I/O Devices

I/O Devices

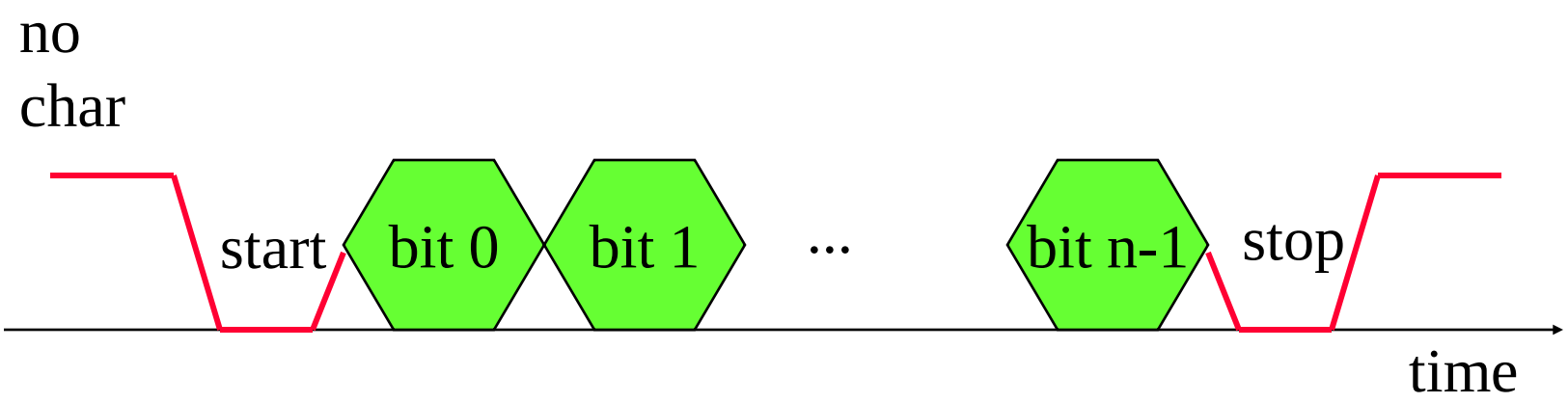
- Universal Asynchronous Receiver/Transmitter (UART)
- Timers and counters
- A/D D/A converter
- Keyboards
- Displays

UART

- Universal asynchronous receiver transmitter
  - provides serial communication.
- Usually integrated into standard PC interface chip.

Serial communication

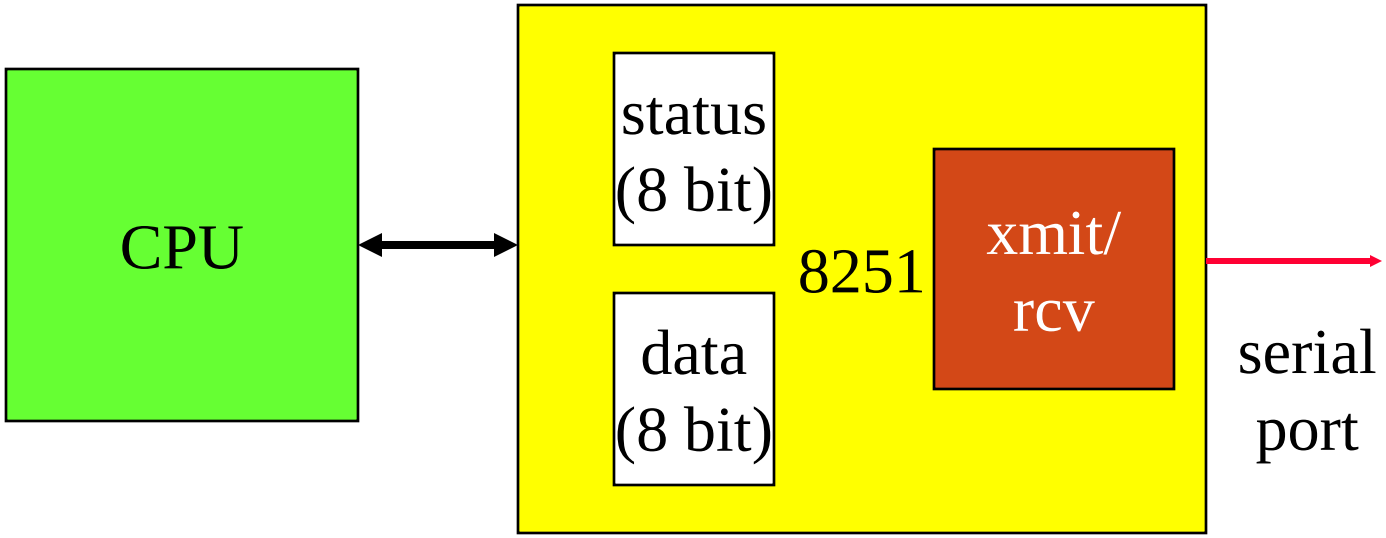
- Characters are transmitted separately:



Serial communication parameters

- Baud (bit) rate.
- Number of bits per character.
- Parity/no parity.
- Even/odd parity.
- Length of stop bit (1, 1.5, 2 bits).

8251 CPU interface

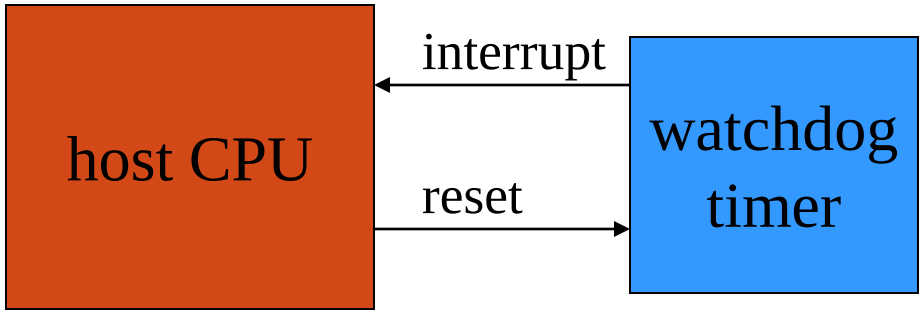


Timers and counters

- Very similar:
  - Registers to hold the current value;
  - An increment input that adds one to the current register value.
- Timer
  - Connected to a periodic clock signal
- Counter
  - Connected to more general (periodic/aperiodic) signals

Watchdog timer

- Watchdog timer is periodically reset by system timer.
- If watchdog is not reset, it generates an interrupt to reset the host.

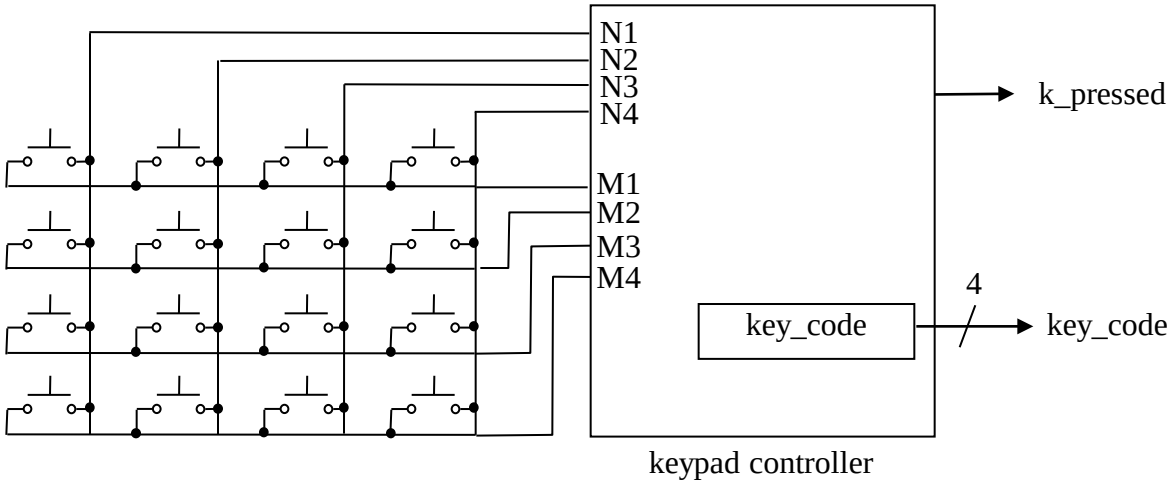


A/D and D/A converters

- A/D converter (ADC)
  - The control signal requires sampling the analog signal and converting it to digital form (binary)
- D/A converter (DAC)
  - Convert the digital signal to the analog signal

Keyboard

- An array of switches

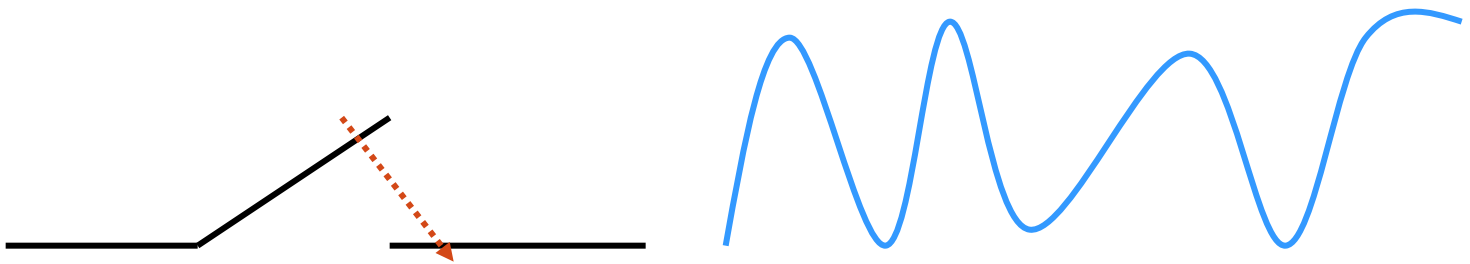


- Button bouncing and debouncing

N=4, M=4

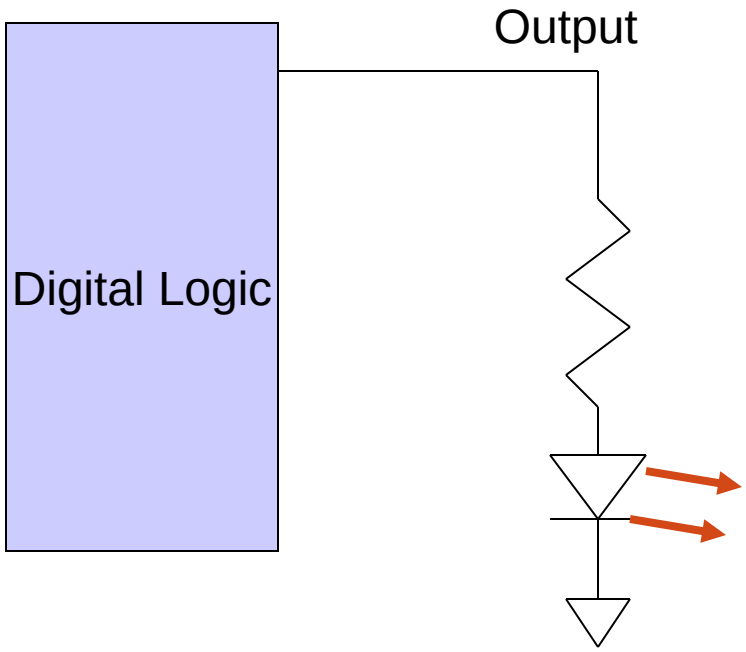
Key Bouncing

- The mechanical contact to make or break an electrical circuit generates bouncing signal



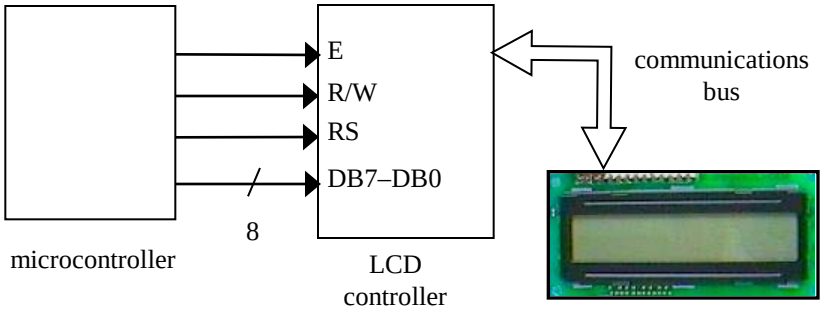
LED

- Light Emitting Diode
  - Use resistor to limit current:



LCD display

- Liquid crystal display
  - The digit input activates the display elements




```
void WriteChar(char c){

  RS = 1;                 /* indicate data being sent */
  DATA_BUS = c;           /* send data to LCD */
  EnableLCD(45);          /* toggle the LCD with appropriate delay */
}
```

LCD Parameters

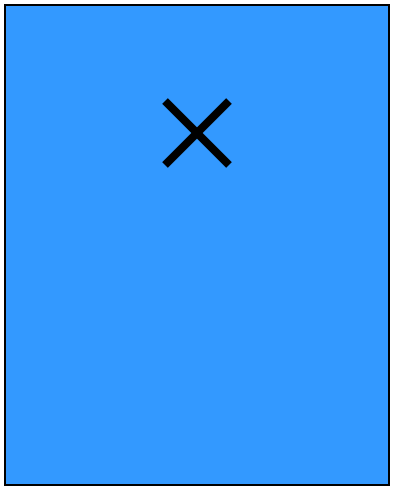
- Resolution
  - Horizontal and vertical size
- Dot pitch
  - Distance between two adjacent pixel
- Response time
  - Time to change the color or brightness
- Refresh rate
  - Number of times the data is drawn
- Others
  - View angles, contrast ratio, aspect ratio, etc

Types of high-resolution display

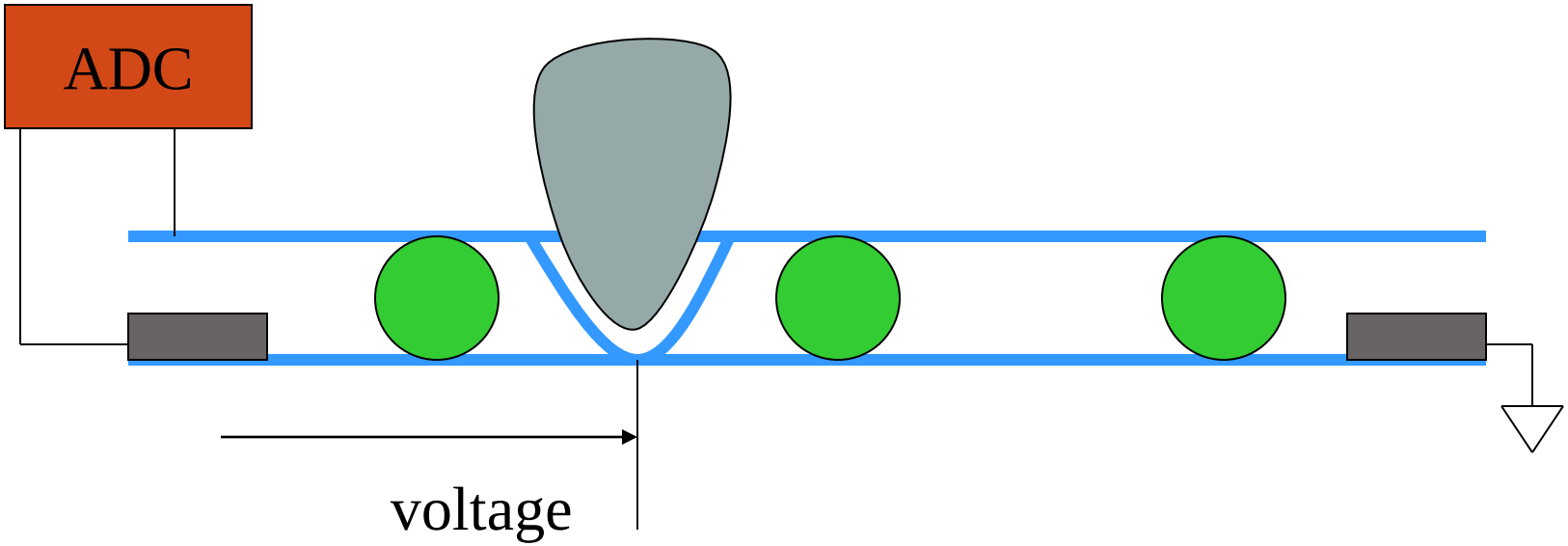
- Cathode ray tube (CRT)
- Liquid crystal display (LCD) panels
- Plasma, etc.

Touchscreen

- Includes input and output device.
- Input device is a two-dimensional voltmeter:

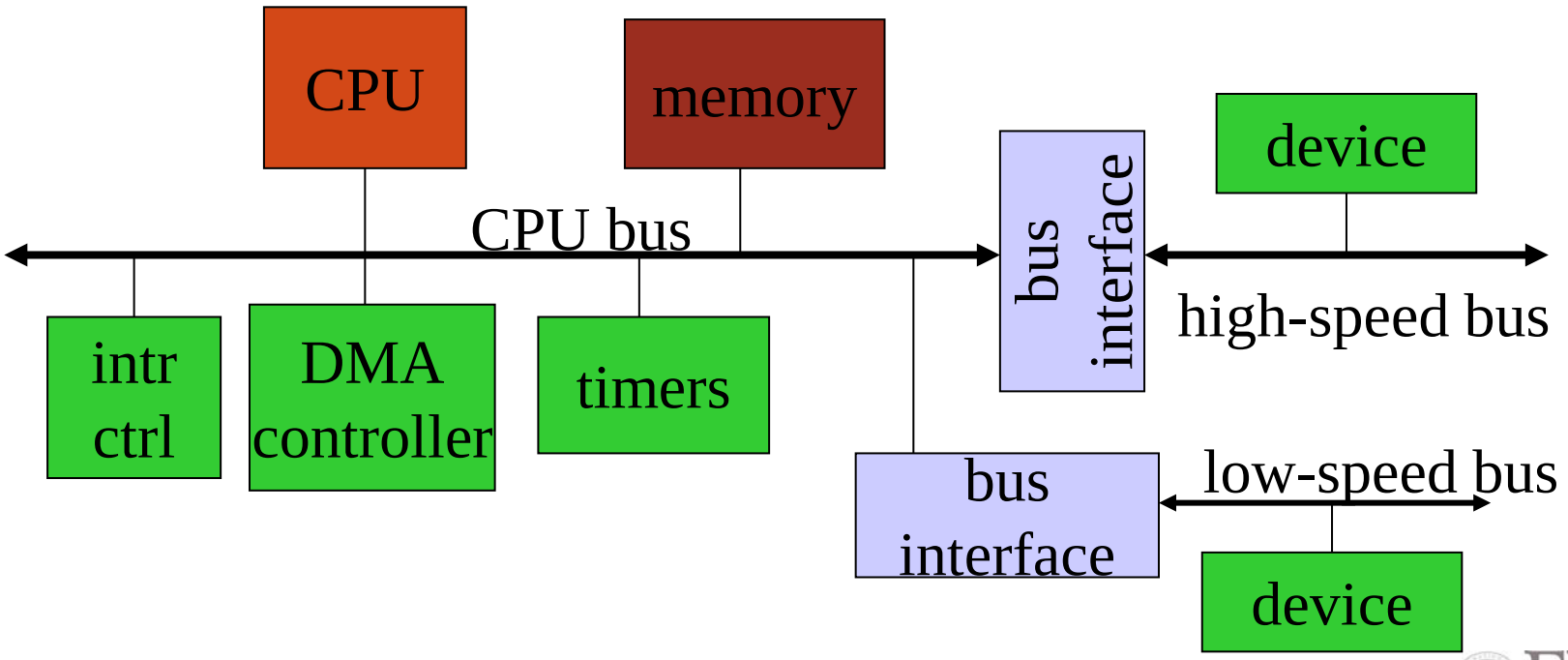


Touchscreen position sensing



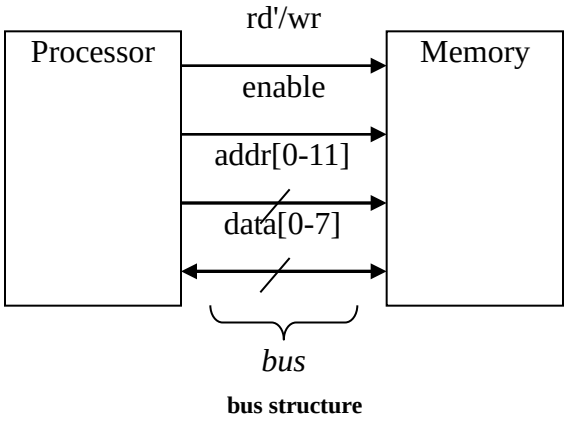
Communications in embedded systems

- Data transfer between processors, memories, and I/O devices
- Usually implemented using buses
  - *bus*



A simple bus

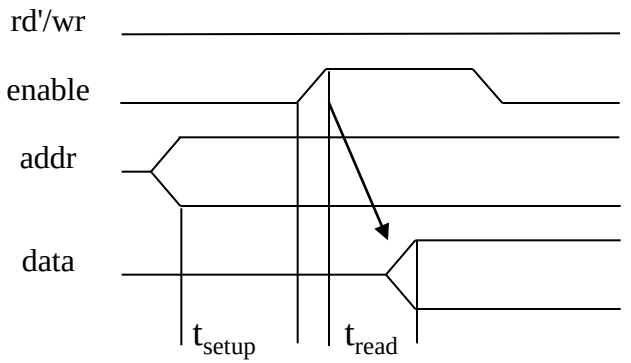
- Wires:
  - Uni-directional or bi-directional
  - One line may represent multiple wires
- Bus
  - Set of wires with a single function
    - Address bus, data bus
  - Or, entire collection of wires
    - Address, data and control
    - bus protocol: rules for communication



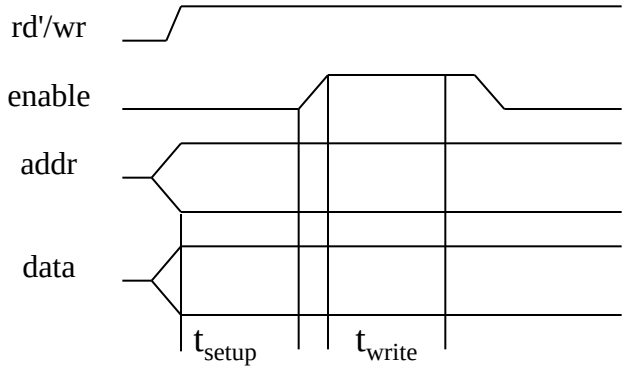
bus structure

Timing Diagrams

- Most common method for describing a communication protocol
- Time proceeds to the right on x-axis
- Control signal: low or high
  - May be active low (e.g., go', /go, or go_L)
  - Use terms *assert* (active) and *deassert*
  - Asserting go' means go=0
- Data signal: not valid or valid
- Protocol may have subprotocols
  - Called bus cycle, e.g., read and write
  - Each may be several clock cycles
- Read example
  - *rd'/wr* set low,address placed on *addr* for at least t_{setup} time before *enable* asserted, enable triggers memory to place data on *data* wires by time t_{read}



read protocol



write protocol

Advanced Communication Interfacing

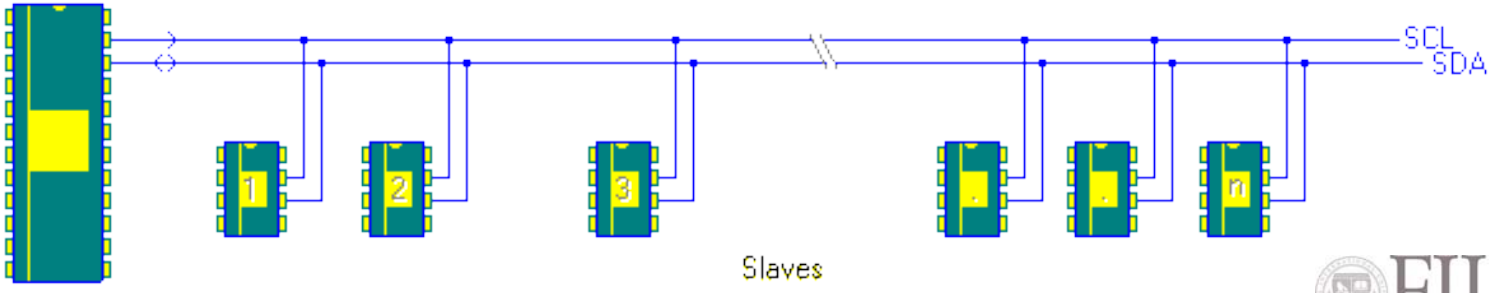
- Wired Communications
  - Serial Communications
  - Parallel Communications
- Wireless Communications

Serial communication

- Single data wire
- Words transmitted one bit at a time
- Higher data throughput with long distances
  - Less average capacitance, so more bits per unit of time
- Cheaper, less bulky
- More complex interfacing logic and communication protocol
  - Sender needs to decompose word into bits
  - Receiver needs to recompose bits into word
  - Control signals often sent on same wire as data increasing protocol complexity

Serial protocols

- I^2C (Inter-IC)
  - Two-wire serial bus protocol
    - Serial data line (SDA)
    - Serial clock line (SCL)
  - Developed by Philips Semiconductors nearly 20 years ago
  - Data transfer rates
    - up to 100 kbits/s and 7-bit addressing (i.e., 128 devices) possible in normal mode
    - 3.4 Mbits/s and 10-bit (i.e., 1024 devices) addressing in fast-mode



Serial protocols

- CAN (Controller area network)
  - All nodes can hear the message, each node filters the messages by itself
  - Protocol for real-time applications
  - Developed by Robert Bosch GmbH
  - Originally for communication among components of cars
  - Data transfer rates up to 1 Mbit/s and 11-bit addressing

Serial protocols

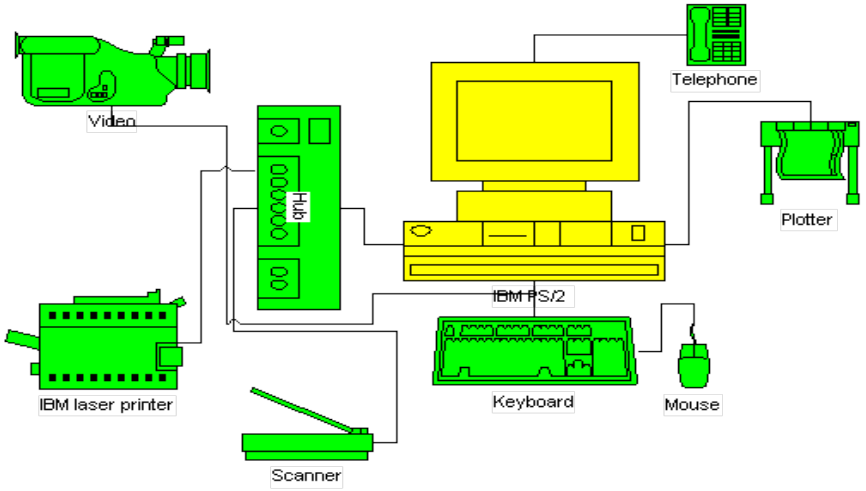
- FireWire (a.k.a. I-Link, IEEE 1394)
  - High-performance serial bus developed by Apple Computer Inc.
  - Designed for interfacing independent electronic components
    - e.g., Desktop, scanner
  - Data transfer rates from 100,200,400 Mbits/s, (new revision up to 800, 1600MBits/s)
  - Maximal distance between two devices are 4.5 meters
  - Maximal number of devices 63
  - Plug-and-play capabilities

Serial protocols

- USB (Universal Serial Bus)
  - Invented in 1995
  - A serial bus that supports up to 127 devices
  - Plug and play
  - Four wires: Vbus, GND, D+, D-
    - D+ high D- low → 1
    - D+ low D- high → 0
  - Data rates:
    - 12 Mbps for increased bandwidth devices
    - 1.5 Mbps for lower-speed devices (joysticks, game pads)
    - 480 Mbps (USB 2.0)
    - 4.8Gbps (experimental)

A Typical USB System

- One and only on host
  - Control media access
- Hub
  - Enable multiple devices to be connected to the same USB bus
  - Detect attachment and detachment of devices and power management
  - Manage both high and low speed device
- Other USB devices
  - Self powered/Bus powered
  - Full-speed/low-speed devices



Parallel communication

- Multiple data, control, and possibly power wires
  - One bit per wire
- High data throughput with short distances
- Typically used when connecting devices on same IC or same circuit board
  - Bus must be kept short
    - long parallel wires result in high capacitance values which requires more time to charge/discharge
    - Data misalignment between wires increases as length increases
- Higher cost, bulky

Parallel protocol

- PCI Bus (Peripheral Component Interconnect)
  - High performance bus originated at Intel in the early 1990's
  - Standard adopted by industry and administered by PCISIG (PCI Special Interest Group)
  - Interconnects chips, expansion boards, processor memory subsystems
  - Data transfer rates of 133 Mbits/s and 32-bit addressing
    - Later extended to 64-bit while maintaining compatibility with 32-bit schemes
  - Multiplexed data/address lines

About PCI-x and PCI-Express

- PCI-x
  - Designed by IBM, HP and Compaq
  - PCI extended, enhanced PCI bus to as much as 4 Gbps
- PCI-Express
  - Point-to-point connection
  - A two-way ***serial*** connection
  - Data is transmitted through two pairs of wires called lane
    - Each lane has transfer rate 2.5Gbps or approx. 200MB/s data rate
    - Multiple lanes can be used
  - Plug and play

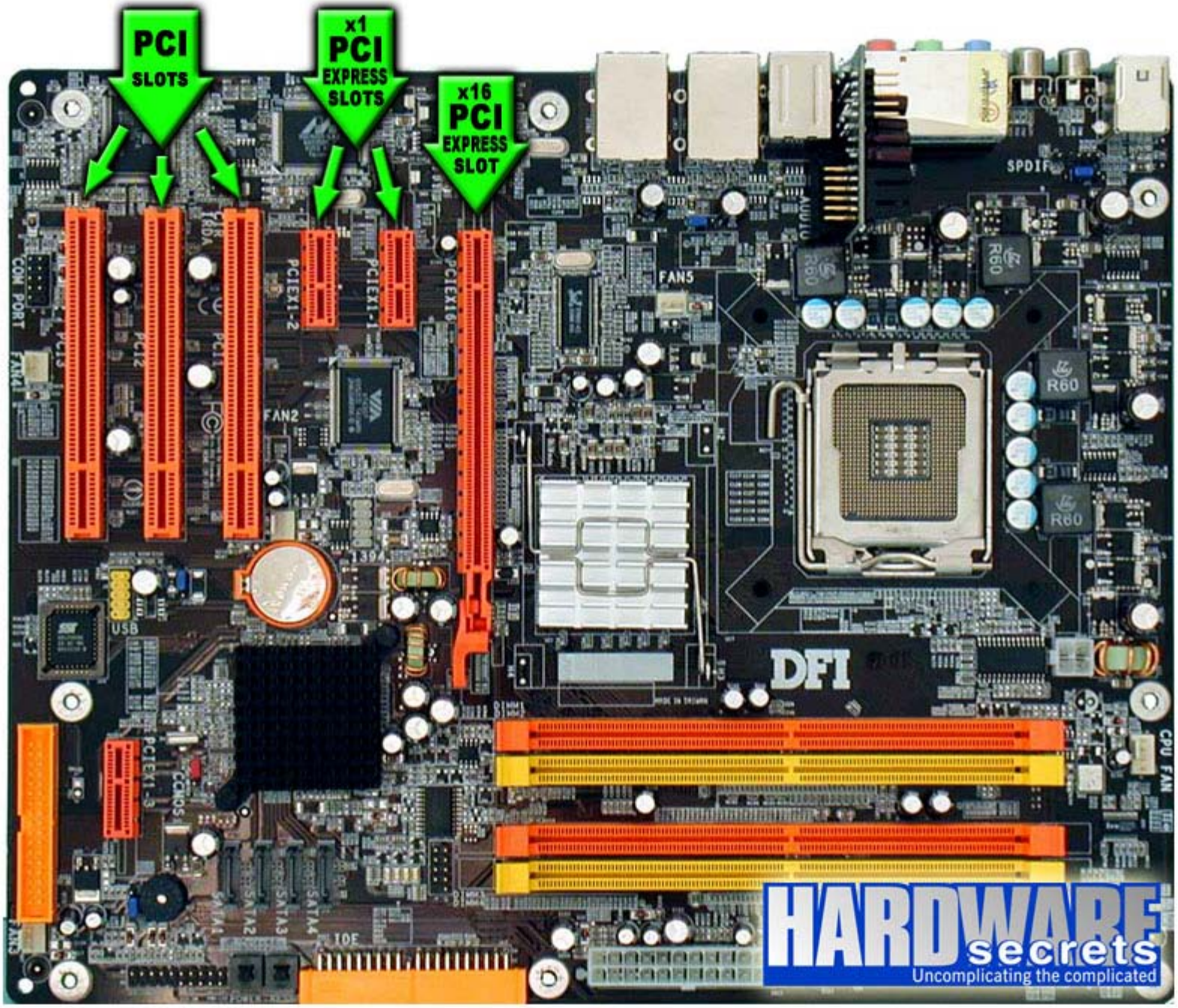
PCI, PCI-x, AGP

Bus	Clock	Number of bits	Data per Clock Cycle	Maximum Transfer Rate
PCI	33 MHz	32	1	133 MB/s
PCI	66 MHz	32	1	266 MB/s
PCI	33 MHz	64	1	266 MB/s
PCI	66 MHz	64	1	533 MB/s
PCI-X 64	66 MHz	64	1	533 MB/s
PCI-X 133	133 MHz	64	1	1,066 MB/s
PCI-X 266	133 MHz	64	2	2,132 MB/s
PCI-X 533	133 MHz	64	4	4,266 MB/s
AGP x1	66 MHz	32	1	266 MB/s
AGP x2	66 MHz	32	2	533 MB/s
AGP x4	66 MHz	32	4	1,066 MB/s
AGP x8	66 MHz	32	8	2,133 MB/s

AGP: Accelerated Graphics Port or Accelerated Graph Port, Intel, 1996

PCI, AGP, PCI Express

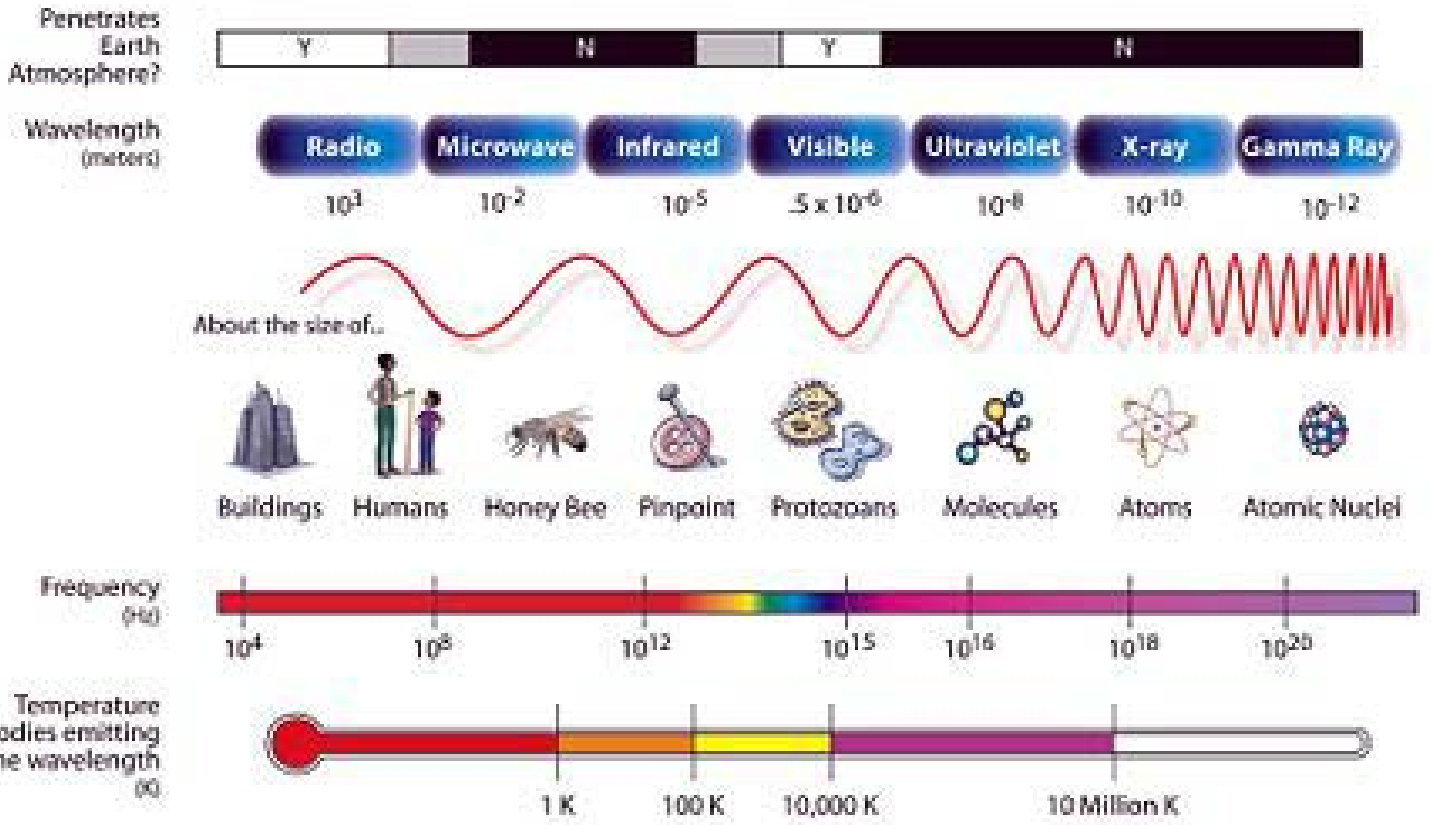
Bus	Maximum Transfer Rate
PCI	133 MB/s
AGP 2x	533 MB/s
AGP 4x	1,066 MB/s
AGP 8x	2,133 MB/s
PCI Express x1	250 MB/s
PCI Express x2	500 MB/s
PCI Express x4	1,000 MB/s
PCI Express x16	4,000 MB/s
PCI Express x32	8,000 MB/s


PCI
SLOTS
x1
PCI
EXPRESS
SLOTS
x16
PCI
EXPRESS
SLOT
SPDIF
FAN5
R60
R60
R60
DFI
CPU FAN
HARDWARE
secrets
Uncomplicating the complicated

Wireless communication

- No need for physical connection
- Infrared (IR)
  - Electronic wave frequencies just below visible light spectrum
  - Turning on/off diode generates 1/0
  - Infrared transistor detects signal, conducts when exposed to infrared light
  - Cheap to build
  - Need line of sight, limited range
- Radio frequency (RF)
  - Electromagnetic wave frequencies in radio spectrum
  - Analog circuitry and antenna needed on both sides of transmission
  - Line of sight not needed, transmitter power determines range

THE ELECTROMAGNETIC SPECTRUM



Wireless protocols

- IrDA
  - Short-range point-to-point infrared data transmission
  - Created and promoted by the Infrared Data Association (IrDA)
  - Transfer rate of 9.6 kbps and 16 Mbps
  - Becoming available on popular embedded OS's

Wireless protocols

- Bluetooth
  - New, global standard for wireless connectivity
  - Based on low-cost, short-range radio link to remove the cables
  - Connection established when within 10 meters of each other
  - No line-of-sight required
    - e.g., Connect to printer in another room

Wireless Protocols

- IEEE 802.11
  - Proposed standard for wireless LANs
  - Layered protocol
  - Specifies parameters for PHY and MAC layers of network
    - provisions for data transfer rates of 1 or 2 Mbps
    - operates in 2.4 to 2.4835 GHz frequency band (RF) or 300 to 428,000 GHz (IR)

Summary

- I/O devices
  - UART, Timer/counter, ADC/DAC, keyboards, display
- Communication and connections
- Advanced communication interfacing