Communication for Embedded Systems

ET2223 Microprocessors, Microcontrollers, and Embedded Systems

Introduction

- Embedded & real-time systems could be standalone or connected
- A real-time system is often composed from a number of periodic (time triggered) and sporadic (event triggered) tasks which communicate their result by passing messages.
- In distributed real-time systems these messages are sometimes sent between processors across a communication device.

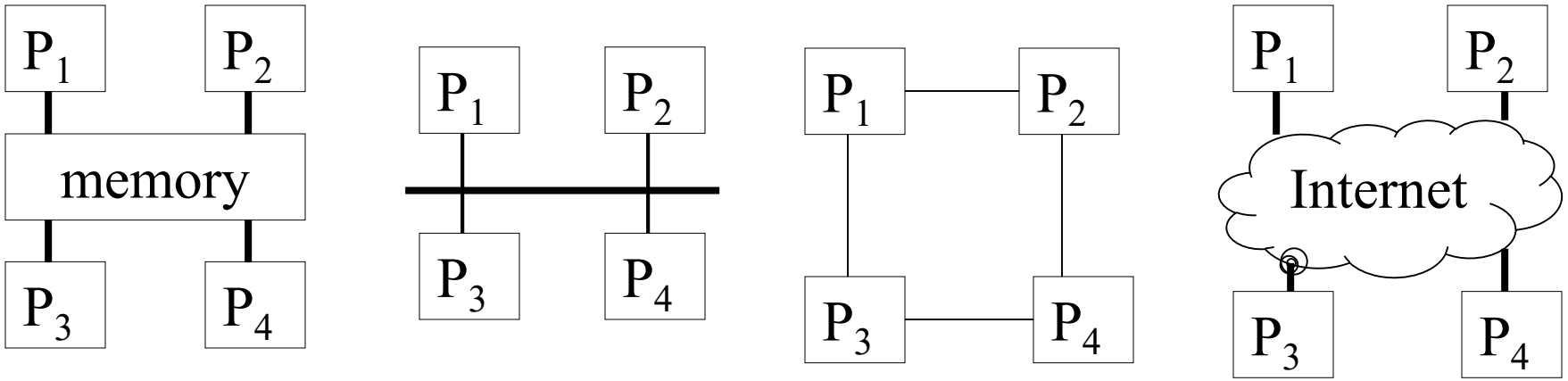
Introduction

- To guarantee that the timing requirements of all tasks are met, the communications delay between a sending task and a receiving task being able to access that message must be bounded.
- For examples
  - Control systems: between sensors and actuators via central computer
  - Multiprocessors: between processors, tasks communicating

Data communication in control systems

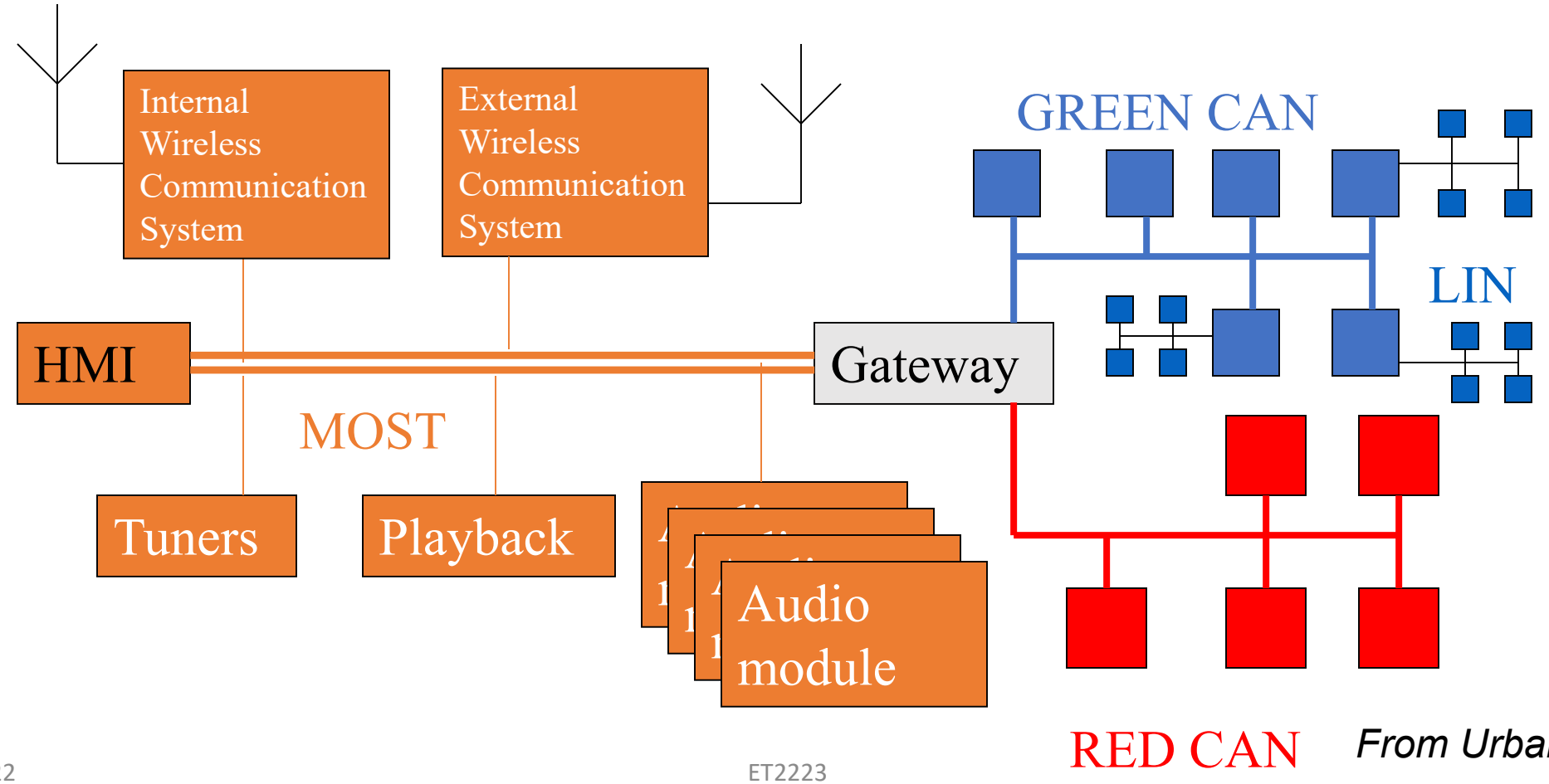
- Control systems need data communication to communicate:
  - Between controllers and plants (controlled devices)
  - Between controllers and sensors
  - Between controllers and other related controllers
  - Between controllers and systems managers/monitors

Basic network architectures



From Urban Bilstrup

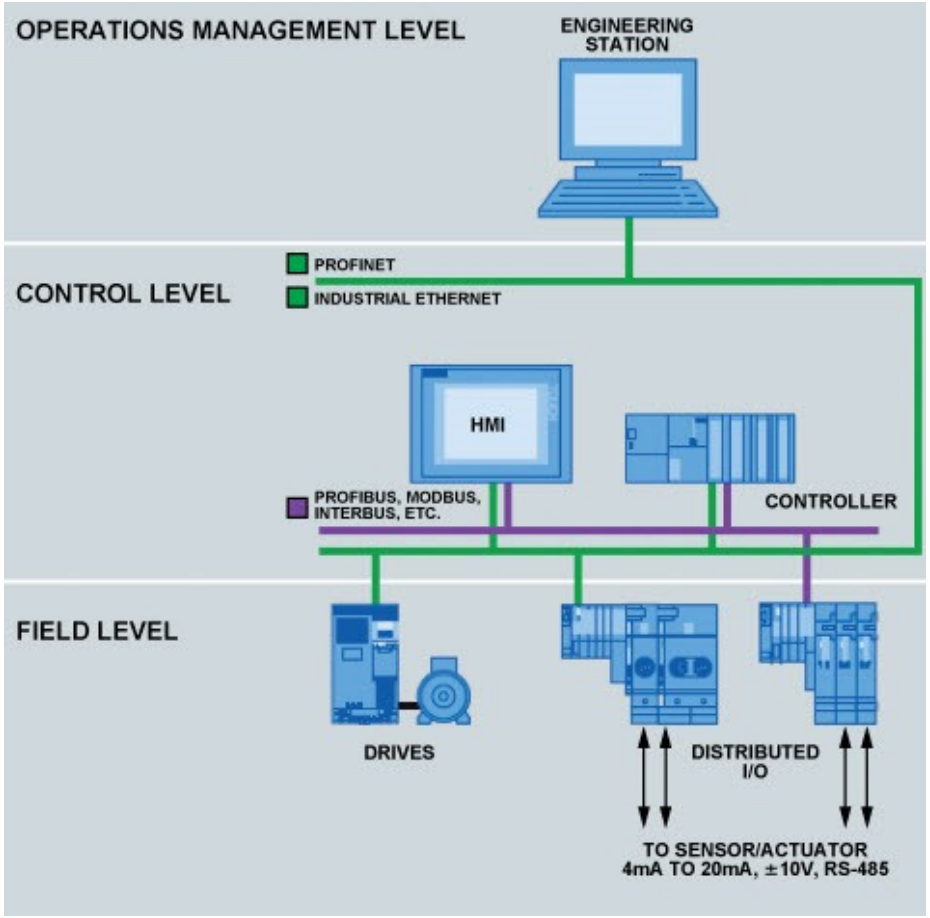
Complex distributed architecture



From Urban Bilstrup

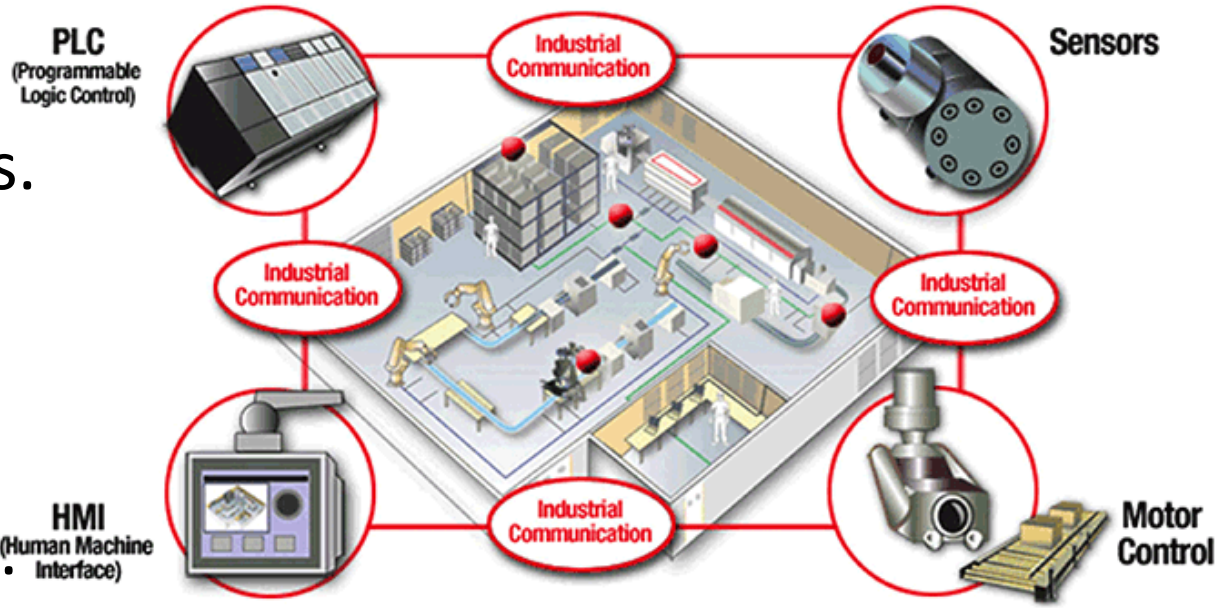
Hierarchical levels of communication

- **Device Level:** This lowest level consists of field devices such as sensors and actuators of processes and machines.
- **Control Level:** This level consists of controllers, distributed control units, and computer systems. The tasks of this level include configuring automation devices, loading of program data and process variables data, supervising control, historical archiving, etc.
- **Information Level:** This is the top level of the industrial automation system which gathers the information from its lower level i.e., control level.



Industrial communication networks

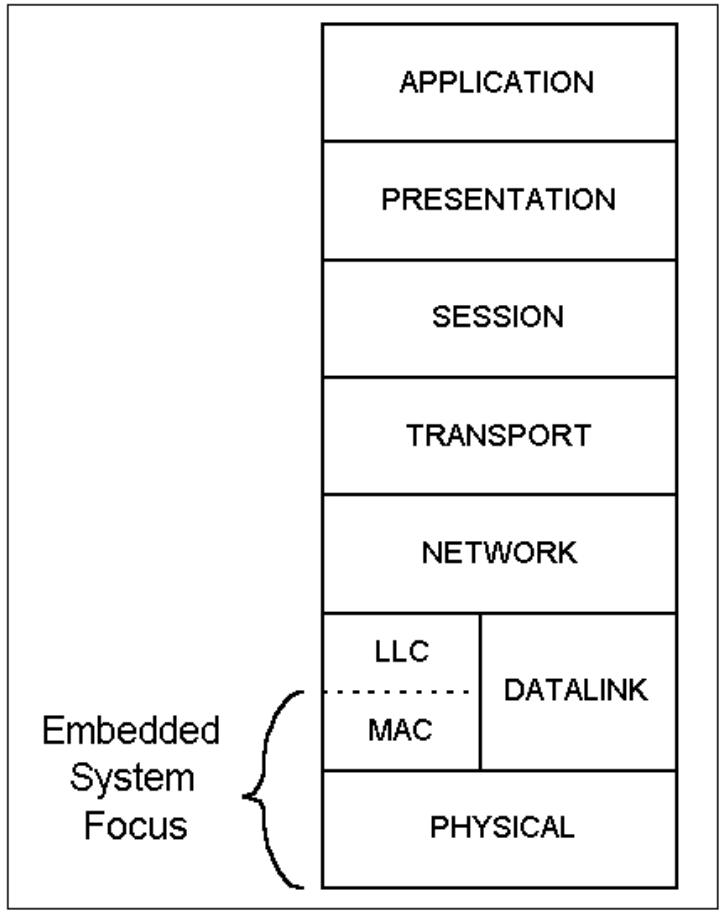
- Industrial control broadly defines the wide range of electronic equipment used in factories, process control plants, and automated facilities for monitoring and controlling manufacturing and other operations.
- It involves machines like robots, computers, machine tools, programmable logic controllers (PLCs), sensors, relays, valves, motors, and measuring instruments.



Industrial communication networks

- There exist many different communication networks designed to interconnect digital control systems to field devices and I/O modules.
- Some common and popular industrial communication standards are:
  - Serial Communication standards such as RS232, RS422 and RS485
  - Highway Addressable Remote Transducer (HART)
  - DeviceNet
  - ControlNet
  - Profibus
  - Foundation Field Bus
- https://www.youtube.com/watch?v=MNmzbMEzkdk

Open System Interconnection



- Intended for computers
- Designed to solve compatibility problem
- Layers provide standard interface and services
- Embedded systems use some standardisation ideas
- Higher layers require lower layers to work

Embedded systems communication concepts

- Point-to-point networks
  - Each node connected to every node
  - Simple and reliable
  - Dedicated links make it easy to meet real-time deadlines
  - Costly due to many wires required
- Shared media networks
  - Nodes are connected via bus or other topologies
  - Less wiring and hence cheaper
  - Easily extendable by adding new nodes to network
  - Complex network protocol

Embedded systems communication concepts

- Event based communication
  - E.g. alarm, user inputs, requests for data from other systems
- State based communication
  - E.g. regular sensor readings
  - Predictability

Event based systems

- Efficient use of network resource
- Needs high reliability (event based data comes once in a while)
- May need acknowledgement
- Hard to predict delay in case of overloading (e.g. alarm)

State based systems

- Messages sent at predefined, regular intervals.
- Less efficient due to regular occupation of communication channel by nodes.
- More tolerance. Missed message may be ok, since the next one will be coming.
- Transient data problem. Sending node has to keep data long enough for other to see. E.g. button pressed may need to be repeated.

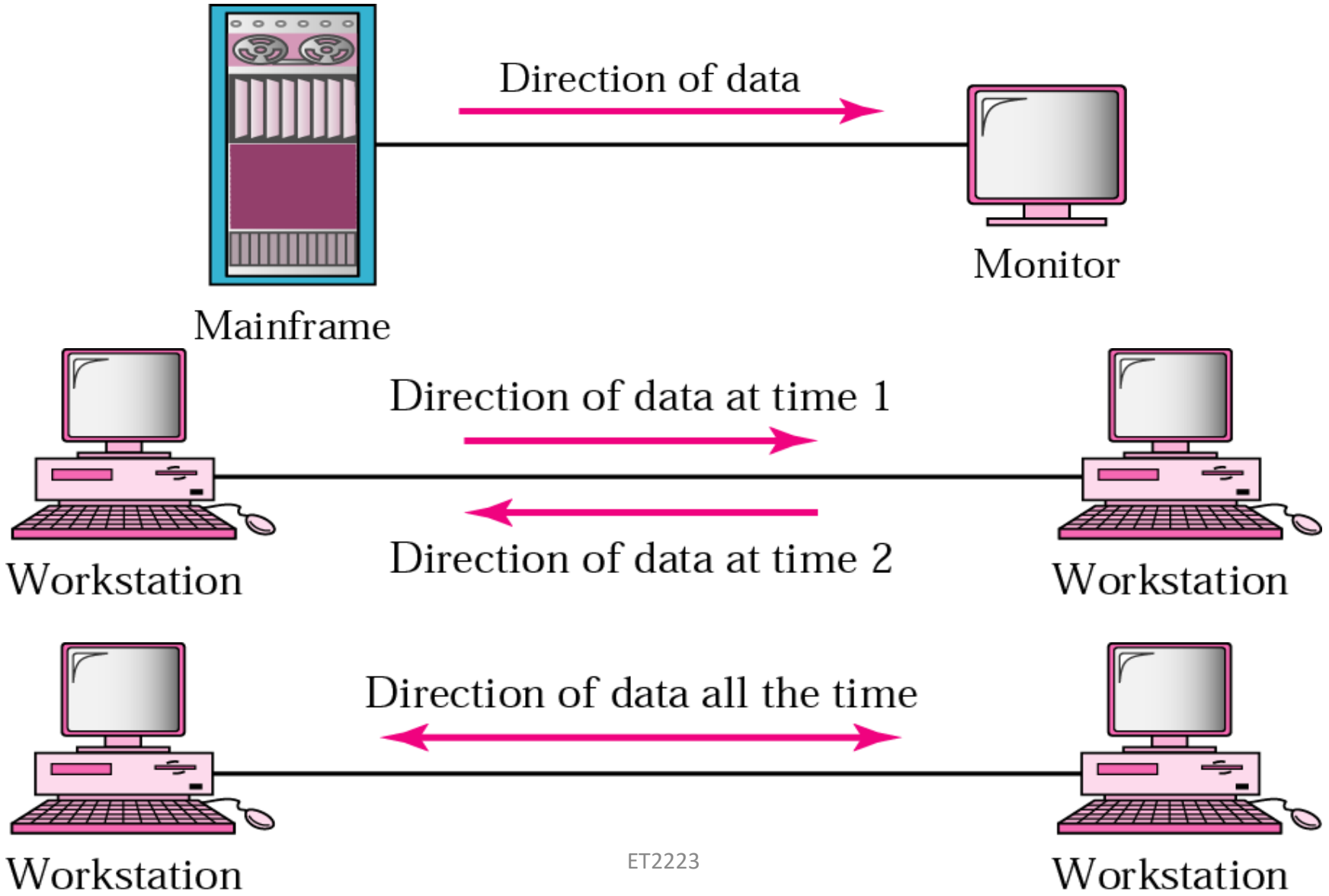
Communication principles

- Layering
  - Break complexity of communication protocol into pieces easier to design and understand
  - Lower levels provide services to higher level
    - Lower level might work with bits while higher level might work with packets of data
  - Physical layer
    - Lowest level in hierarchy
    - Medium to carry data from one actor (device or node) to another
- Parallel communication
  - Physical layer capable of transporting multiple bits of data
- Serial communication
  - Physical layer transports one bit of data at a time
- Wireless communication
  - No physical connection needed for transport at physical layer

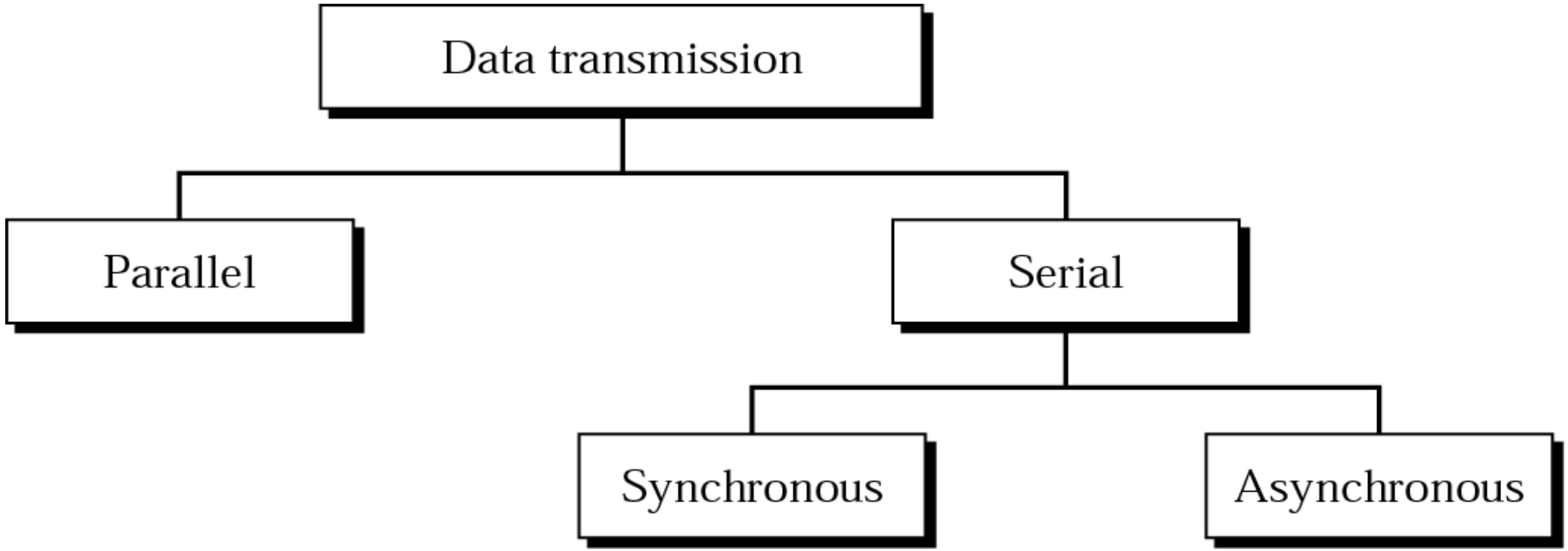
Basic communication methods

- It is essential to understand some of the basic communication methods that can be used to interconnect control systems.
- Characteristics of communication methods:
  - Simplex, Duplex & Semi Duplex
  - Serial Vs Parallel
  - Synchronous Vs Asynchronous
  - Data Throughput

Simplex, Half-duplex, Full-duplex

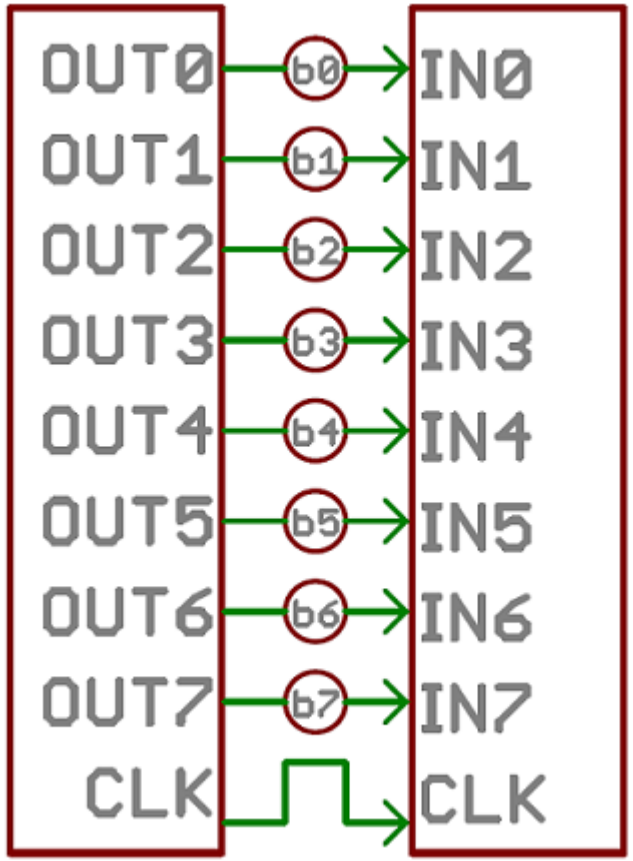


Types of data transfer



Parallel communication

- Parallel interfaces transfer multiple bits at the same time.
- They usually require buses of data - transmitting across eight, sixteen, or more wires.
- It's fast, straightforward, and relatively easy to implement.
- But it requires many more input/output (I/O) lines.

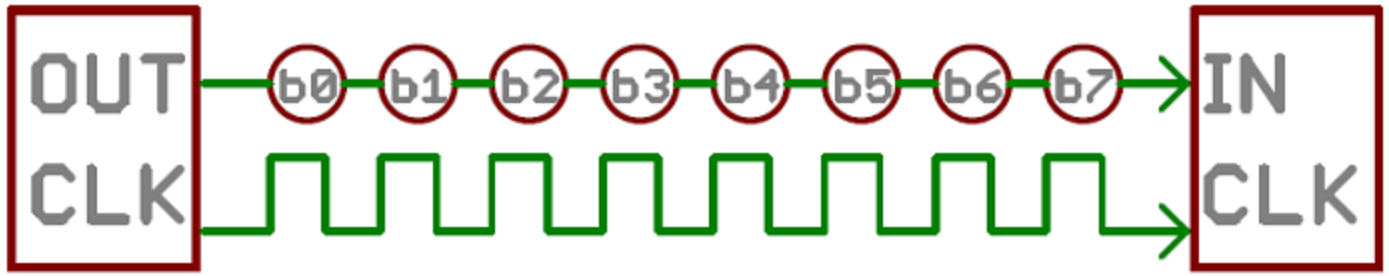


Parallel communication

- 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, because long parallel wires result in high capacitance values which requires more time to charge/discharge, and data misalignment between wires increases as length increases
- Higher cost, bulky

Serial Communication

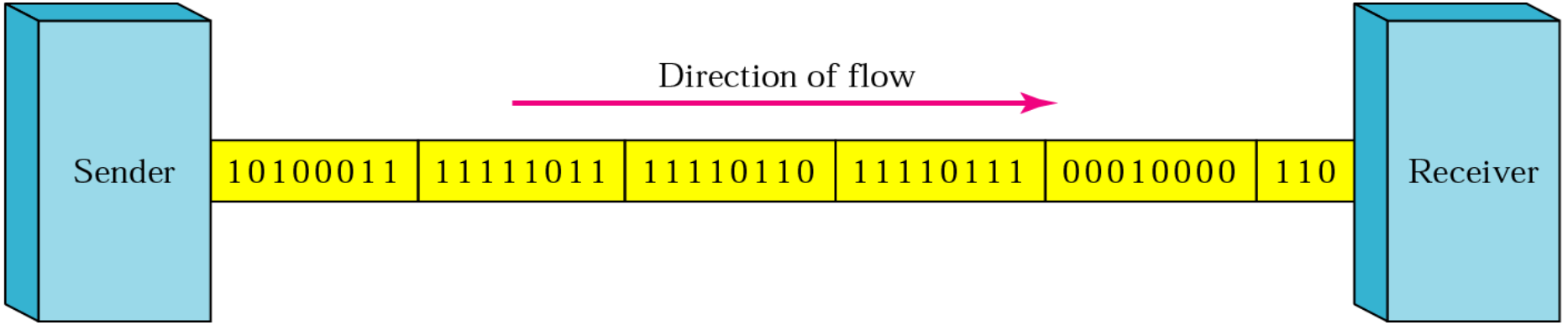
- Serial communication is the process of sending/receiving data in one bit at a time.
- Serial interfaces stream their data, one single bit at a time.
- These interfaces can operate on as little as one wire, usually never more than four.



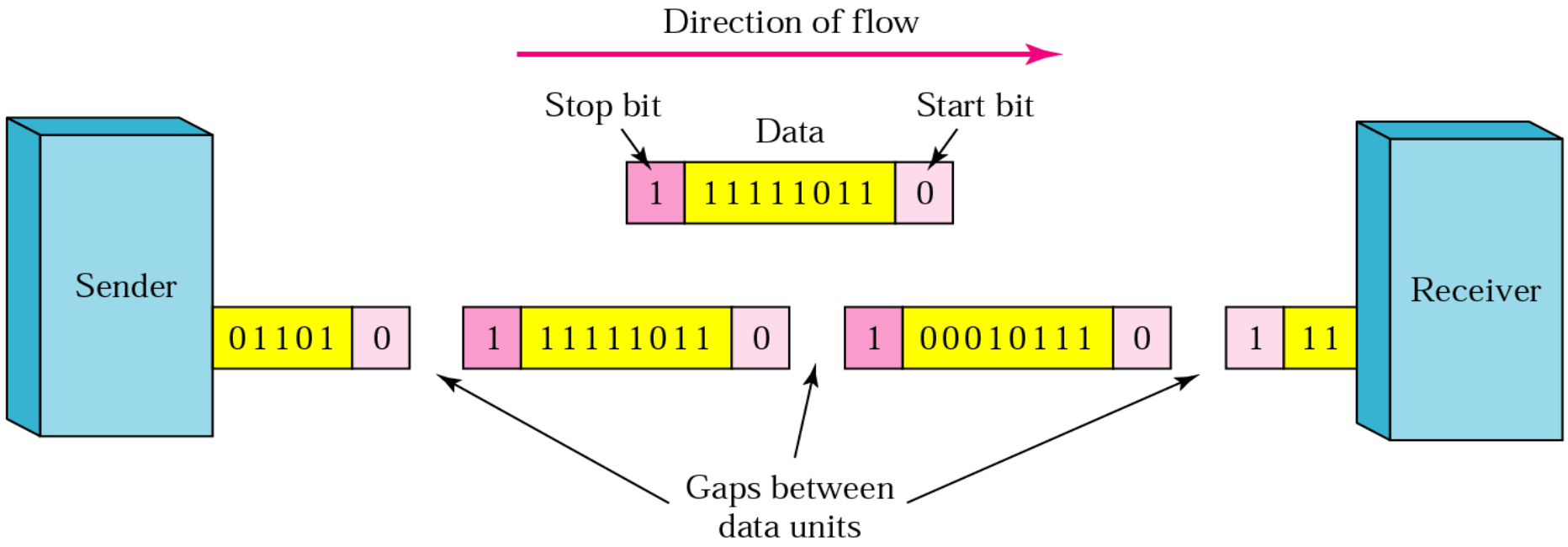
Serial communication

- Single data wire, possibly also control and power wires
- 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

Synchronous serial transfer



Asynchronous serial transfer



Advantages of serial over parallel

- A serial connection requires fewer interconnecting cables and hence occupies less space.
  - The extra space allows for better isolation of the channel from its surroundings.
  - Crosstalk is not a much significant issue, because there are fewer conductors in proximity.
- In many cases, serial is a better option because it is cheaper to implement.
  - Many devices and sensors relevant to control systems have serial interfaces, as opposed to parallel ones, so that they have fewer pins and are therefore less expensive.

Serial communication protocols

- There are various protocols that can be used with digital control systems for serial communication.
  - UART (Universal Asynchronous Receiver/Transmitter)
  - SPI (Serial Peripheral Interface)
  - I2C (Inter-Integrated Circuits)
  - CAN (Controller Area Network)
  - USB (Universal Serial Bus)
  - 1-wire
- https://www.deviceplus.com/how-tos/arduino-guide/arduino-communication-protocols-tutorial/
- https://www.embedded.com/design/connectivity/4023975/Serial-Protocols-Compared

Advanced communication principles

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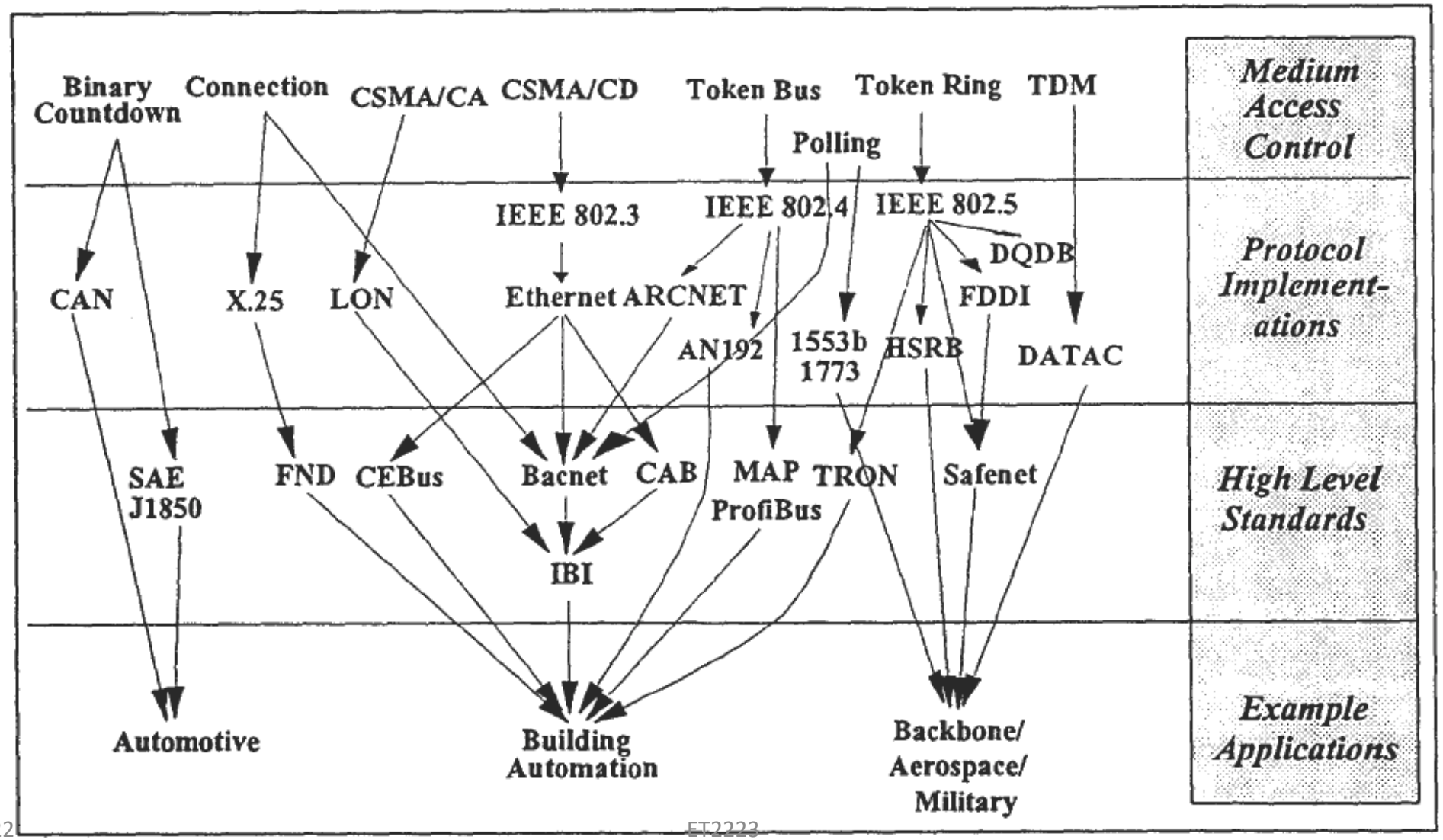
Wireless communication

- Infrared (IR)
  - Electronic wave frequencies just below visible light spectrum
  - Diode emits infrared light to generate signal
  - 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

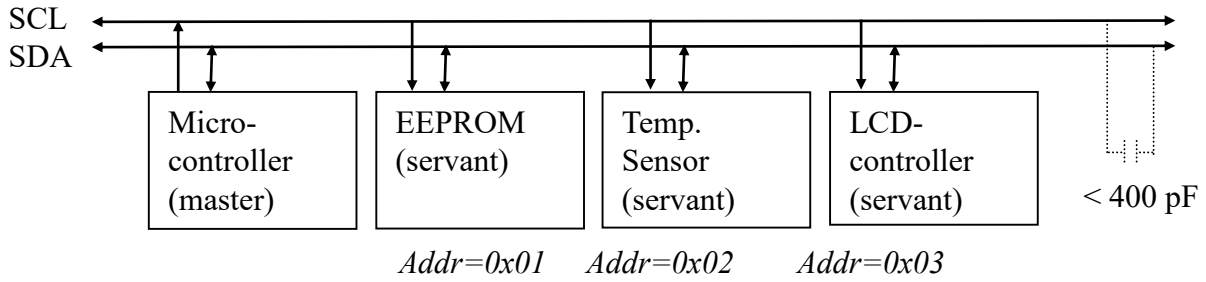
Communication protocols

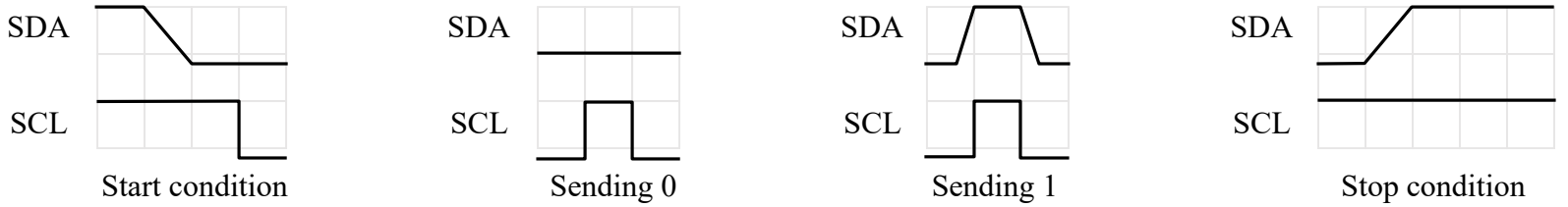


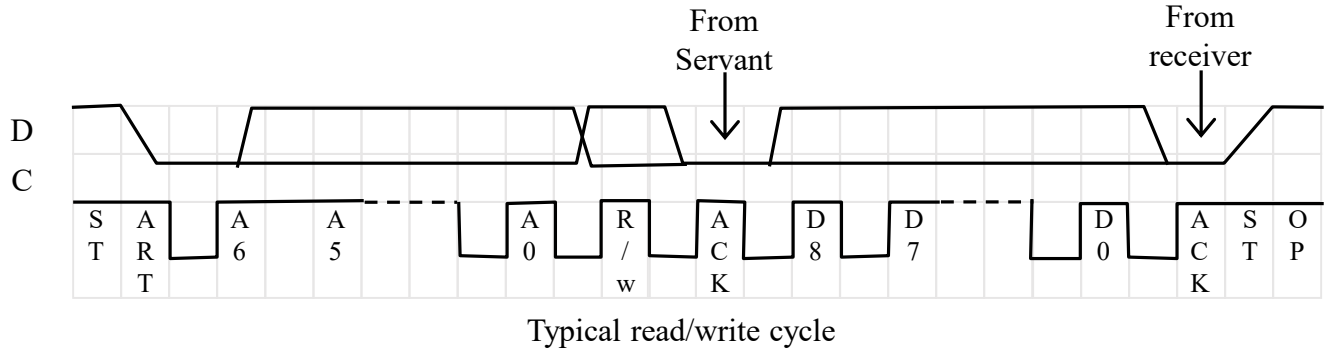
Serial protocols: I^2C

- I^2C
  - Two-wire serial bus protocol developed by Philips Semiconductors nearly 20 years ago
  - Enables peripheral ICs to communicate using simple communication hardware
  - Data transfer rates up to 100 kbits/s and 7-bit addressing possible in normal mode
  - 3.4 Mbits/s and 10-bit addressing in fast-mode
  - Common devices capable of interfacing to I^2C bus:
    - EPROMS, Flash, and some RAM memory, real-time clocks, watchdog timers, and microcontrollers

I²C bus structure







Typical read/write cycle

Serial protocols: CAN

- Controller Area Network
- Protocol for real-time applications
- Originally for communication among components of cars
  - developed by Robert Bosch GmbH
- Applications now using CAN include:
  - elevator controllers, copiers, telescopes, production-line control systems, and medical instruments
- Data transfer rates up to 1 Mbit/s and 11-bit addressing
- Common devices interfacing with CAN:
  - 8051-compatible 8592 processor and standalone CAN controllers

Serial protocols: USB

- USB (Universal Serial Bus)
  - Easier connection between PC and monitors, printers, digital speakers, modems, scanners, digital cameras, joysticks, multimedia game equipment
  - 2 data rates:
    - 12 Mbps for increased bandwidth devices
    - 1.5 Mbps for lower-speed devices (joysticks, game pads)
  - Tiered star topology can be used
    - One USB device (hub) connected to PC
      - hub can be embedded in devices like monitor, printer, or keyboard or can be standalone
    - Multiple USB devices can be connected to hub
    - Up to 127 devices can be connected like this
  - USB host controller
    - Manages and controls bandwidth and driver software required by each peripheral
    - Dynamically allocates power downstream according to devices connected/disconnected

Parallel protocols: PCI Bus

- Peripheral Component Interconnect (PCI) Bus
- 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 127.2 to 508.6 Mbits/s and 32-bit addressing
  - Later extended to 64-bit while maintaining compatibility with 32-bit schemes
- Synchronous bus architecture
- Multiplexed data/address lines

Parallel protocols: ARM Bus

- Designed and used internally by ARM Corporation
- Interfaces with ARM line of processors
- Many IC design companies have own bus protocol
- Data transfer rate is a function of clock speed
  - If clock speed of bus is X, transfer rate = 16 x X bits/s
- 32-bit addressing

Wireless protocols: IrDA

- Protocol suite that supports short-range point-to-point infrared data transmission
- Created and promoted by the Infrared Data Association (IrDA)
- Data transfer rate of 9.6 kbps and 4 Mbps
- IrDA hardware deployed in notebook computers, printers, PDAs, digital cameras, public phones, cell phones
- Lack of suitable drivers has slowed use by applications
- Windows 2000/98 now include support
- Becoming available on popular embedded OS's

Wireless protocols: Bluetooth

- New, global standard for wireless connectivity
- Based on low-cost, short-range radio link
- 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

- Standard for wireless LANs
- Specifies parameters for PHY and MAC layers of network
- PHY layer - physical layer
  - handles transmission of data between nodes
  - 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)
- MAC layer - medium access control layer
  - protocol responsible for maintaining order in shared medium
  - collision avoidance/detection