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Microprocessor and Embedded Systems

Faculty of Automatic Control, Electronics and Computer Science, Informatics, Bachelor Degree

Lecture 9

Serial buses & interfaces

Bartłomiej Zieliński, PhD, DSc

Serial buses & interfaces

Program:

- Serial vs parallel bus
  - *Which is better*?
- Selected solutions
  - **I²C**, SMBus
  - **SPI**, Microwire
  - **1-Wire**

Serial buses & interfaces

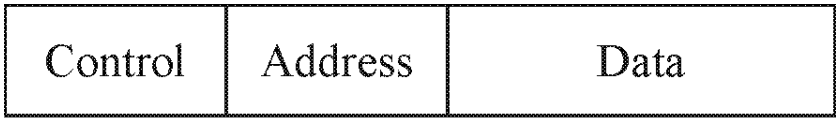
Serial bus	Parallel (classic) bus
Small numer of connections	Large numer of connections
Simple path routing on PCB, easy design, small PCB area	Complex path routing, difficult design, large PCB area
Few or no auxilliary elements Decoding on a logical level	Many auxilliary elements (buffers, registers, decoders, gates, etc.) Decoding on a physical level
Low transmission rate (lower than µp can perform)	High transmission rate (as high as the µp can perform)
Complex data exchange (if software implemented)	Easy data exchange (1-3 commands/exchange)
Addressing space not occupied	Addressing space occupied
Easy and cheap protection against interference	Difficult and expensive protection against interference
Dynamic bit assignment for address, data and control	Static bit assignment for address, data and control

Not always low;
even if low, high enough for many apps

On the other hand, what addressing space is for?

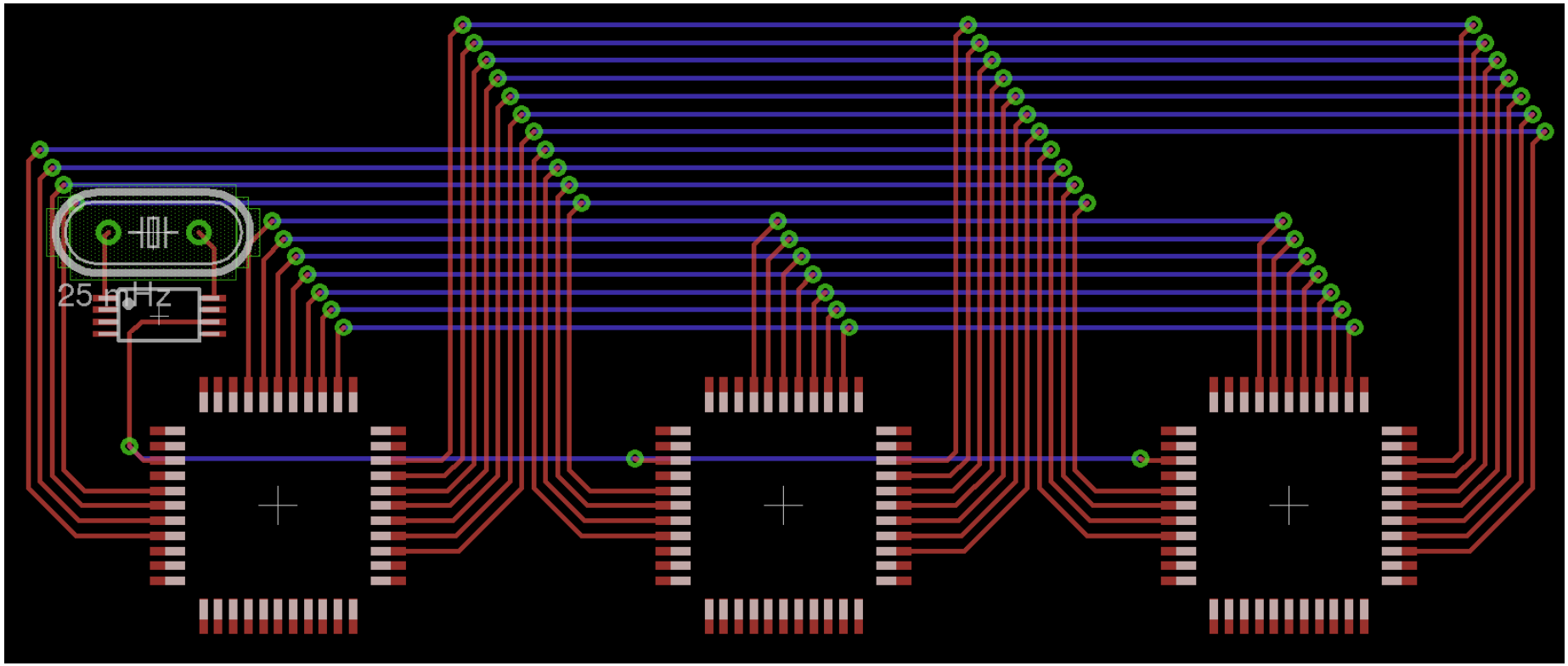
Serial buses & interfaces

- Serial/paralel bus
  - static/dynamic bit assignment



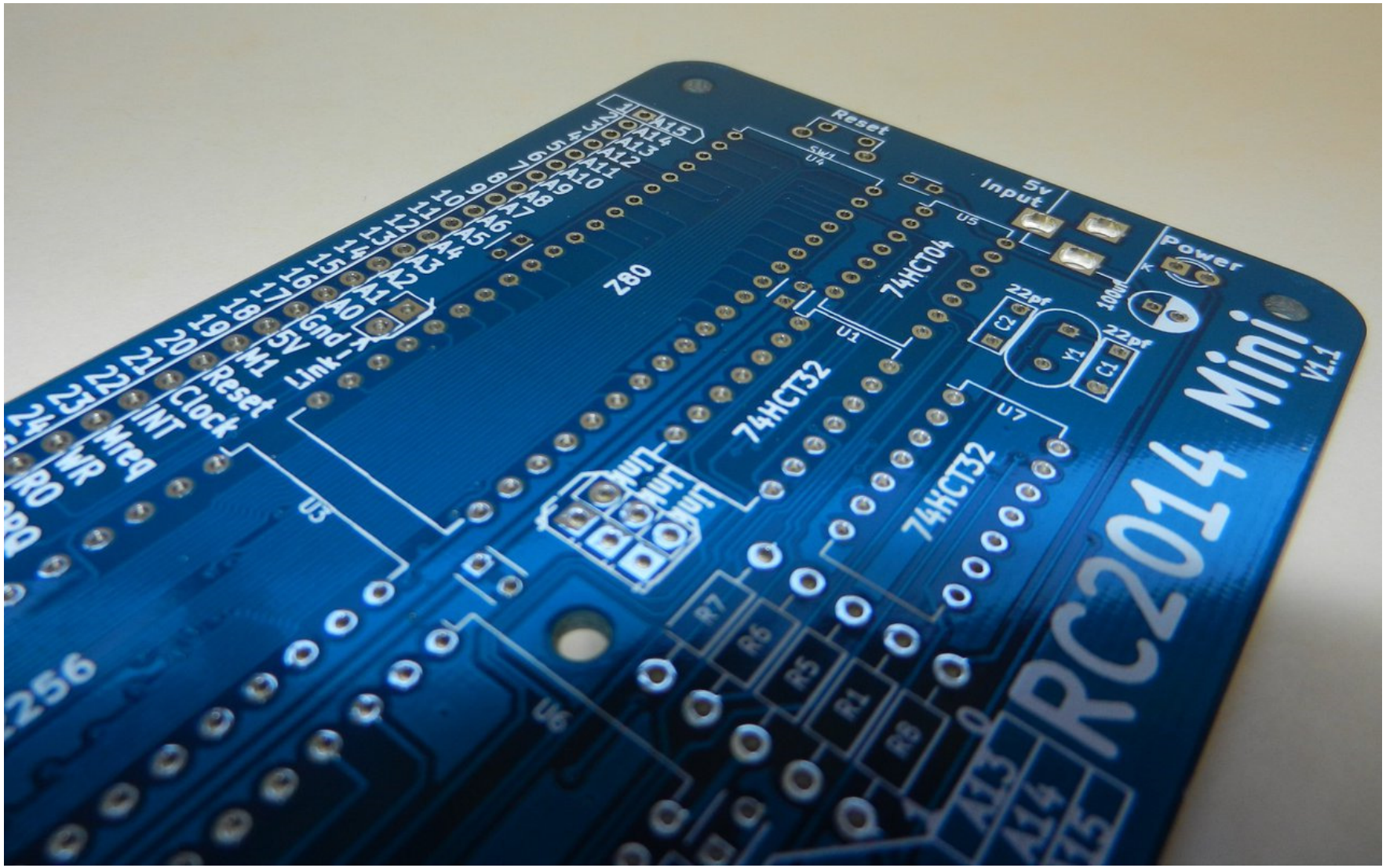
Serial buses & interfaces

- Parallel bus example



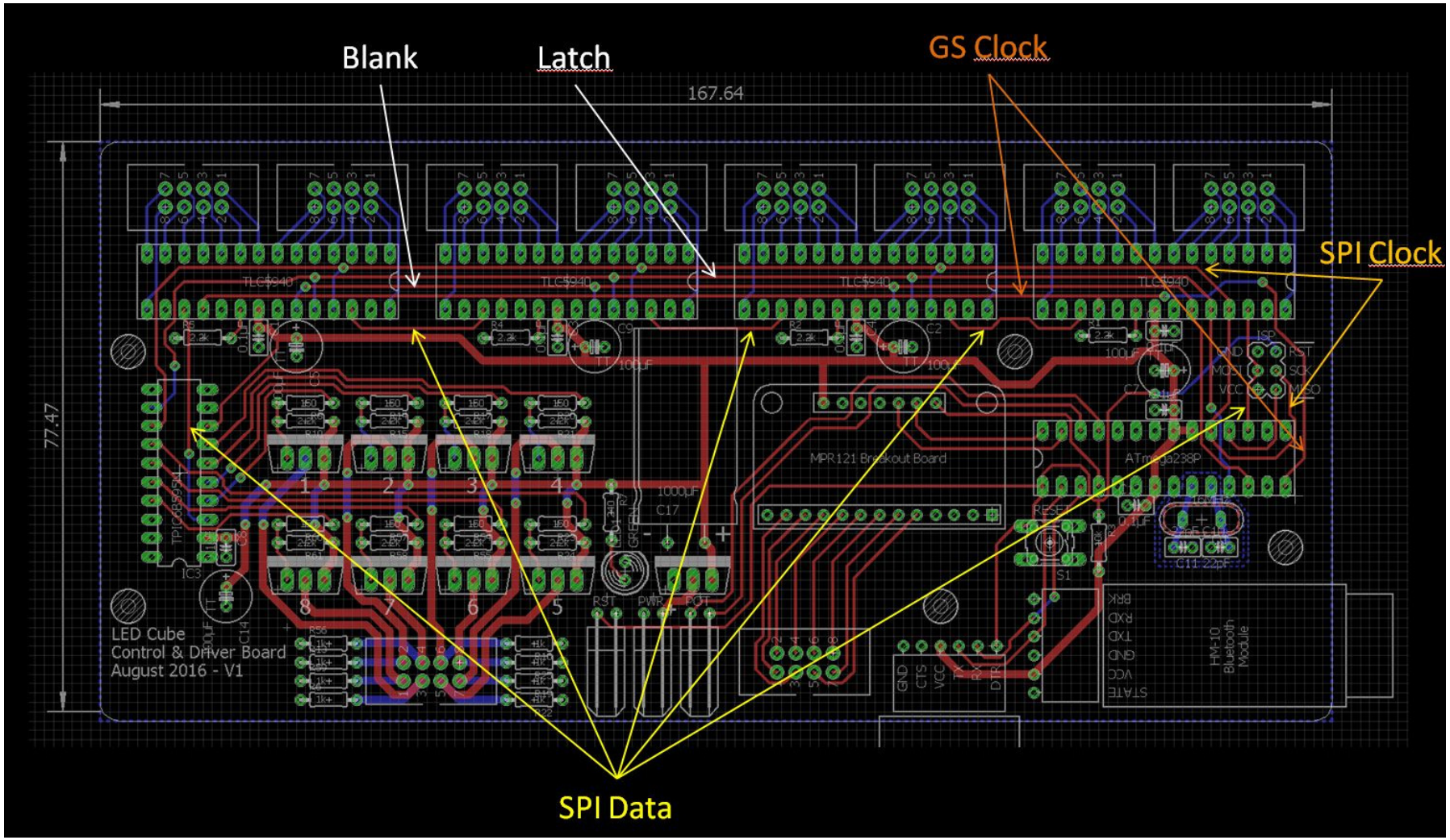
Serial buses & interfaces

- Parallel bus example (2)



Serial buses & interfaces

- Serial bus example



Serial buses & interfaces

- Examples to be discussed (1)
  - I^2C
    - 2 bi-directional OC signals
    - Half-duplex, up to 3.4 Mbps (typical 100 kbps)
    - f_{min}=0 (zero!)
    - Master(s)-slave(s)
    - Unique ID for each IC
  - SMBus
    - Similar to I^2C
    - Up to 100 kbps
    - f_{min}=10 kHz, limited operation time

Serial buses & interfaces

- Examples to be discussed (2)
  - SPI
    - 4 uni-directional lines
    - Synchronous, full-duplex, up to over 10 Mbps
    - 4 modes
    - Master(s)-slave(s)
    - No device ID – physical addressing
  - Microwire
    - Similar to SPI
    - Up to 650 kbps
    - One of the SPI modes

Serial buses & interfaces

- Examples to be discussed (3)
  - 1-Wire
    - 1 (one!) common line for transmission and power
    - Half-duplex, up to 16.3 / 115.2 kbps
    - Master-slave
    - Unique ID among all 1-Wire devices

Serial buses & interfaces

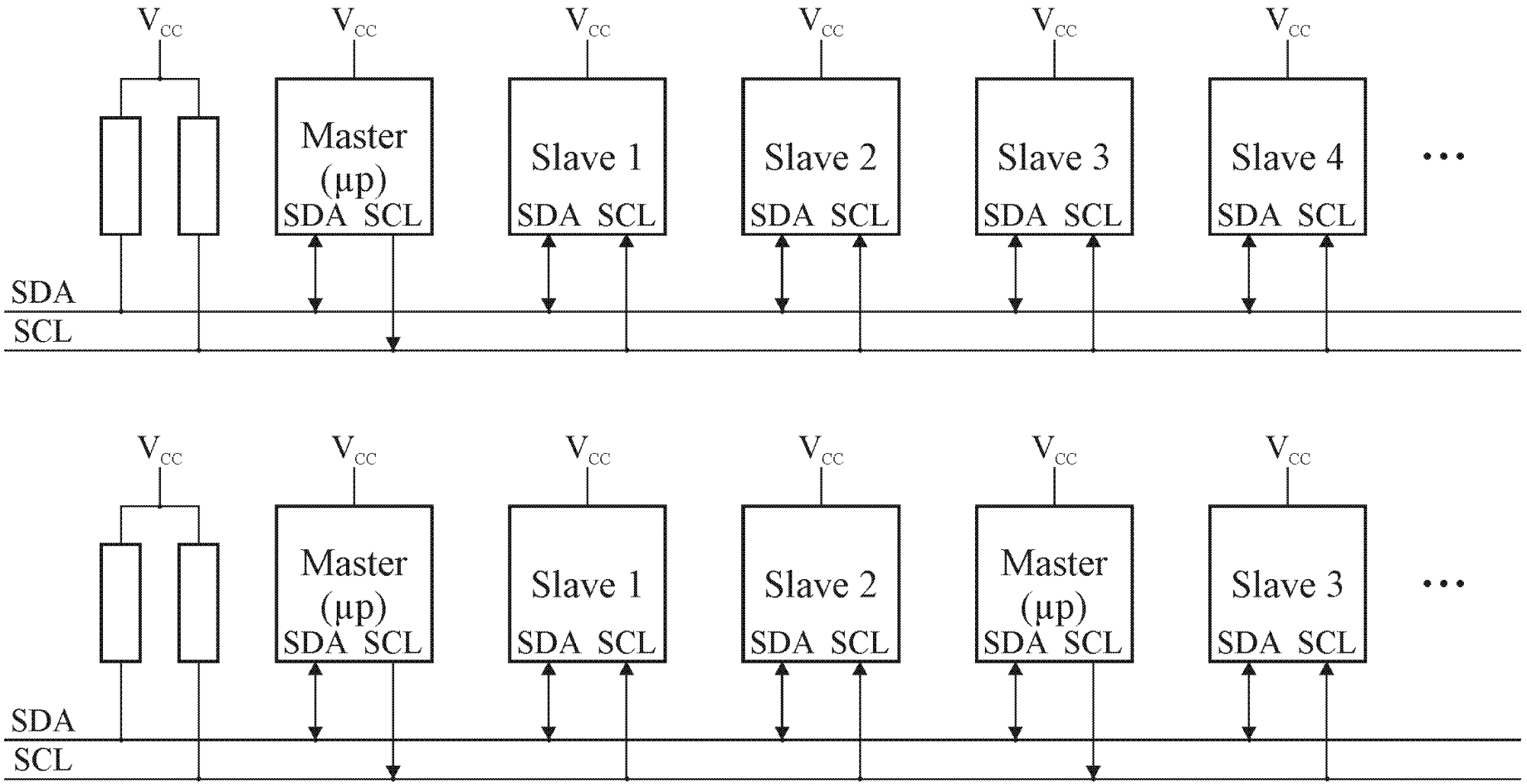
- I^2C
  - *Inter-Integrated Circuit bus* (Philips)
  - 2 OC output lines:
    - SDA (*Serial Data*) – bidirectional data line
    - SCL (*Serial Clock*) – synchronisation clock
  - Master
    - Takes control over the bus and transmission process
    - Sends Start and Stop sequences
  - Slave
    - Allowed to transmit by a Master

Serial buses & interfaces

- I^2C devices
  - Bus controllers (PCF8584), buffers
  - Real time clock (+calendar, +RAM, +EEPROM, +watchdog, +power switch, etc.)
  - Digital „DIP” switches
  - LED or LCD controllers, drivers
  - General purpose I/O ports (+interrupt, + EEPROM, +expander, etc.)
  - Multiplexers and switches
  - EEPROM and SRAM memories
  - Temperature and voltage sensors
  - etc.

Serial buses & interfaces

- I^2C



Serial buses & interfaces

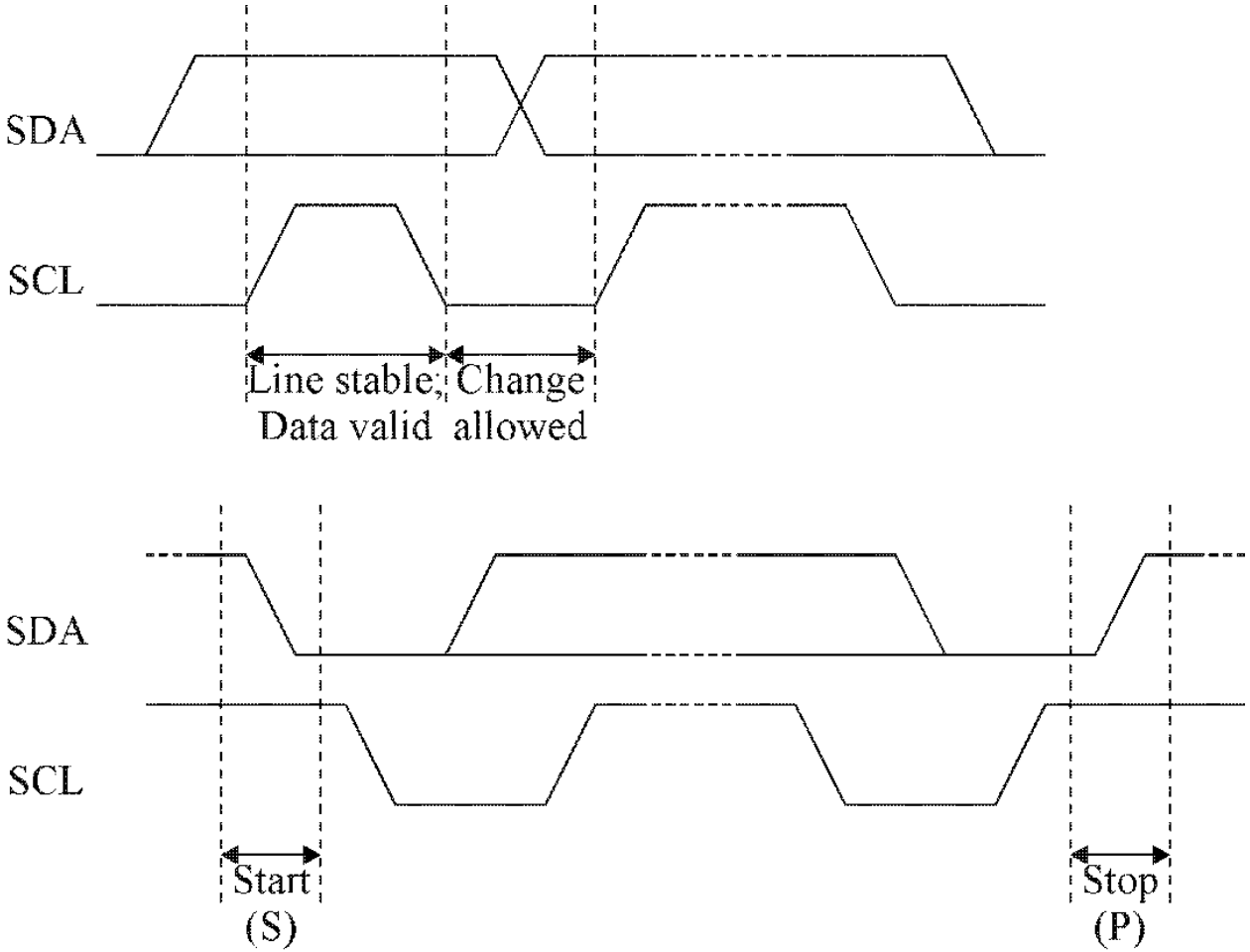
- I^2C properties
  - Unlimited number of IC's
    - Σ capacity ≤ 400 pF/line
    - More IC's – line buffers necessary
  - If more than 1 Master→arbitration procedure
  - Device ID address:
    - Constant part (vendor-defined)
    - Variable part (user-defined)
    - Allows to use multiple IC's of the same type

Serial buses & interfaces

- I^2C transmission rates
  - f_{min}=0→no consequences if transmission stopped
  - f_{max}=100 kbps (standard mode)
  - f_{max}=400 kbps (fast mode)
  - f_{max}=1000 kHz (fast mode plus)
  - f_{max}=3400 kbps (high speed mode)
  - f_{max}=5000 kbps (ultra fast mode)
    - Unidirectional bus only
- The faster rate, the less circuits support it

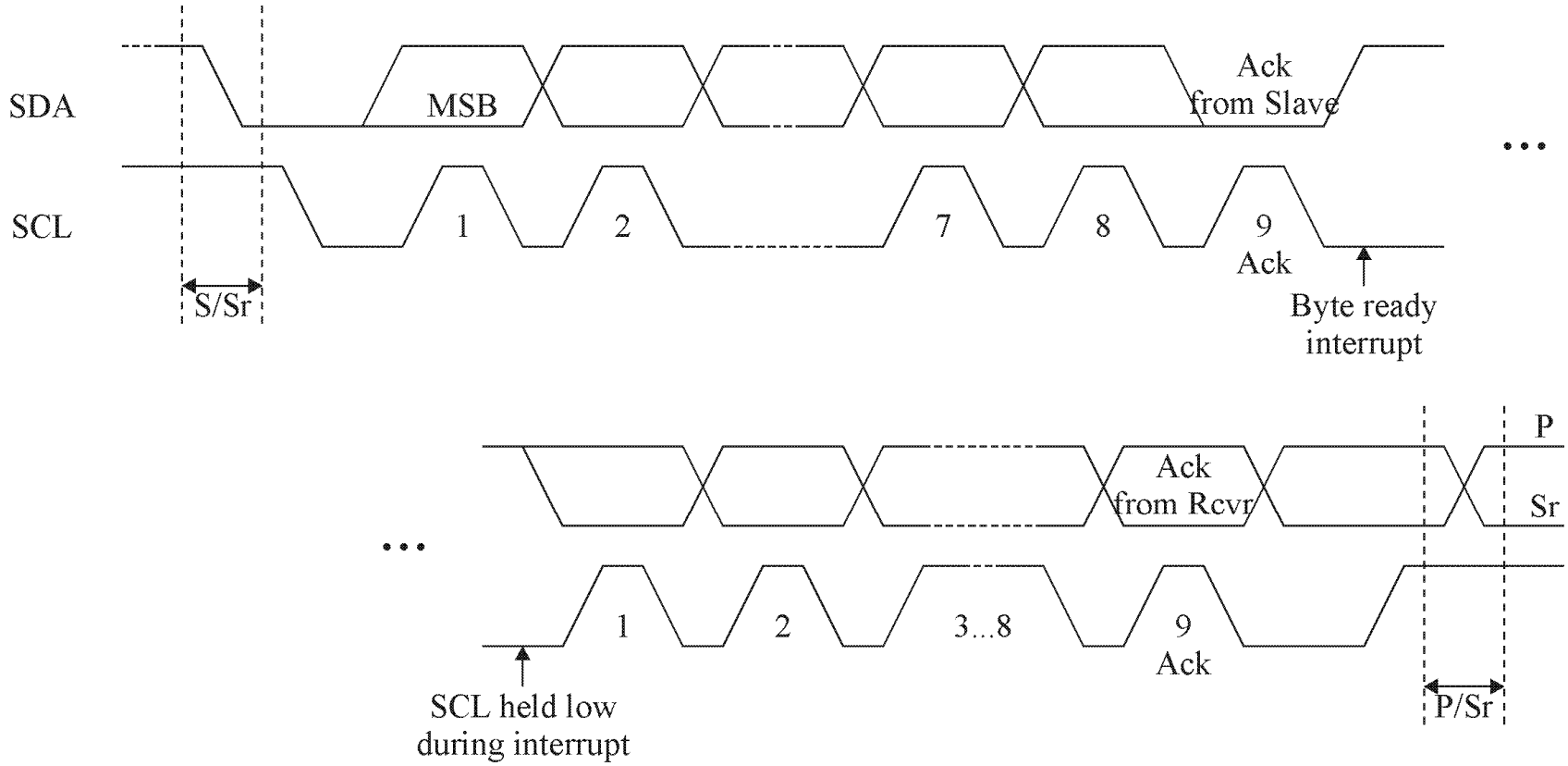
Serial buses & interfaces

- I^2C data transmission
  - Individual bits



Serial buses & interfaces

- I^2C data transmission
  - Byte transmission

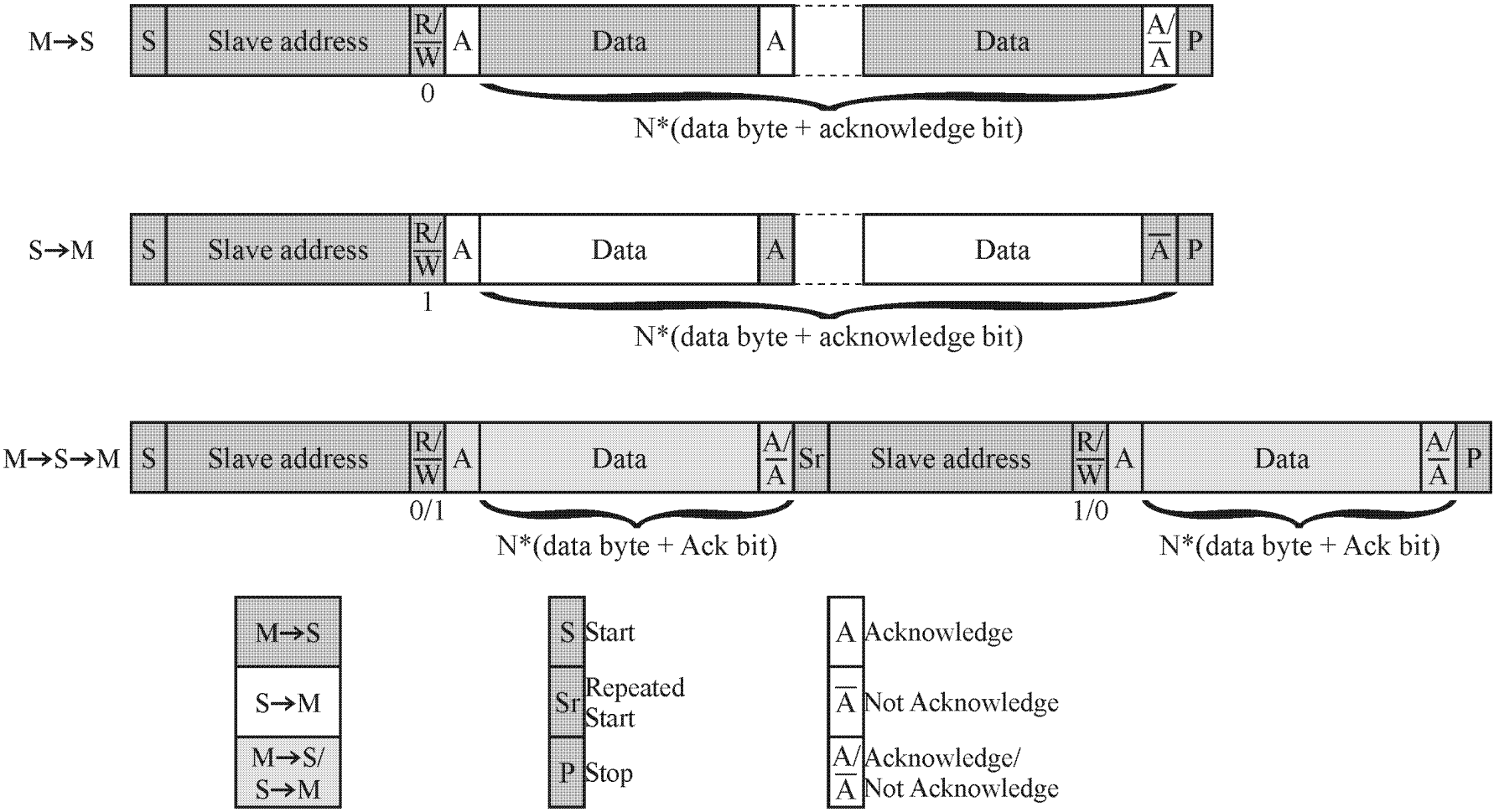


Serial buses & interfaces

- I^2C data transmission
  - Acknowledge
    - Sent after every byte
      - Transmiter releases SDA
      - Receiver pulls SDA low
      - SDA high → Not Ack
    - Not Ack generated:
      - No receiver with the specified address
      - Receiver not ready for communication (busy, e.g., with real-time operation)
      - Command or data not understood
      - No more data can be received
      - Ack must be sent by the Master

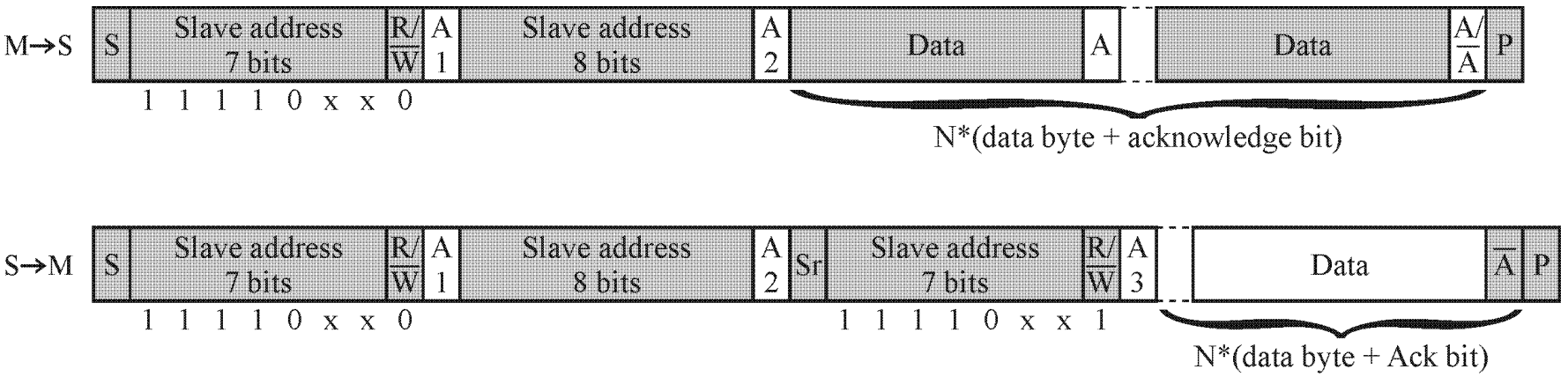
Serial buses & interfaces

- I^2C data transmission
  - Frame transmission



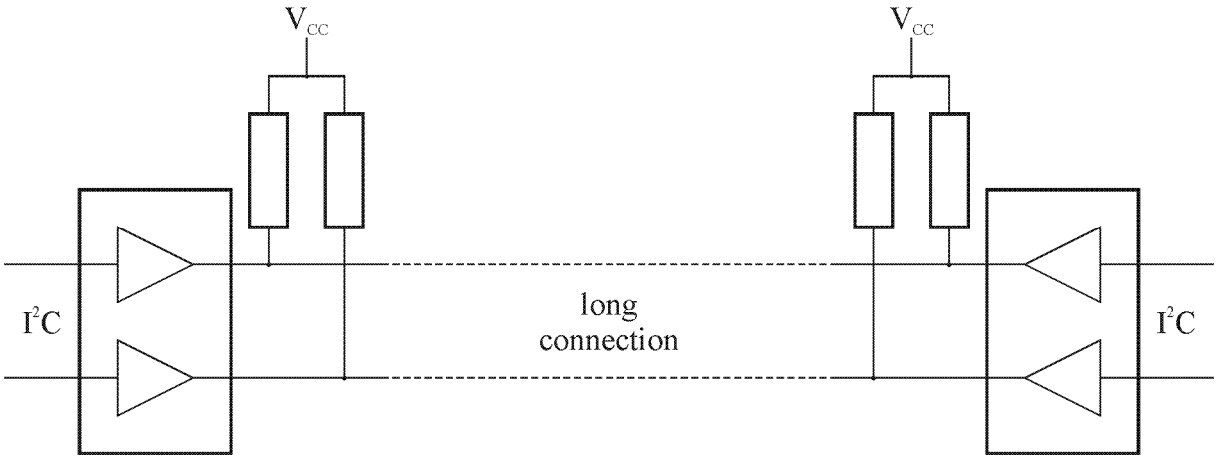
Serial buses & interfaces

- I²C data transmission
  - 10-bit addressing
    - 7b address part – forbidden value
    - Bits „xx” + 8 bits = 10-b address
    - A1 may be generated by many Slaves
    - A2 and A3 generated by only a single Slave



Serial buses & interfaces

- I^2C construction recommendations
  - V_{CC} and GND (or at least GND) between SDA and SCL
    - to avoid crosstalk
  - Bus extender – Σ capacity ≤ 4000 pF/line

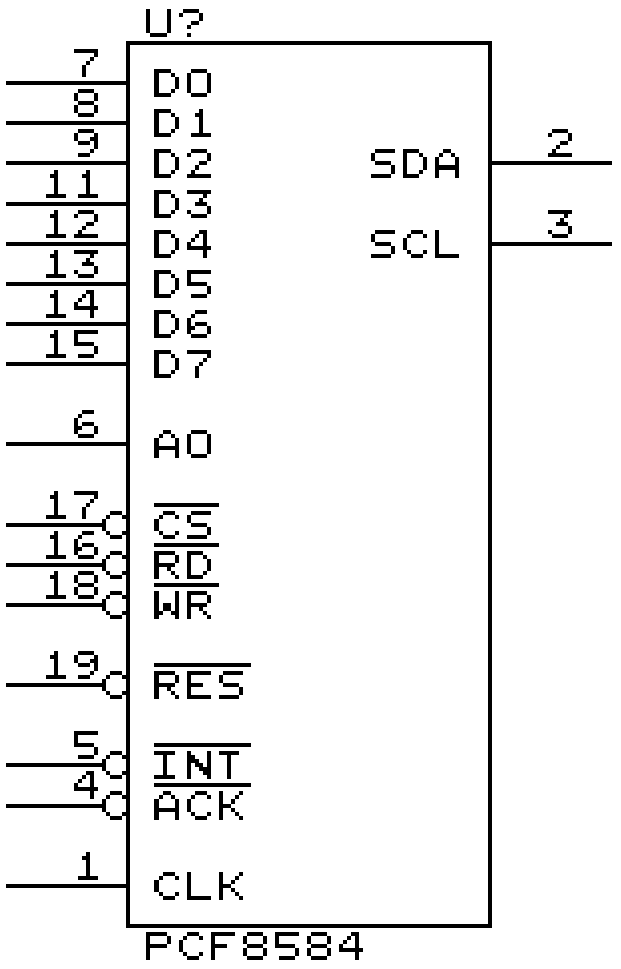


  - Optoisolation
  - Connection to RS232, Centronics (software control)
  - Bus controller

Serial buses & interfaces

- I^2C – PCF8584 bus controller
  - Works with Z80, 8051, 6800, 68000, 8086, etc.
  - Master or slave function
  - Multi-master capability
  - Programmable interrupt vector

We can compare number of signals in parallel and serial buses



Serial buses & interfaces

- SMBus
  - *System Management Bus* (Intel)
  - Limited compatibility to I^2C
    - Transmission rate up to 100 kbps
    - Min f_{clk}=10 kHz (no transmission hang by SCL=0)
    - Operation time limit 25÷75 ms
    - Logic states voltages levels slightly different
    - Current analysis
      - $I^2C \leftrightarrow$ SMBus connection for short distance only
  - Used e.g. in DRAM modules
    - SPD (*Serial Presence Detect*)
    - DRAM memory organisation & parameters

Serial buses & interfaces

- SPI
  - *Serial Peripherial Interface* (Motorola)
  - Bi-directional synchronous transmission
    - MISO (*Master In, Slave Out*)
    - MOSI (*Master Out, Slave In*)
    - SCK (*Serial Clock*)
  - Physical addressing
    - $\overline{\mathrm{SS}}$ (*Slave Select*)
  - „*four-wire serial bus*”
  - One Master/multiple slaves architecture

Serial buses & interfaces

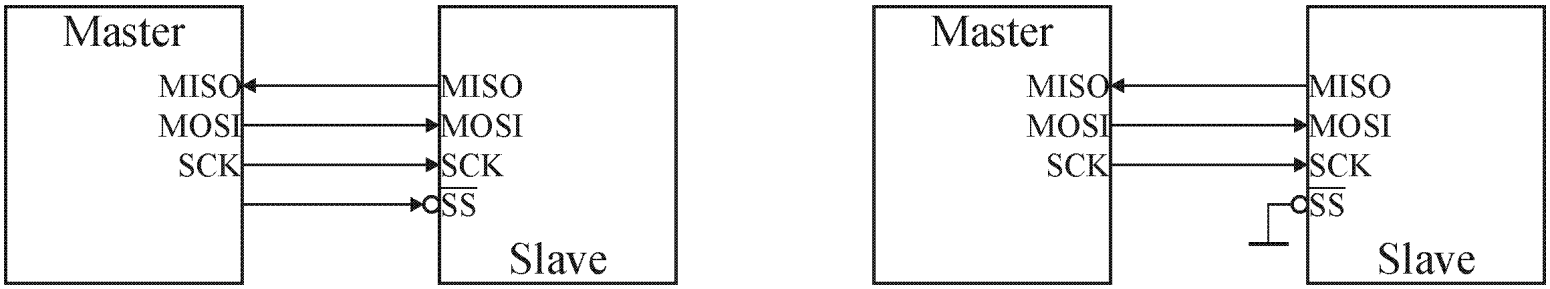
- SPI devices
  - Programmable frequency generators
  - SmartCard interfaces
  - Digital temperature sensors
  - Digital potentiometers
  - Watchdogs
  - EEPROM (+watchdog, +power voltage control, +reset, etc.)
  - …

Serial buses & interfaces

- SPI
  - Typical transmission rate 2.1 Mbps
    - Some say it's not limited
    - Some implementations go over 10 Mbps
    - In µc's – system clock-dependent
  - Configurable data word length
  - Configurable clock polarity & phase
  - SCK
    - Output, when 1 Master
    - Input before transmission, otherwise

Serial buses & interfaces

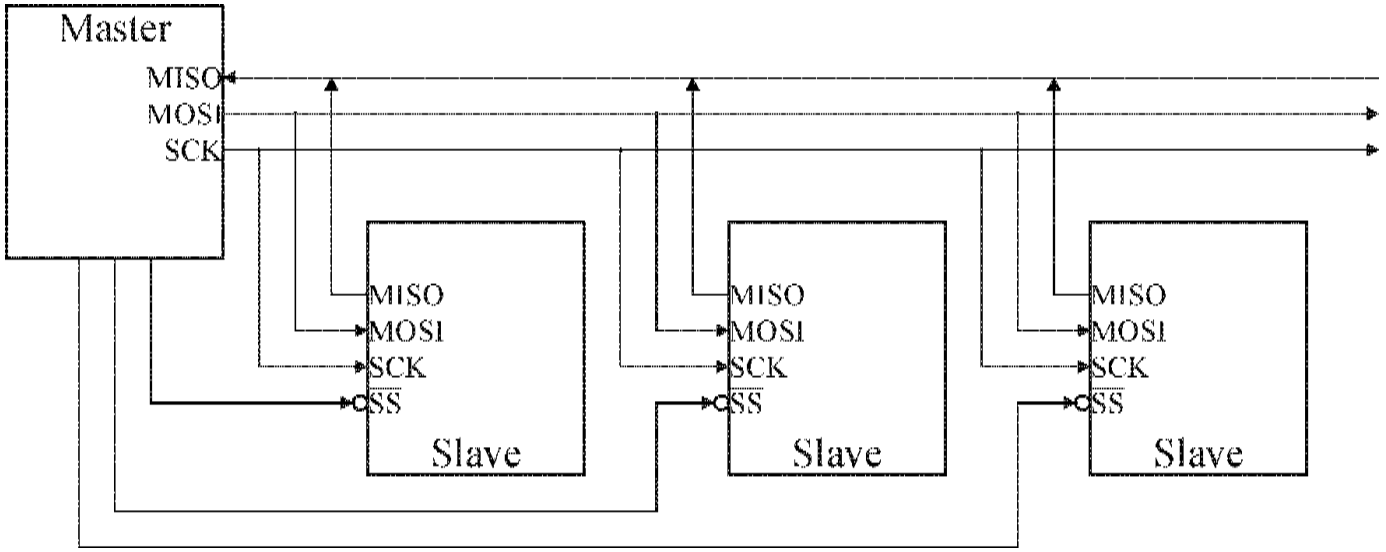
- SPI



  - $\overline{SS}$ pulse may be needed to start slave action (e.g., A/D conversion)
  - $\overline{SS}$ inactive → MOSI high-impedance
    - *not all IC's!*

Serial buses & interfaces

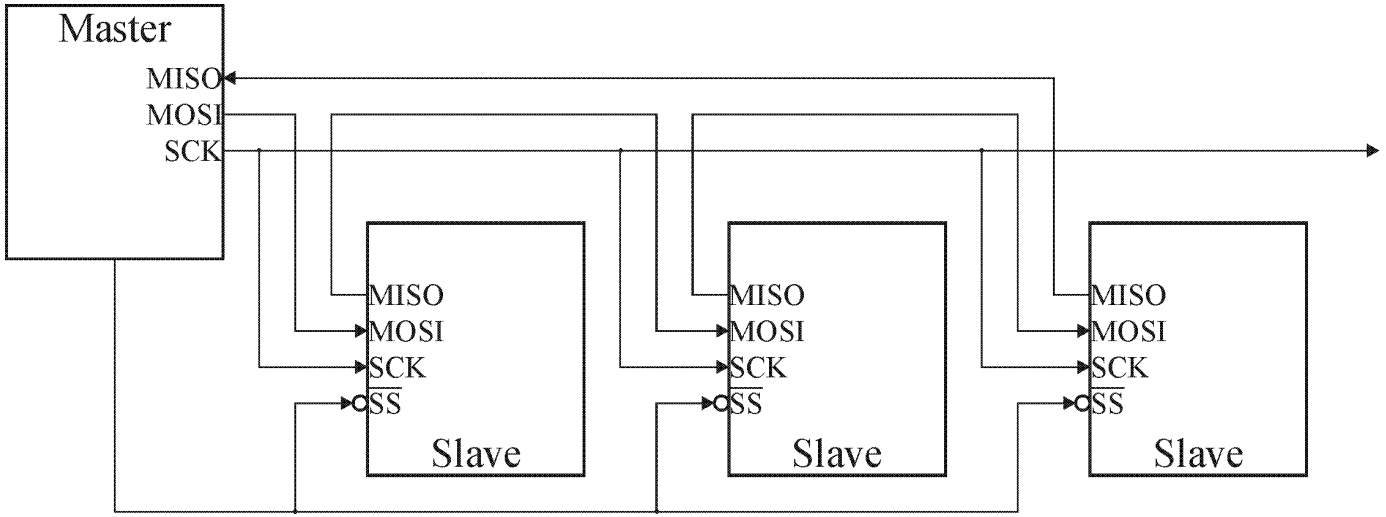
- SPI – more slaves (bus connection)



  - Unlimited number of slaves
  - A decoder can be used if (too) many slaves
  - Master output max. load must be considered

Serial buses & interfaces

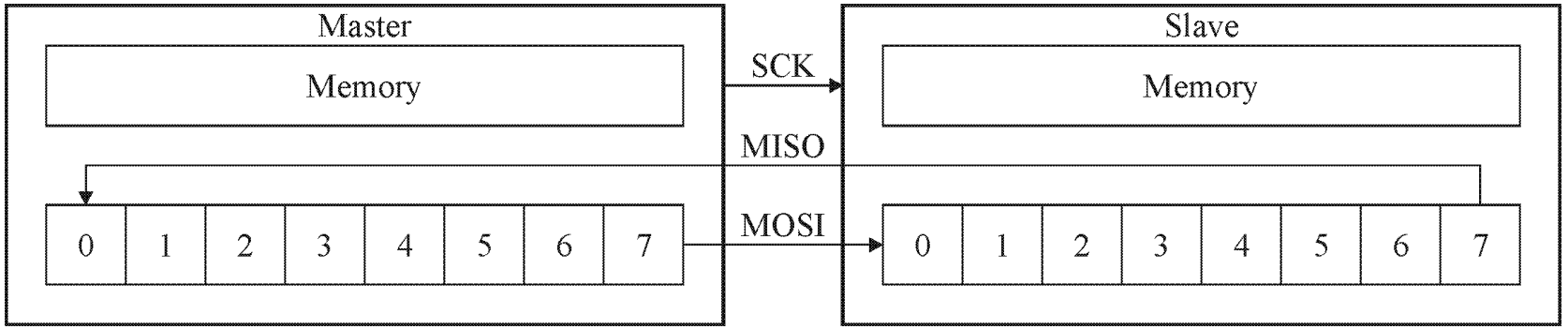
- SPI – more slaves (daisy-chain connection)



  - E.g., set of inputs/outputs
  - SGPIO, JTAG, I^2C

Serial buses & interfaces

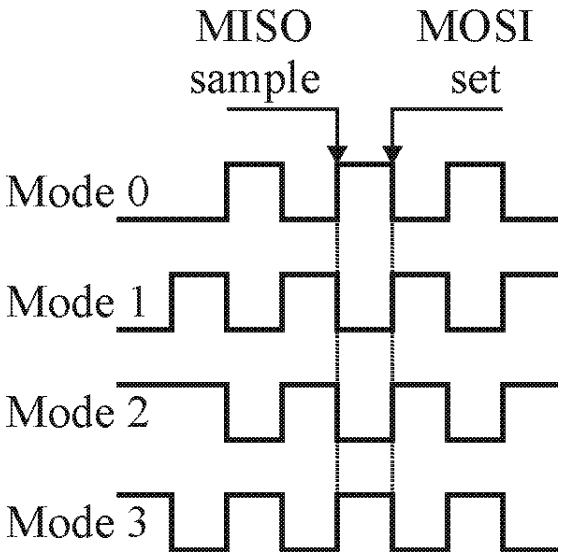
- SPI – data transmission



  - Data word length configurable
    - 8-b, 12-b (ADC, DAC), 16-b (touch screen controllers), …
  - LSB/MSB sequence definable
  - In µc, interrupt upon word completion

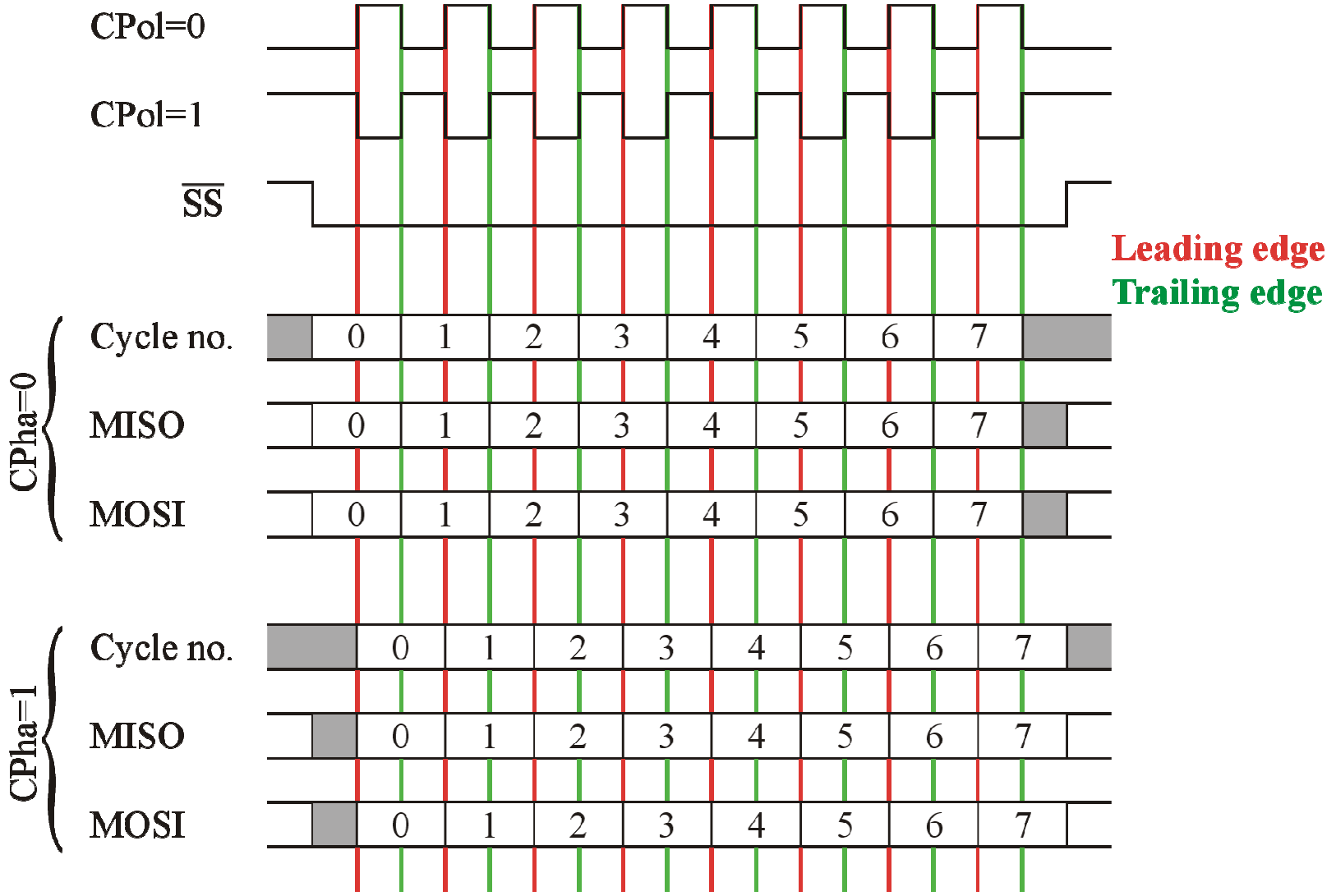
Serial buses & interfaces

- SPI – clock
  - Configurable phase
  - Configurable polarity
  - 4 modes
- Can be set in a Master
- Slave must „guess” the mode
- Difficult when IC’s work in different modes
  - Dynamic Master reconfiguration



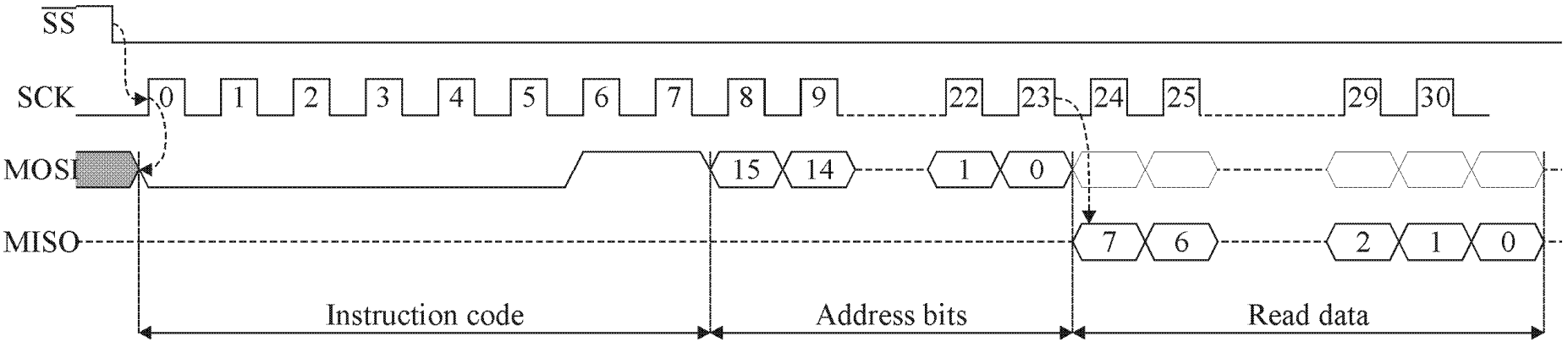
Serial buses & interfaces

- SPI – clock



Serial buses & interfaces

- SPI – memory read example



  - Commands: device-dependent
    - Look into the IC documentation

Serial buses & interfaces

- SPI – µc applications
  - Serial memories access
    - µc = Master
  - Programming µc Flash/EEPROM
    - µc = Slave
  - Can be software-implemented
  - Interrupts
    - Can be implemented with additional signals
    - Neither forbidden, nor specified by the standard

Serial buses & interfaces

- SPI – transmission range extension
  - Typical transmission range
    - Not defined
    - Transmission rate-dependent
  - Extension
    - Using RS-422, RS-485, etc.

Serial buses & interfaces

- Microwire
  - By National Semiconductor
  - Similar to SPI:
    - SI≈MISO, SO≈MOSI, SK≈SCK
    - SPI mode 0 compatible
  - µc always Master
  - $\overline{\mathrm{CS}}$ instead of $\overline{\mathrm{SS}}$
    - Not needed if only one slave

Serial buses & interfaces

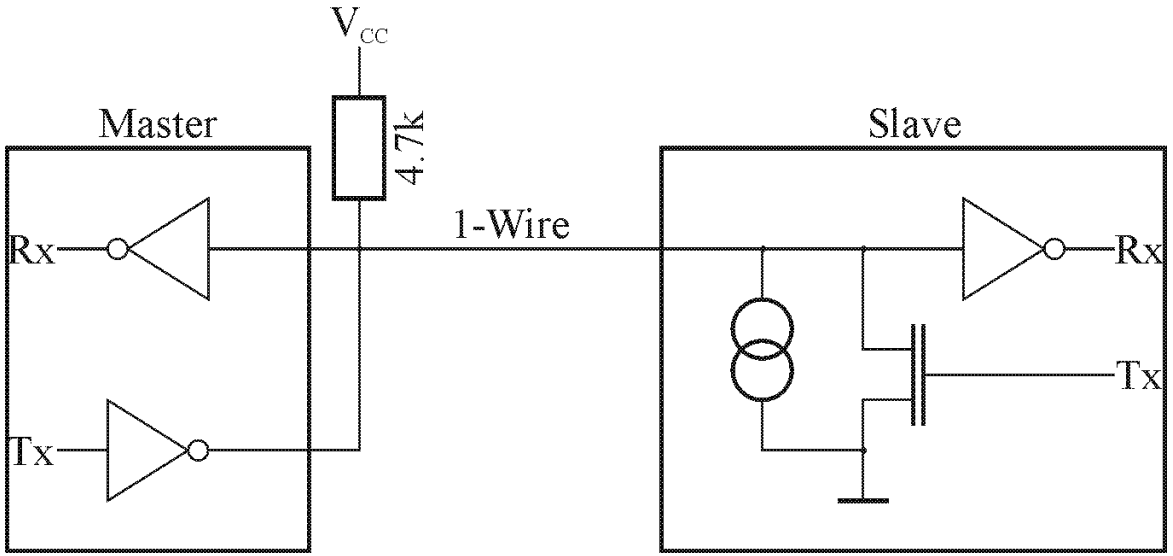
- 1-Wire
  - By Dallas/Maxim
  - Similar to I^2C, but:
    - Lower transmission rates
    - Longer transmission range
    - Only 2 lines including power and ground
  - Large variety of available devices

Serial buses & interfaces

- 1-Wire devices
  - 1-Wire master
  - Line driver
  - Temperature sensors
  - 1-Wire/SPI converter
  - 1-Wire/USB converter
  - 1-Wire/COM converter
  - RAM/ROM/EEPROM memories
  - RTC
  - ….

Serial buses & interfaces

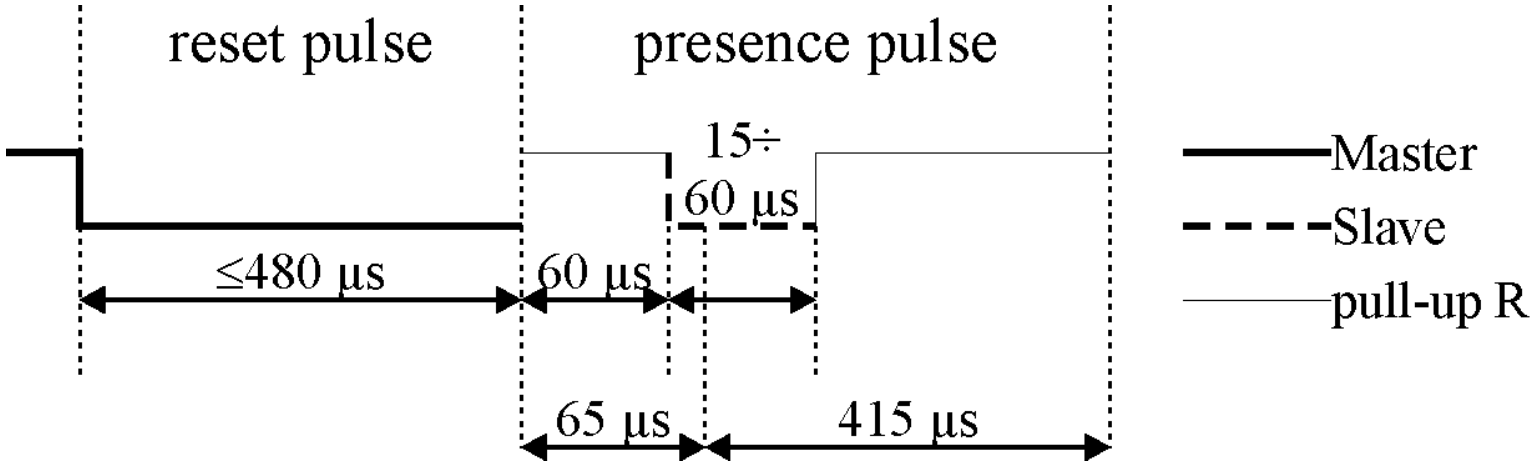
- 1-Wire



  - Synchronous transmission
    - Min rate not defined
    - Standard rate: 16.3 kbps
    - Overdrive rate: 115.2 kbps
    - Bit time: 60 µs + 1 µs recovery time

Serial buses & interfaces

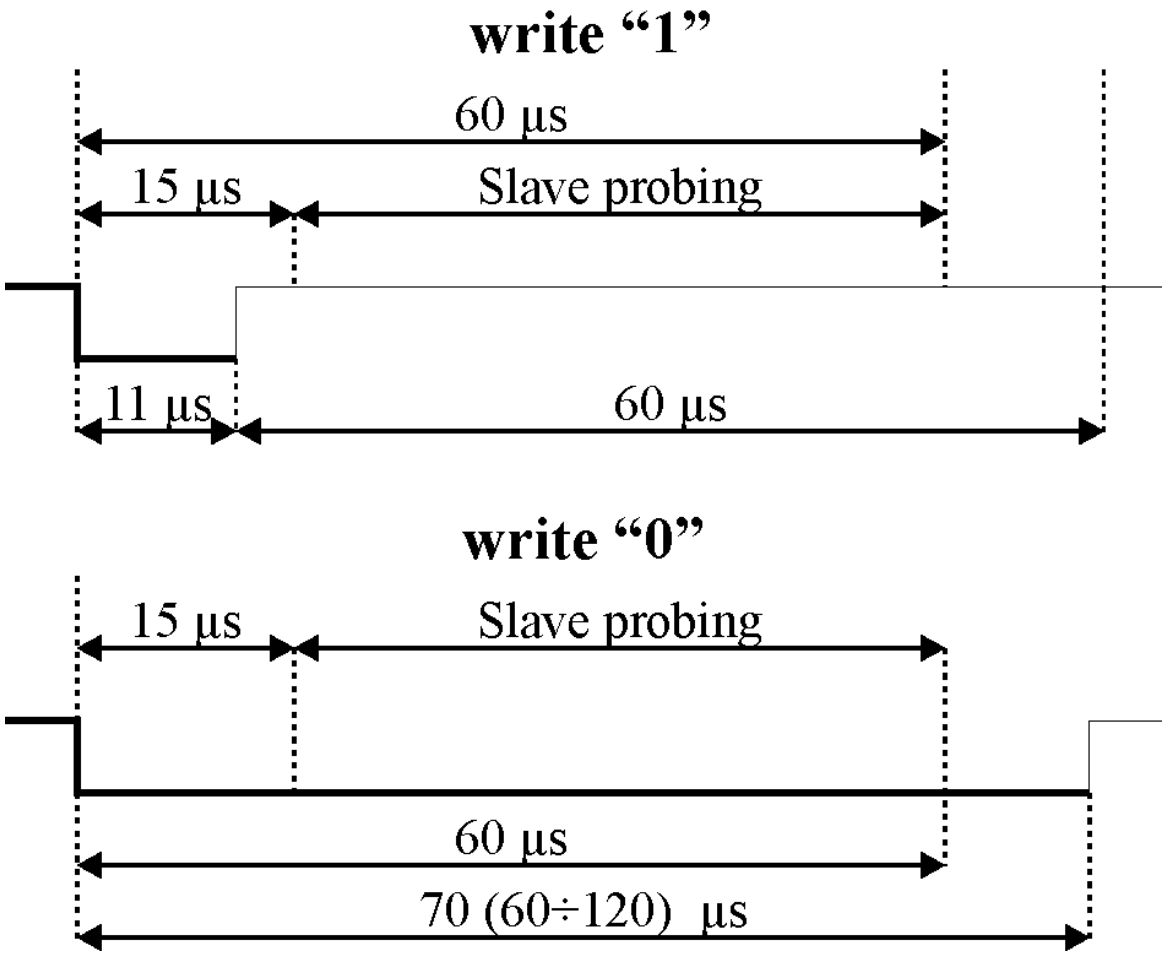
- 1-Wire – transmission
  - Initiation
    - Reset pulse from Master (≤480µs)
    - Presence pulse from Slave (15÷60µs)



    - „0”≥480µs → Slave power off
    - „1” after power off → power on reset

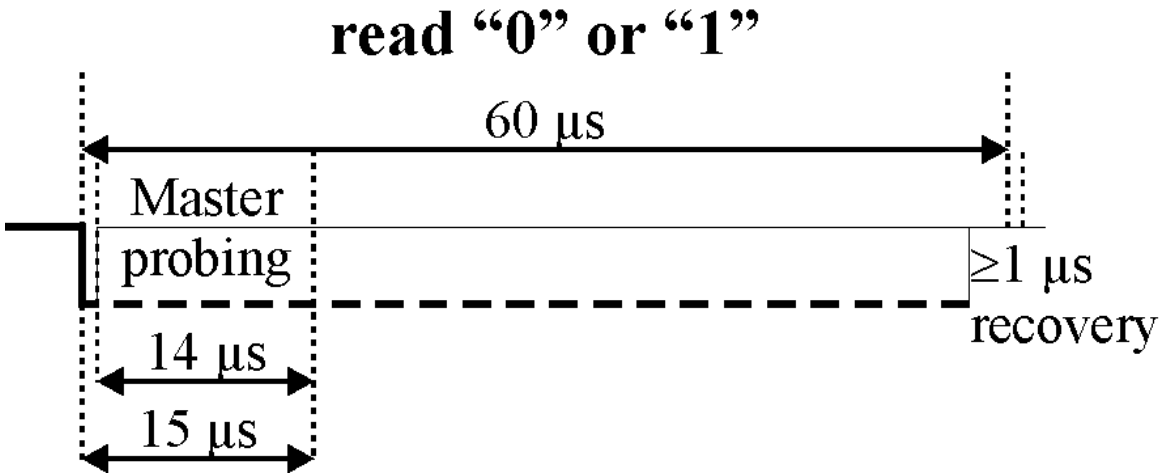
Serial buses & interfaces

- 1-Wire – transmission
  - Master → Slave



Serial buses & interfaces

- 1-Wire – transmission
  - Slave → Master

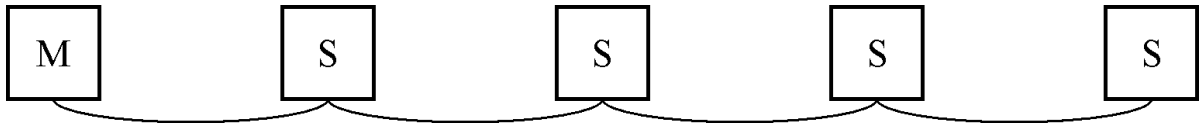


Serial buses & interfaces

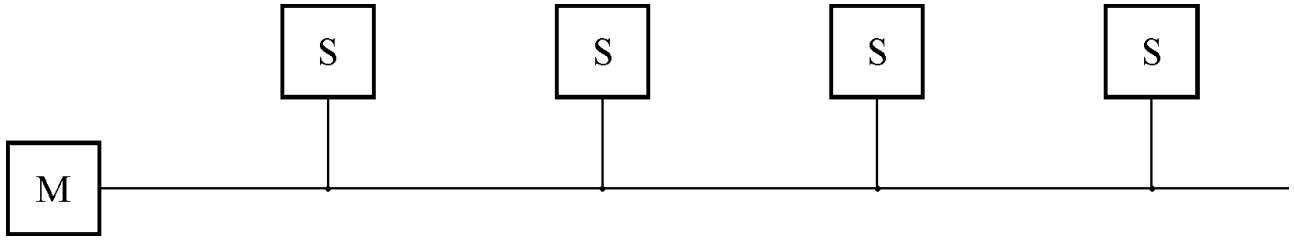
- 1-Wire – addressing
  - Unique device ID
    - B0: IC group code
    - B1÷B6: unique IC ID
    - B7: CRC
  - Search for devices ID
    - Number of connected devices
    - Devices ID’s
    - Binary-tree search based
      - Normal search – all devices connected
      - Conditional search – only „alarm-state” devices (result ready)

Serial buses & interfaces

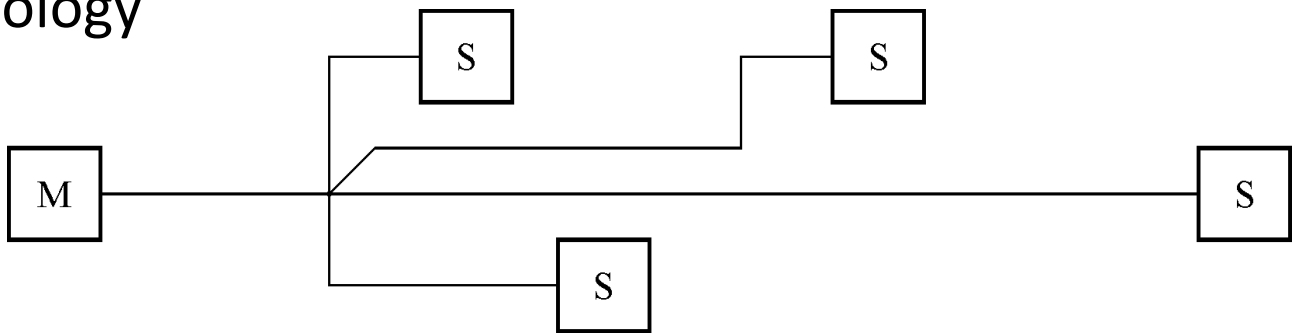
- 1-Wire – MicroLAN
  - Simple/complex network of 1-Wire devices
    - Line topology



    - Tree topology

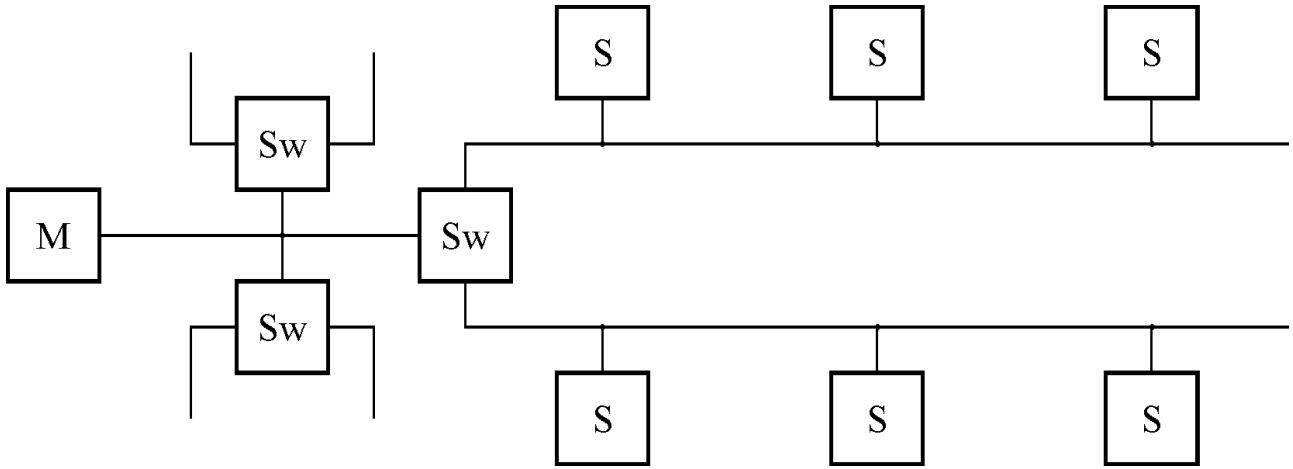


    - Star topology



Serial buses & interfaces

- 1-Wire – MicroLAN
  - Simple/complex network of 1-Wire devices
    - Complex topology



    - DS2409 switch
      - „1-Wire 1-to-2 mux”
      - Control output

Serial buses & interfaces

- 1-Wire – „iButton”

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