Quadruple Single Frequency Receiver System for Ambiguity Resolution On The Fly

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BIOGRAPHIES

Dr. G. Lachapelle is Professor of engineering at The University of Calgary since 1988. He has been involved with GPS developments since 1980. He is the author of numerous papers on the subject and has contributed to the development of several GPS-related software packages.

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ABSTRACT

Resolution of carrier phase ambiguities on the fly (OTF) using a pair (monitor/remote) of single frequency receivers is difficult to achieve reliably in an operational environment due to the unfavorable ratio between carrier phase noise and multipath on the one hand, and the 19 cm wavelength of the Ll carrier on the other hand. The use of the 86 cm wavelength widelane carrier is much more effective but will require, as of early 1994, the use of expensive and still evolving dual frequency codeless receivers. In order to improve the OTF ambiguity resolution time and reliability with single frequency receivers, the use of a quadruple receiver systems consisting of two static monitor units and two mobile remote units mounted on the mobile platform is investigated. The double difference carrier phase ambiguity constraints which can be imposed on such a configuration are described. The ambiguities between the two monitor and between the two remote receivers can be be determined within a few seconds due to the short and fixed baselines between the units. These ambiguities can in turn be used as constraints to reduce the number of potential monitor/remote ambiguity solutions and, therefore, to reduce the time to resolution. The results of tests carried out with a configuration of four NovAtel GPSCard™ units are described. The time to resolution is shown to decrease by 45%.

INTRODUCTION

Ambiguity resolution OTF with widelane observables is an effective and proven method, provided that dual-frequency receivers with stable carrier phase tracking loops are available. There has been many instances however where even P(L2) observations were reported to be unreliable, due a lower signal strength and additional signal interference in that part of the spectrum. With the P code to be encrypted by early 1994, the dual-frequency user will be forced to rely on codeless technology to obtain L2 measurements. While substantial progress is taking place with this technology, it does remain unproven under many operational conditions.

An alternative is to use Ll measurements derived through the C/A code. The advantage in this case is a stronger signal which, with an adequate receiver, can yield continuous carrier phase measurements with relatively few cycle slips under benign dynamics, which is the case of most civilian applications. The feasibility of resolving the ambiguities OTF with a single frequency receiver has been demonstrated for the land, marine and airborne modes of operation [Lachapelle et al 1992b, 1993, Tiemeyer et al 19941. Assuming a relatively short distance between the monitor and remote units (e.g., >25 km, to reduce differential orbital and atmospheric effects) and the availability of at least six satellites with a PDOP ≤ 3, the time to resolution was found to vary between a few tens to 1800 seconds, depending, for one, whether chokering groundplanes were used to minimize carrier phase multipath. The time to resolution was found to be very sensitive on the a ***priori*** standard deviation assigned to the double difference carrier phase observables. While the use of a low standard deviation, e.g., 5 mm, speeds up the time to resolution significantly, it also decreases the success rate and, therefore, reliability. In order to obtain a reasonable level of reliability, the standard deviation has typically to be increased to 10 - 15 mm, increasing thereby the time to resolution substantially. This is due to the unfavorable ratio between the combined effect of carrier phase noise and multipath on the one hand, and the 19 cm wavelength of the Ll carrier on the other hand. The carrier phase noise, which is gaussian and receiver dependent, is typically below the 1 mm level. Carrier phase multipath, in addition to being non-gaussian, an important disadvantage from an estimation aspect, is also much larger and can easily reach 1 cm.

The results described above for a pair of receivers (1 monitor/l remote) are not acceptable from an operational aspect, mainly because of the long time to resolution. Such a long time means that few independent solutions based on different data segments of a sequence of cycle-slip-free observations can be used to verify the ambiguity solutions against each other. A possibility to decrease the time to resolution is to use a multiple receiver configuration. The advantage of such a configuration is more effective averaging of carrier phase noise and multipath, and the presence of ambiguity constraints which can be used to reduce more rapidly the number of potentially correct ambiguity solutions. This concept is tested here with a quadruple receiver configuration, namely two units on the platform, and two units in monitor mode. The concept is also valid for the case where all receiver are moving, with a pair fixed on each platform, e.g., aircraft-to-aircraft positioning.

METHODOLOGY

The quadruple receiver configuration tested herein is shown in Figure 1, where k and ℓ refer to the monitor antennas and i and j to the remote antennas on the platform. Since the three-dimensional position vector k - ℓ and the vector length i - j are known and relatively short (< 100 m) , the double difference carrier phase ambiguities $\Delta\nabla N_{k-\ell}$'s and $\Delta\nabla N_{i-j}$'s can be resolved reliably using a few seconds of observations as in the case of multi-antenna attitude system [e.g., Cannon et al 1992, Lu et al 1993]. The above ambiguities can then be used as constraints in solving the double difference ambiguities between the monitor and remote receivers, e.g., $\Delta\nabla N_{i-k}$, $\Delta\nabla N_{j-k}$, $\Delta\nabla N_{i-\ell}$, and AV $N_{j-\ell}$. Referring to Figure 1, the constraints can be expressed as [Lachapelle et al 1993]:

$$\begin{aligned} \Delta\nabla N_{i-j} &= \Delta\nabla N_{i-k} - \Delta\nabla N_{j-k} \\ \Delta\nabla N_{i-j} &= \Delta\nabla N_{i-\ell} - \Delta\nabla N_{j-\ell} \\ \Delta\nabla N_{k-\ell} &= \Delta\nabla N_{k-i} - \Delta\nabla N_{\ell-i} \end{aligned}$$

These three sets of double difference ambiguity relations yield (n-1)x3 double difference ambiguity equations, where n is the number of satellites observed. The potential ambiguities for each monitor-remote pair shown in Figure 1 are first calculated using a standard OTF procedure. Only the potential ambiguities which satisfy the above equations are retained.

The distance between the two monitor units and that between the two remote units should be sufficiently long, e.g., 100 m, to decorrelate carrier phase multipath. Although this is relatively easy to achieve on an aircraft or ship, total decorrelation cannot be achieved on a smaller platform such as a land vehicle and this will decrease the performance of the system.

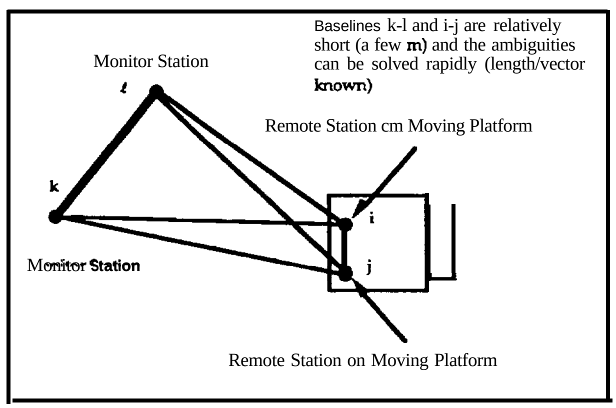

Figure 1: Quadruple Receiver Configuration

FIELD TESTS AND ANALYSIS

The method described in the previous section was tested in land mode using four narrow correlator spacing C/A Ll GPSCard™ units on two different occasions in February and July 1993. The advantage of the GPSCard™ for ambiguity resolution OTF is a higher code accuracy which reduces the initial search area [e.g., Cannon & Lachapelle 1992, Lachapelle et al 1992b]. Each test lasted about 90 minutes. In each case, at least six satellites were available with a PDOP < 3. The measurements were recorded every second. As during previous tests with the GPSCard™, the carrier phase tracking loops performed very well and the carrier phase observations were largely free from cycle slips, an important condition for successful ambiguity resolution OTF with Ll data in view of the long cycle-slip-free data sequences required.

The semi-kinematic (e.g., stop / go) mode was used to obtain an independent and reliable reference solution for the ambiguities using program SEMIKIN™ [Cannon 1990]. Only the kinematic portions of the trajectory were however used to resolve the ambiguities OTF. The vehicle speed during the test ranged from 50 to 100 km / h. The distance k - ℓ between the two monitor antennas was 15 and 6 m during test #l and #2, respectively. That between the two antennas mounted on the suburban vehicle was between 1 and 2 m. Total carrier phase multipath decorrelation could not therefore be achieved. The distance between the monitor stations and the vehicle was ≤ 5 km.

During test #l, only one monitor antenna was equipped with a chokering groundplane. During test #2, all four antennas were fitted with such groundplanes. The use of chokering groundplanes was found to be very effective in reducing carrier phase multipath during previous land and marine tests [Lachapelle et al 1992b, 1993]. The same was found in the present case, as can be seen in Figures 2 and 3. The double difference residuals for k - ℓ, i - j, and k - i, with the correct integer ambiguities held fixed, are shown for SV19-18 and SV17-03, observed during tests #l and #2, respectively. The residuals during test #2 are substantially lower **than** those obtained during test #l. However, significant carrier phase multipath still remains in test #2. That multipath between at least the two antennas on the vehicle is strongly correlated can be seen in Figure 4 which shows the double difference residuals of SV17-03 for k - j and ℓ - i, respectively. As pointed out earlier, this correlation is expected to reduce the effectiveness of the quadruple system since multipath cannot be averaged out as effectively as it would be if it was independent between antennas.

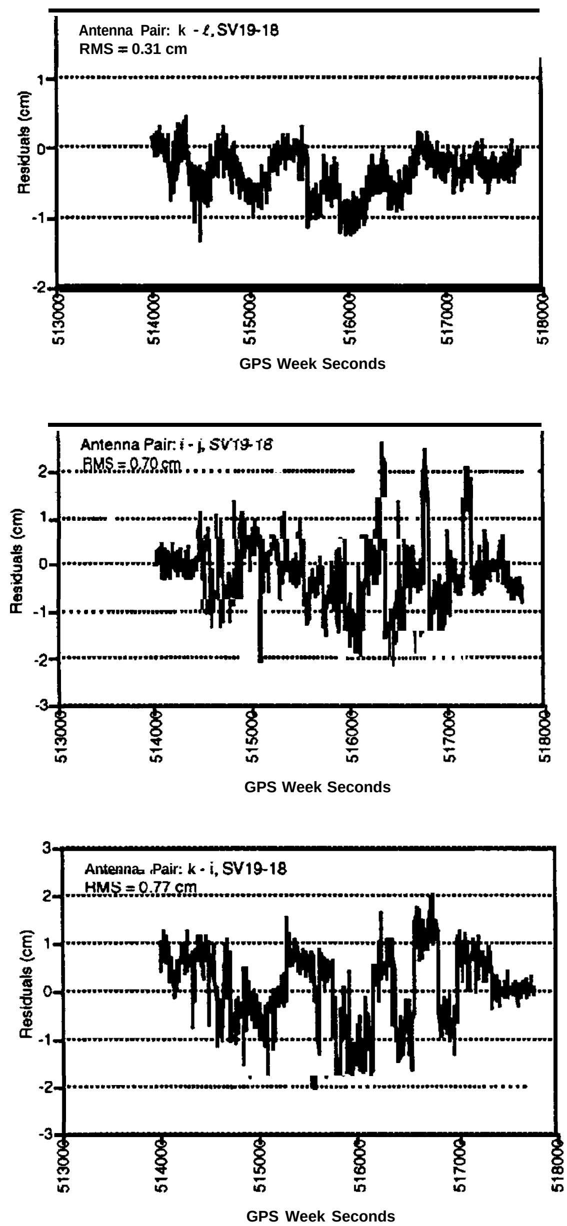

Figure 2: $\Delta\nabla\Phi$ Residuals - Test #1 (No Chokering Groundplanes at three Antennas)

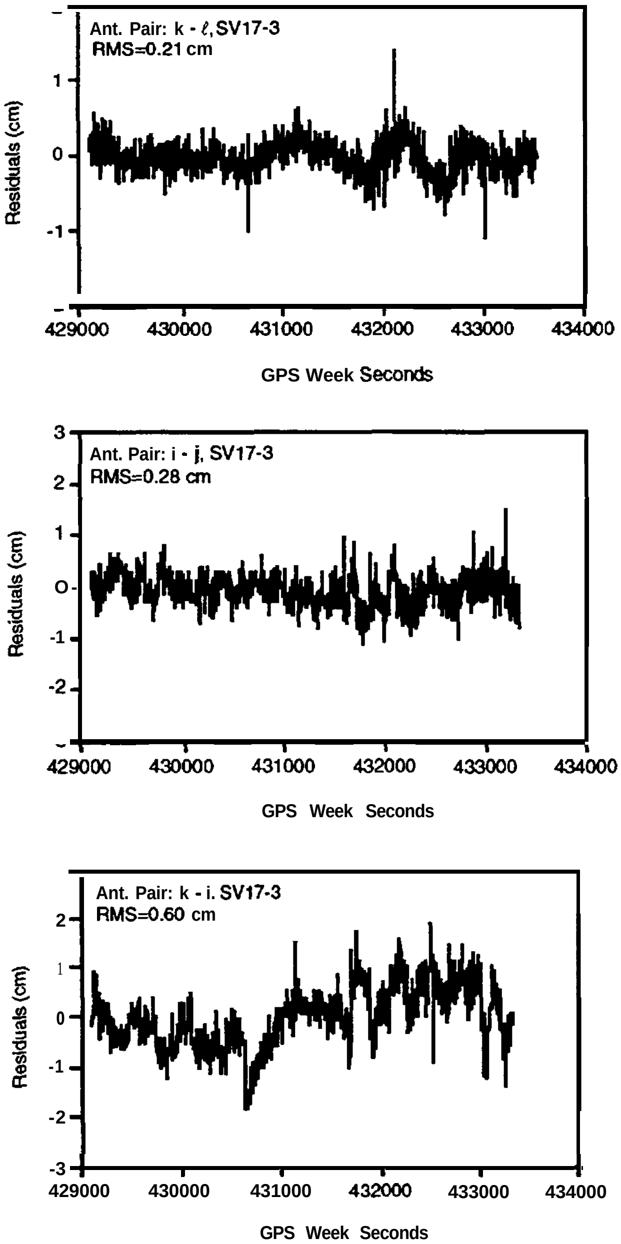

Figure 3: $\Delta\nabla\Phi$ Residuals - Test **#2** (Chokering Groundplanes at all four Antennas)

The ambiguities OTF were resolved with program FLYKIN™ which uses a least-squares search approach [e.g., Lachapelle et al 1992b, 1993]. Four satellites were selected as primary satellites. For each test, the satellite with the highest elevation was used as the base satellite. The double difference carrier phase observations were assigned a *priori* standard deviations of 15 and 10 mm for test #1 and #2, respectively. As discussed earlier, the use of such conservative values will increase the time to resolution but also the reliability of the solution.

In order to assess the performance of the quadruple receiver system as compared to the use of a single pair of receivers, the ambiguities for each pair of monitor/remote receivers were first resolved independently. Some 15 to 20 trials were performed in each case by shifting the starting point forward by 60 seconds. The average observation time required was 810 and 355 seconds for test #1 and #2, respectively. The longer time required for test #1 is due to the absence of chokering groundplanes at three of the four antennas and, consequently, to higher carrier phase multipath (see Figures 2 and 3). The success rate was 100% for most monitor/remote pairs, which indicates that the a *priori* standard deviation selected was not too optimistic.

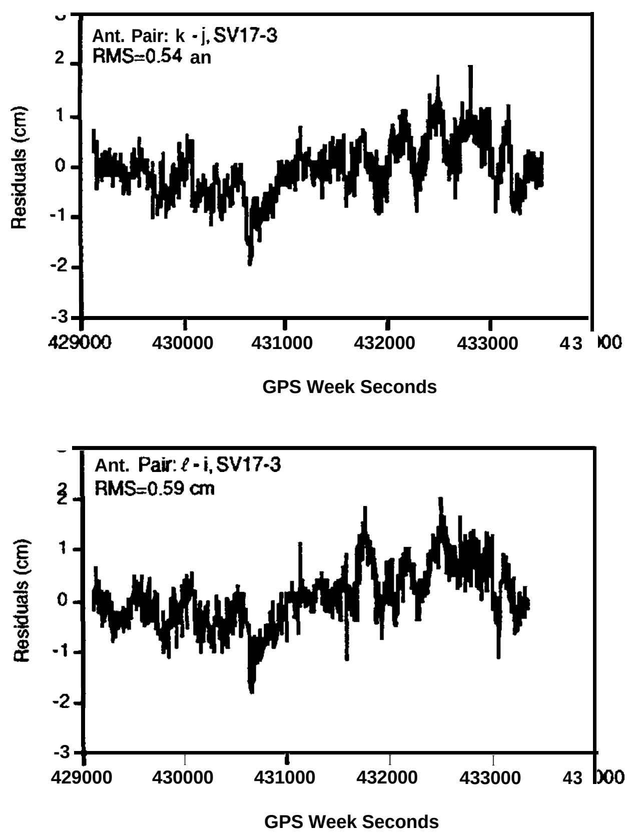

Figure 4: Correlated $\Delta\nabla\Phi$ Residuals Between Pairs of Receivers, Test **#2**

Table 2

Summary of Performance Statistics for Ambiguity Resolution On The Fly with a Quadruple GPSCard™ Configuration

Charactericstics	Test # 1 No chokering ground-plane at 3 antennas	Test #2 Chokering ground-used at all antennas
Average period required for ambiguity resolution using a single pair of receivers without constraint equations	810 secs	355 secs
Average period required for each pair of receivers to go down to 50 potential ambiguity sets	177 secs	47secs
Average number of ambiguity sets which satisfy the constraint equations (out of 50)	8 sets	16 sets
Average period required for ambiguity resolution using constraint equations	471 secs	181 secs
Average imprvement of quadruple receiver configuration over single pair of receivers	42%	48%

The quadruple receiver configuration was analysed using a series of 16 (test #1) and 17 (test #2) trials conducted using starting points shifted some three minutes forward from the previous one to decorrelate code and carrier receiver noise and multipath as much as possible. Once 50 potential ambiguity solutions remainded on each monitor/remote pair, the constraint equations were used to reject the solutions which did not satisfy these equations. This left 8 (test #1) and 16 (test #2) sets of potential solutions. Further processing was then done on each remote-receiver pair using these solutions until a unique solution was obtained on at least one remote-receiver pair. The constraint equations were then used to find the ambiguities of the other remote-receiver pairs. This reduced the time to resolution from 810 to 471 seconds in test #1, and from 355 to 181 seconds in test #2, a gain of 42% and 48%, respectively. The results are summarized in Table 2.

CONCLUSIONS

The multi-receiver configuration approach described herein to resolve the ambiguities on the fly results in a 45% improvement, in term of time to resolution, over the use of a single pair of monitor/remote single frequency receivers. The use of four GPSCard™ units has lead to ambiguity resolution in three minutes. This time will likely decrease for the case of a larger platform where the antennas can be installed farther apart to decorrelate multipath more effectively. This is being tested for the airborne and shipbome cases. The simple selection algorithm used here is being improved to further increase performance. This multi-receiver method, which improves reliability, is also applicable to dual-frequency receivers.

REFERENCES

CANNON, M.E. [1990], High-Accuracy GPS Semikinematic Positioning: Modeling and Results, Navigation, The Institute of Navigation, Alexandria, VA, 37, 1, 53-64.

CANNON, M.E., and G. LACHAPELLE [1992] Analysis of a High Performance C/A Code GPS Receiver in Kinematic Mode. Navigation, The Institute of Navigation, Alexandria, VA, 39, 3, 285-299.

CANNON, M.E., J.B. SCHLEPPE, J.F. MCLELLAN and T.E. OLLEVIER [1992], Real-Time Heading Determination Using an Integrated GPS-Dead Reckoning System, Proceedings of ION GPS-92, Institute of Navigation, 767-773.

LACHAPELLE, G., M.E. CANNON, and G. LU [1992a] High Precision GPS Navigation With Emphasis on Carrier Phase Ambiguity Resolution. Marine Geodesy, 15, 4, 253-269.

LACHAPELLE, G., M.E. CANNON, and G. LU [1992b] Ambiguity Resolution On The Fly - A Comparison of P Code and High Performance C/A Code Receiver Technologies. Proceedings of ION GPS-92, The Institute of Navigation, Alexandria, VA, 1025-1032.

LACHAPELLE, G., C. LIU, G. LU, B. TOWNSEND, M.E. CANNON, and R. HARE [1993] Precise Marine DGPS Positioning Using P Code and High Performance C/A Code Technologies. Proceedings of National Technical Meeting, The Institute of Navigation, Alexandria, VA, 241-250.

LU, G., M.E. CANNON, G. LACHAPELLE, and P. KIELLAND [1993] Attitude Determination in a Survey Launch Using Multi-Antenna GPS Technologies. Proceedings of National Technical Meeting, The Institute of Navigation, Alexandria, VA, 251-260.

TIEMEYER, B., M.E. CANNON, G. LU, and G. SCHÄNZER [1994] Ambiguity Resolution of GPS L1 Carrier Wave Measurements for High Precision Aircraft Navigation. Submitted to National Technical Meeting of The Institute of Navigation, San Diego, 24-26 January 1994.