Accord's Next Generation High Performance GPS/WAAS Receiver Based on the Soft-Correlator™

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BIOGRAPHY

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ABSTRACT

NAV2500™ is the next generation GPS/WAAS receiver from Accord.

Based on the enhanced Soft-Correlator™, the receiver is designed around a single high performance fixed point general purpose Digital Signal Processor (DSP) from Analog Devices and a standard Radio Frequency down converter. The receiver features increased availability of the GPS solution by means of improved speed of signal acquisition and reacquisition along with enhanced signal tracking sensitivity. The 12 channel GPS/WAAS correlator and the navigation module are both realized using a single DSP to offer the performance demanded by a whole new generation of hand held, wireless computing, automotive and timing applications.

The receiver can be configured to track SBAS signals. This generation of receivers feature better TTFF performance and much lower power consumption characteristics over the NAV2300 from Accord.

NAV2500™ employs a configurable in-built soft-demodulator to decode MSK DGPS signals from Beacons. The receiver can also be used as an accurate timing reference, which can be utilized in a variety of synchronization applications. The software Numerically Controlled Oscillator (NCO) in the receiver which is synchronized with the GPS epoch can be programmed to generate frequencies ranging from 100Hz to 10MHz. The timing unit of the receiver is driven by an inexpensive crystal.

INTRODUCTION

Accord is an Independent Algorithm Vendor (IAV) to Analog Devices, Inc. Accord is a Bangalore, India based company, specializing in the development of DSP based algorithms, software and hardware designs.

The philosophy behind the development of the Soft-Correlator™ based GPS receivers is:

- ☐ to continuously improve the receiver's accuracy and availability characteristics without always having to invest in new hardware development and/or customization of silicon
- ☐ to make the complete GPS receiver function available as a library on a family of instruction-set-compatible programmable DSPs from Analog Devices so that reference designs can be created for a wide variety of GPS applications by integrating the GPS receiver library with other communication and multimedia programs
- ☐ to achieve scalable performance characteristics by exploiting the availability of faster DSPs with lower power consumption

- to make the base band processing architecture independent of the RF down converter architecture
- to make the software available on both floating point as well as fixed point families of DSPs from Analog Devices, so that system developers / integrators have a wider range of DSPs to choose from.

This paper briefly explains the architecture of Soft-Correlator™ based GPS receiver and highlights its features.

DSP FOR SOFT SOLUTION OF GPS

A typical software approach to GPS receiver design involves a Radio frequency (RF) front end and a DSP to perform signal processing and navigation tasks (see Figure 1). The RF front end down converts the signal to a sufficiently low Intermediate Frequency (IF) and digitizes it. The digitized IF is processed in the DSP to perform correlation, acquisition and tracking.

In contrast to the software approach, a typical hardware solution does correlation of the IF inside an Application Specific Integrated Circuit (ASIC).

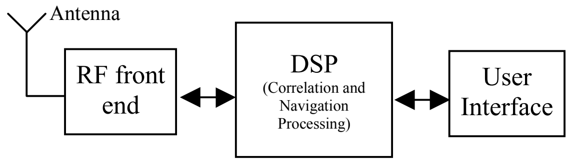

Figure 1: A typical software based GPS receiver architecture.

With a software solution, the improvements in silicon technology can be easily translated into better performance with smaller form factors and lower power consumption, without a hardware redesign as against a hardware solution.

In future, most of the GPS receivers will be driven by the software solution to derive the advantages of high flexibility and scalability.

Integration of GPS with other navigation sensors, such as Dead Reckoning and Inertial Navigation Systems (INS) require extensive data processing and filtering operations. A DSP architecture is ideally suited for this data fusion. A single processor with adequate memory and speed can serve both as a GPS signal processor and a data fusion processor for integration with other navigation sensors.

RECEIVER ARCHITECTURE

The NAV2500™ consists of two principal blocks as shown in Figure 2, namely,

- RF Down Converter
- GPS Signal Processor

This GPS receiver can be used with any standard RF front end. The sampling clock is generated by the GPS Signal Processor. The sampling frequency can be altered to suit frequency plans for different RF front ends.

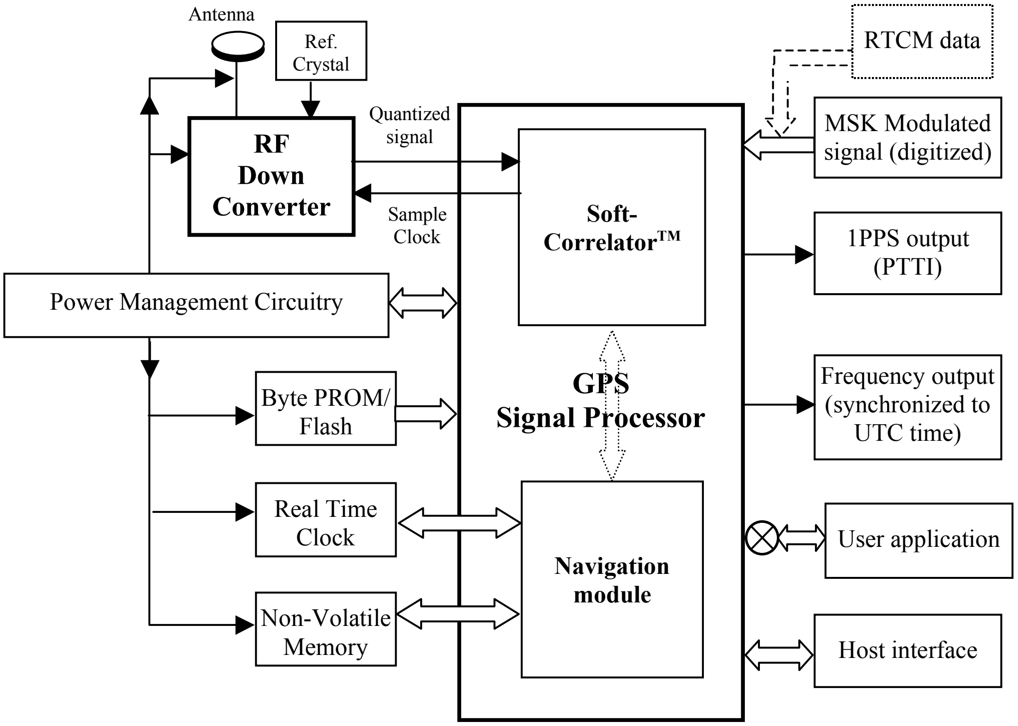

Figure 2: System Block Diagram of NAV2500™ GPS Receiver.

The GPS Signal Processor (DSP) performs all the correlation and navigation tasks.

The ADSSTNAV processor is a programmable fixed-point DSP microcomputer from Analog Devices and is used to realize the GPS Signal Processor in NAV2500^{TM}. The DSP delivers high throughput for both base band signal processing functions as well as high precision floating point arithmetic. The low power architecture with advanced power control mechanism is useful in a variety of applications.

RF Down Converter

The NAV2500 solution is virtually independent of the type of RF down converter. Based on the overall system requirements, the user can choose the most suitable RF down converter for the application. The sampling frequency for the digitized IF is generated in the DSP and it is programmable. The digitized IF output from the RF down converter is connected to one or more high speed serial ports of the DSP.

The solution has a comprehensive set of algorithms to dynamically switch ON/OFF the RF down converter either completely or partially to achieve very low power consumption. These algorithms can be very easily customized to work with different RF devices.

GPS Signal Processor

The two primary blocks of the GPS Signal Processor are:

- ☐ Soft-Correlator^{TM}
- ☐ Navigation module

Soft-Correlator^{TM}

The block diagram is shown in Figure 3

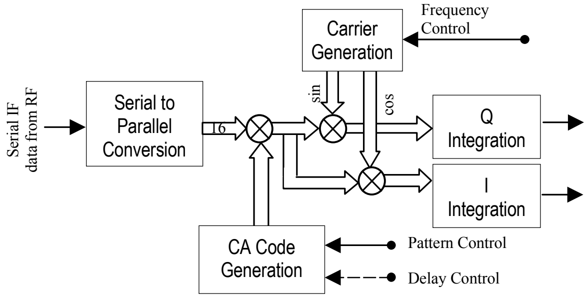

Figure 3: Block diagram of the Soft-Correlator^{TM}

The digital section (DSP) gets samples from the Analog RF section after ADC conversion. The sampled data is despread with local code and then mixed with inphase and quadrature carrier bit streams (generated in software) to yield the inphase and quadrature phase correlation samples. The internal memory of DSP is used to store the local code instead of expending computing resources to generate the code.

The processing is performed on all the correlator channels through the same software eliminating the effect of hardware irregularities in different channels, which often introduces channel bias.

Navigation Module

Navigation tasks are concerned with the generation of user position, velocity and time. The solution can be computed four times per second in the normal mode of operation or once a second in the low power mode of operation.

A comprehensive custom-built floating point library is made use of, leading to a very accurate position and velocity for all satellites with ephemeris. An efficient data base manager integrates into the architecture seamlessly to ensure frequent data updates for all visible satellites. Satellites are programmed into the channels according to the estimates available to ensure faster acquisition and reacquisition. This aids in generating instantaneous navigation output.

The interface between the various modules is flexible, so much so that any module can be plugged in and out as desired.

RECEIVER OPERATION

The receiver operations can be summarized into the following four states:

- ☐ Initialization
- ☐ Search
- ☐ Navigation
- ☐ Power down

The receiver will be in any one of the states at any given instant. The receiver can also transit from one state to another based on the operating condition. Figure 4 gives the state diagram of the receiver operation.

The sequence of operations is explained below:

1. At power on, the receiver enters INITIALIZATION state. The data from the nonvolatile memory and Real Time Clock are read and all the signal channels are programmed.
2. Once the initialization is complete, the receiver enters SEARCH state where it acquires and tracks the satellites to obtain measurements and collect navigation data.
3. The receiver enters NAVIGATION state once it computes user position and velocity.

4. If at any point in time, the receiver is unable to give fix, it goes back to SEARCH state.
5. The receiver will be in NAVIGATION state for 4Hz fix update rate.
6. For 1Hz fix update rate, the receiver enters POWER DOWN state.
7. The receiver continues to be in POWER DOWN state consuming minimum power.
8. The receiver reverts back to NAVIGATION state periodically to update navigation database.
9. If the user commands a receiver restart or factory reset, it enters to INITIALIZATION state.

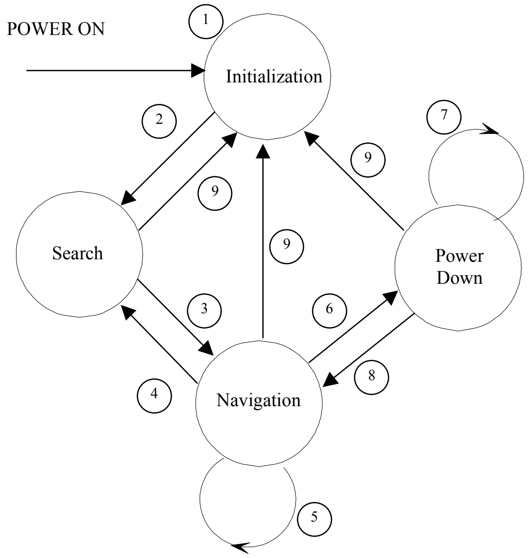

Figure 4: State diagram of the receiver operation.

PERFORMANCE HIGHLIGHTS

Timing Output and Frequency Synthesis

The receiver outputs very accurate pulses synchronized to the UTC second boundaries. The duty cycle of the pulse is user configurable ranging from one millisecond to one second in steps of a millisecond. Either the rising or the falling edge can be synchronized to the UTC second boundary. The Pulse Per Second (PPS) output is driven by a low cost crystal and avoids the use of costly equipment for the generation of accurate clocks. The PPS output, with an accuracy of ±50 nanoseconds, plays an important role where bandwidth and accurate timing are important factors, as in network synchronization and TDMA systems. Accuracy of the PPS output can be significantly improved by configuring the receiver in the “stationary antenna” mode.

The receiver is capable of generating frequencies from 100Hz to 10MHz. The frequency is generated using a software NCO. As this clock is synchronized with the GPS time, its long term stability characteristics are governed by the GPS system while its short term stability characteristics are governed by that of the reference clock used.

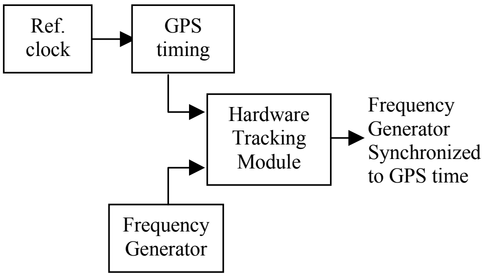

Figure 5: Standard frequency generator synchronized to GPS time

Figure 5 shows a typical time and frequency generator synchronized to GPS time. It requires a tracking system which synchronizes GPS time and frequency generator.

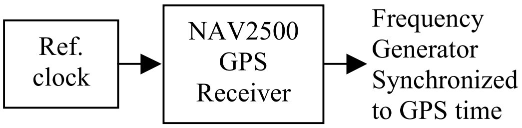

Figure 6: Frequency synthesis using NAV2500$^{\text{TM}}$ receiver.

Figure 6 illustrates the time and frequency generator based on the NAV2500$^{\text{TM}}$.

As can be seen, the hardware tracking loop is completely eliminated using NAV2500$^{\text{TM}}$ while achieving desired performance and delivering unmatched flexibility.

Programmatic Interface

Programmatic Interface (PI) is a distinct feature on the NAV2500$^{\text{TM}}$ that enables the OEMs/users to embed their applications into the DSP along with the GPS core. Custom applications that require powerful DSP architecture can make better use of the programmatic interface feature. A typical example would be the integration of Dead Reckoning sensors where the hybrid navigation filters require both the computation powers of the DSP and the real time GPS outputs.

The GPS core software engages a real time executive to manage the resources of the DSP and provides the interface to the user application.

The PI architecture is flexible to suit various applications by providing sufficient run-time and compile-time resources along with access to real time GPS data.

Programmatic Interface is available to the user in two modes:

- ☐ Periodic Invocation
- ☐ Background Invocation.

Any application that requires periodic invocation can make use of Periodic Programmatic Interface. In this mode, the user application is deterministically invoked by the executive once every second.

The Background Programmatic Interface is recommended for those applications, which do not need deterministic allocation of the CPU time. In this mode, the user application gets to use all the spare CPU time after completion of the GPS activities.

In both modes, the user's application is preempted by GPS (both hardware and software) interrupts.

The entire GPS module is available as a library. A set of source files is provided for the users to build applications. Once the application has been built, the user can execute a series of batch commands in order to create the binary executable file.

A quick three-step sequence summarizes the procedure to use Programmatic Interface:

- ☐ As a first step, the application is developed either in C or in the assembly language of the DSP
- ☐ The application is then linked to the GPS core library
- ☐ Based on the requirements, the application will be invoked either Periodically or Aperiodically.

Receiver Autonomous Integrity Monitoring (RAIM)

The NAV2500^{TM} receiver outputs RAIM protected position and velocity. When there are more than 4 satellites in view, the computed position is used to predict the ranges and the residuals are analyzed. The range errors are translated to position error based on the satellite geometry. If the error is not within acceptable limits the receiver isolates the erroneous measurement and gives a correct position solution. A similar approach is used to monitor velocity as well.

The test statistic based on the range residuals has Chi-square distribution and it is practically insensitive to the user/satellite geometry.

During Navigation State, the consistency of the measurements is verified to detect and isolate multiple satellite failure.

Smart Power Architecture

Towards reducing the power consumption, NAV2500^{TM} has an advanced power management feature to offer – the Smart Power architecture. By incorporating better power management, the NAV2500^{TM} is ideally suited for applications that demand high performance at low power consumption.

Smart Power architecture embeds a variety of power control algorithms blending the features of both hardware as well as software without compromising on any of the performance parameters.

The key elements to this effective design in hardware are:

- ☐ Real Time Clock
- ☐ Power management circuitry
- ☐ Digital Signal Processor
- ☐ Radio Frequency chip

In software, the following enhancements provided by NAV2500^{TM} allow the optimum usage of the hardware resources to achieve maximum power reduction.

- ☐ Sub-second reacquisition
- ☐ Fast converging tracking loops
- ☐ Power management algorithm.

The NAV2500^{TM} offers the following power modes catering to different operational requirements.

Normal mode

In the Normal mode, the receiver continuously tracks satellites all the time and computes upto four position fixes per second.

Power down mode

In this mode, the receiver operates with very little power. The software approach allows the receiver to operate on the signal samples even when the RF is in low power mode, to ensure least active period. With this approach, the power consumption can be as low as 25% of the normal power

Fix-On-Demand mode

This mode is an extension of the Power down mode. The user can command the receiver to output the navigation data once every few seconds. The receiver wakes up at that rate to compute the navigation solution and reverts to the low power state.

Fix-On-Demand mode consumes the least power among the different modes of operation.

The Smart Power architecture tremendously improves on the basic principles of low power architecture by dynamically changing sequences and modes of operation.

Power management circuitry

The power management hardware consists of a regulator and a programmable switch. The DSP controls the flow of power to various segments of the chipset through the switch.

Switching between Power modes

The receiver by default operates in the Normal mode. User can command the receiver to switch over to Power down mode through an ASCII message. On each subsequent power-up, the receiver “remembers" its previous mode. A mode switch from Power down to Normal mode occurs if the user opts for it (say, through a hardware interface).

Intelligent algorithms in the receiver ensure periodic wakeup from power down to update its database (ephemeris, almanac). Under these conditions, the receiver transits to Normal mode till such time as new data is collected and reverts back to the Power down mode subsequently.

Sub-second Reacquisition

Lower power consumption demands fast reacquisition. The contribution of the reacquisition performance of the NAV2500^{TM} is vital to the Smart Power architecture. Typically, the receiver reacquires all the visible satellites in less than 100 milliseconds.

Fast converging tracking loops

In order to provide instantaneous navigation output on reacquisition, it is paramount that the tracking loops converge to the actual values of code phase and carrier doppler as soon as possible. Efficient algorithms ensure code and carrier convergence within 100 milliseconds after reacquisition to enable the PVT solution from the receiver almost instantaneously.

Power management algorithm

The Smart Power architecture has sophisticated power management software that interacts with all the modules of the receiver to ensure reliable low power operation with accurate position and velocity solution.

Figure 7 shows current consumed by the DSP in power down mode.

Figure 8 shows current consumed by NAV2500^{TM} receiver in Normal mode, Power down mode and Fix On Demand mode (for once in 3 minutes fix update rate)

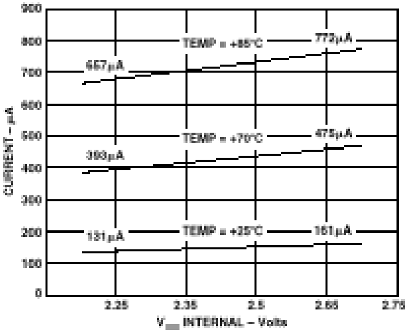

Figure 7: ADSSTNAV current consumption in power down mode

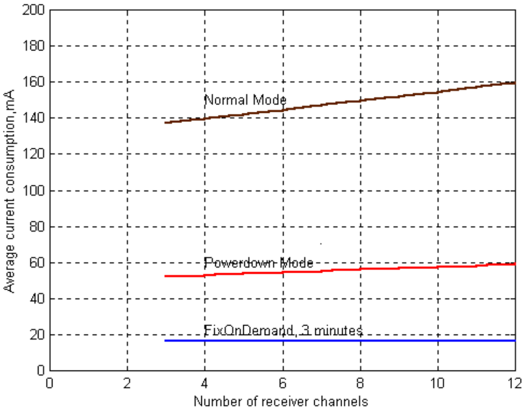

Figure 8: Current consumption of NAV2500^{TM} under different modes

MSK Demodulation for DGPS

The NAV2500^{TM} receiver has a dedicated port which can be configured to receive either ready-to-use DGPS corrections or modulated RTCM data. A built-in software Minimum Shift Keying (MSK) demodulator demodulates RTCM SC-104 differential corrections transmitted by radio beacons.

DGPS signals in the entire maritime radio navigation band (283.5 KHz to 325 KHz) are demodulated by the MSK demodulation software. The demodulator is powered with efficient beacon search algorithm to reduce acquisition time and has a very high sensitivity to work under low SNR conditions.

The automatic signal detection capability eliminates the need for manual tuning. Also, the receiver has auto-bauding feature to detect the transmission rate (25/50/100/200bps) which eliminates the need for configuring the system baud rate manually. The receiver can work with either single (main) carrier transmission (channels spaced at 1 KHz) or dual carrier transmission (spaced at 500 Hz).

One of the major advantages of this unique feature is that NAV2500^{TM} can be used as a complete beacon/GPS receiver with very little external hardware. For example, as shown in Figure 9, an antenna, a simple RF circuit consisting of preamplifiers and an ADC would suffice to integrate both beacon and GPS receivers. This eliminates the usage of an external beacon receiver as shown in Figure 10.

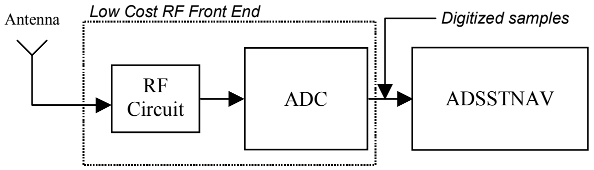

Figure 9: Integrated Beacon/GPS receiver system employing MSK demodulation inside GPS receiver.

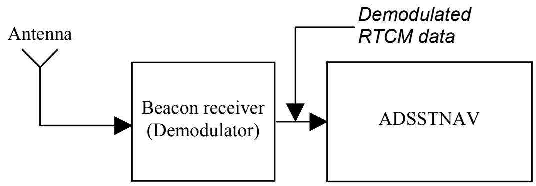

Figure 10: Beacon/GPS receiver system employing external beacon receiver.

SBAS COMPATIBILITY

The NAV2500^{TM} solution has the capability to receive WAAS signals along with the GPS signals. The number of GPS channels and WAAS channels in the receiver can be configured. For example, receiver can be configured as a combination of 10 GPS channels and 2 WAAS channels.

The objectives of the WAAS is to provide improved:

- integrity
- accuracy
- availability
- continuity

The receiver uses the WAAS information to exclude erroneous GPS satellite measurements and to apply differential corrections to the range measurements. It also uses the measurements from the WAAS satellites.

OEM FIRMWARE SUPPORT

The OEM kit is a utility which allows the OEMs to configure the GPS receiver to the specific requirements of each customer. This utility enables the OEM's to define the default configuration of the receiver according to the requirements of the customer. The following gives a brief description of the product. The flow of operations through the OEM kit is as shown in figure below

Figure 11: OEM system description.

Source firmware- the firmware (binary file) which is provided by the designer of the GPS receiver.

OEM kit - The utility, which modifies the input binary file according to the customer's settings.

Modified firmware - The modified binary file which contains the customized settings for the receiver.

APPLICATIONS OF PROGRAMMATIC INTERFACE

Fleet Management System

The popularity of GPS in the automotive sector has been growing very rapidly. GPS is finding variety of uses either as a stand-alone sensor or in a system with other related technologies. Automatic Vehicle Tracking and in particular Car Navigation is one of the fields to have embraced the GPS technology.

A typical example is the use of GPS along with GSM or VHF Radio technologies to realize a Fleet Management System (FMS) to track automobiles.

The Fleet Management System (FMS) is a system for monitoring and controlling fleet of vehicles. It comprises of a central station (host) which communicates with vehicles fitted with a combination of GPS receiver and a GSM modem.

Accord has developed an embedded GSM interface for the NAV2500 using the programmatic interface. Hardware and software requirements of the embedded GSM interface are listed below to present an idea about a typical usage of the programmatic interface.

Requirements related to hardware:

- Run time program memory of 24K bytes and Data memory of 2K bytes
- Processing power of 100K cycles per second on Analog Devices' Fixed point DSP
- Discrete I/Os for sensing emergency (SOS) alarm, receive / transmit signals for null modem interface with GSM module
- Flash memory read / write access for data storage and retrieval for offline processing

Requirements related to software

- FMS to be invoked every second
- Access to the UART of the GPS system for transmission and reception of messages
- Floating point math library for route computations

With all the above resources readily available on the NAV2500^{TM}, this application can be easily integrated to the GPS core.

Without Programmatic Interface, FMS system redesign would be essential with a separate micro controller.

Integration of Dead Reckoning sensors with GPS

In locations where GPS satellite signals are obstructed (urban canyon, foliage, tunnels etc.) and it is still essential to provide navigation guidance, integration of Dead Reckoning (DR) sensors with GPS is essential.

Integration with DR sensors provides increased continuity and higher accuracy.

The hardware required for DR integration includes interface to the odometer (analog or digital), gyroscope (analog or pulse width modulated data) and magnetic compass. The data from these DR sensors need to be sampled and input to the DSP for filtering and integration.

The fusion of DR sensor data and GPS sensor data can be accomplished either at the level of navigation (position, velocity and time) solution or measurements (pseudo range and range rate) level. The receiver has provision for both through the programmatic Interface. A user's own algorithm can integrate navigation solution of GPS and DR measurements easily. Tight coupling can be achieved employing the user algorithm, which should provide aids to carrier tracking (FLL only) and code tracking loops of the GPS sensor.

The user has the flexibility to change the order and bandwidth of the tracking loop that depends on the accuracy and reliability of the sensors used and the type of application. This flexibility allows the user to choose the quality and cost of the DR sensor to be used.

The concept of GPS-DR integration is shown in Figure 12.

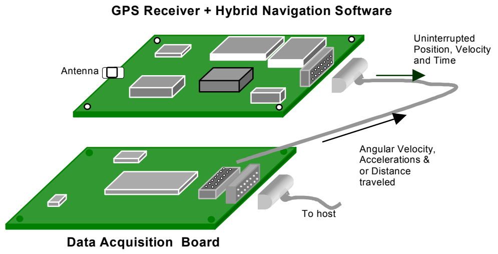

Figure 12: GPS and DR integration.

ROADMAP INTO THE FUTURE

The NAV2500™ GPS Receiver solution has been designed to exploit the benefits of newer generation DSPs from Analog Devices.

With faster DSPs featuring better instruction sets and lower power consumption characteristics from Analog Devices, it will be feasible to offer more powerful algorithms incorporated in the solution to achieve:

- Faster TTFF
- Better signal sensitivity in acquisition, reacquisition and tracking
- Lower receiver power consumption
- Improved Timing and Frequency synthesis by way of carrier phase measurements
- More resources to the user application by way of Programmatic Interface

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