Core Technology Developments and End-user Products at NovAtel

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BIOGRAPHIES

Simon Newby received his M.Sc.E. in Surveying Engineering in 1997 from the University of New Brunswick. where his master's research involved ionospheric modeling with respect to GPS. He joined NovAtel in 1993 and currently supports much of NovAtel's international dealer network.

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Janet Brown Neumann obtained a BSEE from the University of Kansas in 1978 and an MSEE from Iowa State University in 1981. She has been active in GPS software and algorithm development for 13 years, with her recent focus being on carrier phase positioning.

Bryan Townsend received his M.Sc. in Surveying Engineering from The University of Calgary in 1993. His master's research was in the area of GPS and Loran-C. He is currently doing research in the area of GPS multipath error reduction at NovAtel.

ABSTRACT

At lasr year's ION GPS-95 conference in Palm Springs NovAtel released limited details regarding development of new core technologies, and plans for the introduction of end-user products. One year later, several core technologies have come to fruition. and the drive towards integration of these technologies into end-user products has gained even more momentum.

This paper overviews technological and end-user developments at NovAtel during the last 12 months and gives a rare insight into new developments which are on the horizon.

1.0 INTRODUCTION

Development of core technologies continues to be of paramount importance. ION GPS-96 marks the availability of production versions of NovAtel's new dual-frequency receiver, called **MiLLennium™**, and a new 2 cm RTK positioning system called **RT–2™**.

In recent history NovAtel augmented its product line by offering packaged end-user products for the first time. The initial focus was on the GIS market when at last year's ION GPS-95 GISMO™ (GIS MObile and an accompanying post-processor were released.

More demanding geodetic applications are the target of **OUTRIDER™**, which extends the GISMO concept further by adding dual-frequency MiLLennium technology, **RT–2™** for real-time 2 cm positioning, and a fixed ambiguity post-processing package called **SOFTSURV™**.

MiLLennium RT-2, OUTRIDER. and SOFTSURV are all described in this paper.

2.0 MILLENNIUM

MiLLennium is a dual-frequency L1/L2 GPSCard™ designed for a variety of applications including surveying, differential reference stations. and high precision navigation.

In its standard configuration .MiLLennium independently tracks 12 GPS satellites on Ll and L2 and follows the same philosophy as current NovAtel receivers by offering extremely robust tracking loops and high quality low noise observations at high update rates.

,MiLLennium provides Narrow Correlator CIA-code measurements on L 1, P-code measurements on L2 (AS **on),** and full wavelength phase observations on Ll and L2. Proprietary P-code Delay Correlation Technology is used to track the L2 signal in the presence of P-code encryption.

The receiver accepts position and velocity aiding from MS units, has hooks to accommodate the GLONASS system, and accepts 5 MHz and 10 MHz external frequency standards. As with NovAtel's existing LI receivers, MiLLennium features 2.5 bit sampling on its front end for enhanced EM1 immunity as discussed in *Winer et al (I* 996) and *Skidmore and Liu (1996).*

Final integration of the receiver's digital hardware, radio frequencv (RF) deck, custom VLSI ASIC, and controlling software performed during the second half of 1995.

2.1 MiLLennium Receiver **Design**

Figure 1 shows a block diagram of the MiLLennium GPS receiver.

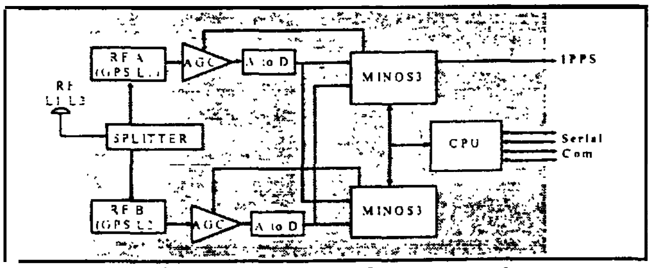

Figure 1: Functional Diagram of NovAtel MiLLennium Receiver

The GPS signal travels from the GPS L1/L2 antenna into an RF splitter which then feeds into two RF modules — one for the GPS Ll signal. the other for the GPS L2 signal. The RF receiver modules downconvert the signal to an internal frequency which can be sampled by the Analogue to Digital (A to D) circuit. The A to D circuit sends digital Ll and L2 samples to each of the two MINOS3 GPS signal processors.

Each MINOS3 GPS signal processor is a custom designed ASIC correlator chip that contains six L1/L2 dual-frequency channels. There are two MIN0S3 chips onboard for a total of 12 dual-frequency channels. Digital signal processing circuitry contained in the MINOS3 chips tracks and processes the downconverted, digitized Ll and L2 signals. MINOS3 output data are passed on to the processor circuitry which calculates pseudorange and carrier phase measurements for each of the channels. and the navigation data. The measurement data are assembled and sent to the user through one of two RS-232 serial ports.

2.2 Systems Integration with MiLLennium

MiLLennium's Eurocard format features the same electrical interface as current NovAtel GPSCards, with the sole exception that +5 VDC is now the only input voltage that is required. The man-to-machine interface remains the same as existing GPSCards although a number of new logs are now available. Therefore, the transition from L 1 GPSCards to dual-frequency GPSCards should be relatively straightforward for the vast majority of users.

2.3 5IiLLennium Test Methodology & Results

An important step in all development cycles is the final analysis of the product performance and a comparison of the results with initial design specifications. A fundamental measure of a receiver's performance is the quality and robusmess of its signal tracking loops. Any degradation here is directly reflected in the receiver's carrier phase and code phase (pseudorange) measurements.

One of the most convenient methods for testing the performance of a receiver's tracking loops is the zero baseline test. It involves collecting measurement data from two test receivers that are connected to one common antenna. Since both receivers track identical signals the measurement biases caused by the atmosphere, satellite clock, and multipath. are correlated. Therefore, the measurement residuals resulting from the double difference processing of the baseline should be unbiased and reflect only the receiver's signal processing noise.

Double difference residuals (DDR's) were computed for the MiLLennium receiver pair. In order to evaluate receiver performance over a wide range of signal-to-noise ratios the DDR's were grouped in 5" "bins" from 0" through to 90°. The r.m.s. of the DDR's in each group are presented in **Figure 3, Figure 4. Figure 5, and Figure 6** together with early Wide Area Augmentation System (WAAS) specifications for each of the four observables

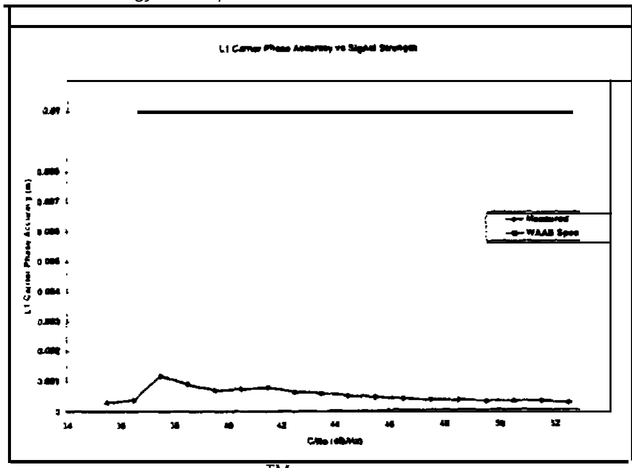

figure 3: MiLLennium™ Ll Carrier Phase Performance

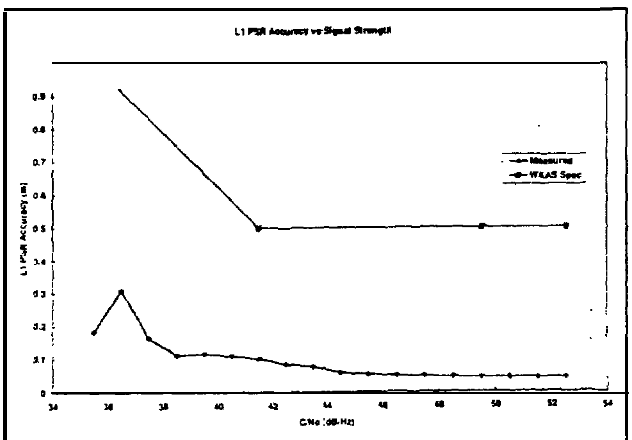

Figure 4: MiLLennium™ L1 Pseudorange Performance

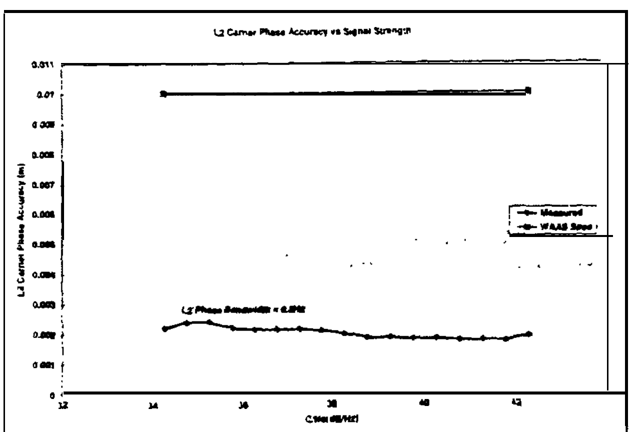

Figure 5: MiLLennium™ L2 Carrier Phase Performance

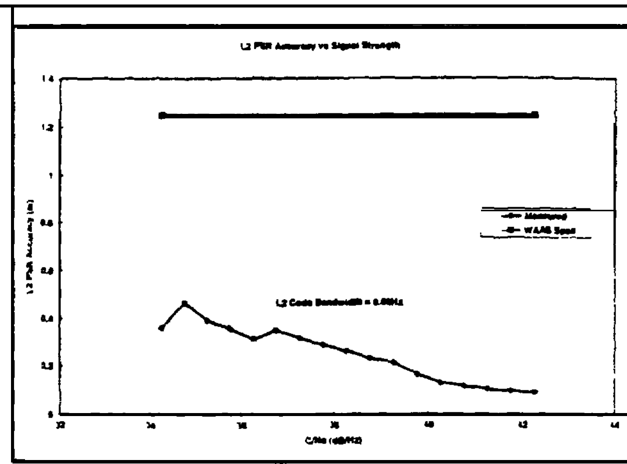

Figure 6: MiLLennium™ L2 Pseudorange Performance

In each case MiLLenniums performance easily satisfied the test specifications. Closer inspection of the DDR's also revealed performance comparable to other commercially available dual-frequency receivers. The tests described above were performed for data that were collected in October 1995. Since that time an exhaustive program of fine tuning at both the hardware and firmware levels has been ongoing with resultant improvements in performance.

3.0 INTRODUCTION TO NOVATEL RTK SYSTEMS

A prototype fixed ambiguity RTK system running on NovAtel's Narrow Correlator Ll platform was completed and successfully demonstrated in September 1993. However, this prototype system displayed several drawbacks which can be considered inherent limitations that hinder even the best of L1 receivers, the most notable of which can be summarized as follows:

- Ll observations cannot successfully model ionospheric delays
- multipath can affect the quality of pseudoranges and can have a huge impact on the size of the initial ambiguity search volume
- ionosphere and multipath can conspire to make the ambiguity search process lengthy and unreliable

Ultimately it was decided that these drawbacks compromised the robustness and utility of the system and further development of the Ll fixed ambiguity approach was deferred until new dual-frequency receiver technology became available.

The prototype fixed ambiguity system incorporated a subset of floating ambiguity algorithms which defined the initial limits of the search volume and which ran in parallel with the fixed solution once the ambiguities had **been** resolved. Testing and development of the fixed ambiguity algorithms revealed very good agreement between the floating and fixed solutions. Testing also revealed that the float solution was more stable than that of the fixed. Thus. the software engineers concentrated on developing the floating ambiguity solution into a commercial product for the Ll hardware platform . . R-T-20.

RT-20 was NovAtel's entry product into the RTK market. Introduced in 1994, and running exclusively on Narrow Correlator single-frequency receivers, RT-20 obtains nominal accuracies of 20 cm or better by continuously determining and updating its estimates of the carrier phase ambiguities. RT-20 positions at update rates as high 5 Hz have proven to be extremely robust. RT-20 is a well known and mature product so a full description is not given in this paper. Instead, the interested reader is directed towards ***Ford & Neumann*** (1994) and ***Newby & Corcoran (1995)*** for more details.

The introduction of the dual-frequency MiLLennium receiver has brought with it NovAtel's newest RTK core technology known as RT-2. This new 2 cm RTK system takes advantage of MiLLennium's dual-frequency technology in the following manner:

- the second frequency is used to dramatically increase the speed and robusmess of fixing the integer ambiguities on shorter baselines
- the combination of Ll and L2 data is used to reduce the effect of the ionosphere on longer baselines

RT-2 provides centimeter level positioning accuracy at high update rates in a system which is robust and **easy to use.** Radio link requirements are kept to a minimum, and positions are provided in a timely manner, i.e., data latency is kept to a minimum. Some of RT-2's more salient characteristics are described below. A more detailed description can be found in ***Neumann er al (1996).***

3.1 RT-2 Overview

Further development of the 1994 prototype fixed ambiguity RTK system into a commercially viable product gained momentum several months ago. RT-2 maintains all of the advantages of the single-frequency RT-30 product (,i.e.. ease of use, robusmess. high update rates. modest radio link requirements, low data latency) while using the MILLennium hardware platform and dual-frequency processing algorithms to achieve improved performance in the following general areas:

- the combination of two Frequencies allows for a technique known as wide laning to be **used** in the ambiguity searching process
- wide laning. and subsequent pass-off to the narrow lane. allows for rapid ambiguity resolution and therefore. centimeter level accuracies in a relatively short space of time
- the ambiguity resolution process is far more robust than that of the single frequency approach
- due to the dispersive nature of the ionosphere. dual-frequency observations are far more effective than single-frequency observations at modeling the ionosphere's effect. This is especially useful on longer baselines. and is utilized to good effect by RT-2

In short, with dual-frequency MiLLennium observations a fixed ambiguity RTK solution is achieved in a robust and rapid manner that is appropriate for a commercial product.

3.1.1 The Reference Station's Message

As with any differential setup (real-time or post-processed) raw data must be available from the reference and remote locations. Thus. an RT-2 remote relies upon reception of raw code and phase data. on both frequencies, from its reference station.

The RT-2 system has adopted a proprietary format RTCA type 7 message which can be generated by any MiLLennium receiver. and whose size is 140 + 92N bits (where N is the number of satellites being tracked). In practical terms, if eight "useful" satellites are tracked at the reference receiver. the resultant type 7 message size is 876 bits.

Base station coordinates must also be transmitted every ten seconds or so, in a message whose size is 192 bits.

Both messages are easily accommodated by a relatively modest radio link.

3.1.2 The RT-2 Remote **Receiver & Field Upgrades**

As noted in Section 3.1.1. reference station messages can be generated by any standard MiLLennium receiver. The remote's hardware platform is identical (i.e., it's also a standard MiLLennium receiver), the only difference being a special firmware load that includes the RT-2 remote's double differencing routines. Of course. for some users interoperability of base and remote is an important consideration. Therefore, the RT-2 remote can also be user-configured for base station operation if desired.

Because the RT-2 algorithms run on any MiLLennium receiver, field upgrades which add RT-2 functionality are readily available for any MiLLennium owner, without the need for any hardware modifications, and without the need to return the receiver to any service facility.

3.1.3 **Latency & "Safety" Issues with RT-2**

The RT-2 algorithms carry over a number of techniques which were initially designed for RT-20, and which were designed to increase the robust nature of the system.

When a user requests 4 Hz positions from an RT-2 remote the receiver will make independent 4 Hz measurements of code and phase without invoking any smoothing or extrapolation.

As discussed in Section 3.1.1 the RT-2 remote also requires code and phase data from the reference station. Intuitively one might expect that 4 Hz positions at the remote would also require that the reference data be broadcast at a 4 Hz rate, which might place unreasonable demands on the system's radio link. Fortunately. because the reference station is stationary it is a relatively straightforward task to predict the temporal behavior of the phase observations. Therefore. in an RT-2 scenario the reference station need only broadcast its observations once every one or two seconds. The remote unit then estimates the temporal behavior of the phase observations using a 3 state extrapolator model. In this manner, accurate 4 Hz reference station data can be constructed using 1 Hz or 0.5 Hz reference data with little perceptible loss in accuracy.

As long as the reference data are sent every one or two seconds. and as long as the satellite geometry is reasonably good. this extrapolation of the reference station's data results in low latency positions (typically < 100 ms) at rates as high as 4 Hz with very little impact on accuracy.

The user can also output "matched positions". In this case the position computation uses time-matched base and remote observations. which provide for a delayed but somewhat more accurate position estimate.

Extrapolated reference data also allow for sanity checking of the reference station's data. For example. when a new set of reference station observations are received at the remote. the remote performs a series of checks whereby the newly received reference station observations are compared with the values output by the extrapolator model for the same time stamp. Because the reference station's data are relatively easy to model, such a comparison should yield fairly good agreement between actual and extrapolated values. If large discrepancies are found then a badly behaving satellite is said to have been detected and its observations are de-weighted. If large discrepancies are detected for all satellites then a badly behaving reference satellite is said to have been **detected and a** new one is chosen. This integrity check offers the distinct advantage that satellite behavior can be easily monitored, accounted for, and adjusted for.

RT-2 utilizes a default 11" to 15" elevation cut-off angle depending on the baseline length. Any satellites below the default elevation cut-off angle are tracked by the receiver and their float ambiguities are determined and maintained, but their observations are severely de-weighted so that they have virtually no impact on the solution. This helps to avoid the use of low elevation satellites and the associated tropospheric, ionospheric. and multipath problems which can arise.

The RT-2 receiver requires at least 4 satellites in order to deliver 3D positions. If obstructions cause high elevation satellites to be lost such that less than 4 satellites are tracked. then the RT-2 receiver will automatically include the low elevation. low weight observations in its solution. This is accomplished by increasing the weights on the Ion elevation satellite observations so that they are included in the position solution. This technique endeavors to deliver continuous positions regardless of satellite blockage, and any resultant loss of accuracy is reflected in the standard deviations of the position.

3.1.4 **Different Baseline Lengths** with **RT-2**

RT-2 utilizes a number of distinctly different double differencing algorithms so that baselines of various lengths can be accommodated in **a** straightforward manner. The receiver automatically switches between short, medium. and long baseline processing without any intervention from the user.

For short baselines (length 5 10 km) double differenced fixed ambiguity routines are used. First the wide lane integer ambiguity is resolved. Then the narrow lane integer ambiguity is determined. and used. as soon as it is deemed to be reliable enough. The resulting accuracy is of the order of 1 to 2 cm CEP.

For medium baselines (10 km ≤ length ≤ 30 km) no handoff from wide lane and narrow lane is attempted.

Instead. a wide lane solution is provided. the accuracy of which is generally of the order of 5 to 15 cm CEP.

For long baselines (length ≥ 30 km) a floating point ionospheric-free linear combination of the Ll and L2 observations is used. For a 35 km baseline this technique yields accuracies of the order of 30 cm CEP. At 100 km the accuracy is of the order of 50 cm CEP.

3.2 RT-2 Performance Summary

In summary. RT-2 provides centimeter level. low latency real-time positions at update rates as high as 4 Hz. The system makes the transition from short to long baselines in a seamless manner without the need for any user intervention. In-built motion detection avoids any requirement for the user to manually issue "stop & go" commands to the receiver.

Field testing has been ongoing for several months at various test sites around the world. Feedback has been positive. and has reinforced the findings of our own in-house test program. Production versions of RT-2 will ship shortly after this conference.

For a full description of RT-2 processing techniques? accuracies, and resolution times the interested reader is strongly encouraged to reference Neumann et *al* (1996).

4.0 END-USER PRODCCTS

At last year's ION GPS-95 conference in Palm Springs NovAtel introduced its first end-user products targeted at the hydrographic and GIS markets. A fully-featured Windows&based post-processing package was also promised for 1996.

This year, with the availability of the MiLLennium and RT-2 core technologies, NovAtel is positioned to introduce end-user solutions for more demanding applications. The first such integration of these key technologies into a packaged solution can be seen in the OUTRIDER geodetic survey package. In parallel with OUTRIDER's development last year's commitment to provide a complete geodetic post-processing package (called SOFTSURV) is also fulfilled.

4.1 OUTRIDER & SOFTSURV

Following last year's teaming agreement with ViaSat Technologies of Montreal. NovAtel came to market with its fit end-user product called GISMO (GIS Mobile). Development of the GISMO saw NovAtel provide all of the core GPS technology and much of the systems integration expertise. ViaSat contributions included GIS-specific controller software and an extremely powerful and fully-featured post-processing package.

OUTRIDER builds upon the well established GISMO product by adding MiLLennium technology and a dual-frequency antenna. Controller software remains largely unchanged and thus offers full attribute tagging of GPS positions and waypoint navigation as standard features. Battery, all cabling, and a custom designed backpack are included.

The controller can capture raw data at a 1 Hz update rate for post-processing back in the office. Positions are genented at a 1 Hz update rate. and meter-level real-time code differential is included as a standard feature As an option an upgrade to include RT-2 is also available to allow for real-time 2 cm positioning. The backpack design includes a compartment which accommodates the real-time system's radio.

As a companion product a Windows-based geodetic post-processing package has also been developed in association with ViaSat Technologies Called SOFTSLRV. this package has much in common with the GISMO posr-processor. Key features of SOFTSLRV include:

- static, rapid static, and kinematic processing
- graphical 2diting of GPS networks for processing
- GPS data integrity analysis tools
- support for multiple datums and map projections
- office generation of waypoint and attribute files for downloading to the controller
- overlaying of ortho-rectified raster images, vector files. and GPS data
- Simple CAD operations
- attribute and position querying
- polyline and polygon generation with area. distance. and perimeter query function
- export of GPS data to RINEX format
- export of GPS data to DXF ASCII, and ARC/INFO™ formats for subsequent import into a GIS

5.0 SUMMARY

In this paper the newest core technologies and end-user products from NovAtel have been discussed.

Development of the new dual--frequency MiLLennium receiver provided the ideal hardware platform for a new 2 cm RTK positioning system called RT-2.

In turn_ these new core technologies have been incorporated into an existing product in order to provide a new end-user product aimed at the most demanding of geodetic applications . . . OUTRIDER. Finally, a new geodetic post-processing package. which also builds upon the success of an existing product. has been discussed . . . SOFTSURV.

In essence, the logical sequence of events where new core technologies have facilitated the development of new en& user products. and where these new end-user products have retained as many elements of an existing product as was feasible. has been described.

Clearly one of the key elements in the cycle described above is that of core technology development. With this in mind, expect to see more core technology developments in the coming months, and more end-user products as a direct result.

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