

Distributed Test System based on LXI Bus

Zhong Li^a, Jiulong Xiong^b, Xiangbin Ye^c

College of Intelligence Science and Engineering National University of Defense Technology
Changsha, China

^a1505237407@qq.com, ^b13787202019@139.com, ^c13873181055@163.com

Abstract. LXI is a new modularization instruments platform standard for automation test system based on Ethernet LAN after GPIB, VXI, PXI instrumentation bus. A type of LXI Distributed test system architecture was given out based on the development of instrumentation bus, LXI bus system structure and main characteristics, then compared and analyzed Drive command triggering, Network news triggering, IEEE-1588 clock synchronization triggering and the LXI triggering bus four kinds of different synchronization test strategies, the appropriate choice may carry on according to the triggering accuracy requirements, test object far and near, the dispersion degree. Finally, the reliability of the system is further analyzed through the application examples of the system.

Keywords: LXI, Bus, Distributed test system, System structure, IEEE1588, Synchronization.

1. Introduction

The instrument bus is a communication and control method for connecting test systems of different instrument modules. Since the 1970s, with the application of computer technology in the field of test instruments, the first-generation test instrument bus GPIB appeared. At present, the instrument bus has experienced the development process from GPIB to VXI and PXI. The GPIB bus instrument has advantages in measuring frequency range, accuracy and functions, but the instrument is large in size and weight, and the data transmission speed is slow. The communication rate of 1 Mbyte/s is far from meeting the current test requirements, and it needs to be used. GPIB cards and cables for program control are costly. VXI systems have a small size and weight, a large number of channels, wide functional coverage and flexible configuration, but VXI systems must use VXI chassis, zero slot controller and 1394- PCI interface card can realize program control, and the cost of building the system is relatively high, mainly used in aerospace and other fields. Although the PXI instrument is smaller, lighter, and less expensive than the VXI instrument, the PXI bus instrument has limited functional coverage, and the instrument variety is far less than that of the VXI instrument. The channel number and electromagnetic compatibility are worse than VXI. A wide range of applications for PXI bus instruments. The common problem faced by current test systems is that the distance between the test equipment and the measured object is limited, and the distance cannot be too far. If the two measured objects are far apart, it is difficult to integrate them into a test system.

Whether it is a GPIB instrument or a VXI or PXI instrument, a dedicated cable, chassis or controller is required to build a test system, which cannot keep pace with the development of computer hardware and software technology. The dilemma of instrument bus development and the continuous development of network technology make the use of the network as a new method of connecting instruments has become a common concern of the test community. The new generation of instrument bus based on LAN: LAN Extensions for Instrumentation (LAN in the field of instruments Extension, referred to as LXI) came into being [1].

In September 2004, Agilent and VXI Technologies jointly launched the LAN-based instrument bus LXI. It is based on industry-standard Ethernet technology and extends the language, commands, protocols, etc. required by the instrument; it combines built-in measurement technology for benchtop instruments, PC standard I/O connectivity, and modularity based on card-based framework systems. The small size and other features make up a new generation of modular instrument platform standards for automated test systems. LXI bus instrument combines the high performance of GPIB instrument, the small size of VXI/PXI instrument and the high throughput of LAN, and considers the timing,

trigger, cooling, electromagnetic compatibility and other instrument requirements. It is a new generation of automatic test system modular architecture platform based on Ethernet [2].

2. The Structure and Characteristics of LXI Bus Test System

2.1 System Structure

In the computer network-based test system, the local area network is the skeleton of the test system. The computer is connected to the test equipment with different interfaces through the LAN router/switch to exchange data and control commands. The test system can include GPIB instruments, VXI, PXI and other plug-in instruments, as well as LXI-based measuring instruments and test modules, as shown in Figure 1. Various LXI units support the open IEEE 8023 and TCP/IP standards, based on Web browsers, IVI-COM drives and standard racks, providing a unified application for users to use [3].

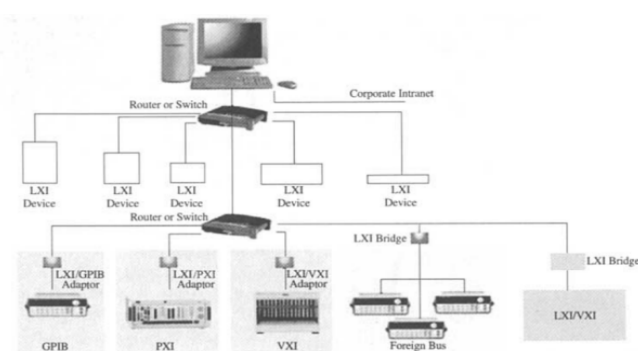


Fig 1. LAN-based Test System

The LXI bus instrument comes with a processor, LAN connection, power supply, and trigger input. Unlike VXI and PXI modules, they require an expensive chassis and cable with power supply, backplane, controller, and MXI card. The signal input and output of the LXI module are completed on the front panel, and the LAN connector and power supply are located on the rear panel. The height of the module is one or two standard rack unit heights, and the width is half rack or full rack width. This design allows the LXI module to be easily mounted on a standard rack, either as a stand-alone instrument or as a modular, it can be easily integrated into other systems.

LXI uses the IVI specification and uses IVI-COM drivers to communicate with other processors or hosts. This simplifies the debugging process of the test system, makes it easy to achieve calibration and fault diagnosis, and makes the interchange between instruments easier. The International LXI Association initially divided LXI-based instruments into the following three levels based on functional differences [4]:

Level C: Basic type. Supports IEEE 802.3 protocol, LAN query function and programming control capability, supports IVI-COM instrument driver, with power, cooling, size, indicator and reset button. Provides standard LAN interface and web browser interface.

Level B: Has all the capabilities of Level C and adds the IEEE-1588 clock synchronization standard. Sub-microsecond synchronization of LXI devices anywhere on the network can be achieved, adding one-to-one and one-to-many LAN messaging modes.

Level A: Has all the capabilities of Levels B and C. It also has hardware fast triggering capability and synthetic instrument operating mode. Its triggering performance is comparable to that of chassis-based instruments. It is similar to VXI's backplane bus and can be reached for adjacent instruments. Timing accuracy of 5 ns/m.

But not all instruments with LAN ports are LXI instruments. The LXI module is built on many industry standards such as IEEE-8023, IVI, and IEEE-1588. To ensure compatibility and interoperability between standards, the LXI standard includes many specialized definitions such as triggering, interrupt handling, mechanical interfaces, addressing, software interfaces, network routing and switching, cooling, EM performance, etc. Simply equipped with a LAN port cannot be achieved.

2.2 System Features

According to LXI standards, standardized small modular instruments are interconnected via an open LAN standard (Ethernet), and all measurements can be controlled and displayed via an Ethernet connection. Operators can even use their own PC for network connection and control. In addition, the LXI standard also supports seamless software exchange between rack-stacked instruments (rack-and-stacks such as GPIB) and LXI modules. Thanks to the continuous development of Ethernet technology, LXI instruments will still occupy a major market share for a long time, so they can also protect their investment.

Compared to traditional card instruments (such as VXI, PXI), LXI modular instruments have the following characteristics [5]:

- Integration is more convenient, no dedicated chassis and zero slot controllers are required.

- Can be operated with a web interface without programming and other virtual panels.

- Connected and used more easily, system programming can be done using general software.

- Easily to achieve calibration and troubleshooting.

- Flexible, can be used alone, and can be modularized to form a powerful complex test system.

- Conducive to retain the use of developed core technology, functional improvements and upgrades are more convenient.

- It can be integrated with older platforms and installed on standard racks.

- It can be distributed anywhere in the world, accessible from anywhere.

When the test project changes, the connection of LXI on the LAN does not have to be changed, which shortens the setup time of the test system.

LXI modules connected to the LAN can work in a time-sharing manner while serving different test projects.

Provide distributed test methods, those powerful, complex, and expensive LXI modules can be shared by multiple test projects, which can fully utilize the features and advantages of each module in the test system, improve module utilization, and reduce test costs.

The LXI platform has a long-life cycle and user investment is guaranteed. Users can get technical support from the development and production department for a long time, and they have to be eliminated without worrying about outdated technology. In addition, because the LXI module itself is equipped with a processor, LAN connection, power supply and trigger input, it does not have to use expensive power supplies, backplanes, controllers and MXI cards and wiring like modular card slots [6].

LXI uses Ethernet technology to introduce peer-to-peer and network management functions, which cannot be achieved with T&M interfaces such as GPIB and MXI [7]. In this way, LXI provides a new automated test system architecture that overcomes the complex and inefficient control of traditional architectures. The LXI standard is widely supported by many instrument manufacturers, covering traditional instruments, modular instruments, and functional module instruments (synthetic instruments or SI), which means that all the testing needs of the user can be met under one architecture including signal source, measurement, radio frequency, power supply. Even if there are strict restrictions on space, there is no need to sacrifice functionality, accuracy and performance.

2.3 Development of LXI Bus Technology

In November 2004, the LXI Alliance was established. The Alliance launched the LXI standard V1.0 in September 2005. Later, in August 2006, July 2007, and September 2008, the LXI standard V1.1, V1.2 and V1.3 were launched. In August 2010, the LXI Alliance updated the standard number, introduced V1.4, and passed the conformance test in May 2011 [8]. In the future, new technical standards will be gradually introduced to improve the LXI standard system. In September 2006, the Chinese LXI consortium was formally established. In the following years, China launched a period of research and development boom in LXI, and the number of papers on LXI reached its peak in 2010. In May 2013, the 2013 International LXI Technology Conference was held in Beijing. The conference focused on the technical challenges and solutions for inter-instrument networking through LXI. In recent years, China has made great progress in the research of LXI bus technology theory and

application technology research. Including Shanxi Haitai, Beijing Aerospace Measurement and Control, Harbin Institute of Technology, Electronic Science and Technology University, Puyuan Jingdian, Ruifeng Synergy and other units are actively tracking and researching LXI and related standards, and have also developed many products [9]. For example, the space static test data acquisition system based on LXI bus developed by Ruifeng.

3. Distributed Test System based on LXI Bus

3.1 Distributed Test System Overview

Distributed test system refers to the connection between measurement equipment and measurement computer that can be used to perform specific functions independently through various local measurement points (LANs) and the Internet (Internet) to achieve measurement resource sharing, decentralized operation, and concentration. Computer measurement network system for management, collaborative work, load balancing, test process monitoring, and device diagnostics [10]. A distributed test system is essentially a real-time system with strict time constraints, which requires that messages transmitted between devices through the field communication network must be completed within a certain period of time. Otherwise, it will lead to system performance degradation, and even catastrophic consequences.

Currently, dedicated real-time communication networks with defined, limited queuing delays, such as FF, CAN, LonWorks, Profibus, are often used in distributed test systems. Although these buses solve the real-time problems better, they have their own advantages and applicable fields. They are not only expensive, but because of market competition and other reasons, their communication standards have not been unified, and various fieldbuses cannot be realized. Interconnection, which hinders the promotion and application of fieldbus technology. In addition, the transmission rate of the fieldbus is not satisfactory, such as FF, the transmission speed of the low-speed bus H1 is 31.25 Kbps, and the transmission speed of the high-speed bus H2 is 1 Mbps, or 2.5 Mbps, which is difficult to meet in real time control requirements.

Contrary to industrial fieldbus technology, Ethernet technology has grown rapidly with the support of standardization organizations such as IEEE, from the initial 10 Mbps Ethernet to 100 Mbps Fast Ethernet and Switched Ethernet, to Gigabit Ethernet and Fiber Ethernet. Ethernet is widely supported by the market because of its strong resource sharing ability, low cost and high communication speed. It is a very effective and economical computer network technology. In addition, the use of Ethernet instead of fieldbus makes it easy to integrate distributed test systems. Therefore, the use of Ethernet as a communication platform for distributed test systems has become a trend.

3.2 Overall Structure of the System

The structure of modern automation equipment system is complex, and many test items need to be completed, such as measuring speed, acceleration, power and frequency, ground telemetry and remote control, etc., there are many monitoring points, and the distribution range is not concentrated, the types of signals to be tested are different, and the accuracy of test data is required. High, traditional testing methods have been difficult to meet the requirements. The design purpose of the LXI distributed test system is to ensure the test accuracy and improve the test efficiency while completing all the test items. If a VXI bus or GPIB bus program-controlled instrument structure is used, it is required to establish an independent test system at each monitoring point, which is composed of a terminal computer and a VXI instrument, a PXI instrument or a GPIB instrument, and then each terminal and server pass Network connections to form a distributed test system. In this structure, each node is controlled by the terminal computer, and the central server does not have the capability of remote control. Each node, regardless of the monitoring parameters, even if only one parameter is monitored, a computer and an instrument form a test system. The system structure is complex and causes system resources to be wasted.

However, if LXI-based, VXI and GPIB and other bus-assisted hybrid bus architectures are used, as shown in Figure 2, the system structure can be simplified, and distributed measurements of different locations and different physical quantities can be realized with high efficiency.

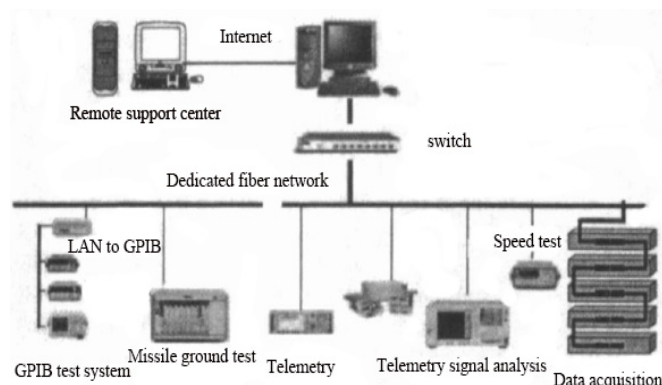


Fig 2. Hybrid bus system based on LXI

In this system, most monitoring points use LXI instruments for measurement and control. Each LXI instrument is directly connected to the network. Since each LXI device has its own processor, no terminal computer is needed at the monitoring node. For some test items, such as missile ground testing, there are relatively mature VXI or GPIB bus systems, and these systems are also connected to the LXI bus system for cost savings. Because many instrument vendors offer GPIB and LAN converters, as well as zero-slot controllers that support network transmission, existing GPIB, VXI, and PXI test systems can be easily accessed throughout the LXI network. [11]. It can be seen that the LXI bus technology simplifies system configuration, saves system resources, and increases system flexibility [12].

3.3 Synchronization Test Implementation Strategy

In distributed testing, synchronous testing is a very common requirement and the most critical technology. It is of particular importance in the field of automated testing. The LXI specification has a rich triggering method. Since LXI is a LAN-based instrument, most of the triggering methods are to transmit trigger signals through the network. This network-based triggering method is only subtle due to factors such as network delay. Trigger accuracy; therefore, the LXI specification retains a hardware trigger interface for LXI devices to meet higher precision triggering requirements.

The LXI instrument allows a total of five trigger modes: 1) trigger mode based on drive command. 2) trigger mode based on LAN message. 3) IEEE-1588 synchronous clock trigger mode. 4) based on LXI hardware trigger bus. 5) vendor-specific hardware trigger mode [13].

3.4 Driver Commands based Triggering Method

The triggering method based on the driving command is realized through the LAN interface, and the control computer transmits the command to the instrument module through the network through the IVI driver program to realize the control of the instrument. This triggering method is one of the most basic functions of the LXI instrument, and it is also the simplest and most direct way to control the operation of the instrument. This type of triggering has no requirement for the instrument's response speed and only supports single-point to single-point control.

3.5 LAN Message based Triggering Method

The LAN message-based triggering method is also implemented through the LAN interface, and all LXI instruments and controllers are connected through a switch. An LXI instrument can send a packet containing trigger information to other one or more instruments over the network to cause other instruments to act. For this type of triggering, the accuracy is generally in the order of milliseconds, so it is only suitable for occasions where the synchronization accuracy is low or the synchronization accuracy is not considered. Of course, it also has the following advantages:

It has great flexibility, and its trigger signal can be sent not only by the main controller, but also by any device, and can be transmitted to any device without passing through the main controller.

The LAN triggering supports both the point-to-point triggering function implemented by the TCP protocol and the multicast triggering function implemented by the UDP protocol, in other words, one device simultaneously sends a trigger signal to multiple devices.

3.6 IEEE-1588 Synchronous Clock based Triggering Method

Synchronous clock triggering can also be called timing triggering, which means that one clock runs inside each LXI instrument, and the time and rate of all clocks are consistent. The operator can set a time according to the clock to achieve the corresponding trigger action, because the clock of each instrument is synchronized, the synchronization of the instrument action can be realized. The following briefly introduces the principle of clock synchronization.

Suppose there are two LXI devices who have offsets. The deviation of the two device clocks can be corrected by the flow of Figure 3. First, the A device sends a data packet to the B device, and the A device records the time $T1$ sent. Because the data has a delay in the transmission process, the B device cannot receive the data packet at the time of $T1 + \text{offset}$, and the received data is received. The time is $T2$, and then the A device sends the recorded time $T1$ to the B device, and the B device also sends a data packet to the A device, and records the transmission time $T3$ and the reception time $T4$ in the B device. At this time, there are four times of $T1$, $T2$, $T3$, and $T4$ in the B device.

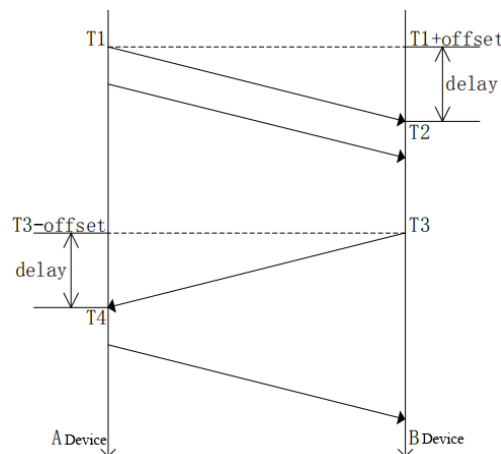


Fig 3. Schematic diagram of synchronous clock algorithm

Through the formulas (1), (2), (3), the deviation offset between the two instrument clocks can be calculated, so that the clock deviations of the two devices can be corrected to obtain a clock synchronized with each other [14]. Compared with LAN triggering, the accuracy of synchronous clock triggering is improved a lot, and the accuracy of its implementation can generally reach sub-microsecond level. Distributed test system triggers with IEEE-1588 synchronous clock, because each instrument is started according to the specified time, instead of starting according to when the command sent by Ethernet is received, the overhead or delay time of Ethernet is triggered. The instrument has no effect. Therefore, the IEEE-1588 synchronous clock triggering mode is particularly suitable for testing tasks such as distributed long-distance synchronous data acquisition, without separately connecting the trigger cable, and is not limited by distance.

3.7 LXI Hardware Trigger Bus based Triggering Method

The trigger signal of the hardware trigger mode is transmitted through the hardware trigger bus. The hardware trigger bus of the LXI device can connect multiple LXI devices into a bus system internally. Several other trigger methods must be implemented by the LAN interface. Due to the influence of software and switches, their trigger accuracy is not high. The LXI Alliance proposes hardware in the LXI specification to ensure that LXI instruments can achieve nanosecond trigger accuracy. Of course, this triggering method also has shortcomings: Limited by the trigger line

connection, this trigger method is not suitable for applications where the test equipment is far apart, such as not applicable to distributed test systems. Because the signal has a delay on the trigger bus, the transmission delay is about 5 ns/m. Using a long trigger bus will increase the delay time of signal transmission and reduce the trigger accuracy.

4. System Application Example

In 2013, Beijing Ruifeng Synergy Technology Co., Ltd. proposed a distributed space static test data acquisition system based on LXI bus. The static test is used to study the strength, stiffness, stress distribution and deformation distribution of the tested part under static load. It is an important means to verify the structural strength and the correctness of static analysis. In the static test, it is necessary to measure various parameters including strain and displacement; and with the development of aerospace technology and the use of new aerospace materials, the number of channels for the data acquisition system of the static test is increasing. many. If the traditional centralized system architecture is adopted, on the one hand, it is necessary to increase the length of the test dedicated cable, which is easy to accumulate errors and affect the accuracy of the measurement; on the other hand, a large number of cable layings complicate the distribution, which not only increases the cost, It is also not conducive to the later maintenance of the system. Therefore, the system uses a distributed system architecture to simplify cable connections and improve measurement accuracy.

The distributed space static test data acquisition system is constructed by VTI's EX1629. The system block diagram is shown in Figure 4 [16]:

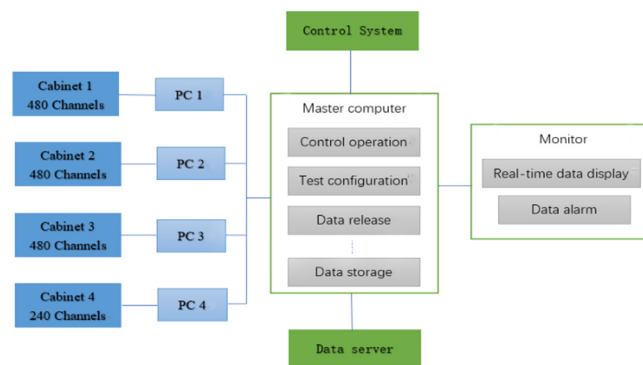


Fig 4. System block diagram

The EX1629 is a 48-channel high-performance remote strain gauge that is based on the LXI bus and meets LXI's Class A standard. Each cabinet in the system has 480 channels. The cabinet can be placed around the test point. The test cable connects the measured objects. The test equipment communicates through the network cable or the test LAN. This not only saves a lot of test cables, but also reduces the line. The loss on the ground also reduces environmental interference and improves the accuracy of the measurement. In addition, the distributed test system also demonstrates the excellent scalability of the LXI bus. If you need to extend the system, you only need to add the corresponding LXI device, such as the EX1629 applied in this system, without the need for additional accessories such as the chassis.

5. Conclusion

In this paper, we research on distributed test system, proposing a hybrid distributed test system based on LXI bus and supplemented by other buses such as VXI and GPIB. For some test objects with scattered locations, many test items, and many monitoring points and non-concentrated test environments, comparing with the centralized test system of the program-controlled instrument structure of the GPIB bus, the system configuration is simplified, the system resources are saved, the flexibility of the system is increased, and the feasibility is more feasible. The four different synchronization implementation strategies of the test system apply to different test environments. Among them,

the IEEE-1588 synchronous clock triggering method does not need to connect the trigger cable separately, and is not limited by the distance. It is especially suitable for large-scale comprehensive test tasks such as distributed long-distance synchronous data acquisition. With further research, the application of distributed test systems based on LXI bus will be more extensive, especially in the testing and fault diagnosis systems of aerospace, aviation, shipbuilding and other defense industries, etc.

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