SIX CHANNEL SPACEBORNE GPS RECEIVER

Richard Sfeir
Roger M. Weninger

Rockwell International Corporation
Autonetics Strategic Systems Division
Anaheim, California

Rockwell International Corporation is developing a lightweight, compact GPS receiver for low earth-orbiting space vehicles. The effort is sponsored by the Defense Advanced Research Projects Agency (DARPA) and monitored by the Air Force Phillips Laboratory. Three flight receivers are scheduled for delivery prior to the end of CY 1991. The first receiver will fly on a technology for autonomous operational survivability satellite planned for launch in 1992.

The receiver has six channels that continuously track four primary GPS satellites and sequentially acquire and track all other visible and healthy satellites on the fifth and sixth channels. It performs pseudorange and continuous-carrier, delta range measurements and estimates time-tagged, three dimensional user position and velocity using an eight-state extended Kalman filter. The Rockwell receiver weighs 8.0 pounds and consumes 12.5 Watts of 28 VDC. This paper will review the receiver design, and present performance results obtained by using a multichannel GPS spaceborne Simulation and Evaluation System (SEVS). The SEVS generates six GPS satellite L1 and L2 RF transmissions representing the signal environment for a low earth-orbiting user.

INTRODUCTION

In February 1990, Rockwell International Corporation was awarded a contract to provide three Global Positioning System (GPS) receivers suitable for use in low, earth-orbiting satellites. The effort is funded by DARPA and managed by the Air Force Phillips Laboratory. The receiver is part of DARPA's Advanced Satellite Technology (AST) program and is designated as AST V GPS receiver. It is a six channel, continuous track receiver that provides three-dimensional, time-tagged position and velocity to support low earth-orbiting satellite navigation operations.

This paper provides a description of the receiver, the simulation and evaluation system (SEVS) used to determine its navigation performance, and the position and velocity errors of the first flight AST V measured with the SEVS. Only receiver errors are considered; no degradation due to GPS space/control segment errors, e.g., selective availability, are considered in this paper.

RECEIVER DESCRIPTION

The GPS receiver design is based on a chipset developed by Rockwell under the AST V contract and the Miniature GPS Receiver (MGR) effort previously performed for DARPA. The MGR chipset consists of: (1) a Gallium Arsenide (GaAs) Monolithic Microwave Integrated Circuit (MMIC) RF/IF Translator, (2) a silicon Frequency Synthesizer, (3) a CMOS Signal Processor, (4) a CMOS Multi-Function Interface and (5) a CMOS Advanced Architecture Micro-Processor (AAMP). Under the Advanced Satellite Technology V program, Rockwell integrated all of the RF/IF functions into a single GaAs MMIC, thus eliminating the need for a separate Frequency synthesizer chip. Furthermore a CMOS/SOS AAMP was used to obtain a high tolerance to single event upsets and to natural space radiation. This chipset is configured with radiation hardened memory and a Temperature Controlled Crystal Oscillator (TCXO) to make up the GPS receiver described herein.

The receiver is shown in Figure 1. It weighs 8.0 pounds, consumes 12.5 watts, and measures 7.8 in. x 7.1 in. x 5.1 in., including flanges. A weight and power breakdown is contained in Table 1. It interfaces with the host vehicle for the L1/L2 GPS RF signal, 28 VDC power, and transfer of binary serial data. The serial data Interface Port (IP) provides (1) asynchronous, bi-directional transfer of 16-bit data words and (2) a 20 microsecond wide output Timemark pulse.

A block diagram of the receiver is shown in Figure 2. The receiver consists of five printed circuit board modules: one RF module, two identical Channel Processing Modules (CPMs), one Data Processing Module (DPM), and one Power Supply module. The modules plug directly into a Master Interconnect Board (MIB) for their electrical interface. The digital modules (1 DPM and 2 CPMs) and MIB are mounted inside an Aluminum housing. The modules are secured to the chassis with wedgelocks and are keyed to prevent cross-plugging. The RF and Power Supply modules are enclosed in separate aluminum housings that attach with screws to the top and bottom of the digital housing, respectively. Six mounting holes are provided in the power supply housing flanges to mount the receiver on a cold plate in the host vehicle.

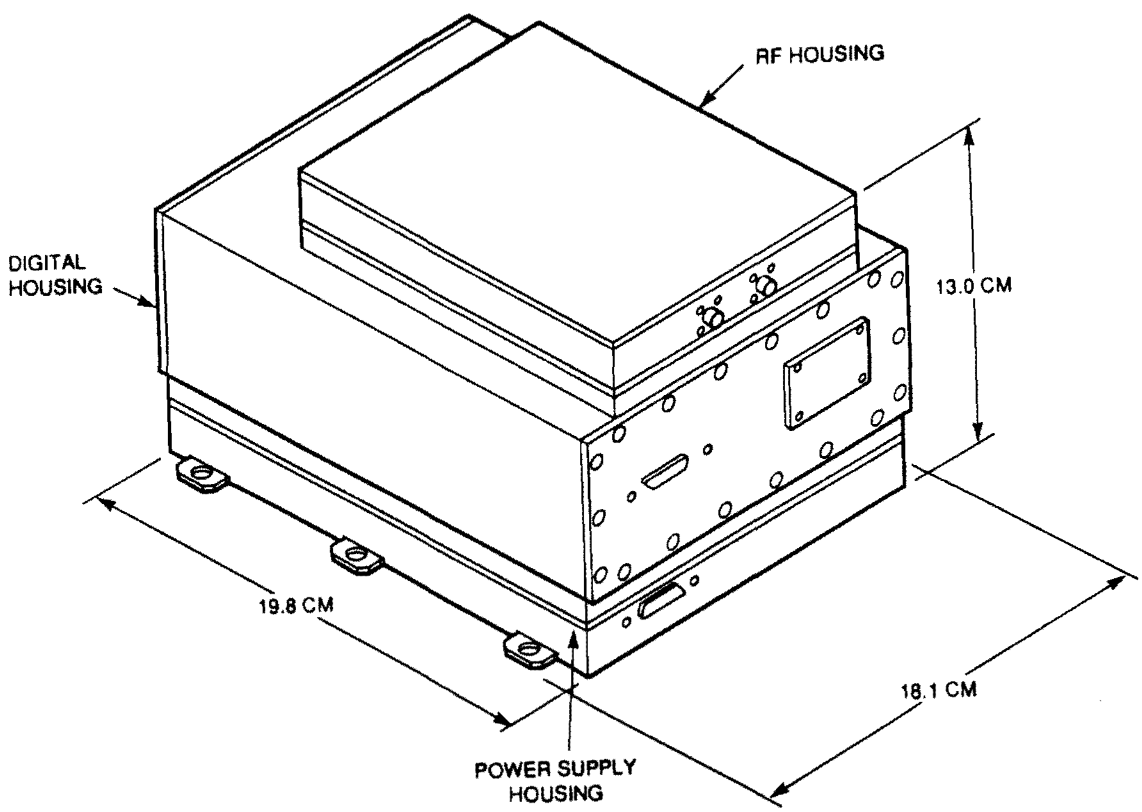


Figure 1. AST V GPS Receiver

Table 1. AST V Weight and Power Breakdown

	CHASSIS	MIB	PS	RF	CPM/DPM	TOTAL
WEIGHT (LBS)	4.45	0.27	0.82	0.62	2.71	7.87
POWER (W)	N/A	N/A	3.9	2.6	6.0	12.5

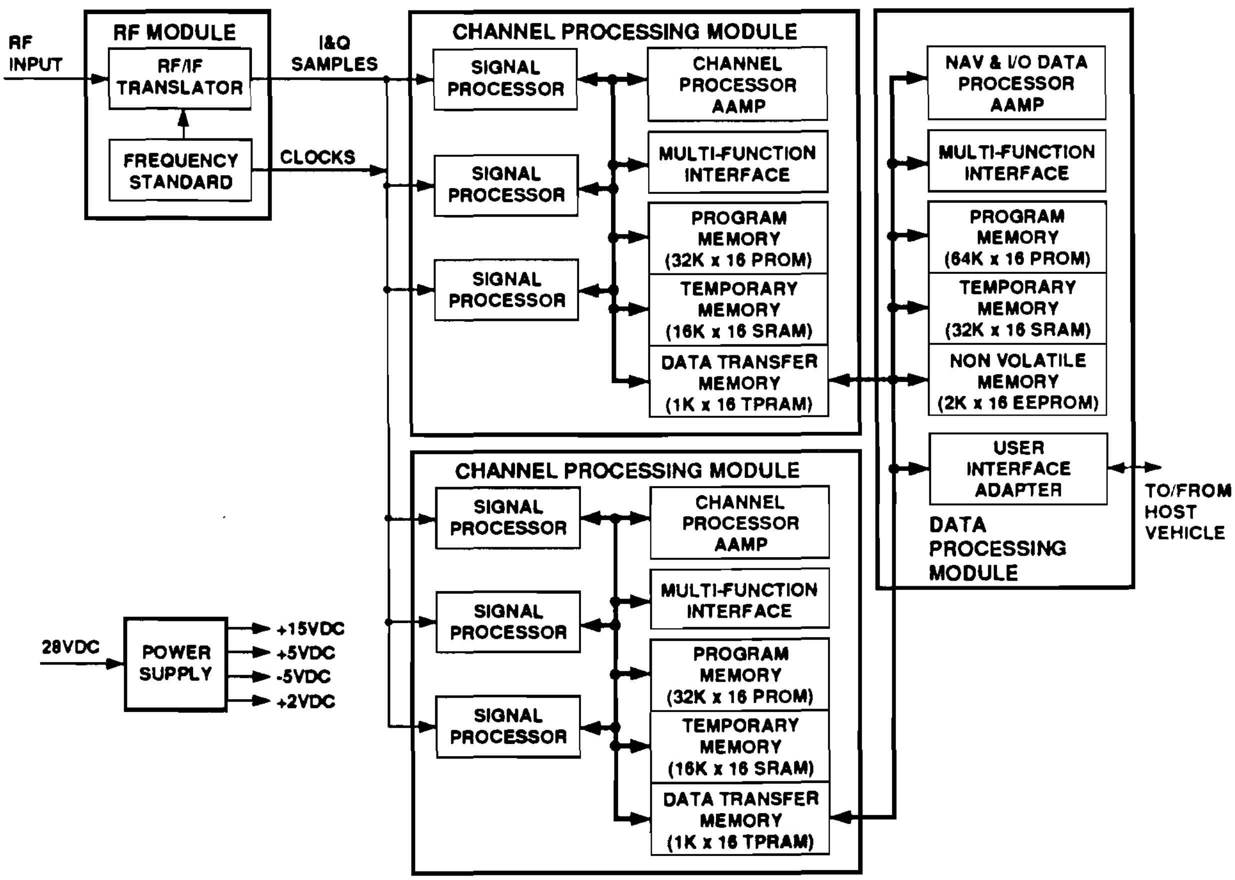


Figure 2. AST V GPS Receiver Hardware Block Diagram

The receiver simultaneously acquires and tracks six GPS signals from any number of healthy GPS satellites occuring within the receiver's antenna field of view. The six channels function independently so that GPS signals and data can be processed in parallel. It continuously tracks four primary satellites on four channels and sequentially acquires all other visible and healthy satellites on the fifth and sixth channels. The four primary satellites are selected to provide minimum Geometric Dilution Of Precision (GDOP) in order to achieve high accuracy navigation.

The receiver operates on either the

L1 (1575.42 MHz) or L2 (1227.60 MHz) GPS signal. L1 is used for general processing and to obtain pseudorange and continuous delta range measurements and L2 is used periodically (nominally every 10 seconds) to obtain a separate set of measurements to aid in correcting for ionospheric propagation delay. The receiver can acquire either or both the Clear Access code (C/A-code), or the Precision code (P-code) depending upon performance requirements. As a general rule when estimated position is not well known C/A code is used for acquisition followed by handover to the P-code.; however, if the estimated position and time error is within +/- 300 P-code chips (+/- 3000 ft), a satellite is acquired directly with the P-code.

The receiver measures pseudorange and delta range with respect to the primary GPS satellites. The pseudorange measurements are derived from the code tracking loop to an accuracy of 1.5 meters. The delta range measurements are derived from the carrier tracking loop by coherently integrating the carrier VCO commands over a 1 second interval to an accuracy of 1.8 centimeters. The measurements are input to the navigation function at a 1 Hz rate. The navigation function estimates, using an eight-state extended Kalman filter, three dimensional position and velocity, plus time. Position and velocity vectors are computed in Earth-Centered-Earth-Fixed (ECEF) coordinates and time is output in both GPS system time and coordinated Universal Time (UTC).

GPS SIMULATION AND EVALUATION SYSTEM (SEVS)

The GPS SEVS used to evaluate the receiver navigation performance is a six channel GPS satellite signal generator operated under software control by a PC-AT386 system. The SEVS is capable of simulating the dynamic L1 and L2 GPS signal environment generated by six GPS satellites as encountered by a low earth orbiting user.

The SEVS provide control and initialization of the receiver via its host vehicle interface, collects receiver navigation performance data in real-time, and post-processes the recorded navigation data along with simulation "truth" data to evaluate receiver performance. The SEVS also has a non real-time scenario generation capability. It allows the operator to specify the host vehicle orbit, the space environment parameters such as ionospheric delays and atmospheric drag coefficient, and system error statistics simulating GPS control and space segment errors. A GPS constellation editor allows the operator to modify the GPS constellation at various simulation time intervals.

TEST DESCRIPTION

The test was conducted with a SEVS scenario, ORB18, that simulates an 18 satellite GPS constellation and a circular user orbit with 800 Km altitude and 112 degrees inclination. The simulation time is 110 minutes which corresponds to slightly more than one orbit duration. The initial user UTC time, position and velocity inputs in ECEF coordinates are:

Time (UTC): 12/25/83 - 16:57:00

Position (ECEF): P_x = 7178137 m
P_y = 0 m
P_z = 0 m

Velocity (ECEF): V_x = 0 m/s
V_y = -3350 m/s
V_z = 7087 m/s

The scenario assumes perfect user initialization input and includes no GPS space/control segments errors.

A graph of the Geometric Dilution Of Precision (GDOP) representative of the primary satellites used to derive the receiver navigation fix is presented in Figure 3. It shows that between simulation times 2300 seconds and 2750 seconds, GDOP grows to a value of approximately 9500. This phenomenon of poor geometry is not expected to occur with a full GPS constellation of 21 (or more) satellites.

TEST RESULTS

During the period of poor geometry (high GDOP), the receiver performance is degraded by more than 50 meters in spherical position error and by as much as 0.5 meter/second per axis in velocity error, refer to Figures 4 and 5, respectively. If this period is not included in the receiver performance analysis, then the receiver rms spherical error in position is less than 4 meters and the rms position and velocity error in any axis is less than 2.6 meters and 0.03 meter/second, respectively. Figures 6 through 12 show the spherical position error and the x, y and z axis position and velocity error for the this time period,i.e., 2800 to 6500 seconds, when GDOP is less than 6. The rms errors for this time period are summarized in Table 2.

Table 2. RMS Navigation Errors (GDOP < 6)

	POSITION (m)	VELOCITY (m/s)
SPHE-RICAL	3.84	-
X	2.53	0.025
Y	1.58	0.018
Z	2.42	0.029

CONCLUSION

This paper described the AST V GPS receiver and the Simulation and Evaluation system used to measure the receiver's navigation performance in a low earth orbit. It was shown that with a GPS constellation of 18 satellites and over a period where GDOP is less than 6, the receiver's rms position and velocity errors per axis are less than 2.6 meters and 0.03 meter-/second, respectively. All error sources external to the receiver were set to zero for the testing described in this paper.

BIOGRAPHIES

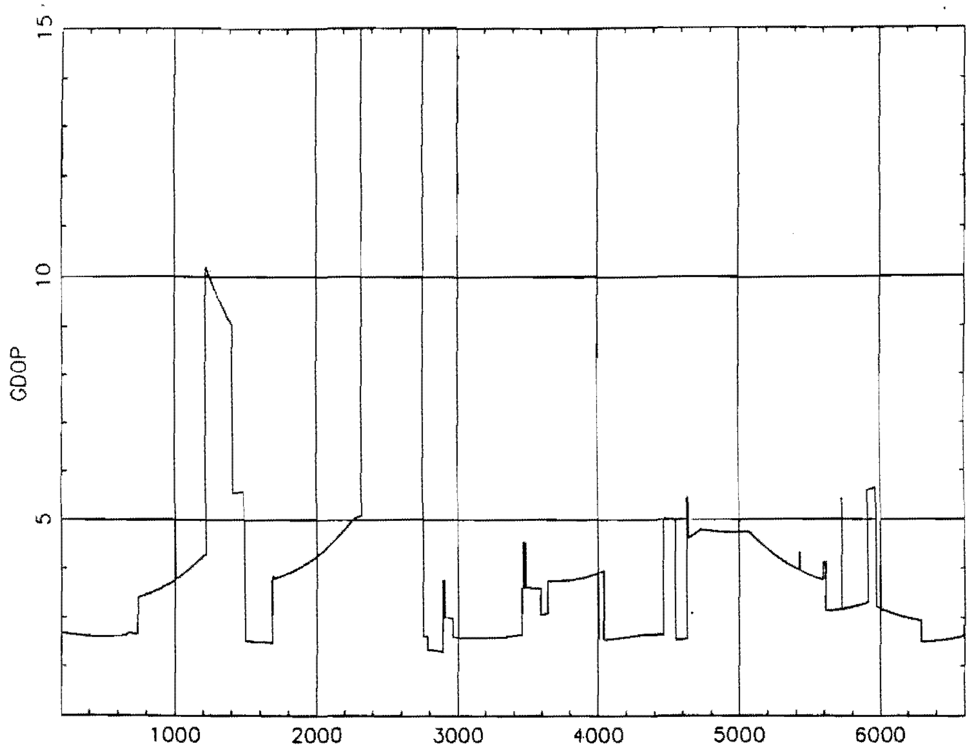
The authors work for the Autonetics Strategic Systems Division (ASSD) of Rockwell International' Defense Electronics Organization. They have been involved with contracts to provide GPS receivers for NASA's Orbital Maneuvering Vehicle, the Navy's SPUR-SAT program and the DARPA/Air Force Advanced Satellite Technology GPS receiver program.

Richard Sfeir is the project system manager for all spaceborne GPS receiver contractual and independent research efforts. He received his MSEE from California Institute of Technology.

Roger Weninger is the program manager for spaceborne GPS receivers. He has over 20 years of experience with navigation systems. He received his MSEE from California State University at Long Beach.

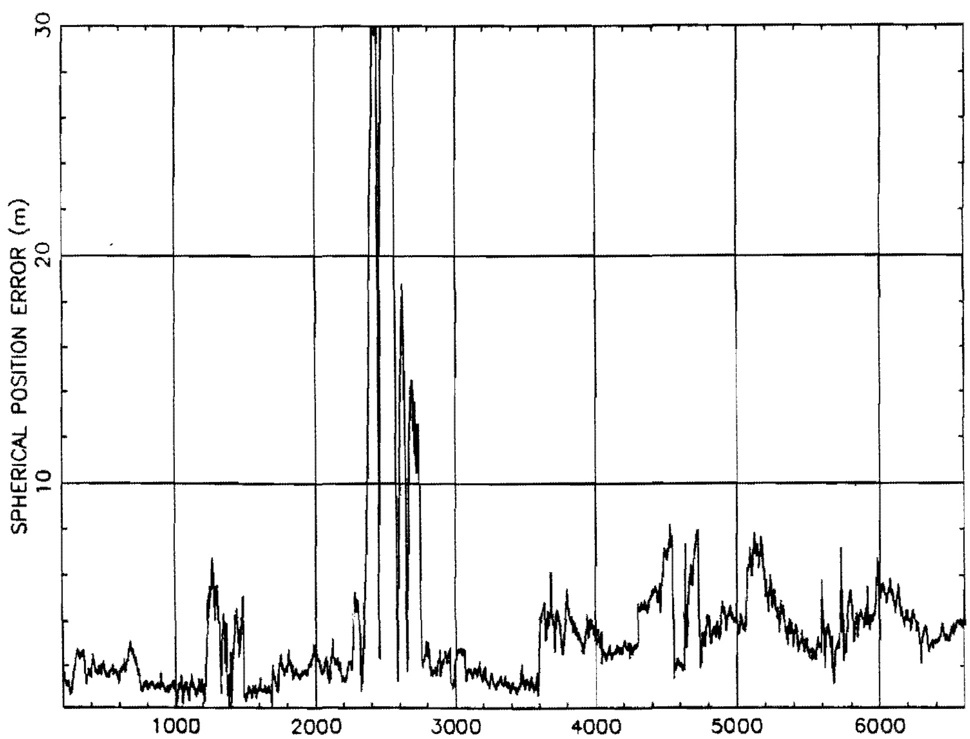
ACKNOWLEDGEMENTS

The authors acknowledge the work performed by Y. Chen, T. Forgette, P. Kelton, and R. Najarian of ASSD and of J. Bruckner, G. Slimak and J. Young of Rockwell's Collins Commercial Avionics in support of this program.



MIN = 2.3036 ( )
MAX = 9497.3428 ( )
SIMULATION TIME (SECONDS)
MEAN VALUE = 25.2648 ( )
STD. DEV. = 377.3967 ( )

Figure 3. GDOP versus Simulation Time



MIN = 0.1912 (m)
MAX = 53.8946 (m)
SIMULATION TIME (SECONDS)
MEAN VALUE = 4.1315 (m)
STD. DEV. = 6.0807 (m)

Figure 4. Spherical Position Error versus Time

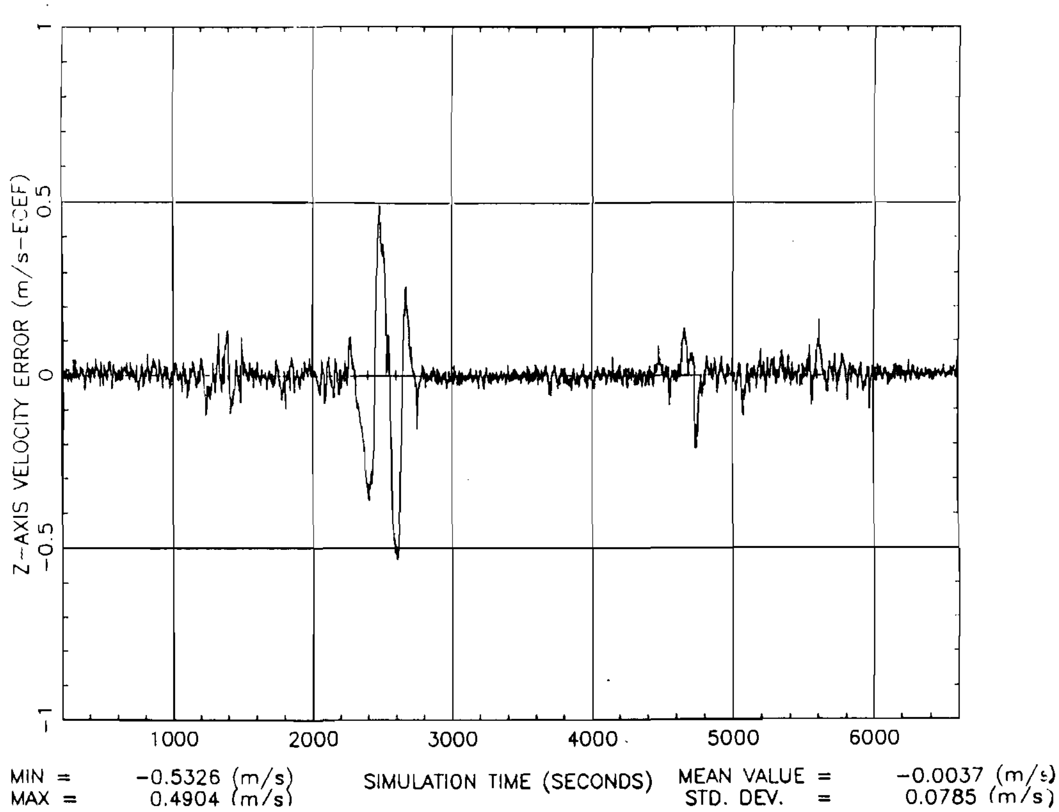


Figure 5. Z-axis Velocity Error versus Time

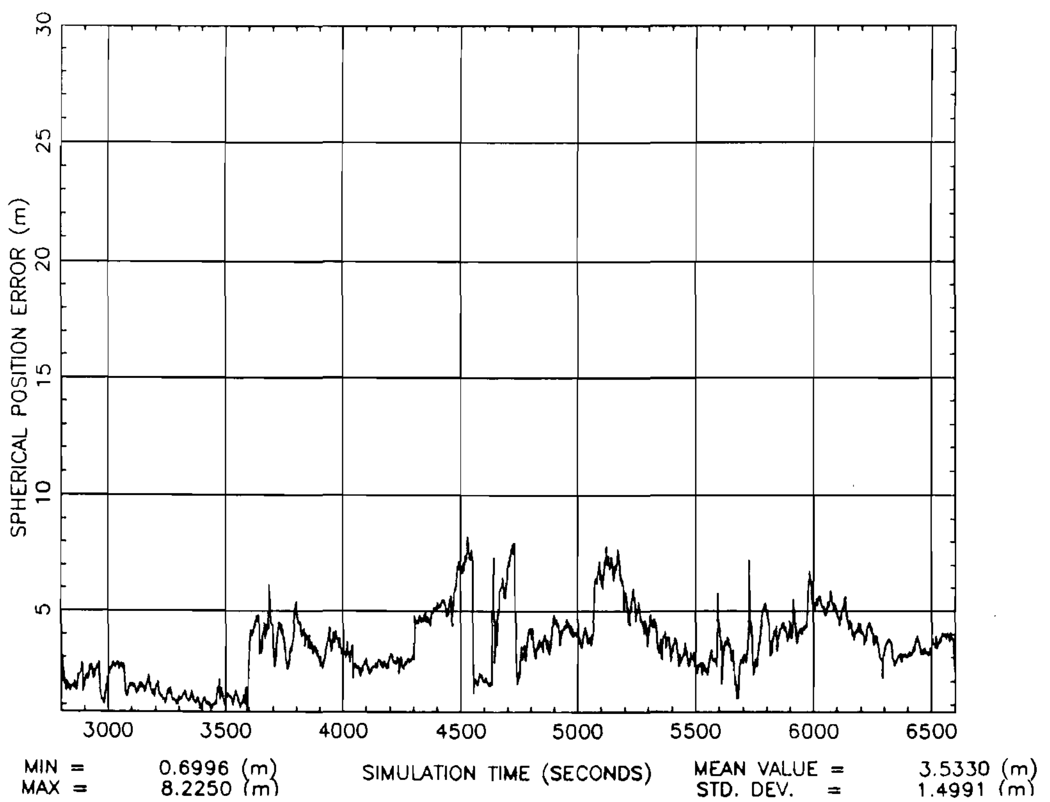


Figure 6. Spherical Position Error when GDOP < 6

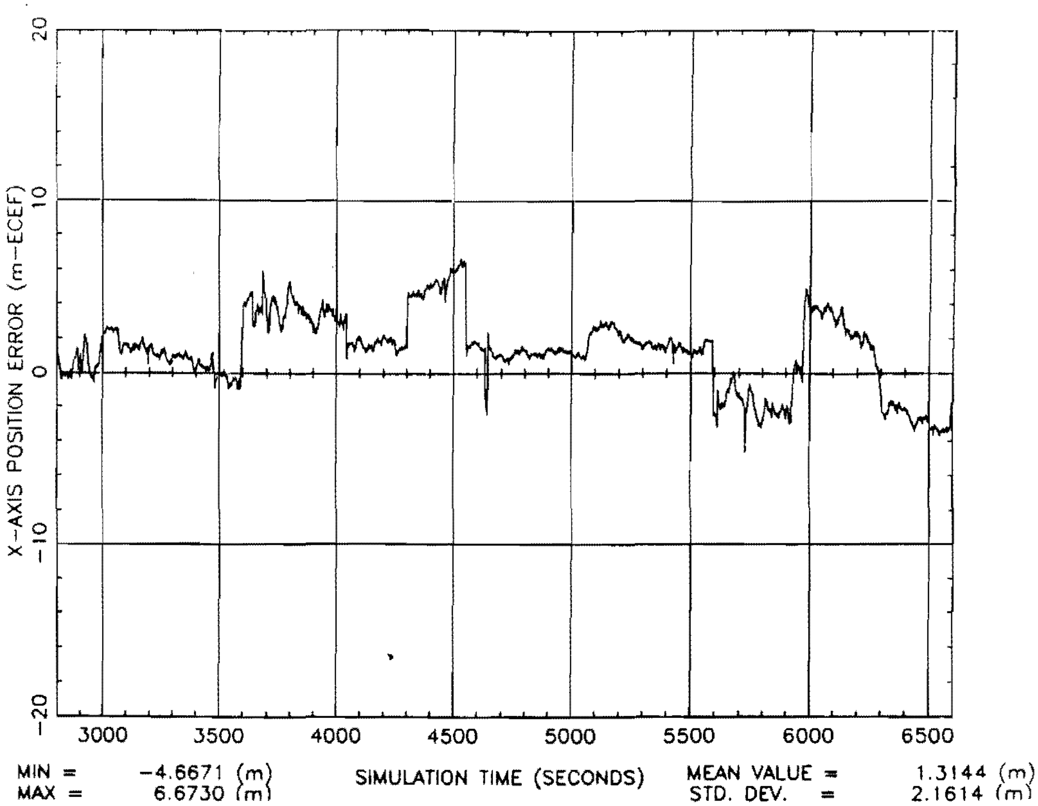


Figure 7. X-axis Position Error when GDOP < 6

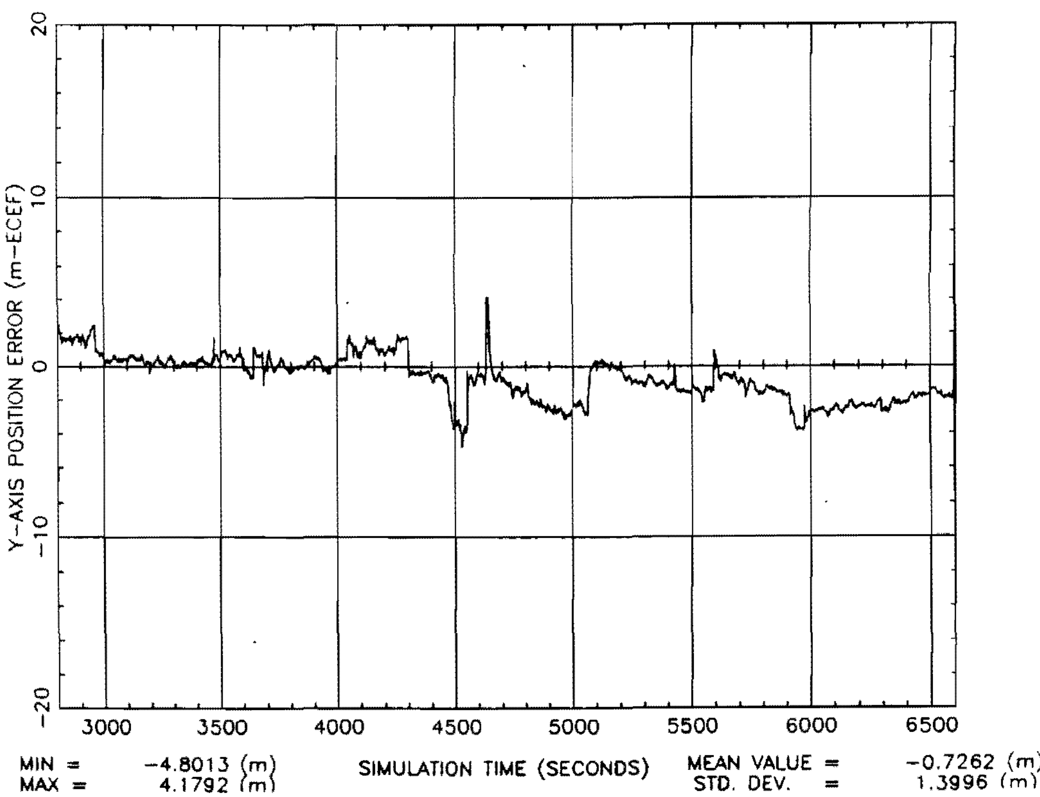


Figure 8. Y-axis Position Error when GDOP < 6

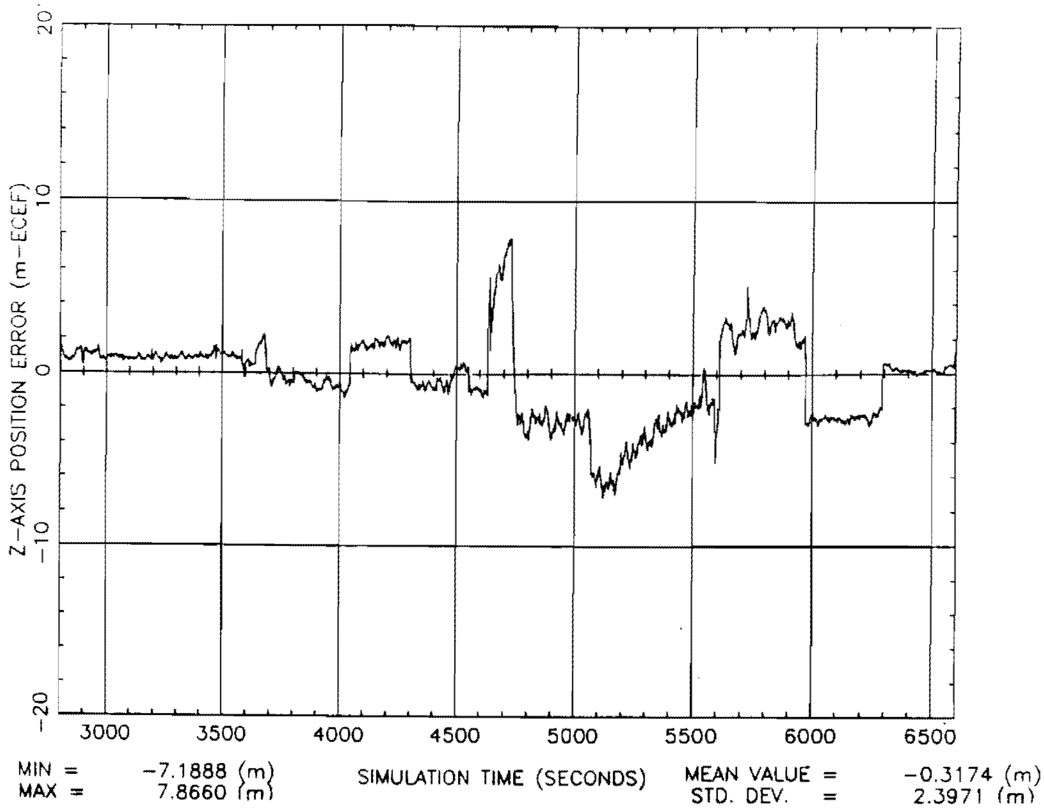


Figure 9. Z-axis Position Error when GDOP < 6

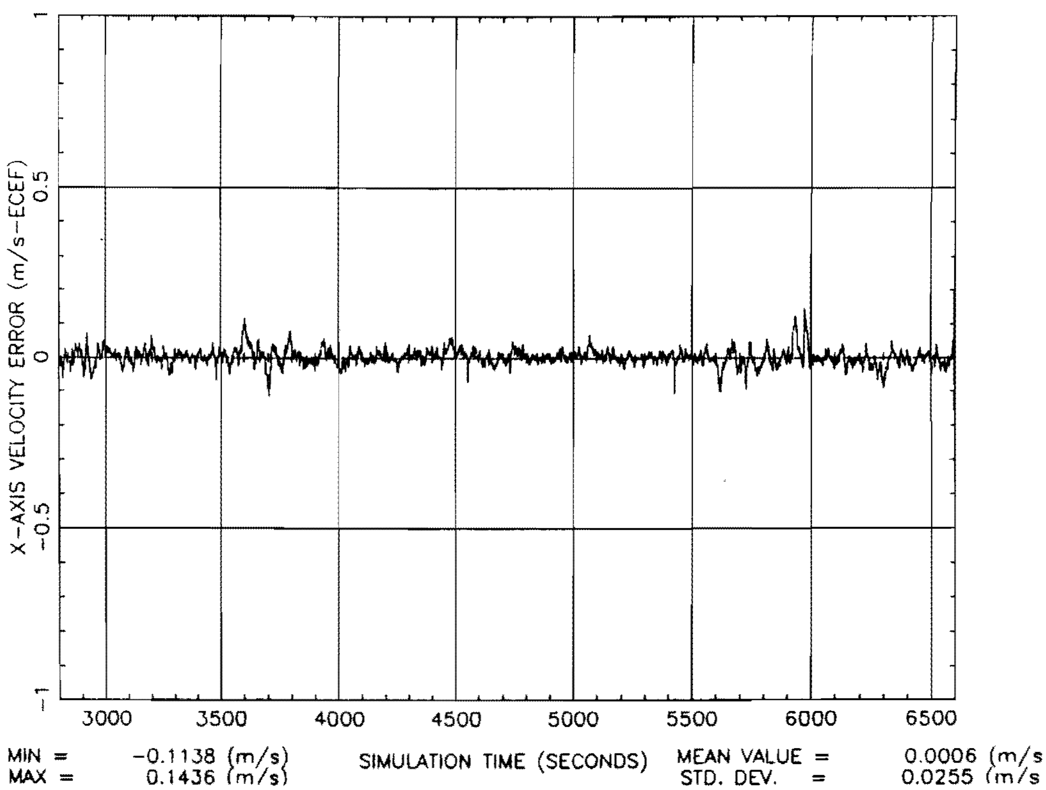


Figure 10. X-axis Velocity Error when GDOP < 6

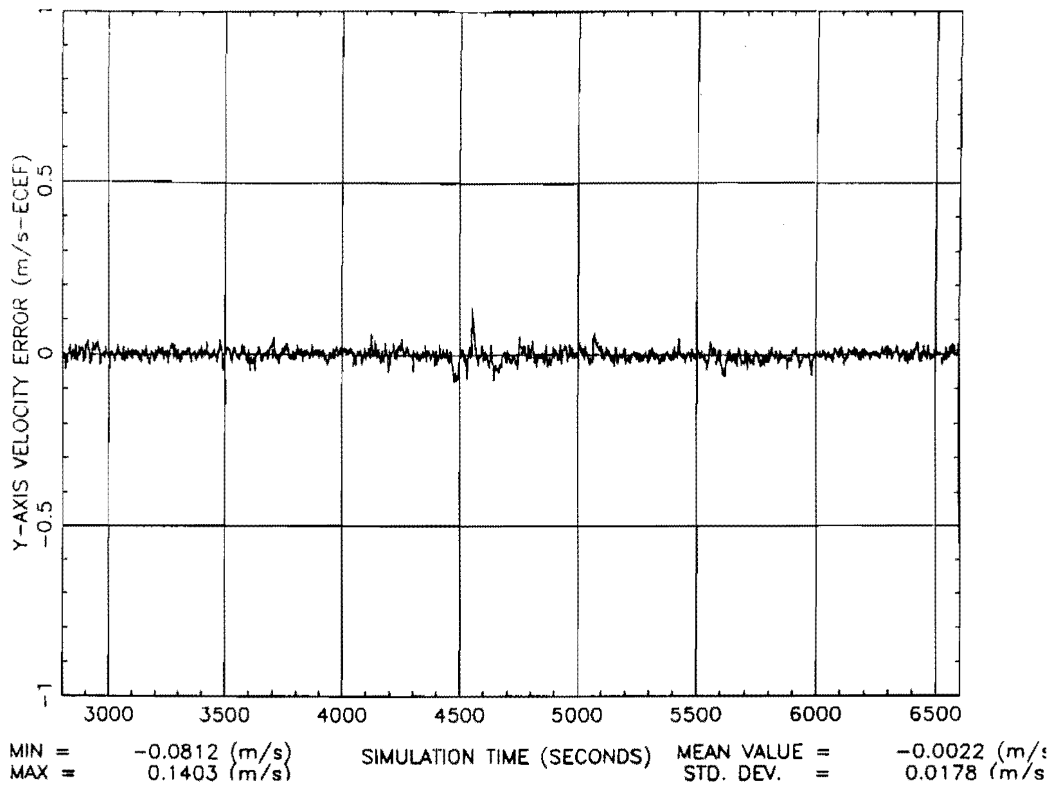


Figure 11. Y-axis Velocity Error when GDOP < 6

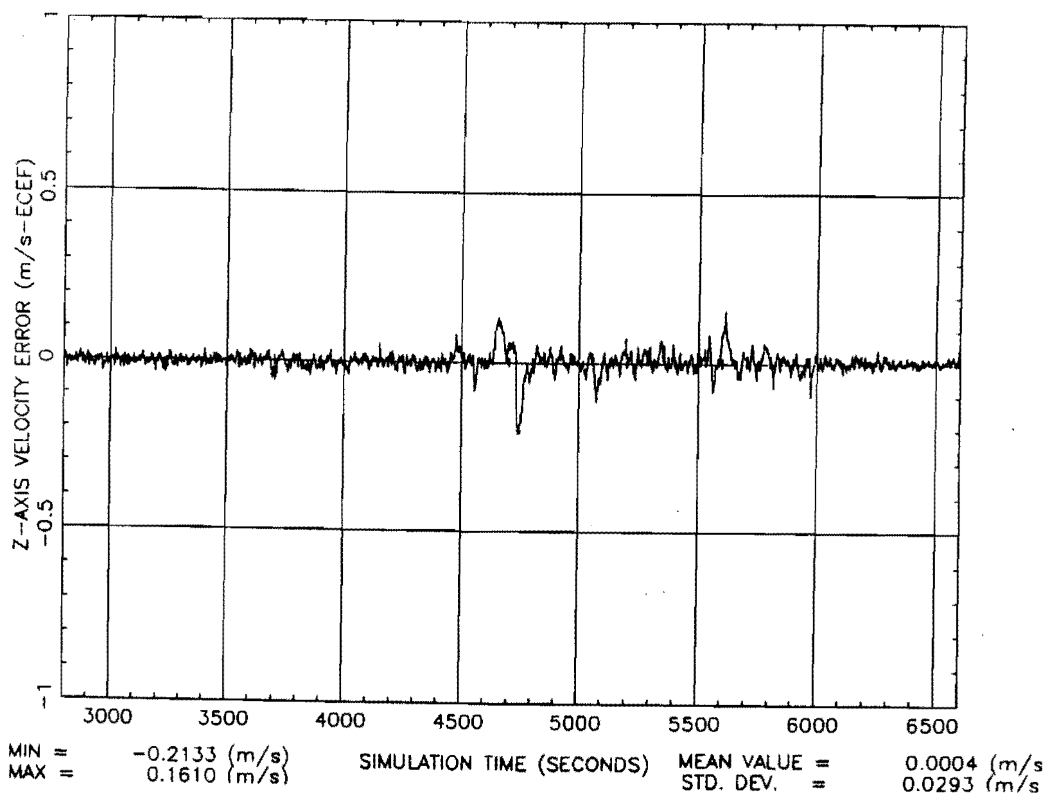


Figure 12. Z-axis Velocity Error when GDOP < 6