The IEEE 1451.4 Proposed Standard

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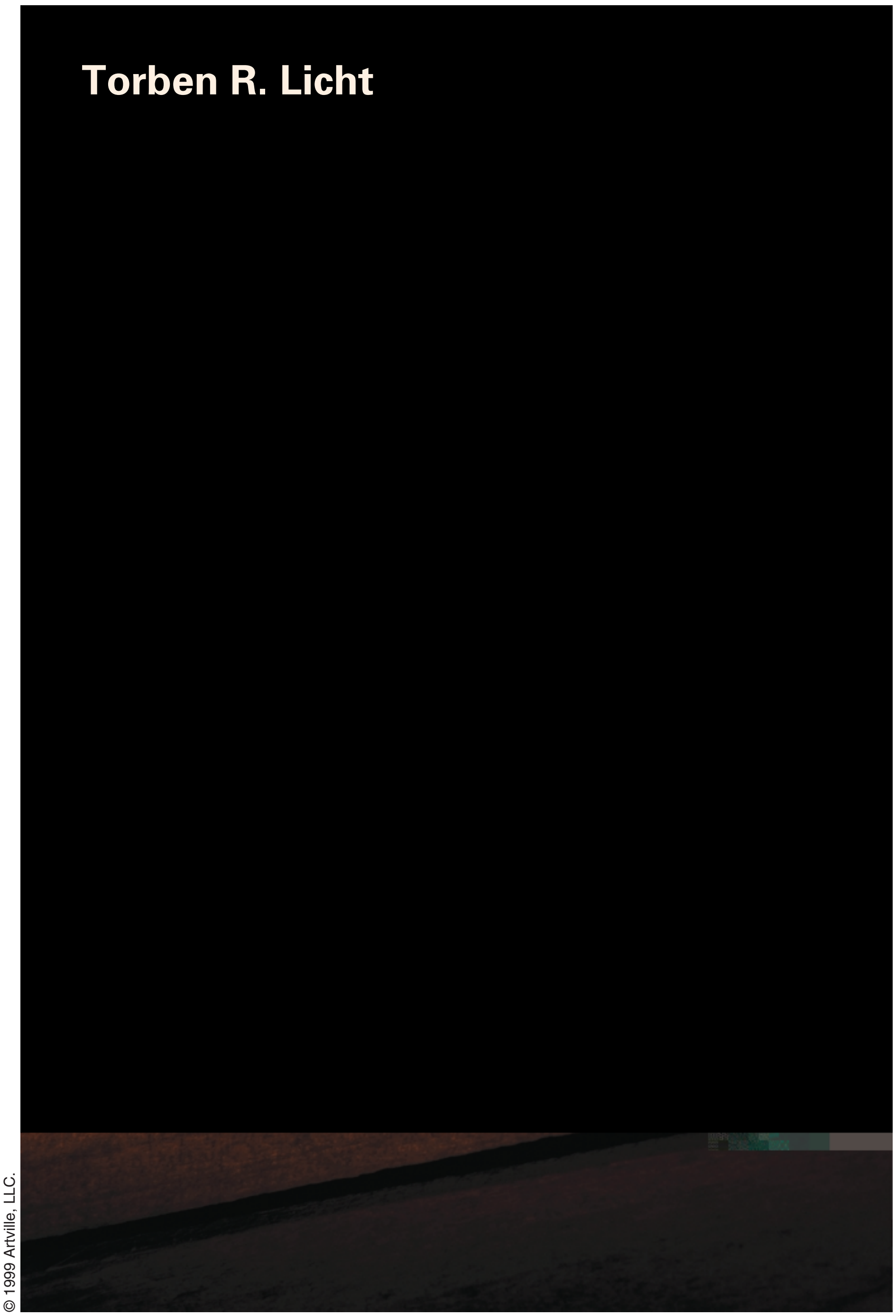

Over the last decade, a number of instrument buses and new ways to communicate with transducers have been introduced, but most of these methods have been useful only to small segments of the transducer community. The transducer community recognized the need for a general standard that would make life easier for the transducer community and began work on the IEEE 1451 series of standards. Furthermore, off-the-shelf integrated circuits for implementing built-in electronic data sheets in small transducers represent a large step forward. This article describes the IEEE 1451.4 standardization effort, building systems with plug-and-play transducers, downloading calibration data, and exploiting the extended functionality.

Objectives for a Standard

The ever-increasing capabilities of electronics and computers and the widespread availability of networks can be exploited to produce large numbers of transducers to measure, characterize, and help model many structures. This creates an increasing demand for "bookkeeping" of transducer data with the associated error probabilities. Therefore, the drive to get transducers with built-in identification, data (e.g., calibration factors), and even extended functionality has increased sharply over the last few years. The IEEE transducer community, in a concerted effort with NIST, started the work on the 1451.4 standard to fulfill the demands and needs of the changing industry. The main objectives of this standard are to:

- Enable plug-and-play capability at the transducer level by providing a common IEEE 1451.4 transducer communication interface compatible with legacy transducers.

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- Enable and simplify the creation of smart transducers.
- Simplify the setup and maintenance of instrumentation systems.
- Provide a bridge between legacy instrumentation systems and the smart mixed-mode transducers.
- Enable the implementation of smart transducers with minimal use of memory.

The existing fragmented sensor market is seeking ways to build low-cost smart sensors. Many implementations of mixed-mode (i.e., able to communicate in both analog and digital modes, but not simultaneously) smart sensors have been developed, but market acceptance has been slow because there is no standard. A universally accepted, mixed-mode transducer interface standard would not only allow for the development of compliant smart sensors and actuators, it could also lead to lower development costs. Therefore, the objective of this project was to develop a mixed-mode transducer interface standard that would allow engineers to choose their transducers without having to think about the networks. This relieves the manufacturer of the burden of supporting a cross product of sensors for multiple networks and helps to preserve the user's investment if it becomes necessary to migrate to a different network standard.

The drive to get transducers with built-in identification, data and even extended functionality has increased sharply over the last few years.

This standard simplifies the development of networked transducers by defining hardware and software blocks that do not depend on specific control networks. It also facilitates the creation of plug-and-play systems containing transducers. The standard describes the following:

- An IEEE 1451.4 transducer containing a mixed-mode interface (MMI) and a transducer electronic data sheet (TEDS).
- The MMI, which is a master-slave, multidrop serial connection. It requires a master device to initiate each transaction with each slave or node according to a defined digital communication protocol. The MMI can use either separate digital and analog connections or two wires for power supply, time-shared analog signals, and digital data. The MMI is used to access the TEDS.
- The TEDS, which has both fixed and dynamic data, is contained in one or more memory nodes on the MMI. (Note: The digital interface is not part of the TEDS templates.)
- A template, which is a software object, describes the data structure of the TEDS. It is implemented in the description language and resides in the transducer block (T-block).
- The description language is a scripted and tagged language that provides a standard method to describe the functionality of an IEEE1451.4 transducer.
- A transducer block is a software object describing the IEEE 1451.4 transducer. It resides in a network capable application processor (NCAP), which is the master device (e.g., an instrument or data acquisition system).

The TEDS residing in the IEEE 1451.4 transducer, provides self-describing capability. It contains fields that describe the type, operation, and attributes of one or more transducer elements (sensors or actuators). By requiring that the TEDS be physically associated with the IEEE 1451.4 transducer, the resulting hardware partition encapsulates the measurement aspects in an IEEE 1451.4 transducer, while the application-related aspects can reside in the NCAP or TEDS.

The IEEE 1451.4 transducer is a sensor or actuator, typically with one addressable device, which will be referred to here as a node, containing TEDS. The digital communication can be used to read the TEDS information and to configure an IEEE 1451.4 transducer.

The T-block is responsible for communication with the IEEE 1451.4 transducer. This task requires external information. This information is contained in the description language and associated files. The description language can be used as an application for communication and configuration, but it does not reside in the IEEE 1451.4 transducer.

An IEEE 1451.4 protocol is used to separate the time-critical part of the communication of the IEEE 1451.4 interface from the T-block. The T-block object located in the NCAP handles the interpretation of the TEDS data for the end user. Further processing of the data may take place both in the NCAP

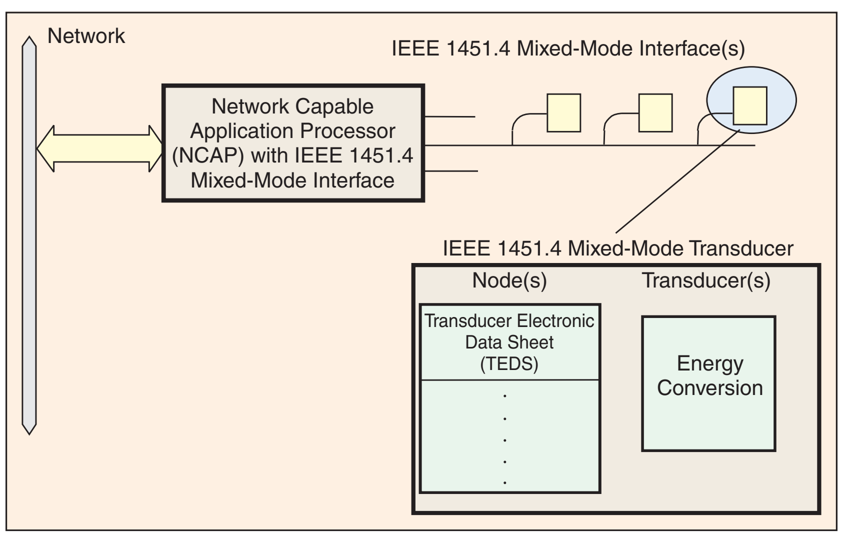

Fig. 1. Context for the mixed-mode transducer and interface.

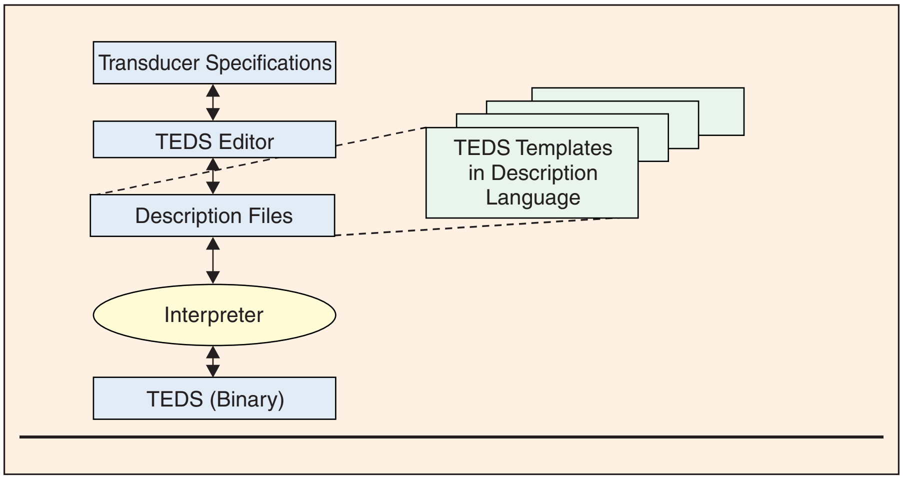

Fig. 2. Description language use.

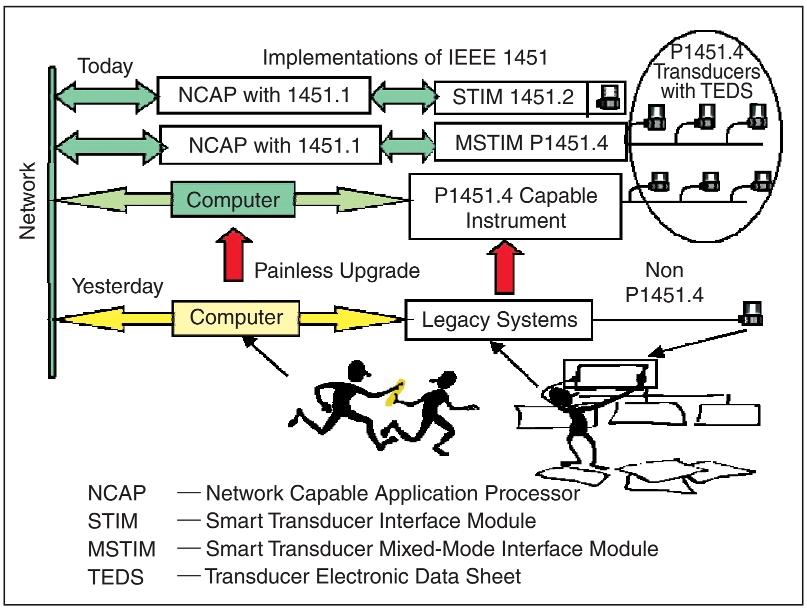

Fig. 3. The P1451 family of standards.

and in other processors in larger systems. The NCAP includes an IEEE 1451.1 object model with an IEEE 1451.4 T-block.

The IEEE 1451.4 MMI can be used for control networks and data acquisition in a variety of applications such as portable instruments and data-acquisition plug-in cards for PCs. The standard does not constrain competitive differentiation in the areas of quality, feature set, and cost and, at the same time, offers the opportunity to design to a common interface that can be used in a wide variety of applications.

Foundation

An IEEE 1451.4 transducer contains a TEDS and MMI. Fig. 1 shows the context for the mixed-mode transducer and interface. An IEEE 1451.4 transducer may sense or control multiple physical phenomena. Each phenomenon sensed or controlled is associated with a node.

If more than one node is included in an IEEE 1451.4 transducer, one of the nodes must have a memory block that holds the node list. A node list contains the IDs of the other node. An IEEE 1451.4 transducer has no more than one node list. If there is only one node inside an IEEE 1451.4 transducer, there is no node list. Each IEEE 1451.4 transducer is connected to an IEEE 1451.4 MMI. Each MMI can have several IEEE 1451.4 transducers attached provided they can act in a passive mode.

To communicate with the nodes inside an IEEE 1451.4 transducer with shared wires, the IEEE 1451.4 transducer is switched into "IEEE 1451.4 mode." This can be achieved by reversing the polarity. While in IEEE 1451.4 mode, the shared lines are used for the digital communication described in this standard and other uses are inhibited. If separate wires are used for the IEEE 1451.4 communication, any other communication can take place simultaneously.

Multiplexing

Multiple IEEE 1451.4 transducers with switch nodes can be connected in a multidrop configuration with one transducer in "active" mode and the rest in "passive" mode. The switch nodes can be used to change the functional mode of each IEEE 1451.4 transducer.

Node lists specify each node's corresponding IEEE 1451.4 transducer(s). This is needed if two (or more) nodes are connected to the same IEEE 1451.4 MMI. A node list is not included if an IEEE 1451.4 transducer contains only one node. If there are more nodes present and no node list is found, then each node will be an IEEE 1451.4 transducer. This permits, e.g., a single thermometer node to be an IEEE 1451.4 transducer.

The TEDS must contain information about the type of transducer which is connected, e.g., if it is a sensor or actuator, and the physical unit being measured. Furthermore, if there are more nodes with memory, the memory shall be considered as contiguous, ranked by this list of nodes.

Communication

The IEEE 1451.4 transducer can be configured via dedicated nodes. The description language contains the information needed to change the configuration.

For example, configuration changes allow:

- Self-test,
- Reset of transducer,

- Multiplexing between transducers in an IEEE 1451.4 transducer,
- Gain shift in an IEEE P 1451.4 transducer, and
- Change of filter settings in an IEEE P 1451.4 transducer.

Enabling or disabling of the analog function of the different IEEE 1451.4 transducers permits several IEEE 1451.4 transducers to be connected to the same IEEE 1451.4 interface. The node list groups the nodes for each IEEE 1451.4 transducer. This makes multiplexing possible.

The Description Language

The description language described in the standard contains the necessary rules for creating unambiguous description files. An interpreter can then handle these and the binary output stored in the transducer. Afterward, the binary content of the transducer can be read and interpreted into the original specifications. A TEDS editor has been created to facilitate these actions. This is, however, not a part of the standard. Fig. 2 shows these relations graphically.

The Family of IEEE 1451 Standards

The proposed standard defines an interface for mixed-mode transducers (i.e., analog or other transducers with digital output for control and self-describing purposes) as part of the P1451 family of standards (see Fig. 3). It establishes a standard that allows mixed-mode transducers to communicate digital informa-

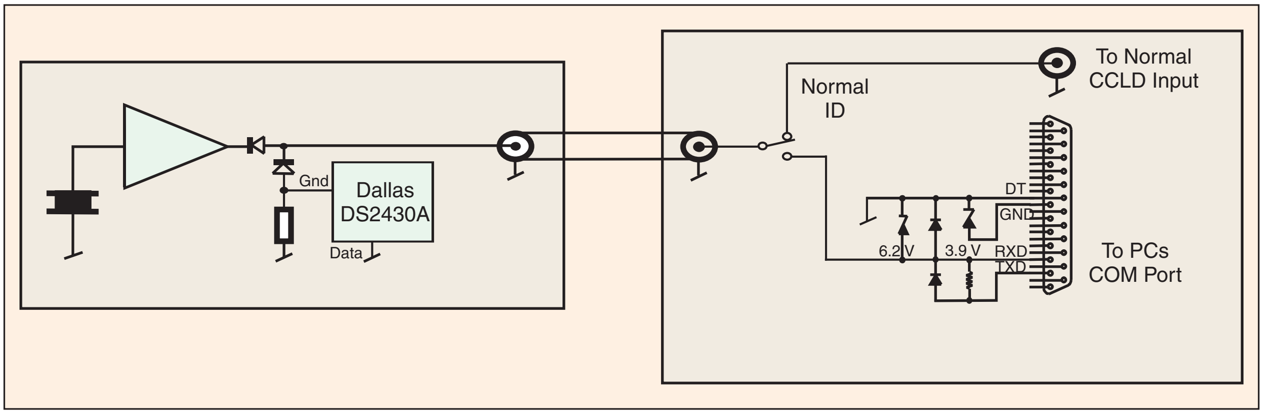

Fig. 4. Principle of implementation of integrated identification with PC support for constant current line drive (DeltaTron, Isotron, ICP, etc.) transducers. Transducer (left) connected via a co-axial cable to interface (right).

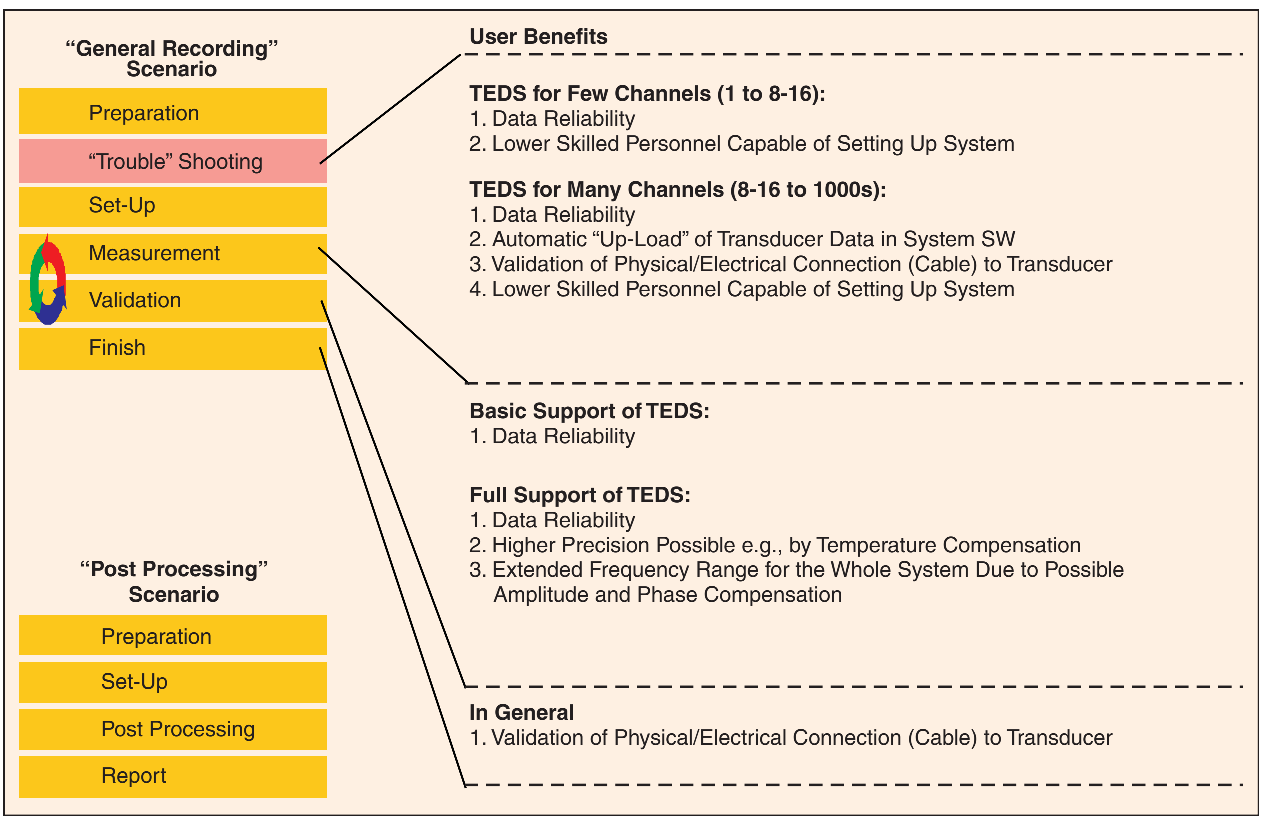

Fig. 5. TEDS impact on the measurement process.

tion with an IEEE P1451-compliant object. Both sensors and actuators are supported, and the P1451.4 interface is invisible from the network's viewpoint. All of the standards in the IEEE 1451 family could be used either as stand-alone or with each other. For example, a "black-box" transducer with a P1451.1 object model combined with a P1451.4-compliant transducer is within the definition of the P1451 family specification.

This standard simplifies the development of networked transducers by defining hardware and software blocks that do not depend on specific control networks.

The IEEE P1451.4 interface is needed to allow the use of existing analog transducer wiring and for those demanding applications where it is not practical to include the network interface (NCAP) with the transducer. Examples of the latter include very small transducers and very harsh operating environments. Each P1451.4-compliant mixed-mode transducer will consist of at least one transducer, the TEDS, and interface logic required to control and transfer data across various existing analog interfaces. The transducer TEDS are minimized and defined such that it contains enough information for the higher level P1451 object.

The IEEE P1451.4 proposed standard allows analog transducers to communicate digitally with an IEEE P1451 object. The standard defines the protocol and interface. It also defines the format of the transducer TEDS. The standard will not specify the transducer design, signal conditioning, or the specific use of the TEDS.

An independent and openly defined standard reduces the risk for potential users, transducer and system manufacturers, and system integrators. This should accelerate the emergence and acceptance of this technology.

Implementation

The two-wire interface demands are set, for example, by the standard co-axial interface used for accelerometers with built-in constant current line drive (i.e., ICP, DeltaTron, Isotron, and several others) amplifiers. Once the requirement for a two-wire interface is fulfilled, the implementation in other transducers, where separate wires are available, poses no problems. By using a reversed-polarity technology for switching between the normal analog mode and the digital communication mode, the chosen principles from the MicroLAN interface fulfils all the stated needs.

This technique enables switching between the analog and the digital mode, using only two standard diodes. Reversing the polarity performs the switching. Fig. 4 shows this principle, which also shows the simplicity of the receiving device. Primarily, an additional supply (here, the COM port is used) is needed to supply the negative voltage for the ID-device. The microcontroller or PC maintain the communication and translation of signals to and from the memory component(s) in the transducer

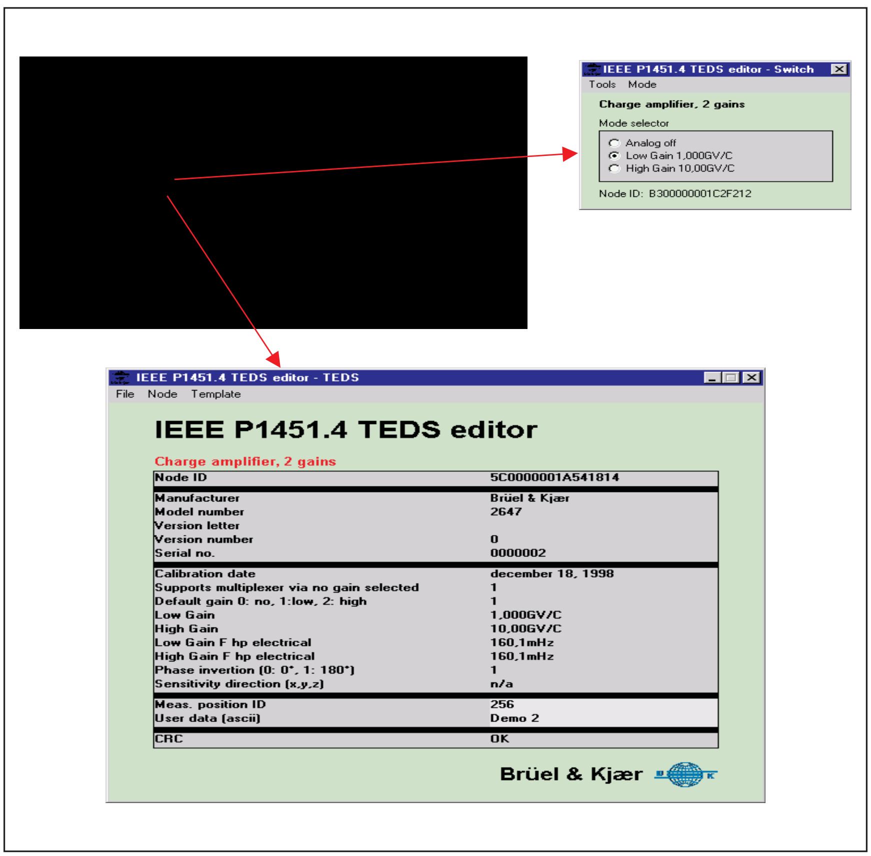

Fig. 6. Example of IEEE P1451.4 TEDS editor for a charge to DeltaTron converter showing the three main areas of the memory (the "fixed" identification field, the "variable" transducer specific template and the "free" comments field). Top left shows the tree structure of the transducer configuration. Top right shows the mode selector.

User Benefits

To describe precisely a given measurement system, all individual components (transducers, preamplifiers, conditioning units, analyzers), including their settings, must be known. In multichannel systems in particular, the customer faces a number of problems including:

- Long set-up times and
- Validation of the position of the transducers.

The implementation of IEEE 1451.4 transducers and systems reduces these problems by incorporating essential identification data (such as type and serial number) within the transducer itself in a TEDS with calibration data such as sensitivity. This allows plug-and-play functionality into the system (Fig. 5).

State of the Art

The standardization, along with available memory and communication devices, has allowed the implementation of a number of products (more than 50 alone from Brüel & Kjær).

Identification

This feature is the main driver for communication with a transducer. Because the memory is used very efficiently, practically all the relevant information is stored inside the transducer, so the needed data are always at hand. This is, essentially, the calibration chart.

Gain Adjustment

Transducers often comprise two portions. A device to transform the physical properties into an electrical signal (e.g., piezoelectric discs and a seismic mass in an accelerometer) and a conditioning circuit. This transforms the output impedance and the signal level to make the signal of practical use outside the transducer. The dynamic range of this electrical circuit is frequently much smaller than the dynamic range of the physical transducer (for an accelerometer, 160 dB are reduced to about 120 dB). This makes a compromise necessary when constructing the transducer. With the new technique, gain switching inside the transducer gives the best working condition for the measurement setup.

Multidrop or Distributed Multiplexing

A charge to the DeltaTron adaptor has been developed with identification in accordance with IEEE P1451.4. It contains a TEDS and extended functionality such as dual gain and multidrop facilities. Fig. 6 shows the content of the TEDS. Multidrop means that several charges to DeltaTron adaptors can be used on the same MicroLAN network as a serial, distributed multiplexer. The main application is to allow charge accelerometers (which are analog transducers) to communicate digital information with an IEEE1451-capable instrument. There are three modes of operation: two gain settings of 1.0 and 10.0 mV/pC and an "analog-off" mode, which is used to implement the multiplexer function.

Analyzer TEDS Support

The Brüel & Kjær PULSE Analyzer is the first analyzer platform to fully support standardized TEDS from the initial setup through the analysis. The system automatically detects the connected transducers and sets their sensitivities, ensuring that the correct conditions are always used when making measurements.

Fig. 7 shows an example of the PULSE system with a Modal Shaker application. A number of windows are opened to show the resulting setup after connection of a triaxial transducer and a "Get-configuration" command. The proper transducer channels are shown in the configuration and the associated sensitivities are used in the channels. The transducers can also be found in the database.

Automated Set-Up of Preamplifiers

The Brüel & Kjær NEXUS range of accelerometer and microphone preamplifiers communicates with the transducers, and the received information is used to set up the preamplifier correctly. The data can also be sent on to a controlling computer. The Endevco Optimal Architecture Sensor Interface System OASIS-2000 is a modular system consisting of a 16-rack enclosure that can be fitted with up to 128 channels per rack to provide power, computer control, and signal conditioning. One of the input modules is an eight channel card Model 482 that supports IEEE 1451.4 and features automatic transducer identification and user-defined output normalization.

Summary

The measurement community is best served by transducers with integrated identification and data. The work in the IEEE group and in the involved companies has brought plug and play to the measurement community. This has helped the transition to larger systems with more transducers and simultaneously introduced a new level of quality into the measurements.

The author encourages both users and transducer manufacturers alike to participate in the discussions of the standard to ensure that the upcoming IEEE standard meets their needs.

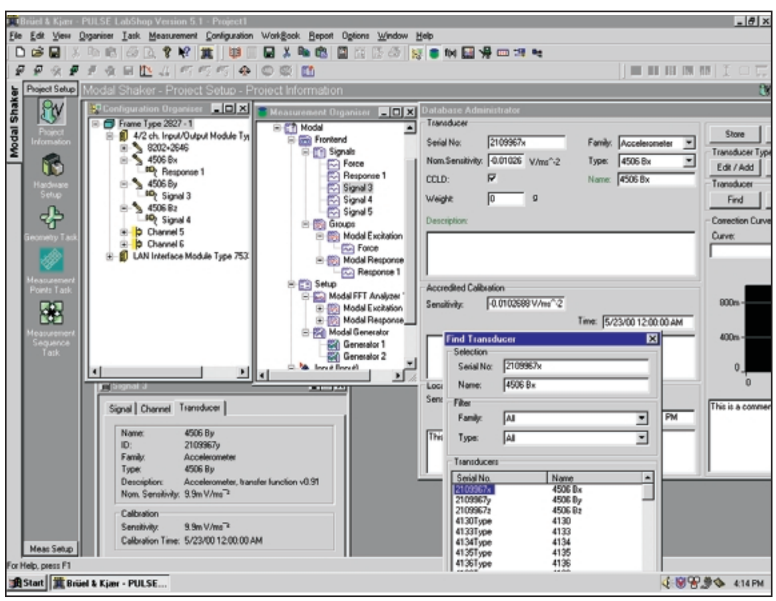

Fig. 7. Pulse Modal Shaker application. A number of windows are opened to show the resulting set-up after connection of a triaxial transducer and a "Get-configuration" command. The proper transducer channels are shown in the configuration and the associated sensitivities are used in the channels. The transducers can also be found in the database.

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Note

ICP is a registered trademark of PCB Piezotronics, Inc.; DeltaTron is a registered trademark of Brüel & Kjær Sound and Vibration; IsoTron is a registered trademark of Endevco Corporation; and MicroLAN is a trademark of Dallas Semiconductor.

Torben R. Licht has been with Brüel & Kjær since 1968. As a MSc in solid-state physics he started designing piezoelectric transducers and stayed within this field for several years. He has also worked in international sales and is well known within the ISO standardization committees dealing especially with calibration of transducers and in the IEEE 1451.4 standardization committee as an IEEE Member. Presently, he is in the innovation group, trying to shape the future strategy of the company.