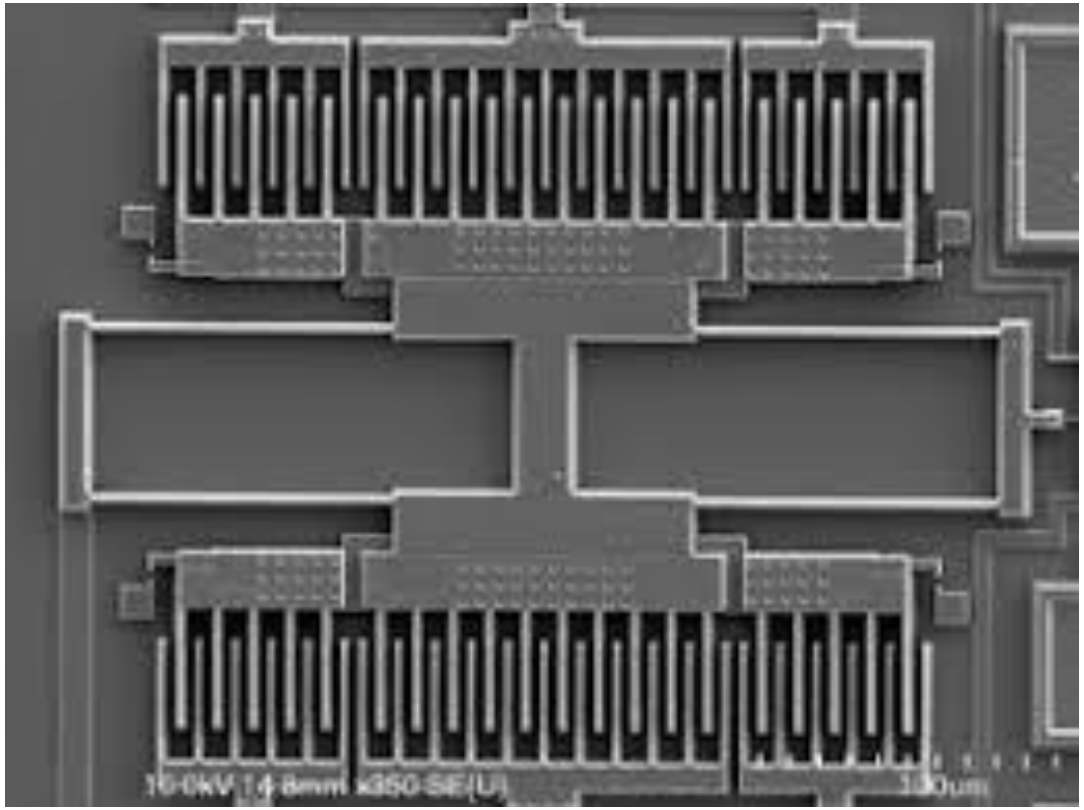
Lecture AMH1 – Analog and digital signals

Dr. Aftab M. Hussain,

Assistant Professor, PATRIoT Lab, CVEST

Sensor systems

- Sensor systems consist of the actual transducer converting a physical signal to electrical, followed by a readout circuit that converts that signal into readable form
- Say in a comb drive structure, we have change in capacitance for given acceleration
- That is converted into change in voltage, amplified, filtered and presented at the output



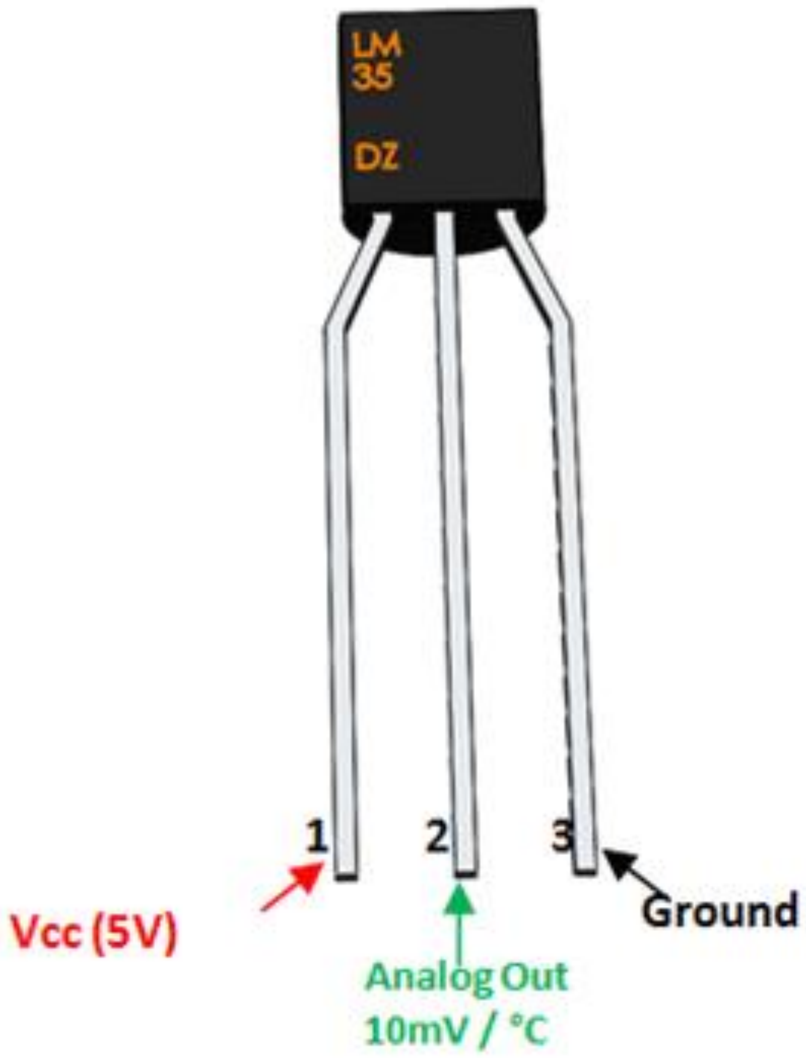
Sensor outputs

- At the output, there are many ways of presenting a sensor reading
- Broadly sensor values can be presented as:
  - Analog signals
  - Digital signals

- Similarly, when communicating with an actuator, the actuator drive circuity acts as a mediator between the actual transducer and the microcontroller

Sensor outputs – Analog

- Analog output is the simplest form of output for a sensor
- It has two pins – the analog output and the ground
- The analog output can be fed directly to some controllers that have a built-in analog to digital convertor (like Arduino), in other cases, an external ADC is required (like Raspberry pi)
- NodeMCU has one “analog read” pin



Sensor outputs – Analog

- Selecting an ADC can be tricky – because analog signals are continuous in time as well as amplitude, and there digital counterparts are discrete in both
- In time axis, the “discreteness” is measured by sampling rate (generally in ksps or Msps)
- In voltage axis, the “discreteness” is measured in the output bits

Sensor outputs – Analog

$\frac{3.3}{4096}$ V $\underline{0.8 \text{ mV}}$

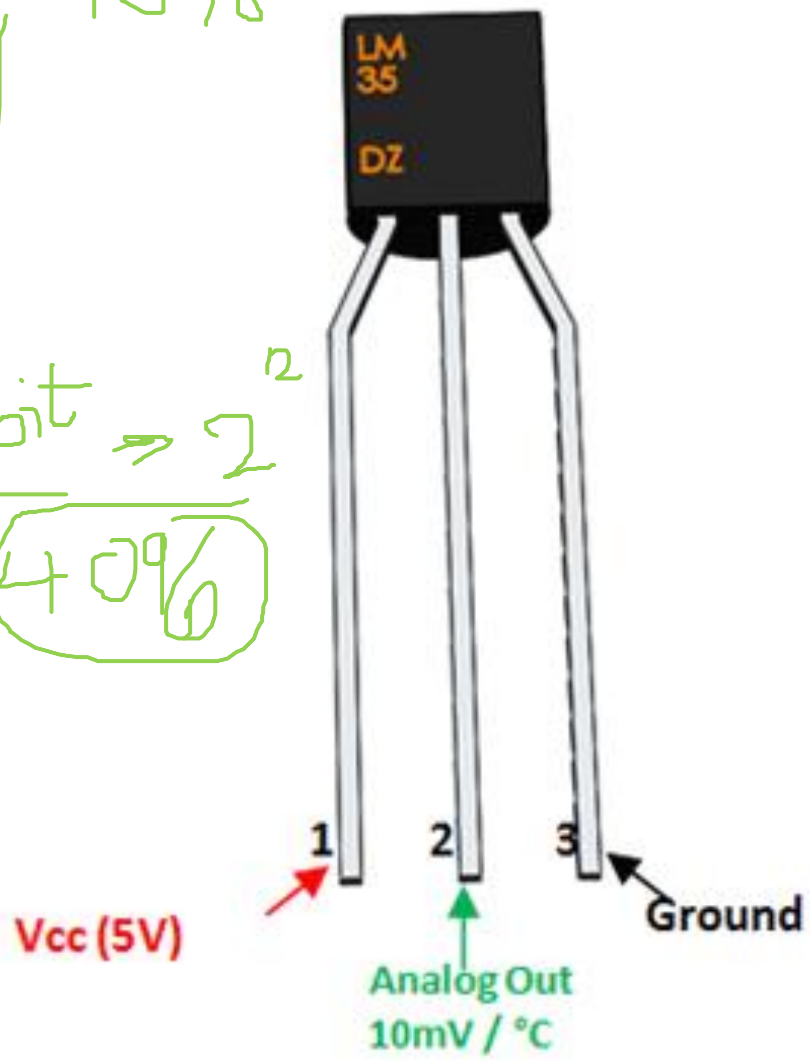
- Example: a 10-bit ADC can output a maximum of 1024 levels, so for a 5 V range, the difference in successive samples is ~5 mV
- Clearly, more bits and higher sampling frequency is ideal
- However, these are competing goals because more bits take more time to process reducing the sampling rate

3.3V

0

12-bit $\rightarrow 2^{12}$

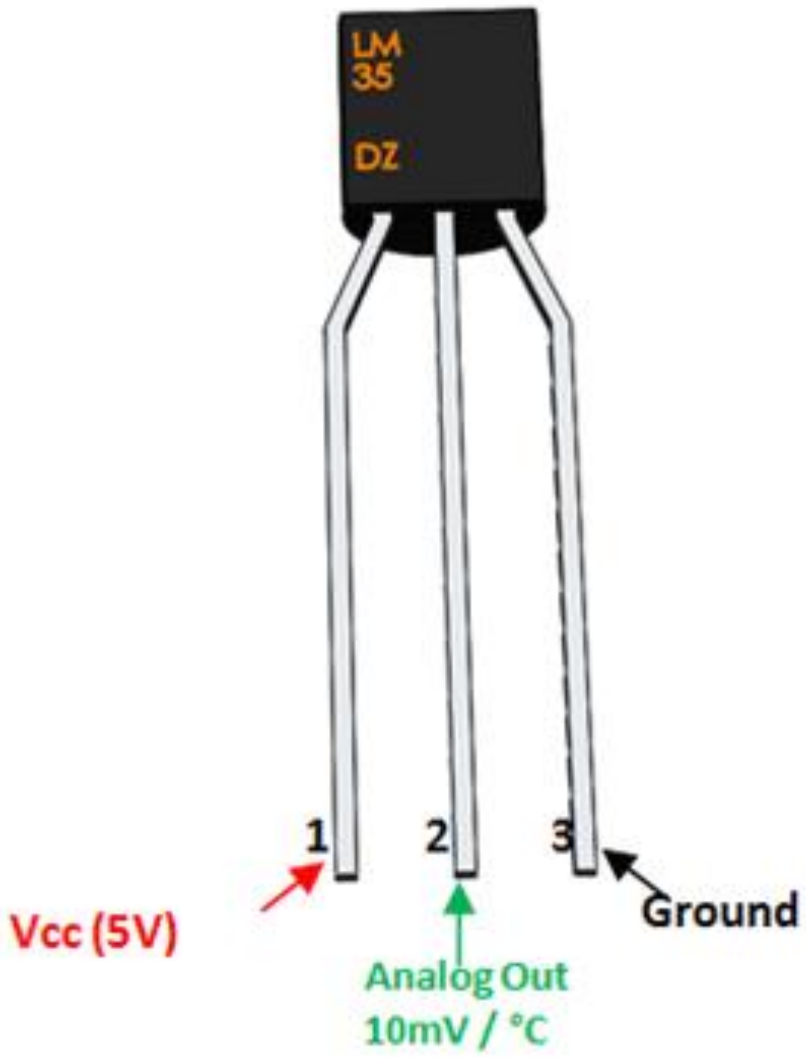
4096



Sensor outputs – Analog

- Advantages:
  - Simple implementation with an onboard ADC (single wire)
  - Continuous output – so can be on demand
  - Infinite resolution

- Problems
  - Needs an ADC
  - Very susceptible to noise
  - The “loading” effect

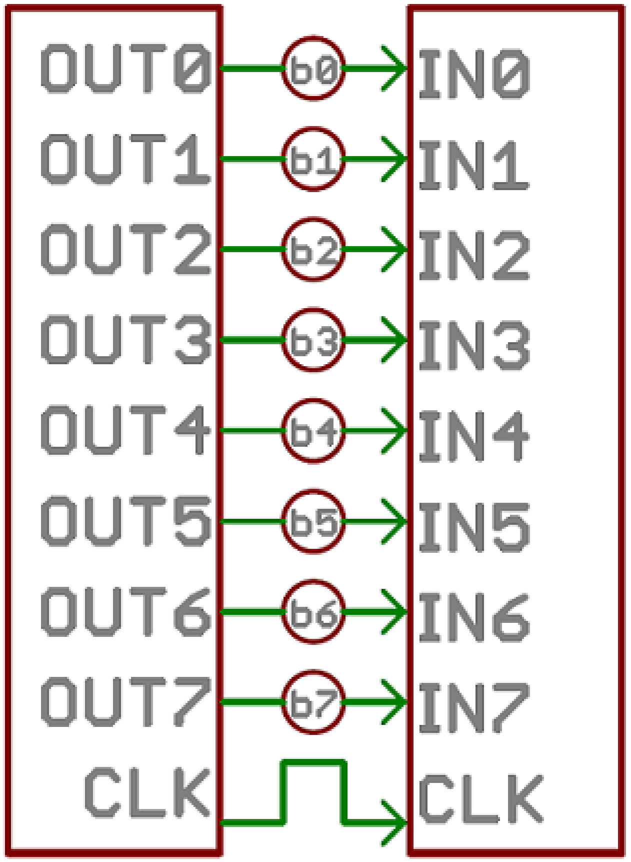


Sensor outputs – Digital

- Digital communication is preferred over analog because it is less susceptible to noise
- There are multiple ways in which you can obtain digital
- Parallel – with each bit on a separate wire
- Serial – with bit transmitted one after the other
- In serial communication we can different protocols:
  - UART (asynchronous)
  - SPI (synchronous)
  - I2C (synchronous)

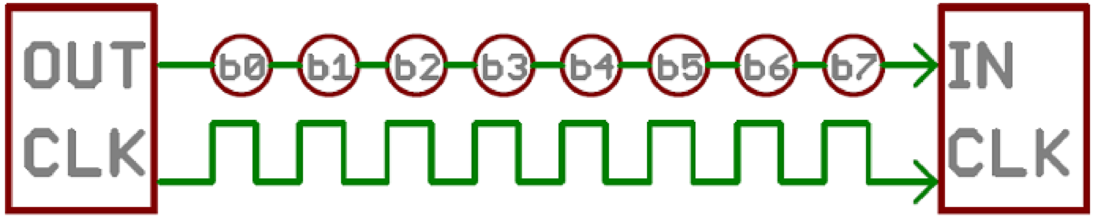
Sensor outputs – Digital – Parallel

- Parallel interfaces transfer multiple bits at the same time
- They usually require **buses** of data - transmitting across eight, sixteen, or more wires
- Advantages:
  - Very high data rates (single clock transfer)
  - Easy to implement
- Disadvantages:
  - Large number of data lines required, specially if number of peripherals are large



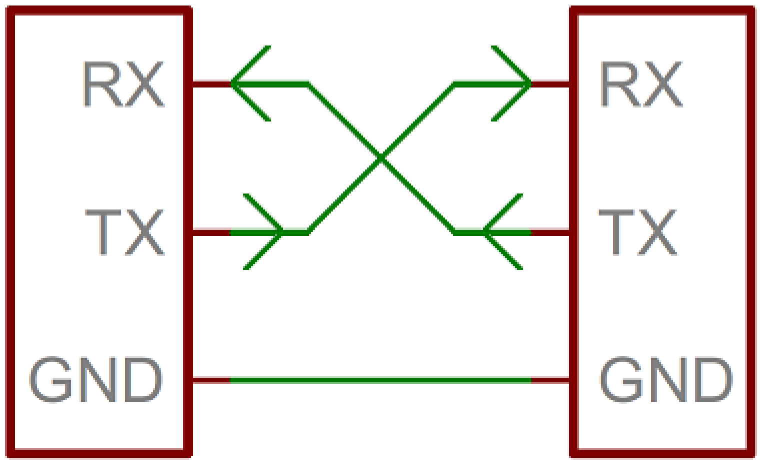
Sensor outputs – Digital – Serial

- Serial interfaces stream their data, one single bit at a time
- These interfaces can operate on as little as one wire
- Serial interfaces can be synchronous and asynchronous
- A synchronous serial interface always pairs its data line(s) with a clock signal, so all devices on a synchronous serial bus share a common clock
- Asynchronous means that data is transferred without support from an external clock signal



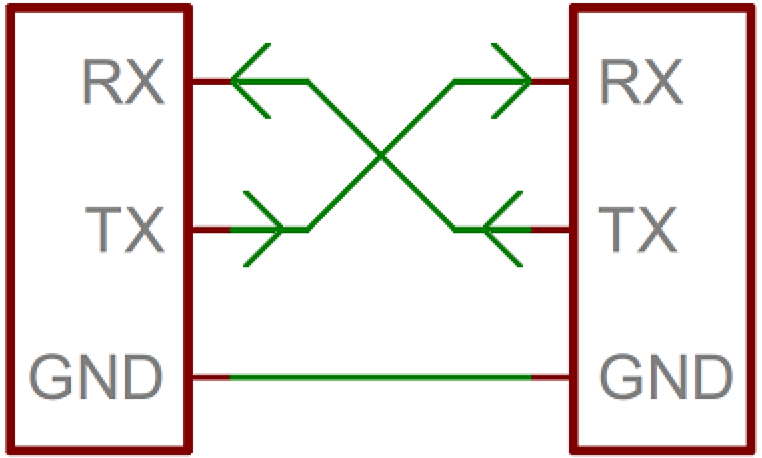
Sensor outputs – Digital – UART

- A universal asynchronous receiver/transmitter (UART) is a serial communication protocol that employs two lines Tx and Rx for communication
- UART support is commonly found inside microcontrollers
- For example, the Arduino Uno - based on the "old faithful" ATmega328 - has just a single UART, while the Arduino Mega - built on an ATmega2560 - has a whopping four UARTs
- NodeMCU has two UARTs



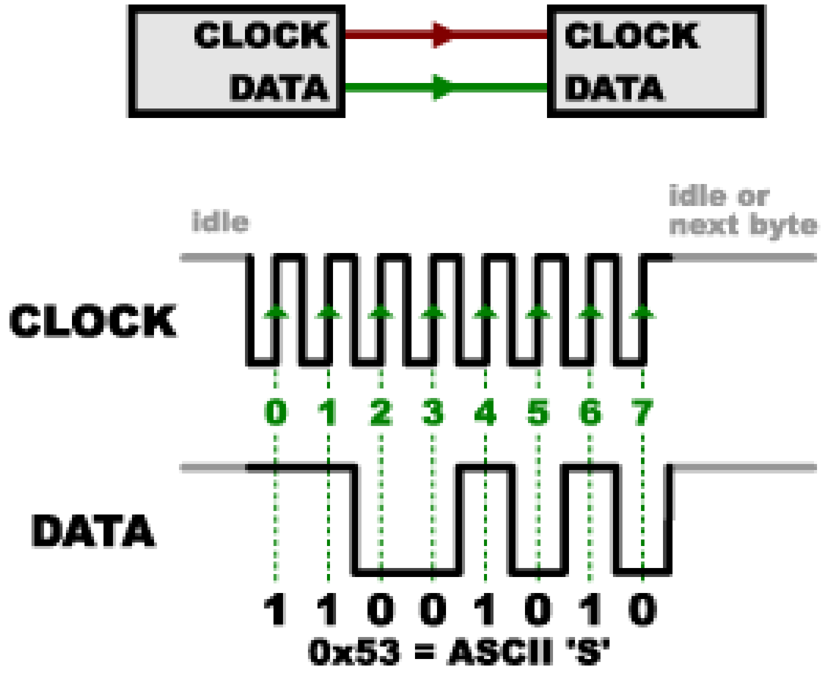
Sensor outputs – Digital – UART

- Advantages:
  - Two line communication
  - Simple to implement in software
  - Legacy protocol
- Disadvantages:
  - No synchronization means we have to make “baud rates” equal manually before communication
  - Low data rate – general baud rate is 9600 bits per second
  - Hardware implementation is complex
  - Needs start and stop bits to sync – which can be wasteful
  - Rx and Tx pins can be very confusing!



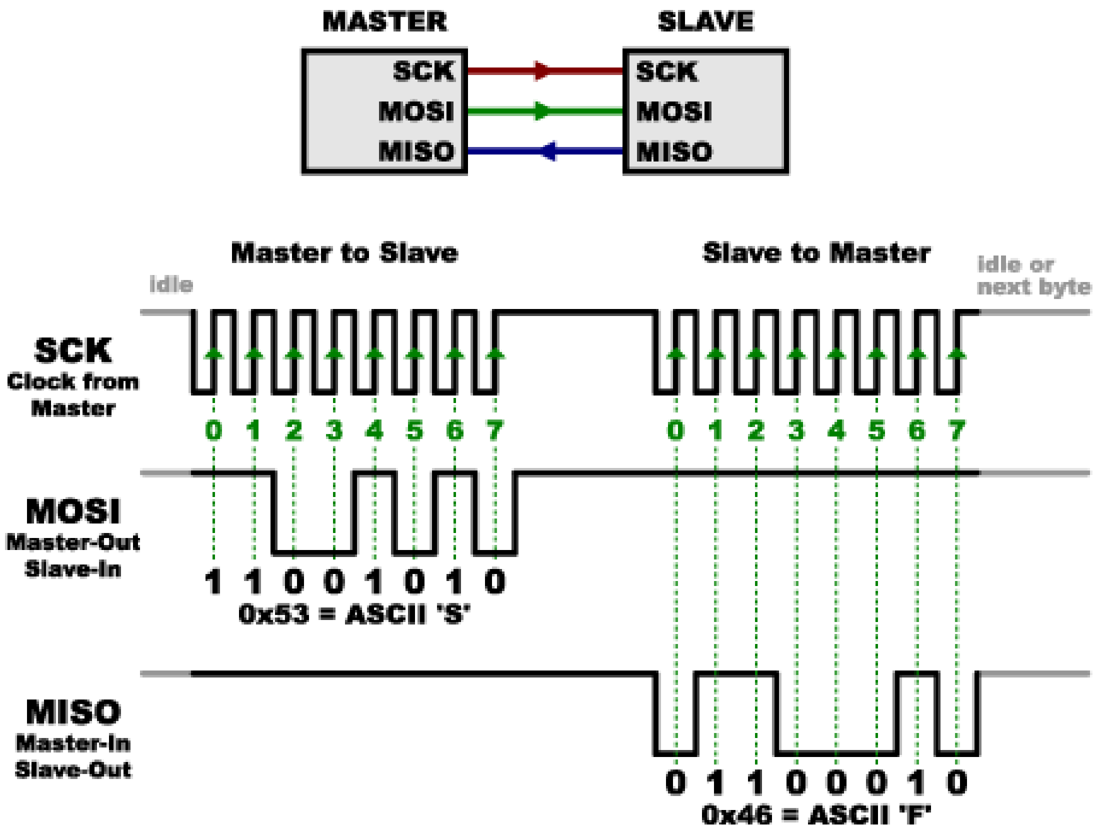
Sensor outputs – Digital – SPI

- SPI is serial peripheral interface
- It's a "synchronous" data bus, which means that it uses separate lines for data and a "clock" that keeps both sides in perfect sync
- The clock is an oscillating signal that tells the receiver exactly when to sample the bits on the data line
- When the receiver detects that edge, it will immediately look at the data line to read the next bit
- Because the clock is sent along with the data, specifying the speed isn't important, although devices will have a top speed at which they can operate



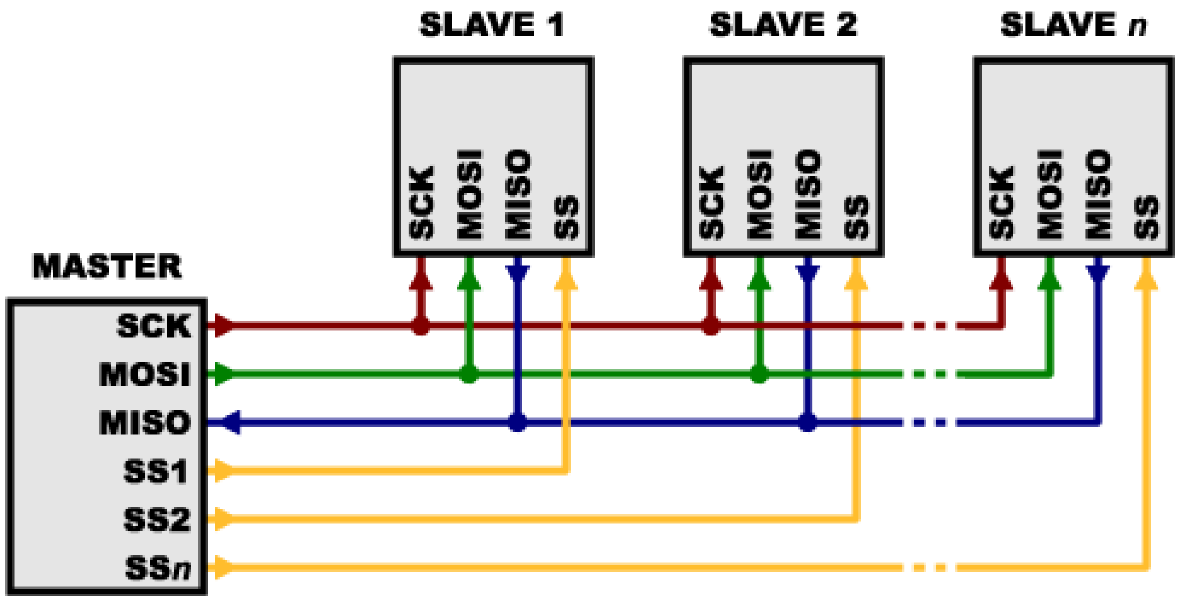
Sensor outputs – Digital – SPI

- We can also configure SPI for duplex communication
- In SPI, only one side generates the clock signal (usually called CLK or SCK for Serial ClocK)
- The side that generates the clock is called the "master", and the other side is called the “slave”
- When data is sent from the master to a slave, it's sent on a data line called MOSI, for "Master Out / Slave In“
- If the slave needs to send a response back to the master, the master will continue to generate a prearranged number of clock cycles, and the slave will put the data onto a third data line called MISO, for "Master In / Slave Out"



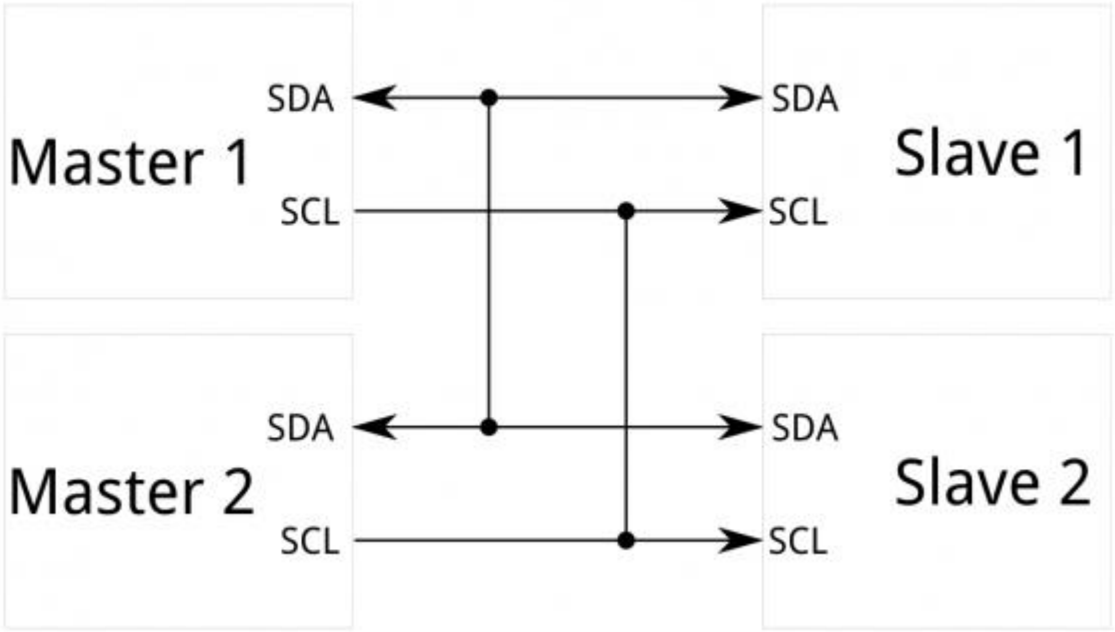
Sensor outputs – Digital – SPI

- Lastly, we can configure SPI for multiple slaves using the same lines for Sclk, MOSI and MISO, but different "slave select" lines
- With this, the slave with its slave select that is enabled will communicate with the master on the same bus, while the others await their turn
- SPI has lots of advantages:
  - Its synchronous so no prearranged baud rates and no start/stop bits
  - Multiple devices on a single bus
- Disadvantages:
  - Too many lines in case of many slaves
  - Only one master per bus



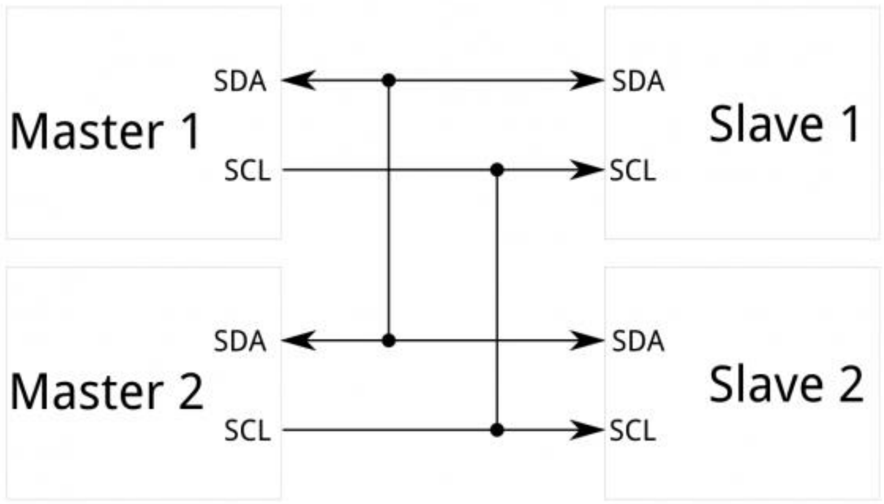
Sensor outputs – Digital – I2C

- The Inter-integrated Circuit (I^2C or I2C) Protocol is a protocol intended to allow multiple slaves to communicate with one or more "master" chips
- I^2C requires a mere two wires, like asynchronous serial, but those two wires can support up to 1008 slave devices
- Also, unlike SPI, I^2C can support a multi-master system, allowing more than one master to communicate with all devices on the bus



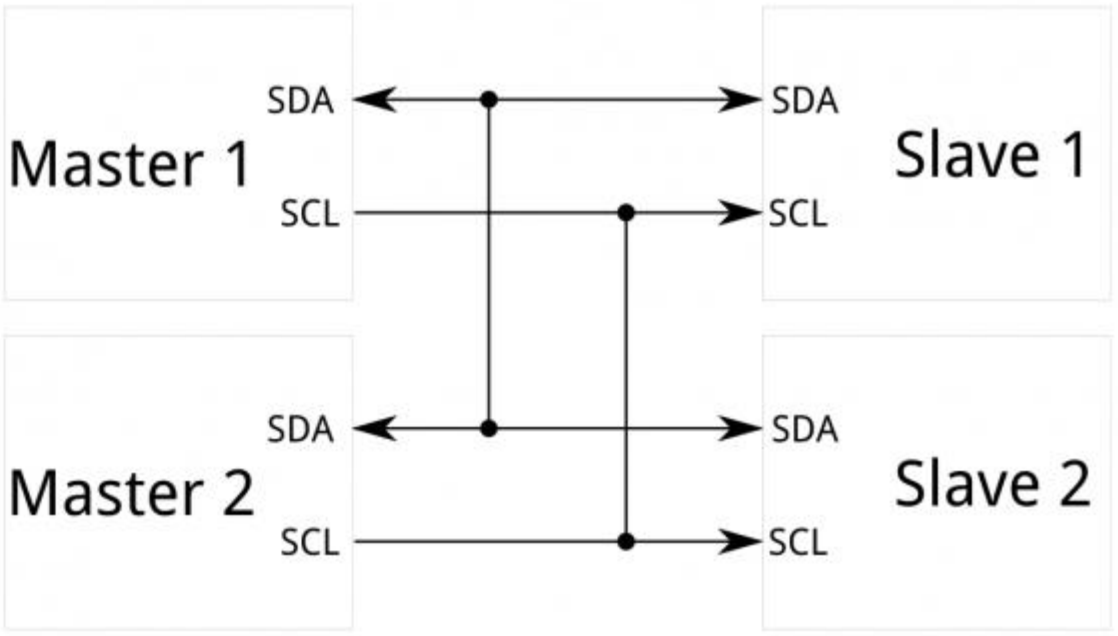
Sensor outputs – Digital – I2C

- Each I^2C bus consists of two signals: SCL and SDA. SCL is the clock signal, and SDA is the data signal
- The clock signal is always generated by the current bus master
- Unlike UART or SPI connections, the I2C bus drivers are "open drain", meaning that they can pull the corresponding signal line low, but cannot drive it high
- Thus, there can be no bus contention where one device is trying to drive the line high while another tries to pull it low
- Each signal line has a pull-up resistor on it, to restore the signal to high when no device is asserting it low



Sensor outputs – Digital – I2C

- Because the devices on the bus don't actually drive the signals high, I^2C allows for some flexibility in connecting devices with different I/O voltages
- In general, in a system where one device is at a higher voltage than another, it may be possible to connect the two devices via I^2C without any level shifting circuitry in between them
- The trick is to connect the pull-up resistors to the lower of the two voltages
- Although this only works in cases where the lower of the two system voltages exceeds the high-level input voltage of the the higher voltage system - for example, a 5V Arduino and a 3.3V peripheral



Sensor outputs – Digital – I2C

- In practice, most I2C peripherals have a defined address – or changeable address based on some external hardware pins
- The device address is first put on the SDA after the SCL is activated so that the correct slave can listen and respond
- Devices are addressed using a 10-bit address with a total of 1008 addresses possible
- In practice, if more than one I2C peripheral is to be connected, make sure there is only one pull up resistance for the complete bus