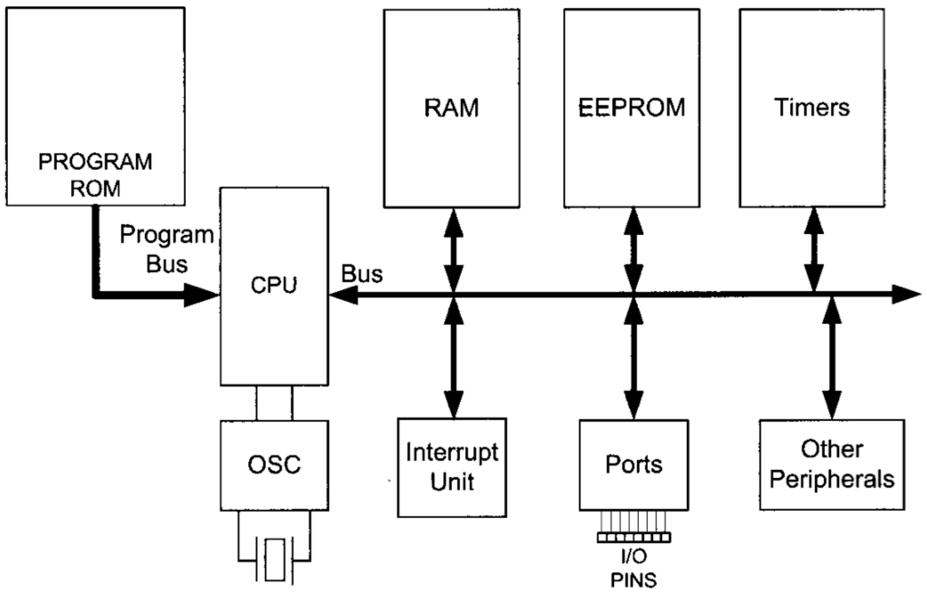
Outline

- Serial Peripheral Interface (SPI)
- Introduction to Analog-to-Digital Convertor
- Example of device with SPI and analog interface
  - MCP9700A: Low-Power Linear Active Thermistor ICs
  - MCP3201: 12-bit A/D Converter with SPI Interface

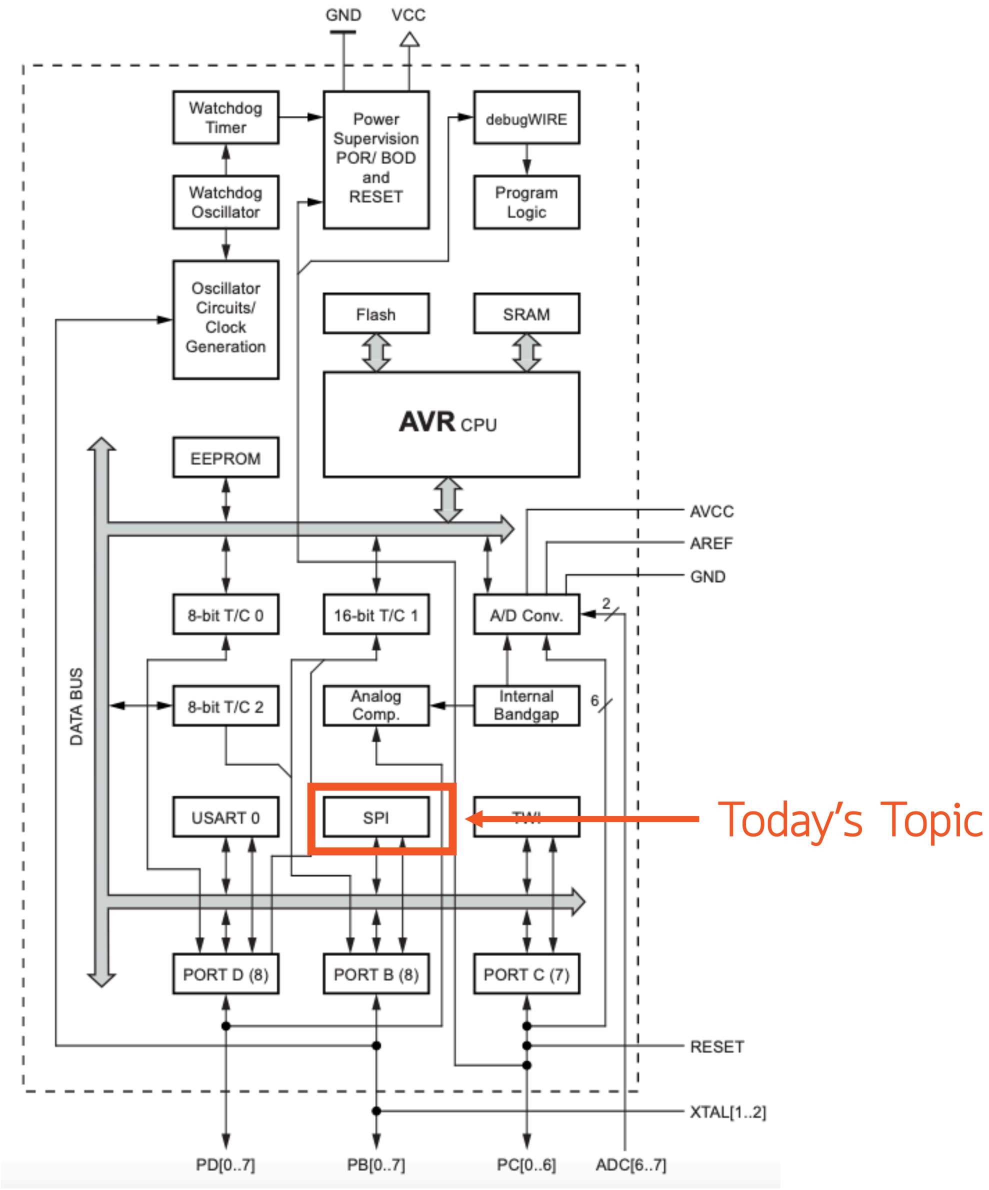
AVR SPI

(Serial Peripheral Interface)

Recall AVR Architecture



Simplified AVR Architecture



ATMega328P Architecture

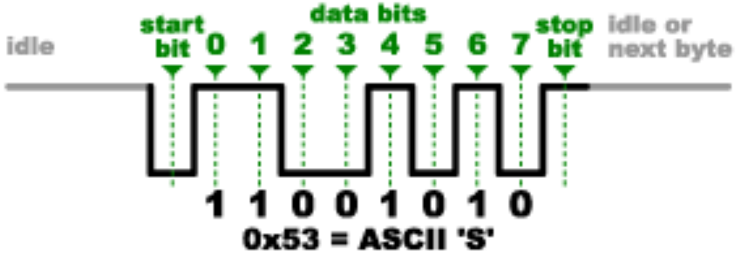
UART Drawbacks

↳ ข้อดี สายน้อย, เป็นที่นิยม

(parity bit, start bit, stop bit)

- Extra start and stop bits are needed for synchronization (more overhead)
- Complex hardware required to send and receive data
- Erroneous transmission when both sides aren't operated at the same speed

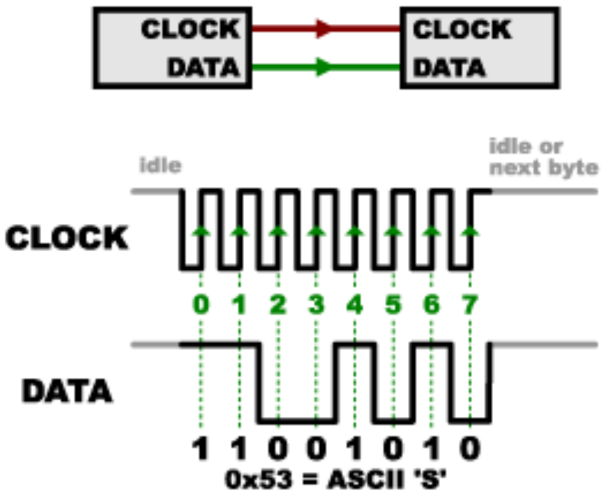
เกิด Error



Source: https://learn.sparkfun.com/tutorials/serial-peripheral-interface-spi/all

Synchronous Serial Communication

- Separate lines for data and clock signals
- Clock tells the receiver exactly when to sample the bits on the data line (could be the falling or the rising edge)

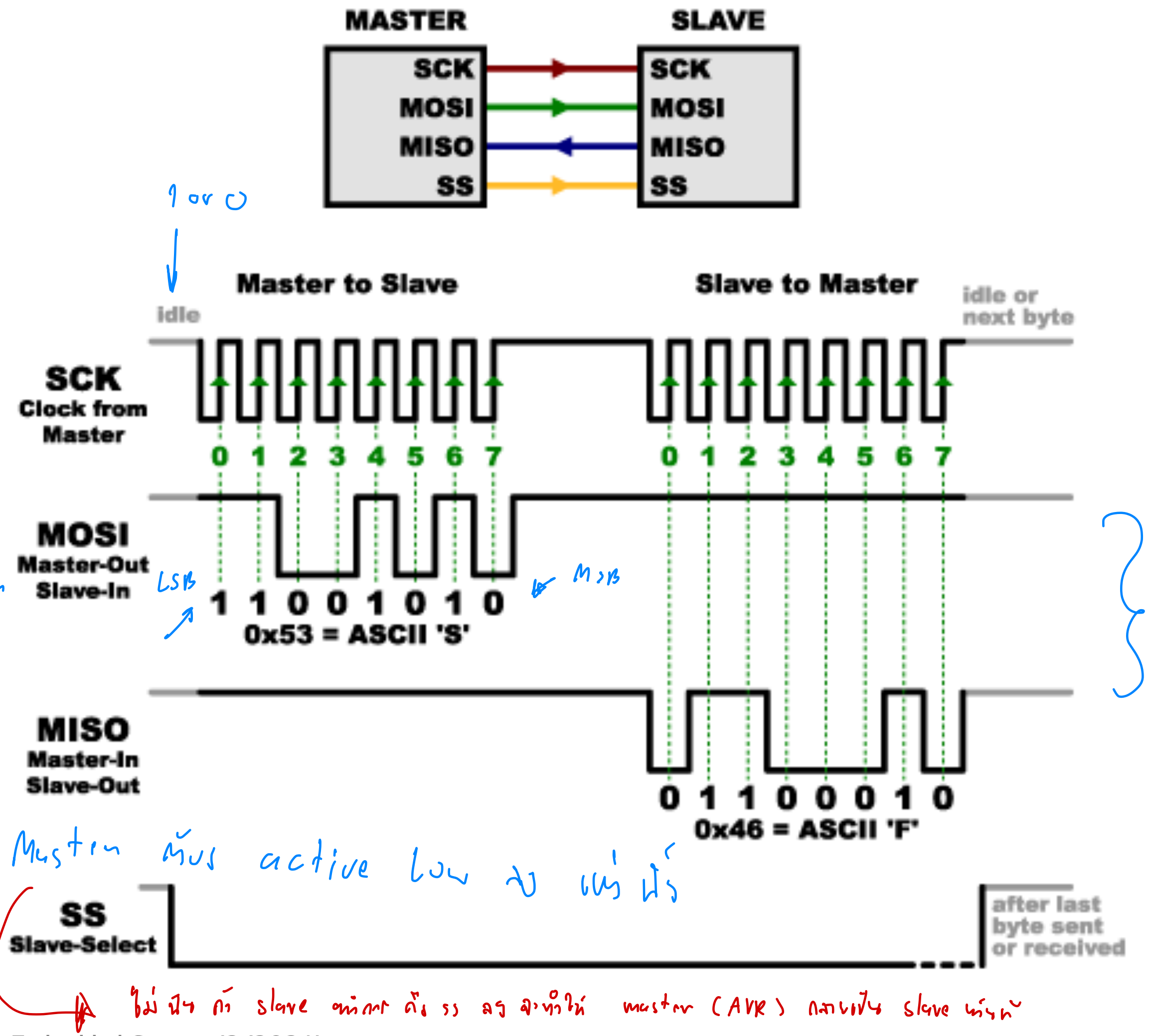


Source: https://learn.sparkfun.com/tutorials/serial-peripheral-interface-spi/all

Serial Peripheral Interface (SPI)

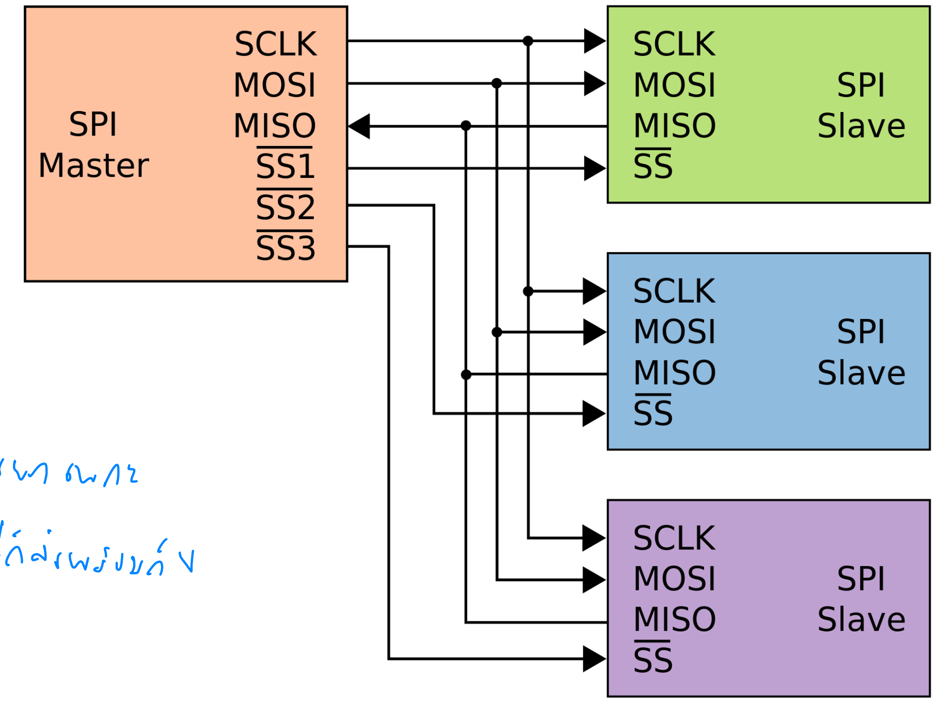
- Synchronous, full duplex master-slave-based interface with support for multiple slaves' device
- Clock is generated on the SCK (serial clock) line by the master
- Data is sent from the master to a slave using the MOSI (master out / slave in) line and from a slave to the master on the MISO (master in / slave out) line
- Chip Select (CS) line is used by the master to select a slave to communicate with

Serial Peripheral Interface (SPI)



ที่แยกเฉพาะ
จะได้ส่งพร้อมกัน

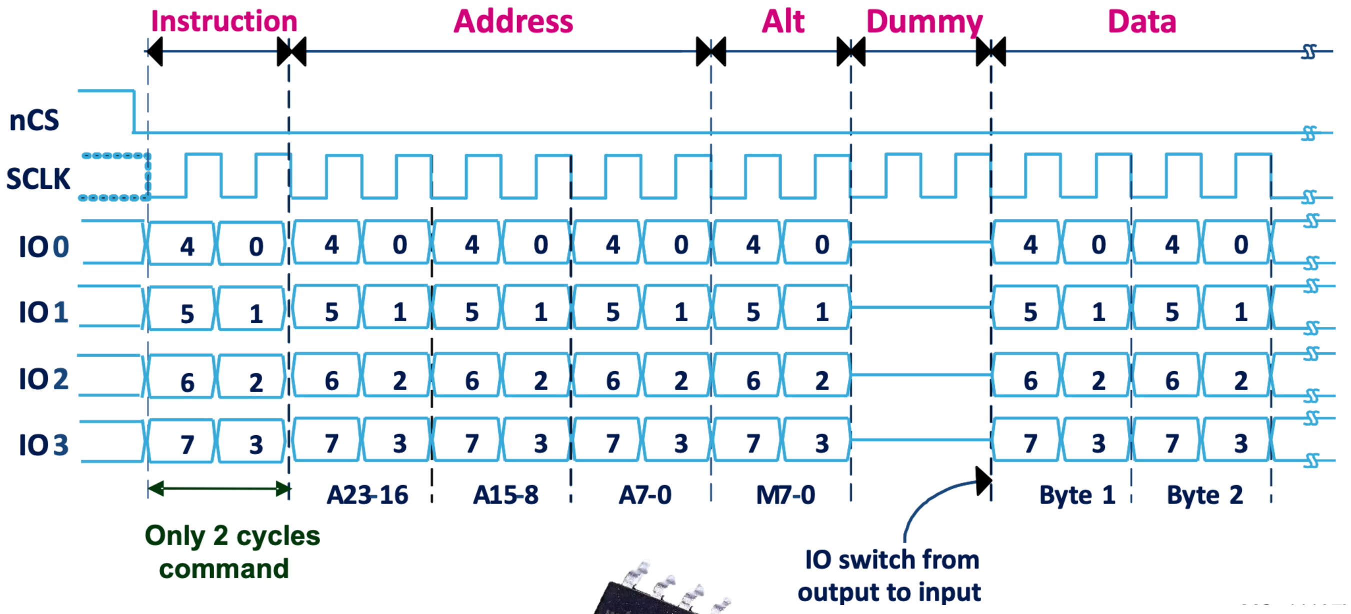
SPI connection with multiple slave devices



Dual/Quad/Daisy-chain SPI

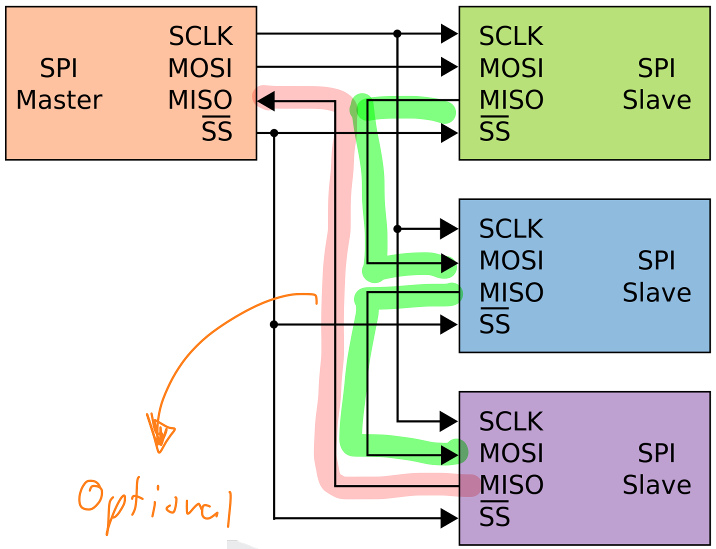
Dual/Quad-SPI Interface Timing Diagram

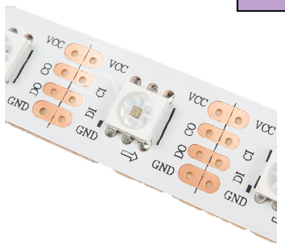
found in many flash memory and high-speed devices



Daisy-chain SPI Connection Diagram

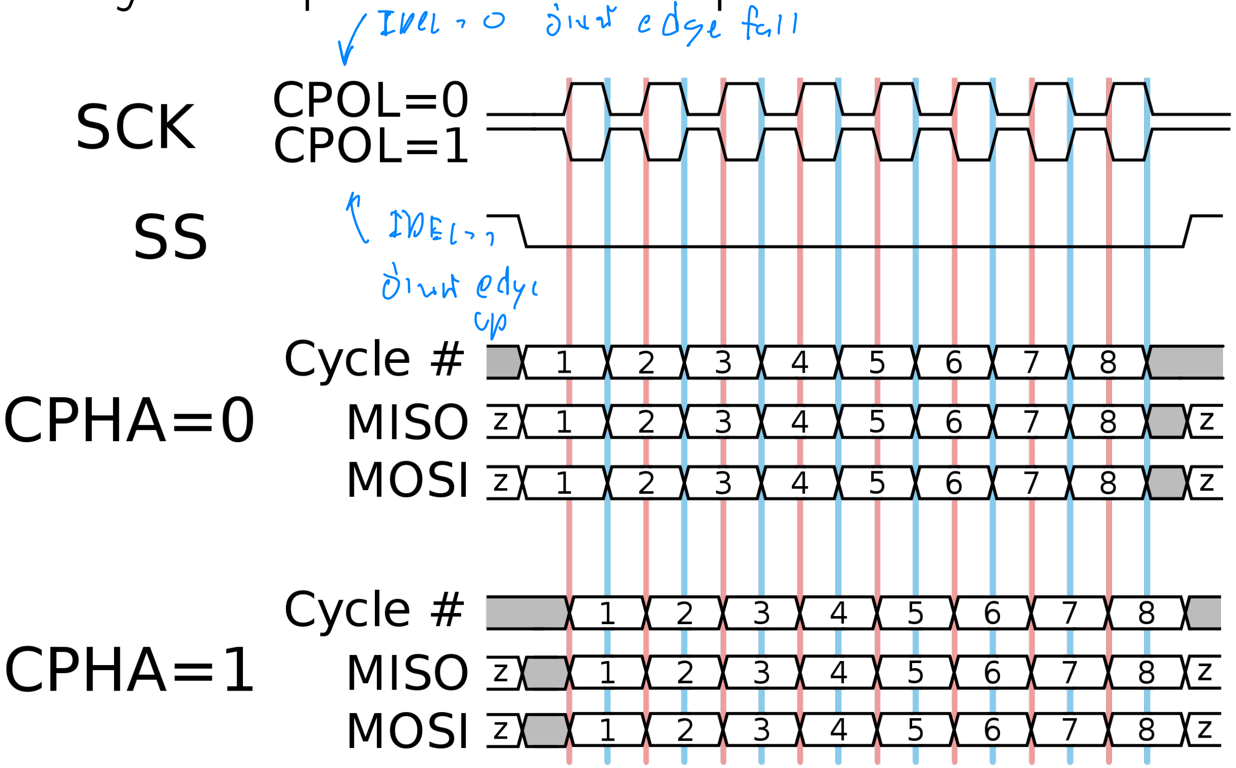
found in some addressable LED strip





Clock Polarity and Phase

- In addition to the clock frequency, the master must configure the clock polarity and phase with respect to the data



The options are usually named CPOL and CPHA (for clock polarity and phase) respectively by convention

SPI Modes

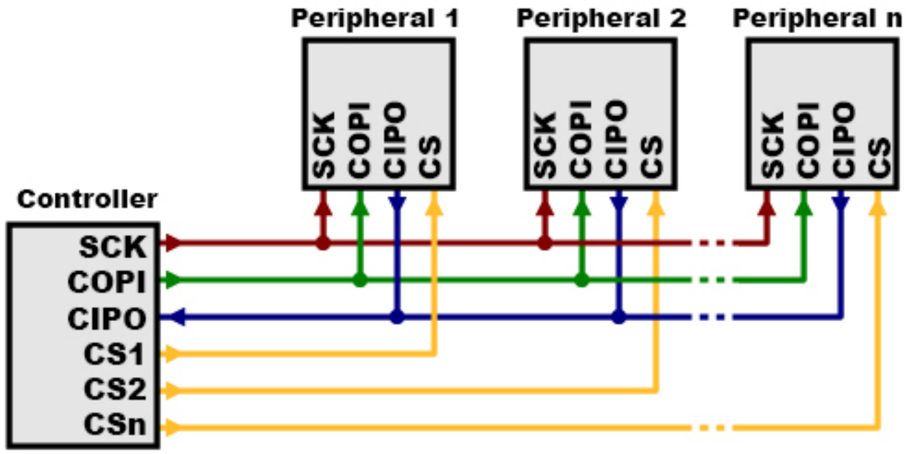
The combinations of CPOL and CPHA are often referred to as SPI modes which are commonly numbered with CPOL as the high order bit and CPHA as the low order bit

Table 19-2. SPI Modes

SPI Mode	Conditions	Leading Edge	Trailing eDge
0	CPOL=0, CPHA=0	Sample (Rising)	Setup (Falling)
1	CPOL=0, CPHA=1	Setup (Rising)	Sample (Falling)
2	CPOL=1, CPHA=0	Sample (Falling)	Setup (Rising)
3	CPOL=1, CPHA=1	Setup (Falling)	Sample (Rising)

SPI Signal Names Redefinition

- In June 2020, the Open-Source Hardware Association has released a resolution to redefine SPI signal names by discontinuing the term Master and Slave

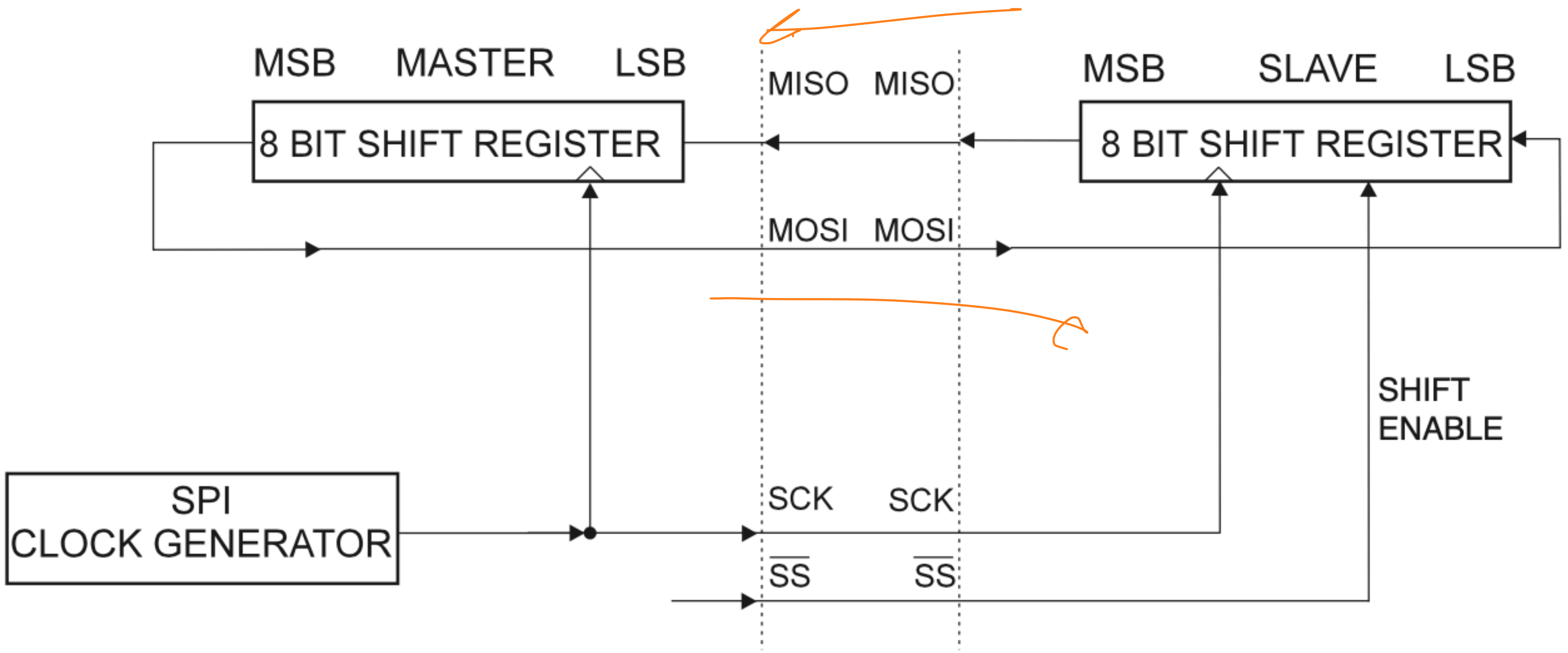


MOSI -> COPI (controller out / peripheral in)
MISO -> CIPO (controller in / peripheral out)

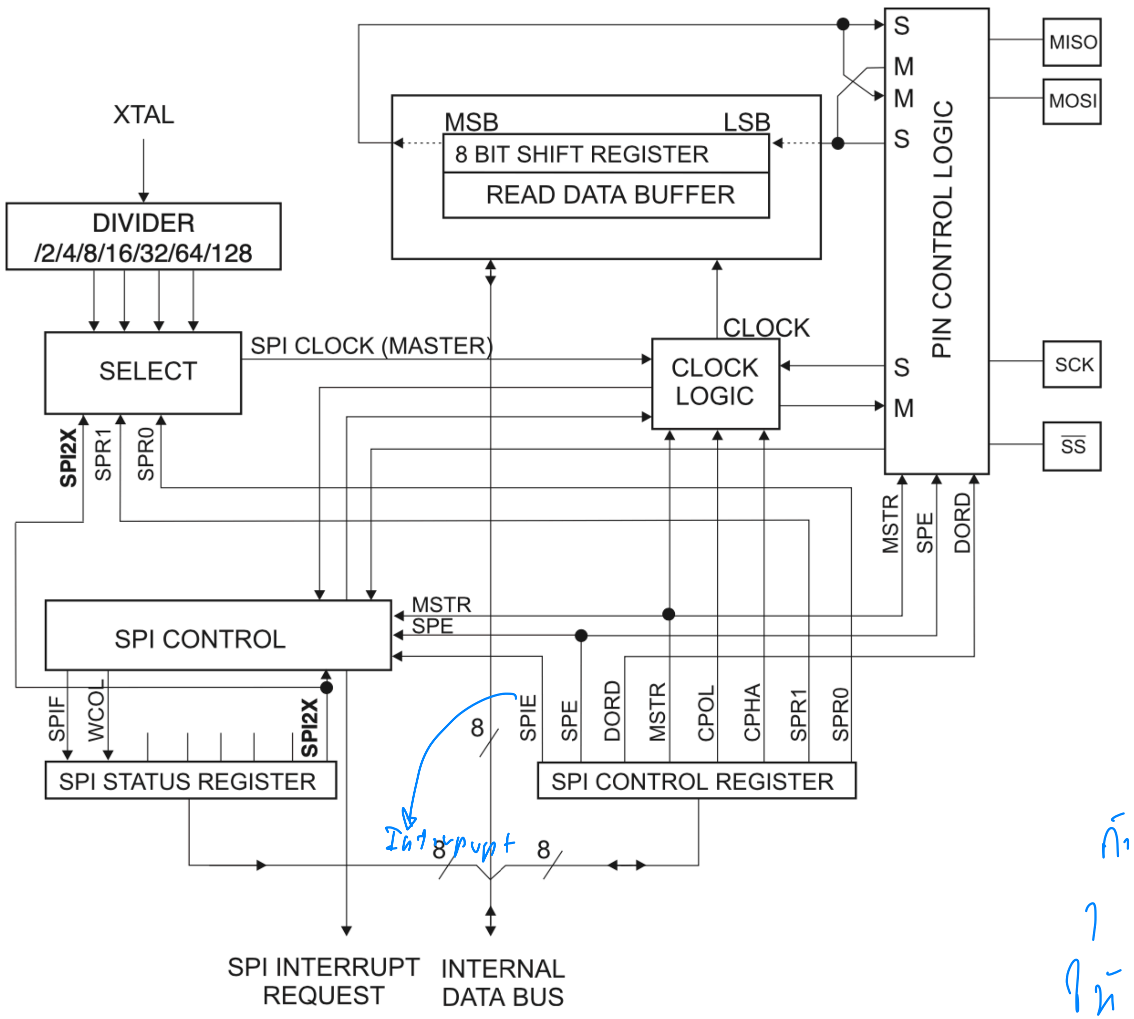
In addition, we usually found the term SDO (Serial Data Out) and SDI (Serial Data In) used in many peripheral devices

Simplify SPI Hardware Implementation

Full Duplex



AVR SPI Module: Block Diagram



SPE => SPI Enable SPCR |= (1<<SPE);

DORD => 1 - LSB first, 0 - MSB first

MSTR => 1 - Master, 0 - Slave
(output) (Input)

*** SS should be output when MSTR is set to 1
DDR = n

CPOL/CPHA => SPI Mode

SPR[1:0] => Clock frequency

SPI2X => Double SPI speed (use with SPR[1:0])

SPIF => Set when serial transfer has completed

*** SPIF will be cleared automatically when we access SPDR after access SPSR while SPIF is set

ก็เป็น 1

ให้อ่าน SPDR ก่อน แล้ว clear SPIF เป็น 0

Pros & Cons

Advantages

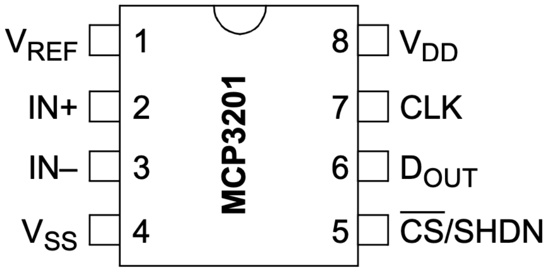
- High speed (compare to asynchronous serial)
- Simpler software/hardware implementation
- Support multiple slaves

Disadvantages

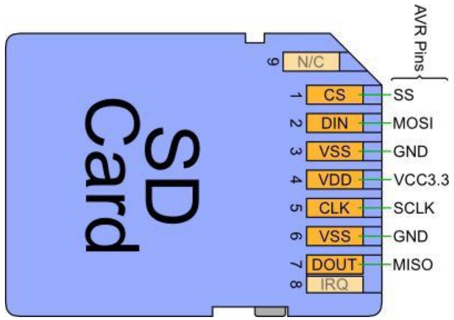
- Require more signal lines
- Data format must be well-defined in advance
- Master controls all communications (no direct slave communication)
- Extra CS lines are needed for each peripheral

Example of the SPI devices

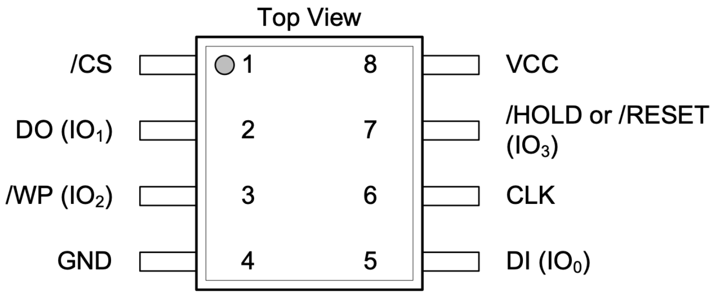
- Interfacing IC e.g. audio codecs, ADC, DAC etc.
- Sensors e.g. temperature, accelerometer, gyroscope etc.
- Memory e.g. flash, EEPROM, MMC, SD Card etc.



12-Bit A/D Converter
with SPI Serial Interface



SD Card

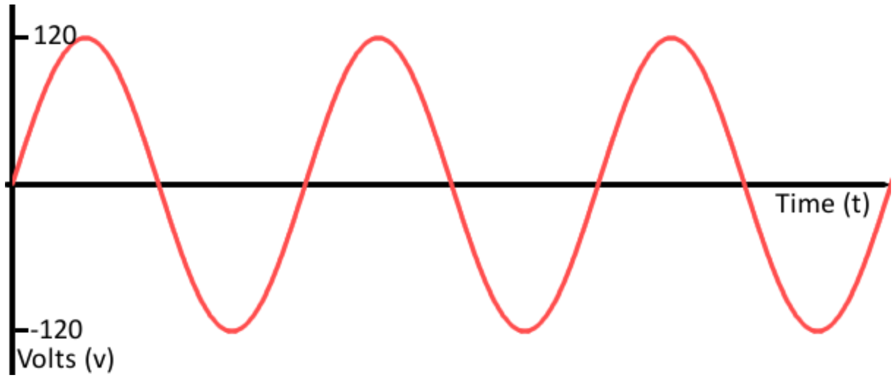


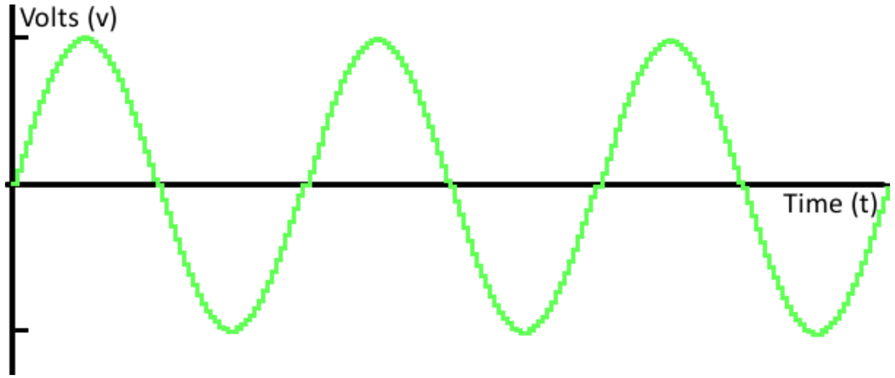
Serial Flash Memory
with Dual/Quad SPI interface

Introduction to Analog to Digital Converter (ADC)

Digital vs Analog Signal

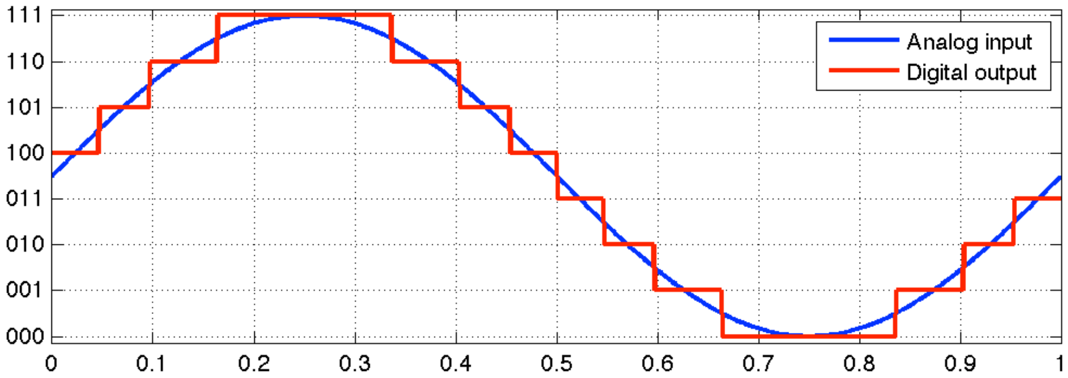
- Analog signals are continuous and have an infinite number of possible values within some range e.g. temperature, humidity etc.
- Digital signals have a limited set of values they can be e.g. HIGH/LOW, 000-111 etc.





Analog to Digital Converter (ADC)

- ADC is a device used to convert an analog signal into a digital signal that can be processed by a microcontroller and/or other digital devices
- ADC differs by its resolution, conversion time, voltage range, interface type, hardware implementation and number of channel



Some ADC Characteristics

- Resolution
  - 8, 10, 12, 16 or 24 bits are common in embedded system design
  - Higher-resolution provide a smaller step size (smallest voltage change that can be distinguished by an ADC)

$$\frac{\textit{Resolution of the ADC}}{\textit{System Voltage}} = \frac{\textit{ADC Reading}}{\textit{Analog Voltage Measured}}$$

$$\frac{1023}{5} = \frac{563}{x}$$

- Conversion time
- Reference voltage
- Interface (Parallel/Serial)
- Number of ADC channels

Example: Linear Active Thermistor ICs

MICROCHIP

MCP9700/9700A
MCP9701/9701A

Low-Power Linear Active Thermistor ICs

Features

- Tiny Analog Temperature Sensor
- Available Packages:
  - SC70-5, SOT-23-3, TO-92-3
- Wide Temperature Measurement Range:
  - -40°C to +125°C (Extended Temperature)
  - -40°C to +150°C (High Temperature) **(MCP9700,** SOT-23-3 and SC70-5 only**)**
- Accuracy:
  - ±2°C (max.), 0°C to +70°C **(MCP9700A/9701A)**
  - ±4°C (max.), 0°C to +70°C **(MCP9700/9701)**
- Optimized for Analog-to-Digital Converters (ADCs):
  - 10.0 mV/°C (typical) **(MCP9700/9700A)**
  - 19.5 mV/°C (typical) **(MCP9701/9701A)**
- Wide Operating Voltage Range:
  - V_{DD} = 2.3V to 5.5V **(MCP9700/9700A)**
  - V_{DD} = 3.1V to 5.5V **(MCP9701/9701A)**
- Low Operating Current: 6 µA (typical)
- Optimized to Drive Large Capacitive Loads

General Description

MCP9700/9700A and MCP9701/9701A sensors with Linear Active Thermistor Integrated Circuit (IC) comprise a family of analog temperature sensors that convert temperature to analog voltage.

The low-cost, low-power sensors feature an accuracy of ±2°C from 0°C to +70°C (MCP9700A/9701A) and ±4°C from 0°C to +70°C (MCP9700/9701) while consuming 6 µA (typical) of operating current.

Unlike resistive sensors, e.g., thermistors, the Linear Active Thermistor IC does not require an additional signal-conditioning circuit. Therefore, the biasing circuit development overhead for thermistor solutions can be avoided by implementing a sensor from these low-cost devices. The Voltage Output pin (V_{OUT}) can be directly connected to the ADC input of a microcontroller. The MCP9700/9700A and MCP9701/9701A temperature coefficients are scaled to provide a 1°C/bit resolution for an 8-bit ADC with a reference voltage of 2.5V and 5V, respectively. The MCP9700/9700A output 0.1°C/bit for a 12-bit ADC with 4.096V reference.

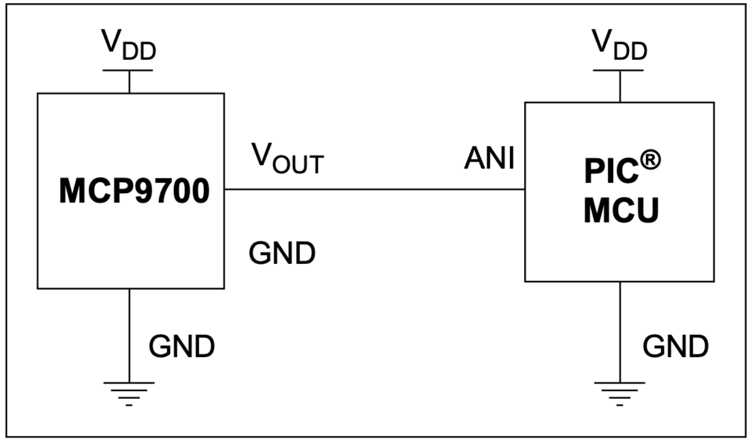
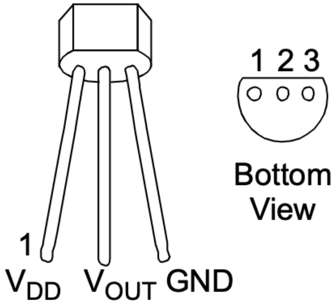


FIGURE 4-1: *Typical Application Circuit.*

3-Pin TO-92
MCP9700/9700A
MCP9701/9701A



Source: https://ww1.microchip.com/downloads/en/DeviceDoc/20001942G.pdf

MCP9700/1(A) Applications Information

4.0 APPLICATIONS INFORMATION

The Linear Active Thermistor™ IC uses an internal diode to measure temperature. The diode electrical characteristics have a temperature coefficient that provides a change in voltage based on the relative ambient temperature from -40°C to 150°C. The change in voltage is scaled to a temperature coefficient of 10.0 mV/°C (typical) for the MCP9700/9700A and 19.5 mV/°C (typical) for the MCP9701/9701A. The output voltage at 0°C is also scaled to 500 mV (typical) and 400 mV (typical) for the MCP9700/9700A and MCP9701/9701A, respectively. This linear scale is described in the first-order transfer function shown in Equation 4-1 and Figure 2-16.

EQUATION 4-1: SENSOR TRANSFER FUNCTION

$$V_{OUT} = T_C \times T_A + V_{0°C}$$

Where:

T_A = Ambient Temperature

V_{OUT} = Sensor Output Voltage

$V_{0°C}$ = Sensor Output Voltage at 0°C (see **DC Electrical Characteristics** table)

T_C = Temperature Coefficient (see **DC Electrical Characteristics** table)

Sensor Output						
Output Voltage, T_A = 0°C	$V_{0°C}$	—	500	—	mV	**MCP9700/9700A**
Output Voltage, T_A = 0°C	$V_{0°C}$	—	400	—	mV	**MCP9701/9701A**
Temperature Coefficient	T_C	—	10.0	—	mV/°C	**MCP9700/9700A**
	T_C	—	19.5	—	mV/°C	**MCP9701/9701A**
Output Nonlinearity	V_{ONL}	—	±0.5	—	°C	T_A = 0°C to +70°C (**Note 3**)

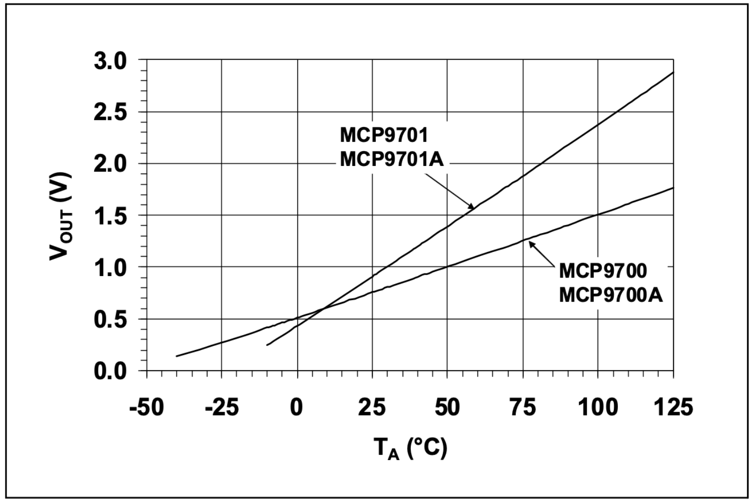


FIGURE 2-16: *Output Voltage vs. Ambient Temperature.*

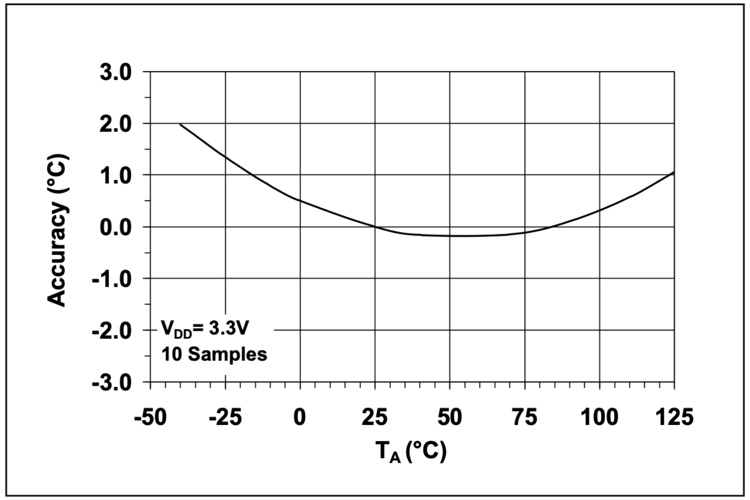


FIGURE 4-2: *Relative Accuracy to +25°C vs. Temperature.*

Example: Single-Channel, Serial 12-Bit ADCs

MICROCHIP

MCP3201

2.7V 12-Bit A/D Converter with SPI Serial Interface

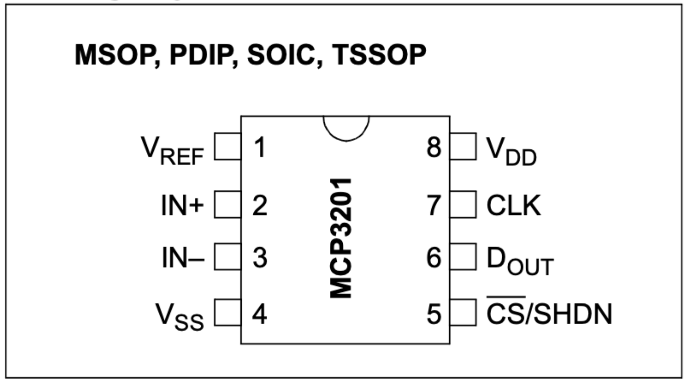
Features

- 12-Bit Resolution
- ±1 LSB max DNL
- ±1 LSB max INL (MCP3201-B)
- ±2 LSB max INL (MCP3201-C)
- On-chip Sample and Hold
- SPI Serial Interface (modes 0,0 and 1,1)
- Single Supply Operation: 2.7V - 5.5V
- 100 ksps Maximum Sampling Rate at V_{DD} = 5V
- 50 ksps Maximum Sampling Rate at V_{DD} = 2.7V
- Low-Power CMOS Technology
- 500 nA Typical Standby Current, 2 µA Maximum
- 400 µA Maximum Active Current at 5V
- Industrial Temp Range: -40°C to +85°C
- 8-pin MSOP, PDIP, SOIC and TSSOP Packages

Description

The Microchip Technology Inc. MCP3201 device is a successive approximation 12-bit Analog-to-Digital (A/D) Converter with on-board sample and hold circuitry. The device provides a single pseudo-differential input. Differential Nonlinearity (DNL) is specified at ±1 LSB, and Integral Nonlinearity (INL) is offered in ±1 LSB (MCP3201-B) and ±2 LSB (MCP3201-C) versions. Communication with the device is done using a simple serial interface compatible with the SPI protocol. The device is capable of sample rates of up to 100 ksps at a clock rate of 1.6 MHz. The MCP3201 device operates over a broad voltage range (2.7V-5.5V). Low-current design permits operation with typical standby and active currents of only 500 nA and 300 µA, respectively. The device is offered in 8-pin MSOP, PDIP, TSSOP and 150 mil SOIC packages.

Package Types



Source: https://ww1.microchip.com/downloads/en/DeviceDoc/21290F.pdf

MCP3201's Timing Diagram

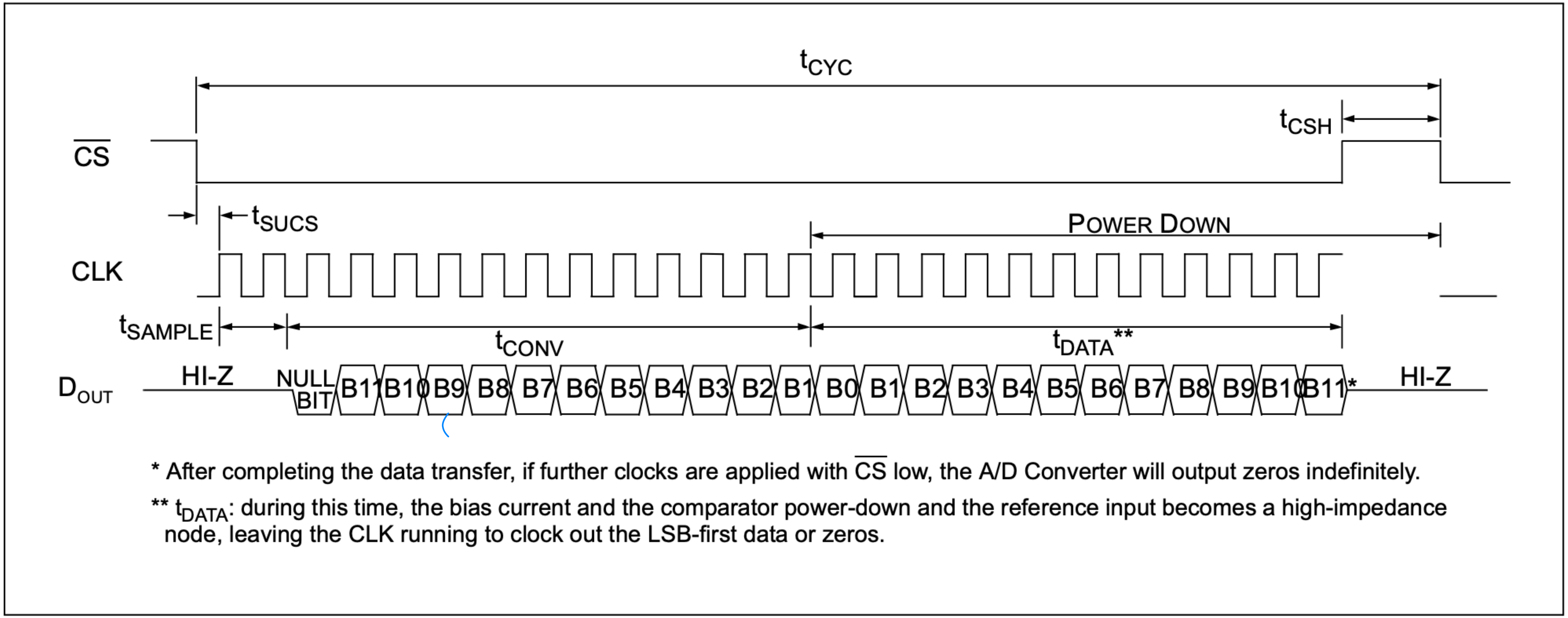


FIGURE 5-2: *Communication with MCP3201 device using LSB first Format.*

MCP3201 with Microcontroller SPI Ports

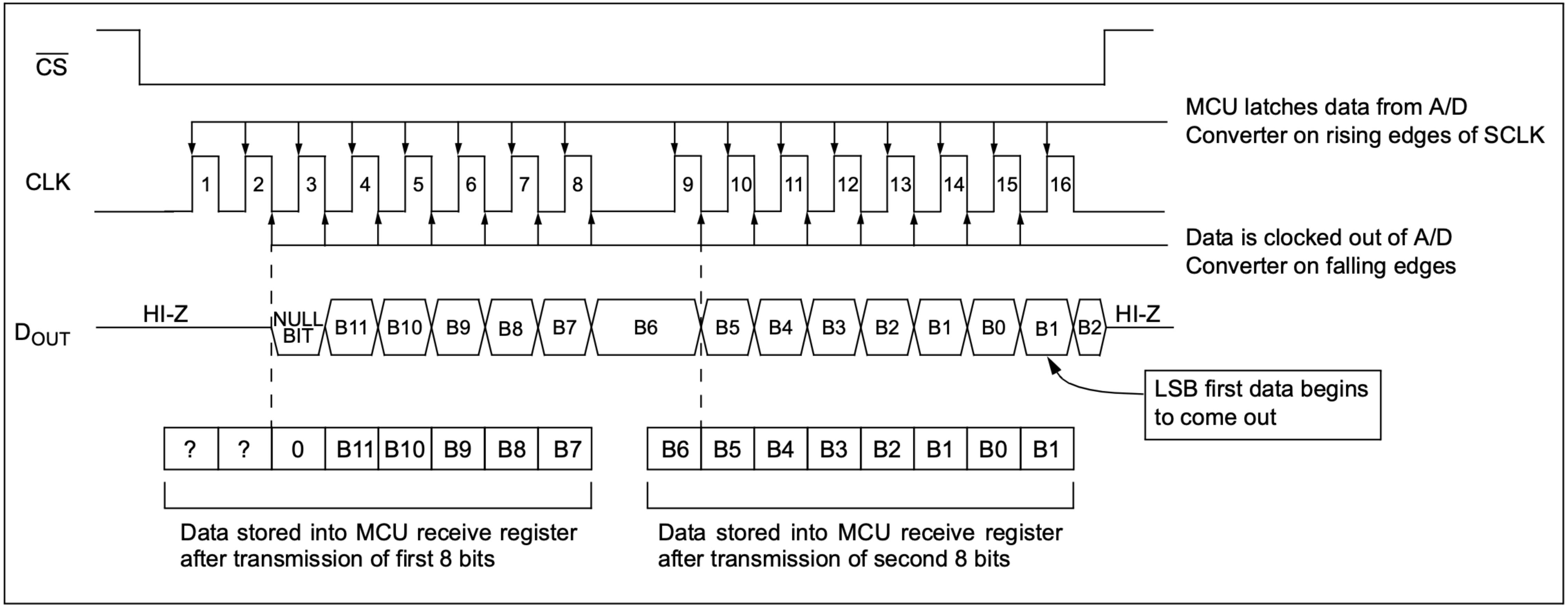


FIGURE 6-1: *SPI Communication using 8-bit segments (Mode 0,0: SCLK idles low).*

Lab 4: AVR SPI Programming

1. Connect a circuit with an ATMega328P, MCP3201 (12-bit ADC with SPI interface) and MCP9700A (analog temperature sensor) and write a program to transmit the current ambient temperature to your PC using a serial port

Extra Problem

1. Adapt your code to use “Bit-banging SPI” instead of the hardware-based SPI peripheral. (Hint: try using what you’ve learned from lab 2 (AVR I/O) to simulate the timing diagram in slide 21/22)