C. GORDON

GENERAL DESIGN SPECIFICATION

TOTAL OZONE MAPPING SPECTROMETER

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Configuration Management:		

GDS CHANGES/MODIFICATIONS:

- Modify GDS to reflect the actual digitizing frequency for the various signals (J. Alvarez to define this rate for some of the thermistors).
- Update Housekeeping signal list.
- update the power requir. table.
- Doug to update section 3.4.12.6.
- Reflect changes in section 3.2.1.3.3.1 of ELM spec in the corresponding GDS section.
- OPM Test connector 37 ; ELM test connector is 15

List of Items to Be Specified by GSFC

List of Items to be Determined by Perkin-Elmer

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1. SCOPE.

1.1 **General.** This specification establishes the general requirements for the Total Ozone Mapping Spectrometer (TOMS) and its major components, and is the main systems-engineering tool for the TOMS program. This document shall be the primary technical specification for the TOMS FM-3 and later instruments, not including ground support equipment. It conforms to the requirements of the TOMS technical specification GSFC TOMS-910-90-001 as negotiated.

This specification follows the format of MIL-STD-490, Appendix VII, "Prime Item Product Function Specification".

1.2 **Classification.** This document specifies the requirements for one engineering, one structural-thermal, and various flight models, as shown in Table 1. The details of the interface and other specialized characteristics of each flight unit shall be specified in detail specifications subordinate to this specification.

Table 1.
TOMS Instrument Part Numbers

Model	Spacecraft	Detail Specification	Assembly Drawing Number
Structural-Thermal Model	N/A	71-0164	371100
Engineering Model	N/A	71-0164	371200
Flight Model 3 (FM-3)	Earth Probe	71-0163	371300
Flight Model 4 (FM-4)	ADEOS	71-0164	371400
Flight Model 5 (FM-5)	Earth Probe	71-0165	371500
Flight Model 6 (FM-6)	Earth Probe	71-0166	371600

1.2.1 **Structural-Thermal Model.** The structural-thermal model shall meet the mechanical and interface envelope, mounting, thermal interface, and weight requirements of the FM-4 flight model.

The STM shall have a representative thermal radiator that is flight-like in size, structural attachment, weight, and optical properties. The STM shall be equipped with electrical heaters the power to which shall be externally controlled by changing the voltage to the heaters. These heaters shall have sufficient capacity to simulate the hot-case fluxes from the sun, earth and spacecraft as well as the heat generated in the TOMS that is to be radiated from this radiator.

The temperature of the TOMS side of the mounting interface with the spacecraft shall be thermostatically controlled to provide the specified operational temperature and temperature gradient on the TOMS side of the interface.

Heaters shall be provided to maintain the TOMS STM above its minimum operating temperature.

1.2.2 **Engineering Model.** The engineering model shall be in the same configuration as TOMS FM-4, shall meet all requirements of this specification with the ADEOS spacecraft interface, and shall pass the acceptance-level environmental tests specified herein, but shall not use screened parts.

1.2.3 **Flight Models.** The flight models shall meet all requirements of this specification, including the interface requirements for the intended spacecraft listed in the applicable detail specification, and shall pass the flight-acceptance-level environmental tests specified herein. TOMS FM-3 shall be a protoflight model and shall pass the qualification-level environmental tests specified herein.

2. APPLICABLE DOCUMENTS.

2.1 Government.

2.1.1 National Aeronautics and Space Administration.

GSFC TOMS-910-90-001, Rev. 1, Total Ozone Mapping Spectrometer, Technical Specification, July 23, 1990.

GSFC 303-TOMS-002, Performance Assurance Requirements for TOMS Instruments, June 1989.

GSFC S-311-P-18, Thermistor, Insulated, Negative Temperature Coefficient.

GSFC Ref. Pub. 1124, Revision 2, Outgassing Data for Selecting Spacecraft Materials.

Radiation Environment for the TOMS Mission, EnviroNET - The Space Environment Information Service, Goddard Space Flight Center, April 1991.

PPL-19, GSFC Preferred Parts List.

NHB 5300.4(3A-1), Requirements for Soldered Electrical Connections.

NHB 5300.4(3G), Requirements for Interconnecting Cables, Harnesses, and Wiring.

NHB 5300.4(3H), Requirements for Crimping and Wire Wrap.

NHB 5300.4(3J), Requirements for Conformal Coating and Staking of Printed Wiring Boards and Electronic Assemblies.

NHB 5300.4(3K), Design Requirements for Rigid Printed Wiring Boards and Assemblies.

2.1.2 **Military Standards and Specifications.**

DOD-D-1000B, Military Specification, Drawings, Engineering, and Associated Lists, Levels 1, 2, and 3, 1983.

DOD-HDBK 263, Electrical Discharge Handbook for Protection of Electrical and Electronic Parts.

DOD-STD-1686, Electrostatic Discharge Program for Protection of Electrical and Electronic Parts.

MIL-P-55110D, Requirements for Printed Wiring Boards, 31 December 1984, and Amendment 4, 2 December 1990.

MIL-STD-461C, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference, 4 August 1986, as amended by Notice 1, 1_April_1987.

MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of, 31 July 1967, as amended by Notice 1, 1 August 1968.

2.1.3 **Federal Standards.**

FED-STD-101C, Test Procedures for Packaging Materials.

FED-STD-209, Clean Room and Work Station Requirements, Controlled Environment.

2.2 **Industry Standards and Specifications.**

82C55A CMOS Programmable Peripheral Interface, Harris Corporation, 1986.

2.3 **Perkin-Elmer Documents.**

54-0040, Lubrication of Ball Bearings, Procedure for, 26 July 1991.

74-0023, Performance Assurance Implementation Plan, 1 January 1991.

74-0024, Configuration Management Plan for TOMS FM 3-6, Issue 1, 8_February 1991.

3. **REQUIREMENTS.**

All requirements of this section shall be verified by test, inspection or analysis.

3.1 **Instrument Definition.** The Total Ozone Mapping Spectrometer instrument(s), hereinafter referred to simply as TOMS, shall provide intensity measurements of the incident solar spectral irradiance and of the spectral radiance of the atmosphere in six specified near-ultraviolet wavelength bands from low earth orbit, using the reflected sunlight from diffuser plates as a reference. The spectral intensity shall be measured with high differential radiometric stability to allow precise detection of trends in the global total ozone distribution.

3.1.1 **Instrument Diagrams.** To assure the correct order of precedence, figures referred to in this specification shall not be made into separate applicable documents, regardless of size, unless they are Class I documents under separate configuration control.

3.1.1.1 **Instrument Concept.** The TOMS measures the radiation reflected from earth or a selectable reference diffuser by means of a scan mirror and grating monochromator as shown in Figure 1. Light from the scene passes through a depolarizer and entrance lens, and then enters the monochromator. Slits on a rotating optical chopper sequentially select one of six wavelength bands for detection by a photomultiplier detector. A separate silicon detector simultaneously monitors the 360-nm reflectance channel to provide both a stable reflectance measurement and a photomultiplier gain check. A mercury lamp provides a wavelength repeatability monitor, while a separate mercury-phosphor lamp provides a transfer standard for calibrating diffuser reflectance.

3.1.1.2 **Functional Block Diagram.** The TOMS shall have the functional subsystems and major components shown in Figure 2.

3.1.1.3 **Exploded View.** Figure 3 shows the physical breakdown of the TOMS hardware, defining the major assemblies and nomenclature. The instrument optics module consists of three major components: the monochromator with its slit and grating assembly, the lower housing, which contains the scanner, chopper, diffuser, wavelength monitor lamp, and the critical signal-processing electronics. The digital and less critical analog electronics are mounted on the supporting pedestal. For historical reasons, certain components are still collectively referred to as the Electronics Module, namely the Digital I/O, Microprocessor, Motor/Heater Driver, and the Low Voltage Supply, although there are four distinct circuit modules. The other modules shown support the Optics Module: the Analog Interface, Motor Control, and Lamp Power Supply.

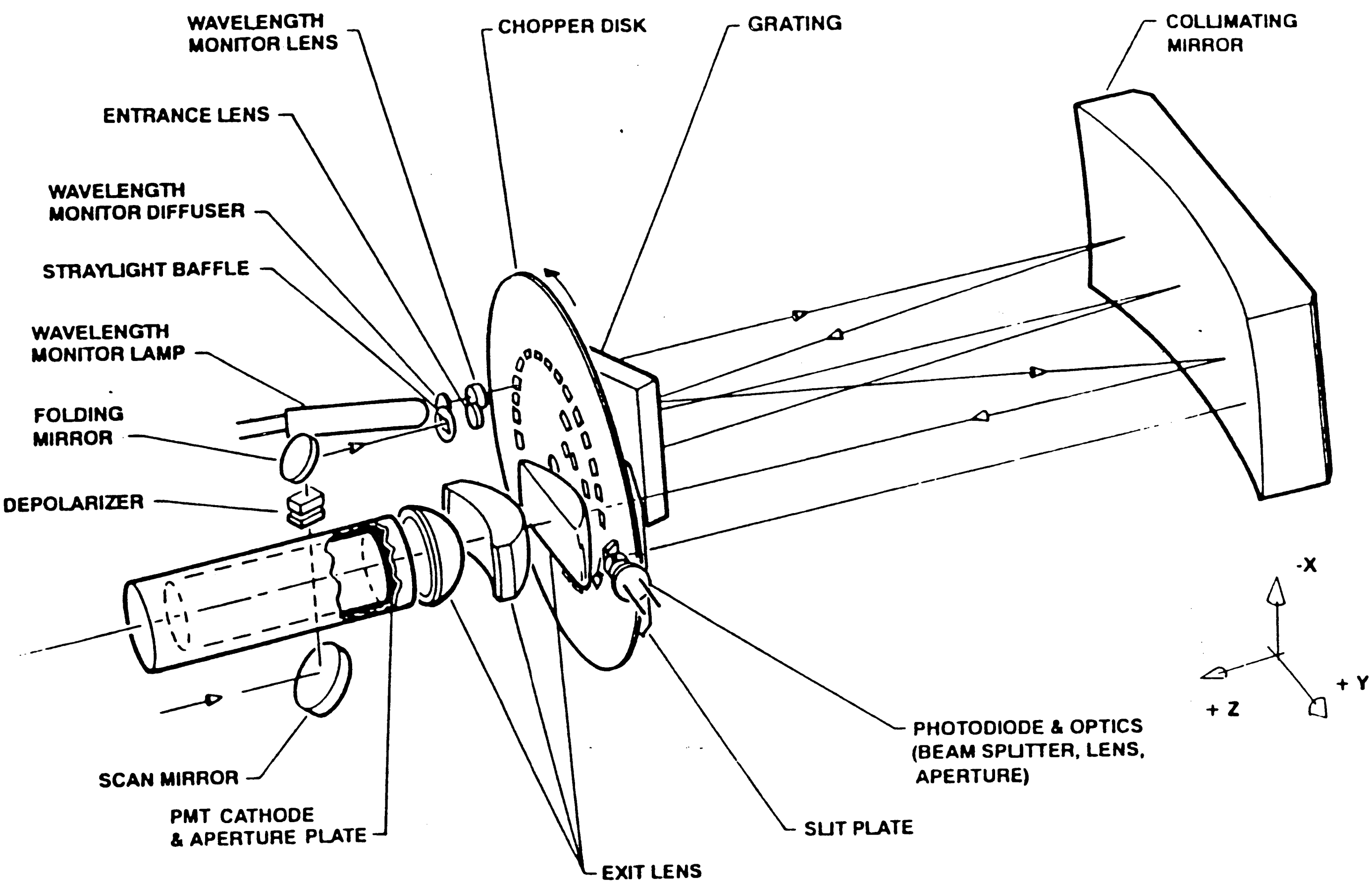

Figure 1. Instrument Concept.

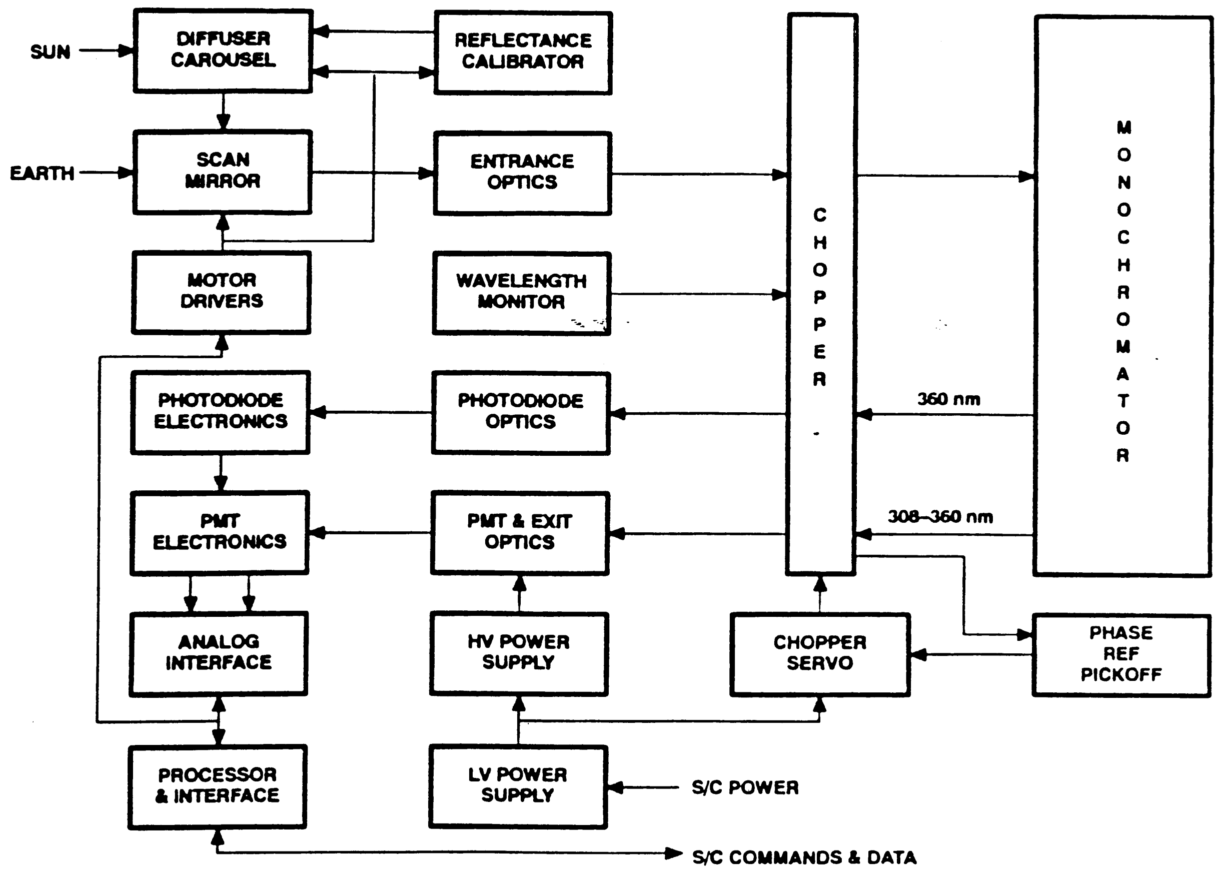

Figure 2. Functional Block Diagram.

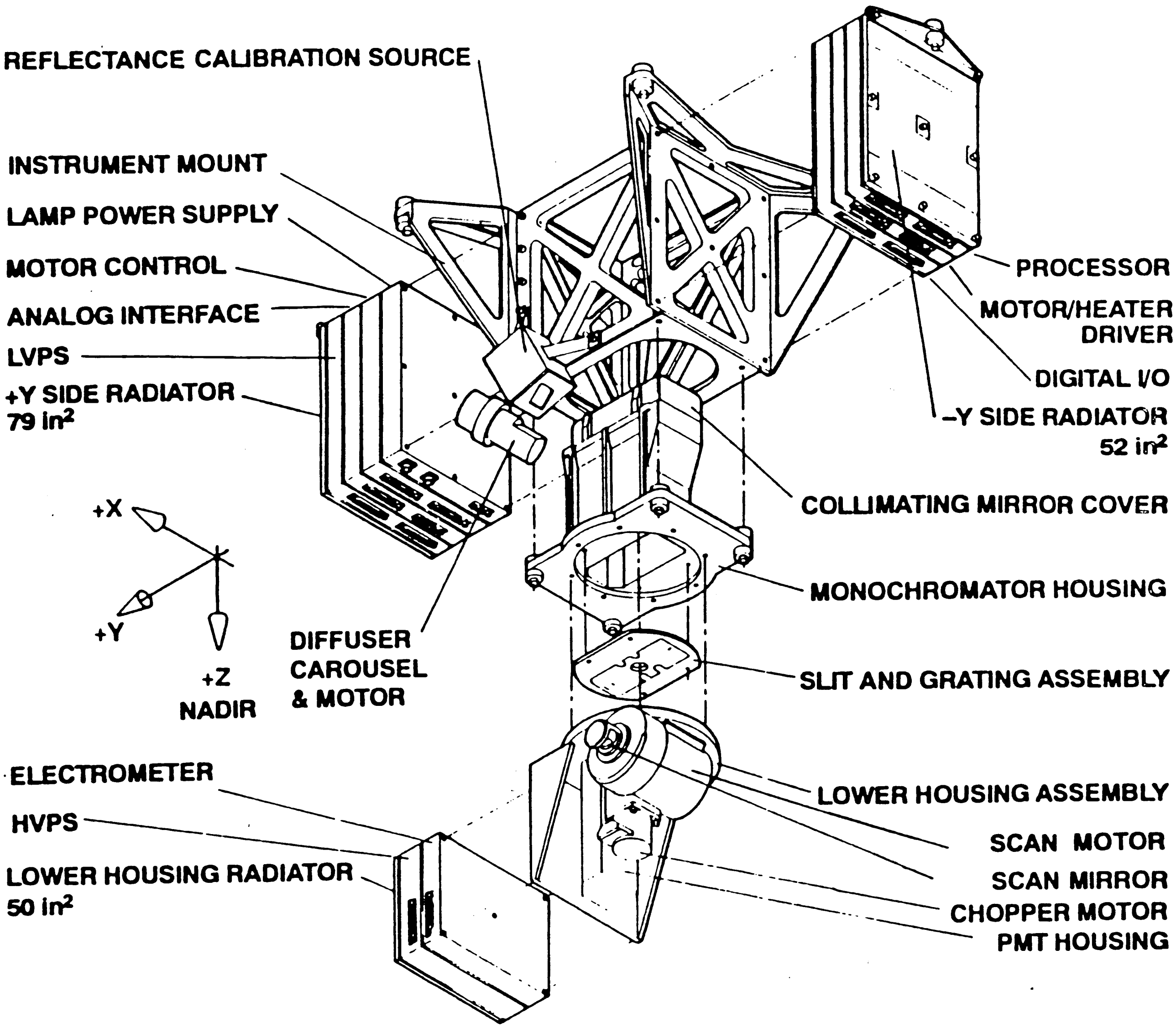

Figure 3. Exploded View.

3.1.2 **Interface Characteristics.** This section defines the interfaces between the TOMS instrument and the spacecraft and between the major components of the TOMS.

3.1.2.1 **Spacecraft Adaptation.** All mounting and interfacing with the designated spacecraft shall be in accordance with the appropriate Interface Control Document (ICD) referenced in the applicable detail specification. The TOMS instruments shall be of a standard design, adapted to various spacecraft by means of (where needed) a diffuser adapter, an electronic adapter, and PROM firmware. The mission-specific characteristics of the adapters and modifications to the firmware shall be specified in the applicable detail specification.

a. **Diffuser Adapter.** To allow for different sun angles on different orbits, different diffuser mounts may be used for different spacecraft.

b. **Electronic Adapter**. To allow for different spacecraft electrical interfaces, the TOMS may include an electronic adapter having standard interfaces with internal circuits, but with spacecraft interfaces depending on the spacecraft to be used. Unless absolutely necessary, the electronic adapter shall not be a physically separate unit, but rather one or more TOMS subassemblies or circuit boards that can be replaced with others having identical internal mechanical and electrical interfaces but different spacecraft interfaces.

c. **PROM Firmware.** TOMS internal operations and timing shall be controlled by software stored in a PROM. All mission-specific timing and other changes shall be implemented by PROM firmware and parameter uploads only.

3.1.2.2 **Mounting and Clear Fields of View (CFOV).** Each TOMS instrument shall be mounted to its spacecraft with a clear nadir-facing field of view for the scanner, a clear view of the sun for the diffuser plate, and a clear view of cold space for the radiation cooler(s). The TOMS coordinates and clear fields of view shall be as shown in Figure 4. The fields of view shown are larger than the actual fields of view to allow for tolerances and out-of-field response. The TOMS mounting plane shall be perpendicular to the nadir direction with the scan plane oriented perpendicular to the nominal spacecraft velocity vector. To assure that the diffuser has a clear view of the sun, the instrument shall be mounted on the spacecraft with the sun predominantly on the -Y side as follows:

a. If the orbit has a PM ascending node (12:00 p.m. - 6:00 p.m.), the instrument +X axis shall be in the direction of the nominal spacecraft velocity vector (instrument facing forward). Solar calibration shall occur over the southern hemisphere at instrument dawn.

b. If the orbit has an PM descending node (6:00 p.m. - 12:00 a.m.), the instrument -X axis shall be in the direction of the nominal spacecraft velocity vector (instrument facing backward). Solar calibration shall occur over the northern hemisphere at instrument sunset.

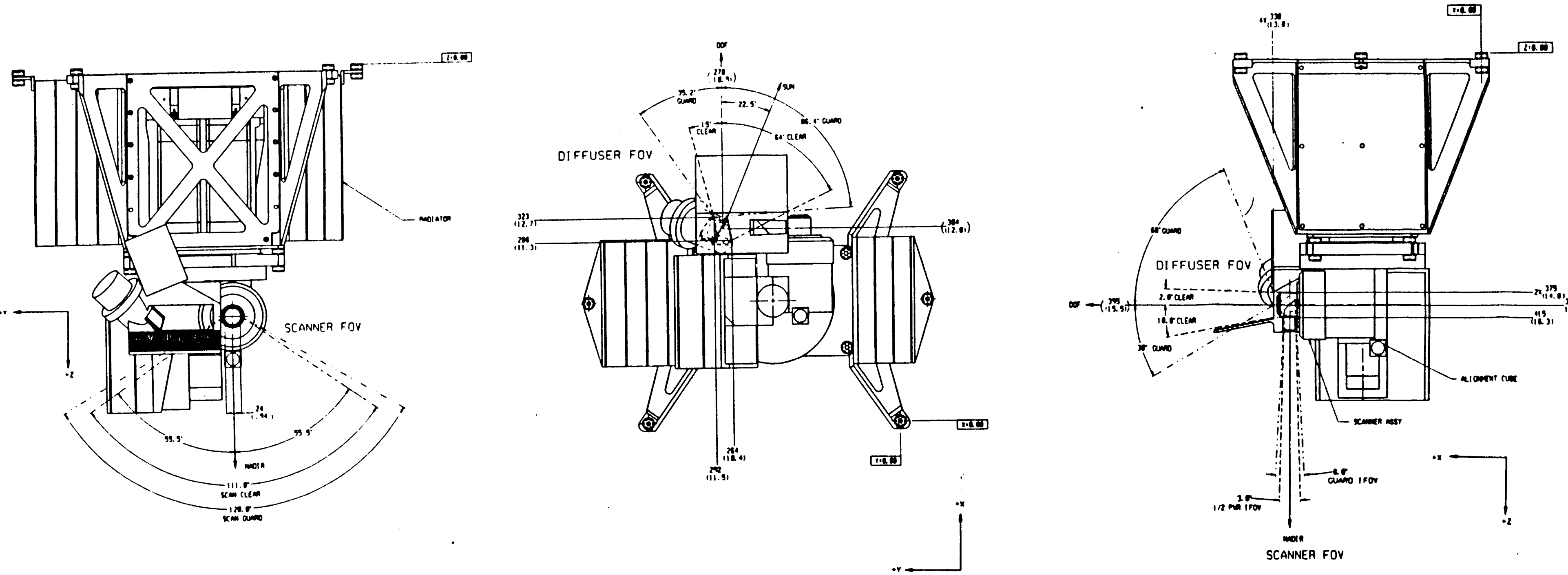

Figure 4. Clear Fields of View.

Note that the sun vector is in the position shown in Figure 4 only when the spacecraft is over the terminator at which solar calibration occurs. During the rest of the orbit the sun vector moves in a cone about the Y-axis, and is obscured at night. All faces of the instrument may see the sun, but the +Y face is usually shaded.

3.1.2.2.1 **Center of Gravity.** The location of the center of gravity shall be approximately as shown in Figures 5A, 5B, and 5C.

3.1.2.2.2 **Scanner Clear Field of View (CFOV).** The scanner shall have a clear field of view in a plane perpendicular to the spacecraft roll axis (nominal velocity vector) centered at nadir, as shown in Figure 4. Note that although the instantaneous field of view (IFOV) is square, it rotates with scan angle, so that the CFOV must be circular. Origins of the scanner CFOV shall be as shown in Table 2.

3.1.2.2.3 **Diffuser Clear Field of View.** The diffuser clear field of view shall be within the envelope shown in Figure 4. The normal to the diffuser may be offset by an azimuth bias in the X-Y plane to allow for the mean sun angle. Origins of the diffuser CFOV shall be as shown in Table 2.

3.1.2.2.4 **Radiator Clear Field of View.** Radiators shall be shaded from the sun and have average diffuse view factors to the spacecraft that shall not exceed 0.50. The origins of the radiator CFOVs shall be as shown in Table 2 if not overridden by the applicable detail specification.

Table 2.
FOV Areas and Origins
Measurements in TOMS coordinates in centimeters (inches)

Item	Area cm^2 (in^2)	X Origin	Y Origin	Z Origin
Scanner CFOV	TBD (TBD)	TBD (TBD)	TBD (TBD)	TBD (TBD)
Diffuser CFOV	16.97 (2.63)	31.67 (12.444)	24.49 (9.641)	39.6 (15.560)
Radiator 1 CFOV	TBD (TBD)	TBD (TBD)	TBD (TBD)	TBD (TBD)
Radiator 2 CFOV	TBD (TBD)	TBD (TBD)	TBD (TBD)	TBD (TBD)
Radiator 3 CFOV	TBD (TBD)	TBD (TBD)	TBD (TBD)	TBD (TBD)

3.1.2.2.5 **Mounting Footprint and Envelope.** The mounting footprint and envelope of the TOMS shall be as shown in Figures 5A, 5B, and 5C.

3.1.2.3 **Alignment.** Alignment of the instrument and its components shall be as follows.

3.1.2.3.1 **Instrument Alignment.** Provision shall be made for alignment mirrors aligned within ±0.5 degree to the scanner rotation axes (nominal directions same as instrument axes in Figure 4). The alignment of the mirrors relative to the instrument axes shall be measured to ±0.05 degree. See notes in Section 6.

3.1.2.3.2 **Scanner Nadir Alignment.** The nadir direction of the scanner (roll axis position) shall be aligned with the spacecraft nadir direction defined by the alignment mirrors with an accuracy of ±0.5 degree and shall be measured to ±0.05 degree.

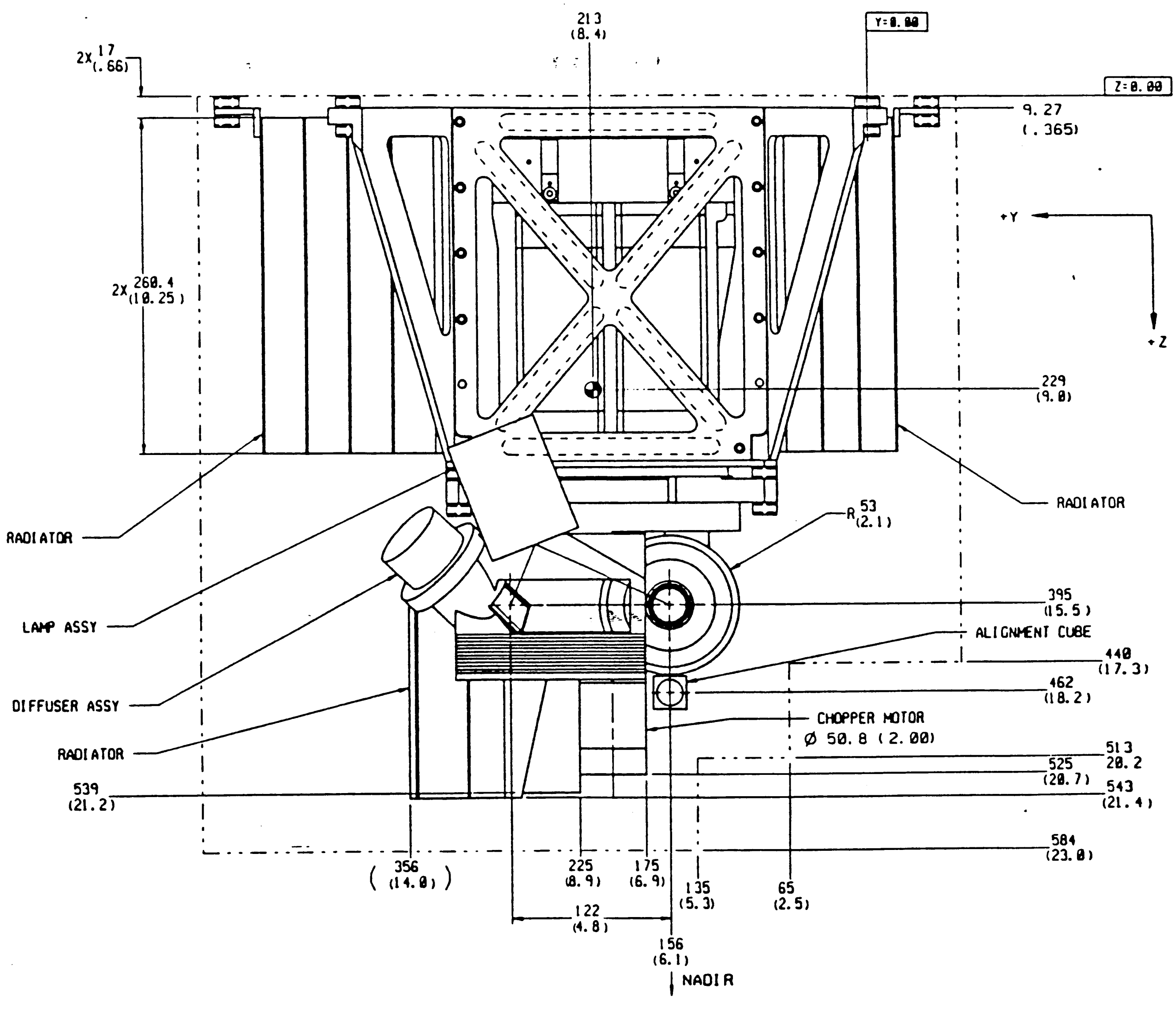

Figure 5A. TOMS Envelope and Mounting (X-View).

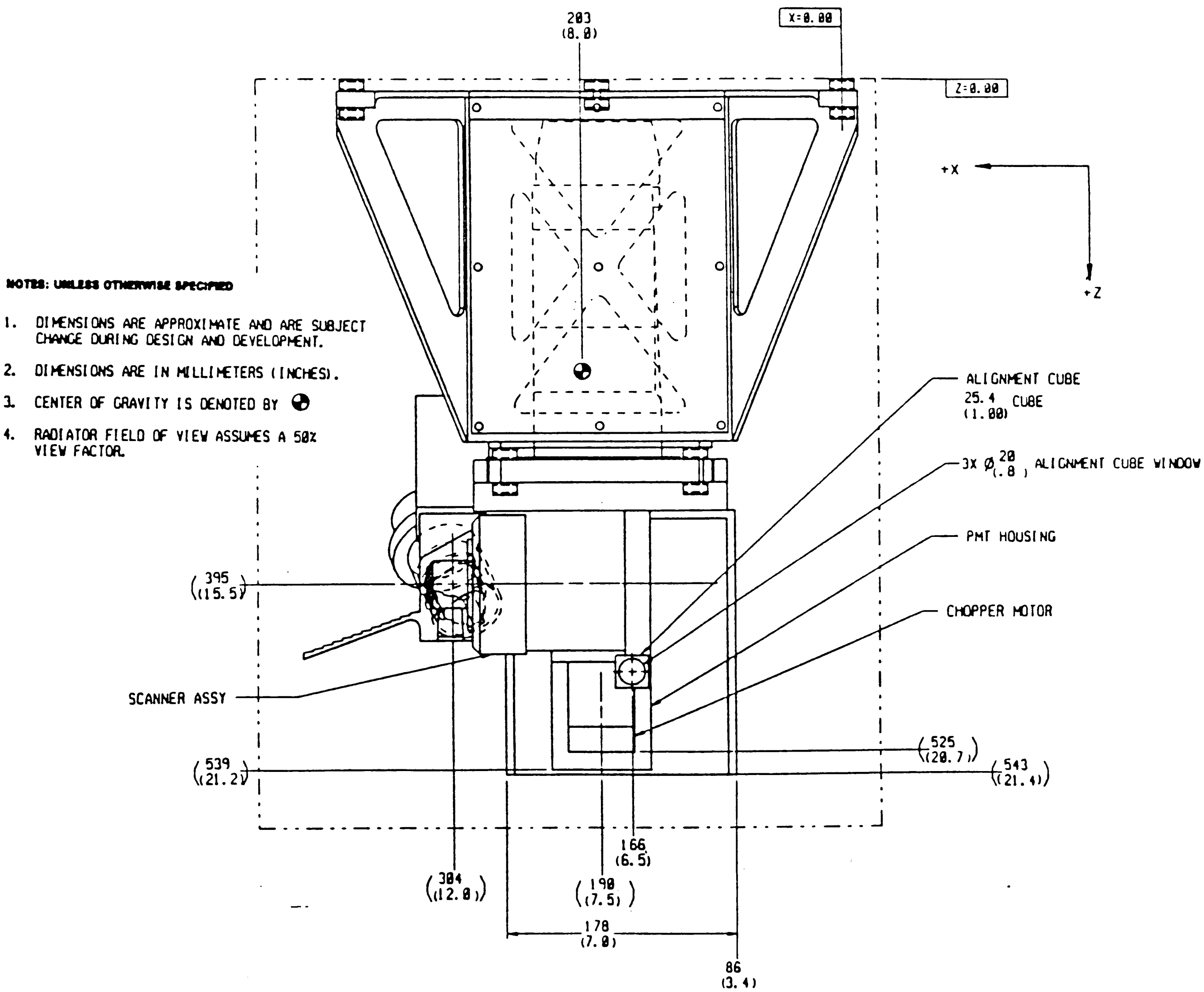

Figure 5B. TOMS Envelope and Mounting (Y-View).

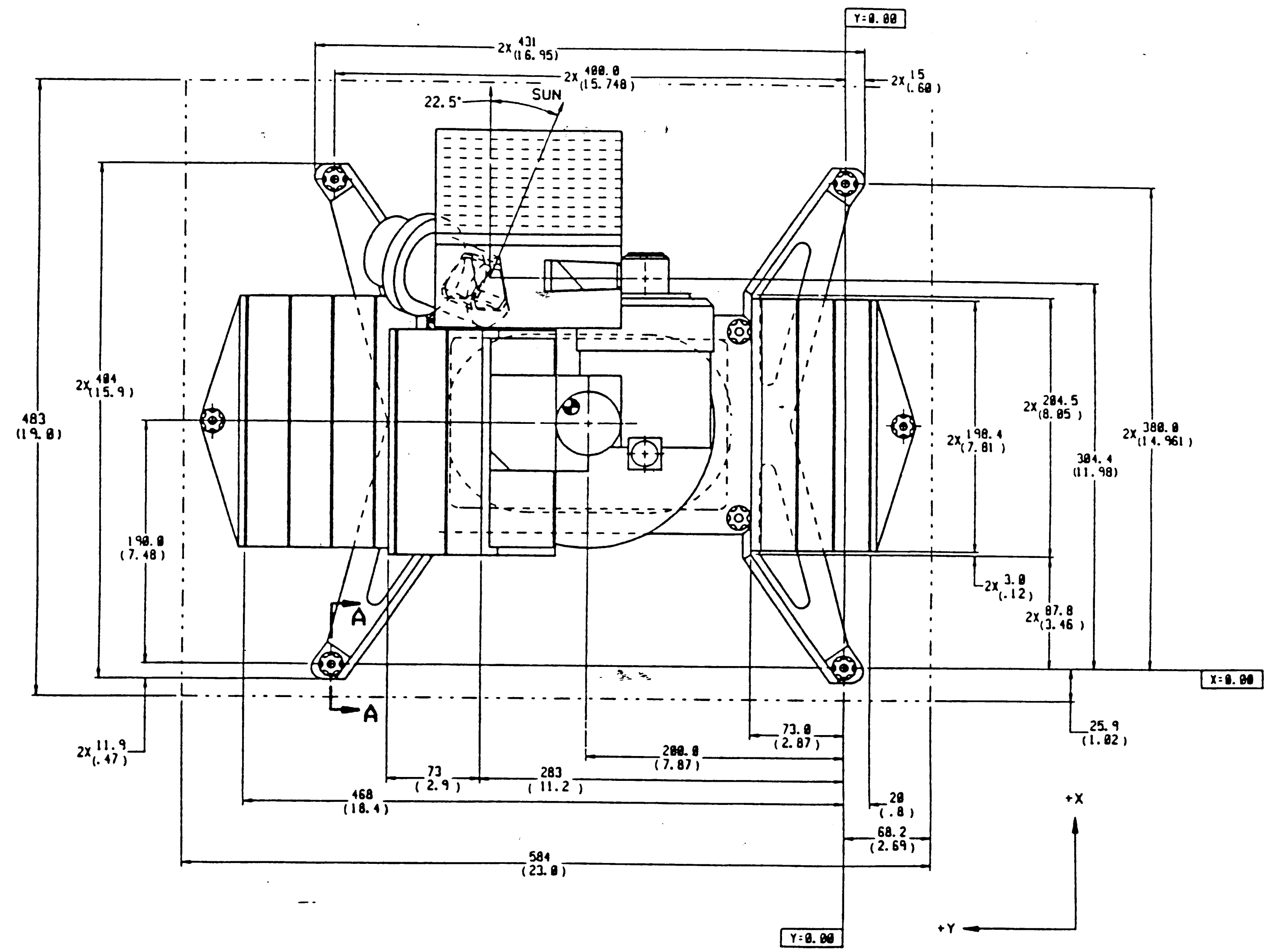

Figure 5C. TOMS Envelope and Mounting (Z-View).

3.1.2.3.3 **Major Component Alignment.** Alignment between mechanical and optical components shall be as shown in Table 3. Azimuth and elevation are relative to XY plane.

Table 3.
Major Component Alignment
I=Initial Tolerance or Knowledge, R=Repeatability or Stability

From	To	Align What	Tolerance	I/R	Units
Scanner	Align Mirror	Angles	±0.05	I	degrees
Scanner	Diffuser	Diff Azim	±0.15	R	degrees
Scanner	Diffuser	Scan Evel	±0.15	R	degrees
Scanner	Entr Optics	Elevation	±0.01	I	degrees
Scanner	Entr Optics	Azimuth	±0.01	I	degrees
Scanner	Entr Optics	X-Position	±0.5	I	mm
Scanner	Entr Optics	Z-Position	±0.5	I	mm
Entr Optics	Entr Slit	X-Position	±0.01	I&R	mm
Entr Optics	Entr Slit	Y-Position	±0.01	I&R	mm
Entr Optics	Entr Slit	Elevation	±0.03	I&R	degrees
Entr Optics	Entr Slit	Azimuth	±0.03	I&R	degree
Exit Slit	PMT Mask	X-Y Position	±0.05	I	mm
Exit Slit	PMT Mask	Z-Posn (Focus)	±0.2	I	mm
Exit Slit	Diode Mask	X-Z Position	±0.01	I&R	mm
Exit Slit	Diode Mask	Y-Posn (Focus)	±0.05	I	mm
Chopper Disk	Slit Plate	X-Y Position	±0.025	I&R	mm
Chopper Disk	Slit Plate	Z-Position	±0.1	I&R	mm
Chopper Disk	PRP	Z-Position	±0.1	I&R	mm

3.1.2.4 **Thermal Interface.** The TOMS instrument shall have its own thermal control system. This system shall be designed to maintain temperature control of the TOMS when the temperature of the spacecraft surface to which it is mounted is between +10°C to +30°C when the TOMS is operating and between -30°C to +55°C when the TOMS is not operating. The instrument shall be designed to limit heat transfer to or from the spacecraft to less than 5W. Contact area, contact thermal gradient and resistance, and radiation interface shall be in accordance with the applicable detail specification.

3.1.2.5 **Spacecraft Power, Command and Data Interface.** The spacecraft power, command and data interface shall be as specified in the applicable detail specification.

3.1.2.5.1 **Power Interface.** The TOMS low-voltage power supply shall supply all TOMS subsystems except for the survival and diffuser heaters. Power interface requirements shall be in accordance with the applicable detail specification. As a design goal, the power supply shall be designed for the worst-case combination of unregulated bus voltage variation, noise and transients for any spacecraft on which the TOMS is expected to fly.

3.1.2.5.2 **Discrete Command Interface.** Discrete commands shall have the interface specified in the applicable detail specification.

3.1.2.5.3 **Command Relays.** Relays shall be provided to switch the instrument power and the survival and diffuser heater power on and off and to enable and disable the photomultiplier high voltage. The interface shall be in accordance with the applicable detail specification.

3.1.2.5.4 **Bilevel Data Interface.** Bilevel telemetry shall have the interface specified in the applicable detail specification. The internal interface for latching relay position confirmation shall be two lines per relay: normally open contact and contact arm (SPST).

3.1.2.5.5 **Passive Analog Telemetry Interface.** Seven thermistors shall be provided for temperature monitoring by the spacecraft or in thermal-vacuum testing when the TOMS is unpowered. The thermistor leads shall be brought out to the spacecraft interface with no signal processing. Provision shall be made for mounting a parallel or series resistor at the interface as specified in the applicable detail specification. Thermistor and load resistance for the passive analog telemetry interface shall be nominally 5K @ 25C. The minimum sampling rate shall be 24 times per orbit.

3.1.2.5.6 **Active Analog Telemetry Interface.** Only the input current shall be telemetered. The spacecraft interface shall be in accordance with the applicable detail specification.

3.1.2.5.7 **Serial Magnitude Command and Mission Data Interface.** Interfaces for serial magnitude commands and mission data shall be in accordance with the applicable detail specification.

3.1.2.6 **Internal Electrical Interface.** To assure adaptability to different spacecraft, the TOMS shall have a standard internal control and data interface. The electronic interfaces between components of the TOMS shall be as specified in the wire list tables in Appendix 10.1. These wire lists refer to interface circuit schematics located in the same appendix. For other details of internal interface characteristics see Major Component Characteristics below.

3.1.2.7 **Test Connectors.** Separate test connectors shall be provided for monitoring internal signals from the optics module and digital electronics. The connector locations and interfaces shall be as shown in the Appendix.

3.1.3 **Major Component List.** Table 4 lists the major systems and subsystems of the TOMS. The interfaces between hardware components shall be as defined above, while the required performance characteristics shall be specified in the documents listed below (see 3.4, Major Component Characteristics, for controlling requirements).

Table 4. TOMS Major Component Specifications	
Specification Title (if separate)	Number
Scanner Subsystem	71-0153 (this)
Motor, Stepper, 3°, Area Scanner	38-0701
Entrance Optics Subsystem (Optical Subsystem)	65-0070
Diffuser Subsystem	71-0153 (this)
Motor, Stepper, 3°, Diffuser Drive	38-0703
Stepping Motor Encoders	71-0187
Reflectance Calibration Subsystem	65-0075
Lamp Power Supplies	71-0186
Monochromator Subsystem (Optical Subsystem)	65-0070
Chopper Subsystem	TBD
Motor, Three-Phase, Brushless, DC	38-0700
Encoder, Brushless DC Motor	65-0064
Chopper Servo Circuits	71-0185
Wavelength Monitor Subsystem (Optical Subsystem)	65-0070
Lamp Power Supplies	71-0186
Photodiode Subsystem	71-0153 (this)
Photodiode, Silicon, Ultraviolet-Enhanced	34-0194
Photodiode Electrometer	71-0181
Photomultiplier Subsystem	71-0153 (this)
Photomultiplier Tube Assembly	39-0366
High Voltage Power Supply	71-0182
Photomultiplier Tube Electrometer	71-0180
Voltage-to-Frequency Converter	71-0183
Electronic Calibration Subsystem	71-0184
Housekeeping Circuits	71-0188
Electronics Module (ELM) (Michigan)	71-0092
Low Voltage Power Supply (LVS)	TBD
Motor and Heater Driver (MHD)	TBD
Microprocessor (MP)	TBD
Spacecraft/Optics Interface (I/O)	TBD
TOMS Instrument Firmware	080086-460
Thermal Control System	TBD

3.2 **Characteristics.**

.2.1 **Performance Characteristics.**

3.2.1.1 **Satellite Orbit Characteristics.** The TOMS shall operate within specification for satellite orbits with the ranges of characteristics listed in Table 5.

Table 5.
TOMS Orbital Parameter Range

Parameter	Minimum Altitude	Maximum Altitude	Units
Orbital Altitude	797±25	955±25	km
Orbital Period (nom)	100.4	104.3	min
Inclination (nom)	98.6	99.3	degrees
Earth Rotation per Orbit (nom)	25.11	26.08	degrees
Ground Speed (nom)	6.64	6.40	km/sec
Scan Width (IFOV center, nom)	108.0	102.0	degrees
Scan Width (IFOV center, nom)	37	35	3° positions
Sun-XZ Plane Angle (initial)	0 to 45	0 to 45	degrees
Sun-XZ Plane Angle (drift)	±7.5	±7.5	degrees

..2.1.2 **Modes.** Primary modes shall be distinguished by having different data formats, operations or deployed components. A difference only in parameters shall not be considered to be a distinct mode.

3.2.1.2.1 **Primary Operational Modes.** The TOMS shall have the primary orbital operating modes listed below. Each mode shall have preset operating sequences and may have different output data content as specified herein. All steps to carry out each TOMS operating mode shall be stored within TOMS and shall be initiated in response to a command from the spacecraft.

Automatic control of the mechanisms and data sampling shall occur during primary operating modes. In addition, real time override functions shall be provided to turn on and turn off power to selected subsystems or reposition the various mechanisms.

Modes shall be entered according to a commanded mode sequence at the end of the current data-taking cycle (except for emergency overrides, if any). Commands may specify parameters. If no mode command is pending at the completion of the current mode, the TOMS shall go to Standby Mode.

Operations confirmed by sensor feedback (such as a reading of the scan encoder) shall have backup timing loops. Timeout durations shall be fixed parameters. Failure of any operation shall be flagged by error codes in the instrument status telemetry. Operations shall be sequential to avoid peak loads on the power supply.

Numeric codes (in hexadecimal) shall be used to indicate the current operating mode in the status record).

a. **Standby (STBY, 00H).** The TOMS electronics, chopper, and detector are on. The scanner and reflectance calibrator are in stow and the cover diffuser is exposed.

b. **Scan (SCAN, 01H).** The scanner successively steps through each of the steps in the scan pattern. The spectrometer measures the radiance backscattered from the earth's atmosphere at the selected wavelengths for each IFOV.

c. **Solar Calibration (SCAL, 02H).** The scanner shall view one of several selectable diffuser plates, which shall be exposed to direct sunlight. The spectrometer measures the solar irradiance via the diffuser.

   The sequence of operation shall be as follows:

   1. Stop scanning if scanning.

   2. Move scanner to view diffuser.

   3. Deploy commanded diffuser.

   4. Take data for the commanded number of data packets.

   5. Move scanner to view the reflectance calibrator.

   6. Take data for the commanded number of data packets.

   7. Move scanner to view diffuser.

   8. Take data for the commanded number of data packets.

   9. Revert to Standby Mode (unless otherwise commanded).

d. **Wavelength Monitoring (WMON, 03H).** This mode is normally initiated by command on the dark side of the orbit. The scanner shall be stowed during this mode. Monitoring shall be performed at night when space radiation is at a minimum.

   The sequence of operation shall be as follows:

   1. Stow scanner if not stowed.

   2. Energize the TOMS wavelength calibration lamp.

3. Wait for lamp to warm up.

4. View a mercury emission line in such a manner as to generate relative response at two equally-spaced wavelength increments centered around the expected Band 5 wavelength position at a rate of at least one sample per chopper revolution for a fixed number of complete chopper revolutions, and telemeter the resulting data.

5. Turn off lamp and revert to Standby Mode (unless otherwise commanded).

e. **Electronic Calibration (ECAL, 04H).** This mode is normally initiated while in Standby Mode by a spacecraft command during the dark side of an orbit. Precise signal currents shall be gated into the TOMS signal processing chains in addition to the currents normally furnished by the photomultiplier tube and photodiode. Unless commanded to remain in this mode or to transfer to another mode, the TOMS shall revert to Standby Mode at the completion of an ECAL sequence.

f. **Diffuser Reflectance Calibration (RCAL, 05H).** The scanner shall be positioned to view the diffuser and the calibration light source and heater shall be enabled. When operating temperature is reached, the scanner shall alternately view the source and the diffuser (repeating steps 6-14 as often as commanded). Calibration shall be performed at night when space radiation is at a minimum.

The sequence of operations shall be as follows:

1. Stop scanning if scanning.

2. Move scanner to view the diffuser.

3. Turn on calibration lamp and lamp heater.

4. Wait for lamp warmup. Control heater after warmup to keep lamp temperature constant.

5. Deploy diffuser to be calibrated.

6. Take data for the commanded number of data packets.

7. Move scanner to view the lamp.

8. Take data for the commanded number of data packets.

9. Turn off lamp and heater, cover diffuser, and revert to Standby Mode, unless otherwise commanded.

g. **Diagnostic Mode (DM, 06H).** The successive light and dark levels of the chopped signal at each wavelength while scanning normally shall be recorded and telemetered with maximum available precision.

h. **Microprocessor Test Mode (MTST, 07H).** In this mode the TOMS processor shall perform memory, output register, and other diagnostic checks and report the results.

i. **Dump Memory Mode (DMM, 08H).** In this mode the TOMS processor shall transmit designated bytes of the commanded RAM bank in place of science data.

j. **Upload Memory Mode (UPM, 09H).** In this mode the TOMS shall accept program code bytes until the commanded number of bytes are received.

k. **Direct Control Mode (DC, 0AH).** This mode shall permits real-time control of the high voltage, scanner, chopper, and diffuser. Real-time commands shall be rejected with an error indication except in this mode. The data format shall be selectable.

l. **Cold Start (Power-On Reset) (COLD).** When power is applied, TOMS shall perform a firmware initialization, and reset all parameters to values stored in ROM. High voltage shall be disabled, and mechanisms shall be left in their current positions. The system shall then enter Direct Control Mode using the primary science data format.

m. **Warm Start (CPU Reset) (WARM).** When the TOMS processor is reset from any source after a cold start has been completed, TOMS shall perform a firmware initialization, and reset all parameters to values stored in ROM. The high voltage setting shall remain unchanged, and mechanisms shall be left in their current positions. The system shall then enter Direct Control Mode using the primary science data format.

3.2.1.2.2 **Launch Mode.** During launch, the TOMS instrument shall be powered off with the scanner and diffusers placed in the protected stow positions. The TOMS diffuser header power shall be on during launch.

3.2.1.3 **Instrument Parameters.** The parameters listed in Table 6 shall either be adjustable before launch (in ROM) or shall be commandable in flight, as shown. The parameters shall be echoed back continuously in a digital subcom (see Table 10).

Table 6.
Instrument Parameters

Parameter	Range	Resolution	Units/Notes
12 MHz divider ratio	15 to 20	1	
Scan dwells per line	35 to 37	2	positions
PMT demodulator phase	0 to 3.069	0.003	degrees
Photodiode demod phase	0 to 3.069	0.003	degrees
ECAL clock phase	0 to 3.069	0.003	degrees
PMT gain adjustment	50 to 100	8 bits	percent
Active SCAL diffuser	0 to 2	2 bits	
Active RCAL diffuser	0 to 2	2 bits	
Set point monochromator heater	+10 to +30	8 bits	°C
Set point lower housing heater	+10 to +30	8 bits	°C
Set point RCAL lamp heater	+10 to +30	8 bits	°C
SCAL duration	0 to 20 min	3 scan lines	
WCAL duration	0 to 20 min	1 scan line	
ECAL duration	0 to 20 min	1 scan line	
RCAL duration	0 to 20 min	2 scan lines	

3.2.1.4 **Command Functions.** Commands shall be transmitted in the formats specified in the applicable detail specification. The commands supported shall be as follows:

3.2.1.4.1 **Relays.** Relays shall be provided for the following discrete command functions. Redundant relays shall be provided as specified herein, and consist of two latching relays connected in three-way switch mode (exclusive-or).

3.2.1.4.1.1 **Power On & Off.** Spacecraft power shall be switched on and off by redundant latching relays located in the power subsystem (two discrete commands required for each relay, on & off). Contact rating shall be 25 A.

3.2.1.4.1.2 **Survival Heater On & Off.** Survival heater power shall be switched on and off by redundant latching relays located in the power subsystem (two discrete commands required for each relay, on & off). Power shall be drawn from the unregulated bus. Heaters shall be electrically isolated from the housing and from power and signal ground. Contact rating shall be 2 A.

3.2.1.4.1.3 **Diffuser Heater On & Off.** Diffuser heater power shall be switched on and off by redundant latching relays located in the power subsystem (two discrete commands required for each relay, on & off). Power shall be drawn from the unregulated bus. Heaters shall be electrically isolated from the housing and from power and signal ground. Contact rating shall be 2 A.

3.2.1.4.1.4 **Memory Select Primary/Secondary.** The active read-only memory bank shall be selected by a latching relay located in the power subsystem (two discrete commands required, on & off). This selection shall override all other memory selection circuitry. The active bank shall be identified in the bilevel telemetry. Contact rating shall be 2 A.

3.2.1.4.1.5 **High Voltage Enable/Disable.** A latching relay located in the power subsystem (two discrete commands required, on & off) shall be used to enable or disable the high voltage supply by breaking the power connection Contact rating shall be 2 A.

3.2.1.4.2 **Discrete Commands.** Discrete commands shall be provided as follows:

3.2.1.4.2.1 **Relay Commands.** Discrete commands used to operate relays shall be as follows:

- Power On A & B
- Power Off A & B.
- Survival Heater On A& B
- Survival Heater Off A& B.
- Diffuser Heater On A& B
- Diffuser Heater Off A& B.
- Memory Select Primary/Secondary
- High Voltage Enable/Disable

Because of the three-way relay connection, only one relay shall be commanded to change state.

3.2.1.4.2.2 **Emergency Off.** The TOMS shall enter the Standby Mode when this discrete command is received. One discrete command is required. A delay of not less than 10 seconds shall be provided for stowing before spacecraft power is turned off.

3.2.1.4.2.3 **Reboot Microprocessor.** This command shall cause an immediate processor reset . The processor shall then execute the Warm Start Mode sequence.

3.2.1.4.2.4 **Spare.** This discrete command relay shall be provided as a spare.

3.2.1.4.3 **Serial Commands.** Serial commands shall be as follows:

3.2.1.4.3.1 **Time Sync.** The minor frame pulse and the Ascending Node pulse shall be used to latch the internal elapsed-time orbit clock (typically once per orbit). The value shall be telemetered in the parameter subcom. This interface shall be as specified in the applicable detail specification.

3.2.1.4.3.2 **Serial Magnitude Commands.** Serial magnitude commands and their parameters shall be those listed in Table 7. Word length shall be 16 bits, transmitted MSB first. The leading (MS) bit shall be 1 for the command itself (Word 1), and 0 for following parameter words, if any (Words 2..N). The next seven bits of Word 1 shall be the command identifier (ID Code). The last eight bits (0-7) of Word 1 may include parameters. All unused bits shall be set to zero.

Table 7.
Serial Magnitude Commands
See Table 6 For Parameter Definitions
Parameter Values in Bits 0-7 of Word 1 Unless Otherwise Noted

ID Code	Mnemonic	Function	Parameter(s)
00H	STBY	Go to Standby (STOW)	None
01H	SCAN	Start Scan	None
02H	SCAL	Solar Calibration	None
03H	WMON	Wavelength Monitoring	None
04H	ECAL	Electronic Calibration	None
05H	RCAL	Reflectance Calibration	None
06H	DM	Diagnostic Mode	None
07H	MTST	Microprocessor Self-Test	
08H	DRAM	Dump Memory	RAM Bank ID (0..1) Start address Byte count
09H	UPLD	Upload Memory	RAM Bank ID (0..1) Start address Byte count Program bytes
0AH	DC	Direct Control Mode	None
0BH	SP	Set Parameter (see Table 7 for ID)	Parameter ID (0..255) Parameter Data (Word 2)
0CH	UD	Use Default Parameter	None
0DH	PS	Position Scanner*	Scanner Position (0..119)
0EH	PD	Position Diffuser*	Diffuser Position (0..119)
10H	RLMP	RCA Lamp Off/On*	Off/On (0..1)

*Valid in Direct Control Mode Only.

Table 7, Continued Serial Magnitude Commands See Table 6 For Parameter Definitions Parameter Values in Bits 0-7 of Word 1 Unless Otherwise Noted			
ID Code	**Mnemonic**	**Function**	**Parameter(s)**
10H	WLMP	WRM Lamp Off/On*	Off/On (0..1)
11H	HV	High Voltage Off/On*	Off/On (0..1)
12H	CH	Chopper Off/On*	Off/On (0..1)
13H	SDF	Selected Data Format*	Normal, Calibration, Diagnostic, Error Log (0..3)

*Valid in Direct Control Mode Only.

3.2.1.5 **Output Data.** The TOMS shall transmit data to the spacecraft through the interface subsystem. All data packets shall be flagged with the orbit clock. The interface subsystem shall edit and format the data as required by the spacecraft.

3.2.1.5.1 **Orbit Clock.** The orbit time count shall be maintained in a 32-bit binary counter clocked at 50 Hz. Stability of the clock shall be better than 5 clock cycles in 220 minutes over the electronics orbital temperature variation. The clock shall be recorded by the Time Sync signals.

3.2.1.5.2 **Bilevel Telemetry Data.** Relay contact closures shall provide confirmation of latching relay status.

3.2.1.5.3 **Serial Data.** Output serial data shall be transmitted in bit-serial format in data packets of fixed length, called TOMS Telemetry Packets (TTP). Each logical packet shall contain data for an integral number of wavelength scan (chopper) cycles. Each packet shall contain a sync code, subcommutated analog housekeeping data, instrument status, and mode-dependent science data. The packet format shall be as shown in Table 8. The default format defined below may be overridden by the applicable detail specification.

Table 8.
TOMS Telemetry Packet Format

Date Item	Bit Position	No. of Bits
Sync Code	0	32
Analog Data Subcom 1 (Table 9: 0,4,8,12,16,20,24,28)	32	12
Analog Data Subcom 2 (Table 9: 1,5,9,13,17,21,25,29)	44	12
Analog Data Subcom 3(Table 9: 2,6,10,14,18,22,26,30)	56	12
Analog Data Subcom 4 (Table 9: 3,7,11,15,19,23,27,31)	68	12
Analog Monitor Group ID (0..7)	80	3
Analog Data Checksum	84	4
Instrument Status Record (Tables 10 - 13)	88	112
Time Stamp (Table 14)	200	1
Mode-Dependent Science Data (Tables 15 - 20)	104	8

3.2.1.5.3.1 **Sync Code.** The 32-bit sync code shall be EACB8AD8H; the sync code pattern shall be inverted in every other packet.

3.2.1.5.3.2 **Analog Data.** Each data item listed in Table 9 shall be subcommutated and transmitted at the rate of four items per packet. The gain and offset of each multiplexer (16—channel assumed) shall be calibrated by measuring the thermistor bias voltage and signal ground as shown in the table. Analog data within a packet shall be unambiguously identified by an ID code, by position, or both, as necessary.

Table 9.
Subcommutated Analog Data
12 data bits per word, 4 words and 3 ID bits per packet
(multiplexer references are thermistor bias voltage)

SCID	Data Item	Symbol	Range	Units
0	Multiplexer #1 Zero Reference	MUX1	0-5	V
1	Multiplexer #1 Voltage Reference	TBV1	0-5	V
2	Power Supply Temperature (LVS)	PST	Note 1	
3	PMT Housing Temperature	PMT	Note 1	
4	Photodiode Housing Temperature	PDT	Note 1	
5	Diffuser Mount Temperature	DMT	Note 1	
6	WRM Lamp Temperature	WMT	Note 1	
7	RCA Lamp/Phosphor Temperature	RLT	Note 1	
8	Monochromator Flange Temperature	MST	Note 1	
9	Monochromator Housing Left Temp.	MHL	Note 1	
10	Monochromator Housing Right Temp.	MHR	Note 1	
11	Housing Baseplate Temperature	HBT	Note 1	
12	Radiator #1 Heater Temperature	RT1	Note 1	
13	Radiator #2 Heater Temperature	RT2	Note 1	
14	Radiator #3 Heater Temperature	RT3	Note 1	
15	Multiplexer #2 Zero	MUX2	0-5	V
16	Multiplexer #2 Voltage Reference	TBV2	0-5	V
17	+5V Logic Voltage	LV	0-6	V
18	PMT High Voltage Monitor	HV	0-2500	V
19	Chopper Motor Voltage	CMV	0-25	V
20	Chopper Motor Current	CMI	0-0.25	A
21	PRP Photodiode Bias	PRPB	0-12	V
22-31	Spares	SPR22-31		

Note 1: Thermistor S-curve with load resistance = thermistor resistance at 20°C.

3.2.1.5.3.3 **Instrument Status.** The instrument status record shall be as shown in Table 10. The data validity flag shall be false for the entire packet if commanded timeouts are not complete, the wavelength scanner drops out of sync, or the scanner, diffuser, calibration, or any other subsystem does not go in the commanded state within the pre-specified timeout period. Instrument parameter data shall be confirmed by a digital subcom. The nadir radiance data shall consist of the two photomultiplier electrometer output readings on the ranges other than the range telemetered in science data format for the nadir scene. The two most significant bits shall identify the range. Serial magnitude command codes shall be those listed in Table 7. Minimum error codes shall be those listed in Table 11. The scanner and diffuser position codes shall be as shown in Table 12 and 13 respectively. The chopper phase error indicator shall have a resolution of 0.003 degrees.

Table 10.
Instrument Status Record

Data Item	Abbrev	Bit Position	No. of Bits
Data Valid (Valid = 1)	DV	0	1
Operating Mode	OM	1	4
Science Data format (0-7)	SDF	5	3
Error Code (Microprocessor Error)	MPE	8	8
Last Magnitude Command Processed	LC	16	16
Parameter Subcom Data	PSCD	32	16
Parameter Subcom ID	PSID	48	5
Boot ROM Select	BRS	53	1
Chopper On/Off	CH	54	1
HV On/Off	HV	55	1
Scanner Position	SP	56	6
Diffuser Position	DP	62	2
WRM Lamp On/Off	WRM	64	1
WRM Lamp Warmed UP	WRW	65	1
RCA Lamp On/Off	RCA	66	1
RCA Lamp Warmed Up	RCW	67	1
RCA Lamp Heater On	RLH	68	1
Lower Housing Heater On/Off	LHH	69	1
Monochromator Flange Heater On/Off	MFH	70	1
Baseplate Heater On/Off	BPH	71	1
Chopper Outer Loop Error	OLE	72	8
Chopper Inner Loop Sync Error Flag	ILF	80	1
Chopper Inner Loop Sync Error Sign	ILS	81	1
ECAL Level (F=Off, 3 Select, 1 ENB/DISBL)	ECAL	82	4
Spares		86	2
Nadir Scene Radiance #1	NS1	88	16
Nadir Scene Radiance #2	NS2	104	16
Instrument Status Checksum	SCK	120	8

Table 11.
Error Codes
F=Fatal; N=Non-Fatal; Codes in Hex

Code	Error	F/N
00H	No Error	-
01H	Command ID Error - undefined command	N
02H	Command Sequence Error - First Word flag in unexpected state	N
03H	Command Data Error - data out of range	N
04H	Command Register Overflow	N
05H	Command Queue Overflow	N
06H	Command Error - Direct Control command not valid in this mode	N
07H	Telemetry Register Underflow	N
20H	CPU Reset	N
21H	RAM Stuck Bit Error	N
22H	EEPROM CRC Error	N
23H	PROM Bank 0 CRC Error	N
24H	PROM Bank 1 CRC Error	N
40H	Scanner Response Failure	N
41H	Diffuser Response Failure	N
F0H	Illegal Interrupt	F
F1H	Improper Code Sequence	F
F2H	RAM Address Error	F
F3H		F

Table 12. Scan Encoder Definition 0=Opaque (Buffer Output High), 1=Transparent (Buffer Output Low) Angular intervals = Sector Angle ±1.5° unless otherwise specified			
Sector Angle, Degrees (+Y=+90°)	**Notes**	**Scan Code ABCDEF**	**Scan Code Octal, Low True**
±180	Stow	110110	66
-118.5 to -178.5	Sector 3 Left	110010	62
-117	RCAL Left #2	110011	63
-114	RCAL Left #1	110001	61
-91.5 to -112.5	Sector 2 Left	111001	71
-90	Calibrate Left	111011	73
-55.5 to -88.5	Sector 1 Left	111010	72
-54	Position 18 Left	111110	76
-51	Position 17 Left	111111	77
-48	Position 16 Left	111101	75
-45	Position 15 Left	111100	74
-42	Position 14 Left	101100	54
-39	Position 13 Left	101101	55
-36	Position 12 Left	101111	57
-33	Position 11 Left	101110	56
-30	Position 10 Left	101010	52
-27	Position 9 Left	101011	53
-24	Position 8 Left	101001	51
-21	Position 7 Left	100001	41
-18	Position 6 Left	100011	43
-15	Position 5 Left	100010	42
-12	Position 4 Left	100110	46
-9	Position 3 Left	100111	47
-6	Position 2 Left	100101	45
-3	Position 1 Left	100100	44

*Negative angles shall correspond to scanning toward the TOMS - Y axis.

Table 12, Continued Scan Encoder Definition 0=Opaque (Buffer Output High), 1=Transparent (Buffer Output Low)			
Sector Center Angle, Degrees (Nadie = 0)	**Notes**	**Scan Code ABCDEF**	**Scan Code Octal, Low True**
0	Nadir	000000	00
3	Position 1 Right	001001	11
6	Position 2 Right	001011	13
9	Position 3 Right	001010	12
12	Position 4 Right	001110	16
15	Position 5 Right	001111	17
18	Position 6 Right	001101	15
21	Position 7 Right	001100	14
24	Position 8 Right	011100	34
27	Position 9 Right	011101	35
30	Position 10 Right	011111	37
33	Position 11 Right	011110	36
36	Position 12 Right	011010	32
39	Position 13 Right	011011	33
42	Position 14 Right	011001	31
45	Position 15 Right	010001	21
48	Position 16 Right	010011	23
51	Position 17 Right	010010	22
54	Position 18 Right	010110	26
55.5 to 88.5	Sector 1 Right	010111	27
90	Calibrate Right	010101	25
91.5 to 112.5	Sector 2 Right	010100	24
114	RCAL Right #1	110100	64
117	RCAL Right #2	110101	65
118.5 to 178.5	Sector 3 Right	110111	67

Table 13. Diffuser Encoder Definition 0=Opaque (High), 1=Transparent (Low)			
Carousel Position, Degrees	**Exposed Diffuser**	**Code ABC**	**Code Octal, Low True**
0	Cover (Stow)	101	5
120	Working	011	3
240	Reference	110	6
Any other	N/A	000	0

3.2.1.5.3.4 **Time Stamp.** The time stamp format shall be as shown in Table 14.

Table 14. Time Stamp Record Data per TOMS Telemetry Packet		
Data Item	**Bit Position**	**No. of Bits**
TOMS Clock Time	0	32
Spacecraft Sync Time	32	32
Time Sync Checksum	64	8

3.2.1.5.3.5 **Science Data Structure.** All science data formats shall use a fixed structure that defines fixed locations for data records and checksums as shown in Table 15.

Table 15. Science Data Structure Data per TOMS Telemetry Packet		
Data Item	**Bit Position**	**No. of Bits**
Scene 0 Data Record	0	112
Scene 1 Data Record	112	112
Scene 0 Data Record Checksum	224	4
Scene 1 Data Record Checksum	228	4
Scene 2 Data Record	232	112
Scene 3 Data Record	344	112
Scene 2 Data Record Checksum	456	4
Scene 3 Data Record Checksum	460	4
(Scene 4-35 Data Records and Checksums)	464	3712
Scene 36 Data Record	4176	112
Scene 36 Data Record Checksum	4288	4
Unused	4292	4

.2.1.5.3.5.1 **Data Record Checksum.** The checksum shall be the 4-bit arithmetic sum, with carries ignored, of all the nibbles(4-bit groupings) in the data record.

3.2.1.5.3.5.2 **Radiance Data.** During each rotation of the chopper data shall be gathered for each band in two chops. Each chop shall consist of a light signal, U, preceded and followed by one dark period, D1, D2, as shown in Figure 6. The dark signals shall be separately integrated and added together to obtain one dark signal D = D1 + D2.

a. **Photomultiplier Data.** The data shall be gathered in three linear ranges. The 2 MSB of each data word shall contain two bits of range data (1..3, MSB first), followed by 14 bits of radiance data for that range. The upper and lower limits of the radiance for each range shall have the nominal values given in Table 16. The values measured for all three ranges shall be transmitted in diagnostic and calibration modes. In the SCAN mode only the normal range is transmitted (selected on board to provide the required radiometric resolution). The slope (gain) for all ranges in common may be adjusted in flight with the PMT gain-adjustment command.

b. **Photodiode Radiance Data.** The photodiode data shall be transmitted as a single 16—bit word of radiance data, corresponding to the linear range 0 to 500 ergs/cm2-sr-nm-s ±2 percent. The two most significant (range) bits shall be zero. The photodiode gain shall not be adjustable in flight.

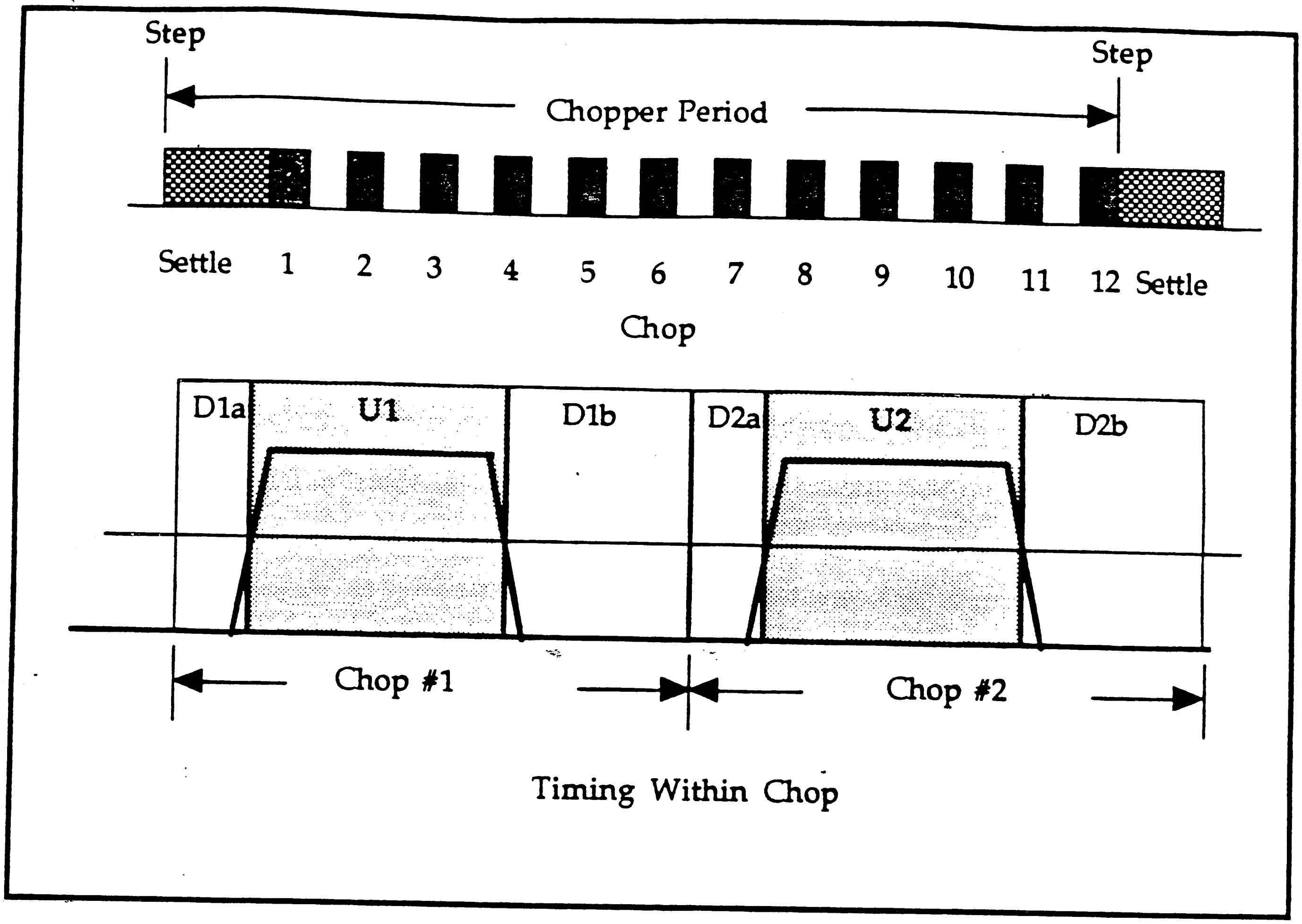

Figure 6. Scanner-Chopper Synchronization and Light and Dark Integration Periods.

Table 16. Photomultiplier Data Ranges		
Range	**Total Range ergs/cm^2-sr-nm-s**	**Normal Range ergs/cm^2-sr-nm-s**
1	0 - 5	0-5
2	0 - 50	5-50
3	0 - 500	50-500

3.2.1.5.3.5.3 **Normal Science Data Record.** Each data sample shall consist of one complete wavelength scan (chopper) cycle. This mode shall be used in Standby, Scan, and Solar Calibration Mode. Each radiance reading shall consist of the sum of the two chops for that band (subscript indicates chop number):

$$R = U_1 - (D1_1 + D2_1) + U_2 - (D1_2 + D2_2).$$

Only the PMT data giving the best radiometric resolution shall be telemetered. Each word shall consist of 2 range bits (most significant) followed by 14 bits of radiance data. Photodiode data shall be identified by range 0. The data format shall be as shown in Table 17.

Table 17.
Normal Science Data Record
Data for each scene, 16 bits per radiance reading (range = 2 MS bits)

Data Item	Bit Position	No. of Bits
Band 1 PMT range and radiance	0	16
Band 2 PMT range and radiance	16	16
Band 3 PMT range and radiance	32	16
Band 4 PMT range and radiance	48	16
Band 5 PMT range and radiance	64	16
Band 6 PMT range and radiance	80	16
Band 1 photodiode range and radiance (range = 0)	96	16

3.2.1.5.3.5.4 **Wavelength Monitoring Science Data Record.** Each data sample shall consist of one complete wavelength scan (chopper) cycle. This mode shall be used in Wavelength Monitoring and Electronic Calibration Modes only. The radiance for each chop shall be transmitted separately as

$$R = U - (D1 + D2).$$

All data ranges shall be telemetered. Each word shall consist of 2 range bits (most significant) followed by 14 bits of radiance or ECAL signal data. The data format shall be as shown in Table 18.

Table 18.
Calibration Science Data Record
Data for each scene, 16 bits per radiance reading (range = 2 MS bits)

Data Item	Bit Position	No. of Bits
Band 5 PMT/ECAL range & signal, chop 1, range 1	0	16
Band 5 PMT/ECAL range & signal, chop 1, range 2	16	16
Band 5 PMT/ECAL range & signal, chop 1, range 3	32	16
Band 5 PMT/ECAL range & signal, chop 2, range 1	48	16
Band 5 PMT/ECAL range & signal, chop 2, range 2	64	16
Band 5 PMT/ECAL range & signal, chop 2, range 3	80	16
Unused (spare)	96	16

3.2.1.5.3.5.5 **Diagnostic Science Data Format.** This format shall be used in the Diagnostic Mode, and shall consist of groups of 12 successive telemetry packets. Each data sample shall consist of one complete wavelength scan (chopper) cycle. Because 12 times as much data is collected during one diagnostic mode scan line, data shall be transmitted only once every 12 scan lines. Each group of 12 packets shall have the same time stamp. The light, U, and dark, D = D1 + D2, values shall be transmitted separately for each range and each chop. Each word shall consist of 2 range bits (most significant) followed by 14 bits of radiance data. Photodiode data shall be identified by range 0.

The data format shall be as shown in Table 19. In the first packet, the dark values for chop 1 as measured by PMT electrometer range 1 shall be telemetered, followed in the next packet by the light value for the same chop and electrometer range in the next packet. Following packets shall transmit the values for successive ranges and then transmit the data for the second chop in the same manner. Photodiode data shall be the same for all ranges.

Table 19.
Diagnostic Mode Science Data Record
Data for each scene, 16 bits per radiance reading (range = 2 MS bits)

Data Item	Bit Position	No. of Bits
Band 1 PMT range and radiance	0	16
Band 2 PMT range and radiance	16	16
Band 3 PMT range and radiance	32	16
Band 4 PMT range and radiance	48	16
Band 5 PMT range and radiance	64	16
Band 6 PMT range and radiance	80	16
Band 1 photodiode range and radiance (range = 0)	96	16

3.2.1.5.3.4.6 **Memory Dump Science Data Format.** This format shall be used to telemeter selected memory contents. The first data record in the science data shall contain the address, the number of bytes in the packet, and the first 10 bytes of data; subsequent records as required shall contain 14 bytes of data, as shown in Table 20.

Table 20.
Memory Dump Mode Science Data Record

Data Item	Bit Position	No. of Bits
First record:		
Address of first memory bytes in this packet	0	16
Number of memory bytes in this packet	16	16
Memory bytes 0..9	32	80
Subsequent records:		
14 Memory bytes	0	112

3.2.1.5.4 **Passive Analog Telemetry.** The temperature of the points listed below shall be monitored by temperature sensors powered from the spacecraft. Unless otherwise specified in the applicable detail specification, thermistors shall be 5K±1 percent at 25°C in accordance with GSFC S-311-P-18, and load resistors shall be 8.66K±1 percent 1/8 W RNR60E8661FS. Other points shall be monitored as part of the engineering data stream.

- Spacecraft Interface.
- Diffuser Housing (thermistor located outside the carousel area and vented).
- Monochromator Housing.
- Lower Housing (Motor Area).
- Radiators 1,2 & 3.

3.2.1.5.5 **Active Analog Telemetry.** The TOMS input power bus current shall be monitored with an active telemetry monitor with an accuracy of ±5 percent or better. The scale factor, bandwidth, output impedance, and ground isolation shall be in accordance with the applicable detail specification.

3.2.1.6 **Spatial Scanning.** The TOMS shall perform a cross-course step-scan with a total field of view designed for contiguous global coverage. Each line scan shall consist of a number of equal-duration step-and-dwell cycles followed by a retrace as shown in Figure 7. The forward scan direction shall correspond to a motion of the IFOV from the -Y to +Y direction when in the PM ascending node configuration and from the +Y to -Y direction when in the AM ascending node configuration.

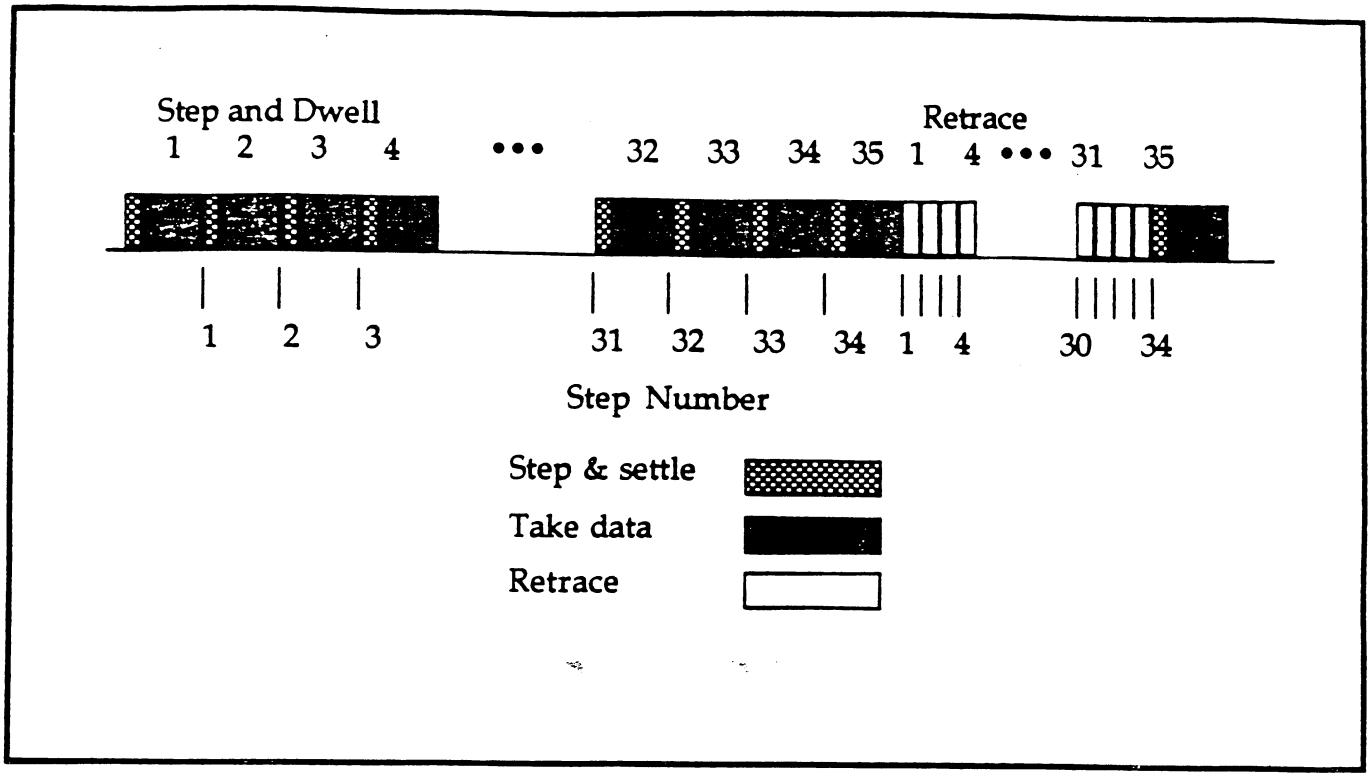

Figure 7. Scan Timing.

3.2.1.6.1 **Instantaneous Half-Power Field of View (IFOV).** The TOMS instrument shall have an instantaneous half-power field of view 3.0±0.1 degrees square for all spectral bands. The IFOV for a given scan position is called a "scene".

3.2.1.6.2 **Full Field of View (FFOV).** Optical definition of the field of view shall assure that 99.95 percent of the energy originates within a 4.0-degree square centered on the nominal IFOV.

3.2.1.6.3 **Clear Field-of-View (CFOV).** No obstruction shall be placed so that it can scatter light into the full field of view. The scan mirror, relay mirror, diffuser, calibration diffuser, and entrance optics shall be sized to encompass the FFOV allowing for beam rotation at applicable scan angles.

3.2.1.6.4 **Step Angle.** The nominal step angle of the scanner shall be equal to 3 degrees.

3.2.1.6.5 **Scan Width.** The number of dwells in a scan shall be selected before launch to provide contiguous spatial coverage between orbits at the equator.

3.2.1.6.6 **Scan Line Period.** The total scan line period shall be an integral multiple of wavelength scan (chopper) cycles with the timing specified as a function of altitude in Table 21 (do not interpolate between altitudes). The scan period (time per line, including retrace) shall be prelaunch-selectable in the range 6 to 8 seconds. The default period shall be selected to provide near-zero underlap at the equator between adjacent scan lines at nadir for a circular orbit at the nominal altitude. The retrace rate shall be separately selected before launch.

Note that the design limits the available dwell time resolution to 10 milliseconds. For intermediate altitudes, dwell times of 0.16, 0.17, 0.18, and 0.19 seconds are available.

Table 21.
Scan Timing vs Altitude

		Orbital Altitude, km	
Parameter	**Units**	**797**	**955**
Scan dwells (chopper revs)		37	35
Scan steps (moves)		36	34
Scan dwell time	seconds	0.150	0.200
Scan time	seconds	5.550	7.000
Retrace chopper revs		5	4
Total chopper revs/line		42	39
Scan line time	seconds	6.300	7.800
Retrace time available	seconds	0.750	0.800
Minimum retrace rate	steps/second	46.7	41.2
Retrace rate	steps/second	50	50
Integration time	seconds	0.118	0.1575
Time/chop	seconds	0.0103	0.0137

3.2.1.6.7 **Scan Accuracy.** The accuracy of the step scan shall be such that lateral image displacement shall not exceed 5 percent of the effective width of an IFOV element at any point along adjacent lines. This error shall not accumulate beyond the effective width of an IFOV element over the instrument lifetime. The above scan accuracies shall be either inherent in the scanning assembly or sensed and corrected.

3.2.1.6.8 **Scan Rate Stability.** The commanded stepping rate within a line scan shall not vary more than ±3 percent.

3.2.1.6.9 **Scan Repeatability.** The repeatability of the line-scan as defined by the centers of the nominal IFOVs making up a line scan and the x-axis alignment target of the TOMS shall be within 0.3 degrees.

3.2.1.6.10 **Diffuser Look.** The scanner shall be capable of viewing the selected diffuser with the accuracy and repeatability listed in Table 3.

3.2.1.6.11 **Source Look.** The scanner shall be capable of viewing the reflectance calibration source with the accuracy and repeatability listed in Table 3.

3.2.1.6.12 **Scanner Stow Position.** A scanner position shall be provided in which the scan mirror is protected from sunlight and the entrance slit is dark. Signal levels from exposure of the instrument to direct sunlight at any angle shall not exceed full scale when the scanner is in the stow position. This position shall also be used to protect the scan mirror from contamination. A hermetic seal shall not be used.

3.2.1.6.13 **Scan Encoder.** The scan position shall be indicated by an absolute digital encoder with a resolution of one scan step or better. Scan encoder output codes shall be per Table 12.

3.2.1.6.14 **Scan Synchronization.** The step scan motor drive pulses shall be synchronized with the wavelength scan as shown in Figure 6 with a maximum instability of ± 0.05 percent of the scene viewing time, non-cumulative.

3.2.1.7 **Diffusers.** The TOMS instrument shall be provided with a minimum of two ground aluminum reflection diffuser plates, prepared as specified in Section 3.4 below, for determination of the response of the TOMS to incident solar radiation.

3.2.1.7.1 **Diffuser Mounting.** The active diffuser plate shall be mounted or deployed in a position that fills the projected full field of view of the instrument at a scanner position. The diffuser shall be mounted or retractable to a position that does not interfere with normal earth observations. The diffuser must have a clear FOV to the sun at one of the earth day/night terminators. Means shall be provided for protection from contamination or exposure to direct sunlight when a plate is not in use for calibration. The protective cover shall be designed to remain closed when the instrument is unpowered, including orbital flight and the launch. The diffuser plates shall be used as reference and working plates for the purpose of providing a control on optical performance degradation through surface contamination. Both shall be protected from exposure. The protective cover may serve as a contamination reference surface with known diffuse reflection properties.

3.2.1.7.2 **Diffuser Heating.** To prevent contamination the diffusers shall be heated above the temperature of anything along any straight line through the opening in the diffuser cover, except for the RCA lamp when it is on. The diffusers shall be heated at all times in orbit as long as diffuser heater power is supplied, whether the TOMS is on or off.

3.2.1.7.3 **Diffuser Stray Light.** The diffuser shall be shaded to prevent illumination by sources other than the sun, including light reflected from other instrument components, either by single or multiple reflection off the diffuser or by direct reflection into the entrance optics. The baffle used shall shade the diffuser from any sources of light outside the clear field of view defined in Figure 4. The diffuser radiance from other sources shall not exceed 1 percent of the diffuser irradiance due to the primary source.

3.2.1.7.4 **Reflectance Calibrator.** An in-flight reflectance calibration system shall be provided which is capable of measuring changes in the ratio of reflectivities of the diffuser plates, at the TOMS wavelength pairs, of 0.1% per year over a three-year assumed mission lifetime. Calibrations can be conducted as frequently as once per orbit (subject to spacecraft power limitations).

3.2.1.8 **Spectral Measurements.** The TOMS instrument shall contain a spectrometer, shuttering system, and photodetector and associated electronics capable of resolving the wavelength band fluxes specified herein, with spectral purity and stray light and dark current rejection adequate for meeting the specifications listed in this section.

3.2.1.8.1 **Wavelength Range.** The TOMS shall operate within the wavelength range from 308.6 to 360 nm.

3.2.1.8.2 **Wavelength Bands.** Six discrete spectral bands with nominal center wavelengths listed in Table 22 shall be provided by the TOMS spectrometer.

Table 22.
TOMS Wavelengths and Nominal Radiance Limits
(Radiance in ergs/cm2-sr-nm-s)

Band #	Center Wavelength	Maximum Radiance	Minimum Radiance
1	360.0 nm	400	10
2	331.2 nm	310	5
3	322.3 nm	203	1.8
4	317.5 nm	170	0.7
5	312.5 nm	110	0.4
6	308.6 nm	55	0.4

3.2.1.8.3 **Wavelength Pairs.** The wavelength pairs in Table 23 will be used for data processing. The instrument design shall minimize any errors in the relative radiance and irradiance measurements in the wavelength pairs.

Table 23.
TOMS Wavelength Pairs

Pair	Band #s	Usage
A	5 - 2	Low-latitude ozone
B	4 - 2	Mid-latitude ozone
C	3 - 2	High-latitude ozone
D	6 - 5	Calibration drift; low latitudes only

2.1.8.4 **Spectral Bandpass.** The TOMS spectrometer shall have a full width, half maximum spectral bandpass of 1.0 nm+0.3 nm-0.0 nm for all bands over its wavelength range. The instrument transfer function shall be determined for each of the wavelength bands from the band center to the 1 percent relative transmission points on both sides of the band. See notes in Section 6 relating to bandpass measure.

3.2.1.8.5 **Wavelength Accuracy.** The centers of each spectral band shall be within 0.10 nm of the specified wavelength for wavelengths less than 340.0 nm and within 0.20 nm for wavelengths greater than or equal to 340.0 nm. Each center wavelength shall be measured to a precision of 0.05 nm.

3.2.1.8.6 **Wavelength Stability.** The TOMS spectrometer shall maintain wavelength stability of the primary ozone measurement band numbers 4, 5, and 6 (Table 22) within 0.005 nm in the orbital operating environment. The ozone reference wavelengths and the surface reflectivity wavelength (bands 1, 2, and 3) require a wavelength stability of 0.01 nm.

3.2.1.8.7 **Wavelength Scan.** The TOMS shall measure the radiance of all the specified wavelength bands within the dwell time of each scanner position as shown in Figure 6. The chop numbers from 1 to 12 shown shall correspond to Bands 1, 2, 3, 4, 5, 6, 6, 5, 4, 3, 2, 1 respectively.

3.2.1.8.7.1 **Instantaneous Field-of-View Registration.** The angular fields of view for each of the six wavelengths shall be registered within 0.1 degrees.

3.2.1.8.7.2 **Image Motion Compensation.** The wavelength scan shall consist of a repeating sequence such that image motion effects tend to cancel to 1st order in the ratio of radiances for the pairs of wavelengths defined below. The difference in the centroids of the two members of each pair shall be less than 0.1 degrees. See notes.

3.2.1.8.8 **Wavelength Repeatability Monitor.** A wavelength repeatability monitor (WRM) shall provide in-flight wavelength calibration of the TOMS spectrometer. The wavelength calibration relative to the pre-launch laboratory calibration shall be monitored by means of a spectral line emission source(s) having one or more lines near the TOMS spectral region and a means for generating a wavelength scan of the line(s). The WRM shall detect a shift of 0.01 nm at the wavelength(s) of the spectral line source(s). The temperature(s) of the light source(s) shall be monitored.

3.2.1.9 **Radiometric Characteristics.** Measurements of the radiances in the six spectral bands shall meet the following requirements.

3.2.1.9.1 **Dynamic Range.** The design maximum radiance shall be 500 ergs/cm^2—sr—nm—s. The maximum expected earth radiance is 400 ergs/cm2-sr-nm-s at 360.0 nm for a solar zenith angle = 0°, scan angle = 0°, R= 1, P = 1 atm condition (see 6.1 for definitions of symbols). The minimum practical earth radiance at total ozone retrieval wavelengths is 0.40 erg/cm^2—sr—nm-sc at 312.5 nm, obtained at the solar zenith angle SZA = 88°, scan angle = 0°, R = 0.6, p = 1 atm conditions. The TOMS spectrometer dynamic range shall be designed to measure both scene radiance and/or solar irradiance over the maximum and minimum expected signal levels presented in Table 22.

3.3.2.1.9.2 **Radiometric Linearity.** The response of the radiometric system shall be characterized by fit functions which make it possible to calculate the ground reflectance and pair signal ratios, including the diffuser calibration but excluding noise and quantization error, so that the systematic errors and instabilities in each measurement shall correspond to no more than ±TBS percent in the measured radiance at 360 nm and ±TBS percent in the radiance ratio for the TOMS wavelength pairs. See notes in Section 6.

3.2.1.9.3 **Radiometric Repeatability.** The corrected mean response of the TOMS radiometric system shall be repeatable to better than 1 percent while viewing the same source under the same conditions but separated in time by at least 24 hours.

3.2.1.9.4 **Signal-to-Noise Ratio.** The signal-to-noise (S/N) ratio shall be greater than 30 at the minimum radiance of 0.40 erg/cm2-sr-nm-s. Improved atmospheric measurements will be obtained at higher light levels.

3.2.1.9.5 **Spectral Stray Light.** When the TOMS instrument is viewing the sunlit earth from space, the total contribution by all unwanted wavelengths to the signal produced by radiation defined by the bandwidth of any TOMS spectral band shall be less than 0.5 percent.

3.2.1.9.6 **Radiometric Resolution.** The signal conditioner, digitizer, and data compression (if used) shall provide radiometric data with a precision of no worse than 0.2 percent of signal (9 bits).

3.2.1.9.7 **Band-to-Band Crosstalk.** No more than 0.1 percent of the signal in any band shall result from crosstalk between bands.

3.2.1.9.8 **Dark Current Rejection.** The instrument shall provide for rejection of dark current and instrument offset by use of optical chopping. See notes. The signal-to-noise ratio (S/N) shall be greater than 30 in Band 5 when the TOMS is subject to peak trapped radiation. At this point the Band 5 radiance shall be 2.0 erg/cm^2—nm—s or greater.

3.2.1.9.9 **Single-Event Upsets.** Design of the instrument shall be resistant to single-event upsets such that no damage occurs and data loss is limited to no more than the equivalent of one scan per orbit.

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3.2.1.10 **Polarization Sensitivity.** The TOMS instrument shall be equipped with optical depolarizer(s) such that the residual detector polarization sensitivity to the incident radiation

Total Dose & Dose Rate is not provided

will be reduced to less than 5 percent over the operational range of angles and wavelengths. The polarization sensitivity is defined as:

$$P = (I_{max} - I_{min}) / (I_{max} + I_{min}),$$

where I_{max} and I_{min} are the maximum and minimum values of intensity measurements of the TOMS instrument resulting from rotating a total linear polarizer between the instrument and an unpolarized light source.

3.2.1.11 **Magnetic Field Sensitivity.** A change in the ambient DC magnetic field of ±1 gauss in any direction shall not change the output signal more than ±0.05 percent.

3.2.1.12 **Temperature Coefficient of Response.** The end-to-end temperature coefficient of responsivity (radiance to digital output) shall not exceed ±4 percent (40000 ppm) per °C).

3.2.2 **Physical Characteristics.**

3.2.2.1 **Mass.** The mass of the TOMS instrument shall not exceed 25 kg, including thermal blankets, with a design goal of 20 kg.

3.2.2.2 **Resonant Frequency.** The minimum fundamental resonant frequency of the TOMS instrument shall be greater than 100 Hz in any orthogonal direction when mounted to a rigid structure.

3.2.2.3 **Uncompensated Angular Momentum.** The TOMS total instantaneous peak angular momentum component along any axis shall not exceed 0.01 newton-meter-second.

3.2.2.4 **Power.** The orbital average power during the normal operating modes shall be 14 watts or less, excluding operational heater power. Maximum heater power shall be as follows, unless otherwise specified in the applicable detail specification.

a. Operational Heaters: 8.0 W.

b. Diffuser Heater: 2.0 W.

c. Survival Heater: 10.0 W.

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3.2.2.5 **Grounding and Shielding.** Grounding and shielding requirements are as follows.

3.2.2.5.1 **Input Power Isolation.** The spacecraft input power return shall be isolated from the housing and from TOMS signal grounds by at least 1 megohm.

3.2.2.5.2 **Output Power Isolation.** TOMS signal returns (all lines) shall be isolated from the housing by at least 10 Megohms. Separate analog and logic supply buses shall be used, and grounded together in the neighborhood of the analog-to-digital conversion circuits.

3.2.2.5.3 **Local Shields and Returns.** Critical analog circuits (including but not limited to the electrometers, chopper speed control, phase reference pickup, high voltage control amplifier) shall be shielded from other circuits and the housing by Faraday shields connected to local analog signal ground. Separate ground planes shall be used under these circuits, tied to local analog ground. Logic circuits shall have ground planes tied to logic ground. If there are thermal planes, they shall be connected to chassis ground but shall be shielded from sensitive circuits. For details see Power Supply Characteristics below.

3.2.2.5.4 **Grounding Stud.** A stud shall be provided on the mounting base of the instrument for grounding purposes.

3.2.3 **Reliability (Lifetime).** The TOMS shall be designed for a minimum lifetime of two years in orbit.

3.2.4 **Maintainability.** Preflight maintainability requirements shall be in accordance with GSFC TOMS-910-90-001.

3.2.5 **Environmental Characteristics.** Environmental conditions for the TOMS instruments may vary between launch vehicles and spacecraft. The TOMS shall be designed to meet the requirements of this specification during and after exposure to the environments specified herein.

3.2.5.1 **Transportation, Storage and Handling (Nonoperating).** The TOMS shall operate and meet the requirements of this specification after exposure to any combination of the following environments while packaged in the TOMS shipping containers.

3.2.5.1.1 **Ambient Air Temperature.** The ambient temperature range shall be -10 to +40 °C, maximum transient 5 °C per hour.

3.2.5.1.2 **Ambient Pressure.** The ambient pressure range shall be 400 Torr to 795 Torr.

3.2.5.1.3 **Humidity.** The relative humidity shall be in the range 10 to 100 percent relative, no internal condensation permitted.

3.2.5.1.4 **Static Acceleration.** Maximum semi-steady state accelerations shall be limited to 3g in any direction.

3.2.5.1.5 **Transient Shock and Vibration.** Shipping and storage containers and handling procedures shall be designed and implemented to protect the TOMS at a 6g fragility factor.

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3.2.5.1.6 **Cornerwise Drop.** Shipping and storage containers and handling procedures shall be designed and implemented to protect the instrument when the container is dropped in accordance with FED-STD-101 Method 5005.1 Level B.

3.2.5.2 **Functional Test, Checkout and Prelaunch Operations.** The TOMS shall operate and meet the requirements of this specification during and after exposure to any combination of the following environments.

3.2.5.2.1 **Ambient Air Temperature.** The ambient temperature range shall be 0°C to +40°C, transient 5 °C per hour.

3.2.5.2.2 **Ambient Pressure.** The ambient pressure range shall be less than 10^{-5} Torr or 795 Torr.

3.2.5.2.3 **Humidity.** The relative humidity shall be controlled in the range 35 to 70 percent, no condensation permitted.

3.2.5.3 **Launch and Post-Launch Operations (Non-Operating).** The TOMS shall operate and meet the requirements of this specification after exposure to any combination of the following environments.

3.2.5.3.1 **Launch Temperature.** The launch and post-launch non-operating temperature range at the TOMS S/C interface shall be -30°C to +55°C with survival heater(s).

3.2.5.3.2 **Launch Pressure Change.** During the launch, the ambient pressure shall decrease from a maximum of 790 Torr to 1×10^{-10} Torr or less at a maximum rate of 18 Torr per second.

3.2.5.3.3 **Acoustics.** The acoustic vibration spectrum shall be in accordance with Table 24.

3.2.5.3.4 **Random Vibration.** The random vibration spectrum shall be in accordance Table 25.

3.2.5.3.5 **Sine Vibration.** The sine vibration spectrum shall be in accordance with Table 26.

3.2.5.3.6 **Shock.** The shock spectrum shall be in accordance with Table 27.

3.2.5.3.7 **Acceleration.** The TOMS instrument shall be designed to withstand the loads stated in Table 28 (RSS of ±19.7 g's of static acceleration), in each of the three orthogonal axes of the instrument, a single axis at a time.

Table 24. Acoustic Test Levels		
	One-Third Noise Level (dB) re: 0.00002 Pa	
Frequency Range (Hz)	Qualification	Acceptance
25		
32	128	125
40	129.5	126.5
50	130	127
63	131	128
80	131.5	128.5
100	133	130
125	133	130
160	133	130
200	135	132
250	135	132
315	135	132
400	132	129
500	131.5	128.5
630	131.5	128.5
800	130	127
1000	130	127
1250	130	127
1600	127	124
2000	126	123
2500	125	122
3150	124.5	121.5
4000	123	120
5000	122	119
6300	121.5	118.5
8000	121	118
10000	120.5	117.5
Overall	145	142
Duration	1 to 2 min*	1 min

* Protoflight Qual = 1 min/axis, Prototype Qual = 2 min/axis

Table 25. Random Vibration Levels - All Axes		
	Power Spectral Density (g^2/Hz)	
Frequency Range (Hz)	**Qualification**	**Acceptance**
20 - 40	+6 dB/Oct	+6 dB/Oct
40 - 1000	0.08	0.036
100 - 200	-12 dB/Oct	-12 dB/Oct
Overall Level	10.1 g rms	6.8 g rms
Test duration	1 or 2 min/axis*	1 min/axis

* Protoflight Qual = 1 min/axis, Prototype Qual = 2 min/axis

Table 26. Sine Vibration Levels - All Axes		
	Vibration (g)	
Axis	**Frequency Range (Hz)**	**g (peak)**
X	5-40 40-70 70-100	4 15 7
Y	5-40 40-100	12.75 4.5
Z	5-40 40-60 60-100	12.75 3.8 2.0
Sweep Rate	4 octaves/minute	

Table 27. Shock Levels - All Axes		
	Shock Response Spectrum (g)	
Frequency Range (Hz)	**Qualification**	**Acceptance**
100 - 800	+8 dB/oct	+8 dB/oct
800 - 3000	420	300

Table 28. Acceleration (g's)		
X	**Y**	**Z**
±15.0	±6.0	±11.25

3.2.5.4 **Orbital Operations.** The TOMS shall be designed to operate and meet the requirements of this specification during exposure to any combination of the following environments.

3.2.5.4.1 **Temperature.** The operating temperature range for the instrument shall be +10°C to +30°C, measured at the spacecraft side of the mounting interface.

3.2.5.4.2 **Pressure.** The orbital pressure shall be 1 x 10^{-14} Torr.

3.2.5.4.3 **Space Radiation.** The worst-case mission charged-particle environment shall be as shown in Figure 1 through Figure 19 of the Radiation Environment for the TOMS Mission (see Applicable Documents section).

3.2.5.4.3.1 **Radiation Dose.** Radiation dose as a function of shielding shall be in accordance with Figures 14 and 15 of the Radiation Environment for TOMS Missions. Note that use of a safety factor is required, see 3.3.9.

3.2.5.4.3.2 **Peak Orbital Flux.** Peak trapped spectra at the worst time in the orbital life and the worst point in the orbit shall be in accordance with **TBS**.

3.2.5.4.3.3 **Orbital Microphonic Vibration Levels.** The double amplitude of vibration shall be **TBD** inches, from 5 Hz to 200 Hz.

3.3 **Design and Construction.**

3.3.1 **Parts, Materials, and Processes.**

3.3.1.1 **Electrical, Electronic, and Electromechanical (EEE) Parts Selection.** Selection and derating of EEE parts shall be in accordance with GSFC-303-TOMS-002.

3.3.1.2 **Material and Process Control.** Material and process selection and control shall be in accordance with GSFC-303-TOMS-002.

3.3.2 **Electromagnetic Compatibility.** The electromagnetic compatibility design precautions in GSFC-TOMS-910-90-001 shall be followed. The following default specifications generally follow the MIL-STD-461C requirements for class A2a equipment, but may be overridden by the applicable detail specification per 1.2.

3.3.2.1 **Conducted Susceptibility.** The TOMS shall operate within specification over the range of input voltage with superimposed ripple, and spikes at the levels specified in Method CS01 and CS06.

3.3.2.2 **Radiative Susceptibility.** The TOMS shall operate within specification when subjected to the radiation levels specified in MIL-STD-461C, Class A2a, Method RS03, with a maximum frequency of 1 GHz.

3.3.2.3 **Conducted Interference.** TOMS conducted interference shall not exceed the following limits.

a. **Inrush.** Inrush current shall be limited to 300 percent of maximum sustained current and must be damped within 250 microseconds.

b. **Ripple Current.** Power-line conducted emissions shall not exceed the levels specified in MIL-STD-461C, Class A2a, Method CE03.

c. **Line Transients.** Low-frequency line transients in the range 0.1-100Hz shall not exceed 0.5 A peak-to-peak.

3.3.2.4 **Radiated Interference.** Radiated emissions shall not exceed the levels specified in MIL-STD-461C, Class A2a, Method RE02, with a maximum frequency of 1 GHz.

3.3.3 **Identification and Marking.** TOMS components shall be appropriately identified by name, serial number, supplier name, and contract number using a marking method suitable for use in high vacuum. Like items at the subassembly level shall be serialized. The serial numbers of parts, components, and devices shall be recorded on assembly documents at the time of installation. All connectors shall be appropriately labeled with the designators specified in the Appendix.

3.3.4 **Workmanship.** Workmanship requirements shall be as follows.

3.3.4.1 **Hand Soldering.** Hand soldering shall be performed in accordance with NHB 5300.4(3A-1).

3.3.4.2 **Other Processes.** None identified as of this revision.

3.3.5 **Interchangeability.** TOMS instruments shall be interchangeable except for the diffuser and electrical adapters, and for PROMs holding specific flight parameters.

3.3.6 **Safety.** System safety requirements shall be in accordance with GSFC-303-TOMS-002.

3.3.7 **Human Engineering.** Not applicable.

3.3.8 **Standards of Manufacture.** The following requirements shall apply in addition to requirements for the use of approved materials and processes (see 3.3.2)

3.3.8.1 **Cleanliness and Contamination Control.** The cleanliness of all instrument components shall be established and maintained during fabrication, assembly, cleaning, servicing, test, handling, transportation, and operational activities in accordance with GSFC-303-TOMS-002. The assembly of all optical components and assemblies, the marriage of the electronics assemblies with the optics module, and the assembly of the monochromator housing to the lower housing shall be accomplished in a Class 100,000 controlled environment as defined in FED-STD-209. Temperature shall be controlled at 70 ± 5 degrees F; humidity shall be controlled at $45 \pm 5\%$.

3.3.8.2 **Manufacturing Documentation.** Formal documentation shall be used to control and record the flow of hardware at all times. Starting with the assembled module or printed circuit board, assembly route sheets shall be used to document assembly configuration and all fabrication, assembly, and test operations. The route sheets for all subassemblies shall become part of the log book for each assembled component. Log books shall be used to document and control all movements, storage, tests, and other activities pertaining to GFE under contractor control.

3.3.8.3 **Operator Training and Certification.** All critical operations such as soldering, welding and coating which impact the reliability or quality of the TOMS instrument shall be performed by trained, certified personnel.

3.3.8.4 **Electrostatic Discharge Control.** Procedures for electrostatic discharge control shall be in accordance with GSFC-303-TOMS-002 as implemented by 74-0023.

3.3.8.5 **Use of Connector Savers.** Flight connectors shall be protected by connector-savers in accordance with 74-0023. Mating and demating shall be recorded in instruments logs.

3.3.9 **Design Constraints.** Designs shall meet the following constraints.

3.3.9.1 **Drafting Standards.** Drawings shall be prepared in accordance with DOD-D-1000, Level 2.

3.3.9.2 **Optical Design.** Optical design constraints shall be in accordance with GSFC TOMS 910-90-001.

3.3.9.3 **Mechanical Design.** Mechanical and mechanism design constraints including torque margins shall be in accordance with GSFC TOMS 910-90-001.

3.3.9.4 **Venting.** All subassemblies, cables, blankets, or other components containing lubricants, oils, adhesives, or other materials that have the potential to outgas a substance that could contaminate the diffuser surface shall be vented away from the diffusers.

3.3.9.5 **Thermal Design.** Thermal design of electronics shall assure meeting the worst-case temperature limits for EEE parts as provided in the derating guidelines of Appendix B of PPL-19.

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other organic mat'l
that could contaminate
any of the optical surface

3.3.9.6 **Radiation Shielding Design.** Radiation shielding design shall provide a safety factor of 2 for the effects of space radiation during the minimum TOMS mission life time in the TOMS 955 km, 99.3 degree orbit.

3.3.9.7 **Electrical Design.** Electrical design constraints shall be in accordance with GSFC TOMS 910-90-001.

3.3.9.8 **Circuit Decoupling.** Circuit decoupling shall assure that power-line voltage variation and noise is rejected to a level comparable to the specified circuit offset or noise level.

3.3.9.9 **Printed Wiring Board Design.** Design of printed wiring boards shall conform to the requirements of MIL-P-55110D (Amendment 4), NHB 5300.4(3J), and NHB 5300.4(3K).

3.3.9.10 **Electrostatic Discharge.** The design shall include applicable provisions for Electrostatic Discharge Control using DOD-HDBK-263 and DOD-STD-1686 as guidelines.

3.3.9.11 **Processor and Logic Design.** Design of processor and instrument logic shall allow for detection and recovery without damage from single-event upset in any external instrument register.

3.3.9.12 **Software Design.** Software design constraints shall be in accordance with GSFC TOMS 910-90-001 and GSFC 303-TOMS-002. In the event of conflict between these two documents, the latter shall govern.

3.4 **Major Component Characteristics.** The performance requirements of the TOMS are most conveniently developed by subsystem, except that interface characteristics listed above are organized by subassembly. Most subsystems fit in a single assembly. The critical characteristics of the major subsystems of the TOMS listed in Table 4 shall be as specified below to establish interfaces and allocate performance requirements.

3.4.1 **Scanner.** The scanner subsystem includes the scan motor and scan encoder, located in the Scanner Assembly. The scan mirror is physically part of this assembly.

3.4.1.1 **Mechanism Design.** The stepping mechanism shall be a direct-drive three-phase Y-connected stepping motor with magnetic detents and a hollow shaft for the light path. The step angle shall be 3.0±0.15 degrees. The shaft inner diameter shall provide a clear aperture sufficient to accommodate the diagonal of the clear field of view.

Note: For a clear FOV of 5.0 degrees, this requires that the diameter be large enough to pass a beam diverging at 7.07 degrees.

3.3.9.9
PWB
NHB 5300.4(3J) or
MIL-P-55110
document requirement
differ significantly

3.4.1.2 **Single-Step and Settle Time.** The scan mechanism shall step and settle to and remain within ±0.05 degrees 32 milliseconds after the application of the step signals, with an external load inertia of 250 gm-cm^2 (mirror plus encoder) and viscous friction **TBD**, including scan encoder but not motor rotor.

3.4.1.3 **Retrace Rate.** The scan mechanism shall be capable of retracing at 50 steps per second. Phase lag at the maximum retrace rate shall not exceed one step.

3.4.1.4 **Scan Drive Signals.** The scan drive circuit shall supply the stepping motor drive signals in accordance with Table 36, with the step and retrace rates specified in Table 21 or in the applicable detail specification for altitudes not covered in Table 21. Note that the driver is disabled after settling to conserve power.

3.4.1.5 **Scanner Peak Power.** The scan motor shall draw no more than 10W peak at 22V, measured across the motor terminals.

3.4.1.6 **Scan Encoder.** The scan encoder shall have six tracks with the code listed in Table 12, selected to prevent a single-point failure of the nadir reference. Polarity shall be such that angles identified as negative shall correspond to scanning toward the TOMS -Y axis. Positions shall be provided as shown for diffuser calibration and stow on either side of nadir. Light-emitting diodes (LED's) for tracks A,B,C and for tracks D,E,F shall be in series (two chains of three) with redundant power connections. Current drawn by each of the two LED chains shall not exceed 6 mA at 12V. Output levels shall be CMOS-compatible. See notes in Section 6 for explanation of code.

3.4.2 **Entrance Optics.** The entrance optics, located in the Entrance Optics Assembly, shall determine the TOMS IFOV using the monochromator entrance slit as a field stop, and reduce the residual polarization to the required level. The entrance optics subsystem includes the scan mirror, depolarizer, relay mirror, objective lens, field stop and baffles. The scan mirror is physically part of the scanner assembly, and the field stop is part of the monochromator assembly (the entrance slit). See section 3.1.2.3.3 for alignment requirements for these assemblies.

3.4.2.1 **Clear Aperture.** The entrance optics clear aperture, including tolerances, shall be sufficient to accommodate the diagonal of the clear field of view.

Note: For a clear FOV of 5.0 degrees, this requires that the clear aperture be large enough to pass a beam diverging at 7.07 degrees.

3.4.2.2 **Image Quality.** Distortion or defocusing of the image, variation in transmission, the effects of chromatic aberration, or reflected or scattered light striking the internal surfaces shall not produce an effective monochromator wavelength shift of more than 0.005 nm for any wavelength band.

3.4.2.3 **Transmission.** Transmission including mirror reflectance shall exceed 60 percent for the TOMS wavelength bands, including the effects of space radiation over the specified lifetime.

3.4.2.4 **Temperature Coefficient of Transmission.** The temperature coefficient of transmission of the entrance optics, including the reflectance of the scan and relay mirrors, shall not exceed 300 ppm/°C.

3.4.2.5 **Entrance Optics Scintillation Efficiency.** Refractive material shall not have a scintillation efficiency for 4 MeV electrons exceeding that of fused silica.

3.4.3 **Diffuser Subsystem.** One of three diffuser surfaces (working, reference, and cover) on the faces of a rotating three-sided diffuser carousel (an equilateral triangular prism) shall be selectable by use of a stepping mechanism for viewing by the scan mirror. The diffuser carousel shall be mounted within a housing. One diffuser surface shall be visible at a time through an aperture in the housing while the other faces are protected. Only the cover diffuser surface shall be exposed in the stow position.

3.4.3.1 **Diffuser Plate Preparation.** Each diffuser plate and all surrounding surfaces in close proximity to the diffuser plate shall be fabricated from 6061-T6 aluminum stock which shall be machined by a process which avoids contamination by oils. The diffuser optical surface shall then be ground with iron-free, pure, 180 mesh, aluminum oxide grit (65+35/-25 micron) until a uniform surface is obtained. The surface shall be washed with distilled water, dried with compressed dry nitrogen, then coated with evaporated aluminum 1000±50Å thick, and overcoated with MgF_2 400±50 Å thick.

3.4.3.2 **Diffuser Size.** Each finished diffuser surface and the diffuser aperture shall have an effective clear aperture at a minimum 10% larger than the projection of the clear field of view of the entrance optics on the diffuser plane. No unfinished part of the diffuser shall be visible through the aperture.

3.4.3.3 **Diffuser Location.** The center of the active diffuser shall be located in the instrument X-Y plane, so that the scan angle is 90 degrees. The active diffuser surface normal shall have direction cosines in the TOMS coordinate system of

$$(e_x,e_y,e_z) = (1,-1,-1)/\sqrt{3},$$

with the alignment tolerances listed in Table 3.

3.4.3.4 **Diffuser Positioning.** The azimuthal angle of the diffuser shall be repeatable with respect to the scanner as specified in Table 3. Relative positioning of the reference and working diffuser shall be repeatable to ±0.3 degrees.

3.4.3.5 **Diffuser Positioning Mechanism.** The stepping mechanism shall be driven by a 3—degree three-phase Y-connected stepping motor with magnetic detents. The mechanism shall position the diffuser carousel within ±0.15 degrees, including the effects of mechanism unbalance in a 1g-field, and motor static friction.

3.4.3.5.1 **Diffuser Mechanism Stepping Rate.** The diffuser mechanism shall step at 25 steps per second with an internal moment of inertia not exceeding 725 gm-cm^2 (including encoder) plus a diffuser carousel inertia not exceeding 150 gm-cm^2 for a total of 875 gm-cm^2.

3.4.3.5.2 **Diffuser Drive Signals.** The motor drive circuit shall supply the stepping motor drive signals in accordance with Table 36.

3.4.3.5.3 **Diffuser Mechanism Peak Power.** The diffuser positioning motor shall draw no more than 10W peak at 22V, measured across the motor terminals.

3.4.3.5.4 **Diffuser Position Encoder.** The diffuser encoder shall have three readout stations separated by 120 degrees, each corresponding to a stable position of the stepping mechanism. Three light-emitting diodes (LEDs) at the read station shall be driven in series with the code listed in Table 13. The working and stowed LEDs shall be wired in series, where the reference LED shall be wired independently. Current drawn by the LED chains shall not exceed 6 mA at 5V each. Output levels shall be CMOS-compatible, low true.

3.4.3.6 **Diffuser Heating.** The diffuser carousel shall be thermally isolated and heated. The heater shall be connected to the spacecraft power bus with no control other than the on/off relay. The heater resistance shall be selected to dissipate the maximum power allowed by the power specifications in 3.2.2 above at the maximum spacecraft steady-state bus voltage specified in the applicable detail specification.

3.4.3.7 **Diffuser Baffle.** A baffle shall be used to limit radiation onto the diffuser to that coming directly from the sun during solar calibration. Detailed requirements for the baffle shall be provided in the applicable detail specification.

3.4.4 **Reflectance Calibration Subsystem.** This subsystem shall consist of a reflectance calibration assembly and a remotely-located lamp power supply. The reflectance calibration assembly shall contain a low-pressure mercury-lamp within a lamp housing with exiting diffuser, a heater and a temperature monitor. A phosphor-coated diffuser shall be mounted within the exit diffusers. The scanner shall alternately view the diffuser being calibrated and the lamp diffuser.

3.4.4.1 **Illumination.** Lamp brightness and positioning shall assure that the signal is no greater than 80 percent of full scale in the scan mirror position, and that there is a minimum signal greater than the specified minimum scene radiance. The lamp assembly shall be mounted so that the normal of the exit diffuser bisects the angle between the diffuser carousel and the scanner, assuring symmetric illumination of the two components. The optical extent of the source shall be masked to match the projection of the entrance optics clear field of view on the surface of the lamp exit diffuser.

3.4.4.2 **Accuracy of Illumination.** The average ratio of the illumination of the diffuser carousel and the scanner shall be repeatable to ±0.1 percent per year of operation.

3.4.4.3 **Quantizing Accuracy.** The quantizing accuracy (radiometric resolution) for this measurement shall be ±0.05 percent of signal (with signal averaging).

3.4.5 **Monochromator Subsystem.** The monochromator subsystem shall consist of the housing, collimating mirror, and grating and slit assembly. The monochromator assembly shall also include a temperature sensor on the slit plate and two temperature sensors to measure housing temperature differential on the entrance and exit slit sides, for evaluation of mirror tilt in the direction of dispersion (see Table 9).

3.4.5.1 **Monochromator Design.** The monochromator subsystem shall be designed to select the wavelength bands specified herein with the requisite stray light rejection, wavelength accuracy and stability, and to support the wavelength calibration.

3.4.5.2 **Wavelength Monitor Entrance Slit Location.** Two entrance slits for the 296.7 nm mercury line shall be positioned on the slit plate so that each exit beam is centered on one edge of the 312.5 nm (Band 5) exit slit. The entrance slits shall have a nominal spectral width of 0.625 nm with the inner edges positioned no more than 0.25 nm apart. The actual width and separation of the slits in mm depends on the linear dispersion in mm per nm.

3.4.5.3 **Chopper Track Location.** The optical design shall determine the center of rotation and the radial locations and radial widths of the chopper disk tracks such that the entrance and exit beams are interrupted without vignetting by the chopper, or mixing of the signals from the two wavelength monitor entrance slits.

3.4.5.4 **PRP Slit Location and Size.** The center of the phase reference pickup (PRP) entrance slit may be offset from the monochromator entrance slit as required, provided the chopper slit is offset by the same amount. The width of the PRP entrance slit tangential to the direction of motion of the chopper shall have the same angular width as the chopper PRP slot when viewed from the distance of the virtual image of the receiving phototransistor. The height of the PRP slit shall be sufficient to assure filling the phototransistor aperture in the radial direction.

3.4.5.5 **Monochromator Transmission.** Transmission of the monochromator, including the mirror reflectance and grating efficiency and the exit optics specified further below shall be at least 30 percent.

3.4.5.6 **Temperature Coefficient of Transmission.** The temperature coefficient of transmission of the monochromator (entrance slit to either detector) shall not exceed 600 ppm/°C.

3.4.5.7 **Photodiode Exit Optics.** The photodiode exit optics shall consist of a beamsplitter and exit lens system. The photodiode exit optics shall image the grating mask on the photodiode mask to reduce stray light from outside the grating. The mask shall be foreshortened as needed to match the grating mask image.

3.4.5.7.1 **Beamsplitter.** The beamsplitter shall reflect 50 ± 10 percent of the 360 nm beam leaving the corresponding monochromator exit slit towards the photodiode exit optics. The remainder of the unabsorbed light shall be transmitted to the photomultiplier exit optics.

3.4.5.7.2 **Beamsplitter Stability.** The beamsplitter transmittance and reflectance shall have a long-term stability of ±0.1 percent per year.

3.4.5.7.3 **Photodiode Exit Optics Imaging.** The photodiode exit optics shall image the grating mask on the photodiode mask to reduce stray light from outside the grating.

3.4.5.8 **Photomultiplier Exit Optics.** The photomultiplier exit optics shall image the grating mask on the photomultiplier photocathode mask to reduce stray light from outside the grating. The size of the mask shall be nominally 9 mm square, with maximum diagonal not exceeding 13 mm.

3.4.5.9 **Exit Optics Stray Light.** Transmitting surfaces shall be coated to reduce reflections and the rear side of the exit slit plate and the interior of the exit optics housing shall be blackened and baffled as required to reduce stray light reflected from the optical surfaces and rescattered to the detectors to less than 1 part in 10,000 compared to the direct beam.

3.4.5.10 **Exit Optics Scintillation Efficiency.** Refractive material shall not have a scintillation efficiency for 4 MeV electrons exceeding that of fused silica.

3.4.6 **Chopper (Wavelength Scanner) Subsystem.** The entrance beam of the monochromator shall be chopped on the collimating mirror side by a rotating chopper disk. The chopper shall contain slots which rotate over the monochromator exit slits to pass one wavelength band at a time. The Phase Reference Pickup (PRP) shall consist of a light-emitting diode in the lower housing and a phototransistor in the monochromator, with processing electronics to provide a once-per-revolution index pulse.

3.4.6.1 **Chopper Disk Design.** The chopper disk shall contain tracks for the monochromator entrance slits (main and calibration), for the exit slits for each wavelength band, and for the Phase Reference Pickup. The track layout shall be fixed for all TOMS models. A sector shall be used for scanner step-and-settle, and twelve sectors shall be used for two samples each of the six wavelengths at 50 percent duty cycle. The sequence of wavelength selection slots shall be in accordance with Table 29. This layout was derived from Table 13 to provide 120,000 VFCCLK counts per revolution (0.003 degrees per count). The chopper shall rotate so that the entrance slots pass in front of the monochromator entrance slit in the order given in the table.

Exit angles shall be the supplement of the entrance angles plus an optically-determined allowance for exit aberrations to avoid vignetting the beam.

Slit edge location tolerances shall be ±0.012 degrees.

There shall be no measurable crosstalk between wavelength monitor entrance slits as a result of the finite radial width of the chopper entrance slots.

Table 29. Chopper Slot Sequence in Azimuth Angles in Degrees Reference position is center of PRP slot			
Slit/Band	Wavelength, nm	Entrance Slot Start	Entrance Slot End
1	360.0	0.000	12.312
2	331.2	24.624	36.936
3	322.3	49.248	61.560
4	317.5	73.872	86.184
5	312.5	98.496	110.808
6	308.6	123.120	135.432
6	308.6	147.744	160.056
5	312.5	172.368	184.680
4	317.5	196.992	209.304
3	322.3	221.616	233.928
2	331.2	246.240	258.552
1	360.0	270.864	283.176
PRP	N/A	339.380	339.620
WRM1	296.7	98.496	110.808
WRM2	296.7	172.368	184.680

3.4.6.2 **Chopper Servo.** The chopper disk shall be driven by a brushless DC motor with an electronic commutator and speed control. Subsystem interfaces shall be as specified in the interface section above. Detailed characteristics of the servo and its components shall be specified in the chopper subsystem specification referenced in Table 4.

3.4.6.2.1 **Chopper Speed Reference (VFCCLK).** The chopper speed shall be controlled by comparing the tachometer output clock TACHSIG with a clock TACHREF derived from the high-frequency crystal-controlled clock VFCCLK used to control the voltage-to-frequency converters.

3.4.6.2.2 **Chopper Phase Reference (PRPREF).** The chopper phase shall be controlled by comparing the falling edge of the Phase Reference Pickup Pulse (PRPSIG) defined below, with the rising edge of the Chopper Phase Reference signal, PRPREF.

3.4.6.2.3 **Chopper Phase Jitter.** The speed control shall assure that the chopper phase jitter at any point does not exceed 400 microradians rms.

3.4.6.2.4 **Chopper Phase Error.** A signed byte (7 bits plus sign) shall be provided that indicates the difference in VFCCLK counts between PRPSIG and PRPREF. The sign shall be positive if PRPREF occurs first. The count shall not carry, but shall lock up at full count. The counter shall be read during the next scanner step interval.

3.4.6.3 **Phase Reference Pickup and Phase Reference Pulse (PRP).** The PRP slot on the chopper shall be used to gate the light beam between a light-emitting diode located in the lower housing and a phototransistor located in the pickup unit in the monochromator.

3.4.6.3.1 **PRP Slot and LED Mask Location and Size.** The center of the PRP slot on the chopper shall pass over the center of the PRP entrance slit 1.500 degrees of revolution before the leading edge of the first wavelength slot on the chopper is centered over the entrance slit. The PRP slot shall have a width corresponding to 0.24±0.012 degrees in azimuth measured at the center of the slit from the chopper axis of rotation and a radial height of 2.0±0.2 mm. The width of the LED mask tangential to the direction of motion of the chopper shall have the same angular width as the chopper PRP slot when viewed from the distance of the virtual image of the receiving phototransistor. The radial heights of the slots and mask shall be sufficient to assure filling the phototransistor aperture in the radial direction.

3.4.6.3.2 **PRP Signal Processing.** The PRP shall produce a roughly triangular light pulse with a full width at half maximum of 0.24±0.05 degrees, which shall be processed to produce a logic signal called the PRP signal (PRPSIG). The length of the phase reference signal shall be 100±50 microseconds. The falling edge shall be the active edge.

3.4.6.3.3 **PRP Delay Stability.** The signal shall be processed and the photodiode current regulated to achieve an overall delay stability over the lower housing operating temperature range of ±100 microradians.

3.4.7 **Wavelength Monitor Subsystem.** The monitor shall consist of a mercury lamp illuminating a transmission diffuser. A lens shall collect the diffuse light to illuminate two slits on the monochromator slit plate, selected alternately by the chopper (two samples/revolution). The subsystem and subtier specification shall specify the performance of the lamp, lamp mount, lamp power supply, and illumination system. Diffuser and lens shall be appropriately masked to control stray light that might interfere with meeting the requirements below.

3.4.7.1 **Illumination Uniformity.** The two entrance slits shall be equally illuminated at 296.7 nm within ±2 percent, including all effects of initial misalignments.

3.4.7.2 **Long-Term Illumination Stability.** The ratio of the 296.7 nm illumination of the two entrance slits shall be stable over the instrument life to ±0.5 percent, including all effects of lamp arc wandering, lamp darkening, thermal expansion, and other influences on beam position.

3.4.7.3 **Signal-to-Noise Ratio.** Variation in 296.7 nm signal illumination resulting from all sources of noise, including but not limited to photoelectron statistics, lamp noise, and power supply ripple and noise, shall not exceed ±1 percent of the signal for one wavelength chopper cycle.

3.4.7.4 **Wavelength Monitor Lamp Power.** The power input to the lamp power supply shall not exceed 3.0 W (high line, current limit conditions).

3.4.8 **Photodiode Subsystem.** An ultraviolet-sensitive silicon detector shall be illuminated by the photodiode exit optics in the monochromator subsystem. Subsystem specifications apply to the diode, the effects of instability in the local diode bias supply, and its associated electrometer.

3.4.8.1 **Quantum Efficiency.** The quantum efficiency shall be at least 40 percent at a wavelength of 360 ±10 mm.

3.4.8.2 **Long-Term Stability.** The long-term stability of response shall be ±5 percent per year or better.

3.4.8.3 **Temperature Coefficient of Responsivity.** The end-to-end responsivity, from input radiant power to output pulse rate, shall not vary more than ±1000 ppm/°C, including variations in quantum efficiency and electronic gain.

3.4.8.4 **Offset Stability.** The end-to-end offset stability after demodulation shall be better than ±0.02 percent of full scale over orbital temperature variations of ±0.2°C per orbit (1000 ppm/°C).

3.4.8.5 **Delay Stability.** The delay stability of the analog signals from the photodiode electrometer shall be ±5 microseconds.

3.4.8.6 **Linearity of Response.** The end-to-end variation of gain with signal level shall not exceed ±0.05 percent over the dynamic range.

3.4.8.7 **Diode Connection and Bias.** The diode shall be connected and biased to provide a negative signal out of the electrometer.

Response linearity
1%
long term stability
.5%
diode bias -
zero bias

3.4.9 **Photomultiplier Subsystem.** The photomultiplier detector, high-voltage power supply, and at least the first electrometer amplifier shall be integrated into a single assembly. The subsystem shall also include the ranging amplifiers.

3.4.9.1 **Quantum Efficiency.** The quantum efficiency shall be at least 12 percent for any of the TOMS wavelength bands.

3.4.9.2 **Long-Term Stability.** The long-term stability of response shall be ±5 percent per year or better.

3.4.9.3 **Temperature Coefficient of Responsivity.** The end-to-end responsivity, from input radiant power to output pulse count, shall not vary more than ±0.575 percent per °C, including variations in photocathode sensitivity, high voltage, multiplier gain, and electronic gain. See Section 6 notes, Table 40.

3.4.9.4 **Offset Stability.** The end-to-end offset stability shall be better than ±0.02 percent over orbital temperature variations of ±0.2°C per orbit (1000 ppm/°C).

3.4.9.5 **Signal Delay Stability.** The delay stability of each signal shall be ±2.5 microseconds.

3.4.9.6 **Delay Matching Between Ranges.** The delays of the different range signals shall be matched to ± 2.5 microseconds.

3.4.9.7 **Linearity of Response.** As a design goal, the end-to-end variation of gain (output counts / photocathode energy) with signal level shall not exceed ±0.05 percent over the dynamic range.

3.4.10 **Voltage-to-Frequency Conversion.** Analog-to-digital conversion of the photomultiplier and photodiode signals shall be performed by voltage-to-frequency converters. The binary pulse-amplitude-modulated output signals VFCRNG1, VFCRNG2, VFCRNG3, and VFCPD shall drive accumulators in the digital interface subsystem.

3.4.10.1 **Resolution.** Resolution shall be at least 14 bits using the reference clock generated by the interface subsystem when up/down counts are accumulated over two chop times.

3.4.10.2 **Synchronization.** The VFC's shall be synchronized by the leading edge of the clock signal VFCCLK listed in Table 33 and the signals VFCTRAN and VFCCOLR (see Figure 8 and related discussion). The photodiode VFC shall be synchronized in the same manner as the photomultiplier VFCs to assure comparability of data.

3.4.10.4 **Reference Source.** A common precision supply shall be used to provide the reference voltage for the photodiode and photomultiplier analog-to-digital conversion. Separate references shall be used for housekeeping and electronic calibration.

3.4.10.5 **Temperature Coefficient.** The end-to-end conversion gain from analog input to digital output rate shall not vary more than ±100 ppm per °C. See Section 6 notes, Table 40.

3.4.10.6 **Offset Stability.** The end-to-end offset stability shall be better than ±0.02 percent over orbital temperature variations of ±0.2°C per orbit (1000 ppm/°C).

3.4.10.7 **Signal Delay Stability.** The delay stability of each signal shall be ±2.5 microseconds.

3.4.10.8 **Delay Matching Between Ranges.** The delays of the different range signals shall be matched to ± 2.5 microseconds.

3.4.10.9 **Linearity of Response.** The end-to-end variation of gain (output counts / input signal) with signal level shall not exceed ±0.05 percent over the dynamic range.

3.4.11 **Electronic Calibration Subsystem.** Precise signal currents shall be injected into the TOMS signal processing chains in addition to the currents normally furnished by the photomultiplier tube and photodiode. This calibration shall be performed at night with the scanner stowed, so that there is no signal from the sensors except DC offsets.

3.4.11.1 **Electronic Calibration Method.** A special-purpose digital-to-analog converter shall produce a precise voltage signal, which shall be chopped with the control signal ECALCLK and fed to the electrometer summing nodes through resistors to produce quasilrapeziodal current pulses. A minimum of seven levels shall be used to test the PMT electrometers, corresponding nominally to radiance levels of 400, 133.3, 40, 13.33,4,1.333, and 0.4 ergs/cm^2-sr-nm-s. A minimum of three levels shall be used to test the PD electrometer, corresponding nomially to radiance levels of TBD. Timing shall be the same as when scanning. The ECAL level shall be set once per scan line by a 3-bit command using the optics port. The level shall be changed at the same time that the scanner begins to retrace. ECALCLK timing shall be as specified below.

nominally

3.4.11.2 **Electronic Calibration Accuracy.** The calibration shall provide test signal currents accurate to ±0.5 percent over 24 hours and ±10 percent over the operating life.

3.4.12 **Housekeeping Subsystem.** A synchronous voltage-to-frequency converter with multiplexed input shall be used to digitize the analog signals in Table 9. The binary pulse-amplitude-modulated output signal HKVFC shall be accumulated in the Electronics Module as specified below.

3.4.12.1 **Multiplexer Channels.** The subsystem shall be capable of measuring up to 32 different voltages using two 16-channel multiplexers. Each multiplexer shall measure its own zero (ground) reference and full-scale.

3.4.12.2 **Input Dynamic Range.** The dynamic range of the subsystem shall be 0 to +5V.

3.4.12.3 **Full Scale Calibration.** Calibration accuracy shall be ±10 LSB (±0.25 percent) or better over the TOMS operating temperature range.

3.4.12.4 **Offset Stability.** Offset stability shall be ±2 LSB or better over the TOMS operating temperature range

3.4.12.5 **Synchronizing Clock.** The housekeeping voltage-to-frequency converter shall operate at the VFCCLK frequency specified in Table 33.

3.4.12.6 **Reference Voltage.** The housekeeping subsystem shall contain a precision bias supply, buffered to bias thermistors. The buffer amplifier shall be short-circuit protected at twice the expected current and shall be capable of driving a 1.00K load with no more than 0.01 percent loss of regulation. To avoid noise and line drop, separate reference supplies shall be used to provide the reference voltages for other subsystems. The reference voltage shall be measured (see Table 9).

3.4.12.8 **Thermistor Circuit.** Thermistors shall be 30 K±1 percent at 25°C in accordance with GSFC S-311-P-18. Each thermistor shall be connected in series with a bias resistors, with signal taken from the common point. Resistors shall be 37.4K±0.1 percent 1/8 W RNR60E3742BS for maximum sensitivity at +20°C (midpoint of operating temperature range). Thermistors shall be connected to the signal return side and shall not be linearized by additional circuitry. Each thermistor shall be bypassed to signal return with 0.1 microfarads located at the multiplexer input.

3.4.13 **Optics Module Port.** A bidirectional parallel port shall be used to read data and send signals with low synchronization requirements between the optics module subsystems described above and the interface subsystem described below. The analog interface and motor control assemblies shall contain 3-port bidirectional latches (82C55 or equivalent). The signals transferred shall be as listed in Table 30 and the ELM control ports interface signals shall be as listed in Table 31. The HV Gain Adjustment shall have a dedicated byte to reduce the possibility of disturbance.

3.4.13.1 **System Reset.** The system power-on high-true RESET signal shall be transmitted to the remote latches. When a power-on reset occurs, the chopper shall be enabled and the high voltage, calibration lamps and electronic calibration shall be disabled. The high voltage shall be immediately reset to the value stored in backup memory, if valid; otherwise it shall be set to the default value. If a warm boot occurs, the high-voltage register be checked for validity and reset if necessary.

3.4.13.2 **Read/Write Restrictions.** Read/write operations shall occur only during the scanner step and settle time (if once per scene) or after scanner retrace but before the start of the next scan line (if once per line or less).

Table 30.
Data Transferred Through Optics Module Port (High True)
Read/Write Frequency: Times per Scan Line or S=Once per Scene

Device Address	Port	Function	Destination	Freq	Bits	Position
0	A	HV Gain Adjust (FF=Off)	OPM-AI	<<1	8	0 to 7
0	B	Housekeeping Address	OPM-AI	4	5	0 to 4
0	B	Spare	OPM-AI		3	5 to 7
0	C	ECAL Level (F=Off)	OPM-AI	<1	4	0 to 3
0	C	High Voltage Disable	OPM-AI	<<1	1	4
0	C	Spare	OPM-AI		3	5 to 7
1	A	Scan Encoder	ELM-I/O	S	6	0 to 5
1	A	Chopper Inner Loop Lo	ELM-I/O	S	1	6
1	A	Chopper Inner Loop Hi	ELM-I/O	S	1	7
1	B	Chopper Phase Error	ELM-I/O	S	8	0 to 7
1	C	Diffuser Encoder	ELM-I/O	<<1	3	0 to 2
1	C	Spare	ELM-I/O		1	3
1	C	Reflectance Lamp Disable	OPM-MC	<<1	1	4
1	C	Wavelength Lamp Disable	OPM-MC	<<1	1	5
1	C	Chopper Enable	OPM-MC	<<1	1	6
1	C	Inner Loop Error Reset	OPM-MC	1	1	7

NOTE: AI: Analog Interface CCA, MC: Motor Control CCA, I/O: Digital I/O CCA

Table 31.
ELM Port Signals

Bit	Control Port (Write Only)	Data Port (Read/Write)
7 (MSB)	Read-	D7
6	Write-	D6
5	A1 Port Select (MSB)	D5
4	A0 Port Select (MSB)	D4
3	Device Select 3 (DS3) (MSB)	D3
2	Device Select 2 (DS2)	D2
1	Device Select 1 (DS1)	D1
0 (LSB)	Device Select 0 (DS0) (LSB)	D0
N/A	Microprocessor RESET	N/A

NOTE: Signals DS2 and DS3 are not used.

4.14 **Electronics Module Digital Interface (I/O) and Microprocessor (MP).** This subsystem consists of timing logic, the interfaces between the other TOMS subsystems and the central processor, and the bilevel and serial command and data interface with the spacecraft. Spacecraft interfaces and command formats shall be in accordance with the applicable detail specification as provided above (see 3.1.2). The processor shall control the optical system according to the commands received from the S/C and collect the data as specified herein and assemble the data into packets and transmit it according to the applicable detail specifications.

3.4.14.2 **Subsystem Outputs to Optics Module.** The interface subsystem shall generate the signals listed below.

3.4.14.2.1 **Optics Port Control.** The port shall be operated as specified below.

3.4.14.2.1.1 **Optics Port Initialization.** After power-on reset the remote ports shall be initialized to operate as shown in Table 32. Input data from the optics module is not latched; the processor must wait for settling before reading the port after stepping a motor. The chopper phase error is measured once per wavelength scan (chopper revolution) and shall be read during the next scanner step interval.

Table 32.
Remote 82C55 Initialization (Data in Hex)

Device	Port	DS1	DS0	A1	A0	Data	Function
0	A	1	0	0	0	V V	HV Stored Value
	B	1	0	0	1	00	HK Address 0
	C	1	0	1	0	0F	ECAL Off
	Control	1	0	1	1	80	Ports A, B, C output
1	A	0	1	0	0	None	None (input)
	B	0	1	0	1	None	None (input)
	C_{lower}	0	1	1	0	None	None (input)
	C_{upper}	0	1	1	0	F	Chopper On, Lamps Off
	Control	0	1	1	1	93	Ports A, B, C_{lower} input, C_{upper} output

3.4.14.2.1.2 **Remote Port Update and Verification.** After initialization the output ports shall be updated as necessary either by rewriting the data or by using the single-bit update feature of the remote 82C55s. The data shall be refreshed at least once per scan line to reject single-event upset.

3.4.14.2 **Reference Signals.** The reference signals listed in Table 33 shall be derived from a 12.00 MHz primary crystal oscillator with a stability of better than ± 1 part in 2^{18} over a period of 220 minutes. The processor clock and peripheral clock PCLK shall be 4.00 and 2.00 MHz respectively. All signals shall be transmitted with a maximum delay of 0.25 microseconds and with 10 to 90 percent rise and fall times of 0.2 microseconds or less.

3.4.14.2.1 **VFC Reference Clock.** The voltage-to-frequency converter (VFC) reference clock shall be generated from the processor clock by dividing it as shown in Table 33. The frequency of the clock shall be determined by a parameter loaded in PROM. The chopper rotates at 1/120,000 of the VFC clock frequency. The design shall permit division ratios of 15, 16, 17, 18, 19, and 20 as a minimum. Duty cycle shall be 50 ±20 percent.

3.4.14.2.3 **VFC Synchronization.** The voltage-to-frequency converters shall be synchronized by two signals derived from the VFC clock and demodulation sequence.

3.4.14.2.3.1 **VFC Color Sync (VFCCOLR).** This signal shall be low during the first down-counting period of each chop, as shown in Figure 8. Skew shall not exceed 100 nanoseconds. Note that the first down-counting period overlaps the scanner settling time.

Table 33.
Reference Signals
Divide 12 MHz oscillator frequency by number in divide column

		797 km		955 km	
Function	**Symbol**	**Divide**	**kHz**	**Divide**	**kHz**
VFC clock	VFCCLK	15	800	20	600
VFC color sync	VFCCOLR	See text			
VFC transition sync	VFCTRAN	See text			
Chopper phase reference	PRPREF	1.8E6	0.00667	2.4E6	0.00500
Orbit clock	ORBCLK	240000	0.05	240000	0.05

3.4.14.2.3.2 **VFC Transition Sync (VFCTRAN).** This signal shall consist of a delayed burst of 12 cycles at twice the chop rate, with the trailing edges synchronous with the transition between up and down counting as shown in Figure 8. Skew shall not exceed 100 nanoseconds.

3.4.14.2.4. **Chopper Phase Reference (PRPREF).** This signal shall be generated by dividing VFCCLK down to the chopper rotation frequency specified in Table 21, or in the applicable detail specification for orbital altitudes not specified. Duty cycle shall be 50±20 percent.

3.4.14.2.5 **Housekeeping Control Signals.** The housekeeping multiplexers shall be programmed with a 5-bit address as shown in Table 9 that changes four times per scan line. The block of four data words thus accumulated shall be identified with a 3-bit block ID code.

3.4.14.2.6 **Electronic Calibration Commands.** The following signals shall be sent to the electronic calibrator. The electronics calibration sequence (software-controlled) shall consist of 9 scan lines, with each line corresponding to a single ECAL level. The ECALCLK signal shall be supplied continuously .

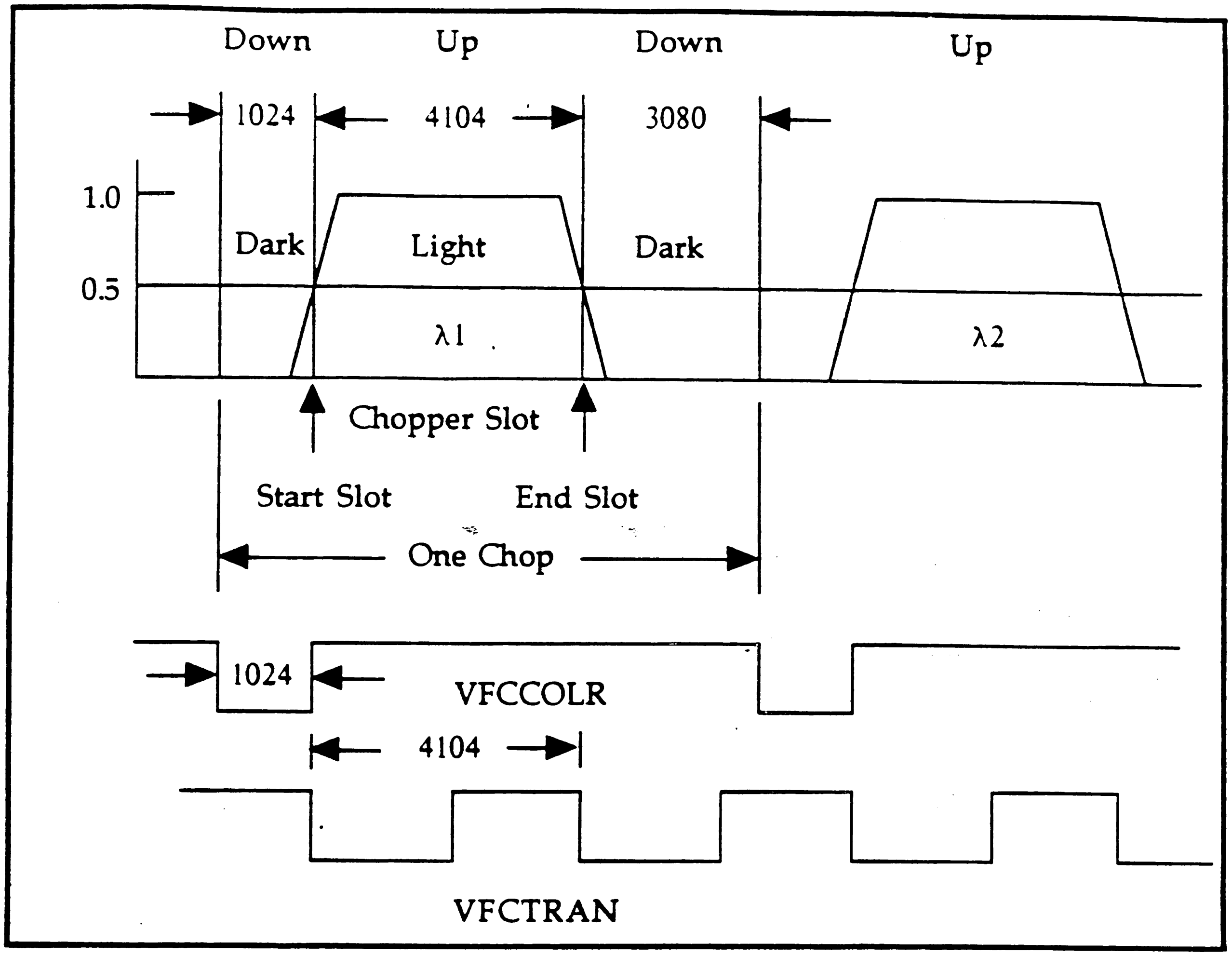

Figure 8. VFC Controls and Demodulation Timing.

3.4.14.2.6.1 **Electronic Calibration Level (ECALEVL[0..3]).** The signal level shall be sent to the optics module through the optics port. The level selection shall be coded 00H..08H; level 0FH shall correspond to ECAL off.

3.4.14.2.6.2 **Electronic Calibration Chopper Drive (ECALCLK).** The electronic calibration voltage shall be chopped by a voltage having the same timing as the accumulator control signals. There are two down and one up periods for each chopper slot as shown in Figure 8, with two slots per color for each chopper revolution. The timing shall be determined by counting down the VFC Reference Clock, starting from the trailing edge of the Phase Reference Pulse, delayed by up to 1023 clock pulses by a separately adjustable delay. A different delay is required because the calibration signals are applied in front of the electronics and therefore must occur earlier by a time equal to the delay of the electrometers and amplifiers. The relative timing of the slot edges shall be as specified in Table 29 (0.003 degrees of rotation = 1 VFCCLK period).

3.4.14.3 **Subsystem Inputs from Optics Module.** The interface subsystem shall receive the signals listed below besides those listed in Tables 30 and 31.

3.4.14.3.1 **Photodetector VFC Inputs.** Four signals VFCRNG1, VFCRNG2, VFCRNG3, and VFCPD shall be received. These signals shall be synchronous with VFCCLK (see Table 33) with a maximum delay of 0.25 microseconds and with 10-90 percent rise and fall times of 0.2 microseconds or less. The average number of pulses present (high true) is proportional to detected signal current.

3.4.14.3.2 **Housekeeping VFC Input.** The HKVFC signal shall be synchronous with VFCCLK with a maximum delay of 0.25 microseconds and with 10-90 percent rise and fall times of 0.2 microseconds or less. The average number of pulses present (high true) is proportional to detected signal voltage.

3.4.14.3.4 **Passive Analog Telemetry.** Two wires from each of 7 thermistors shall pass out to the spacecraft interface with the loading or signal conditioning specified in the applicable detail specification.

3.4.14.4 **Signal Processing.** The subsystem shall process the signals as follows.

3.4.14.4.2 **Photodetector Synchronous Demodulation and Accumulation.** Synchronous demodulation shall be based on a program of 120,000 counts per chopper revolution. Counts from each VFC shall be accumulated for each wavelength band. Counts in the down and up periods shall be accumulated separately and subtracted as required. There are two down and one up periods for each chopper slot as shown in Figure 8, with two slots per color for each chopper revolution. The timing for the demodulation shall be determined by counting down the VFC Reference Clock, starting from the trailing edge of the Chopper Phase Reference (same nominal time as PRP trailing edge), delayed by up to 1023 clock pulses separately for the photomultiplier and the photodiode (the maximum delay is about 3.1 degrees in chopper rotation). The relative timing of the slot edges shall be as specified in Table 29. The photodiode signal shall be demodulated with the same timing as Band 1 (360 nm), but with a different delay.

3.4.14.4.3 **Housekeeping VFC Signal Accumulation.** The housekeeping signals shall be accumulated by the processor in a 12-bit accumulator. Four samples shall be taken during the retrace time of the scan mechanism, increasing the housekeeping channel by 1 (module 32) for each sample.with a minimum range of 12 bits. The value in the accumulator shall be saved in the array element indicated by the current housekeeping subcom address.

3.4.14.5 **Outputs to Motor/Heater Driver (MHD).** The interface subsystem shall generate the signals listed below.

3.4.14.5.1 **Scanner Step Commands.** The scanner shall be stepped at the trailing edge of the Chopper Phase Reference clock. Timing is uncritical and may be interrupt-driven. Step and enable signals shall be generated to operate the scan motor drive circuits. The 3-bit motor state and absolute motor position shall be tracked by the processor and updated for each step. In retrace, the phase reference shall be disregarded and the motor stepped at a constant rate of 50 steps per second. Note that the number of scan and retrace steps is one less than the number of scan positions.

3.4.14.5.2 **Diffuser Step Commands.** When enabled, the diffuser carousel positioning motor shall be stepped at a constant rate of 25 Hz. Timing is uncritical and may be interrupt-driven. The carousel position encoder shall be sampled within 1 millisecond before the next step is due. The 3-bit motor state and absolute motor position shall be tracked by the processor and updated for each step. The motor shall be disabled when the commanded encoder position is reached.

3.4.14.6 **Processor Hardware Characteristics.** The critical characteristics of the processor shall be as follows.

3.4.14.6.1 **Clock Rate.** The processor shall be synchronized with the 12 MHz master oscillator used to generate VFCCLK. Operating frequency shall be derated in accordance with PPL-19 Appendix B.

3.4.14.6.2 **Watchdog Timer.** The processor shall be equipped with a watchdog timer that shall reset the processor if not continually updated. The watchdog timer shall time out in one scan line or less.

3.4.14.6.3 **Peripheral Readback.** All memory elements such as registers, timers, etc shall be capable of readback for checking single event upset, or else shall be refreshed.

3.4.14.7 **Processor Software Characteristics.** The critical characteristics of the software system shall be as follows.

3.4.14.7.1 **Error Handling.** The processor shall at least detect the error conditions listed in Table 11 and handle them as specified below.

3.4.14.7.1.1 **Error Codes.** Error codes shall be in accordance with Table 11. Other errors added to this list shall be documented in the software design specification and instrument manuals.

3.4.14.7.1.2 **Error Logging.** The processor shall maintain an error stack of at least 16 8-bit error codes. The error code on the top of the stack shall be transmitted in the digital status data record and the stack popped.

3.4.14.7.1.3 **Error Response.** Errors shall be classified as fatal or non-fatal. Fatal errors shall cause a restart. If a data error occurs the current data packet shall be flagged invalid. An error code of zero shall indicate normal operation.

3.4.14.7.1.4 **Timer Interrupt Error (Fatal).** Failure of the principal timing interrupt to occur within a timing window shall generate a fatal error.

3.4.14.7.1.5 **Illegal Interrupt (Fatal).** All interrupt vectors shall be coded so that if an unused interrupt occurs a fatal error shall be generated.

3.4.14.7.1.6 **Improper Code Sequence (Fatal).** Unused code space shall be coded so that a jump to that space results in a fatal error.

3.4.14.7.1.7 **Command ID Error (Non-Fatal).** The processor shall check the validity of all serial commands. If an invalid command is detected an command an error code shall be placed on the error stack and the command shall be disregarded. If a valid command is detected, the processor shall enter the commanded mode using the parameters uploaded in the command, if any.

3.4.14.7.1.8 **Command Sequence Error (Non-Fatal).** An error shall be recorded and the command rejected if the command parameter words are in an incorrect sequence (parameter word without command ID word).

3.4.14.7.1.9 **Command Data Error (Non-Fatal).** The processor shall check the validity of all uploaded parameters. If the data is meaningless or out of range an error code shall be placed on the error stack and the command disregarded.

3.4.14.7.1.10 **Command Register Overflow (Non-Fatal).** An error shall be generated if more command bits are sent than the command register will hold.

3.4.14.7.1.11 **Command Queue Overflow (Non-Fatal).** An error shall be generated if more commands are sent than the command queue will hold.

3.4.14.7.1.12 **Telemetry Register Underflow (Non-Fatal).** An error shall be generated if the data register is not fully shifted out.

3.4.14.7.1.13 **Reset (Non-Fatal).** The processor shall check the status of all mechanisms and reset to Standby Mode with default parameters stored in ROM. The bilevel reset status output shall be set true, and cleared when a valid spacecraft command is received. The reset error code shall be generated. This error is non-fatal because it reports the existence of a previous fatal error. The orbit clock shall not be reset.

3.4.14.7.1.14 **Memory Errors.** Errors shall be generated when incorrect memory operation is detected (memory verification fails).

3.4.14.7.1.15 **Mechanism Response Error (Non-Fatal).** The processor shall maintain backup counts for all mechanism positions to be compared with encoder readouts. If an encoder does not reach the expected state an error shall be generated and the mechanism repositioned to a reference position. A window shall be maintained for PRP timing verification; if the PRP does not occur in the expected window an error shall be generated and the data flagged invalid.

3.4.14.7.1.16 **Backup Timeout Error (Non-Fatal).** All operations involving a wait for a status condition or interrupt shall have backup timeouts.

3.4.14.7.1.17 **Data Overrun and Underrun Errors (Non-Fatal).** Errors shall be generated if the spacecraft does not read data often enough, so that data storage capacity is exceeded. The data validity flag shall be set false and the data set to zero if data is requested before it is ready.

3.4.14.7.1.18 **Register Errors (Non-Fatal).** An error shall be recorded when an instrument register is read back and found to have an incorrect value.

3.4.14.7.2 **Mechanism, Lamp, and High-Voltage Enable/Disable.** Mechanisms and lamps shall be independently controllable only in Direct Control Mode.

3.4.14.7.3 **Register Refresh.** The processor shall continually check the status of latches and registers or refresh them. There shall be no latch in the system which cannot be verified unless it is continually updated or operates in a self-resetting way (a free-running counter, for example)

3.4.14.7.4 **Data Storage.** At least two scan lines of data shall be stored, including all status and housekeeping data and packet headers.

3.4.14.7.5 **Watchdog Timer Update Rate.** The watchdog timer shall be refreshed at least once each chopper cycle.

3.4.15 **Power and Driver Subsystem.** This subsystem shall contain the discrete command relays (if used), the low-voltage power supply, the heater control circuits, and the motor drivers.

3.4.15.1 **Low-Voltage Power Supply.** The power supply shall be designed to operate from the input bus whose characteristics are stated in the power interface specifications and to meet the electromagnetic compatibility specifications herein, unless otherwise specified in the applicable detail specification. The output characteristics of the main power supply shall be as shown in Table 34. Precision references, where needed, shall be generated at the point of use. Outputs shown with different ground symbols shall be connected at only one point. This shall be the instrument star ground, connected to spacecraft digital signal ground, except that the optics +5V ground GL2 shall be connected to the ±12V ground only near the voltage-to-frequency converters.

Table 34. Power Supply Output Characteristics Ground column identifies isolated returns			
Function	**Voltage**	**Noise m V pp**	**Ground**
Logic power (electronics)	+5V±0.1V	50	GL1
Logic power (optics)	+5V±0.2V	100	GL2
Analog power	+12V±0.2V	100	GA
Analog power	-12V±0.2V	100	GA
Motor and heater power	+24V±1V	400	GM
High voltage power bus	+36V±2V	300	GHV

3.4.15.2 **Subsystem Power Consumption.** TOMS subsystems shall draw power from the low-voltage power supply as indicated in Table 35.

Table 35. Subsystem Power Requirements (Maximum Bus Currents) Total +24V power assumes load timesharing					
Subsystem	**+5V mA**	**+12V mA**	**-12V mA**	**+24V mA**	**+36V mA**
Scanner	2	14	2	460	0
Diffuser	2	7	2	460	0
Heaters (total)	0	0	0	420	0
Reflectance Calibrator	0	0	0	80	0
Chopper and PRP	0	57	19	151	0
Wavelength Monitor	2	0	0	120	0
Photodiode & Electrometer	0	7	7	0	0
Photomultiplier, HV, Electrometer	6	21	21	0	18
Voltage-to-Frequency Conv	3	57	49	0	0
Electronic Calibrator	15	18	27	0	0
Housekeeping	2	39	26	0	0
Interface (Elec Adapter)	100	0	0	0	0
Processor, Power & Drivers	420	0	0	0	0
Totals mA (peak at one time)	552	220	153	611	18

3.4.15.3 **Stepping Motor Drivers.** The stepping motor drivers shall drive the stepping scanner and diffuser mechanisms listed above.

3.4.15.3.1 **Motor Connection.** Motors shall be Y-connected, center open (and unavailable), driven by shielded twisted triple. Current and impedance levels shall be in accordance with the specifications of the respective subsystems above.

3.4.15.3.2 **Stepping Motor Drive Signals.** The motor drive circuit shall consist of a 3-phase 6—switch bridge driven by four logic-level signals (Phase 1,2,3 and Enable). The logic signals shall be generated by the processor and be latched in a parallel port. A logic low on the enable input shall disconnect all bridge switches. The drive sequence shall be as shown in Table 36. Motion shall be clockwise when viewed from the output shaft when driven with the forward code sequence.

Table 36.
Stepping Motor Drive Sequence
3-Phase Y-Connected Center Open, 6-Switch Bridge Drive
H=High, L=Low, X=Open

Forward (CW)		Reverse (CCW)	
Step (Mod 6)	**Bridge Output Ph 1 Ph 2 Ph 3**	**Step (Mod 6)**	**Bridge Output Ph 1 Ph 2 Ph 3**
0	H L L	5	H H L
1	H L H	4	L H L
2	L L H	3	L H H
3	L H H	2	L L H
4	L H L	1	H L H
5	H H L	0	H L L
Disable	X X X	Disable	X X X

3.4.15.3.3 **Motor Drive Pulse Hold Duration.** The stepping motor current pulse duration shall be 32±1 milliseconds or the step period, whichever is less (hold the enable input true for 20 milliseconds after leading edge of last step).

3.4.15.4 **Current Limit.** Stepping motor drivers shall be current-limited or otherwise protected at 0.6 A ± 5 percent.

3.4.16 **Thermal Control Subsystem.** The thermal control subsystem shall control the TOMS subsystem operating temperatures in accordance with Table 37 in the TOMS orbital environment with the spacecraft thermal interfaces defined above and in the applicable detail specification. Separate heaters may be used as necessary to control the monochromator flange, lower housing (with PMT as the reference). The total number of operational heaters shall not exceed 4, excluding the lamp and diffuser heaters. The PMT heater control system shall have a limit cycle of ±0.1 °C or less. Lamp and diffuser heater requirements shall be as defined in the applicable paragraphs above. Survival heaters shall keep the instrument in the -10°C to +30°C temperature range when the TOMS power is off.

Table 37. Thermal Subsystem Operating Temperature Control Requirements (°C)			
Subsystem/Area	**Initial**	**Orbital Var'n**	**Over Life**
Photomultiplier	20±1	±0.2	±1
Lower Housing Assembly	20±5	±2	±3
Monochromator Flange	20±2	±2	±3
Monochromator Differential	0±0.1	±0.2	±0.2
Pedestal-Mounted Electronics	-10 to +30	-10 to +30	-10 to +30

3.4.17 **Instrument Housing.** The instrument housing shall support the instrument components in the specified environments and maintain the measured alignment accuracy with the spacecraft and the specified alignments between subsystems. Ports and access shall be provided for test and adjustment operations.

3.5 **Qualification.** TOMS FM-3 shall be a protoflight model and shall pass the qualification-level environmental tests as specified herein.

4. PRODUCT ASSURANCE.

4.1 **Product Assurance Provisions.** The product assurance program shall be conducted in accordance with the provisions of 74-0023, in conformity with the requirements of GSFC 303-TOMS-002. TOMS configuration management shall be in accordance with 74-0024.

4.1.1 **Responsibility.** Perkin-Elmer shall be responsible for product assurance activities in accordance with the 74-0023.

4.1.2 **Access for Government Representatives.** Access for government representatives shall be provided as required by GSFC 303-TOMS-002.

4.1.3 **Special Tests and Examinations.** Tests and examinations shall be conducted according to the cross-reference matrix in Table 38, which lists all tests including those tests performed only for design verification or qualification. Unless otherwise specified, characteristics of major components shall be verified at lower levels of assembly in accordance with the verification provisions of the subtier specifications referenced in Table 4.

4.2 **Quality Conformance Inspections.**

4.2.1.1 **Item Definition (Configuration and Nomenclature).** Drawings, specifications and lists shall be inspected for nomenclature consistent with this specification.

4.2.1.2 **Interfaces.** Verification of spacecraft interfaces shall be as specified in the applicable detail specification. Verification of internal interfaces shall be performed as specified below according to released test and integration procedures.

4.2.2 **Characteristics Verification.** The TOMS shall meet or exceed the characteristics specified in section 3.2 above when verified in accordance with the method specified below.

4.2.2.1 **Satellite Orbit Characteristics.** The compatibility of the scan program and the wavelength scan frequency with the specified orbit timing shall be verified by analysis.

Table 38.
Verification Cross-Reference Matrix
I=Inspection, A=Analysis, T=Test, F=Protoflight or Flight Only

Characteristic	Characteristic Reference	Verification Reference	I	A	T		F
Instrument Concept	3.1.1.1	4.2.1.1	X				
Functional Block Diagram	3.1.1.2	4.2.1.1	X				
Exploded View	3.1.1.3	4.2.1.1	X				
Interface characteristics (All)	3.1.2	4.2.1.2	X		X		X
Major Component List	3.1.3	4.2.1.1	X				
Satellite Orbit Characteristics	3.2.1.1	4.2.2.1		X			
Primary Operational Modes	3.2.1.2.1	4.2.2.2			X		
Launch Mode	3.2.1.2.2	4.2.2.2			X		
Instrument Parameters	3.2.1.3	4.2.2.3			X		
Relay	3.2.1.4.1	4.2.2.4			X		
Emergency Off	3.2.1.4.2.2	4.2.2.5			X		
Reboot Microprocessor	3.2.1.4.2.4	4.2.2.6			X		
Serial Commands	3.2.1.4.3	4.2.2.7			X		
Output Data	3.2.1.5	4.2.2.8			X		
Orbit Clock	3.2.1.5.1	4.2.2.9			X		
Bilevel Telemetry Data	3.2.1.5.2	4.2.2.8			X		
Serial Data	3.2.1.5.3	4.2.2.10			X		
Sync Code	3.2.1.5.3.1	4.2.2.8			X		
Analog Data	3.2.1.5.3.2	4.2.2.8			X		
Instrument Status	3.2.1.5.3.3	4.2.2.8			X		
Time Stamp	3.2.1.5.3.4	4.2.2.8			X		
Science Data Structures	3.2.1.5.3.5	4.2.2.8			X		
Passive Analog Telemetry	3.2.1.5.4	4.2.2.8			X		
Active Analog Telemetry	3.2.1.5.5	4.2.2.8			X		
Spatial Scanning	3.2.1.6	4.2.2.11			X		
IFOV	3.2.1.6.1	4.2.2.12			X		
Full Field of View	3.2.1.6.2	4.2.2.12			X		
Clear Field of View	3.2.1.6.3	4.2.2		X	X		
Step Angle	3.2.1.6.4	4.2.2.13			X		
Scan Width	3.2.1.6.5	4.2.2.11			X		

Table 38, Continued Verification Cross-Reference Matrix I=Inspection, A=Analysis, T=Test, F=Protoflight or Flight Only							
Characteristic	**Characteristic Reference**	**Verification Reference**	**I**	**A**	**T**		**F**
Scan Line Period	3.2.1.6.6	4.2.2.11		X	X		
Scan Accuracy	3.2.1.6.7	4.2.2.13			X		
Scan Rate Stability	3.2.1.6.8	4.2.2.14			X		
Scan Repeatability	3.2.1.6.9	4.2.2.13			X		
Diffuser Look	3.2.1.6.10	4.2.2.11			X		
Source Look	3.2.1.6.11	4.2.2.11			X		
Scanner Stow Position	3.2.1.6.12	4.2.2.11			X		
Scan Encoder	3.2.1.6.13	4.2.2.15			X		
Scan Synchronization	3.2.1.6.14	4.2.2.16			X		
Diffusers	3.2.1.7	4.2.2.17	X				
Diffuser Mounting	3.2.1.7.1	4.2.2.18	X				
Diffuser Heating	3.2.1.7.2	4.2.2.19		X	X		
Diffuser Stray Light	3.2.1.7.3	4.2.2.20			X		
Reflectance Calibrator	3.2.1.7.4	4.2.2.21		X	X		
Spectral Measurements	3.2.1.8	4.2.2.22		X			
Wavelength Range	3.2.1.8.1	4.2.2.22		X			
Wavelength Bands	3.2.1.8.2	4.2.2.22		X			
Wavelength Pairs	3.2.1.8.3	4.2.2.22		X			
Spectral Bandpass	3.2.1.8.4	4.2.2.23			X		
Wavelength Accuracy	3.2.1.8.5	4.2.2.23			X		
Wavelength Stability	3.2.1.8.6	4.2.2.24		X			
Wavelength Scan	3.2.1.8.7	4.2.2.25			X		
Field-of-View Registration	3.2.1.8.7.1	4.2.2.12			X		
Image Motion Compensation	3.2.1.8.7.2	4.2.2.26	X	X			
Wavelength Repeatability Monitor	3.2.1.8.8	4.2.2.27	X	X			
Dynamic Range	3.2.1.9.1	4.2.2.28			X		
Radiometric Linearity	3.2.1.9.2	4.2.2.29			X		
Radiometric Repeatability	3.2.1.9.3	4.2.2.30			X		
Signal-to-Noise Ratio	3.2.1.9.4	4.2.2.31			X		
Spectral Stray Light	3.2.1.9.5	4.2.2.32			X		

Table 38, Continued Verification Cross-Reference Matrix I=Inspection, A=Analysis, T=Test, F=Protoflight or Flight Only							
Characteristic	**Characteristic Reference**	**Verification Reference**	**I**	**A**	**T**		**F**
Radiometric Resolution	3.2.1.9.6	4.2.2.31			X		
Band-to-Crosstalk	3.2.1.9.7	4.2.2.33		X	X		
Dark Current Rejection	3.2.1.9.8	4.2.2.34			X		
Polarization Sensitivity	3.2.1.10	4.2.2.35			X		
Magnetic Field Sensitivity	3.2.1.11	4.2.2.36			X		
Temperature Coefficient of Response	3.2.1.12	4.2.2.37			X		
Mass	3.2.2.1	4.2.2.38	X				
Resonant Frequency	3.2.2.2	4.2.2.39			X		
Uncompensated Angular Momentum	3.2.2.3	4.2.2.40		X			
Power	3.2.2.4	4.2.2.41			X		
Main Heater	3.2.2.4a	4.2.2.41			X		
Diffuser Heater	3.2.2.4b	4.2.2.41			X		
Survival Heater	3.2.2.4c	4.2.2.41			X		
Grounding and Shielding	3.2.2.5	4.2.2.42	X				
Input Power Isolation	3.2.2.5.1	4.2.2.43			X		
Output Power Isolation	3.2.2.5.2	4.2.2.44			X		
Local Shields and Returns	3.2.2.5.3	4.2.2.42	X				
Reliability (Lifetime)	3.2.3	4.2.2.45		X			
Maintainability	3.2.4	4.2.2.46		X			
Transportation, Storage and Handling (Nonoperating)	3.2.5.1	4.2.2.47		X			
Functional Test, Checkout and Prelaunch Operations	3.2.5.2	4.2.2.8	X				
Launch Temperature	3.2.5.3.1	4.2.2.49			X		
Launch Ambient Pressure	3.2.5.3.2	4.2.2.50		X			
Acoustics	3.2.5.3.3	4.2.2.51		X			
Random Vibration	3.2.5.3.4	4.2.2.52		X	X		
Sine Vibration	3.2.5.3.5	4.2.2.53		X	X		
Shock	3.2.5.3.6	4.2.2.54			X		
Acceleration	3.2.5.3.7	4.2.2.55		X	X		

Table 38, Continued Verification Cross-Reference Matrix I=Inspection, A=Analysis, T=Test, F=Protoflight or Flight Only							
Characteristic	Characteristic Reference	Verification Reference	I	A	T		F
Orbital Temperature	3.2.5.4.1	4.2.2.56			X		X
Orbital Pressure	3.2.5.4.2	4.2.2.56		X			
Space Radiation	3.2.5.4.3	4.2.2.57		X			
Orbital Microphonics	3.2.5.4.4	4.2.2.58			X		
Design and Construction	3.3	4.2.3	X				
EEE Parts Selection	3.3.1.1	4.2.3	X				X
Material and Process Control	3.3.1.2	4.2.3	X				X
Electromagnetic Compatibility	3.3.2	4.2.3.1	X		X		
Identification and Marking	3.3.3	4.2.3	X				X
Workmanship	3.3.4	4.2.3	X				X
Hand Soldering	3.3.4.1	4.2.3	X				X
Other Processes	3.3.4.2	4.2.3	X				X
Interchangeability	3.3.5	4.2.3.2	X				X
Safety	3.3.6	4.2.3.3	X				X
Standards of Manufacture	3.3.8	4.2.3	X				X
Cleanliness and Contamination Control	3.3.8.1	4.2.3	X				X
Manufacturing Documentation	3.3.8.2	4.2.3	X				X
Operator Training and Certification	3.3.8.3	4.2.3	X				
Drafting Standards	3.3.9.1	4.2.3.4	X				
Optical Design	3.3.9.2	4.2.3.4	X				
Mechanical Design	3.3.9.3	4.2.3.4	X				
Venting	3.3.9.4	4.2.3.4	X				
Thermal Design	3.3.9.5	4.2.3.4	X				
Radiation Shielding Design	3.3.9.6	4.2.3.4	X				
Electrical Design	3.3.9.7	4.2.3.4	X				
Circuit Decoupling	3.3.9.8	4.2.3.4	X				
Printed Wiring Board Design	3.3.9.9	4.2.3.4	X				
Electrostatic Discharge	3.3.9.10	4.2.3.4	X				
Processor and Logic Design	3.3.9.11	4.2.3.4	X				

Table 38, Continued Verification Cross-Reference Matrix I=Inspection, A=Analysis, T=Test, F=Protoflight or Flight Only							
Characteristic	Characteristic Reference	Verification Reference	I	A	T		F
Software Design	3.3.9.12	4.2.3.5	X				
Shipping Containers	5.1	4.2.5	X				
Marking for Shipment and Storage	5.2	4.2.5	X				
Connector Protection	5.3	4.2.5	X				X
Airport Security	5.4	4.2.5	X				
International Shipment	5.6	4.2.5	X				X
Inspections	5.7	4.2.5	X				X

4.2.2.2 **Primary Operational and Launch Modes.** Proper sequence and function in each mode shall be verified by operating the instrument, observing the mechanism functions, and reviewing the telemetered data. Launch Mode shall be tested by placing the instrument in Standby Mode and turning the power off. Mechanisms should remain in safe positions.

4.2.2.3 **Instrument Parameters.** The behavior of the instrument shall be observed to verify that the operation is consistent and the telemetered values agree with the fixed or commanded parameters. All parameter uploads shall be checked to verify that out-of-range parameters are rejected.

4.2.2.4 **Relay Commands.** Operation of command relays and the function controlled shall be verified. The bilevel telemetry outputs shall correctly indicate the state of each relay, with the signal levels prescribed by the detail specification.

4.2.2.5 **Emergency Off Warning.** This discrete command input shall be stimulated and instrument shall enter Standby Mode with all mechanisms stowed within the time limit.

4.2.2.6 **Reboot Microprocessor.** This discrete command input shall be stimulated and the mircoprocessor shall execute the warm start sequence.

4.2.2.7 **Serial Commands.** Serial command format shall be as specified in the applicable detail specification. Command response shall be verified in software testing, at the interface subsystem level, and at the instrument level. The TOMS shall be sent each command and the response shall be verified along with the values of any uploaded parameters. Illegal commands with unused or conflicting codes shall also be sent. All possible commands shall be tested and it shall be verified that the instrument rejects all illegal commands with the appropriate error message.

4.2.2.8 **Output Data.** Data format and content shall be verified in software testing, at the interface subsystem level, and at the instrument level. Testing shall verify that stimulation of each data source is correctly reflected in the output data.

4.2.2.9 **Orbit Clock.** The orbit clock shall be measured at a test point for a period of 220 minutes with a precision counter-timer to verify the clock stability. The numerical output in the digital data stream shall be consistent with this measurement. Note that the time of receipt of a data packet is not the time at which it was taken.

4.2.2.10 **Serial Data.** Data format shall be compared with the logical format specified above and the physical format specified in the applicable detail specification.

4.2.2.11 **Spatial Scanning.** The coverage shall be verified by analysis to show that the scan program meets the coverage requirements. The scanner shall be tested to show that it follows the intended program and scans in the specified direction, and that it can step to all encoder positions including reflectance calibration source, diffuser, and stow positions.

4.2.2.12 **Field of View and FOV Registration.** The TOMS field of view shall be measured in directions parallel and perpendicular to the direction of dispersion for each wavelength band. The measurement shall be accomplished by recording the instrument's response to a line source not exceeding 0.15 degrees in angular extent. The measurement shall be made with the scan mirror in the nadir detent and the line source adjusted axially to the approximate center of the field of view. The IFOV, FFOV, and field-of-view registration shall be calculated from the data. Allowance for the finite width of the line source shall be included in the acceptance criteria.

4.2.2.13 **Step Angle, Scan Accuracy, and Scan Repeatability.** The scan motor step size, step location, and repeatability shall be measured at the motor level.

4.2.2.14 **Scan Rate Stability.** The stability of the scan rate shall be measured during the scan at the instrument level using test points connected to the motor step signal.

4.2.2.15 **Scan Encoder.** The scan encoder code shall be checked at the instrument level by recording the encoder output with the scanner position in single-step mode.

4.2.2.16 **Scan Synchronization.** The scanner motor control signals shall be compared to the Chopper Phase Reference signal to verify the relative timing.

4.2.2.17 **Diffusers.** The number of diffusers shall be verified by inspection and demonstration of the diffuser selection operation.

4.2.2.18 **Diffuser Mounting**. The direction of the active diffuser normal shall be measured with respect to the instrument axes to verify that it agrees with the mounting angle specified in the applicable detail specification.

4.2.2.19 **Diffuser Heating.** An analysis shall be performed to determine whether the diffuser temperature is greater than all points in the line of sight. The temperature of the diffuser shall be measured in thermal vacuum testing using the diffuser and housing temperature sensors, which shall be precalibrated at the subassembly level.

4.2.2.20 **Diffuser Stray Light.** Reduction of diffuser stray light shall be demonstrated by an irradiance response test. This test shall be conducted at the system level using an FEL lamp mounted on a fixture to simulate the full range of solar illumination conditions in orbit. Measurement intervals shall not exceed one-half the IFOV width (Nyquist criterion). Data shall be obtained in solar calibration (SCAL) mode for all wavelength bands for the full range of illumination conditions while viewing the diffuser when illuminated and when shadowed by a mask. In addition, the response of the instrument shall be measured for each lamp position when a mask is moved in front of the light source to shadow all portions of the instrument except the diffuser. The test shall demonstrate that the stray light rejection is met for all illumination angles.

4.2.2.21 **Reflectance Calibrator.** The accuracy of the calibrator shall be verified by analysis and specification and testing of components. The function shall be tested at the instrument level to show that the measured intensities are consistent with the analysis of calibrator requirements.

4.2.2.22 **Spectral Measurements, Wavelength Range, Bands, and Pairs.** Compliance with the required configuration shall be established by design review.

4.2.2.23 **Spectral Bandpass and Wavelength Accuracy.** The spectral bandpass shall be measured for each band using a dye laser.

4.2.2.24 **Wavelength Stability.** Wavelength stability shall be established by mechanical, optical, and thermal analysis.

4.2.2.25 **Wavelength Scan.** Proper operation of the wavelength scanner (chopper) shall be demonstrated at the instrument level and verified by measuring the relative jitter of the chopper synchronization signals through test points. The effect of the commandable signal demodulator delays on the output digital signal levels shall be measured and recorded.

4.2.2.26 **Image Motion Compensation.** The accuracy of the image motion compensation shall be demonstrated by analysis and by verification that the layout of the chopper is consistent with this specification.

4.2.2.27 **Wavelength Repeatability Monitor.** The accuracy of the wavelength monitor shall be demonstrated by analysis and by drawing review and inspection of the assembly for consistency with the analysis and subtier specifications.

4.2.2.28 **Dynamic Range.** The dynamic range of the system shall be verified by analysis and by tests with sources of known intensity to verify the ranges.

4.2.2.29 **Radiometric Linearity.** The gain of the instrument shall be measured as a function of intensity to obtain a radiometric response calibration. The fit shall be a saturation-type with no offset at low level. The linearity and temperature dependence of the gain may be measured using a combination of constant and chopped light signals. The constant light source shall be adjusted to give various average signal output values, which shall be monitored.

To measure the change with temperature or light level, the AC source intensity shall be adjusted so that the digital output of the instrument jitters around one value (splitting the noise peak). The reading of the source monitor corresponding to this level shall be recorded. The temperature or DC stimulus shall be changed to produce the same condition, and the reading of the stimulus monitor recorded. This approach is capable of measuring changes of ± 0.01 percent or better, providing the sources and the AC source monitor are stable.

4.2.2.30 **Radiometric Repeatability.** The instrument shall be operated in simulated orbital thermal environment to demonstrate the required repeatability.

4.2.2.31 **Signal-to-Noise Ratio and Radiometric Resolution.** The instrument shall be illuminated with the minimum radiance at 312.5 nm and shall demonstrate the required signal-to-noise ratio and radiometric resolution.

4.2.2.32 **Spectral Stray Light.** Spectral stray light rejection shall be demonstrated by analysis and by observing the daytime sky with and without blocking filters.

4.2.2.33 **Band-to-Band Crosstalk.** Recovery of the detector and detector circuits when stimulated with the most rapidly-changing expected signals from band to band shall be demonstrated by analysis and testing at the subassembly level. For this test, the photomultiplier and photodiode shall be illuminated with a pulsed light source (LED or equivalent).

4.2.2.34 **Dark Current Rejection.** The instrument offset shall be measured as a function of temperature with no stimulus. The offset shall not change by more than one quantization interval in any wavelength band.

4.2.2.35 **Polarization Sensitivity.** The sensitivity of the instrument to polarized light shall be measured for all wavelength bands by recording the instrument's response while observing a diffuse source through a linear polarizer of known efficiency. The polarizer shall be rotated through a minimum of 180 degrees and the instrument's response shall be recorded at least every 10 degrees of polarizer rotation. Either the diffuse source shall provide unpolarized light or the test shall be conducted to eliminate any error due to polarization of the source.

4.2.2.36 **Magnetic Field Sensitivity.** The instrument shall be immersed in a 1 gauss field in the X, Y, and Z directions and the change in output measured when the field is reversed.

4.2.2.37 **Temperature Coefficient of Response.** When illuminated by a stable light source, the instrument responsivity shall not change with more than the required temperature coefficient when the instrument temperature is varied over the operating temperature range.

4.2.2.38 **Mass.** The instrument shall be weighed to establish the mass.

4.2.2.39 **Resonant Frequency.** The instrument shall be subjected to low-level sinusoidal vibration to map the resonances.

4.2.2.40 **Uncompensated Angular Momentum.** The inertia of all rotating components shall be measured or calculated and used to verify the total angular momentum by analysis. Motor suppliers shall provide total internal moment-of-inertia data as part of the end-item data package for each motor.

4.2.2.41 **Power.** Power drawn by the instrument and its heaters shall be measured in thermal vacuum testing as specified in the applicable detail specification.

4.2.2.42 **Grounding and Shielding.** Drawings shall be inspected and resistance between ground returns shall measured to establish compliance.

4.2.2.43 **Input Power Isolation.** The resistance between spacecraft power and instrument output signal returns shall not be less than the value specified in the applicable detail specification.

4.2.2.44 **Output Power Isolation.** The resistance between output returns shall not be less than the value specified in the subtier power supply specification when measured prior to connecting the power supply returns to instrument star ground.

4.2.2.45 **Reliability (Lifetime).** Reliability shall be verified by radiation shielding, trend, and lifetime analyses as provided in GSFC-303-TOMS-002 to demonstrate that the instrument will meet the intended life.

4.2.2.46 **Maintainability.** Compliance with the specified maintainability factors shall be demonstrated by analysis presented at the Critical Design Review.

4.2.2.47 **Transportation, Storage and Handling (Nonoperating).** Analysis of packaging design and standard package test data shall verify that the instrument will not exceed its design loads during transportation.

4.2.2.45 (Reliability Demonstration
also 4.2.2.46 Maintainability

4.2.2.48 **Functional Test, Checkout and Prelaunch Operations.** The instrument shall not be subjected to environmental conditions exceeding those specified.

4.2.2.49 **Launch Temperature.** The instrument shall be tested for survival over the launch temperature range.

4.2.2.50 **Launch Pressure Change.** Survival of the launch pressure transient shall be established by a venting analysis.

4.2.2.51 **Acoustics.** The instrument shall not suffer any damage and shall operate within specification after being subjected to the equivalent of acoustic levels in Table 24.

4.2.2.52 **Random Vibration.** The instrument shall be not suffer any damage and shall operate within specification after being subjected to the random vibration levels in Table 25.

4.2.2.53 **Sinusoidal Vibration.** The instrument shall be not suffer any damage and shall operate within specification after being subjected to the sinusoidal vibration levels in Table 26.

4.2.2.54 **Shock.** The instrument shall be not suffer any damage and shall operate within specification after being subjected to the shock levels in Table 27.

4.2.2.55 **Acceleration.** The instrument shall be not suffer any damage and shall operate within specification after being subjected to the acceleration levels in Table 28

4.2.2.56 **Orbital Temperature and Pressure.** The instrument shall be tested in thermal vacuum for survival over the non-operating temperature range and subsequent proper operation over the operating or qualification orbital temperature range, as applicable.

4.2.2.57 **Space Radiation.** Verification shall be performed as follows, using the specified safety factor:

a. **Radiation Dose.** Analysis of the expected life of dose-sensitive parts shall be performed as required in GSFC-303-TOMS-002, allowing for shielding as designed (also see life verification above).

b. **Single-Event Upset.** The single event upset rate shall be verified by analysis using peak linear energy transfer spectra, allowing for shielding as designed.

c. **Peak Trapped Flux.** Particle-radiation-induced noise limits shall be verified by analysis of background events seen in the detectors. Lots of optical materials subject to fluorescence and phosphorescence from impurities shall be tested to assure acceptability.

4.2.2.58 **Orbital Microphonic Vibration Levels.** Operation of the instrument mechanisms shall not produce microphonic noise in excess of the specified signal-to-noise ratio.

,.2.3 **Design and Construction.** Quality controls shall be established in accordance within the requirements of GSFC-303-TOMS-002 and the provisions of the Perkin-Elmer PAIP to verify that the specified design and process controls are met.

4.2.3.1 **Electromagnetic Compatibility.** Electromagnetic compatibility testing shall be performed according to the requirements of the applicable detail specification.

4.2.3.2 **Interchangeability.** Compliance with interchangeability requirements shall be verified by design review.

4.2.3.3 **Safety.** Compliance with the safety requirements of GSFC 303-TOMS-002 shall be monitored during all phases of instrument development, fabrication, and testing as implemented in 74-0023.

4.2.3.4 **Design Constraints.** Compliance with electrical, mechanical and optical design constraints in GSFC TOMS-920-90-001 and GSFC 303-TOMS-002 shall be verified by prerelease drawing reviews and program milestone design reviews in conformity with the Design Assurance and Reliability requirements of GSFC-303-TOMS-002, as implemented in 74-0023.

4.2.3.5 **Software Design.** Software design and documentation shall comply with all requirements of GSFC 303-TOMS-002 as implemented in 74-0023.

4.2.5 **Preparation for Delivery.** Packaging shall be inspected to verify compliance with the protection requirements.

5. PREPARATION FOR DELIVERY.

All requirements of this section shall be verified by test, inspection, or analysis.

5.1 **Shipping Containers.** For shipping and storage a special container shall be provided and used for all transport. Within this container TOMS shall be bolted to a multipurpose handling fixture. The instrument and fixture shall be sealed in a dry-nitrogen-purged bag. The instrument shall be protected from excessive vibration and shock loading during shipping by wrapping the fixture in a low outgassing foam material. Accelerometers mounted on the handling fixture shall document the maximum shock load to which the TOMS has been exposed.

The container shall be purged before shipment with dry, clean nitrogen and sealed. All containers shall be designed to be lifted using a fork-lift or be mounted on a pallet so designed. Ground support and test equipment shall be packaged separately from the instrument.

5.2 **Marking for Shipment and Storage.** All interior and exterior enclosures and containers shall be legibly marked with the quantity, item name, part number, buyer's name and address, contract number, and serial number. In addition, each package or container shall be conspicuously marked "U.S. Government Property -- Items for Spaceflight Use".

5.3 **Connector Protection.** All unmated connectors shall be protected by suitable covers at all times during storage or shipment.

5.4 **Airport Security.** Transit liaison shall be arranged by the GSFC Security Officer (Telephone 301-982-2233). Preflight arrangements shall be made to avoid inspection of delicate equipment by untrained personnel. Equipment subject to such damage shall be plainly marked on the exterior of the container. A description of the contents of each container shall be made available to the GSFC Security Officer and to the airport authorities. To insure against damage by inspection, equipment shall be packaged in such a way that it can be safely handled if inspection becomes mandatory.

5.5 **International Shipment.** TOMS shall be shipped internationally by air and within the destination country by air or by normal surface transportation. TOMS shall always be loaded, transported, handled, and unloaded under the supervision of a representative from NASA. TOMS shall be packed in the shipping box in its original condition whenever it is transported between sites.

5.6 **Inspections.** All inspections for Customs, or any other purpose, shall be done in a class 100,000 clean room.

6. NOTES.

6.1 **Theoretical Foundations.** The UV radiation received by the TOMS instrument in the total-ozone bands consists mainly of solar radiation that has penetrated through the stratosphere and has been reflected back by the dense tropospheric air and the surface. Ozone, being concentrated in the stratosphere above the region in which most of the radiation is backscattered, acts as an attenuator of this radiation. By determining the amount of this attenuation in the ozone absorption bands, the amount of ozone above the reflecting surface can be accurately estimated. More than 80 percent of the ozone is located above the tropopause, whereas all clouds, most of the aerosols, and approximately 80 percent of the atmosphere are located below it. This almost complete separation of the ozone from the scatterers and reflectors minimizes errors caused by vertical profile shape, clouds, aerosols, and other tropospheric variables.

The TOMS measures the radiance, I, at six wavelengths at each scene sample. It also periodically measures the solar flux, F, at the satellite at these six wavelengths. The ratio, I/F (sometimes called the Earth's geometric albedo), is used to determine the total ozone, Ω. The pressure, P_o, of the reflecting surface and three angles must also be known for accurate ozone retrieval. The solar zenith angle, Θ_o, from the IFOV and the zenith angle of the satellite, Θ, also from the IFOV, are needed for calculating the optical slant path, S (= sec Θ + sec Θ_o), of the UV light down through the atmosphere and back to the satellite. The azimuth angle, Φ, between the Sun and the satellite (from the IFOV) is also needed for calculating the scattering phase function.

For π units of incident solar flux, the total backscattered radiance, I, at wavelength λ can be expressed as the sum of two terms as follows:

$$I(\lambda, \Theta, \Theta_o, \Phi, R, P_o, \Omega) = I_o(\lambda, \Theta, \Theta_o, \Phi, P_o, \Omega, S) + \frac{T(\lambda, \Theta, \Theta_o, \Phi, P_o, \Omega, S)\, R}{1-RS^b(\lambda, P_o, \Omega, S)} \quad (6.1\text{-}1)$$

where R is the effective reflectivity of the reflecting surface, S represents the dependence on ozone profile shape, T is the atmospheric transmission, and S^b is the atmosphere-to-surface backscatter fraction. The arguments are given in parentheses.

The first term of equation 6.1-1, I_o, is the intensity of the purely atmospheric backscattered radiation that is the intensity when the surface reflectivity is zero. The second term is the direct and diffuse radiation reflected by the surface. The longest TOMS wavelength, 360 nm, being outside the ozone absorption band, is used to determine the effective Lambertian surface reflectivity, R. The five shortest wavelengths are used in pairs to determine the total ozone, Ω, at different latitude zones and solar zenith angles.

The algorithm is fundamentally very simple. Given the optical slant path, S, the scene reflectivity, R, and the surface pressure, P_o, the average columnar amount of total ozone, Ω, in the IFOV is obtained by a lookup and interpolation procedure, using a table of precomputed radiances.

The radiance tables were created by using a set of climatological ozone vertical profiles, determined for three latitude bands using balloon ozonesondes .

In the analysis for ozone, the wavelengths are always used in pairs to cancel sources of error such as aerosol scattering, cloud altitude errors, detector gain-errors, etc.

The slit-weighted effective ozone absorption coefficients and the sensitivity to temperature and wavelength changes are listed in Table 39. The parameter Ω is the slant path ozone amount in atm-cm.

Table 39. Slit-Weighted Absorption Coefficients and Sensitivities At Potential TOMS Wavelengths							
Wavelength nm	Ozone Absorption Coefficient (atm cm)$^{-1}$				Temperature Gradient	Wavelength Gradient	Solar flux Gradient
	U=0.0	0.2	0.62	1.16	%/A	%/A	%/A
308.6	2.897	2.894	2.889		0.19	-1.11	-2.00
312.5	1.596	1.594	1.591	1.587	0.24	-1.53	0.17
317.5	0.860	0.860	0.858	0.857	0.24	-0.50	-1.54
322.3	0.467	0.466	0.464	0.462	0.26	-0.58	-0.80
331.2	0.134	0.133	0.133	0.133	0.36	-4.26	-0.10
360.0	0	0	0	0	0	0	0.15

6.2 **N-Value Definitions and Errors.** Atmospheric ozone content is tabulated as a smooth function of the logarithms of the ratios of the pair values, with the logarithm of the ground reflectance as a parameter:

$$\Omega = \Omega(\lambda, \Theta, \Theta_o, \Phi, N_p, N_R, P_o), \qquad (6.2\text{-}1)$$

where the N-values N_p and N_R are defined as follows:

$$N_p = -100 \log_{10} (I\lambda_1/I\lambda_2), \qquad (6.2\text{-}2a)$$

$$N_R = -100 \log_{10} (\pi I_1), \qquad (6.2\text{-}2b)$$

where $I_{\lambda 1}$ and $I_{\lambda 2}$ are the measured radiances for the two members of a wavelength pair (λ_1 being the shorter), and I_1 is the radiance in Band 1 (360 nm), referred to $1/\pi$, the reflectance from a perfectly white diffuse surface.

Instrument errors contribute by affecting the angles and N-values which are used to enter the tables.

For a given set of angles the total ozone is very approximately a linear function of the N-values, for a given cloudtop pressure:

$$\Delta\Omega \approx (\delta\Omega/\delta N_R)\, \Delta N_R + (\delta\Omega/\delta N_p)\, \Delta N_p. \qquad (6.2\text{-}3)$$

The relative weighing of the different pairs depends on latitude and is TBS.

Because the N-values are defined by logarithms, it is the fractional errors in the radiances that are are important:

$$\Delta N_R = -k\, \Delta I_1/I_1 \qquad (6.2\text{-}4a)$$

$$\Delta N_p = -k\, (\Delta I_{\lambda 1}/I_{\lambda 1} - \Delta I_{\lambda 2}/I_{\lambda 2}), \qquad (6.2\text{-}4b)$$

$$\Delta N_p = -k\ (\Delta I_{\lambda 1}/I_{\lambda 1} - \Delta I_{\lambda 2}/I_{\lambda 2}), \qquad (6.2\text{-}4b)$$

where k is a numerical constant.

There are several main sources of error in the radiance measurements: error in the instrument reading for each member of the pair, error in the instrument reading of the diffuser radiance, error in the ratio of the diffuser reflectance for the two members of the pair (due to unknown wavelength dependence) and, for the reflectance channel (Band 1), error in the absolute reflectance of the diffuser.

6.3 **Specification Notes.** The following notes apply to the specifications indicated.

6.3.1 **Instrument Alignment.** The alignment mirrors are placed on the scan assembly to avoid tolerance buildup. The scanner must be separately aligned with the nadir direction.

6.3.2 **Scanner Nadir Alignment.** The scanner can be aligned no better than the scan accuracy and repeatability permit.

6.3.3 **Spectral Bandpass.** Analysis shows that the full-width at half maximum is not the parameter that should be controlled; it should be the area of the slit function

$$\Delta\lambda = \int R(\lambda)\ d\lambda,$$

where the transmission R(l) is dimensionless. The variance (or other measure of dispersion) should also be controlled to prevent crosstalk.

6.3.4 **Image Motion Compensation.** The Nimbus TOMS wavelength samples were arranged so that not only did the centroids match exactly, the variance of the sample position matched exactly as well. Four chops were used to make it possible to match the variances. Analysis shows that matching the variances makes no difference in the errors obtained scanning a sinusoidal bar pattern with a period of two IFOVs (Nyquist rate). This means that using four chops per wavelength is unnecessary; two are sufficient.

6.3.5 **Dark Current Rejection and Monitoring.** The purpose of the chopper is not to reject ordinary dark current, which is very small and swamped by other offsets, but to reject radiation-induced dark current which is much larger. The dark current should not increase substantially in the radiation environment expected on any of the missions (at the time of solar maximum); this is basically a shielding requirement, plus a requirement to use low-scintillation glasses. The Nimbus TOMS radiation-resistant design used fused silica for the photomultiplier faceplate and lenses because of its low scintillation efficiency.

The "dark current" measured in the diagnostic mode is not dark signal but simply the reference side of the chopped signal, which contains a "light" contribution of about 3 percent.

Most of the "dark current" offset (DC voltage at the electrometer output) is actually just electrometer voltage offset, and much of the dark current actually comes from interdynode leakage, not photocathode current. A special measurement of dark current would require a complex electrometer design that would compromise the main function.

6.3.6 **Radiometric Linearity**. TOMS has several piecewise linear ranges which cover the dynamic range in a quasi-logarithmic fashion. In general, the gain and offset of each range must be known, as well as any correction for nonlinearity of the primary detector. This correction is complex because the signal is chopped and because low-level signals must be divided by the high level signals from the diffuser. To attain the ultimate accuracy these corrections must be made by a detailed algorithm to be given eventually in these notes.

6.3.7 **Scan Code**. This code is an extension of the code used on the Nimbus TOMS. To allow for scanning different scan widths it is centered at nadir and uses all 50 positions available. The following discussion is adapted from the Nimbus TOMS design note by M. McCollum.

Six tracks are required to encode all positions with a full 360 degrees of rotation. Coded outputs are provided for the following positions: Forty-one 3-degree scan positions, left and right stow positions, left and right calibration (diffuser-viewing) positions, and for the five intervening sectors, for a total of 50 positions allowed by the code.

The code is a modified Gray code selected to minimize position ambiguity. Because only one bit is permitted to change state for each step, readout error is limited to one step. An exception is necessary at the nadir position for reasons of redundancy. No codes are repeated.

To eliminate single point failures, two sets of LED's are used, one set of LED's in series illuminates tracks A, B, and C, while another set illuminated tracks D, E, and F. The code provides that at least one bit be true for each set of LED's, except for the reference (nadir) position, which is all zeros. This code has 50 available states. A double failure is required to lose the nadir reference. Two bits change state only on either side of nadir. There is never any ambiguity in practice if there is no attempt to read the encoder on the fly, waiting until after scan motor settling before reading. Use of the Gray code is not essential but is good practice.

6.4 Error Budget Derivation.

6.4.1 **Amplitude Stability.** Because no absolute measurements are being made, the limiting requirement is that for ±1% radiometric repeatability. Effects which limit the reproducibility of readings are mainly thermal drifts in orbit and sensitivity to changing magnetic fields in orbit. Noise presumably averages out, except for chopper jitter which is second-order and creates a bias.

Table 40 shows the error budget. The optics temperature coefficients budgeted are larger than the calculated values; the reflectance of an aluminum surface changes about ±100 ppm/°C and the transmittance of a fused silica surface changes only about ±9 ppm/°C. The high voltage power supply is assumed to be driving 9 stages of gain with a feedback resistor tracking of ±50 ppm/°C. It is legitimate to combine these errors in rms fashion because they have random signs and there are many of them.

6.4.2 **Phase Stability.** The TOMS is a synchronously modulated and demodulated so that both amplitude and phase errors are important. Errors influence the radiometric repeatability. For a trapezoidal waveform of period q and rise time q_r in angular units, the signal out of the demodulator relative to a signal zero-peak level of unity is

$$S = (1 - \Theta_r/\Theta)/2.$$

The error in the signal when the modulator and demodulator are out of phase by an angle $\Delta\Theta$ is second-order, given by

$$\Delta S/S = -2\Delta\Theta^2/(\Theta_r\ \Theta\ S).$$

Because this error is second-order, any offset (static error) will increase the jitter, and any zero-mean angular jitter will lead to an offset, so that it is not allowable to average the signal. For the TOMS chopper, the rise angle Θ_r is 20.7 milliradians and the slot period is 430 milliradians.

The rms value of the fractional random error in signal is

$$\sigma^2(\Delta S/S) = 8\sigma_j^2(2\Delta\Theta_s^2 + \sigma_j^2)/(\Theta_r\ \Theta\ S)^2.$$

Setting the drift plus static error $\Delta\Theta$ sequel to the phase jitter σ_j, we can solve for the required static error plus drift (or jitter) as follows:

$$\Delta\Theta_s = 0.45\ (\sigma\Theta_r\ \Theta\ S)^{1/2}$$

This equation determines the short-term stability required for ozone pair calibration; it does not apply to the 360 nm reflectance channel, which also has a stability term. The specification calls for a radiometric repeatability of ±1 percent and a diffuser pair calibration trend error of ±0.1 percent per year. The first specification governs the response to orbital temperature variations, while the second specification governs the short-term stability during reflectance calibration, which is also affected by long-term chopper phase drift because the error is second-order. The second specification is more stringent. Taking a short term-stability (jitter) requirement of ±0.02 percent allocable to the phase error, we obtain total error budgets of 0.300 microradians (7.2 microseconds at 797 km) for static error and drift separately, and 600 microradians (14.2 microseconds at 797 km) for rms jitter.

Table 40.
Error Budget for Radiometric Repeatability

Parameter	Valve	Units	Error, ppm	Notes
Required Repeatability	10000	ppm	10000	
Temperature variation in orbit	0.5	°C		
Optics temp coefficient				
- Entrance optics	300	ppm/°C	150	Analysis
- Monochromator & exit optics	600	ppm/°C	300	Analysis
Electronics temp coefficient				
- PMT temp coefficient	15000	ppm/°C	7500	Spec
- HVPS gain temp coefficient	60	ppm/°C	450	9x50 ppm
- Electrometer temp coefficient	500	ppm/°C	250	Budget
- VFC temp coefficient	100	ppm/°C	250	Budget
Chopper phase drift	200	ppm/°C	250	Budget
Magnetic field effect	500	ppm	500	Budget
RMS error			7550	
RMS/requirement			0.76	
Worst-case error			9650	
Worst-case/requirement			0.97	

10. **APPENDICES.**

10.1 **Interconnection List.** Interfaces between the components of the TOMS shall be as defined below.

10.1.1 **Spacecraft Interface.** The details of the spacecraft interface shall be as provided in the applicable detail specification.

10.1.2 **Optics Module Port Interface.** This port shall be connected through a 37-pin D subminiature socket connector as specified in Table 41 (**TBD**).

(Attach wire lists following this section, assign table numbers, bind separately?)

10.1.3 **Test Connectors.** Test connectors shall be provided on the analog and digital interface assemblies as specified in Tables 42 and 43. All signals shall be isolated by a series resistance of at least 10K located at the source. To prevent crosstalk, wire bundles in the instrument and test cable shall be shielded as shown in the table (all power lines within single power shield, etc). The overall cable shield shall be connected to housing ground. All internal shields shall be connected to instrument grounds as noted.

Table 41.
Optics Module Interface
Connector 37-pin D Subminiature Crimp GSFC 311P409-4S-B-15

Pin	Signal Name	Shield	Signal Function
1			
20			
2			
21			
3			
22			
4			
23			
5			
24			
6			
25			
7			
26			
8			
27			
9			
28			
10			
29			
11			
30			
12			
31			
13			
32			
14			
33			
15			
34			
16			
35			
17			
36			
18			
37			
19			

Table 42.
Test Connector Interface (Optics Module)
Connector 25-pin D Subminiature Crimp GSFC 311P409-3S-B-15

Pin	Signal Name	Shield	Signal Function
1	HOUSING	Cable	Housing potential (cable shield)
14	LSHLD	Logic	Logic shield connection
2	TACHREF	Logic	Chopper reference clock (delayed)
15	TACH	Logic	Chopper speed feedback
3	V/F#0	Logic	Photodiode V/F output
16	V/F#1	Logic	PMT Range 1 V/F output
4	V/F#2	Logic	PMT Range 2 V/F output
17	V/F#3	Logic	PMT Range 3 V/F output
5	HKVFC	Logic	Housekeeping VFC output
18			
6	Others TBD		
19			
7			
20			
8			
21			
9			
22			
10			
23			
11			
24			
12			
25	ASHLD	Analog	Analog signal shield connection
13	HVMON	Analog	PMT high voltage monitor

Table 43.
Test Connector Interface, Digital Electronics
Connector 25-pin D Subminiature Crimp GSFC 311P409-3S-B-15

Pin	Signal Name	Shield	Signal Function
1	HOUSING	Cable	Housing potential (cable shield)
14	+36V	Power	High voltage supply bus
2	+24V	Power	Motor voltage
15	+12V	Power	Analog voltage
3	+6.5V	Power	Photodiode and encoder power
16	+5V	Power	Logic voltage
4	GND	Power	Star ground and power shield
17	-12V	Power	Analog voltage
5	STEP	Logic	Scan step command
18	PRPREF	Logic	Chopper phase reference
6	VFCCLK	Logic	VFC Clock
19	DEMOD#0	Logic	Accumulator phase control
7	DEMOD#1	Logic	Accumulator phase control
20	DEMOD#2	Logic	Accumulator phase control
8	DEMOD#3	Logic	Accumulator phase control
21	ORBCLK	Logic	Orbit clock
22			
10	Others TBD		
23			
11			
24			
12			
25			
13			