IEEE 1451: transducer networking

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Keywords: IEEE 1451, transducer, Smart Sensors , transducer network, Wireless Sensor Network

Introduction

This paper explores the application of rapidly maturing terrestrial transducer technologies, in particular IEEE-1451 to space applications. We propose that the application of these technologies to sensors and actuators on spacecraft will bring significant benefits in terms of harness reduction, simplified integration and testing, and better quality systems.
In this paper we introduce the IEEE-1451 and highlight some of the key concepts that we believe are of most relevance for spacecraft applications.

The background to IEEE-1451

The commercial transducer market for terrestrial applications is extremely diverse. Transducers are used in most industries, for example, aerospace, automotive, industrial control, manufacturing, and process control.
Transducer manufacturers are seeking ways to build low-cost, smart Transducers to meet the continuous demand for more sophisticated applications and ease of uses. Smart transducers (sensors or actuators) provide value-added functions such as signal conditioning or amplification, signal conversion (analogue / digital), and also self-identification, self-diagnostics, adaptive calibration, engineering unit conversion of output data, etc.
Until recently, transducers have been connected to instruments or computer systems by means of point-to-point interfaces, often using a multiplexing scheme to share resources such as analogue-to-digital converters or signal conditioning electronics. The integration, of transducers within a system was complex because of cable wiring, error prone manual entry of device data, and manual system configuration. The concepts of computer networking have gradually migrated into the transducer community. The networking of transducers in a system can provide flexibility, scalability, improve system performance, and ease system installation, upgrade, and maintenance. The rapid development and emergence of smart transducer and field network technologies have made the networking of smart transducers a very economical and attractive solution for a broad range of measurement and control applications. However, with the multitude of incompatible network specifications that have been created, a certain degree of confusion and uncertainty has arisen about which network(s) to support.
In view of this situation the Technical Committee on Sensor Technology of IEEE's Instrumentation and Measurement Society has sponsored a series of projects, designated as IEEE P1451, to address these issues through the development of a family of smart transducer interface standards for connecting transducers to networks.
The remainder of this paper describes the work carried out in the frame of IEEE-1451.

1. IEEE P1451, Standard for a Smart Transducer Interface for Sensors and Actuators

The IEEE P1451 project is divided into six subprojects, which were charged with defining hardware and software standardized methods to support smart transducers and network connectivity. The IEEE P1451 projects aim is to reduce industry's effort to develop and migrate to networked smart transducers. The ultimate goals of this family of standards are to provide the means for achieving transducers-to-network interchangeability and transducer-to-networks interoperability.
Two classes of devices are described by the standards: the Network Capable Application Processor (NCAP) and the transducer modules. A NCAP forms the bridge between any network and the transducer modules. IEEE 1451.1 describes a common software object model for the NCAP. Different versions are required depending the networks and the transducer modules type. IEEE 1451.2 transducers are embedded in the Smart Transducer Interface Module, connected to the NCAP by means of a digital point-to-point link; IEEE P1451.3 transducers are located in a number of Transducer Bus Interface Module, connected to the NCAP by a multidrop bus; IEEE P1451.5 transducers are embedded in wireless nodes communicating with the NCAP wirelessly; IEEE P1451.4 transducers can be connected to NCAP or TBIM through the mixed mode interface; IEEE P1451.0 defines common functionality for interoperability among the IEEE 1451 family.

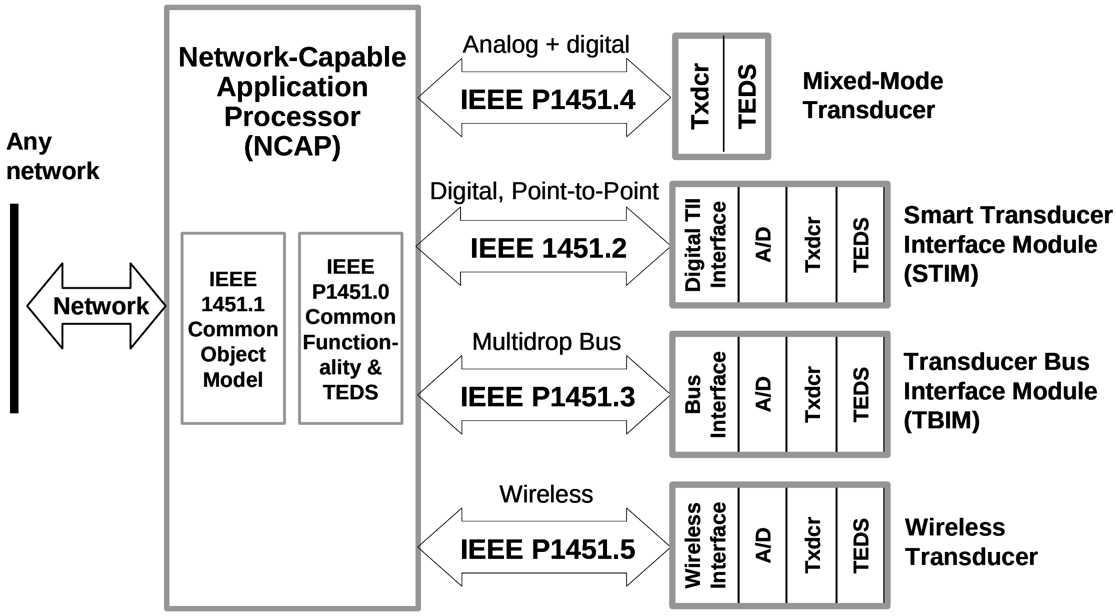

Figure1: IEEE 1451 Family of Smart Transducer Interface Standards

1.1 IEEE Std 1451.1- Networked Smart Transducer Model.

The IEEE 1451.1 standard, published in 1999, defines a common object model for a networked smart transducer and the software interface specifications for each class representing the model. Some of these classes form the blocks, components, and services of the conceptual transducer. The networked smart transducer object model encapsulates the details of the transducer hardware implementation within a simple programming model. This makes programming the sensor or actuator hardware interface less complex by using an input/output (I/O)-driver paradigm. The network service interfaces encapsulate the details of the different network protocol implementations behind a small set of communications methods. The model of the networked smart transducer is shown in Figure 2.

1.2 IEEE Std 1451.2- Transducer to Microprocessor Communication Interface.

IEEE 1451.2 standard, published in 1997, was designed to gain a standard way to specify the device operation and calibration, a standard physical interface between the transducer and the communications device, and the ability to use standardized off-the-shelf components to build smart transducers.
This standard defines the Transducer Electronic Data Sheet (TEDS) and its data format, the Smart Transducer Interface Module (STIM) and the digital interface including connector pin allocation and communication protocols between the transducers and microprocessor.
The TEDS, stored in a nonvolatile memory attached to a transducer, contains fields that fully describe the type, attributes, operation, and calibration of the transducer. It enables self-identification of transducer and "plug and play" capability. The TEDS contains information such as manufacturer, transducer model number, serial number, measurement range, sensitivity, calibration information.

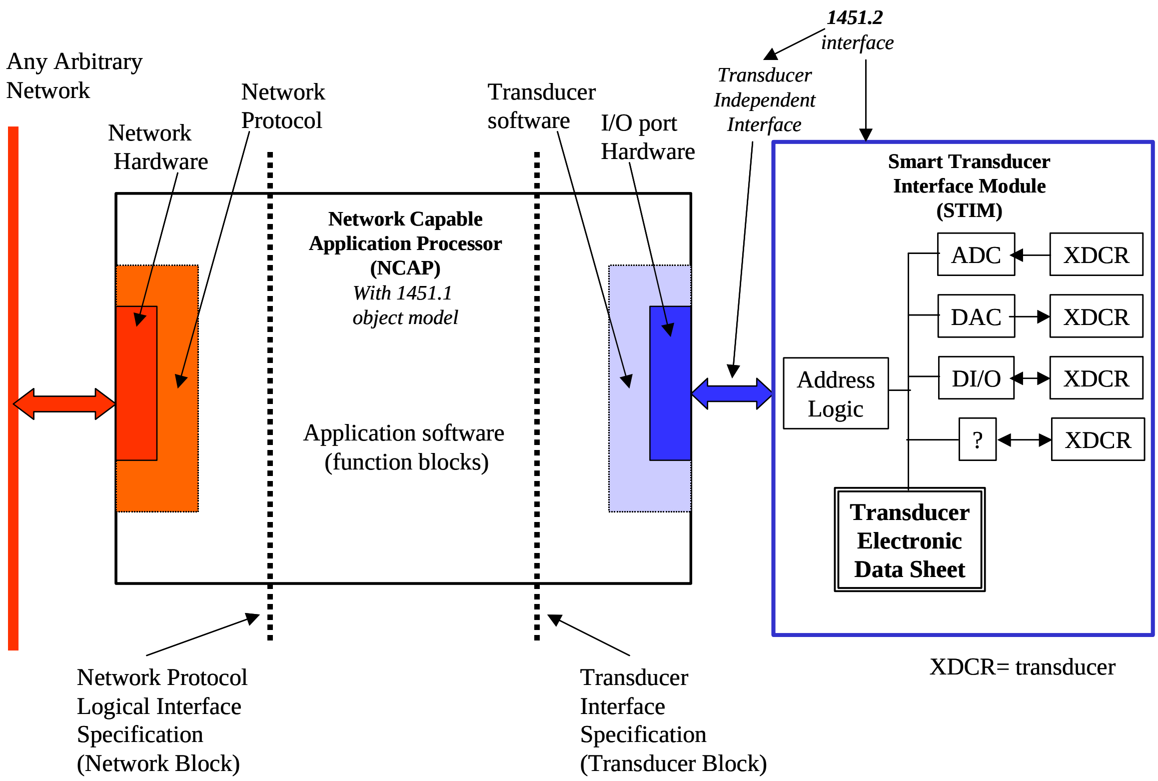

Figure 2: Framework of IEEE 1451.1 and 1451.2 Interfaces

1.3 IEEE P1451.3, Distributed Multidrop System for Interfacing Smart Transducers

The IEEE P1451.3, approved by IEEE, publication in progress, develops a smart transducer interface standard for a distributed, multidrop transducer bus or network. The standard defines electrical interfaces, Transducer Electronic Data Sheet (TEDS), channel identification protocols, hot swap protocols, time synchronization protocols, and read and write logic functions used to access the TEDS and transducer data.

The objective is to handle the requirements of a distributed system with a large array of transducers (in the order of hundreds), which needs to be read in a synchronized manner. The bandwidth requirements of these transducers might be relatively high, in the order of several hundred kilohertz, with time correlation requirements in tens of nanoseconds. A number of issues are considered including self-identification of nodes and cohabitation of different type of transducers on the bus.
The physical representation of the proposed IEEE P1451.3 standard uses a single transmission line to supply power to the transducers and to provide the communications between the bus controller and the Transducer Bus Interface Modules (TBIM). A transducer bus is expected to have one bus controller and many TBIMs. A TBIM may contain one or more different transducers. The NCAP contains the controller for the transducer bus and the interface to the network that may support many other buses.

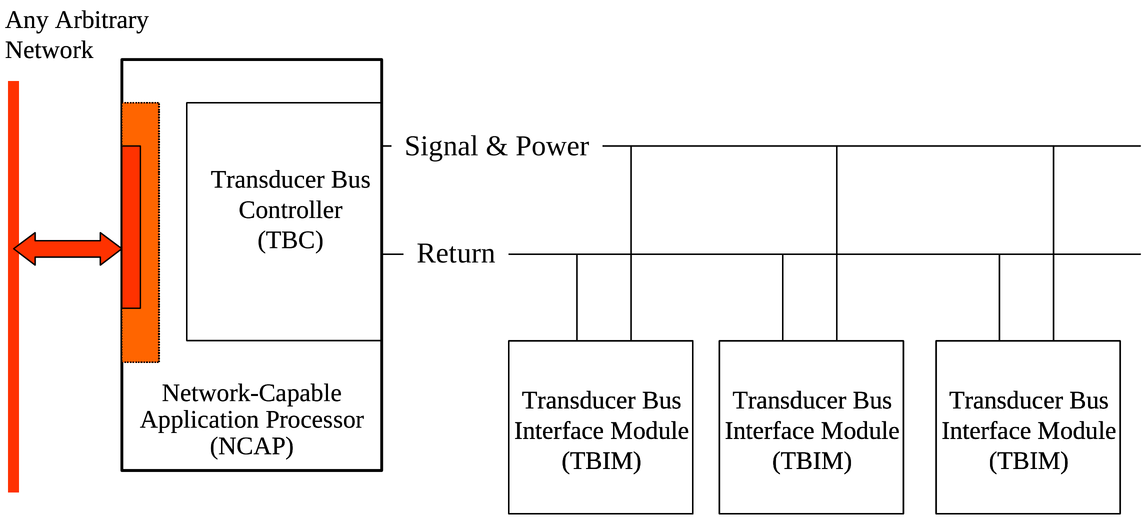

Figure 3: Physical representation of the IEEE P1451.3

1.4 IEEE P1451.4, Mixed- mode Transducer and Interfaces

The IEEE P1451.4, in process of ballot, is a proposed standard that defines a mechanism for adding self-identification technology to traditional analogue-mode sensors and actuators, and is intended to support both legacy devices and devices where there are significant constraints on the logic that can be integrated with the device. IEEE P1451.4 defines the concept of a mixed-mode transducer that supplies both an analogue and digital interface. The analogue electrical interface provides a signal (voltage, current) representing physical phenomenon (temperature, pressure, force, etc.). The serial digital interface can be used to read the TEDS information and to configure the transducer.
There are two types of mixed-mode interfaces, defined in the standard: Class 1 interfaces define a scheme for sequentially switching between analogue mode and digital TEDS mode on a single pair of transducer wires; most sensor types will implement a form of the Class 2 interface, which separates the digital TEDS interface from the analogue sensor output. The analogue input/output of the transducer is left unmodified, and the 2-wire TEDS interface is added in parallel to the analogue interface. Using this approach, plug and play mechanisms can be implemented with virtually any type of amplified or unamplified sensor or actuator.
The digital portions of both Class 1 and Class 2 interfaces are identical, based on the 1-Wire [3] protocol from Maxim/Dallas Semiconductor. Commercially available 1-Wire EEPROMs provide low-cost, 2-wire solutions for adding TEDS to sensors.

1.5 IEEE P1451.5, Wireless Transducer networks

This project, study group in action, will establish a standard for wireless communication methods and data format for transducers. The standard will define a TEDS based on the IEEE 1451 concept, and protocols to access TEDS and transducer data. It will adopt necessary wireless interfaces and protocols to ease the use of technically differentiated, existing wireless technology solutions.
IEEE 1451.5 will Support multiple wireless protocols, including the IEEE 802.11x, 802.15. x RF Standards and facilitate adoption of future innovations in wireless technology. It will create a framework for developing profiles on top of existing industry standards.

1.6 IEEE P1451.0, Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats

IEEE P1451.0 will be a new standard containing a common set of functions, communications protocols and TEDS formats for various physical communications media. It will aid interoperability among IEEE 1451 standards and simplify the creation of standards for different physical layers.

2. Applicability of IEEE P1451 to space

The IEEE P1451 family of standards addresses a large number of issues to support smart transducer networking. A great deal of work has been done in defining interfaces, and classifying sensors and actuators. The transducers considered range from simple analogue and digital devices up to more complex, multifunctional devices, with interconnection via both wired and wireless interfaces. Several key concepts have been elaborated, including the transducer electronic data sheets and transducer independent interfaces, and some very interesting system topologies have been explored.
The remainder of this paper considers how these concepts can usefully be applied to spacecraft development, and suggests how they may be beneficial. In particular, ESTEC is currently actively investigating two solutions directly derived from IEEE P1451 for future application in space, namely:

- A IEEE 1451.3 type multidrop transducer bus based on 1-Wire technology
- A IEEE 1451.5 type wireless transducer network based on IEEE 802.15.4 [4]

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