High Gain Advanced GPS Receiver

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Introduction

The NAVSYS High Gain Advanced GPS Receiver (HAGR) is a digital beam steering receiver designed for GPS satellite radio navigation and other spread spectrum applications. The modular hardware architecture and flexible reprogrammable software receiver design allows the HAGR to be configured to support a variety of different user applications. The HAGR is available for both commercial (C/A code) and military (P(Y) code) operation. This white paper describes the principle of operation and the various configuration options available for the HAGR product.

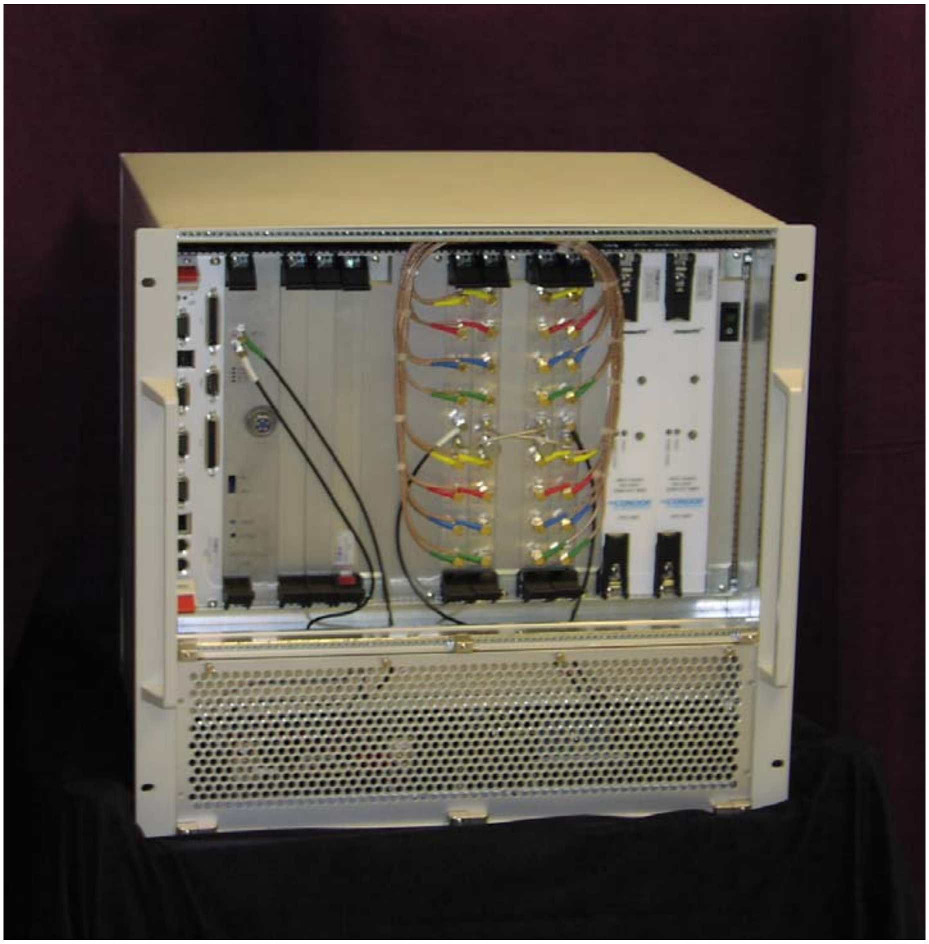

Figure 1 HAGR Assembly

HAGR System Architecture

The HAGR system architecture is shown in Figure 2. The signal from each antenna element is first digitized using a Digital Front-End (DFE). This bank of digital signals is then used to create the composite digital beam-steered signal input for each of the receiver channels by applying a complex weight to combine the antenna array outputs. As shown in Figure 2, the array weights are applied independently for each of the satellite channels. This allows the antenna array pattern to be optimized for each satellite signal tracked.

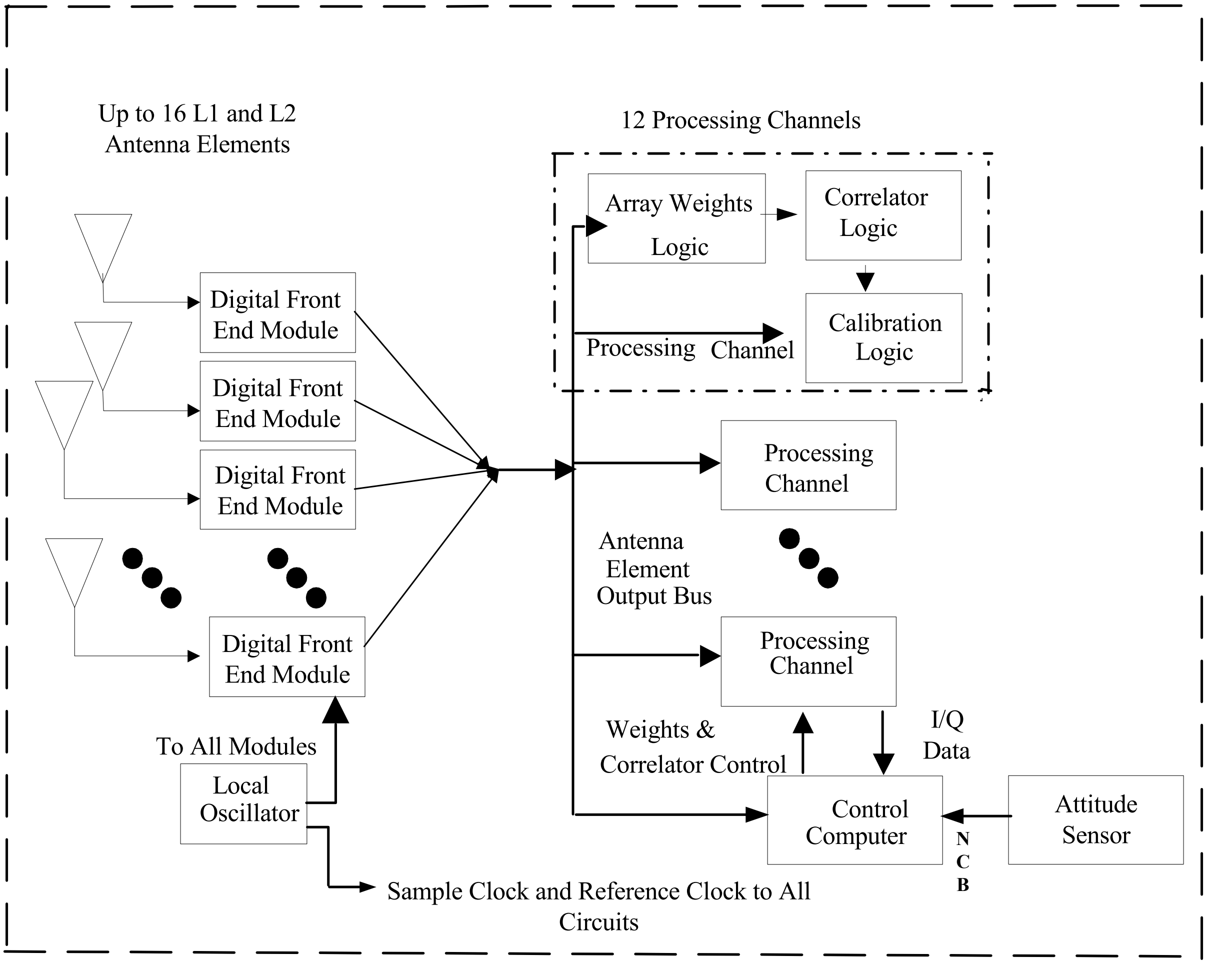

Figure 2 HAGR System Architecture

The weights for each channel are dynamically downloaded through software control. The HAGR software can automatically calculate the beam steering pattern for each satellite based on the known receiver location, the broadcast GPS satellite location and the input attitude of the antenna array. For static applications, the array can either be configured pointing north (the default attitude) or the actual attitude is programmed into the configuration file. For mobile applications, the antenna array attitude is input through a serial port from either a magnetic compass and tilt sensor or and inertial navigation system. The HAGR also includes a mode where the antenna weights are read from a user definable file based on the satellite azimuth and elevation. Matlab tools exist for creating these antenna weights based on specific user requirements.

In Figure 3 and Figure 4, the antenna patterns created by the digital antenna array are shown for four of the satellites tracked. The HAGR can track up to 12 satellites simultaneously. The antenna pattern provides the peak in the direction of the satellite tracked (marked 'x' in each figure). The beams follow the satellites as they move across the sky. Since the L2 wavelength is larger than the L1 wavelength, the antenna beam width is wider for the L2 antenna pattern than for the L1.

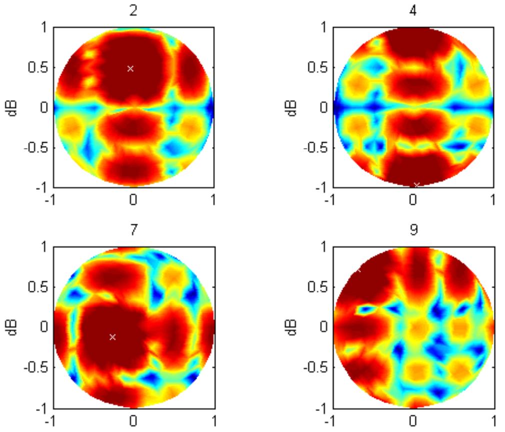

Figure 3 L1 Antenna Pattern

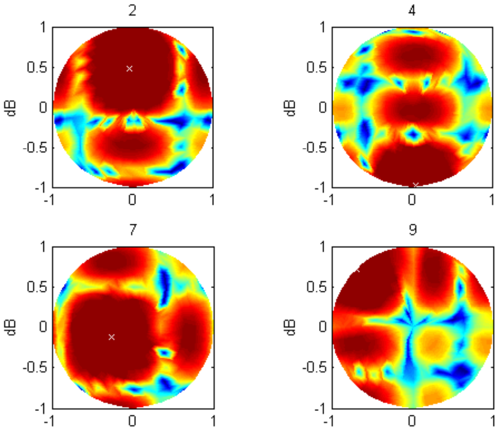

Figure 4 L2 Antenna Pattern

Alternative Antenna Arrays

The HAGR is designed to operate with a variety of different antenna array configurations. The antenna layout of the individual elements (L1 and L2) is defined through a configuration file. In Figure 5, two alternative 7-element antenna arrays are shown. On the left is shown the NAVSYS' miniature 7-element L1/L2 antenna array. On the right is shown a full-size antenna array composed of 7 single element antennas laid out with half-wavelength (9.5 cm) spacing. When using 7 antenna elements, +8 dB of gain will be provided on each satellite signal from the HAGR digital beam steering. In Figure 6, an array with sixteen L1/L2 antenna elements laid out in the 4x4 grid is shown. This produces the beam pattern shown in Figure 3 and Figure 4, which provides up to 12 dB gain in the direction of the GPS satellites. The number of elements can be further increased. In Figure 7 an array pattern with 109 elements is shown which will provide over +20 dB gain in the direction of each satellite.

Figure 5 7-Element Mini-Array and CRPA

Figure 6 Sixteen Element Antenna Array

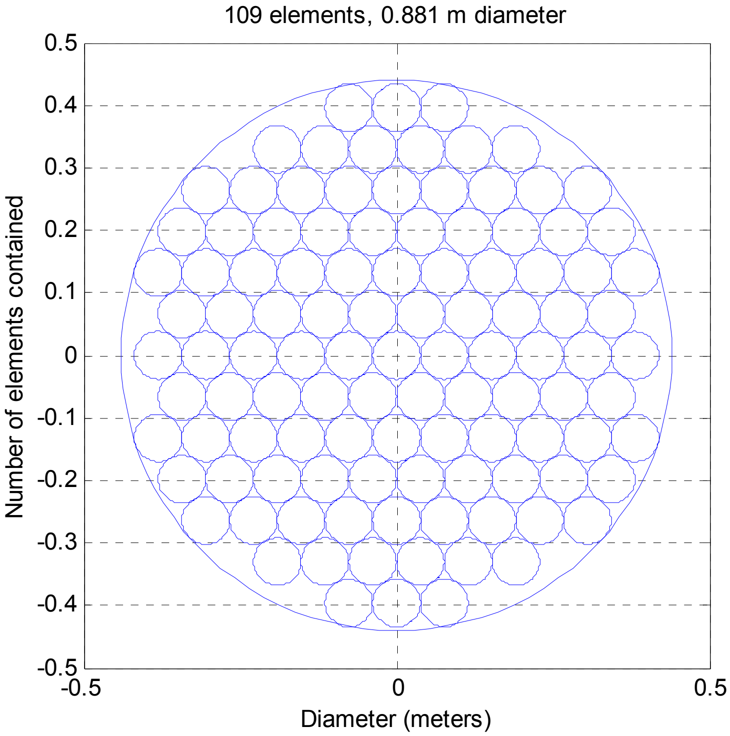

Figure 7 109 Element Antenna Array Configuration

HAGR Hardware Configurations

The HAGR adopts a modular hardware architecture that allows it to be scaled based on the user's desired performance level. An example configuration is shown in Figure 8. Each HAGR includes the following subsystem elements: one or more Digital Front-End (DFE) card(s) which digitally sample the GPS RF signals all operating using common local oscillator signals and sample clocks provided by the local time generator and synthesizer module; one or more Digital Beam Steering Cards (DBS) which combine the digitized antenna signals and provide 12 digital composite signal outputs to the Correlation Acceleration Card (CAC) which performs the GPS signal correlation and tracking functions under control of the host computer. These cards are installed in a Compact PCI backplane, as shown in Figure 1.

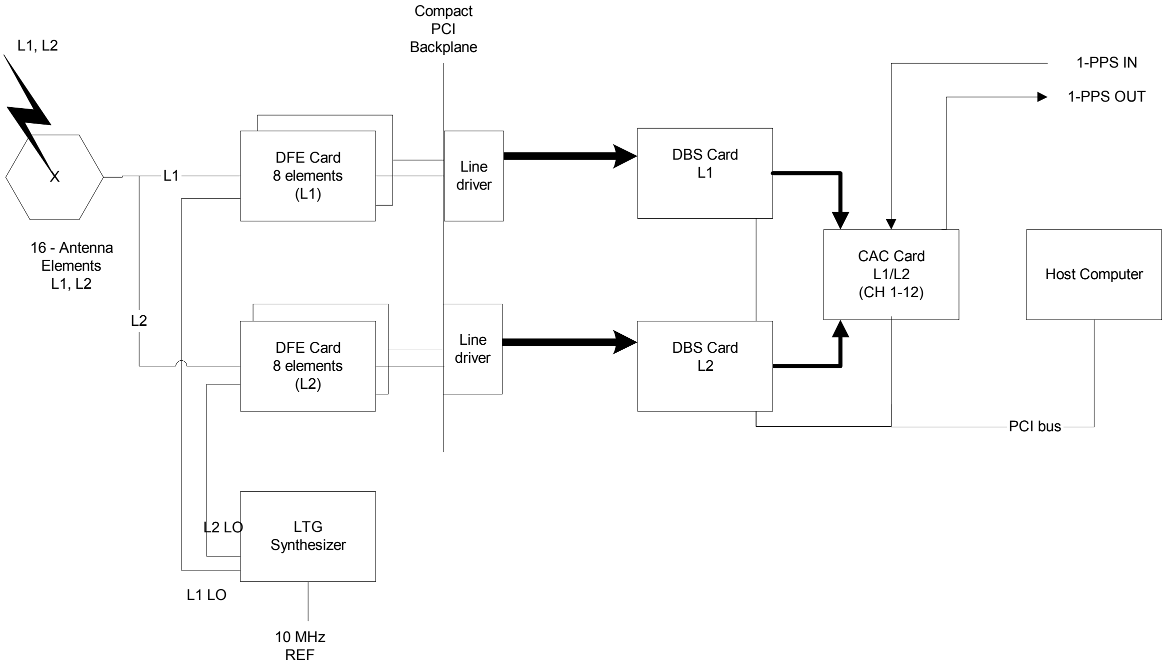

Figure 8 HAGR 16-element L1/L2 Configuration

The number of DFE boards is dictated by the number of antenna elements included in the antenna array. Each DFE board includes the capability to digitize eight antenna elements (see Figure 9). The output of the DFE card is an LVDS serial data stream including the 40 Msps 12-bit samples from each of the eight antennas connected. The DFE card can be configured to sample either the L1 or L2 frequencies through filter selection. In the example shown in Figure 8, four DFE cards are needed to sample the 16 L1 antenna signals and the 16 L2 antenna signals from an array such as that shown in Figure 6. Only a single DFE card, for example, would be needed to sample the 7-element L1 array shown in Figure 5.

The digitized antenna signals are combined in the DBS board. Each board has the capability of combining 16 different antenna input signals and creating 12 different composite signal outputs. For the configuration shown in Figure 8, two DBS boards are needed, one to handle the L1 antenna signals and one to handle the L2 antenna inputs. For an L1-only application, only a single DBS board is required.

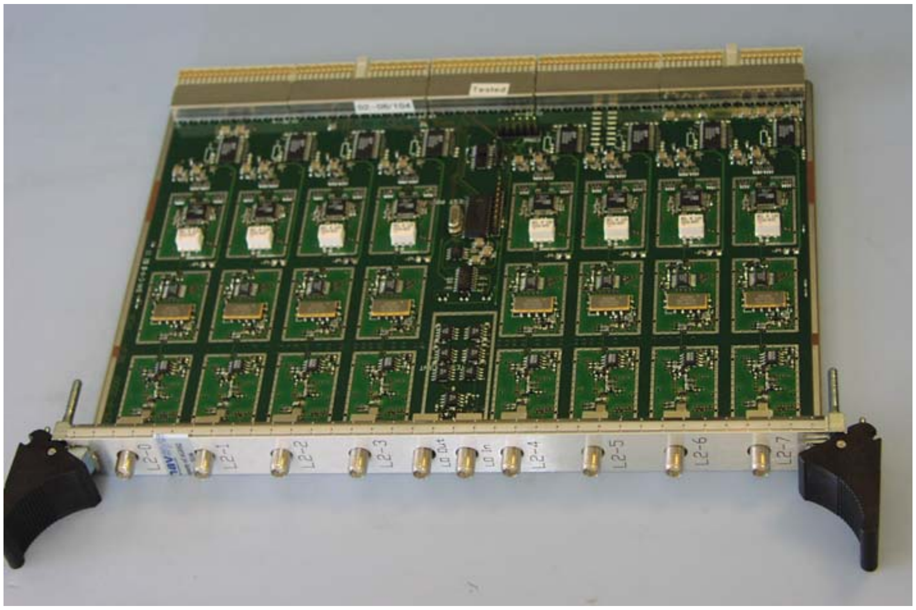

Figure 9 Eight antenna element DFE Card

The GPS signal processing is performed on the Correlation Accelerator Card (CAC). This includes four Xilinx FPGAs to perform the GPS code generation, correlation and carrier mixing functions. The CAC card can be configured for either C/A code or P(Y) code operation and is reprogrammable through FPGA bit files downloaded at the start-up of the HAGR. The raw correlation outputs (I/Q data) is provided at a 1-kHz rate through the PCI bus interface for up to 12 satellite channels for C/A code, P(Y) L1 and P(Y) L2 operation.

Some of the alternative HAGR configurations that can be ordered are listed below. Customized configurations can be assembled to meet individual customer requirements.

16 Element L1/L2 Antenna Array	12 Channel (Satellite) P(Y) (PPS).
16 Element L1 Antenna Array	12 Channel (Satellite) C/A (SPS).
7 Element L1/L2 Antenna Array	12 Channel (Satellite) P(Y) (PPS).
7 Element L1 Antenna Array	12 Channel (Satellite) C/A (SPS).
1 L1/L2 Element	6 or 12 Channel (Satellite) P(Y) (PPS).
1 L1 Element	12 Channel (Satellite) C/A (SPS).

HAGR Software Architecture

The HAGR includes our highly flexible Software GPS Receiver (SGR) software application, which allows dynamic reconfiguration and optimizing of the HAGR for different applications.

The SGR software design provides a detailed command structure to allow all of the receiver initialization and signal processing parameters to be adjusted by the user. The receiver controller accepts commands and parameters from command and configuration files or alternatively from the keyboard user input. Tracking data and processing messages are sent to a display screen throughout the real-time processing, and data is written to output files for post-processing.

The HAGR software includes the following main functions:

1. Track GPS satellites
2. Compute Navigation solutions (standalone and differentially corrected)
3. Compute Differential Corrections
4. Interface with other computers through a serial port (API)
5. Output many different types of data to log files
6. Operate in Post process with logged data files
7. Display real time and post process data to watch windows
8. Perform digital beam steering and calibration

The HAGR software runs on a standard Pentium class PC computer. This facilitates data collection and transfer of data for analysis through standard network interfaces. Matlab tools are provided that facilitate reading the different data files logged and plotting or analyzing this data.

CONCLUSION

Modular design and flexible reprogrammable architecture adopted for the HAGR allow it to be easily configured to meet our customer's needs. The software receiver design also simplifies the addition of new user specific modules which can be quoted on request. The performance advantages of the digital beam steering approach for our customer's applications are listed below.

- Digital beam steering increases the observed GPS signal-to-noise ratio.
- Increase in gain to each satellite increases the GPS measurement accuracy.
- Beam steering directivity reduces the effect of code and carrier multipath error.
- Phase coherent signal sampling allows precise carrier phase time transfer.

Applications for the HAGR include: precise GPS positioning, GPS reference station differential correction generator, remote differential operation, kinematic GPS positioning, precision time transfer. Some of the recent applications and test results of the HAGR are described in the following references.

"Test Results of a Digital Beamforming GPS Receiver in a Jamming Environment," Brown and N. Gerein, ION GPS 2001, Salt Lake City, Utah, September 2001.

"Test Results from a Digital P(Y) Code Beamsteering Receiver Designed for Carrier Phase Time Transfer," A. Brown and N. Gerein, ION GPS 2001, Salt Lake City, Utah, September 2001.

"Test Results from Digital P(Y) Code Beamsteering Receiver for Multipath Minimization," A. Brown and N. Gerein, NAVSYS Corporation, ION 57th Annual Meeting, Albuquerque, New Mexico, June 2001.