

A Smart Network Sensor System for Distributed, Synchronous Data Acquisition

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1 Abstract

Typical test and monitoring systems are based on stand-alone instrumentation and require point-to-point analog wiring, which usually results in cumbersome cabling and connectors, bulky instrumentation, susceptibility to EMI/RFI noise pick up, lack of system flexibility, and a compromised signal-to-noise ratio (SNR). This paper describes a smart network sensor solution with multi-drop sensor architecture and smart digital output sensors interconnected to a network interface controller through a common digital transducer bus

2 Introduction

Several measurements of different types of measurements are typically required in aircraft testing and on-board monitoring application, including pressure, temperature, strain, flow, vibration, etc. As many as four to ten wires from each sensor carry small analog signals and power to and from the analog signal conditioning and data acquisition instrumentation. For large numbers of sensors, this translates into large numbers of wires that add weight and occupy significant space. In many instances, a significant amount of time is spent making sure that the right sensor was connected to the right signal conditioner or data acquisition channel (configuration control).

Traditional measurement systems based on analog transducers and stand-alone instrumentation result in bulky electronic boxes and in large, long and heavy bundles of cables carrying small analog signals that are susceptible to EMI/RFI noise pick up, and are difficult to manage. Furthermore, opportunities to add new sensors to existing systems designs are severely limited because of the difficulty in accommodating additional cabling and signal conditioning electronics in the available space.



Figure 1a - The Problem: Current measuring systems require large numbers of interconnecting cables resulting in added cost, weight, complexity, and lower reliability and performance

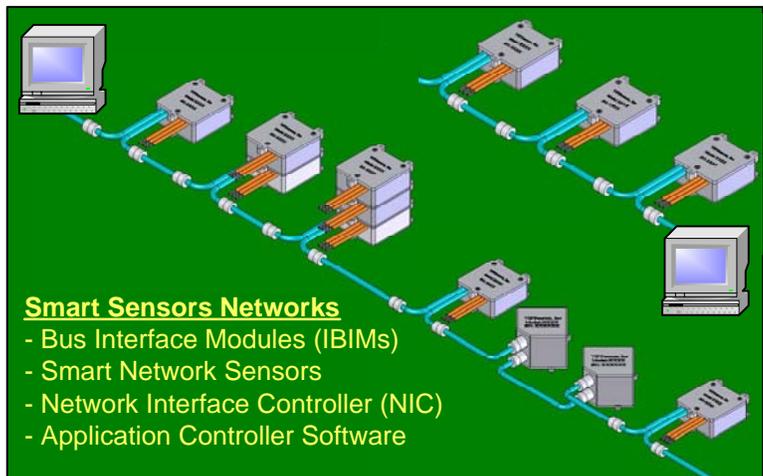


Figure 1b - The Solution: The proposed Smart Sensors Network System consists of smart digital output sensors and transducer modules interconnected to a Network Interface Controller (NIC) through a multi-drop digital serial bus. Small electronic modules interface any traditional analog transducer to the bi-directional digital bus

Aircraft monitoring systems, for example, include hundreds of pounds of cables and connectors. Ground and flight tests of commercial airplanes use approximately 7,000 transducers and associated signal conditioners, and all of those interconnecting cables are very difficult to manage. A typical test setup of a large number of channels is shown in Figure 1a.

The Smart Network Sensor solution described in this paper is a multi-drop sensor architecture with smart digital output sensors interconnected to a network interface controller (NIC) through a common digital transducer bus. This new system integrates all of the required measurement functions in a small size electronic module that can be placed inside a traditional transducer, thus making it a “Smart Sensor” with digital output, or as a separate module that will interface any traditional analog transducer to the bi-directional digital bus. The sensor network system reduces cabling and connectors, provides a common interface for multiple types of sensors, easily supports the addition of new sensors, and improves reliability.

Many digital networks presently exist³ but lack one or more features such as: the ability to synchronously acquire data from multiple distributed nodes, could not be implemented in a small package, or lack the bus speed to acquire data from multiple nodes at high sampling rates. IEEE 1451.3² defined a smart sensor network that addressed many of these technical issues; unfortunately manufacturers have not adopted this standard because of the difficulties implementing it in a small package with low power consumption.

3 Sensor Network Advantages

Minimum Interconnecting Cables

The number of cables and cable lengths dictated by traditional star topologies of interconnecting analog transducers to a central signal processing equipment has a detrimental impact on all aspects of a measurement system. These factors decrease the accuracy and reliability of measurements, decrease system performance, and increase system operating costs.

The multi-drop sensor network architecture of the proposed system allows drastic reduction of interconnecting cables. The Smart Sensor System interconnects all of the transducers through a common digital bus cable. The centralized, bulky electronic boxes typical of traditional measurement systems are replaced with miniature modules strategically distributed throughout the setup.

High Reliability

Reliability is improved by reducing the total number of interconnecting cables and including Build-in-Test (BIT) features. Self test adds a higher level of confidence that a given measurement channel is alive and working properly.

High Performance

Large numbers of analog transducers result in difficult-to-manage, large and long bundles of cables carrying analog signals which are susceptible to being corrupted by EMI/RFI noise. Cables carrying digital signals are more immune to these problems and are easier to interface than cables carrying analog signals.

Higher measurement accuracy is obtained by digital correction over the operating temperature range of both the transducers' sensitivity and the analog signal conditioning instrumentation.

Distributed Simultaneous Sampling

The proposed system has the ability to simultaneously acquire data even though the analog-to-digital converters (ADC) are distributed among the various smart sensor nodes.

Easy to Design, Use and Maintain

The primary concern of users of sensor information is to accurately measure physical phenomena in engineering units such as Pascal, meters, m/sec², g's, PSI, etc. To achieve this goal, the user needs to take into account installation issues such as types of transducers to their measurement system; and selecting the proper analog amplifier settings (sensitivity-gain normalization, type of filter, excitation voltage-current, etc.) for each analog transducer.

Transducer Electronic Data Sheet ¹ (TEDS) stored in each smart sensor and interface module helps to reduce the complexity of the system design, integration, maintenance and operation.

Features such as transducer identification, self-test, test setup configuration, configuration status, etc. can be performed under computer control with minimal need for any manual trimming or adjustments. The smart sensors and interface modules exhibit plug-and-play features to ease the measurement system usage.

Scalable -Flexible System

The new network measurement system accepts different types of transducers, including traditional analog types as well as new smart network sensors. It allows for easy expansion or reduction in the number of measurement channels. This is possible with the use of IntelliBus Interface Modules (IBIM).

Small Rugged Packaging

The proposed measurement system components are small, lightweight and packaged to operate under demanding environmental conditions typical of aerospace applications such as high vibration, high temperature, high pressure, humidity, EMI/RFI, etc.

Minimum Cost

Design, operating and maintenance costs are drastically reduced by implementing a system with all of the above listed attributes. The initial capital investment may be similar or slightly higher than traditional systems; however, this marginal additional expense is far outweighed by savings in other areas.

A standard hardware interface for all transducer types will eventually reduce the capital equipment costs. A standard software interface (standard data interchange) would greatly reduce ongoing operating and maintenance costs.

4 System Description

The proposed Smart Sensors Network System is a distributed sensor instrumentation system with synchronous/simultaneous sampling consisting of smart digital output sensors and transducer modules interconnected to a Network Interface Controller (NIC) through a multi-drop digital serial bus (IntelliBus). Small electronic modules called IBIM's (IntelliBus Interface Modules) are used to interface any traditional analog transducer to the bi-directional digital bus (see Figures 2 and 3).

Smart Networked Sensors include the sensors element, analog signal conditioning, analog-to-digital conversion, and digital signal processing & communications functions in one mechanical package. They communicate directly to the transducer bus.

The **IntelliBus Interface Modules** (IBIM's) contain all the functions of a measurement system except the sensor element. They make an analog transducer become "smart" so that they can interface to the digital transducer bus. See Figure 2.

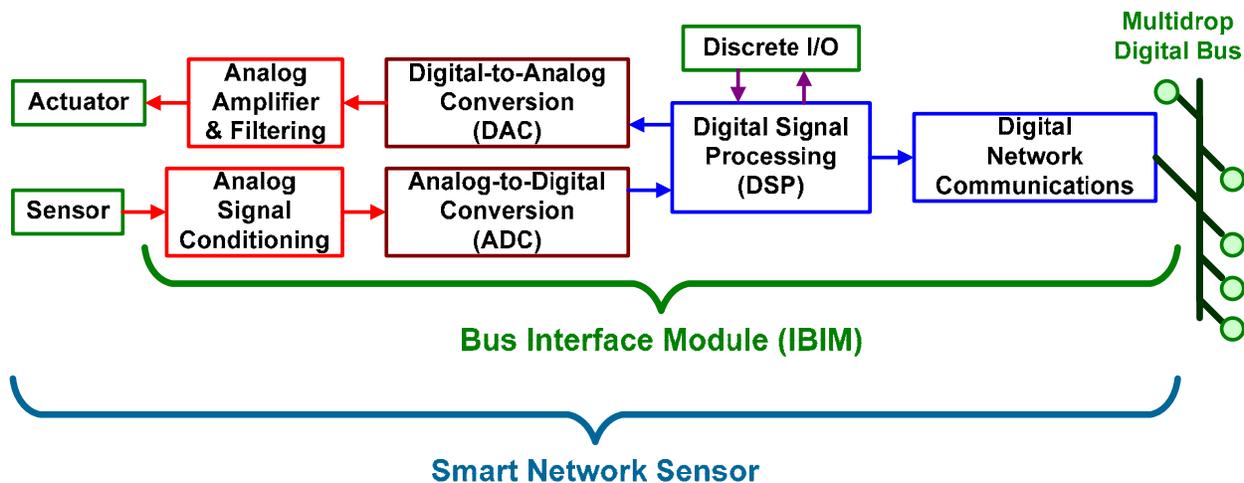


Figure 2: Smart Sensor Functional Diagram

The **Network Interface Controller (NIC)** provides a gateway between the transducer bus (Intellibus) and an on-board computer or, depending on the configuration, with a downstream wired Ethernet port or telemetry system. The NIC communicates digitally with the IntelliBus Interface Modules (IBIM) through a standard digital transducer bus.

The NIC is the master of the digital network (only 1 IBIM can transmit at any given time after receiving a command from the NIC). The NIC provides DC power and synchronization signals to achieve synchronous/simultaneous data sampling among all the sensors and IBIM's on the Transducer Bus.

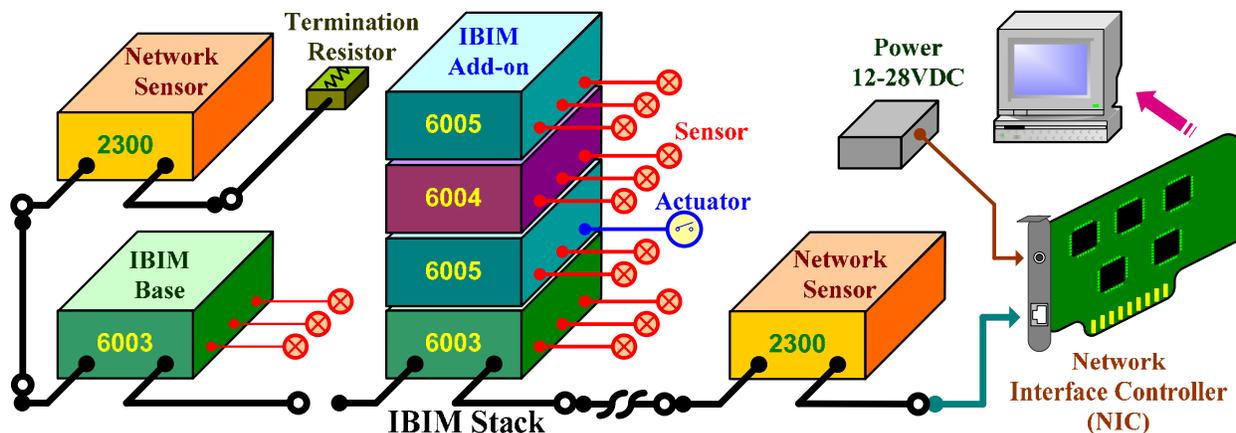


Figure 3: Smart Sensor Network System Concept

IBIM's are designed as stand-alone, distributed sensors and control nodes; software algorithms are implemented in their internal microprocessor to sense, process the signals, and, based on the obtained data, control actuators and switches; this feature increases the flexibility and attraction of the Intellibus architecture system.

VIP Sensors' newly introduced family of transducer modules may be configured as stand-alone distributed modules as shown in Figure 4a, or they can be stacked in order to increase the channel density per node as shown in Figures 4b and 4c. Up to seven modules may be stacked up with one network interface base unit to form up to 39-channel signal conditioner-data acquisition assembly in 1.5 x 1.5 x 5.8 inches.

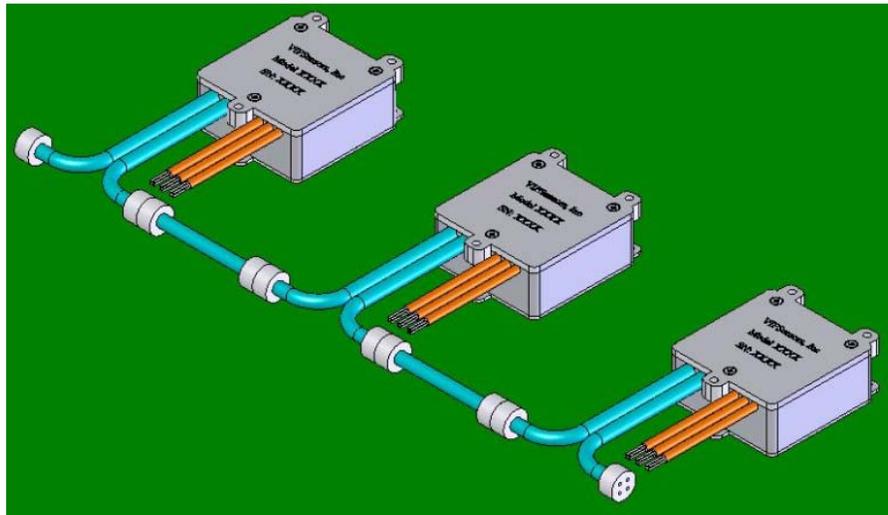


Figure 4a - Base Modules - three channels each, one network node per module

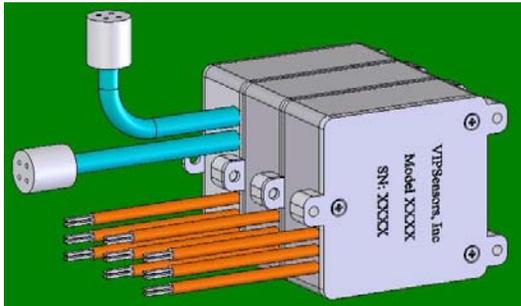


Figure 4b- Horizontal module stack configuration

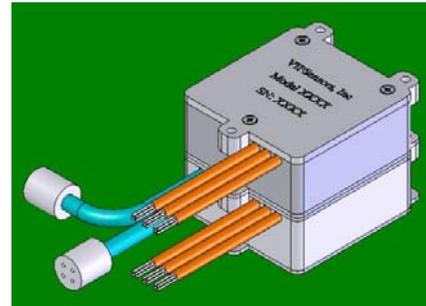


Figure 4c - Vertical module stack configuration

IntelliBus, the transducer network bus protocol used in VIP Sensors' newly developed system, is an isochronous, half-duplex, multipoint serial bus running at 15Mbps. Its physical layer consists of a 2-wire shielded-twisted-pair (RS-485) plus power and ground wires. Power can be from 12 to 28 VDC.

All of the sensors and IBIM channels may be sampled simultaneously and synchronously. There are less than ± 9 nanoseconds of cycle-cycle and period jitter. The sample rate of each smart sensor and IBIM in the bus is set independently.

Up to 510 nodes (smart sensors and/or IBIM's) can be addressed by the NIC. The number of IBIM's that can be connected to a NIC depends on the number of channels in each IBIM node, bus speed, power consumption, length of the cable, and sampling rate. The higher the sampling rate, the lower the number of transducer channels. The current design is limited to 15 Mbps bus speed and 7 Amperes DC supply. Twenty-five (25) nodes at 600 feet and 64 nodes at 300 feet have been proven to work properly at the 15 Mbps rate.

Plug and Play is one of the most useful features of the new networked system. Since all devices in the transducer bus each have a Transducer Electronic Data Sheet (TEDS) stored in local non-volatile memory, the NIC is able to discover what devices are on the bus, and interrogate their configuration settings, status, etc.

Plug and play facilitates replacement of units that are not working properly and facilitates changes in the system configuration; increasing or decreasing the number of measurement channels becomes an easy task.

Intellibus was originally designed by Boeing and has been deployed successfully in various aerospace programs.

5 IBIM Detail Description

VIP Sensors' newly developed IBIM's (see Figure 5) have three channels of low-noise instrumentation amplifiers input with programmable gain (0.5 to 1000), and programmable offset that allow conditioning of different transducer types such as strain gages, accelerometers, thermocouples, pressure transducers, etc. Each of the front-end amplifiers is followed by two selectable 3-pole anti-aliasing filters. There is one 16-bit A/D converter per channel with a programmable sample rate of up to 250 ksps, but the aggregate rate for all three channels can not be greater than 300 ksps.

Over-sampled data is acquired simultaneously in all three channels and piped into a powerful DSP processor capable of implementing real time digital signal processing algorithms, such as FFTs, digital filters, data correction over temperature, linearization, etc.

A 64th -order, low-pass FIR filter is provided as a standard feature, which allows the selection of various corner frequencies and filter shapes. Different filters (types and corner frequencies) are easily implemented by choosing the proper filter coefficients and storing them as part of TEDS through the transducer bus.

The Digital Signal Processor (DSP) configures each IBIM channel according to the stored TEDS information or any new configuration sent by the NIC. It also performs self test under the NIC command.

IBIMs (base or stand alone units) communicate to the transducer bus through a Network Device Interface (NDI) which handles the Intellibus digital bus protocol. Add-on IBIMs used to form stacks do not have the NDI logic, and they communicate to the NIC through the IBIM base.

Not including the cables, the 3-channel IBIM weighs less than 50 grams (1.8 oz.) and its dimensions are 1.5 in. x 1.57 in. x 0.7 in. The 3-channel IBIM consumes less than 2 watts (excluding power to sensor) when operating with 24VDC. It consumes less than 1.5 watts when operating with 12 VDC.

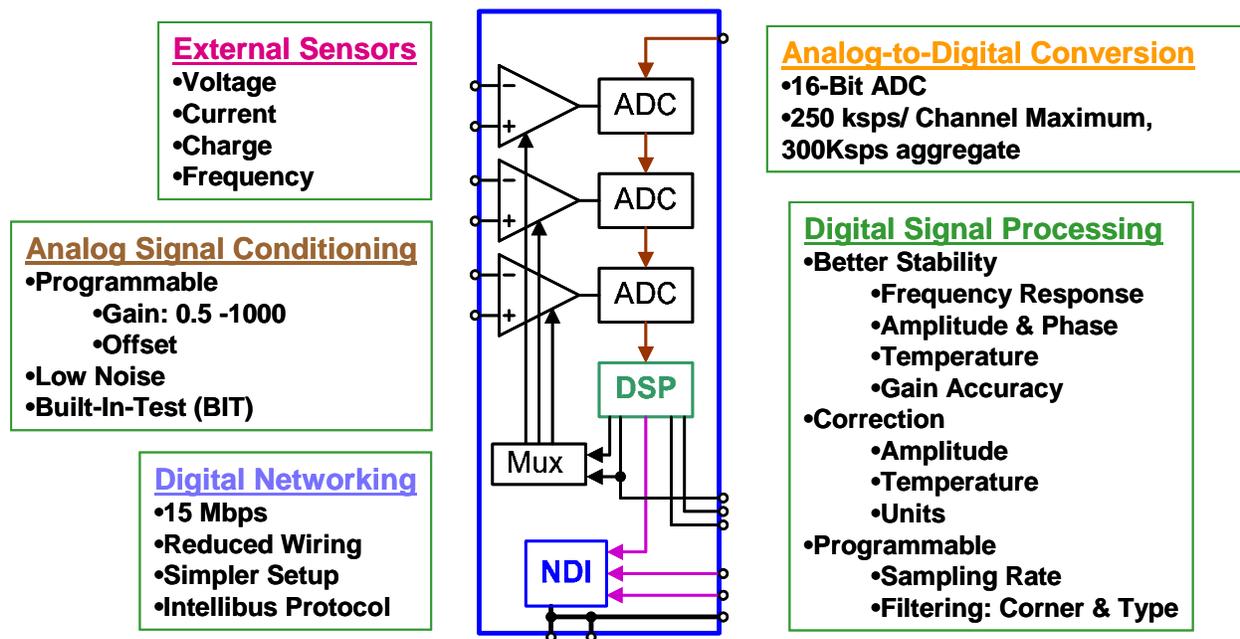


Figure 5: IBIM Block Diagram

6 NIC Detail Description

The Network Interface Controller (NIC) controls the transducer bus activity. It is a gateway between the transducer bus and other commonly used buses such as Ethernet, PCI (computer bus), Arinc429 and Mil-1553 (avionics), etc. The current VIP Sensors NIC is designed as a PC-X plug-in card and supports two transducer buses.

The NIC controls various functions, such as changing the data collection rate, programming different scales and different filters, and performing data analysis and data fusion in order to better manage the network bandwidth, etc.

The following are some of the main functions performed by the Application Software through the NIC.

- Assigns Channel Addresses
- Reads/Writes TEDS
- Initiates IBIM Diagnostics/Self-Test
- Configures IBIM's Amplifier Settings (Gain, Offset, Sampling Rate)
- Synchronizes Sampling Rate Among Multiple IBIMs by issuing Software Trigger Commands
- Establishes Digital Sampling Schedules
- Time Tagging
- Collects and stores data in disk

7 Conclusion

VIP Sensors has developed and proved a new miniaturized Smart Sensor Network Measurement System, which represents a paradigm shift from a centralized to a distributed processing measurement approach. It significantly reduces the number and lengths of cables, the components size, and system weight. It provides greater flexibility in design, configuration and installation. All of these advantages translate into cost savings throughout the life of a program.

The high processing power provided by the DSP and the high level of integration provided by today's commercial off-the-shelf (COTS) integrated circuits (ICs) allows for this design to be very flexible and capable of easily and quickly integrating functions for onboard or field diagnostics and prognostics such as Kalman filtering, order and trend analysis in a very small, light weight, and cost effective package.

8 References

- [1] IEEE 1451.2 - A SMART TRANSDUCER INTERFACE for SENSORS and ACTUATORS - Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats.
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- [3] Perry Sink, "A Comprehensive Guide to Industrial Networks, Part 1: Why Use an Embedded Network or Fieldbus, and What Are the Most Popular Standards?" Sensors Magazine, June 2001 - <http://archives.sensorsmag.com/articles/0601/28/index.htm>

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