

APPLICATION OF IEEE P1451 'SMART TRANSDUCER INTERFACE
STANDARD' IN CONDITION BASED MAINTENANCE

Bill Wright

PCB Piezotronics, Inc.
1632 Corporate Landing Parkway
Virginia Beach, VA 23454
757-427-0705, bwright@pcb.com

Mike Dillon

The Modal Shop
1775 Mentor Avenue
Cincinnati, OH 45212
513-351-9919, mdillon@modalshop.com

Abstract: IEEE P1451 is the proposed standard for interfacing sensors and actuators to the digital world of micro-controllers, processors and networks. The goal of this standard is to reduce the complexities designers face in establishing digital communication with transducers and actuators. IEEE P1451 defines the bus architecture, addressing protocols, wiring, calibration and error correction thus enabling a building block approach to system design with plug-and-play modules. System Integrators, Instrument Developers, Engineers or End Users can simply plug their IEEE P1451 compliant sensors and actuators together with measurement and communication modules to form a measurement system that allows transducers to interface directly to established networks and control systems.

Keywords: Smart Sensor; Portable Data Collector; Plug-and-Play; Condition Monitoring; Tool Wear; Networks; WEB Pages

Introduction: Techniques for machinery fault prediction under development, and published at these proceedings, are utilizing multiple sensors with unique algorithms to extract useful information from the spectral properties of signals. Methods such as wavelet analysis, Hilbert transform analysis, adaptive neural networks, performance analysis, nonlinear characterization and multifunction data fusion with embedded sensors are some examples. Implementing these solutions in the past has required stand alone instrumentation with dedicated proprietary hardware, most often paired with a computer. To deploy these solutions in the field today would be expensive due to the added costs of components like computers, spectrum analyzers, signal conditioners, interfaces and memory. The answer to this problem is a plug-and-play architecture where sensors and actuators are linked together through a series of common interfaces to modules designed not only to process the signals but to interface to existing communication networks. This approach eliminates full featured, more expensive components such as computers and stand alone instruments.

Background: The history of sensor buses began with analog systems; 2-wire voltage, bridge type, IEPE, 4-20 mA, etc... In the mid to late 1960's PCB Piezotronics got it's

start by pioneering the art of integrating microelectronics into piezoelectric sensors with the development of the IEPE (Integrated Electronics, PiezoElectric) signal conditioning system. These analog buses worked well in each environment and except for a few proprietary systems, provided one parameter per bus or connection. A need developed, mainly in the process control industry, to connect sensors and transducers directly to digital networks, over a common interface, for factory automation and closed loop control. The large growth in slow speed sensors (for the measurement of temperature, pressure and position for example) contributed to the development of digital bus architectures such as Fieldbus, Profibus, LonWorks, and DeviceNet. These systems have drawbacks and problems like bandwidth limitations, proprietary hardware and the major design work needed to interface with existing sensors.

The traditional lines are blurring that separate the analog transducer from the signal conditioning and data acquisition front end of a measurement system[1]. As micro-processors, micro-controllers, ADCs and their related electronics have become smaller, more powerful and less expensive over the years, the more advantages there are to putting this increased functionality into the transducer. As factory and office networks have expanded, so have network ready devices and peripherals. “The network is the computer”. This has led to the development of the proposed industry standard interface for the connection of transducers and actuators to micro-controllers and to connect micro-controllers to networks. It is a logical extension of the General Purpose Interface Bus (GPIB or IEEE 488), except that this brings standardization to sensors instead of instruments. Fig. 1 shows the building blocks for the implementation of a smart sensor interface.

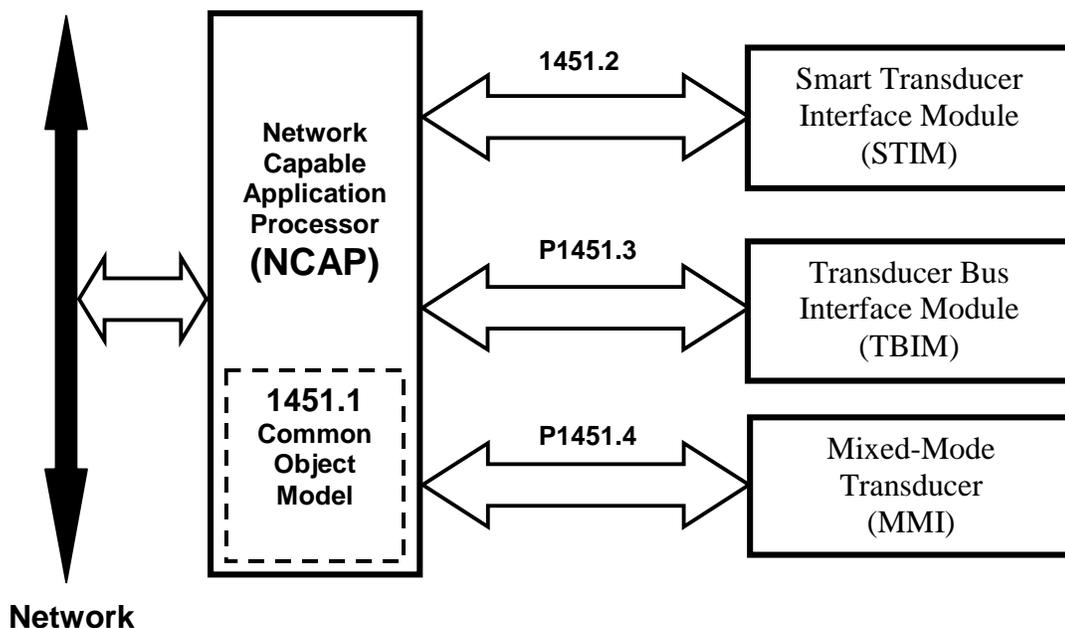


Fig. 1: Functional Block diagram of IEEE P1451

Example of Typical Application: Consider the case of a condition monitoring system being established for milling machines in a large factory. A measurement system is needed for monitoring the health of bearings inside the milling machine and to detect tool wear or damage. Traditional methods of vibration measurements using portable data collectors to monitor bearing health have failed in this application due to the varying operating conditions of the milling machine. Spindle movement and intermittent cutting operations effect the vibration signatures and can mask the vibration measurements of the bearings completely. The measurement system must take into account the various states of the machine and record vibration measurements at predetermined intervals.

An intelligent tool condition monitoring method is also needed to automatically detect tool wear or damage instead of replacing the tool at regular intervals or discovering defects in material after operation. Several direct sensing methods have been developed using multiple sensors to detect vibration, force, acoustic emission, temperature and motor current. Tool wear is a very complex process and is best detected with sensor fusion, feature extraction and pattern recognition[2].

A spectrum analyzer or data acquisition system with a dedicated personal computer could be adapted to work in this environment with various inputs from the control system for timing. This was considered to be too expensive and cumbersome to be implemented across the factory, on every line, at every machine. A low cost system needed to be developed that could accept inputs from various sensors, process the information and notify operators of impending failures or problems. With IEEE P1451 compatible components such as vibration sensors and actuators, a Smart Transducer Interface Module and a Communications Module, a measurement system can be constructed to implement the functions needed and communicate throughout the factory's network. A solution is illustrated below in Figure 2 and an explanation of the building blocks of IEEE P1451 follows.

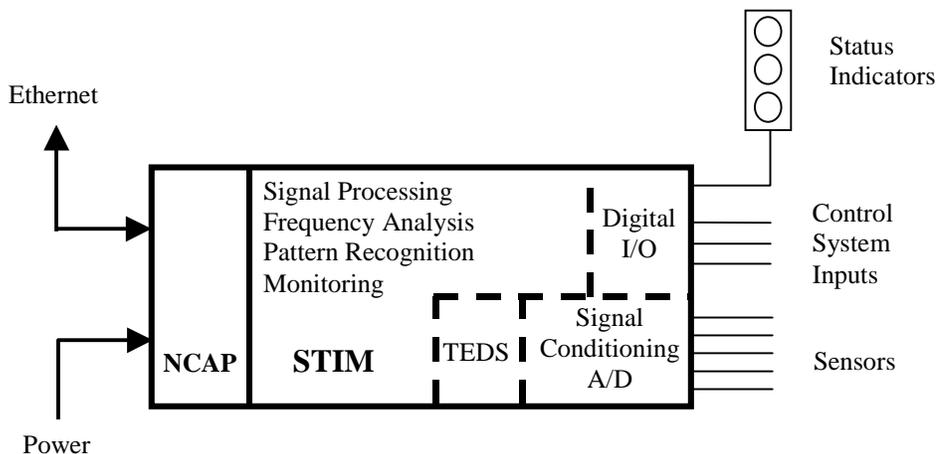


Fig 2: IEEE P1451 implementation of Machine Condition Monitoring System

IEEE 1451.1 Network Capable Application Processor (NCAP): The first section of the standard defines the interface for connecting network capable processors to control networks. The NCAP is the smart sensor's window to the outside world. Any control network may be connected to any transducer, or group of transducers, with an appropriately configured NCAP. This building block of the IEEE P1451 standard would typically consist of a processor with an embedded operating system and a sense of time. The processor would have some sort of communications stack for whatever network protocol was being used. If the NCAP were to be used through Ethernet, for example, it would have a TCP/IP protocol stack and perhaps a 10BaseT connector. Figure 3 illustrates an example of such a NCAP. The benefit of this approach is that the design

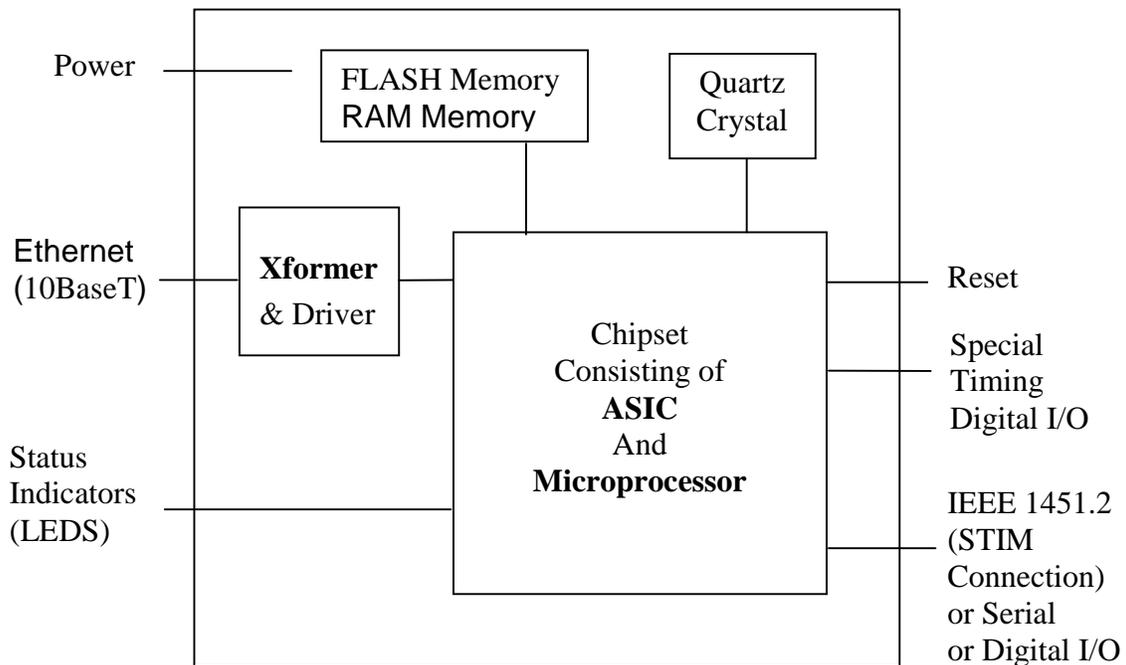


Fig. 3: Network Capable Application Processor (NCAP)

and development of these building blocks are left to the experts in this field, such as Hewlett Packard, Maxim Integrated or Analog Devices. These companies can keep abreast of the latest network protocols and buses and produce the modules that will interface smart transducers with existing networks. A system designer who is knowledgeable about the process he is trying to implement a solution for, need not worry about the network or computer interface; simply choose the module he intends to use for his particular application and plug it into his design. With additional code built into the NCAP, this module could act as a micro WEB Server with WEB pages providing information about the transducers connected to it.

IEEE 1451.2 Smart Transducer Interface Module (STIM): This section of the standard specifies a digital interface and serial communication protocol that allows any transducer, or group of transducers, to receive and send digital data using a common interface. This common interface, called the “Transducer Independent Interface” (TII), is a 10-wire serial I/O bus that is similar in many ways to the IEEE 488 bus. The TII implements a serial data exchange with allowances for handshaking and interrupts, has defined power supply lines and permits hot-swapping of modules for plug-and-play capability. Any transducer can be adapted to the 1451.2 protocol with a Smart Transducer Interface Module, or STIM. This building block of the 1451 standard is the heart of the measuring system. It can be as simple as a switch connected to a 4-bit processor, or as complex as a 255 channel device running an individual process. The STIM performs the duties of signal conditioning, signal conversion and linearization. With added hardware it can perform functions such as spectrum analysis, fuzzy pattern recognition, adaptive noise canceling or any specific algorithm needed. The success of IEEE P1451 depends on the development of STIM’s to meet individual needs and special applications. Figure 4 illustrates one example of a STIM and how it would interface with an NCAP through the TII.

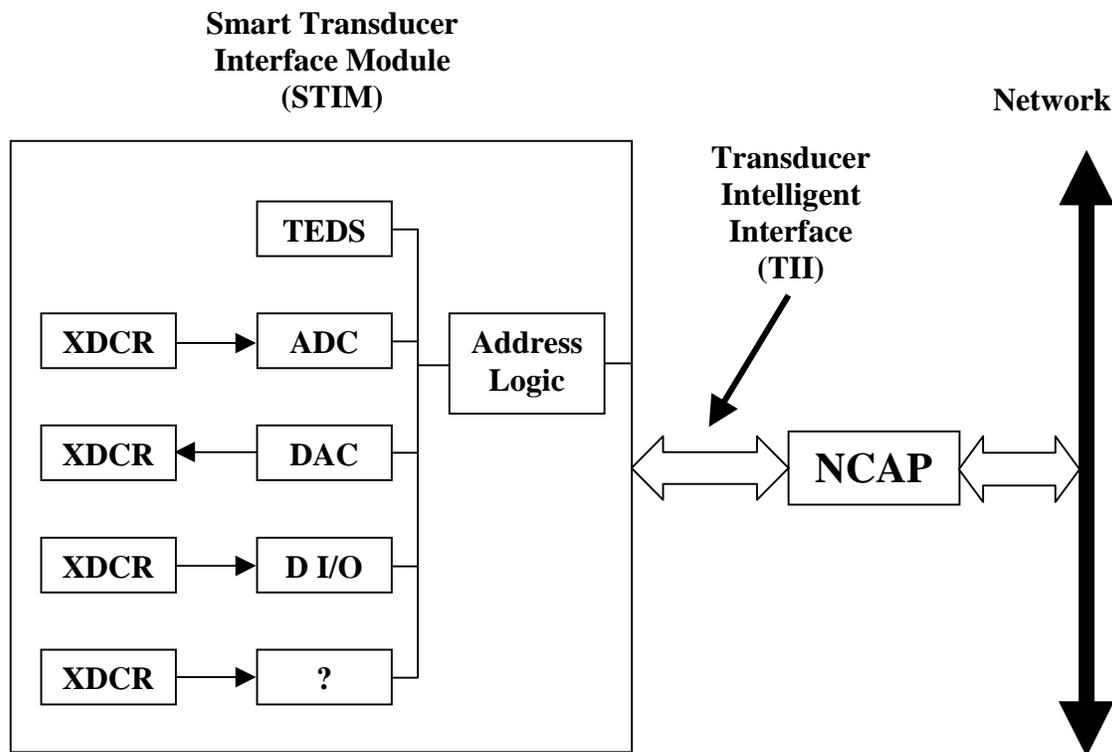


Fig. 4: Overview of a STIM and how it associates through the TII to an NCAP

Integral to this standard is the definition of the format for the Transducer Electronic Data Sheet (TEDS). Information about the STIM and the transducers attached to it are digitally stored within it. This includes transducer identification, channel information,

physical location, calibration, and correction data. The TEDS is the key to making plug-and-play devices because for the first time it provides a standardized set of mechanisms and information that can be used by applications to adapt to device changes automatically[3].

IEEE P1451.3 Distributed Multidrop Systems: This portion of the proposed standard will define a digital interface for connecting multiple physically separated transducers and allows for time synchronization of data. This transducer bus will facilitate communications, data transfer, triggering, and synchronization[4].

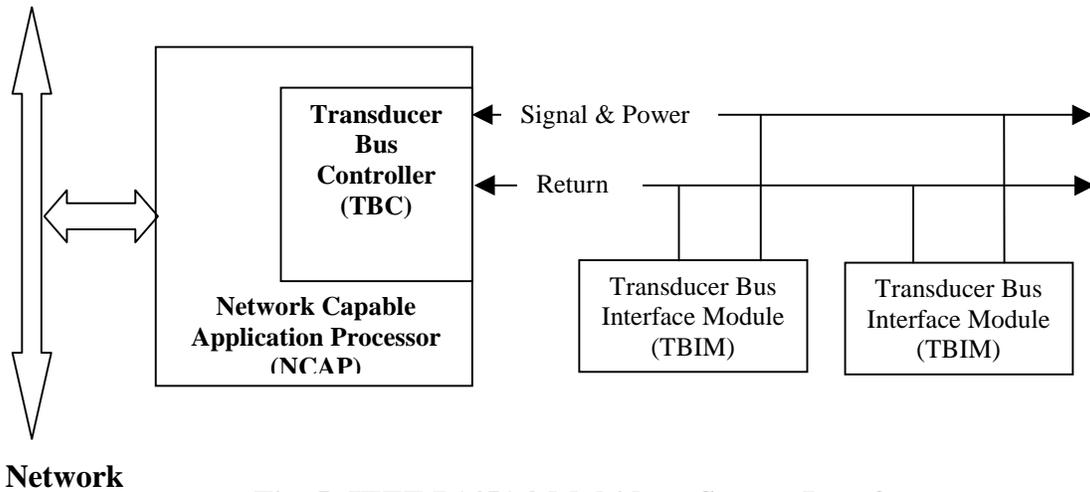


Fig. 5: IEEE P1451.3 Multidrop System Interface

A representation of IEEE P1451.3 with the functional blocks of the NCAP, Transducer Bus Controller, and the Transducer Bus Interface Modules is shown in Figure 5. A single transmission line is used to supply power to the TBIM's and to provide communication to the Bus Controller. The NCAP contains the controller for the bus and the interface to the broader network. A TBIM may contain from one to many different transducers and the bus may contain many TBIM's. This will allow a distributed network of sensors and actuators all connected through a common interface.

IEEE P1451.4 Mixed-Mode Communication Protocol and Interface: A Mixed-mode Communication Interface is defined in IEEE P1451.4 to bridge the gap between legacy systems and IEEE P1451 architectures. This standard allows analog transducers to communicate digital information, for the purposes of self identification and configuration, over the same medium. A Transducer Electronic Data Sheet (TEDS) is defined for traditional analog sensors to store information such as model number, serial number, sensitivity and calibration parameters inside the transducer. The term "mixed-mode" refers to the operation of the transducer in either its traditional analog (sensing) mode, or in its digital (communication) mode, during which transducer can be reconfigured, or its TEDS can be retrieved or updated. The transducer functions normally when the voltage supply is forward biased and will output its analog

measurement signal. When the sensor is reversed biased, the traditional analog circuitry is disabled and the TEDS memory can be accessed[5]. The circuit schematic is outlined in Figure 6 illustrating the reverse bias technique.

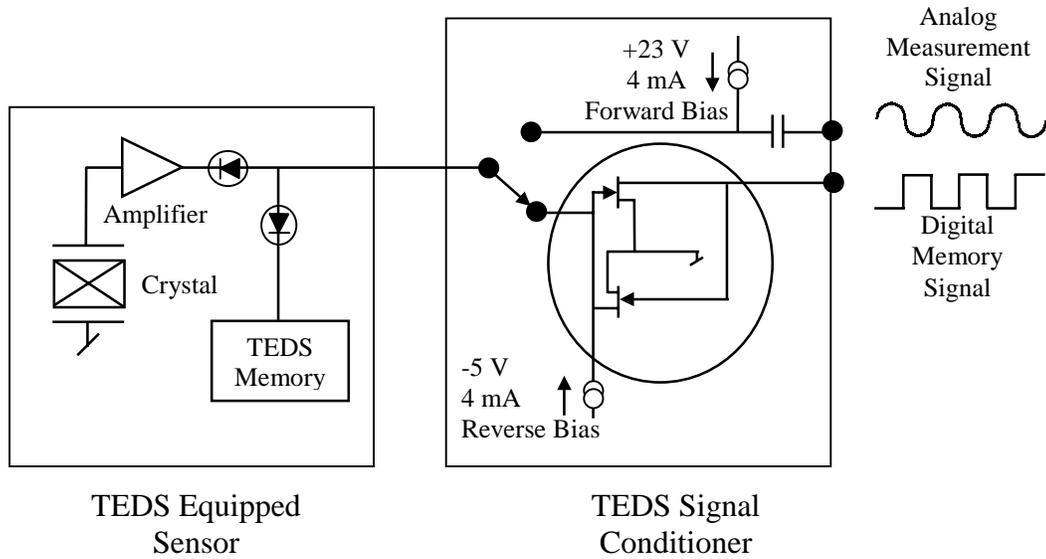


Fig 6: Circuit Schematic for IEEE P1451.4

Although the example given is specific to IEPE (Integrated Electronics, PiezoElectric) devices, the preliminary standard generalizes the configuration of this mixed mode interface for a wider range of transducers. Some legacy transducers systems may require more than one line for operation. For instance, certain devices may require a constant voltage source, and a separate line for the transduced output signal. In this case, the analog power line is defined as the data line while in the digital mode. This configuration is outlined in the following table. A similar reverse polarization scheme disables the analog circuitry, and activates the digital communication.

MODE	PHYSICAL WIRE		
	A	B	C
Normal Mode	Power	Signal	Ground
Digital Mode	Data	<Unused>	Ground

This configuration can be generalized in the following table:

MODE	PHYSICAL WIRE	
	A	B
Normal Mode	Power	Ground
Digital Mode	Data	Ground

While in digital mode, the P1451.4 transducer can identify itself by transmitting the contents of its memory. This is the capability most commonly associated with P1451.4. However, part of this memory may contain information as to how the P1451.4 transducer may be configured. After receiving this information, a host to the P1451.4 bus (likely a 1451.2 STIM) can issue a command to the transducer to configure itself into a number of different configurations. One immediate use of this capability is to implement a multi-drop sensor bus. Figure 7 outlines a transducer with such capability.

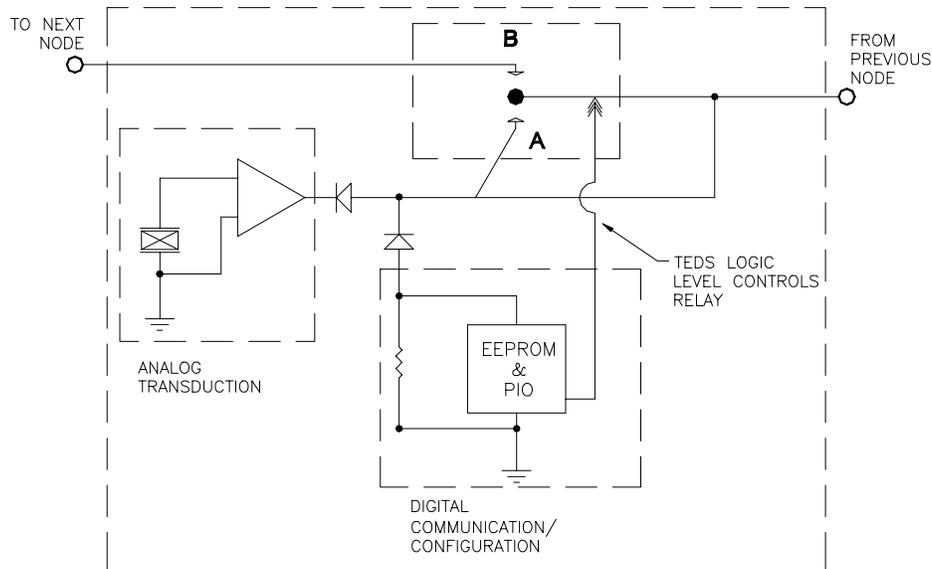


Fig 7: Self-Configuring P1451.4 Transducer

The transducer in Figure 7 contains 3 distinct components, each of which are enclosed by a dashed boundary. The first, labeled “Analog Transduction” represents an IEPE type of sensor which has been available for over 20 years. The second, labeled “Digital Communication/Configuration” adds the mixed-mode capability promised by IEEE P1451.4. Together with the “Analog Transduction” component, it forms the transducer outlined in Figure 6. However, the digital hardware in this particular transducer also has an extra pin which is held at logical high or logical low upon command. This logic level, in turn, controls the position of switching hardware found in the third component of the transducer. The “A” position of this switching hardware directs the power/signal line to this particular node. The “B” position of the switching hardware directs power/signal line to another transducer.

By arranging these self configuring transducers appropriately as shown in Figure 8, we build what effectively becomes a multi-drop sensor bus of mixed mode transducers. Note that the digital circuitry in Figure 7 is always connected to the bus. That is, when the bus is pulled low, all nodes of the network are visible to the controller (again, this is likely to be a 1451.2 STIM). The protocol of this P1451.4 network is such that each node shown in Figure 8 has a unique identification. The network protocol also permits the master to

poll the entire bus to uniquely identify each node. With this data, the master consecutively toggles each node to its “B” (or pass-through) position.

The master then commands Node 1 to toggle to its “A” position. The master then releases the bus from negative bias. All digital circuitry is then disabled, and only the analog circuitry of Node 1 is exposed to the constant current, positively polarized line bias. The “Analog Transduction” section of Node 1 ensues to bias and operate in its traditional manner, and high fidelity measurements possible with IEPE sensors can be taken by the master (STIM).

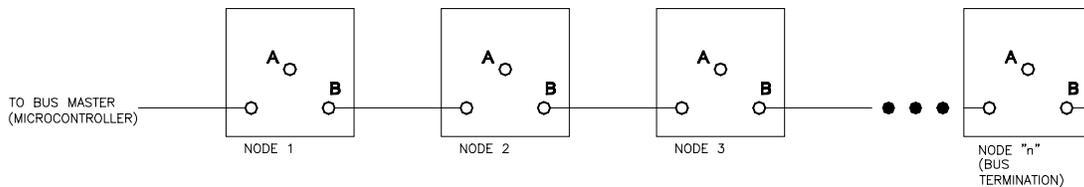


Fig 8: P1451.4 Multi-drop Sensor Bus

When the measurements phase for that particular node is complete, the master pulls the line low to disable the analog circuitry and “wake up” the digital circuitry of the entire bus. The master commands Node 1 to toggle to its “B” position, then commands Node 2 to its “A” position. Analog measurements can then be made from “Node 2”. This process is repeated for each of the “N” nodes on the network.

Conclusions: The hardware interfaces and communication protocols being defined under IEEE P1451 will enable instrumentation manufacturers to design and produce solutions for machinery condition analysis systems at a significantly lower cost than traditional methods. The proposed standard takes advantage of established networks so that sensors and transducers can be leveraged onto popular field networks with familiar, inexpensive, off-the-shelf wiring and networking components. The standard’s plug-and-play philosophy allows freedom of choice between transducers, field networks and interface modules. Standard Internet and Intranet links allow access to distributed devices from any remote site and enables customized and familiar IP addressing.

References:

- [1] Richard Bono, Mike Dillon, Kevin Gatzwiller and David Brown, New Developments in Multichannel Test Systems, Sound and Vibration Magazine, August 1999
- [2] Pan Fu, A.D. Hope and G.A.King, An Intelligent Tool Condition Monitoring System, The 52nd meeting of the Society for Machinery Failure Prevention Technology, pp.397-406 (1998).
- [3] Hewlett-Packard Application of Industrial Ethernet. www.hprie.com
- [4] IEEE-P1451 A Smart Transducer Interface Standard for Sensors and Actuators. www.ic.ornl.gov/p1451
- [5] The Modal Shop TEDS Developer Kit Manual, SW-0028, www.modalshop.com.