A Modular Re-programmable Digital Receiver Architecture

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BIOGRAPHY

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Alison Brown is the President of NAVSYS Corp. She has a PhD in Mechanics, Aerospace, and Nuclear Engineering from UCLA, an MS in Aeronautics and Astronautics from MIT, and an MA in Engineering from Cambridge Univ. She was a Draper Fellow at Charles Stark Draper Lab. She worked six years for Litton developing GPS and inertial navigation systems. In 1986 she founded NAVSYS Corp.

Richard Slosky has a BA in Mathematics with a concentration in Physics. He was a project manager for Technology for Communications International for six years. He then spent 10 years as a Technical/Project Manager for GTE. He joined NAVSYS Corp. in 1997.

ABSTRACT

The many diverse applications of GPS have led to the development of a wide variety of specialized GPS receiver products. However, any custom receiver design results in significantly higher priced equipment than the conventional OEM receiver due to design changes, equipment changes, and the loss of economies of scale. In this paper, a modular re-programmable digital and software based GPS receiver architecture is described that can be easily and cost-effectively adapted for a variety of advanced GPS applications for military, commercial and space.

NAVSYS' re-programmable Advanced GPS Receiver (AGR) is a special purpose GPS receiver system designed to provide enhanced signal processing for special-purpose GPS applications and advanced test capability. The AGR signal processing provides highly accurate TSPI data even in stressed environments (e.g. high dynamics or low signal-to-noise) and allows low-level access to the GPS tracking loop parameters which can be used to optimize performance. Eight channels are provided with data output rates from 1 Hz to 1kHz. The system utilizes NAVSYS' GPS digital front-end (DFE) sensor technology.

NAVSYS' GPS DFE sensor technology is adaptable to custom requirements. The DFE can be a single element or it can be implemented as a phased array. Coherency between elements is maintained with common clock circuitry. The DFE can provide 1-bit to 8-bit data at sample rates from 2 MHz to 60 MHz. Multi-frequency DFE inputs are able to track GPS (L1 or L2), Pseudolite (Lx), L5, etc.

The AGR is a flexible system accommodating a variety of front ends, data transmission methods, and allows real-time processing or data storage and playback for post-test processing. The AGR can be configured to fit specific requirements with "Key-Word" changes or software modifications.

The AGR is supported by NAVSYS' Matlab GPS signal simulation toolbox to assist in system optimization. The signal simulation toolbox can be used as an analysis aid to assist in test and evaluation of GPS receivers. Data output from the AGR can be used as inputs to the toolbox to optimize receiver parameters that can then be adjusted in the AGR for optimum performance.

INTRODUCTION

Many GPS receiver applications require hardware and software configurations that are different from the configurations found in high volume production receivers. OEM receivers exist that allow a developer to adjust certain parameters, and only within a limited range. Hardware and firmware modifications to OEM receivers can be very difficult and costly, and the OEM manufacturer may not be interested in making such modifications. A need exists for a receiver that can be customized and modified to fit particular applications.

An example application for such a receiver is missile tracking for test and evaluation. The dynamics of the missile would cause a standard receiver to lose lock, and the cost of building a custom receiver can not be justified for only a few flights. This paper describes the NAVSYS approach to building a digital GPS receiver system that is modular and re-programmable, allowing it to be optimized for high dynamic flights and other applications[1].

OVERALL ARCHITECTURE

The overall modular architecture is shown in **Figure 1**.

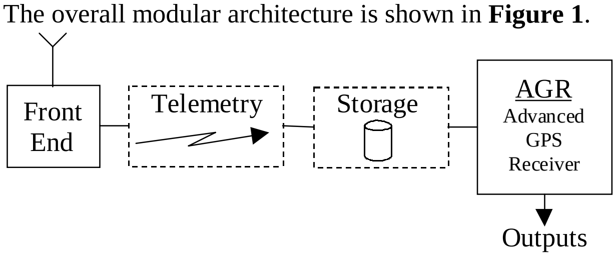

Figure 1 Modular Architecture

With the modular architecture, a variety of digital front ends can be employed, depending on the particular application. The front ends can be single elements, or multiple elements combined in a phased array. The front end frequencies can be L1, L2, or a new frequency. The RF bandwidths can be adjusted to pass C/A code, P/Y code, or a new modulation.

With the modular architecture, the digitized data from the front ends can be passed directly into the receiver, or they can be passed through a variety of telemetry links and possibly stored for later playback. These options are illustrated in **Figure 2**. This separation of the front end from the tracking and navigating hardware provides significant flexibility and potential cost reduction, especially if the receiver portion will be lost after each use (such as a weather balloon or sonobuoy).

The AGR receiver is PC based, which further adds to the modular and re-programmable nature of the system. A custom Correlator Accelerator Card (CAC) in the receiver provides the carrier and code tracking and the millisecond integrations. The tracking software executes on the PC's processor. All tracking parameters (such as tracking loop bandwidths) are keywords that can be modified by the user through a menu or a command file.

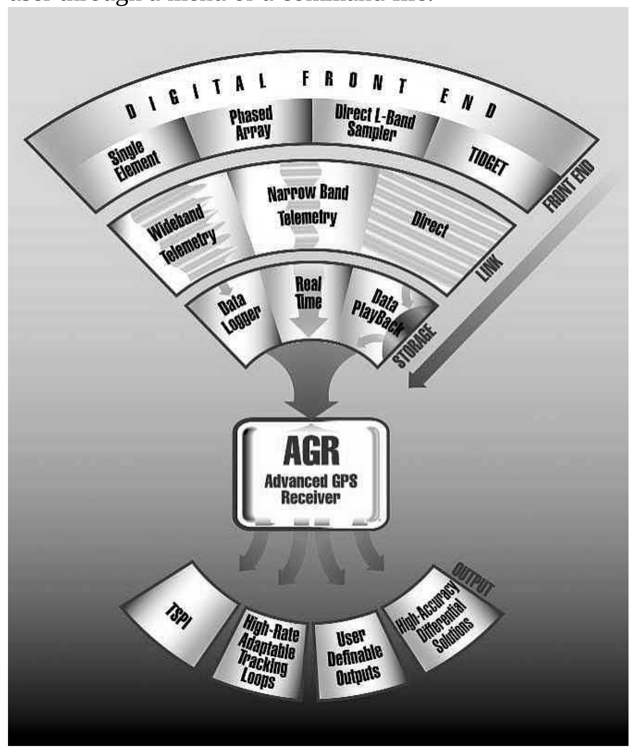

Figure 2 Modular Architecture Options

The receiver can output to the display or a disk all the relevant tracking and navigation parameters at rates up to 1 kHz. The receiver can input or output differential corrections. The navigation solution can be a standard solution, a differentially corrected solution, or a kinematic solution. Because the receiver software is all PC based, it can be easily re-programmed to perform new tasks not currently envisioned. The performance spec for the AGR is shown in Table 1.

FRONT END ARCHITECTURE

The basic digital front end (DFE) architecture is shown in **Figure 3**. The Local Oscillator (LO) frequency is chosen to produce a desired Intermediate Frequency (IF) out of the mixer. The LO is adjusted to different values for tracking L1, L2, or other signals. The SAW filter rejects the frequencies outside the band of interest. Different filters can be installed to pass C/A code only, or the full P/Y code spectrum. The sample clock is usually set at least twice as high as the SAW filter bandwidth to satisfy the Nyquist sampling requirements.

Table 1 AGR Performance Specifications

Technical Specifications	
GPS Frequency	L1, 1575.42 MHz
Source	C/A code (SPS)
Channels	8 channels
Correlation	Adjustable Spacing
Operating Specifications	
Peak Vehicle Dynamics	
Velocity	10,000 m/sec
Acceleration	100 g
Jerk	100 g/sec
Position Update Rate	1-1000 Hz
Raw Data Output Rate	1-1000 Hz
Time To First Fix	40 secs (cold – no time or position)
Re-Acquisition	10 secs to valid position
DFE Input Signals	
Center Frequency	1227.6 to 1575.42 MHz
Nominal Signal Level	-136 to-86 dBm
Signal Bandwidth	0 to 20 MHz
CW or Noise Interference Levels at DFE Input	
Center Frequency ± 10 MHz	10 dB above weakest
1200 to 1600 MHz	<-80 dBm
Outband Interference	<-20 dBm
Built-in Modules	DGPS (reference and remote) Timing Reference
DFE Output Signals	
Digital Samples	I, Q, or I&Q
A/D	1-4 bits
Sample Rate	2-25 MHz
IF Frequency	70 MHz
User Configuration Parameters Selectable through configuration file or user interface	Vehicle Dynamics Track Thresholds DLL and PLL or FLL bandwidths and thresholds DFE characteristics Correlator spacing Data logging rates Satellite selection methods

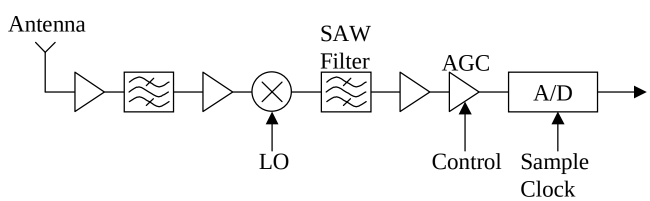

Figure 3 Basic Front End Architecture

An example front end is shown in **Figure 4**. This front end is a TIDGET[2], which also contains a data buffer for storing snapshots of data that can be sent on a low bandwidth telemetry link.

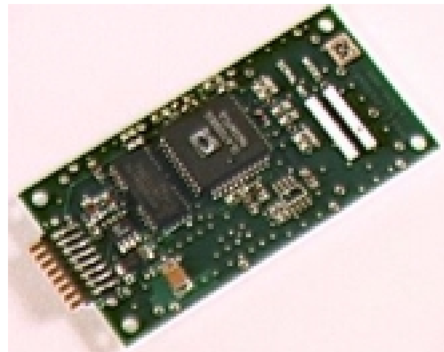

Figure 4 TIDGET Digital Front End

ADVANCED GPS RECEIVER ARCHITECTURE

The heart of the re-programmable receiver is the PC based Advanced GPS Receiver (AGR). The AGR contains the Correlator Accelerator Card (CAC) in a standard ISA slot, and tracking software that runs on the PC's processor. The CAC contains eight channels for tracking eight satellites. Each CAC channel performs the functions shown in **Figure 5**. The PC controls the inputs to each channel, so parameters such as the initial Doppler frequency and final IF can be easily set. The card is based on field programmable gate arrays. The code for the gate arrays is downloaded from the PC each time the system is initialized, so the gate arrays can be easily re-programmed as well.

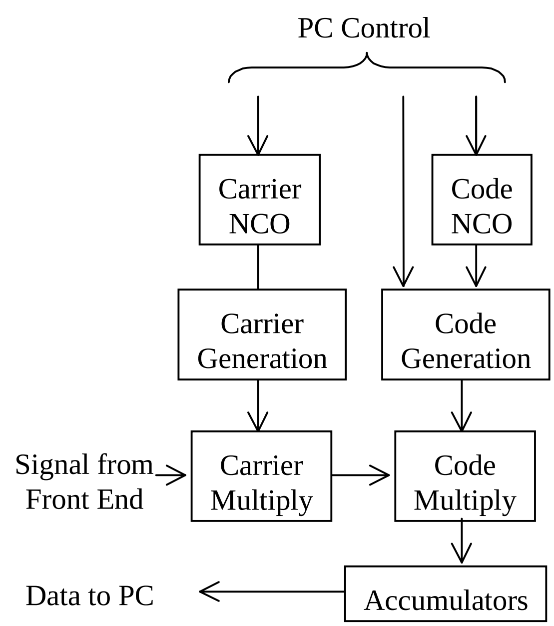

Figure 5 Correlator Accelerator Card Functions

The software is written in C and implements all the code and carrier tracking loops, including possible aiding of the loops from inertial sensors or other sources. The navigation solution can be a least squares solution or a Kalman filter solution. Differential corrections can be input to the system or the system can act as a reference station outputting differential corrections.

Because the sampled IF data is separate from the receiver and can be stored (logged) onto disk, the AGR can operate in a post-processing mode. This allows tracking and navigation information to be used that is not available in real-time to the receiver. It also allows parameters, such as loop bandwidths, to be adjusted and optimized after the raw data is gathered.

All software parameters that might need to be changed are keywords that can be manually adjusted through menus or through command files that are read on initialization. The basic philosophy is that only constants (such as the speed of light) are hard coded; all other parameters are keywords. This philosophy means that the same code can be used for a wide variety of applications without recompiling.

The AGR can be housed in a standard desktop PC or in a ruggedized PC. **Figure 6** shows an AGR in a ruggedized PC.

MATLAB TOOLBOX SUPPORT

During the development of the re-programmable architecture, MATLAB was used to simulate all the functions of the receiver architecture before the system was built. This MATLAB based GPS simulation toolbox can now be used to generate simulated DFE data files for any mission profile or test configuration. The overall flowchart for the MATLAB simulation is shown in **Figure 7**.

Figure 6 Ruggedized AGR

The MATLAB toolbox can also be used to analyze, track, and navigate actual DFE recorded data, although the MATLAB simulation is much slower than the real time AGR. The real data is logged to disk using the optional logging capability shown in **Figure 1**. The stored data is then input to the simulation instead of the data that would be output from the Simulate Receiver Front End block.

Alternatively, simulated front end data can be stored and played back into the AGR for testing AGR functions and possible mission scenarios. The mission scenarios could include jamming or high dynamics that could possibly stress the receiver system.

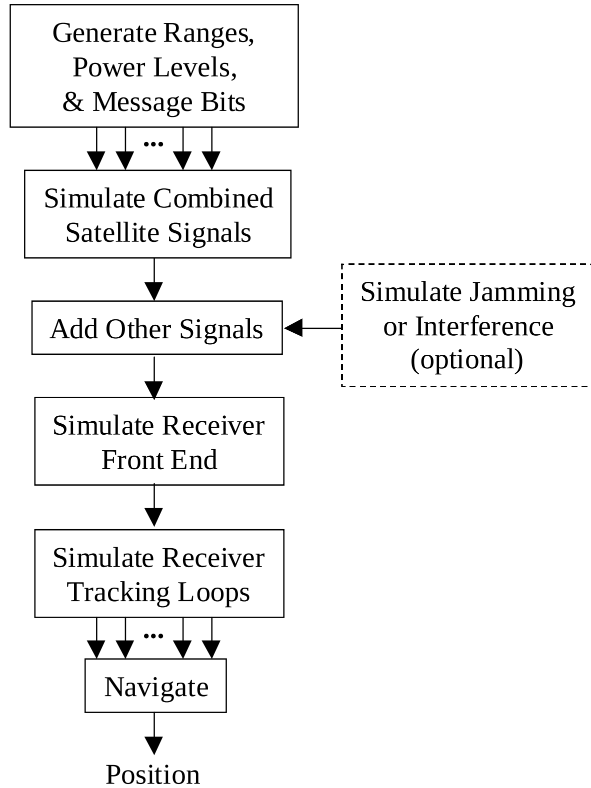

Figure 7 MATLAB Simulation

The modular nature of the architecture allows enhancements to be designed and tested in MATLAB before the operational hardware or software is modified. It also allows actual raw data or tracked data to be analyzed with the full capabilities of MATLAB to investigate new or unique situations and signal environments.

APPLICATIONS

Because of the receiver's modular and re-programmable nature, NAVSYS has been able to use the system for a variety of applications including:

High Dynamic Missile Tracking – using the TIDGET DFE as a digital translator

Radiosondes and Dropsondes – using the TIDGET sensor with a low rate FM telemetry link[3], [4], [5]

Sonobuoy – using the TIDGET sensor integrated with the sonar telemetry data link [6], [7], [8] LocatorNet – locating cellular phones with embedded TIDGET sensors[9]

Digital Beam Steering – using multiple DFEs and a custom digital beam steering card as a spatial antenna array[10]

CONCLUSION

This paper has described a modular and re-programmable receiver architecture that can be used for a variety of applications where standard receivers would not work well. The re-programmable nature of the receiver makes it ideal for specialized jobs that require customization to optimize the performance of a GPS receiver.

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