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TIMED

Thermosphere - Ionosphere - Mesosphere - Energetics and Dynamics

GPS Navigation System (GNS) Requirements

The Johns Hopkins University
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1. General

1.1 Introduction

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) is designing a spacecraft called TIMED to study the interaction between the sun and earth's atmosphere. TIMED is an acronym which stands for Thermosphere, Ionosphere, Mesosphere, Energetics, and Dynamics. To correlate spacecraft position and time with instrument measurements, TIMED will include an on-orbit navigation capability. Navigation will be provided by a GPS Navigation System (GNS) that accesses Standard Positioning Service (SPS) signals broadcast from the constellation of GPS satellites. GPS is a space-based radionavigation system which is managed by the U.S. Air Force (USAF), the system operator. The purpose of this document is to define TIMED GNS system requirements.

1.2 Document Scope

This document defines top level GNS system requirements, specifically

- mission level GNS navigation, event prediction, and orbit estimator requirements
- derivative (flow-down) GNS design requirements
- top level interface requirements between the TIMED spacecraft and GNS

Design goals are also identified and defined. These design goals do not flow down directly from mission level GNS requirements but nevertheless are considered highly desirable design features. These features will be implemented assuming sufficient resources are available.

1.3 Follow-on GNS Specification and Requirement Documents

Detailed GNS performance and interface requirements shall be provided in a follow-on GNS Performance and Interface (P&I) specification. GNS test requirements shall be documented in a separate GNS test plan as required by the TIMED Component Environmental Specification. To address complex software issues in an explicit manner, software requirements shall be given in a separate GNS software requirements document.

2. Reference Documents and Information

The following documents form a part of this document to the extent specified herein.

2.1 JHU/APL Documents

Item	APL Document Title	Number
2.1.1.	TIMED Component Environmental Specification	7363-9010
2.1.2	TIMED Product Assurance Implementation Plan	7363-9028
2.1.3	TIMED Spacecraft General Instrument Interface Specification (GIIS)	7363-9050
2.1.4	TIMED System Requirements Document	7363-9001
2.1.5	TIMED EMC Control Plan and EMI Performance Requirements Specification	7363-9038
2.1.6	TIMED IEM to Wire Wrap Conversion Spreadsheet	---

2.2 External Documents

Item	External Document Title	Number
2.2.1	Navstar GPS Space Segment / Navigation User Interfaces	ICD-GPS-200 Rev c
2.2.2	Electronic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference	MIL-STD-461B
2.2.3	Measurement of Electromagnetic Interference Characteristics	MIL-STD-462 (Notice 2)
2.2.4	PCI Bus Standard Document	---
2.2.5	CCSDS Recommendation for Space Data System Standards, Time Code Formats	CCSDS 301.0-B-2
2.2.6	Global Positioning System - Theory and Practice, third edition, published by Spring-Verlag Wien New York	---

2.3 Acronyms and Abbreviations

1PPS	One Pulse Per Second
A/D	Analog to Digital
ACS	Attitude Control System
ASIC	Application Specific Integrated Circuit
BPSK	Binary Phase Shift Key
C &T	Command and Telemetry
C&DH	Command and Data Handling system
C/A	GPS Coarse Acquisition code
CCSDS	Consultative Committee for Space Data Systems
CIO	Conventional International Origin
CIS	Conventional Inertial System
CTS	Conventional Terrestrial System
CUC	CCSDS Unsegmented time Code format
CW	Continuous Wave
DOD	Department of Defense
ECEF	Earth Centered Earth Fixed coordinate system
EDAC	Error Detection And Correction
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
FOM	Figure of Merit
FOV	Field of View
FPGA	Field Programmable Gate Array
G & C	Guidance and Control System
GIIS	General Instrument Interface Specification
GNS	GPS Navigation System
GPS	Global Positioning System
GSE	Ground Support Equipment
GTA	GPS multi-channel Tracking ASIC
HSKP	Housekeeping telemetry
I/F	Interface
IEM	Integrated Electronic Module
IF	Intermediate Frequency
JHU/APL	Johns Hopkins University Applied Physics Laboratory
L1	Designator for GPS signal of carrier frequency 1575.42MHz
LEO	Low Earth Orbit
LHC	Left Hand Circular polarization
LNA	Low Noise Amplifier
MDC	Mission Data Center
MOC	Mission Operations Center
NB	Narrow Band
NF	Noise Figure
PCA	Point of Closest Approach
PCI	Peripheral Component Interface
POC	Payload Operations Center
PPM	Parts Per Million
PRN	Pseudo-Random Noise
PVSET	Position, Velocity, Sun Vector, Event(flags), Time
RF	Radio Frequency
RHC	Right Hand Circular polarization
RMS	Root Mean Square

SPS	Standard Positioning Service
SRAM	Static Random Access Memory
SSR	Solid State Recorder
SV	Space Vehicle
TBD	To Be Determined
TIMED	Thermosphere, Ionosphere, Mesosphere, Energetics and Dynamics
TOV	Time-Of-Validity
TTFF	Time to First Fix
TTSF	Time to Subsequent Fix
USAF	United States Air Force
UTC	Universal Time Code standard
UTC(USNO)	UTC maintained by the United States Naval Observatory
WB	Wide Band
WGS	World Geodetic System
WRT	With Respect To

3. GNS System Overview

3.1 Requirements

The GNS shall operate autonomously and provide the following services to the TIMED spacecraft.

- continuous real time spacecraft position,velocity, and sun-vector
- accurate time transfer
- propagation of orbit elements capable of estimating future spacecraft position
- prediction of ground contact event times
- prediction of on-orbit events (terminator crossings and South Atlantic Anomaly crossings)
- full redundancy

To permit meeting performance requirements during anomalous geodetic and solar activity, periodic uploading of physical parameters (solar flux, geomagnetic index, and polar wander) shall be supported.

A detailed breakdown of mission level and flow-down requirements is given in follow-on sections of this document.

3.2 System Description

The GNS design will be based on use of SPS ranging signals broadcast from the constellation of GPS satellites. The SPS ranging signal, referred to as L1, is centered at a frequency of 1575.42 MHz. L1 is Binary Phase Shift Key (BPSK) modulated. The modulation consists of two components that are modulo-2 summed : (1) a 1.023 MHz Pseudo-Random Noise (PRN) code known as the coarse acquisition (C/A) code and (2) a 50 hz navigation message. The C/A code sequence repeats every 1 ms. The GNS receiver demodulates the received code from the L1 carrier, and detects the time offset between the received and a locally generated replica of the code. The receiver also reconstructs the navigation message data.

To compute TIMED spacecraft position, velocity, and time, the GNS must determine the range to four or more GPS satellites. The propagation time to each GPS satellite is obtained by determining the difference between transmit and receive times of the C/A code. The range to each GPS satellite is computed by multiplying each propagation time measurement by the speed of light.

The navigation message transmitted from each GPS satellite provides data required to support the position determination process. Data includes information to determine satellite time of transmission, satellite position, satellite health, satellite clock correction, time transfer to UTC, and constellation status.

3.3 GNS Implementation

Two card slots have been reserved in each spacecraft Integrated Electronic Module (IEM) for housing GNS electronic components. The two GNS cards are called the GNS receiver card and the GNS dual processor card respectively and together with the GNS antenna comprise one complete GNS system. Two redundant GNS systems shall be installed on the TIMED spacecraft.

A set of GNS cards is installed and connected in each IEM as illustrated in the block diagram of Figure 3-1. The GNS cards connect to each other through the IEM backplane. In addition, the GNS interfaces to the IEM Command and Data Handling (C&DH) processor card, Uplink card, Command and Telemetry (C&T) card, and IEM power supply. (The solid state recorder, uplink receiver, and downlink transmitter cards also located in the IEM have no direct connections to the GNS).

There are no direct electrical connections between the redundant GNS systems located in separate IEMs.

3.3.1 GNS Antenna

The GNS antenna elements shall be mounted on pedestals located on the optical bench. Each GNS antenna shall be mounted on a separate pedestal and point towards zenith. The antenna outputs will be connected to the GNS receiver cards using low loss coaxial cable.

3.3.2 GNS Receiver Card

The GNS receiver card is comprised of an RF preamplifier module, an RF downconverter module, and baseband electronics including a multi-channel GPS Tracking ASIC (GTA). Both sides of the card are populated with components, with the GTA electronics mounted on the side opposite the RF preamplifier and downconverter modules. The preamplifier module provides out-of-band filtering and low noise amplification of the GPS L1 signal. The RF downconverter frequency translates the received RF L1 down to analog baseband, quantizes the analog baseband, and outputs digital baseband to the GTA.

The GTA works with loop filter software in the tracking processor to implement a complete multi-channel GPS baseband receiver. The GTA implements local C/A code generation, carrier generation, and digital correlation functions. The GTA also implements a local GPS clock as well as periodic measurements of integrated carrier and code phase. The GTA will support up to 12 receiver channels.

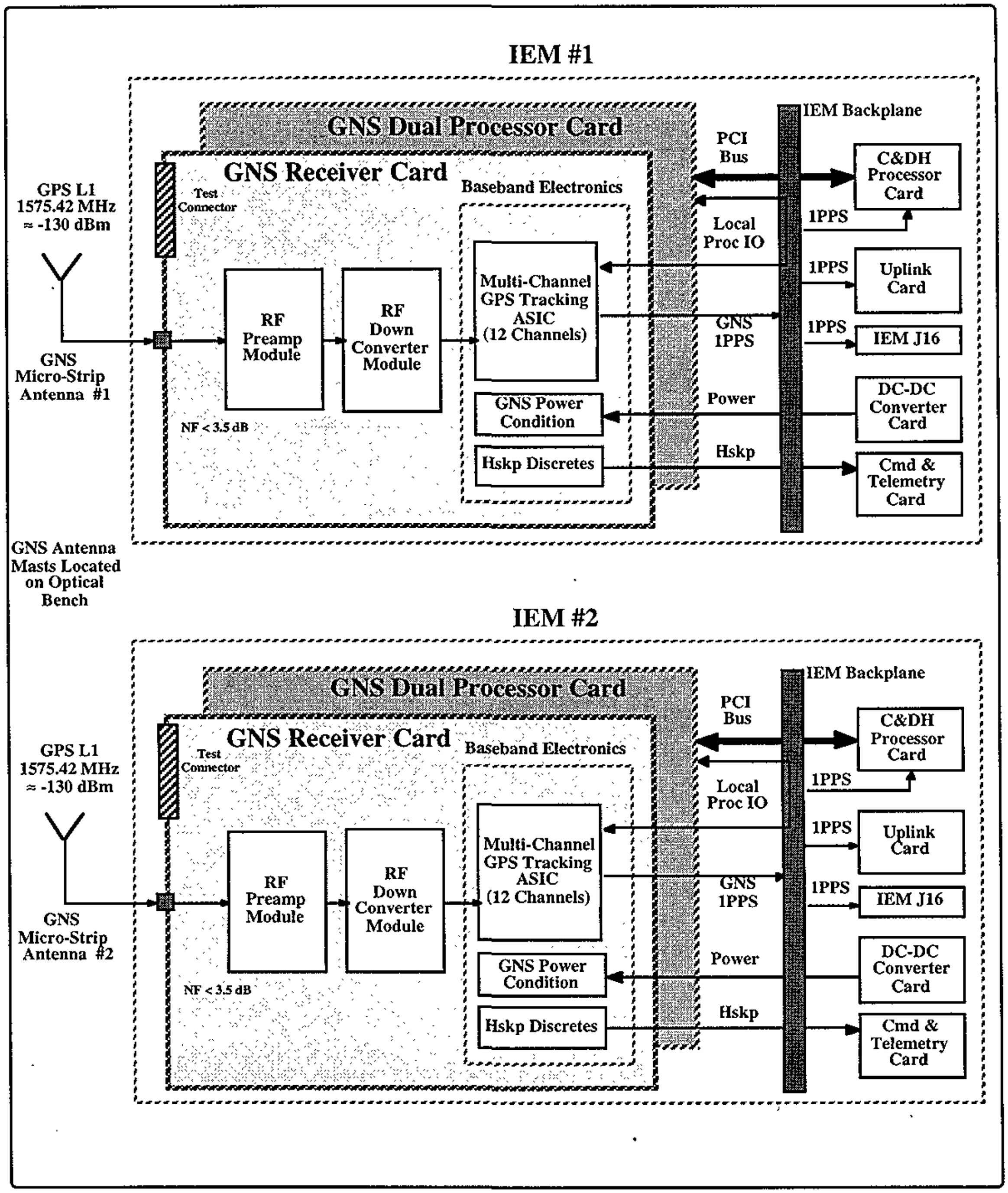

Figure 3-1 -- TIMED GPS Navigation System (GNS)

3.3.3 GNS Dual Processor Card

The GNS dual processor card includes two Mongoose V processors mounted on opposite sides of the card. These processors are referred to respectively as the tracking processor and the navigation processor. Each includes two Mbytes of SRAM memory and share 4 Mbytes of Flash Memory. Each processor design includes a FPGA to implement PCI bus arbitration logic and other supporting functions. The GNS navigation processor shares a common core design with the C&DH processor and the flight computer used in the attitude system.

The tracking processor connects to the GTA through a local processor bus routed through the IEM backplane and together with the GTA implements a multi-channel GPS baseband tracking receiver. Each receiver channel tracks the baseband carrier and C/A code of a particular GPS satellite. The navigation processor uses code measurements taken from each channel to compute the respective pseudo-range between the TIMED spacecraft and the corresponding GPS satellite tracked by each channel. (Pseudo-range is actual range plus a bias due to GNS clock error). Software installed on the GNS navigation processor performs GNS navigation based on pseudo-range measurements and navigation data output from the tracking processor.

The navigation processor is also utilized to implement spacecraft communications and executive control functions. The GNS connects to the C&DH processor via the IEM PCI bus and all GNS communication to the spacecraft is realized through the IEM C&DH.

4. TIMED GNS Interface Definition

4.1 Overview

4.1.1 Scope

This section defines the required electrical interface between the GNS subsystem and the TIMED spacecraft. Figure 4-1 illustrates interface between the GNS cards and the IEM. A more detailed definition is given in the remainder of this section.

Detailed electrical interface specifications (interface circuits, impedance, scaling, etc.) as well as interface data specifications are given in the GNS Performance and Interface (P&I) document.

4.1.2 GNS Card Description

Each GNS card installed in the IEM consists of a thermally conductive aluminum core populated on both sides with electronic boards or modules. Each GNS card is secured in the IEM by a cam card lock mechanism.

An Airborne 220 pin connector is mounted at one end of each of the GNS cards. The Airborne connectors plug into the IEM backplane which connects the GNS cards to other IEM cards as shown in Figure 4-1. Detailed signal pinout to the backplane is given in reference document 2.1.6.

The GNS receiver card, in addition to interfaces through the IEM backplane, includes an RF connector and two test connectors. The RF connector receives the 1575.42 MHz signal from the GNS antenna. The test connector provides access to analog and digital test points. These connectors are mounted at the opposite end from the airborne connector and are accessed through the IEM cover plate.

A test connector is also installed on the GNS processor card. This connector carries two sets of serial interfaces, one to the tracking processor and one to the navigation processor. These interfaces are required during integration and test to load program software and operate test debug software.

On the GNS processor card, a local processor interface and other miscellaneous connections are carried between processors through a feedthrough type connector. These interfaces are considered internal to the GNS and are specified in the GNS P&I document.

4.1.3 IEM Power Distribution and Power Return

The IEM backplane is a circuit board structure which includes a number of power return ground planes. The power return planes are common to all IEM analog and digital returns and are electrically bonded to the IEM frame structure. Power will be distributed to the IEM cards, including the GNS receiver card, on wide power tracks interleaved between the power return planes.

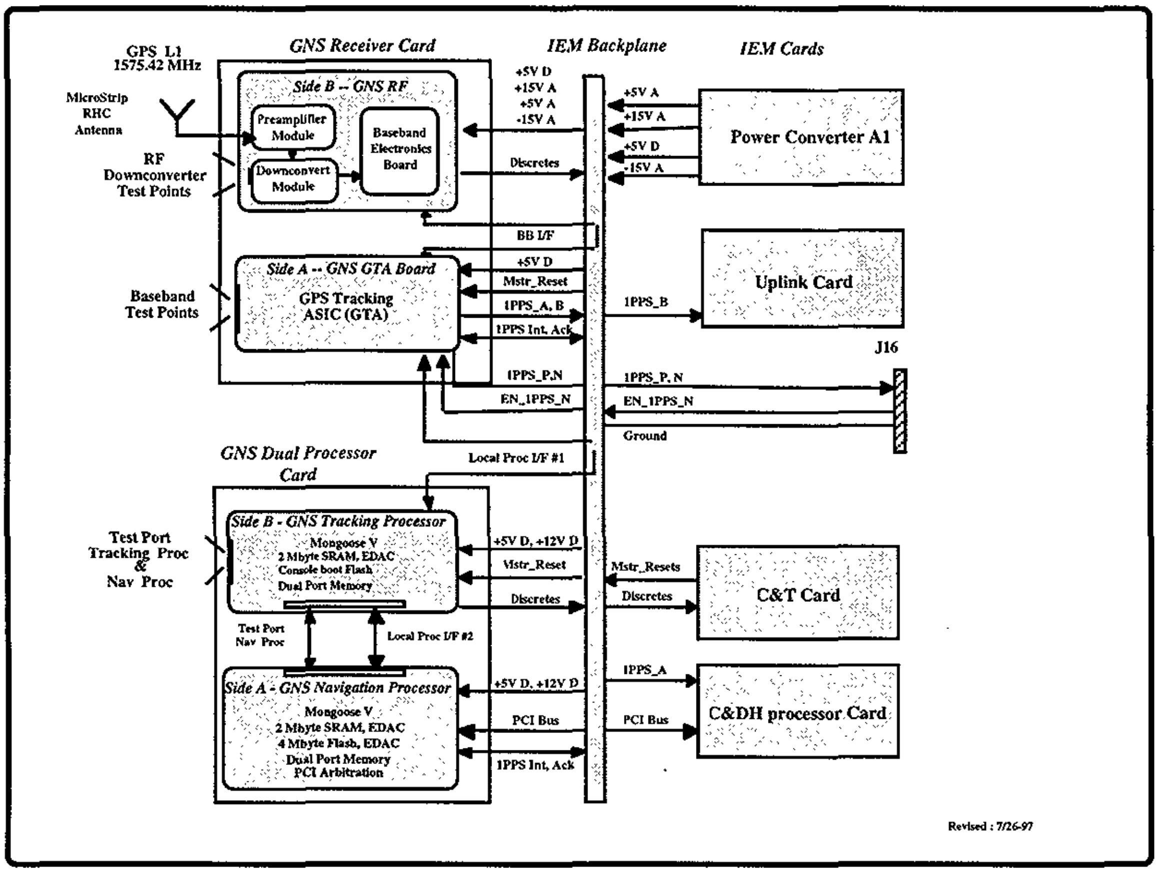

Figure 4-1 -- GNS Interface

4.1.4 GNS RF Ground

The aluminum core of each card shall be in electrical contact with the conductive IEM card slides. Pressure applied by the card lock mechanism assures low contact resistance between the card core structure and the IEM housing. RF module and digital electronics board ground planes shall be electrically bonded to the aluminum core. Contact resistance between any two bonding surfaces shall not exceed 2.5 milliohms.

4.2 GNS IEM Backplane Interface Definition

4.2.1 Power Interface

4.2.1.1 DC-DC Converter Card

A DC-DC converter card located in the IEM converts the spacecraft 28 volt bus to the voltage levels required for digital and analog electronics installed in the IEM. Voltages required to support the GNS cards are specified below. The GNS cards shall operate off the same power converters supplying power to adjacent IEM cards.

4.2.1.2 Power Switching

The GNS cards are powered on or off by a spacecraft relay command which switches +28 volt power to the IEM DC-DC converters. The IEM C&DH processor card, the Command and Telemetry Interface card, and SSR card are switched in common with the GNS.

4.2.1.3 GNS Input Voltages Required

Input voltages required for operation of each GNS card are indicated in Table 4-1.

4.2.1.4 Power Requirements

Total GNS power drawn through each voltage input is given in Table 4-1 below. These figures apply at nominal input voltage conditions for the complete range of temperatures over which the IEM operates.

The maximum steady state power is drawn during the GPS navigation mode and the figures given below apply to this mode. Lesser amounts of power shall be drawn during search and test states and these lesser power figures remain to be determined.

Power is drawn through the +12.0 v line only during those times when the GNS processor flash memory is being loaded with program code. This occurs mainly prior to launch when new program code is written. It is anticipated to be a rare or non-existent occurrence on orbit. As a result steady state power drawn on the +12 v line is essentially zero as shown.

With respect to the GNS receiver card, the power drawn is nearly constant; it may change (slowly) a small amount as a function of GNS temperature. With respect to the GNS processor +5 v digital input, abrupt power step changes (to be determined) will occur as the GNS sequences from the search to the navigation state.

Table 4-1 -- GNS Power Input Requirements

Input Voltage	Designation	Max Steady State Power [mw]	Peak Power During Flash Load [mw]
GNS Dual Processor Card			
+5.0 v (digital)	+5v_D	7500	< 7500
+12.0 v(digital)	+12v_D	0	1440
GNS Receiver Card			
+5.0 v (digital)	+5v_D	350	350
+5.0 v (analog)	+5v_A	825	825
+15.0v (analog)	+15v_A	330	330
-15.0 v (analog)	-15v_A	75	75
Total Max Steady State Power >		9080	

4.2.1.5 Voltage Regulation

Static regulation of each voltage input to the GNS shall be regulated to within ±3% of its nominal value listed in Table 4-1. This requirement is applicable over the complete range of temperatures experienced by the IEM (-29°C to +55°C at IEM mounting surface), and over the complete range of loads (GNS and non-GNS) experienced by the IEM DC-DC converter. The effects of +28 v line voltage input variation to the IEM DC-DC converter and voltage set tolerance are also accounted for in this requirement.

Dynamic regulation (output response due to input voltage transients and step load changes) shall be within ±2% for CS01 and CS06 tests defined in the TIMED EMC Control Plan and EMI Performance Requirements Specification. Dynamic regulation shall be within ±3% during step loads on the IEM DC-DC converter. The ±3% step load regulation applies to a change in load from 50% to 100% of full load.

4.2.1.6 Inrush Current

The GNS cards shall not be required to provide current limiting on power input lines during power turn-on. Any current limiting shall be accomplished within the IEM power converter card. During integration and test of the GNS breadboard, the peak inrush current through each input voltage shall be measured to 10 ma accuracy.

4.2.1.7 Power Line Noise

4.2.1.7.1 Voltage Spikes

Voltage spikes on any power input to the GNS cards shall not exceed 150 mv peak-to-peak (pp). Spectral components shall be limited to a band from 10 kHz to 10 MHz. This requirement is applicable over the complete range of environmental temperature extremes (-29°C to +55°C) seen at the IEM mounting surface, and for all IEM loads experienced by the respective DC-DC converter.

4.2.1.7.2 Voltage Ripple

Voltage ripple on any input power line to the GNS cards shall not exceed 100 mv pp at the DC-DC converter operating frequency. This requirement is applicable over the complete range of environmental temperature extremes (-29°C to +55°C) seen at the IEM mounting surface, and for all IEM loads experienced by the respective DC-DC converter.

4.2.1.8 On-Board Regulation

The +15 volt input to the GNS receiver card is converted by an on-board regulator to +5 volts to provide power to RF analog circuits that are very sensitive to power line noise. A second on-board regulator shall be implemented to regulate the +5 volt digital input down to the +3.3 volts required by the GTA. Additional regulators may be added as needed.

4.2.1.9 GNS Tolerance to Power Faults

4.2.1.9.1 Reverse Voltage Protection

Not Required

4.2.1.9.2 DC Low Voltage Survival

The GNS system shall survive without permanent damage a low voltage condition -- defined as greater than 0 volts and less than 5% below nominal-- on any power input for an indefinite period of time.

4.2.1.9.3 Overvoltage Survival

The GNS system shall survive without permanent damage an overvoltage condition of 25% above nominal on any power input with the exception of the +5.0 volt digital input. The +5.0 volt digital input shall survive a 20% overvoltage condition. These requirements apply to an overvoltage time duration of 15 ms or less.

4.2.2 *GNS 1PPS Interface*

The GNS subsystem shall maintain and transfer accurate time. One component of time transfer is a one pulse per second (1PPS) epoch aligned with UTC one second epochs to ±100 μs accuracy. The GNS shall distribute 1PPS epochs to the following IEM cards as listed below (the 1PPS signal originates on the GNS receiver card).

Interface	*1PPS Signal Designation*
Uplink card	1PPS_B
C&DH processor card	1PPS_A
IEM connector J16	1PPS_P, 1PPS_N
GNS Nav processor	1PPS_NAV_INT
GNS Tracking processor	1PPS_TRK_INT

4.2.3 GNS Reset Interfaces

The GNS shall implement the capability to detect a number of external triggering events and subsequently reset GNS processors and reboot program code. GNS reset interfaces are given as follows.

4.2.3.1 Discrete Master Reset

The GNS shall reset both GNS processors on detection of the IEM master reset signal. A discrete master reset signal will be generated in the IEM and input to the GNS processor and receiver cards over the backplane. This signal connects to all IEM boards and exhibits a reset pulse following power turn-on of the IEM. This signal is generated by the IEM to initiate IEM processor program boot operations, including the boot of GNS program software.

A number of additional IEM events will initiate generation of a discrete IEM master reset. For example, a master reset is generated when an IEM reset contingency command (sent from the ground) is detected. Also, the master reset is generated whenever the C&DH processor resets.

4.2.3.2 GNS Reset Via GNS Ground Command

The GNS shall implement a capability to reset both GNS processors on receipt of a GNS reset command originating from the TIMED ground station. The GNS reset command shall be input to the GNS card as a unique address placed on the PCI bus by the C&DH processor. The PCI interface hardware on the GNS processor card will detect this address and initiate the reset of both GNS processors. (The C&DH processor will also have the same capability. The core processor board design will include a mechanism so that different reset addresses may be assigned to the C&DH and GNS processors). The GNS reset command is a contingency type command used to reset only the GNS dual processors (instead of the entire IEM).

4.2.3.3 Console Reset

The GNS shall implement a capability to reset both GNS processors on receipt of a console reset discrete originating in the GNS Ground Support Equipment (GSE). This signal shall be carried through the serial port test connector located on the GNS processor card. This reset capability is intended for use during software debug, integration, and test.

4.2.3.4 Software Reset

The GNS shall implement a capability to reset either the tracking processor and/or the navigation processor by software instructions executed by the navigation processor. This is a feature intended for development and test of the GNS.

4.2.3.5 GTA Reset

The GTA on the receiver card shall implement two types of resets, called GTA reset and PPS reset respectively. A GTA reset causes the entire GTA except the 1PPS output circuit to be reset. Any reset of the tracking processor shall initiate a GTA reset.

A PPS reset to the GTA causes the 1PPS circuits (and as a result the 1PPS output epochs) to be reset. Only the IEM master reset discrete shall initiate a PPS reset of the GTA. The intent is to preserve any timing information in the 1PPS output during a local GNS reset; the 1PPS output is reset only in the event of a general IEM reset.

4.2.4 Local Processor IO Bus

A local processor bus shall be implemented and carried through the IEM backplane to connect the GNS tracking processor to the GTA on the receiver card. This interface is required to carry code correlation data (at an approximate 0.667 ms interrupt rate) and carrier/code phase measurements (at one second rate) from the GTA to the tracking processor. In addition channel assignments and acquisition aiding information must be carried from the tracking processor to the GTA. Local processor bus signals are listed in Table 4-2 below.

Table 4-2 -- Local Processor IO Bus Signals

Signal	Description
A[0] through A[15]	GNS Processor bus address lines (first sixteen)
D[0] through D[15]	GNS Processor bus data lines (lower sixteen)
IO_SEL_N	Enables GTA address decode
I1_SEL_N	Spare GTA address decode line
WR_0_N	Write strobe (0)
WR_1_N	Write strobe (1)
RD_	Read Strobe
AS_N	Address strobe
DRDY	Data ready indicator
INT_AIC	Interrupt to tracking processor, 667µs rate, initiates code correlation data transfer
INT_MIC	Interrupt to tracking processor, 1 second rate, initiates measurement data transfer
GNS_Reset_N	Assertion causes GTA reset
Ground	Ground connection
GTA_ENABLE_N	Assertion by tracking processor enables GTA interface operation

4.2.5 GNS Receiver Baseband Interface

The IEM backplane shall be utilized to carry a number of digital baseband signals from side B of the GNS receiver card to side A. These signals are listed and described below.

Table 4-3 -- Baseband Interface Signals

Signal	Description
Sample_CLK	Digital CMOS level signal derived from division of reference oscillator output. Used by the GTA to sample downconverter digitized baseband outputs
SIGN	Digitized baseband output (#1 of of two bit A/D output). Indicates voltage polarity of analog baseband signal.
MAG	Digitized baseband output (#2 of of two bit A/D output). Indicates voltage magnitude of analog baseband signal.
Return 1	Signal return track (connects from ground on side A to ground on side B)
Return 2	Signal return track (connects from ground on side A to ground on side B)

4.2.6 PCI Bus

The GNS shall connect to the IEM PCI bus designed for communication between IEM components. The GNS shall conduct all GNS-spacecraft communications over this bus. GNS communications include GNS command packet inputs, instrument data packet output, and telemetry data packet output.

All GNS PCI bus data shall be routed through the C&DH processor and shall be controlled by the C&DH PCI master.

The IEM PCI bus is a subset of and compatible with the PCI bus standard version 2.1. The subset of PCI signals that connect the GNS card to the IEM PCI bus are listed as follows.

Table 4-4 -- GNS PCI Bus Signals

PCI Signal	Description
CLK	Bus clock input to all PCI devices
FRAM#	Driven by current master and indicates beginning and duration of an access
AD[16] through AD[31]	PCI address / data lines (sixteen address/data lines)
C/BE#[0] through C/BE#[3]	Defines bus command or bytes enabled
IRDY#	Master output signal indicating it is ready to complete impending data phase of transaction
TRDY#	Target output signal; indicates ability to complete current data phase of transaction
DVSEL#	Target output signal;indicates target has decoded address and has become active target
PAR	Maintains even parity across address/data and C/BE lines;driven by target for read data phases
MSTR_RST#	Reset used to bring all PCI-specific registers, etc. to a consistent state
PERR#	Parity error indicator; driven by target after parity error detected
STOP*	
Ground	Ground Connections

4.2.7 Discrete Housekeep Data

The GNS shall output a number of discretes over the IEM backplane to the C &T card. These outputs represent selected measurements of GNS current, voltage, receiver AGC, and temperature. These outputs are processed by the C&T card and packed into spacecraft housekeep telemetry packets. The outputs are DC analog signals and shall be compatible with the spacecraft housekeep data collection system (4 volts full scale for voltage and current). For temperature measurement, an AD590 or equivalent is installed on the respective GNS card. The discrete housekeep functions and a description are listed in Table 4-5 as follows:

Table 4-5 -- GNS Discrete Telemetry Housekeep Functions

GNS Signal ID	IEM Label	Description
Source : GNS Receiver Card Side B		
Temp_1_P	Temp_1_P	High (+ volt) side of temperature transducer (AD590)
Temp_1_N	Temp_1_N	Low (- volt) side of temperature transducer (AD590)
+5V_D V	TM_VOLT_0	Scaled voltage proportional to +5.0 v (dig) input voltage to receiver card side B (RF component side)
+5V_A V	TM_VOLT_1	Scaled voltage proportional to +5.0 v (analog) input voltage to receiver card side B (RF component side)
+15V_A V	TM_VOLT_2	Scaled voltage proportional to +15.0 v (analog) input voltage to receiver card side B (RF component side)
AGC	TM_VOLT_13	Scaled voltage proportional to RF power input (2 MHz BW)
+5V_A I	TM_VOLT_14	Scaled voltage proportional to +5.0 v (analog) input current to receiver card
-15V_A V	TM_VOLT_15	Scaled voltage proportional to -15.0 v (analog) input voltage to receiver card
Source : GNS Processor Card Side B		
+12V_D V	TM_VOLT_7	Scaled voltage proportional to +12.0 v (digital) input voltage to GNS processor card side B (tracking proc side)
Temp_3_P	Temp_3_P	High (+ volt) side of temperature transducer (AD590)
Temp_3_N	Temp_3_N	Low (- volt) side of temperature transducer (AD590)

4.2.8 Discrete Inputs Supporting Core Processor Design

The GNS dual processor card includes a common processor board design with the C&DH processor and flight processor. The common core design includes a number of discrete signal inputs to identify the card (GNS, C&DH) and configure accordingly. These inputs are outlined in Table 4-6. The IEM backplane shall strap these inputs such that the GNS dual processor is properly configured when installed in the IEM GNS dual processor card slot.

Table 4-6 -- Common Processor Discretes

Signal Name	Description
SIDE A/B POS	These pins indicate to the processor which IEM (#1 or #2) it is installed in. This is an artifact of the common core processor design and is used by the C&DH processor to configure virtual addresses.
MSTR/TARG#	This input is used to indicate to the processor whether it is allowed or not allowed to be a PCI bus master. For the GNS processor, these inputs will be configured to not allow it to be the bus master.

4.3 RF Interface

Each of the two GNS antennas will be mounted on a separate pedastal located on the optical bench of the spacecraft. The IEMs are located under the -Z panel. A coaxial cable, approximately 6 to 8 feet in length, shall connect each antenna RF L1 output to its respective GNS receiver. (Each of the two cables actually consists of two sections. One section of cable connects from the antenna to a bulkhead connector on the -Z panel, the other section connects from the bulkhead connector to the IEM GNS). At the IEM the cable shall connect to a SMA type RF connector located on the backend of the GNS card.

4.4 Test Connector Interface

4.4.1 GNS Receiver Card Test Points

4.4.1.1 Interface Definition

Two test connectors shall be installed on the GNS receiver card, one on each side. On side B, a 15 pin test connector brings out test points from the RF downconverter module. On side A, a 37 pin test connector provides access to GTA test points. Each set of test points shall be listed and defined in the GNS P&I specification.

The receiver test point connectors are located to provide access when the receiver card is installed in the IEM. The IEM cover shall be designed with slots at the appropriate locations to provide access.

4.4.1.2 Test Point Access

GNS receiver test points are accessed during GNS bench level test and IEM integration. It is anticipated only a subset of the GTA test points on side A will be accessed during spacecraft integration.

It is required (by the TIMED EMC Control Plan and EMI Performance Requirements Specification) that access to test points during spacecraft integration provide at least 1000 ohms of ground isolation between the spacecraft and any GSE. To this end those receiver test points to be accessed (potentially) during spacecraft integration shall be output in the form of differential RS-422 compatible signals. The GNS GSE shall provide differential receive and isolation circuits required to meet GSE/spacecraft isolation requirements.

4.4.1.3 Test Point Short Circuit Protection

All GNS receiver analog test points shall include sufficient resistive isolation to withstand a short condition for an indefinite length of time without damage or degradation to GNS system performance. All digital test points shall be either enabled by external inputs or sufficiently buffered so as to withstand a short condition for an indefinite length of time without damage or degradation to GNS system performance.

4.4.2 GNS Processor Serial Test Port Interface

4.4.2.1 Serial Interface Definition

A test connector shall also be installed on the GNS processor card that is accessible through the IEM cover. This connector shall carry two serial ports to the navigation processor and two serial interface ports to the tracking processor. These test ports are utilized to load program code, load debugger code, and monitor test debugger data. It is anticipated access is required through IEM and spacecraft level integration and test. Each set of test points shall be listed and defined in the GNS P&I specification to follow.

4.4.2.2 Test Port Short Circuit Protection

All GNS processor test points shall include sufficient isolation to withstand a short condition for an indefinite length of time without damage or degradation to GNS receiver performance.

4.4.2.3 GSE/Spacecraft Isolation

The GNS processor test port connector will be accessed during ambient spacecraft level integration and test. To access the GNS test ports, the GSE must be designed to provide GSE/spacecraft isolation as specified in the TIMED EMC Control Plan and EMI Performance Requirements Specification.

4.5 Mechanical Interface

4.5.1 Card Form and Fit

Card Envelope :	The GNS receiver and processor components shall be installed on the IEEE P1101.7-95 standard Stretch SEM-E card
Card-Lock Structure :	Cam lock
Backplane Connector :	Airborne 220 pin connector
Connector Keying :	Yes
RF Connector :	SMA , female

Test Connectors

Processor card :	37 pin subminiature MDM type D with male pins
Receiver card side A :	37 pin subminiature MDM type D with male pins
Receiver card side B :	15 pin subminiature MDM type D with male pins

4.5.2 Card Spacing

The height of any component installed on either side of the GNS dual processor card shall not exceed 0.3 inches as measured from the exposed surface of the printed wire board. Components on the B side of the GNS receiver card shall not exceed 0.75 inch in height measured from the heat sink surface. The height of any component installed on side A of the GNS receiver card shall not exceed 0.3 inches as measured from the exposed surface of the printed wire board.

4.5.3 Weight Budget

The weight budget for each GNS system is listed as follows. It does not include the weight of the antenna pedestal.

GNS antenna radiating element and ground plane assembly :	0.275 kg
GNS RF cable (8 feet, 0.29" OD) (Includes bulkhead SMA connector):	0.4 Kg
IEM GNS Receiver Card :	0.75 Kg
IEM GNS Processor Card :	0.75 Kg
Total Weight :	2.175 Kg

4.5.4 Knowledge of Center of Gravity

Prior to IEM installation the center of gravity of the fully populated GNS card shall be measured along length and width to 0.1 inch accuracy.

5. Functional Requirements

The GNS shall meet all functional requirements defined in this section over the range of input voltage conditions given in section 4 of this document and over the range of IEM thermal and radiation environments given in section 6 of this document.

5.1 Antenna System Requirements

5.1.1 Electrical Requirements Applicable to Antenna Assembly

Each GNS antenna consists of a micro-strip antenna element (including a ground plane) installed on a GNS antenna pedestal. The antenna electrical requirements given in this section apply to the GNS antenna element/ground plane assembly.

5.1.1.1 RHC Antenna Gain

Each GNS antenna must exhibit a gain -- for a RHC polarized signal -- greater or equal to +4 dBic. along zenith. (Zenith is defined as the direction perpendicular to the ground plane and extending outward from the pedestal; the local horizon is defined as the plane containing the ground plane.) At elevations greater than 10° above the local horizon, gain for a RHC signal shall be at least -3 dBic. These requirements are applicable over a ±2.5 MHz band centered about a frequency of 1575.42 MHz.

5.1.1.2 VSWR vs. Frequency

The nominal output impedance of each antenna shall be 50 ohms. The VSWR shall be 1.5:1 or less over the passband of ±2.5 MHz about the carrier frequency.

5.1.1.3 Sidelobe Gain Constraints

On a surface extending from 0° to -90° below the local horizon, the antenna gain for RHC signals shall not exceed -7 dBic over at least 90% of the surface.

5.1.1.4 LHC Suppression

On a surface extending from 10° to 90° above the local horizon, the gain of a received left hand circular (LHC) polarized signal relative to a RHC signal shall be no greater than -7 dB over at least 90% of the surface. On a surface extending from +10° to -90° relative to the local horizon, the antenna gain for LHC polarized signals shall not exceed -9 dBic over 90% of the surface.

5.1.1.5 Antenna Phase Center Uncertainty WRT "Look" Angle

The phase center locations of each antenna may vary slightly as a function of the angle at which the wavefront enters the antenna. As a goal, for signals entering at an elevation ranging from 10° to 90° above the horizon and azimuth ranging from 0° to 360°, the phase center shall vary less than ±0.01 inches (1 sigma).

5.1.2 GNS Antenna Spacecraft-Integration Requirements

5.1.2.1 Antenna Location

Each GNS antenna, mounted on its pedestal, shall be located on the spacecraft optical bench and point towards zenith. The distance between pedestals is approximately 46 inches. Each antenna shall be cabled to its respective GNS card located in the IEM chassis mounted under the -Z panel.

5.1.2.2 Antenna Field of View (FOV)

Each GNS antenna shall have an unobstructed field of view (FOV) down to at least 0 degrees with respect to the local horizon. The local horizon plane is taken as the XY plane containing the base of the ground plane.

5.1.2.3 Ground Plane Area

The antenna pedestal shall be capable of mounting the antenna element and ground plane. The ground plane diameter shall be ≤ 7 inch.

5.1.2.4 Percent Coverage

With the antenna installed on the spacecraft, on the surface 10° or more above the local horizon, antenna gain for a RHC signal shall exceed -4 dBic over at least 90% of the surface. These requirements apply over a ±2.5 MHz band centered about a frequency of 1575.42 MHz.

5.1.2.5 Knowledge of Antenna Phase Center Location

To meet navigation performance requirements, it is required the location of each GPS antenna phase center be known to an accuracy of ±0.125 inch (1 sigma) with respect to the spacecraft center of mass. As a goal, the phase centers shall be known to an accuracy of 0.01 inch (1 sigma).

Vibration experienced during spacecraft flight qualification test and during launch may cause the end mass of the GPS antenna pedestals to permanently shift position a slight amount. The required knowledge of phase center location to 0.125 inch accuracy extends to post-launch following all vibration induced effects. It is anticipated verification of requirements and goals will require a survey of antenna pedestal location during installation and supporing analysis of test/launch vibration effects.

5.1.2.6 Measurement of Antenna Gain and Phase

Measurements of GNS antenna gain characteristics at 1575.42 MHz shall be acquired during tests conducted with the spacecraft RF mockup. The gain shall be measured at 2° increments over a solid sphere about the antenna. Gain shall be measured to an accuracy of 1 dB.

As a goal, antenna phase characteristics shall also be measured, to an accuracy of 0.5 degree. It is also a goal that differential phase between the two GNS antennas be measured to 1 degree accuracy.

5.1.2.7 Measurement of Antenna Isolation

In addition to the GNS antennas, an S-Band transmit antenna -- intended for contingency spacecraft telemetry operations -- will be located on the zenith deck of the spacecraft. During the spacecraft RF mockup test, isolation between the transmit antenna and each GNS antenna shall be measured. Isolation shall be measured at the S-Band transmit frequency of 2215.00 MHz., the GNS L1 frequency of 1575.42 MHz, and at transmitter sideband frequencies specified in the spacecraft RF mockup test plan. Measurements shall be made to at least 1 dB accuracy.

Given the +10 dBm GNS receiver out-of-band susceptibility requirement given in section 5.2, and an S-Band output of approximately 3 watts, isolation between the S-Band and GNS L-Band antenna of at least 25 dB is required.

S-Band command receive antennas will also be located on the zenith deck of the spacecraft. During the spacecraft mockup tests, isolation between the GNS antennas and the S-Band receive antennas shall be measured at the GNS L1 frequency of 1575.42 MHz and the 2039.6458 MHz S-Band receive frequency.

5.1.2.8 Antenna Ground

The GNS antenna ground plane shall be grounded to structure by connecting the outer shield of the RF coaxial cable at two structure points, namely, (a) the honeycomb deck under the optical bench, and (b) the IEM cover. The DC contact resistance of each connection shall be 2.5 milli-ohm or less.

5.1.2.9 Cable Loss

To constrain the system noise figure, the cable length and loss characteristics (including the -Z panel bulkhead connector) shall be considered so as to maintain less than 0.5 dB loss between the GNS antenna and the GNS receiver card.

5.2 Receiver Requirements

5.2.1 RF Requirements

5.2.1.1 GPS L1 Signal Characteristics

The TIMED GNS receiver shall be capable of receiving and tracking GPS L1 C/A signals. The characteristics of the GPS spacecraft signals are defined in reference document 2.2.1.

The L1 C/A signal characteristics pertinent to design of the GNS receiver are restated below.

5.2.1.1.1 Receive Frequency

The nominal GPS L1 carrier frequency is 1575.42 MHz.

5.2.1.1.2 Carrier Phase Noise

The phase noise spectral density of the unmodulated L1 carrier shall be such that a phase locked loop of 10 Hz one-sided noise bandwidth shall be able to track the carrier to an accuracy of 0.1 radians rms.

5.2.1.1.3 Receive Polarity

The received signal shall be right-hand circularly (RHC) polarized. The ellipticity for L1 shall be no worse than 1.2 dB.

5.2.1.1.4 Receive Signal Level

In low earth orbit (LEO) the minimum L1 C/A signal strength will be -128 dBm. received in a 0 dBic RHC polarized antenna. This specification applies for any GPS satellite 5° or more above the local horizon. (This is 2 dB greater than a signal received on the ground since there is no atmospheric attenuation of signal).

5.2.1.1.5 Signal Structure and Bandwidth

The L1 carrier is BPSK modulated by the Modulo-2 addition of the C/A code and 50 Hz navigation message. The C/A code chip rate is 1.023 MHz and code length is 1023 chips (1 ms). In the frequency domain the carrier is suppressed and the spectrum is a sinc function with nulls spaced at ±k *1.023 MHz about the carrier frequency (k is an integer). Filtering in the GPS spacecraft limits the bandwidth to ±10.23 MHz centered about the carrier frequency.

Although the GNS receiver uses only the SPS L1 C/A signal, the precise positioning service (PPS) signal , L1 P, is also broadcast from each GPS satellite. The L1 P carrier is 90° phase shifted with respect to the L1 C/A carrier and is BPSK modulated by the P code and Y code. Code modulation of the L1 P signal is coherent with modulation of the L1 C/A signal but occurs at a higher 10.23 MHz rate. The L1 P signal is not used by the TIMED GNS receiver.

5.2.1.2 System Noise Figure

The system noise figure (NF), as seen at the RF connector input to the GNS receiver card, shall not exceed 3.5 dB (equivalent to noise temperature of 359 K).

5.2.1.3 RF Passband

The RF passband is established in the bandpass filter installed in the preamplifier module. The 3 dB double-sided passband shall be 36 MHz ±3 MHz. The 90 dB bandwidth shall be 250 ±25 MHz. Signal skirt selectivity shall be monotonic to greater than 90 dB below the 3 dB bandwidth points.

5.2.1.4 Out-of-Band Suppression [Preselectivity]

At frequencies outside the RF 90 dB passband, gain relative to levels in the operational passband shall be suppressed at least 90 dB. During acceptance testing this requirement shall be verified from DC to 10 GHz excluding the L1 passband.

5.2.1.5 Operational Passband [IF Selectivity]

The receive operational bandwidth (passband) is established in the IF filters in the RF downconverter module. To accommodate the signal bandwidth of 2.046 MHz, plus Doppler and oscillator offsets, the IF 1 dB double-sided bandwidth shall be 1.8 MHz minimum centered about the nominal carrier frequency, and the 6 dB passband shall be no greater than 2.8 MHz. The 25 dB bandwidth shall be 3.5 MHz or less. Signal skirt selectivity shall be monotonic to ≥ 25 dB below the 1 dB bandwidth points.

5.2.1.6 Gain Ripple in Operational Passband

The gain within the 1 dB operational passband shall not vary more than ±1 dB peak-to-peak (p/p) about a straight line average. This requirement is applicable over the 1 dB operational bandwidth.

5.2.1.7 Phase Non-linearity

The phase of the signal passing through the IF shall not deviate more than ± 6.0 degrees p/p about a straight line curve fit over the 1 dB operational bandwidth.

5.2.1.8 Time Delay Variation Through Passband

The effective time delay of the C/A signal through the operational passband may vary with Doppler frequency due to asymmetries in passband gain/phase characteristics. It is required that time delay of the signal shall not vary more than ±3 ns for Doppler variations up to ±50 kHz about the carrier center frequency. This requirement is to be verified by analysis using actual measured passband characteristics assuming ±0.5 chip correlation-type delay locked loop tracker.

5.2.1.9 Survivable Input Power Levels

The GNS receiver shall survive an RF signal level of +10 dBm (total) applied for a maximum time interval of 1 minute. Subsequent to removal of the perturbing signal level, the GNS shall operate without any degradation in performance. This requirement is applicable to signal frequencies within a bandwidth of 39 MHz centered about the L1 carrier. Outside of this bandwidth the survivable power level increases to +20 dBm as shown in the GNS survivability envelope depicted in Figure 5-1. These specifications are applicable at the RF input to the GNS receiver card.

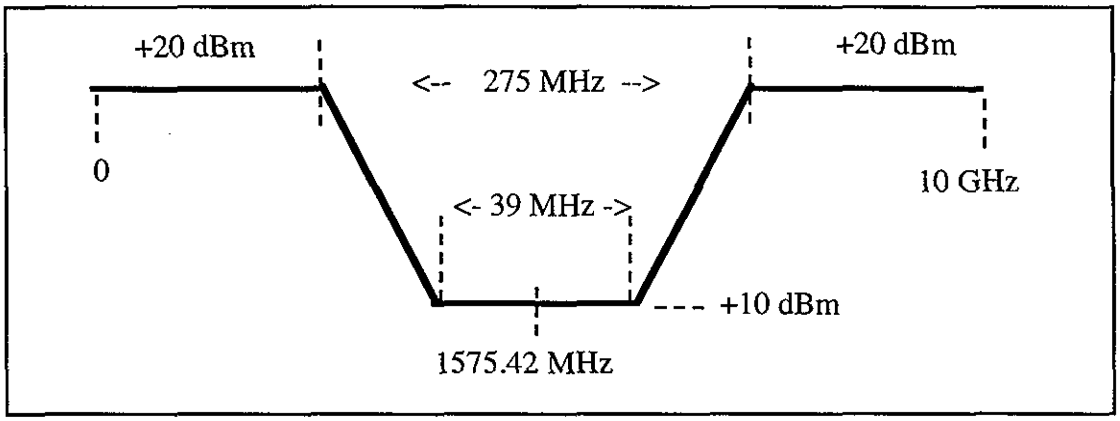

Figure 5-1 -- GNS Survivable Power Level Envelope

5.2.1.10 EMI Susceptibility

5.2.1.10.1 CW Susceptibility

The degradation in receiver carrier to noise (C/N_0) shall be less than 1 dB for an interfering CW signal level ≤ -120 dBm. This requirement applies to any CW tone in a 2.8 MHz band centered about the L1 carrier of 1575.42 MHz. The susceptibility envelope including CW outside of this band is depicted in Figure 5-2. These susceptibility requirements apply to signals seen at the RF input to the GNS receiver card.

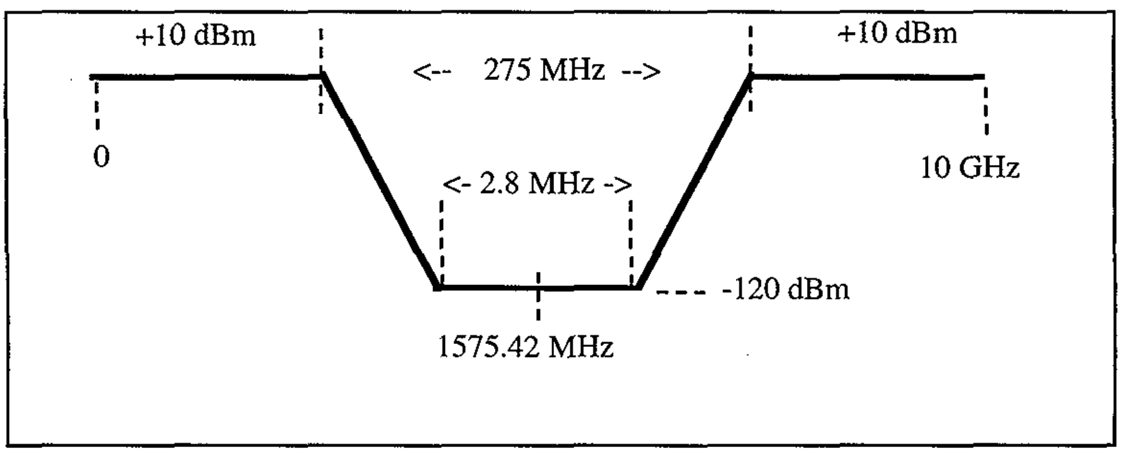

Figure 5-2 -- GNS Susceptibility to CW Envelope

5.2.1.10.2 Wide Band Susceptibility

The degradation in receiver carrier to noise (C/N_0), due to interfering wideband (WB) signals, shall be less than 1 dB for a wideband signal spectral density of -180 dBm / Hz or less in the 2.8 MHz band centered about 1575.42 MHz. (Assuming 25 dB minimum isolation between the S-Band transmitter antenna and the GPS receive antenna, this imposes a -155 dBm / Hz requirement on the S-Band transmitter output in the GNS passband).

5.2.2 DC Input Impedance

The DC input impedance of the GNS receiver shall be 1 ohm or less. This requirement is imposed to prevent any charge buildup on the radiating element of the antenna prior to or after launch.

5.2.3 Tracking Requirements

5.2.3.1 Receiver Channel Definition

The GNS includes a multi-channel GPS tracking receiver function. Each channel shall be have the capability to track the L1 carrier and C/A code of a designated satellite, collect raw carrier/code phase data (to compute pseudorange and Doppler to the respective satellite), demodulate the GPS message, and output to the navigation software. GNS receiver channel requirements are listed as follows.

5.2.3.2 Number of Simultaneous Receiver Channels

The GPS multi-channel receiver shall be capable of simultaneously tracking at least 10 GPS satellite L1 C/A signals.

5.2.3.3 Receiver Channel Space Vehicle Assignment

Each GPS receiver channel shall be capable of tracking the L1 C/A signal from any of the 32 GPS satellites as defined in reference document 2.2.1. (Each GPS space vehicle (SV) is designated by an ID number which ranges from 1 to 32. Each channel is assigned to a particular SV).

Each receiver channel may be assigned to track an SV independent of other receiver channel assignments. For example, all receiver channels may be assigned to track the same SV, or all receiver channels may be assigned to track different SVs, or any mix of these assignments (i.e., some identical, some different).

5.2.3.4 Low Earth Orbit (LEO) Signal Dynamics

Due to motion of the TIMED spacecraft on-orbit, GPS signals received by the GNS will exhibit Doppler signal dynamics. Doppler signal dynamics vary as a function of orbit altitude. The GNS must meet all performance requirements for orbit altitude in the range of 450 km to 650 km.

Worst case signal Doppler dynamics are seen at the lowest altitude of 450 km. Each GPS receiver channel shall be capable of acquiring and tracking GPS signals with LEO Doppler dynamics as listed below. These specifications meet or exceed Doppler seen by a satellite in 450 km circular orbit.

Maximum Doppler :	±50 kHz
Maximum Doppler Rate :	±100 Hz/Second
Maximum Jerk :	±0.1 Hz/Second/Second

5.2.3.5 RF Power Level Operating Range

Due to GNS antenna gain variations and variation in power output by the GPS satellite, the power input to the GNS receiver will vary from -132 dBm to -115 dBm. Each channel of the GPS receiver shall be capable of acquiring and tracking the GPS L1 carrier and C/A over this range of signal levels plus a 3 dB margin at the low end and a 5 dB margin at the high end (-135 dBm to -110 dBm). These required operational power levels are applicable at the GNS receiver card RF connector input. All navigation requirements given in follow-on sections of this document shall be satisfied over this range of signal power levels unless otherwise specified.

5.2.3.6 Selective Availability

Selective availability is a protection technique that can be employed by the Department of Defense to deny full system accuracy to unauthroized users. Selective availability decryption shall not be implemented in the GNS receiver. Mitigation techniques however may be implemented in the navigation software to enhance performance when selective availability is applied.

5.2.3.7 Uncertainty in Carrier and Code Phase Measurement

Each channel of the receiver shall be capable of measuring integrated carrier phase and C/A code phase over consecutive 1 second measurement time intervals. These measurements are used by the navigation software to compute TIMED position and velocity. GNS errors in navigation position will include a receiver component of error due to uncertainties in the code phase measurements. Measurement accuracy requirements for integrated carrier phase and code phase are stated in following paragraphs.

5.2.3.7.1 Integrated Carrier Phase Uncertainty

The major factor contributing to uncertainty in measurement of GPS carrier and code phase is the presence of selective availability modulation on each satellite signal. For the situation where the selective availability modulation is absent, the uncertainty in integrated carrier phase measured by each receiver channel shall not exceed 2 radians (1 sigma). The uncertainty figure applies to the difference in integrated phase measurements from consecutive one second time intervals. This requirement applies over the range of signal levels, Doppler and Doppler rate, and IEM temperatures specified in other sections of this document. This requirement does not include the effects of antenna multipathing.

5.2.3.7.2 Differential Channel to Channel Carrier Phase

The uncertainty in carrier phase between any two channels-- derived by taking the difference between integrated carrier phase over the same one second time interval and tracking the same SV -- shall not exceed 1 degree (1 sigma). This requirement applies over the range of signal levels, Doppler and Doppler rate, and IEM temperatures specified in other sections of this document. This requirement does not include the effects of antenna multipathing.

5.2.3.7.3 C/A Code Phase Uncertainty

For the situation where the selective availability modulation is absent, the uncertainty in the C/A code phase measured by each receiver channel shall not exceed 0.025 chips (1 sigma) measured over a one second time interval. (One chip is one C/A code clock period. This requirement is equivalent to a range uncertainty of approximately 7.3 meters). This requirement applies over the range of signal levels, Doppler and Doppler rate, and IEM temperatures specified in other sections of this document. This requirement does not include the effects of multipathing.

5.2.3.7.4 Differential Channel to Channel Code Phase

The uncertainty in code phase between any two channels-- derived by taking the difference between code phase measurements from the same one second time interval and tracking the same SV -- shall not exceed 0.0025 chips (1 sigma). This requirement applies over the range of signal levels, Doppler and Doppler rate, and IEM temperatures specified in other sections of this document. This requirement does not include the effects of antenna multipathing.

5.2.3.8 Knowledge of C/A Code Time Delay Through Receiver

The fixed component of C/A code time delay through each receiver channel, measured from the C/A modulation input to the local C/A code replica, shall be known to an uncertainty of 0.1 µs. over the range of signal levels, Doppler and Doppler rate, GPS SVs, and IEM temperatures specified in other sections of this document. Channel to channel time differences shall be less than 0.1 µs.

5.3 Time Transfer Requirements

5.3.1 Accuracy of Time Transfer to C&DH Processor

The GNS shall derive GPS time from the navigation solution and shall transfer time to the C&DH processor accurate to within ±100 µs wrt to UTC(USNO) time. Time transfer is implemented using a one pulse per second (1PPS) epoch and an associated time tag. The time tag identifies the time of each GPS 1PPS epoch.

5.3.2 GPS 1PPS Epoch Alignment With UTC Epochs

The GPS 1PPS shall be actively "steered" by the GNS and maintained to occur within ±100 µs of UTC(USNO) time epochs.

5.3.3 Time Set On Entry to GPS Navigation

Prior to entry to GPS navigation, the accuracy of time transferred shall reflect the last coarse time set of GNS time. After entry to GPS navigation, the GNS clock is precision time set by the navigation solution and time is transferred within the ±100 μs accuracy requirement.

5.3.4 GPS 1PPS Step at Navigation (Precision) Time Set

On entry to the GPS navigation state, the GPS 1PPS must be momentarily stepped to synchronize with UTC(USNO) one second time epochs. The time step shall be implemented by a one time delay of the GPS 1PPS output. The delay required will range from 0 to 1 second. A warning flag shall be set in the time tag data quality indicator output 1 second prior to the step.

5.3.5 Pulse-to-Pulse GPS 1PPS Epoch Stability

Active steering of the GPS 1PPS output will result in a small amount of pulse-to-pulse time jitter. After initial precision time set, the GPS 1PPS pulse-to-pulse time jitter shall not exceed ±100 μs peak deviation about the one second average time interval.

5.3.6 Time Code Definition

A time tag shall be transferred over the PCI bus to the C&DH processor with each GPS 1PPS. The time code standard, consistent with the C&DH processor design, shall be the CCSDS unsegmented time code (CUC) defined in CCSDS reference document CCSDS 301.0-B-2. The time tag is a 32 bit binary number representing the number of seconds from the starting time epoch defined to be hour 0, January 6, 1980. Successive time tags monotonically increment.

The time tag shall be read out from the GNS under control of the C&DH processor. Timing is illustrated in Figure 5-3.

5.3.7 Leap Seconds

In the event a downstream user needs to convert the CUC time code to a UTC calendar format, a knowledge of leap seconds since the starting epoch (Jan 6 1980) is required. To this end the GNS shall include the capability to telemeter the current number of leap seconds given in the GPS navigation message. The downlinking of the number of leap seconds shall be initiated by GNS command. On the ground this data is available for distribution from the MDC data base.

5.3.8 GNS Time Set and Transfer At Power Up

At power up GNS time shall begin at a time tag value of 0. Prior to any GNS coarse or navigation time set, time transferred shall equal the number of integer seconds which have elapsed since power up.

5.3.9 Coarse Time Set Prior to Navigation (Command Requirement)

Prior to entry to the GPS navigation state, the GNS must successfully acquire and track 4 or more GPS satellites. For fast acquisition, GNS time must be set to within 5 seconds of actual time. This is referred to as coarse time set. To this end the GNS shall implement the following GPS time set command capabilities :

- set GNS time to a 1 second resolution
- increment or decrement GNS time to a 1 second resolution

Coarse setting of GNS time shall require supporting MOC time set and measurement capabilities. Accuracy of GNS coarse time set will be dependent on ground system (MOC) design.

5.3.10 Time Coast

In the event the GNS drops out of the GPS navigation state(due to signal blockage, signal jamming, or ground command), the GNS shall continue to transfer time. However, since time is no longer available from the navigation solution, the time transferred shall drift wrt UTC. The time drift shall not exceed 10 μs per second (≈0.864 seconds per day).

5.3.11 Time Quality Indicator

The time tag, output at a one second rate to the C&DH processor, shall include an indicator of time quality. As a minimum the following information shall be included.

- a flag indicating if GNS time has been coarse set
- a warning flag if the next 1PPS output will be stepped to align with UTC 1PPS epochs
- a flag indicating if GNS time is determined by the GPS navigation solution
- a figure of merit (FOM) estimating the uncertainty in time transferred and whether time is within specified requirements

5.4 GPS Navigation Requirements

5.4.1 Orbit

The GNS shall meet all navigation, event prediction, and orbit estimation requirements stated in this document while operating in a low earth orbit (LEO) environment. As described in the TIMED Systems Requirements Document (JHU/APL document number 7363-9001), the TIMED spacecraft will be inserted into orbit at a nominal altitude of 625 km and 74.4° inclination angle.

The TIMED orbit altitude will decrease over the life of the mission. All GNS requirements stated in this document shall be met for minimum orbit altitude of 450 km. Worst case GPS signal Doppler and Doppler rates due to spacecraft motion in LEO (assuming circular 450 km orbit altitude) are given in other sections of this document.

5.4.2 Position and Velocity (PV) Requirement

The flight GNS shall estimate and distribute time tagged spacecraft position and velocity (PV) in real time. In the GPS navigation mode PV is computed based on pseudorange and integrated carrier phase measurements. Two sets of PV data shall be output -- one set is given in the ECEF coordinate system, the other is given in the ECI coordinate system. Each coordinate system is specified below.

The PV data given in the ECEF coordinate system is routed by the C&DH processor to the instruments over the 1553 bus and is also packed into spacecraft housekeeping data packets. The PV data given in the ECI coordinate system is routed only to the Guidance and Control (G&C) system.

5.4.3 PV Reference Coordinates (ECEF)

Spacecraft position and velocity shall be given in Earth-Centered Earth-Fixed - Conventional Terrestrial System (ECEF-CTS) coordinates, a right-handed coordinate system which rotates with the earth. The +x axis points in the direction 0° longitude, and the +y axis points in the direction 90° E longitude; x-y lie in the equatorial plane that is normal to the earth polar north axis (+z axis). The +z axis intersects the surface of the Conventional International Origin (CIO), which is the mean location of the north pole over the 1900-1905 time interval. Detailed specifications of the ECEF coordinate system, CIO, and DOD World Geodetic System 1984 (WGS-84) are given in the reference document 2.2.6.

Positions shall be given in geodetic coordinates of latitude, longitude, and height (units of degrees, degrees, meters). Velocity is given in local east, north, and up components (m/sec).To transform position and velocity to geodetic coordinates, the ellipsoidal model of the earth's shape as defined by WGS-84 is used.

5.4.4 PV Reference Coordinates (ECI)

Spacecraft position and velocity shall also be output in Earth-Centered Inertial-Conventional Inertial System (ECI-CIS) coordinates, a right-handed coordinate frame in inertial space. Position and velocity shall each be given in the form of 3 element Cartesian coordinates relative to the J2000 reference frame, defined in reference document 2.2.6.

5.4.5 Sun Vector (S) Requirement

The GNS shall estimate the position of the sun relative to the earth and output to the C&DH along with the PV and time tag estimates. The sun position shall be given in the form of a sun vector (S) which lies along the line drawn from the center of the earth to the center of the sun. The sun vector shall be given in the form of a 3 element Cartesian vector relative to the J2000 reference frame and shall be normalized to unity.

5.4.6 Data Rate

Position, velocity, and sun vector data sets shall be output at a 1 Hz rate.

5.4.7 Accuracy of P,V, S, and Time

Accuracy requirements for position and velocity and sun vector outputs are given as follows.

Measurement	Uncertainty (10 Minutes After TTFF)	Uncertainty (10 Hours After TTFF)
Position	300 meters (3 sigma, each axis)	300 meters (3 sigma, each axis)
Velocity	500 cm/sec (3 sigma, each axis)	25 cm/sec (3 sigma, each axis)
Sun Vector	0.06 degrees (3-sigma)	0.06 degrees (3-sigma)
Time	±100 µs (3-sigma)	±100 µs (3-sigma)

5.4.8 PVS Time-of-Validity (TOV)

The PVS and time tag data are generated synchronous with respect to the GPS 1PPS epoch. P,V, and S each are valid at the instant of the 1PPS epoch and PVS time-of-validity (TOV) is identified by the respective time tag.

Each PVS is computed prior to the GPS 1PPS epoch and placed in an interface buffer. Each set is readout by the C&DH processor on receipt of the GPS 1PPS epoch as illustrated in Figure 5-3.

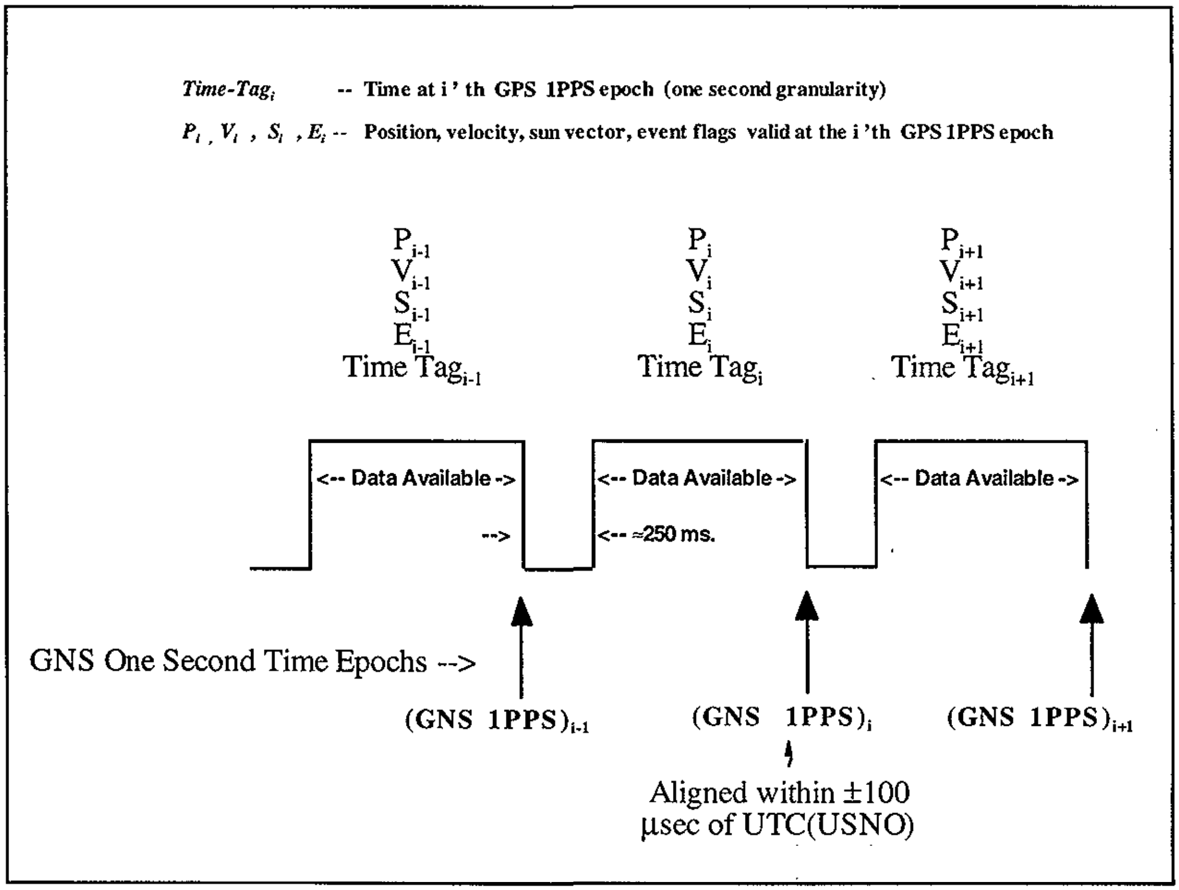

Figure 5-3 -- Distribution of PVSE and GPS 1PPS Time Epoch

5.4.9 Fixed Location Navigation Test Capability

The GNS, for test prior to launch, shall have the capability to operate at a fixed earth site location and navigate using GPS satellite signals. All position and time requirements given in this document are applicable for this state of operation.

5.4.10 Navigation Data Quality Indicator and Status Flags

The PVS data, output at a one second rate to the C&DH processor, shall include a navigation quality indicator and status flags. As a minimum the indicator shall include the following.

- a flag indicating if valid PVS data is available
- a figure of merit (FOM) estimating the uncertainties in PVS transferred and indicating whether PVS is within specified requirements
- a flag denoting whether the PVS data is derived by GPS navigation or Non-GPS navigation (see subsequent sections)
- a flag denoting whether the PVS data is derived by GPS navigation or flywheel operation (see subsequent sections)

5.4.11 Command and Telemetry Requirement

All PVS data sets output by the GNS shall be recorded on the SSR. (As stated by the GIIS document, PVS data shall be merged by the C&DH with spacecraft housekeeping telemetry and recorded on the SSR).

5.5 Event Detection and Prediction

5.5.1 Real Time Contact Detection

5.5.1.1 Contact Event Flag

In line with mission operation goals of semi-autonomous spacecraft operation, the GNS shall detect and provide notification of contact events in real time. The intent is to support autonomous on/off downlink transmitter and real time telemetry operation over designated contact sites.

Real time contact events shall be specified to the C&DH processor in the form of a contact event flag. A flag shall be sent to the C&DH processor once each second and shall be in the "set" state whenever the TIMED spacecraft is over a designated contact. (It is anticipated the flag will be used by the C&DH to control transmitter and telemetry system operation).

5.5.1.2 Designated Primary and Backup Contacts

Real time contact events shall be predicted for the primary contact site and a backup site. The default primary site is the JHU/APL MOC and the backup site shall be selected prior to launch from a list of contact sites stored in non-volatile GNS memory. The GNS command capability shall exist to change designated primary and backup sites.

Two different contact event flags shall actually be output to the C&DH processor. One flag indicates contact for the primary site, the second flag indicates contact for the backup site.

5.5.1.3 List of Contact Sites and Locations

The latitude and longitude coordinates for ground station contact sites shall be stored in GNS non-volatile memory. Ground station sites shall be entered or modified by GNS command. The number of contact sites stored in GNS memory shall not exceed 12.

5.5.1.4 Definition of a Valid Contact

The default definition of a valid contact, i.e., a contact for which predictions are generated, is defined as follows.

Contact duration from rise to set time :	> 5 minutes
Contact rise/set time definition :	Point where signal line of sight broaches 0 degrees elevation above the local horizon as defined by the WGS-84 reference ellipsoid

The contact duration of 5 minutes minimum is a default value which may be changed by ground command.

5.5.1.5 Uncertainty of Predicted Contact Event Time

Contact rise and set times shall be predicted to an uncertainty of less than 5 seconds

5.5.1.6 Contact Flag Lead/Lag Time

The contact flag output to the C&DH processor shall be set 30 seconds prior to the contact rise time and reset 30 seconds following contact set time. This is a default value which may be changed by ground command.

5.5.2 Detection of Terminator Crossing Events

5.5.2.1 Terminator Crossing Event Flag

In line with mission level goals of semi-autonomous spacecraft operation, the GNS shall detect and provide notification of suborbital terminator crossing events in real time. Notification of events in real time shall be sent to the C&DH processor in the form of a terminator crossing event flag. The flag shall be sent to the C&DH processor once each second. The terminator crossing flag shall be set when the spacecraft position, projected to the surface of the WGS-84 reference ellipsoid, is in sunlight, and reset when the spacecraft is in shadow.

5.5.2.2 Uncertainty of Predicted Events

The uncertainty of predicted terminator crossing events shall be less than 5 seconds.

5.5.2.3 Flag Transition Times

The terminator crossing flag shall transition between the set and reset states coincident with the predicted event time (to a granularity of 1 second).

5.5.3 Detection of SAA Events

5.5.3.1 SAA Event Flags

In line with mission level goals of semi-autonomous spacecraft operation, the GNS shall detect and provide notification of South Atlantic Anomaly (SAA) events in real time. Notification of events in real time shall be sent to the C&DH processor in the form of a SAA event flag. The flag shall be sent to the C&DH processor once each second. The SAA event flag shall be set whenever the spacecraft is located within the SAA event zone and reset when it leaves the event zone.

5.5.3.2 Definition of SAA Zone

The boundaries of the SAA zone shall be defined by geodetic coordinates of latitude and longitude. The physical model of the earth as defined by the DOD World Geodetic System 1984 (WGS-84) is assumed. (Specific latitude and longitude coordinates defining the SAA zone may be entered by GNS command).

5.5.3.3 Uncertainty of Predicted Events

The uncertainty of predicted SAA crossing events shall be less than 5 seconds.

5.5.3.4 SAA Flag Lead and Lag Times

The SAA event flag shall be set within one second of the predicted time of entry to the SAA zone and reset within one second of predicted SAA exit time.

5.5.4 Output List of Predicted Contact and SAA Events

A list of future contact and SAA events shall be generated and output to the C&DH processor. The list of event predictions is output so the MOC will be aware of TIMED's autonomously generated events.

An updated list shall be generated every 12 hours and shall include all valid primary and backup site contacts occuring in the next 60 hour time span. The 60 hour time span shall begin with the time of validity of the state vector used to propagatate orbit position. The list shall indicate the rise/set times for each contact.

The list shall identify the entry/exit times of the first 15 SAA events in the respective 60 hour time span.

The accuracy of the event predictions shall be < 5 seconds.

5.5.5 Event Propagation During Flywheel or Non-GPS Navigation

During flywheel or non-GPS navigation operation, event flags and the list of predicted events shall be based on the orbit propagated from the TIMED state vector. The uncertainties of predicted time of events may grow with time. No requirements shall be placed on the rate of growth in predicted time of events during flywheel or non-GPS navigation.

5.5.6 Predicted Event Quality Indicators

The list of predicted events shall include a data quality indicator. An indicator shall also be provided that denotes whether event predictions are derived by GPS navigation or by propagation of the last good state vector (i.e., flywheel or non-GPS navigation).

5.5.7 Event Detection and Prediction Telemetry Requirements

The contact event flags, the terminator crossing event flag, and the SAA event flag are output once per second to the C&DH processor. The C&DH processor shall merge these event flags with spacecraft housekeeping data and record on the SSR. (The C&DH also will distribute these flags to the instruments over the 1553 bus.)

The list of predicted contact and SAA events shall be output in the form of a GPS packet every 12 hours and shall be recorded on the SSR.

5.5.8 Contact and SAA Event Command Requirements

To support the real time event prediction function the GNS shall include the following ground GNS command capabilities

- capability to select a designated backup site from list of contact sites
- capability to overwrite coordinate location of any contact site stored in GNS memory
- capability to modify the coordinates defining the SAA zone
- capability to modify lead and lag times of contact event flags
- capability to modify definition of valid pass length
- capability to disable/re-enable output of event flags

5.6 Two-Line Element Set Orbit Estimators

The GNS shall generate orbit elements, in the form of NORAD 2-line compatible element sets, to support generation of antenna positioning information (in the ground system) for future ground contacts. Given the propagation accuracy required, one NORAD set shall be generated by the GNS for each contact and is valid only for that contact.

5.6.1 NORAD 2-Line Element Output Requirements

The GNS shall compute and output NORAD 2-line element sets for the primary and the backup ground sites. A group of element sets shall be computed and output every 12 hours. Each group shall include 2-line element sets for each valid primary and backup contact (a maximum of 15 for each site) spanning the next 60 hour time interval. The beginning of each 60 hour interval is defined as the time of validity of the state vector used to propagate spacecraft position. The definition of a valid contact (i.e., difference between predicted rise and set times > 5 minutes) are given in other sections of this document.

Each group of 2-line element sets shall be computed and placed on the SSR prior to each cluster of primary site contacts. This assures the age of the most recent group downlinked during any cluster is not any older than 12 hours. Age is defined as the time difference between current GNS time and time of validity of the propagation state vector.

As a note of explanation, contacts at each site occur in clusters of 2 or 3 successive orbits; clusters repeat at approximate 12 hour intervals.

5.6.2 Propagation Accuracy

The NORAD 2-line element sets shall be capable of propagating spacecraft position to < 4 km accuracy (3 sigma) along and across track. These requirements shall be met by 2-line orbit elements spanning 36 hours from the propagation state vector time of validity.

The propagation accuracy requirements given assume nominal solar flux activity. During periods of anomalous solar or geomagnetic activity, the accuracy of propagated spacecraft position (using 2-line elements) may be degraded. Analysis to date -- using solar flux data from solar cycle 22-- indicates 4 km propagation accuracy will still be met during periods of high solar activity. However, past periods of high solar activity are not perfect indicators of future solar activity. To mitigate any performance degradation of the 2-line element sets during unusually high solar activity, the GNS shall support the command capability to periodically load solar flux and geomagnetic index parameters.

5.6.3 Orbit Elements Dissemination During Non-GPS Navigation Modes

In the event the GNS is flywheeling or in the non-GPS navigation mode, the GNS shall continue to output orbit elements at 12 hour intervals. These orbit element sets shall be based on propagation of the last known good TIMED state vector.

5.6.4 Orbit Elements Data Quality Indicator

A flag shall denote whether the elements sets are derived in the GPS navigation or non-GPS navigation mode. (Non-GPS navigation is described in other sections of this document.)

5.7 Attitude Data Input Requirement

Attitude data output by the G&C and collected by the C&DH processor shall be sent by the C&DH processor to the GNS. Attitude data is generated at a one second rate synchronous to the GPS 1PPS output and shall be available for input to the GNS at the same rate. Each attitude data set shall include the time tag at which the attitude is valid. (It is anticipated attitude data will be utilized by the GNS to monitor GNS antenna pointing status and alert the GNS in the event the spacecraft is pointing off-nadir ; also for calculating Kalman filter measurement noise as a function of signal-to-noise).

5.8 Non-GPS Navigation Requirement

5.8.1 State Vector Propagation

The GNS shall implement a commandable mode called non-GPS navigation. The essential feature is generation and distribution of position, velocity, sun-vector, event flags, and time (PVSET), orbit estimators, and event predictions based on propagation of a TIMED state vector. Regardless of the tracking state and health of the GNS multi-channel receiver, the navigation software shall not use GNS receiver range and Doppler measurements for updating the navigation state vector. The format and rate of data product outputs shall remain the same as for the GPS navigation mode with the exception of status flags which shall indicate the non-GPS navigation mode.

5.8.2 Command and Telemetry Requirements

The non-GPS navigation mode shall be enabled by command. The command that enables this mode shall also include the seed state vector and 1-sigma uncertainties for orbit propagation. A command shall be required to change from the non-GPS navigation mode back to the GPS navigation mode.

Regardless of the fact that receiver pseudorange and carrier phase measurements are not used for navigation in this mode, the GNS receiver shall continue to operate and measure pseudorange and carrier phase. Standard GNS status, output at the 1 Hz rate, shall continue to include tracking channel status. High rate diagnostic data, if enabled, shall continue to include receiver channel pseudorange and carrier phase measurement data.

5.8.3 Rate of Growth in Time Error

When the Non-GPS navigation mode is enabled, the GNS clock and 1PPS epoch outputs shall not be perturbed. The 1PPS epochs and time tags shall continue to be output but will drift wrt UTC because of offsets in the GNS reference oscillator. The GNS uncorrected drift rate shall be less than 0.864 seconds per day.

5.8.4 Time Drift Rate Correction

To reduce the effective drift rate, this mode shall include a capability to program the GNS reference oscillator rate correction in the GTA to a resolution of at least one part in 100 million. The rate correction shall be an uplink command indicating a delta change to the current value in the rate register.

5.8.5 Rate of Growth in Position and Velocity Error

In the non-GPS navigation mode the errors in propagated spacecraft position and velocity will grow with time. (With reasonably stable solar flux activity, it is anticipated growth in position error will typically be less than 4 km over a 24 hour interval.) Actual error growth is a complex function of solar activity, geomagnetic activity, propagator design, and accuracy of the initial state vector used for propagation. Characterization of actual position and velocity error growth in the non-GPS navigation mode requires on-orbit experience.

No requirements shall be placed on the rate of growth of position and velocity errors in the non-GPS navigation mode.

5.9 Operation Requirements

5.9.1 Spacecraft 3-Axis Stabilization Required

The TIMED spacecraft must be 3 axis stabilized with the GNS antennas pointing within 10° of zenith for reliable GNS GPS signal acquisition and subsequent GPS navigation. PVSET accuracy requirements previously stated in this document apply only when pointing is within 10° of zenith.

5.9.2 Autonomous Navigation

The GNS shall be capable of acquiring GPS signals and navigating indefinitely without any ground command inputs. Specifically, the GNS shall have the capability to autonomously acquire GPS satellite signals, perform GPS navigation, and set GNS time from the navigation solution.

Figure 5-4 is a state transition diagram illustrating the sequence between GPS search and GPS navigation. As shown, the GNS must first acquire 4 or more GPS satellite signals before GPS navigation can begin. However once initial signal acquisition is completed, and the navigation state is entered, the GNS shall continue to navigate indefinitely. In this state -- assuming spacecraft attitude stability is maintained -- valid navigation, event prediction, and orbit estimation data products shall continue to be output.

Two different capabilities shall be implemented to acquire GPS signals. These capabilities, referred to as sky search and aided search, are described in following paragraphs.

In the event of GPS signal blockage or jamming, due to for example a spacecraft that is not attitude stable, or is in the sun safe mode, GPS signal tracking and navigation in general cannot be consistently maintained. However, upon removal of the perturbing condition, the GNS shall automatically search and re-acquire GPS signals, and resume GPS navigation operations.

5.9.3 Sky Search

5.9.3.1 Sky Search Definition

The GNS shall implement a capability -- called sky search -- to acquire GPS satellite signals without a coarse knowledge of GPS satellite position, TIMED spacecraft position, or UTC time. Once initiated, the GNS shall continue sky search until four or more GPS satellite signals are acquired; following signal acquisition transition to GPS navigation is automatic.

In the event the spacecraft is not 3-axis stabilized in sky search, GPS signal acquisition generally will not occur. However, upon spacecraft attitude stabilization the GNS shall acquire GPS signals. Spacecraft tumbling, intermittent GPS signals, and interfering signals that may be experienced prior to spacecraft 3-axis stabilization shall not in any way degrade acquisition performance once spacecraft stabilization and proper GPS antenna pointing has been restored and any interfering signals are no longer present.

During sky search, the GNS shall allow an option to transition to fast (aided) acquisition. Aided acquisition requires data inputs from the ground system and in that sense is not an autonomy feature. However, aided acquisition obtains GPS signals much faster than sky search, and for that reason is included as an option to be utilized at the discretion of mission operations.

At power up, by default the GNS shall begin a sky search.

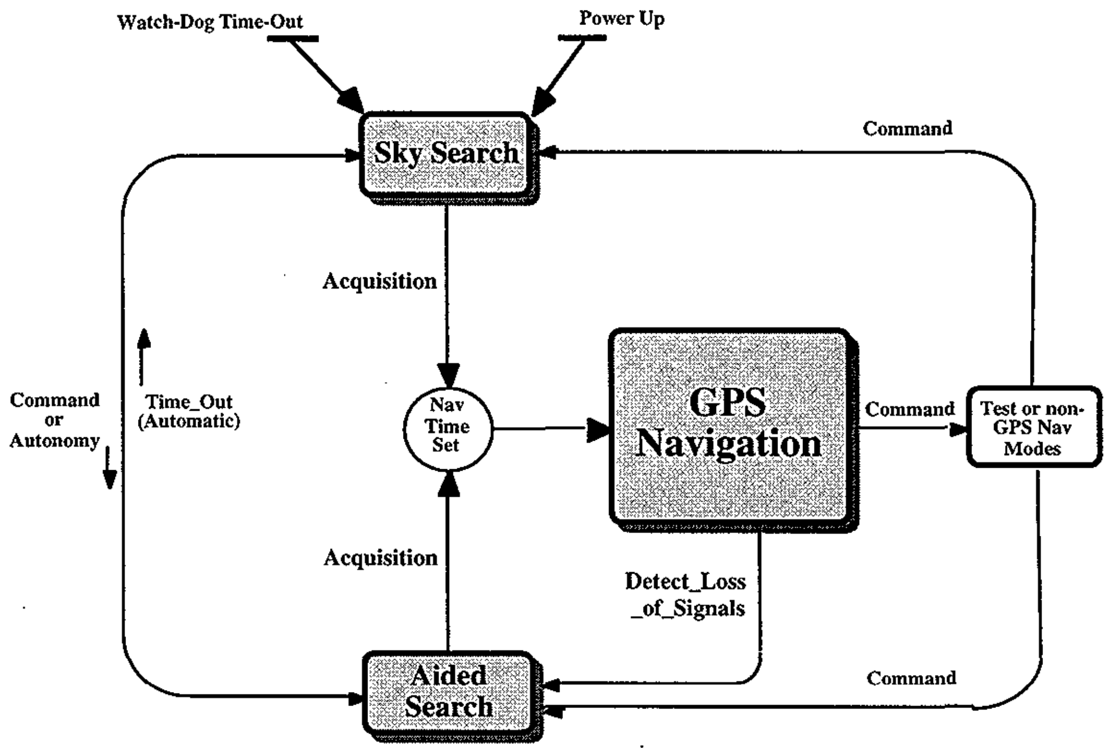

Figure 5-4 -- GPS Search and Navigation Sequence States are depicted by rounded rectangles and transition paths by lines. Each transition path is labeled with the type of event that initiates the respective transition. The GNS is in only one state at any given time

5.9.3.2 Sky Search TTFF (Cold Start)

Signal acquisition in sky search, measured from time of entry to the sky search state to output of the first navigation data set, shall take 30 minutes or less with a 90% probability. This requirement is applicable over the entire range of signal power levels and signal Doppler and Doppler rate previously specified.

5.9.4 Aided Search

5.9.4.1 Aided GPS Search Definition

An aided search capability shall be implemented to provide the option for fast GPS signal acquisition. This capability requires prior storage of a GPS almanac, TIMED state vector, and coarse set of GNS time.(Acquisition of a particular GPS satellite signal by a receiver channel requires a two dimensional search of Doppler frequency and code phase -- with a coarse knowledge of GPS and TIMED spacecraft position, the range and Doppler of in-view GPS satellites may be coarsely determined, and the receiver search range for carrier Doppler and code phase is greatly reduced. As a result the GPS signals are acquired in a relatively short time).

5.9.4.2 Design Goal -- Aided Search Time To First Fix (Warm Start)

As a design goal, GPS signal acquisition and output of the first navigation data set (position, velocity, sun vector, and event flags) shall occur within two minutes or less with a 90% probability of success. Start time is defined as that moment when the receiver is commanded to the aided search state. This requirement is applicable over the entire range of signal power levels and signal Doppler and Doppler rate previously specified. Also the following GNS almanac age, coarse time set, and TIMED orbit accuracy requirements apply.

Requirements To Support Aided Search:

Age of GPS almanac :	< 7 days
Knowledge of orbit position (computed from TIMED state vector)	< 35 km
GNS Clock Uncertainty (prior to acquisition) :	< 5 seconds

5.9.4.3 Detection of Failure to Acquire in Aided Search

In the event GPS signals are not acquired in the aided search state within 5 minutes, the GNS shall have the capability to detect this condition and revert to an expanding search range (of Doppler, GPS satellites) to acquire GPS signals. The aided search may fail, for example, if the coarse time entered in the GNS is in error by an amount significantly greater than 5 seconds.

5.9.5 Autonomous Reacquisition of Signal

5.9.5.1 Definition of Reacquisition

If 3-axis stabilization of the spacecraft is temporarily lost and the GPS antennas point off-zenith, intermittent GPS signals and jamming may occur, and the receiver section of the GNS may not be able to reliably track a sufficient number of GPS satellites to support navigation. The GNS shall have the capability to detect this condition and -- upon restoration of normal GPS signals-- shall automatically attempt to re-acquire GPS signals using aided search capabilities. Spacecraft tumbling, intermittent GPS signals, or interfering signals that may be experienced during the disturbance shall not in any way degrade aided search performance once the disturbance is removed.

Reacquisition of GPS signals will be based on propagation of the last known good state vector (PVT) to estimate range and Doppler acquisition aids. In the interim, during signal search, all navigation data products shall continue to be transferred to the spacecraft , i.e. flywheel as defined in subsequent paragraphs.

5.9.5.2 Reacquisition of GPS Signal (Time to Subsequent Fix)

Reacquisition time, also referred to as time to subsequent fix, is dependent on the time difference between the disabling event and subsequent restoration of GPS signals. As a design goal, if consistent GPS signal levels are restored within 60 minutes, the time to subsequent fix (TTSF) shall not exceed two minutes with 90% probability.

5.9.6 Flywheel Operation

In the event the GNS transitions out of the GPS navigation state to a signal search state, due to signal blockage or jamming, the GNS shall continue to output PVSET data based on propagation of the last known "good" state vector. After the GPS signal is restored, and the GNS re-acquires four or more GPS satellites, PVSET data set generation and output shall be based on use of GPS pseudorange and carrier phase measurements.

During flywheel, generation of PVSET data is carried out in essentially the same manner as during the non-GPS navigation mode (previously defined). The rate of growth in position, velocity, and time errors shall be no worse than for the non-GPS navigation mode.

5.9.7 Transition to Other Modes

Absent any GPS commands from ground control, the GNS will be in either the GPS navigation state or one of the signal search states. Transition to a test or non-GPS navigation mode shall be initiated only by ground command. To transition from a test or non-GPS navigation mode back to a GPS acquisition mode shall require a ground command.

Test modes are intended only for contingency use on-orbit and shall be used only with the concurrence and oversight of GNS design representatives.

5.9.8 Launch and Early On-Orbit Configuration

It is anticipated at least one GNS system will be powered on during launch through orbit insertion. However, GPS signals are blocked by the fairing prior to orbit insertion and GPS signal acquisition cannot occur. The GNS shall implement a launch configuration capability to address GNS early on-orbit operation. The essential features of this capability are as follows

- The GNS is sent a notice of orbit insertion by the C&DH when the separation switch fires. The notification shall include the time of orbit insertion.
- The GNS begins distribution of standard output products (e.g, P,V,S,E) at orbit insertion based on propagation of the orbit insertion point state vector (loaded prior to launch)
- Prior to launch, an 'arming' command must be sent to the GNS to enable the GNS launch configuration. The GNS shall not respond to the notice of orbit insertion unless previously 'armed'.
- Prior to launch, the TIMED orbit insertion point state vector and GPS almanac must be loaded and GNS time must be set to an accuracy of 1 second or better.
- The GNS initiates aided GPS signal search at orbit insertion
- Regardless of the state of GNS receiver signal acquisition after orbit insertion, the GNS computes and distributes P,V,S,E data based solely on orbit insertion point state vector propagation (this is the non-GPS navigation mode). In order to transition to GPS navigation, a GNS command must be sent from the ground.

The orbit insertion notice is generated in the C&DH processor based on detection of the separation switch telltale. More specific requirements relating to GNS launch configuration capability follow.

5.9.8.1 TIMED Orbit Insertion Point State Vector

Use of the non-GPS navigation capability following launch requires the load of a TIMED state vector prior to launch. The state vector must correspond to that point in the orbit where it is anticipated the separation switch will fire, i.e., the orbit insertion point. The TIMED orbit insertion state vector (P,V) must be expressed in the ECEF-CTS reference frame. The V will be as seen by an earth-fixed observer. (The insertion point is fixed relative to the earth and therefore ECEF coordinates are not dependent on launch time). The state vector shall also include a covariance matrix.

5.9.8.2 Insertion Point Notification

The GNS will initiate non-GPS navigation on receipt of the orbit insertion notification from the C&DH processor. At that point in time PVSET data will be computed and distributed at the normal one second rate based on propagation of the orbit insertion state vector. To allow the GNS to perform integrity checks, the orbit insertion notice must also include the time of orbit insertion to 1 second resolution.

In the event the GNS detects integrity errors in the orbit insertion notification, the GNS will default to the GPS navigation mode, i.e., PVSET data will be based on the GPS navigation solution following successful acquisition of GPS satellite signals.

5.9.8.3 Pre-Launch Operation Requirements

To support the GNS launch configuration, in addition to load of a TIMED orbit insertion state vector, a GPS almanac no older than 7 days must be loaded into the GNS data base. Also the GNS time must be coarse set to an accuracy of 1 second or better with respect to UTC. Finally, the 'arming' command which enables GNS response to the orbit insertion notice must be sent.

With regard to loading a GPS almanac and setting time prior to launch, this can be accomplished by direct command from the ground system. However, if access to GPS satellite signals is available, a fresh almanac and precision time set can also be obtained by tracking GPS satellites. After GPS navigation begins, 12.5 minutes of uninterrupted tracking is required to obtain a new GPS almanac. Also, following GPS navigation, uninterrupted power must be applied to the GNS through launch in order to maintain GNS time.

5.9.9 GNS Autonomous Integrity Monitor

The GNS shall implement an autonomous capability to detect the integrity of distributed navigation and time. Specifically, integrity algorithms shall be implemented that detect and isolate GPS satellite signals that degrade the solutions of navigation and time. Algorithms used will be based on checking the self-consistency of measurements (of overdetermined solutions) and requires the capability to track at least 5 satellites simultaneously. Use of the anomalous satellite shall be excluded until it is ascertained the fault has been cleared.

The GNS shall also check health flags included in each GPS navigation message. No GPS satellite shall be used for navigation that has any health flags raised. Also no satellite shall be used that outputs default navigation data. Health flags and indicators to be checked include (but are not limited to) the following :

- Navigation data flags (8 total)
- Health of Spacecraft flags (6 total)
- Alert flag (in HOW word)
- Synchronization flag (in HOW word)

As a goal, the GNS shall also verify the consistency of GPS ephemeris and time data included in the GPS message. Contiguous sets of ephemeris shall be checked to verify consistency in GPS satellite position. Only GPS satellites with consistent ephemeris data shall be used for navigation. Likewise successive HOW word, Z count, GPS week count, and GPS clock corrections must be consistent.

The GPS status output shall include integrity monitor status and shall list any GPS satellites excluded from use. GNS navigation and time outputs will include a figure of merit (FOM) estimating the quality of the respective solution and warning of any degradation in accuracy.

5.9.10 GNS Software Reprogrammability

The GNS shall include a capability to load new program software through the TIMED spacecraft command link. The GNS shall also implement a capability to dump (via spacecraft telemetry downlink) the contents of re-programmed memory locations. (The capability to dump GNS memory contents is required in order to allow mission operations to verify re-programmed memory contents in the MOC prior to execution of new program code.)

During the interval of program software load and subsequent memory verification operations, the GNS is not required to navigate and provide navigation data product output. During this time interval the GNS 1PPS output shall remain undisturbed relative to its last time set. GNS 1PPS drift relative to a reference UTC 1PPS shall be less than 0.864 seconds per day.

5.9.11 Power Save Configuration

Deleted

5.9.12 Dual GNS Operations

The spacecraft supports the capability to power-up and operate both GNS systems simultaneously. In this event, each GNS shall operate independently of the other, and data products from each GNS shall be stored on the respective IEM SSR. Any GNS command packets sent from the ground station must direct the commands to a selected GNS.

The primary GNS, i.e., the GNS selected for distribution of navigation data products to the on-board instruments, shall be chosen by the primary C&DH processor. No GPS commands shall be required to select the primary GNS.

There is no requirement for a capability to transfer data from one GNS to the alternate GNS.

5.9.13 Non-Volatile Memory Requirement

To support the requirement for autonomous GNS operation, the GNS processors shall include a section of non-volatile writable memory for data storage. All information required to support autonomous operation shall be stored in non-volatile memory and restored at power-up. Examples of data that must be stored in non-volatile memory are listed below. All data required to be stored in non-volatile memory shall be identified in the GNS Software External Interface Control Document.

- Default contact site coordinates (up to 12 sets)
- SAA zone coordinates
- GPS antenna gain pattern

5.10 Telemetry Requirements

5.10.1 Housekeep Data Discretes

As outlined in section 4, nine GNS housekeeping data discretes shall interface to the IEM Command and Telemetry (C&T) card. These signals represent GNS input voltage, current, receiver AGC, and temperature measurements. The C&T shall scale, sample, and merge with spacecraft housekeeping data packets, and store on the SSR.

5.10.2 Non-Packetized GNS Science Data

As previously stated, GNS 'science' data products PVSET will be output at a 1 Hz rate to the C&DH over the IEM PCI bus. In the C&DH these products are merged with other spacecraft data and imbedded in spacecraft housekeeping data packets recorded on the SSR. These products are referred to as non-packetized data since they are only one component of a telemetry data packet.

5.10.3 GNS Status

The PVSET data products shall each include data quality indicators and flags as previously specified. In addition, GNS operational status shall be output to the C&DH processor at a 1 Hz rate. As a minimum the following shall be included.

- GNS state or mode (i.e., sky search, aided search, GPS navigation, flywheel, non-GPS navigation, launch configuration, test mode)
- tracking status of individual receiver channels (e.g., SV assignment, lock status)
- receiver AGC health status
- GNS command verification status
- time tag (or equivalent) indicating status time of validity to 1 second resolution

Additional GNS data items will be output at lower (than 1 Hz) sampling rates. These items include pseudorange data, code phase data, and carrier phase data from each channel. A complete definition of lower rate GNS data products shall be defined in the GNS Software External Interface Control Document.

5.10.3.1 GNS Command Verification

To verify the receipt and acceptance of GNS command packets, the GNS shall include command verification data in the 1 Hz GNS status. During real time command contacts, GNS status (including command verification), shall be downlinked real time in spacecraft housekeeping telemetry packets and processed in the MOC. GNS status -- output at a 1 Hz rate to the C&DH processor -- will be received at the MOC within a few seconds following the command uplink. The GNS command verification data may be examined to verify GNS acceptance.

GNS command verification data shall include as a minimum the following information.

- Acceptance/Rejection status of last GNS command received
- Monotonic count of accepted GNS commands (Modulo 256)

The count of accepted GNS commands may be reset by GNS command.

5.10.4 GNS Orbit Ephemeris and Event Prediction Telemetry Packets

As specified in prior sections, the GNS shall output orbit estimators and event prediction tables every 12 hours. These data shall be formatted as individual GNS telemetry packets. GNS telemetry data packets shall conform to the 2080 bit telemetry packet format specified in the TIMED GIIS document. These telemetry packets shall be sent to the C&DH processor over the IEM PCI bus and subsequently recorded on the SSR for eventual downlink. (Each packet consists of 80 bits for primary and secondary headers and 2000 data bits). The total volume of orbit estimator and event prediction data in any one 24 hour interval shall not exceed 10 Kbytes.

5.10.5 Standard GNS Data SSR Volume Requirements

Standard GNS data outputs recorded on the SSR include the non-packetized PVSET 'science' data, GNS status data, orbit estimators, and event prediction data. These products are standard in that they are continuously output on a default basis and represent the minimum GNS data that must be recorded on the SSR. A detailed definition of standard data products is in progress ; a specification of the total volume of standard GNS data stored on the SSR over any 24 hour period is deferred to the GNS Software External Interface Control Document.

5.10.6 High Rate Diagnostic Data Requirement

For early on-orbit GNS test, the GNS shall implement a capability to output high rate diagnostic data. This data is recorded on the SSR and telemetered during a subsequent contact. As a minimum, the capability to output the following shall be implemented.

- 1 Hz integrated carrier phase, C/A code phase, and pseudorange measurements from each receiver channel

- Selected components of the GPS navigation message , e.g.
  - GPS ephemeris
  - GPS almanac
  - leap seconds
- the Kalman filter covariance matrix
- GPS integrity monitor status

The carrier phase, C/A code, and pseudorange measurement data shall include all data sufficient to perform navigation (after-the fact) in a ground navigator. The periodic output of each of the above data sets shall be enabled or disabled by ground command.

High rate diagnostic data shall be formatted as individual GNS telemetry packets. GNS telemetry data packets shall conform to the 2080 bit telemetry packet format specified in the TIMED GIIS document.

The average high rate diagnostic output data rate shall not exceed 1500 bytes per second. GNS high rate diagnostic data requires ground commands for initiation and termination. Recording of high rate data will require proper management of the SSR by mission operations personnel to assure sufficient recording capacity.

5.10.7 GNS Memory Dump Requirement

For test, before and after launch, the GNS shall implement a capability to dump selected portions of GNS processor memory to the SSR. The processor (navigation or tracking processor) and specific memory locations (or data base parameters) to be dumped shall be specified and initiated by ground command. The memory dump data shall be output as individual GNS telemetry packets. GNS telemetry data packets shall conform to the 2080 bit telemetry packet format specified in the TIMED GIIS document.

The detailed definition of GNS data base parameters which may be selected for data dump shall be specified in the GNS P&I document.

GNS memory dump data is not a regular output and requires ground commands for set-up and initiation. Recording of memory dump data will require proper management of SSR recording operations by mission operations personnel to assure sufficient recording capacity.

5.11 Required Real Time Command Capabilities

The GNS is autonomous and shall not require commands for operational maintenance. However -- for test, contingency operations, and extended performance -- the GNS shall implement a capability to receive and execute real time commands. A summary of general command capabilities is specified in this section. A list of specific GNS commands and command structures will be defined in the GNS P&I Specifications.

GNS commands shall be configured in the MOC in the form of GNS command packets. GNS command packets will be sent in real time from the MOC and transported to the spacecraft through the TIMED uplink. The C&DH processor will reconstitute GNS command packets transmitted to the spacecraft and send to the GNS over the PCI bus.

5.11.1 Aided Search

The GNS shall implement all commands required to support aided GPS signal search operations. These commands include coarse GNS time set, GPS almanac load, and TIMED state vector load as described in prior sections.

5.11.2 Enable High Rate Diagnostic Telemetry

The GNS shall include the capability to enable/disable telemetering of GNS high rate diagnostic data.

5.11.3 GNS Memory Load

The GNS shall implement the command capabilities to load new program software in flash memory (with the exception of flight boot block software).

The GNS shall implement command capabilities to load new parameters into the GNS data base, for example, a new GPS almanac, new solar flux data, a new reference oscillator offset rate. A complete list shall be specified in the GNS External Software Interface Control document.

5.11.4 Initiate GNS Memory Dump

The GNS shall implement command capabilities to initiate telemetering of selected portions of GNS memory. One use of this command is to support verification of GNS memory loads.

The command capability shall be implemented to initiate telemetry of specific GNS data base parameters, for example the GPS almanac. A specific list of GNS data parameters which may be dumped by command shall be given in the GNS External Software Interface Control document.

5.11.5 Contact Event Prediction

The GNS shall implement commands to allow modification of contact event prediction parameters as described in previous sections of this document. These command capabilities are summarized below.

- capability to select a designated backup site from list of contact sites
- capability to change the designated primary site
- capability to overwrite coordinate location of any contact site stored in GNS memory
- capability to modify lead and lag times of contact event flags
- capability to modify definition of valid pass length
- capability to disable/re-enable output of contact event flags

5.11.6 Mode and State Selection Commands

The GNS shall include the command capability to initiate transitions from the GPS navigation mode to the non-GPS navigation mode, the launch configuration state, or a test mode. A command is required to re-enable the GPS navigation mode.

5.11.7 SAA Zone Coordinates

The GNS shall implement command capabilities to modify the coordinates defining the SAA zone.

5.11.8 IEM Power Save

Deleted

5.11.9 GNS Reset

As previously described, a GNS hot reset command may be sent over the PCI bus. This is a contingency type command and is implemented in PCI interface hardware. GNS processor software does not interpret or implement this command.

6. Environmental Requirements

6.1 EMC Design and Performance

The GNS shall survive, perform as required, and not degrade the operation of other subsystems when the IEM is subjected to the MIL-STD-461B EMC and EMI tests specified in the TIMED EMC Control Plan and EMI Performance Requirements Specification 7363-9038. These requirements apply with the GNS cards installed in a fully assembled and operational IEM.

6.2 TIMED S-Band Transmitter Interference

The TIMED spacecraft will include an S-Band transmitter and antenna for telemetry downlink. The amount of out-of-band signal coupled from the S-Band antenna to the RF input to the GNS receiver card shall not exceed the GNS CW susceptibility, wideband susceptibility, and survivability limits previously specified in section 5.2 of this document.

6.3 Thermal Environment

6.3.1 GNS Cards

The GNS shall be designed to meet all performance requirements stated in this document over the range of IEM baseplate temperatures of -29°C to +55°C in vacuum (these are test levels specified in the TIMED Component Environmental Specification 7363-9010). This requirement applies with the GNS cards installed in a fully assembled and operational IEM.

During test and mission operations, the junction temperature of any GNS component installed on a GNS card shall not exceed 100°C. For hybrid devices, a maximum case temperature shall be required on a case-by-case basis after the thermal analysis is complete.

6.3.2 Antenna Elements

Each GPS antenna element shall be mounted on a separate antenna pedestal located on the optical bench. The thermal design of the antenna elements, pedestal, and mounting to the optical bench shall maintain the temperature of the antenna elements within -100°C through +75°C for all anticipated on-orbit conditions. The GNS shall meet all performance requirements stated in this document over this range of GPS antenna element temperatures.

6.3.3 Non-Operating Temperature Limits

As required by the Component Environmental Specification, the GNS processor and receiver cards shall survive -- without damage or degradation in performance-- non-operating temperature limits of -34°C to +60°C. The GPS antennas elements shall survive non-operating temperature limits of -100°C to +75°C.

6.4 Radiation Requirements

6.4.1 Total Ionizing Dosage

Parts selected for the GNS shall survive a total ionizing dose of 5 krads (Si) without failure (MIL-M-38510 radiation hardness level M).

6.4.2 Proton Fluence Level

Consistent with section 2.7.2 of the Component Environmental Specification, all components used in the GNS shall be capable of withstanding without failure a total fluence of 1.6 E+10 Protons/cm^2 for protons with energy above 10 MeV.

6.4.3 Single Event Effects

6.4.3.1 Latch-up Immunity

All parts used in the GNS shall be latchup immune.

6.4.3.2 Single Event Upsets

The spectrum of Proton fluence levels for the TIMED mission are given in section 2.7.2 of the TIMED Component Environmental Specification. Single event upsets (SEU) which may occur in GNS components as a result of this environment shall not compromise flight system health or mission performance. Any SEU experienced by the GNS shall be correctable and shall not cause any permanent degradation in GNS performance.

6.5 Mechanical Environment Requirements

6.5.1 Sine and Random Vibration

The GNS shall be capable of surviving -- without degradation in performance -- the protoflight random vibration test levels and sine vibration test levels specified in the Component Environmental Specification. This requirement applies to the GNS cards installed in a fully assembled and operational IEM and to the GPS antenna/pedestal/cable assembly. The GNS shall be powered during IEM and spacecraft vibration tests, but performance requirements are not required to be met during vibration.

6.5.2 Shock

As stated in section 2.8.3 of the Component Environmental Specification, all spacecraft components including the GNS shall be installed during spacecraft level clamp band testing. The GNS shall survive this test without degradation in performance. Although no shock response levels are specified directly for the GNS or IEM, the GNS mechanical design must take into consideration the shock levels at the clamp-band (specified in the Component Environmental Specification) and the distance of the IEM from the clamp-band. GNS performance requirements are not required to be met during clamp band testing.

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December 9, 1997

To: Distribution

From: R. J. Heins

Subject: Distribution of TIMED GPS Navigation System Requirements Document

Attachment: GPS Navigation System Requirements Document 7363-9336

The attached document is provided for your files.

Robert Heins
R. J. Heins

RJH:kahj

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