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SENSORS SESSION

Globally Corrected GPS (GcGPS): C-Nav GPS System

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Biography

Mr. John Roscoe-Hudson is a Systems Development Manager in the GPS Services Group with C&C Technologies, Inc. Mr. Roscoe-Hudson has degrees in Industrial Automation and Process Control and Electrical and Electronic Engineering from the University of Wales College, Newport, Gwent, U.K.. He has over 20 years of offshore oil exploration, engineering, and positioning experience in Seismic Exploration and Construction Survey industries. Mr. Roscoe-Hudson's primary responsibilities are the development and integration of equipment and systems for hydrographic and offshore construction survey positioning and data acquisition projects.

Mr. Tenny Sharpe is Director of Deere programs at NavCom Technology Inc. Mr. Sharpe received a B.S. in Physics from Case Institute of Technology in 1969 and a M.S. in Computer Science from the University of California, Los Angeles in 1976. Mr. Sharpe has over 30 years experience in the development of aerospace and industrial electronics. His specializations are software and systems design for GPS navigation systems. He is the chief architect and program manager of the StarFire WADGPS.

Abstract

C&C Technologies, Inc., GPS Services Group has embarked on a program to provide 'global' corrected GPS (GcGPS) positioning services for the hydrographic and offshore oil field exploration, survey and construction industries.

To achieve this goal, C&C Technologies has partnered with NavCom Technology Inc., a wholly owned subsidiary of John Deere & Co., to provide both a continental implementation of a Wide Area Differential GPS (WADGPS) system which provides a new level of accuracy across continental distances, and also by use of technology from the Jet Propulsion Laboratory to implement a worldwide GPS positioning solution with accuracies of the order of a few decimeters. These systems are designed for dual frequency GPS signal operations and are based on several key technical developments:

Low-cost, high-quality, dual frequency GPS receivers were developed for use as both reference receivers and mobile receivers;

Special dual frequency extended smoothing techniques were developed which allow the use of refraction corrected measurements for both the reference and mobile receivers, resulting in removal of ionosphere as an error source, and in significant reduction in errors due to multipath - two of the largest error sources in a WADGPS system;

A new L-band satellite communication receiver was developed which uses a single, multi-function antenna designed to receive both of the GPS frequencies (L1 and L2) and the Inmarsat L-band communication frequencies (1525-1565MHz);

Wide area Correction Transform (WCT) correction algorithms were developed which exploit the dual-frequency architecture of the system to generate a single set of corrections uniformly accurate across any continental region resulting in lower bandwidth requirements and more centralized processing; redundant subsystems and monitoring equipment are utilized to provide a high degree of system reliability, availability and service integrity;

The Real-Time correction algorithms were developed by JPL, and implemented in their Real Time GIPSY software (RTG). RTG exploits the dual-frequency architecture of the system to generate a single set of corrections uniformly accurate across the entire world, which also results in lower bandwidth requirements and centralized processing. Redundant subsystems and monitoring equipment are utilized to provide a high degree of system reliability, availability and service integrity;

The paper reviews errors in GPS measurements, the StarFire system architecture, infrastructure, GPS performance, and user equipment. Surface navigation positioning examples are provided for the current operational system and the future directions that are planned for the systems continued implementation is outlined.

Traditional Pseudorange Correction

Traditional Differential GPS (DGPS) relies on the concept that the errors in the position at one location are similar to those for all locations within a given (local) area. By recording GPS measurements at a point with known coordinates, the local GPS observation errors can be quantified and one pseudorange correction for each GPS satellite observation can be computed. By transmitting these pseudorange corrections to remote mobile users and applying them in real-time (less than 30 seconds), the remote mobile user accuracy of GPS, with or without SA 'dither', for instantaneous horizontal positioning is reduced to less than 5 meters (and even sub-meter with modern commercial survey grade GPS receivers) 95% of the time. DGPS is now a well-practiced technique for areas such as Navigation, onshore and offshore Surveying and Mapping etc.

In traditional, DGPS, where pseudorange corrections are generated at a reference station (or network), an all-in-view policy is adopted. By transmitting these individual corrections for the 'all in view' satellites (at the reference), to the mobile user, they can only apply the pseudorange corrections for the 'common in view' satellites observed at the mobile location.

In order to minimize (as far as possible) any errors that may be introduced, it is imperative that the reference station and the mobile user are able to track the same GPS satellites and thus the maximum baseline distance is one limiting factor. Another is that the accuracy of the mobile user position can be degraded by as much as several decimeters for every 100Km of the baseline distance separation between the reference station and the mobile user. This is due to geographic spatial de-correlation errors introduced by the different ionosphere delays and GPS satellite orbit differences between the DGPS Reference Site and each individual mobile GPS users position.

The reference station (or network) computes not only a Pseudorange Correction (PRC) for each satellite, but a Range Rate Correction (RRC), is also computed. Thus, the mobile user is able to model the time varying characteristics of the pseudorange correction over the time intervals in which they are 'periodically' generated at the reference station and applied at the mobile location (the age of correction).

In summary, DGPS pseudorange corrections combine together into one correction all the errors produced by the GPS satellite Ephemeris, Clock, and earth atmospheric delays at one and the same time for the reference station.

GPS Measurement Error Sources

GPS user range error and bias sources can be identified as follows:

Ephemeris data--Errors in the location of the GPS satellite in its orbit
Satellite clock--Errors in the atomic clock signal, including SA
Ionosphere--Errors caused by ionospheric effects
Troposphere--Errors caused by tropospheric effects
Multipath--Errors caused by reflected signals entering the GPS receiver antenna
Receiver--Errors in the measurement of time/range caused by thermal noise, computation accuracy, and inter-channel biases

Ephemeris error is due to the small inaccuracies of the broadcast GPS message of the GPS satellite location. It is typical that the radial component of this error is the smallest: the along-track and cross-track errors are larger by an order of magnitude. The ‘line of sight’ projections of the GPS satellite positioning error affect each GPS observer differently.

Satellite Clocks are fundamental to the NAVSTAR GPS system so that the one-way ranging measurement process can be accomplished. Each satellite broadcasts it’s own clock adjustment values so as to allow the user to develop accurate GPS satellite clock predictability. These satellite clock errors affect both the C/A- and P-code users in the same way, which result in a residual clock error for each GPS satellite. All GPS observers receive an identical satellite clock error.

Ionosphere errors or delays are unique to the local area for each GPS observer, and are introduced due to free electrons in the ionosphere. GPS radio signals do not travel at the vacuum speed of light as they transit this region. The modulation on the signal is *delayed* in proportion to the number of free electrons encountered. The ionosphere is usually reasonably well behaved and stable in the temperate zones; however, near the equator or magnetic poles it can fluctuate considerably. *The solar 11-year activity cycle also affects the ionosphere and causes 'scintillation' effects, which are problematical along the geo-magnetic equator when the solar cycle is at its peak.* This local error can be resolved by the use of dual frequency, L1 and L2, observations by the GPS observer.

Troposphere errors are another deviation from the vacuum speed of light, and are unique to the local area for each GPS observer. Variations in temperature, pressure, and humidity all contribute to variations in the light speed of radio waves. Both the code and carrier will have the same delays, and use of a reliable model can reduce most of this error.

Multipath Errors are caused by reflected signals entering the antenna of the GPS receiver and masking the real correlation peak. These effects tend to be more pronounced in a static receiver near large reflecting surfaces. Monitor or reference stations require special care in locating so as to avoid unacceptable errors. The first line of defense is to use the combination of antenna cut-off angle and antenna location that minimizes this problem.

Receiver Errors vary from GPS unit to GPS unit. Initially most commercial GPS receivers were 'sequential', in that one or two tracking channels shared the burden of locking on to four or more satellites. As chip technology improved, it was common to place three or more tracking channels on a single inexpensive chip. As the size and cost have shrunk, techniques have improved and 'parallel' multi-channel receivers are common. Most modern GPS receivers use an all digital design the allow very low signal noise and phase tracking design solutions.

What does this all mean?

The accuracy and stability of 'real-time' corrected GPS navigation solutions are dependant on:-

- How well the GPS signal environmental errors are measured and the computed corrections are applied by the mobile GPS user (ie; Ephemeris, Clock, Ionosphere, and Troposphere errors)
- How good the GPS antenna mounting location is selected (ie; Multipath errors).
- The quality of the GPS receiver itself (ie; Receiver errors).

The StarFire Correction Service

Figure 1 shows an overview of the StarFire WADGPS network. At a conceptual level, it is similar to other wide-area dGPS systems such as the Federal Aviation Administration's **W**ide **A**rea **A**ugmentation **S**ystem (WAAS).

For the WCT networks, a number of reference/monitor sites are distributed across the continental U.S., Europe, South America and Australia. (sites in green)

For the RTG network, another set of reference/monitor sites are distributed across the entire world (sites in red).

Each reference site sends dual frequency observables for all satellites in view as well as system integrity information to two redundant network processing hubs (NPH) via terrestrial communication links (sites in blue).

The NPHs combine the GPS RAW observables from all of the WCT sites, in a particular continental region and generate a single set of wide-area corrections (WCT) based on refraction corrected measurements. The corrections are sent, via landlines, to the land earth station for uplink to the geo-stationary, L-band communications satellite for broadcast to suitable equipped users throughout the continental service area.

In addition, the NPHs combine the GPS RAW observables from all of the RTG sites, for the entire world, with the WCT site observations and generate a single set of real-time GIPSY corrections (RTG) based on refraction corrected measurements. Again, the corrections are sent, via landlines, to the land earth station for uplink to the geo-stationary, L-band communications satellite for broadcast to suitable equipped users throughout the Inmarsat global service areas.

The dual-frequency GPS user equipment receives the corrections broadcast from the communications satellite, applies them to its own observed, refraction corrected pseudoranges and performs a navigation solution. The resulting corrected GPS position; velocity and time (PVT) are output from the user equipment to other subsystems on the platform/vehicle/vessel to support the navigation positioning control requirements.

Although similar at the conceptual level to other WADGPS architectures, the StarFire system has several important features that discriminate it from more conventional designs. Foremost is the optimization of the system to exploit the use of dual frequency GPS receivers for both the reference sites and the mobile user equipment. This approach is made practical by the availability, from by NavCom Technology Inc., of a relatively low-cost, high-performance, compact, dual frequency GPS receiver

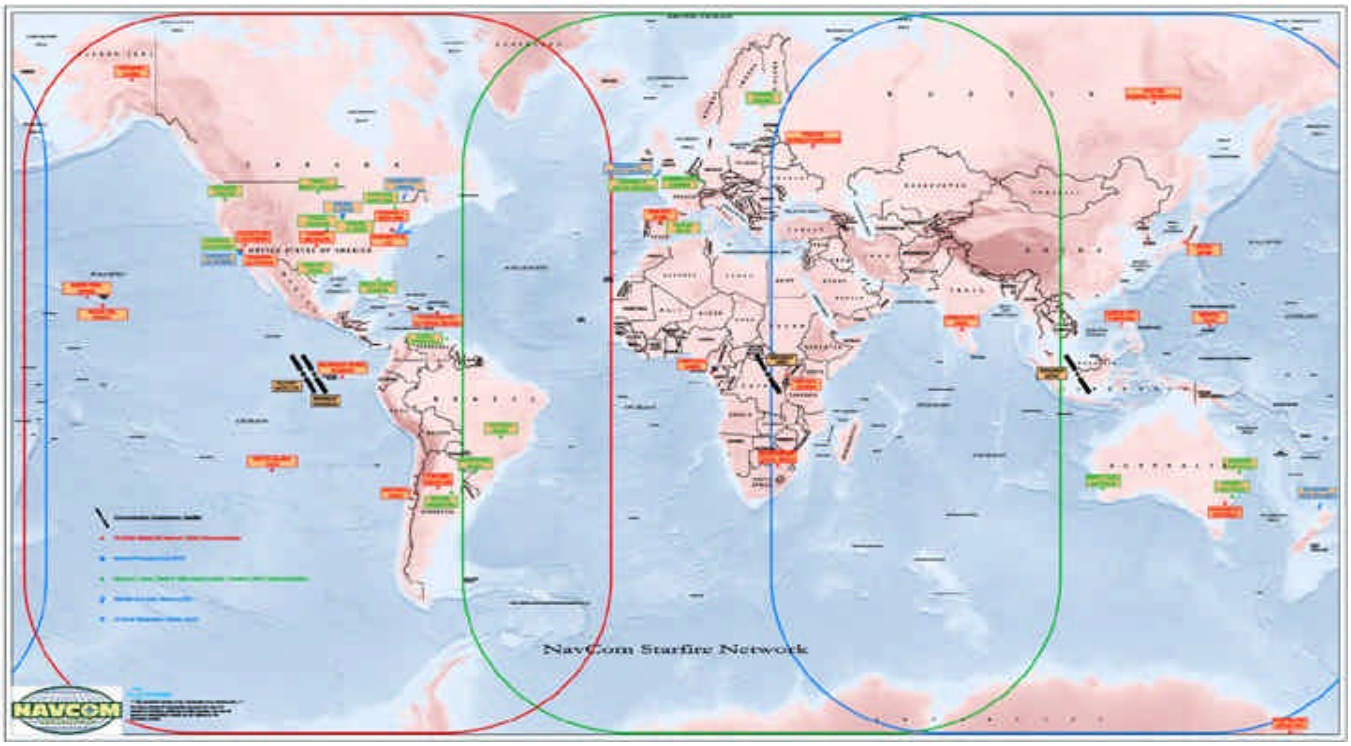


Figure 1. Overview of the StarFire Global Networks

StarFire Ground Reference Network

Figure 2 shows the overall topology of one of the StarFire Ground Reference Networks (GRN) for WCT (CONUS), in the continental U.S. It is comprised of seven reference/monitor sites, two redundant network-processing-hubs and an uplink facility for the geostationary communications satellite.

Each of the reference/monitor sites is configured with an identical set of equipment including:

a) Two redundant NCT2000D GPS reference receivers which send a full set of dual frequency observables for all satellites in view to both of the redundant processing hubs,
b) A fully packaged production StarFire GPS user equipment unit which serves as an independent monitor receiver,
c) Communications equipment (routers, ISDN modems),
d) A remotely controlled power switch and UPS module.

The main communication lines used to link the reference sites with the network processing hubs are frame relay private virtual circuits (orange and blue lines in Figure 2). Each frame relay circuit is backed up with an ISDN dial up line that is activated automatically from either of the network processing hubs in the event any frame relay connection fails.

The same implementation is used for the communication lines to and from the hubs and the geo-stationary satellite land earth station (LES) uplink facility. The LES facilities are also provided with dual, on-line, redundant L-Band signal modulation equipment rack to further ensure that no single point of failure can affect the transmission of the StarFire correction message signals.

The GPS user equipment units located at each of the reference sites, called monitor units, operate independently. They receive the broadcast correction stream from the geo-stationary communications satellite, perform corrected GPS navigation and report their positioning results back to the processing hubs using the same communication lines as the reference receivers.

In addition to the corrected GPS positioning results, the monitor data includes the received signal strength of the L-band communications satellite, packet error statistics, age of StarFire corrections, signal strengths for the received GPS satellites, PDOP and other operating parameters. This data, from all of the GRN sites, is continuously monitored by an Alert Service processor which automatically generates E-mail and pager messages to on-call network service engineers in the event of a StarFire GPS reference site, correction signal, or service failure.

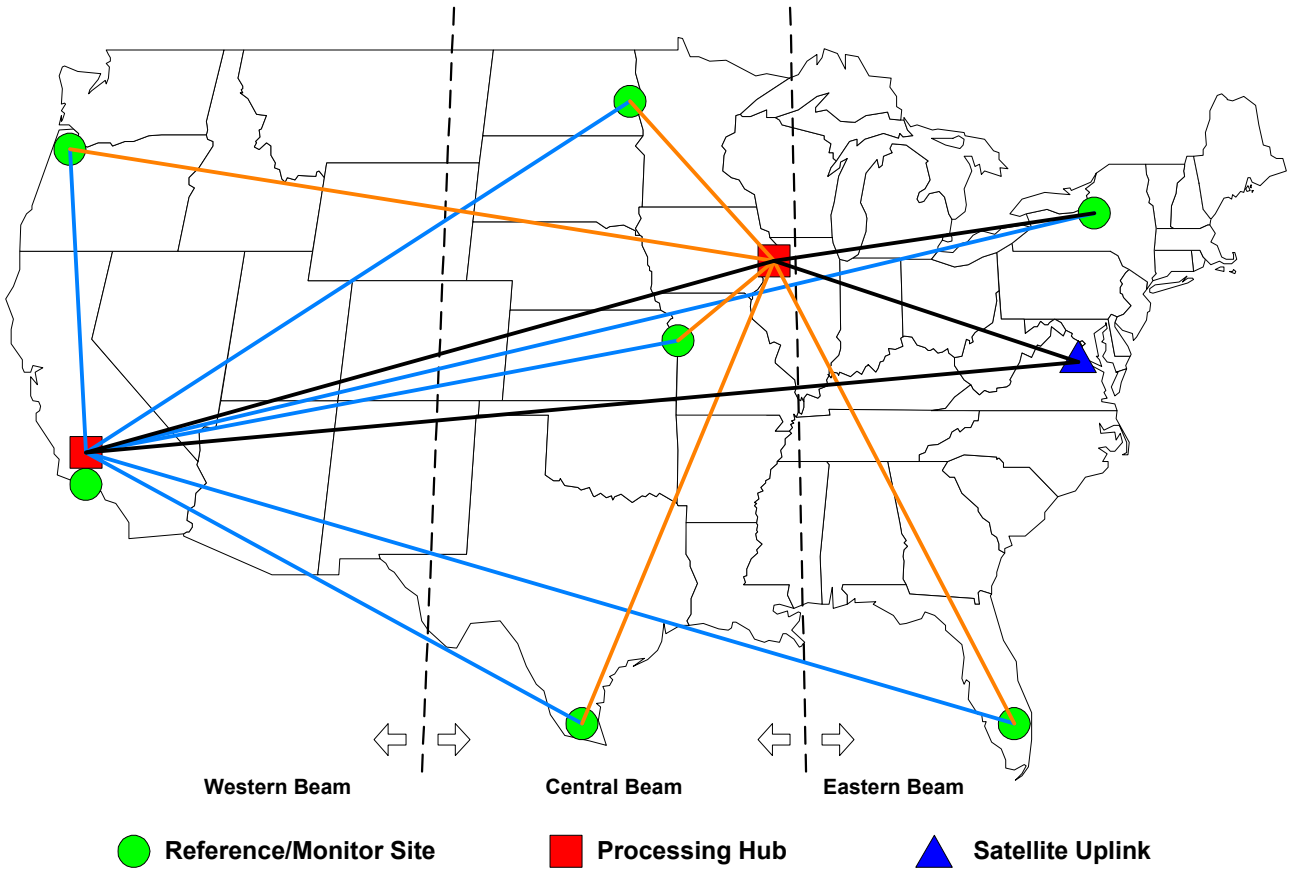


Figure 2. StarFire WCT Ground Reference Network for North America

Wide Area Correction Transform (WCT)

The algorithm used at the processing hubs to compute the StarFire WADGPS corrections is named Wide area Correction Transform (WCT). The WCT uses the following inputs:

a) dual frequency observables (CA code pseudoranges, L1 carrier phase, P2 code pseudoranges and L2 carrier phase) for all of the GPS satellites tracked at the GRN reference receivers, delivered at 1Hz in real time,

b) broadcast ephemeris records from the GRN reference receivers delivered in real time,

c) a configuration file defining the precise location (±2cm) of each of the GRN reference receiver antennas as determined from network solutions based on the IGS worldwide control stations.

The list of NavCom Technology's current StarFire WCT network locations are seen in Table 1.

The dual frequency observables are used to form smoothed, refraction corrected pseudoranges, which are free of ionosphere delay and, due to extended smoothing, virtually free of multipath. These are then normalized with respect to receiver clock offsets and modeled site troposphere delays. Finally, the normalized pseudoranges for each satellite are combined in a weighted average to form a single, wide area pseudorange correction for that satellite. A similar process is performed using the finite difference of the carrier phase to generate pseudorange rate corrections. The ensemble of these corrections for all satellites in view is formatted into a tightly packed, binary message and sent from the hub to the uplink facility for broadcast on the geo-stationary communications satellite.

Because the WCT uses refraction corrected pseudoranges, the resulting corrections are free of the errors caused by spatial decorrelation of ionosphere delays that are inherent in single frequency corrections. When dual frequency mobile receivers are used which employ the same refraction corrected techniques, a single set of corrections can be used across the entire continental service area with uniform, high accuracy.

WCT Continental Networks

	North America
1	Redondo Beach, CA
2	Portland, OR
3	Fargo, ND
4	Kansas City, MO
5	Weslaco, TX
6	Moline, IL
7	Belleglade, FL
8	Syracuse, NY
	Australia
9	Perth A
10	Perth B
11	Sydney
12	Brisbane
13	Melbourne
	Europe
14	Tampere, Finland
15	Madrid, Spain
16	Goonhilly, U.K.
17	Zweibruken, Germany
	South America
18	Rosario, Argentina
19	Horizontina, Brazil
20	Catalao, Brazil

Table 1. The location of StarFire WCT GPS Ground Reference Network Sites

Two major advantages result from having one consolidated set of corrections for the entire service area:

a) Bandwidth requirements on the geo-stationary communications satellite are minimized. This results in a significant cost savings since the price of leased satellite channels is roughly proportional to the broadcast power required which is directly proportional to the bandwidth required.

b) The correction computation algorithm, including the final weighting, is done at a centralized facility (at the network processing hubs) instead of being performed by the user equipment based on location dependent models. This enables improvements and upgrades to the WCT to be made, in most cases, without requiring changes to the algorithms in the mobile user equipment. This is a significant logistic benefit when, as is the case now with StarFire, thousands of user equipment units are deployed across the continental U.S.

Real Time GIPSY (RTG)

Over the past 20 years the California Institute of Technology's Jet Propulsion Laboratory has evolved into one of the premier centers for research in precise orbit determination. The venerable GIPSY-OASIS software suite, used by research teams worldwide for geodetic analysis and orbit determination was developed at JPL.

Over the last six years, the GPS group at JPL has created a system, based on adaptations and refinements of the core GIPSY algorithms, which operates in real time to produce high precision GPS corrections suitable for broadcast to navigation users. This system, called Real Time GIPSY (RTG), accurately estimates and models many parameters and error sources in the GPS satellite system using real time data received via the Internet from a worldwide network of GPS reference receivers.

Two key correction factors are computed for transmission to the user navigation receivers:

1) Clock corrections for each active GPS satellite are computed every few seconds. Like the WCT method, these corrections are based on refraction corrected measurements and are therefore optimized for dual frequency user equipment.

2) Orbit corrections for each active GPS satellite are computed every few minutes. Computation of these corrections is facilitated by measurements from a globally distributed network of reference receivers that provide observability of the orbit errors with sufficient geometry.

JPL/NASA Global GPS Network (GGN)

In support of NASA's positioning requirements for many of their space and terrestrial projects, JPL and NASA have established a network of approximately 60 globally distributed GPS reference receivers called the Global GPS Network (GGN). As part of the RTG development, twenty-three of these receiver sites, to date, have been linked to a processing center at JPL via the Internet. Analysis and monitoring of the latency and reliability of real time Internet GPS data transfers has been an important component of the RTG program [http://gipsy.jpl.nasa.gov/igdg/].

The complete list of these sites and installation locations are seen in Table 2.

JPL GLOBAL Network

1	Cordoba, Argentina
2	Christiansted, Virgin Islands
3	Fairbanks, Alaska, USA
4	Galapagos Island, Ecuador
5	Greenbelt, Maryland, USA
6	Goldstone, USA
7	Dededo, Guam
8	Krugersdorp, South Africa
9	JPL T/F, Pasadena, USA
10	Kokee Park, Hawaii, USA
11	Madrid, Spain
12	Mbarara, Uganda
13	Ross Island, Antarctica
14	Mauna Kea, Hawaii, USA
15	Moscow, Russia
16	Franceville, Gabon
17	Lamont, Oklahoma, USA
18	Quezon City, Philippines
19	Santiago, Chile
20	Tidbinbilla, Australia
21	USNO Master Clock, USA
22	Usuda, Japan
23	Yakutsk, Russia

Table 2. The location of JPL/NASA's Global GPS Network Sites

RTG and StarFire

NavCom Technology, Inc., has teamed with JPL in a joint effort to merge the RTG technology and JPL/NASA GGN with the StarFire system. The major benefits and elements of synergy between the two systems include:

1) Both systems are optimized for dual frequency GPS user equipment capable of producing refraction corrected measurements.

2) The orbit and clock corrections produced by the RTG process are globally uniform. One set of corrections is generated for all active satellites, which is applicable worldwide. This provides a bandwidth advantage similar to the WCT method.

3) The level of accuracy obtained by dual frequency GPS user equipment with RTG broadcast corrections is exceptional, approximately 10-cm. (one sigma horizontal).

It is the goal of this effort to achieve a reliable, worldwide signal distributed over the StarFire communications satellite channels that will deliver 10cm. accuracy.

StarFire Positioning Accuracy and Test Results

Figure 3 shows WCT (CONUS) position accuracy results for a 24-hour test on a stationary control point taken on August 27, 2000.

> Typically, 24-hour accuracy results are less than 30 cm, one-sigma, per horizontal axis. Results compiled over the last year, including the onset and peak of solar cycle #23, show this level of performance to be relatively independent of solar activity and its associated ionosphere disturbances.
>
> Accuracy performance has also been found to be independent of location within the service area.

These results are attributed to the dual frequency, refraction corrected techniques on which the StarFire system is based.

Figure 4a shows RTG position accuracy results for a 15-hour period on a stationary control point undertaken in mid-2001, while Figure 4b show the same data in a scatter plot view.

The results show the performance that is to be expected when the full RTG correction service is fully operational.

Figure 3. StarFire Dual Frequency Navigation, 24 Hours

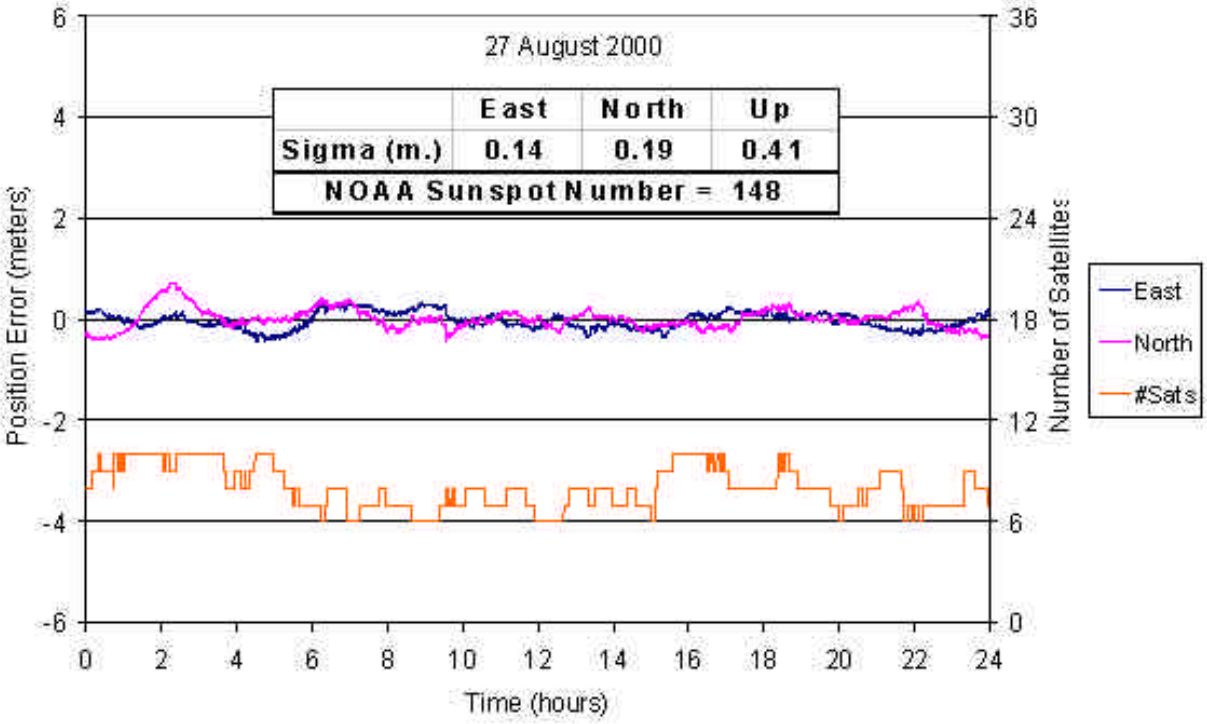


Figure 4a Navigation Results Using RTG Global GPS Corrections
15 Hours Stationary Over a Geodetic Control Point

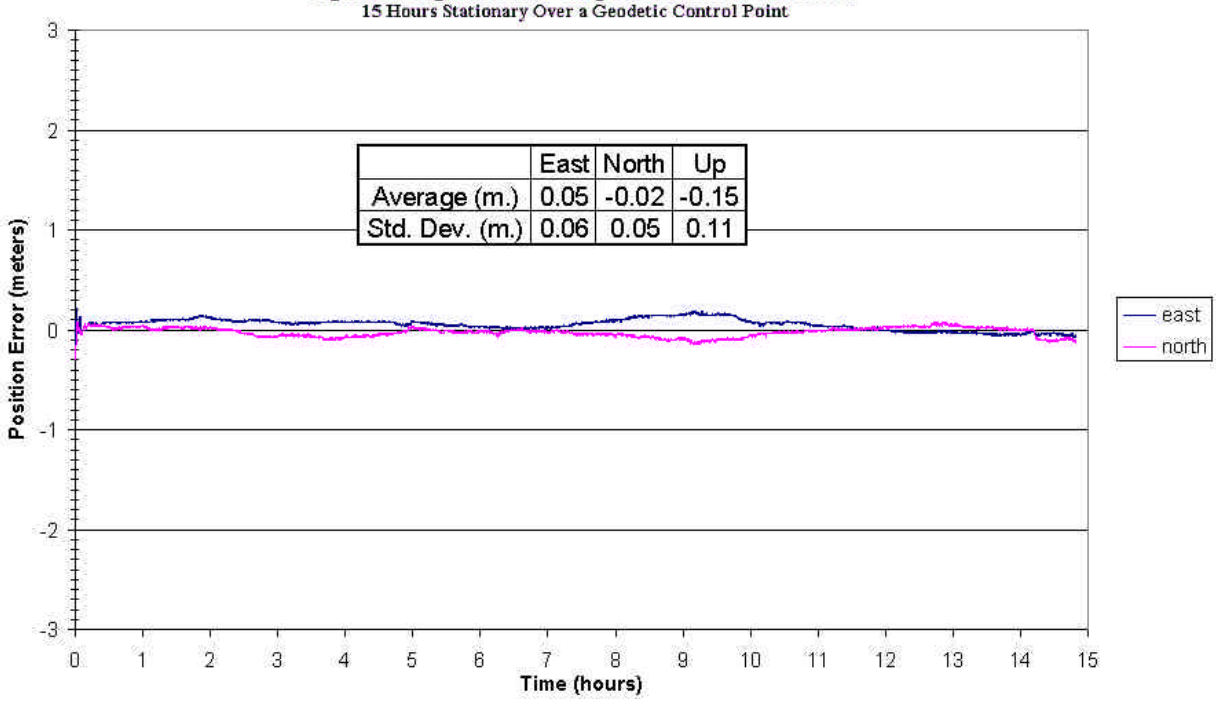
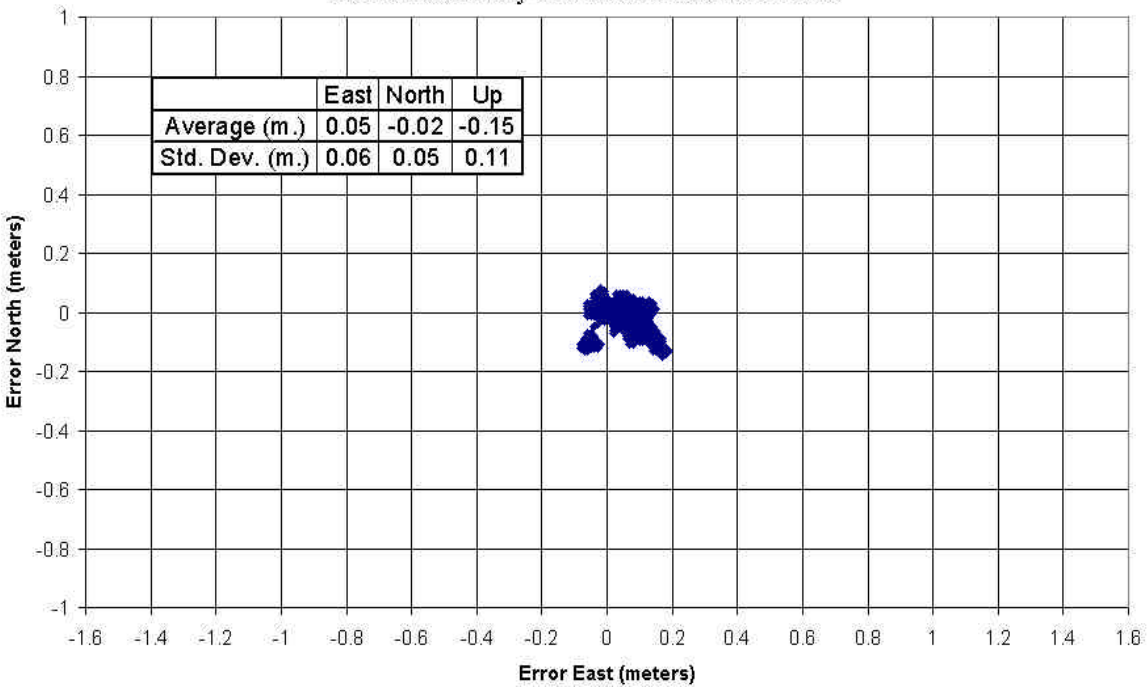


Figure 4b Navigation Results Using RTG Global GPS Corrections
15 Hours Stationary Over a Geodetic Control Point



GPS User Equipment

Figure 5 shows the major components of the StarFire network GPS user equipment as packaged for C-Nav.

a) A multi-function antenna assembly is used which is capable of receiving the L1 and L2 GPS frequencies as well as the Inmarsat receive frequency band. The gain pattern of this antenna is designed to be relatively constant even at lower elevation angles. This allows for an efficient link budget when the unit is operated at higher latitudes where the elevation of the geo-stationary communications satellite is low.

b) An L-band receiver was developed to acquire, track, down convert, sample and demodulate the StarFire data stream broadcast from the geo-stationary communications satellite. The receiver is frequency agile across the Inmarsat receive band under software control.

c) A state-of-the-art, dual frequency GPS receiver module, designed and produced by NavCom, provides the most important enabling technology in the user equipment.

Connections for the external interfaces of the C-Nav user equipment are provided through a sealed 8-pin connector. Power requirements are DC, with an input range of between 10 to 40 volts. Data interfaces include both RS232 serial data ports and also a CAN Bus.

The Dual Frequency GPS Engine

The GPS engine is a compact, high-performance, dual frequency device aimed at OEM applications. In the C-Nav user equipment, it is mounted inside the lower housing and interfaces to the digital board of the L-band receiver via an RS232 serial port. StarFire WCT and RTG corrections are input from the L-band receiver and 5Hz PVT data is output to the L-band receiver onboard processor for transmission via the external interfaces (RS-232 and CAN Bus).

The GPS engine has twelve (12) dual frequency GPS channels, ten (10) of which are allocated for GPS signal tracking and the remaining two (2) for WAAS, L-Band, signal tracking. It produces GPS observables of the highest quality suitable for use in the most demanding applications including millimeter level static surveys.

Key features of the GPS engine include:

- A patented multipath reduction technique is built into the digital signal processing ASICs of the receiver. This greatly reduces the magnitude of multipath distortions on both the CA code and P2 code pseudorange measurements. When combined with extended, dual frequency code-carrier smoothing, multipath errors in the code

pseudorange measurements are virtually eliminated.

- A patented technique is used to achieve near optimal recovery of the P code from the anti-spoofing Y-code resulting in more robust tracking of the P2/L2 signals.

- The compact size (4" x 3"x 1") of the Geodetic Grade, Dual Frequency, GPS engine allows it to be readily integrated into the StarFire GPS User package.

- The GPS engine provides a high-resolution 1pps output signal, synchronized to GPS time. This signal is used by the L-band communications receiver to calibrate its local oscillator and thus accelerate acquisition of the StarFire correction signal. NavCom Technology has also patented this technique.

The measurement processing of the GPS engine software version in the StarFire GPS user equipment is designed to be fully compatible with the StarFire WCT and also the RTG correction signals.

Dual frequency code and carrier phase measurements are used to form smoothed, refraction corrected code pseudoranges. These are adjusted with the StarFire WADGPS corrections and used in a weighted least squares fix to generate position, velocity and time (PVT) estimates that are output at either 1Hz or 5Hz under software control.

Figure 5. Major Components of the Offshore C-Nav GPS User Equipment

Offshore Applications of the C-Nav GPS System

StarFire system and GPS user equipment is currently used in a number of agricultural applications that include crop yield mapping, field documentation GIS/Mapping, operator assisted steering and automatic steering. Over 7,000 units have been produced and are in use for these agricultural applications.

For the offshore survey, navigation and construction industry, the C-Nav GPS System has been introduced so as to bring to the offshore industry the opportunity of using the proven StarFire network corrections and the dual-frequency, high-accuracy GPS user equipment in the various continental StarFire WCT operational areas. The global StarFire RTG operation are currently under interim testing and evaluation on the Inmarsat Americas geo-stationary communications satellite, and is scheduled to be available worldwide in the very near future.

The C-Nav GPS System is a viable alternative to existing pseudorange DGPS navigation positioning systems. One major advantage, especially over long 'baseline' distances where errors caused by spatial decorrelation of ionosphere delays are always present in traditional DGPS applications, is the ability for the C-Nav GPS receiver to measure and correct for the user's local ionospheric delays.

To date, the C-Nav GPS receiver has been utilized and tested on offshore positioning projects, using the StarFire WCT (CONUS) corrections alongside exiting DGPS systems.

Figure 6 shows a comparison of a C-Nav GPS receiver unit and a DGPS 'Coast Guard Beacon receiver as compared to a POS/MV Inertial Navigation System conducted over a 100 sail line test period, onboard a C&C Technologies hydrographic survey vessel project.

From figure 6, the RMS differences, for each survey line traverse, between a Coast Guard Beacon DGPS Receiver and a POS/MV reference position show sub-meter agreement.

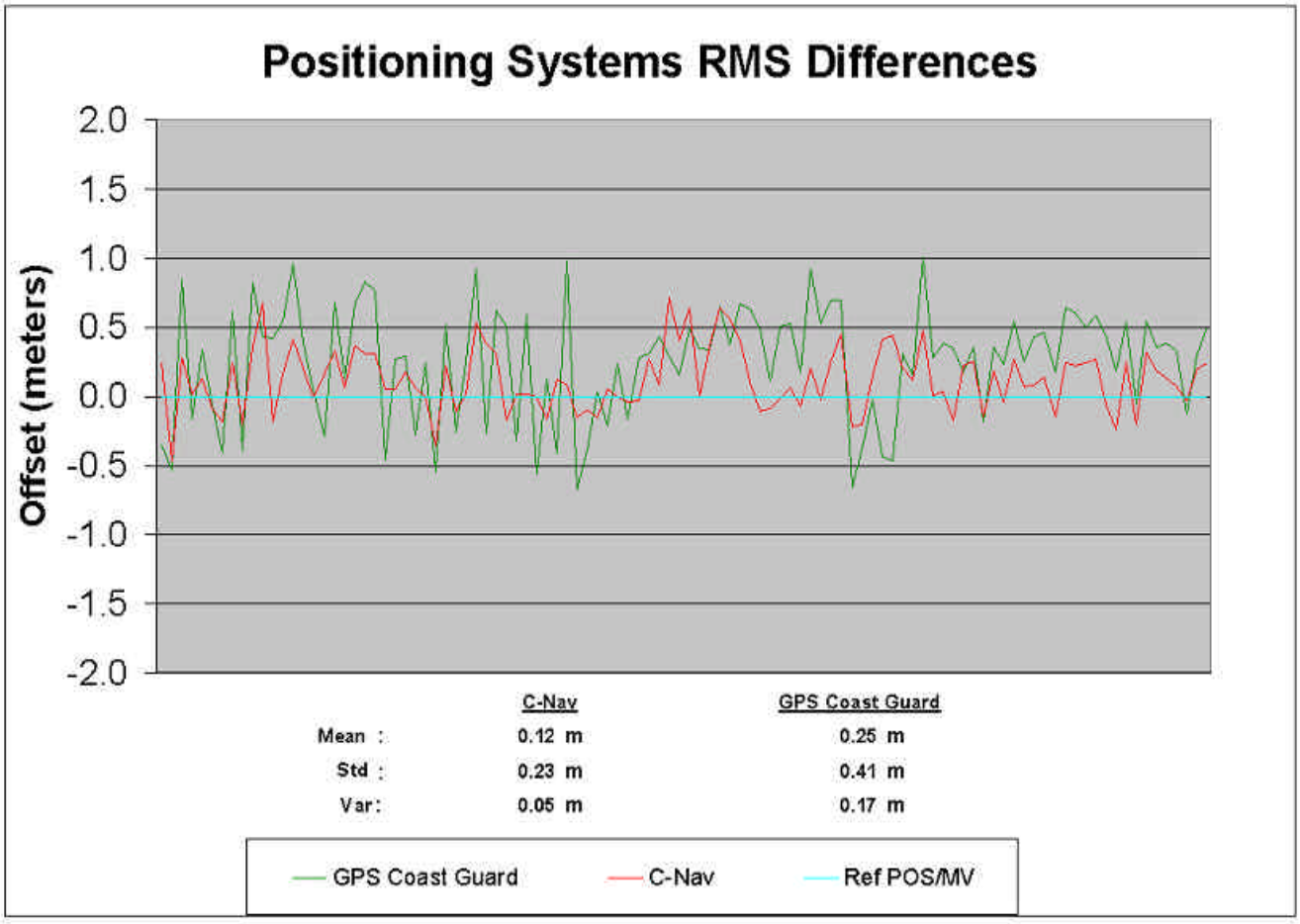


Figure 6 Comparisons of RMS Differences of C-Nav and DGPS

However, the C-Nav GPS receiver using StarFire WCT corrections show closer agreement with the POS/MV reference position and has less unit variance or deviation. Remember, all three systems onboard the vessel, were used in a dynamic operating mode and as such, vessel movement and offset layback alignments affect the analysis shown for all three systems and these effects are not accounted for in the example provided..

The accuracy and repeatability of the C-Nav GPS equipment, with the StarFire correction signal service, surface positioning can be seen to be more than comparable with existing DGPS operations.

Applications for the C-Nav GPS equipment and the StarFire correction signal services include:

- Dynamic Vessel positioning
- Jacket and Template positioning
- Work Boat operations
- Dredging operations and surveying
- Geophysical, Geotechnical, and Geodetic surveying
- Hydrographic surveying
- Oceanographic surveying
- Offshore construction surveying
- Pipeline construction, maintenance, and route surveying
- ROV support positioning
- Commercial diving support positioning
- Underwater cable route, installation, maintenance surveying

The C-Nav GPS System

The basic C-Nav GPS System comprises the following items:

1 C-Nav GPS Receiver
1 C-Nav Control (CnC) Display Unit
1 100 foot Interconnect Cable
1 DC Power Cable
1 C-Nav Operations Manual
1 Set Software Utilities
1 C-Nav GPS Receiver Data and Power Y-Cable

C-Nav Features

The C-Nav system provides the user with industry standard NMEA sentence information. These are:-

GGA - Global Positioning System Fix Data
GLL - GPS Latitude and Longitude Data
GSA - GPS Mode, Satellites used for navigation, and DOP Data
GST - GPS Satellites Position Error Statistics (RAIM compliance)
RMC - GPS Recommended Minimum Specific Data
VTG - GPS Velocity, Track made good and Ground speed Data
ZDA - GPS UTC Date & Time Data

In addition, the C-Nav system provides additional NMEA sentence information in the form of 'proprietary' messages, as follows:-

NAVQ - StarFire Navigation Quality
NETQ - StarFire Network Quality (to be implemented)
RXQ - StarFire Correction Signal Quality
SATS - GPS Dual Frequency (L1/L2) Satellites in view

Other information and data provided by the C-Nav GPS receiver are the calculation of RTCM SC-104 Type 1 pseudorange correction (PRC) binary messages for all satellites 'in view'. These RTCM Type 1 messages are provided so that the user can output to 3rd party interface devices or standard DGPS L1 only receivers. The RTCM Type 1 binary messages are computed by the C-Nav GPS receiver based on the current PVT solution and re-computation of the errors from the L1 range observations. This can be accomplished due to the efficiency and processing power, embedded, in the GPS engine. The

RTCM Type 1 PRC's are output every 5 seconds when enabled.

The user can also obtain information from the C-Nav GPS receiver from the RS232 RAW GPS observations data port. The proprietary data format can be decoded by the use of a purpose built software utility. The use of the software allows the 'binary' information to be stored to a file that can subsequently be converted to a RINEX ASCII format file for post-processing analysis.

The C-Nav GPS receiver provides PVT information at either a 1Hz data rate or a and 5Hz data rate. This is selectable by the user.

Extensive Quality Assurance and Control information is available from the C-Nav GPS System. The primary source of information to achieve this is by the use of the C-Nav Control Display Unit (CnC Display Unit). Alarm conditions and warnings are provided to the user, as is the ability to obtain all of the information on the operation, and performance of the C-Nav GPS receiver and the StarFire network. Additional information is provided by Receiver Autonomous Integrity Monitoring (RAIM) compliance NMEA GPS Statistic (GST) message.

The CnC Display Unit functions as a key element of the C-Nav GPS System. Besides providing the information and control functions for the user, in an easy to read LCD format and by simple keypad control, the CnC Display Unit also ensures that all NMEA messages are immediately output to the user interface, upon receipt from the GPS receiver with zero latency time, and that the C-Nav recomputed, local position, RTCM 'binary' correction messages are re-routed to a separate RS232 data port so that the user can use separately as required.

The C-Nav GPS Receiver and the CnC Display Unit are firmware driven. Thus tools are supplied to allow the user to upgrade the operating firmware for both units in the field. By simple email or ftp receipt of any required 'binary' flash memory program files, the user can quickly and easily reprogram the internal processors operating program code from their Windows 95/NT operating system running on a computer or laptop.

In Conclusion

The operational StarFire Network Processing Hubs with their over redundancy of GPS observations, real-time network monitoring and backup processing and communication links are providing 100% user correction utilization and availability.

The StarFire network correction signals are providing accurate, stable, and precise user positioning solutions in real-time. This is giving existing GPS users reliable and repeatable GPS navigation positioning that ensures the efficiency of their business and operations

C-Nav and the StarFire RTG correction network are a truly **G**lobally **c**orrected **GPS** solution. All the required components essential to accurate real-time positioning have been packaged into an integrated 'masthead' unit with a 'below deck' control display unit. The equipment can quickly and easily be installed on any offshore vessel, vehicle, or platform.

Comprehensive QA and QC information are available from the C-Nav GPS System that allows the user to monitor the navigation solution performance and accuracies.

Other GPS user packaging is available. Development is ongoing to provide new hardware designs for a variety of GPS applications.

Ongoing development is underway to provide 'global' RTG corrections, for all suitably equipped GPS users. The goal is to provide decimeter level positioning accuracies, at any time, and at any geographic location within the current worldwide geo-stationary communication satellite footprints.

JPL/NASA have specified, and are planning, to utilize the RTG correction signals in space flight operations to provide centimeter level positioning in real-time.

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