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WHITE PAPER

What IEEE 1588 Means for Your Next T&M System Design

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Timing and synchronization are crucial in building test and measurement (T&M) systems, which makes the IEEE 1588 Precision Time Protocol's ease of use and high performance especially attractive to system designers. This white paper offers an overview of the benefits IEEE 1588 brings to T&M systems, especially when paired with LXI Class B instrument capabilities, and illustrates how these capabilities can be integrated into instruments that can serve as powerful building blocks for creating high performance test systems.

IEEE 1588 Overview

IEEE 1588 specifies a Precision Time Protocol (PTP) that may be used to synchronize clocks in a T&M system. When a T&M system implements PTP, each instrument, computer, or other controller in the system contains a clock. PTP allows synchronizing all these clocks and keeping them synchronized. PTP requires data communications between all devices; in T&M systems, this is typically implemented using Ethernet LAN. Other time synchronization methods have been used in T&M applications, including Network Time Protocol (NTP), Global Positioning Satellite (GPS) based systems, and hard-wired distribution of reference oscillator signals. However, when compared with these alternatives, IEEE 1588-based systems provide more precise and accurate synchronization while offering the benefits of standard Ethernet LAN networking connections. Also, there are signs that IEEE 1588 will become widely used outside the T&M industry, leading to wider availability and lower costs for IEEE 1588 systems based on greater economies of scale.

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LXI Instruments and IEEE 1588

LXI Overview

The LXI (LAN eXtensions for Instrumentation) Consortium is made up of members from most major T&M companies. Since its formation several years ago, the Consortium has developed and released standards for the use of Ethernet networking in instrumentation. The Consortium has recognized the potential of the IEEE 1588 protocol, so the LXI Standard requires that support for it be included in several classes of LXI instruments. Additional information on the LXI Consortium is available at www.lxistandard.org.

LXI Classes

The LXI Standard defines three classes of devices. The baseline class, Class C, defines a consistent LAN implementation, and a Web browser interface for setup, control and data access; it also requires an IVI instrument driver for a programmatic interface. Class B builds on Class C by requiring a common sense of time using IEEE 1588 and peer-to-peer LAN messaging. Class A builds on both Classes C and B by adding a high performance, hard-wired trigger bus for applications with stringent timing requirements. Although this white paper refers specifically to LXI Class B, LXI Class A devices also incorporate all Class B capabilities.

LXI Class B Details

The IEEE 1588 specification includes provisions for configuring many aspects of PTP to suit a wide variety of applications. It was intentionally designed to be flexible and to meet the needs of many industries, not just T&M. Furthermore, this specification only standardizes how the timing functions work, not how they are used in any given application nor what meaning is given to the timestamps they provide. Although this flexibility is helpful in fostering wider adoption of IEEE 1588 in multiple industries, it can be a barrier to interoperability and ease of use in specific industries. Therefore, the LXI Class B specification provides additional direction for the configuration and use of IEEE 1588. These additional specifications were chosen to tailor and optimize IEEE 1588's operation and use in T&M systems, ensuring compatibility and interoperability between all LXI Class B and A instruments.

The LXI Class B specification defines:

- A standard implementation of IEEE 1588, including tailoring for T&M applications
- A standard meaning for the timestamps provided by IEEE 1588
- A standard peer-to-peer LAN messaging protocol incorporating timestamps
- A standard configuration mechanism for connecting events, triggers, and actions
- A standard logging mechanism for recording important events with timestamps

Benefits of IEEE 1588 and LXI Class B for T&M System Design

Many (if not most) T&M systems can benefit from a precise sense of time common to all system components. The variety of T&M instruments and their applications is very broad and so is their need for precision clock synchronization. The particular capabilities needed and the degree of precision required vary from one instrument or application to the next, but the following examples illustrate a broad cross-section of test system needs.

Measurement Data Time Stamping

Time stamping measurement data (that is, associating a time with each data point) is widely used in T&M applications. For example, time stamps are useful for maintaining quality control and satisfying regulatory requirements. However, they are only useful for such purposes if their accuracy and precision are known and reliable. Through the use of the IEEE 1588 PTP protocol, LXI Class B instruments can be synchronized to a single time source of sufficient quality to meet the application's requirements, eliminating the problems caused by out-of-sync clocks, as well as the labor, inaccuracy, and risk of error associated with manually synchronizing clocks in multiple instruments and controllers.

When all the instruments in a T&M system share a common sense of time, data from multiple instruments can be reliably correlated after the fact simply by comparing and sequencing time stamps. There's no need to check that data is transferred from the instruments quickly and in the correct sequence because the time stamps can be used to put the data in the proper sequence when necessary.

System troubleshooting is a particularly useful application of this correlation capability. Many modern instruments can record important events, such as measurement triggers and error conditions, and these events can be time stamped like any other data. By collecting and correlating these event records using the time stamps, the exact sequence of events can be reconstructed, even when multiple instruments are involved, for verifying correct system operation and tracking down the source of any problems that occur.

Synchronizing Measurement Triggers

Time stamping data isn't the only use of synchronized clocks. LXI Class B instruments allow users to initiate measurements or other actions, such as sourcing a voltage, at a specific time. Used in this way, these IEEE 1588 capabilities allow coordinating the test system's operation without the need for hard-wired trigger cables or precise timing of commands sent from a central controller. LXI Class B instruments can also synchronize actions using peer-to-peer LAN messages. A message sent from one LXI device to another can trigger an action either immediately upon receipt (analogous to a hard-wired trigger cable) or at a future time. These synchronization capabilities are particularly valuable when the components of the system are so widely separated that it's impractical to connect them with physical trigger cables.

Reducing or Avoiding System Latency Effects

One potential drawback of using LAN to interconnect T&M systems is the variability in latency and timing of LAN when compared with other communications busses. Although this is not an issue in many applications, systems with stringent timing requirements must account for LAN timing characteristics. Using time to coordinate and synchronize triggers and actions eliminates this consideration in most applications.

LXI Class B instruments can achieve better real-time trigger performance than hard-wired trigger systems by compensating for internal latencies. For example, if an instrument requires 10 milliseconds to prepare to take a measurement, then the measurement taken with that instrument will always lag behind the actual trigger by 10 milliseconds. Using time-based triggers, however, allows the instrument to compensate by starting the preparation 10 milliseconds before the time specified for the trigger, so the measurement will occur precisely at the trigger time, not 10 milliseconds later.

System Design Considerations

An LXI Class B system consists of a set of LXI devices, which can be instruments, controllers, or other components. Each contains an IEEE 1588 clock and all are interconnected via an Ethernet network. When the system is first powered on, a best master clock algorithm runs on all the devices and the highest quality clock in the system becomes the Grand Master clock. All the other clocks then synchronize themselves with the Grand Master clock. If a device is added or removed from the system, the best master clock algorithm will run again if necessary to identify a new Grand Master clock.

Slave clocks synchronize with the master by exchanging special Ethernet messages with it that contain time stamps. The PTP algorithms use these time stamps to adjust the slave clocks gradually until they are synchronized with the master. It may take several minutes for all the clocks to become synchronized. The master and slaves then continue to exchange periodic messages to keep themselves synchronized.

Performance Considerations

There are many possible performance measures for an IEEE 1588-based test system. The application will typically determine which measures are most important for a specific system, but two are broadly useful. The first is the accuracy of the master clock—how closely it represents “correct” time. This is mostly outside the scope of IEEE 1588, being determined primarily by the quality of the Grand Master clock and the method used to set it and maintain correct time. High quality master clocks that use the Global Positioning Satellite (GPS) network to obtain and maintain correct time are widely available.

A second useful general measure of IEEE 1588 system performance is synchronization accuracy—how closely the slave clocks synchronize and stay synchronized with the master clock. Several factors contribute to this measure, including the PTP algorithms themselves, the Ethernet network configuration and design, and the design of the slave clocks and the instruments containing them.

Other useful performance measures reflect the interface between the IEEE 1588 logic and the rest of the instrument. For example, consider an instrument that has been configured to output a voltage at a certain time. When the IEEE 1588 clock reaches that time, logic will detect it and trigger the instrument to output the voltage value. Due to internal processing, etc., there will invariably be a delay between the time the clock reaches the target value and the appearance of the output voltage. This delay is a useful measure of the interface latency.

A basic understanding of what goes into an IEEE 1588 instrument can be helpful in choosing instrumentation for a specific T&M system design. ***Figure 1*** illustrates the components typically involved in implementing IEEE 1588 in an instrument:

- IEEE 1588 Clock—This is where the local time value is maintained.
- IEEE 1588 Clock Control—This block, in conjunction with the PTP code and packet processing blocks, adjusts the clock to obtain/maintain synchronization.
- IEEE 1588 Packet Processing—This block detects the special IEEE 1588 packets on the network and performs necessary processing.
- PTP Stack—This implements the overall PTP control using the other blocks as needed.
- Instrument Interface—This block provides time-related services to the rest of the instrument, such as time-based triggers, timestamp values, etc.

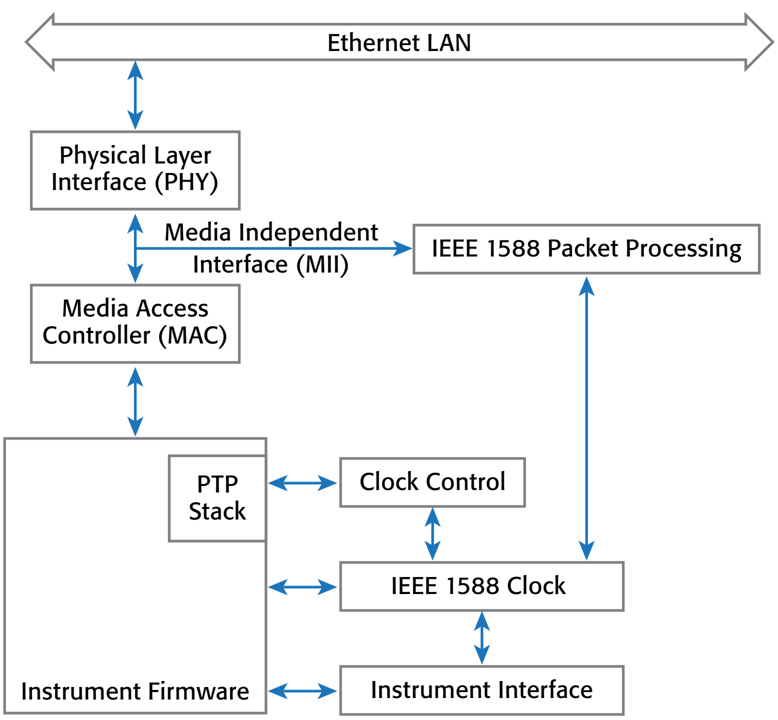

Figure 1.

Deciding which of these blocks to implement in hardware and which to implement in firmware is crucial to providing test system builders with an instrument with the desired timing system performance. The IEEE Clock, Clock Control, and Packet Processing blocks have a significant impact on synchronization accuracy, so for all but the least demanding T&M applications, look for instruments that implement these blocks in dedicated hardware or in FPGA logic. Commercial microprocessors and PHY chips are available with dedicated, built-in IEEE 1588 hardware support. There are performance advantages to having the logic as electrically close to the Ethernet as possible, so choosing an instrument with a PHY chip with IEEE 1588 logic is recommended for demanding applications.

The IEEE 1588 Clock block is often implemented as counter chain driven by a precision oscillator. The oscillator stability becomes an important factor affecting synchronization accuracy in demanding applications. A stable oscillator keeps the clock accurate during the intervals between updates from the master clock.

The Instrument Interface block does not affect synchronization accuracy, but it does impact time stamping accuracy and time-based trigger accuracy. If this block is implemented in firmware, normal firmware processing delays and overhead can degrade the accuracy of measurement time stamps and the delays between time-based triggers and action. For critical applications, choose an instrument in which this block is implemented in hardware.

User Interface Considerations

Timing has always been an important consideration for test system designers and programmers, but most are not accustomed to dealing with time in the direct way that IEEE 1588 allows. One simple but effective approach is to treat time-based triggers the same as any other trigger source, such that any action that can be triggered by a command sent over via Ethernet or by a hard-wired trigger cable can also be triggered at a given time or in response to a LAN trigger message. Similarly, any internal function that can generate a trigger output, such as measurement complete or output settled, should also be able to generate an appropriate LAN message.

A more advanced approach allows the test system integrator to program a test system simply by drawing a timing diagram, which is then converted by software into a series of time-based actions sent to the appropriate instruments. Such an approach uses the time values on the diagram directly, without the need to convert them into delay values or to compensate for communications or controller processing time and latencies.

IEEE 1588-Based Instruments as T&M System Building Blocks

Keithley's Model 3706A System Switch/Multimeter offers a good example of how a commercial test instrument with IEEE 1588/LXI Class B capabilities can serve as a useful and cost-effective building block when constructing a T&M system. A little background may be helpful in understanding the advantages instruments of this type offer the test system builder.

For many test and measurement applications, using a PC as a controller for communicating to separate instruments or using slot-based systems with integral controllers is perfectly adequate. For other situations, however, those approaches are either overkill—and therefore overly expensive—or not quite up to the task. These applications benefit from the additional capabilities and flexibility that script-based instruments like the Model 3706A can offer. With script-based instruments, small test systems with a few instruments can be built without a separate controller; one of the instruments acts as the controller and coordinates the operation of the other instruments. Large systems can be divided into subsystems of a few instruments each, with each subsystem coordinated by a script-based instrument. This simplifies system design and can help improve performance. With LXI script-based instruments, such subsystems can be widely physically separated, such as in assembly lines, scientific applications, or RF testing applications.

Keithley's embedded Test Script Processor (TSP®), an on-board microprocessor that can store and execute short programs (scripts) on the instrument itself, makes the Model 3706A capable of performing tests independent of a separate controller. By making it unnecessary to transfer instructions and results back and forth from instrument to controller constantly, this processor allows for significantly higher overall T&M system performance by eliminating controller and communications latencies.

TSP also provides for a general purpose scripting language with computation and program flow control capabilities extended with Instrument Control Library (ICL) commands for executing instrument functions. ICL commands can be sent individually to the instrument from a controller or multiple commands can be grouped into a script that can be executed by a single command sent remotely or from the front panel. Test scripts can be created using the built-in Web-based editor or by using the Test Script Builder (TSB) Integrated Development Environment (IDE).

The Model 3706A's combination of switch mainframe and multimeter offers many of the functions system builders need most often in system design. It contains six slots for plug-in switch cards in a compact enclosure that easily accommodates the needs of medium-to-high-channel-count applications. A fully loaded mainframe can support up to 576 two-wire multiplexer channels for unrivaled density and economical per-channel costs. The inclusion of the multimeter makes it a tightly integrated switch and measurement system that meets the demanding application requirements of a functional test system and also provides the flexibility needed in stand-alone data acquisition and measurement applications.

The capabilities provided in IEEE 1588-2002 and the LXI Class B specification are fully integrated into the Model 3706A. Measurements made with the integrated 7½-digit multimeter can be time-stamped using the IEEE 1588 clock. LXI Class B LAN trigger messages and IEEE 1588 time-based triggers are treated like any other trigger event. The Model 3706A has a flexible event system that allows a TSP script to run in response to a trigger. The script can perform any desired combination of instrument functions in response to the trigger. Because scripts can also send LXI Class B LAN messages, this means any instrument event can trigger a LAN message to trigger or control other LXI Class B instruments.

The Model 3706A includes the standard LXI Class B Web pages for configuring networking and IEEE 1588 functions, as well as Web pages for instrument control and script editing. LXI Class B event logging is also provided.

Conclusion

IEEE 1588 adds valuable capabilities to T&M equipment. Combining IEEE 1588 and LXI Class B with the programmability of an intelligent instrument such as the Model 3706A creates an invaluable test system building block with industry-leading power and ease of use.

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