following system characteristics. The altimeter is composed of completely redundant chains (except for the MTU and antenna) both of which are comprised of Ku and C-band channels.

5.5.1 Command Capability

The Radar Altimeter shall be commandable to various modes through the spacecraft interface via ground up-link as specified in FSC-968-GR1008.

5.5.2 Programmability

The complete Radar Altimeter-resident operational program(s) shall be capable of being reprogrammed through the spacecraft interface via ground up-link.

5.5.3 Operational Frequencies and Bandwidths

Each Radar Altimeter chain shall consist of two channels capable of operating at 13.6 GHz (± 160 MHz) and 5.3 GHz (± 160 MHz and ± 50 MHz). They shall operate either in combination or independently. Each channel shall utilize a chirp acquisition sequence. The coarse acquisition will be accomplished with a 5 MHz bandwidth (coarse chirp). After this acquisition cycle is complete then the Radar Altimeter shall automatically switch to the 320 MHz bandwidth or fine chirp mode of acquisition until it is locked up.

5.5.4 Bandwidth Switching

The 5.3 GHz channel shall be capable of switching operations from the 320 MHz bandwidth to the 100 MHz bandwidth via ground command.

5.5.5 Waveform Samples

The Radar Altimeter shall provide 128 waveform samples per channel as characterized in Figure 3, which in-turn shall be combined to 64 allocations per channel for the telemetry data stream. During dual frequency operation, waveform samples shall be made available for one channel at 10 sets per second and for the other channel at 5 sets per second. The Radar Altimeter shall also be capable of outputting 10 sets per second for either channel. When the Radar Altimeter is operating in only a single channel configuration, waveforms shall be output at 10 sets per second.

5.5.6 PRF

The Radar Altimeter Ku-band channel PRF shall be nominally 4000 pps minimum and the C-band channel shall be nominally 1000 pps minimum. See Figure 4.

5.5.7 Probability of Success

With both the Ku-Band and C-Band channels operating, the Radar Altimeter reliability shall be such that the probability of accomplishing 3 years of on-orbit operations is at least 90%.

In order to meet this requirement the Radar Altimeter shall be configured as two parallel chains (A&B), each of which shall meet the requirements of this specification. Ground commands will determine which chain (A or B) is operational. Both chains shall be fully calibrated and tested.

Also, it is desired that the Radar Altimeter be capable of operating at least 2 additional years on-orbit.

5.5.8 Antenna Subsystem

The Radar Altimeter shall include an integral antenna subsystem capable of also being fed by the CNES/Poseiden 13.6 GHz Radar Altimeter. All the hardware necessary to couple the CNES/Poseidon Radar Altimeter to the antenna and isolate it from the NASA TOPEX Radar Altimeter shall be provided within the NASA Radar Altimeter effort described by this document. It is required that at least 30 dB (with a goal of 40 dB) of isolation be provided between the output port of either Radar Altimeter to the input of the other.

5.5.9 Compatibility

The Radar Altimeter 13.6 and 5.3 GHz channels shall be operationally compatible with each other. They shall be compatible with the independently supplied CNES/Poseidon 13.6 GHz Radar Altimeter described in the associated documentation listed in Section 3. The NASA/TOPEX and CNES/Poseidon Radar Altimeters must never be operated simultaneously in their respective "Track Modes." There must exist no mode in which the NASA/TOPEX Radar Altimeter can transmit a pulse into the open CNES/Poseidon receiver or vice versa without at least 30 dB of isolation.

5.6 Altimeter Modes

As a minimum, the following modes are required for each channel of the Radar Altimeter. Although initiation of these modes will be by ground command (real time or on-board spacecraft computer issued), the Radar Altimeter shall be internally protected against improperly sequenced commands. Simultaneous operation of two like modes, one per channel, is a requirement. Simultaneous operation of two different modes per channels is not a requirement. The Ku-Band channel or C-Band channel shall be capable of operating independently from each other if one is in a "non-Track" mode.

5.6.1 Off Mode

In this mode, the Low Voltage Power Supply (LVPS) TWTA power supply and C-band SSA power supply shall be OFF. No power shall be applied internal to the Radar Altimeter. Spacecraft power may or may not be applied to the spacecraft Radar Altimeter interface. In all the remaining modes the LVPS is activated and the Radar Altimeter is in the ON state.

5.6.2 Idle - (Low Power Mode)

In this mode, the Radar Altimeter shall be in its least active state. The power consumption of the entire Radar Altimeter (Ku-band and C-band) in this mode shall not exceed 150 watts. In this mode the transmitters shall be in an inactive state (no power applied).

5.6.3 Standby Mode

In this mode the transmitters shall be in an active state (power applied) but not transmitting. Waveform sampler output shall be available. AGC shall be operational. The power consumption of the Radar Altimeter in this mode shall not exceed 200 watts.

5.6.4 Calibrate Mode

5.6.4.1 Calibrate I

This mode shall be used to calibrate the Radar Altimeter height bias, AGC characteristics, receiver characteristics and Signal Processor characteristics. It shall be available for both channels.

Once the Calibrate Mode is selected it shall be automatically sequenced through 17 steps.

For steps 1 through 16 the transmitted chirped pulses shall be inserted into the receiver through a calibrated attenuation path whose attenuation shall be incremented in steps of 2 dB over a range of 32 dB centered at a pre-determined nominal operating point which is indicative of the normal operating signal level. Dwell time at each attenuation setting shall be at least 5 seconds.

5.6.4.2 Calibrate II

For this mode the receiver shall operate with no injected signal (noise only, no transmitted chirped pulses, 0 attenuation). The filter bank shall be swept in range. Waveform sample data and receiver levels shall be made available to the spacecraft telemetry. The AGC circuitry shall be operational in this mode.

The power consumption of the Radar Altimeter in this mode shall not exceed 225 watts.

5.6.5 Track Mode 1

This shall be the nominal operational tracking mode. Tracking parameters for this mode shall be optimized during the early design stages. The Ku band channel and the C-band channel shall operate over a 320 MHz bandwidth. The power consumption for this mode shall not exceed 225 watts.

The telemetry shall be the nominal format with either Ku or C-band waveforms available at a 10 per second rate, while the other channels waveforms shall be available at 5 per second rate. Selection of which waveforms shall be available at the 10 per second rate will be by ground command.

5.6.6 Track Mode 2

This mode shall be similar to Track Mode 1. However the C-band channel shall operate in the 100 MHz bandwidth mode only. The altimeter power consumption shall not exceed 225 watts.

The telemetry format shall be the same as for Track Mode 1.

5.6.7 Track Mode 3

This mode shall be similar to Track Mode 1 except only the Ku-band channel shall be operational. It shall operate with a 320 MHz bandwidth.

The power consumption of the Radar Altimeter shall not exceed TBD watts.

The telemetry format shall be similar to Track Mode 1 except zeros will be inserted in place of any C-band channel data.

5.6.8 Track Mode 4

This shall be an operational tracking mode wherein certain system parameters may be varied (user selectable). These parameters shall be variable via ground data commands. A default set of parameters shall be stored in memory for operation of this mode before any changes or uploads are made. Single parameters or multiple parameters may be changed in this mode via 1 to TBD (63) ground commands (block load commands). This is not considered the ground reprogrammable mode (see Section 5.6.9). In this mode, parameters may be varied under fixed guidelines to achieve optimum Radar Altimeter performance.

5.6.9 Up-Link Program Mode

In this mode the Adaptive Tracker Unit microprocessor shall be reprogrammable via ground command. The standard operational program(s) and the executive routine for command decoding shall be resident and always available for execution via ground command.

5.6.10 Dump Mode

In this mode the program memory shall be dumped via the TM link. The contents of the active adapter tracker memory shall be dumped in the telemetry.

5.6.11 Test Modes

Provisions shall be made for special test modes to be used primarily for Radar Altimeter ground checkout, calibration, and testing purposes as required.

At least the following test modes shall be implemented.

5.6.11.1 Test Mode 1

The Radar Altimeter shall only transmit the coarse chirp pulse (5 MHz bandwidth). The telemetry format shall be the same as for the normal pulsed operation. The Radar Altimeter shall track the ocean surface in this mode. The 5 MHz bandwidth shall be used in the initial acquisition sequence.

5.6.11.2 Test Mode 2

The Radar Altimeter shall only transmit the fine chirp pulse (320 MHz). The telemetry format shall be the same as for normal chirp pulse operation. Tracking of the ocean surface shall be performed.

5.6.11.3 Test Mode 3

When commanded to this mode the Radar Altimeter Calibrate Mode attenuator shall be frozen in its present state.

5.6.11.4 Test Mode 4

When commanded to this mode the Radar Altimeter Digital Filter Unit filter bank shall be swept in range to detect interference. There shall be no RF transmission.

5.6.11.5 Test Mode 5

When commanded to this mode the Radar Altimeter shall operate with a threshold type tracker only. The Radar Altimeter shall track in this mode.

5.6.11.6 Test Mode 6

When commanded to this mode, only the track mode error shall be used to update the tracker. The Radar Altimeter shall track in this mode.

5.6.11.7 Test Mode 7

In this mode the Radar Altimeter shall transmit RF energy. However, the height tracking loop and AGC loops shall be frozen at fixed points.

5.6.11.8 Test Mode 8

In this mode the synchronizer control frame shall not be updated with the alpha beta tracker (previous values shall be sent at the burst rate). The Primary Height Rate will be set to zero.

5.6.11.9 Test Mode 9

Same as Test Mode 8 except the previous Primary Height Rate shall update the syncronizer at the burst rate.

5.6.12 Other Modes

Many other modes (configurations) shall be available via a combination of pulse commands, data commands and use of the Track Mode 4 option.

It is intended that Track Mode 1 shall be the nominal operating mode during the TOPEX mission. Calibration modes will be used periodically throughout the mission to monitor system performance.

5.7 Altimeter Data Interface

The Radar Altimeter shall provide scientific, and status and engineering data for inclusion in the spacecraft telemetry. The spacecraft will provide for clocking-out these data to the telemetry data stream. All data with the exception of indicator bits shall have a binary weighting and shall be presented to the spacecraft telemetry system ordered from most significant bit (MSB) to least significant bit (LSB) with the MSB occurring first in the bit stream. Engineering data, consisting of all monitored voltages, currents, temperatures, etc. not requiring reporting each altimeter minor frame, shall be subcommutated and identified.

Science data, consisting of 9824 bits of serial digital data, will be clocked into the data stream by a serial digital data channel provided by the spacecraft. These bits will represent approximately 1 second of Radar Altimeter data. This data will be asynchronous with the spacecraft data frames.

Another serial digital data channel shall be provided for Radar Altimeter engineering data at a rate of 125 bps. This channel's common data and clock lines shall be shared with the science data channel with separate enable lines associated with each.

Exclusive of the Radar Altimeter temperature monitoring that is included in the its telemetry stream, provision shall be made for mounting of TBD thermistors to monitor Radar Altimeter/ spacecraft thermal interfaces, and key internal (TBD) Radar Altimeter subsystem temperatures when the Radar Altimeter is either on or off. Thermistor reference voltage, signal conditioning and sampling will be provided by the spacecraft. These thermistors' data will be a part of the spacecraft housekeeping telemetry stream. Digital monitoring of relays (Tell Tales) will be handled by the spacecraft and will be part of the spacecraft housekeeping telemetry stream.

The Radar Altimeter shall provide for interfacing with a redundant spacecraft telemetry system.

5.8 Physical Constraints

Power - 225 watts max except where noted (paragraphs 5.6.1, 5.6.2, 5.6.3)

Mass - 192 kilograms without contingency, Radar Altimeter baseplating will be provided by the spacecraft contractor

Antenna Diameter - $\leq$ 1.5 m

Volume - minimum 0.67 ± .05 m^3

5.9 Interface Constraints

5.9.1 Telemetry

Redundant Serial Data System

Science Data - 9750 bps

Engineering Data - 125 bps

5.9.1.1 Science Telemetry

The Science Telemetry available from the Radar Altimeter shall consist of the information contained in Appendix B.

5.9.1.2 Engineering Telemetry Data

The engineering telemetry data available from the altimeter shall consist of the information contained in Appendix C.

5.9.2 Timing

5.9.2.1 Time of Day

The Radar Altimeter shall be capable of accepting a 48 bit serial data time tag (LSB = 1 μsec) by using a sample enable line which latches spacecraft time. Time shall then be clocked into the Radar Altimeter by its own internal clock (208 KHz).

5.9.2.2 Reference Signal

The output of a stable redundant 5 MHz oscillator will be provided to the Radar Altimeter. This shall be the basic reference for all internal timing signals, pulse repetition frequencies and radio frequencies.

5.9.3 Command

The Radar Altimeter shall be capable of being commanded (modes/configuration) by the following types of commands:

5.9.3.1 Discrete Commands

The spacecraft will provide 18 discrete commands provided at a maximum rate of 1 per second. This voltage will operate relays and will be high for 35 ms. It will consist of a 28 v pulse and associated ground closure.

5.9.3.2 Data Commands

The spacecraft will provide 2 serial digital command channels for Radar Altimeter use. Separate command enables are required for each channel. One set of clock and data signals is required from the spacecraft for the two channels. The commands will consist of 16 bit words, transferred in a serial manner, at a maximum data rate of 1000 bps.

The final Radar Altimeter command structure will be defined in the TOPEX Specific Sensor Interface Specification for the NASA Radar Altimeter FSC-968-GR1008 by the spacecraft contractor.

5.9.4 Alignment

Provision shall be made for mechanical alignment of the Radar Altimeter antenna electrical boresight to a known marked reference surface (or optical reference mirrors) within an absolute uncertainty of less than .05°. Mechanical and/or thermal distortions caused by the launch and in-orbit environments shall not cause the alignment of the Radar Altimeter electrical boresight to vary outside this value.

5.9.5 Mass Properties

Altimeter mass properties including mass, center of gravity, moments of inertia, and products of inertia shall be determined, documented and periodically updated as required for spacecraft mass properties determination. The overall Radar Altimeter weight report shall be updated monthly.

The coordinate system used for mass properties data shall be defined and shall be compatible with that used on the spacecraft.

Required measurement accuracies are as stated below:

mass	± 0.1 LB or ± 0.2%
C.G.	± .06 in.
moments of inertia	± 1.5%
products of inertia	± 2%

5.10 Power Constraints

5.10.1 Voltage

The Radar Altimeter shall utilize unregulated satellite bus power. The dc bus voltage characteristics are 28^{+7}_{-5} volts dc (measured at the altimeter input) supplied redundantly to the to the Radar Altimeter. Voltage excursions outside of these limits shall not damage the Radar Altimeter.

5.10.2 Operating

The Radar Altimeter shall operate during the planned TOPEX/Poseidon Mission lifetime when the CNES Radar Altimeter is OFF. The current baseline Mission Plan is that the NASA Radar Altimeter will operate 95% of the time, and the CNES Radar Altimeter will operate 5% of the time.

5.10.3 Overcurrent Protection

All power supplies shall incorporate current limiting circuitry which will cause automatic shut-down in the event the input current exceeds 125% to 150% of peak operating current during operations other than turn-on.

5.10.4 Overcurrent Protection Over-Ride

The low voltage power supply protective features shall be capable of being bypassed by ground pulse command.

5.10.5 Current Surge

The Radar Altimeter shall use a sequenced turn-on with associated transients as follows:

a. The battery bus is applied by the spacecraft.

b. TBD seconds later the Low Voltage Power Supply will be commanded on. The rate of change of current shall not exceed 20 ma/usec, steady state current of 5 amps shall be attained within 50 msec, and the maximum transient current shall not exceed 6.25 amps.

c. 5 seconds later, the Ku-band TWTA shall be commanded on. The rate of change of current shall not exceed 50 ma/usec, steady state current of 0.36 amps shall be attained within 500 msec, and the maximum transient current shall not exceed 0.5 amps.

d. TBD seconds later, the C-band Solid State Amp shall be commanded on. The rate of change of current shall not exceed 20 ma/usec, steady state current of 1 amp shall be attained within 200 msec, and the maximum transient current shall not exceed 3.0 amps.

e. The TWTA Beam can be commanded on after the filament has warmed up for approximately 3-1/2 minutes. The rate of change of current shall not exceed 50 ma/usec, steady state current of 2.5 amps shall be attained within 250 msec, and the maximum transient current shall not exceed 7.0 amps.

5.10.6 Grounding and Bonding

Grounding and bonding shall adhere to requirements of the spacecraft to instrument interface control documents FSC-968-GR1008 and FSC-968-GR1007.

5.11 Electromagnetic Interference

The Radar Altimeter shall be designed to comply with the TOPEX Project Electromagnetic Control Plan, and its associated requirements which will measure at or over specific frequencies and bandwidths the following as a minimum:

1. Conducted Emissions, Unregulated Power Lines
2. Conducted Emissions, Signal and Command Lines
3. Conducted Susceptibility, Unregulated Power Lines
4. Spike Conducted Susceptibility, Unregulated Power Lines
5. Radiated E Field Emissions
6. Magnetic Induction Field Spike
7. Radiated Susceptibility
8. Radiated Emissions, Spurious and Harmonic
9. Transient In-rush Current, Power Line
10. Transient Turn-Off Voltage, Power Line
11. Bonding Measurement

This Electromagnetic Control Plan and associated requirements will be provided by the spacecraft contractor.

5.12 Thermal Design

The Radar Altimeter Thermal Control System shall be designed in cooperation with the spacecraft contractor in such a way that the Radar Altimeter component internal temperatures are maintained within their allowable limits during testing and flight launch and in-orbit.

The Spacecraft Thermal Control will be accomplished by the use of heaters, heat pipes, radiators, louvers, MLI blankets, and paints, and will provide mounting deck temperatures between 0 and 35°C with a maximum gradient of 15°C among all Radar Altimeter subsystems within the TOPEX Instrument Module.

The temperature limits the Radar Altimeter baseplate shall be exposed to are as follows:

	Hot	Cold	Comments
Flight	35°C	0°C	VACUUM, Altimeter operating within specification
Design	45°C	-10°C	VACUUM, Altimeter operating within specification
Test	55°C	-23°C	VACUUM, Altimeter operating out of specification acceptable
Survival	60°C	-28°C	VACUUM, Altimeter must survive with power OFF

Provision shall be made for the implementation and operation of thermal control heaters. These heaters will be provided by the spacecraft contractor. Provision shall be made for the implementation of spacecraft contractor provided temperature sensors, powered and conditioned by the spacecraft data handling subsystem, for readout in the spacecraft housekeeping data when the Radar Altimeter is "On" or "Off."

5.12.1 Thermal Gradients Across Base Plates

Gradients between the baseplates of any Radar Altimeter subsystems (units) during this normal operating mode will not exceed 15°C between any two points. This requirement is primarily on the spacecraft thermal control system.

5.12.2 Transients

Transients during operating and non-operating modes shall not exceed 10°C per hour when interfaced with the spacecraft thermal control system.

5.12.3 Spacecraft Thermal Design Interaction

Provision shall be made for interaction with the spacecraft contractor to ascertain the design and performance adequacy of the spacecraft/Radar Altimeter thermal interface as specified in FSC 968-GR1008.

5.13 Thermal Testing

The Radar Altimeter shall as a minimum meet the requirements of the TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, 672-30-001 PAR Revision B.

5.14 Radiation and Particles Environment

The TOPEX Radar Altimeter shall be designed and developed to operate over the predicted TOPEX mission cumulative electron and proton dose quantities and predicted particle bombardment rates as described in the controlling documents specified in Section 3.1.

5.15 Magnetic Properties

The total uncompensated magnetic moment of the Radar Altimeter in the flight configuration shall be less than 2.0 ampere-turn-meter, and shall be determined by analysis to an accuracy of 0.10 ampere-turn-meter. See also FSC 968-GR1008.

5.16 Mechanical Design

The Radar Altimeter shall be designed to withstand the mechanical environments of the TOPEX mission induced by a launch using the Ariane 42P launch vehicle, and testing as defined in the

"TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, 672-30-001 PAR Revision B.

5.17 Pressure/Vacuum Operation

The Radar Altimeter shall be capable of operation at normal ambient pressures for bench and spacecraft level tests. It shall also operate with minimal changes in calibration or operating characteristics in a pressure of 10^{-5} torr or less. It shall not be required to operate in transition between these pressure extremes. The Radar Altimeter shall not be sealed; outgassing or pressure equalization ports shall be provided, and these shall be RF shielded. After going from ambient room pressure to vacuum (the transition shall be 15 minutes or less to achieve 10^{-4} torr or less) the Radar Altimeter will not be required to operate for at least 12 hours. After going from vacuum to ambient room pressure, immediate operation is required.

5.18 Mechanical Testing

Altimeter structural/mechanical testing shall as a minimum meet the requirements of the "TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, 672-30-001 PAR Revision B.

5.19 Radar Altimeter Software

The deliverable requirements for software are specified in Section 13. It shall also be required that any existing programs, modifications to existing programs or new programs be specified, documented and described to GSFC before implementation. After CDR the design shall be under "Change Control" and after PER the code shall be under "Change Control".

6.0 MAINTAINABILITY, TEST POINTS AND INTERCHANGEABILITY

6.1 Maintainability

External tuning and alignment adjustments shall be kept to a minimum. All such adjustments, if required, shall be readily accessible after the Radar Altimeter system is installed in the spacecraft.

6.2 Test Points

The Radar Altimeter shall provide, on a separate connector, monitor signals for system level test and troubleshooting purposes. All signals brought to this connector shall be buffered to prevent external loading and/or short circuits from affecting Radar Altimeter operation.

Signals for subsystem level testing and troubleshooting shall be provided at test points accessible external to the subsystem package such that package integrity shall not be violated.

6.3 Interchangeability

All units, assemblies, and subassemblies bearing the same part number shall be functionally and dimensionally interchangeable. Furthermore, no adjustments shall be required when hardware is interchanged. Separate calibrations shall be provided for all units, assemblies, and subassemblies.

7.0 ENGINEERING REQUIREMENTS

The practices and procedures required by the "TOPEX Radar Altimeter Performance Assurance Requirements," document April 1988, GSFC 672-30-001-PAR, Revision B, shall be accomplished.

7.1 Documentation

All required drawings delivered for the Radar Altimeter shall conform to the requirements of DoD-D-1000B, Category A, Form 3. All other drawings delivered shall conform to good engineering practice.

7.2 Mechanical and Electrical Drawings

Documentation in these categories shall include all working drawings and lists of drawings used during the course of the Radar Altimeter development.

7.3 Test and Calibration Plans, Procedures, Specifications and Reports

Documentation in these categories shall include all test plans, procedures, specifications, and reports used in evaluating the adequacy of the Radar Altimeter design in meeting the requirements of this specification. In addition, copies of specifications of vendor-procured items shall be included.

7.4 Calibrations and Functional Descriptions

Documentation shall include necessary data for reduction of ground test and orbit data to engineering units and applicable corrections for the scientific data.

7.5 Log Books

Throughout the inspection, test phase, and the operational phase prior to delivery of the Protoflight Unit Radar Altimeter and RASE, a separate logbook shall be maintained for each major component or subsystem, as well as for the software for each, as a means of documenting the continuous history of these items. Each log shall be identified as to the equipment or software to which it pertains, shall be maintained in chronological order, and shall account for all periods of time including idle periods and any shipment of the item. Subsequently, throughout the spacecraft acceptance test program, launch range processing, operations control center training period, launch, and the T+30 day checkout period, similar logbooks shall be maintained.

7.5.1 Content

Entries shall be complete, and self-explanatory, and shall include, but not be limited to, the following:

a. Data and time of entry

b. Identity of test, operation, or inspection

c. Environmental conditions

d. Characteristics being investigated

e. Parameter measurements

f. Complete identification of instrumentation used, including serial number and next calibration due date.

g. Failure observations and failure report reference

h. Accumulated operating time

i. Cumulative number of duty cycles to date

j. Discrepancies between the item tested and pertinent specifications or drawings

k. Repair and maintenance record

l. Record of pertinent, unusual, or questionable occurrences involving the equipment

m. Actions taken to have "quick fixes" in test formalized

n. Identities of individuals making entries

o. Calibration data for components and for higher levels of assembly (when applicable)

p. Configuration record

7.5.2 <u>Initiation, Maintenance, and Final Disposition</u>

An equipment log shall be initiated for each component from the time of first electrical or mechanical activation as a complete, functionally operating item. All the requirements of this paragraph shall be imposed on all subcontractors or suppliers of components regardless of tier. At the time of component integration into a higher level subsystem, the individual component logs shall be combined into an appropriate subsystem log provided that individual components cannot be operated independently of the remainder of the subsystem. The system log shall contain a record of serial number, date of installation and if appropriate, date of removal of each subsystem or component. Also, the component log shall be reinitiated for each component for the period that the component is removed from the subsystem for individual operation. These logs shall be delivered to NASA with the Protoflight Unit Radar Altimeter and RASE. Those logs associated with the remaining support phases identified in Section 4.0 shall be delivered upon completion of each remaining phase.

7.6 Time Cycle Sensitive Component Logs

Separate logs shall be initiated for each item or component which is known to have limited life (i.e., less than 52600 mission hours under normal duty cycle). These logs shall contain the following information:

a) Item identification (name, part number, serial number).

b) Lifespan (operating hour or cycles) during which reliable operation may be expected.

c) Running log of time or cycles expended to date, including time and date of each "on" and "off" occurrence.

d) Estimated number of hours or cycles of useful life remaining.

8.0 ANALYSES

Some of the deliverable analyses listed in Section 13.0 are defined in more detail as follows.

8.1 Link Analyses

Link analyses shall be performed for each channel (5.3 GHz and 13.6 GHz) to determine the expected operational (on orbit) signal to noise ratios at which the altimeter will be operating.

These analyses shall be performed for worst case, nominal and best case conditions. All unknowns which have to be estimated will be given a nominal, and worst case value. Media effects such as sigma naught versus sea state, atmospheric losses and RF attenuation losses in up to 2 mm/hr of rain, etc., shall be included in the calculations. As measurement characteristics of actual hardware become available they shall be incorporated in the link analyses.

8.2 Thermal Analysis

A detailed thermal analysis shall be supplied. The results of this analysis shall conclusively prove that adequate temperature margins exist for all critical components under all environmental conditions and Radar Altimeter modes. As a minimum, this thermal analysis shall identify potential hot spots in the equipment, heat generating sources, methods for transmitting heat to the spacecraft structure, and effects of operation of the Radar Altimeter on temperature sensitive parts. This analysis shall also cover any inflight thermal affects on the antenna and feed structure which may affect optical and RF alignment. See also Section 5.9.4 and 5.12.3.

8.3 Structural Analysis

A mechanical stress analysis shall be supplied. This analysis shall demonstrate adequate structure design margins for the Radar Altimeter when subjected to the environmental levels specified within the "TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, 672-30-001 PAR Revision B.

8.4 Data Error Analysis

A detailed data error analysis shall be supplied. This analysis shall be based on measured parameters of the Protoflight Unit Radar Altimeter, and shall update the predicted Error Budget Estimate presented in the Technical Plan and at the PDR and CDR.

8.5 PAR Reliability Analysis

8.5.1 FMECA

Failure mode, effect, and criticality analyses (FMECA) shall be provided in accordance with the "TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, GSFC 672-30-001-PAR Revision B.

8.5.2 Parts and Devices Stress Analysis

A Parts and Devices Stress Analysis shall be provided in accordance with the "TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, GSFC 672-30-001-PAR, Revision B.

8.5.3 Worst Case Analysis

A Worst Case Analysis shall be established in accordance with the "TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, GSFC 677-30-001-PAR, Revision B.

8.5.4 Trend Analysis

A Trend Analysis shall be provided in accordance with the "TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, GSFC 677-30-001, Revision B.

9.0 SAFETY PROGRAM

A Safety Program shall be accomplished in accordance with the "TOPEX Radar Altimeter Performance Assurance Requirements" document, April 1988, GSFC 677-30-001-PAR, Revision B.

10.0 RADAR ALTIMETER SYSTEM EVALUATOR (RASE) REQUIREMENTS

The purpose of the RASE shall be to exercise the Radar Altimeter in all of its modes, and to help ascertain that the Radar Altimeter meets all of the requirements of this specification. All or part of the RASE shall be used for every phase of Radar Altimeter electrical testing, i.e., when the Radar Altimeter is a stand-alone unit during laboratory testing, when it is integrated with the spacecraft, and during prelaunch checks.

The RASE shall undergo a complete test program of its own. There shall be a RASE Test Plan, Test Procedure, Calibration, and Test Report. These tests shall completely characterize the RASE. They shall be used to verify the inputs to the Radar Altimeter.

The Radar Altimeter performance to be measured by the RASE shall be determined from measurements on the following functions as a minimum:

a. Acquisition

b. Tracking

c. Mode control and selection

d. AGC characteristics

e. Transmit signal characteristics

f. Closed-loop transient response

g. Engineering telemetry data

h. Power consumption

i. Internal calibration mode(s)

j. Radar Altimeter Reprogramming

The following types of equipment shall be included in the RASE.

10.1 Return Signal Simulator (RSS)

The RSS equipment within the RASE shall provide the RF test signal that simulates ocean backscatter of the transmitted Radar Altimeter signals at Ku-band and C-band for evaluation of the Radar Altimeter's performance. The timing, frequency spectrum, and power levels of the output signal are to be controllable, predictable, and measurable with sufficient accuracy to establish the Radar Altimeter performance over the dynamic range required. The RSS shall be manually and automatically controllable by the RASE, and shall be capable of dynamic simulations (that is dynamically changing $H_{1/3}$ $\dot{h}$, $\ddot{h}$, signal level, etc.).

10.2 Interfacing, Altimeter Control and Data Collection, Recording and Analysis Equipment

This equipment within the RASE shall interface to the Radar Altimeter in an identical manner as the spacecraft. The interfaces provided shall be at least the following:

(1) Power,

(2) Data System

(3) Command System

(4) 5 MHz, and

(5) Timing.

The RASE shall meet the interface specifications of the Radar Altimeter for these interfaces. Time-tagging of data shall be provided to the degree required to verify performance of Section 5.4.3.

The RASE shall provide a power interface which shall simulate the spacecraft power system.

Automatic control of the Radar Altimeter by the RASE shall be via the command interface. All commands possible within the restrictions of the spacecraft command system shall be capable of being issued to the Radar Altimeter by the RASE.

The RASE shall receive the scientific and engineering data from the Radar Altimeter via the data system interface. The RASE shall automatically control the RSS, and receive data from the RSS relative to understanding and recording the specific test set-up of the RSS and its performance. These data shall be recorded and analyzed by the RASE. These analyses shall be accomplished to determine the capability of the Radar Altimeter to meet the requirements of this specification and to provide calibration data for the Radar Altimeter.

A computer with appropriate interfaces to the Radar Altimeter and a complement of standard peripheral equipment shall be provided for the above functions of the RASE, other than power. Automated testing of the Radar Altimeter shall be permitted. Simultaneous data processing from previous test runs, or while conducting a current test run shall be required on a separate computer system. Analysis required to verify health and welfare shall be provided real-time.

Existing programs, modifications to existing programs and new programs shall be specified, flow charted and described to GSFC before implementation. After the CDR the design shall be under "Change Control" and after the PER the code shall be under "Change Control."

10.3 Standard Test Equipment

A complement of standard, commercially available test equipment shall be integral to the RASE. This equipment shall be used for signal measurements, calibrations, and other purposes for determining the ability of the Radar Altimeter to meet the requirements of this specification.

11.0 ADMINISTRATION

11.1 Administrative Plan

APL shall prepare an Administrative Plan for GSFC approval which defines the manner in which TOPEX Radar Altimeter management considerations required by this document and its references will be implemented and conducted by APL. This Administrative Plan, as a minimum, shall define the following:

11.1.1 Project Team

The Project Team key members and their respective roles and responsibilities, their group assignment, mailing address and telephone number shall be defined. The manner in which orderly additions or changes to this organization will be accomplished shall be defined. Its membership shall be reported in the Monthly Program Status Reviews and written Progress/Status Reports.

11.1.2 Work Breakdown Structure

A Work Breakdown Structure shall be established which defines the elements comprising the Radar Altimeter development activities that must be accomplished. A description of the activity to be accomplished within each element of the Work Breakdown Structure shall be provided. The "Handbook for Preparation of Work Breakdown Structures," NHB 5610.1 shall be followed. This Work Breakdown Structure shall be subject to Change Control. It shall be reported on in the Monthly Program Status Reviews and written Progress/Status Reports.

11.1.3 Progress/Status Reporting

Monthly written Progress/Status Reports shall be submitted by the 20th of the month, for each preceding month's activity, which documents for the record the following:

Technical Progress

Power Estimate

Mass Estimate

Problems

Solutions

Potential and Real Design Changes

Schedule Status versus Plans

Make or Buy Determinations

Long-Lead Procurements

Performance Assurance Information

Action Items and Status

Meetings Conducted

Planned Meetings for the following 2 Months

Trips Conducted

Trips Planned for the following 2 Months

GSFC specification "Contractor Prepared Monthly Periodic and Final Reports," S-250-P-1c shall be followed.

11.1.4 Schedules

Schedules shall be defined for each element of the Work Breakdown Structure. The progress of each individual element shall be monitored. Where change is necessary this information shall be presented at the Monthly Program Status Reviews and within the written Progress/Status Reports.

11.1.5 Resource Planning, Analysis, Control and Reporting

Resource plans shall be defined for each element of the Work Breakdown Structure. The categories that shall be established for the plan and actuals shall be

Direct Man Months

Indirect Man Months

Direct Manpower Costs Including Benefits

Inhouse Contractor Costs

Indirect Manpower Costs

Procurement Costs

Fee

Total Inhouse

Purchases[11]

Other Subcontracts[12]

The actual resources accrued against these resource plans shall be documented. A narrative analysis of the resource status for each area shall be provided documenting the reasons for deviating from the plan. Any problems created by deviations from the plan shall be identified. The corrective action accomplished or planned shall be identified for each problem listed. An overview of the resource

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[11]Each individual item within this category valued in excess of $2,500 shall be itemized in another separate report section showing Planned Purchase Request Date, Actual Purchase Request Date, Planned Contract Award Date, Actual Contract Award Date. Assessments shall be included if actual dates deviate from the planned dates explaining the cause, what the impact will be and what will be accomplished to minimize or eliminate the effects of the identified impact(s).

[12]Same as footnote 11.

status shall be provided at each Monthly Program Status Review. Cost Reassessment Sessions by FY quarter shall be conducted with GSFC to review progress versus plans and internal adjustments shall be accomplished to accommodate unexpected occurrences. Similar planning and reporting shall be established for purchases and other subcontracts in excess of $25,000.

11.1.6 Make or Buy Determinations

A Make or Buy Determination shall be accomplished for each element of the Work Breakdown Structure which clearly establishes the most cost effective manner of acquiring the required end item(s). Comparisons with industry available items shall be furnished. This information shall be presented at the Monthly Program Status Reviews and within the Progress/Status Reports.

11.1.7 Long-Lead Item Procurement Program

A long-lead item procurement program shall be established for items whose procurement delivery date has been established by the vendor to be in excess of 12 months. Their status shall be continuously appraised and presented at the Monthly Program Status Reviews, major reviews, and within the Progress/Status Reports.

11.1.8 Procurement Packages

The following procurement documentation from inception shall be furnished for each end item (i.e., task, support service, hardware, software) worth $25,000 or more

Request for Proposal

Specifications

All Proposal Responses

Proposal Evaluation

Contract/Purchase Order[13]

11.2 <u>Technical Plan</u>

A Technical Plan shall be prepared and submitted for approval which describes the implementation approach to satisfy the instrument requirements, interfaces to the spacecraft, and technical support related to spacecraft integration and pre- and post-launch mission support as defined by this specification.

12.0 PERFORMANCE ASSURANCE PLAN AND PROGRAM

A Performance Assurance Plan and Program for the TOPEX Radar Altimeter effort shall be established in accordance with the "TOPEX Radar Altimeter Performance Assurance Requirements," April 1988, GSFC Document 672-30-001-PAR, Revision B. Maximum utilization of existing in-house reliability and quality assurance capabilities shall be incorporated into the plan/program. Augmentation as necessary shall be provided to ensure that this program is completely capable of achieving the NASA Performance Assurance requirements throughout the design, fabrication, test, launch and orbital lifetime of the TOPEX Radar Altimeter. This program shall provide the early and prompt detection of actual or potential deficiencies, system incompatibilities, and marginal quality trends

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[13]Requires NASA approval prior to award

or conditions which could result in unsatisfactory quality. It shall also provide the necessary timely and effective management controls.

13.0 DELIVERABLE ITEMS

This section lists the TOPEX Radar Altimeter Program deliverable items, the quantity where appropriate of each item to be delivered, and the scheduled delivery data. All deliverables will become the property of the government. The required NASA action is also indicated.

Item Hardware	Qty	Date/Months After Go-Ahead	NASA Action
1. Protoflight Model (PFM)	1	October 15, 1990	DD 250 Sign-off
2. Radar Altimeter System Evaluator (RASE)	1	October 15, 1990	"
3. Matching Drill Fixtures (Templates)	1	August 1, 1989 & October 15, 1990	"
4. Mass Models	1	October 2, 1989	"
5. Antenna Model	1	March 15, 1989	"
6. Boresight Alignment Fixture	1	October 15, 1991	"
7. Handling Fixtures	1	October 2, 1989 & October 15, 1990	"
8. Spare Parts		October 15, 1990	"

Technical Support

1.	Spacecraft Integration and Test, Control Center Operations Training, Launch Support, and Post-Launch Engineering Assessment Support	As specified	
2.	TOPEX Flight Segment Review Support	As specified	

Reviews/Meetings

1.	Preliminary Design (PDR)[14]	February 3-4, 1988	Approval
2.	Critical Design (CDR)[15]	November 15-16, 1988	Approval
3.	Pre-Environmental (PER)[16]	July 17, 1990	Approval
4.	Consent to Ship (CSR)[17]	October 9, 1990	Approval
5.	Monthly Program Status (MPSR)	3rd Tuesday each Month	
6.	Quarterly Cost Reassessment Reviews (QCRR)	Every 12th Tuesday	Approval
7.	Program Level	Once/Year	
8.	Sensor/Spacecraft Interface Meetings	As Required	

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[14]Applicable documentation listed for each of these reviews shall be provided in the quantities indicated within this specification, the Administrative Plan or the Performance Assurance Plan, 30 calendar days in advance.

[15]Same as footnote 14.

[16]Same as footnote 14.

[17]Same as footnote 14.

Documentation

1.	Technical Plan	15		Approval
2.	Performance Assurance Plan	15		Approval
3.	Administrative Plan	15		Approval
4.	Radar Altimeter System System Specification	15	PDR Preliminary CDR Final	Approval Approval
5.	Interface Description Document	15	PDR Preliminary CDR Final	Approval Approval
6.	Procurement Packages (> $25K)	5	As Released	Info
7.	Materials and Process Control List	12	10 Working Days Prior to PDR/CDR	Approval
8.	As-Designed Parts List	12	10 Working Days Prior to PDR/CDR	Approval
9.	As-Built Parts List	12	CSR	Info
10.	Radar Altimeter Design & Operational Characteristics Description	15		
	a. Draft		At PDR	Info
	b. Update		At CDR	Info
	c. Final		At CSR	Approval
11.	Protoflight Unit Software Documentation	15		Approval
	a. Software Description Document			
	1. Design Analyses		At PDR/CDR	
	2. Flow Charts with Descriptions		At PDR/CDR	
	3. Specifications		At CDR	
	b. Test Plan		At CDR	
	c. Test Report		At PER	
	d. Software Listing		AT PER/CSR	
	e. Change Information (post-CDR)	20	As Generated	
12.	Acceptance Test Plan	12	At CDR	Approval
13.	Acceptance Test Procedure	12	At PER	Approval
14.	Acceptance Test Report	12	At CSR	Approval

15. RASE Design Description	15		
a. Draft		At CDR	Info
b. Final		At PER	Approval
16. RASE Software Documentation	15		Approval
a. Software Description Document			
1. Flow Charts with Descriptions		At PDR	
2. Specification		At CDR	
b. Test Plan		At CDR	
c. Test Report		At PER	
d. Software Listing		At PER	
e. Change Information		As Generated	
17. RASE Test Plan	12	PDR	Approval
18. RASE Test Procedure	12	CDR	Approval
19. RASE Test Report	12	PER	Approval
20. System Level Analyses			Review
a. Link Analyses		At PDR/CDR	
b. Thermal Analysis of Interface & Complete Unit		At PDR/CDR/PER	
c. Structural Analysis of Interface & Complete Unit		At PDR/CDR/PER	
d. Data Error Analysis & Budget Estimate		At PDR/CDR	
e. Failure Mode Effect & Criticality		At PDR	
f. Parts & Devices Stress Analysis		30 Days Prior to PDR/CDR	
g. Hazard Analysis		At PDR	
h. Worst Case Analysis		At PDR/CDR	
i. Trend Analysis		10 Days Prior to PER/CSR/MPSR	
j. System Design Margins		At CDR	
k. System EMC/RFI Analysis		At PDR/CDR	
21. Other Documentation, as described in the Performance Assurance Requirements		As specified	As specified
22. APL Related Technical Memoranda	4	As Released	Info
23. Drawings	2 sets	PDR CDR CSR	Info

24.	Alignment & Calibration Books	12	At CSR	Info
25.	Antenna Patterns	2 sets	At CSR	Info
26.	RASE Data Tapes		As Required	Info
27.	Progress/Status Reports		20th of Each Month	Info
28.	Resource Reports		20th of Each Month	Info
29.	Archieval Photographs[18]	2 ea 8x10" Prints 1 negative	As Generated	Info

[18]High-resolution, minimum grain (produced with 6x7 cm format type camera with electronic flash, or equivalent).

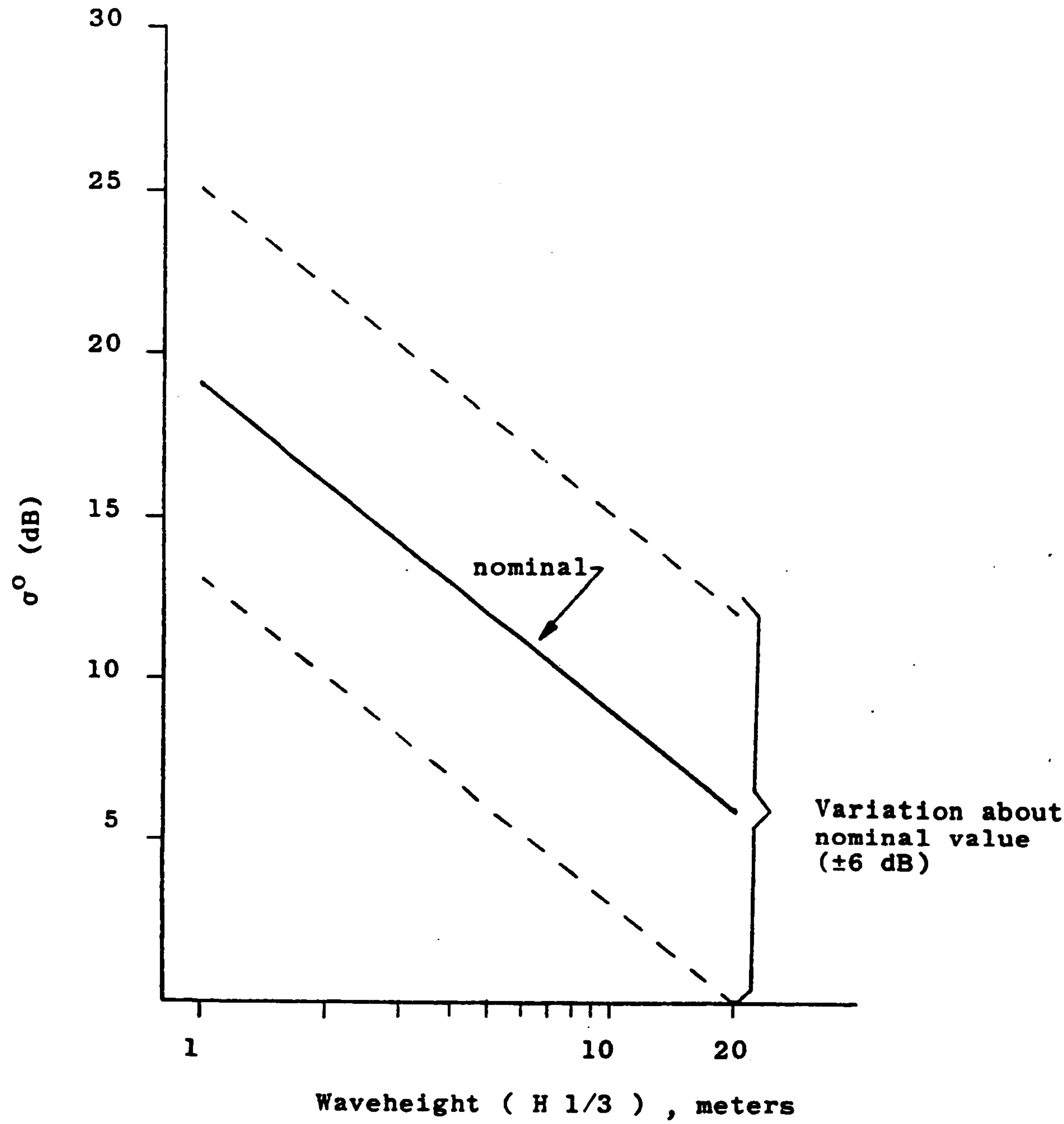


Figure 1. σ^0 vs. $H_{1/3}$ Model

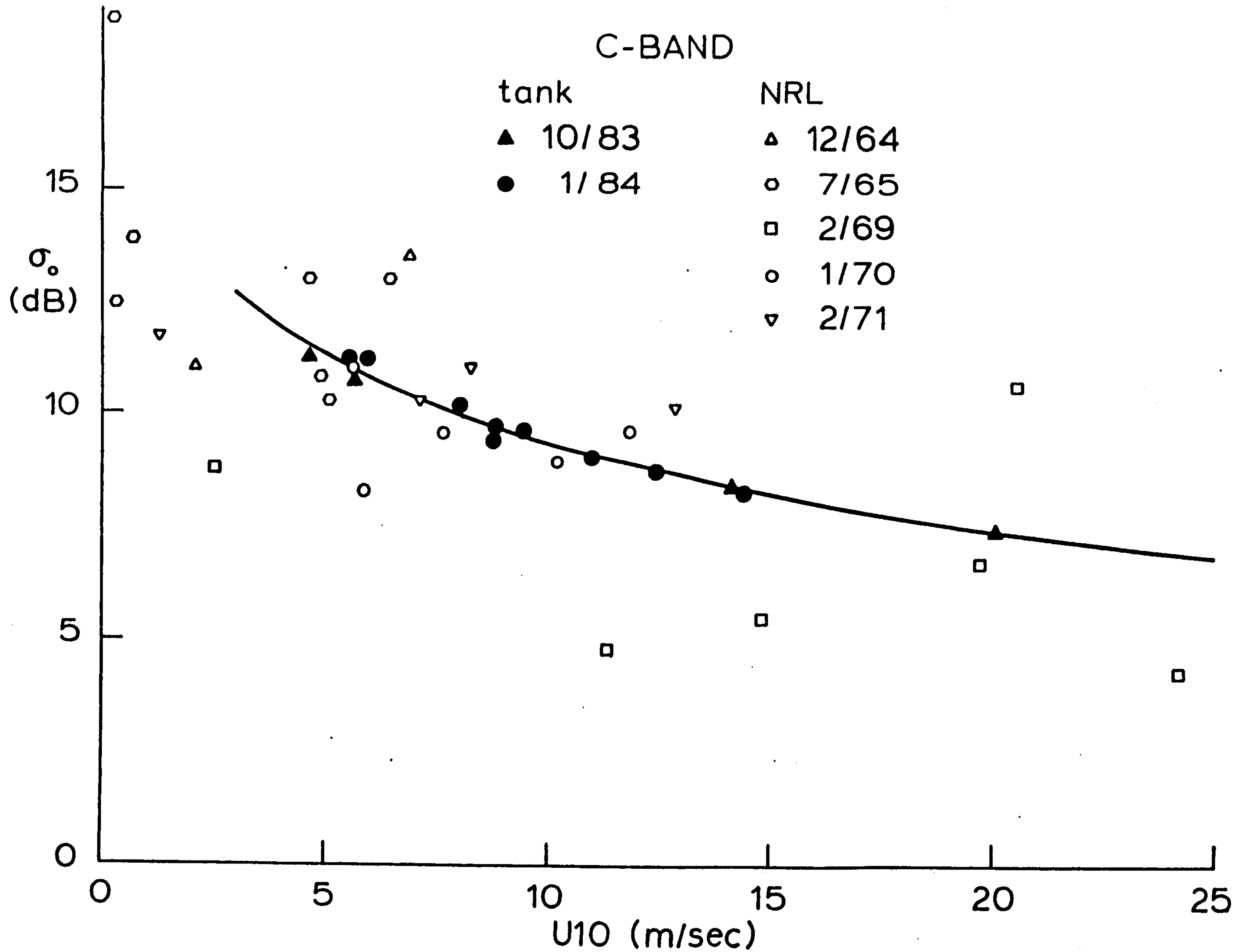


Figure 2. C-band Sigma 0

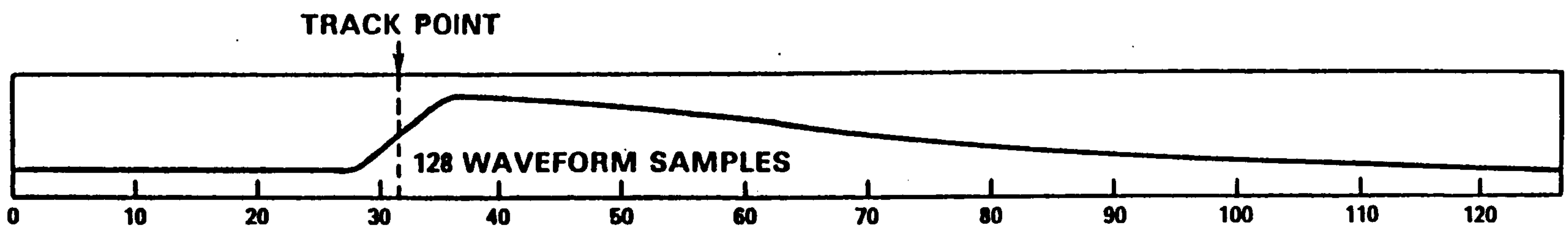


Figure 3. TOPEX Gate Formation

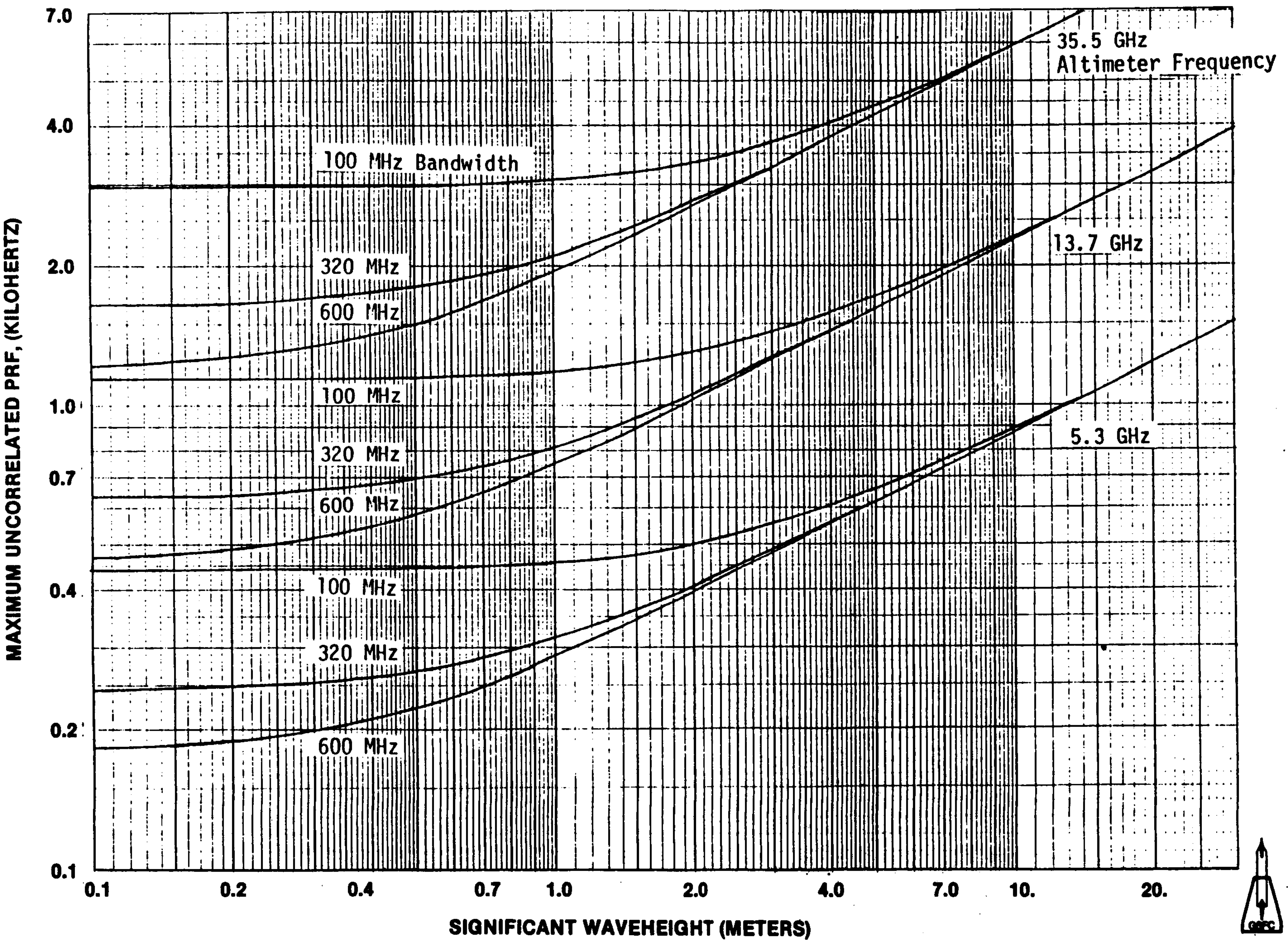


Figure 4. Uncorrelated PRF vs. SWH for Radar Altimeter at 1334 Kilometers Altitude

APPENDIX A

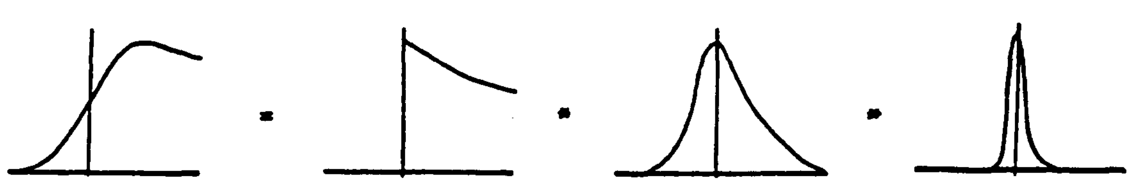
FUNDAMENTAL RADAR ALTIMETER MEAN RETURN MODEL

The fundamental model to be used describes the mean radar return as the convolution of the three separate terms: 1) a "flat-sea" surface impulse response function $P_{FS}(t)$, which includes the effects of the antenna patterns and of attitude angle (i.e., off-nadir angle); 2) an effective radar-observed sea-surface elevation probability density function $q_s(t)$, which includes the significant waveheight (SWH); and 3) the radar altimeter system's point-target response function, $s_r(t)$, which includes the transmitted effective pulse shape as observed through the system receiver. This convolution is sketched below.

CONVOLUTION OF:

(RADAR ALTIMETER MEAN POWER RETURN WAVEFORM)	=	(FLAT-SEA IMPULSE RESPONSE (INCLUDES ANTENNA PATTERN & OFF-NADIR ANGLE)		SURFACE ELEVATION DENSITY FUNCTION FOR "SCATTERING ELEMENTS"		RADAR ALTIMETER SYSTEM POINT-TARGET RESPONSE (INCLUDES TRANSMITTED PULSE SHAPE))

$$W(t) = P_{FS}(t) * q_s(t) * s_r(t)$$



An additional model parameter is an additive noise baseline b on which the above convolution result W(t) sits. The three separate terms in the waveform convolution are described in the following paragraphs; the entire model, as well as discussion of some specific computational details, is presented in [Hayne, 1981].

The flat-surface impulse-response function $P_{FS}(t)$ is given by

$$P_{FS}(t) = A_o \exp(-\delta t)\, I_o(t^{\frac{1}{2}}\beta)\, U(t)$$

with

$$\delta = (4/\gamma)\,(c/h)\,\cos(2\xi)$$

and

$$\beta = (4/\gamma)\,(c/h)^{\frac{1}{2}}\,\sin(2\xi)$$

where

$I_o(.)$ is the modified Bessel function,

$U(.)$ is the unit step function,

c is the speed of light

h is the spacecraft altitude

ξ is the attitude angle, and

δ is an antenna beamwidth factor which, for a beam pattern assumed to be Gaussian in off-axis angle, is given in the expression

$$\frac{4}{\gamma} = \frac{\ell n\ 4}{\sin^2(\theta w/2)} \quad .$$

where θ_w is the usual antenna angle full width between half-power points. The amplitude factor A in the above $P_{FS}(t)$ contains several other factors important to received power calculations but not to SWH or height, and these are more fully described in [Hayne, 1981]. This $P_{FS}(t)$ is based on work summarized in a review paper by [Brown, 1977].

The radar-observed surface elevation density function $q_s(t)$ has been taken as a Gaussian function in past altimeter designs. A slightly more general form is the "skewed Gaussian," actually the first two terms in a general Gram-Charlier series, given by

$$q_s(t) = \frac{1}{\sqrt{2\pi}\,\sigma_s} \left\{ 1 + \frac{\lambda_s}{6} \left[\left(\frac{t}{\sigma_s} \right)^3 - 3 \left(\frac{t}{\sigma_s} \right) \right] \right\} \exp \left[- \frac{1}{2} \left(\frac{t}{\sigma_s} \right)^2 \right] ,$$

where σ_s is the surface rms elevation (expressed in two-way ranging time units), and λ_s is the sea surface skewness. It has been assumed in radar altimetry that SWH is four times the surface rms elevation. The altimeter's onboard SWH and tracking algorithms will be designed assuming that the skewness λ_s is zero, but any ground-based research-level data processing should more fully explore the correct form for $q_s(t)$ and the correct λ_s.

The system point-target response $s_r(t)$ for modeling and simulation studies is taken as the idealized $(\sin x / x)^2$ function, with its adjacent nulls (except for the main beam at 0) spaced at two-way ranging time values of (1/BW) where BW is the receiver bandwidth. In analyzing data from an actual altimeter, the actual sampled system point-target response from ground-based testing and from calibration mode data will be used.

REFERENCES

Brown, G. S., "The Average Impulse Response of a Rough Surface and Its Applications," IEEE Trans. Antennas and Propagat., Vol. AP-25, No. 1, January 177, pp. 67-74.

Hayne, G. S., "Radar Altimeter Waveform Modeled Parameter Recovery," NASA TM 73294, August 1981.

APPENDIX B

TOPEX RADAR ALTIMETER SCIENCE DATA FRAME FORMAT

Name	# Bits	Quantity	Total Bits/Words
Frame Sync Word	48	1 Frame	48/6
Spacecraft Time	48	1/Frame	48/6
Ku Calibrate Attenuator	8	1/Frame	8/1
C Calibrate Attenuator	8	1/Frame	8/1
Current Mode	8	2/Frame	16/2
Mode Change Type	8	2/Frame	16/2
Coarse Height[1]	16	20/Frame	320/40
Primary Fine Height[1]	16	20/Frame	320/40
Height Rate[1]	16	20/Frame	320/40
Secondary Height Differences[2]	16	20/Frame	320/40
Ku AGC	8	20/Frame	160/20
C AGC	8	20/Frame	160/20
Ku SWH	8	10/Frame	80/10
C SWH	8	10/Frame	80/10
High Rate Waveforms[3,6]	512	10/Frame	5120/640
High Rate Scaling[4]	8	10/Frame	80/10
Low Rate Waveforms[3,6]	512	5/Frame	2560/320
Low Rate Scaling[4]	8	5/Frame	40/5
Synchronizer Mode Bits	16	1/Frame	16/2
Last ATA Command	16	1/Frame	16/2
Last ICA Command	16	1/Frame	16/2
Operation Mode Byte	8	1/Frame	8/1
Spares	8	6/Frame	48/6
Frame Checksum	16	1/Frame	16/2
TOTAL			9824/1228

The altimeter frames shall occur approximately once per second.

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[1]These shall always be Ku except when the altimeter is in the C Band only mode.

[2]This shall always be the difference in the Ku & C heights except that it shall be meaningless in the C or Ku Band only modes.

[3]The waveforms are selectable, by ground command, to be Ku or C. It shall not be possible to assign both low and high rate waveforms to be Ku (or C).

[4]There shall be one scaling word associated with each waveform. This word consists of scaling/mode information and a Ku/C identifier.

[6]One waveform consists of 64, 8 bit samples of the return signal.

APPENDIX C

TOPEX RADAR ALTIMETER ENGINEERING DATA FRAME FORMAT

Name	# Bits	Quantity	Total Bits/Words
Sync Byte	8	1/Frame	8/1
Command Echo	24	8/Frame	192/24
Memory Dump	8	34/Frame	272/34
Status Byte	8	1/Frame	8/1
Last Reset Time	48	1/Frame	48/6
Spacecraft Time	48	1/Frame	48/6
Engineering Measurement	8	50/Frame	400/50
Spare	8	6/Frame	48/6
TOTAL			1024/128

Engineering measurements shall consist of temperature, analog voltages/currents, and digital telltales from the various altimeter boxes. These shall be subcommutated from the ICA in TBD order.

The altimeter engineering data frames shall occur once every 8.192 seconds.

APPENDIX D

ABBREVIATIONS AND ACRONYMS

APL	Applied Physics Laboratory of The Johns Hopkins University
bps	bits per second
CDR	Critical Design Review
CNES	Centre National D'Etudes Spatiales
CSR	Consent to Ship Review
dB	decibels
e	electrons
ESA	European Space Agency
FY	Fiscal Year
GSFC	Goddard Space Flight Center
$H_{1/3}$	Significant Wave Height (SWH)
JPL	Jet Propulsion Laboratory
kbs	kilobits per second
LSB	Least Significant Bit
m	meters
MHz	megahertz
MPSR	Monthly Program Status Review
ms	millisecond
MSB	Most Significant Bit
NASA	National Aeronautics and Space Administration
ns	nanosecond
PDR	Preliminary Design Review
PER	Pre Environmental Review

ppm	parts per million
pps	pulses per second
PRF	pulse repetition frequency
QCRR	Quarterly Cost Reassessment Reviews
RASE	Radar Altimeter Signal Evaluator
RSS	Return Signal Simulator
TBD	to be determined
TM	Telemetry
TPO	TOPEX Project Office
WFF	Wallops Flight Facility

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13. ABSTRACT *(Maximum 200 words)*

This document provides the guidelines by which the TOPEX Radar Altimeter hardware development effort for the TOPEX flight project shall be implemented and conducted. The conduct of this activity shall take maximum advantage of the efforts expended during the TOPEX Radar Altimeter Advanced Technology Model development program and other related Radar Altimeter development efforts. This document complies with the TOPEX Project Office document 633-420 (D-2218), entitled, "TOPEX Project Requirements and Constraints for the NASA Radar Altimeter" dated December 1987.

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