A GPS Digital Phased Array Antenna and Receiver

Dr. Alison Brown, Randy Silva; *NAVSYS Corporation*

ABSTRACT

NAVSYS High Gain Advanced GPS Receiver (HAGR) uses a digital beam-steering antenna array to enable up to eight GPS satellites to be tracked, each with up to 10 dBi of additional antenna gain over a conventional receiver solution. This digital, PC-based architecture provides a cost-effective solution for commercial applications where more precise GPS measurements are needed.

The additional gain provided on the satellite signals by the HAGR enables sub-meter pseudo-ranges to be observed directly on the C/A code and also improves the accuracy of the GPS carrier phase observations. The directivity of the digital beams created from the antenna array also reduces multipath errors, further improving the accuracy of DGPS corrections generated by the HAGR and the navigation and timing solution computed. This paper describes the beam steering array and digital receiver architecture and includes test data showing the HAGR performance.

HIGH GAIN ADVANCED GPS RECEIVER DESIGN

The HAGR design is based on NAVSYS' Advanced GPS Receiver (AGR) PC-based digital receiver architecture[1] integrated with a digital beam steering array. Using a proprietary digital beam steering (DBS) board NAVSYS is able to combine data from as many as 16 antennas and create a multi-beam antenna pattern to apply gain to up to eight GPS satellites simultaneously.[2]

The HAGR phased array antenna is shown in Figure 1 and the HAGR electronics includes the components shown in Figure 2. The multi-element antenna array is assembled using commercial antenna elements. The antenna outputs are fed to a Digital Front End (DFE) assembly that includes a custom RF-board that digitizes each of the received L1 signals. The digital output from the DFE assembly is then passed to a custom Digital Beam Steering (DBS) board installed in the AGR Personal Computer that performs the digital signal processing required to implement the digital beam steering operations. The AGR PC also includes a custom Correlator Accelerator card (CAC) that performs the C/A code correlation and carrier mixing on each satellite channel.

Depending on the level of performance desired, the antenna array and DFE assembly can be populated with two, four, nine or sixteen antenna elements. The antenna elements are spaced ½ wavelength apart. The Digital Beam Steering board is operated through software control from the AGR PC. This applies the array spatial signal processing algorithms to form the digital antenna array pattern from the multiple antenna inputs, adjusts the antenna array pattern to track the satellites as they move across the sky, and applies calibration corrections to adjust for offsets between the individual antenna and DFE channels and alignment errors in the positioning of the antenna elements and array assembly.

The GPS signal processing is performed by the HAGR Correlator Accelerator Card (CAC) also operated under software control from the PC. This performs the code and carrier tracking on each satellite signal. The HAGR PC-based software computes the navigation solution using the satellite data and can also be configured to record raw measurement data or generate differential GPS (DGPS) or kinematic GPS (KGPS) corrections.

ANTENNA ARRAY BEAM PATTERNS

The beam pattern created by the digital antenna array is a function of the number of elements used in the array and the elevation angle of each satellite being tracked. In Figure 3, simulated beam patterns are shown for the different HAGR antenna configurations.

HAGR SIGNAL-TO-NOISE RATIO COMPARISON TESTING

The HAGR digital beam forming has the effect of increasing the signal-to-noise ratio from the GPS satellites. In Figure 4 to Figure 6, performance data is shown from a HAGR unit compared against two conventional GPS reference receivers[3]. From these plots, it can be seen that the HAGR C/N_0 is significantly higher than the reference receiver, demonstrating the effect of the gain from the digital beam forming.

HAGR PSEUDO-RANGE NOISE

The HAGR pseudo-range measurement accuracy was demonstrated by plotting the difference between the pseudo-range and the contiguous carrier phase observations. This difference is a function of the pseudo-range measurement noise, the carrier-phase noise (a minimal effect) and the code/carrier divergence caused by the ionosphere (which is constant over short time intervals). This data is plotted in Figure 7 through Figure 9 and shows that the pseudo-range variance is between 0.6 to 1 meter for the <u>unfiltered</u> HAGR data. It should be noted that with carrier smoothing, this variance is reduced even further. The observed pseudo-range noise compares closely with that predicted by the improved C/No. For example, at a C/No of 54 dB-Hz, theory predicts a pseudo-range variance of 0.4 meters. Our data shows an observed variance of 0.5 meters for the same C/No.

KINEMATIC GPS TEST RESULTS

The kinematic performance of the HAGR antennas was tested by setting each of the antennas on two survey marks separated about 1.5 meter apart. The NAVSYS's kinematic GPS software was used to process the data. A 10 degree elevation mask angle was selected. Figure 10 shows the processing results. During the test, 6 valid satellites were available. These test results show that the kinematic GPS positioning error achieved a standard deviation of 3 mm (1-sigma) in the north and east directions and 7 mm (1-sigma) vertically. This is consistent with a carrier phase measurement accuracy of 3 mm (1-sigma). This shows that the multipath errors on the carrier phase are maintained on the order of a few millimeters by the HAGR beam forming.

CONCLUSION

In this paper, the design, performance and test results of the NAVSYS High Gain Advanced GPS Receiver (HAGR) have been presented. The benefits of the HAGR for the following applications are summarized below.

<u>Differential Reference Station</u>
The gain applied to the GPS signals by the antenna array improves the signal strength observed in the tracking loops by up to 10 dBi (for the 16-element array option). This will improve the pseudo-range residual noise from the HAGR's delay lock loops by a factor of 3. The improved pseudo-range accuracy results in higher precision in differential corrections generated by this reference receiver. The variance on unfiltered 1-Hz pseudo ranges collected into the HAGR was shown to be between 0.5 and 1 meters.

<u>Multipath Rejection</u>
The antenna array digital signal processing algorithms applied by the programmable Digital Beam Steering (DBS) PC-board. This attenuates any multipath signals received while applying gain to the direct path GPS satellite signals. The combination of these effects is to significantly reduce the residual multipath error in the AGR's delay lock loops and pseudo-range and comer phase observations.

Interference Rejection

The antenna array digital signal processing algorithms applied by the programmable DBS-board can be programmed to apply nulls as well as generate gain through forming beams. By placing nulls on interfering signals, the DBS-board can also be used to reject interference sources or signals from GPS jammers.

Kinematic GPS

The high-accuracy pseudo-range and carrier phase observations provided by the HAGR allow it to provide kinematic positioning accuracies of better than 1 cm.

ACKNOWLEDGEMENT

Much of this work was sponsored under the Air Force SBIR contract F19628-97-C-0029, "High Gain Portable GPS Antenna Array for Ionospheric Monitoring."

---

[1] E. Holm, A. Brown, R. Slosky "A Modular Reprogrammable Digital Receiver Architecture," ION 54th Annual Meeting, Denver, CO, June 1998

[2] A. Brown, R. Silva, G. Zhang, "Test Results of a High Gain Advance GPS Receiver," ION 55th Annual Meeting, Cambridge, MA, June 1999.

[3] A. Brown, J. Wang, "High Accuracy kinematic GPS Performance Using a Digital Beam-Steering Array," ION GPS '99, Nashville, TN, Sept. 1999.

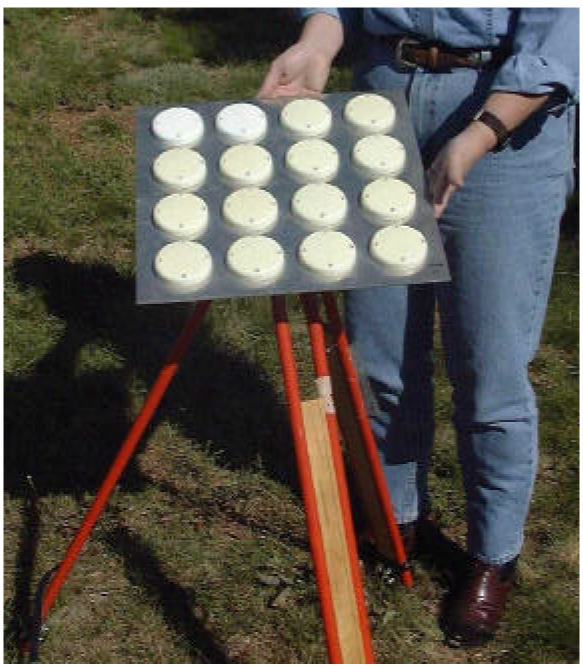

Figure 1 HAGR 16 element antenna array

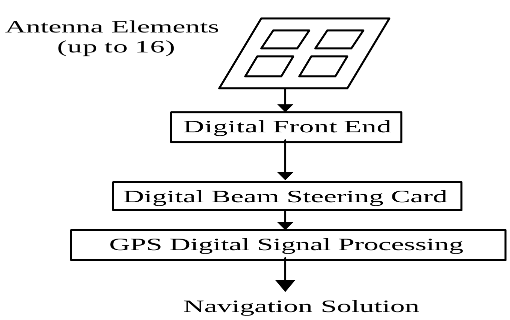

Figure 2 High Gain Advanced GPS Receiver Design

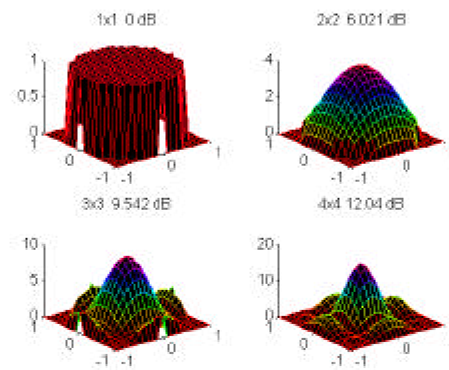

Figure 3 Typical antenna beam patterns

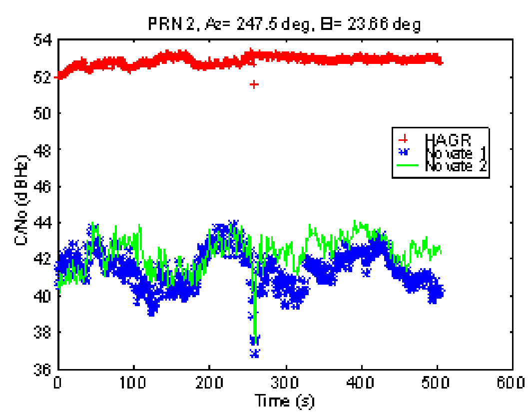

Figure 4 SNR Comparison Between 16-Antenna HAGR and Reference Receiver for PRN 2

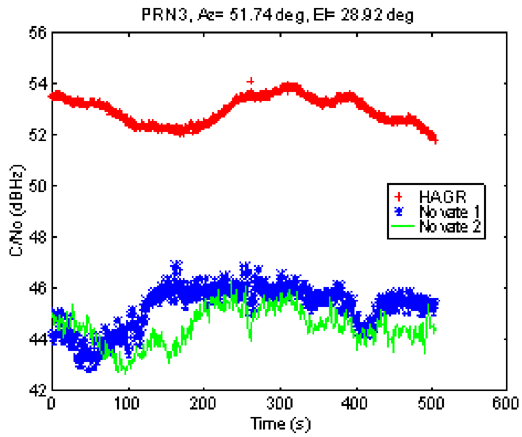

Figure 5 SNR Comparison Between 16-Antenna HAGR and Reference Receiver for PRN 3

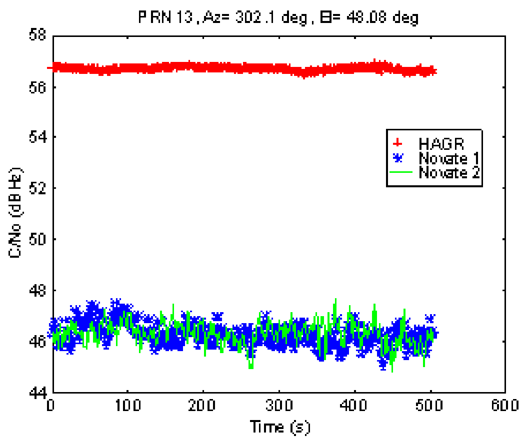

Figure 6 SNR Comparison Between 16-Antenna HAGR and Reference Receiver for PRN 13

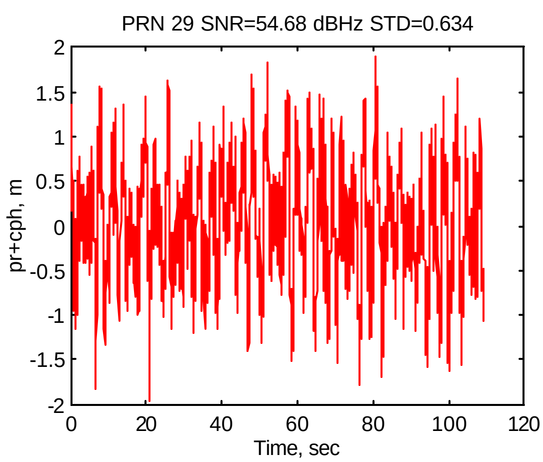

Figure 7 HAGR Difference between Pseudo -Range and Carrier Phase for PRN 29

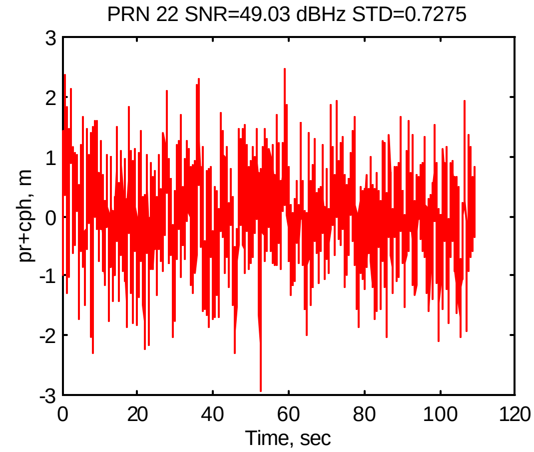

Figure 8 HAGR Difference between Pseudo -Range and Carrier Phase for PRN 22

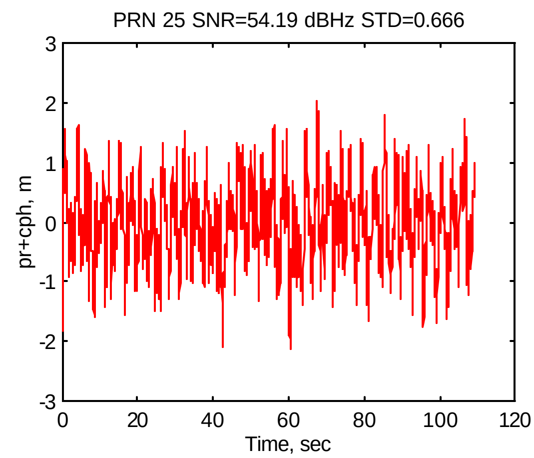

Figure 9 HAGR Difference between Pseudo -Range and Carrier Phase for PRN 25

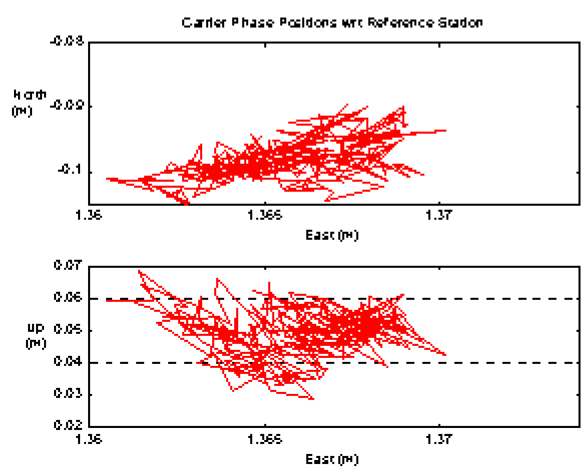

Figure 10 KGPS positioning error