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# HOW TO CHOOSE THE BEST INSTRUMENT CONTROL BUS FOR YOUR APPLICATION

National Instruments

# Agenda

- **Instrument Control Basics**
- **Bus Characteristics**
  - GPIB, USB, PCI, PCI Express, Ethernet/LAN/LXI
- **Head-to-Head Comparison**
  - Setup
  - Bandwidth
  - Latency
  - Distributed/Remote Systems
  - Physical Ruggedness
- **Hybrid Systems**

# Selecting an Instrument Control Bus

**PXI**Express™

PCI



**Fast Ethernet**



PCI   
**EXPRESS™**



GPIB

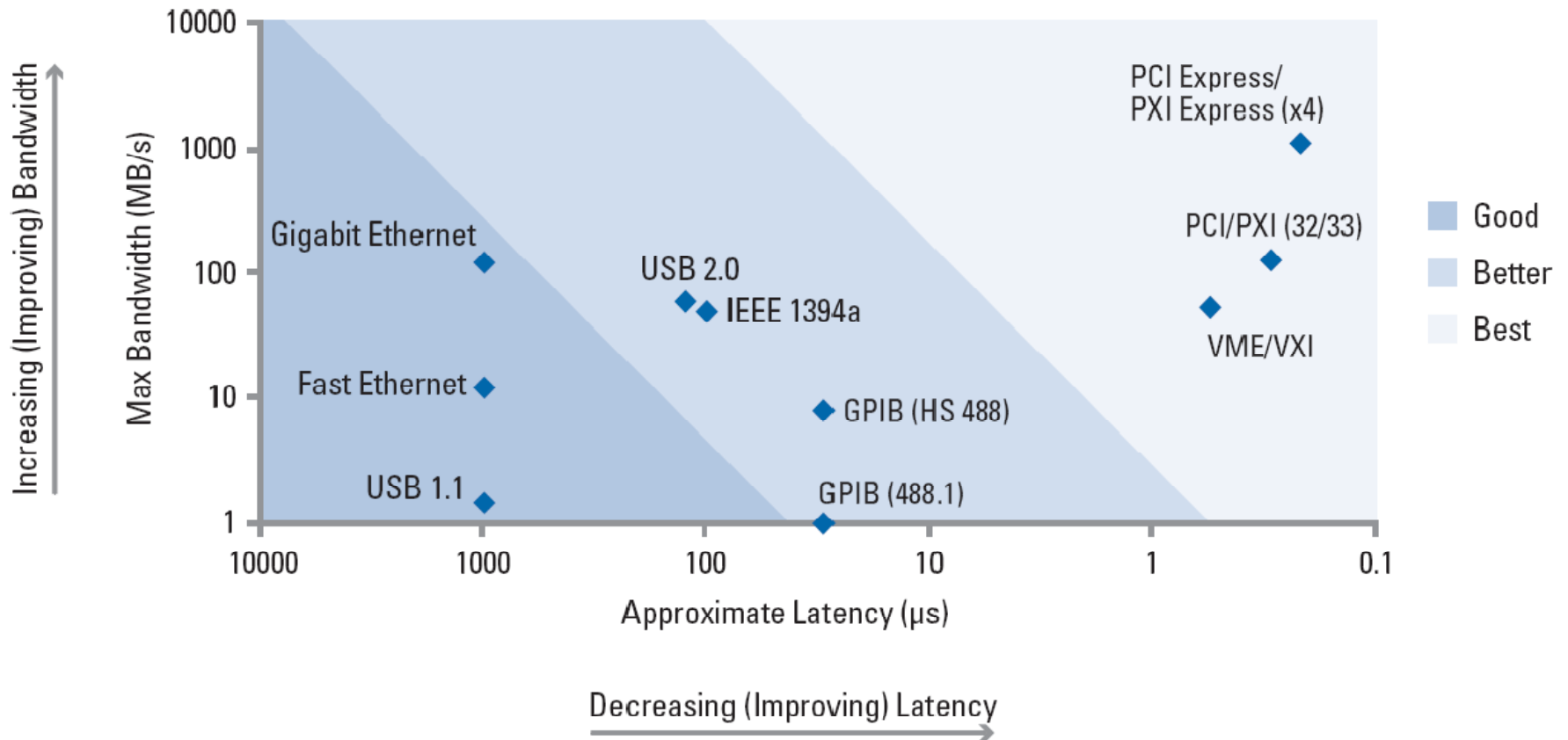
**Gigabit Ethernet**



**VMEbus**

**CompactPCI®**

# Latency versus Bandwidth



# GPIB/IEEE-488

**HS488 Max Bandwidth: 8 MB/s**  
**488.1 Max Bandwidth: 1.8 MB/s**  
**Bandwidth Distribution: Shared**  
**Bandwidth Rating: Good**  
**Latency Rating: Better**

- More than 30 years of compatibility
- Robust and reliable
- Widest industry adoption
- Largest installed base of instruments
- Ideal for:
  - Automating existing equipment
  - Hybrid systems
  - Systems requiring highly specialized instruments



# USB

**Max Bandwidth:** 60 MB/s (Hi-Speed USB)

**Bandwidth Distribution:** Shared across all ports

**Bandwidth Rating:** Better

**Latency Rating:** Better

- PC ubiquity
- Simplest plug-and-play connectivity (autodetection)
- Ideal for:
  - Portable desktop and benchtop applications
  - Small, low-cost systems



# Ethernet/LXI

**1000BaseT Max Bandwidth:** 125 MB/s

(Gigabit Ethernet)

**100BaseT Max Bandwidth:** 12.5 MB/s

(Fast Ethernet)

**Bandwidth Distribution:** Shared across network

**Bandwidth Rating:** Better

**Latency Rating:** Good

- Remote capabilities
- PC ubiquity
- LXI adds optional timing and triggering
  - Synchronization through IEEE 1588 (Class B)
  - Triggering support (Class A)
- Ideal for:
  - Distributed systems
  - Remote monitoring





# PCI and PCI Express

**PCI Express Bandwidth:** (x1) 250 MB/s –  
(x16) 4000 MB/s

**PCI Express Bandwidth Distribution:**  
Dedicated per device

**PCI Max Bandwidth:** 132 MB/s

**PCI Bandwidth Distribution:** Shared

**Bandwidth Rating:** Best

**Latency Rating:** Best

- Best bandwidth and latency
- PC ubiquity
- Enables lower instrument cost
- Ideal for:
  - High-performance systems
  - Data-intensive systems



# PXI and PXI Express

**PXI Express Bandwidth:** (x1) 250 MB/s –  
(x8) 2000 MB/s

**PXI Express Bandwidth Distribution:**  
Dedicated per device

**PXI Max Bandwidth:** 132 MB/s

**PXI Bandwidth Distribution:** Shared

**Bandwidth Rating:** Best

**Latency Rating:** Best

- Best bandwidth and latency
- Based on rugged CompactPCI physical standard
- Adds timing and synchronization to CompactPCI
  - Trigger bus
  - Star trigger
  - 10 or 100 MHz shared system clock

Ideal for:

- High-performance systems
- Integration of several types of instruments
- Timing and synchronization



# Head-to-Head Comparison

- Setup
- Bandwidth
- Latency
- Distributed/Remote Systems
- Physical Ruggedness

# 1. 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

# Many Factors Affect Performance

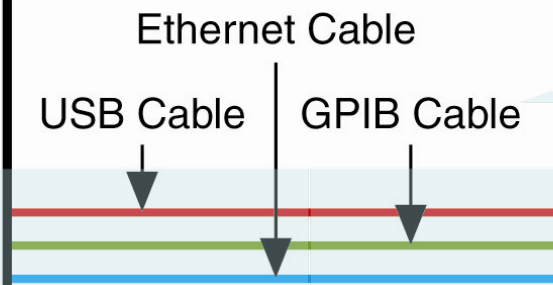
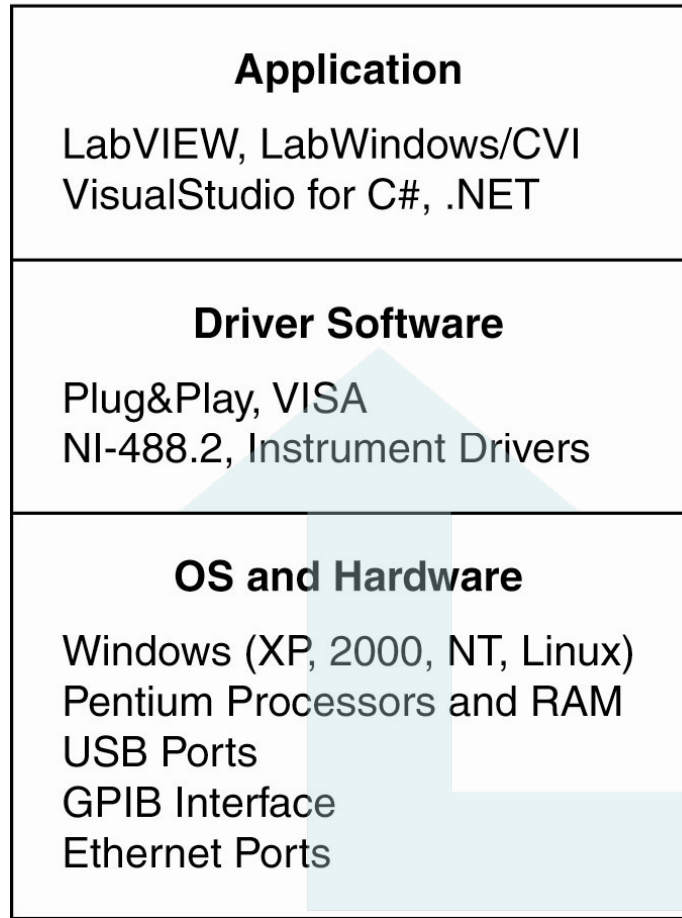
- **Offloading:** Performing computation on PC rather than the instrument
- **Transfer size:** The number of bytes in each transfer
- **Data format:** Waveform transfers support different formats: ASCII, binary
- **Synchronous versus asynchronous operations:**  
Synchronous call often better for small transfers, depending on the number of parallel tasks

# Practical Implementation of the Bus

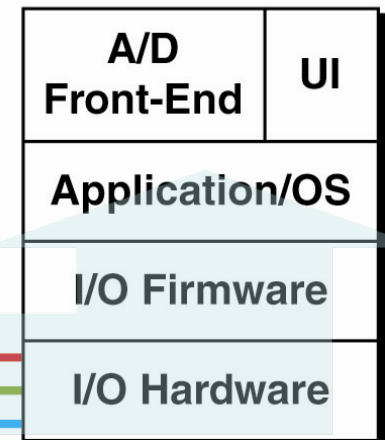
- Theoretical numbers on throughput are rarely achieved
- Bottlenecks occur
  - When a faster bus is routed through a slower bus
  - In poorly implemented communication firmware
- There can be very apparent performance differences between different vendors' implementations

# Performance Comparison

## Host PC



## Instrument



# Test System for Comparison

## Application

- LabVIEW 8.20
- Identical IVI function calls



## OS and Hardware

- Windows XP
- Pentium processor
- Hi-Speed USB ports
- GPIB interface
- Ethernet via Gigabit switch

PCI (PXI)

Ethernet (100BaseT)

Hi-Speed USB

GPIB (488.1)

NI  
Arbitrary Waveform  
Generator

NI PXI  
Digitizer

Agilent  
Oscilloscope

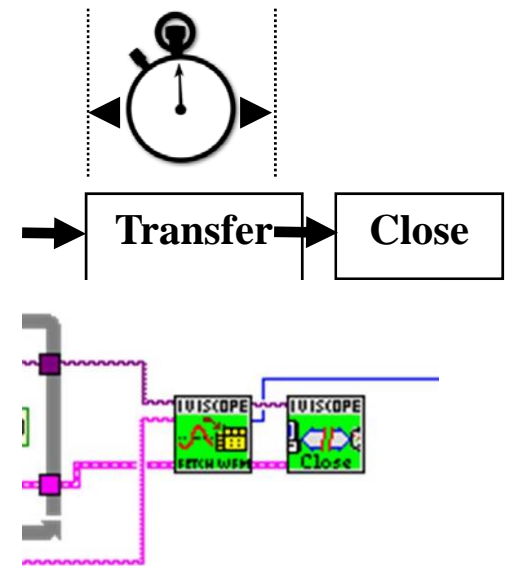
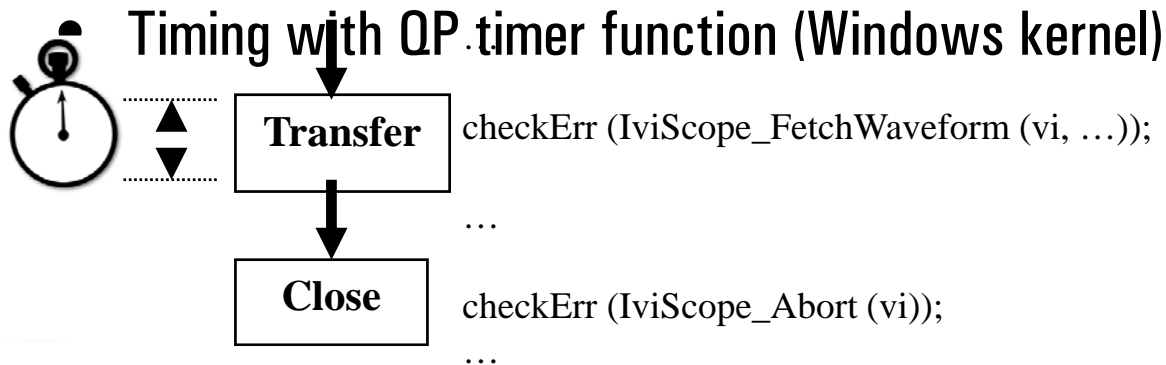


## 2. Bandwidth

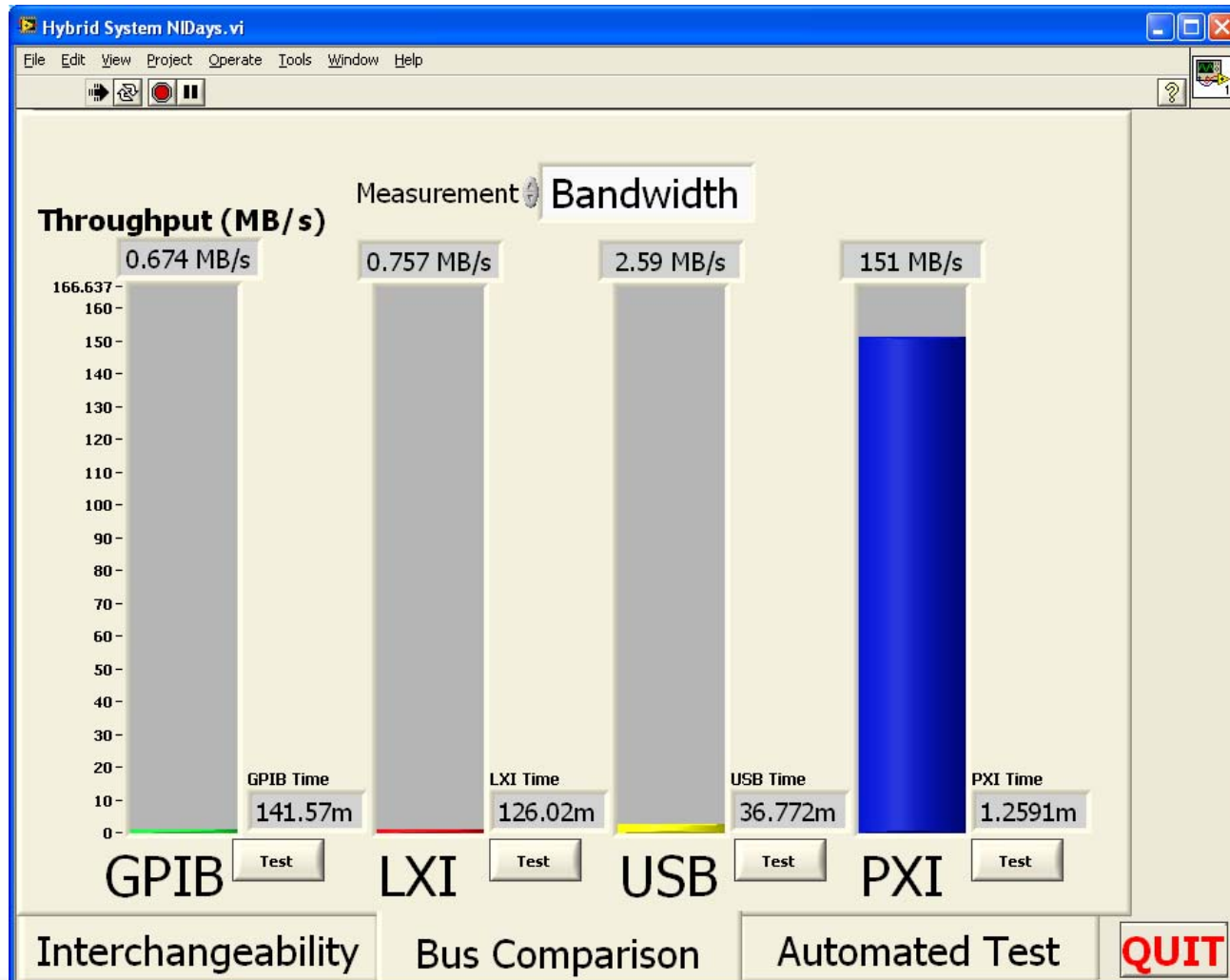
Bus	Ideal Bandwidth (MB/s)	Distribution
GPIB	1.8 (488.1)	Shared
	8 (HS488)	
USB	60 (Hi-Speed USB)	Shared
Ethernet/LXI	12.5 (Fast)	Shared
	125 (Gigabit)	
PCI	132	Shared
PCI Express	250 (x1)	Dedicated per device, per direction
	4000 (x16)	

## 2. Bandwidth Experiment

- Using identical IVI function for each bus
- Transferring 100,000 samples
- Averaging 100 trials for each bus
- Measuring data transfer only



# Bandwidth Experiment Results

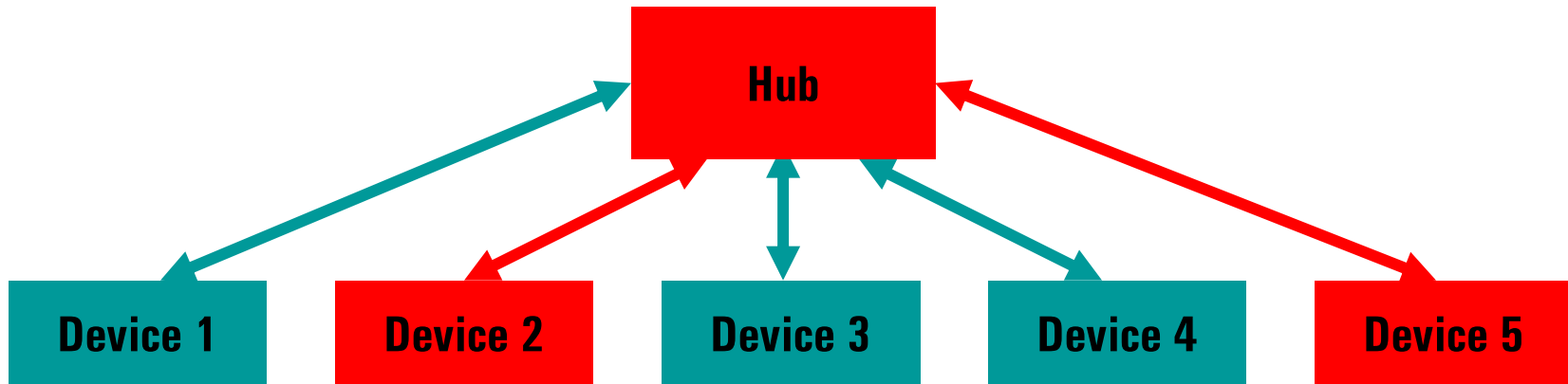


# 3. Latency

Bus	Latency (microseconds)
Ethernet/LAN/LXI	1000 (Fast) 1000 (Gigabit)
USB	1000 (USB 1.1) 125 (Hi-Speed USB)
GPIB	30
PCI	0.7
PCI Express	0.7 (x1) 0.7 (x4)

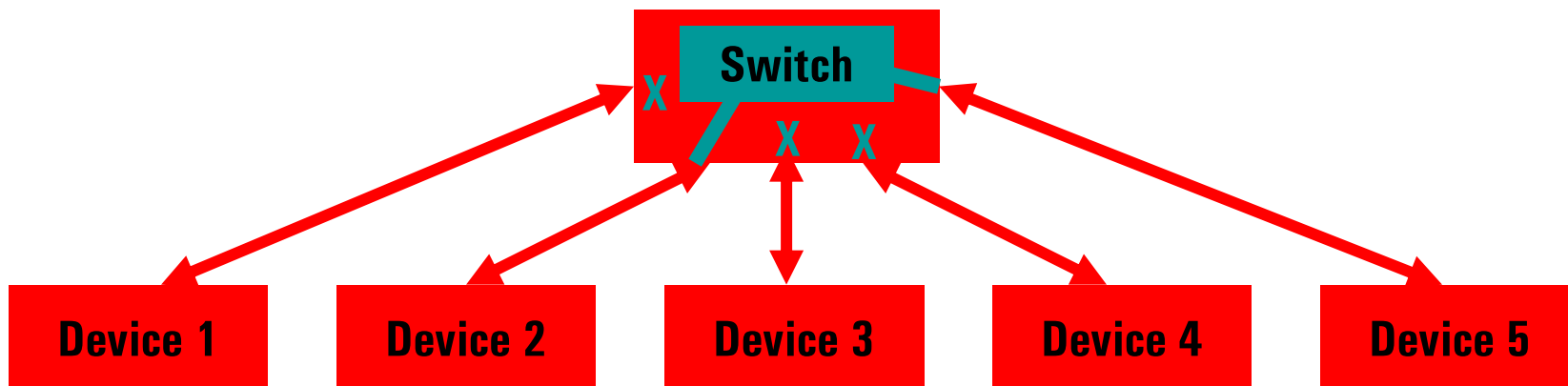
Source: Bus specifications and 2005 NI benchmark testing

# Shared Ethernet Using a Hub



- Only one Ethernet network
- Only bus master can transfer data
- Collisions are resolved by random delays before next request

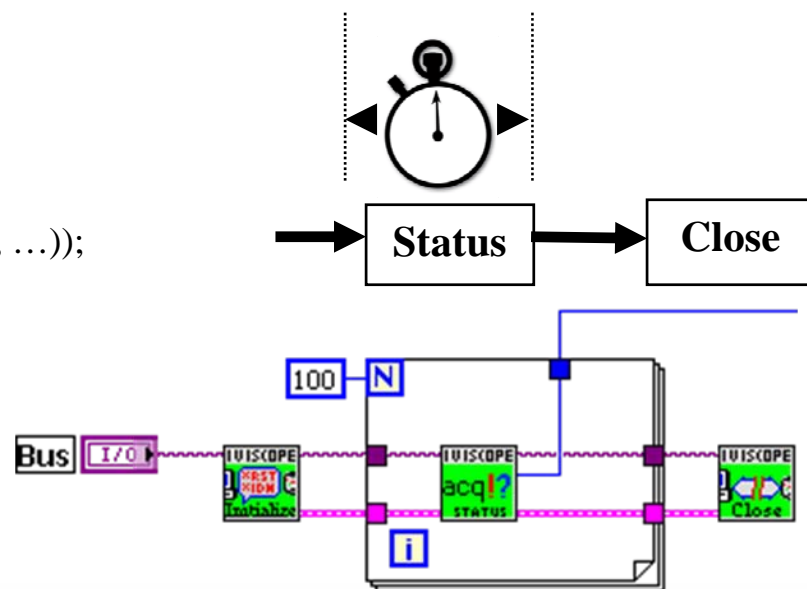
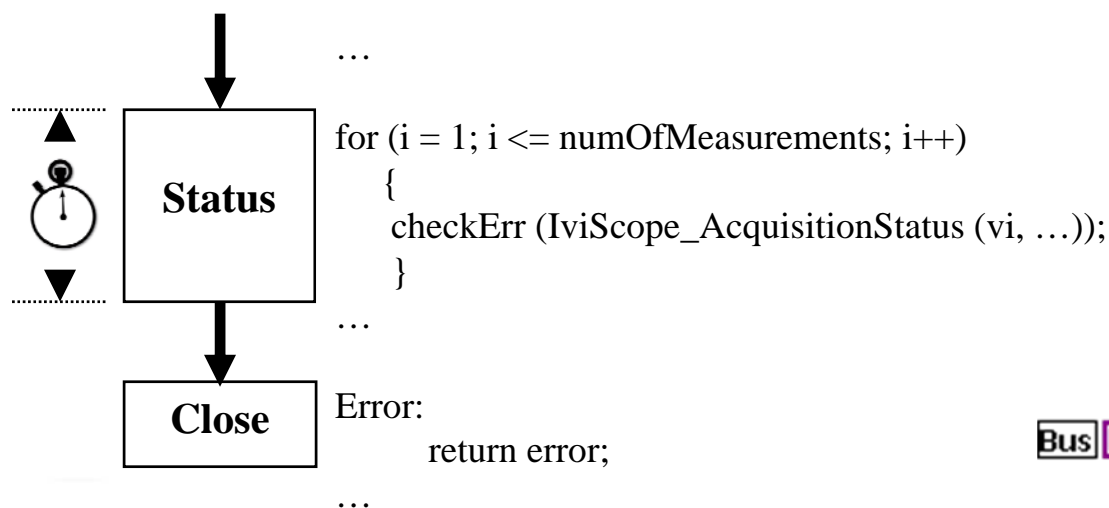
# Point-to-Point Ethernet Using a Switch



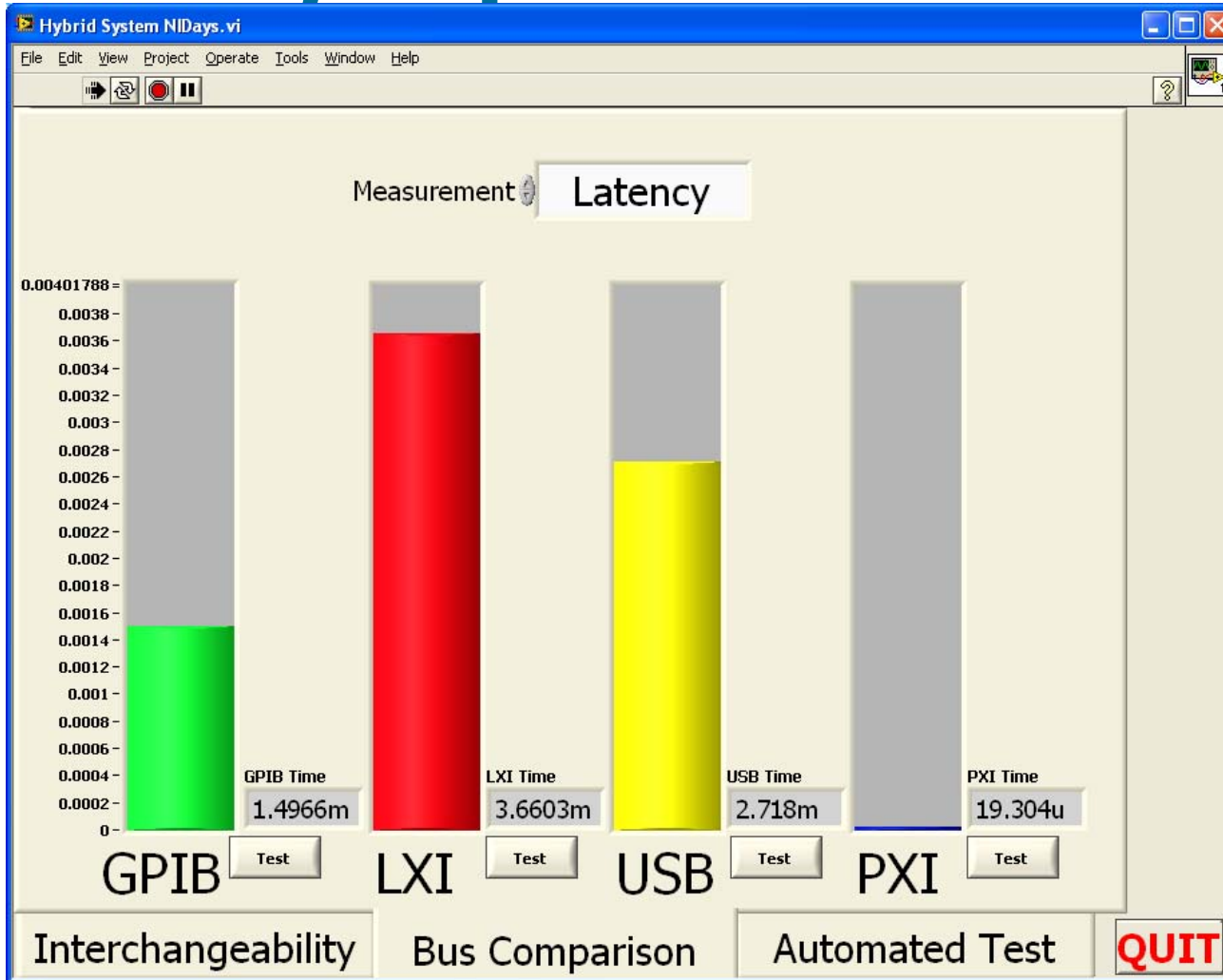
- Multiple point-to-point Ethernet networks
- Each device shares bus master with switch port on local link
- Collisions are resolved by queuing delays and jitter in switch

# 4. Latency Experiment

- Using identical IVI function for each bus
- Querying for acquisition status 100 times
- Timing with QP timer function (Windows kernel)



# Latency Experiment Results





# Test System for Comparison

## Application

- LabVIEW 8.20
- Identical IVI function calls



## OS and Hardware

- Windows XP
- Pentium processor
- Hi-Speed USB ports
- GPIB interface
- Ethernet via Gigabit switch

PCI (PXI)

LXI

Hi-Speed USB

GPIB (488.1)

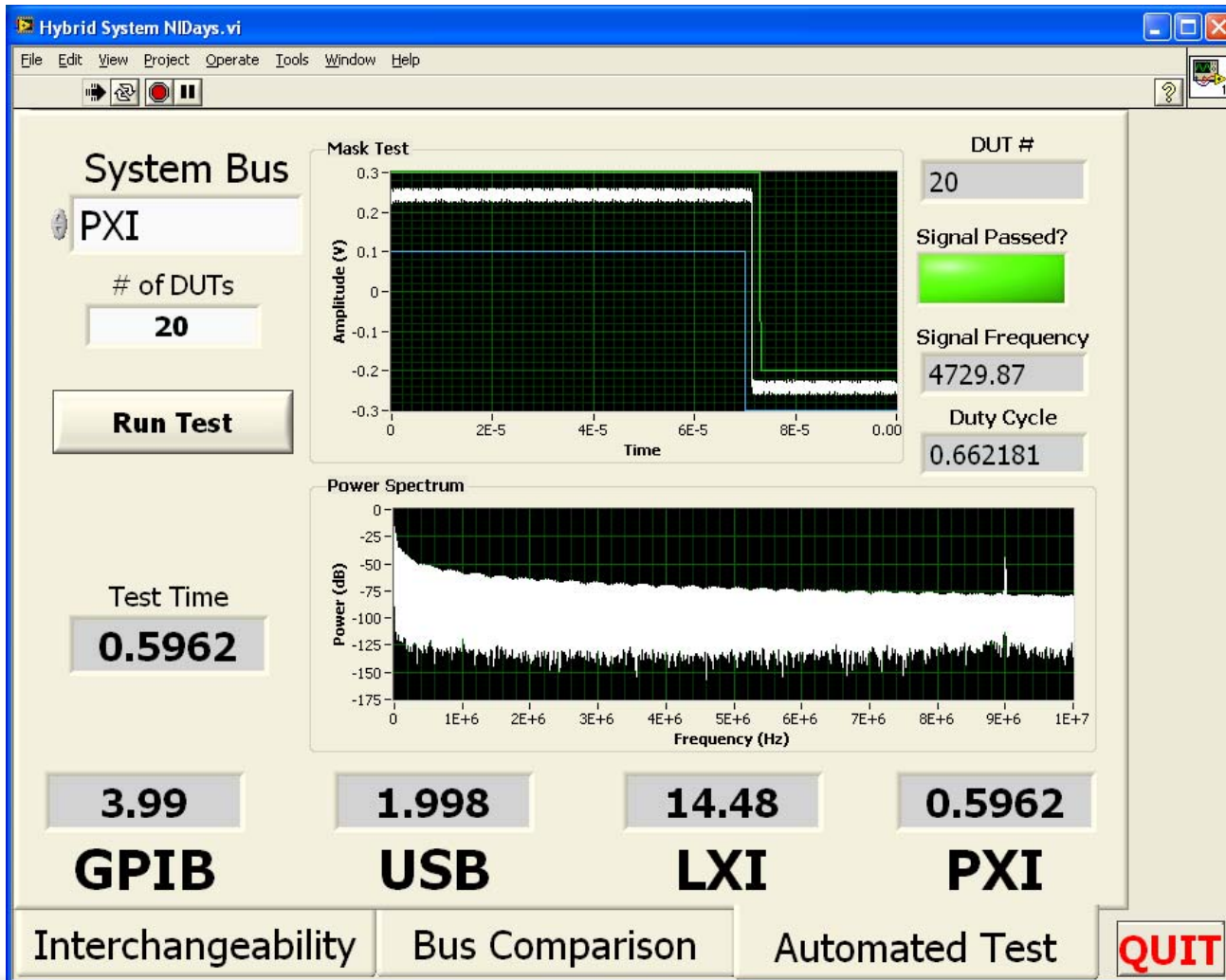
NI  
Arbitrary Waveform  
Generator

NI PXI  
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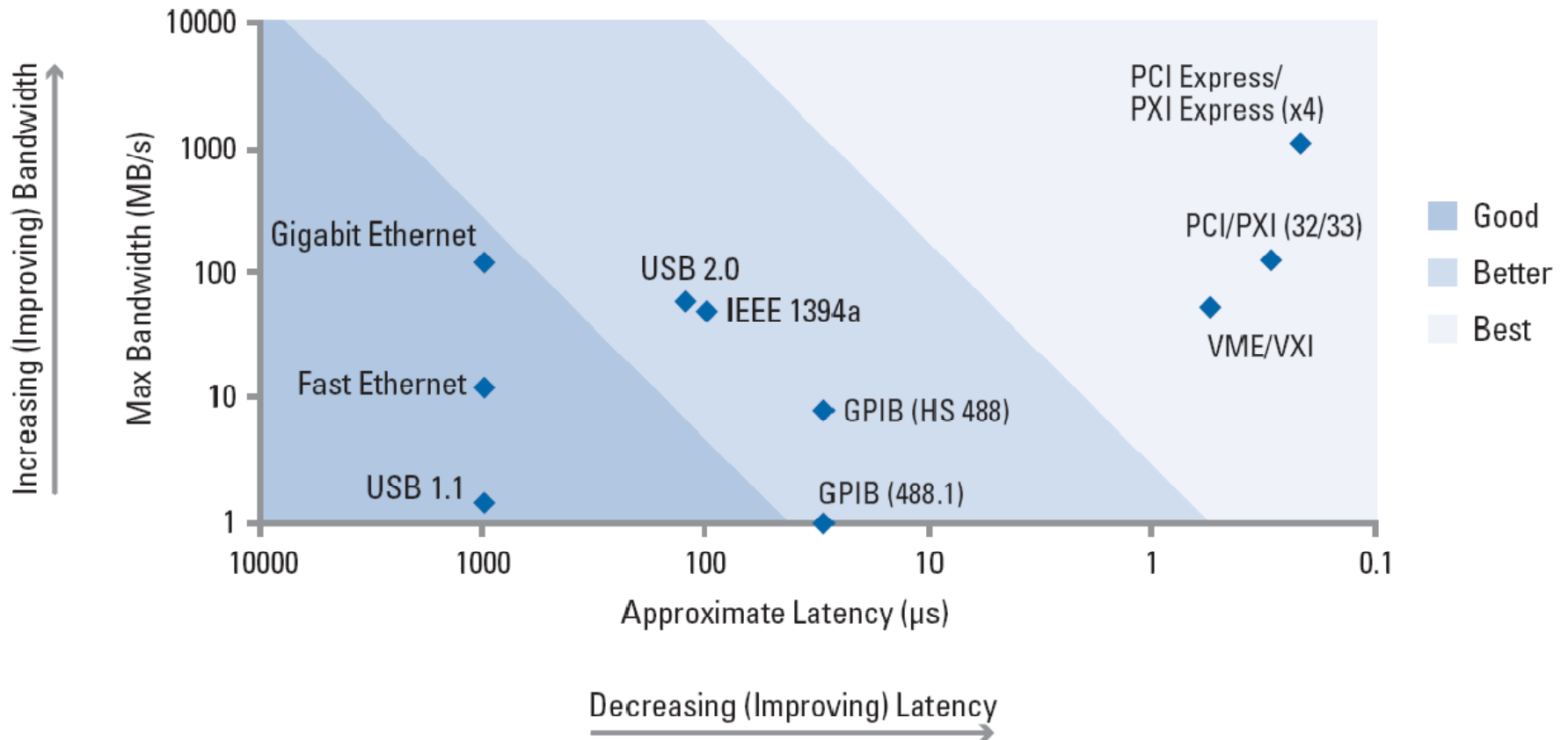
Agilent  
Arbitrary Waveform  
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Oscilloscope

# Automated Test Example



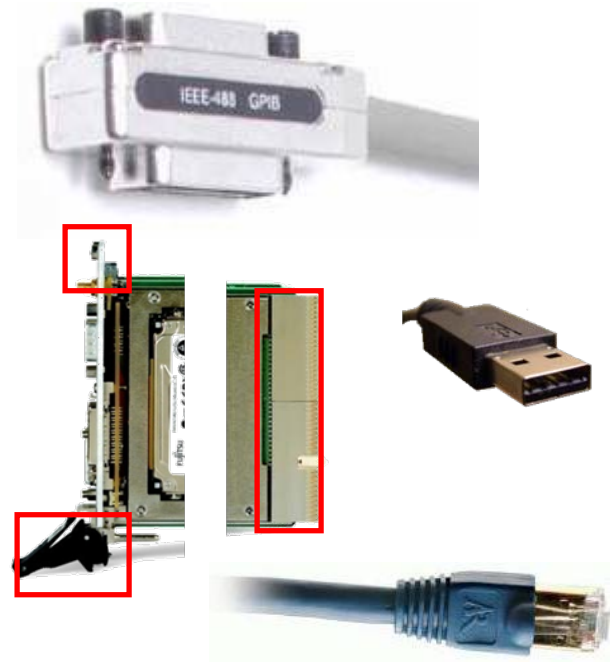
# Latency versus Bandwidth



## 4. 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

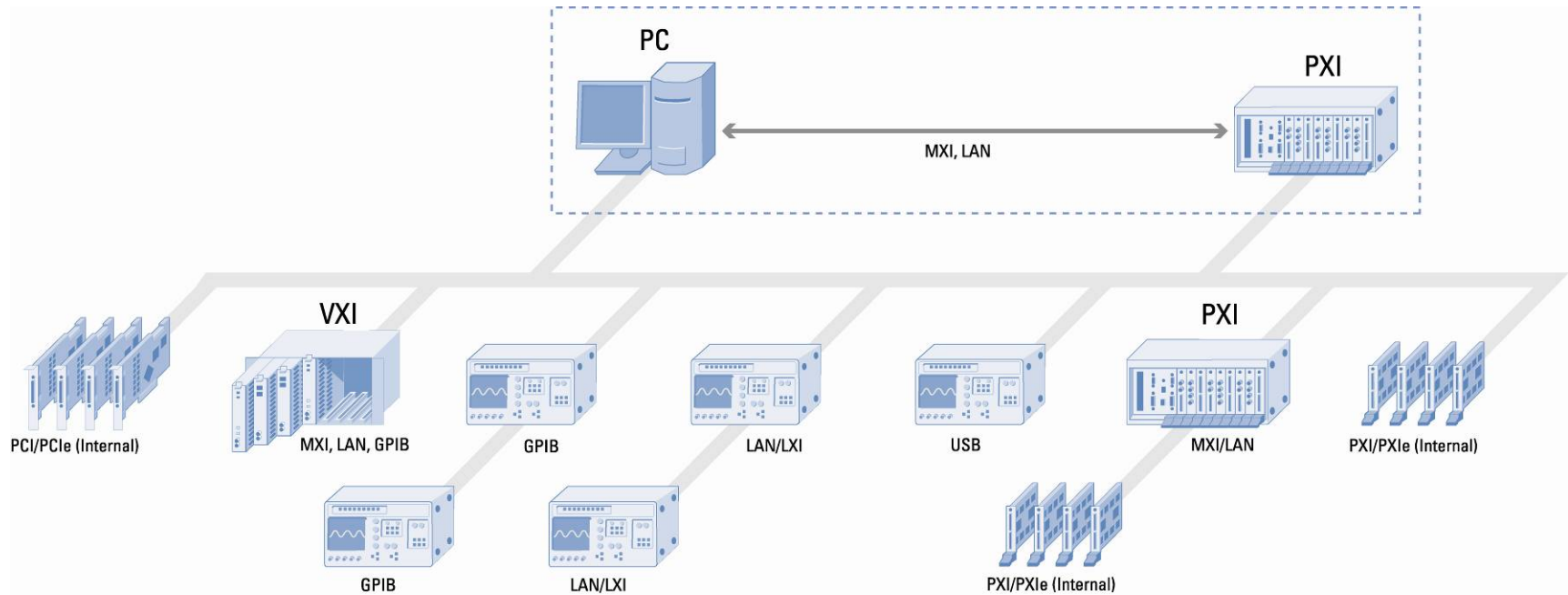
# 5. Ruggedness

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

# The Right Bus for Your Application

- No single bus technology solves all needs
  - GPIB → stand-alone instrument reuse, specialized instruments
  - PCI/PCI Express → best bandwidth and latency performance
  - PXI/PXI Express → best bandwidth and latency + timing and triggering
  - USB → autodetecting plug-and-play connectivity
  - Ethernet/LAN/LXI → distributed or remote systems
- Hybrid systems are often needed to integrate several technologies

# Hybrid Systems Provide Flexibility



# Layered Approach to Hybrid System

## System Management

- NI TestStand, DIAdem

## Application

- LabVIEW, LabWindows™/CVI,  
LabVIEW SignalExpress, VB, C, C++

## Measurement and Control Services

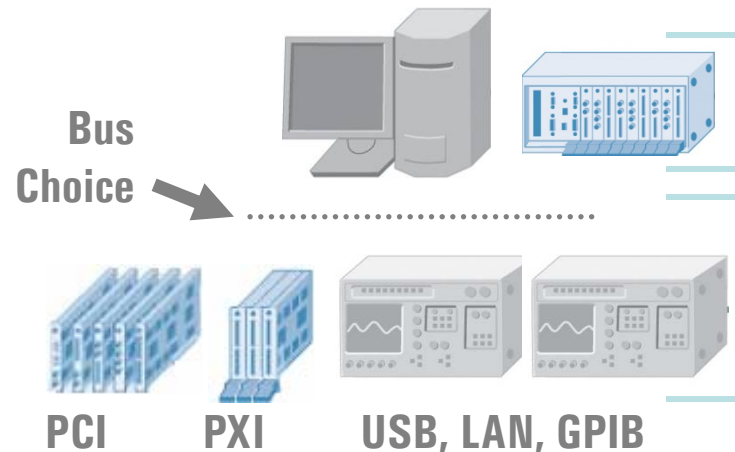
- VISA, LabVIEW PnP, IVI, MAX, NI-DAQmx

## Computing

- PXI, VXI, Desktop/Server/Laptop PC


## Device I/O

- Instruments, Data Acquisition, Vision, Motion





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