UiO : University of Oslo

FYS3240
PC-based instrumentation and microcontrollers

Computer buses and interfaces

Spring 2017– Lecture #7

Bekkeng 30.01.2017

Abbreviations

- B = byte
- b = bit
- M = mega
- G = giga = 10^9
- k = kilo = 1000
- K = 1024 (= 2^{10})

The most common data acquisition buses available today

- PCI
- PCI Express
- PXI
- PXI Express
- USB
- Ethernet

Internal PC bus

Some important bus parameters:

- Bandwidth (MB/s)
- Serial / Parallel
- Shared / dedicated resource
- Maximum bus length
- Latency (delay)

No bus is perfect for all needs and applications!

8b/10b encoding

- In telecommunications, **8b/10b** is a line code that maps 8-bit symbols to 10-bit symbols to achieve **DC-balance** and provide enough state changes to allow reasonable **clock recovery**.

- 8b/10b used in USB 3.0, SATA, PCI express, some Ethernet standards etc.

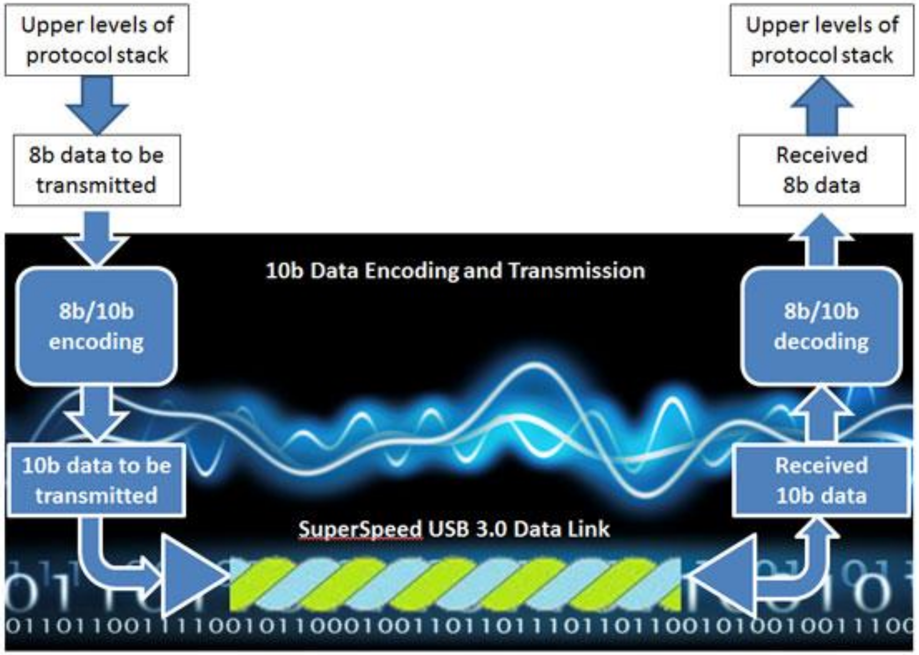
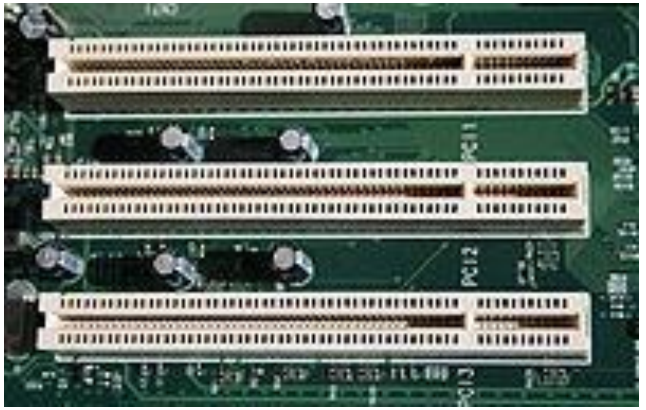
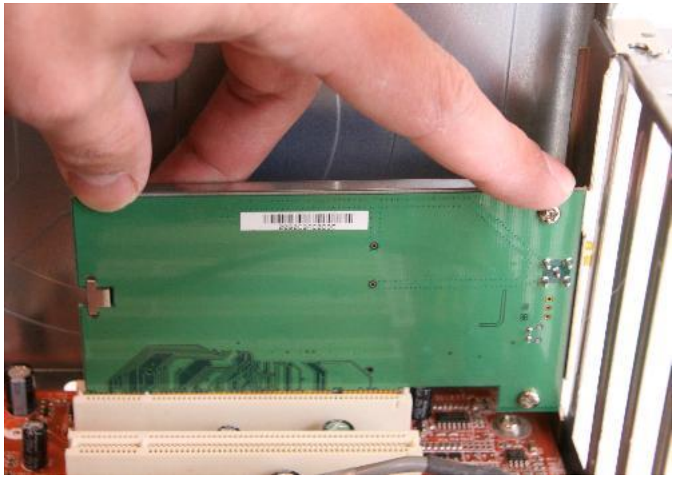


Figure from Lecroy



PCI

- PCI = (Peripheral Component Interconnect)
- Supports 32 and 64 bits
- <u>Shared</u> parallel bus!
- Maximum bandwidth (peak) of **132 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)



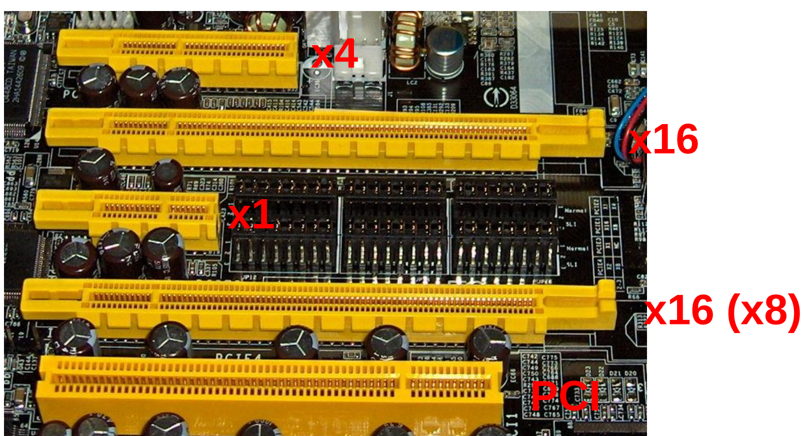
PCI Express (PCIe)

- 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
  - *v1: 250 MB/s (duplex) per lane*
  - *v2: 500 MB/s (duplex) per lane*
  - *v3: 985 MB/s (duplex) per lane*
  - *v4: 1969 MB/s (duplex) per lane*

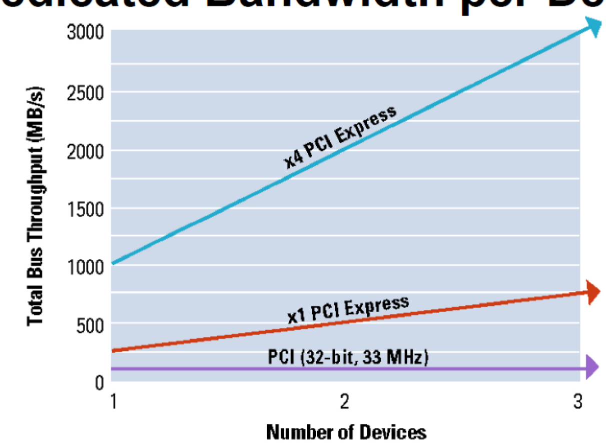
16 lane slot:

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

V4: 2014 - 2015

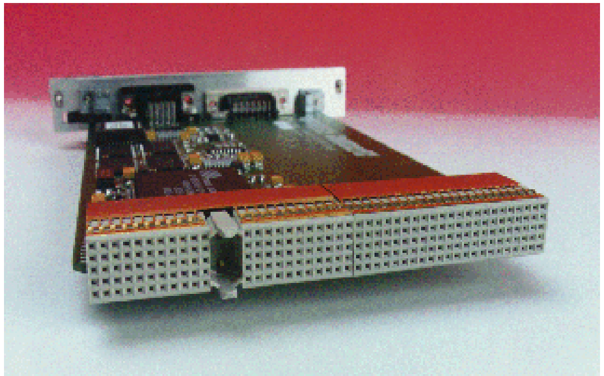


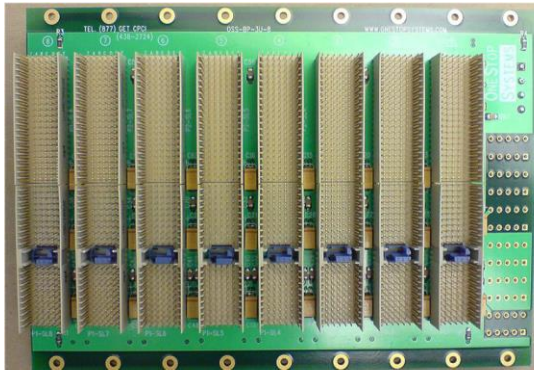
Dedicated Bandwidth per Device

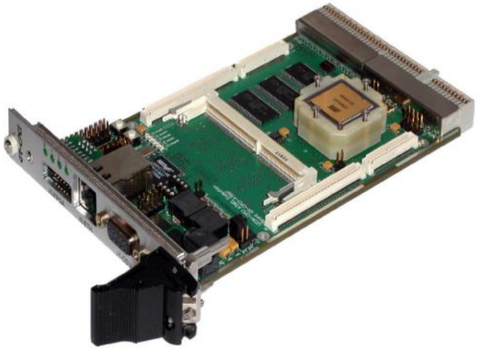


CompactPCI

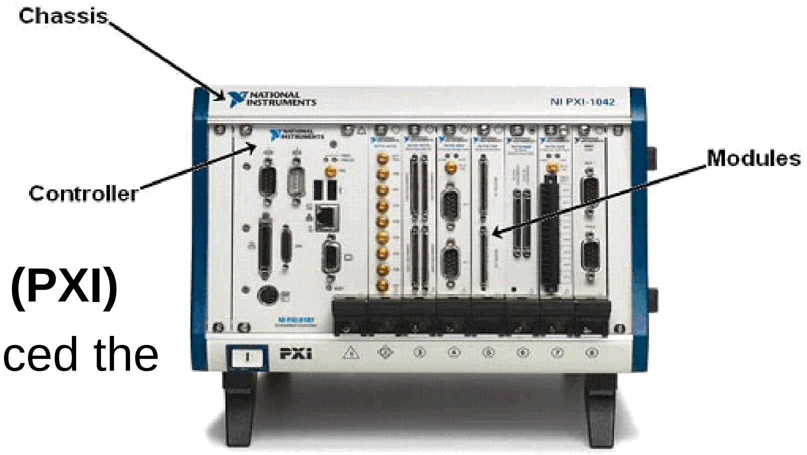
- It is electrically a superset of PCI with a different (smaller) physical form factor
- CompactPCI supports twice as many PCI slots
- Compact PCI cards are designed for front loading and removal from a card cage. The cards are firmly held in position by card guides on both sides, and a face plate which 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.







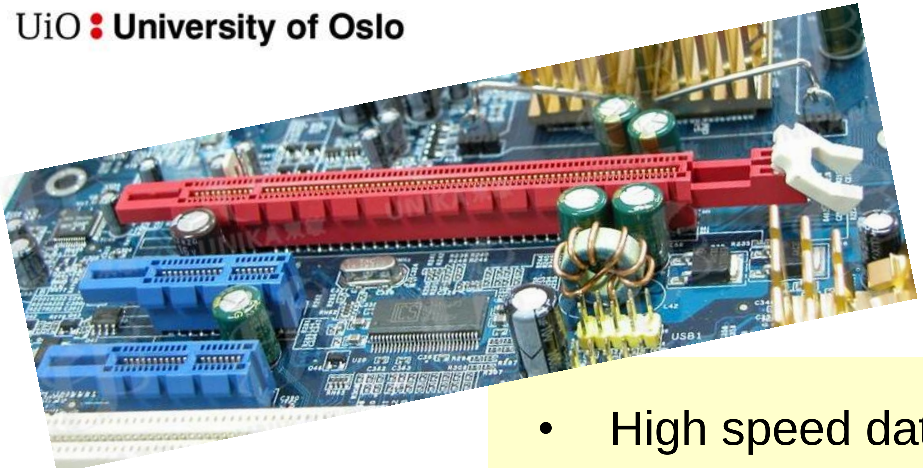
PXI and PXI-Express



- **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

ExpressCard

- Successor technology to PCMCIA and PC Card standards.
- Form factor of a peripheral interface designed for laptop computers
- Commonly used for DAQ cards, network cards and modems for laptops
- Serial bus
- 480 Mb/s (USB 2.0 mode) or 2.6 Gb/s (PCIe mode)



Towards serial buses
- PCI Express, USB, SATA ...

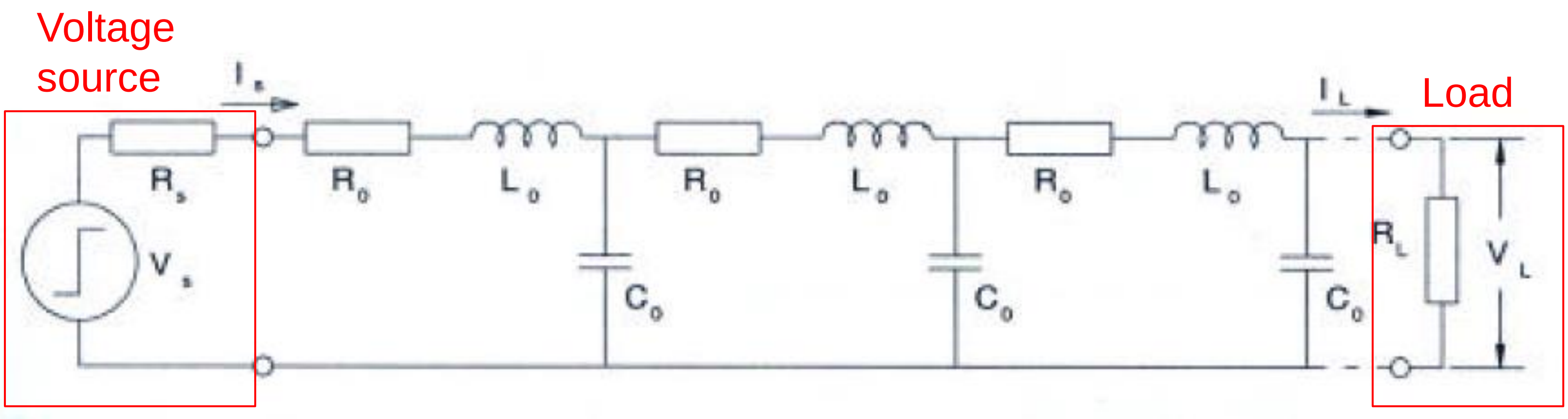
- High speed data transfer on long cables: the bits on different wires may not reach the receiver circuit exactly at the same time. Not the case on serial lines → may increase speed without problems
- Crosstalk between lines at high frequency is avoided by using one or two data lines only
- Hence, parallel 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, eSATA) and USB

External computer ports and buses

- RS-232
- RS-422
- RS-485
- USB
- FireWire (IEEE 1394)
- Thunderbolt

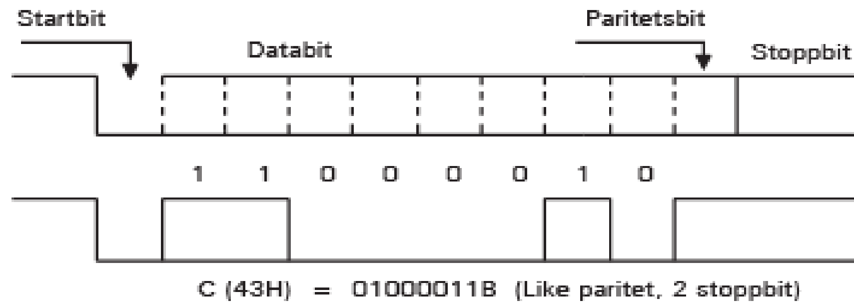
Not directly available on the computer, but a converter attached to USB or RS-232 can be used. Or get a PCI/PXI card

Transmission line equivalent circuit

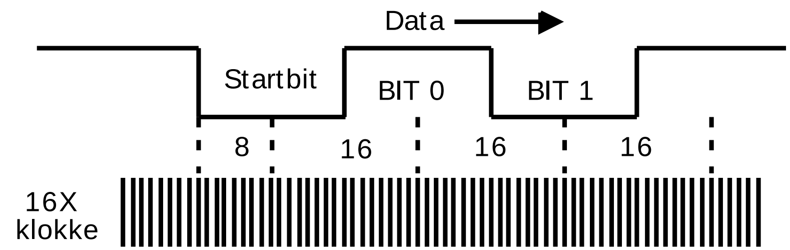


The source (sensor) resistance R_s and the total cable capacitance C ($n*C_0$) creates a low pass filter with cut off frequency $f = 1/(2\pi R_S C)$

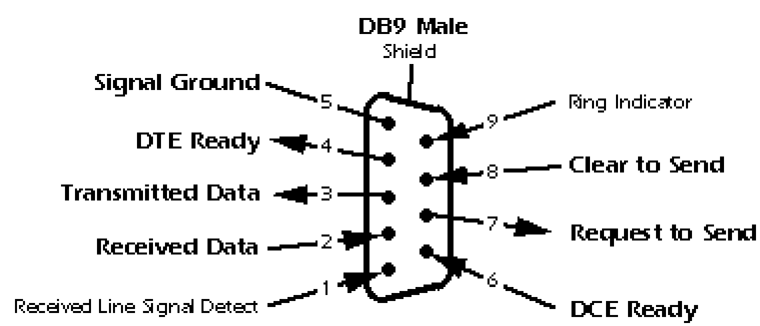
Serial port: RS-232



- 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 meters at full speed
  - depends on cable capacitance (2500 pF)
- Standard: max data rate about 20 kB/s
  - 115.2 kbits/s is common, 1 Mbit/s exist
- Minimal 3-wire connection is:
  - Rx, Tx and GND (two way data flow)
- Common ground (between transmitter and receiver)
  - Can create noise problems




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



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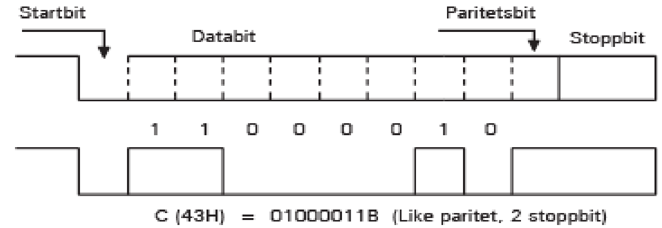
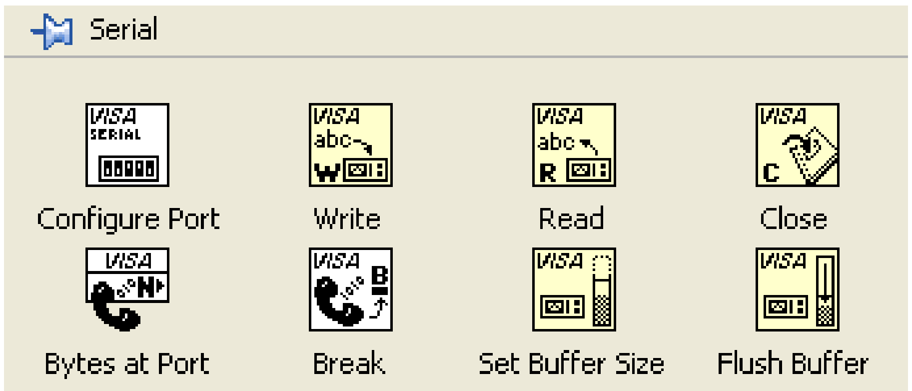
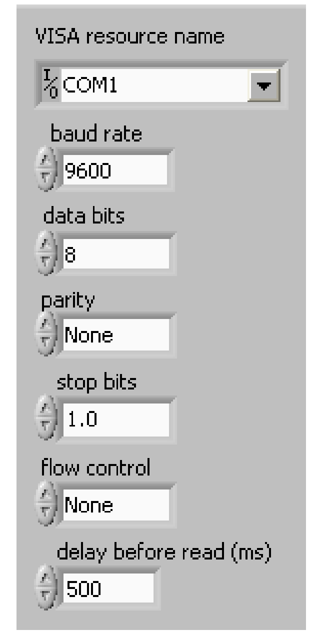
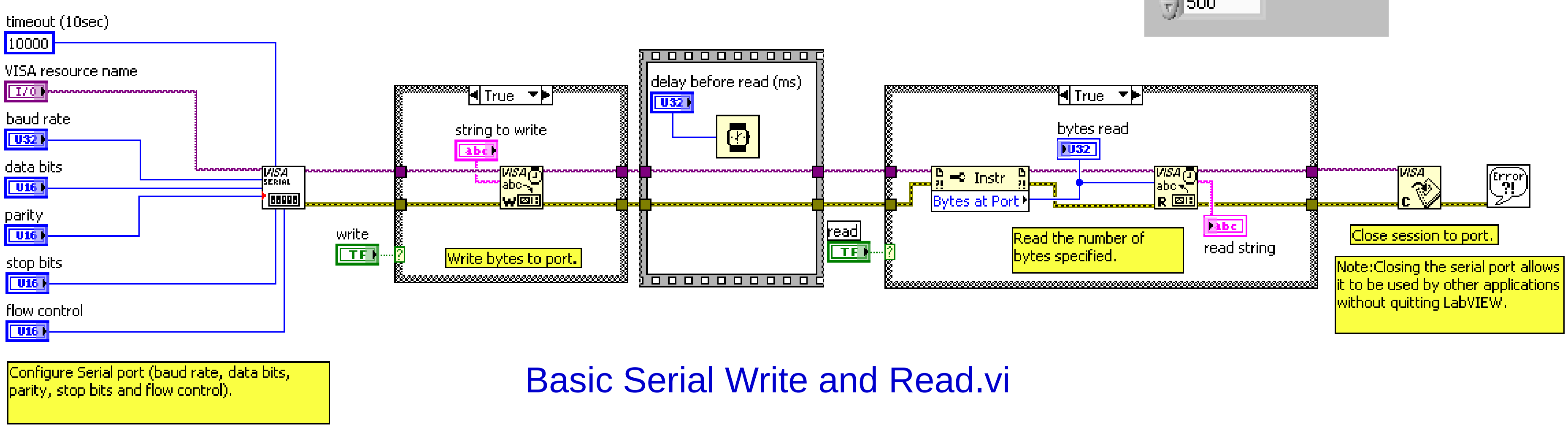
LabVIEW Serial: RS-232





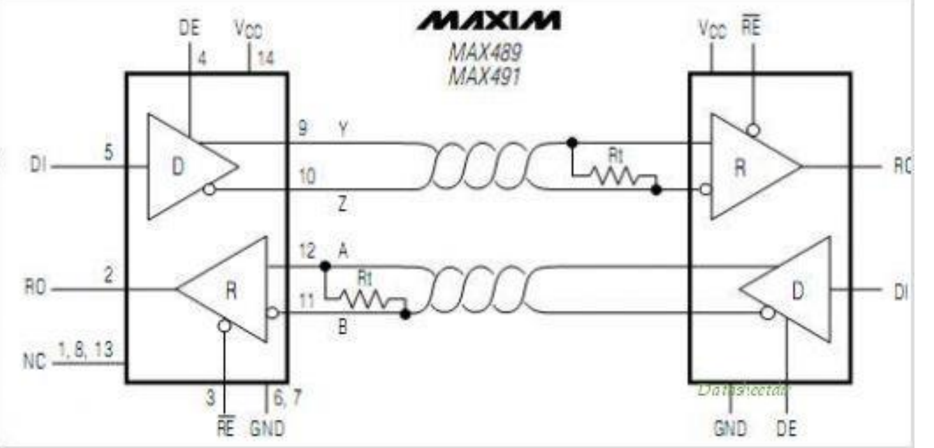




Basic Serial Write and Read.vi

RS-422

- Multi-drop interface with a single transmitter but multiple receivers
- 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 multiple 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**
  - 26 ns * $3*10^8$ m/s * 0.65 = 5.07 m (USB 2.0)

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

USB 3.0 Connector Pinouts[45]

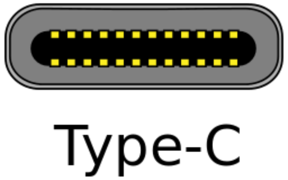
Pin	Color	Signal name ("A" Connector)	Signal name ("B" Connector)	Description
Shell	N/A	Shield		Metal housing
1	Red	VBUS		Power
2	White	D−		USB 2.0 differential pair
3	Green	D+		
4	Black	GND		Ground for power return
5	Blue	StdA_SSRX−	StdB_SSTX−	SuperSpeed transmitter differential pair
6	Yellow	StdA_SSRX+	StdB_SSTX+	
7	N/A	GND_DRAIN		Ground for signal return
8	Purple	StdA_SSTX−	StdB_SSRX−	SuperSpeed receiver differential pair
9	Orange	StdA_SSTX+	StdB_SSRX+	

- Power: 500 mA or 2.5 W (USB 2.0), 900 mA or 4.5 W (USB 3.0)
- Increase the cable length up to 30 m by using:
  - USB repeaters (up to five repeaters)
  - Active Cables (bus-powered)

New USB standards in 2015

- *USB 3.1 Gen2: 10 Gb/s*

- *USB Type C*
  - a new small reversible-plug connector for USB devices
  - up to 100 W power supported

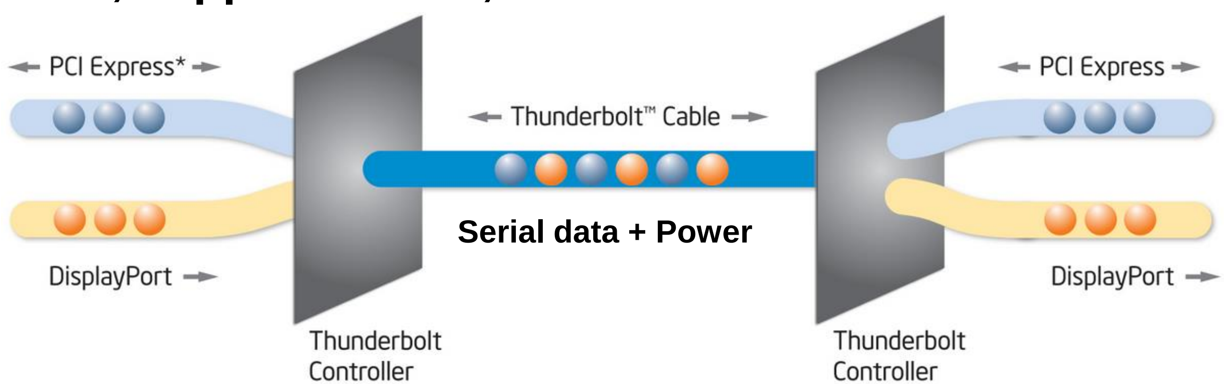


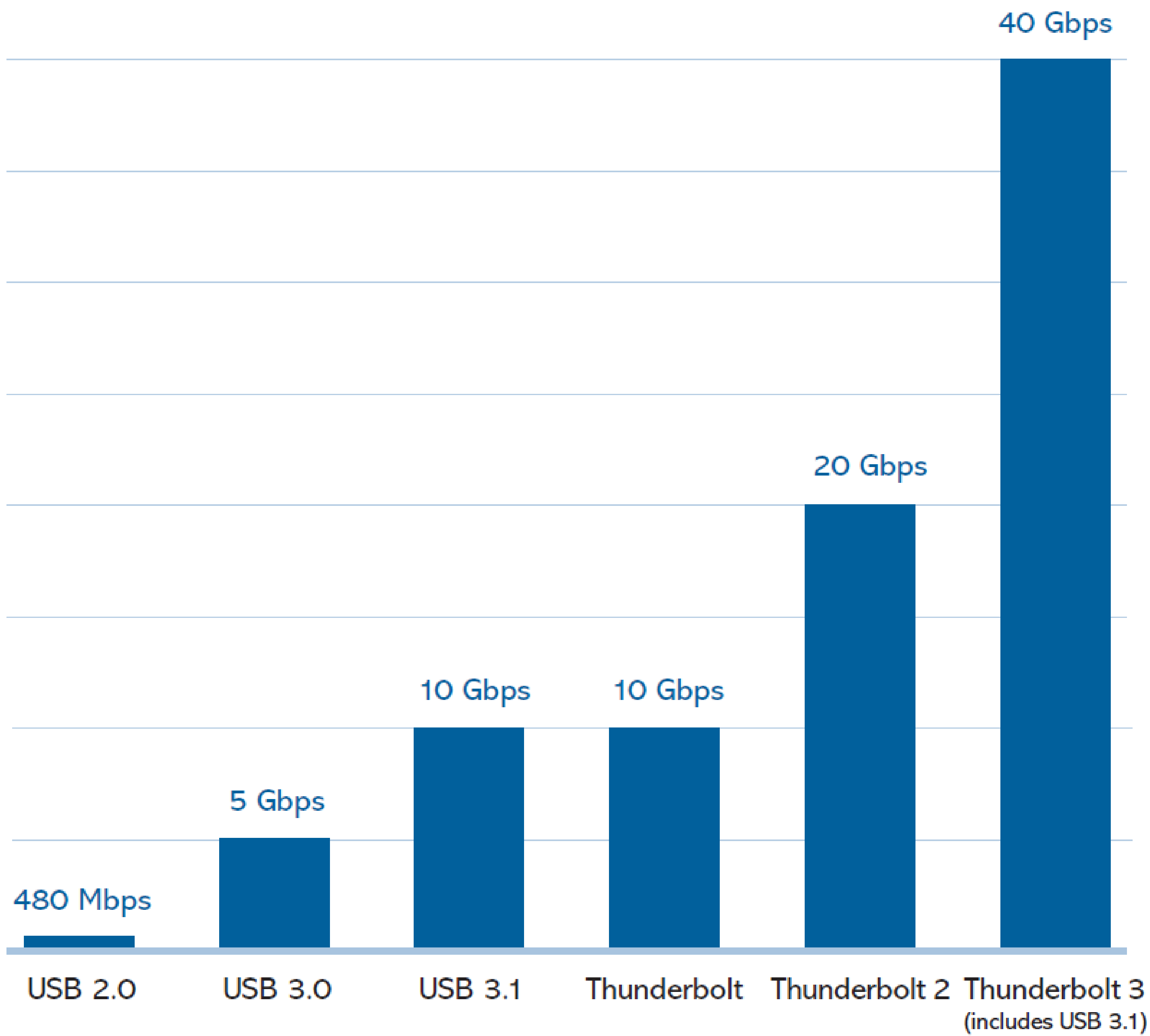
Thunderbolt

- Developed by Intel.
- Commercially introduced by Apple
  - *Introduced on Apple MacBook Pro in 2011*
- The connector is Mini DisplayPort (electrically identical to DisplayPort)
- **Bi-directional 20 Gb/s**
  - **Thunderbolt v1: 10 Gb/s on two channels in each direction**
  - **Thunderbolt v2: 20 Gb/s on one channels in each direction**
  - Power: 550 mA, 18 V (9.9 W) for v1 and v2
- Combines PCI Express and Display Port
- **Maximum cable length of 3 meters** (100 m with optical)
- Can daisy chain up to 6 devices
- **Thunderbolt v3: 40 Gb/s, support USB-C, 100 W charging**

Mini DisplayPort

Mini DisplayPort on a MacBook Pro




40 Gbps
20 Gbps
10 Gbps
10 Gbps
5 Gbps
480 Mbps
USB 2.0
USB 3.0
USB 3.1
Thunderbolt
Thunderbolt 2
Thunderbolt 3
(includes USB 3.1)

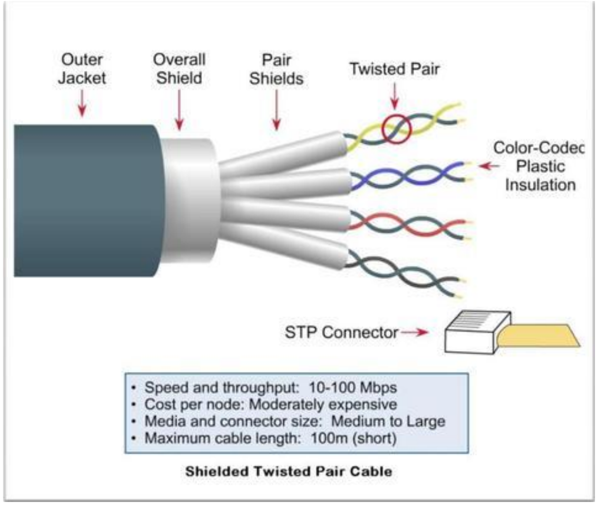
Ethernet network

RJ45

- **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
    - Can also use converters and fiber optic cables to extend to many kilometers
  - Must use Category 5 cable or better (4 twisted, usually unshielded) pairs)
- Must configure an IP-address and a subnet

Ethernet network II

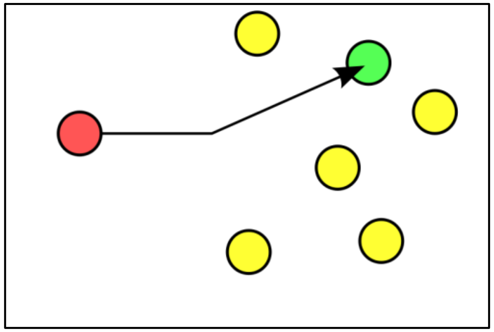
- Category 6 cable (Cat 6)
  - today standard for Gigabit Ethernet
  - backward compatible with the Category 5/5e
  - suitable for 10-Gigabit Ethernet (10GBASE-T)
- PC connection to an Ethernet network
  - **NIC** (Network Interface Controller/Card) for PCI or PCIe
  - Every NIC has a unique 48-bit serial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



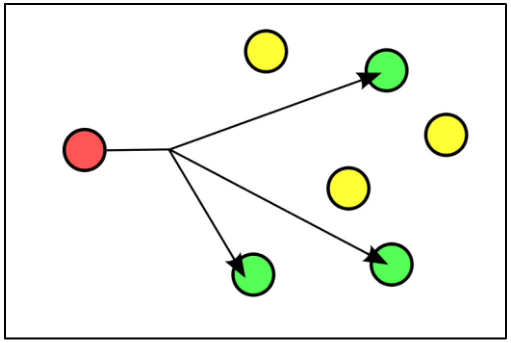
PCIe x4
dual port NIC

Unicast, multicast and broadcast

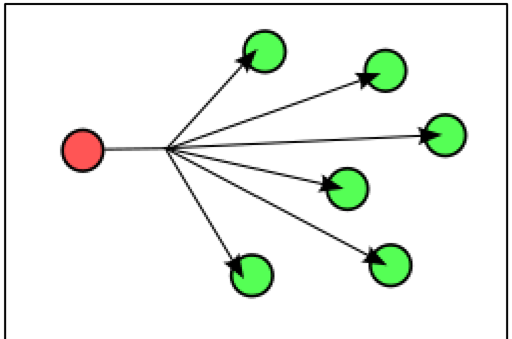
- Unicast
  - Sending of messages (packages) to a single network destination identified by unique address.



- Multicast
  - A transmission to a group on the network
  - To receive data a client must join the multicast group
  - Multicasting uses the **IGMP** (Internet Group Management Protocol) and requires an IGMP-compliant switch



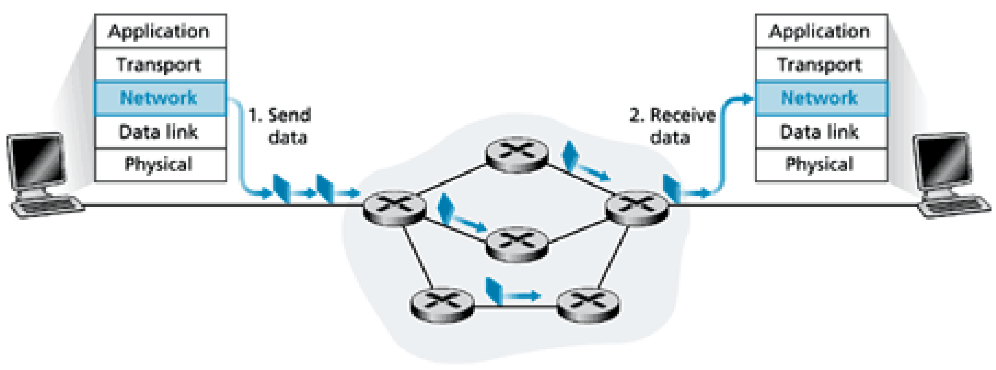
- Broadcast
  - Transmitting the same data to all possible destinations (every device on the network)



LAN

- A **local area network (LAN)** is a computer network that connects computers and devices in a limited geographical area
  - usually high data-transfer rates

- Ethernet is the most commonly used LAN technology



IP and TCP

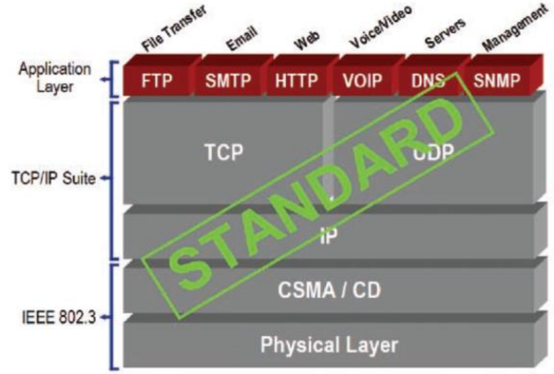
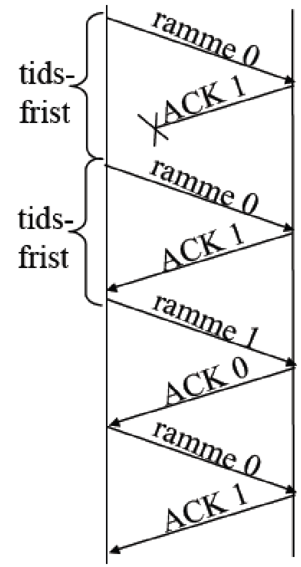


Figure 1- Standard, unmodified Ethernet stack

- TCP and IP are two of the most important communication protocols used for the Internet
- TCP = Transmission Control Protocol, IP = Internet Protocol
- TCP complements the Internet Protocol (IP), which is unreliable
- **TCP/IP**: IP handles addressing and routing of message, <u>while TCP provides a reliable and in sequence data delivery </u>without errors, loss (no packets are lost) or duplication
- TCP:
  - Flow control (does not send data faster than the receiver can read)
  - Saturation control (slower transmission when network problems)
  - Retransmission of data when needed (data lost or not acknowledged in time)
- Example of use of TCP/IP: File transfer (FTP), HTTP

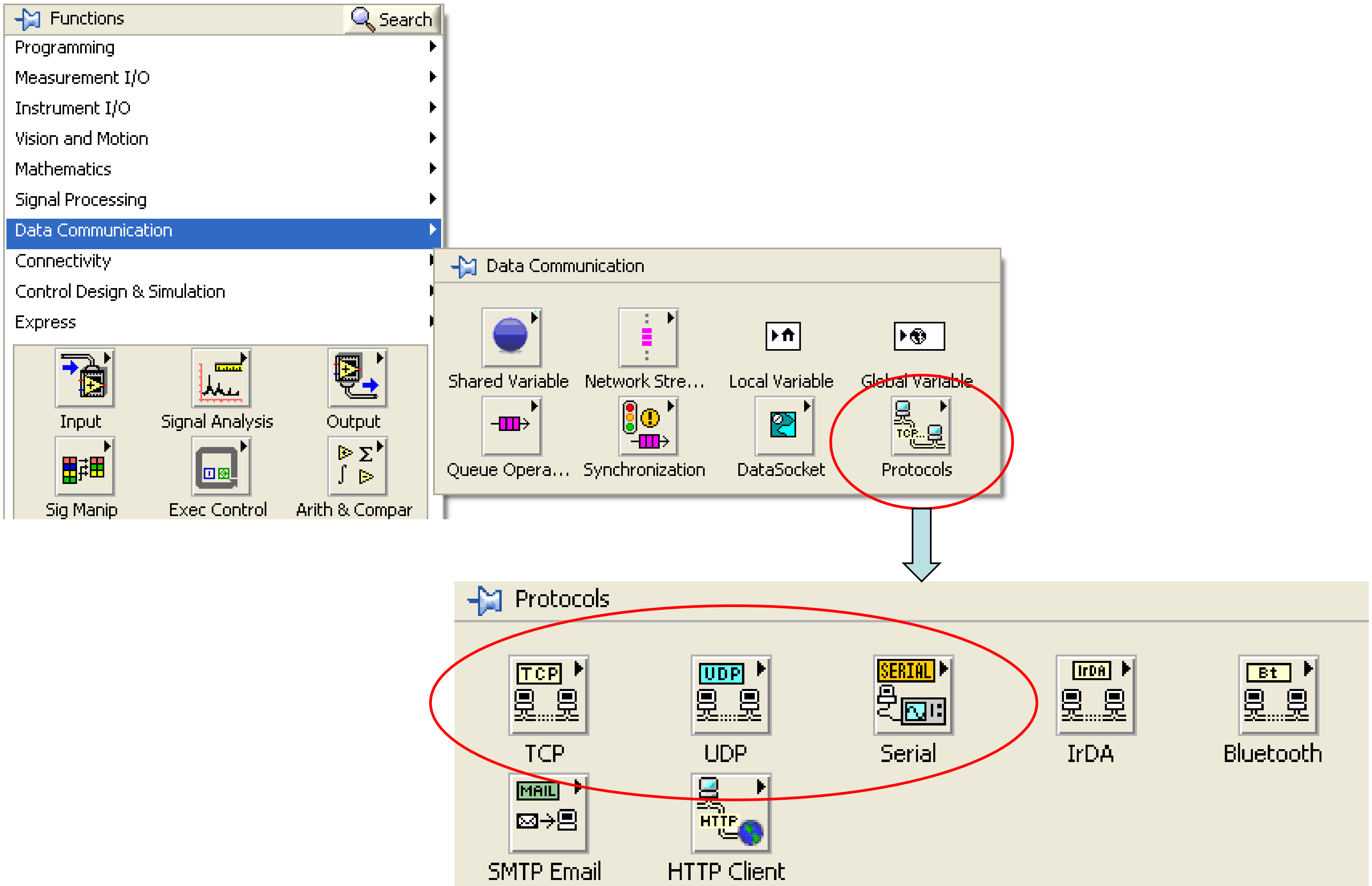


TCP

- TCP is a connection-based protocol, which means that a connection must be established before transferring data
  - Data transmission occurs between a client and a server
  - TCP permits multiple, simultaneous connections

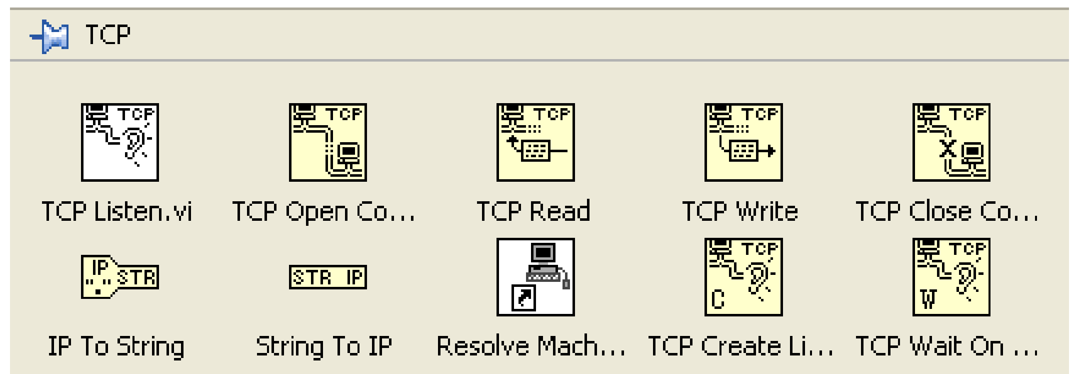
- In order to establish a TCP connection you have to specify **an address** and **a port** at that address
  - The port numbers allow different applications on the same computer to share network resources simultaneously
  - In TCP (and UDP) port numbers start at 0 and go up to 65535. Numbers in the lower ranges are dedicated to common Internet protocols (like 21 for FTP and 80 for HTTP).

LabVIEW Data Communication

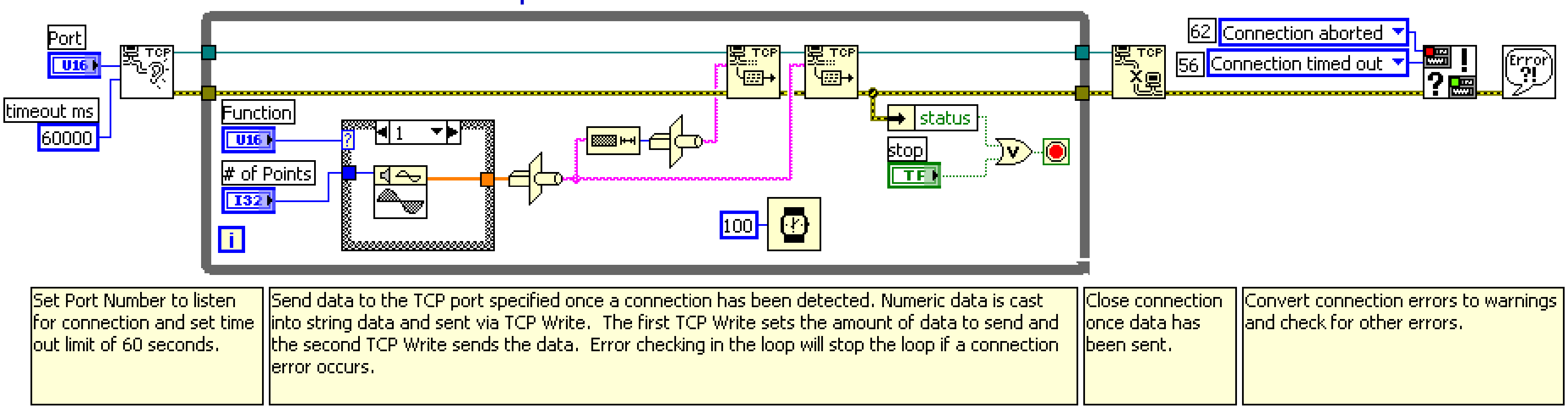


LabVIEW TCP Example

Demonstrates how to set up a TCP connection, and send data to a specified port once a connection (from a client) has been established



Simple Data Server.vi



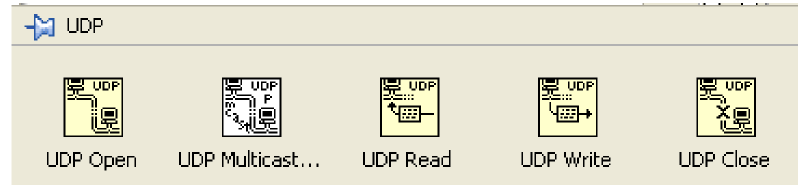
UDP

- Used for broadcast and multicast of data
- **Not reliable (packets can be lost)**
- UDP:
  - No flow control
  - No saturation control
  - No retransmission of data
- **UDP share the same delivery problems as IP**
- **However,**
  - UDP does not wait to confirm a connection before data transmission, and therefore no delay is introduced
  - Small overhead (compared to TCP)
  - UDP send rate only limited by the rate of data generation, CPU, clock rate and access to Internet bandwidth

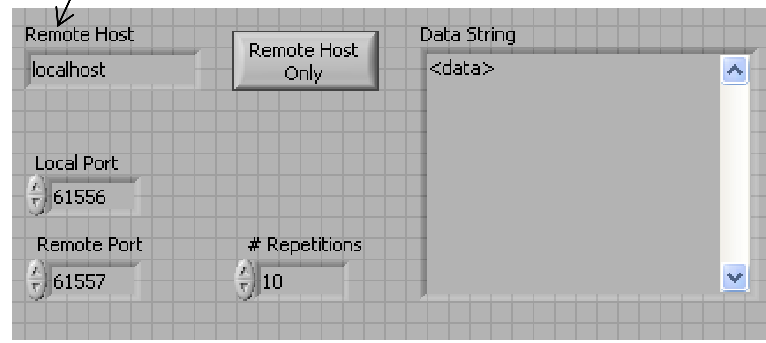
UDP is fast

- Example of use of UDP:
  - Video-conference (video distribution)
  - Sensor data distribution
  - NTP (network time protocol)

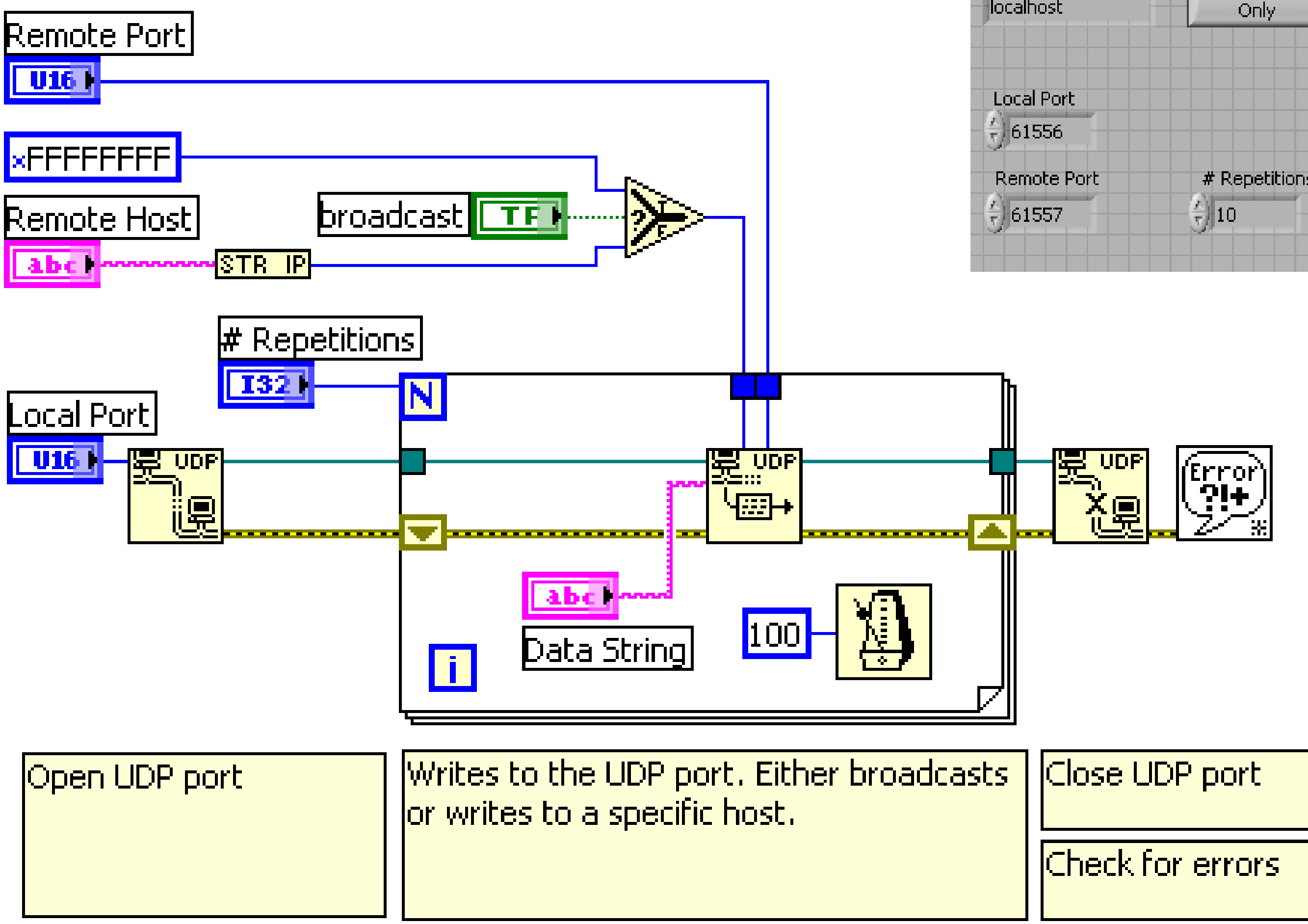
LabVIEW Example: UDP Send



localhost = this machine; IP = 127.0.0.1 (used for testing)



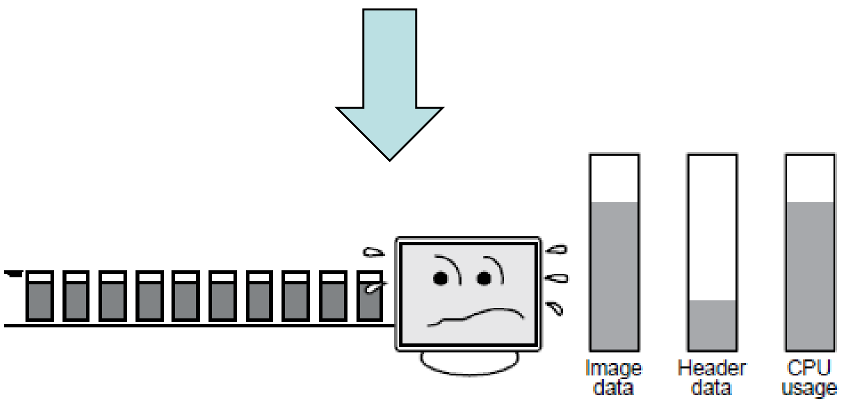
UDP Sender.vi



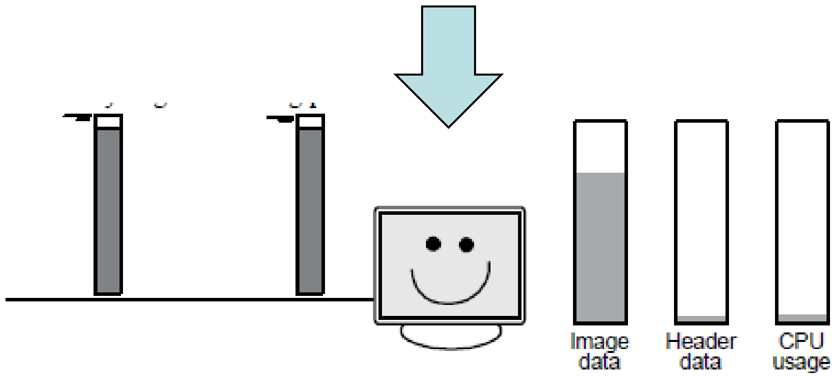
UDP broadcast address: 255.255.255.255

Jumbo frames

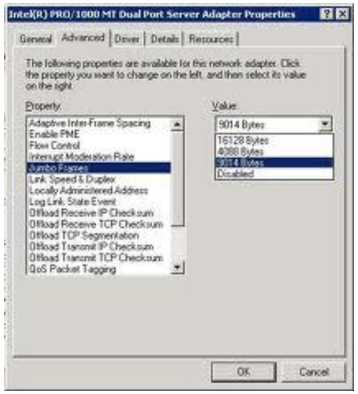
- In the early days of networking the maximum packet (frame) size was 1518 bytes.
- With today's high transmission rates, the task of analyzing each packet can overwhelm the CPU.



- By using jumbo packets, you can transmit the same amount of data with fewer packets.
- Though you save a small amount of bandwidth (by using fewer headers), you dramatically reduce CPU usage because your PC spends less time analyzing packets.

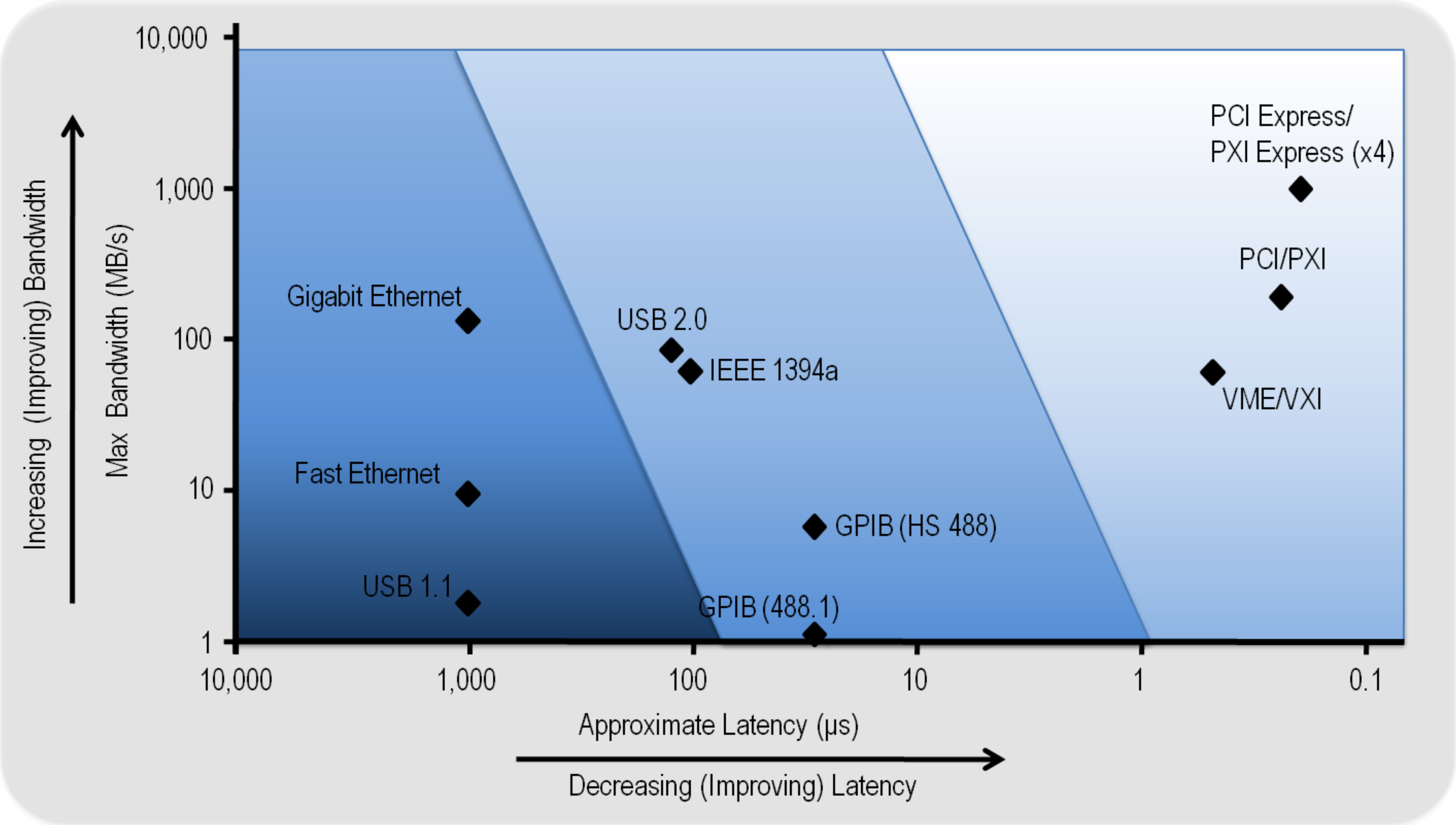


A common jumbo frame size is 9 kB (8192 bytes is often used), though IPv4 supports jumbo packets up to 64 kB. Make sure that your NIC supports jumbo frames



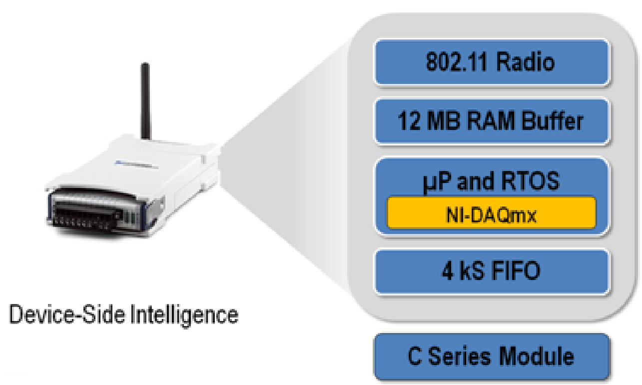
LAC - Configure

Bus bandwidth and latency

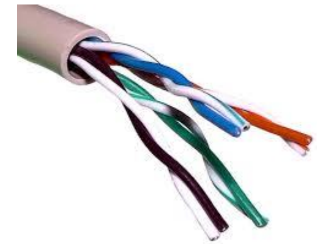


Wireless networks

- Pros
  - With Wi-Fi and Ethernet DAQ devices you can perform remote measurements at distances as far reaching as the wireless network allows
  - Can be used where wiring is difficult or cost-prohibitive
  - Flexibility
- Cons
  - “Low” bandwidth
  - Less reliable than a cabled connection
  - Possible security restrictions



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.
- Twisted pairs also minimize loop area – minimize inductance coupling (remember Faraday's law)

Integral form

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$