IEEE P1451.3 A STANDARD FOR NETWORKED TRANSDUCERS

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ABSTRACT

IEEE P1451.3 is an attempt to define a standard that will allow a transducer manufacturer to build transducers that have a wide range of price and performance but which are all inter-operable within a system. The standard will allow for simple devices with relatively low data sampling rates and moderate time correlation requirements to be designed and built. At the other end of the spectrum will be devices that have bandwidth requirements to several hundred kilohertz and time correlation requirements in the range of nanoseconds. It is expected that devices from either end of the spectrum will be able to peacefully coexist in the same system. In the physical realm a single transmission line will be used to supply power to the transducers and to provide the communications between the bus controller and the transducers. A bus is expected to have one bus controller and many transducers. A Network Capable Application Processor (NCAP) contains the controller for the bus and the interface to the broader network, such as NexGenBus, that may support many other nodes, NCAPs and transducer buses. A bus controller will only reside in an NCAP if the transducer bus exists within a hierarchy of networks; it may reside in a host computer or other device. This paper discusses the approach being taken and gives the status of the standard.

GENERAL CAPABILITIES

IEEE P1451.3 is an attempt to define a standard that will allow a transducer manufacturer to build transducers that have a wide range of price and performance but which are all inter-operable within a system. The standard will allow for simple devices with relatively low data sampling rates and moderate time correlation requirements to be designed and built. At the other end of the spectrum will be devices that have bandwidth requirements to several hundred kilohertz and time correlation requirements in the range of nanoseconds. It is expected that devices from either end of the spectrum will be able to peacefully coexist on the same bus. Figure 1 is a representation of what is expected in the physical realm. As shown in the diagram a single transmission line will be used to supply power to the transducers and to provide the communications between the bus controller and the Transducer Bus Interface Modules (TBIM). A bus is expected to have one bus controller and many TBIMs. The bus controller may reside in a Network Capable Application Processor (NCAP) when the system requires a network with many TBIMs. A bus controller may reside in a host computer or data recorder as well. A Transducer Bus Interface Module (TBIM) may contain from one to many different transducers.

There are a number of functions that will need to be accomplished over the transducer bus. Table 2 is a list of the major functions that will need to be performed. These functions are required by both the very large, complex systems and by the very simple systems consisting of just a few transducers. The IEEE P1451.3 working group is preparing a standard that will allow systems from the very simple to large complex systems to be built using the same interfaces. In order to accomplish this, five different communications channels have been defined. Each communications channel will have a different center frequency and bandwidth. Each of the five communications channels are listed in Table 1 along with a brief description of its expected function. The communications channels will share the medium with the power required to operate the transducers. For high power transducers the power that can be applied over the communications cable may be inadequate so it will be acceptable to power the transducers with a separate power supply.

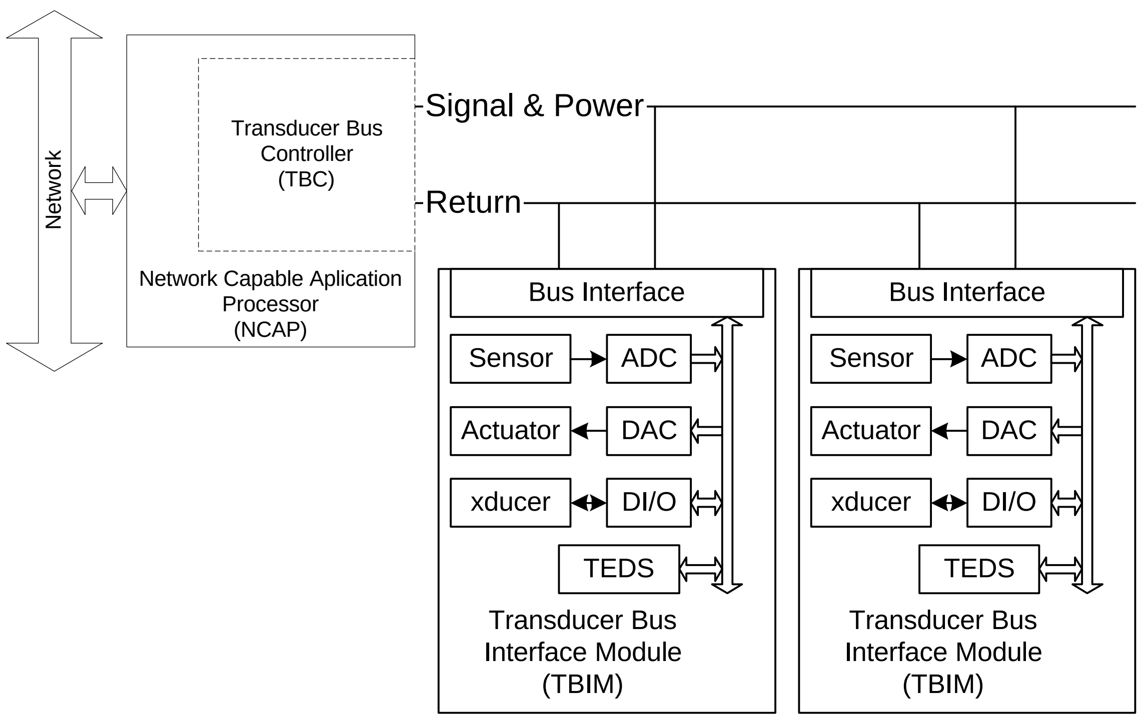

Figure 1 Physical representation of the IEEE P1451.3

The combinations of different communications channels creates a large number of possible systems configurations. This makes it difficult for the manufacturers of Bus Controllers to know how many of what features should be included. In an attempt to mitigate this problem the standard defines five levels of complexity which are referred to in the standard as Tiers 0 through 4. As shown in Figure 2 the simplest systems, Tier 0 systems, will have only one communications channel, the Bus Management Communications channel. The Bus Management Communications channel is used to establish the basic bus communications that will allow the bus controller to determine the capabilities of the TBIM and configure the other communications channels within the TBIM. The Bus Communications channel will be at a fixed frequency, or at least one of a small set of frequencies, that every bus controller will be able to use. For these simple systems all Communications functions will share the same communications channel. They have the least bandwidth available for the transmission of data and that bandwidth must be shared among all TBIMs on the bus. This makes for the simplest and lowest cost TBIMs and bus controllers.

The most complex systems, Tier 4 systems, are represented in Figure 3. In this figure the maximum capability is achieved by using all of the communications channels. In this diagram both the Bus Management and TBIM communications channels are available for setting up the system. The initial discovery of the TBIMs on the bus and the setup of the communications channels are performed using the Bus Management communications channel. The set up of the transducers is then accomplished using the higher bandwidth available over the TBIM communications channel. Operational commands and status reads can also be performed using the TBIM communications channel. Multiple data transfer communications channels are provided to accommodate a high data bandwidth or large numbers of transducers. Clock synchronization is achieved among all of the devices using a dedicated Synchronization communications channel and triggers are supported using a dedicated Trigger communications channel. If there are some transducers in this system which do not need the high data bandwidth or do not support all of the communications channels they can be triggered and read or written using the TBIM or Bus Management communications channels.

Systems with levels of complexity between these two extremes are also allowed in the standard. In addition the ability to mix devices with the various levels of complexity in the same system is required. For example a Tier 4 capable TBIM could be operated in a system with a Tier-0 bus controller. The system will not be able to take advantage of all of the capabilities of the TBIM but it will work. In a similar condition a Tier 0 TBIM can be used in a system with a Tier-3 bus controller. All communications with this TBIM must be handled over the Bus Management communications channel and will be slower but it will work. One reason for this mix of capabilities

Table 1 Bus Communications Channels

Function	Description
Bus Management	This bi-directional communications channel provides all of the capabilities required for a system to be able to identify the TBIMs on the transducer bus, determine their capabilities, set them up and operate them. It communicates at a frequency(s) defined in the standard and must be in all TBIMs. It operates in a command/response mode and has a relatively low bandwidth.
TBIM	The TBIM Communications channel is also bi-directional and provides most of the capabilities of the bus management communications channel but at a frequency(s) that can be defined by the system. It has a higher bandwidth. It cannot perform the discovery function or the initial bus setup (see Table 2).
Data Transfer	This uni-directional communications channel is used to transfer data from the TBIMs to the bus controller or from the bus controller to the TBIMs. There may be many of these in a system operating at different center frequencies. They can be used for high bandwidth data transfers or they can be shared by many transducers by using Code Division/Multiple Access (CDMA) techniques.
Synchronization	This function will be performed by supplying a sine wave clock at a relatively high amplitude over the wires. The frequency of this clock will be defined in the standard once the physical layer is fully defined and will probably be in the 10 to 100 MHz range.
Triggers	Triggers are a special form of a command from the bus controller to the TBIM that either commands a TBIM to take some action or enables it to take some action at a future time. For the most complex systems triggers may be applied over this separate communications to guarantee timing.

is to allow control functions and even diagnostics to be performed without impacting the data being transmitted over the other communications channels.

Table 2—Functions performed in a TBIM

Function	Comments
Discovery	Discovery is the process by which that the TBC can learn what devices are installed on a particular bus.
Bus Set Up	Bus set up involves reading the Transducer Electronic Data Sheets (TEDS) and any other required control structures from the TBIMs and using that information to configure the interface to the bus.
Transducer Set Up	Transducer set up involves reading the TEDS and any other required control structures from the TBIMs and using that information to configure each transducer on the TBIM as required for the system.
Control	Control functions involve the control commands that are required to control the operation of the TBIM while the system is being set up or when it is running.
Status	Each TBIM has a status register or registers that are used to inform the TBC of the condition or state of the TBIM. These registers can be read over the bus.
Service Request	A service request is much like a computer interrupt. As such it allows a TBIM to inform the TBC that something has changed within the TBIM. The main difference between an interrupt and a service request is that there is no guaranteed response time between when a service request is invoked and when the system gets around to servicing it.
Data Reads and Writes	The transmission of data between the TBIMs and the TBC is the primary purpose of this standard. There are several ways that these functions can be performed in the standard depending upon which communications channels are available and being used.
Triggers	A trigger is a specialized command that is used to cause a TBIM to take a specific action. For example a trigger might cause a sensor to take 1000 samples of an input and transfer the data to the TBC.
Synchronization	The synchronization function is used to synchronize the clocks in the TBIMs with the clock in the TBC.
Memory Downloads	It will be necessary at times to load the contents of the memory in a device. These facilities may or may not be available to the user since they are mainly intended for use when manufacturing the TBIMS but they may be desirable when upgrading devices in the field.

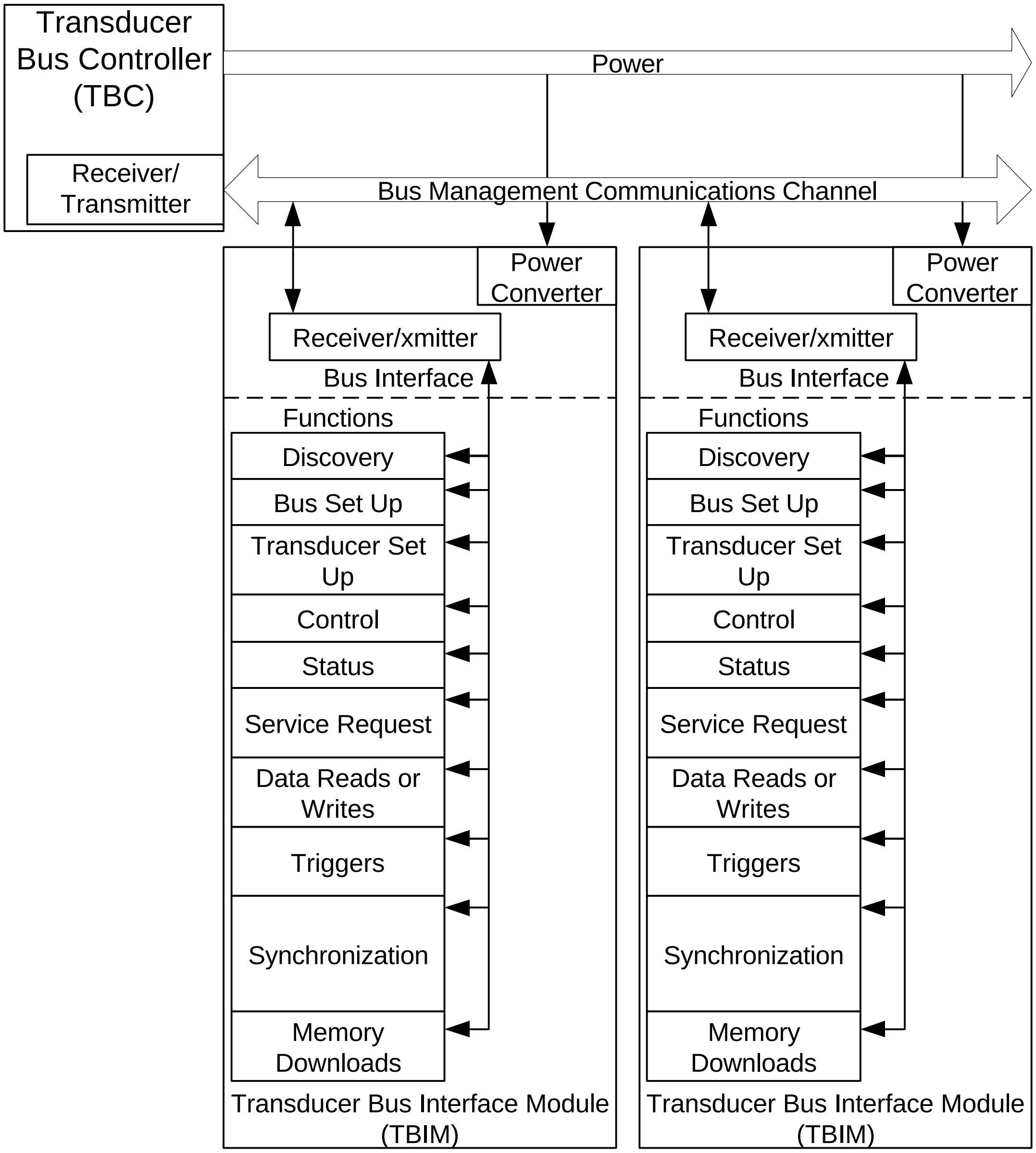

Figure 2 Simple System

IMPLEMENTATION OF THE COMMUNICATIONS CHANNELS

There are several techniques that will be used to implement the various communications channels. The most basic of these techniques is frequency division multiplexing. This means that each communications channel will be operated at a different center frequency. For example the Bus Management communications will operate at one of a small set of possible frequencies. A narrow bandwidth will be provided for this channel since it is primarily used to initiate the setup of the system. The TBIM communications channel will be assigned a different center frequency and a wider bandwidth to allow higher speed communications. The center frequency for this communications channel can be programmed into the TBIM by the bus controller over some range of frequencies. The TBIM Communications channel is expected to be time-shared using a command-response protocol with the bus controller providing the control function. The Data Transfer Communications function may be operated in several different ways. One way is to time-share this channel, with the trigger acting as the command and the response coming on a separate frequency channel. Another way is to assign a different center frequency to each TBIM and to allow the TBIM to control access to the data channel. This would be most useful for sensors. For actuators the bus controller would need to control the channel. Another mechanism is to use spread-spectrum techniques to allow several TBIMs to share one center frequency with different spreading codes assigned to each TBIM. In fact all of these techniques are expected to be used at different tiers in the system. The actual techniques required in a given system will depend upon the total system bandwidth and the number of transducers required. The advantage of using the radio frequency communications techniques over a wired communications path is that power can be supplied over the same medium. The amount of power that can be supplied over a given set of wires will depend on how the system is implemented. The standard specifies that DC power shall be supplied to the TBIM. However with the use of a coupler which contains an AC to DC converter, AC power can be supplied over the transducer bus. This technique is useful when large amounts of power are required or the bus is very long.

WIRELESS TECHNIQUES

Wireless techniques are not being included in the standard at this time for several reasons. The major reason being that while wireless techniques are great for many applications, systems with many transducers that must remain in place for long periods of time the ability to provide power over the communications medium is an overriding need for this standard. However, many on the working group have a desire to move to wireless for some applications in the future and some are working on them now. The group is considering wireless when decisions are made with the intention that the standard can be expanded to include wireless capability or a new standard can be derived from this one with minimum changes in the future.

TRANSDUCER BUS INTERFACE MODULES

TBIM and Transducer Identification

Each TBIM must be identified and set up by the bus controller before it is able to function in the system. To identify the TBIM the manufacturer assigns each TBIM a unique identifier called the Universal Unique Identifier or UUID. This identifier is a pattern of eighty bits that are defined using the algorithm defined in IEEE 1451.2 to guarantee uniqueness. A procedure is defined in the standard to allow the bus controller to identify the UUID of each device on the bus over the Bus Management communications channel. The identification of the TBIM allows the bus controller to determine the communications capabilities of the TBIM and to set them up. It also identifies the number of transducers in the TBIM and can assign them a transducer identifier. At this point it is possible to switch the communications to the TBIM communications channel which operates at a higher speed than the Bus Management communications channel. The transducer identifier is then used in all subsequent communications with that transducer. Once the assignment of a transducer identifier is accomplished the bus controller can then read the Transducer Electronic Data Sheets (TEDS) to determine the nature and characteristics of each transducer. If it is determined that the system does not need a particular transducer then that transducer can be assigned a transducer identifier of zero and the transducer will not respond again until a different transducer identifier is assigned.

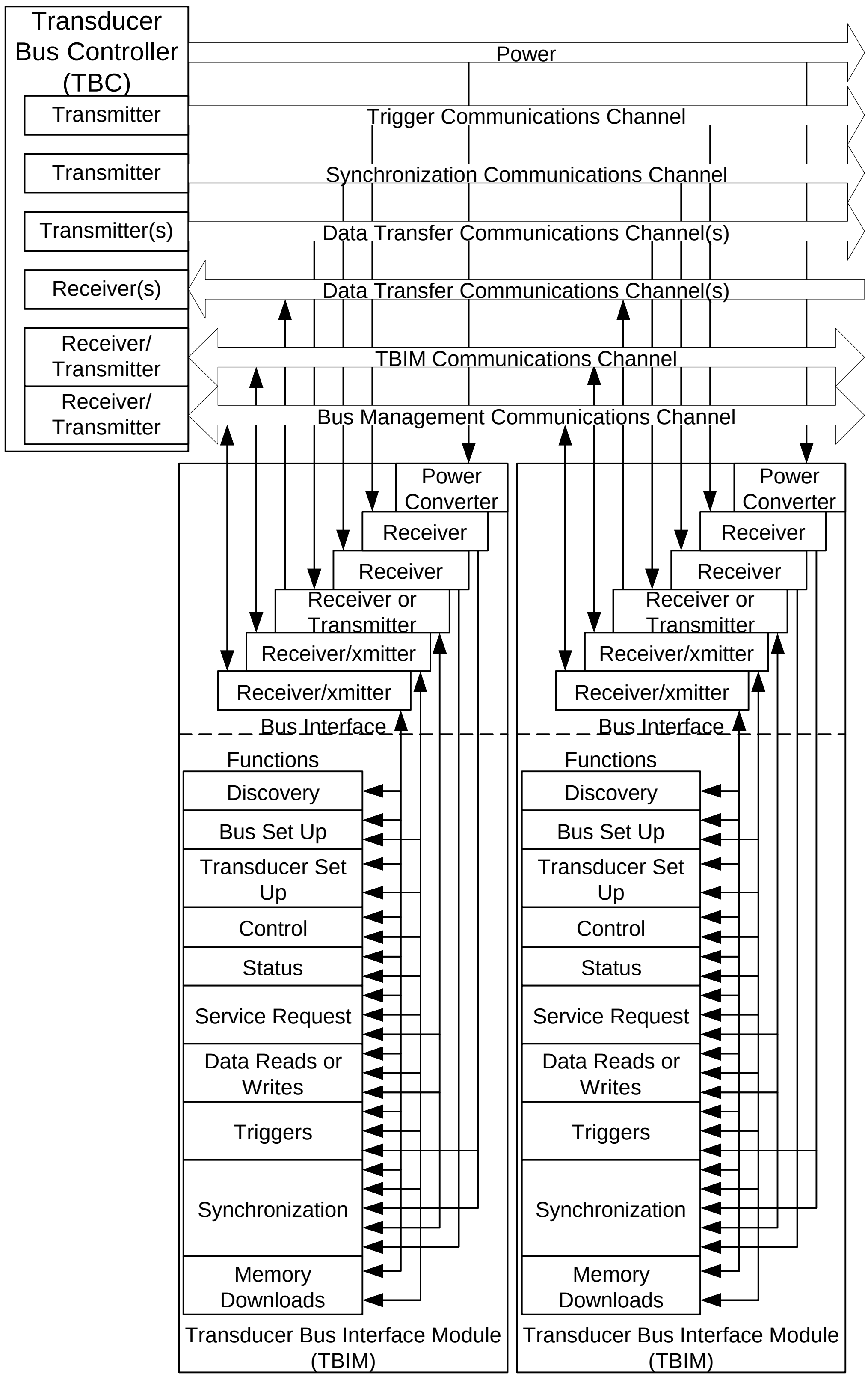

Figure 3 Complex System

Transducer Electronic Data Sheets

There are several Transducer Electronic Data Sheets (TEDS) which are defined for this standard. They can be classified in many ways. Some are machine-readable and are used to allow the bus controller to determine the characteristics of the device and others are text based and are used to give a human operator an understanding of the device. Three of the machine readable TEDS are required for system operation and all of the remaining TEDS are optional. For systems where small size or extreme operating environments do not allow the TEDS to be stored in the TBIM, a procedure is provided to allow the TEDS to be stored on a remote server. A remote TEDS is known in the standard as a “virtual” TEDS.

Required TEDS - There are three TEDS that are required for operation of the system. The Communications TEDS will describe to the system the communications capabilities of the TBIM. This will include such things as which communications channels are implemented and the range of operating frequencies. It will also define whether or not the TBIM has CDMA capabilities. The Module Meta-TEDS defines the characteristics of the TBIM as a whole. There is one Module Meta-TEDS for each TBIM. The Transducer Specific TEDS then describe the characteristics of each individual transducer. There is one Transducer Specific TEDS for each transducer in the TBIM. In general these TEDS will be small containing only a few hundred bytes. However, the memory requirements for the TBIM will vary depending on the number of transducers in the TBIM.

Optional TEDS - There are several optional TEDS under consideration by the working group. All of the TEDS allowed in IEEE 1451.2 will probably be included. The optional TEDS which is expected to be utilized the most often is the Calibration TEDS. This TEDS provides the constants necessary to convert the raw data into an engineering units form for sensors or to convert data from engineering units form to the form required by an actuator. Several other TEDS types are being considered. A Transfer Function TEDS can be used to describe the characteristics of a transducer in response to varying input frequencies. A Digital Filter TEDS can be used to define the coefficients needed to set up a digital filter to obtain a desired frequency response. A Control Commands TEDS may be used to determine the allowable commands and the acceptable arguments for those commands. This type will be useful when setting up the electronics associated with a transducer.

TRANSDUCERS

There are four general classes of transducers and various attributes that can be applied to each of them. In addition, transducers may be classified as virtual if they are used to sense or control some condition within a TBIM that does not directly impact the outside world. Virtual transducers and control commands may perform similar functions. The choice of which to use in a given TBIM is up to the TBIM manufacturer. The main difference between the two is that virtual transducers may have TEDS associated with them that allow the system operator to deal in engineering units without a detailed knowledge of the bit patterns required to obtain the desired results. The following paragraphs describe each of the different classes of transducers.

Sensors - A sensor measures some physical parameter on demand and returns digital data representing that parameter. On the receipt of a trigger, the sensor starts the collection and storing of a data set within the TBIM. The data set may contain one or many samples of the parameter. The timing of the individual samples in the data set is controlled by the TBIM and is a function of the operating mode of the sensor. A sensor responds to a read command by returning the appropriate data set. If a new data set is not available, the transducer repeats the same data that was returned on the previous read command with a flag that indicates that the data was previously read.

Event sensor - An event sensor is used to determine that a specific event has happened and the time when the event occurred. The time may be determined and returned by the TBIM or may be determined by the TBC when the event is received. A trigger arms an event sensor to detect the occurrence of an event. The event may be a digital signal transition or an analog signal crossing a setpoint. An event sensor may be configured to signal an event on high-to-low transitions or low-to-high transitions, or both. The present state of an event sensor may be determined by reading the status.

Virtual actuators and sensors within a TBIM may be associated with an event sensor to allow changing analog setpoints, hysteresis, or reading the value being sensed. This association is communicated to the TBC through the grouping information in the Module Meta-TEDS.

Actuator - An actuator causes a physical or virtual output action to occur that is related to the data set sent to the actuator. The actuator output changes state to match the appropriate data set when a trigger occurs. The timing of the data output process is under the control of the TBIM if there is more than one data point in a set.

An actuator may be built which does not require a data set be written to it before it performs an action. This type of device always uses a default data set or no data at all and performs a predefined action upon the receipt of a trigger.

General Transducer - The General Transducer is any transducer that does not meet the timing requirements for one of the other three transducer types. The standard will allow for the General Transducer type but it is not expected to be "Plug and Play." Special software will be required to use it.

TRANSDUCER ATTRIBUTES

The following paragraphs define the operating characteristics that are common to all transducer types. Each attribute describes a particular mode of operation for a transducer. Some of these attributes are mutually exclusive and others can be enabled at the same time.

SAMPLING ATTRIBUTES

The sampling attributes determine the relationship between the trigger and the sampling of the data by a sensor or the application of a sample to the output of an actuator.

Trigger initiated attribute - A transducer with this attribute active begins acquiring or outputting a data set immediately upon receipt of a trigger. The timing of the remaining samples in the data set is under the control of the TBIM. If a trigger acknowledge is required it will be sent as soon as the first sample is processed. A typical example of this type of device would be a sensor that uses a sample-and-hold (S/H) circuit followed by a successive approximation or flash type A/D converter. When the trigger is received, the S/H would be pulsed to store a sample of the data. At this time the trigger acknowledge would be sent to the TBC. The A/D would then convert the data to a digital form and store it in the data set memory in the TBIM. After an interval specified in the Transducer Specific TEDS, the process of sampling, converting and storing a second sample would occur. This process continues until all samples required for the data set are available. At this time the sampling stops until another trigger is received.

Free running attribute - A sensor with this attribute active shall measure some physical parameter autonomously and continuously when enabled. The data being acquired and converted is discarded until a trigger is received. Once a trigger has been received the next sample converted is stored in the TBIM as the first word in the data set. Consecutive samples are stored in the TBIM until the entire data set is completed. At this point the transducer returns to discarding samples until the next trigger is received.

An actuator with this attribute active shall apply the previous data set in accordance with its End of Data Set Operation attribute. As a new data set is received from the transducer bus it will be held in the TBIM until a trigger is received and applied to the output at the appropriate time.

BUFFERED ATTRIBUTE

A transducer with this attribute active has multiple buffers to store multiple data sets. One buffer is being read from a sensor or applied to an actuator output while other buffers are available to be filled. A characteristic of a transducer with this attribute active is that the data available to be read or applied is always the data that was available in a buffer before the most recent trigger.

END OF DATA SET OPERATION ATTRIBUTES

These attributes determine the action that an actuator will take when it reaches the end of a data set. These attributes describe ways to allow actuators to smoothly transition from one data set to another. While this is desirable in most cases, there will be instances when a rapid transition to another condition is required i.e. emergency shutdown. For these cases, a second actuator transducer in the same TBIM may be used which executes the transition to the new condition or control commands may be used.

Hold attribute - This attribute is applied actuators. An actuator with this attribute active will apply all of the samples in a data set and then continue to apply the last word in the data set until a new trigger is received.

Recirculate attribute - This attribute is only used with actuators. An actuator with this attribute active applies all of the samples in a data set to the output, then returns to the beginning of the data set and repeats the application of the same data set. It will keep repeating this operation until another trigger is received. When returning to the beginning of a data set or to a new data set the appropriate sample interval must be maintained.

STREAMING ATTRIBUTE

A transducer with this attribute active begins to acquire data or to apply data when the initial trigger is received. Subsequent data samples are processed without waiting for a trigger. Since there are limited mechanisms for collision detection on the transducer bus, any TBIM with one or more sensors operating in the streaming mode must be able to support a dedicated data communications channel.

After the first trigger a sensor transmits a new data set as soon as it is acquired. This requires a dedicated data communications channel be available to the TBIM. Multiple sensors within a single TBIM may share this data channel but sensors in another TBIM shall not use it.

An actuator with the streaming attribute active applies the data written to it at the appropriate time after it has been received. An actuator with the buffers attribute active immediately switches to the next buffer after applying all of the data in the current buffer.

HELPING THE WORKING GROUP.

There are two ways that the working group could use your help. One would be by becoming a member of the working group and volunteering your expertise to the preparation of the standard. The other would be by becoming a balloter. Balloters review the standard when the working group believes that it is ready for submission and vote to either accept or reject the standard. All votes are accompanied by comments that will be used to make the standard more useful once it is finally approved. To help out in either of these two ways, please send an e-mail message to the following address: larry.a.malchodi@boeing.com.

If you would like to review some of the documentation that the working group has developed to date it can be accessed at the following web site: http://www.ic.ornl.gov/p1451/