What's New from NovAtel

Simon Newby & Wendy Corcoran
NovAtel Communications Ltd., 6732 8th Street N.E.
Calgary. Alberta, Canada T2E 8M4

BIOGRAPHY

Simon Newby received his B.Sc. in Surveying and Mapping Sciences in 1987 from North East London Polytechnic. He received his M.Sc.E. in Surveying Engineering in 1992 from the University of New Brunswick. where his Masters research involved ionospheric modelling with respect to GPS. In 1992 Simon joined Leica Heerbrugg's GPS products group as a customer support engineer. In 1993 he joined NovAtel GPS as a customer support and applications engineer. More recently he has assumed responsibility for support of NovAtel's dealer network.

Wendy Corcoran graduated from the University of New Brunswick in 1986 with a B.Sc. in Surveying Engineering. After graduation she joined Norstar Instruments and worked in GPS software development In 1989 she joined Ashtech as an applications engineer. In 1991 Topcon and Ashtech signed an OEM agreement and Wendy joined Topcon to establish their GPS division. Wendy has been with NovAtel GPS for the past year as product manager for surveying and mapping products.

ABSTRACT

At ION GPS-94 detailed specifications were presented for an affordable new 20 cm real-time positioning system … RT-20. One year down the road. with many units in the field and with many 100's of hours of use. field results are presented which underline the performance, utility and robusmess of this exciting new technology.

The new NovAtel MiLLennium dual-frequency receiver is discussed, and plans for new end-user and OEM products are revealed.

INTRODUCTION

This paper summarizes those technologies — recent, new, and forthcoming — which constitute NovAtel's GPS product tine. A summary of the real time 20 :entimerre RT-20 technology is presented and a brief overview of two multipath mitigation technologies is given. Brief details of the upcoming MiLLrnium dual-frequency receiver are presented, and NovAtel's first end-user GPS products are introduced.

RT-20 BACKGROUND

To date, NovAtel's GPS products have been based on Narrow Correlator L1 technology. This technology made real-time C/A-code positioning at the metre level available for the first time in a high performance receiver that was suitable for a wide variety of very challenging applications.

Historically. users of satellite navigation systems have demanded positions of a higher quality than those currently available. Thus, in GPS Circles we have seen an ever increasing trend towards real-time phase-based positioning systems.

In line with these market trends and pressures, NovAtel began development of a fixed ambiguity RTK system based on its LI GPSCard By September 1993 the first system was completed and successfully demonstrated However, the fixed ambiguity approach displayed several drawbacks which can be considered inherent limitations with even the best Ll 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 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 robusmess and usability of the system. Thus. further development of the Ll fixed ambiguity approach was deferred until new dual-frequency receiver technology became available.

The fixed ambiguity system relied upon a subset of floating ambiguity algorithms which were used to define 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 approach revealed very good agreement between the floating and fixed solutions. This 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.

RT-20 Philosophy

In essence, the RT-20 algorithms are a suite of double differencing routines which compute and continuously improve the remote receiver's estimate of each satellite's phase ambiguity. It is important to note that the algorithms never attempt to fix the ambiguities to integer numbers — instead, the estimate of each ambiguity remains unfixed at all times. In practical terms this means it is very unlikely that the system will select incorrect values for the ambiguities. In turn, this means that a solution can always be computed provided that continuous phase data are available from at least 4 satellites.

This scenario has immediate advantages over that of the fixed ambiguity approach where an "all or nothing" approach must be accepted by the user.

As with any differential setup (real-time or post-processed) raw data must be available from both reference and remote locations. The RT-20 remote relies upon reception of raw code and phase data from a reference station. To this end. any NovAtel full data Narrow Correlator receiver can be used to broadcast the necessary RTCM type 3 (reference station coordinates) and type 59 messages (reference station code and phase dam). Table **1** lists the salient characteristics of the type 3 and type 59 messages.

Message type	Number of bits (maximum)	Update rate (suggested)
3	180	10 s
59	990 *	2 s
* Assuming 12 satellites being tracked		

Table 1: Main Characteristics of the Reference Station's Data Transmission

C!eariy, the demands placed on the radio link are relatively modest. and it is possible to broadcast the necessary reference station messages using a 1200 baud radio link. This is especially true if less than 12 satellites are being tracked.

Typical RT-20 Accuracy

Immediately after power up and reception of the reference station's data the RT-20 remote outputs what essentially amounts to a code differential solution. Narrow Correlator code measurements allows for metre level positioning in this instance. However, a few seconds later the RT-10 floating ambiguity algorithms begin estimating the ambiguities for each satellite, and the solution rapidly starts to improve. After 2 to 3 minutes a nominal horizontal accuracy of 20 cm CEP is typically obtained. With continuous phase lock the accuracy improves further to 2 to 5 cm CEP. This process of a gradually evolving position is most easily likened to that of a gradual transition from a code only differential solution to that of a phase only differential solution — at power up the solution is almost entirely based on code measurements ... after several minutes the solution is based purely on phase data

Figure 1 illustrates typical static and kinematic convergence times for a short baseline (< 10 km) scenario. It can be seen that kinematic accuracies are comparable to those of the static case, the main difference being convergence times which are nominally three times longer.

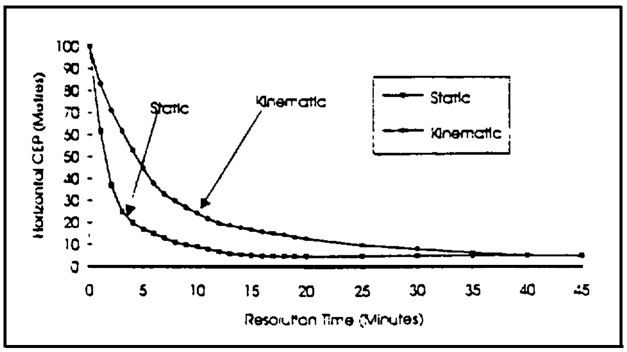

Figure 1: RT-20 Accuracy vs. Convergence Time for Short Baselines

Latency & Safety Issues with RT-20

The RT-30 algorithms **utilize a number of novel** techniques which are **designed to** increase the robust nature and usability of the system.

An RT-20 remote can generate its positions at user-selectable rates as high as 5 Hz. In NovAtel receivers a 5 Hz update rate means that raw code and phase data are being measured by the remote receiver five times per second – there is no smoothing or extrapolation involved.

However, the double-differencing RT-20 algorithms require code and phase data from a reference station. Clearly. broadcasting reference station data at rates as high as five times per second would 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 behaviour of the phase observations. Therefore. the RT-20 reference station need only broadcast its observations once every two seconds. The remote unit then estimates the temporal behaviour of the phase observations using a 3 state extrapolator mode!. In this manner, accurate 5 Hz reference station data can be constructed using real 0.5 Hz data with no perceptible loss in accuracy. The quadratic 3 state filter has an r.m.s. accuracy of 3% of a wavelength (= 6 mm) over 2 seconds, or 30% of a wavelength (= 60 mm) over 6 seconds. Clearly, the 2 second update rate for reference station data is preferable.

Extrapolators of this type appear to be gaining popularity and have recently been documented by Landau & *Vollath (1995)* and *Lopucha et al. (1995).*

The extrapolator also helps in greatly reducing data latency times of the RT-20 position updates so that they are typically less than 70 ms. This means that when the user stops moving so does the solution . . . almost instantaneously. This scenario often isn't true of other RTK systems.

The extrapolated reference station data are compared with real data at the **update** rate specified by the data link. If large discrepancies are found then a badly behaving satellite is said to have been detected and its observations will be 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 behaviour can be easily monitored, accounted for. and adjusted for.

RT-20 utilizes a default 12.5" elevation cut-off angle. Any satellites below 12.5" are cracked by the receiver and their 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 and ionospheric problems which can arise.

The RT-20 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-20 receiver will automatically include the low elevation. low weight observations in its solution. This is accompiished by increasing the weights on the low elevation satellite observations so that they are included in the position solution. This technique endeavours to deliver continuous positions regardless of satellite blockage, and the resultant *loss* of accuracy is reflected in the standard deviations of the position.

Multipath considerations With RT-20

Because the initial positions are so closely coupled to the code measurements it is imperative to have good quality pseudoranges. Narrow Correlator pseudoranges aid considerably in this respect, but in the presence of poor multipath conditions even the Narrow Cot-relator's enhanced multipath immunity may not always be as good as one would like. If reference and remote receivers are equipped with choke ring ground planes the effects of multipath can be minimized. However, in many applications this is not always a practical option. For this reason, the RT-20 receiver also runs Multipath Elimination Technology (MET) as a standard feature. MET, which is described in more detail later in this paper, removes some 25% to 50% of the residual code multipath. runs within the receiver firmware. and helps to confine the **size** of the initial search volume which is used by RT-20's double differencing algorithms.

Ionospheric Considerations with RT-20

The ionosphere and multipath play very important roles in the utility of phase-based Ll positioning systems. Multipath has already been discussed within the sphere of an RT-20 solution, but ionospheric delays are too important to overlook.

During periods of peak ionospheric activity the group delay experienced at GPS frequencies can be as much as 50 m at zenith and three times as much for a satellite at the horizon. The ionosphere is a dispersive medium at radio frequencies ... a property which is fully exploited by dual-frequency receivers by combining observations made on the Ll and L2 frequencies. However, L 1 receivers lack the second frequency and must rely on alternative techniques to estimate the ionosphere's effect. Typically, with Ll receivers we either ignore the ionospheric effect altogether or we attempt to model it using one of several empirical models which are **available.** Empirical ionospheric models are extremely limited in their ability to model the effect and on the average can only remove 50% of the ionospheric delay. Therefore, the residual ionosphere after such modelling is usually a major source of error for which we cannot correct

Differential processing removes much of the ionospheric effect. but the spatial correlation of the ionospheric delay between **reference** and remote locations becomes weaker as the baseline length increases, and differential processing becomes less effective in its ability to remove the effect In a code differential scenario this results in decreasing accuracy as baseline lengths increase.

In Ll phase-based systems the effect is far more severe and can result in a complete inability to resolve ambiguities with any degree of confidence. In fact. in the fixed ambiguity approach the general rule of thumb is that baseIine lengths of 15 km to 20 km should not be exceeded if ionospheric problems are. to be avoided. RT-20's floating ambiguity approach circumvents these problems by never attempting to fix the ambiguities. Instead, the system accepts the fact that ionospheric decorrelation will impact on the result. and reflects the impact accordingly by showing Larger standard deviations. Figure 2 shows RT-20 accuracy versus baseline length. We see that a solution is always available, albeit of reduced quality as the baseline length increases. Typically, under steady state conditions, RT-20 delivers better than half a metre accuracy CEP. after a period of extended phase lock, over baselines of 50 km.

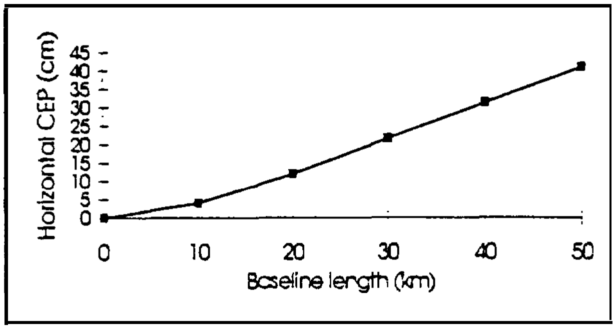

Figure 2: RT-20 Accuracy vs. Baseline Length

To summarize, we can state that the very nature of the RT-20 floating solution overcomes the baseline length limitations **suffered** by fixed ambiguity solutions, and offers a seamless transition from short to long baselines.

Current RT-20 Applications

Production versions of RT-20 have been available since January 1995. Since then many units have been delivered to customers and many 100's of hours of field use have been accumulated. The applications for this technology have proven to be many and varied, and include:

- robotics guidance
- precision guidance for agriculture
- precision earth moving
- precision mining
- collision avoidance systems for heavy machinery
- container tracking systems
- truck guidance alarm systems
- seismic surveying
- GIS I surveying
- hydrographic surveying and dredging
- land slide monitoring

In all cases, the RT-20 approach has delivered accurate positions which tie in closely with the system's design specifications. Novel new applications for the technology will undoubtedly continue to emerge.

Summary Float vs. Fixed - Pros & Cons

The previous paragraphs have reviewed some of the major problems which are faced by Ll only phase-based RTK positioning systems. Some the ways in which RT-20's floating solution overcomes or minimizes many of the limitations have **also** been explained. Table 2 summarizes the various advantages and disadvantages of the L 1 floating solution versus L 1 fixed solutions.

Ford & .Veumann (1994) presents a thorough overview of the RT-20 technology. The interested reader is directed towards this reference if more details are required.

L1 FLOATING AMBIGUITY RT-20	Ll FIXED AMBIGUITY SOLUTION
ADVANTAGES	
• always converges • always gives a position • not CPU or RAM intensive • statistics good indicators of accuracy • foolproof operation • seamless transition from short to long baselines • low cost platform	• can give centimetre level accuracy for short baselines
DISADVANTAGES	
• typically decimeue level accuracy	• easier to pick the wrong answer • difficult to know if the answer is correct • too long to get a good positioa • too much CPU and RAM required • doesn't work for long baselines • experience needed to operate • too long to get good position at start up and after loss of lock • operational constraints

Table 3: Advantages and disadvantages of the RT-20 floating ambiguity solution vs. L 1 fixed ambiguity solutions

MULTIPATH MITIGATION TECHNOLOGIES

Multipath signals often cause a bias within the receiver measuring process. Unlike other systematic biases which affect GPS pseudorange and carrier phase observations. multipath effects are not correlated between antenna locacioas. This means that no form of differential processing, either real-time or post-processed, removes the effect. In real-time applications pseudorange multipath at the reference station will cause errors in the pseudorange corrections. In turn, these errors propagate into position errors at the remote locations.

Traditionally, GPS users have attempted to overcome multipath effects by using choke ring ground planes or by carefully selecting sites for antenna placement. Depending on the intended application both of these methods are either wholly impractical or quite impossible to implement. In a bid to offer more acceptable means for reducing the effects of multipath NovAtel has concentrated on a regime of advanced signal processing techniques which eliminate the requirement for ground plane choke rings and avoid the need for careful site selection.

Multipath Elimination Technology (MET)

Narrow Cot-relator technology is inherently immune to the effects of multipath. In a standard Narrow Cot-relator design the power of the early and late correlators is equalized However, in the presence of multipath, the correlation function is affected in such a way that is non-symmetric and skewed (Figure 3).

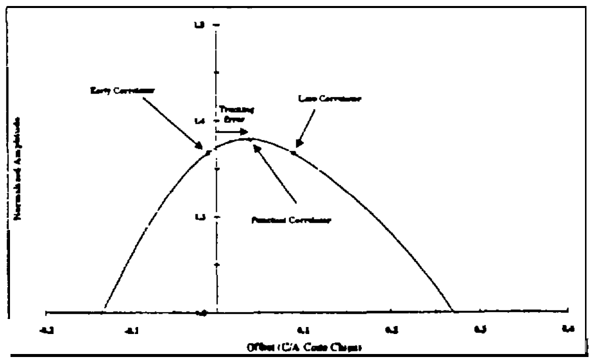

Figure 3: Tracking Error Due to Multipath

Although the power of the early and late cot-relators has been equalized, it is easy to see that a tracking error still results

MET differs significantly from the Narrow Correlator method outlined above — it adds two additional correlators (one either side of the correlation function's peak) so that there are two early correlators and two late correlators. Rather than equalizing the power at the correlators, MET positions the correlators either side of the peak of the correlation function (Figure 4).

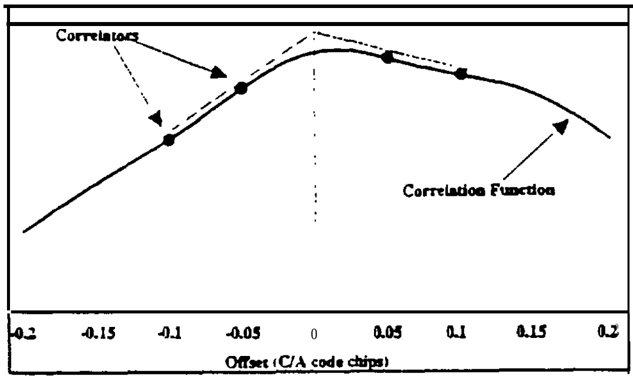

Figure 4: Early Late Slope (ELS) Technique

By positioning the correlators in such a way early slope and the late slope information is determined. The early late slope (ELS) information is then **used** to correct the receiver's delay lock loop thereby reducing the effects of mul tipath

Extensive testing has demonstrated that MET is effective at removing 25% to 50% of residual code multipatb. MET is available as a firmware upgrade for any 12 channel NovAtel GPSCard — operation is totally transparent to the user, there is no impact on data latency times or data update ntes, and there is always an improvement in pseudorange quaIity in the presence of multipath.

Multipath Estimating Delay Lock Loop (MEDLL

Patented MEDLL technology offers a far more rigorous approach to the reduction of multipath effects than that of MET. In essence, MEDLL extends the MET concept further by adding multiple correlators so that the shape of the entire correlation function can be determined (Figure 5).

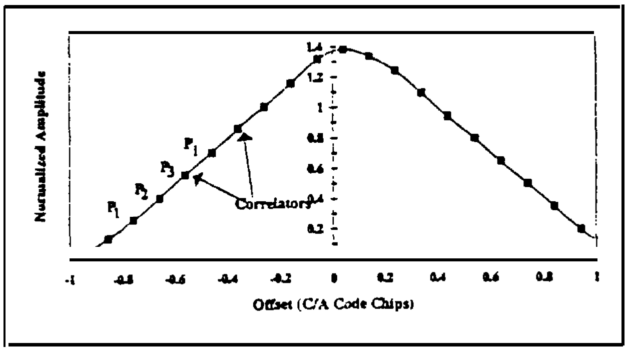

Figure 5: multiple Correlator Sampling of the Correlation Function

MEDLL decomposes the correlation function into its direct and multipatb components — the amplitude, delay, and phase of each multipath component is estimated. Each estimated multipath correlation is **then subtracted from the** measured correlation function. The net effect of this process results in an estimate **of the direct** path correlation function. All that remains is to apply **a standard early-late** delay-lock-loop to the direct path component, tbereby providing an optimal estimate of the code loop tracking error.

First prototypes of the .MEDLL concept were successfully tested on a signal channel receiver design over a year ago. Since that time the MEDLL concept has been extended and implement in a fulI 12 channel receiver design which necessitates the use of multiple GPSCards. Each GPSCard in the MEDLL **receiver** is linked to **one common RF** deck and an OCXO which minimizes inter-channel biases. The ,MEDLL receiver features exactly the same data interface as a *NovAtel* GPSCard

In April 1995 MEDLL receivers were used during 101 successful Category III landings which were performed by Wilcox Electric at the FAA Tech. Center. The same MEDLL technology is incorporated in those receivers which will be delivered to Wilcox Electric for use in the FAA's WAAS program.

Tests have demonstrated that MEDLL receivers successfully account for some 90% of the residual multipath effect.

To date, MEDLL technology has been used to estimate and remove code multipath. The next step in the technology's development concentrates on removal of phase multipath. It is also thought that there may be some scientific interest in producing a version of the MEDLL receiver which can serve as a "multipath meter." The utility of such a receiver will be examined.

For a full insight **into** MET and MEDLL technologies the interested reader is directed towards *Townsend & Fenton* (1994). *Townsend et al.* (1995a and 1995b). and van Nee er al. (1994).

DUAL-FREQUENCY TECHNOLOGY

NovAtel's MiLLeArn **dual-frequency** receiver features two custom designed ASIC 12 channel correiator chips to give a total of 24 configurable tracking channels. In its standard configuration MLLenium independently tracks Narrow Correlator C/A-code on Ll, P-code on L2 (AS on), and provides full wavelength phase observations on Ll andL2.

MiLLenium follows the same philosophy as current NovAtel Ll GPScards and offers extremely robust tracking loops, high quality low noise observations available at high update rates (up to 10 Hz). rapid position **update rates** (up to 5 HZ). and enhanced EM1 immunity which is achieved through a combination of 2.5 **bit** sampling on the nctiver's front end and a well designed RF deck.

The receiver is in OEM Eurocard format and features the same electrical interface as current NovXtel GPSCards. The receiver's user interface also remains the same as existing GPScards. Therefore, the transition from Ll to dual-frequency should be effortless for the vast majority of existing NovXtel GPSCard users.

The receiver accepts position and velocity aiding from NS units. and has hooks to accommodate the GLONASS system. MiLLenium accepts 5 Mhz and 10 Mhz external frequency standards, and a real-time 2 cm option will be offered shortly after production units ship.

MiLLenium uses patent pending P-code Delayed Correlator Technology in order to track the L2 P-code.

END-USER PRODUCTS

NovAtel's innovative Narrow Cot-relator OEM GPSCard first came to market in late 1992. Since that time the company has established a solid reputation as a manufacturer of high performance OEM receivers. NovXtel is augmenting its line of OEM products by adding end-user products targetted at specific applications. The first of such product offerings are aimed at hydrographic and GIS users. A fully-featured Windows&based post-processing package will also be offered in 1996.

Hydrographic **Surveyor, GPSDredger, and HYPACK™**

NovXtel GPS has entered into **a** distribution agreement with Coastal Oceanographics Inc. to distribute HYPACK™ software with Hydrognphic Surveyor and GPSDredger GPS receivers.

The Hydrographic Surveyor is available as a PC card receiver or as an environmentally sealed Narrow Correlator receiver — both units accept RTCM 104 differential corrections and both are compatible with Coast Guard Beacon Receiver corrections. Metre-level positions are available at user-selectable rates as high as 10 Hz, and raw data can be logged for post-processing at rates as high as 20 Hz. A full upgrade path to GPSDredger is also offered.

GPSDtedger (also available in PC format or packaged format) offers the same feature set but adds real-time 20 centimetre RT-20 technology. **GPSDredger accuracies are available only** when using reference stations that transmit RT-20 messages — these could be from local NovXtel reference receivers or from ACCQPOINT'S RTK-FM service **Coast Guard Beacon** Receivers are not capable of broadcasting the necessary reference station data. In **RT-20** mode positions are available at rates as highas5Hz.

Both receivers are offered as part **of a** complete packaged solution that includes Coastal Oceanographic's HYPACK software. HYPACK for Windows@ is **a** complete hydrographic surveying and dredging software package which includes modules for:

- survey&sign
- data editing and sorting
- digitizing and plotting
- volume computations
- data collection
- DXF import/export
- cross sections

Apart from adding full **support** for NovAtel receivers, HYPACK also supports multiple hydrographic sensors including echo sounders, side scan sonar, magnetometers, gyro compasses, heave-pitch-roll sensors, and many others.

GISMO (GIS Mobile)

Following a recent teaming agreement with GIS experts ViaSat Technologies of Montreal, NovAtel now offers its frst entry product into the GIS market. The GISMO **(GIS** SlObilej is a complete backpack system which includes a ruggedized Narrow Correlator receiver, battery, antenna. controller, and alI cabling. The backpack was custom designed by mountaineers to offer day-long comfort and ease-of-use, and features novel routing channels so that cabling is tucked away neatly.

Included in the **GISMO** package is a Windows@ post-processing package that offers interactive or batch pseudorange differential processing for merre-level accuracy. The software offers a host of useful features including:

- overlaying of ortho-rectified vector and raster images
- GPS and vector editing — simple CAD functions, distance and area computations
- user defined data dictionaries
- attribute and position querying
- export to DXF, ASCII, dBase, and others

- support for multiple datums and map projections
- analysis tools for data integrity

In the field the hand-held controller software gives the user maximum flexibility to control the collection and attribute ragging of GPS data Audible and visual alarms alert the user to problems such as poor GDOP, too few satellites. loss of radio link etc. etc. Real-time code differential and RT-20 upgrades are available for GISMO. and MET technology is included as a standard feature to help counter the effects of multipath.

GISMO packages are available with or without the controller. and GISMO ships with controller software for DAP 9000, Corvallis and Husky FS2 units so mat reinvestment in costly hand-held data collectors is not always required

SUMMARY

Plans for new and emerging products from NovAtel have been discussed. In future months, expect to see more technology, more end-user products, and more teaming agreements.

REFERENCES

Ford. T.J., and J. Neumann (1994). **NovAtel's** ***RT20 – A Real Time Floating Ambiguity Positioning System,*** Proceedings of ION '94. Salt Lake City. September 20-23, pp.1067-1076.

Landau, H., C. Pagels, and C. Vollath (1995). ***Development and Implementation of a Centimeter-Accurate Real-Time-Kinematic Positioning System,*** Proceedings of ION '95, Palm Springs, September 12-15, in press.

Lapucha, D.. R. Barker, and z. Liu (1995), ***High-Rate Precise Real-Time Positioning Using Differential Carrier Phase,*** Proceedings of ION '95, Palm Springs, September 12-15, in press.

Townsend, B.R.. and P. Fenton (1994). **A *Practical Approach to the Reduction of Pseudorange Multipath Errors in a Ll GPS Receiver,*** Proceedings of ION '94, Salt Lake City, September 20-23. pp. 143-148.

Townsend, B.R., D.J. Richard van Nee, P.C. Fenton. and K.J. Van Dierendonck **(1995a),** ***Performance Evaluation of the Multipath Estimating Delay Lock Loop,*** Proceedings of ION 1995 National Technical Meeting. Anaheim, January 18-20.

Townsend B.R. P. Fenton. and D.J. Richard van Nee (1995b), L.l ***Carrier Phase Multipath Error Reduction Using MEDLL Technology Proceedings*** of ION '95, Palm Springs. September 12-15, in press.

van Nee. D.J.Richard. J. Siereveld, P. Fenton. and B. Townsend (1994), The ***Multipath Estimating Delay Lock Loop: Approaching TheoreticaL Accuracy Limits. Proceedings*** of PLANS '94. Las Vegas, April 11-15. pp.246-251.