UiO : University of Oslo

FYS3240
PC-based instrumentation and microcontrollers

Computer buses and interfaces

Spring 2011 – Lecture #5

Bekkeng 15.1.2011

The most common data acquisition buses available today

Bus	Waveform[1] Streaming	Single -Point I/O	Multidevice	Portability	Distributed Measurements	Example
PCI	132 MB/s (shared)	Best	Better	Good	Good	M Series
PCI Express	250 MB/s (per lane)	Best	Better	Good	Good	X Series
PXI	132 MB/s (shared)	Best	Best	Better	Better	M Series
PXI Express	250 MB/s (per lane)	Best	Best	Better	Better	X Series
USB	60 MB/s	Better	Good	Best	Better	NI CompactDAQ
Ethernet	125 MB/s (shared)	Good	Good	Best	Best	NI CompactDAQ
Wireless	6.75 MB/s (per 802.11g channel)	Good	Good	Best	Best	Wi-Fi DAQ

Internal computer buses

- Internal bus connectors (card slots) makes it possible to insert peripheral electronic boards
- Important buses today:
  - PCI
  - PCI Express

PCI

- PCI = (Peripheral Component Interconnect)
- Supports 32 and 64 bits
- Shared parallel bus!
- Maximum bandwidth (peak) of **133 MB/s** (32-bits at 33 MHz)
- 33 MHz and 66 MHz versions
- Theoretical maximum of 532 MB/s (64 bits at 66 MHz)
- However, anything above 32 bits and 33 MHz is only seen in high-end systems)

PCI-X

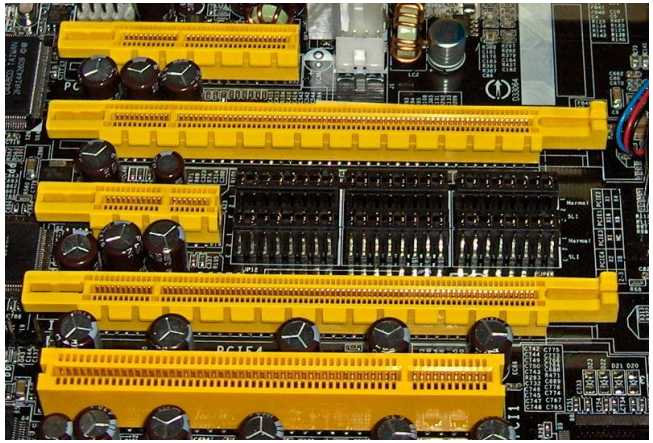
- Satisfied the higher bandwidth demanded by servers
- Running at up to four times the clock speed of PCI (33 MHz x 4), but is otherwise similar in electrical implementation and uses the same protocol
- Maximum bandwidth of 1064 MB/s (64-bit at 133 MHz)
- Parallel interface
- PCI-X has been replaced in modern designs by PCI Express

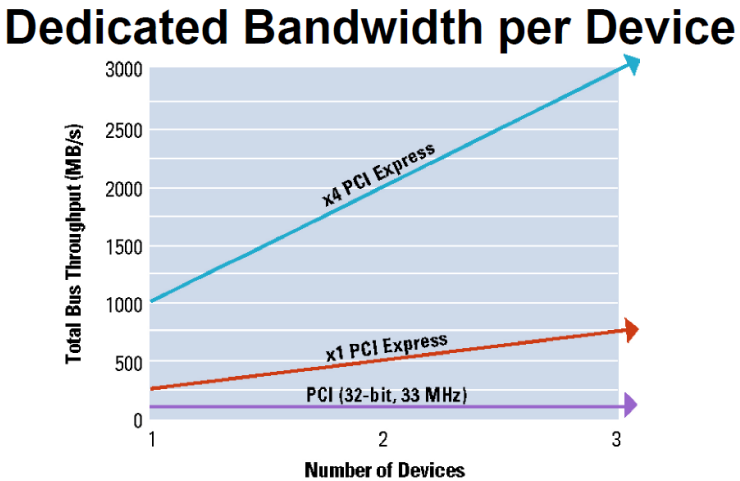
PCI Express (PCIe)

- A point-to-point serial bus, rather than a shared parallel bus architecture
- PCIe slots may contain from one to thirty-two lanes, in powers of two (1, 2, 4, 8, 16 and 32).
- Dedicated bandwith for each device/slot
  - *x1 : bandwith of 250 MB/s (duplex)*
  - *x4 : bandwith of 1 GB/s (duplex)*
  - *x16: bandwith of 4 GB/s (duplex)*

16 lane slot:

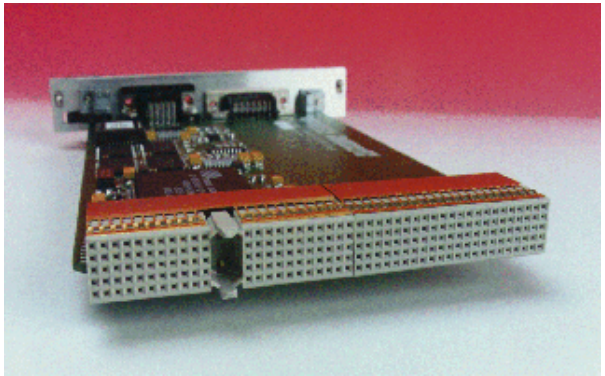
- **v1.x**: 4 GB/s (32 Gb/s)
- **v2.x**: 8 GB/s (64 Gb/s)
- **v3.0**: 16 GB/s (128 Gb/s)

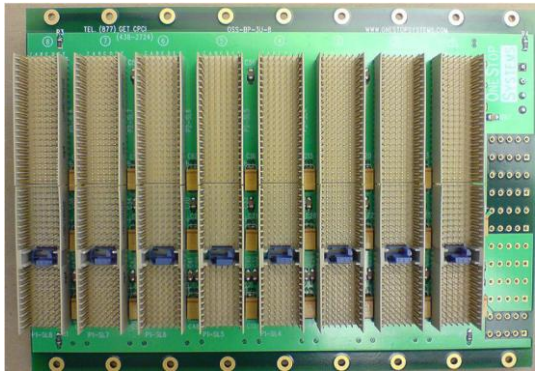




CompactPCI

- It is electrically a superset of PCI with a different (smaller) physical form factor
- CompactPCI supports twice as many PCI slots
- Compact PCI cards are designed for front loading and removal from a card cage. The cards are firmly held in position by card guides on both sides, and a face plate which solidly screws into the card cage.
- Cards are mounted vertically allowing for natural or forced air convection for cooling
- Better shock and vibration characteristics than the card edge connector of the standard PCI cards
- Allows hot swapping, a feature that is very important for fault tolerant systems and which is not possible with standard PCI.





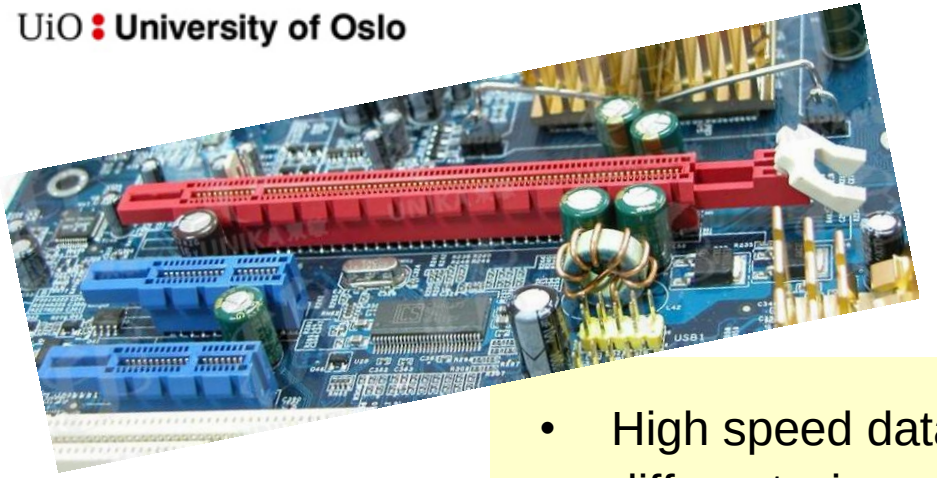
PXI and PXI-Express

- **PXI = PCI eXtensions for Instrumentation (PXI)**
- National Instruments developed and announced the PXI specification in 1997
- Based on and compatible with **CompactPCI**
- PXI defines a rugged PC-based platform for measurement and automation systems
- Gives the ability to expand your system far beyond the capacity of a desktop computer with a PCI/PCIe bus.
- One of the most important benefits PXI offers is its **integrated timing and triggering features**. Without any external connections, multiple devices can be synchronized by using the internal buses resident on the backplane of a PXI chassis
- By taking advantage of PCI Express technology in the backplane, PXI Express increases the available PXI bandwidth from 132 MB/s to 8 GB/s

PCMCIA (PC Card)

- PCMCIA = *Personal Computer Memory Card International Association*
- *"PC Card" is the name used for PCMCIA 2.0*
- PCMCIA is the form factor of a peripheral interface designed for laptop computers
- Commonly used for DAQ cards, network cards and modems for laptops
- Maximum data rate:
  - PCMCIA : 7.8 MB/s
  - PC card : 133 MB/s

- Parallell bus, 32 bit wide
- Successor : ExpressCard
  - Serial bus
  - 480 Mb/s (USB 2.0 mode) or 2.6 Gb/s (PCIe mode)



Towards serial buses

- PCI Express, USB, SATA ...

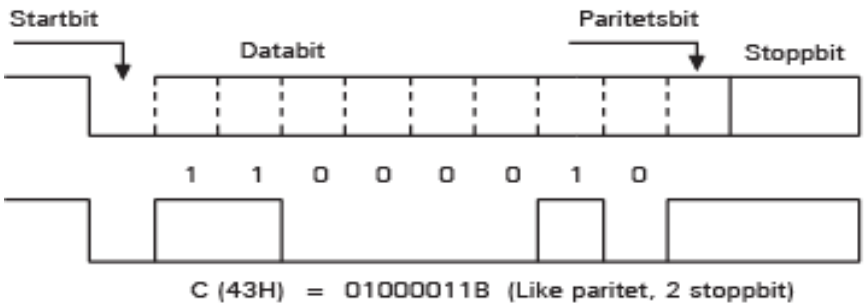
- High speed data transfer on long cables: the bits on different wires may not reach the receiver circuit exactly at the same time. Not the case on serial lines → may increase speed without problems
- Crosstalk between lines at high frequency is avoided by using one or two data lines only
- Hence, parallel cables are more expensive in production
- Serial internal buses give less motherboard routing, simpler layout and smaller dimensions
- PCIe is just one example of a general trend away from parallel buses to serial interconnects.
- Other examples include Serial ATA (SATA) USB, SAS (Serial Attached SCSI) and FireWire

External computer ports and buses

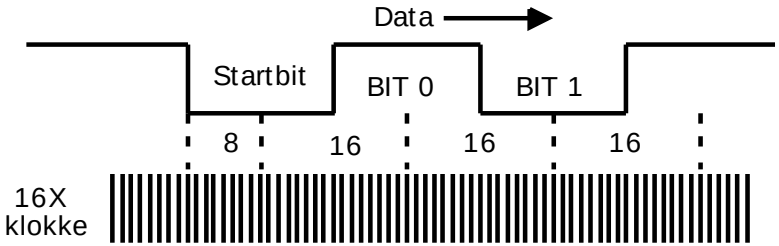
- RS-232
- RS-422
- RS485
- USB
- FireWire (IEEE 1394)

Not directly available on the computer, but a converter attached to USB or RS-232 can be used

Serial port: RS-232

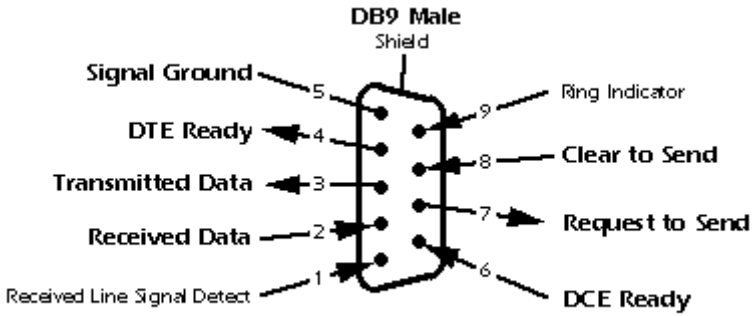


- Point-to-point interface
- Single-ended data transmission
- Common bit frequencies are from 9.6 kHz up to 115.2 kHz (or higher)
- Maximum cable length (rule of thumb) is about 15 -20 meters at full speed
  - depends on cable capacitance
- Maximum data rate about 20 Kbit/s
- Minimal 3-wire connection is:
  - Rx, Tx and GND (two way data flow)



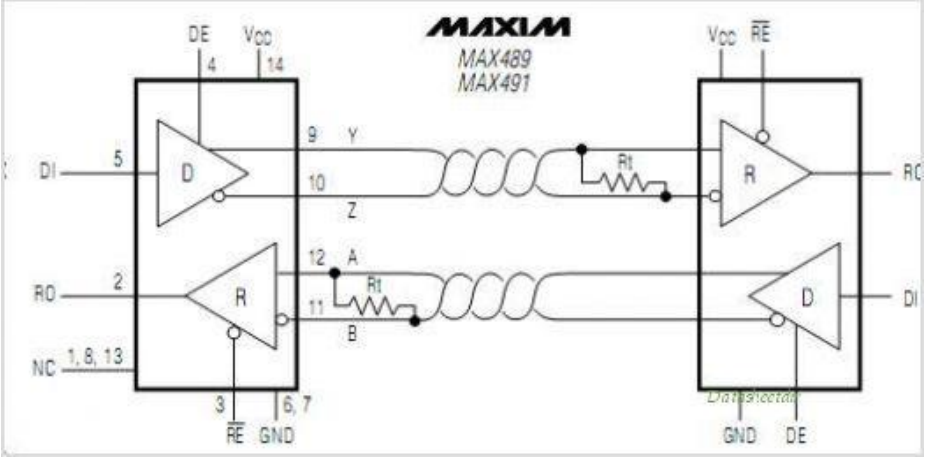

```
Data:    +(3-25 V) (0)
         -(3-25 V) (1)
Control: -(3-25 V) (0)
         +(3-25 V) (1)
```

- Common ground (between transmitter and receiver)
  - Can create noise problems



RS-422

- Multi-drop interface with a <u>single transmitter</u> but <u>multiple receivers</u>
- Differential data transmission (balanced transmission)
  - *Cancel out the effects of ground shifts and induced noise signals that can appear as common mode voltages on a network*
- Maximum cable length (rule of thumb) is about 1200 meters
- Maximum data rate is 10 Mbit/s
  - *Depends on cable length*



RS-485

- Upgraded version of RS-422
- Multi-point network consists of <u>multiple drivers and receivers</u>

USB (Universal Serial Bus)

- Theoretical maximum data rates:
  - USB 1.0 – Jan 96 : 12 Mb/s
  - USB 1.1 – Sep 98 : 12 Mb/s
  - USB 2.0 – Apr 2000 : 480 Mb/s
  - USB 3.0 – Aug 2008 : 5.0 Gb/s (*SuperSpeed*)
    - commercially available in 2010

- **Maximum cable length of 5 meters**

- Differential signaling (twisted pairs)
  - +5V 0V D+ D-

- Possible solutions (?) to increase the cable length:
  - USB hubs as active USB repeater(s)
  - Active Cables (bus-powered, one-port hubs)

FireWire – IEEE 1394

Theoretical maximum data rates:

- 1394a-2000 (FireWire 400) : 400 Mb/s
- 1394b-2002 (FireWire 800) : 800 Mb/s
  - FireWire S1600 and S3200 (2007)
    - 1.6 and 3.2 Gb/s (compete with USB 3.0)
    - Commercial available in 2010
- 1394c-2006 : 800Mb/s over Ethernet-cable

- Used for digital video equipment
- Cable length is limited to 4.5 meters, although up to 16 cables can be daisy chained using active repeaters up to a total cable length of 72 meters
- Not as common as USB!

GPIB/IEEE-488

- GPIB = General Purpose Interface Bus
- 8-bit, parallel bus (shared bandwidth)
- Every device on the bus has a unique 5-bit address (in the range from 0 to 30)
- The standard allows up to 15 devices to share a single physical bus of up to 20 meters total cable length
- Active extenders allow longer buses, with up to 31 devices
- The maximum data rate is about 1 MB/s.
- The later HS-488 extension allows up to 8 MB/s
- Used in laboratory setups, for control and data transfer (for more than 30 years)
- **Enables networking of instruments for automation of experimental setup**

VXI

- Based on the VME bus
  - A multi-processor bus
  - Used in the high-end (and high cost) market
  - For the professional market, primarily in industrial, military, aerospace, communication and control applications, in particular where robustness is required
  - Expensive and power hungry
- VXI stands for **V**ME e**X**tensions for **I**nstrumentation
- Has additional bus lines for timing and triggering
- Maximum data rate of 160 MB/s
- The basic building block of a VXI system is the mainframe or chassis
- Because VXI is based on the older VME bus, which is not a part of modern computer architectures, it cannot take complete advantage of the advances in PC technology and thus bring the benefits of mainstream software, lower cost, and high performance to the end user

Ethernet network

- LAN (local area network)
  - a computer network that connects computers and devices in a limited geographical area
- 1000BASE-T (IEEE 802.3ab) is a standard for gigabit Ethernet over copper wiring
  - Theoretical maximum data rate of 125 MB/s
  - Each network segment can have a maximum length of 100 meters
  - If longer cables are required, the use of active hardware such as repeaters, or switches, is necessary
  - Must use Category 5 cable or better (4 twisted, usually unshielded) pairs)

RJ45

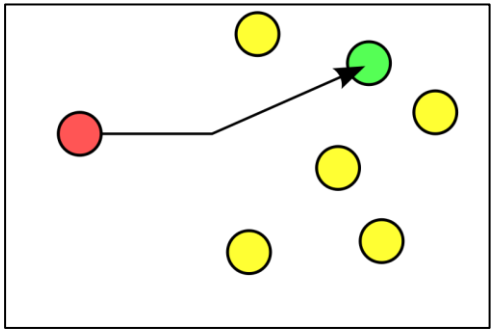
Ethernet network

- Category 6 cable (Cat 6)
  - today standard for Gigabit Ethernet
  - backward compatible with the Category 5/5e
  - suitable for 10-Gigabit Ethernet (10GBASE-T)
- PC connection to an Ethernet network
  - NIC (Network Interface Controller/Card) for PCI or PCIe
  - Every NIC has a unique 48-bit serial number (MAC address) stored in a ROM

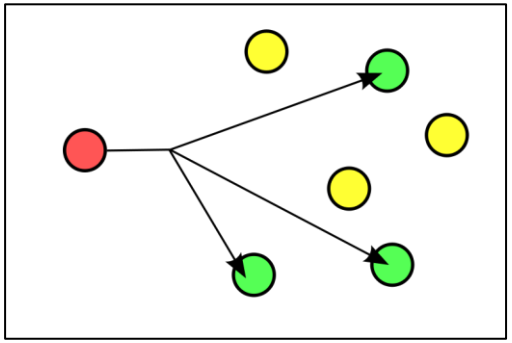
PCIe x4
dual port NIC

Unicast, multicast and broadcast in computer networks

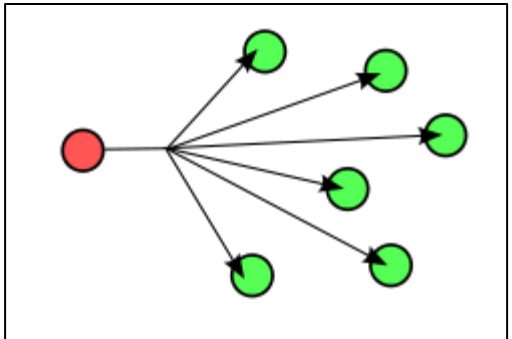
- Unicast
  - sending of messages (packages) to a single network destination identified by a unique address.



- Multicast
  - sends data only to *interested* destinations by using special address assignments



- Broadcast
  - transmitting the same data to all possible destinations (every device on the network)



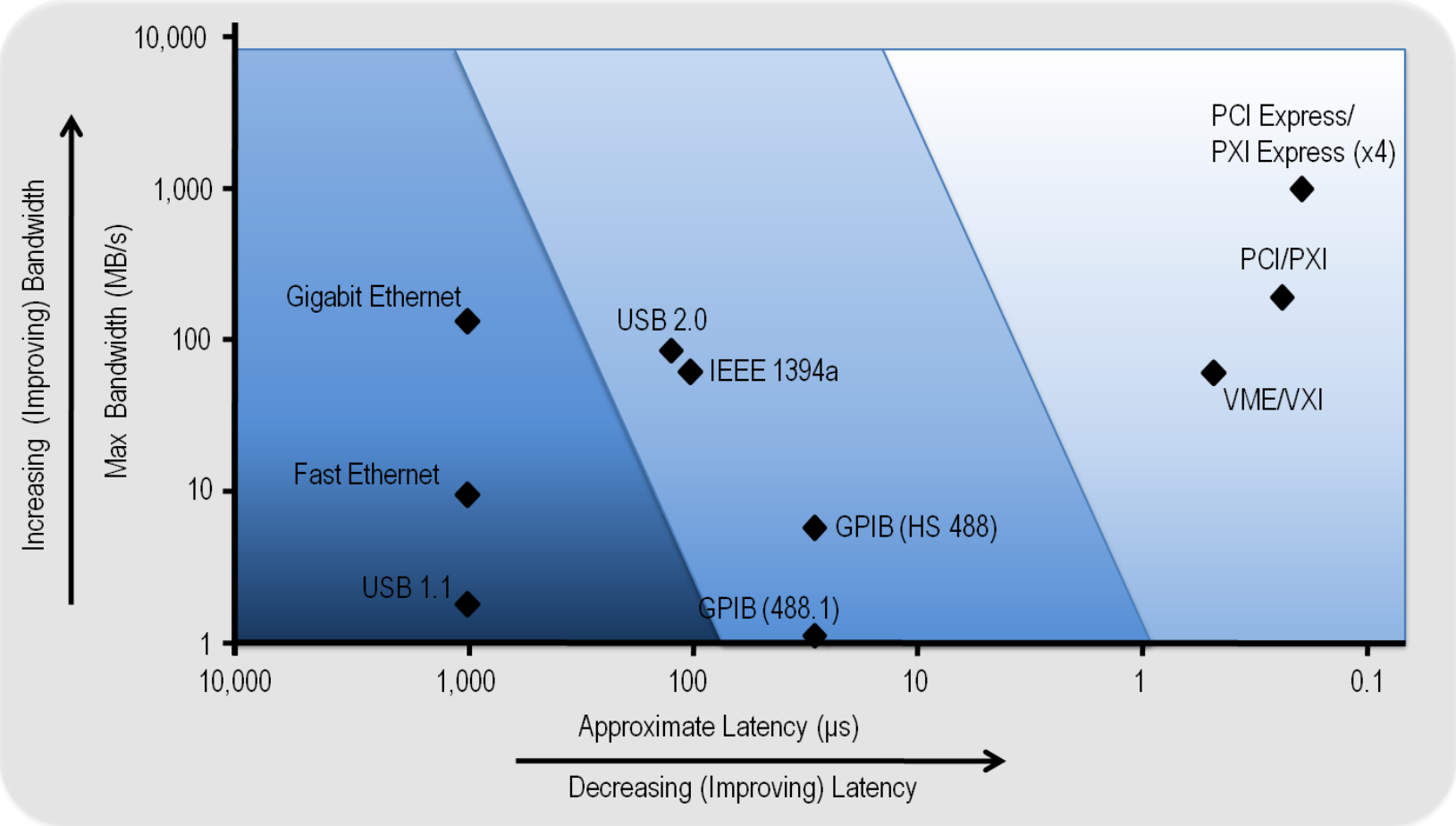
LXI

http://www.lxistandard.org/

- **LXI = LAN eXtensions for Instrumentation**
- The LXI standard defines the communication protocols for instrumentation and data acquisition systems using Ethernet
- Synchronization based on IEEE 1588 Precision Timing Protocol
- Three LXI device classes:
  - C : baseline with LAN capabilities, web interface, and IVI drivers
  - B : adds expanded triggering, such as multicast and peer-to-peer communications between instruments and time-based trigger events
  - A : adds a wired trigger bus for precision triggering
- With support for LXI you can control instruments and monitor measurements remotely.
- Ideal for distributed systems and remote monitoring

IVI = Interchangeable Virtual Instrument

Bus bandwidth and latency comparison



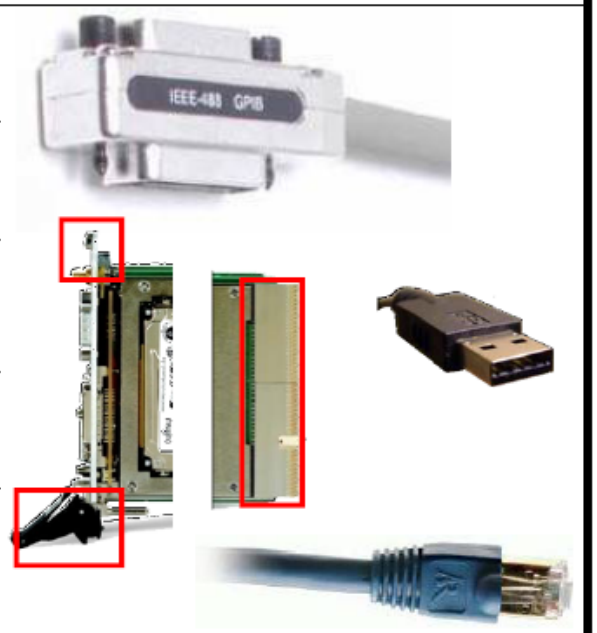
Comparison - setup

Bus	Setup	Notes
Ethernet/LXI	Good	Configure IP address and subnet
GPIB	Better	Search bus for instrument
PCI	Better	Power down first; then Windows autodetects, autoconfigures
PCI Express	Better	Power down first; then Windows autodetects, autoconfigures
USB	Best	Instrument autodetects, autoconfigures

Comparison - Distributed Capability

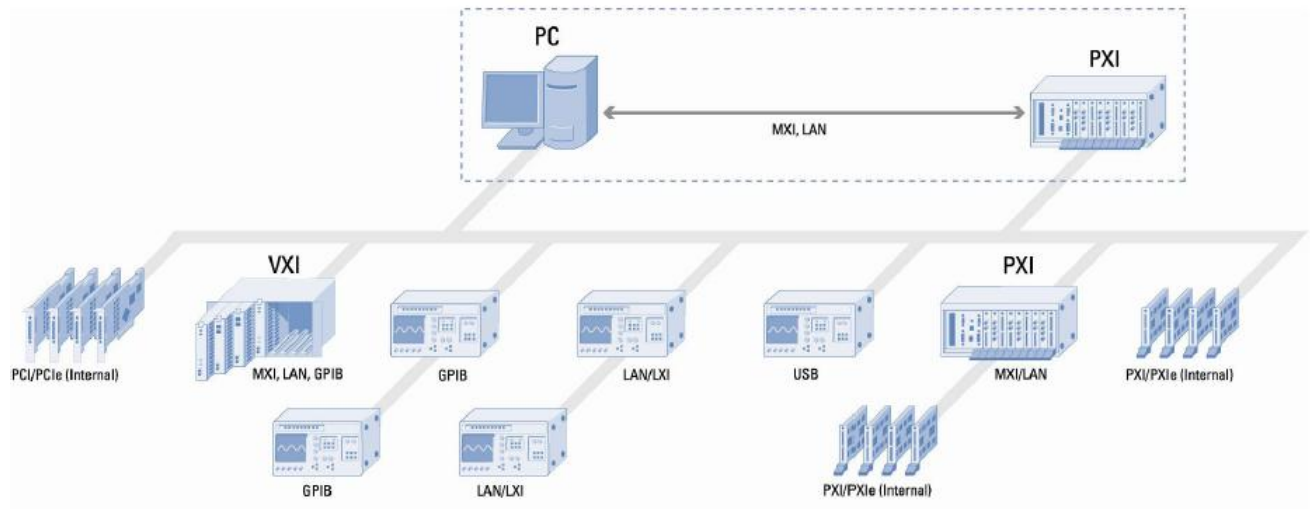
Bus	Max Length	Notes
PCI	Internal PC bus	Fiber-optic MXI extends to 200 m
PCI Express	Internal PC bus	MXI-Express extends
USB	5 m	Not easily extended
GPIB	20 m	Fiber-optic cables extend to 2 km
Ethernet/LXI	85 to 100 m	Fiber-optic cables extend to kilometers

Comparison - Ruggedness

Bus	Ruggedness	Connector
Ethernet/LXI	Good	
USB	Good	
PCI	Best (for PXI)	
PCI Express	Best (for PXI Express)	
GPIB	Best	

Hybrid system architecture

- Often beneficial to combine multiple instrumentation buses
- No bus is perfect for all needs and applications
- Use available instrument control hardware for GPIB, USB, Ethernet, LXI, LAN etc.



NI PXI-8433/2 (RS485/422)
High-Performance, Isolated 2-Port Serial Interface
Features | Specifications | Data Sheet

NI PCI-GPIB/LP
High-Performance GPIB Controller for Low-Profile PCI
Features | Specifications | Data Sheet

http://ni.com/icfundamentals

Instrument Control Fundamentals: Hardware and Bus Technologies

Read in English | Print | PDF

6 ratings | 3.00 out of 5

As part of the National Instruments Instrument Control Fundamental Series, this set of tutorials helps you learn about a specific instrument control topic through theory explanations and practical examples.

This document is part of the Instrument Control Fundamentals Series

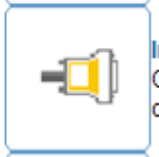
What You Learn

Many of today's instrument control applications consist of a broad range of instrument control hardware and bus technologies. Some of these buses include GPIB, serial, USB, Ethernet/LAN, PCI/PCI Express, PXI/PXI Express, and IEEE 1394. This set of tutorials and concept documents provides information on all these different hardware and bus technologies.

Visit the Test System Development Resource Library to learn how to incorporate instrument control into an automated test system.

Comparing Instrument Hardware Buses

See the similarities and differences between all the different instrument control hardware buses.



Instrument Control with the GPIB Hardware Bus

Obtain more information on the GPIB instrument control hardware bus and how to control your GPIB instrument.

Instrument Control with the USB Hardware Bus

Explore information on how to control your USB instrument and how this hardware bus works.

Differential signaling & twisted pairs

- Two wires carry equal and opposite signals and the receiver detects the difference between the two.
- Noise sources introduce signals into the wires by coupling of electric or magnetic fields and tend to couple to both wires equally. The noise thus produces a common-mode signal which is cancelled at the receiver .
- This method starts to fail when the noise source is close to the signal wires; the closer wire will couple with the noise more strongly and the common-mode rejection of the receiver will fail to eliminate it. This problem is especially apparent in long cables as one pair can induce crosstalk in another, and it is additive along the length of the cable.
- Twisting the pairs counters this effect as on each half twist the wire nearest to the noise-source is exchanged. Providing the interfering source remains uniform, the induced noise will remain common-mode.
- The twist rate (twists per meter) makes up part of the specification for a given type of cable. Where nearby pairs have equal twist rates, the same conductors of the different pairs may repeatedly lie next to each other, partially undoing the benefits of differential mode. For this reason it is commonly specified that, at least for cables containing small numbers of pairs, the twist rates must differ.