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Integrated Communications and Navigation Module

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***Abstract*— An iridium communications and navigation module (ICNM) has been developed for movement tracking applications. External interfaces to the ICNM include Ethernet, RS-232, and Serial Peripheral Interface (SPI) Bus. The module is powered by Power over Ethernet (PoE) or a +24VDC connection. The ICNM fits within the standard PC104 form factor, but utilizes a Modular Component and Sensor Bus (MCSB) interface specification for the high density connector. The ICNM includes a GPS receiver and accelerators for satellite and inertial tracking. The module manages all of the satellite communication control, encryption, and navigation functions that enable its rapid integration as a component into larger systems.**

***Index Terms*—wireless, communications, Iridium, GPS, tracking, satellite**

I. Introduction

The ICNM is ideally suited for low data rate secure mobile to mobile or mobile to fix site(s) data communications where terrestrial based communications networks may not be available. Applications include secure world-wide tracking of assets, equipment monitoring, data collection, and automatic transportation location, etc.

A. Satellite Communications

The movement towards a ubiquitous network environment has been approaching reality in dense urban areas, due to the continued fast growth of terrestrial broadband communications. These broadband services include wireless local area network (LAN), optical fiber networks, digital subscriber lines (DSL), and cellular phone networks. With that said, there still exist many areas that lack communications services due to economic and geographical barriers. The existing terrestrial communications services have a large physical footprint which can be vulnerable to natural disasters, local service interruptions, and sabotage. In trying to address these concerns and provide a ubiquitous network for data connectivity, satellite systems have the biggest impact on meeting that realization. Satellite systems offer greater flexibility by providing wide coverage areas and greater resistance to vulnerabilities such as terrorist attacks or natural disasters. By taking advantage of satellite data communications, several advance technologies have been developed that have moved society closer to future ubiquitous network infrastructures, where these systems are not only used to supplement terrestrial networks but are also used as valuable tools for creating new applications.

B. Low Earth Orbit (LEO) Satellite Communications

A LEO is typically defined as an orbit with an altitude between 160 km and 2,000 km above mean sea level. Satellites which are at a lower altitude have less free space loss and therefore less power is required for the communications link. The main advantage to using a LEO satellite over a Geosynchronous (GEO) satellite is that the LEO ones are closer to the earth, hence requiring less power [1]. LEO satellites take advantage of this fact and typically use lower power units along with non-tracking antennas. This reduces the size requirement for the ground hardware and rf exposure levels. The disadvantage is that since the orbital period is smaller than that of the earths, the satellite is not always in view as it makes its orbital path. For a LEO satellite system to provide near continuous coverage a satellite constellation, which consists of multiple satellites functioning in a relationship that provides coordinated ground coverage, must be formed. Examples of LEO constellations include the Global Position System (GPS), Iridium, Globalstar, ORBCOMM, and Global Navigation Satellite System (GLONASS). LEO satellite constellations are able to still provide capacity even when a satellite fails, due to the continuous movement of the LEO constellation relative to the ground segment. A GEO system, by contrast, would suffer an entire regional system outage if an operational satellite were to fail. If a ground terminal has a partially obstructed view of the sky, the communications link may be made once the satellite(s) path moves to an appropriate clear sky view in a LEO configuration.

LEO satellite systems offer significant advantages over GEO satellite systems for use in mobile satellite services. The advantages are the result of an orbit selection which enhances the quality of services to low power mobile and vehicle mounted satellite systems. These enhancements come from the fact the satellite is physically closer to the earth than other satellite orbits. In comparison to a GEO satellite orbit with an altitude of 35,786 km, a satellite in a LEO orbit of 780 km has an additional free space gain of 19 to 32 dB, depending on the position of the LEO satellite relative to the ground segment. Figure 1 below illustrates the amount of free space loss experienced from going from a satellite with a LEO altitude of 780 km out to a GEO altitude.

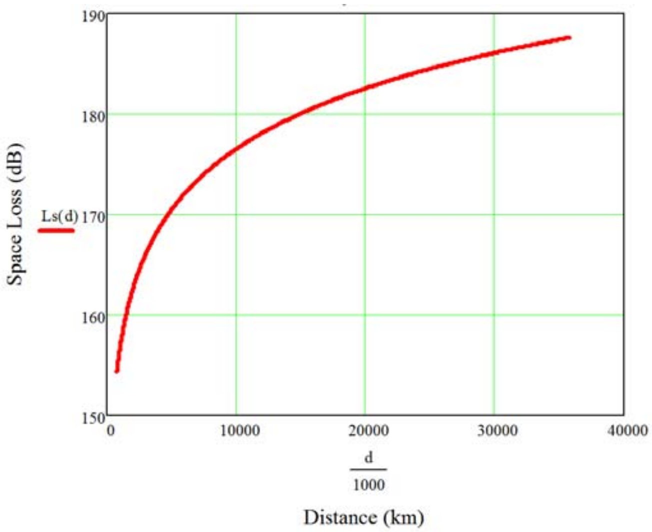

Fig. 1. Free Space Loss as a Function of Distance

By reducing the distance to the satellite, the communications link is available at much lower radio frequency (rf) power levels. In reducing the rf power level requirements, component size, power supply, and rf safety distances are all reduced. This allows for mobile satellite devices to use lower gain omni-directional antennas. The mobile device is then not constrained by larger high gain directional antennas that must track the satellite.

Another advantage to the LEO system is that the signal delay is dramatically reduced. A two-way propagation path to a GEO satellite has a delay of 240 ms, as compared to 6.7 ms for a typically LEO satellite. These delays only represent the elapsed time for the signal propagating through space. Additional time needs to be added for the coding and decoding process in digital systems.

C. Iridium Satellite System

The Iridium satellite constellation consists of 66 LEO satellites, not including in-orbit spares. This constellation which covers the poles, provides complete global satellite voice and data services. The ICNM discussed in this paper only supports data service. The satellites in the Iridium constellation are cross linked in space, providing a fully meshed network in space. The approach of networking the satellites together in space as opposed to terrestrial network infrastructure in-between ground earth stations allows for the satellites to talk directly to each other in space. This in space networking is referred to as Inter-Satellite Links (ISL)s. The Iridium system uses this ISL along with a Global System for Mobile (GSM) based telephony architecture. Iridium uses a time division duplex scheme, where the uplink and downlink use a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). Each of the 66 LEO satellites is connected to its four adjacent satellites by the ISL. This form of connectivity allows greater flexibility in where the earth stations can be physically located. The added functionality of the ISLs removes the constraint that the satellites' footprint must always be connected to an earth station for connectivity. Iridium has a dedicated gateway in Hawaii, where it supports secure communications. Table 1 gives a high level overview of the Iridium constellation.

TABLE I. IRIDIUM SATELLITE CONSTELLATION

Number of satellites	66
Number of planes	6
Height	780 km
Subscriber to satellite	L-band 1616-1626.5 MHz
Intersatellite	Ka-band 23.18-23.38 GHz
Earth station segment (Uplink/Downlink)	Ka-band 29.1-29.3 GHz / 19.4-19.6 GHz

II. DEVELOPMENT OF THE ICNM

The ICNM supports two serial ports and one Ethernet port. The ICNM relies on being powered from either the J1 connector (+28V pins) or via PoE.

Each of the electronic peripherals and main electronic board adhere to the PC104 plus form factor in mechanical specification, but not the electrical signal definition. Figure 2 provides a top view of the populated ICNM board.

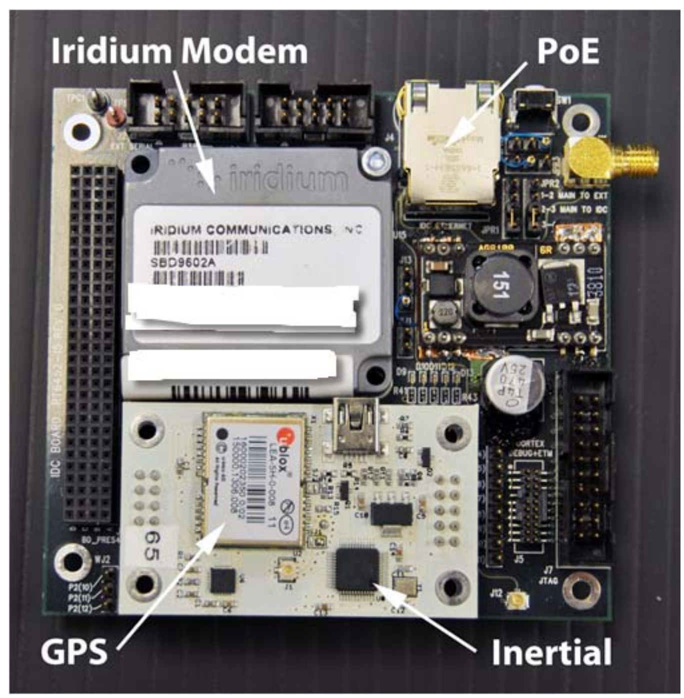

Fig. 2. ICNM Board Populated with Electronics

III. EMBEDDED FEATURES

Figure 3 shows a simplified block diagram of the embedded components contained within the ICNM which include the microprocessor, satellite transceiver, GPS receiver, accelerometer, magnetometer, power conditioning, and multiple user interfaces.

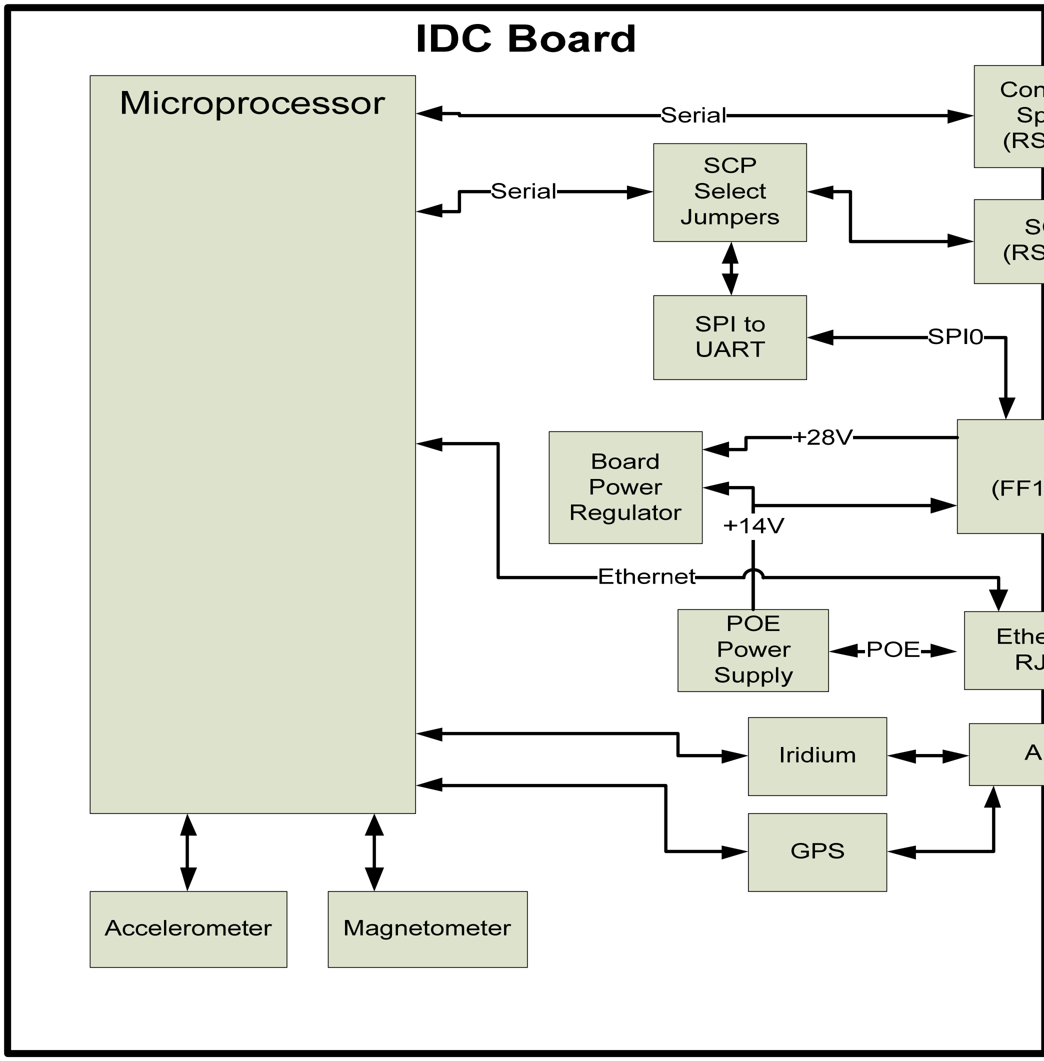

Fig. 3. Block Diagram for ICNM

A. Microprocessor

The LPC1768FBD100 is an 32-bit Advanced RISC Machine (ARM) Cortex-M3 microcontroller running at frequencies up to 100 MHz. Sandia selected this processor based on its low power consumption, its processing power, and its ability to support the high level of integration required for this embedded application. Some of the peripheral complements of this processor include 512 kB or flash memory, 64 kB of data memory, four Universal Asynchronous Receiver-Transmitters (UARTs), Serial Peripheral Interface (SPI), Ethernet Media Access Control (MAC), Universal Serical Bus (USB) interface, 8-channel 12-bit Analog-to-Digital Converter (ADC), 10-bit Digital-to-Analog converter (DAC), and two Synchronous Serial Port (SSP) controllers.

B. Software Design

The ICNM is designed to simply pass message payloads. Payloads can be American Standard Code for Information Interchange (ASCII) or binary. The ICNM currently does not provide any encryption services but it could be easily added to make the message passing secure. The Keil RTX Real-Time Operating System was used. The IEC 60730 Class B library was used for the CPU Registers, SRAM, and FLASH.

Embedded C++ Programming Language.

- One time object creation at startup
- No object deletion
- Simple C based methods to interface C++ objects to libraries/RTOS that don't know C++
- Classes represent devices/protocols/messages
  - Examples of devices represented/managed by classes:
    - UART, SPI, NVMEM, Timers, I^2C, Timers
    - Iridium, GPS, Accelerometer
  - Examples of protocols represented/managed by classes:
    - Control Port, Iridium

C. Power Requirements

The ICNM can either be powered from a +28 VDC supply to the J1 connector or via PoE from the RJ45 jack. While the development team has not yet optimized the ICNM for low power consumption, the current power consumption has been measured from a +28 VDC supply as:

Idle with GPS off: 35 mA
Idle with GPS on: 80 - 95 mA
Iridium Receive: 95 mA
Iridium Transmit: 120 - 300 mA

D. Satellite Transceiver

For data communications, the Iridium 9602 single board transceiver was used to provide Short Burst Data (SBD) connectivity to the Iridium satellite network. The 9602 transceiver interfaces to the ICNM via a single multi-pin interface connector and a single RF connector. The ICNM is controlled by the ICNM microprocessor via ATtention (AT) commands by a serial interface at 3.3 V digital signal levels. The Iridium SBD protocol provides a low latency, world-wide coverage area of an efficient network transport capability for transferring short data messages between devices and centralized host computer structures.

E. GPS Receiver

The u-blox5 programmable GPS receiver module was chosen for the ICNM based on its performance, size, low power consumption, and connectivity options. This module has built-in flash memory that enables specific configuration settings in a non-volatile RAM. One of the two configurable UART interfaces for serial communications is used by ICNM. Included with the module is a built-in patch antenna, which can also be reconfigured to work with external and active GPS antennas. The high sensitivity of this receiver is ideal for acquiring and tracking extremely weak signals, lending itself to the use of covert or small GPS antennas. This module also features a power saving mode. Below are some of the acquisition and sensitivity specifications for this GPS module.

- 50-channel u-blox 5 engine
- Up to 4 Hz position update rate
- < 1 second Time-To-First-Fix (TTFF) for hot starts
- 29 second TTFF for cold starts
- -144 dBm sensitivity for cold starts
- -160 dBm sensitivity for tracking and reacquisition

F. Accelerometer

The ICNM contains a 3-axis digital output linear accelerometer from STMicroelectronics. The LIS3LV02DQ accelerometer has a selectable full scale range of ±2g or ±6g, with a measurement bandwidth of 640 Hz for all axes. The accelerometer has the ability to produce an inertial wake-up or free-fall interrupt signal after a predefined acceleration threshold has been exceeded in any one of axes. This device is interfaced to the microcontroller via an I^2C/SPI interface.

G. Magnetometer

The magnetometer used by the ICNM is the Honeywell HMC5432. It is capable of measuring a ±4 gauss magnetic flux density at 7 milli-gauss resolution. The measurements are made with a 116 Hz update rate. The magnetometer communicates via a two-wire I^2C bus as a slave device to the microprocessor.

Fig. 4. ICNM Installed in Portable Enclosure

IV. Conclusion

The ICNM uniquely combines key components for satellite tracking and data movement into a small package with an embedded microprocessor to provide a device which is adaptable to many different applications. Sandia's design of the unit allows for its integration into larger more complex systems or to be used as a standalone application.

V. Vita

Paul C. Haddock received a B.S. degree in electrical engineering from New Mexico Institute of Mining and Technology, and an M.S. and Ph.D. degree in electrical and computing engineering from New Mexico State University. In 1998, he joined Sandia National Laboratories where he currently is a Senior Member of the Technical Staff (SMTS) working in the Communications and Electrical Systems Technology organization (06622). Previous to this, he worked at Los Alamos National Laboratories in the high power microwave area. His current research interest lies in remote sensing of the earth's atmosphere for microwave propagation. Dr. Haddock is a member of the Institute of Electrical and Electronics Engineers, Inc., and Eta Kappa Nu.

John W. Hatley received the B.S. degree in computer engineering from the University of New Mexico, Albuquerque, NM, in 1980. He is currently a Principal Member of the Technical Staff (PMTS) at Sandia National Laboratories in the Communications and Electrical Systems Technology organization (06622). Earlier papers include "Automatically Generating Procedure Code and Database Maintenance" by John W. Hatley (NAIUA Symposium 1994). While at Sandia, Hatley has worked in database design for Ingress and Oracle based systems, developed Web based applications using ColdFusion development system, and since then Mr. Hatley has been designing and developing embedded systems for communication and control applications.

William D. Morse received the B.S. degree (Summa Cum Laude) in engineering from Wright State University, Dayton, Ohio, in 1987, and the M.S. degree (University Graduate Fellow) in electrical engineering from The Ohio State University, Columbus, Ohio, in 1989. He is a military veteran having served in the U.S. Navy submarine service. In 1989, he joined Sandia National Laboratories where he currently is a Distinguished Member of Technical Staff (DMTS) working in the Transportation Safeguards and Surety Program Office (06620). He has conducted research and development in human augmented and robotic nuclear component transport, mobile multi-arm robotic manipulation, tactical ground robotics, autonomous micro air vehicles, multi-modal robotic systems, intelligent targeting, networked weapon targeting, novel weapon platforms, tactical special material deployment systems, blast survivability, and threat analysis. His current research interests are related high surety transport systems. He is a member of the Institute of Electrical and Electronics Engineers the Society of Automotive Engineers. He is also a licensed professional engineer in the state of New Mexico.

Robert D. Tooley is currently a Member of Technical Staff (MTS) at Sandia National Laboratories in the Communications and Electrical Systems Technology organization (06622). While at Sandia, Tooley has worked in the area of International Nuclear Safeguards, developing instruments for the IAEA in Vienna, Austria. He also designed subsystems for Survivable Mobile Vehicles for the Air Force.

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