Computer buses and interfaces

The most common data acquisition buses available today

- PCI
- PCI Express

Internal PC bus

- PXI
- PXI Express
- USB
- Ethernet

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.

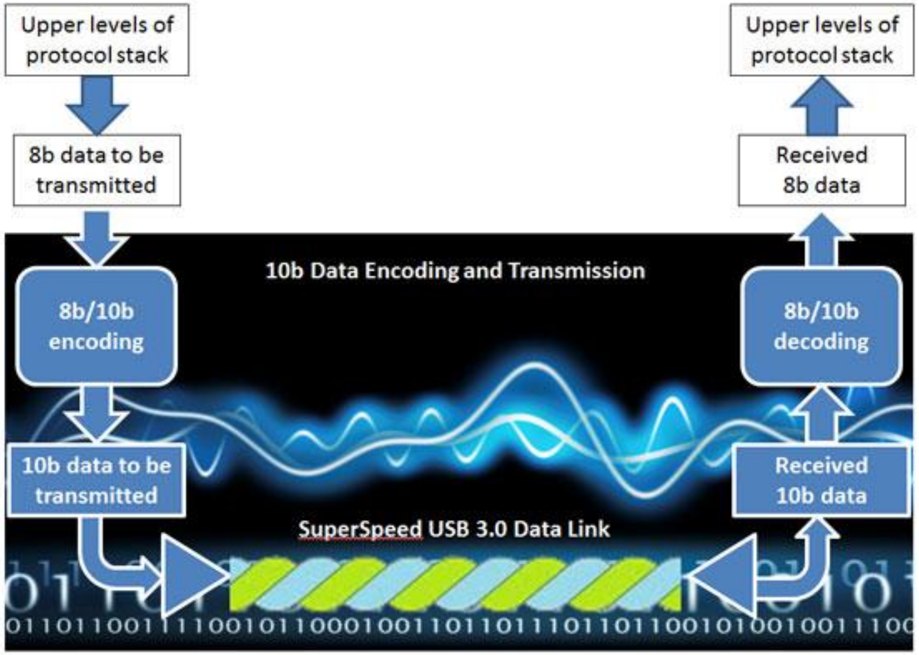
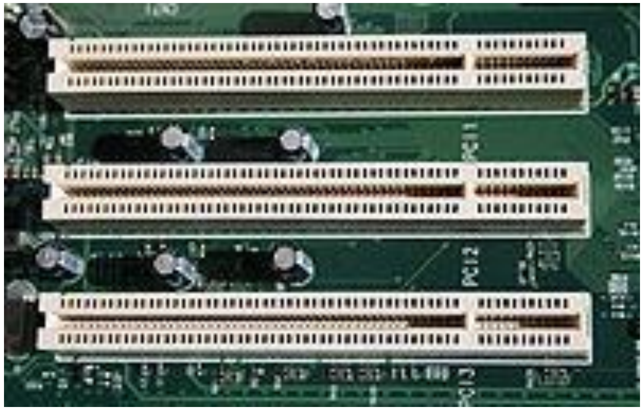
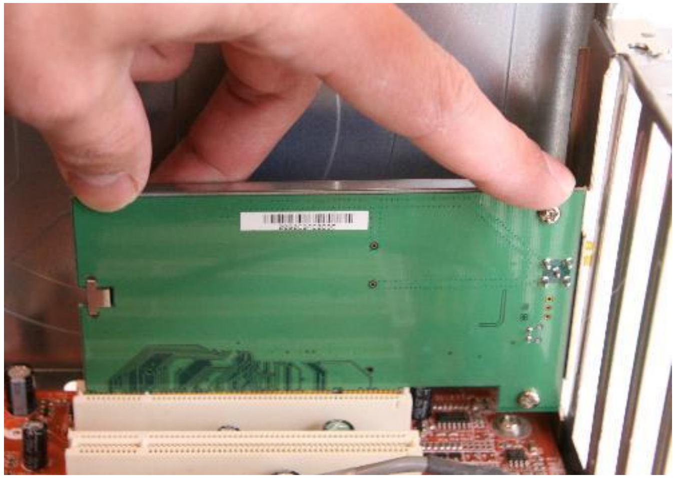


Figure from Lecroy

PCI



- PCI = (Peripheral Component Interconnect)
- Supports 32 and 64 bits
- Shared 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)



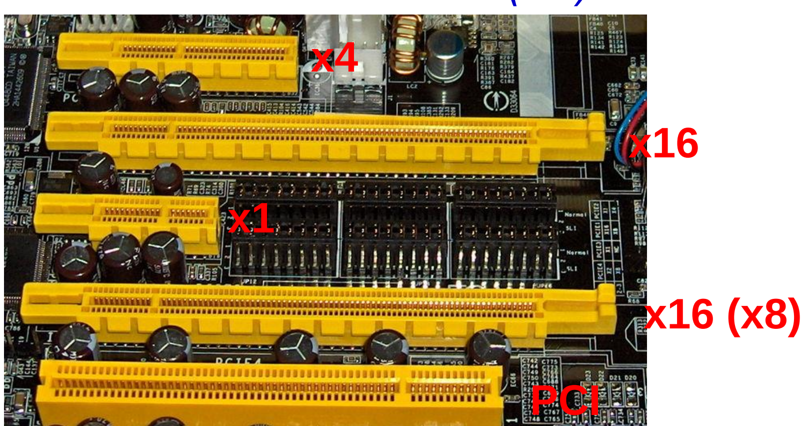
PCI Express (PCIe)

- 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 bandwidth 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*
  - *v5: 3.938 GB/s (×1)*

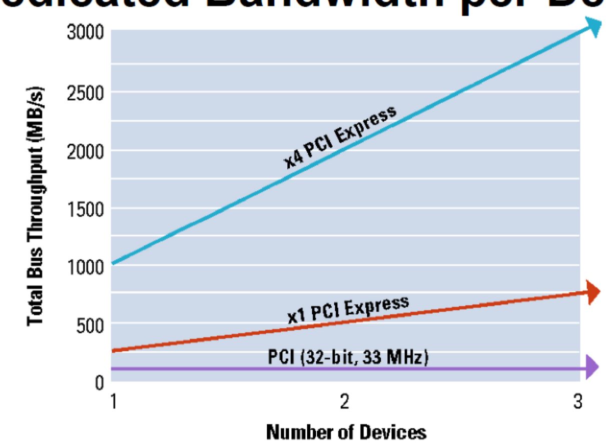
16 lane slot:

- **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.:31.51 GB/s
v5: 63 GB/s

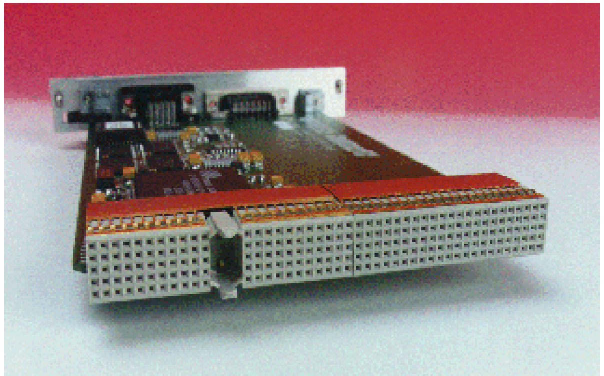


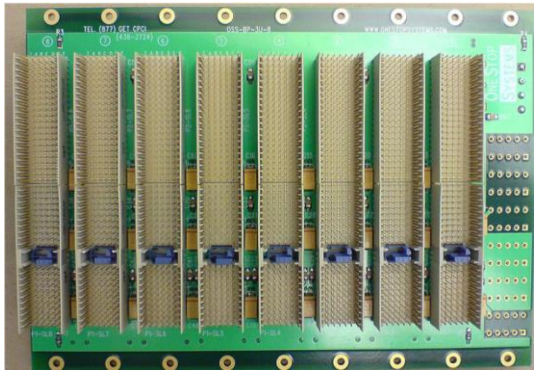
Dedicated Bandwidth per Device

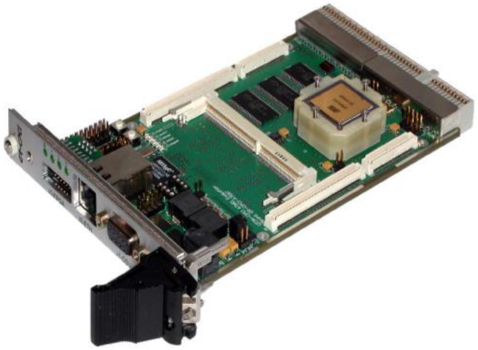


CompactPCI

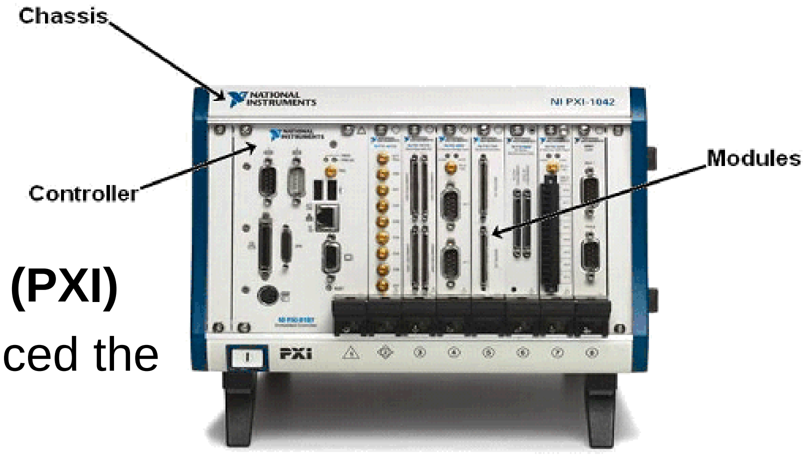
- It is electrically a superset of PCI with a different (smaller) physical form factor
- CompactPCI supports twice as many PCI slots
- Compact PCI cards are designed for front loading and removal from a card cage. The cards are firmly held in position by card guides on both sides, and a face plate which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







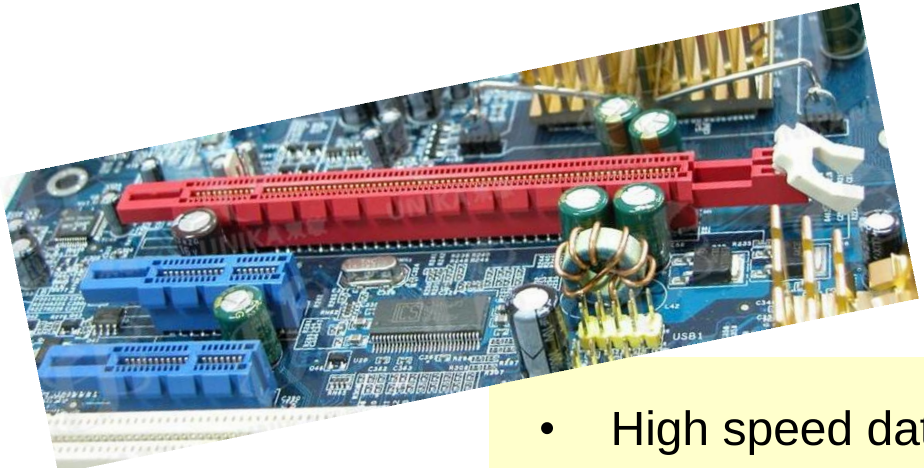
PXI and PXI-Express



- **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 ...

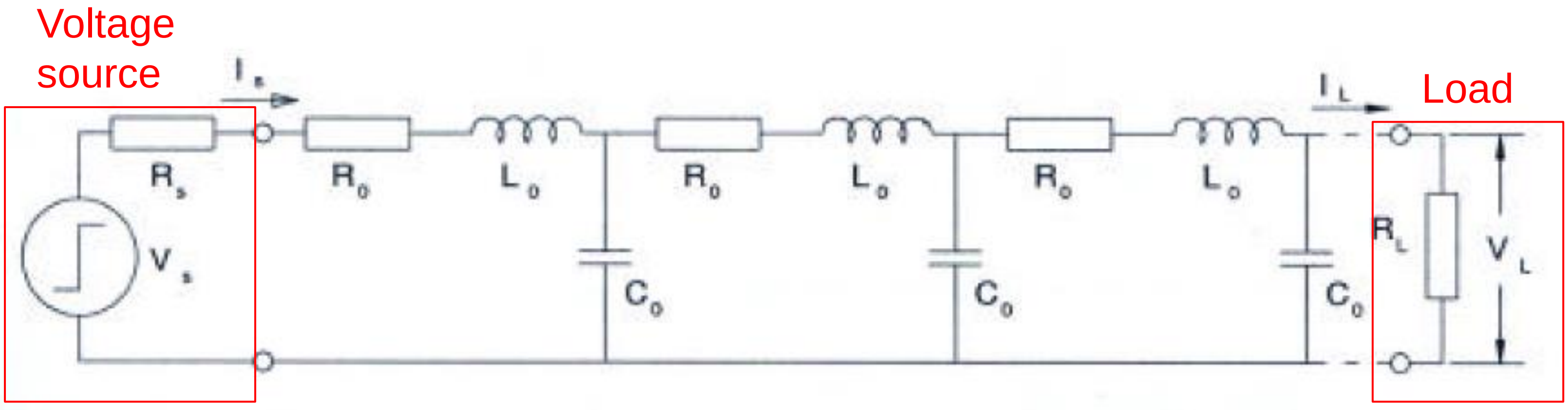
- High speed data transfer on long cables: the bits on different wires may not reach the receiver circuit exactly at the same time. Not the case on serial lines → may increase speed without problems
- Crosstalk between lines at high frequency is avoided by using one or two data lines only
- Hence, parallel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

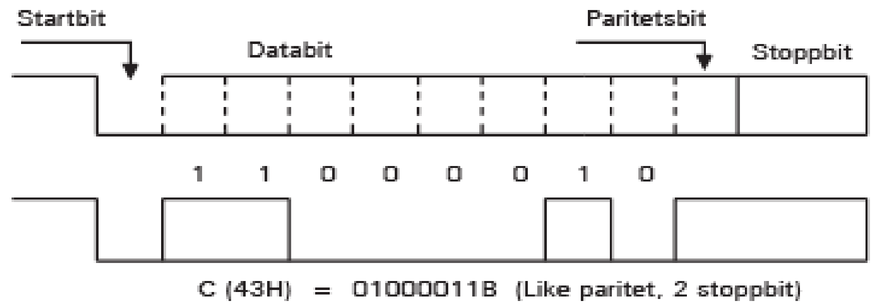
Not directly available on the computer, but a converter attached to USB or RS-232 can be used. Or get a PCI/PXI card

Transmission line equivalent circuit



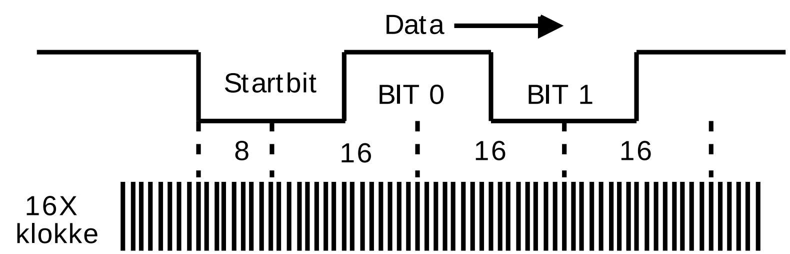
The source (sensor) resistance R_s and the total cable capacitance C ($n*C_0$) creates a low pass filter with cut off frequency $f = 1/(2\pi R_S C)$

Serial port: RS-232

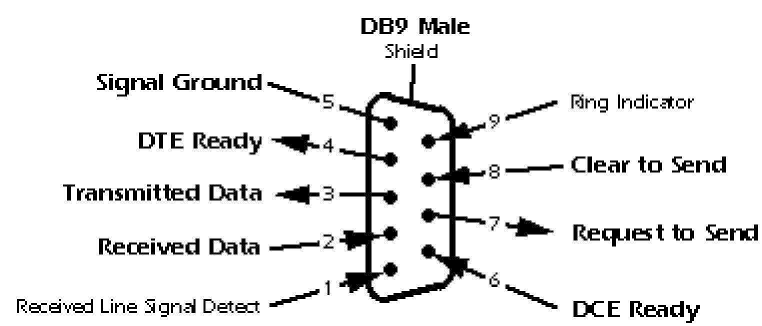


- Point-to-point interface
- Single-ended data transmission
- Common bit frequencies are from 9.6 kHz up to 115.2 kHz (or higher)
- Maximum cable length (rule of thumb) is about 15 -20 meters at full speed
  - depends on cable capacitance
- Maximum data rate about 20 KBit/s
- Minimal 3-wire connection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

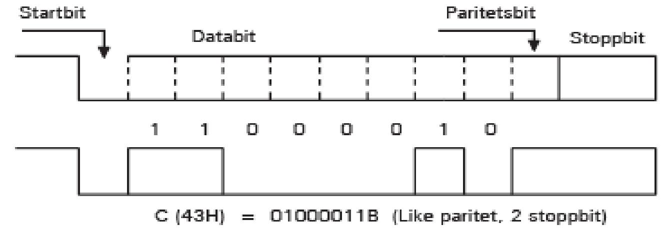
- Common ground (between transmitter and receiver)
  - Can create noise problems

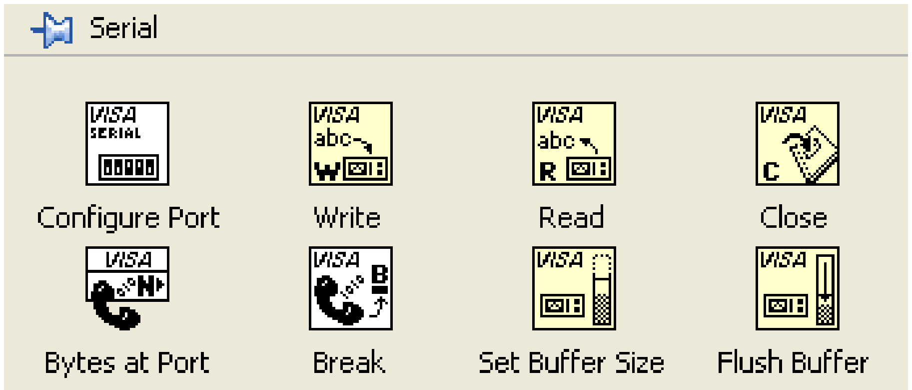


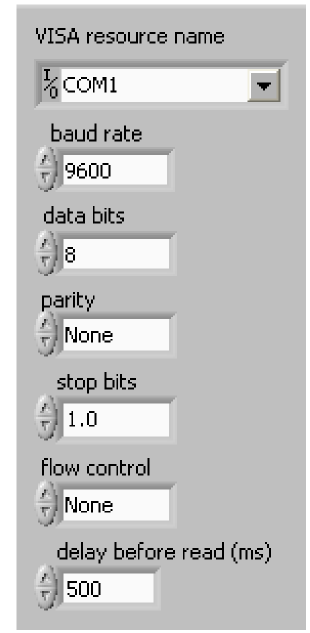

```
Data:    +(3-25 V)  (0)
         -(3-25 V)  (1)
Control: -(3-25 V)  (0)
         +(3-25 V)  (1)
```

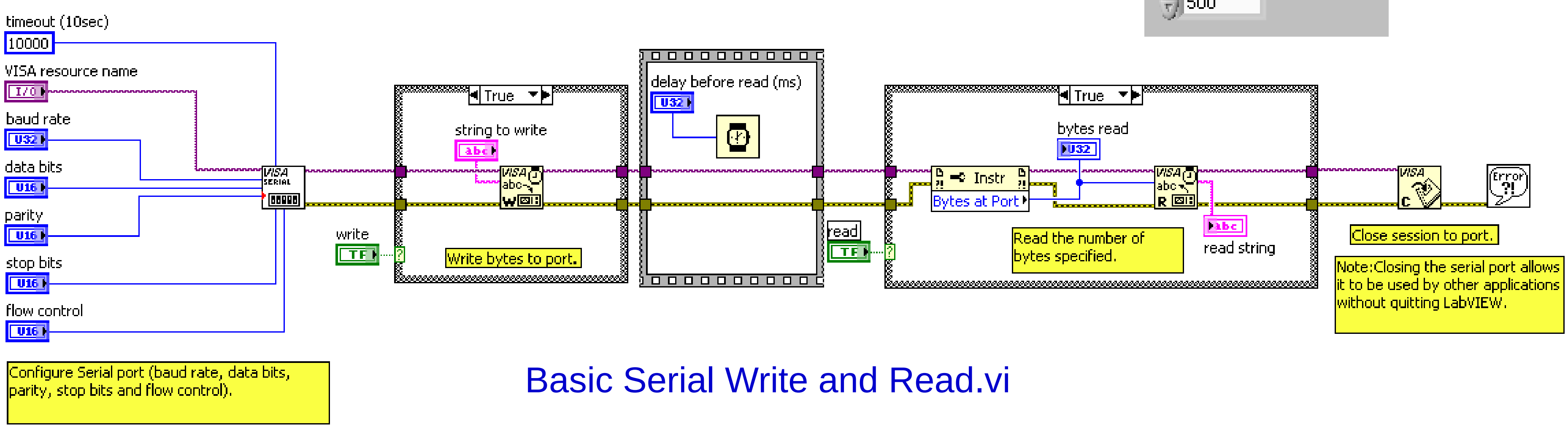


LabVIEW Serial: RS-232





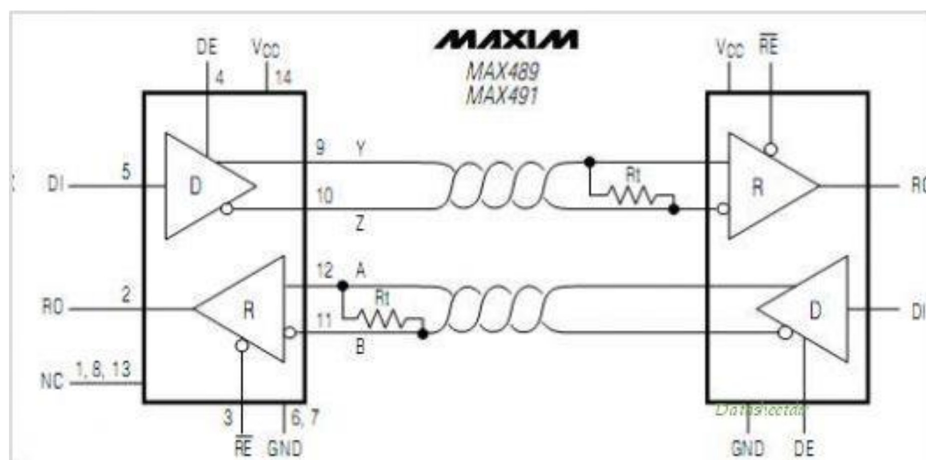




Basic Serial Write and Read.vi

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 multiple drivers and multiple receivers

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]

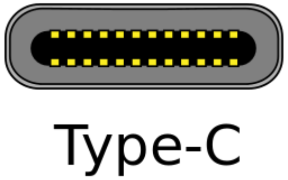
Pin	Color	Signal name ("A" Connector)	Signal name ("B" Connector)	Description
Shell	N/A	Shield		Metal housing
1	Red	VBUS		Power
2	White	D−		USB 2.0 differential pair
3	Green	D+		
4	Black	GND		Ground for power return
5	Blue	StdA_SSRX−	StdB_SSTX−	SuperSpeed transmitter differential pair
6	Yellow	StdA_SSRX+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

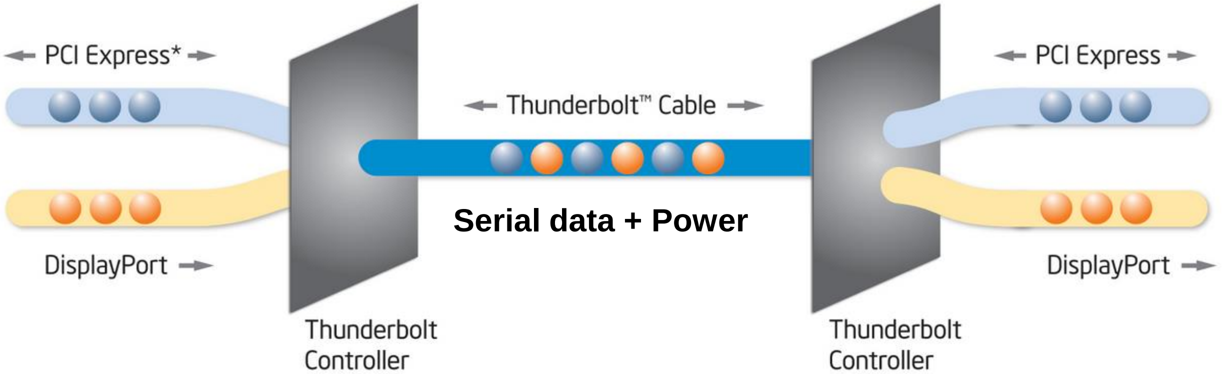


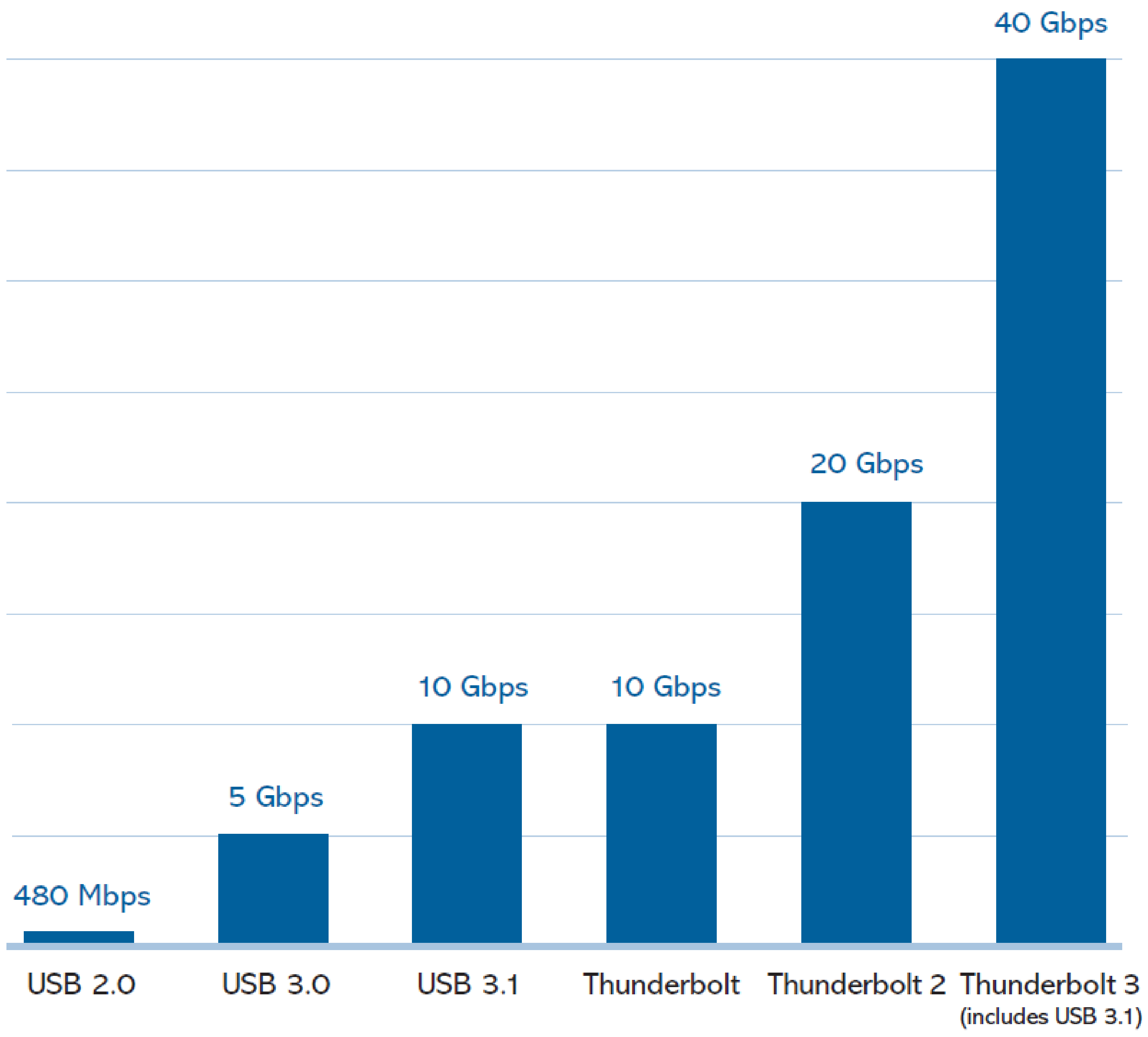
Thunderbolt

- 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)

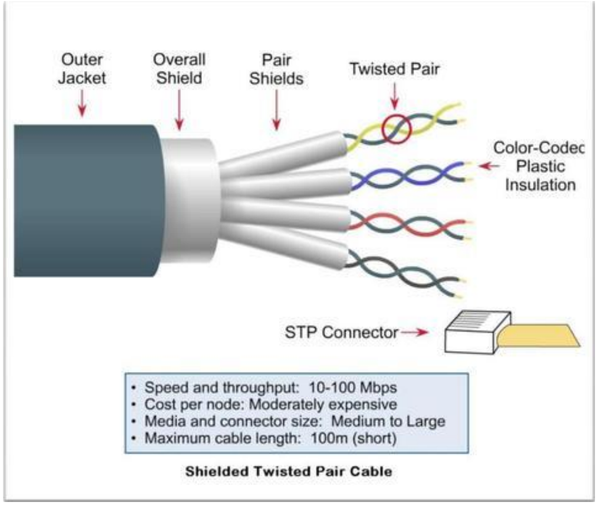
Ethernet network

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

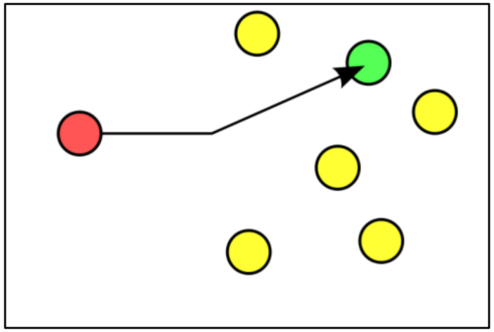
- Category 6 cable (Cat 6)
  - today standard for Gigabit Ethernet
  - backward compatible with the Category 5/5e
  - suitable for 10-Gigabit Ethernet (10GBASE-T)
- PC connection to an Ethernet network
  - **NIC** (Network Interface Controller/Card) for PCI or PCIe
  - Every NIC has a unique 48-bit serial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



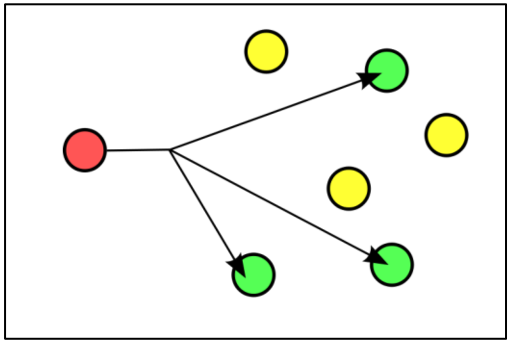
PCIe x4
dual port NIC

Unicast, multicast and broadcast

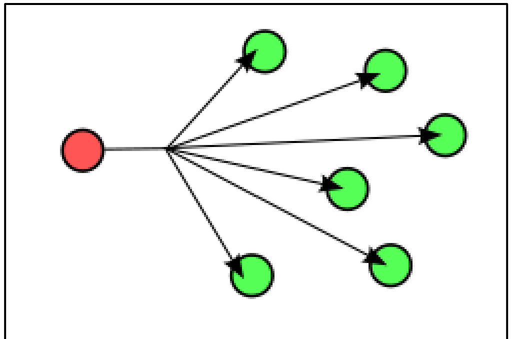
- Unicast
  - Sending of messages (packages) to a single network destination identified by unique address.



- 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



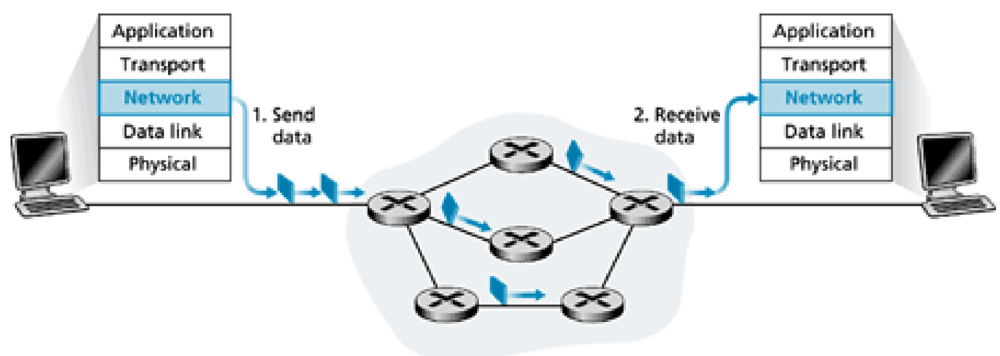
- Broadcast
  - Transmitting the same data to all possible destinations (every device on the network)



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

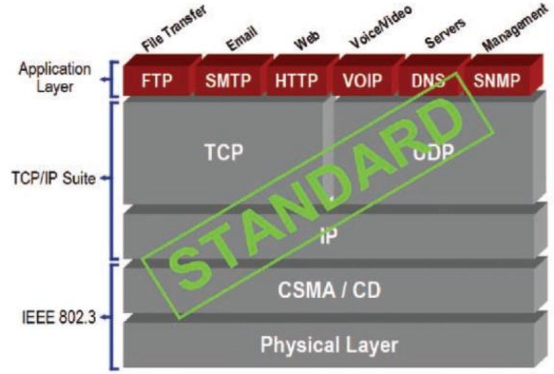
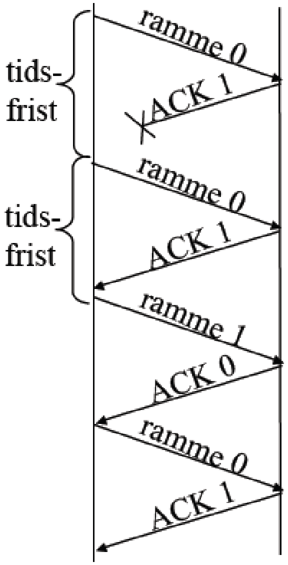


Figure 1- Standard, unmodified Ethernet stack

- 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, while TCP provides a reliable and in sequence data delivery 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

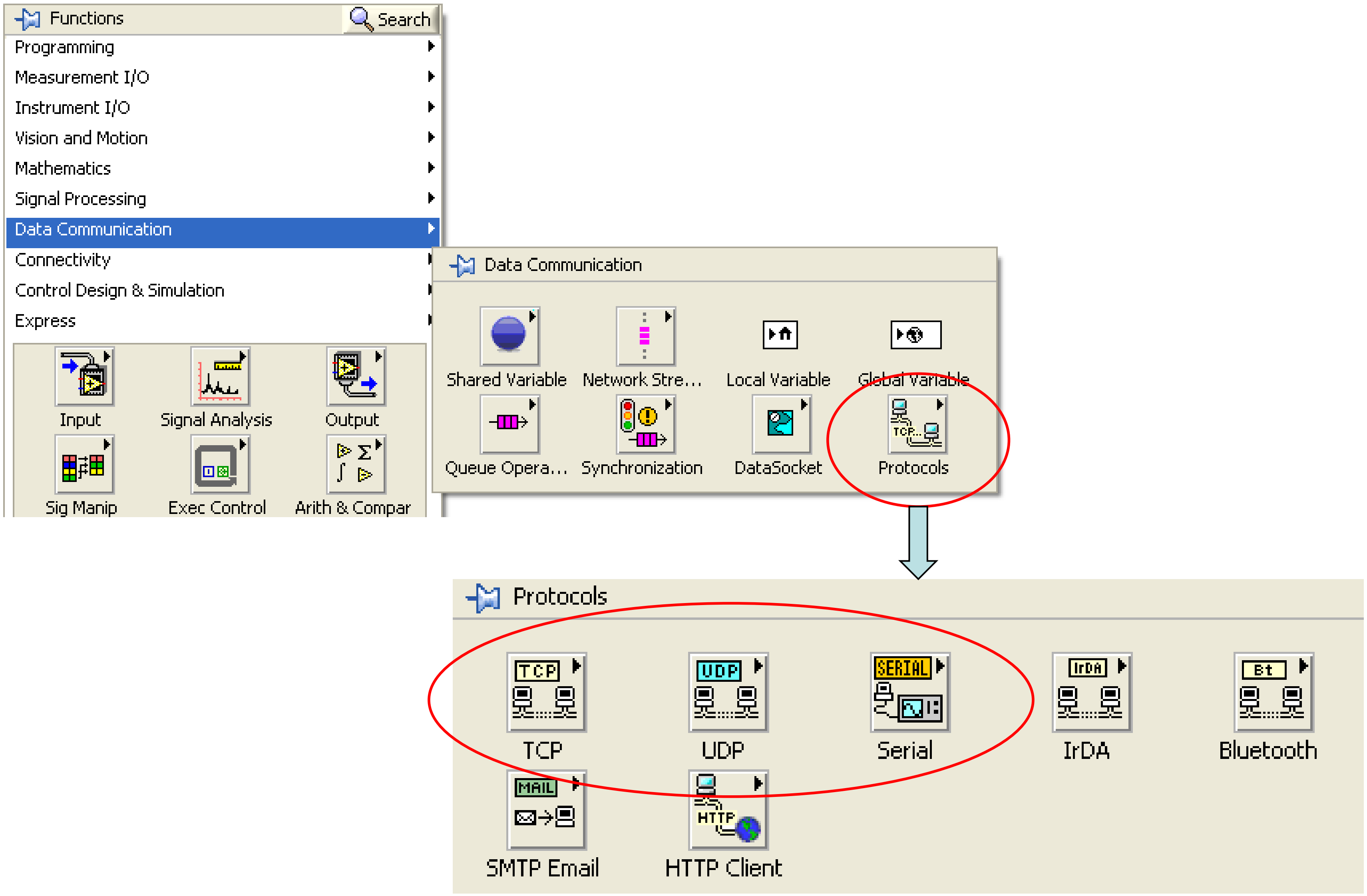


TCP

- 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

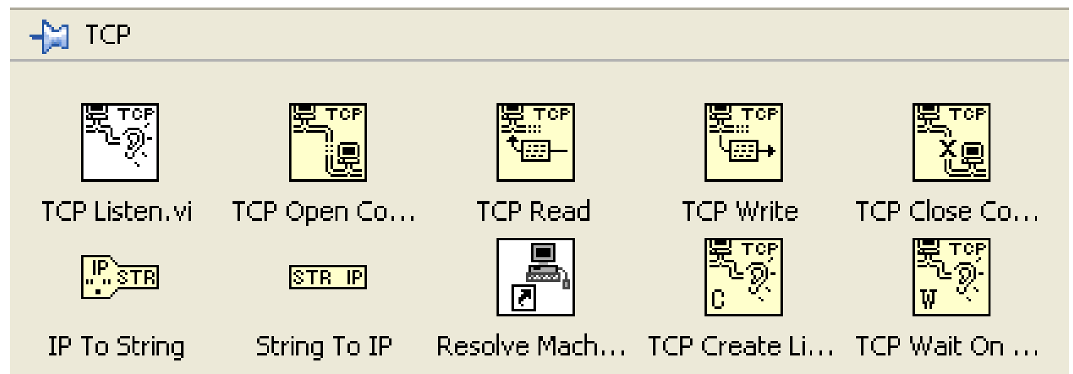
- In order to establish a TCP connection you have to specify **an address** and **a port** at that address
  - The port numbers allow different applications on the same computer to share network resources simultaneously
  - In TCP (and UDP) port numbers start at 0 and go up to 65535. Numbers in the lower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

LabVIEW Data Communication

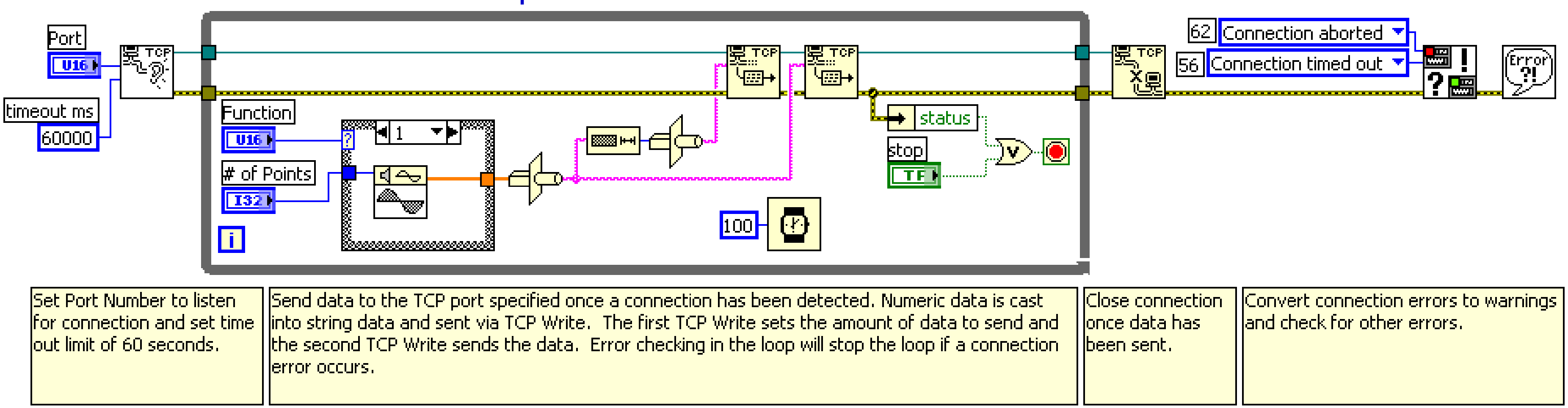


LabVIEW TCP Example

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



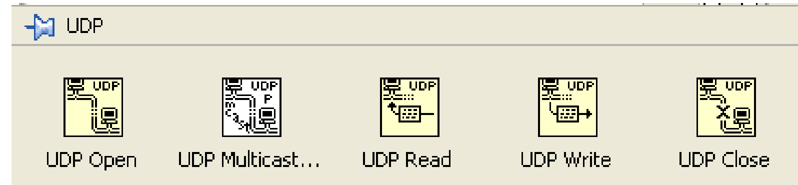
UDP

- 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

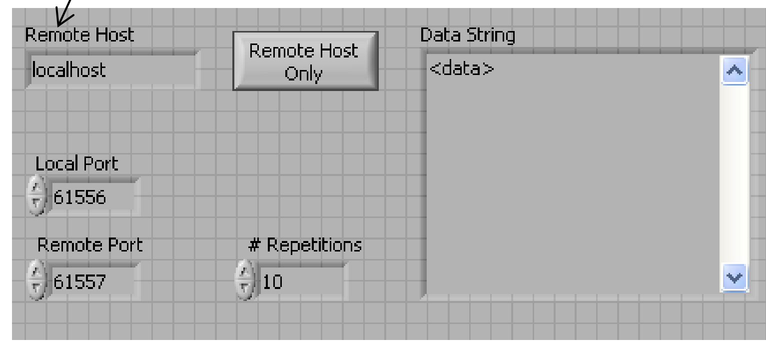
UDP is fast

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

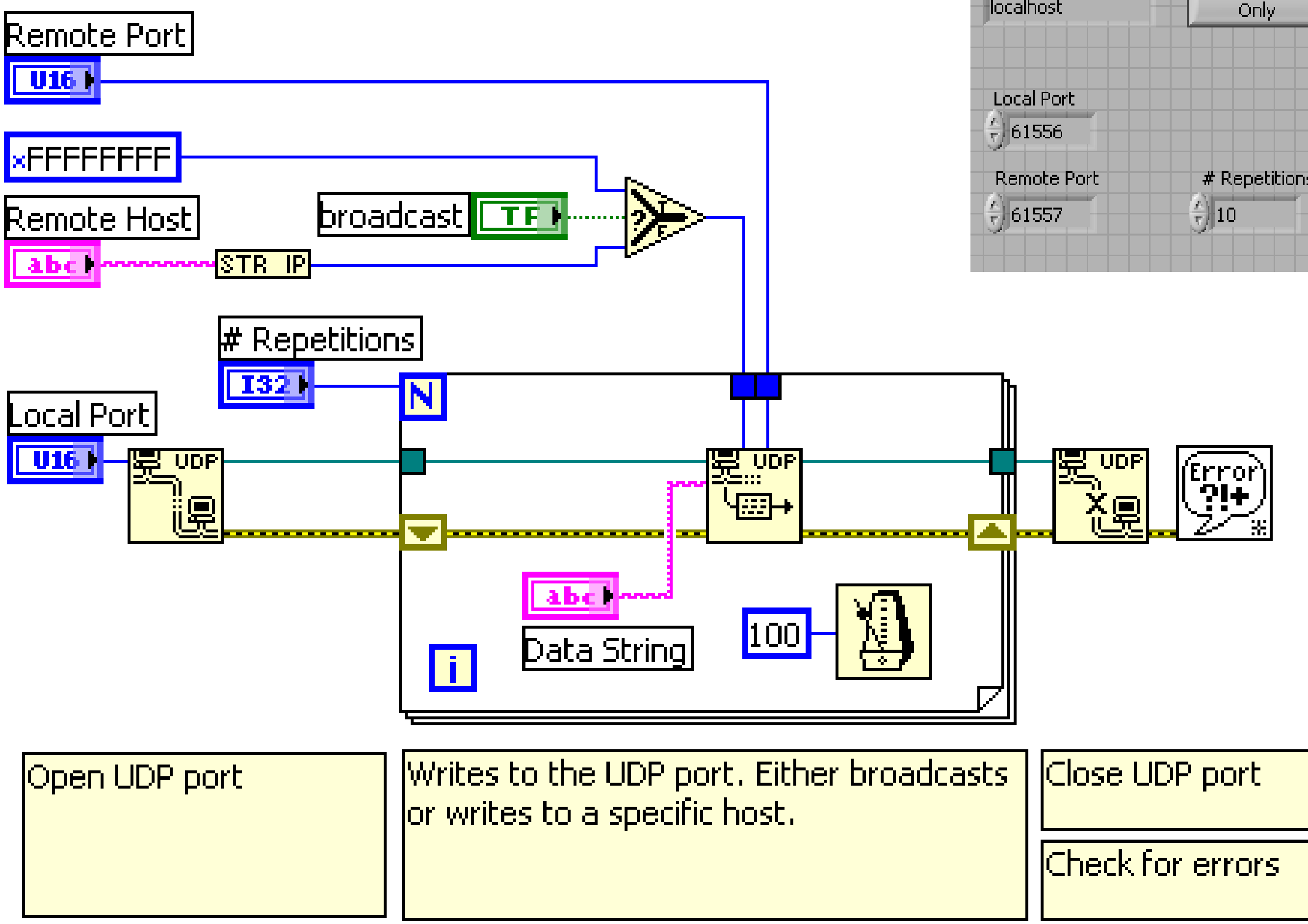
LabVIEW Example: UDP Send



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



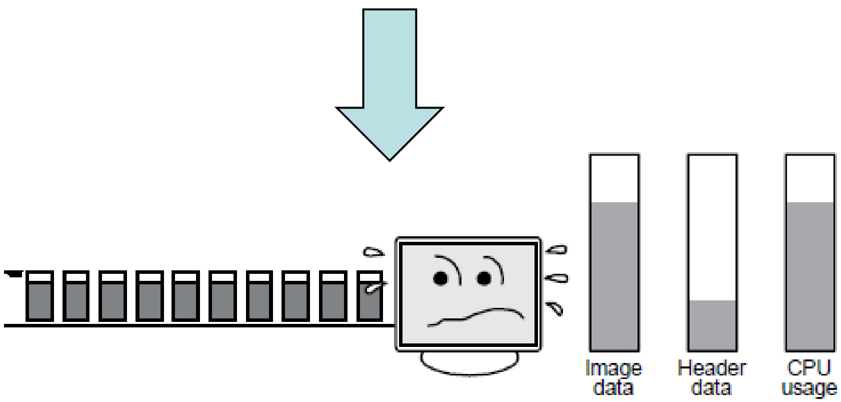
UDP Sender.vi



UDP broadcast address: 255.255.255.255

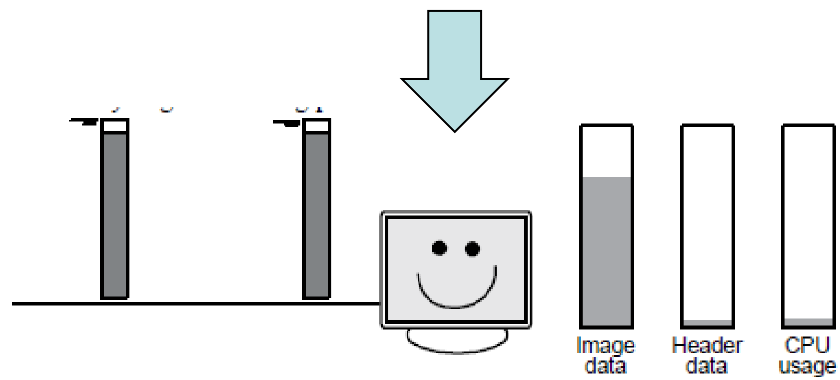
Jumbo frames

- 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.



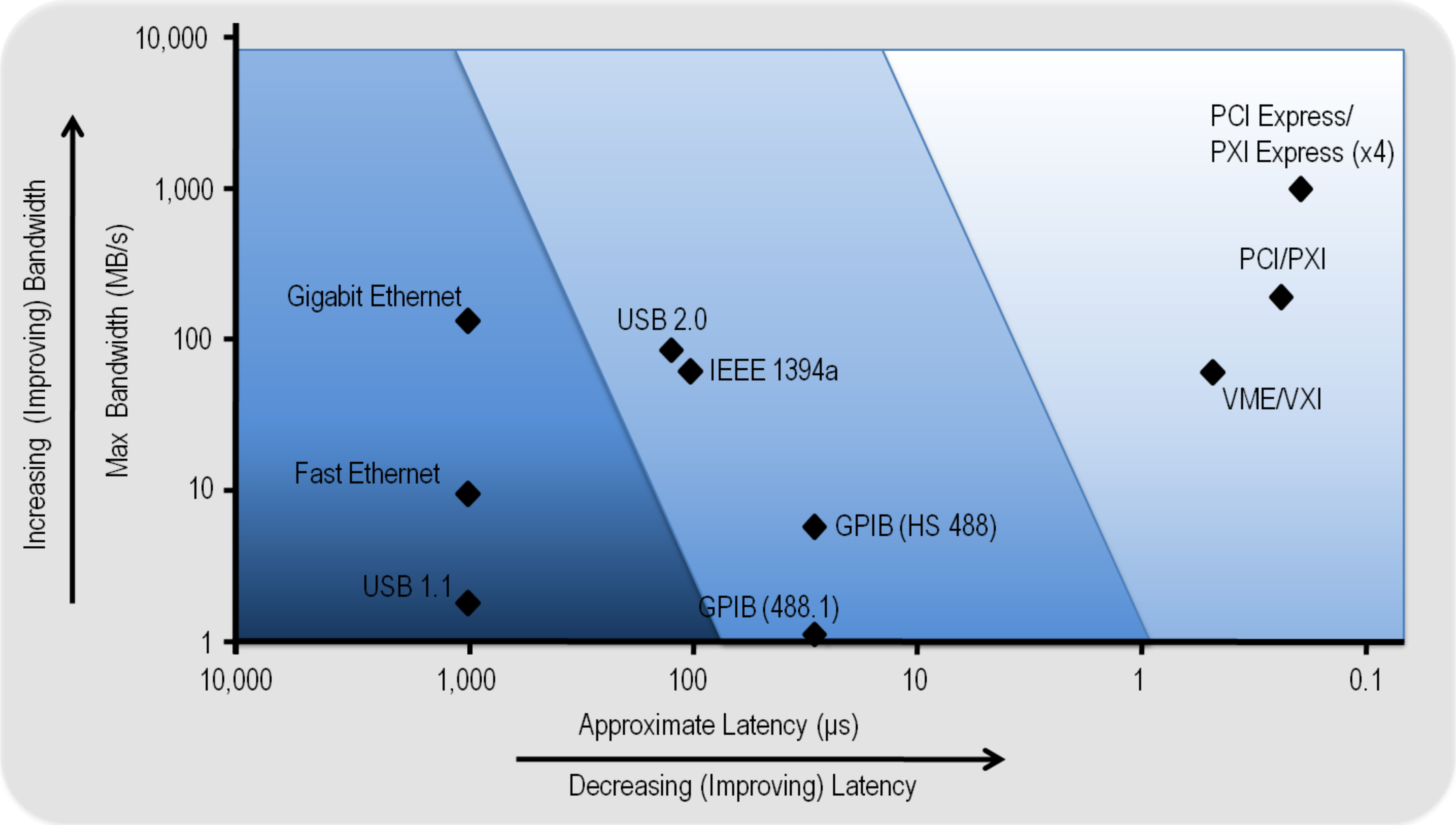
A common jumbo frame size is 9 kB (8192 bytes is often used), though IPv4 supports jumbo packets up to 64 kB. Make sure that your NIC supports jumbo frames

- 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.



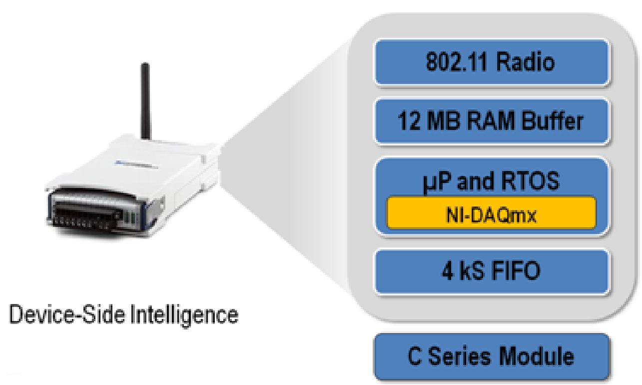
LAC - Configure

Bus bandwidth and latency

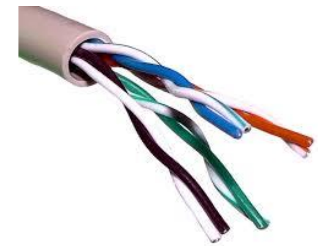


Wireless networks

- 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

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

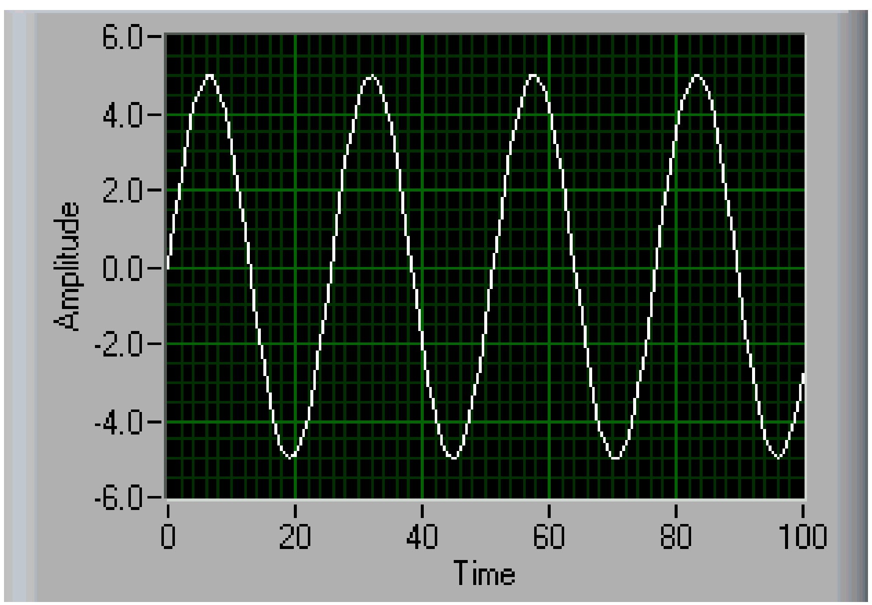
Abbreviations

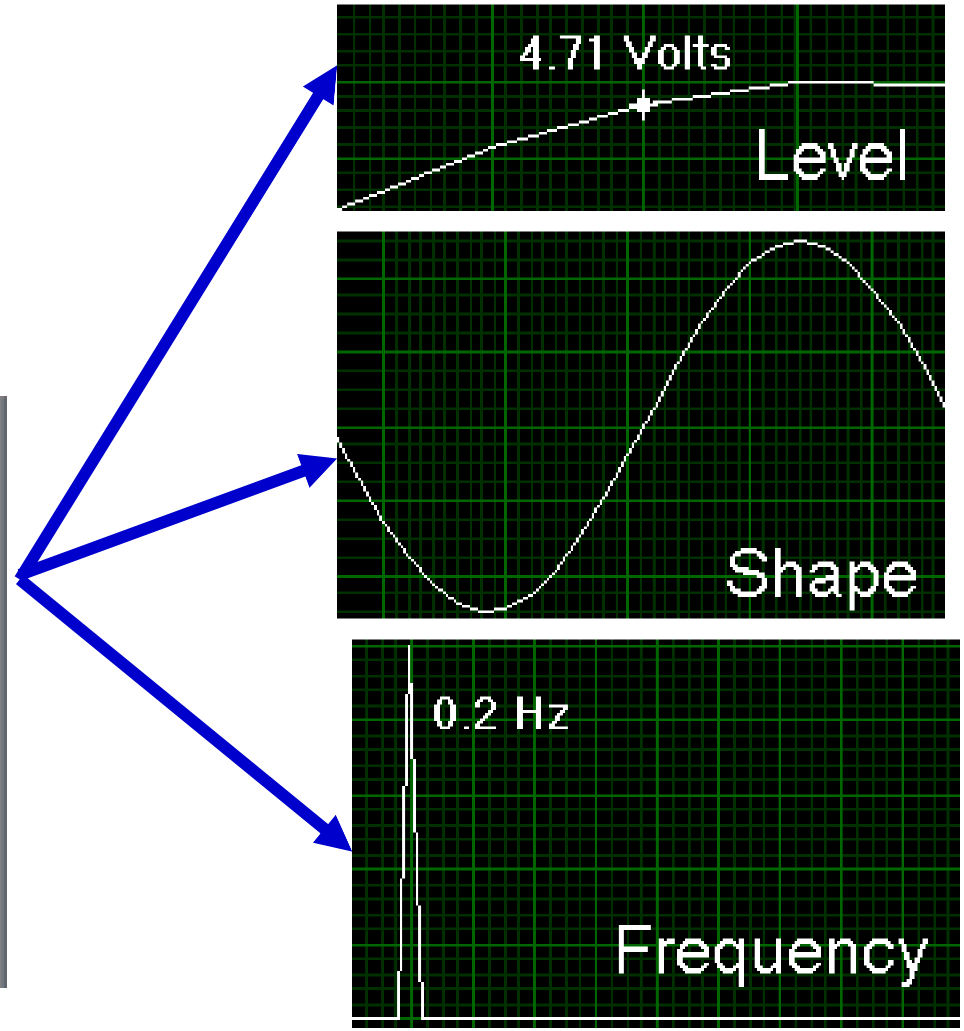
- B = byte
- b = bit
- M = mega
- G = giga = 10^9
- k = kilo = 1000
- K = 1024 (= 2^{10})

Analog Signal Information

Three types of information:

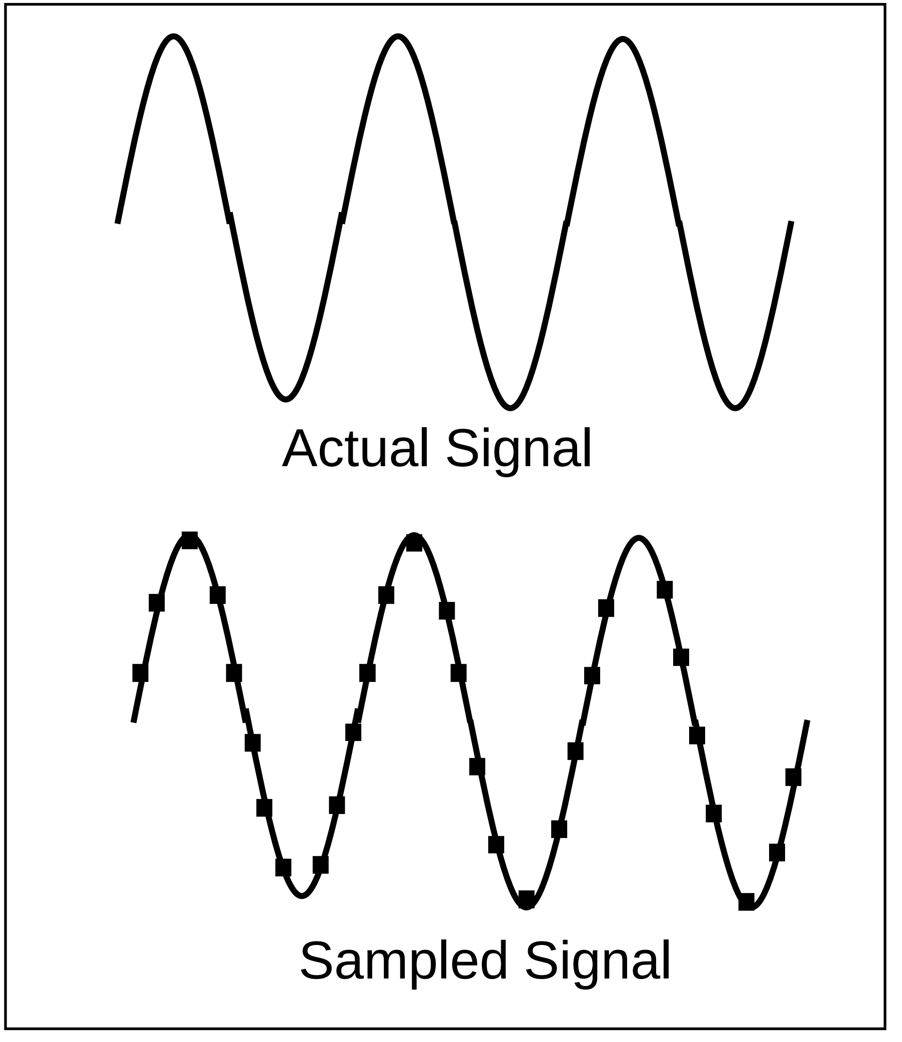
- Level
- Shape
- Frequency



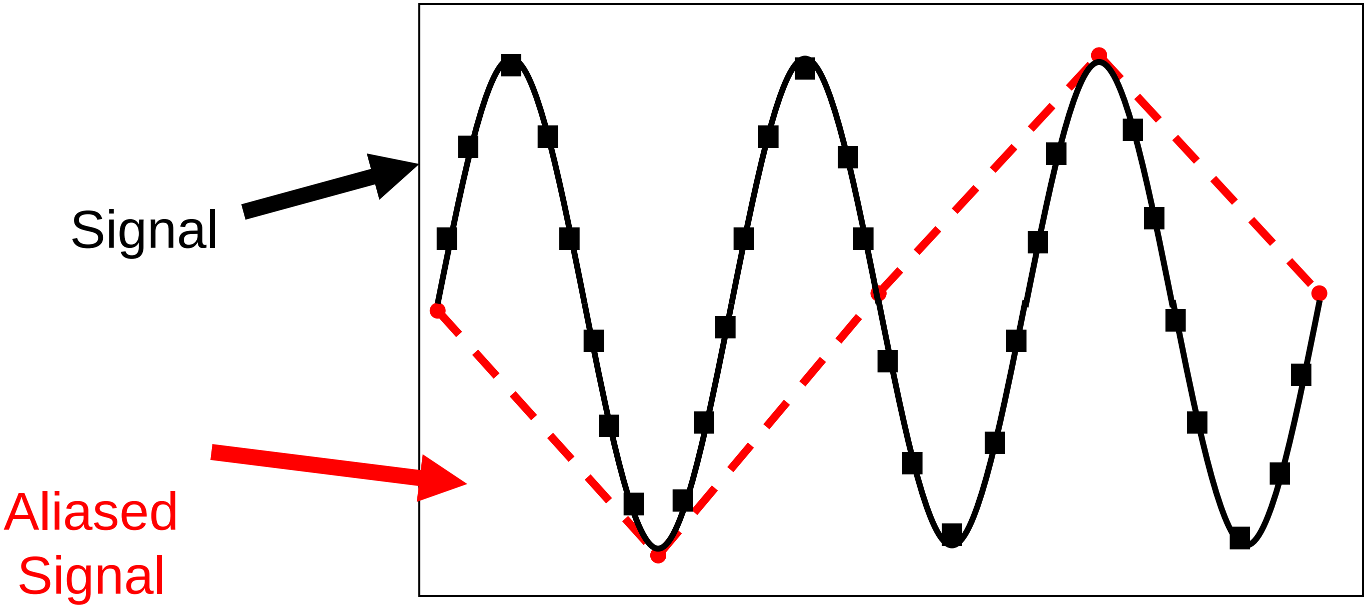


Sampling Considerations

- An analog signal is continuous
- A sampled signal is a series of discrete samples acquired at a specified sampling rate
- The faster we sample the more our sampled signal will look like our actual signal
- If not sampled fast enough a problem known as aliasing will occur

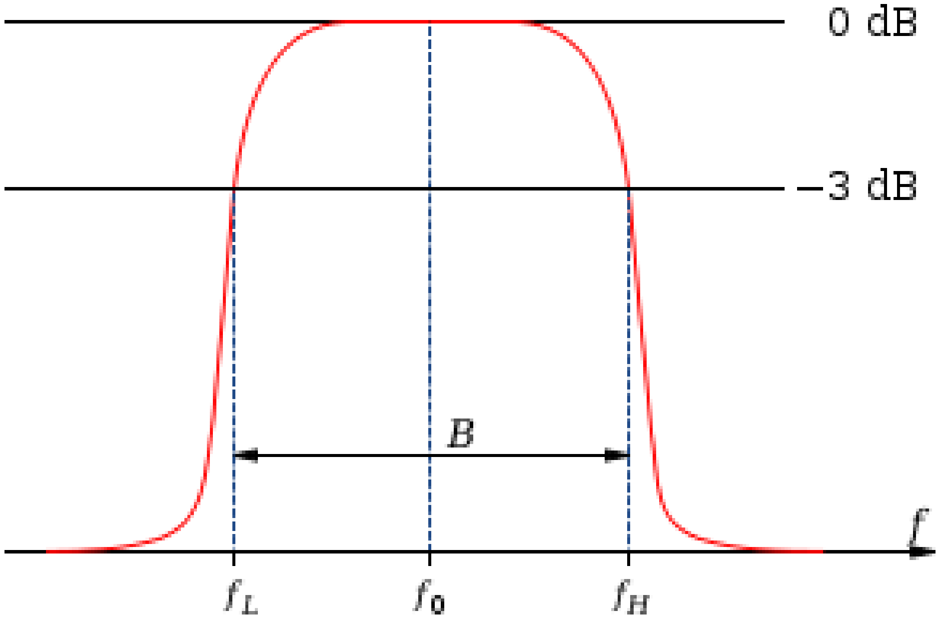


Aliasing



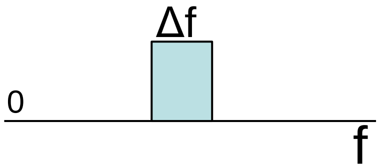
Bandwidth of a filter

- The bandwidth B of a filter is defined to be between the -3 dB points



Sampling & Nyquist's Theorem

- **Nyquist's sampling theorem:**
  - **The sample frequency should be at least twice the highest frequency contained in the signal**
- Or, more correctly: The sample frequency should be at least twice the bandwidth of your signal
    - In mathematical terms: $f_s \geq 2 * \Delta f_{signal,}$ where $\Delta f_{signal} = f_{high} - f_{low}$



- However, to accurately represent the shape of the signal, or to determine peak maximum and peak locations, a higher sampling rate is required
  - Typically a sample rate of 10 times the bandwidth of the signal is required.

ECG signal

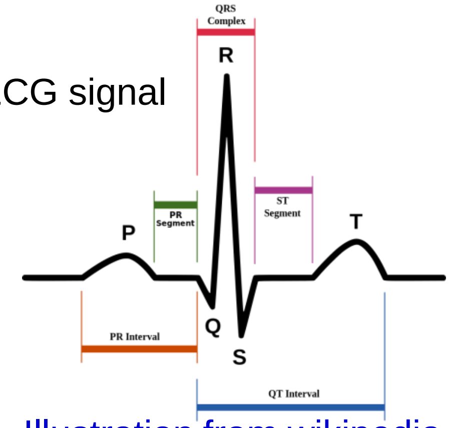
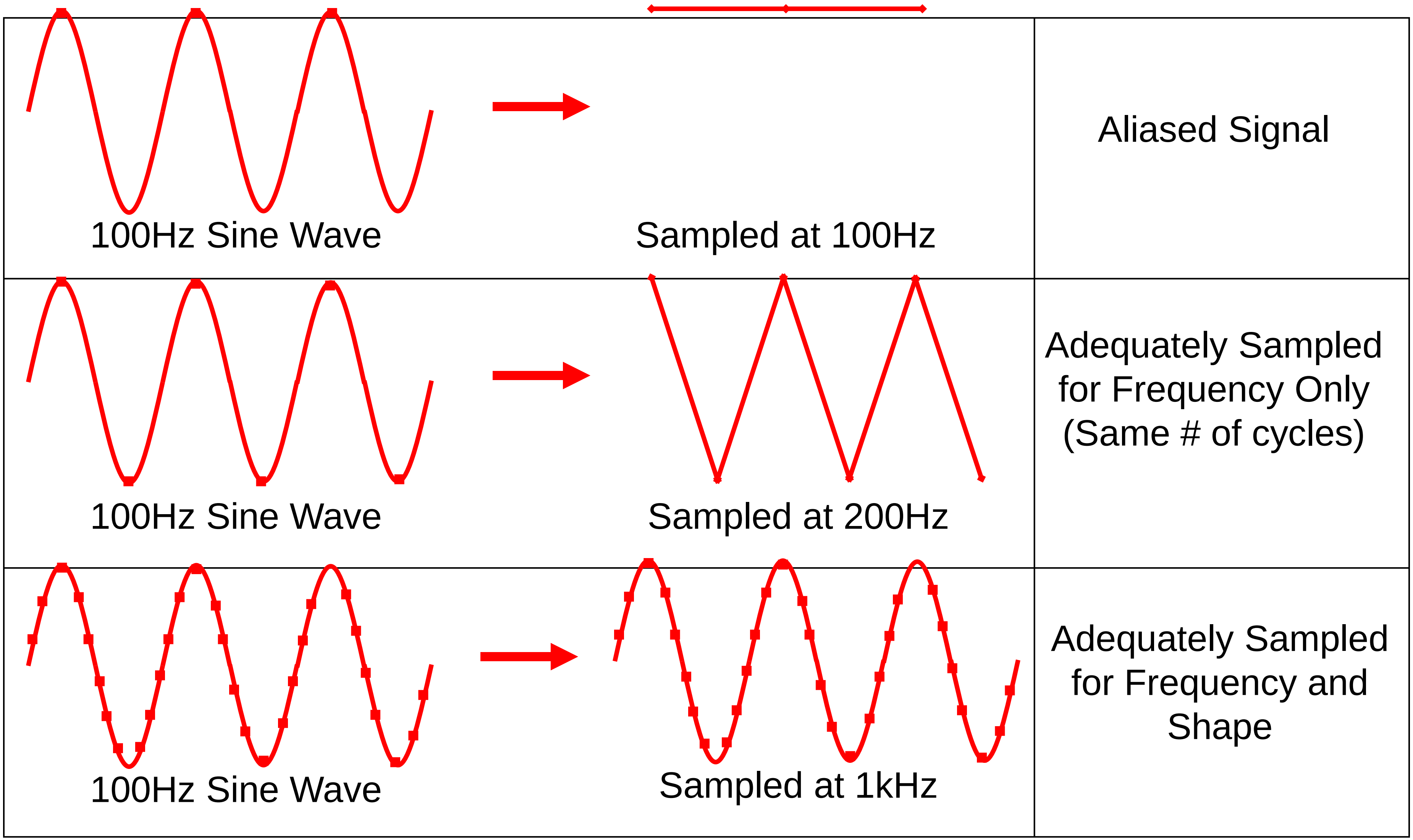
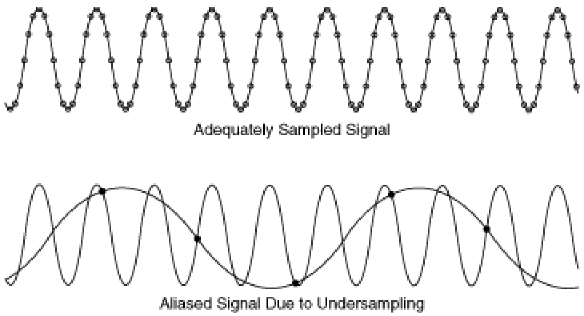


Illustration from wikipedia

Sampling Example



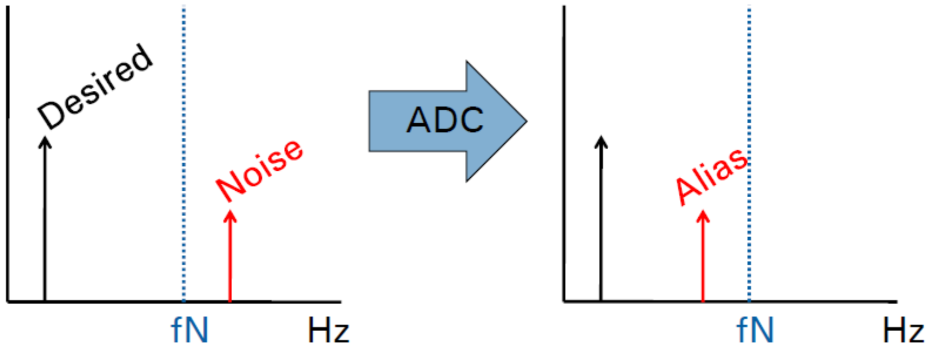


Hardware Filtering

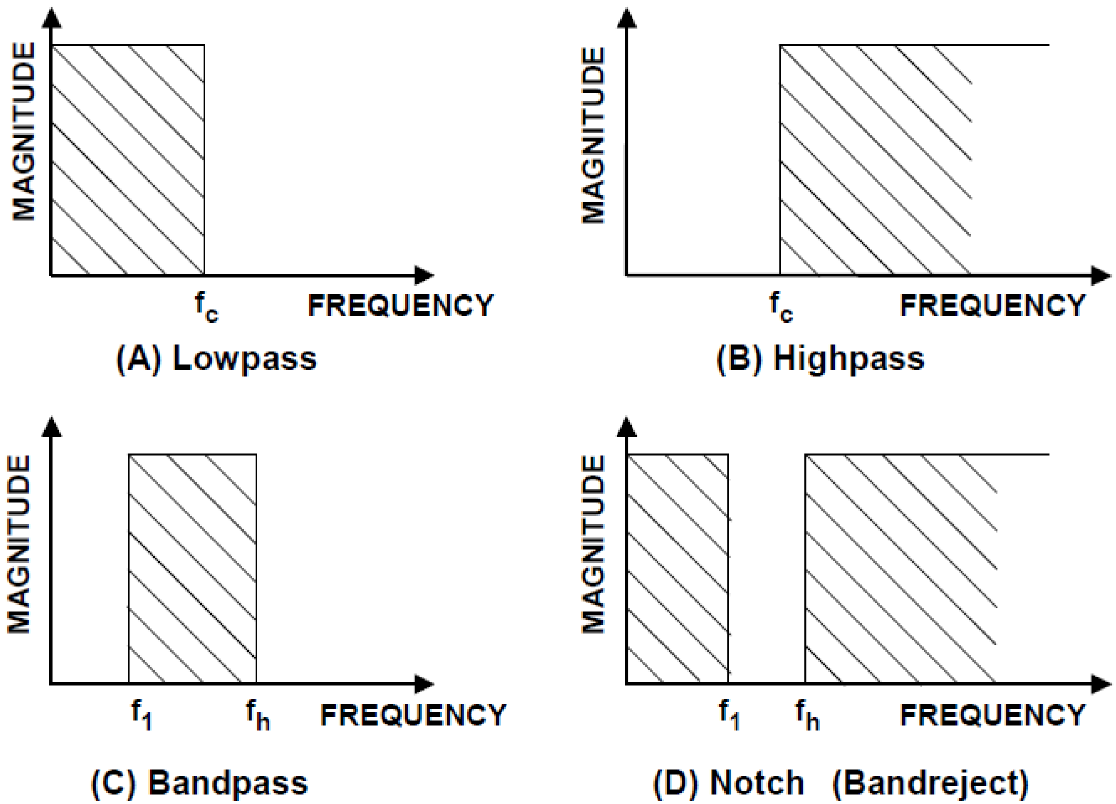
- Filtering
  - To remove unwanted signals from the signal that you are trying to measure

- **Analog <u>anti-aliasing low-pass filtering</u>** before the A/D converter
  - To remove all signal frequencies that are higher than the input bandwidth of the device. If the signals are not removed, they will erroneously appear as signals within the input bandwidth of the device (known as aliasing)

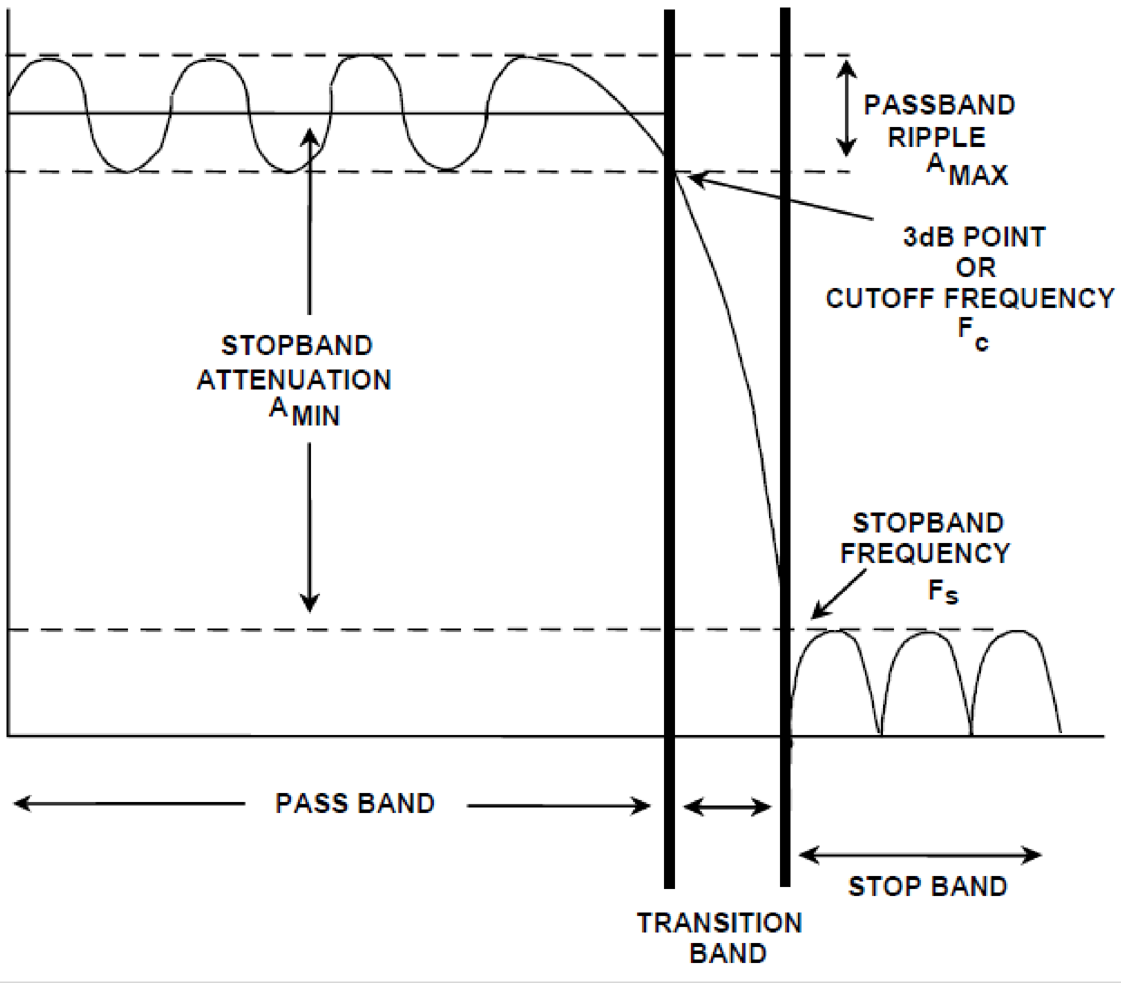
Frequency Domain:



Idealized Filter Responses

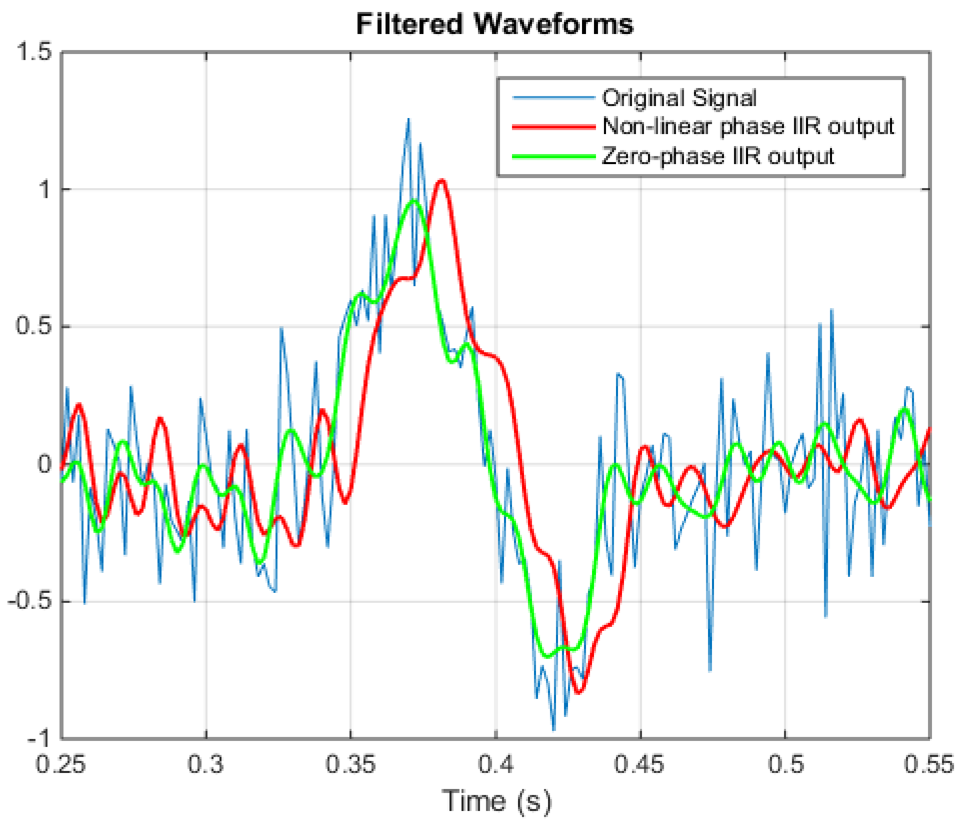


Filter parameters



A filter will affect the phase of a signal, as well as the amplitude!

Filtering example

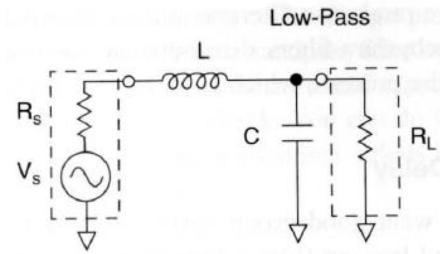


Example from MathWorks

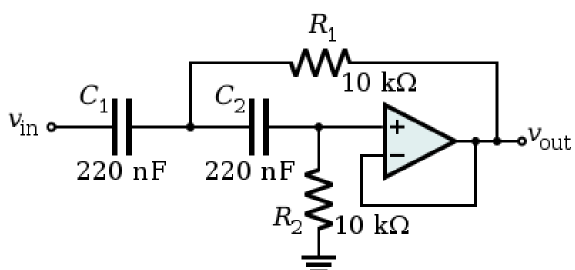
In post-processing (non-real time) a **zero-phase digital filter** can be used, by processing the input data in both the forward and reverse directions

Analog filters

- **Passive filters**:
  - RC, LCR
  - (often inductors L are avoided, but they are needed for high Q-factor)

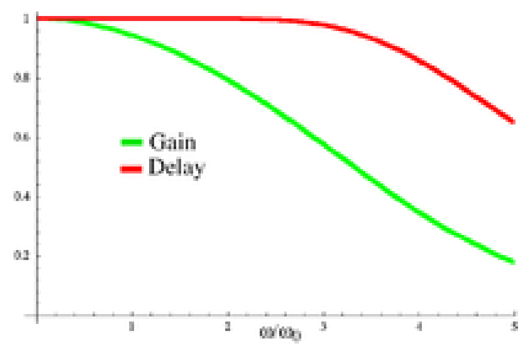


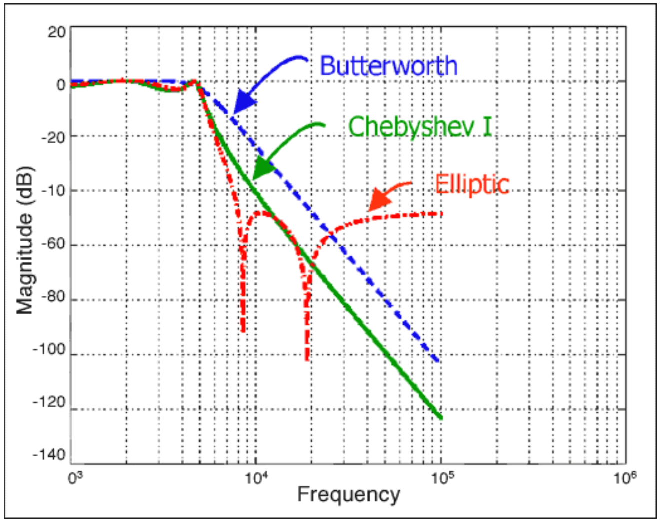
- **Active filters**
  - opamp + R and C



- Some common filter characteristics
  - Butterworth
  - Chebyshev
  - Bessel (constant group delay in pass band)
  - Elliptic

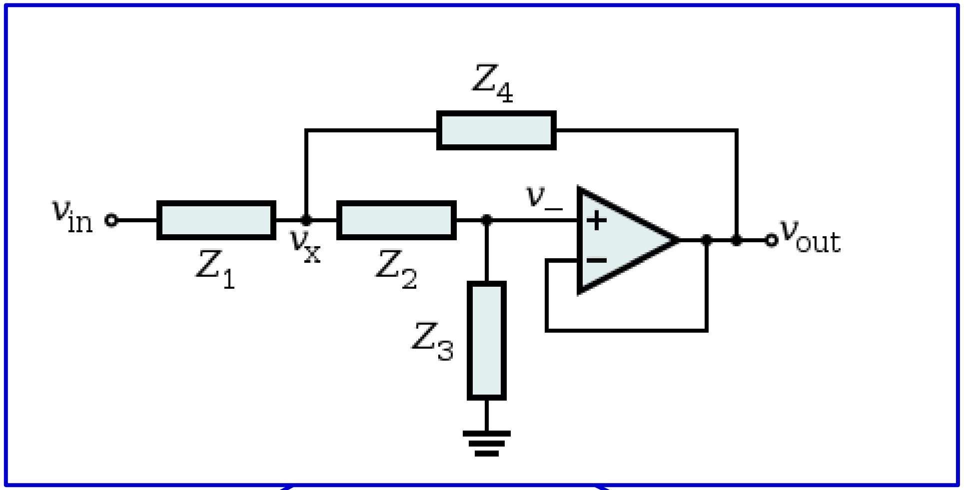
Bessel



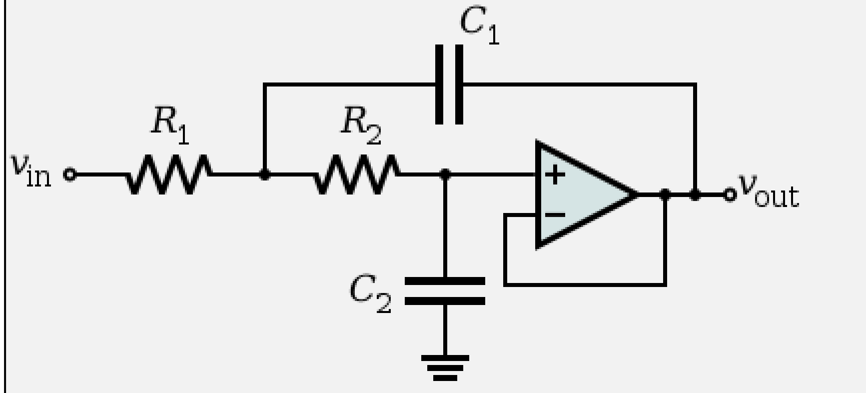


Sallen-Key - Active analog filter

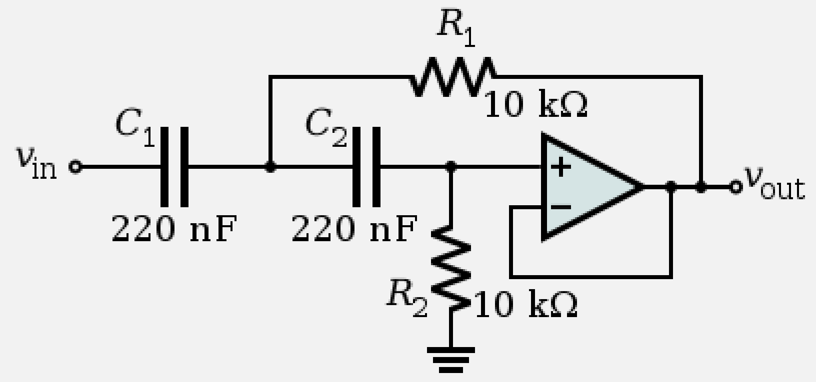
Structure



LP

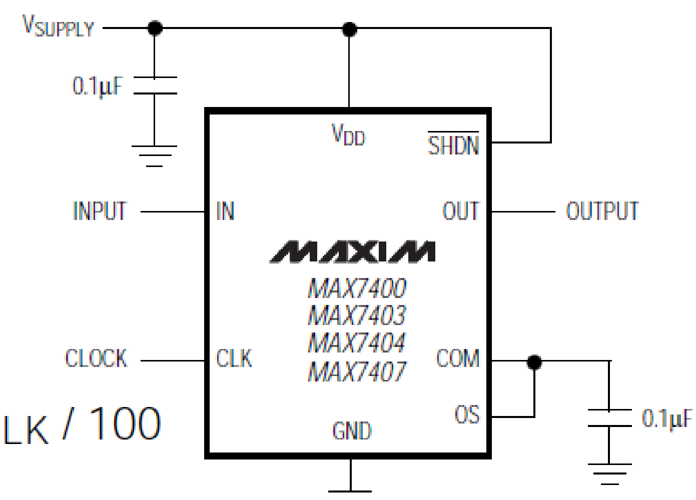


HP

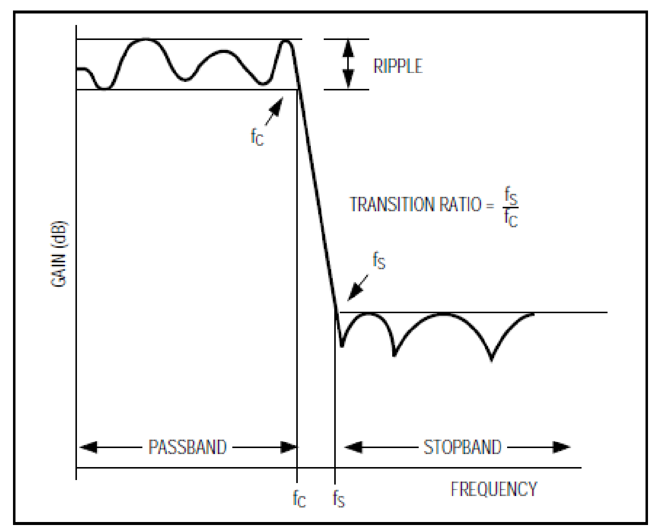


Switched-Capacitor Filter

- Can be suitable as an ADC anti-aliasing filter if you build your own electronics
- Be aware of possible clock noise (add RC-filters before and after)
- The corner frequency (cut-off) fc is “programmable” using an external clock
- Example:
  - MAX7400 8th-order,lowpass, elliptic filter
  - MAX7400 has a transition ratio (fs/fc) of 1.5 and a typical stop band rejection of 82dB

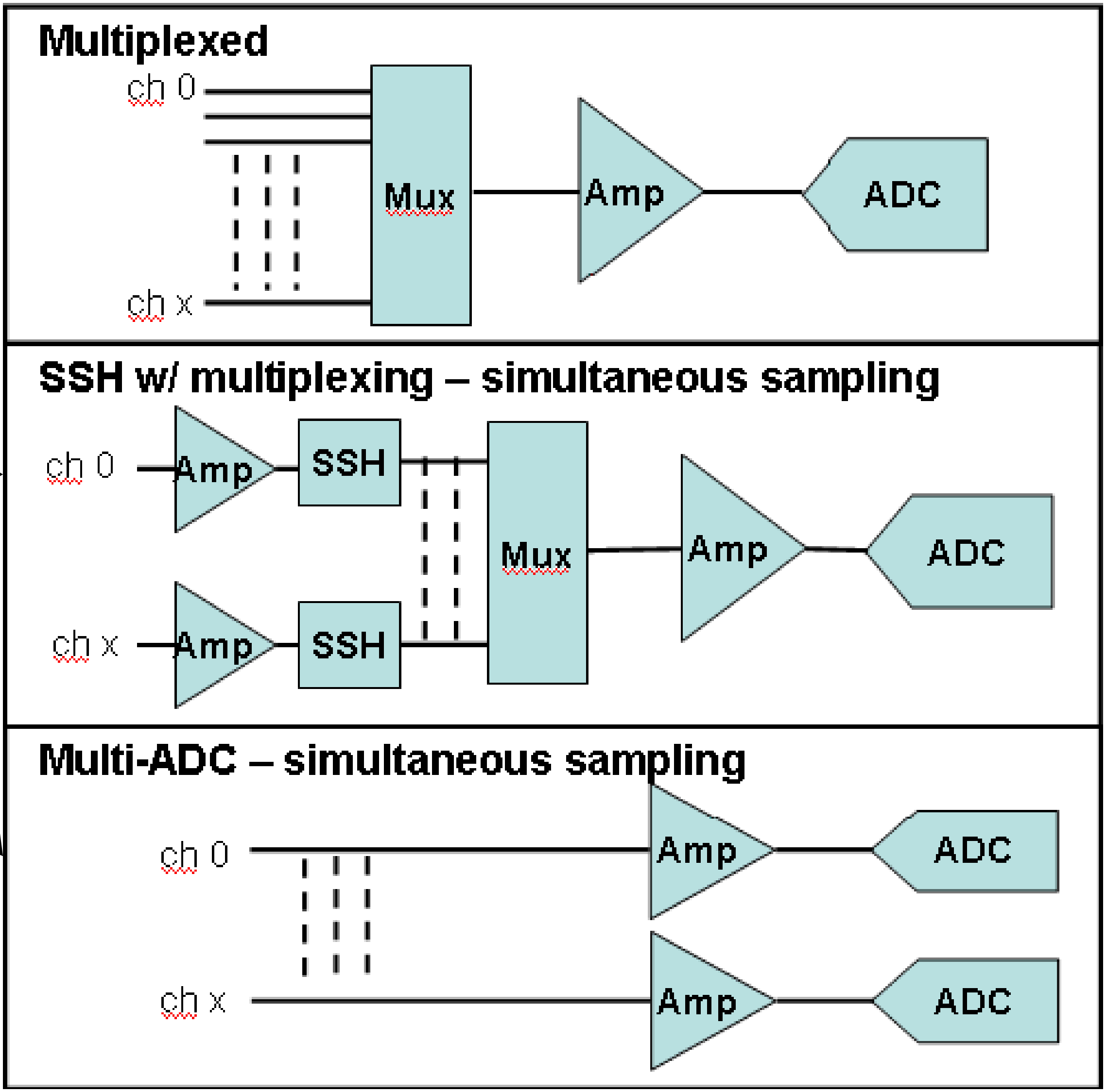


$f_C = f_{CLK} / 100$



ADC architectures

- Multiplexed
- Simultaneous sampling
  - One ADC, multiple Sample-and-Hold registers
  - Multiple ADCs



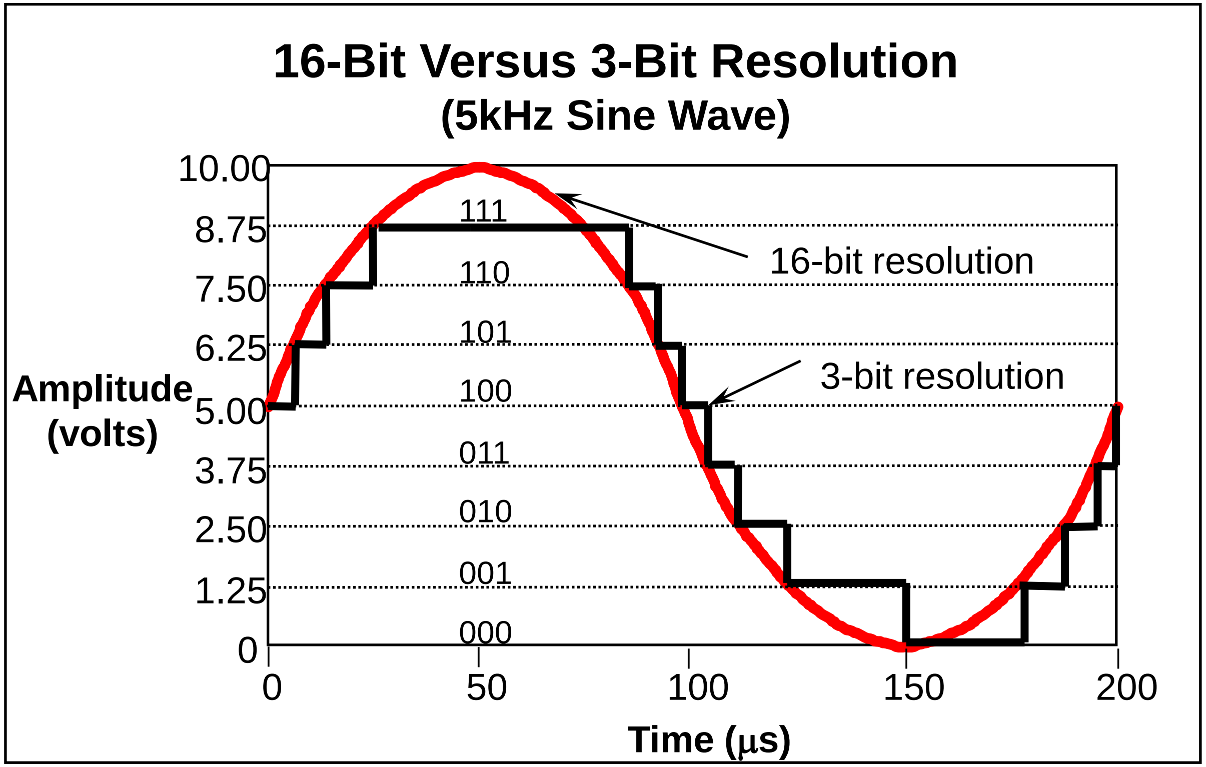
ADC resolution

- The number of bits used to represent an analog signal determines the resolution of the ADC
- Larger resolution = more precise representation of your signal
- The resolution determine the smallest detectable change in the input signal, referred to as code width or LSB (least significant bit)

$$code\ width = \frac{device\ range}{2^{resolution}}$$

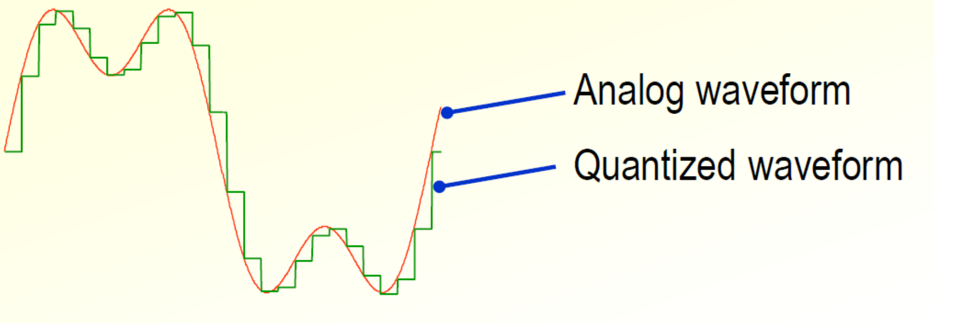
Example:

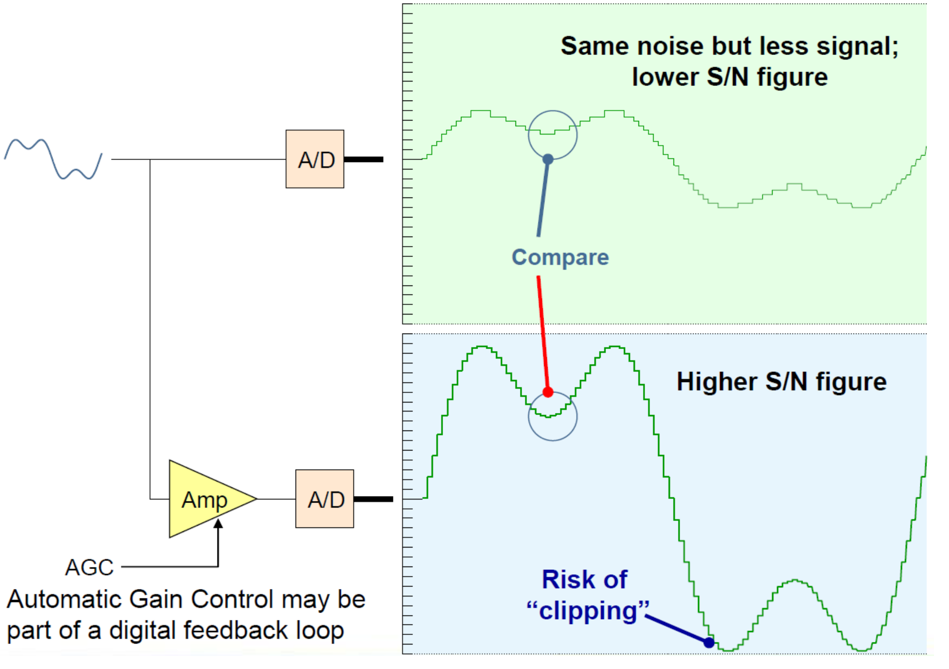
$$\frac{device\ range}{2^{resolution}} = \frac{10}{2^{16}} = .15\ mV$$



Digital signals: Bits, dynamic range, and SNR

- SNR = signal to noise ratio
- The number of bits used determines the maximum possible signal-to-noise ratio
- Using the entire ADC range (using an amplifier) increases the SNR
- The minimum possible noise level is the error caused by the quantization of the signal, referred to as **quantization noise.**





ADC oversampling

- Oversampling means to sample faster than the Nyquist rate, which is given by $fs = 2 *\Delta f_{signal}$
- The SNR of an ideal N-bit ADC (due to quantization effects) is:

  $SNR(dB) = 6.02*N + 1.76$

- If the sampling rate is increased, we get the following SNR:
  - $SNR(dB) = 6.02*N + 1.76 + 10* \log_{10}(OSR)$
  - $OSR = f_s/f_{nyquist}$
- Oversampling makes it possible to use a simple RC anti-aliasing filter before the ADC
- After A/D conversion, perform digital low-pass filtering and then down sampling to $f_{nyquist}$
- Effective resolution with oversampling $N_{eff} = N + 1/2 *\log_2 (f_s/f_{nyquist})$, where N is the resolution of an ideal N-bit ADC at the Nyquist rate
  - If $OSR = f_s/f_{nyquist} = 1024$, an 8-bit ADC gets and effective resolution equal to that of a 13-bit ACD at the Nyquist rate

Trigger (from hardware or software)

- A trigger is a signal that causes a device to perform an action, such as starting a data acquisition. You can program your DAQ device to react on triggers such as:
  - a software command (software trigger)
  - a condition on an external digital signal
  - a condition on an external analog signal
    - E.g. level triggering

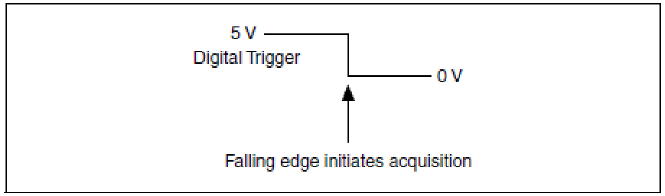


Figure 13-1. Falling-Edge Trigger

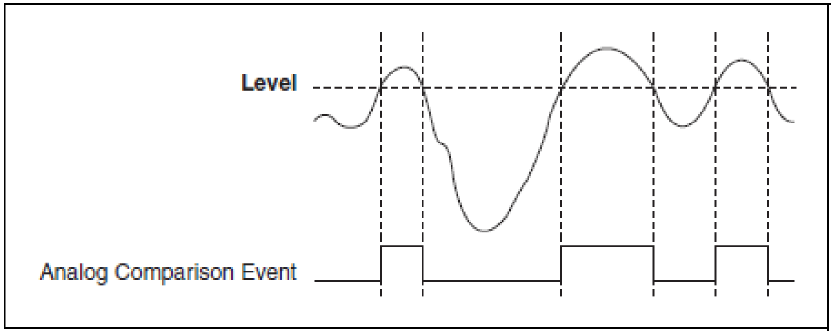
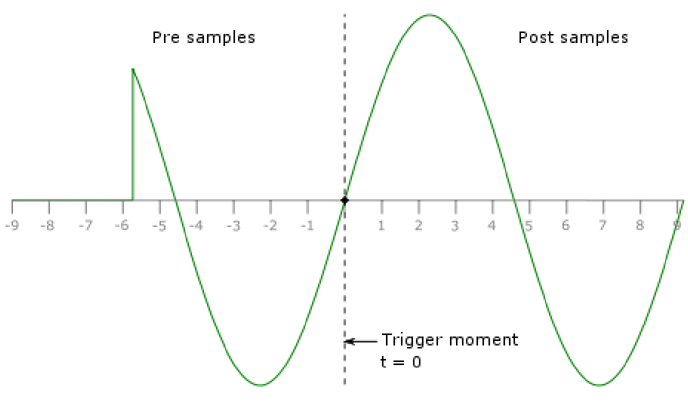


Figure 13-4. Above-Level Analog Triggering Mode

Important trigger types

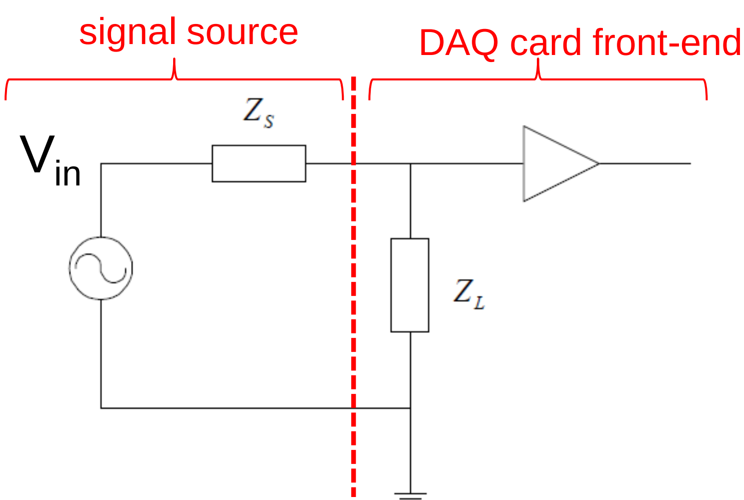
- **Start trigger**
  - start data acquisition when an external digital signal have e.g. a rising edge.

- **Pre-trigger**
  - Uses a data buffer (circular buffer)
    - Can include a specified number of samples before the trigger event.
    - Useful for e.g. high speed imaging.



Considerations for analog signals

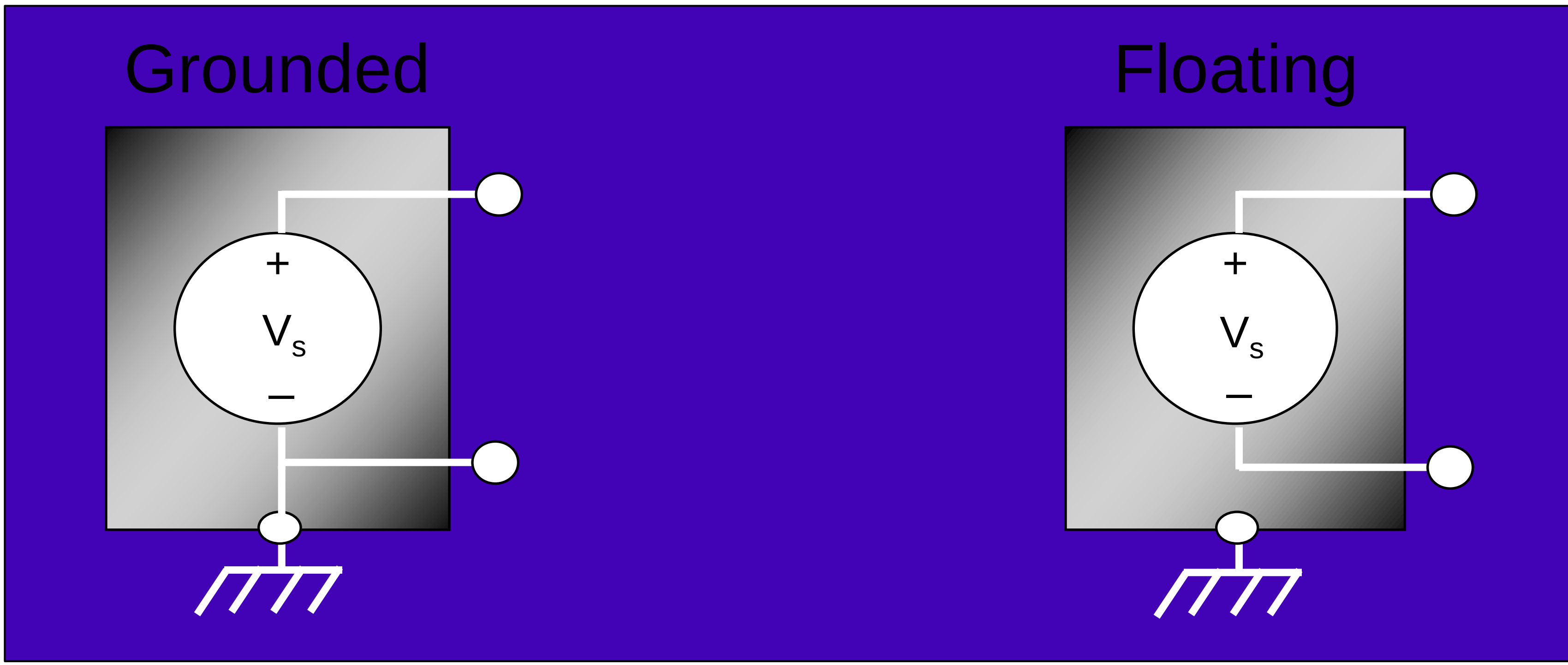
- Signal source - grounded or floating
- Source impedance
  - The DAQ device must have a much higher input impedance than the signal source
  - This is usually not a problem as the DAQ devices are designed to have a very high input impedance (MΩ – GΩ range)
- Single-ended & differential signals



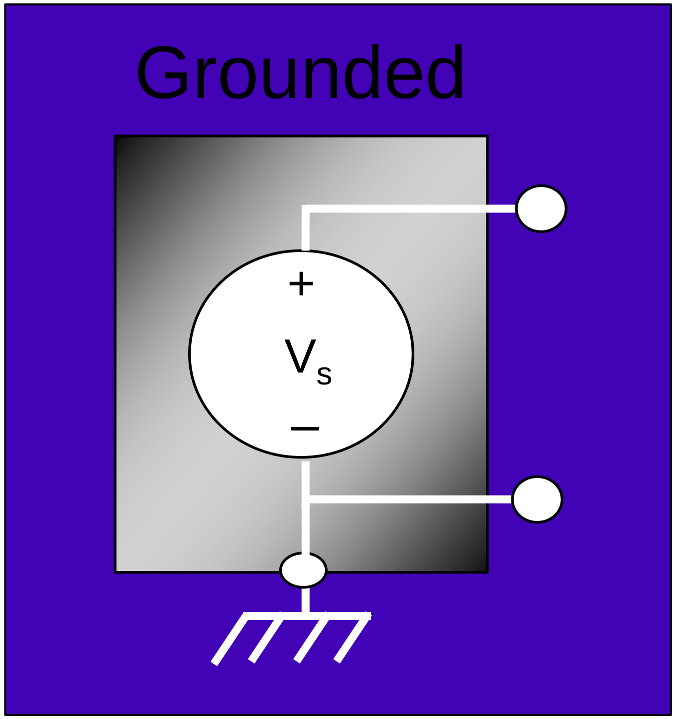
$$V_{out} = \frac{Z_L}{Z_s + Z_L} \cdot V_{in}$$ (voltage divider)

I = V / Z

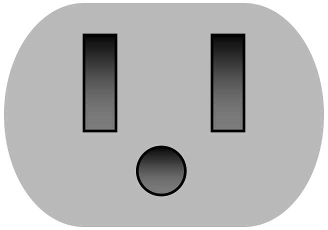
Signal Source Categories



Grounded Signal Source

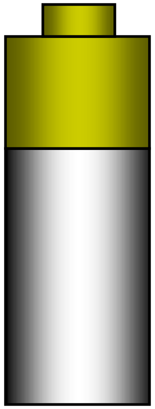


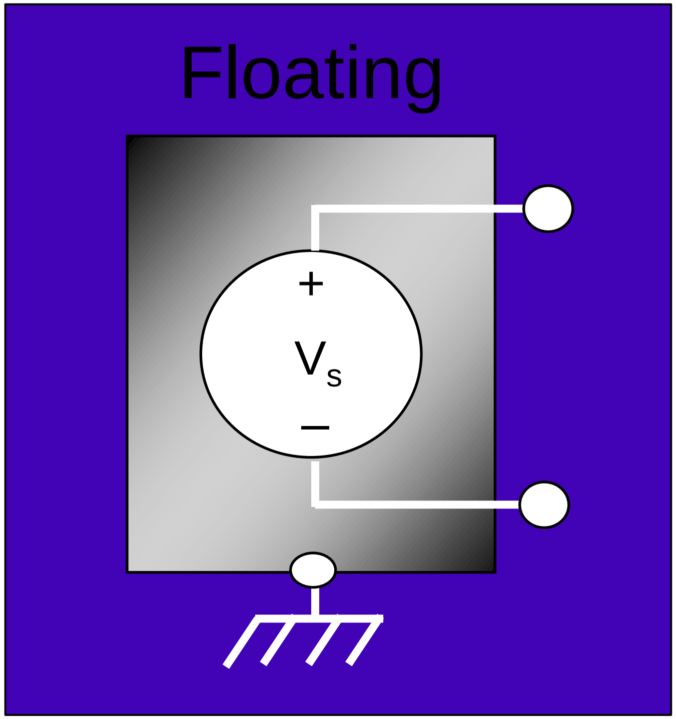
- Signal is referenced to a system ground
  - earth ground
  - building ground
- Examples:
  - Power supplies
  - Signal Generators
  - Anything that plugs into an outlet ground



Floating Signal Source

- Signal is NOT referenced to a system ground
  - earth ground
  - building ground
- Examples:
  - Batteries
  - Transformers
  - Isolation Amplifiers





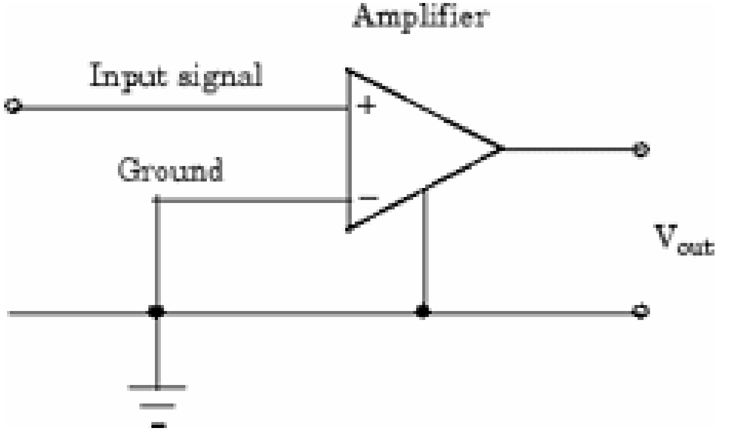
DAQ-card input signal configuration

- DAQ input channels can be configured in two ways:
  - Differential
  - Single-ended
    - Referenced Single-Ended (RSE)
    - Non-Referenced Single-Ended (NRSE)

- The optimal connection depends on how your signal is grounded

Single-ended (SE) signals

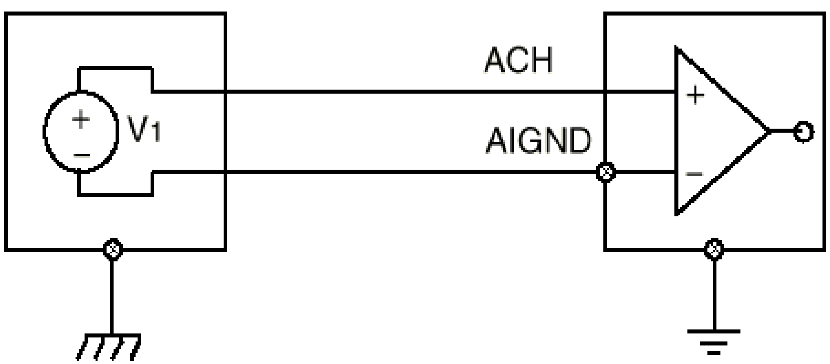
- One signal wire for each input signal
- Can be used for the following conditions:
  - High-level input signals (greater than 1 V)
  - Short cables
  - Properly-shielded cables or cables traveling through a noise-free environment
  - All input signals can share a common reference point (ground)
- To types of connections:
  - Referenced Single-Ended (RSE)
  - Non-Referenced Single-Ended (NRSE)



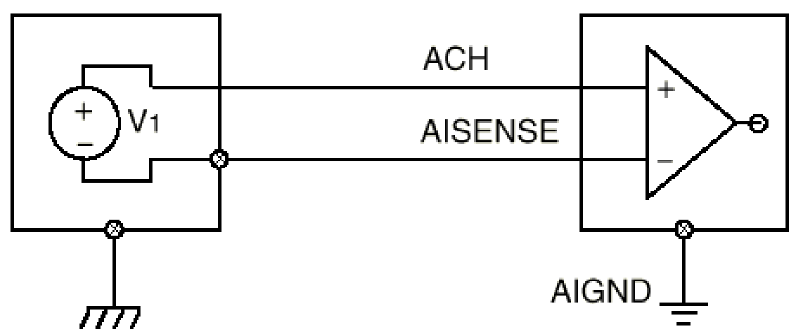
RSE vs. NRSE configuration

- The **<u>RSE</u>** <u>configuration is used for floating signal sources</u>. In this case, the DAQ hardware device itself provides the reference ground for the input signal.
- The **<u>NRSE</u>** <u>input configuration is used for grounded signal sources</u>. In this case, the input signal provides its own reference ground and the hardware device should not supply one.
  - Measurement made with respect to a common reference (AISENSE), not system ground (AIGND)
  - AISENSE is floating

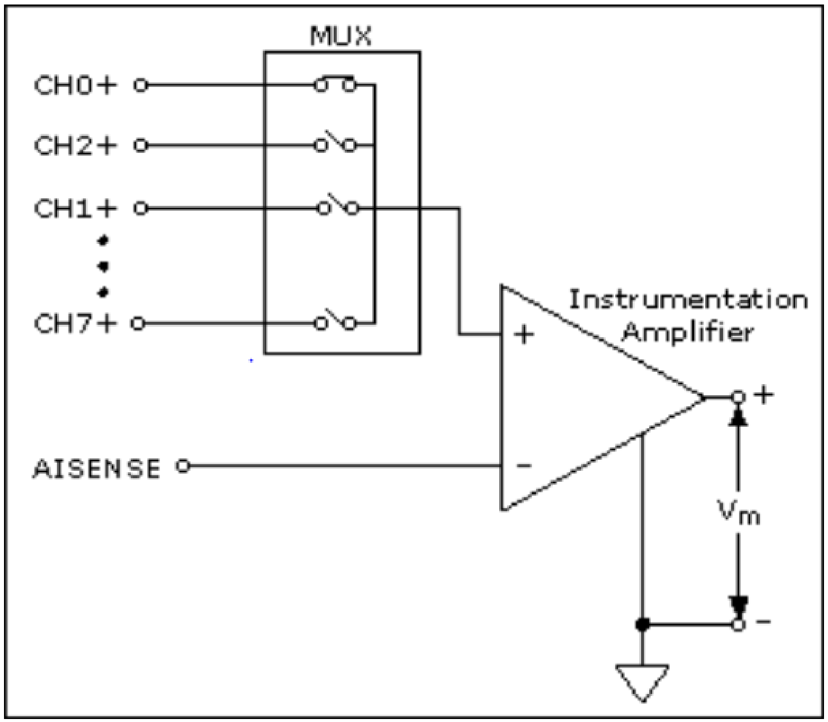
RSE



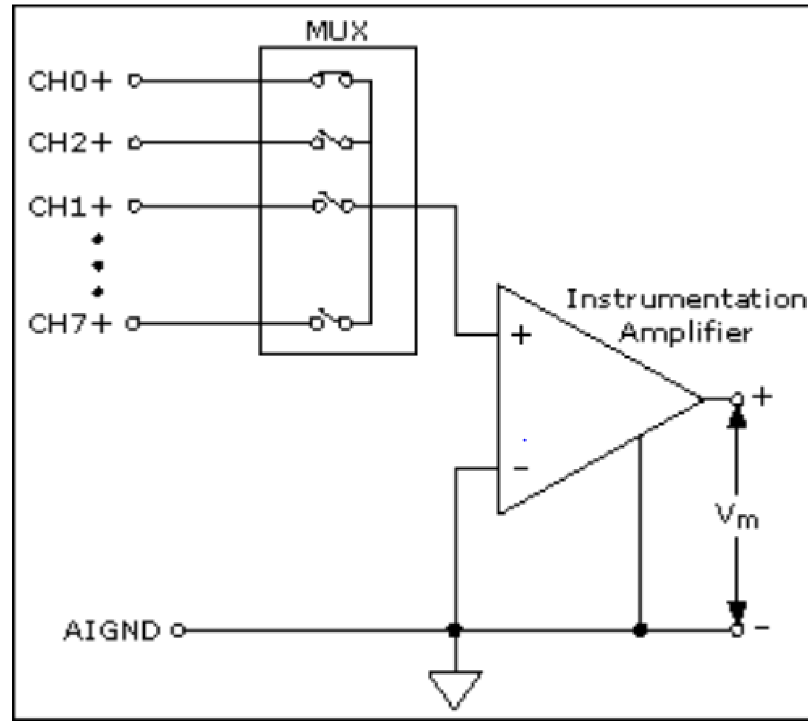
NRSE



NRSE

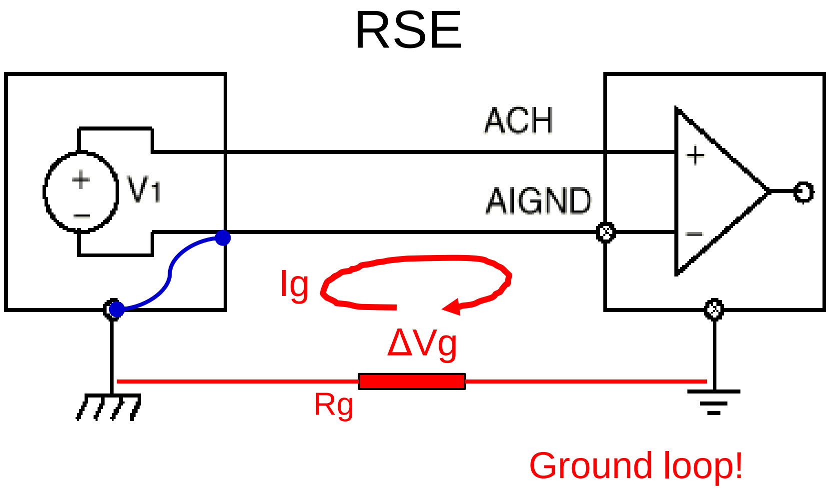

MUX
CH0+
CH2+
CH1+
CH7+
Instrumentation Amplifier
+
−
AISENSE
+
V_m
−

RSE


MUX
CH0+
CH2+
CH1+
CH7+
Instrumentation Amplifier
+
−
+
V_m
AIGND
−

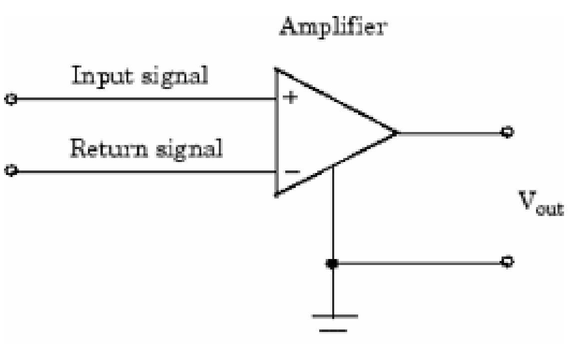
Ground loop illustration

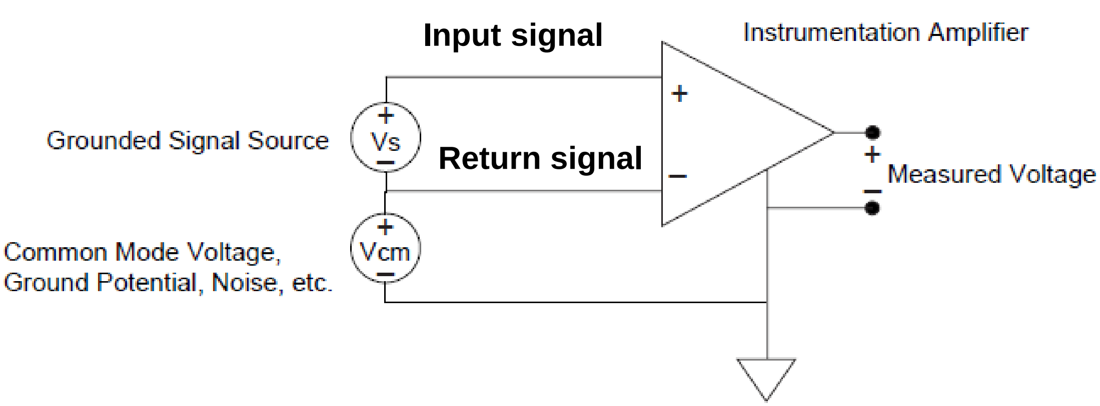
The blue connection to ground <u>must not be added</u>, since it creates a ground loop (red)

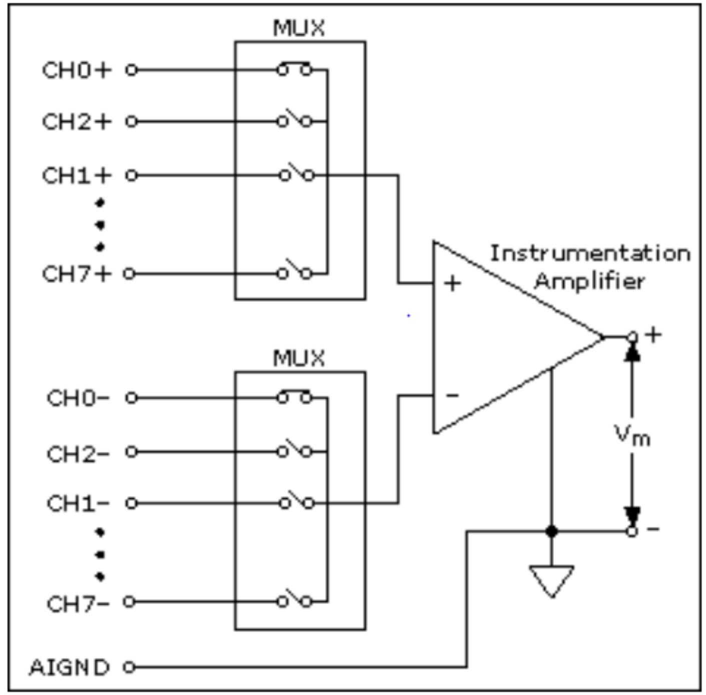


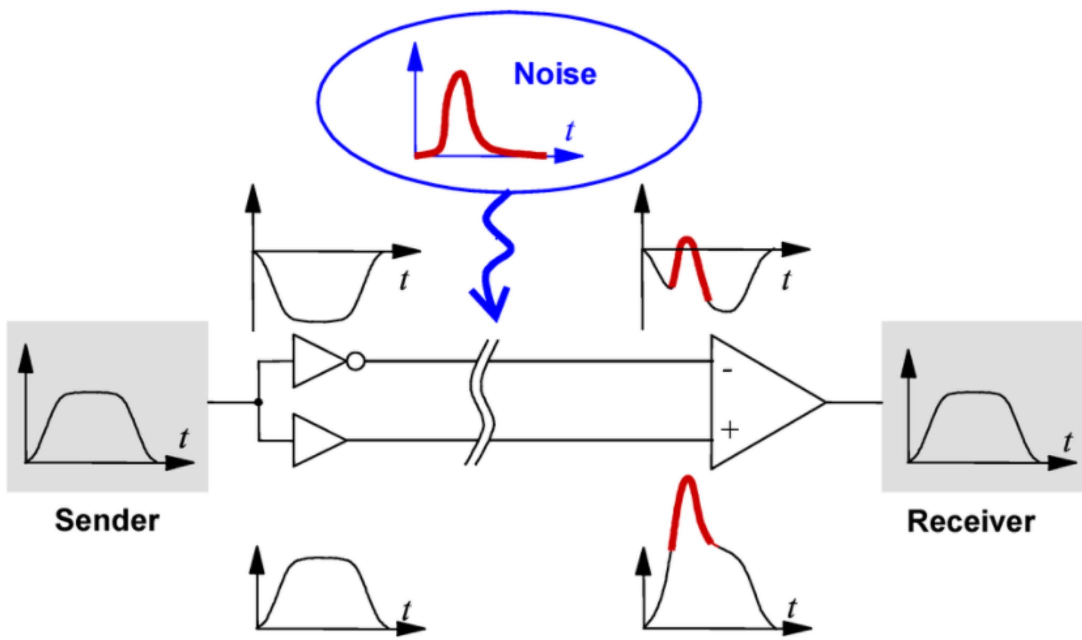
Differential signals

- Two signal wires for each input signal (input and return signals)
- The measurement is the voltage difference between the two wires
- Recommended for the following conditions:
  - Low-level signals (less than 1 V)
  - Long cables
  - The input signal requires a separate ground-reference point or return signal
  - The signal leads go through a noisy environment
- DAQ devices with instrumentation amplifiers can be configured as differential measurement systems
- Any voltage present at the instrumentation amplifier inputs with respect to the amplifier ground is called a common-mode voltage
- The instrumentation amplifier rejects common-mode voltage and common-mode noise

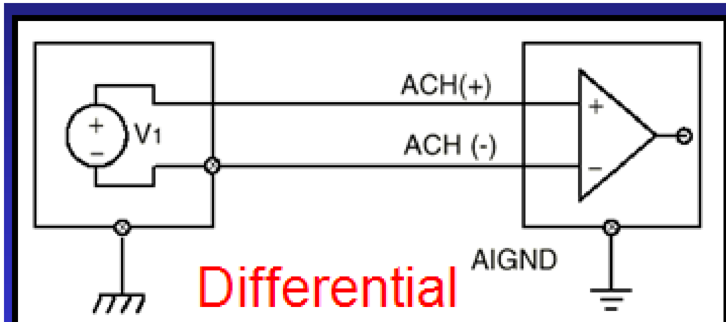





MUX
CH0+
CH2+
CH1+
CH7+
MUX
CH0-
CH2-
CH1-
CH7-
AIGND
Instrumentation
Amplifier
+
-
+
-
Vm

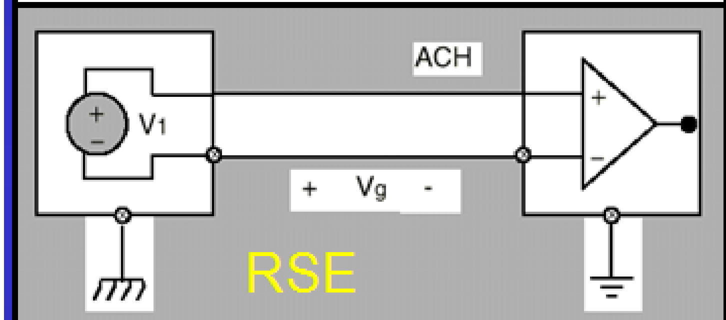

Noise
t
t
t
-
+
Sender
Receiver
t
t
t

Options for Grounded Signal Sources



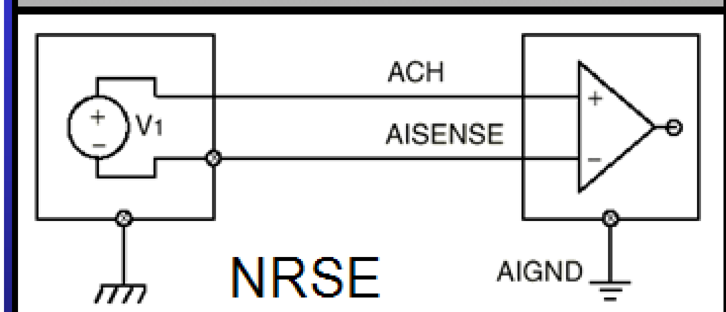
BETTER

+ Rejects Common-Mode Voltage
- Cuts Channel Count in Half



NOT RECOMMENDED

- Voltage difference (Vg) between the two grounds makes a ground loop that could damage the device

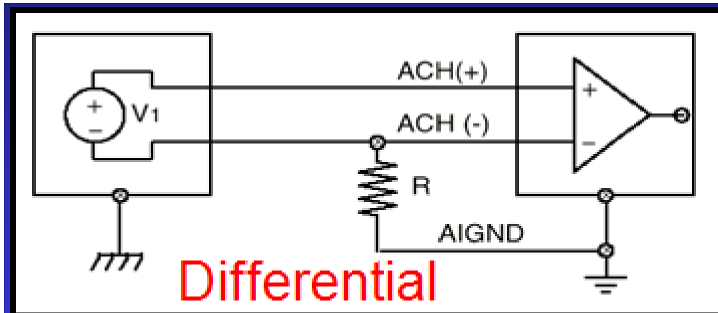


GOOD

+ Allows use of entire channel count
- Doesn't reject Common-Mode Voltage

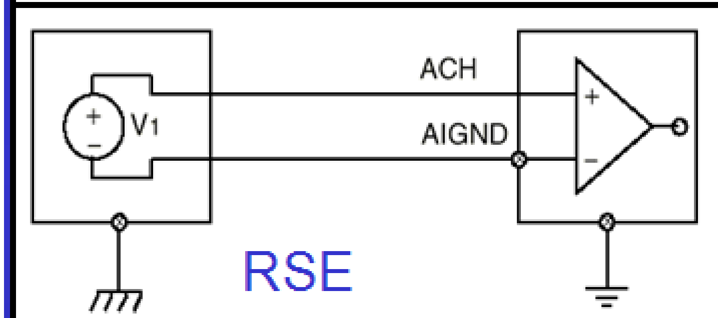
From NI manuals for DAQ devices

Options for Floating Signal Sources



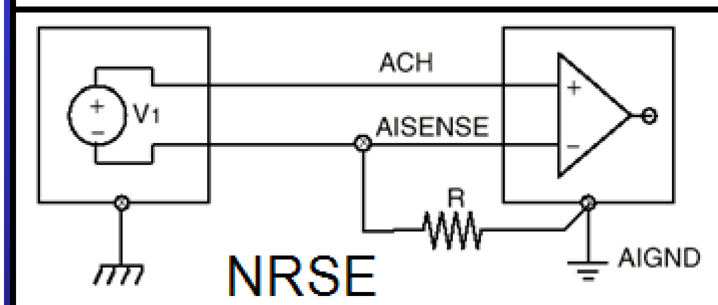
BEST

+ Rejects Common-Mode Voltage
- Cuts Channel Count in Half
- Need bias resistors



BETTER

+ Allows use of entire channel count
+ Don't need bias resistors
- Doesn't reject Common-Mode Voltage



GOOD

+ Allows use of entire channel count
- Need bias resistors
- Doesn't reject Common-Mode Voltage

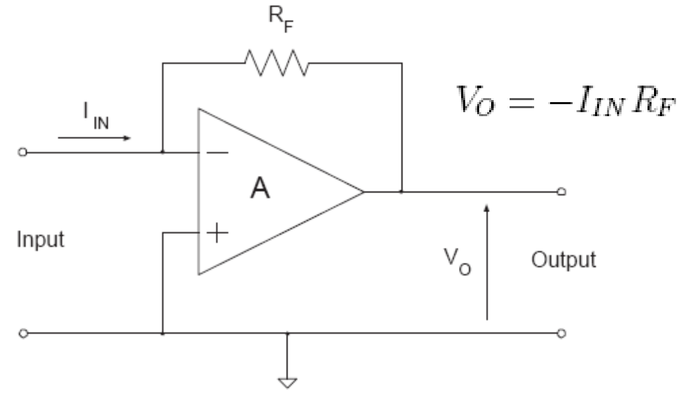
From NI manuals for DAQ devices

Signal conditioning

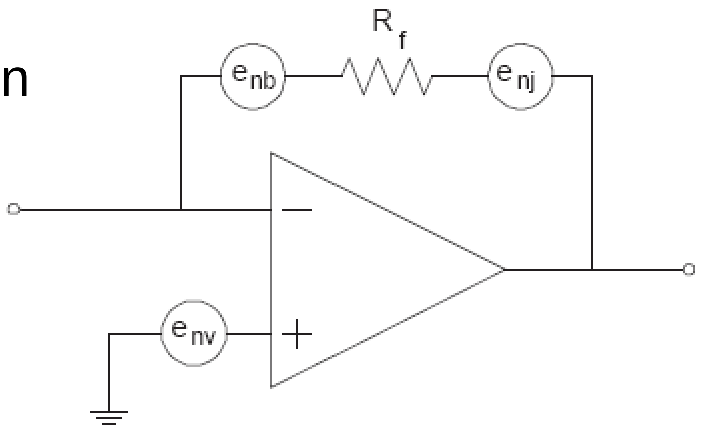
- Signal conversion
  - E.g. current-voltage converter
- Amplification
- Attenuation
  - Voltage divider
- Filtering
  - Anti-aliasing

Current-to-voltage converter

- Transimpedance amplifier (Feedback Ammeter)
- Recommended connection for small currents
- Sensitivity determined by Rf
- Add a capacitor Cf in parallel with Rf to avoid oscillations
- Rf usually large to achieve a large gain
- e_{nb} dominate for large Rf



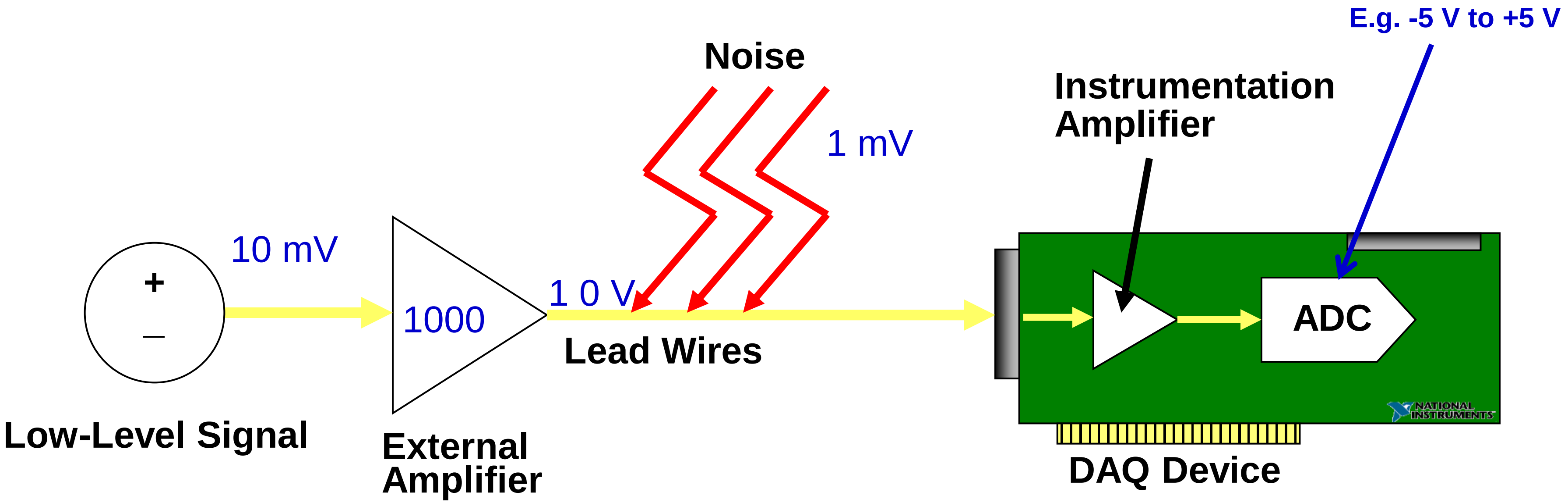
Noise equivalent circuit:



e_{nb} = input current noise * Rf
e_{nv} = input voltage noise
e_{nj} = thermal noise (voltage)

Amplification

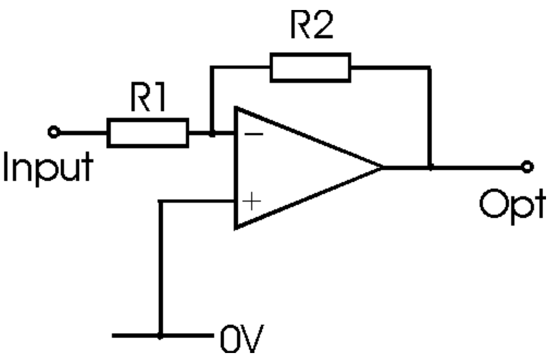
- Used on low-level signals (less than around 100 mV)
- Maximizes use of Analog-to-Digital Converter (ADC) range and increases accuracy
- Increases Signal to Noise Ratio (SNR)



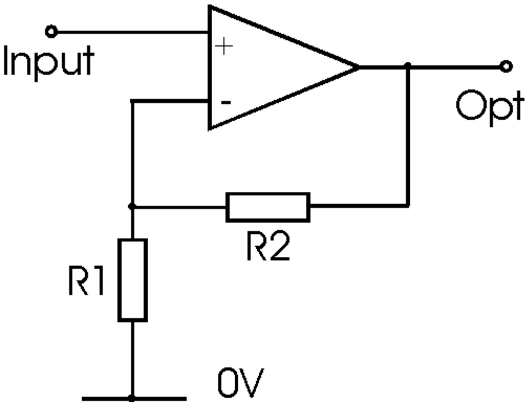
SNR = V_{signal}/V_{noise} = (10 mV * 1000) /1 mV = 10 000

$$SNR = 20 \log\left(\frac{V_{signal}}{V_{noise}}\right)$$

Operational amplifier (Op-amp)



- Inverting op-amp amplifier
  - Vo = -R2/R1 * Vi

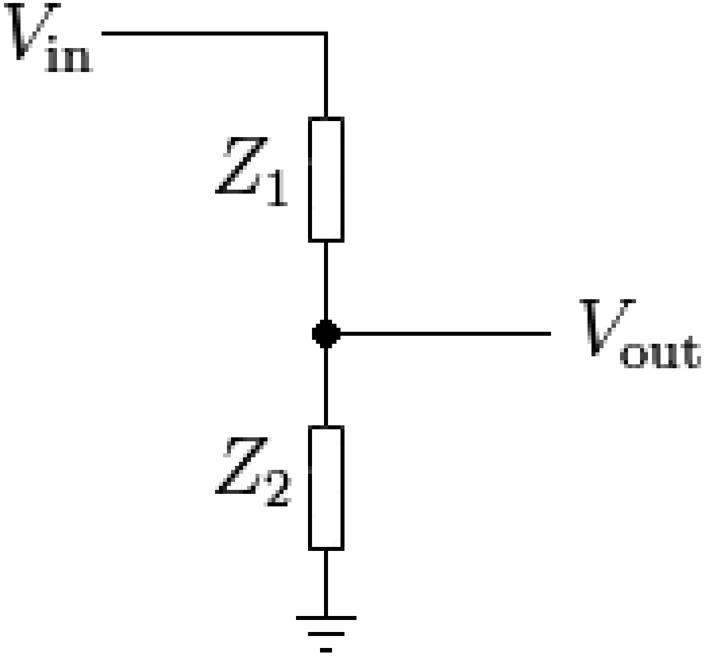


- Non-inverting op-amp amplifier
  - Vo = (1+R2/R1) * Vi

- Non-inverting op-amp amplifier useful when a **high impedance** input is needed
- Inverting op-amp amplifier useful when a **low impedance** input is needed
- Non-inverting op-amp amplifier gives less noise (due to G = 1+R2/R1 instead of G = -R2/R1

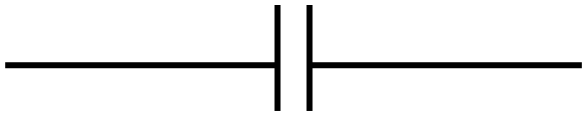
Attenuation

- Voltage divider
- A circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{in})
- Can be needed to get a high-level signal down to the acceptable DAQ-card range

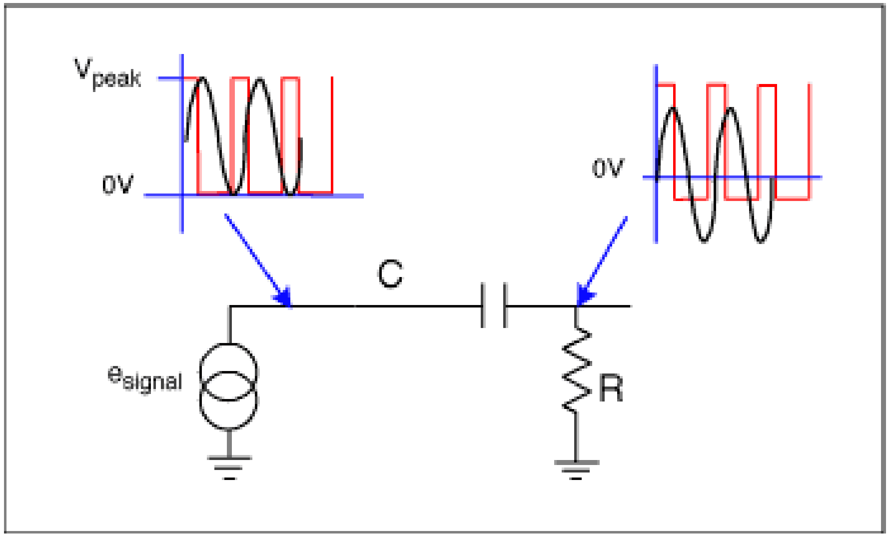


Input Coupling

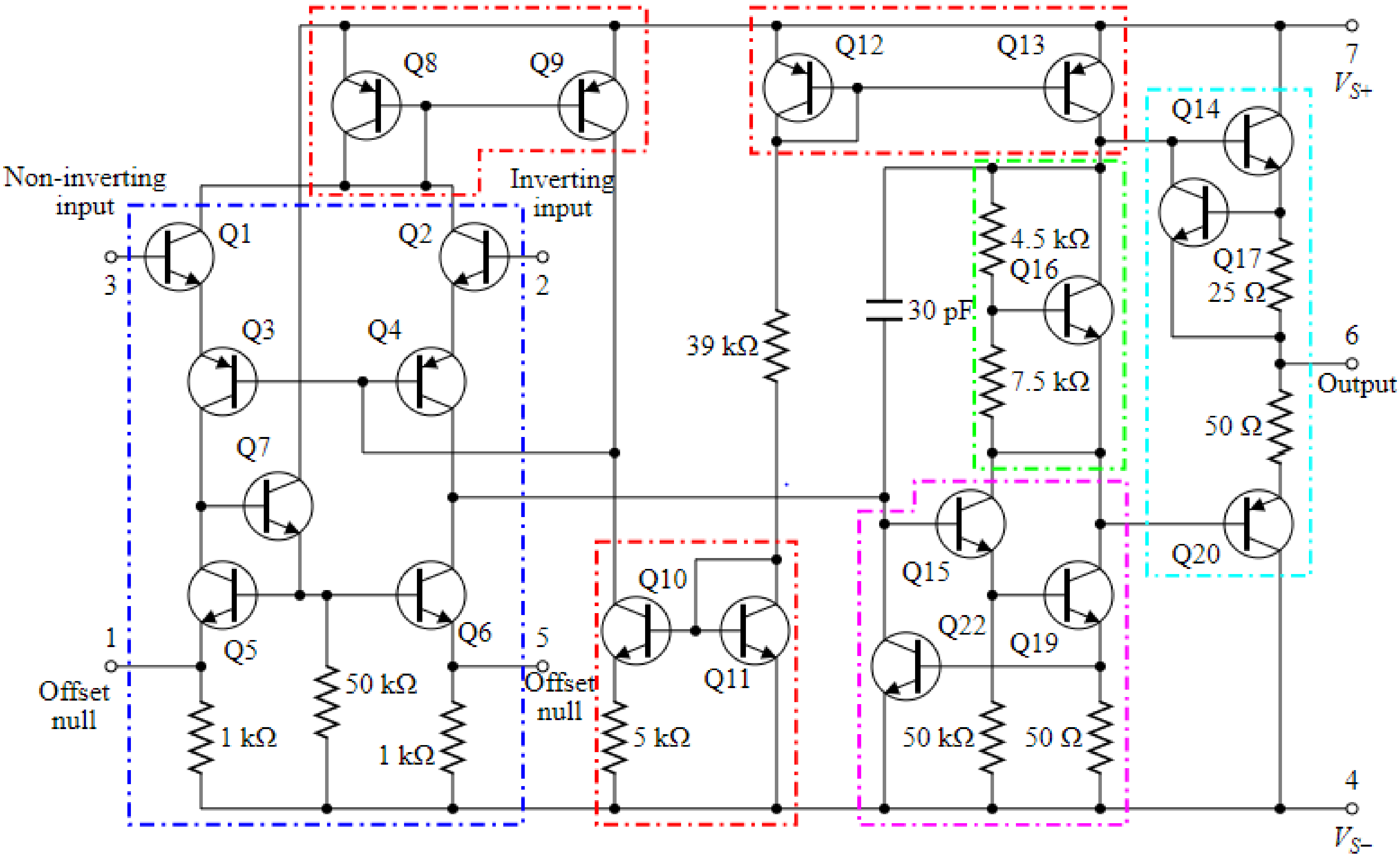
- Use AC coupling when the signal contains a large DC component. If you enable AC coupling, you remove the large DC offset for the input amplifier and amplify only the AC component. This configuration makes effective use of <u>the ADC dynamic range</u>



C



A component-level diagram of the common 741 op-amp. Dotted lines outline: current mirrors; differential amplifier; class A gain stage; voltage level shifter; output stage.



PC-based data acquisition

General-purpose computer

- With a Personal Computer (PC) we mean a **general-purpose computer**. Such systems are easy to expand with more memory, and more I/O ports etc.
- A PC is designed to be able to run all kind of application programs that you can buy or intend to develop. A general-purpose computer need to be ready for new device drivers and software to run hardware it doesn't know about yet, like new printers or hard drives, and it need to run different application programs.
- The PC usually need to run several programs at the same time on the CPU by sharing CPU time between the different applications (multitasking), or by running different applications in parallel on different CPUs or different CPU cores. The typical PC today have two or four CPU cores, but can have up to 20 cores with ten CPU cores on two CPUs

Intel Architecture example

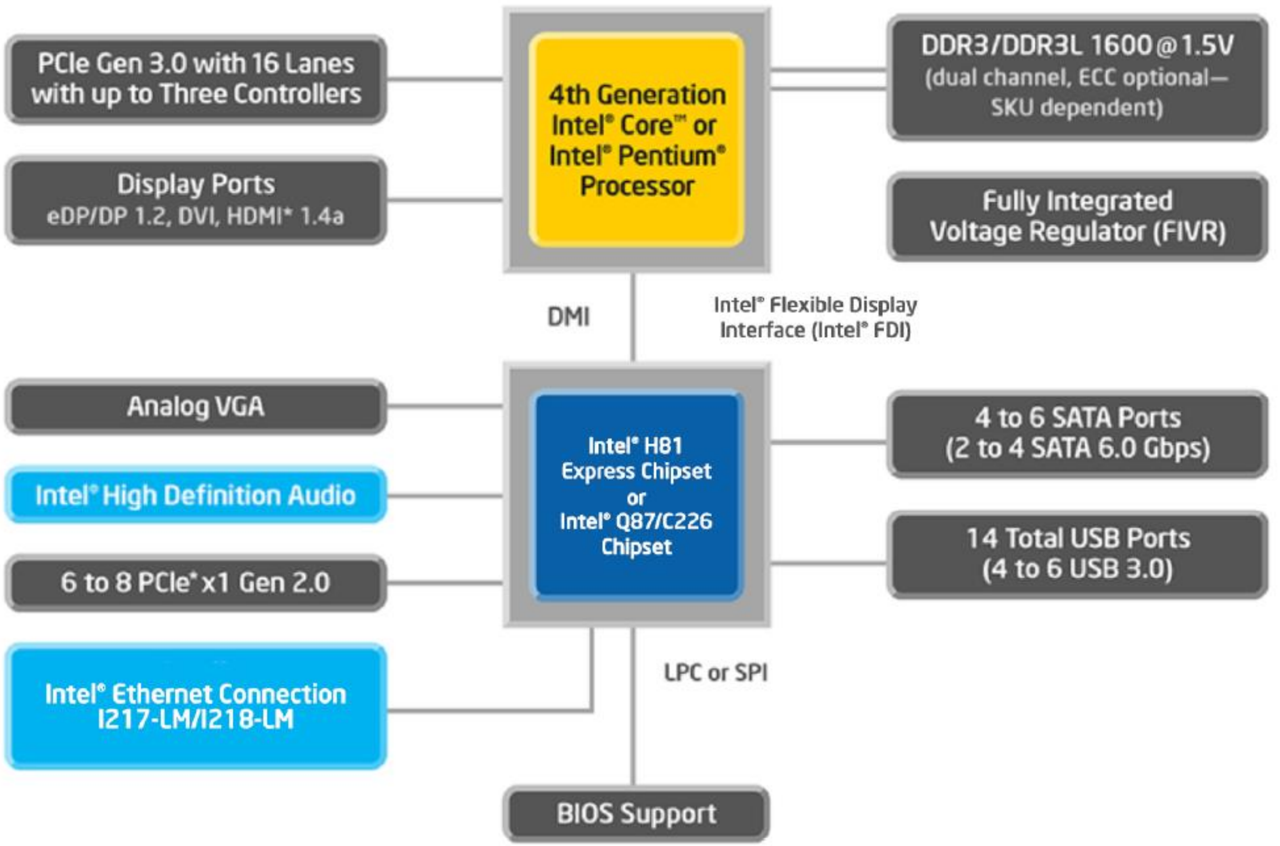


Figure 1: Typical system based on the Intel® Core™ i7 processor

General Purpose Operating Systems (OS)

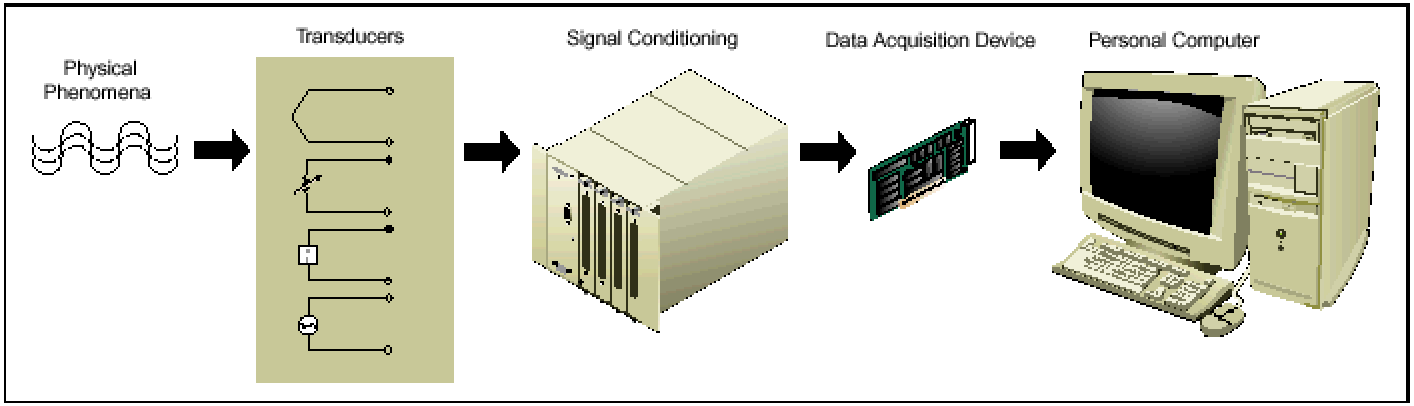
- Windows, Linux, MacOS, Unix
  - Processor time shared between programs
  - OS can preempt high priority threads
  - Service interrupts –keyboard, mouse, Ethernet…
  - <u>Cannot ensure that code finish within specified time limits!</u>

Data acquisition (DAQ)

- **Data acquisition involves measuring signals (from a real-world physical system) from different sensors, and digitizing the signals for storage, analysis and presentation.**

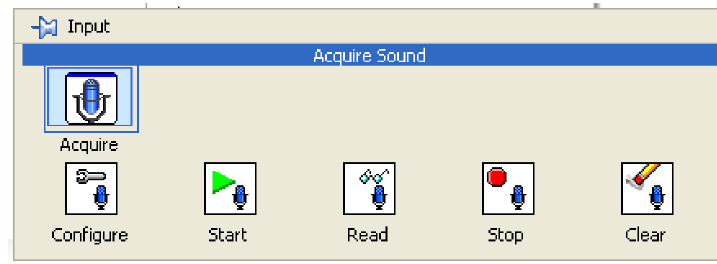
- Analog input channels can vary in number from one to several hundred or even thousands

Computer-based DAQ system:

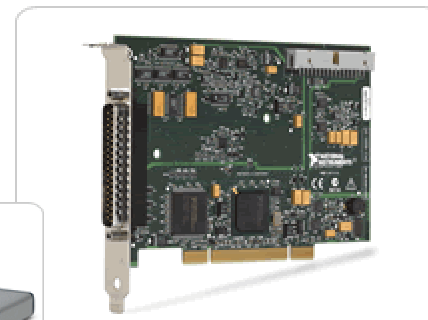


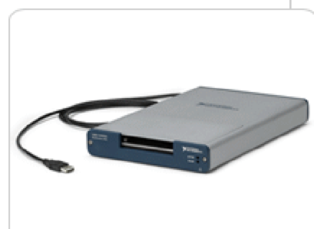
From Simple to advanced PC-based DAQ systems ….

- DAQ using the PC sound card
  - AC, low frequencies (10 – 20 kHz)

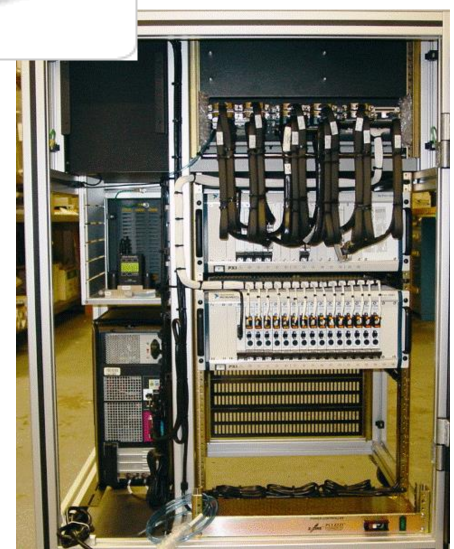


- PC with plug-in PCI DAQ card(s)
- PC with a USB DAQ device





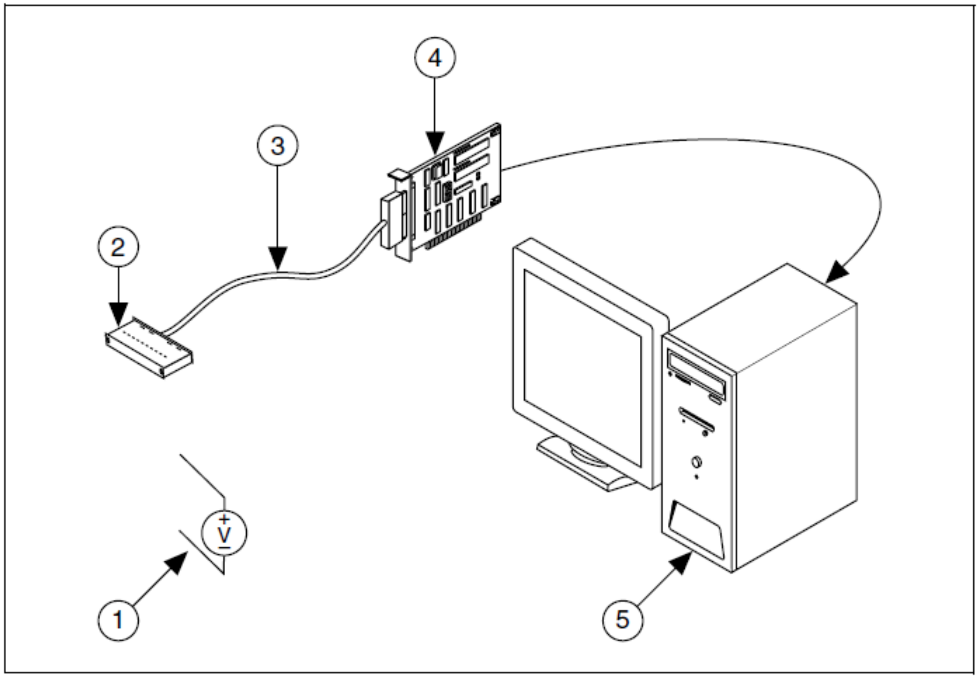
- DAQ system with hundreds of measurement channels
  - multiple connected PXI systems



Overview of a PC-based Data acquisition (DAQ) system

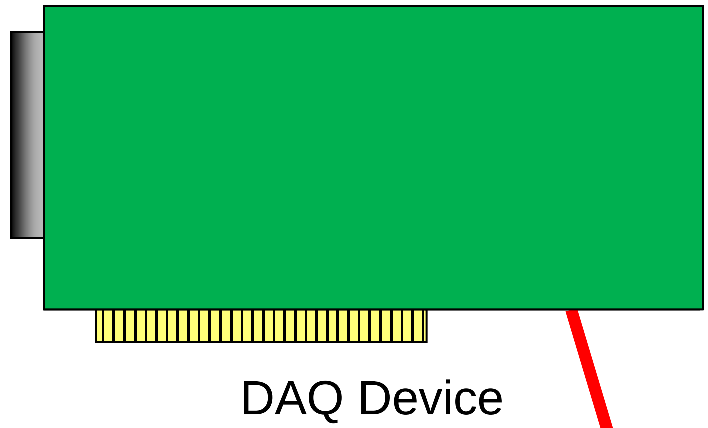
A DAQ system consists of:

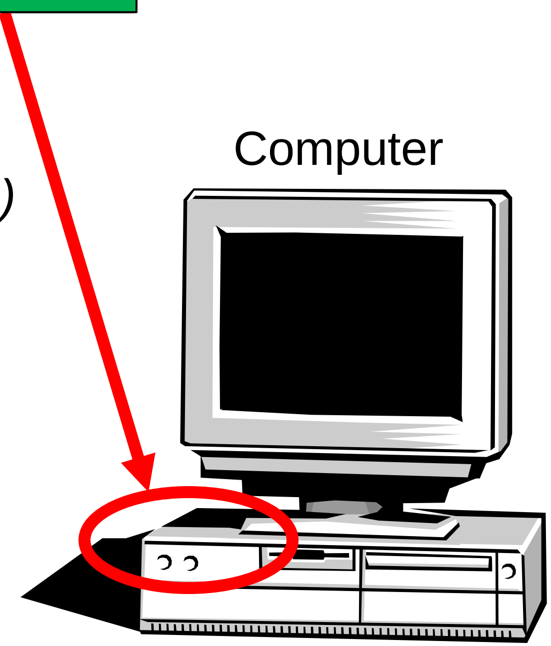
- Sensors (transducers)
- Signal Conditioning
- Cables
- DAQ hardware
- Drivers
- Software



1	Sensors and Transducers	4	DAQ Hardware
2	Signal Conditioning	5	Personal Computer and DAQ Software
3	Cable Assembly		

DAQ Device





- Most DAQ devices have:
  - Analog Input
  - Analog Output
  - Digital I/O
  - Counters
    - Frequency measurements (*digital edge counting)*
    - Angular measurements from angular encoders (*quadrature encoders)*

- Connects to the bus of your computer
  - PCI, PXI, PCIe, PXIe, or USB

Device Drivers

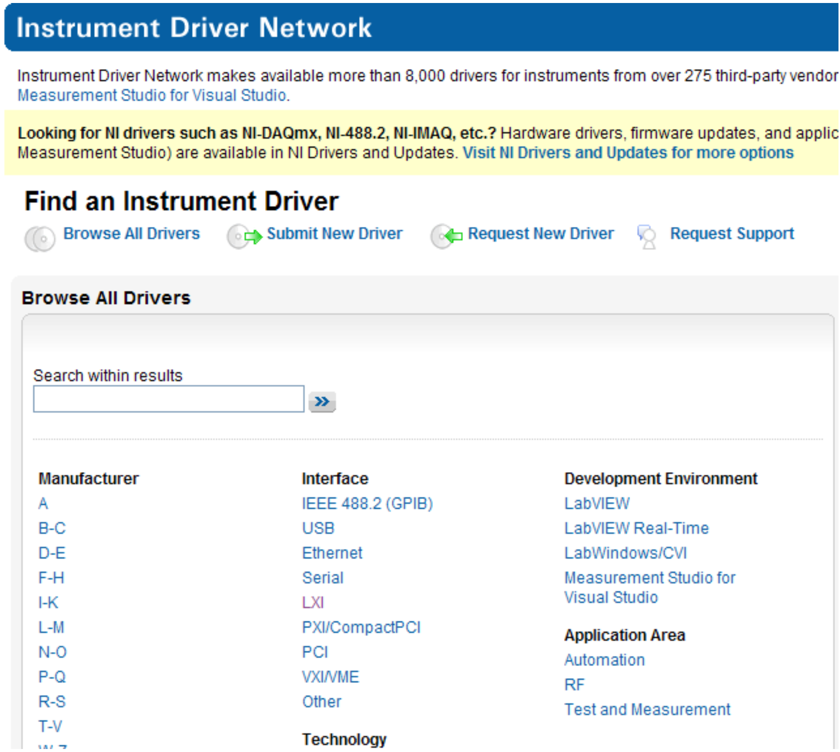
- In computing, a device driver or software driver is a computer program allowing higher-level computer programs to interact with a hardware device.

- A driver typically communicates with the device through the computer bus or communications subsystem to which the hardware connects. When a calling program invokes a routine in the driver, the driver issues commands to the device. Once the device sends data back to the driver, the driver may invoke routines in the original calling program. Drivers are hardware-dependent and operating-system-specific.

Example: NI Instrument Drivers - IDNET

- All NI hardware is shipped with LabVIEW driver software
- Driver upgrade to the latest version available at www.ni.com
- Many third-party vendors also ship LabVIEW drivers with their instruments

ni.com/idnet



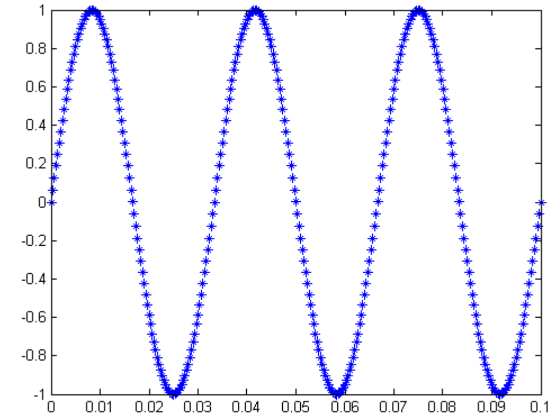
VISA

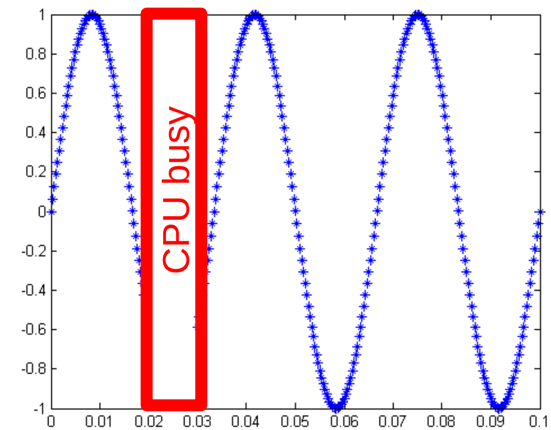
- VISA = Virtual Instrument Software Architecture.
- NI-VISA is the NI implementation of the VISA standard.
- LabVIEW instrument drivers are based on the VISA standard, which makes them bus- and platform-independent.
- Supports communication with instruments via:
  - GPIB
  - Serial
  - Ethernet
  - USB
  - PXI

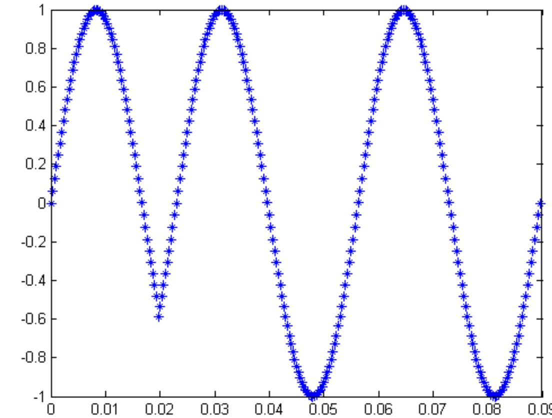
CPU busy example

- 30 Hz sinus signal sampled at 3 kHz (top figure)
- Assume a non real-time system used, without DMA and FIFO.
  - If the CPU get busy with something else between 0.02 seconds and 0.03 seconds, this section of the sine wave does not get sampled (middle figure)
- The computer will then interpret the sine wave as shown in the bottom figure, unaware that the <u>samples are not evenly spaced in time</u>
  - This will give a wrong result if we do a frequency analysis of the signal.

Therefore, DMA and FIFO buffers are used to compensate for non real-time properties of the operating system

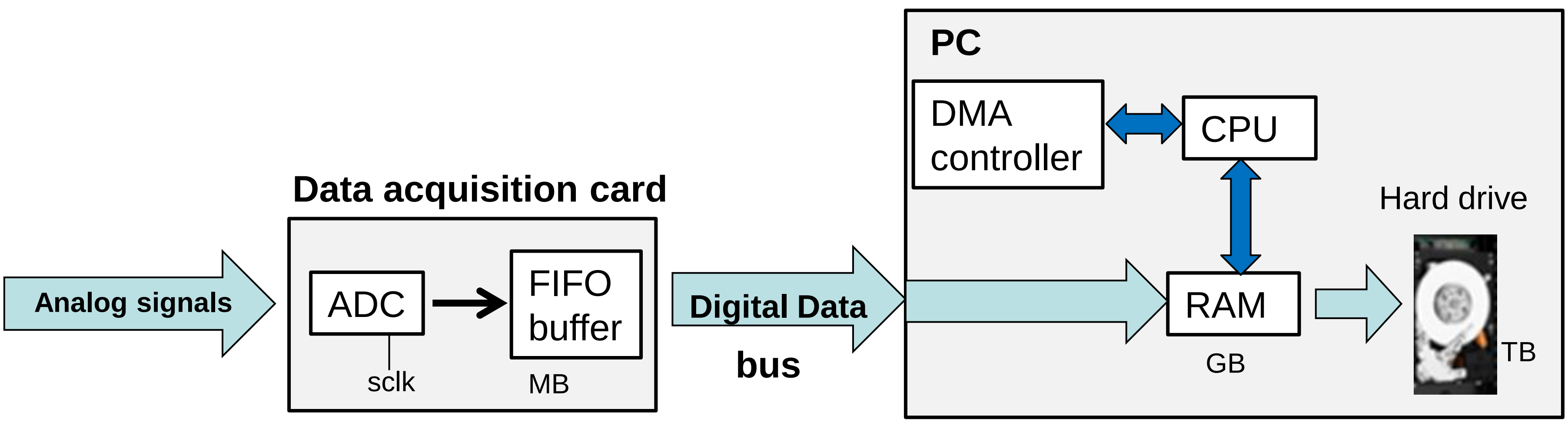






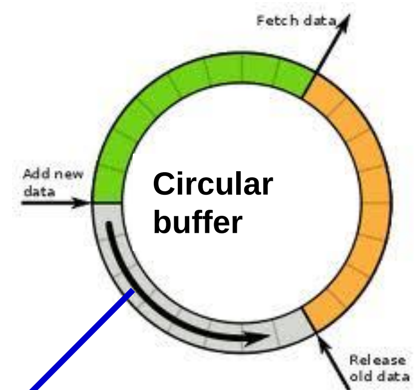
Transferring Data from DAQ-card to hard drive

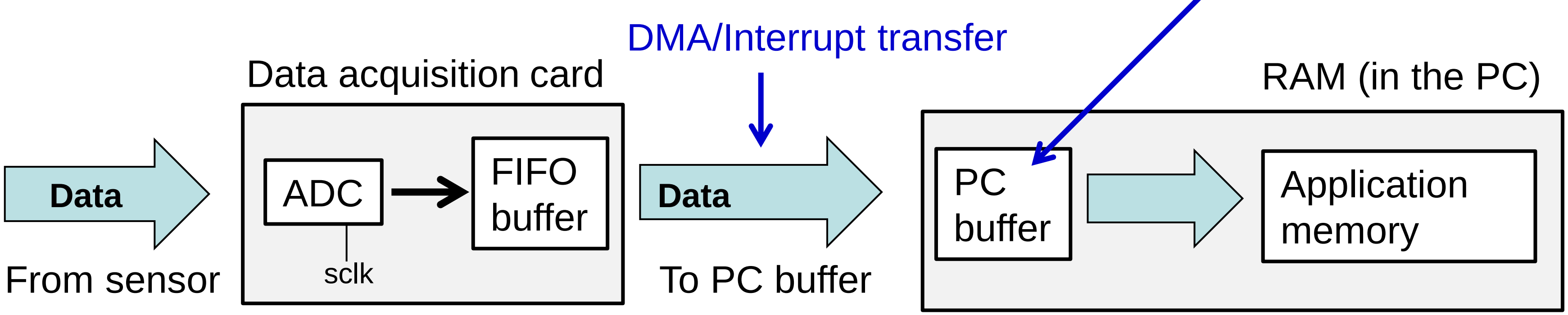
- Acquired data are stored in the hardware's first-in first-out (FIFO) buffer.
- Data is transferred from the DAQ-card FIFO buffer (of fixed size) to PC RAM using interrupts or DMA, across e.g. the PCI/PCI Express bus and the computer I/O bus.
- The samples are then transferred from RAM to hard drive via the computer I/O bus.



Continuous data acquisition

- To implement a continuous data acquisition on a non real-time system a **PC buffer** is needed in addition to the FIFO buffer on the DAQ card
- The PC buffer is a **circular buffer** in the computer RAM
- When we perform a DAQ-read in our application software we read the values out of the circular buffer and into a “variable” in our application program





DAQ data overwrite and overflow

- An **overwrite error** indicates that information is lost and occurs when the software program does not read data from the PC buffer quickly enough. Samples that are written to the circular PC buffer are overwritten before they are read into the application memory.
  - Solution: use **Producer-Consumer** architecture.
- An **overflow error** indicate that information has been lost earlier in the data acquisition process. Overflow errors indicate that the First In First Out (FIFO) memory buffer onboard the data acquisition card has reached its maximum capacity for storing acquired samples and can no longer accept new samples. An overflow error is symptomatic of a bus transfer rate that falls short of the requested data input rate.
  - Solution: use a Direct Memory Access (**DMA**) transfer mechanism.

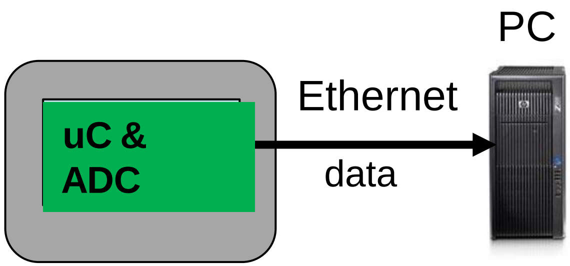
Remote control and data distribution

- **Remote Control**
  - Enabling another computer to connect to the experiment and control that experiment remotely.

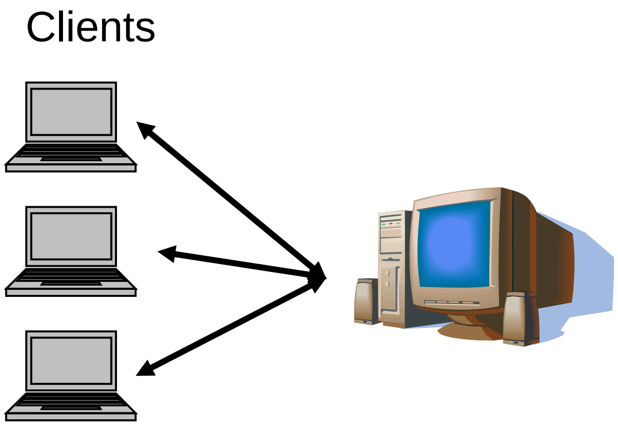
- **Distributed Execution**
  - A system architecture that shares the acquisition and analysis of the test among several computers.

Distributed DAQ examples

- **Remote DAQ**
  - Transfer data from a remote DAQ device to a single PC for display and storage



- **Networked (distributed) DAQ**
  - Distribute measurement data to several clients connected to a network
  - Enable a central computer to acquire all of the data from several machines and then process or store that data



PC-based data acquisition

Data streaming to a storage device

Data streaming

- Data written to or read from a storage device at a <u>sustained rate</u> is often referred to as **streaming**

- Trends in data storage
  - *Ever-increasing amounts of data (**Big Data**)*
  - *Record "everything" and play it back later*
  - *Hard drives: faster, bigger, and cheaper*
  - *Solid state drives*
  - *RAID hardware*
  - *PCI Express*
    - *PCI Express provides higher, dedicated bandwidth*

Key system components for high-speed streaming

- Hardware Platform with High-Throughput and Low-Latency
  - PXI/PCI Express bus
- High-Speed Data Storage
  - Hard Disk Drives (HDDs) in RAID
  - Solid-State Drives (SSDs)
- Software for Streaming to Disk at High Rates
  - Parallel programming
  - Fast binary file format

Determining Storage Format

When determining the appropriate storage format for the data, consider the following:

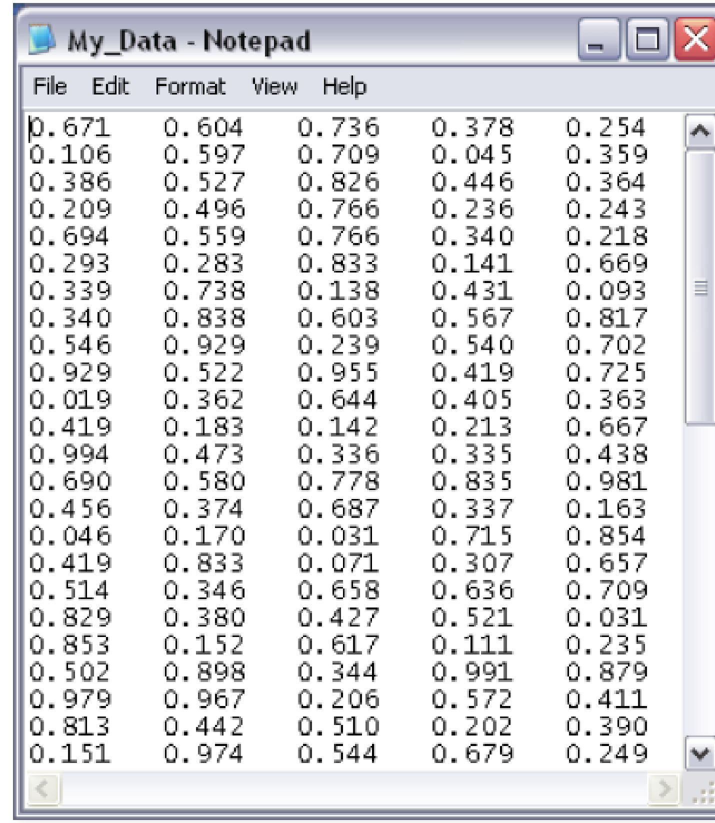
- At what sample rate will you acquire data?
- How much data will you acquire?
- Will you need to exchange data with another program?
- Will you need to search your data files?

- ASCII (text)
- Binary
- TDMS
- INI
- Spreadsheet
- AVI
- XML

Configuration files (→ INI, XML)

ASCII Files

- **Pros**
  - Human-readable
  - Easily portable to other applications such as Microsoft Excel
  - Can easily add text information (first line) for each data column

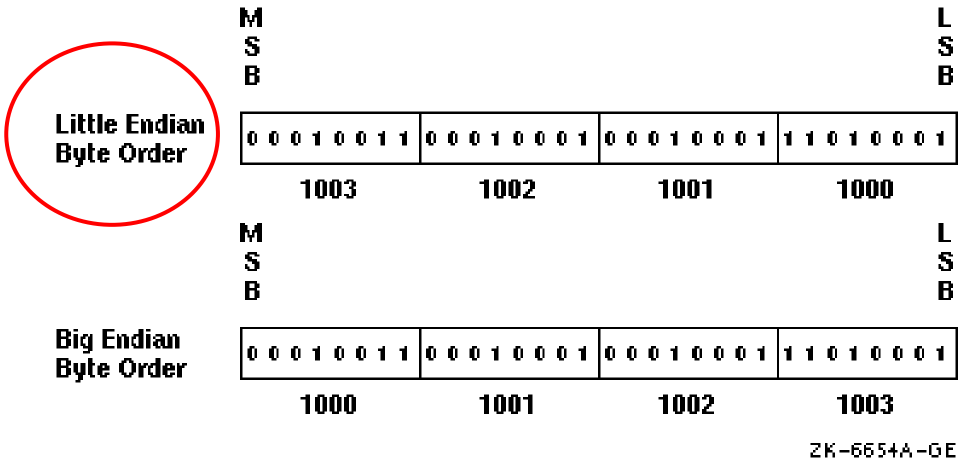


0.671	0.604	0.736	0.378	0.254
0.106	0.597	0.709	0.045	0.359
0.386	0.527	0.826	0.446	0.364
0.209	0.496	0.766	0.236	0.243
0.694	0.559	0.766	0.340	0.218
0.293	0.283	0.833	0.141	0.669
0.339	0.738	0.138	0.431	0.093
0.340	0.838	0.603	0.567	0.817
0.546	0.929	0.239	0.540	0.702
0.929	0.522	0.955	0.419	0.725
0.019	0.362	0.644	0.405	0.363
0.419	0.183	0.142	0.213	0.667
0.994	0.473	0.336	0.335	0.438
0.690	0.580	0.778	0.835	0.981
0.456	0.374	0.687	0.337	0.163
0.046	0.170	0.031	0.715	0.854
0.419	0.833	0.071	0.307	0.657
0.514	0.346	0.658	0.636	0.709
0.829	0.380	0.427	0.521	0.031
0.853	0.152	0.617	0.111	0.235
0.502	0.898	0.344	0.991	0.879
0.979	0.967	0.206	0.572	0.411
0.813	0.442	0.510	0.202	0.390
0.151	0.974	0.544	0.679	0.249

- **Cons**
  - Large file size
  - Slow read and write

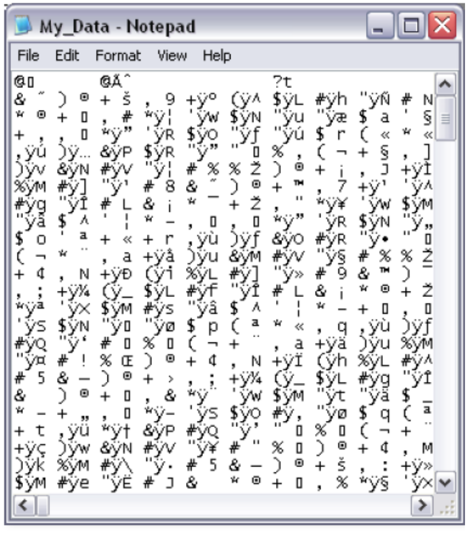
Binary Files

Two different architectures for handling memory storage:



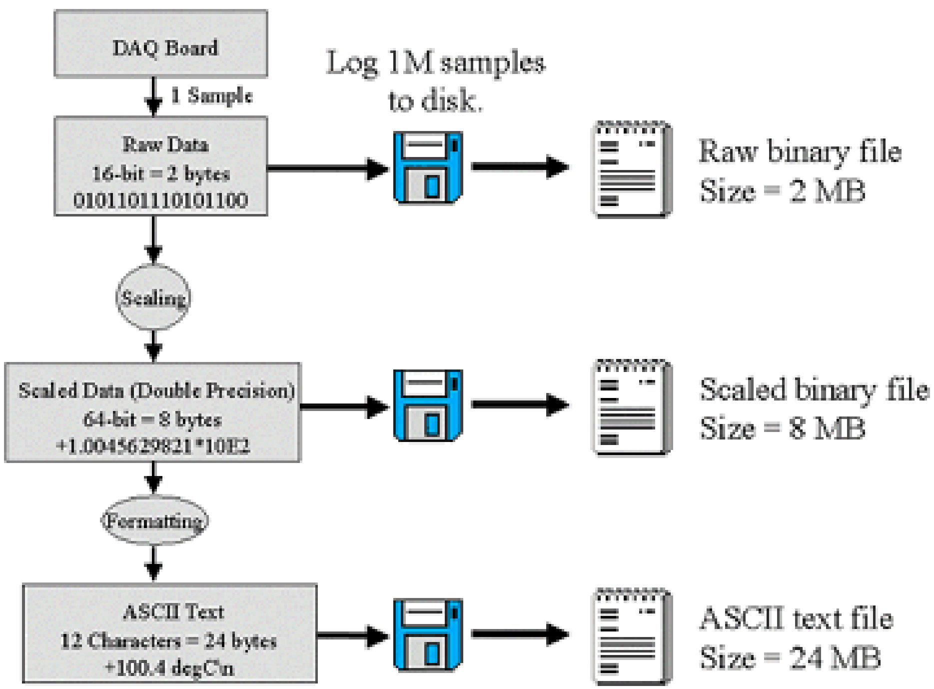
- **Pros**
  - Compact file size
  - Fast streaming
- **Cons**
  - Not human-readable
  - Less easily exchangeable
    - Need to know the file format to read the data

- Windows and Linux use Little Endian format.
- A **big-endian** machine stores the most significant byte first, at the lowest byte address.
- A **little-endian** machine stores the least significant byte first.



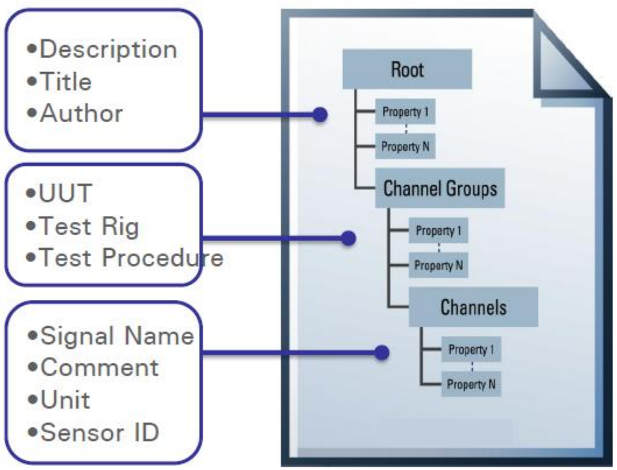
Data Types – file size

- Reduce file size
  - 1 I16 sample = 16 bits = 2 bytes
  - 1 DBL sample = **64 bits = 8 bytes = 4X increase in bandwidth**



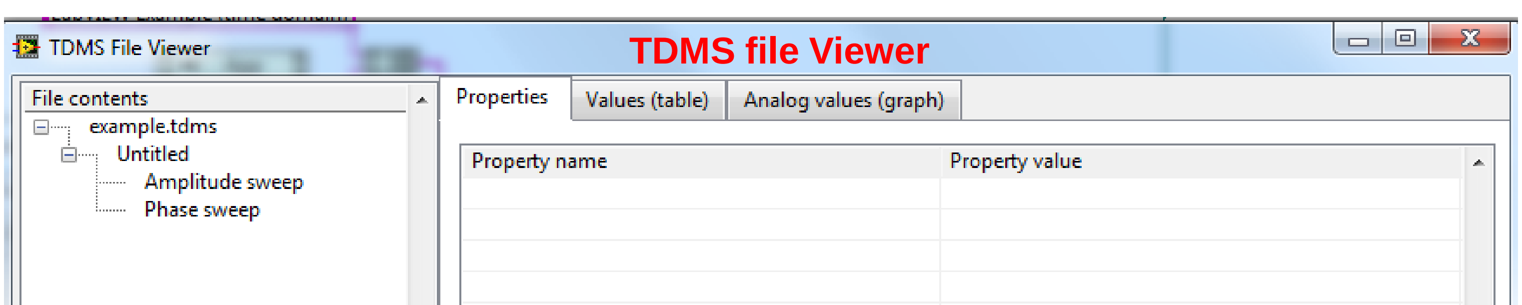
TDMS

- A file format from National Instruments
- TDMS = Technical Data Management Streaming
- Three levels of hierarchy
- Microsoft Excel add-in
- C-DLL
- Can download reader for Matlab

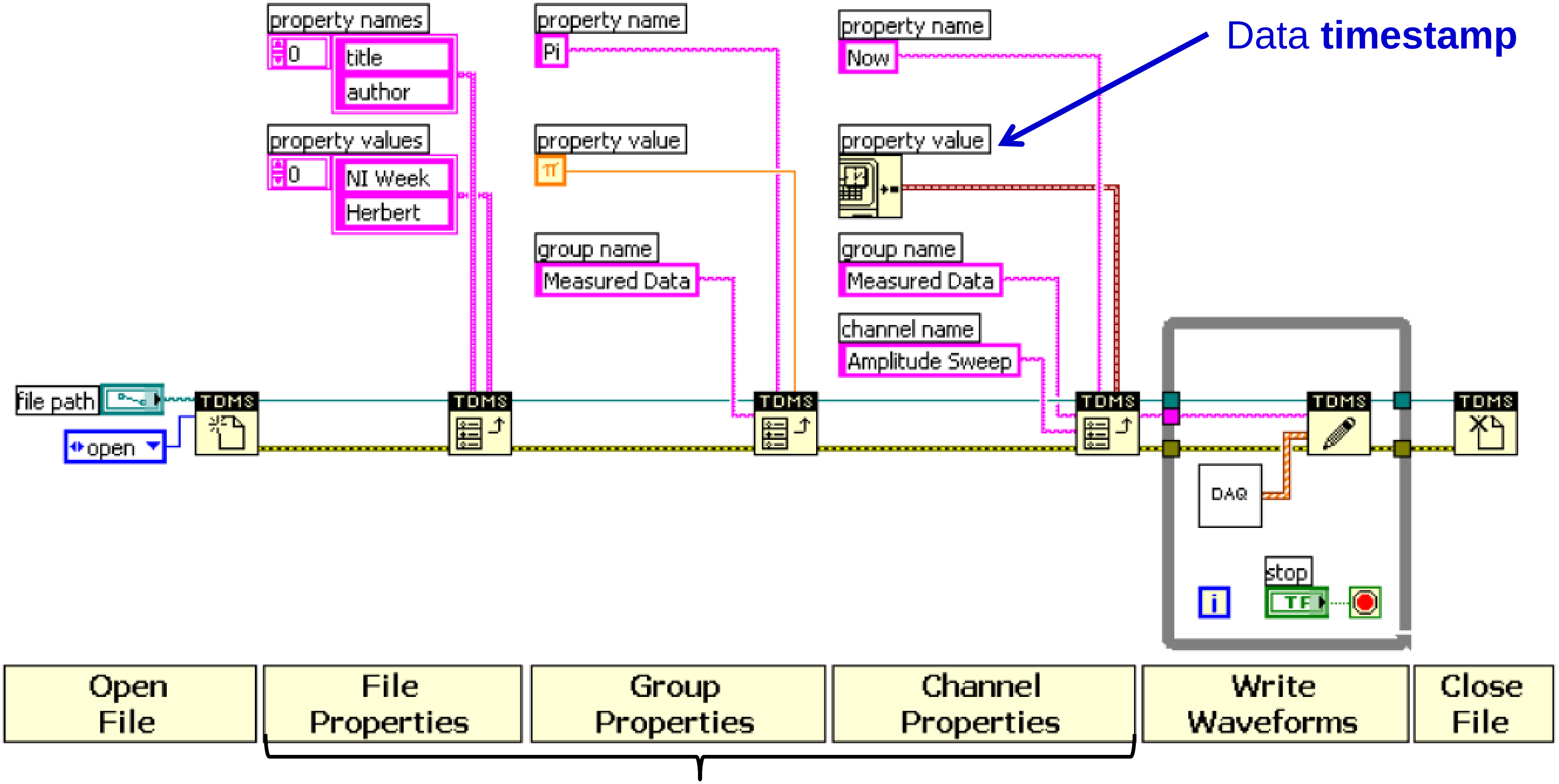


- *Optimized for high-speed streaming*
- *Single file*
  - *Binary header*
  - *Binary data*

ni.com/tdm



TDMS –Write Data and Set Properties



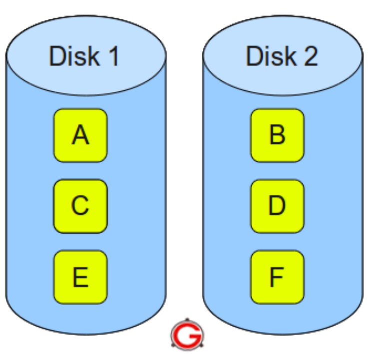
E.g. sample rate, UUT/sensor names, channel names

	ASCII	Binary	XML	Database	TDMS
Exchangeable	✓		✓		✓
Small Disk Footprint		✓			✓
Searchable				✓	✓
Inherent Attributes			✓		✓
High-Speed Streaming		✓			✓
NI Platform Supported	✓	✓	✓	✓*	✓

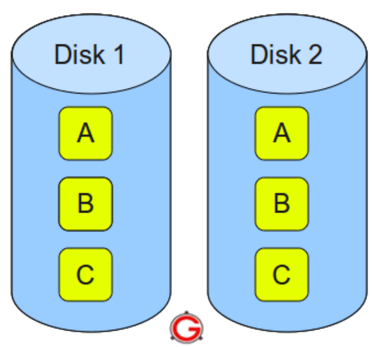
*May require a toolkit or add-on module.

RAID introduction

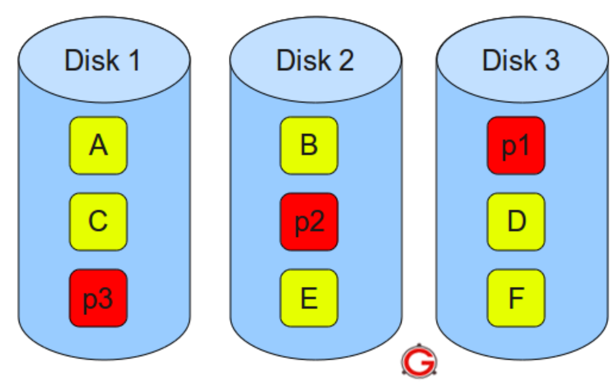
- RAID = Redundant Array of Independent Drives.
- RAID is a general term for mass storage schemes that split or replicate data across multiple hard drives.
  - **To increase write/read performance and/or increase safety (redundancy)**



<u>RAID 0</u> – Blocks Striped. No Mirror. No Parity.



<u>RAID 1</u> – Blocks Mirrored. No Stripe. No parity.



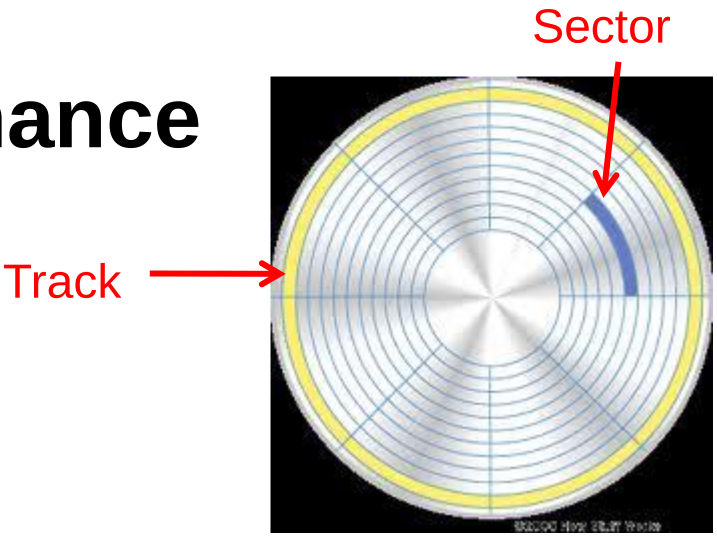
<u>RAID 5</u> – Blocks Striped. Distributed Parity.

RAID examples

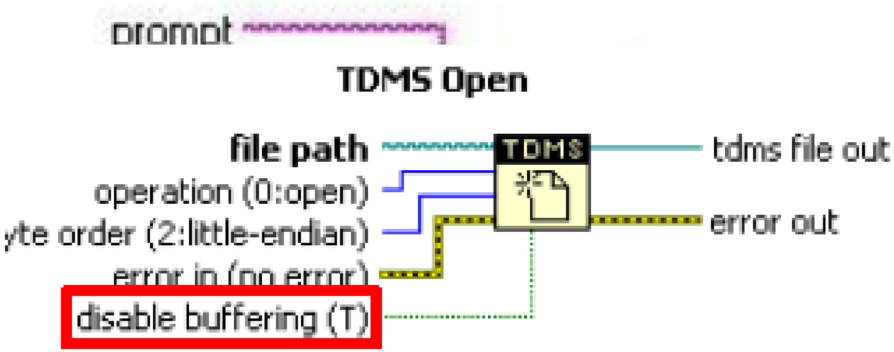
- Internal RAID of the workstation/PC
- Network attached storage (NAS) with RAID
- Server RAID
- Externally connected RAID (e.g. to the PXIe chassis)
- In-chassis PXI RAID
- SSDs (FLASH circuits) on a PCIe card



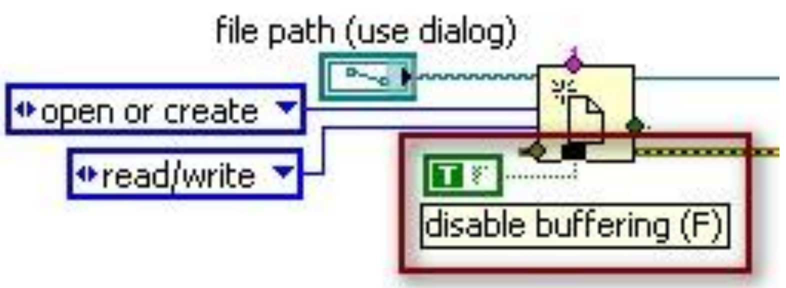

Increase DAQ I/O Performance



- Use the option to **disable buffering (unbuffered file I/O)** in **Windows API**
  - Optimizes streaming applications
  - Important for RAID systems
  - Supported in LabVIEW



- Note that you must <u>read from or write to the file in **integer multiples of the disk sector size**</u> (usually 512 bytes)
- The data can span multiple sectors but must fill each sector completely
- If the data is not a multiple of the sector size, you must pad the data with filler data and delete the filler data before the data is used



Remote Terminal Units

Remote Terminal Unit

A remote terminal unit (RTU) is a microprocessor-based electronic device used in industrial control systems (ICS) to connect various hardware to distributed control systems (DCS) or supervisory control and data acquisition (SCADA). RTUs are also referred to as remote telemetry units or remote tele-control units.

RTUs pass sensor data from input streams in control loops to an output stream to be forwarded on to centralized control in an ICS. RTUs automatically negotiate connections to either local or remote controls.

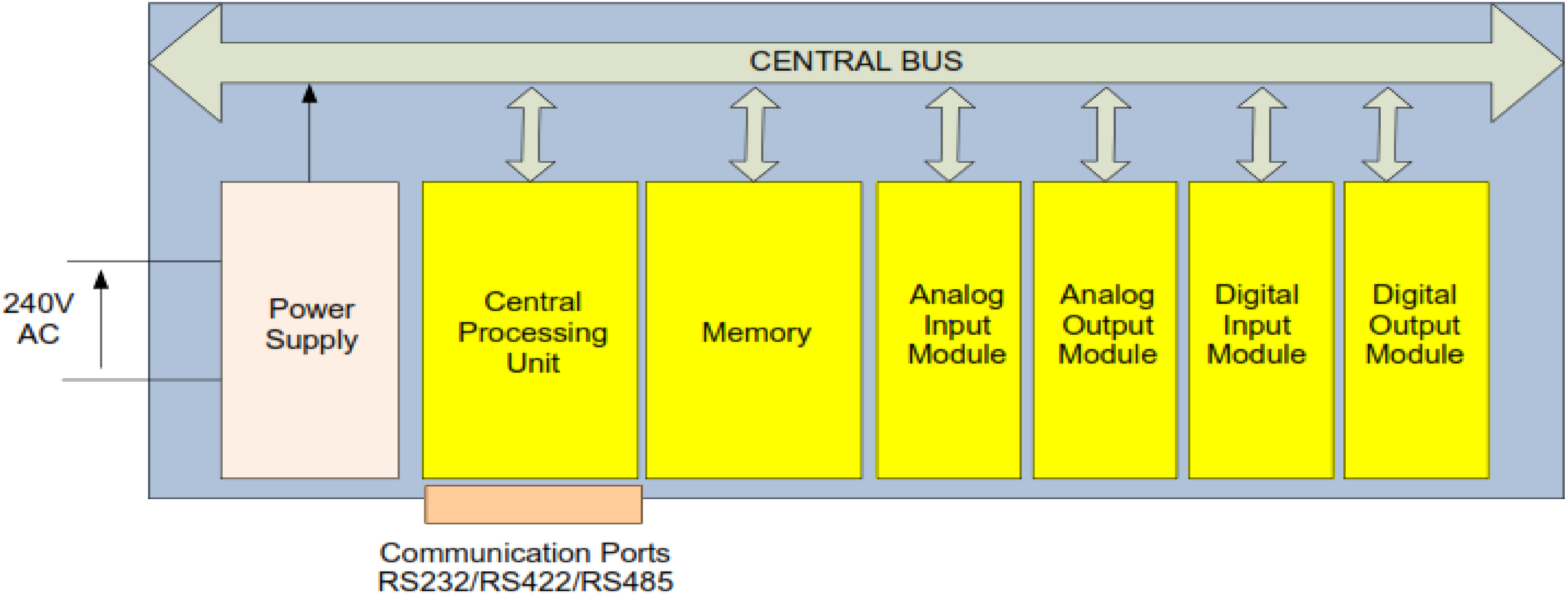
Found everywhere ICS are used, RTUs are part of the systems used in several processes, including:

- Petrochemical (oil) and refineries
- Nuclear power plants
- Agriculture
- Quality control
- Chemical plants
- Sewage treatment plants
- Food processing
- Automobile manufacturing
- Pharmaceutical manufacturing
- Water treatment plants

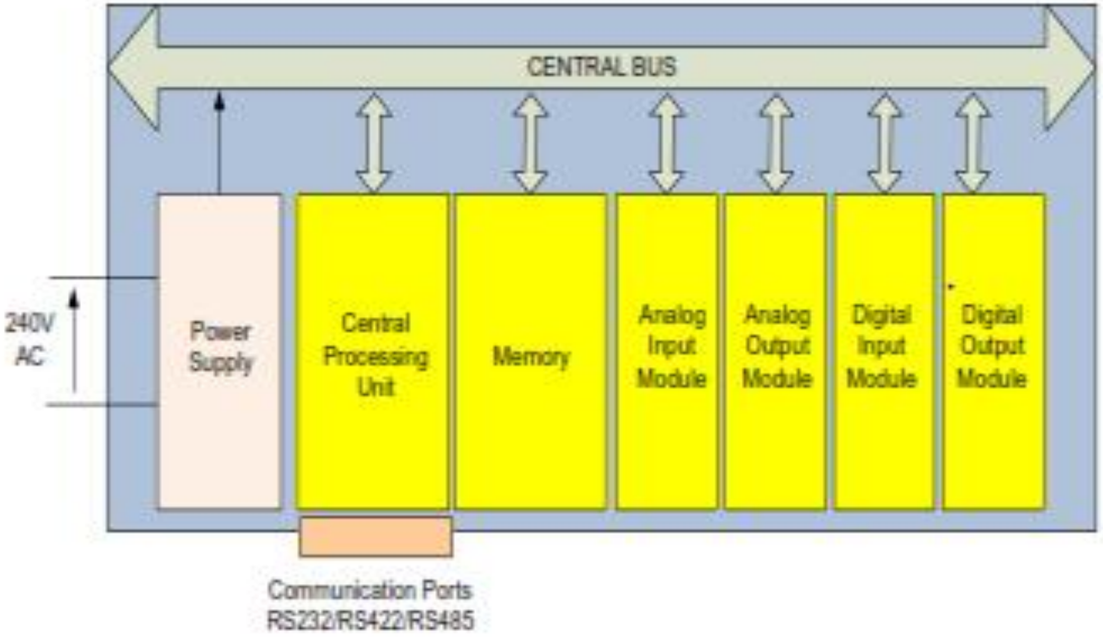
RTUs monitor both analog and digital field data. An RTU gets the data from sensors monitoring target industrial process variables and then forwards that data onto centralized monitoring and control. The hardware of an RTU contains the setup software required to connect data output streams, communication protocols and built-in troubleshooting. The devices are often powered by AC mains with DC converters and sometimes battery backup.

Remote Terminal Units

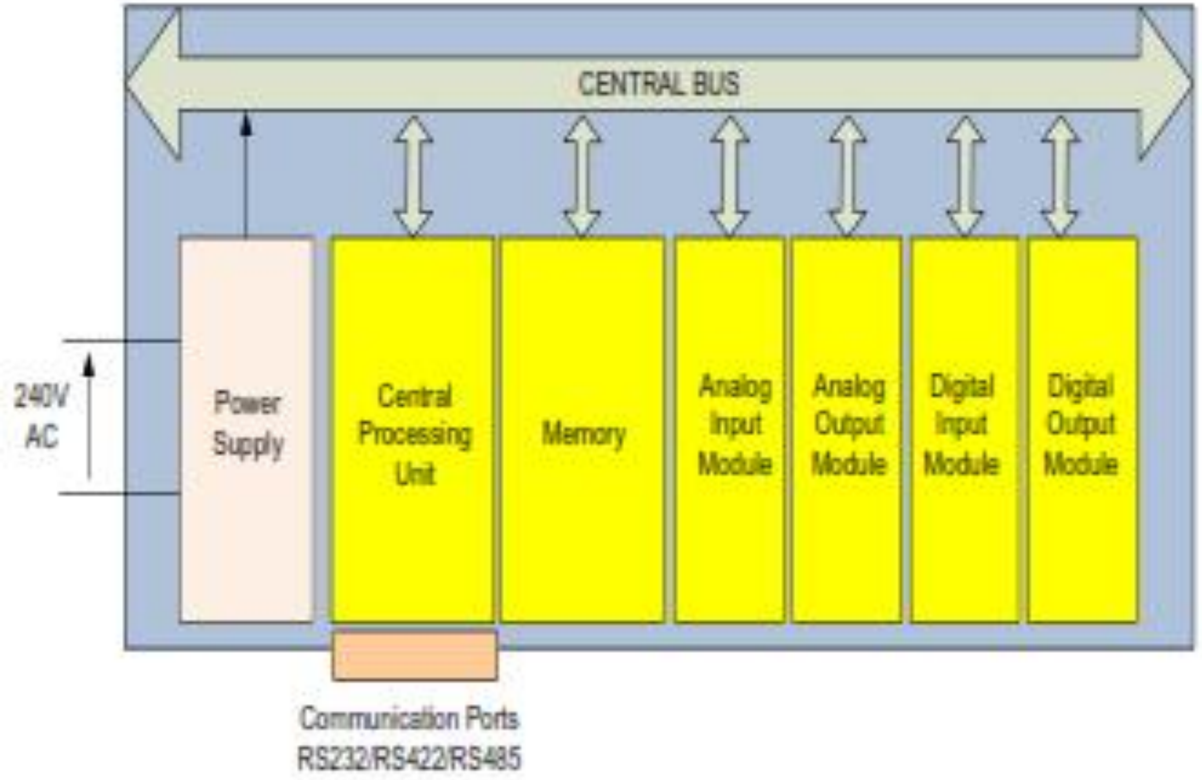
Remote Terminal Units (RTUs) are essentially industrial PC based systems which are responsible for collecting field information and data. Typical RTU hardware modules consist of several components



Remote Terminal Units



Remote Terminal Units



Typical RTU hardware modules consist of several components....

Power Supply

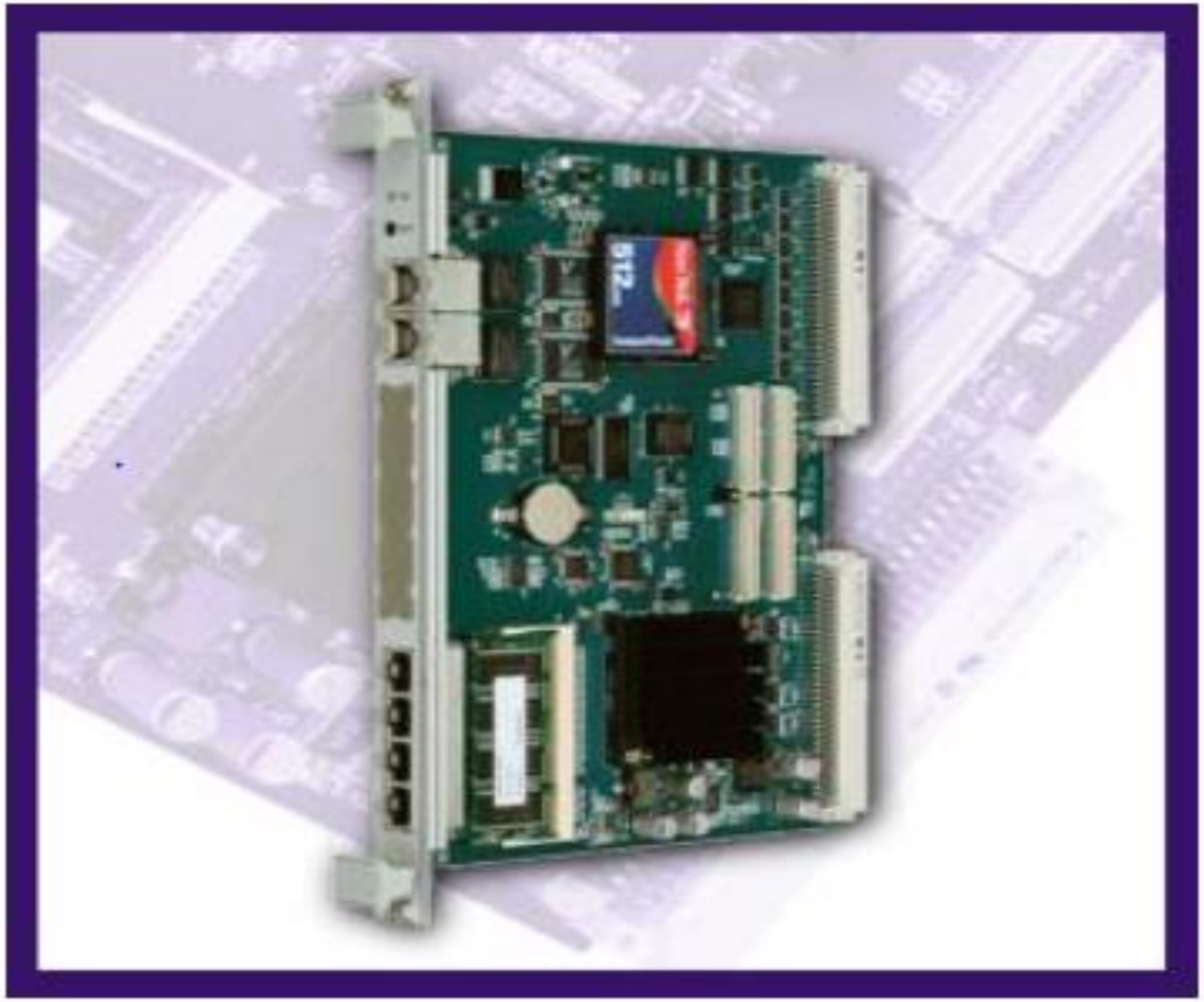
- Typically converts the 240V AC supply into a low voltage DC output, for powering the digital and analogue hardware in the RTU; typically 5Vdc and 12Vdc. In some cases, industrial equipment will operate on 24V and 48V technology

Typical RTU hardware modules consist of several components….

Central Processing Unit (CPU)

- **The central processing unit is usually a 16bit or 32bit microprocessor based system. The processor unit will usually contain a modest amount of memory internal to the chip.**

- **The processor is usually driven by a real time clock, which may include a calendar feature to enable time stamping of events.**



Remote Terminal Units

Typical RTU hardware modules consist of several components....

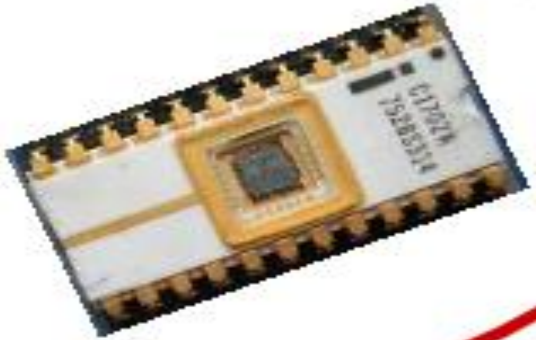
Memory

- **When more memory is needed, external memory is usually used which interfaces to the processor. This can be in the form of EPROM, RAM, or Flash Memory.**

- **It is common to see systems with a combination of these memory technologies.**

Memory

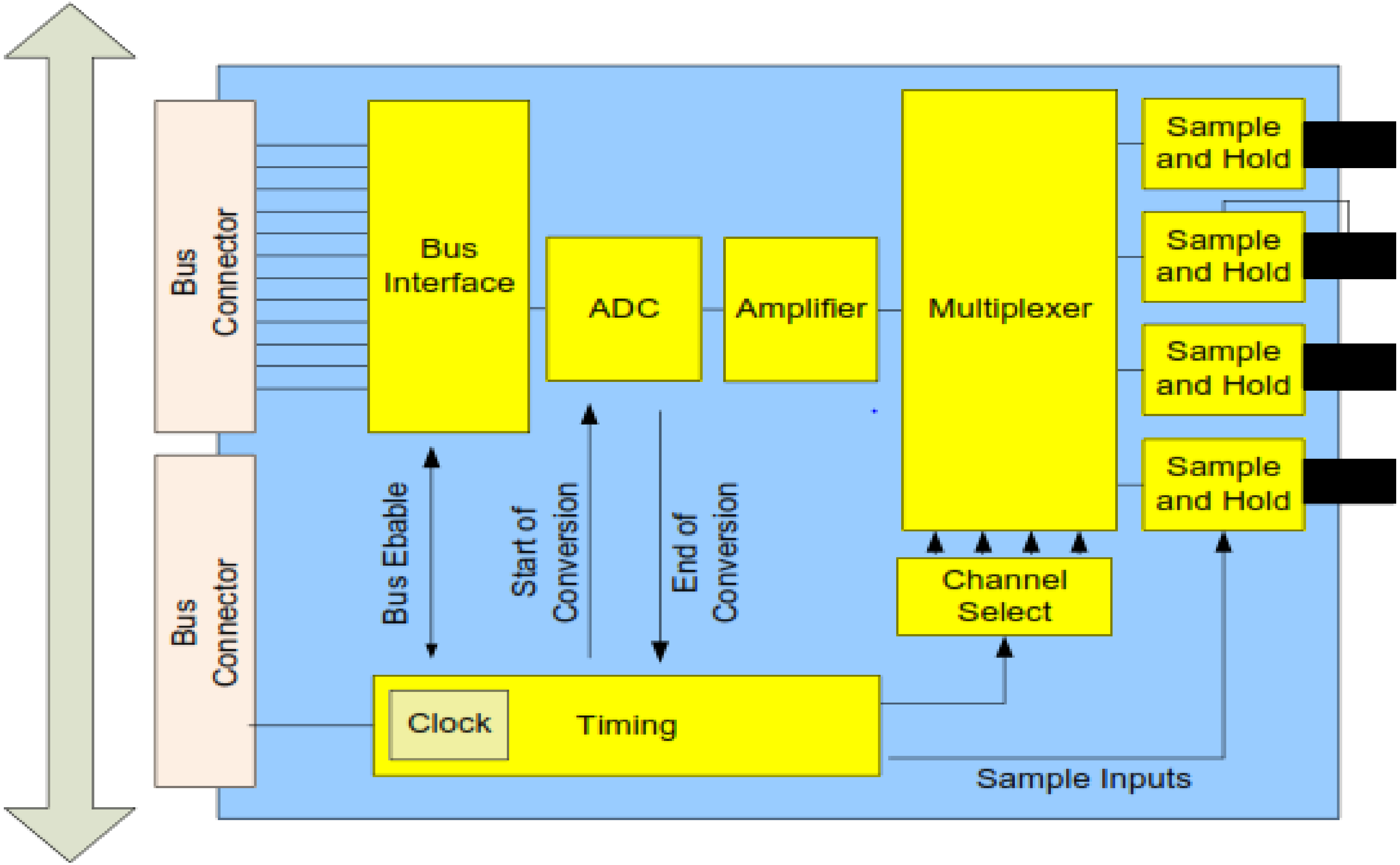
EPROM



RAM

FLASH

Analogue Inputs



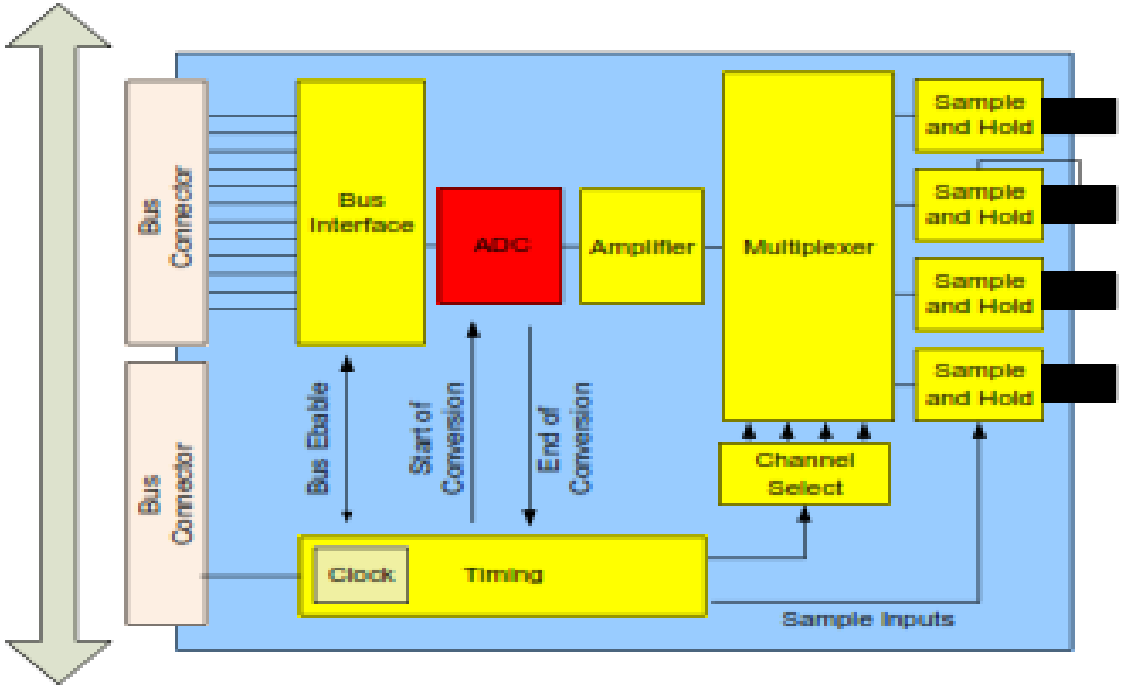
Analogue Inputs

(1) Analogue to Digital Converter (ADC)

The Analogue to Digital Converter device is at the heart of this module.

It is important to choose a device which is capable of meeting the demands of your application.....

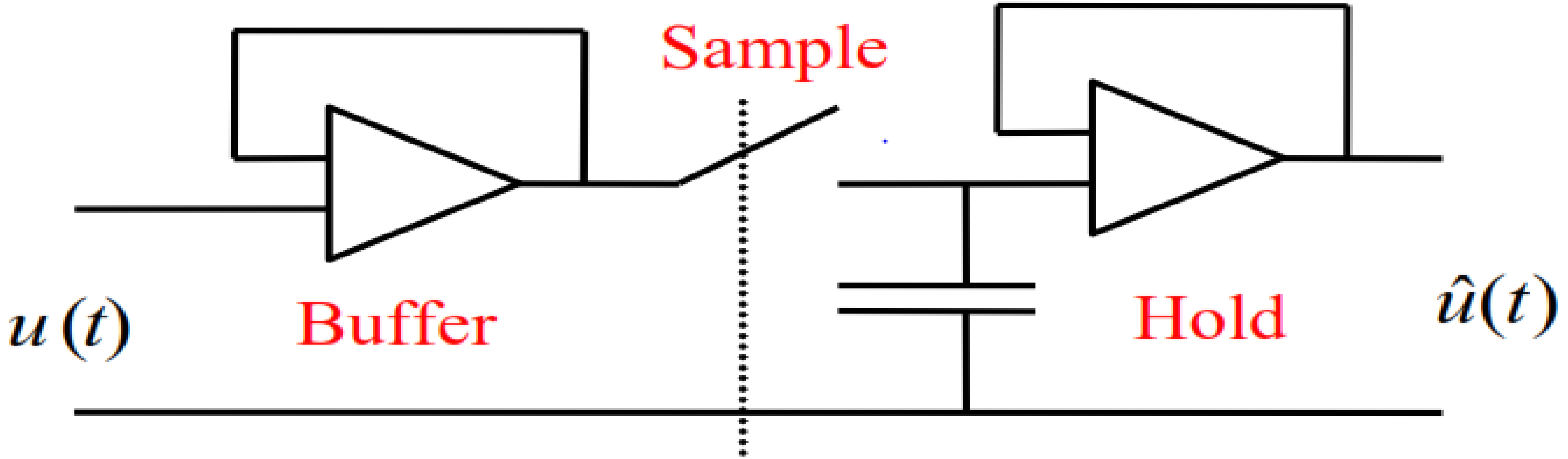
- **The speed and resolution of ADC converters can vary significantly between devices. Usually, there is a trade off between the two - the faster the ADC, the lower the resolution you can typically achieve.**



Analogue Inputs

(2) Sample and Hold Circuitry

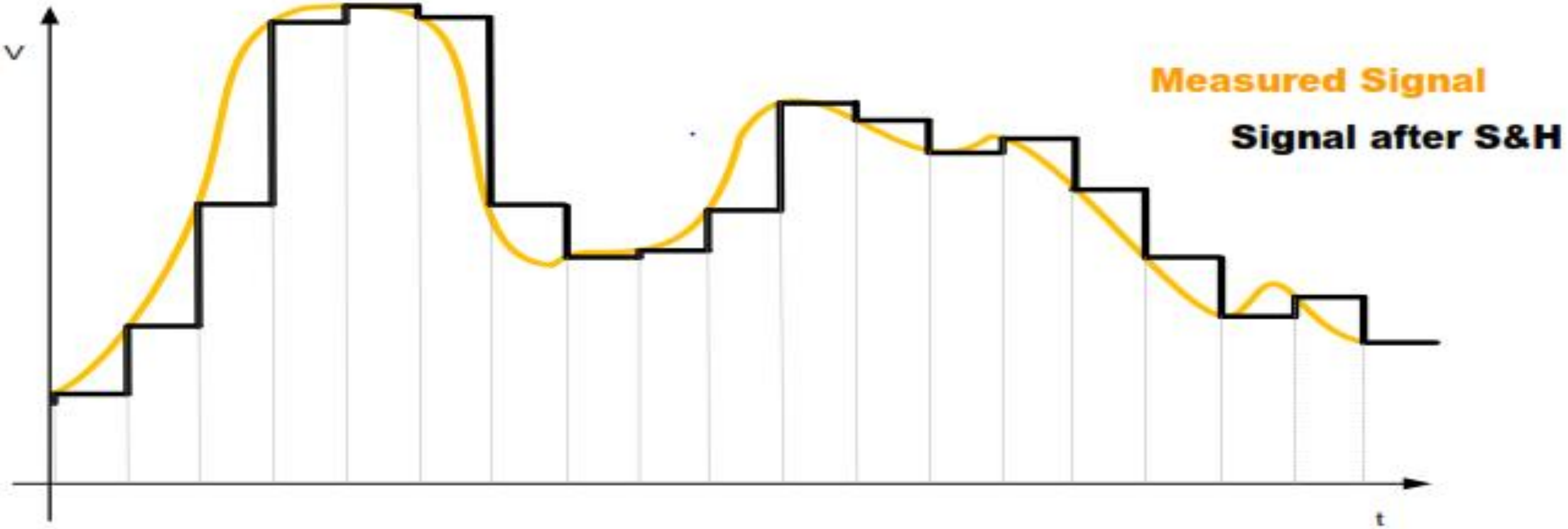
- **ADCs require a fixed amount of time in which to perform the conversion to a digital signal; the conversion is not instantaneous. For this reason, a sample and hold circuit is required.**



Analogue Inputs

(2) Sample and Hold Circuitry

- **This circuit samples the analogue input and holds the signal value until the ADC has time to complete the conversion.**

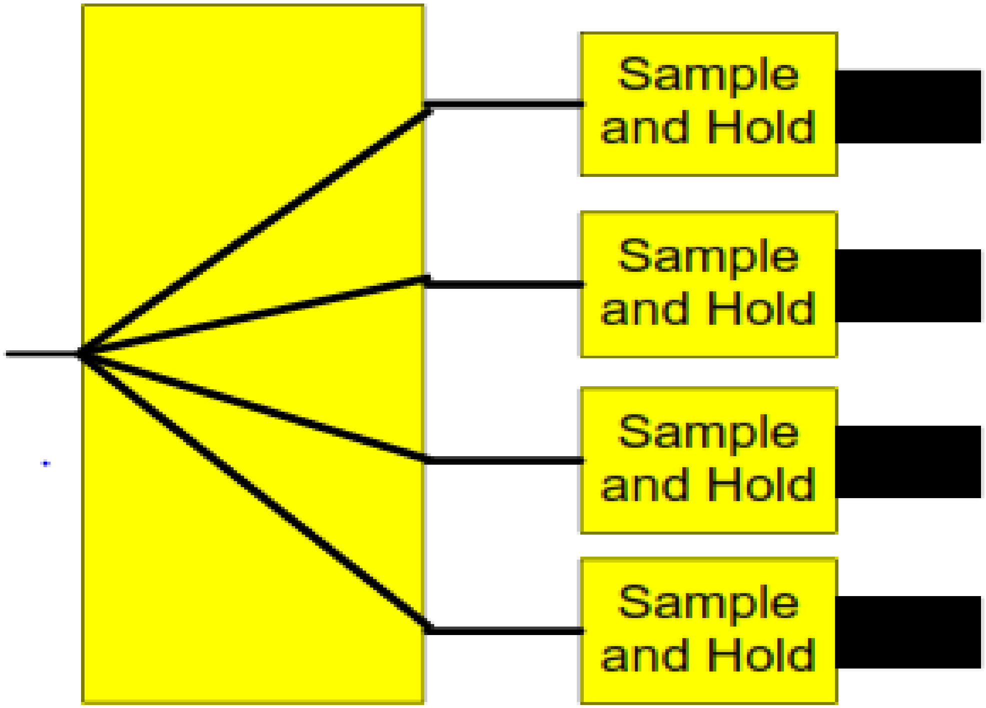


Remote Terminal Units

Analogue Inputs

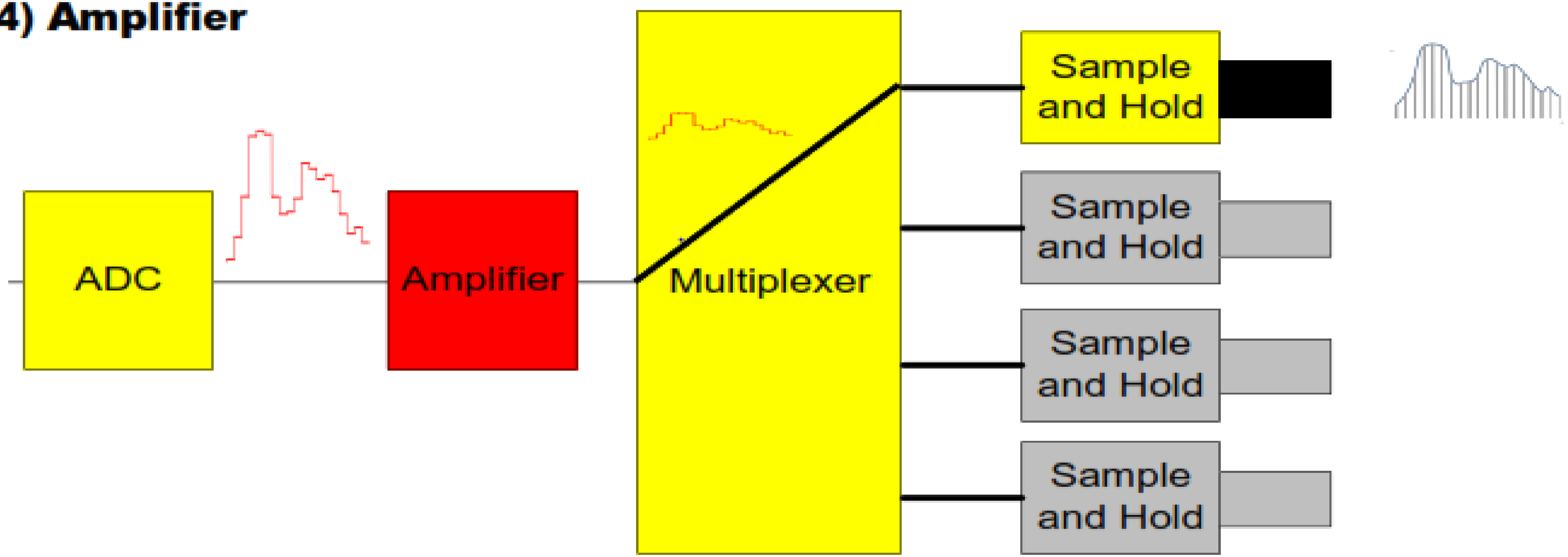
(3) Multiplexer

- **A multiplexer is a component which sequentially samples many inputs, and switches the samples to the output in sequence. The output is then passed to the ADC.**



Analogue Inputs

(4) Amplifier

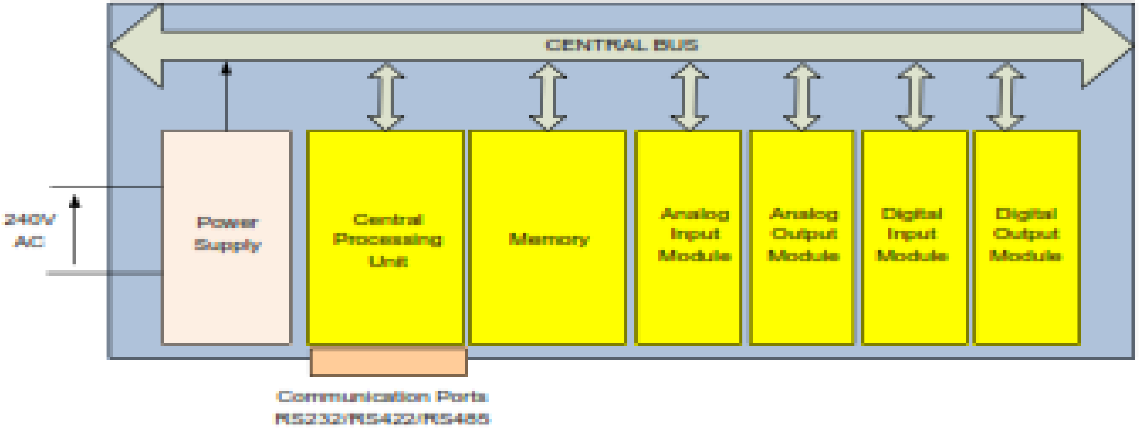


- **An amplifier may be needed (Note: not always needed!) to match the range of the analogue signal to the input range of the ADC device. This can be important if we have very small analogue signals from a sensor. Without the amplifier we may lose measurement resolution.**

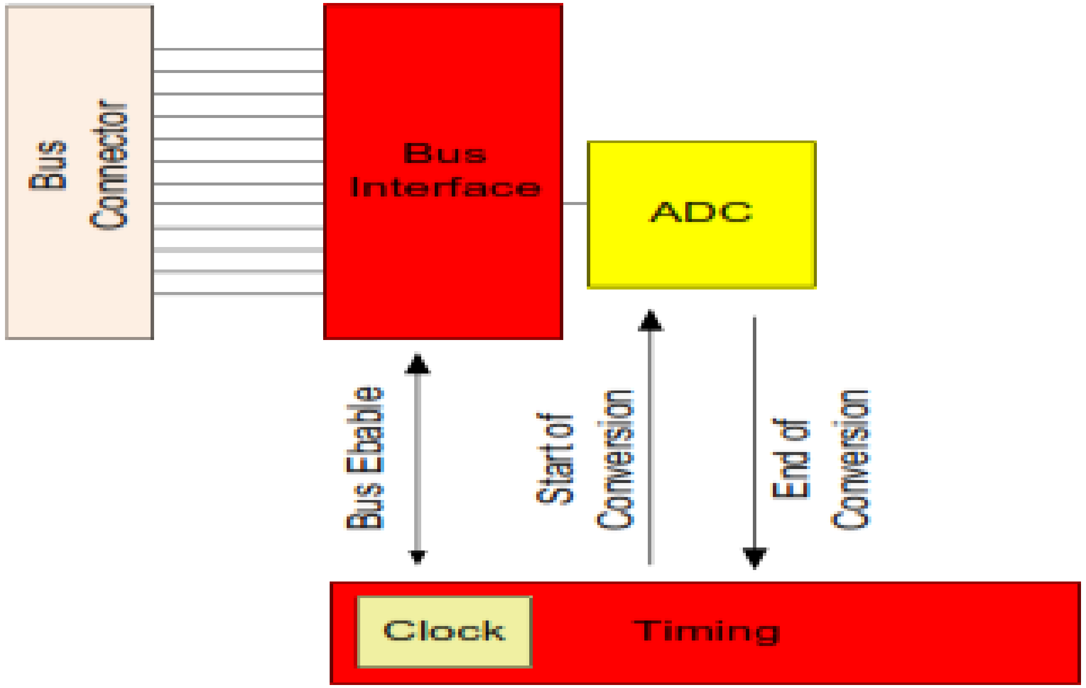
Remote Terminal Units

Analogue Inputs

(5) Bus Interface and Timing Unit



- **The bus interface circuit makes sure that data is only put onto the bus when needed. This is important to avoid data conflict with other devices sharing the bus (i.e. bus contention problems).**



Analogue Outputs

- Analogue outputs perform the opposite function to inputs.
- They convert digital signals to analogue signals using a DAC (digital to analogue converter).
- It is common to have several analogue output channels.
- These outputs are typically used to interface with analogue devices, and perhaps instrumentation such as oscilloscopes.

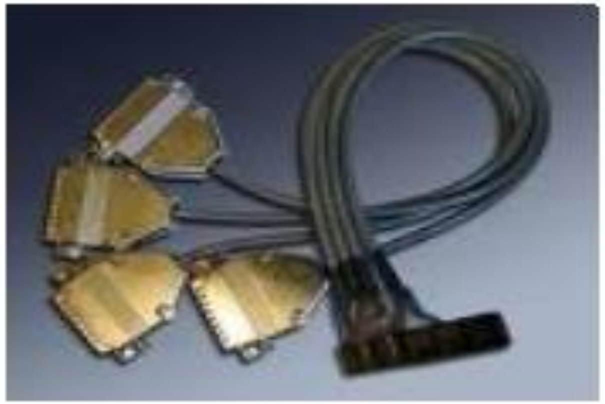
Digital Inputs and Outputs

- Digital Inputs are usually for status and alarm signals.
- It is quite common to see digital input boards with 16, 32, or even 64 digital input channels.
- Digital output modules can be used to send simple ON/OFF signals. (e.g. for relays/ switches)
- They are particularly useful for enabling or disabling devices. You may see LED indicators for each output to give a quick visual on the status of these lines

Remote Terminal Units

Communication Interfaces

- **Often, these are RS232, RS422 or RS485. They are used to interface to operator stations, diagnostic terminals etc.**



A rack / enclosure

- All the electronics is typically housed in a standardised 19" industrial control rack (e.g. VME rack), or a commercially supplied enclosure.

Remote Terminal Units

A rack / enclosure

- **Protecting components.**
- **Moisture or dust prevention**
- **Shielding to prevent Electromagnetic Interference (EMI).**

Introduction to SCADA Systems

What is SCADA?

Supervisory **C**ontrol **A**nd **D**ata **A**cquistion

- Collect measurements and status data from the process
- Remotely intervene in the process
- Centralized system platform
- Based on distributed I/O

Applicable Processes

- Oil or Gas prodcution facilities
- Piplelines for gas, oils, chemicals or water.
- Railway/Transportation Process
- Nuclear, Gas, Hyrdo generation plants

SCADA is used around the world to control all kinds of industrial processes — SCADA can help you increase efficiency, lower costs and increase the profitability of your operations.

The typical control room

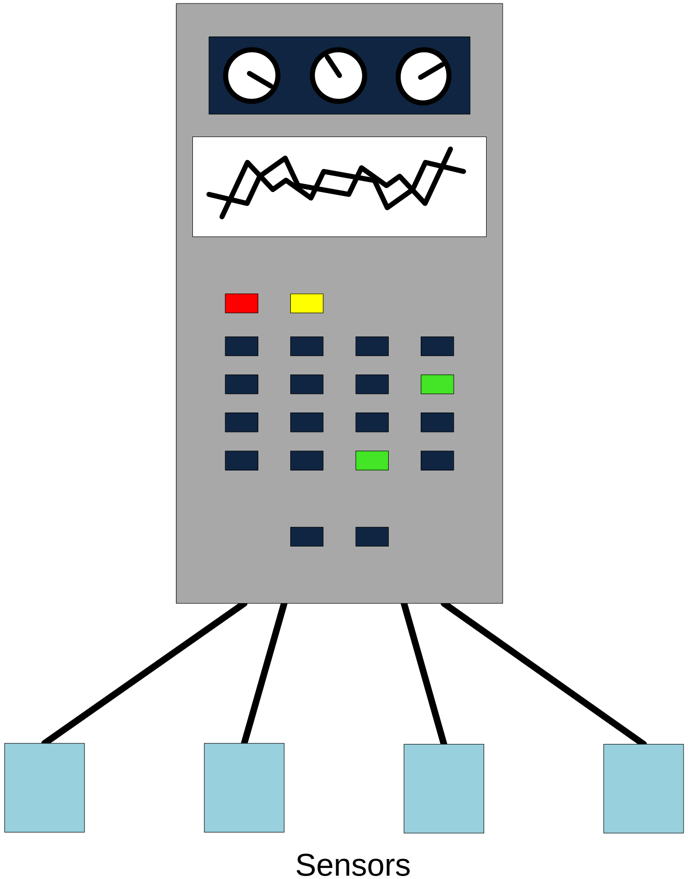
Real-Time Monitoring and Control Increases Efficiency and Maximizes Profitability

Here are few of the things you can do with the information and control capabilities you get from a SCADA system:

- Access quantitative measurements of important processes, both immediately and over time
- Detect and correct problems as soon as they begin
- Measure trends over time
- Discover and eliminate bottlenecks and inefficiencies
- Control larger and more complex processes with a smaller, less specialized staff.

Classic SCADA systems

The very first SCADA system implemented a Sensor to Panel type scheme:



- **It consisted of:**
  - **(1) an array of sensors**
  - **(2) control panel of meters**
  - **(3) lights and recorders**

An operator would then be in charge of various control knobs which would exercise supervisory control.

Classic SCADA systems

Whilst these systems are relatively unsophisticated, they can still be seen in practice today in manufacturing plants, factories, and power generating facilities

Classic SCADA systems

A Sensor to Panel type SCADA system has the following advantages:

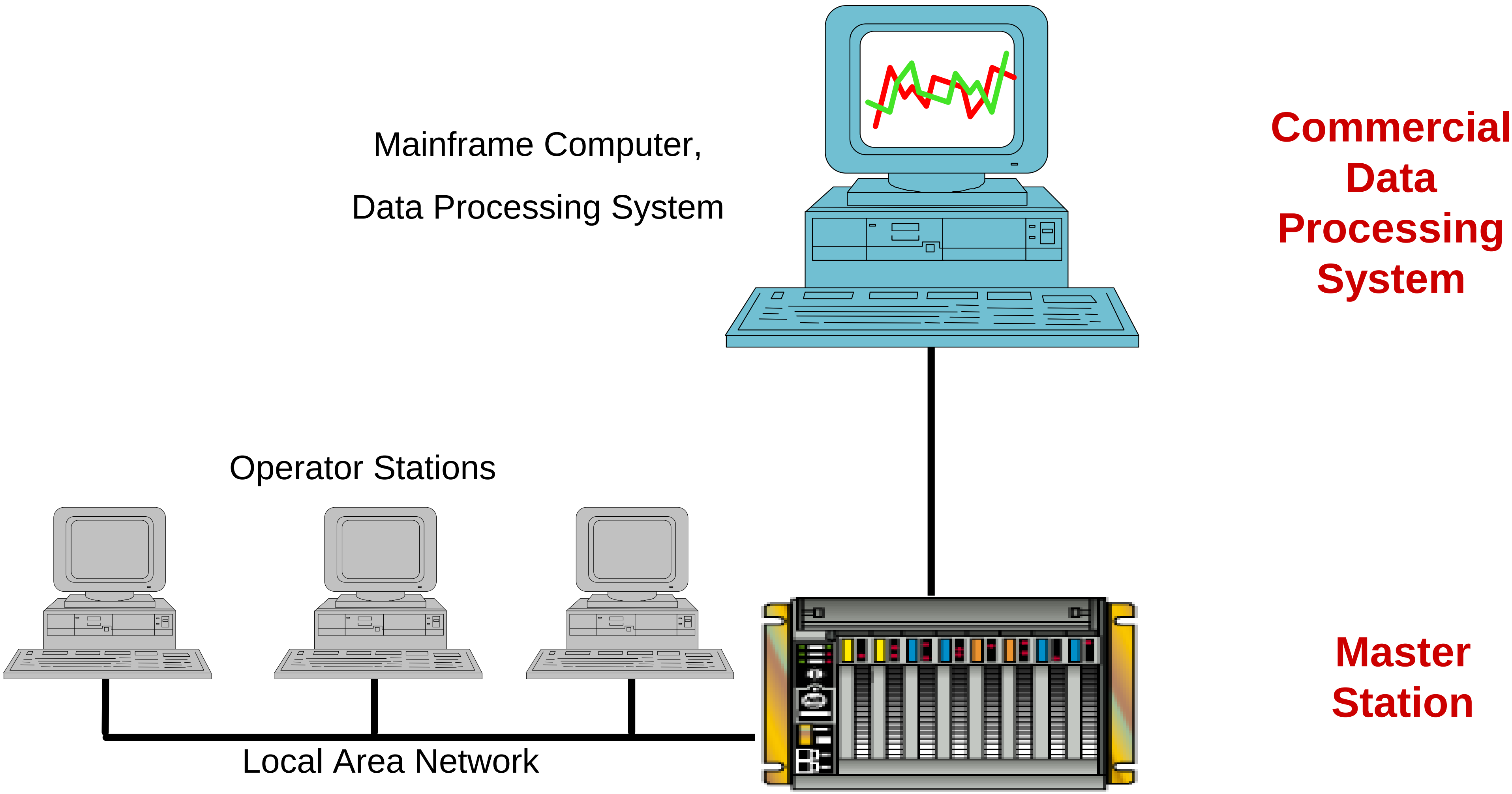
- **It is a simple system – no CPU, memory, or software programming**
- **Sensors are directly connected to meters, lights etc.**
- **Cheap and easy to add extra switches and indicators**

Classic SCADA systems

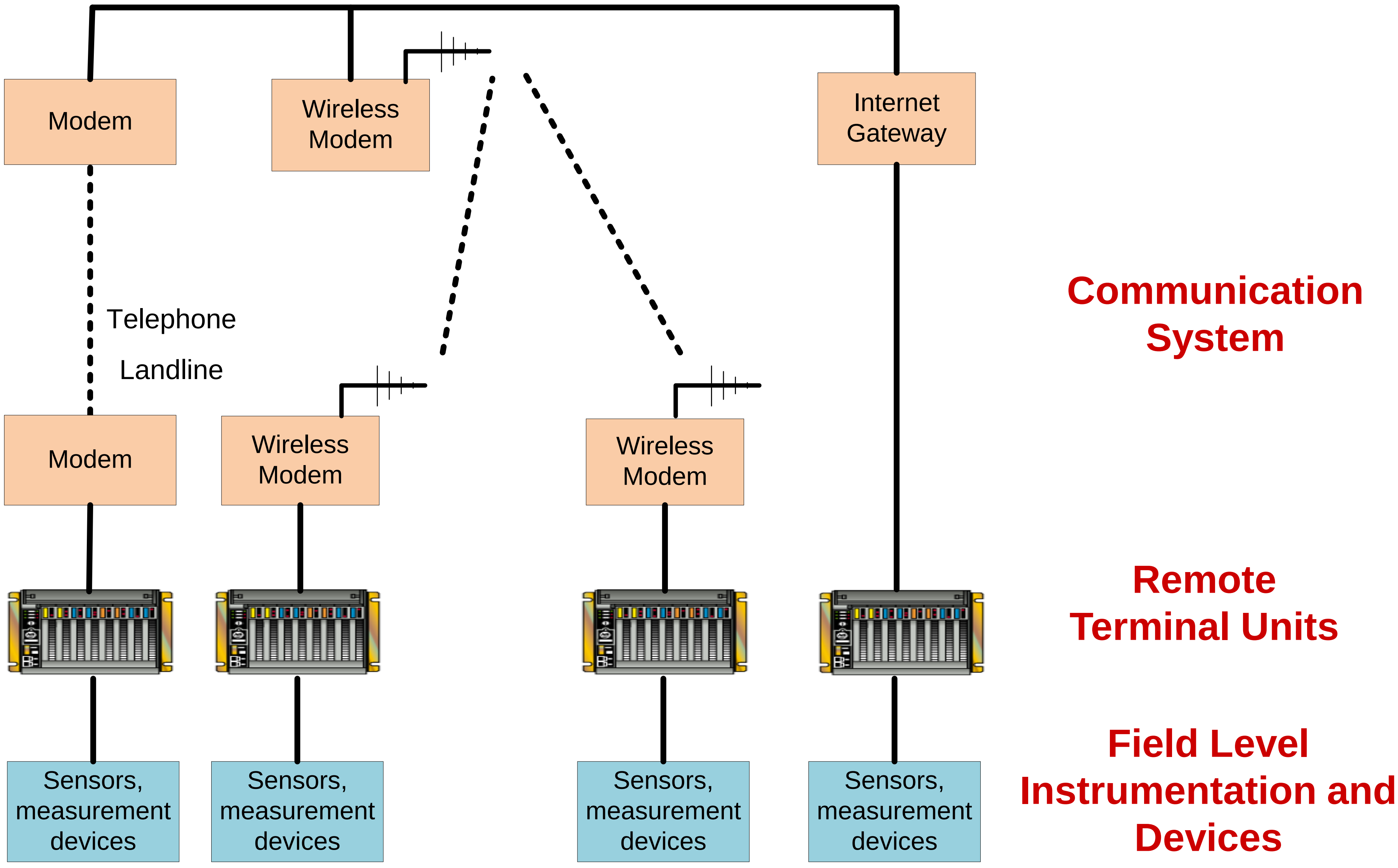
…but the following disadvantages:

- **As the system expands, the amount of wiring becomes unmanageable.**
- **Re-configuring system is very difficult**
- **The amount of data that can be retrieved is very limited**
- **Storage of data is minimal**
- **No off site monitoring of data or alarms.**
- **Somebody has to watch the control panel 24 hours a day.**

A typical modern SCADA system now has five levels of hierarchy:



Modern SCADA System



Modern SCADA System

A typical modern SCADA system now has five levels of hierarchy:

- **(1) Field Level Instrumentation and Control Devices**

  Sensors and Process Control Equipment are used for obtaining measurements and data from the environment.

- **(2) Remote Terminal Units**

  These are essentially industrial PC based systems which are responsible for collecting field information and data.

- **(3) Master Station**

  It is the responsibility of the Master unit to collect all the data acquired from the RTUs. The Master unit displays data and enables the operator to perform remote maintenance and control tasks via a Human Machine Interface (HMI).

Modern SCADA System

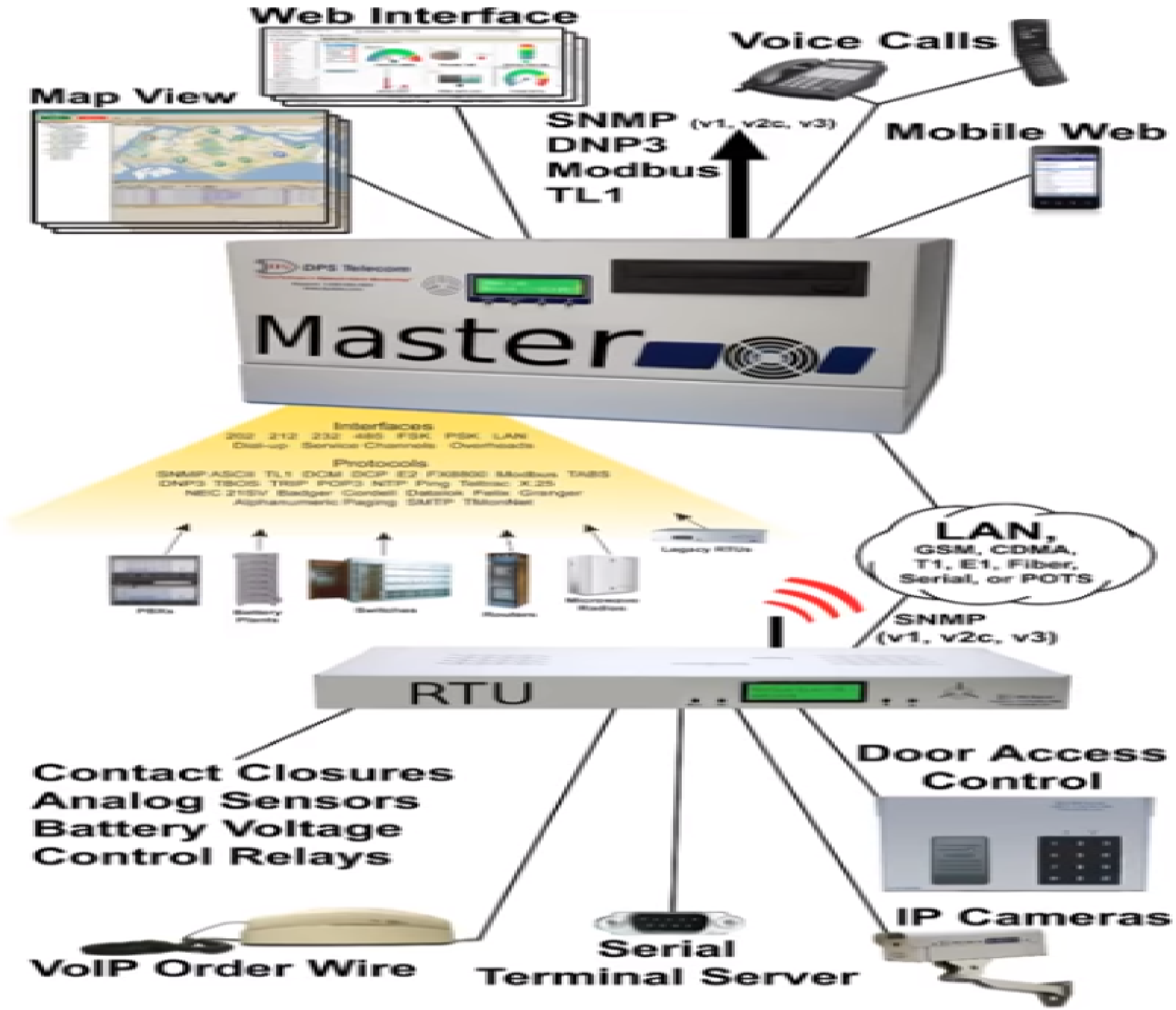
- **(4) Communication System**

  A communication system is required to link the RTUs to the Master Unit. The communication medium depends upon the location of the RTUs, and the technology available.

- **(5) Commercial Data Processing System**

  In larger telemetry systems, a separate data processing system may be available to co-ordinate and manage large volumes of data - useful for storing backup data, and determining long term data trends.

Example from DPS Telecom



Modern SCADA System


2008-04-18 13:58
ABB

SCADA Software

The key components of any SCADA software platform are worth noting:

- **Graphical User Interface**
- **Alarm monitoring**
- **Trend monitoring**
- **Remote Terminal Unit Interface – health checking**
- **Scalability (Modular systems)**
- **Database (data storage)**
- **Networking**
- **Distributed Processing**

SCADA Software

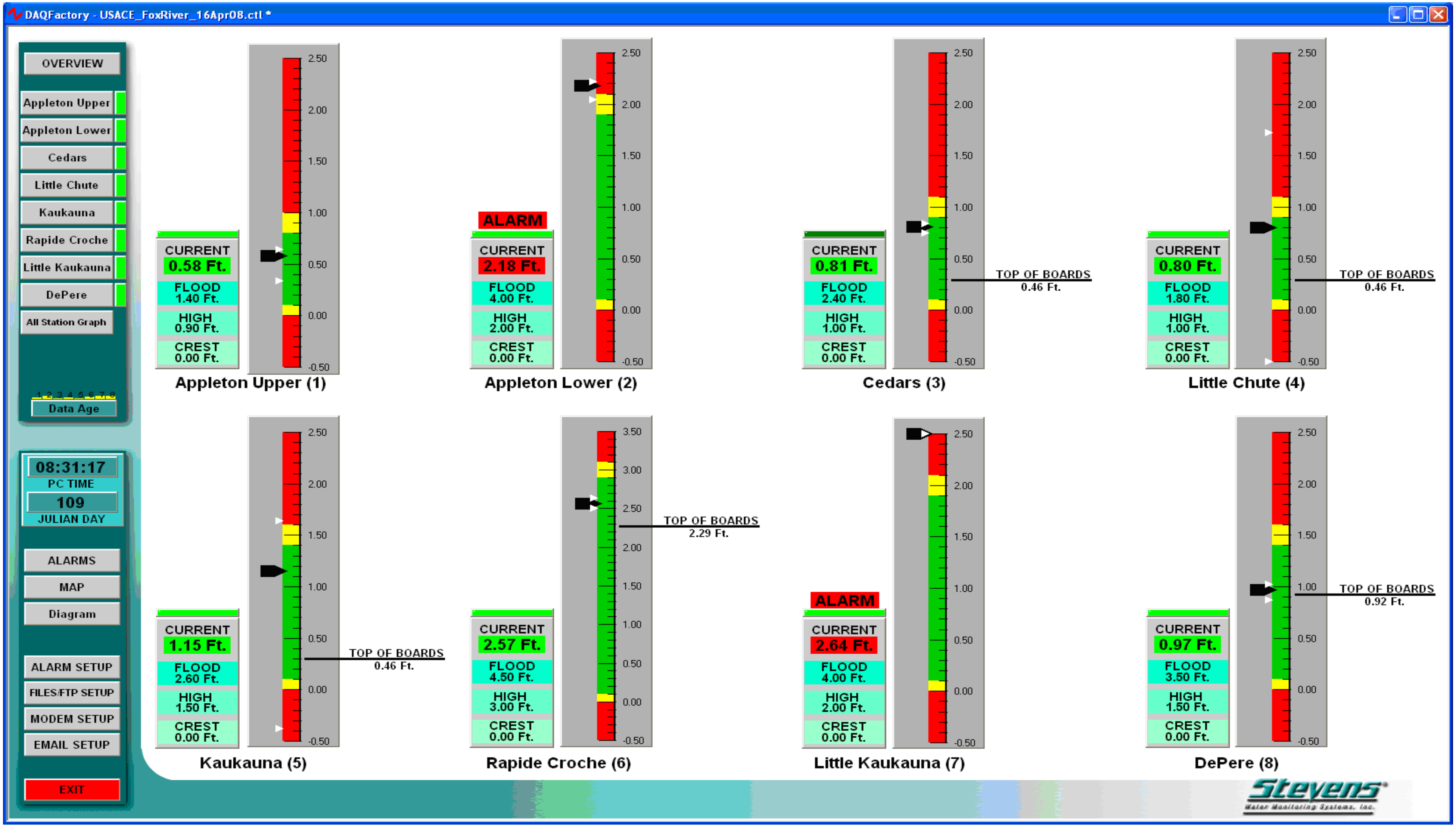
SCADA software can typically come in two forms; proprietary or open.

- **Proprietary software is written by individual companies to work with their own hardware. These systems are typically sold as a complete hardware and software solution.**

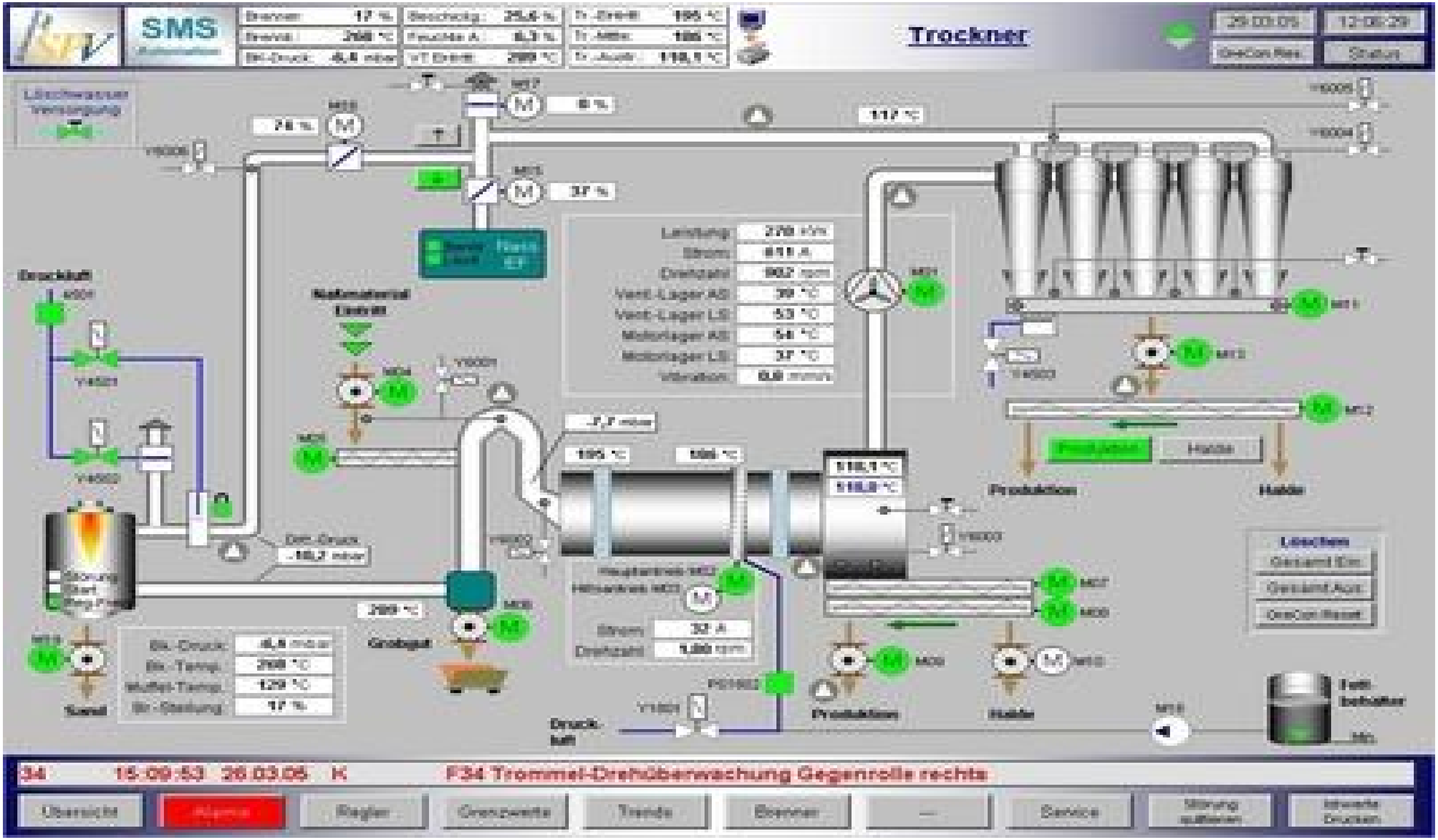
- **Open software is typically written by independent companies, and they target their software to work with a number of different manufacturers hardware**

Modern SCADA System

Graphical User Interface….

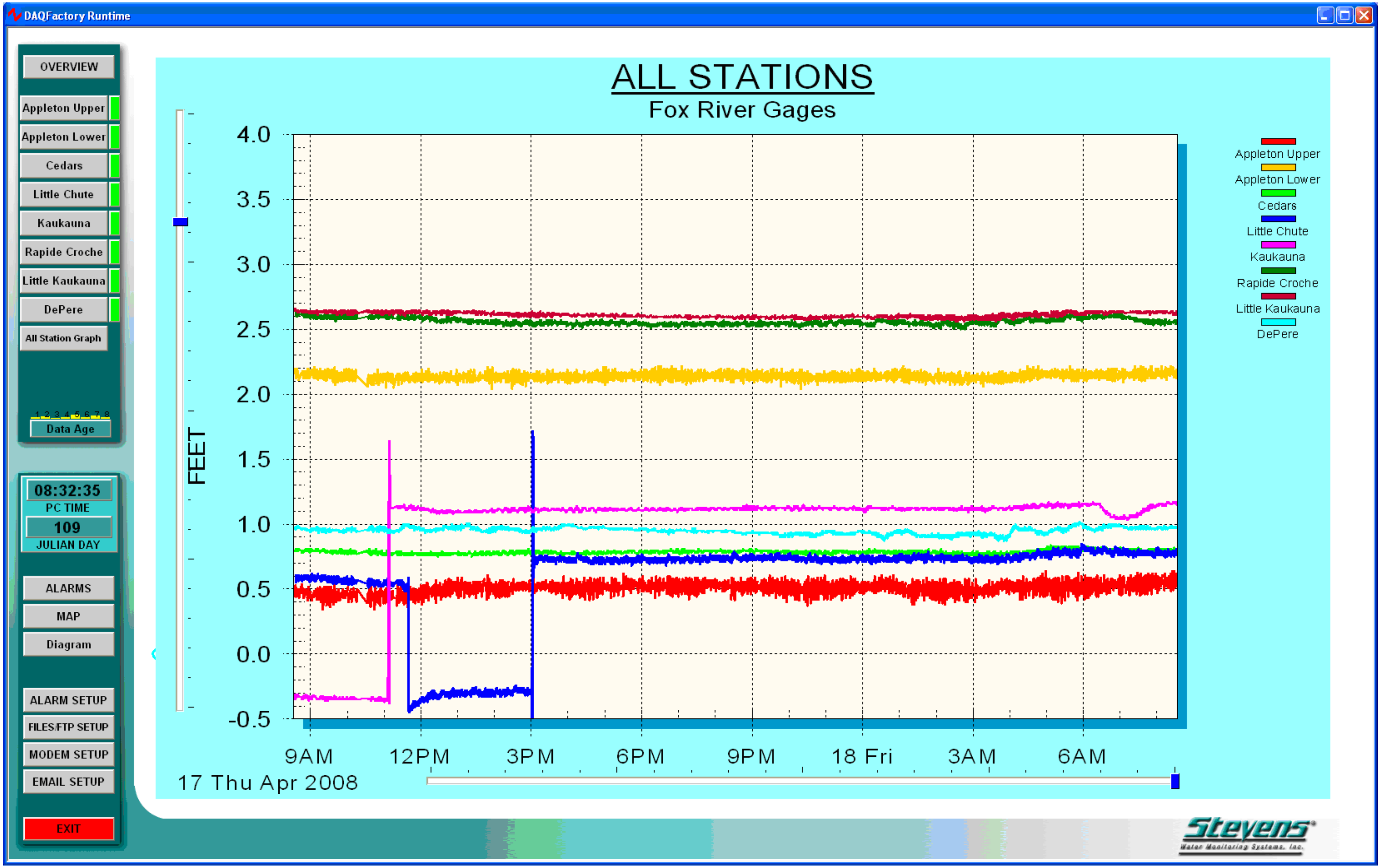


Modern SCADA System



Modern SCADA System

Trend monitoring….



SCADA System Implementation

- **Consideration always has to be given to the cost versus quality of the system.**

- **It is always worth assessing the opportunity to integrate the SCADA system into existing communication networks. Possible options - existing LAN networks, telephone lines, or even radio/wireless systems.**

- **Do not compromise the existing communication network. It must not interfere with other existing facilities.**

- **Reliability is always an important consideration. However, is it justifiable to spend, for example, ten times more on a particular type of system, when it only improves the reliability by 1%??**

….As with most engineering problems, compromise might be necessary!!

Distributed Control Systems

Other advantages, which may be less direct but often have greater impact in the longer term include:

- **Greater understanding of the manufacturing process,**
- **Better production scheduling**
- **Greater flexibility**
- **Shorter 'lead times' in designing new products.**
- **Faster identification of faults**
- **Ability to identify deterioration in equipment before failure**

Who buys DCS equipment?

Water and waste water treatment industry

Oil and gas industry

Pharmaceutical industry

Pulp and paper industry

Automotive industry

Metal and mining industry

Other process industries

Power industry

Chemicals industry

Distributed Control System Market

How big is the market?

Projection for 2018……………. **$19.8** billion

Software

Hardware

Services

Introduction to Distributed Control System

SIEMENS

Rockwell Automation

Allen-Bradley

YOKOGAWA

ABB

EMERSON™

Honeywell

SUPCON

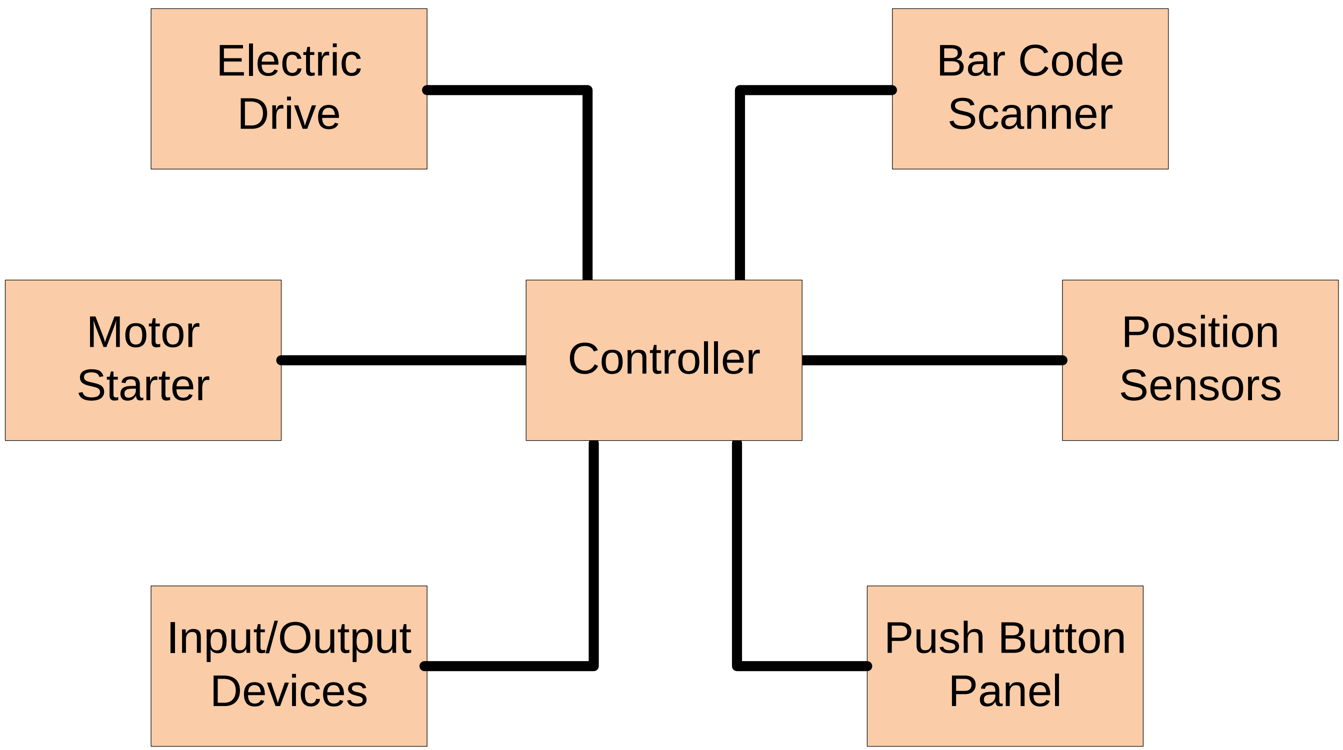
invensys

http://www.abb.co.uk/product/seitp334/102b314866674ccdc12572bb0031ea42.aspx?productLanguage=us&country=GB

Programmable devices and controllers → manufacturing system is much more flexible. We will take a look at two types of flexible system:

The centralised controller cell

Each control device is mounted in a different location within the production cell and may require a different electrical interface to the controller.



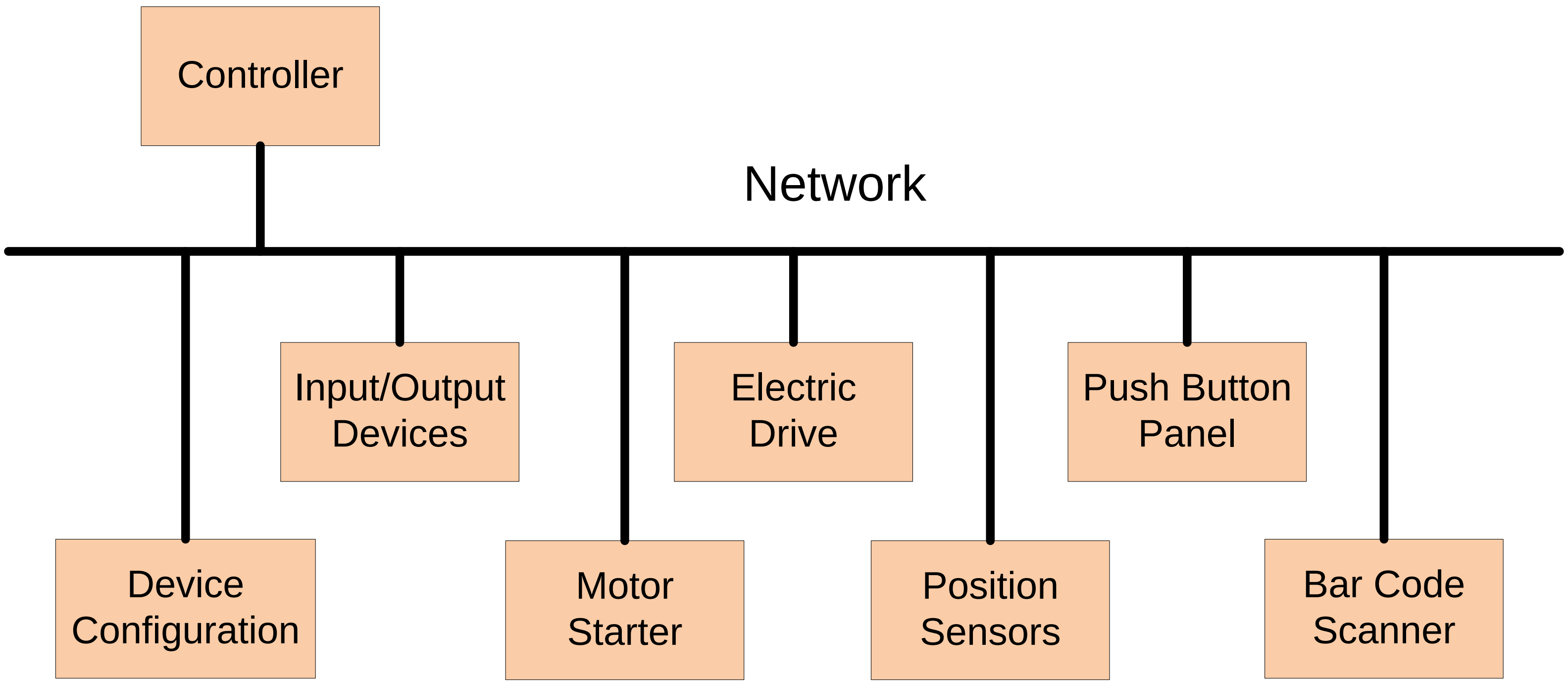
The centralised controller cell

Limitations to this type of system?....

- **Numerous wires must be run around the cell from component to controller.**
- **As cell complexity increases, so does the complexity of the wiring, increasing costs and proving difficult to troubleshoot in the event of a fault.**
- **It may be difficult to connect all the wires to the controller simply because of the physical size of the connectors.**
- **The centralised controller can be reprogrammed to meet changing production needs but each cell must be re-programmed separately at the location of the controller.**
- **If new sensors or actuators are needed for the cell additional work may be needed to provide new interfaces to the controller (lots of interfaces available!)**

The networked controller cell

To overcome the problems highlighted with the centralised controller system, a network solution is now typically employed → a **fieldbus** solution,



- **A fieldbus** is a commonly shared communication medium, to which all devices and controllers may be connected. It then enables efficient communication between all the components of the production cell.

The networked controller cell

Significant advantages over the centralised controller system:

- **Normally only one set of communication wires plus power lines are needed.**
- **Typically only one connection to each component from the network, reducing the overall wiring cost.**
- **All the components have a standard interface to the controller via the network. New devices can be connected easily.**
- **Diagnostics and fault finding are simplified.**
- **The controller can operate over a greater geographical area.**

The networked controller cell

This is the concept behind **distributed control systems**. A distributed control system is a networked control system with a fieldbus at its heart (e.g. CAN, Profibus and Modbus).

A distributed control system may be defined as follows:

- **A distributed control system is one composed of several autonomous intelligent devices, which cooperate in achieving an overall goal. These intelligent devices are capable of supporting processes and coordinating their activities, through the exchange of information via means of a communication network**

SUPCON

ECS -700 Engineer Configuration Training

Hardware

Zhejiang SUPCON Technology Co.,Ltd

Content

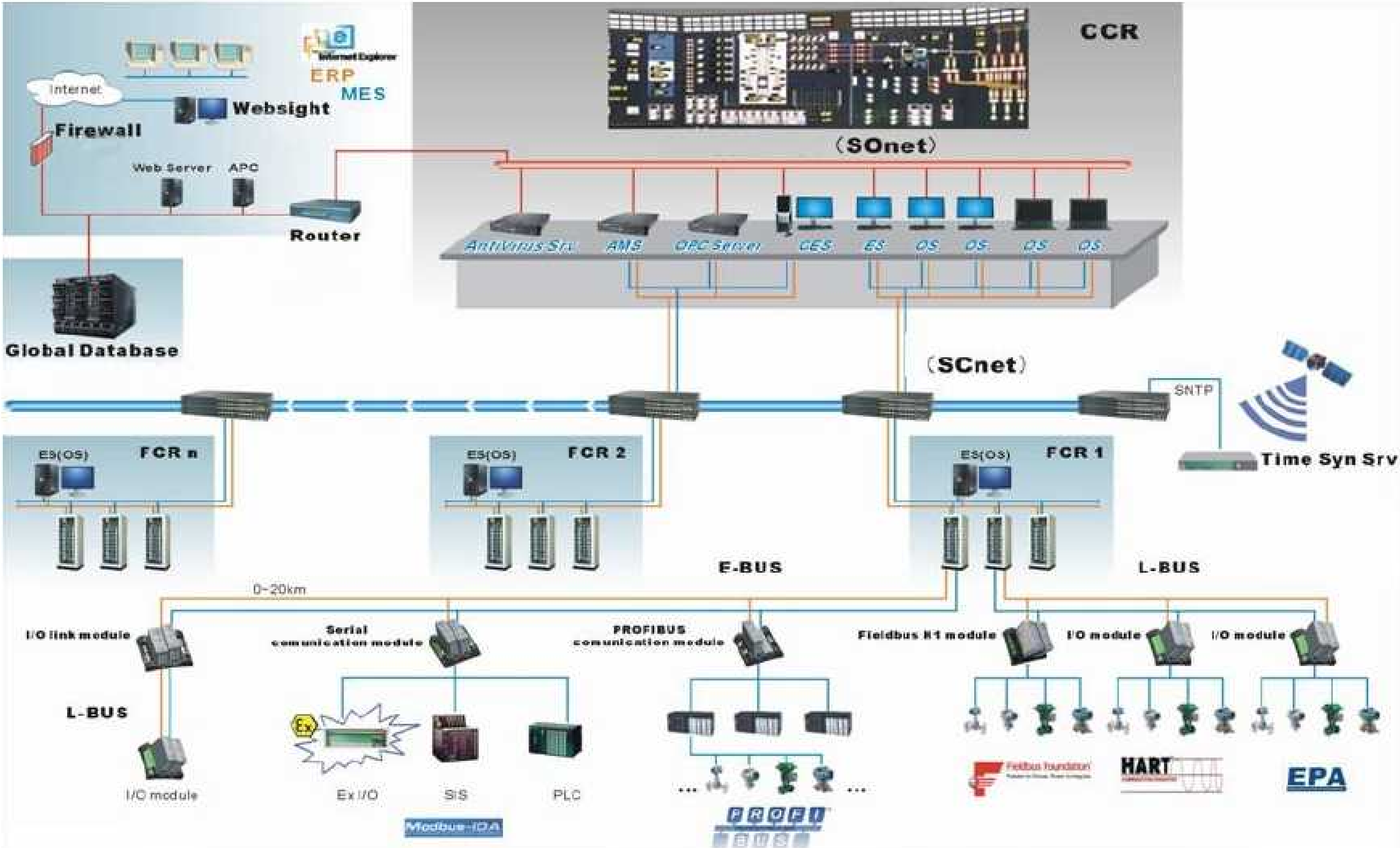
1. **System Architecture (√)**
2. Control Node
3. Operation Node
4. Network

- **General introduction**

WebField ECS - 700 DCS

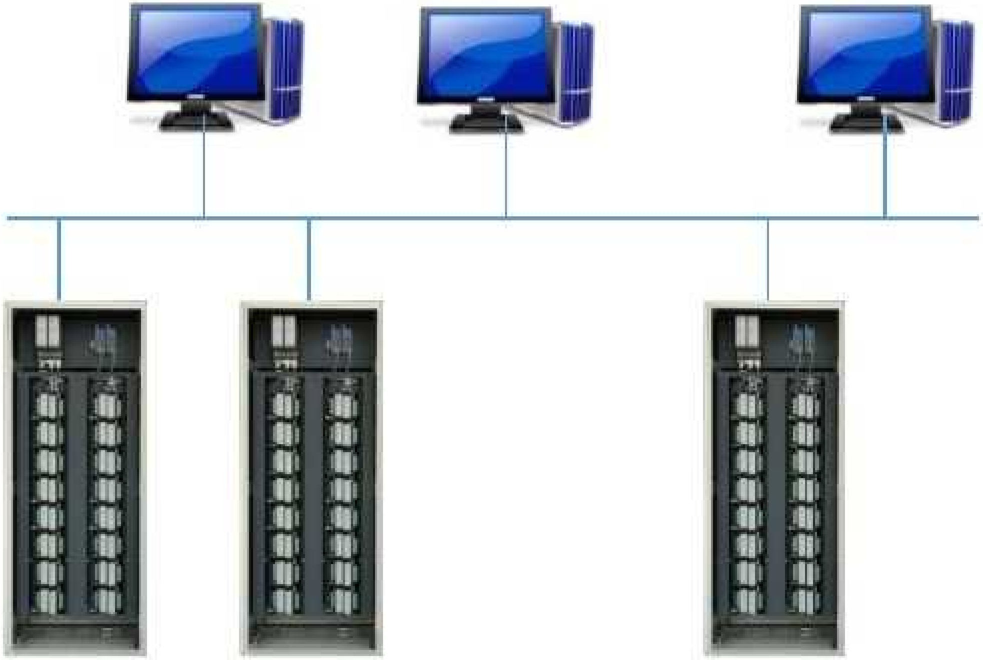
WebField	ECS	700	DCS
Registered Trademark	Series Name	Serial Number	

DCS: Distributed Control System


CCR
Internet
ERP
MES
Websight
Firewall
Web Server
APC
Router
(SOnet)
Antivirus Srv
AMS
OPC Server
CES
ES
OS
OS
OS
OS
Global Database
(SCnet)
SNTP
Time Syn Srv
ES(OS)
FCR n
ES(OS)
FCR 2
ES(OS)
FCR 1
E-BUS
L-BUS
0~20km
I/O link module
Serial comunication module
PROFIBUS comunication module
Fieldbus H1 module
I/O module
I/O module
L-BUS
Ex
I/O module
Ex I/O
SIS
PLC
Modbus-IDA
PROFI BUS
Fieldbus Foundation
HART
EPA

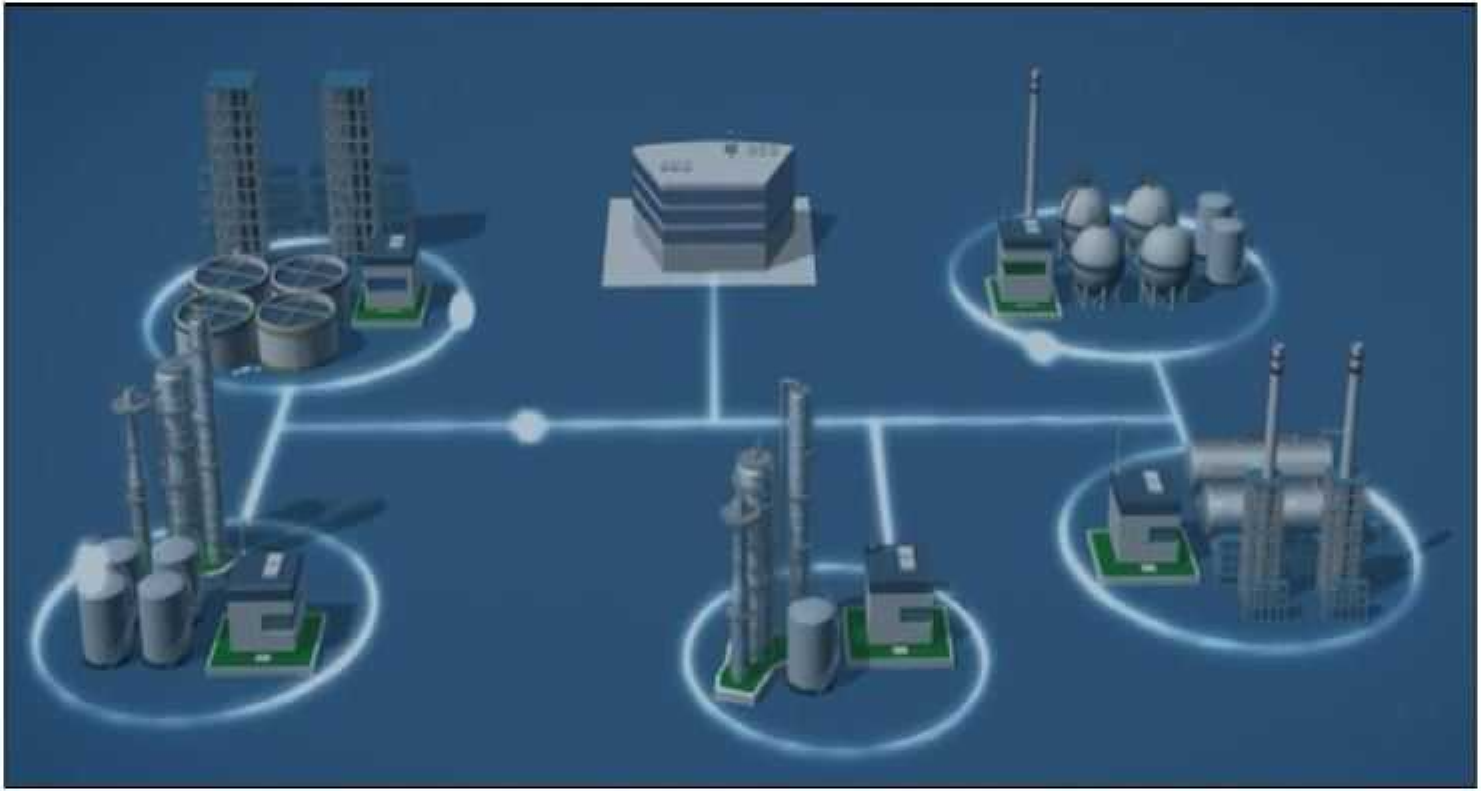
Hardware

- Operation node
- Network
- Control node

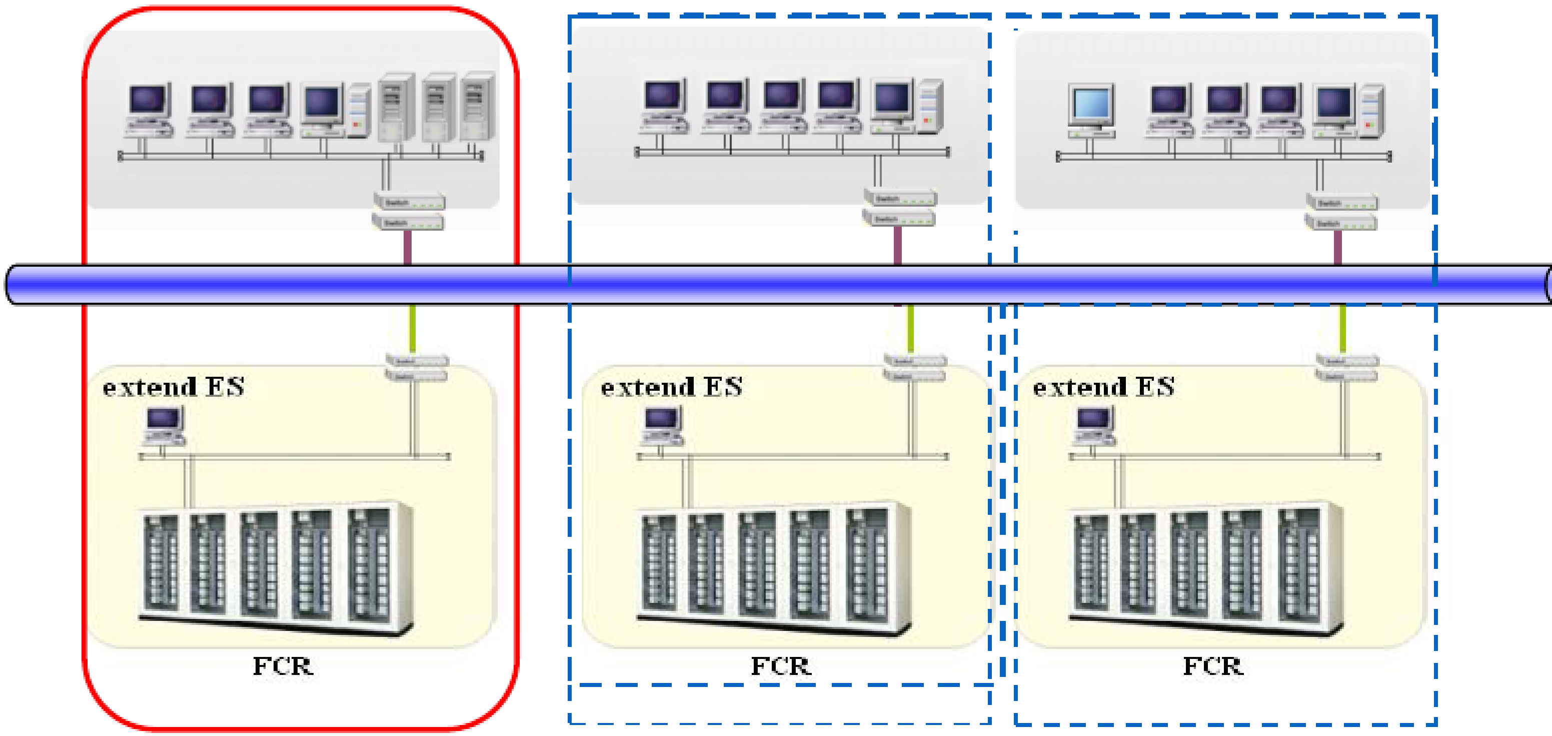


- **Domain**

Control domain & Operation domain



Domain setting



- **System scale**

Domain：60 control domains, 128 operation domains
Each domain ：
Control domain: 60 control nodes, total capacity 65,000 points
Operation domain: 60 operation nodes
Each control station:

Type		FCU711-S	FCU712-S
I/O	Total	≤2000	≤4000
	AI	≤1000	≤2000
	AO	≤500	≤1000
	DI	≤2000	≤4000
	DO	≤1000	≤2000

- Features

System features

- Openness
- Safety
- Easy to use
- Real-time
- multi-people configuration
- Powerful system supervision

- **Component**

Cabinet

Power supply

Control unit (controller & base)

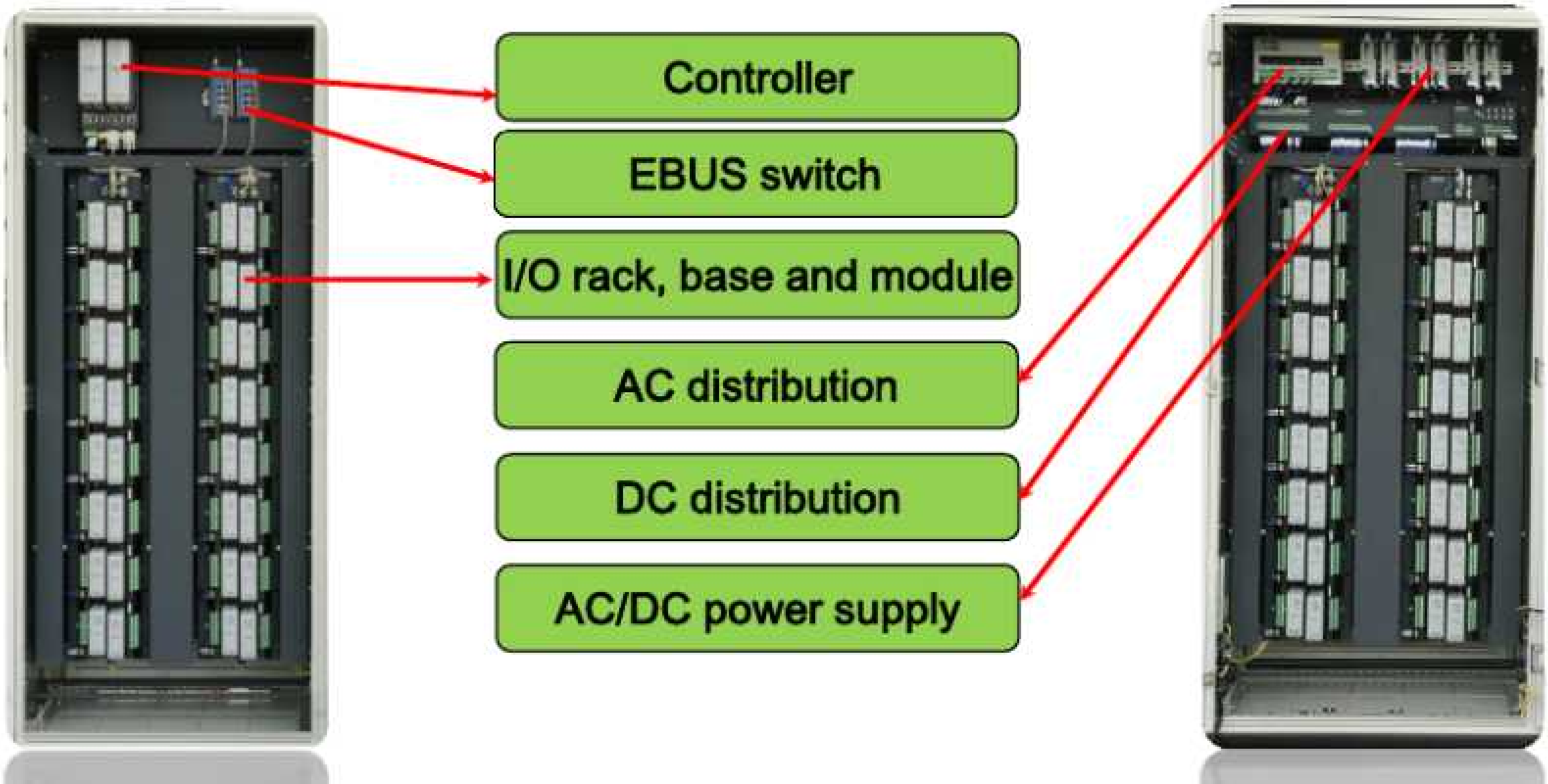
I/O rack

I/O module unit (I/O module & base)

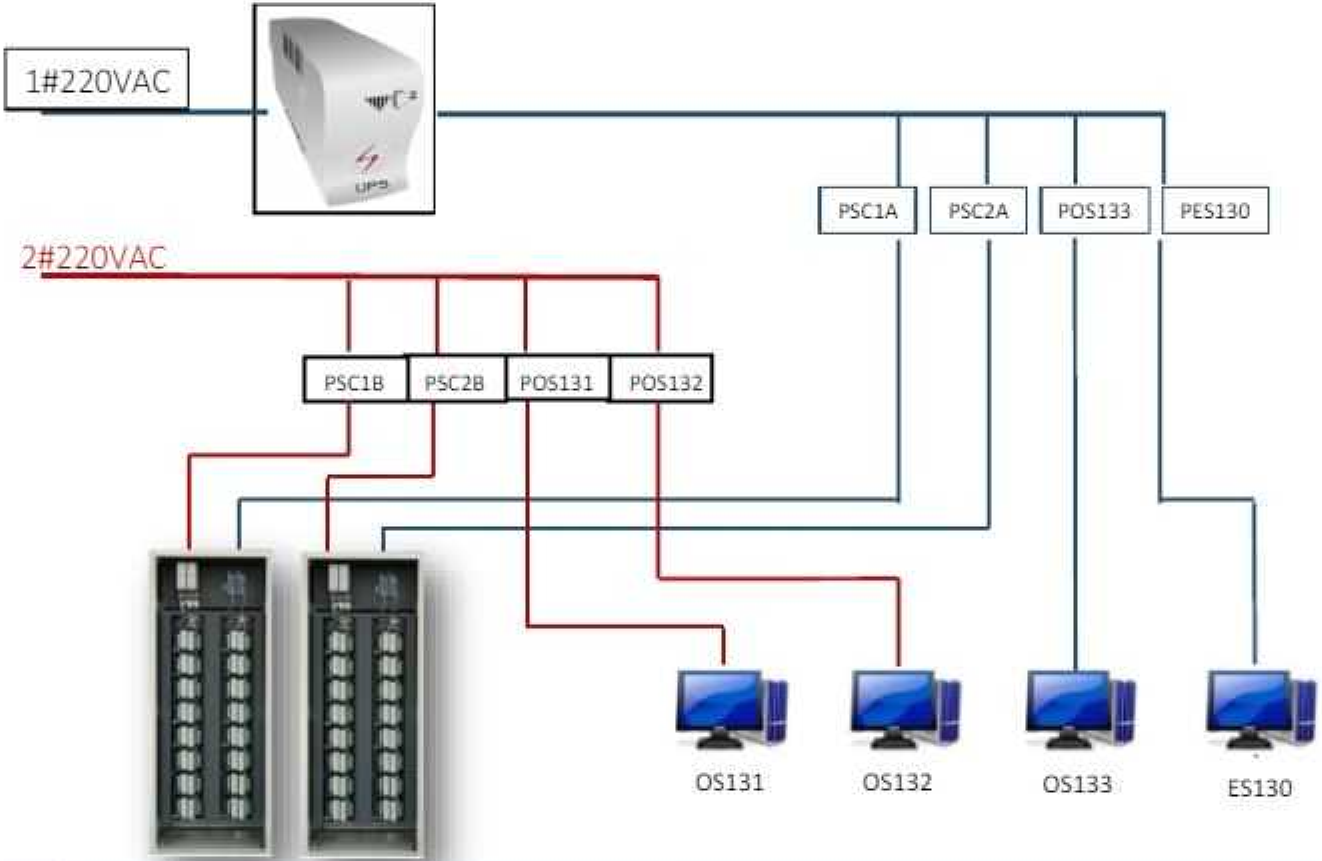
Switch

Control node

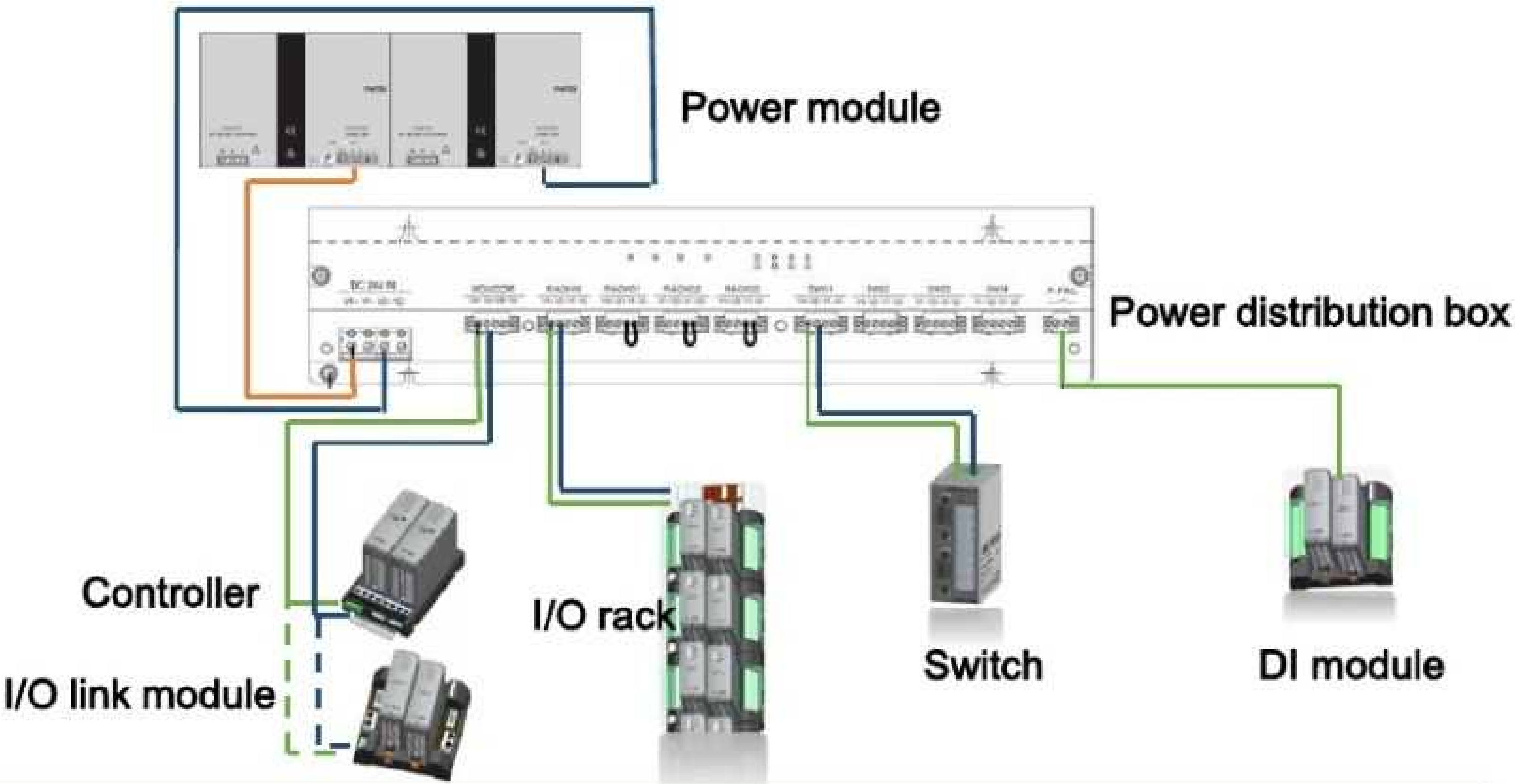
- Cabinet



- Power supply - AC



- Power supply - DC



- I/O rack

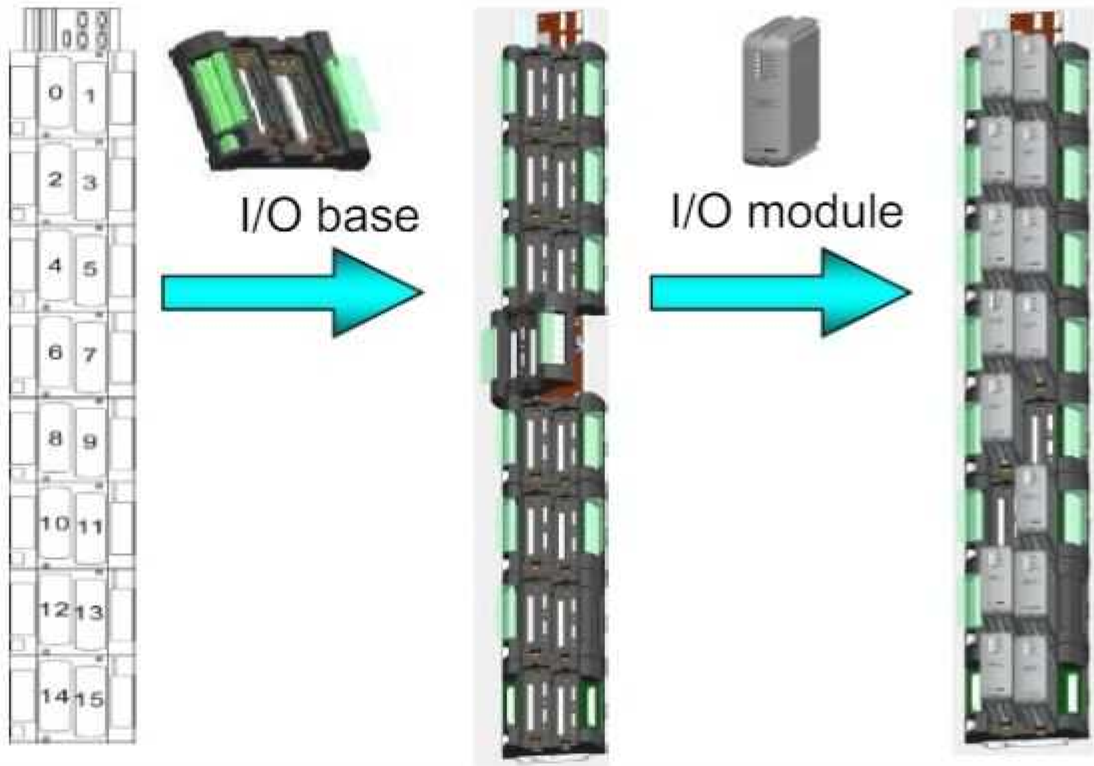
I/O Rack(long):
CN721

I/O Rack(short):
CN722

CN722
- 4 I/O Bases
- 8 I/O modules (0-7)

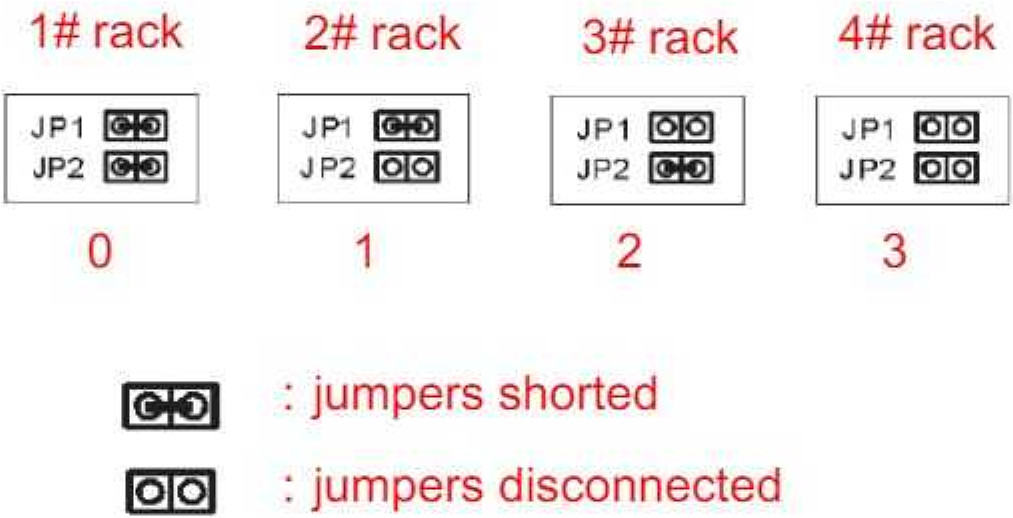
CN721
- 8 I/O Bases
- 16 I/O modules (0-15)

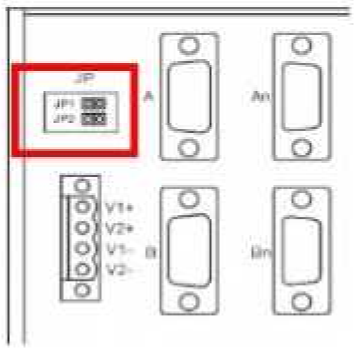
- I/O rack



- I/O rack address

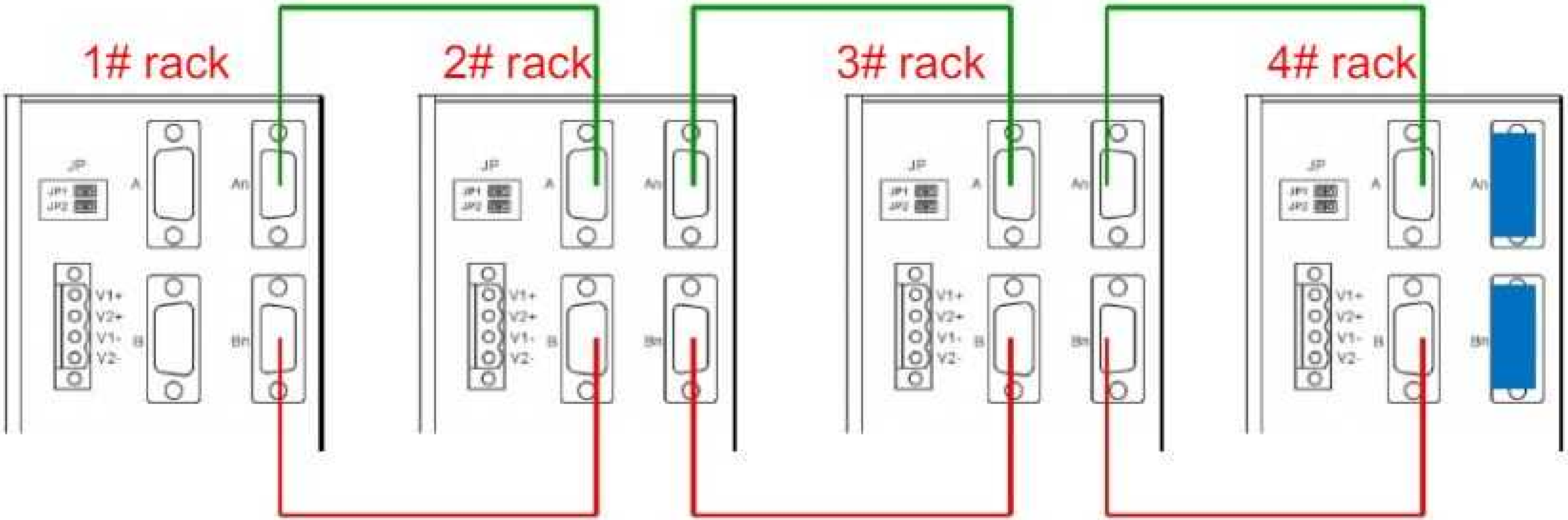
One cabinet: 4 I/O racks





中控 · SUPCON

- **I/O rack connection**



Note: A pair of 120Ω terminal resistances is needed in the last rack.

Control node

中控·SUPCON

- **Modules**

I/O link module

Function:

connect the controller with the extended I/O modules

Controller

Function:

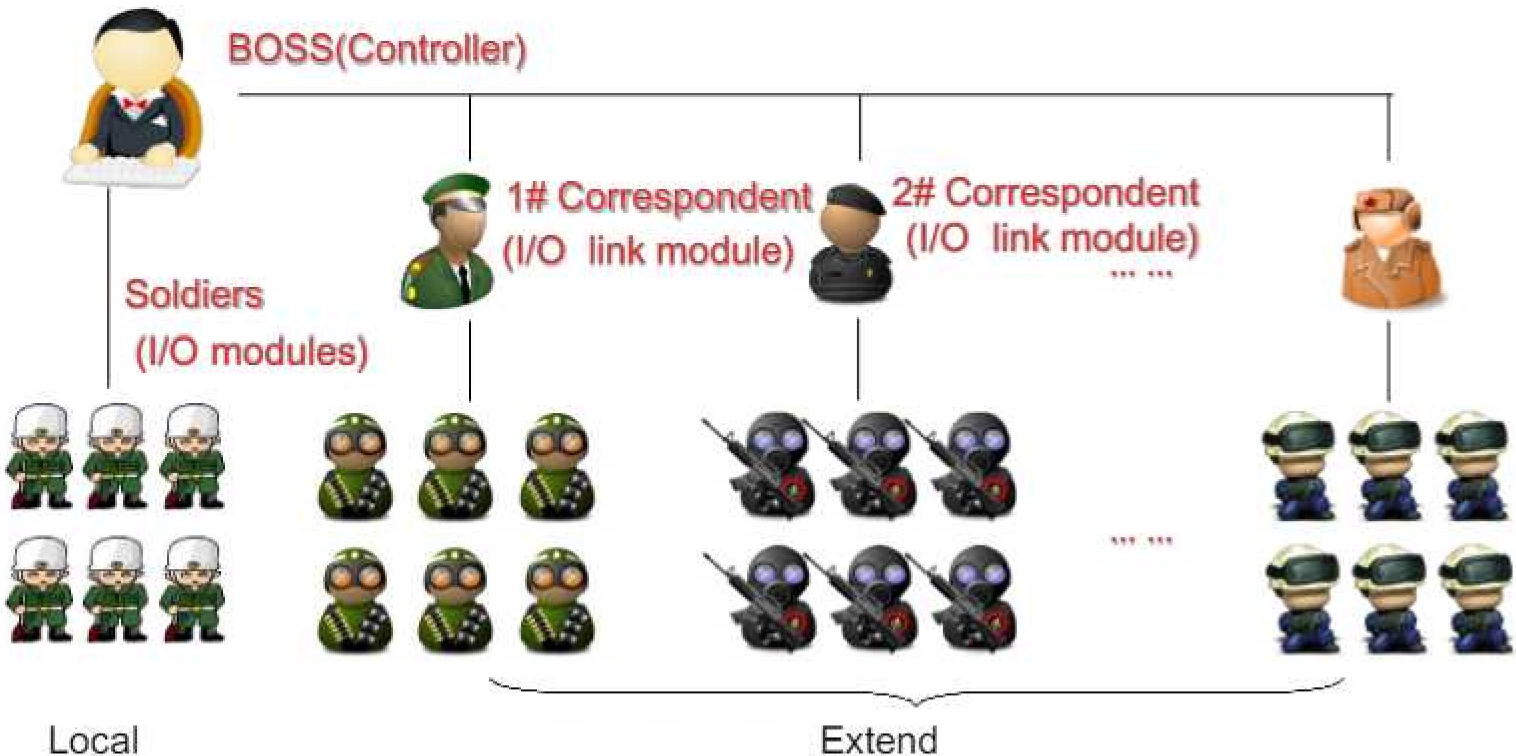
control, rocess, manage....

I/O module

Function:

signals sampling

- Modules


BOSS(Controller)
1# Correspondent
(I/O link module)
2# Correspondent
(I/O link module)
... ...
Soldiers
(I/O modules)
... ...
Local
Extend

- **Control unit**

Composed of the controller FCU712-S(FCU711-S) and the base MB712-S

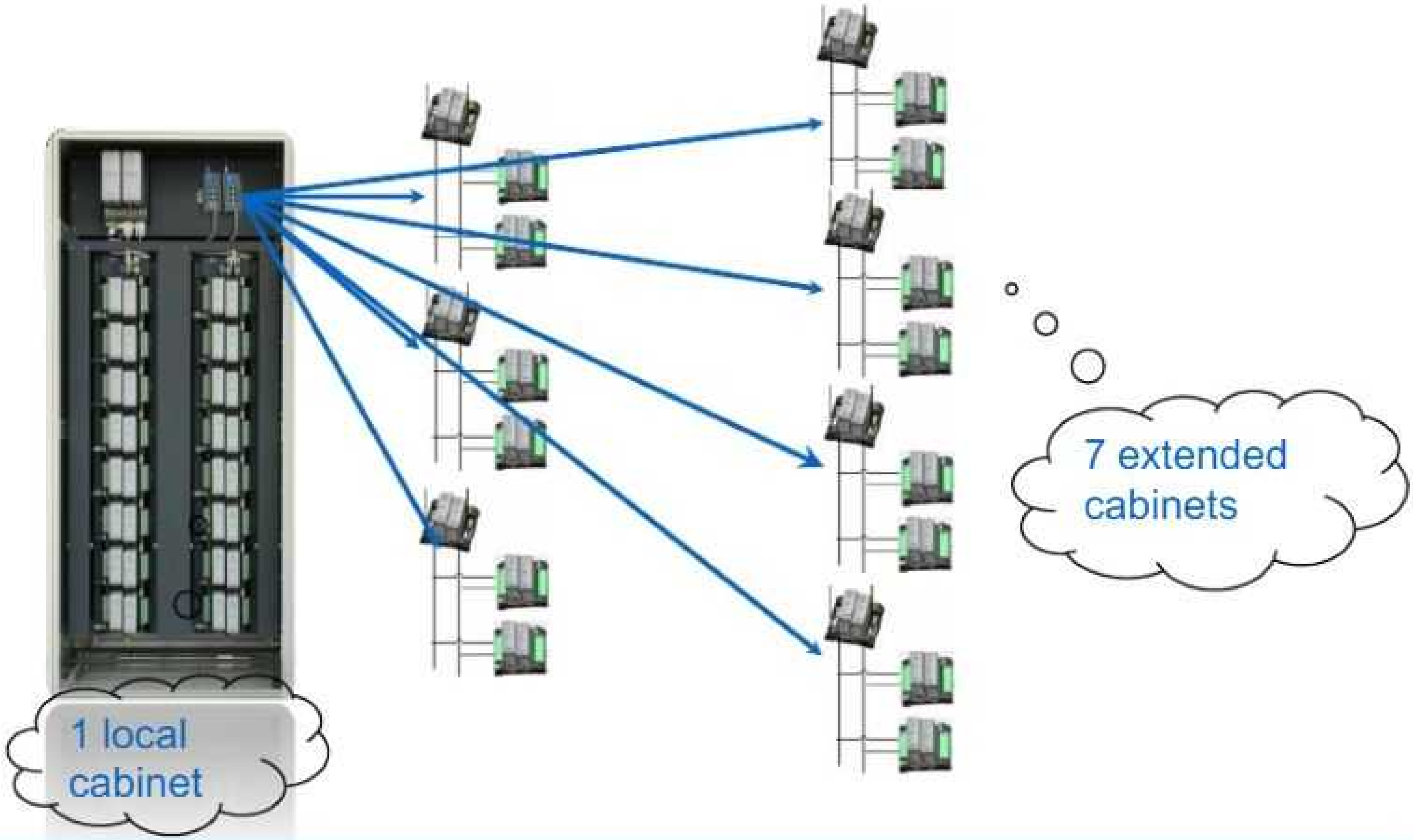
- Control unit - features of Controller

Controller features

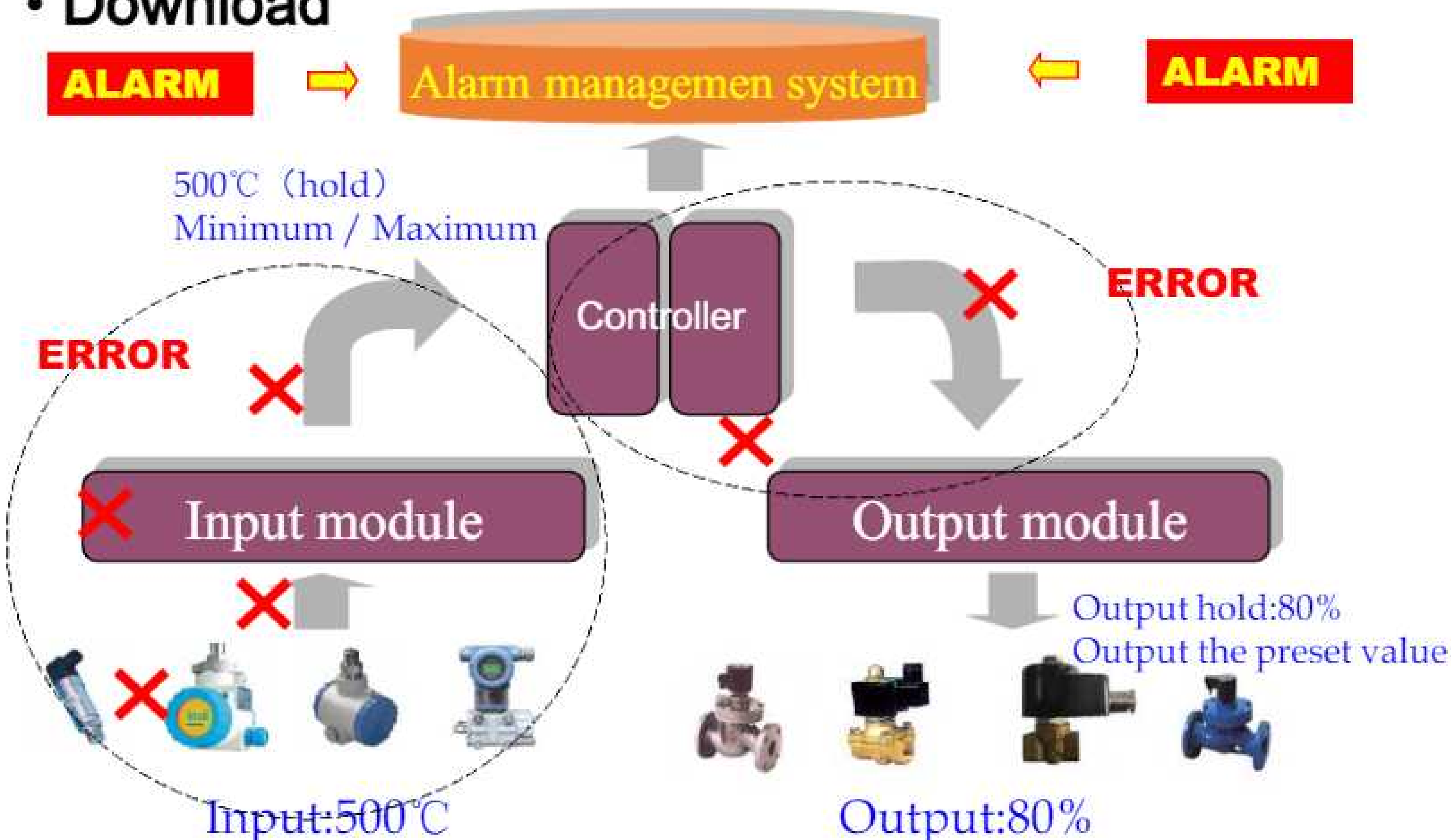
- 1:1 redundancy
- Scanning period: 100ms (basic period), 20ms(quick period)
- Capacity: 4 local I/O racks, 28 extended I/O racks
- System scale: 60 control domains, 60 operation domains. (60 nodes in each domain)
- Fault security:to ensure the I/O signal realiable during system's failure
- Download on line

Control node

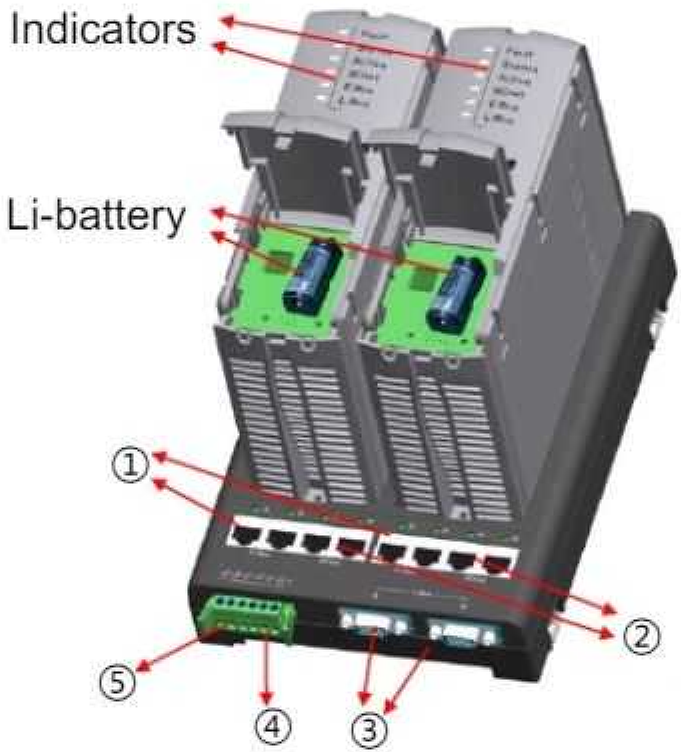
- Capacity



- Download


ALARM
Alarm managemen system
ALARM
500℃（hold）
Minimum / Maximum
ERROR
Controller
ERROR
Input module
Output module
Output hold:80%
Output the preset value
Input:500℃
Output:80%

- **Control unit**



① E-BUS A/B: A /B network interface of I/O expansion bus (between Controller and I/O link module)

② SCnet A/B: A/B network interface of process control network (between CS and ES/ OS)

③ L-BUS A/B: A/B network interface for local I/O bus

④ 24VA, 24VB, GND: terminals for two redundant 24V DC power distribution

⑤ CLK+/-: Second pulse differential signal high / low level

- **Control unit - Indicators**

indicators	Status	Other status	Instruction
Fault (red)	OFF	ON	Hardware fault
		Flashing	-
Status (green)	ON	OFF	-
		Flashing	No configuration, or in configuration update process, or in configuration recovery process
Duplex (green)	ON	OFF	Whether in working state or not: working controller indicator is on, and standby controller indicator is off
SCnet (green)	ON	OFF	Redundant network fault
		Flashing	Ethernet address conflict; or single network fault
E-Bus (green)	ON	OFF	Redundant network fault
		Flashing	Single network fault
L-Bus (green)	ON	OFF	Fault in one pair of two pairs of redundant buses
		Flashing	Some network fault

- **Control unit - Li-battery backup**

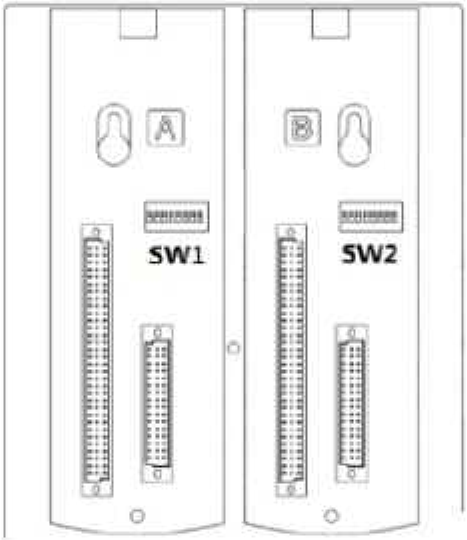
CR123A
(3.0V)

FCU712-S

CR2032
(3.0V)

FCU711-S

- **Control unit - Address setting**



SW1: DIP switch for domain address

FCU712-S: 0~59

FCU711-S: 0~15

SW2: DIP switch for node address

2~126

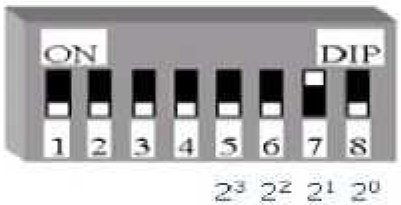
e.g.： 2 （decimal code）

↓

1 0 （binary code）

↓ ↓

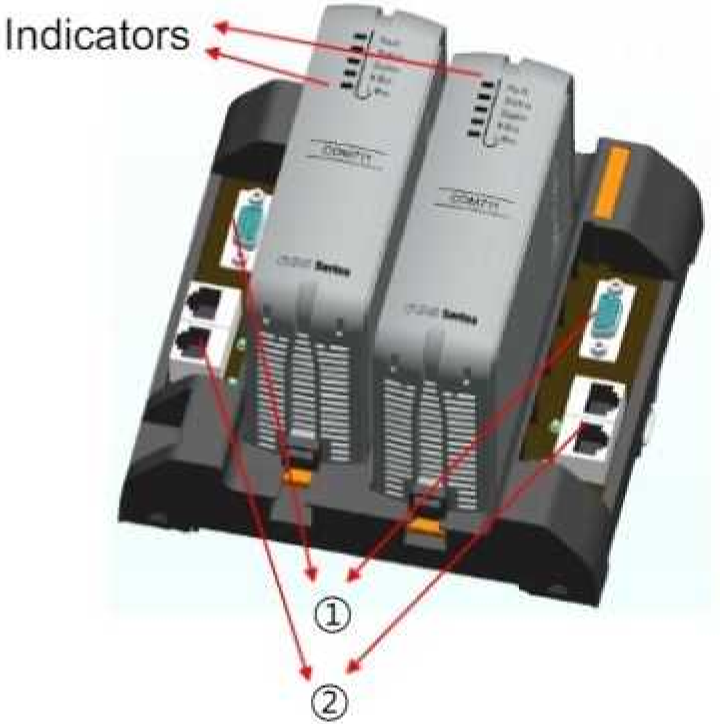
ON OFF



- **I/O link unit**

Composed of I/O link module COM711-S and the base MB722-S

- I/O link unit

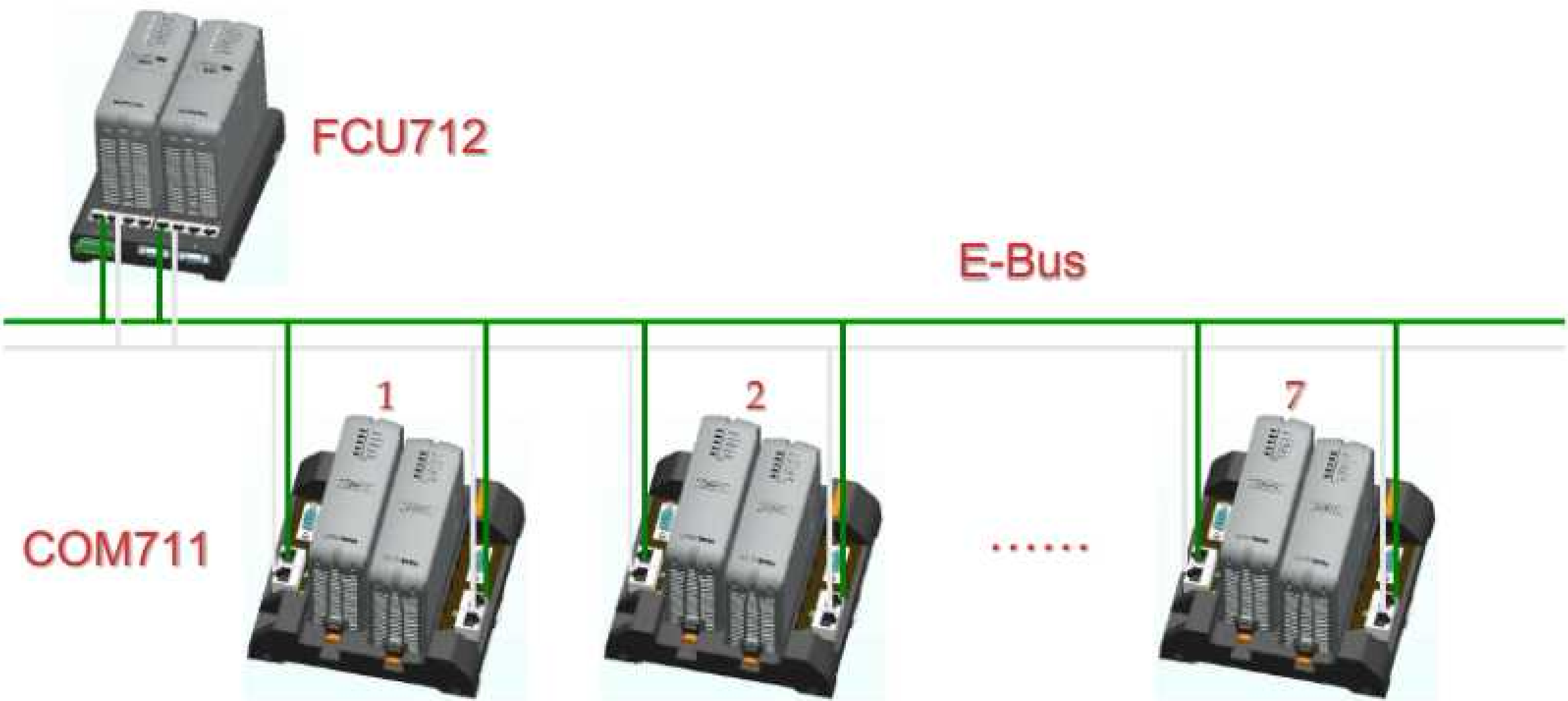


① L-BUS A/B: A/B network interface for local I/O bus

② E-BUS A/B: A /B network interface of I/O expansion bus (between Controller and I/O link module)

中控·SUPCON

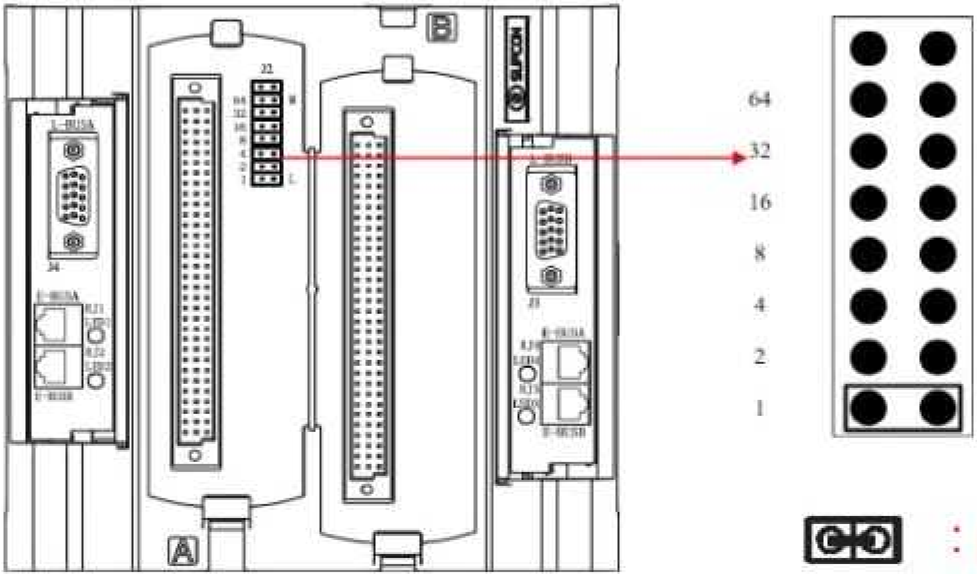
- I/O link unit



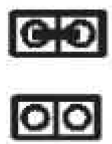
- **I/O link unit - Indicators**

Name	Status	Instruction
Fault (red)	On	Internal fault occurs
	Off	Normal
Status (green)	On	Configuration
	Flash	No configuration
Duplex (green)	On	Work card
	Off	Spare card
E-Bus (green)	On	Normal
	Flash	Signal-loop I/O expansion bus fault or Ethernet address confliction
	Off	Two-loop I/O expansion bus fault
L-BUS (green)	On	Normal
	Flash	Signal side local I/O bus fault
	Off	Two sides local I/O bus fault

• I/O link unit - Address setting



Address range:1~7



: jumpers shorted

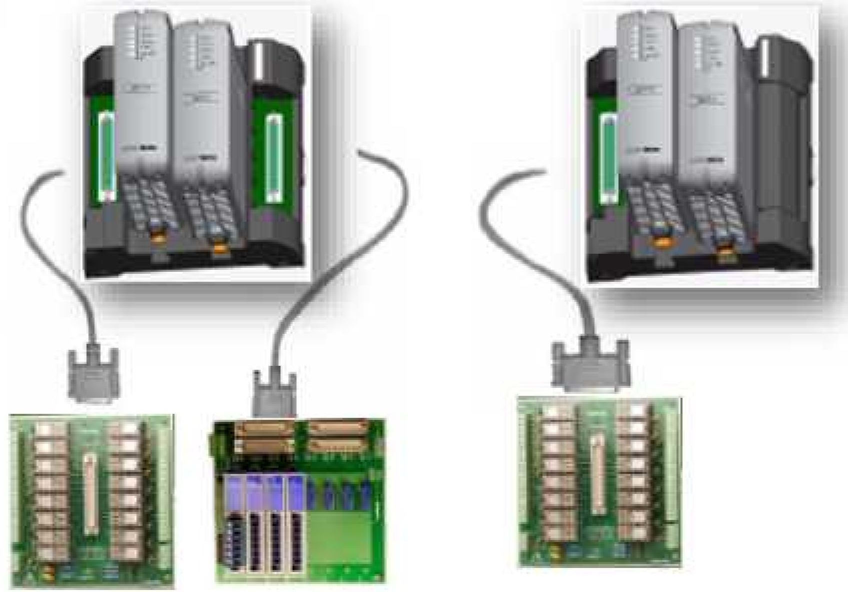
: jumpers disconnected

- **I/O module unit**

Composed of two I/O modules and one base
(terminal board available)

single mode

redundant mode



• I/O module unit - Indicator

indicator	Fault (red)	Status (green)	Duplex (green)	L-Bus (green)	Supply (green)
Description Status	Fault indicator	Running indicator	Work/Standby indicator	Communication indicator	power supply status indicator
OFF	Normal	--	Standby	Communication link break	Abnormal power supply
ON	Severe fault	Normal	Work	Normal	Normal
Flashing	--	No configuration	--	IP confliction	--

- **I/O module unit - I/O module**

Type	Properties
AI711-S	8-channel current/voltage input module (type II / type III signal)
AI722-S	8-channel TC input module
AI731-S	8-channel RTD input module
AO711-S	8-channel current output module (type II / type III signal)
DI711-S	16-channel digital input module
DO712-S	16-channel digital output module

- I/O module unit - Base

  ✓ MB735-S： for two not redundant I/O modules.

  ✓ MB736-S：for two redundant I/O modules.

• I/O module unit - Base

- ✓ MB745-S：for two not redundant I/O module.
- ✓ MB746-S：for two redundant I/O module.

- Safty barrier terminal board
- Relay terminal board

- **I/O module unit - I/O module**

1 AI711-S

✓ 8- channel

✓ channel-to-channel isolation

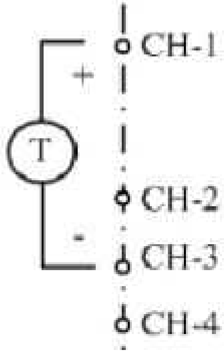
✓ Signal type: (0-5)V,(1-5)V, (-10-10)V,
(0-10)mA, (4-20)mA

✓ power supply

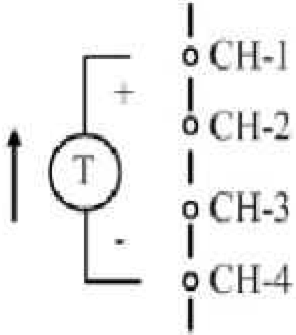
- **I/O module unit - I/O module**

1 AI711-S

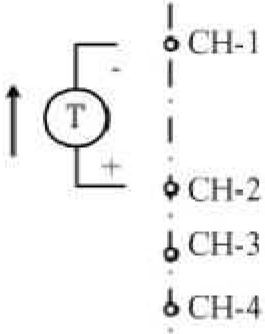
Voltage signal



Current signal



Current signal by power supply



- **I/O module unit - I/O module**

2 AI722-S

✓ 8- channel

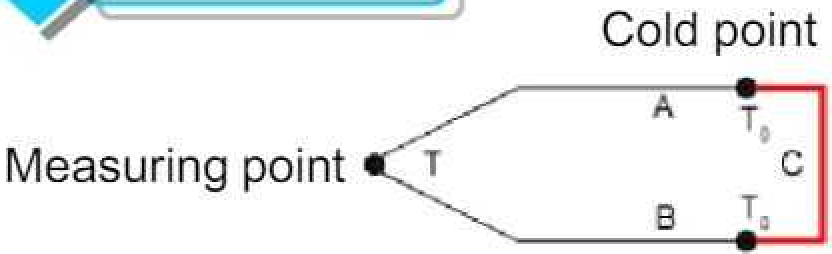
✓channel-to-channel isolation

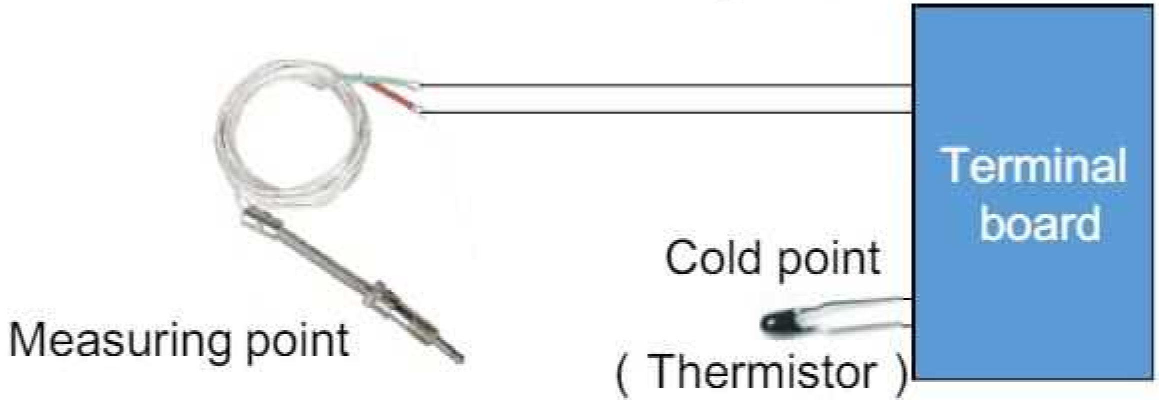
✓ Signal type: TC, (-20~80)mV、(-100~100)mV

✓Cold-end compensation

- **I/O module unit - I/O module**

2 AI722-S



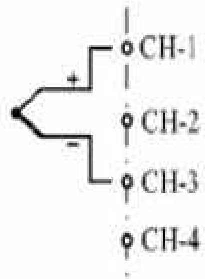


中控 · SUPCON

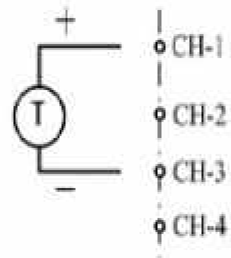
- **I/O module unit - I/O module**

2 AI722-S

TC signal



Voltage signal



33 and 34 are cold junction compensation resistance connection terminals.

- **I/O module unit - I/O module**

3 AI731-S

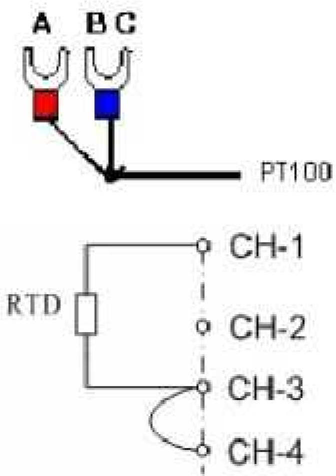
✓ 8- channel

✓ channel-to-channel isolation.

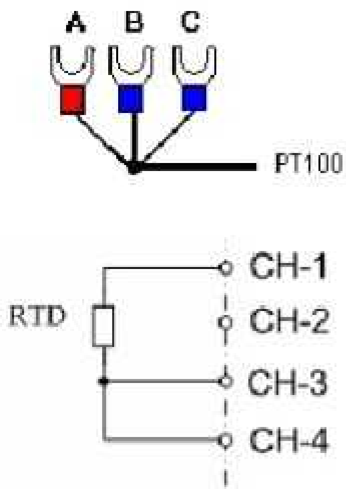
✓ Signal type:Pt100, Cu50, (1-400)Ω, (2-1000)Ω

- **I/O module unit - I/O module**

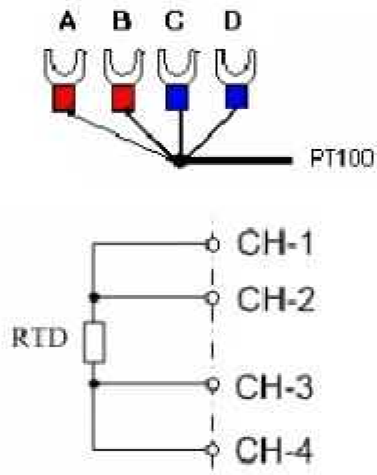
3 AI731-S



Two-wire



Three-wire



Four -wire

- **I/O module unit - I/O module**

4 AO711-S

✓ 8- channel

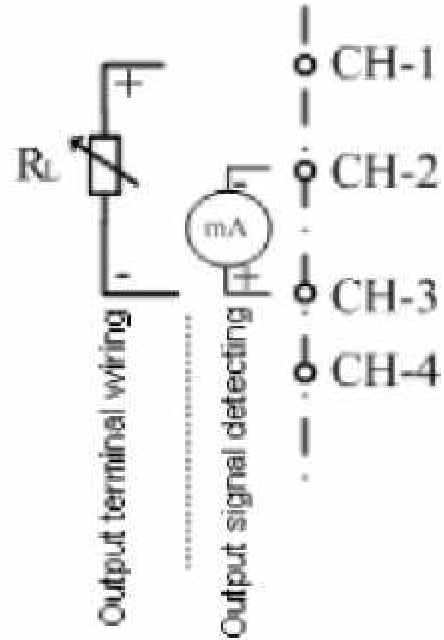
✓ channel-to-channel isolation

✓ Signal type: (4~20)mA, (0~10)mA, (0~20)mA

• I/O module unit - I/O module

4 AO711-S

Output wiring
Detecting wiring



- **I/O module unit - I/O module**

5 Digital Signal

DI711-S

✓16- channel, group isolated.

✓ Signal type: contact, electric-level

DO712-S

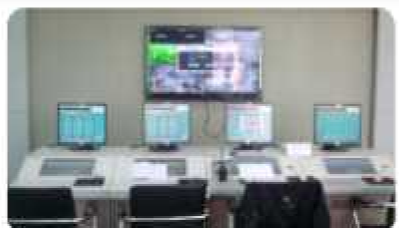
✓16- channel

✓ Signal type:24V, Pulse

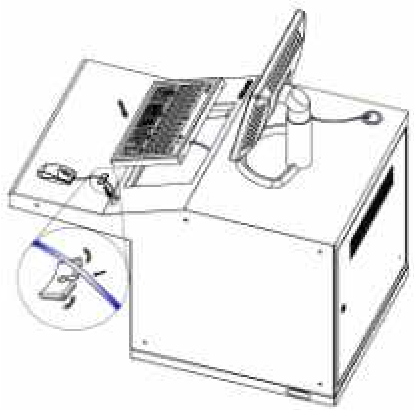
Content

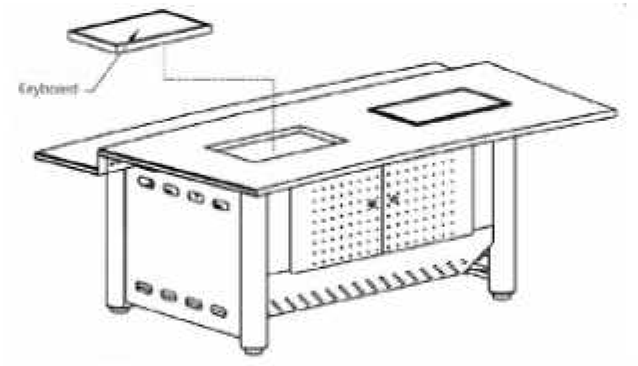
中控·SUPCON

Operation node



- Operation desk





- **Operator keyboard**

OP036-V

Operation node

- **Operating system**

Recommended: dual-core≥1.8G, Memory≥1G, harddisk≥80G, Video memory≥32MB

Operating system: Windows 7 Professional SP1 x32/x64,
Windows XP professional SP2,
Windows 2003 Server Standard SP1,
Windows 2008 Server R2 Standard

- **Operation node**
  - Operator station

  Operator stations access real-time data from control stations directly and send operating commands to control stations.
  - Chief engineer station

  The platform for configuration server, engineering configuration and system management.
  - Extended engineer station

  The platform for engineering configuration and system management.

Operation node

- **Operation node**

VF builder

chief engineer station

VFExplorer

extended engineer station

VFLaunch

opeation station/server

- Server

  - Data server

  Redundancy available. Provide alarm history records, operation domain variables real-time data server,SOE server.

  - Historical data server

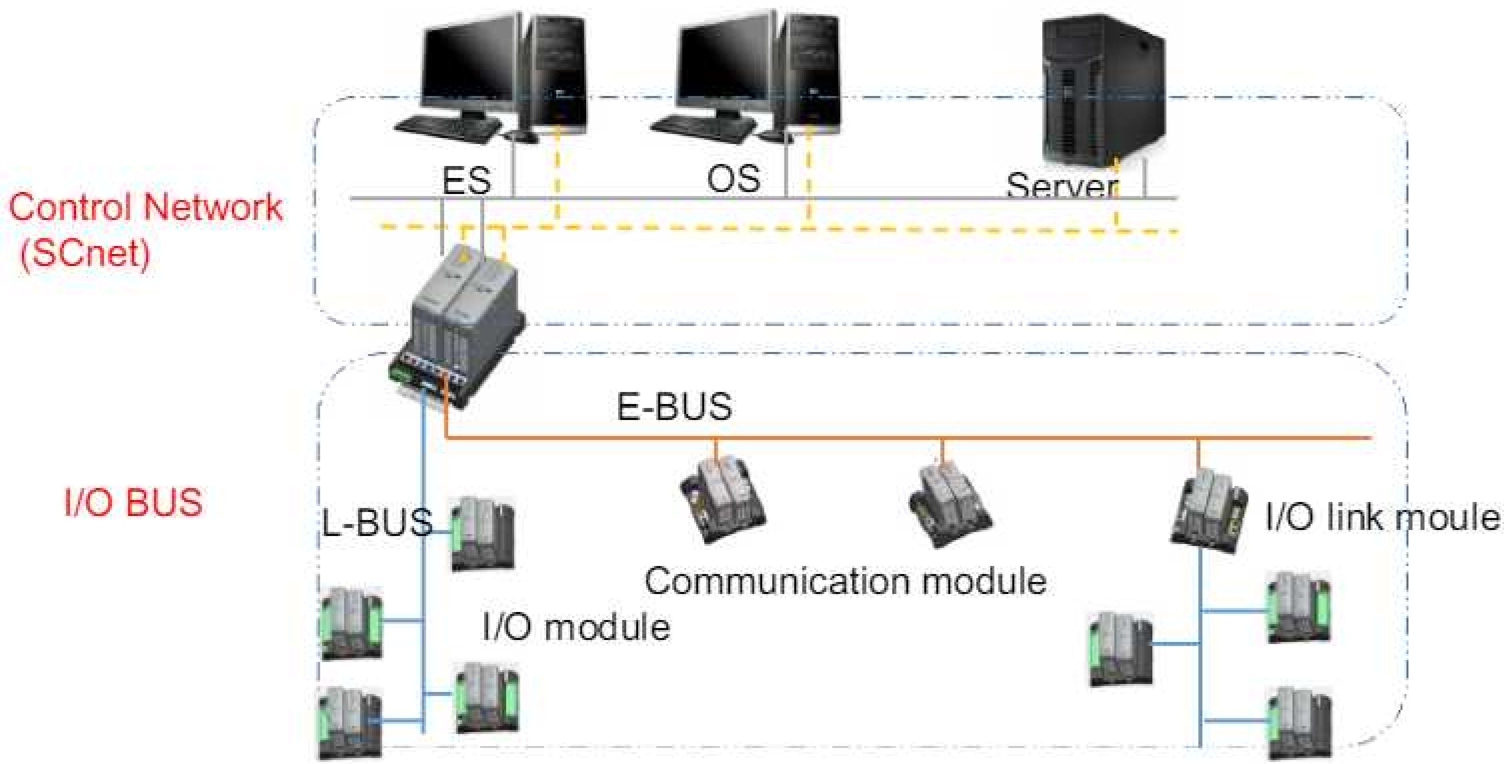
  Redundancy available. Provide trend history records.

  - Time synchronization server

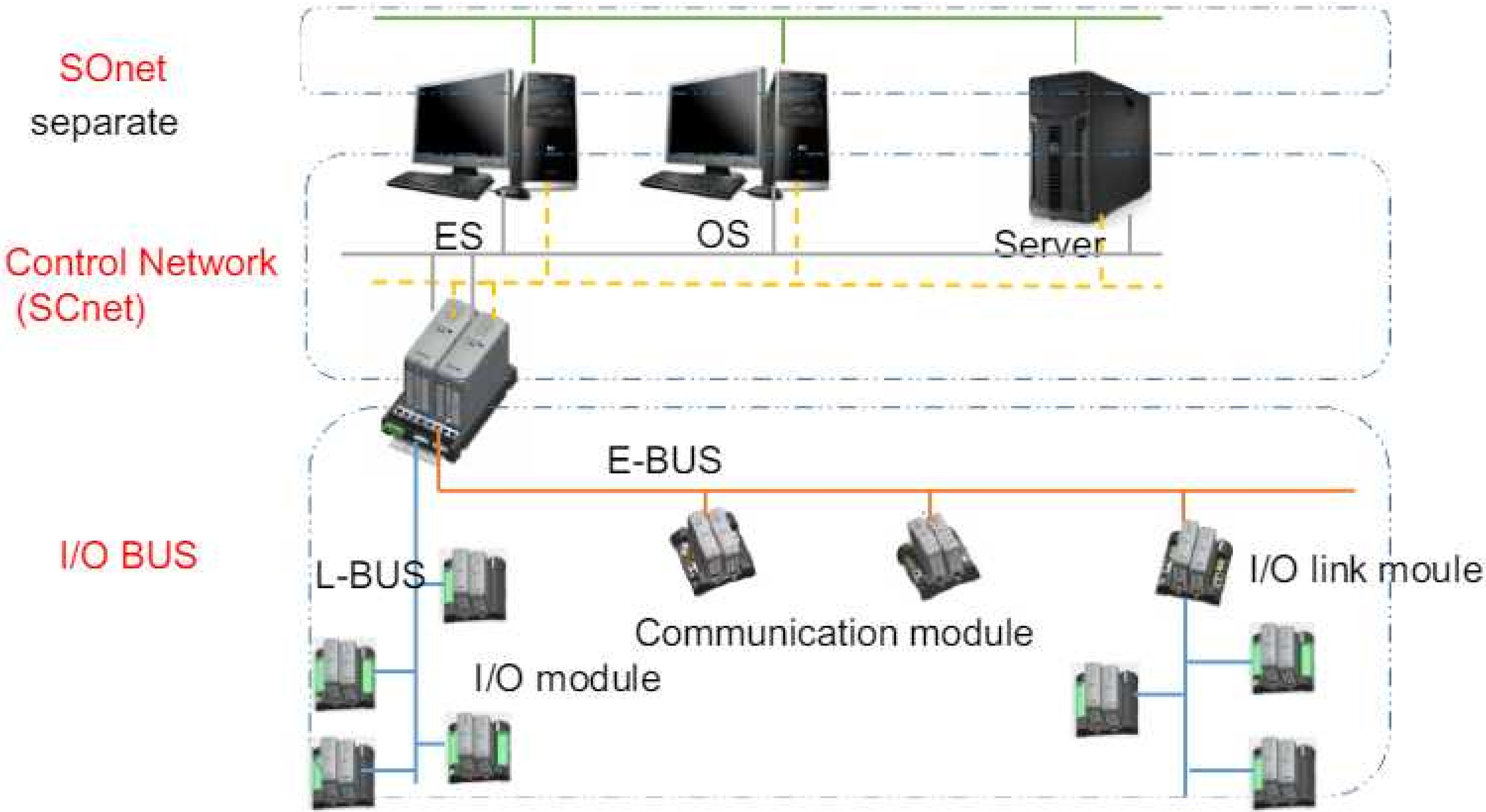
  Provide the time synchronization for the system.

Network

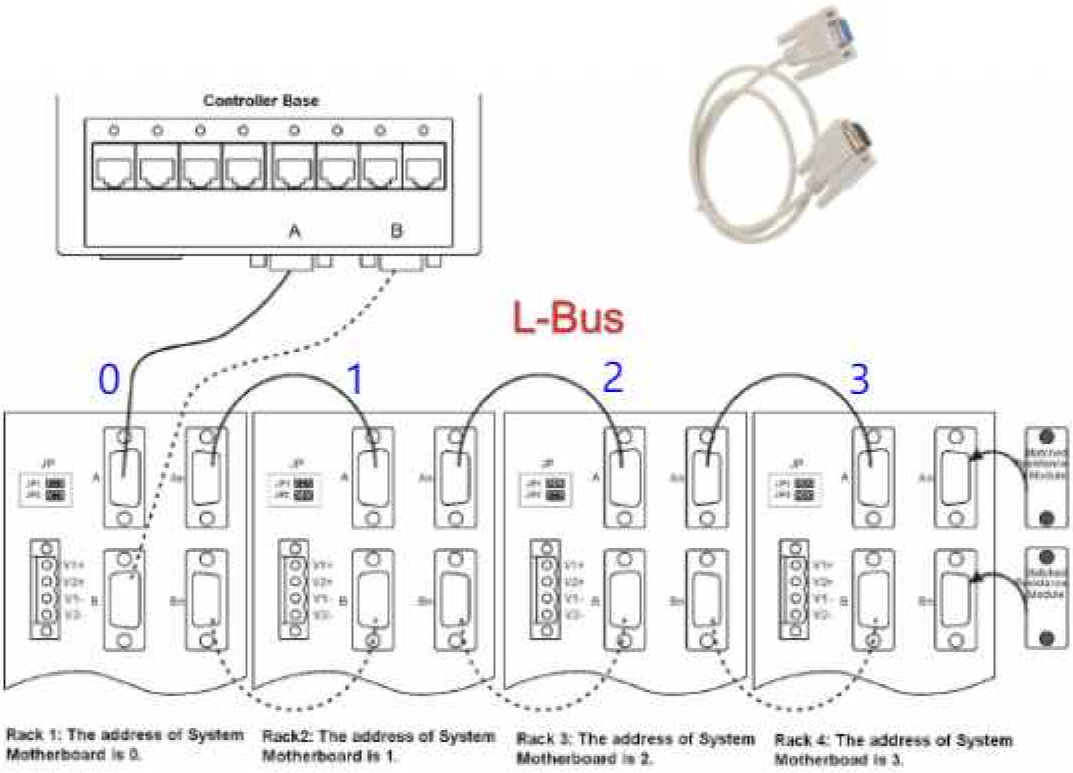
中控·SUPCON

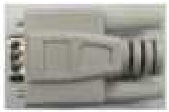


Network


SOnet
separate
Control Network
(SCnet)
I/O BUS
ES
OS
Server
E-BUS
L-BUS
I/O link moule
Communication module
I/O module

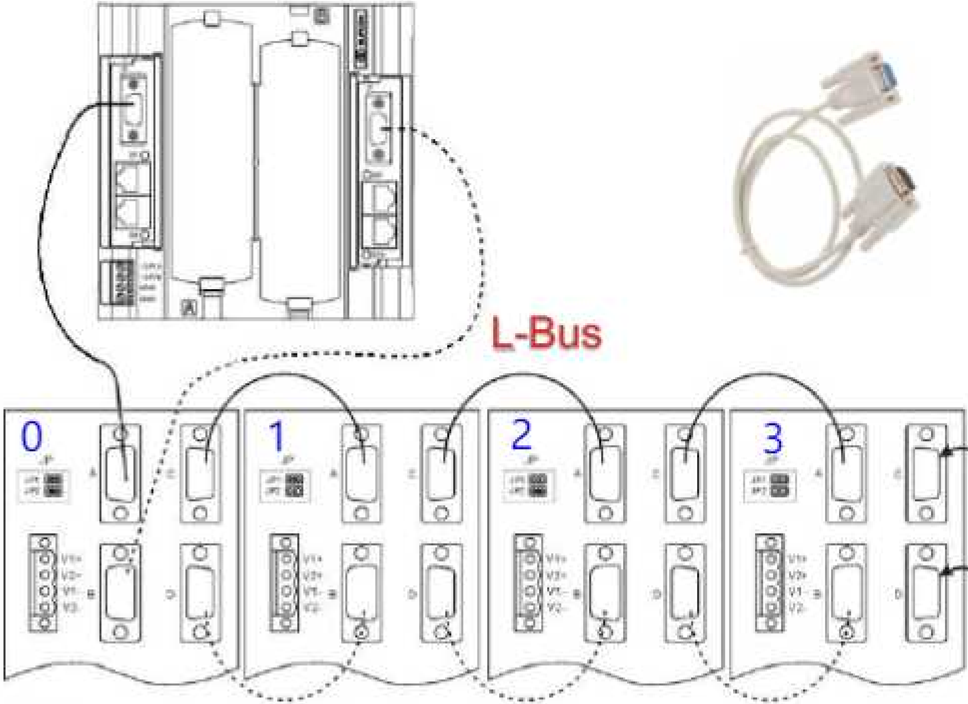
- **L-BUS - local cabinet**

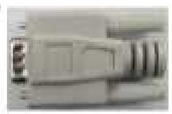




Matched resistance module

- L-BUS - extended cabinet

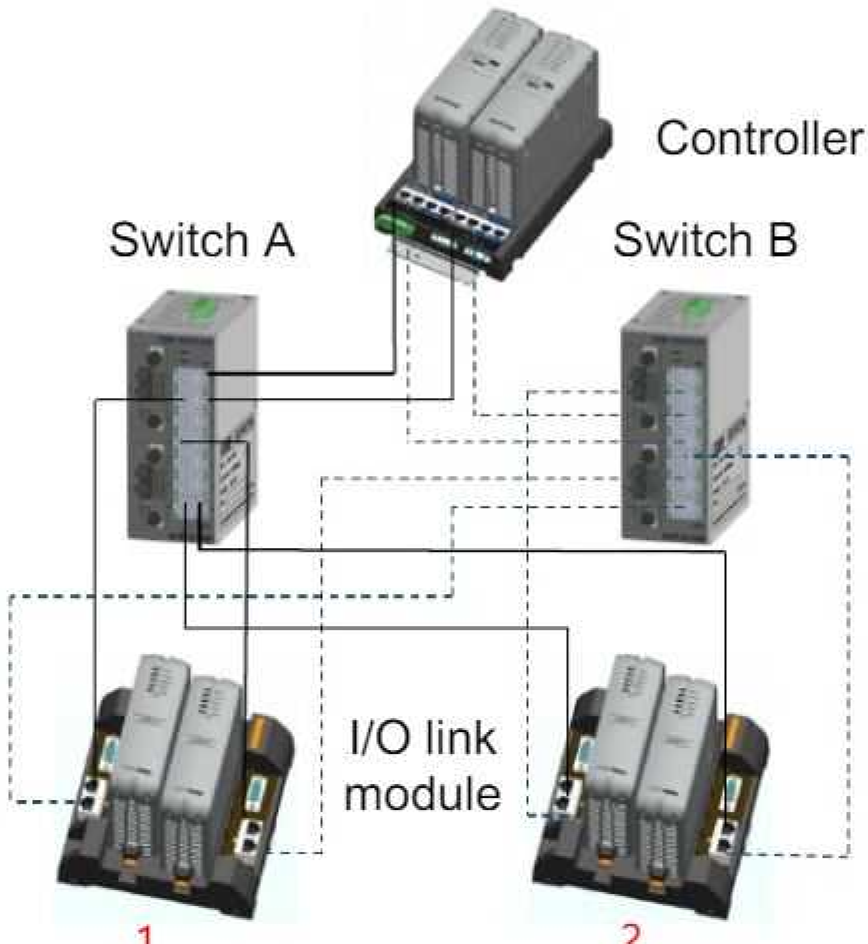




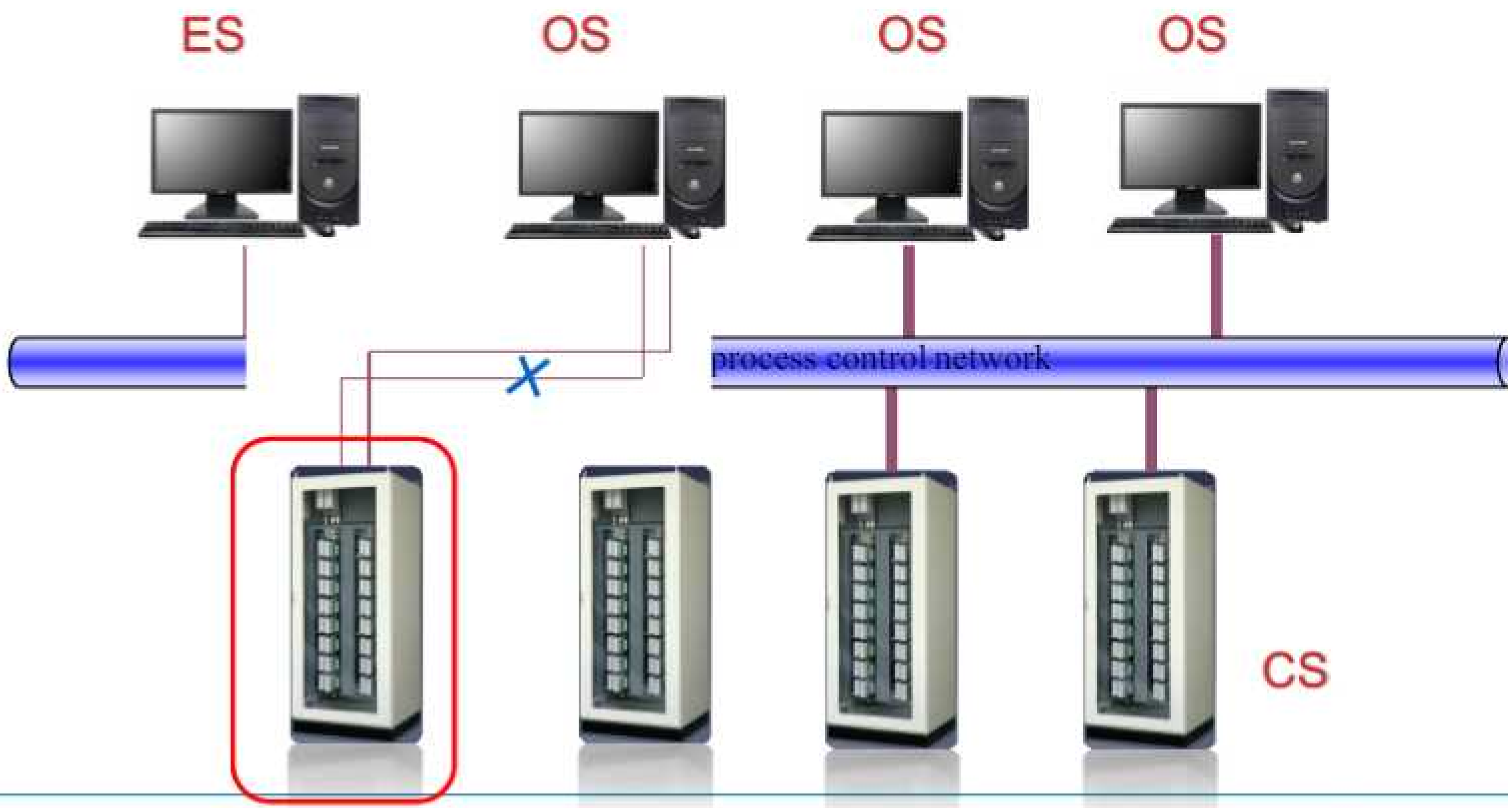
Matched resistance module

中控·SUPCON

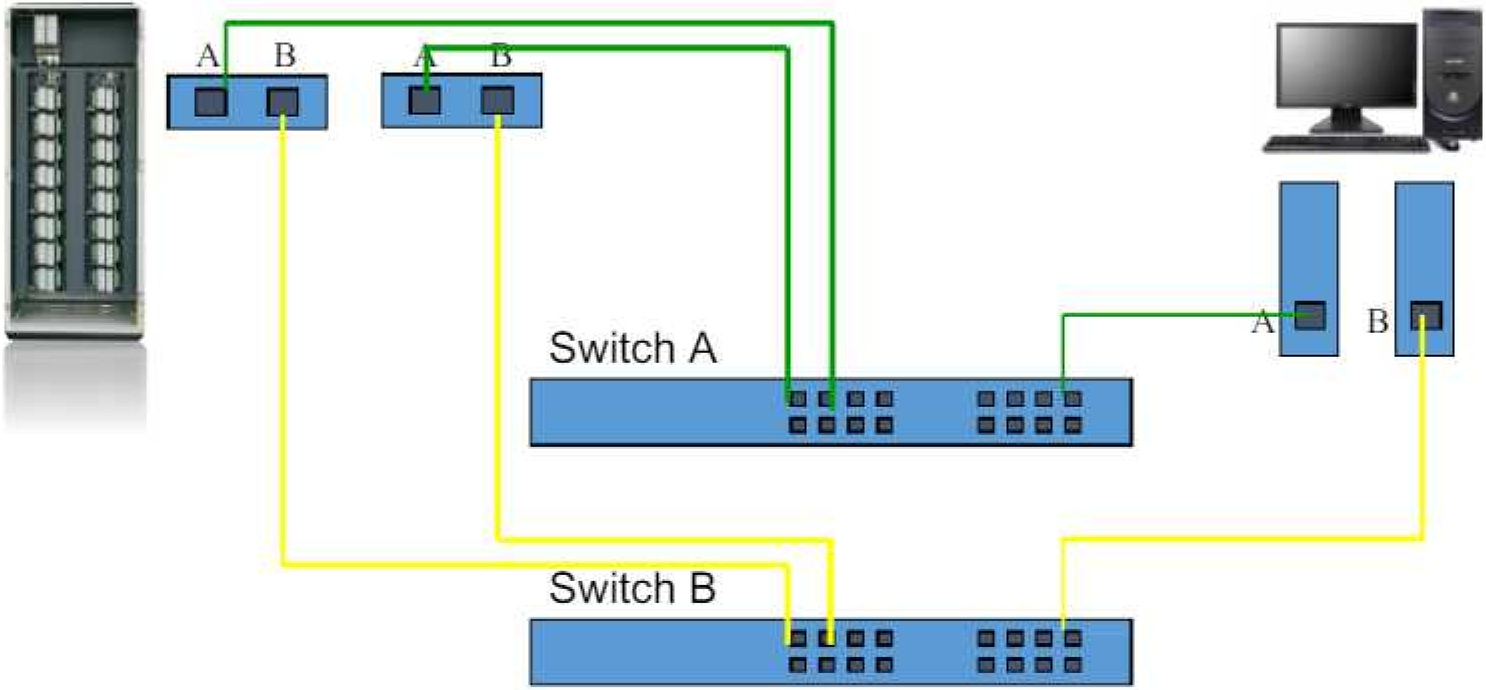
- E-BUS



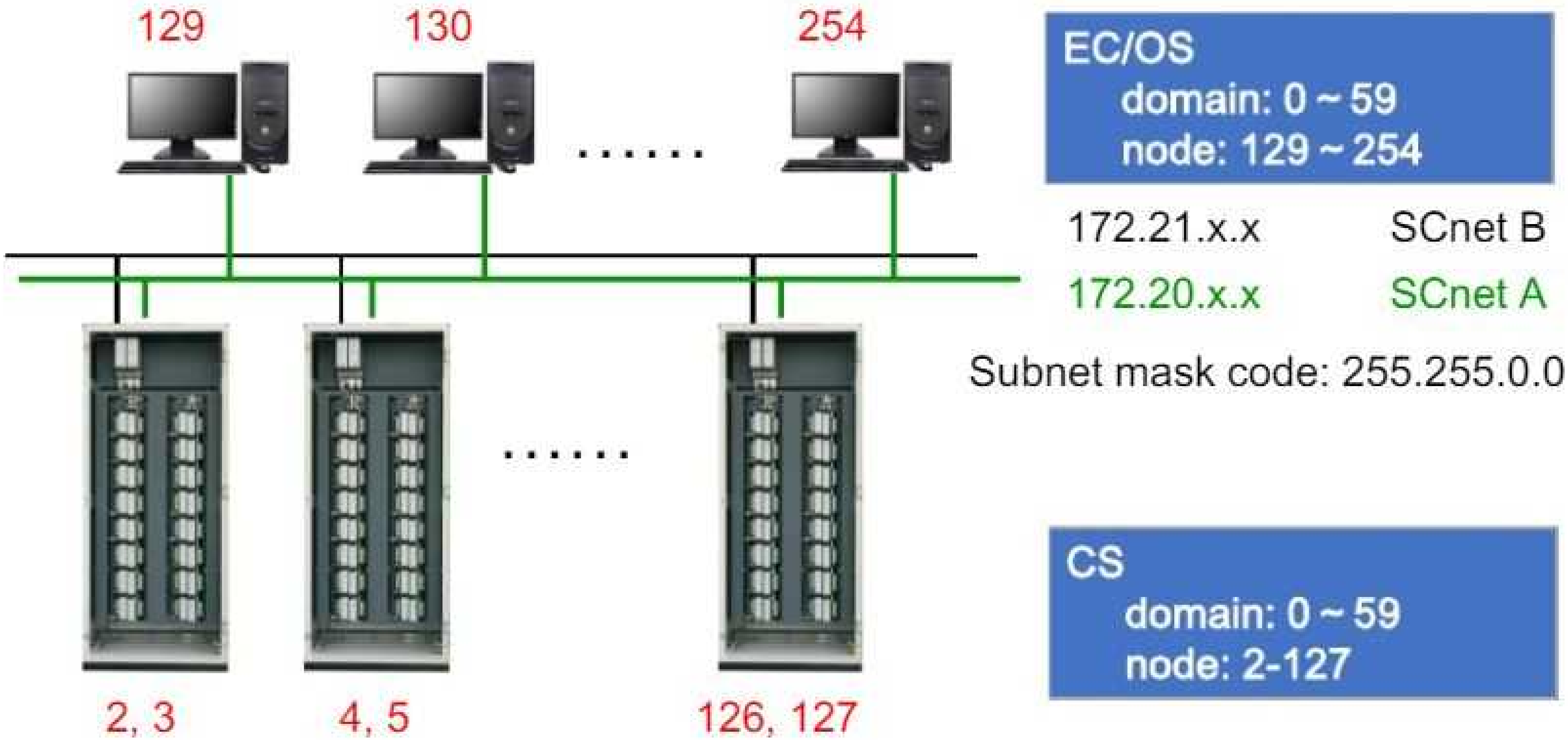
- SCnet



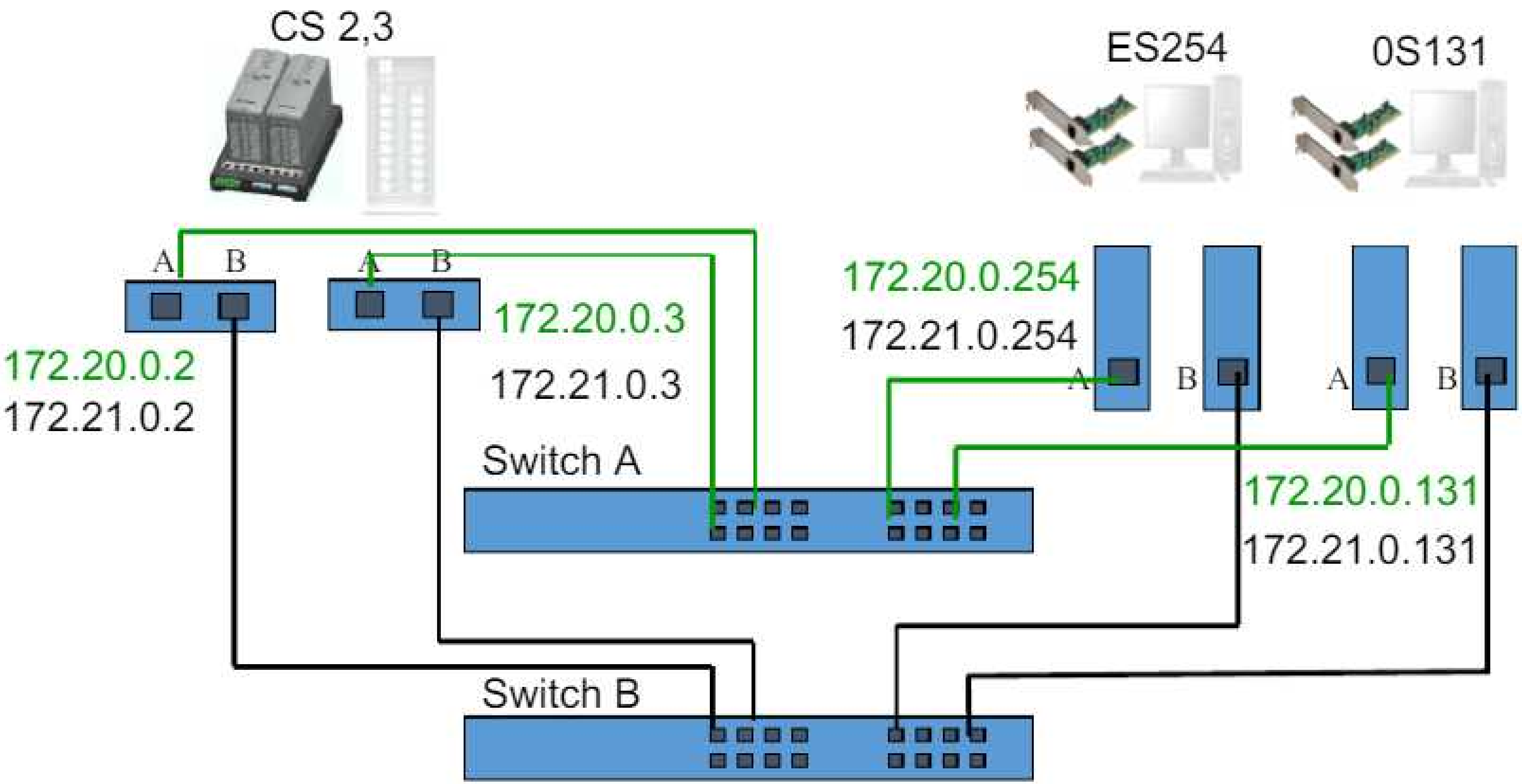
- SCnet



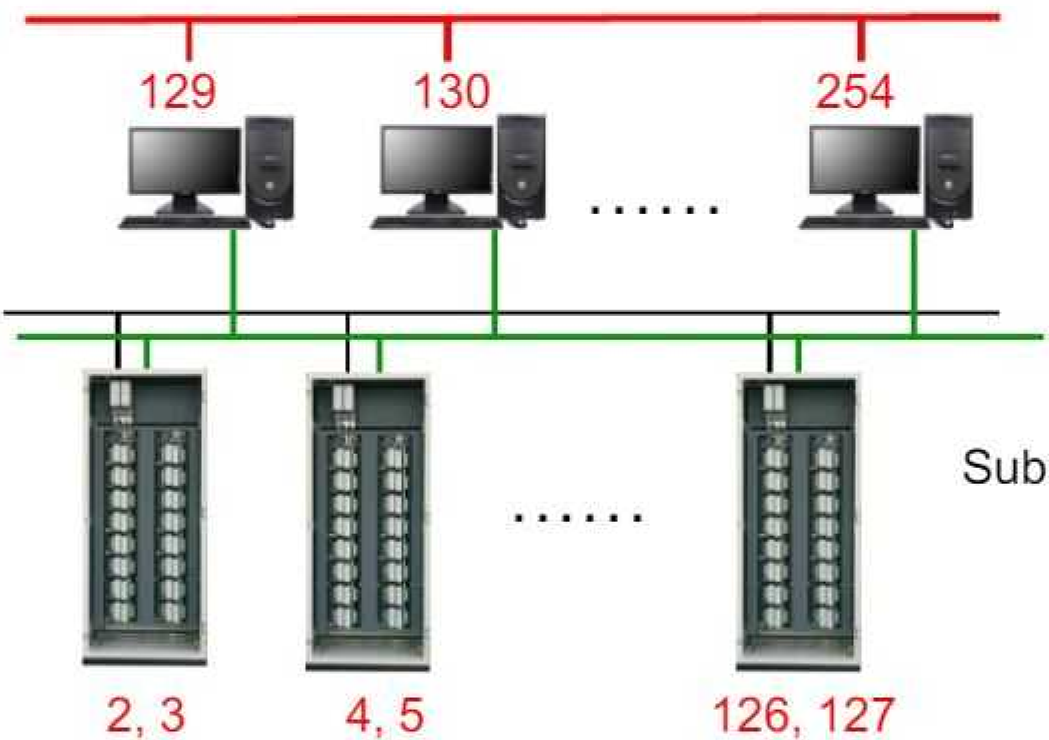
- SCnet


129
130
254
……
EC/OS
domain: 0 ~ 59
node: 129 ~ 254
172.21.x.x
SCnet B
172.20.x.x
SCnet A
Subnet mask code: 255.255.0.0
……
CS
domain: 0 ~ 59
node: 2-127
2, 3
4, 5
126, 127

- **SCnet**

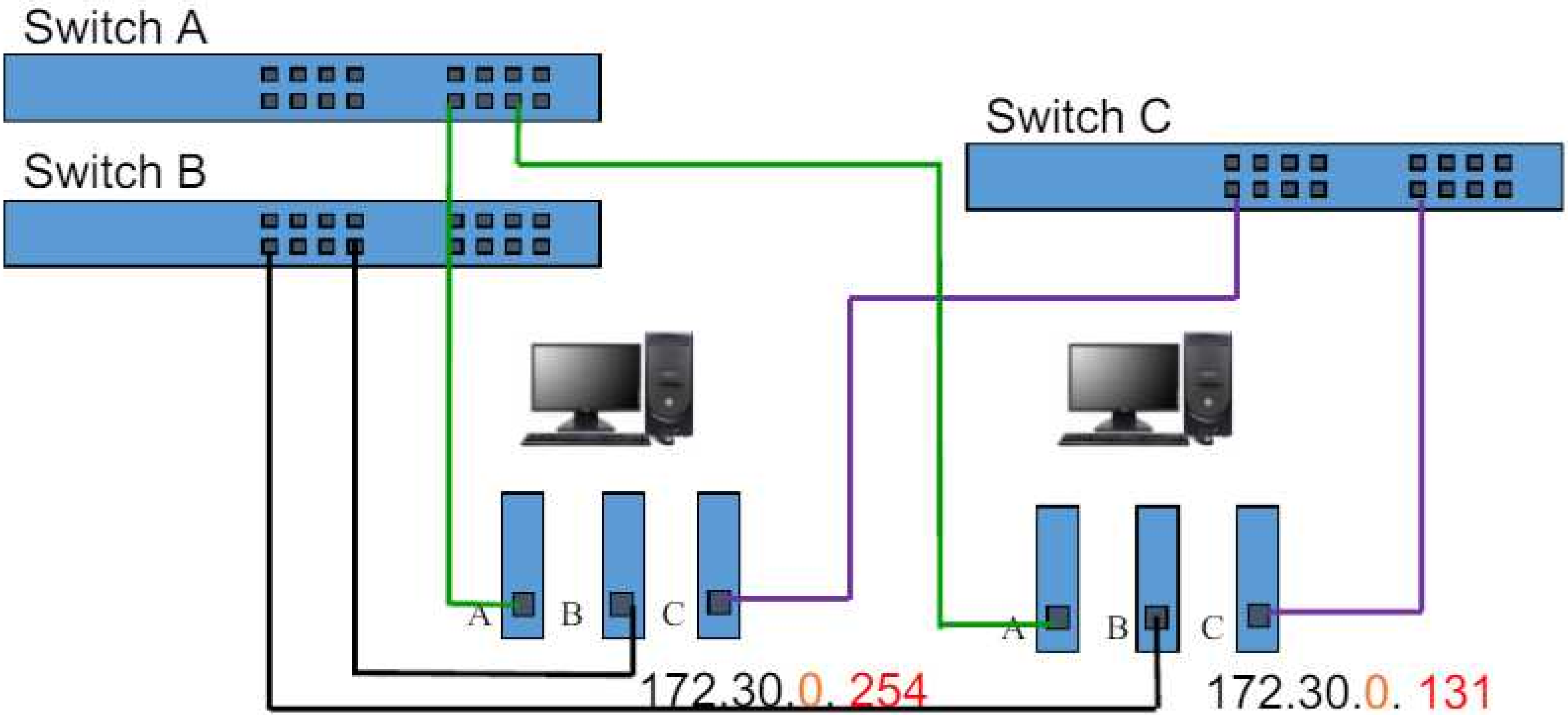

CS 2,3
A
B
A
B
172.20.0.2
172.21.0.2
172.20.0.3
172.21.0.3
Switch A
Switch B
ES254
0S131
172.20.0.254
172.21.0.254
A
B
A
B
172.20.0.131
172.21.0.131

• SOnet - Separate

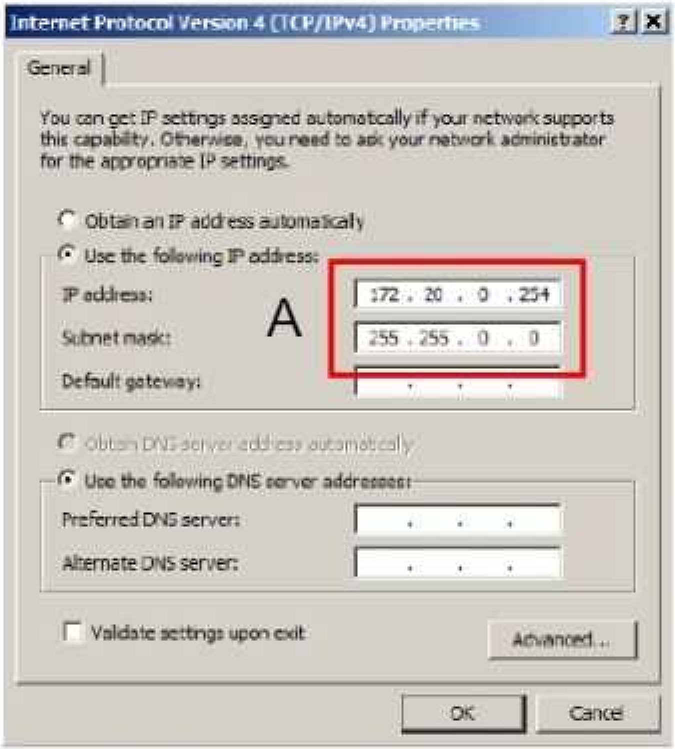


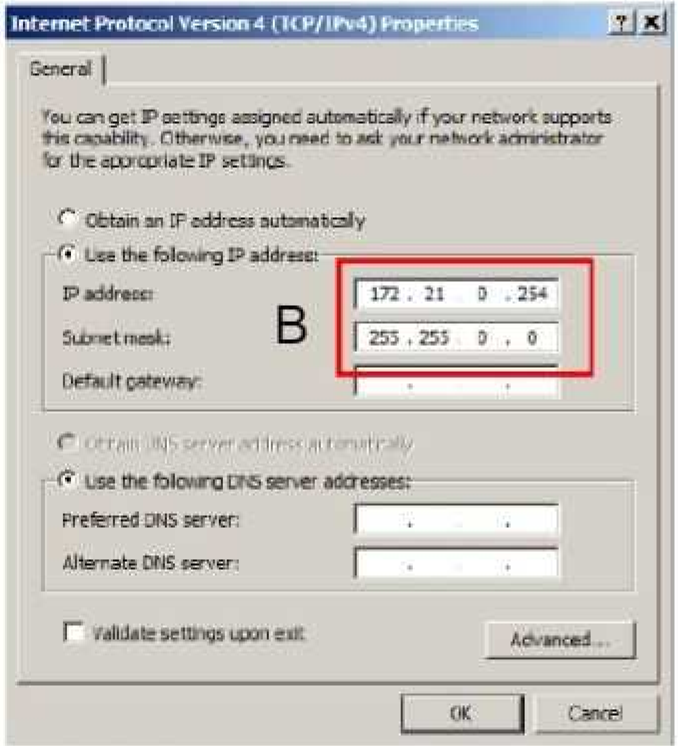
Subnet mask code: 255.255.0.0

- SOnet - Separate



- IP address setting

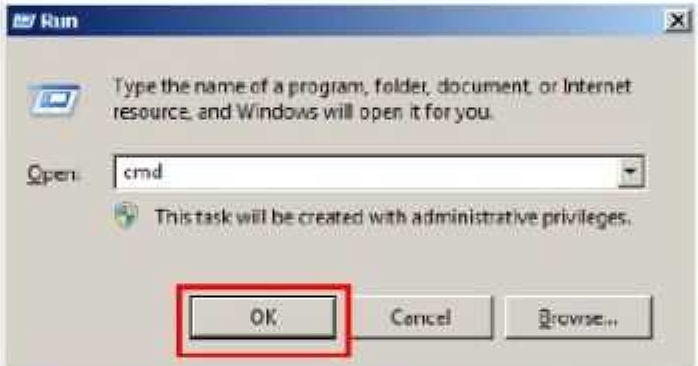




Network

- **Network test**

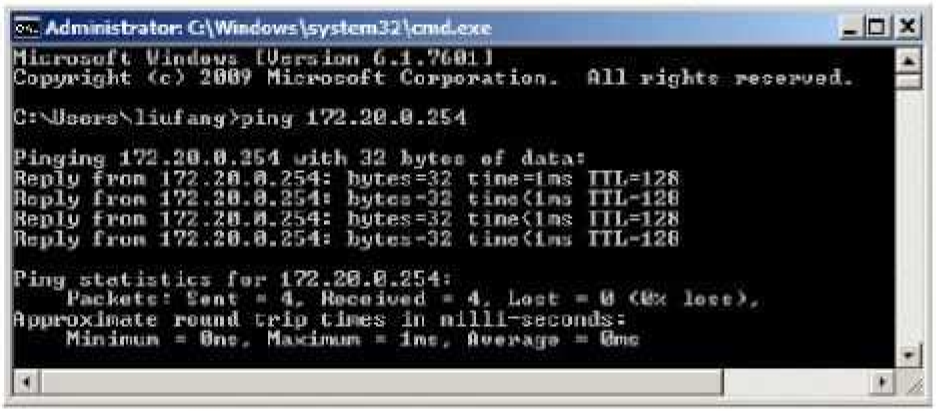
+R



ping 172.20.*.*

ping 172.21.*.*

ping 172.30.*.*



THE END
THANK YOU！

浙江中控技术股份有限公司
ZHEJIANG SUPCON TECHNOLOGY CO.,LTD.

CAN: Controller Area Network

Introduction:

- CAN is a serial bus system especially suited to networking several intelligent devices, such as sensors and actuators, within a machine or automation cell.

- It is a serial bus system with multiple master capabilities. i.e. several CAN nodes can try to transmit data at any one time.

- Each message carries an identifier that establishes a priority system.

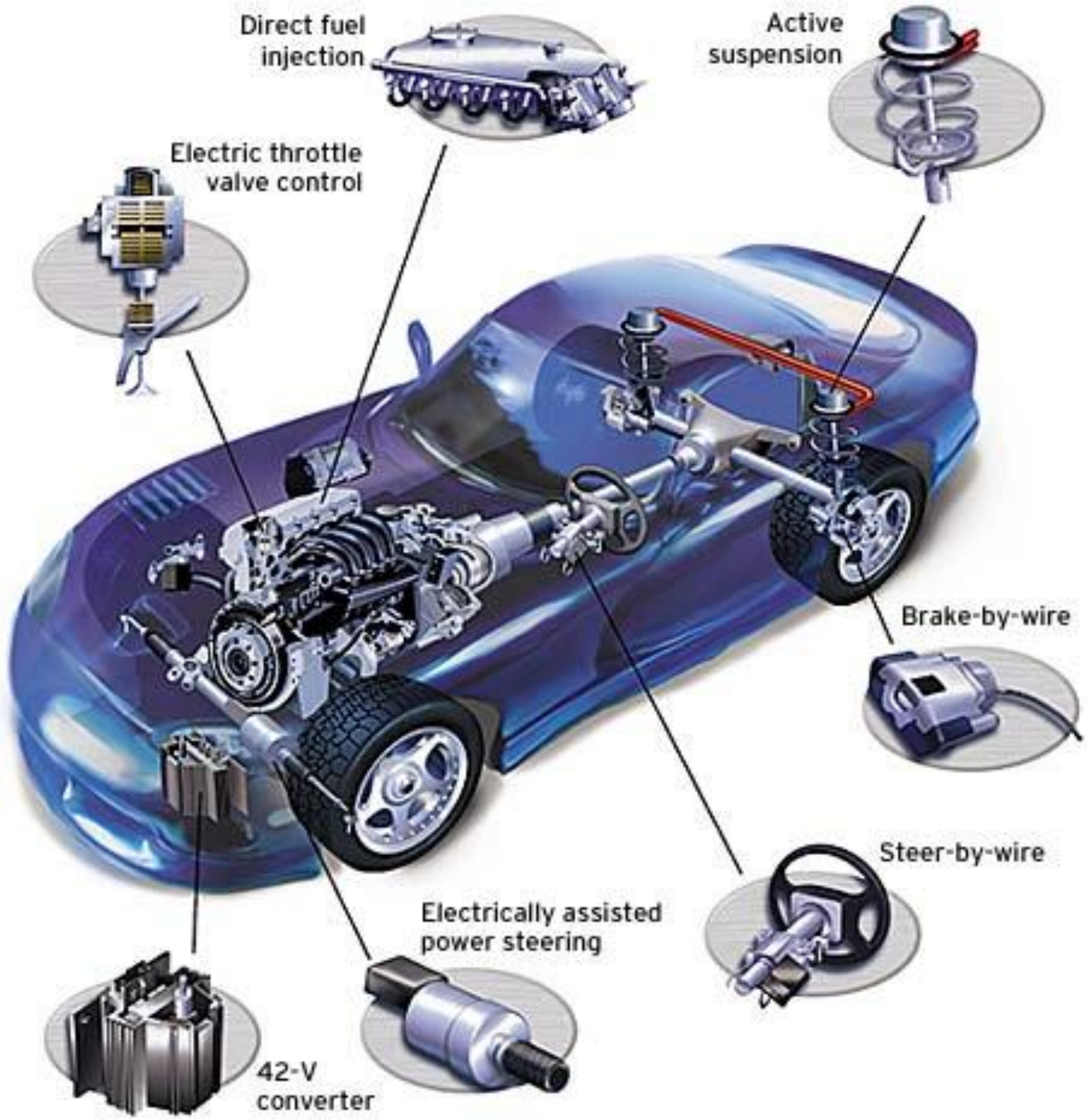
- The CAN bus does not need addressing of nodes in the conventional manner. Instead, messages are sent to all nodes.

CAN: Specification

CAN was developed in the 1980s by Robert Bosch GmbH

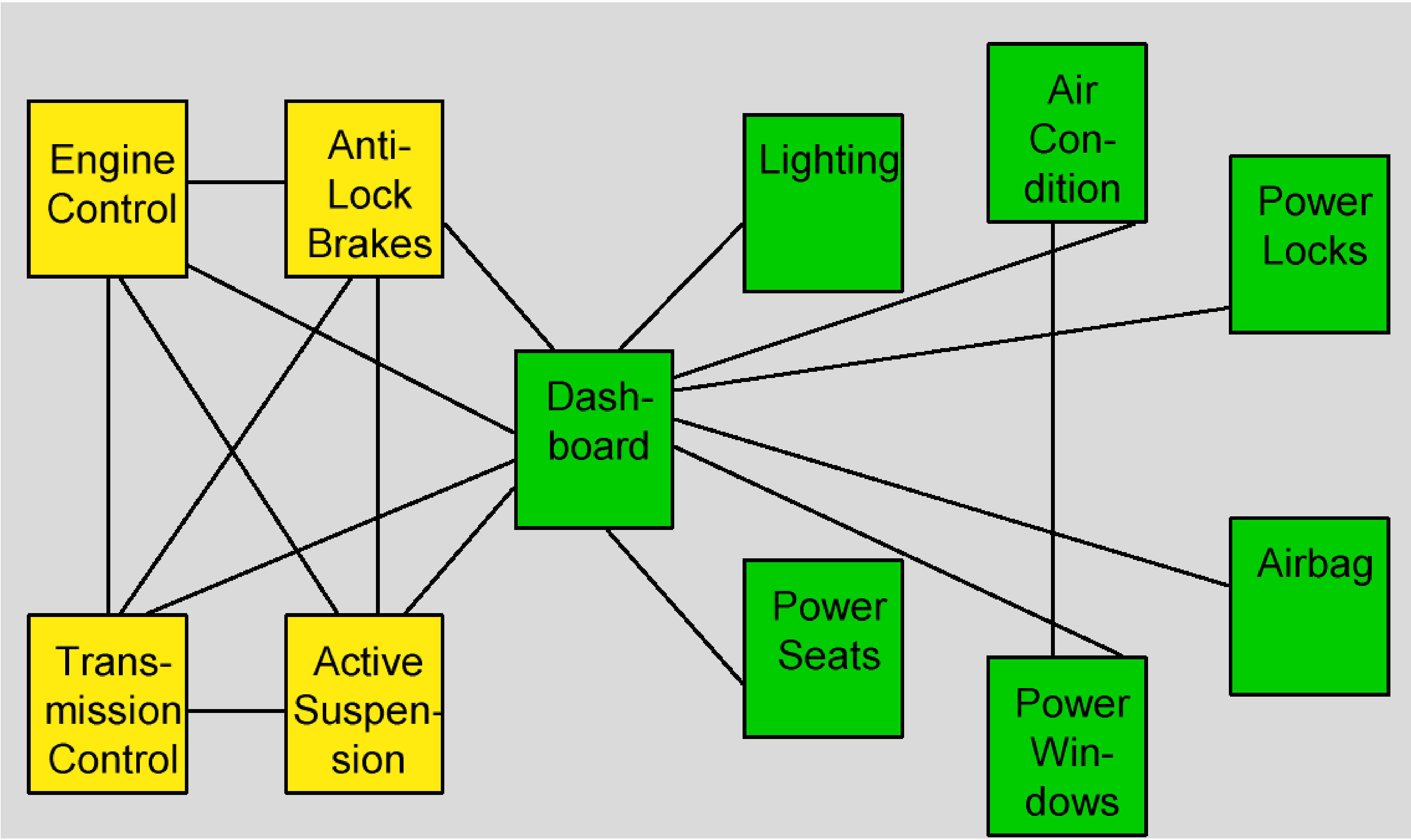
- Originally…… to overcome communication problems between control systems in cars. Anti-Block Braking Systems (ABS) and Acceleration Skid Controls (ASC)

- Now…… many other applications - agricultural machinery, medical instrumentation, elevator controls, fairground rides and industrial automation control components

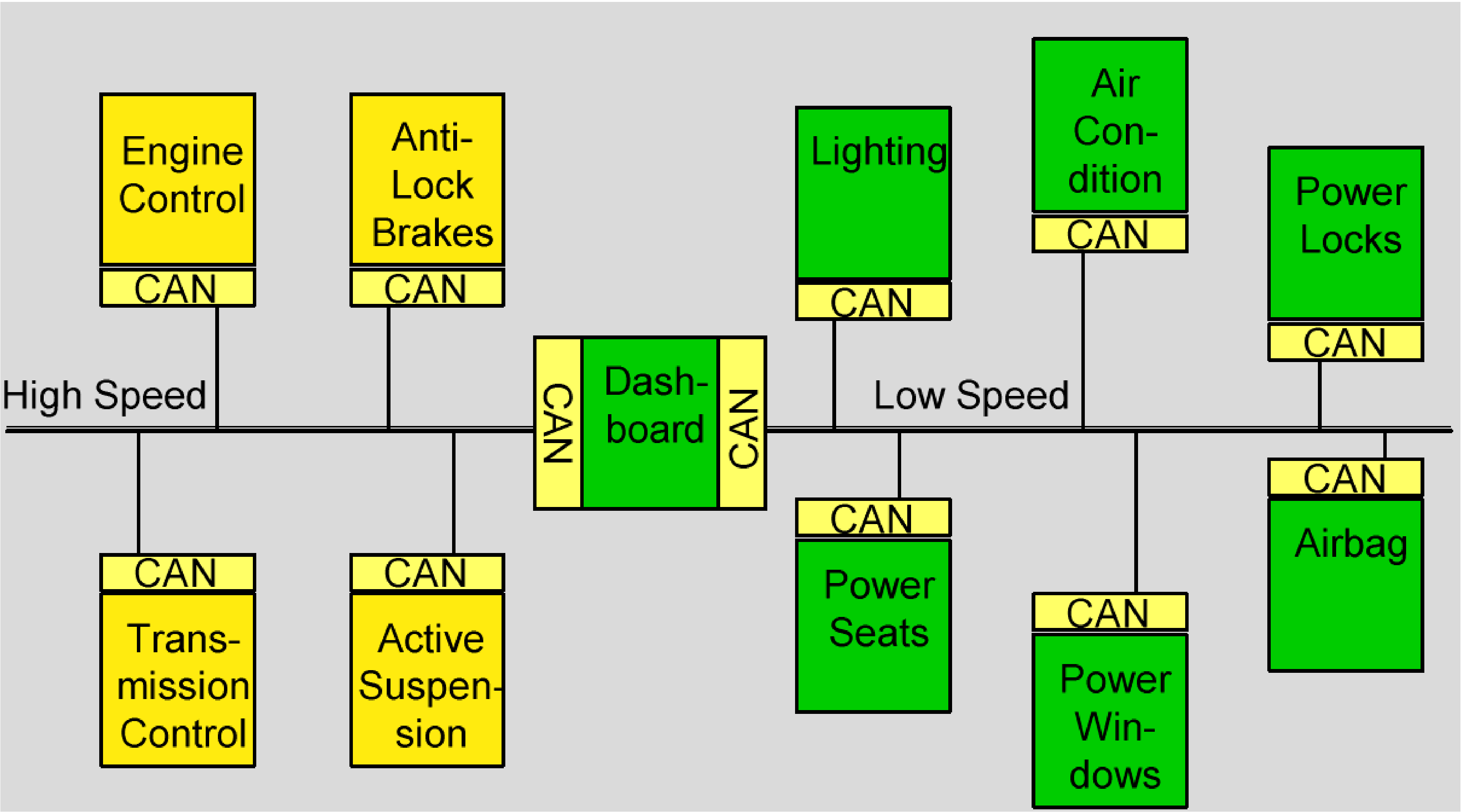


Direct fuel injection
Active suspension
Electric throttle valve control
Brake-by-wire
Steer-by-wire
Electrically assisted power steering
42-V converter

Before CAN – Individual Connections

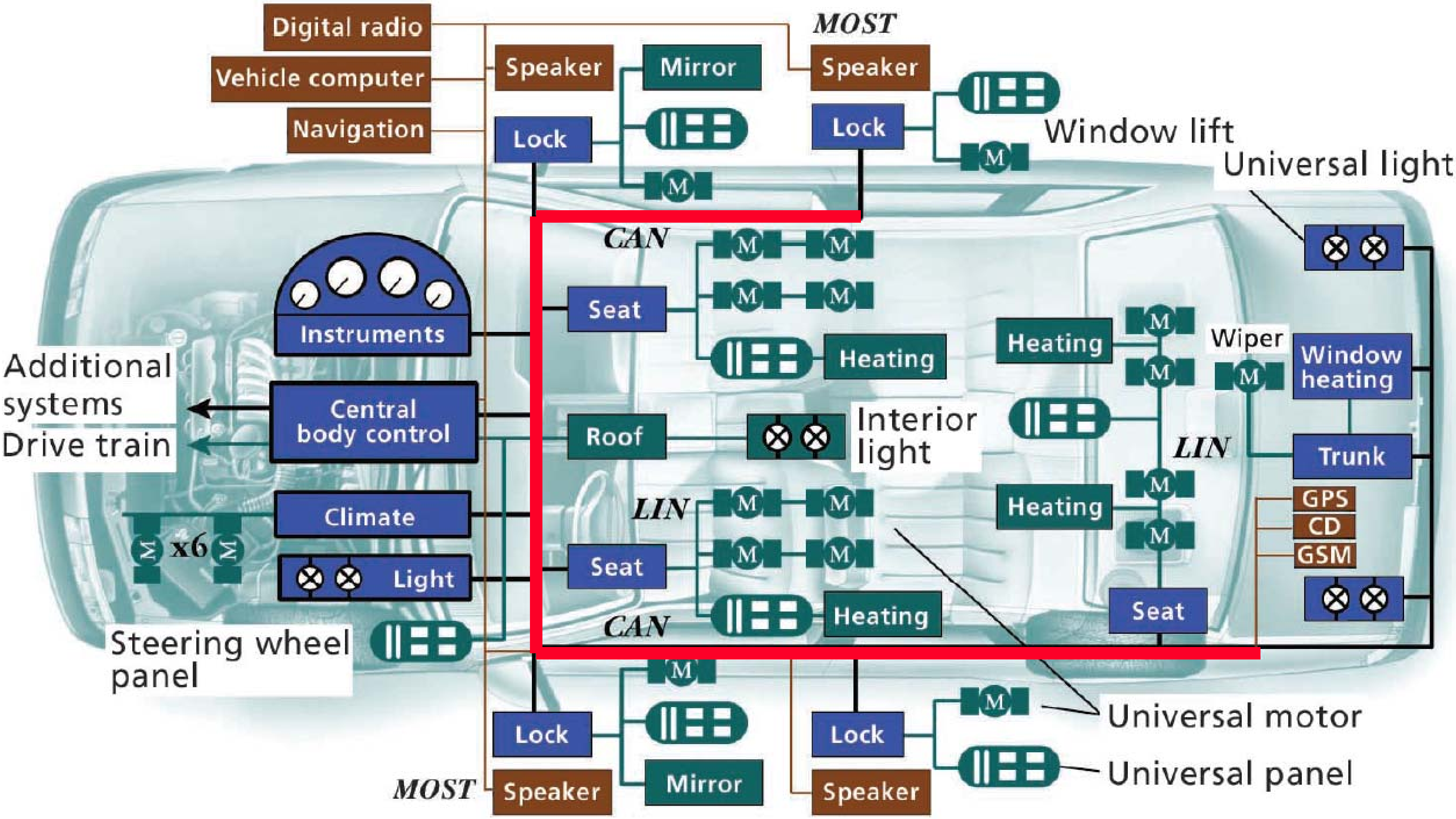


With CAN



Engine Control
CAN
Anti-Lock Brakes
CAN
Lighting
CAN
Air Con-dition
CAN
Power Locks
CAN
High Speed
Low Speed
CAN
Dash-board
CAN
CAN
Trans-mission Control
CAN
Active Suspen-sion
CAN
Power Seats
CAN
Power Win-dows
CAN
Airbag

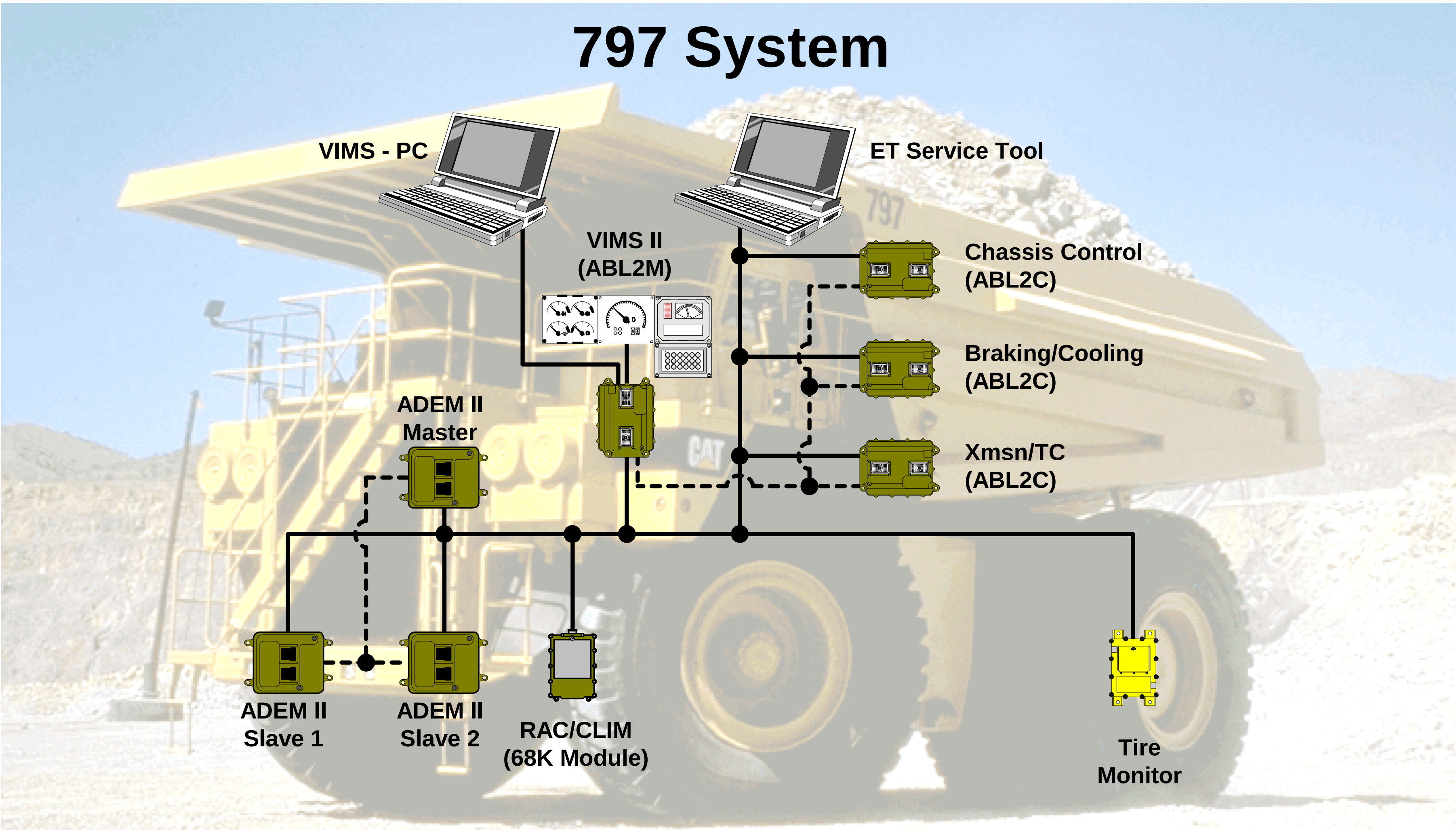
CAN Is Central To Automotive Networks



CAN Controller area network
GPS Global Positioning System
GSM Global System for Mobile Communications
LIN Local interconnect network
MOST Media-oriented systems transport

[Leen02]

CAN (SAE J1939) Example: Caterpillar 797



CAT Datalink

CAN SAE J1939 Datalink

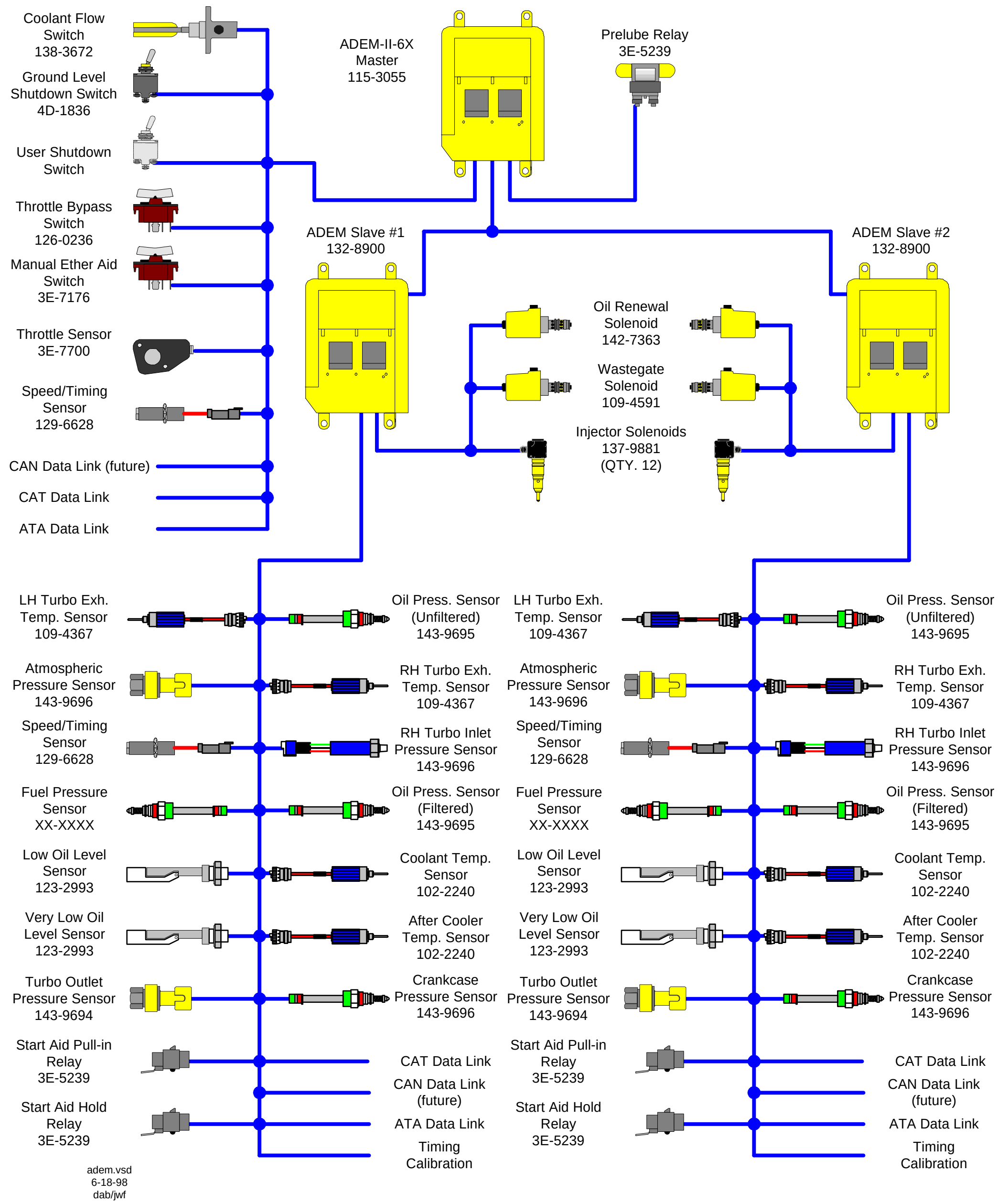
+ 195 sensors and actuators

+ wireless data link

797sys.vsd
6-18-98
dab/jwf
Warning: All paper copies of this document are uncontrolled

[Slide courtesy of Caterpillar Inc.]

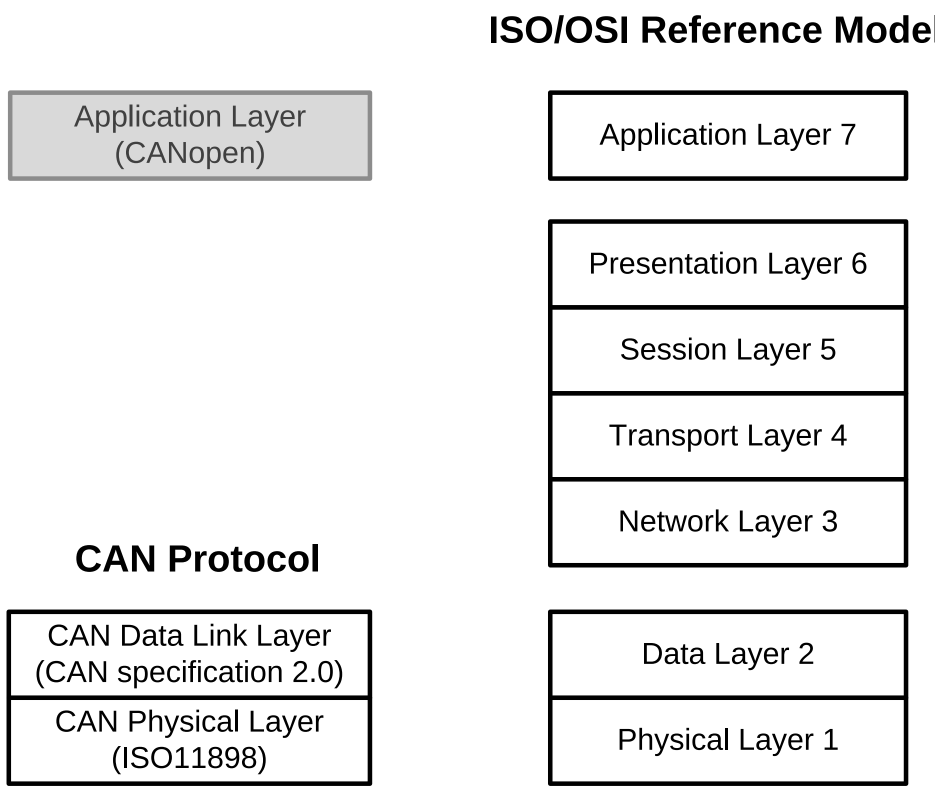
ADEM II Engine Control



[Slide courtesy of Caterpillar Inc.]

CAN ISO/OSI Reference Model

- In terms of the 7 layer ISO/OSI Reference Model, the functionality of CAN Specification 2.0 can be interpreted as a two layer protocol.



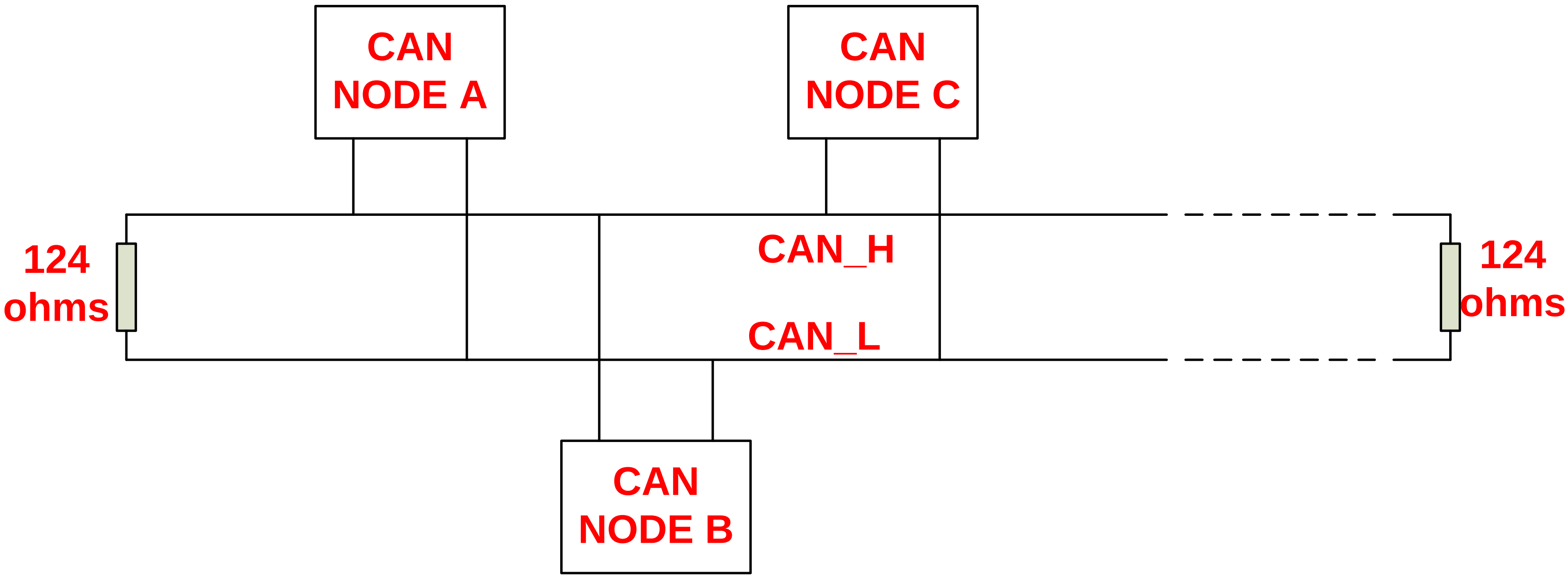
CAN Physical Layer

- The physical medium typically used to implement CAN networks is a differentially driven two wire bus line with a common return.

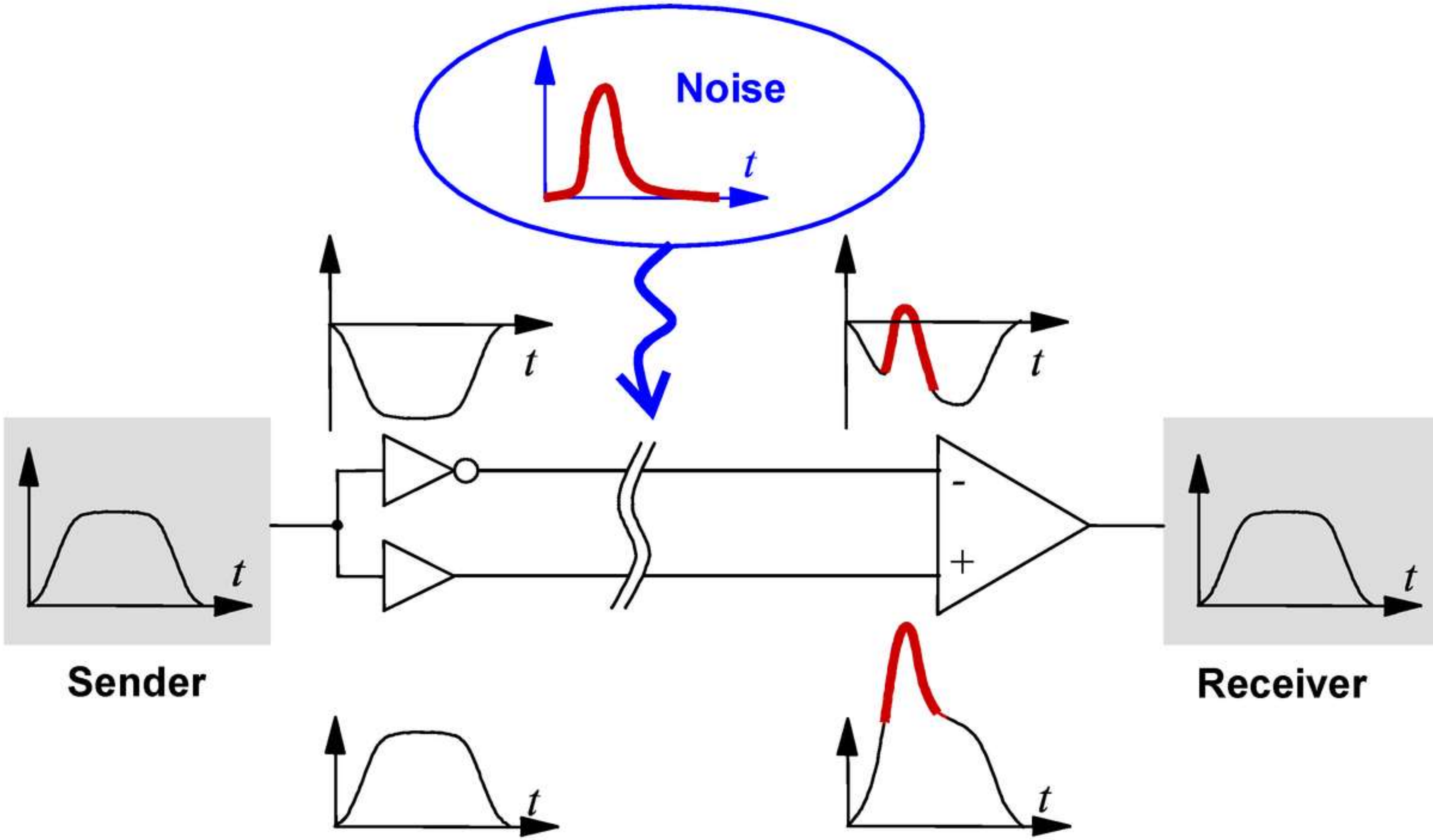
- The differentially driven wires are called CAN_H and CAN_L, according to the polarity of the differential voltage between them

- The CAN bus must also be terminated at both ends by resistors with a recommended value of *124Ω* (in practice120Ω is usually used – standard value)

CAN Physical Layer



CAN Physical Layer



CAN Physical Layer

- The maximum length of the CAN bus depends on the baudrate at which it will be used

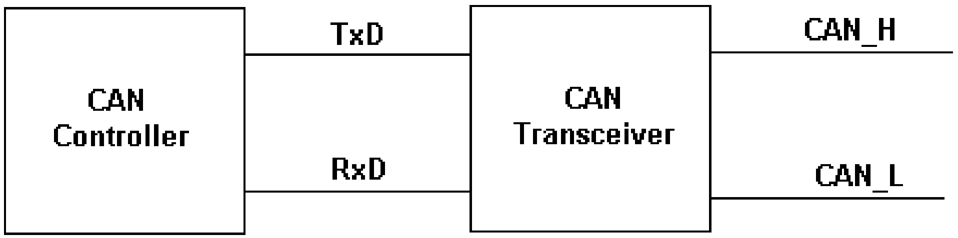
CANopen* specifies

Baudrate	**Bus Length**
1Mbit/s	25m
800Kbit/s	50m
500Kbit/s	100m
250Kbit/s	250m
125Kbit/s	500m
50Kbit/s	1000m
20Kbit/s	2500m
10Kbit/s	5000m

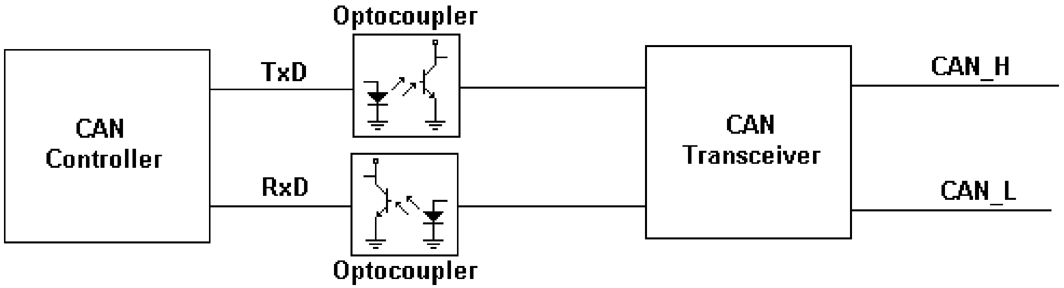
Physical Connection

➢ CAN controller uses a CAN transceiver for connecting to the bus and complying with ISO11898.

➢ It is possible to connect to the bus directly, or via optical isolation. Optical isolation improves RF interference.

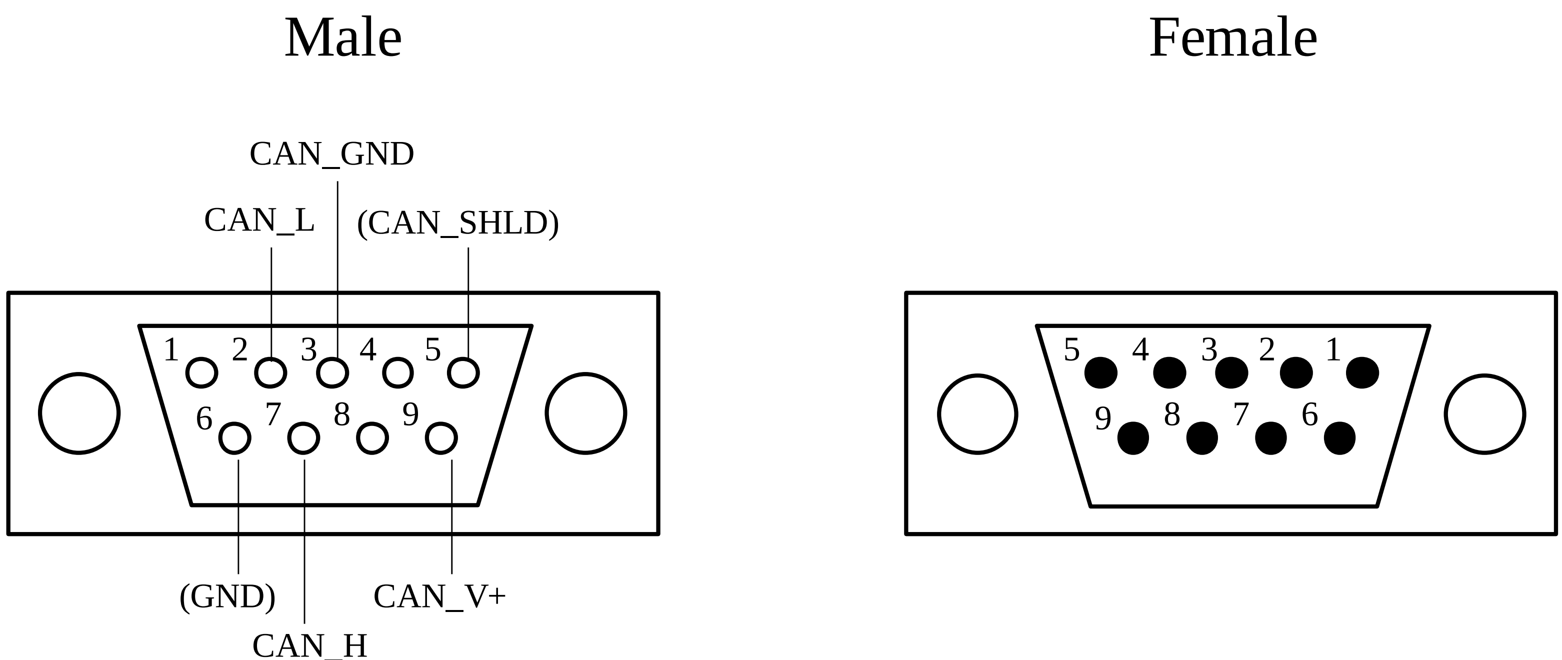


➢ Some CAN controllers interpret TxD and RxD differentially, rather than comparing them to ground.



Physical Connection

➢ CANopen recommends the use of a 9-pin D-Sub connector (DIN41652).

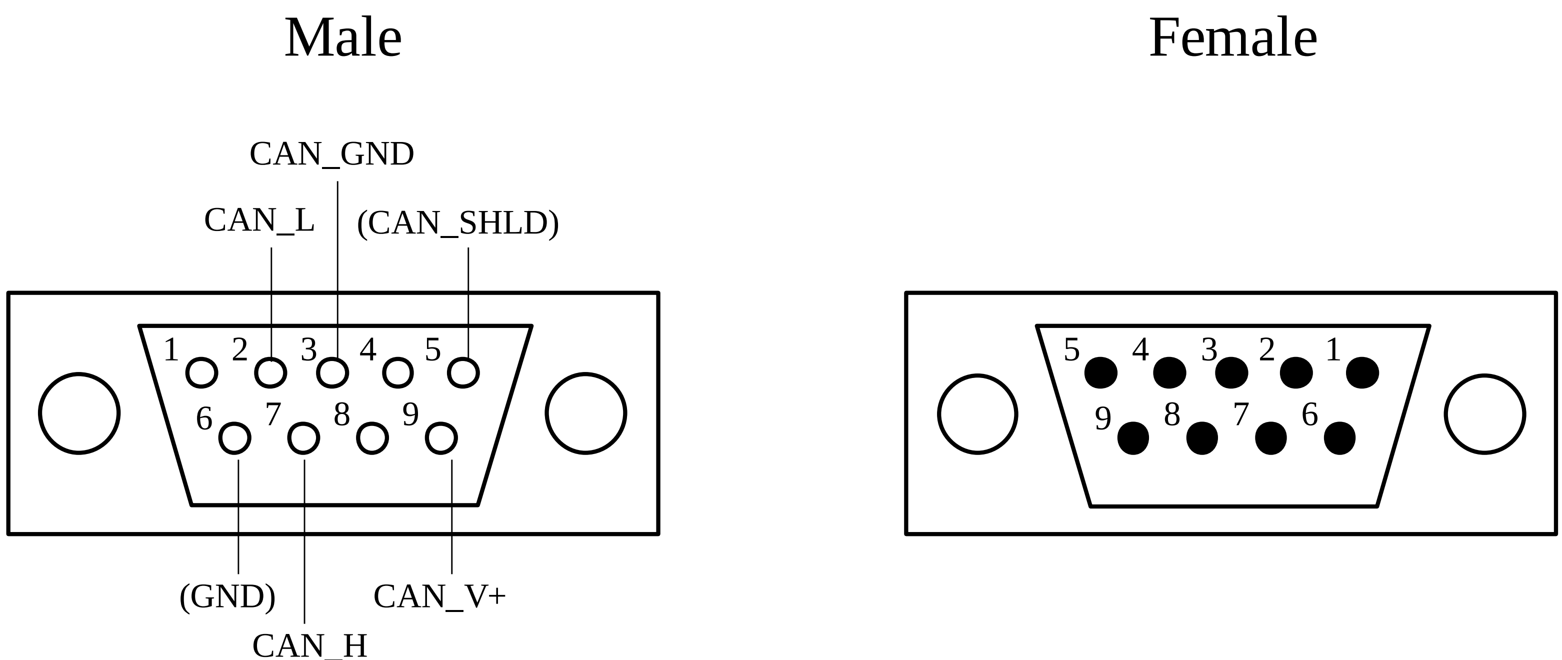


Physical Connection

Pin	Signal	Description
1	Reserved	
2	CAN_L	CAN_L bus line (dominant low)
3	CAN_GND	CAN Ground
4	Reserved	
5	(CAN_SHLD)	Optional CAN Shield
6	(GND)	Optional CAN Ground
7	CAN_H	CAN_H bus line (dominant high)
8	Reserved	
9	(CAN_V+)	Optional CAN external positive supply (dedicated for supply of transceiver and optocouplers, if galvanic isolation of the bus nodes applies)

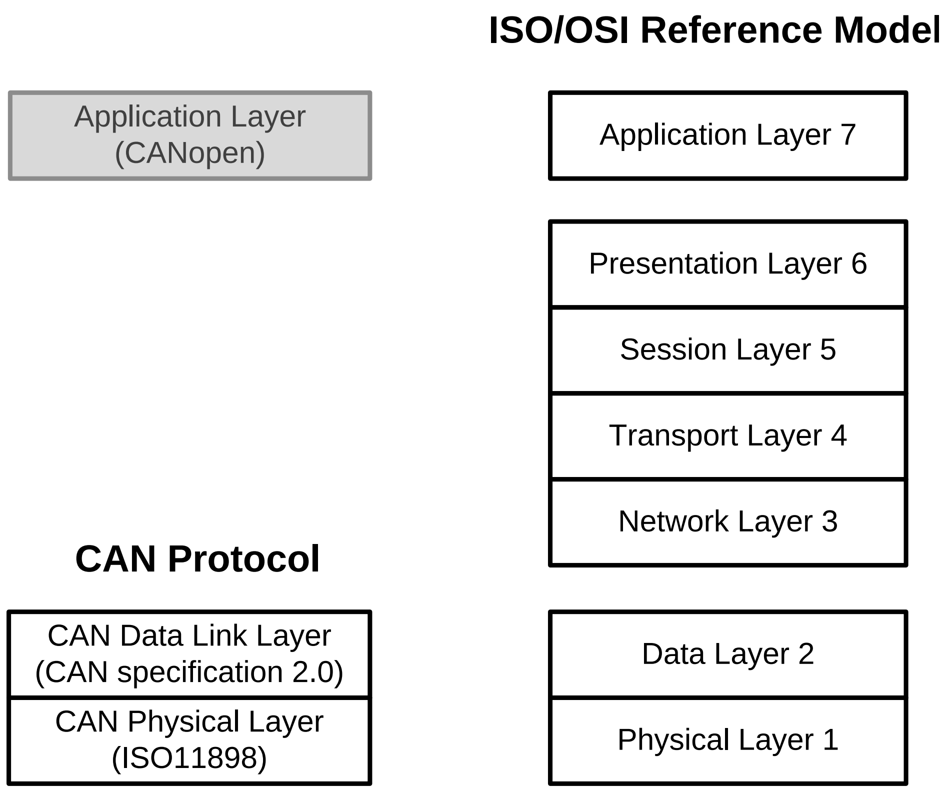
Physical Connection

➢**Reserved Pins** – often left unused for possible future development of protocol.



CAN ISO/OSI Reference Model

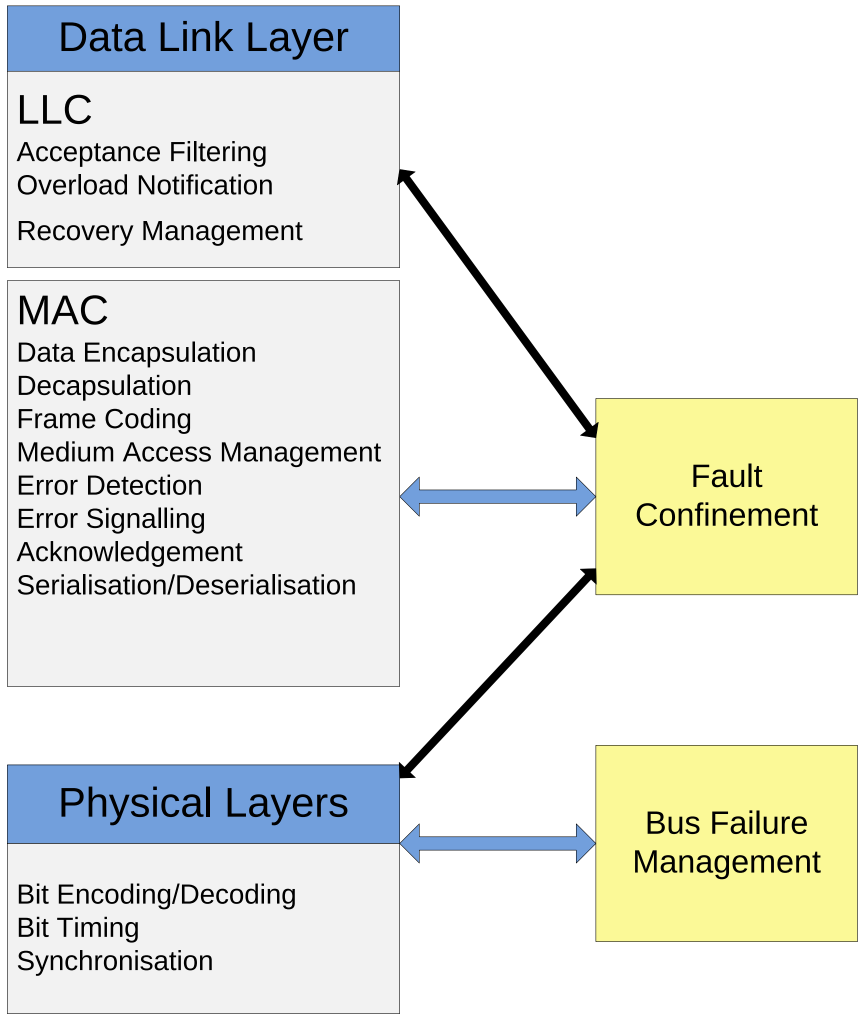
In terms of the 7 layer ISO/OSI Reference Model, the functionality of CAN Specification 2.0 can be interpreted as a two layer protocol.



CAN Data Link Layer

- The Data Link Layer can be divided into two sub-layers: the *Medium Access Control* and the *Logical Link Control*.

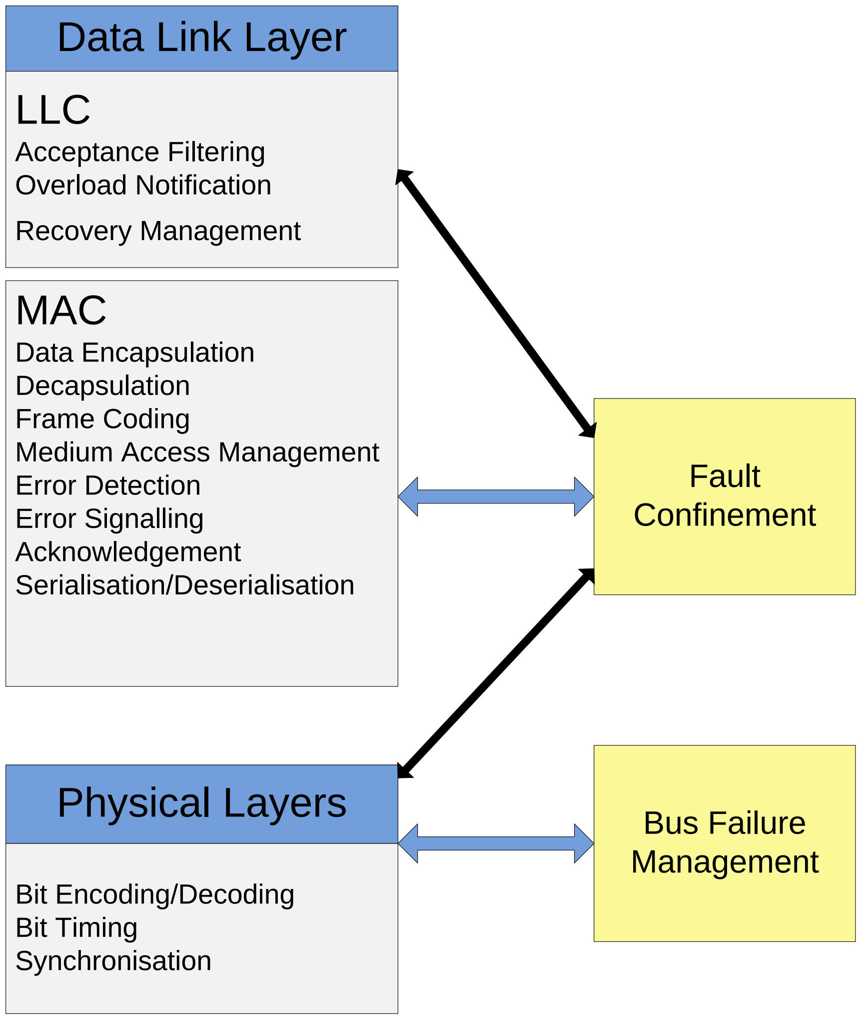
- The Medium Access Control component is responsible for determining which node in the network is assigned control of the bus for message transmission



CAN Data Link Layer

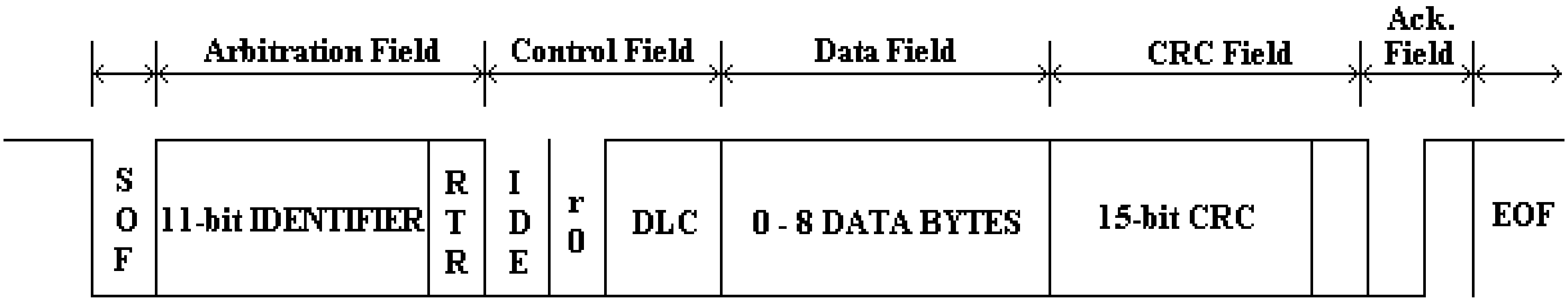
- The Logical Link Control ensures that the higher layers in the network are provided with an interface that is independent of the underlying layers (the Physical Layer and the Medium Access Control).

- Logical Link Control is responsible for the detection and correction of errors when data are exchanged through the bus i.e. it must implement an error-safe transmission mechanism.



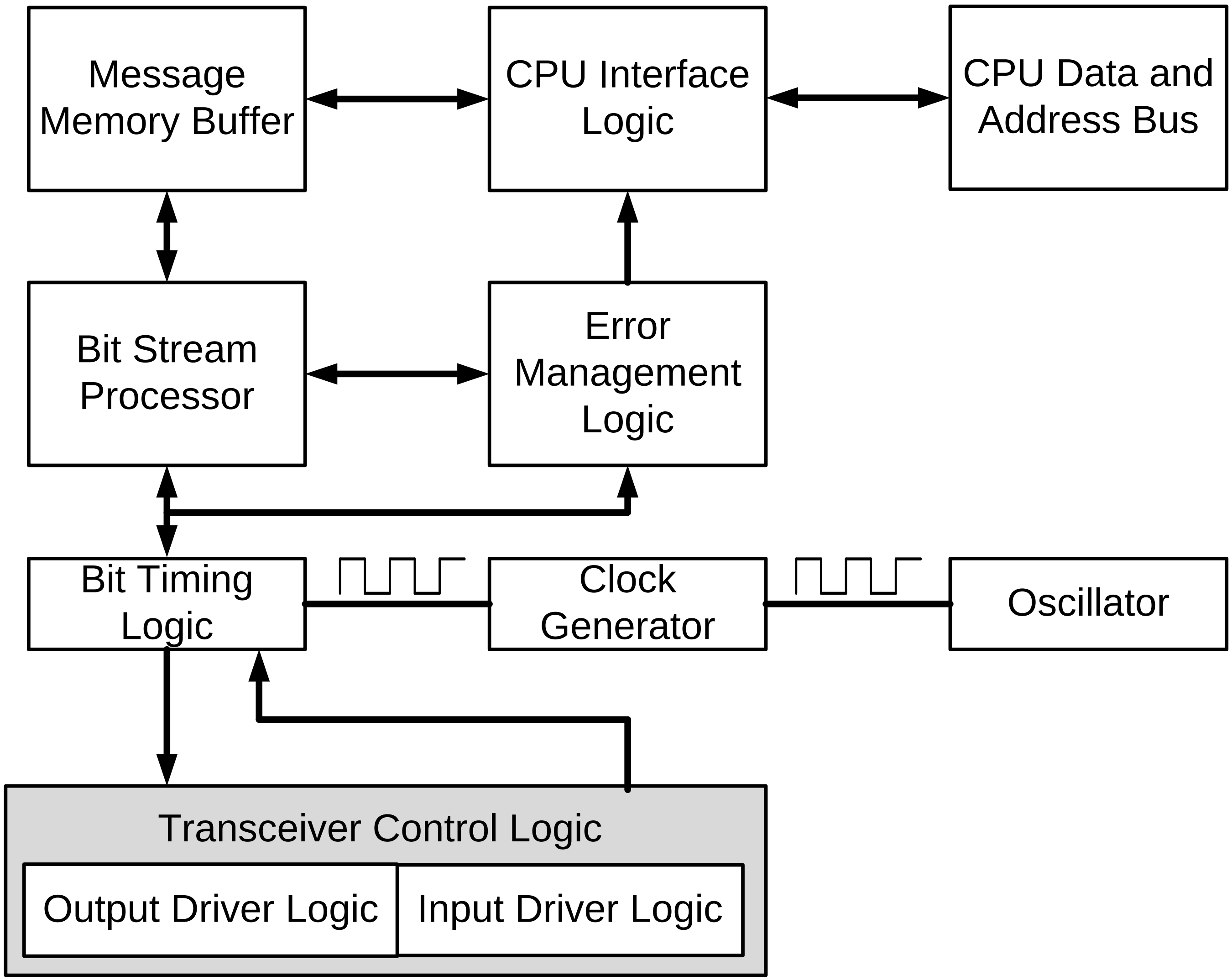
Frame Formats

The CAN 2.0-Part B standard data frame…



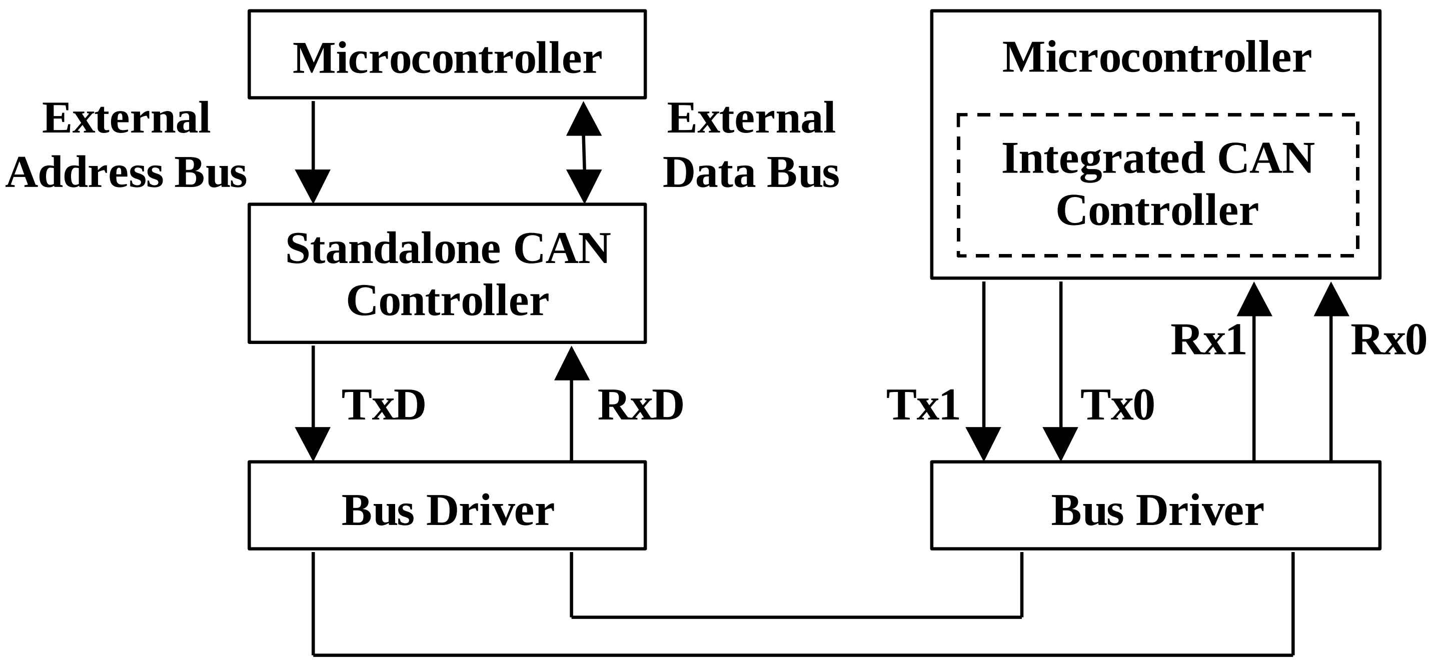
CAN Hardware Implementations

All CAN controllers share a common structure:



Stand-alone versus Embedded CAN controllers

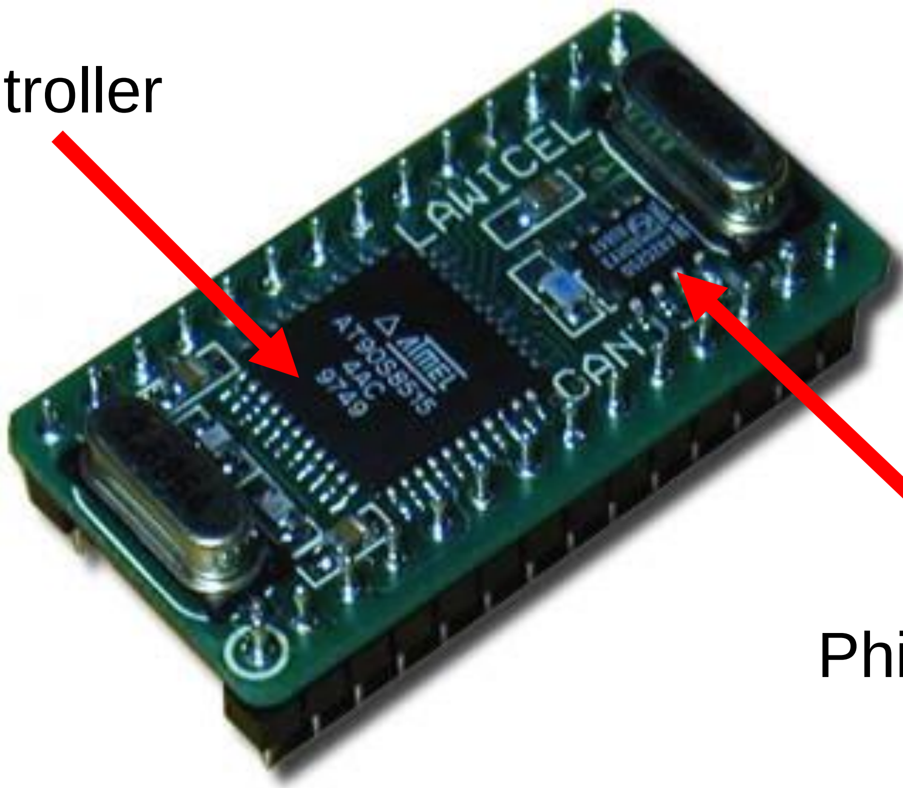
A distinction can be made between stand-alone CAN controllers and embedded CAN controllers.



CAN Hardware Implementations

Stand-alone versus Embedded CAN controllers

Atmel microcontroller

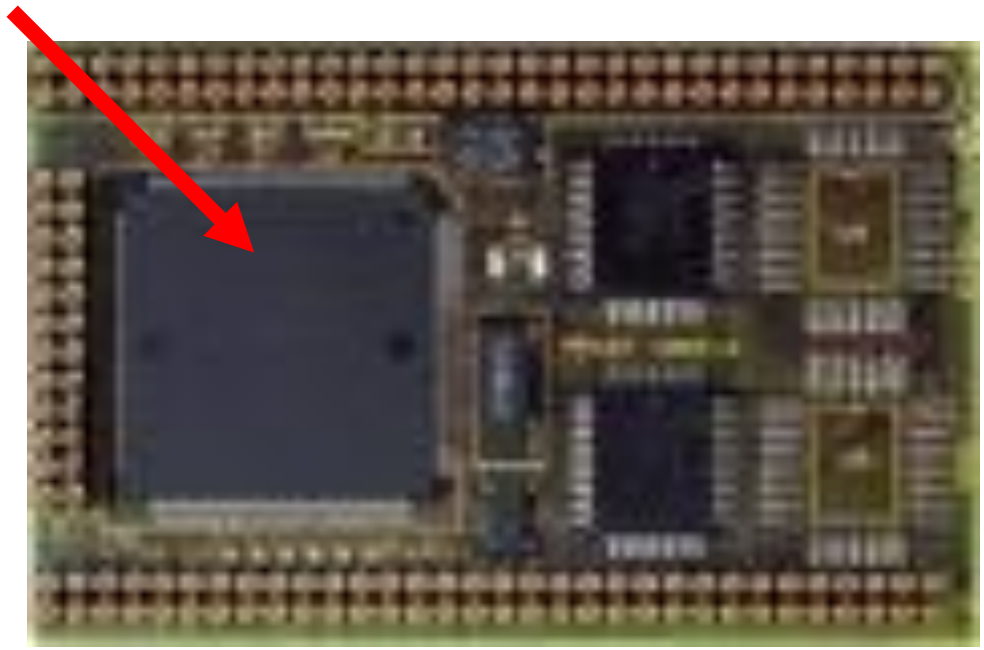


Philips SJA1000

- ***Stand-alone CAN controllers*** are CAN hardware implementations encapsulated in one physical integrated circuit. For example the SJA1000 chip from Philips.

Stand-alone versus Embedded CAN controllers

Siemens C167 microcontroller – onboard CAN hardware



➢***Embedded CAN controllers*** are CAN hardware implementations that are provided as an additional embedded peripheral within a microcontroller. For example the C167 chip from Siemens.

Network Selection Criteria

- Several criteria must be considered when choosing a network/bus for a particular Distributed Control Application.

The following issues should all be considered:

- physical characteristics,
- network layout,
- maximum distances,
- simplicity and flexibility in network configuration,
- product availability
- proprietary rights (i.e. whether or not a network is 'open')