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BIOGRAPHY

Mike Martin is Inertial Navigation System/Global Positioning System (INS/GPS) project manager for Boeing Guidance, Navigation, and Sensors. Previously, he was technical director for the Joint Product Development Team, which developed the MIGITS™ family of INS/GPS products. In his thirteen years with this organization, he has held a number of engineering management positions, primarily in the areas of advanced systems engineering and analysis. Prior to joining Boeing, he was a project engineer at The Aerospace Corporation and a product planner at Ford Motor Company. He is a graduate of the Massachusetts Institute of Technology, where he received B.S. degrees in electrical engineering, management, and mathematics in 1973, M.S. degrees in mechanical engineering and management in 1975 and 1977, and a Ph.D. in mechanical engineering in 1978.

Bruce Detterich holds BS and MS degrees in engineering from Loyola University in Los Angeles. He has worked at Autonetics, now known as Boeing Guidance, Navigation, and Sensors, for 32 years. His first experience with GPS was in the late 1970's in an experiment which flew a Texas Instruments receiver in a Minuteman Missile. That project successfully acquired and tracked the only SVs available at the time from in-silo launch through reentry vehicle deployment. Since then he has held positions as a lead or chief system engineer on the Peacekeeper (MX) and Small ICBM Guidance and Control development programs. He has been involved in all phases of a system's life cycle, from experimental component development through operational deployment and support. He is presently involved in a variety of programs as a Principal Engineering Specialist, but primarily participates in the development and application of Autonetics' Miniature Integrated GPS/INS Tactical System (MIGITS™), and low-cost IMUs. He is a member of the IEEE and belongs to the Communications, Signal Processing, and Antennas and Propagation Societies.

ABSTRACT

A wide variety of applications can benefit from integrated Inertial Navigation System/Global Positioning System (INS/GPS) technology. However, in many situations the end user has a preference for a specific GPS receiver. Additionally, in most cases, the user does not desire to expend the time and money necessary to perform a custom INS/GPS integration, but instead wants a low cost off-the-shelf solution. To address these applications, Boeing has developed the Digital Quartz IMU - Navigation Processor (DQI-NP) product as an extension of its Miniature Integrated GPS/INS Tactical System (MIGITS™) family of integrated INS/GPS products.

This paper describes the DQI-NP product architecture, overall design approach, and development history. DQI-NP development is complete, and the product is currently in low rate production. The DQI-NP design is described in more detail, along with key performance parameters.

The DQI-NP consists of production solid state DQI hardware, with the addition of a navigation processor adapter (NPA). The NPA provides input/output (I/O) level conversion and electromagnetic interference (EMI) filtering for interfacing with the DQI. INS/GPS software resides within the DQI, and provides either loose or tight coupling, depending on the application. The standard data protocol employs the Precision Lightweight GPS Receiver (PLGR) message set. The DQI-NP is small (52 cubic inches), lightweight (2.65 pounds), and low power (17 watts).

DQI-NP provides an available, low cost, commercial off-the-shelf, nondevelopmental-item (COTS/NDI) solution to a variety of commercial and military applications.

INTRODUCTION

The DQI-NP product is an relative of the C-MIGITS™ II (Reference 3) product, which in turn stemmed from a Rockwell interdivisional Joint Product Development Team (JPDT). Prior to the Defense and Aerospace Operations of Rockwell becoming part of Boeing, the JPDT developed several generations of the Miniature Integrated GPS/INS Tactical System (MIGITS™) product family. These low-cost accurate INS/GPS products incorporated various Rockwell commercial and military receivers, in conjunction with multisensor IMUs (GIC-100 and IMU-202), and, later, the Boeing Digital Quartz IMU (DQI), a solid state tactical grade IMU based on micromachined Quartz technology. The development history is summarized in Table 1, and more details are available in References 1 - 3.

Table 1. MIGITS™ Product Family History

Product	Intro	Comment (GPS; IMU)
C-MIGITS™	1992	5-Ch, L1, C/A code; GIC-100
P-MIGITS™	1993	5-Ch, LI, P(Y) code; IMU-202
M-MIGITS™	1994	10-Ch, L1/L2, P(Y) code; DQI
DWS-MIGITS™	1995	10-Ch, L1/L2, P(Y) code; DQI
C-MIGITS™ II	1996	5-Ch, L1, C/A code; DQI
Ch: Channel; L1/L2: link 1/link 2 C/A: coarse/acquisition C, P, M MIGITS™: C/A code, P code, Modular MIGITS™ DWS: Dispenser Weapon System P(Y): Precise (Encrypted)		

MIGITS™ development efforts from the beginning were aimed at providing a turn key INS/GPS capability at minimum cost. With the development of C-MIGITS™ II, a step change in cost was achieved by eliminating the use of a separate navigation processor and capitalizing on the surplus throughput and memory available with the existing DQI processor. Two input/output (I/O) interfaces were added to the basic DQI, at minimal cost, to satisfy C-MIGITS™ II needs. Integrated INS/GPS software was then hosted in the DQI processor. All this provided an opportunity for further product line expansion.

Many customers have, for various reasons, a preferred GPS receiver that differs from the ones in the standard MIGITS™ products. By exploiting the hardware and software changes developed for C-MIGITS™ II, it was apparent that a standard INS could be developed that allowed easy integration with the GPS of choice, to provide a tightly or loosely coupled INS/GPS navigator with minimal integration cost/risk. That product is the DQI-NP.

DQI-NP DESCRIPTION

System Overview

DQI-NP (Figure 1) combines a Boeing digital quartz inertial measurement unit (DQI IMU) with a navigation processor adapter (NPA), which provides I/O level conversion and EMI filtering. The DQI-NP then interfaces with any user selected GPS receiver that conforms to standard (user selectable) RS-232 or RS-422 electrical interfaces, and a standard message protocol. Currently, the PLGR message protocol is supported, with ability to add others as needed.

Figure 1 DQI-NP System With PLGR GPS Receiver

The DQI-NP block diagram in Figure 2 shows the primary system interfaces. DQI-NP provides tightly or loosely coupled INS/GPS navigation as well as the normal IMU functionality. Angular rates and angular accelerations are output at 600 Hz, and changes in attitude and velocity are output at 100 Hz, all using the standard Advanced Medium Range Air to Air Missile (AMRAAM) IMU interface/protocol.

Navigation and attitude data are output over the host vehicle input/output (HVIO) interface, which is an asynchronous serial RS-232 or RS-422 interface (user selectable). The navigation software is integrated with the basic IMU software in the IMU processor. This is possible because of the large memory and throughput margins of the basic DQI. Also, the DQI power supply is used to power NPA active components, eliminating the need for a separate power supply and minimizing NPA cost.

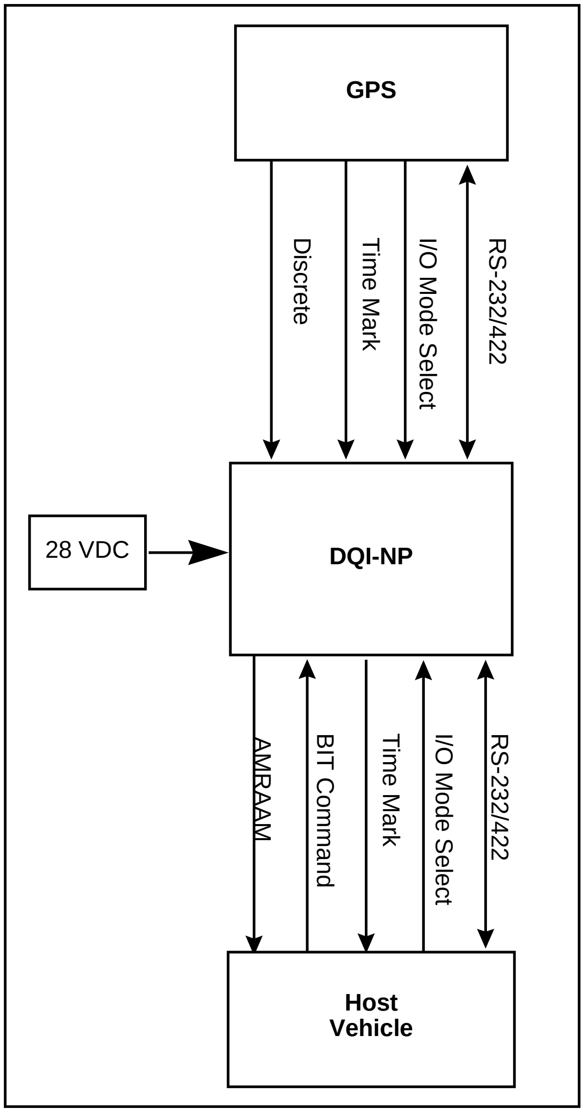

Figure 2 DQI-NP Top Level Block Diagram

Inertial Measurement Unit

The overall DQI design is discussed in Reference 4. The DQI architecture (Figure 3) features a Texas Instruments (TI) TMS320C31 (“C31”) digital signal processor (DSP) and three SPROC high speed signal processors. The C31 functions as the parallel bus master and interfaces to the SPROCs via the bus address and data lines. DQI inertial sensor data enters the processor system via memory mapped counter registers and serial ports in each SPROC. Gyro data from the X, Y, and Z quartz rate sensors (QRS) are fed through analog to digital conversion (ADC) and undergo digital filtering/decimation in the SPROCs to enter the C31 at a 600 Hz rate. Monitored voltages and temperatures are also digitized, and are processed by the X SPROC. Accelerometer data from the X, Y, and Z vibrating quartz accelerometers (VQAs) are digitized by a

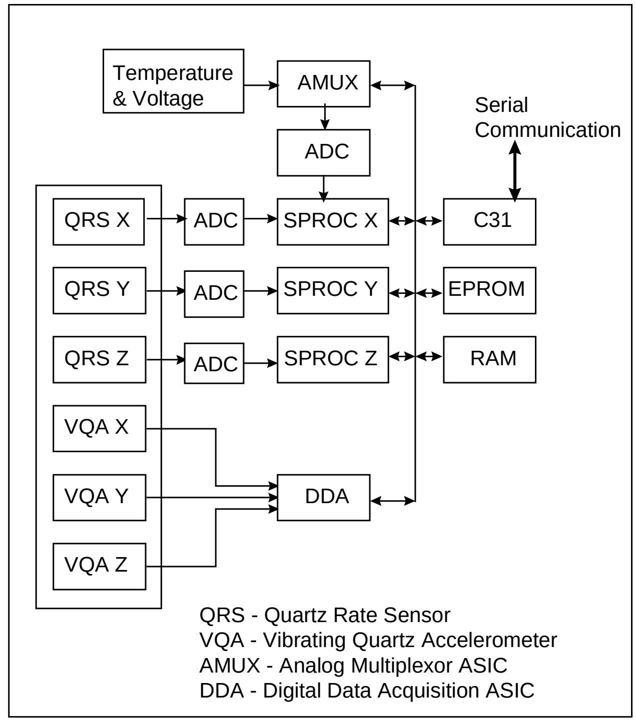

Figure 3. Overall DQI Functional Architecture

digital data acquisition (DDA) application specific integrated circuit (ASIC) and enter the C31 at 2400 Hz

DQI C31 serial input/output (I/O) mode is controlled by a discrete, which selects either AMRAAM output-only protocol, or a bi-directional high speed test mode employing the C31 high speed serial port. Test mode is not intended for general use. There is also a 100 Hz discrete output from the DQI.

Navigation Processor Adapter (NPA)

The NPA (Figure 4) provides three functions: (1) EMI filtering of externally supplied 28 VDC (MIL-STD-704), (2) pass through of synchronous serial AMRAAM/test ports, and (3) level conversion and buffering of signals. A more detailed breakdown of the signal specifics is given in Figure 5.

The NPA EMI filter duplicates the circuit design in production for the standard DQI product, but is repackaged onto a different PWB, which it shares with the NPA active components and unique connectors.

The basic DQI contains, in addition to the AMRAAM interface, two bi-directional I/O channels driven by dual universal asynchronous receive/transmit (DUART) devices. The NPA contains RS-232 and RS-422 line drivers/receivers to provide level conversion for signals to/from the core DQI. Selection of which interface to use for the host vehicle I/O (HVIO) or GPS I/O is via a "strap" selection pin (open or grounded).

The NPA features 15 kV electrostatic discharge (ESD) protection on all connector pins. Military temperature range components are employed, and integrated circuits (ICs) are packaged in hermetic ceramic packages. That is done to address life/reliability concerns, because the NPA case is not hermetically sealed.

Mechanical Design

The NPA case (Figure 6) is a two piece metal stamping, fabricated from corrosion resistant Nickel Copper 752 material. It features an EMI-tight soldered construction. The printed wiring board (PWB - Figure 7) is mounted rigidly to the case with stainless steel hardware. The entire interior cavity is potted with high density polyurethane to provide part dampening and prevent moisture damage to electronic components.

The NPA (Figure 8) mounts directly on top of the DQI, mates directly to the DQI connector, and has the same outside dimensions as the DQI. It uses staggered external connectors to accommodate EMI shielded connector backshells, while preserving enough board area for required components. The 37 pin I/O connector that carries (among other things) IMU data is reversed in gender from the DQI connector, to prevent improper connection to factory test equipment.

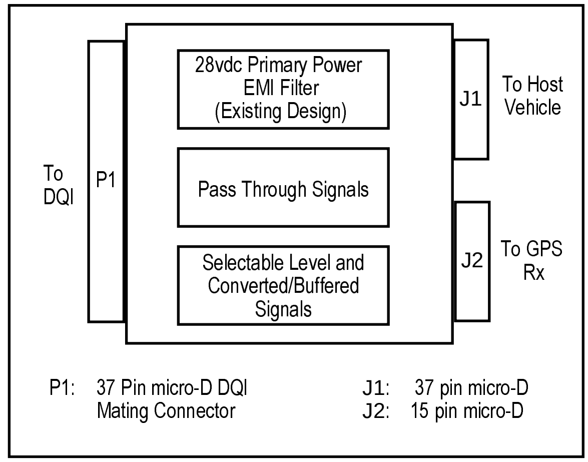

Figure 4. DQI-NP Adapter Top Level Block Diagram

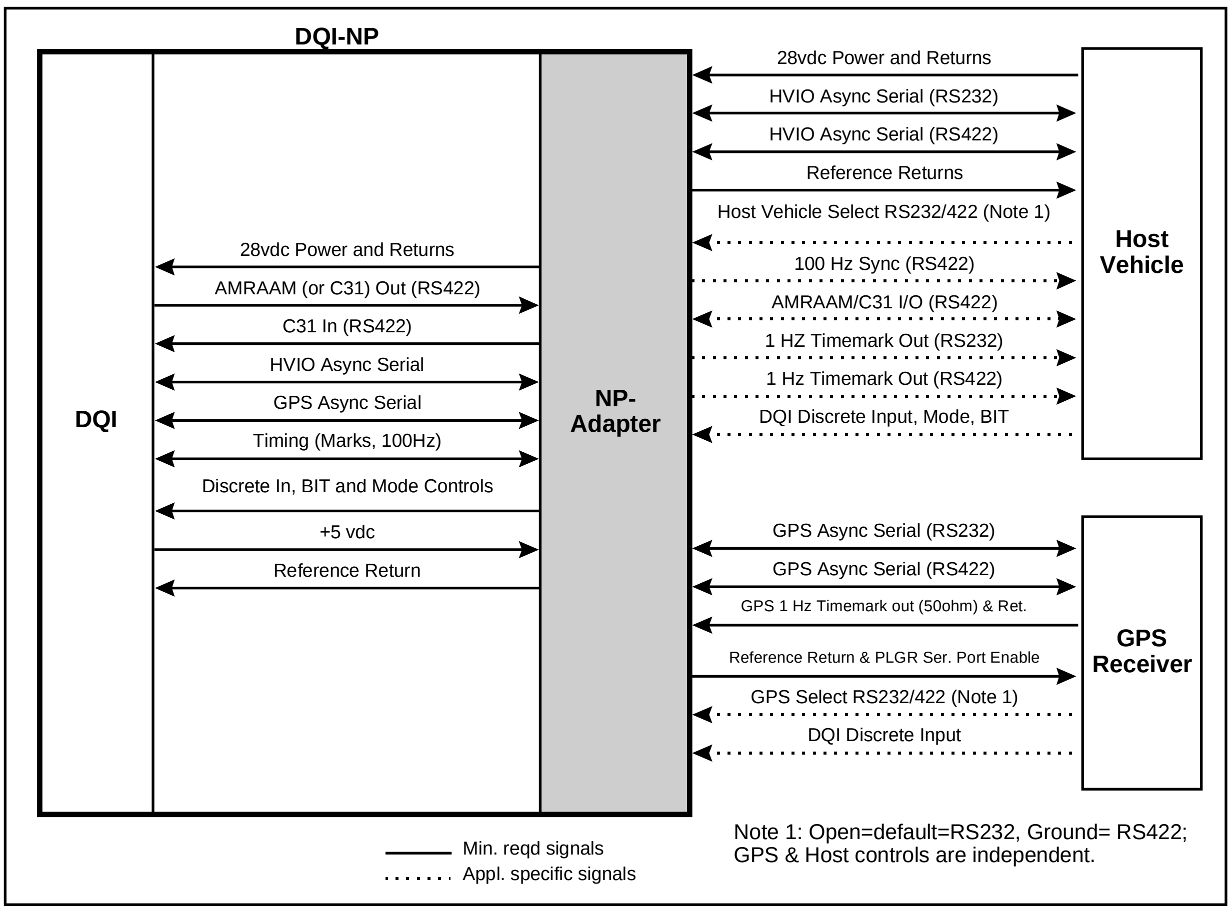

Figure 5. DQI-NP Interfaces

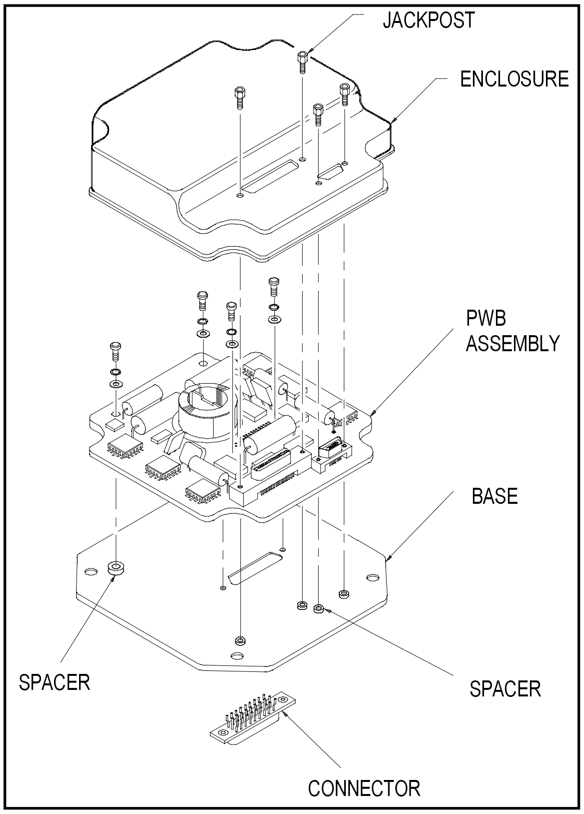

Figure 6. NPA Exploded View

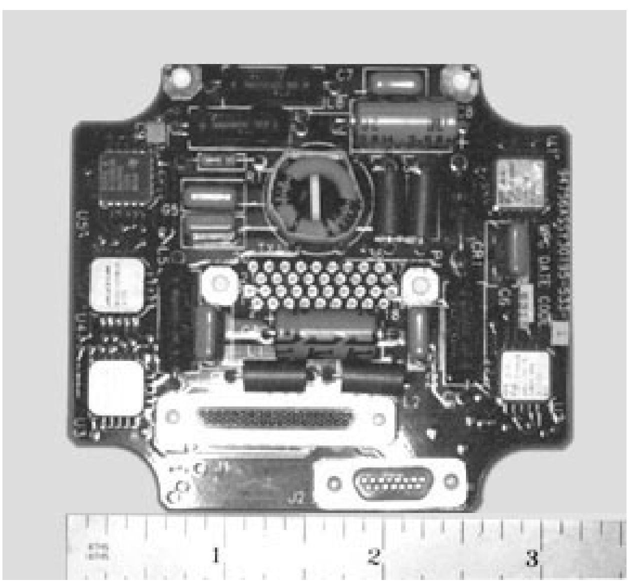

Figure 7. NPA Printed Wiring Assembly

Software

DQI-NP software is the same software used in C-MIGITS™ II (Reference 3) and is described in detail in Reference 5. It features a 28 state Kalman filter, and may be run either loosely coupled, using the GPS navigation solution to update the INS, or tightly coupled, using GPS pseudo range and delta pseudo range measurements directly. Because of security restrictions on use of corrected GPS measurements, it is usually used in loosely coupled mode when operated in conjunction with a military receiver.

FACTORY PROCESS FLOW

DQI-NP assembly flow is shown in Figure 9. The NPA PWB is assembled, and in circuit test performed before installation of the bottom plate. Thermal cycling environmental stress screening (ESS) test is then performed, and a functional test is done prior to sealing the enclosure. Another functional test is then done prior to potting. The NPA is mated to an off-the-shelf DQI, software installed, and a final acceptance test performed before shipping the unit.

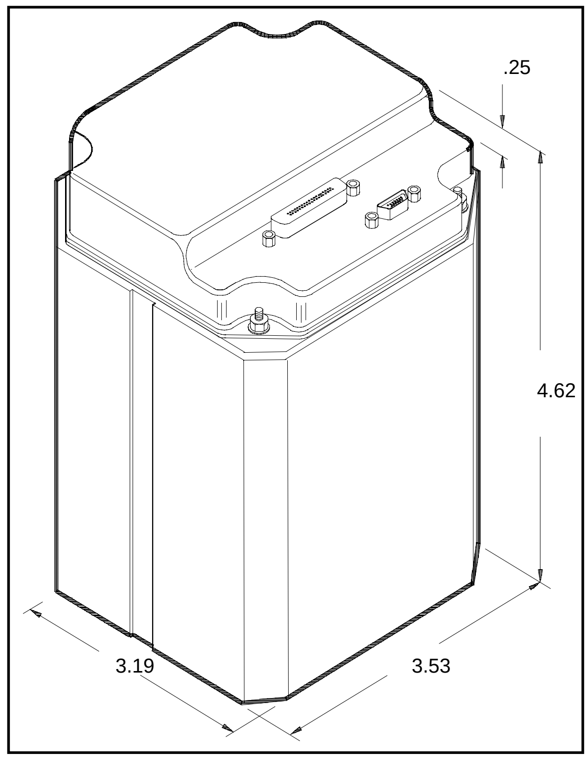

Figure 8. DQI-NP Exterior View and Dimensions

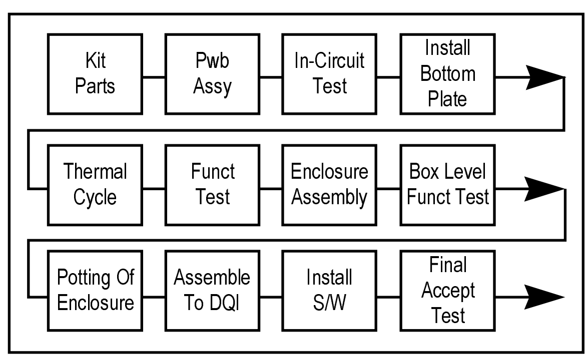

Figure 9. DQI-NP Factory Process Flow

DQI-NP OPERATION

DQI-NP operating modes and transitions, summarized in Table 2, are the same as for C-MIGITS™ II. These are described in more detail in References 3 and 5.

CHARACTERISTICS AND PERFORMANCE

With GPS available, position, velocity, and time (PVT) accuracy is that of the selected GPS receiver. Environmentally, it operates from -54 C to +71 C. The unit has been tested in vibration environments of 6 Grms, and shocks of 20 G (11 ms, half sine). The DQI-NP has been shown to operate through the EMI conditions shown in Table 3. In addition, it is ESD protected (per MIL-STD-1686 Class III) for 4,000 to 15,000 volts.

Table 2. Mode Transition Table

From/ To	Test	Init	Fine Align	Air Align	Trans-fer Align	Air Nav	Land Nav	GPS Only
Test	-	A	-	-	-	-	-	-
Init	C	-	A	A	A	-	-	-
Fine Align	C	C	-	-	-	A	A	A
Air Align	C	C	-	-	-	A	A	A
Transfer Align	C	C	-	-	-	A	A	A
Air Nav	C	C	-	-	-	-	-	A
Land Nav	C	C	-	-	-	-	-	A
A = automatic, C = commanded								

Table 3. DQI-NP EMI Specifications (MIL-STD-461C/462)

Reqt.	Specification
CE03	Power Lines, 15 kHz to 50 MHz
CE07	Switching spikes
CS01	Power lines, 30 Hz to 50 kHz, 2.8 V rms
CS02	Power lines, 50 kHz to 400 MHz, 1 V rms
CS06	Spikes, 200 V, 0.15 μs and 10.0 μs
RE02	Electric fields, 14 kHz to 10 GHz
RS03	Electric fields, 14 kHz to 10 GHz, ≤ 10 V/m

SUMMARY

DQI-NP provides small size, low-cost, integrated (loosely or tightly coupled) INS/GPS capability for a number of GPS receivers. It is in production and available today as a commercial off-the-shelf product applicable to a wide variety of applications.

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