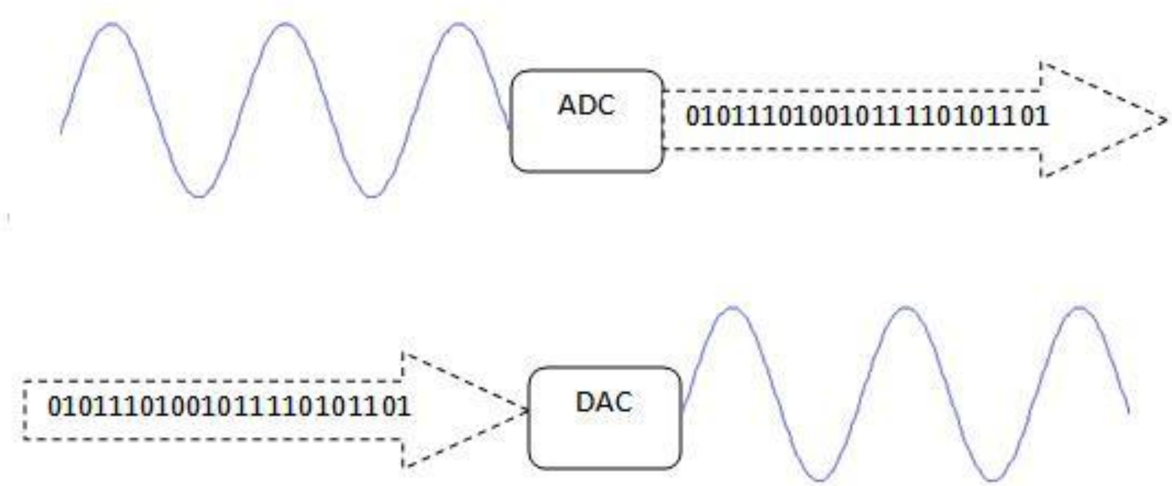
I/O Devices – ADC/DAC

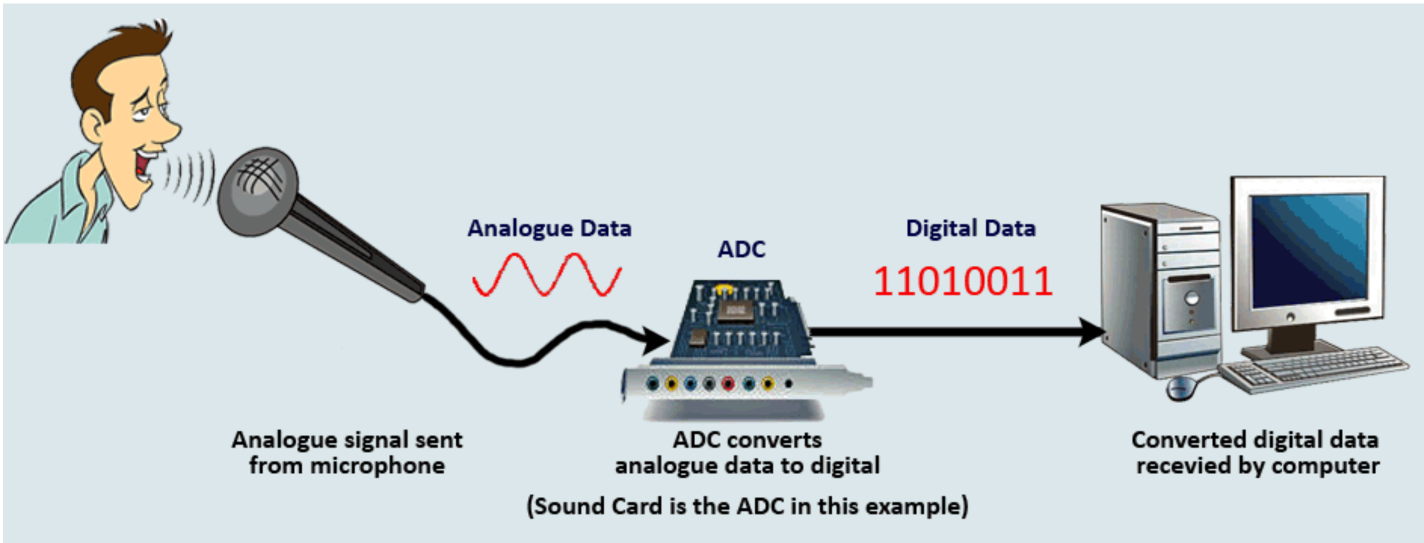
EECS 388 – Spring 2023

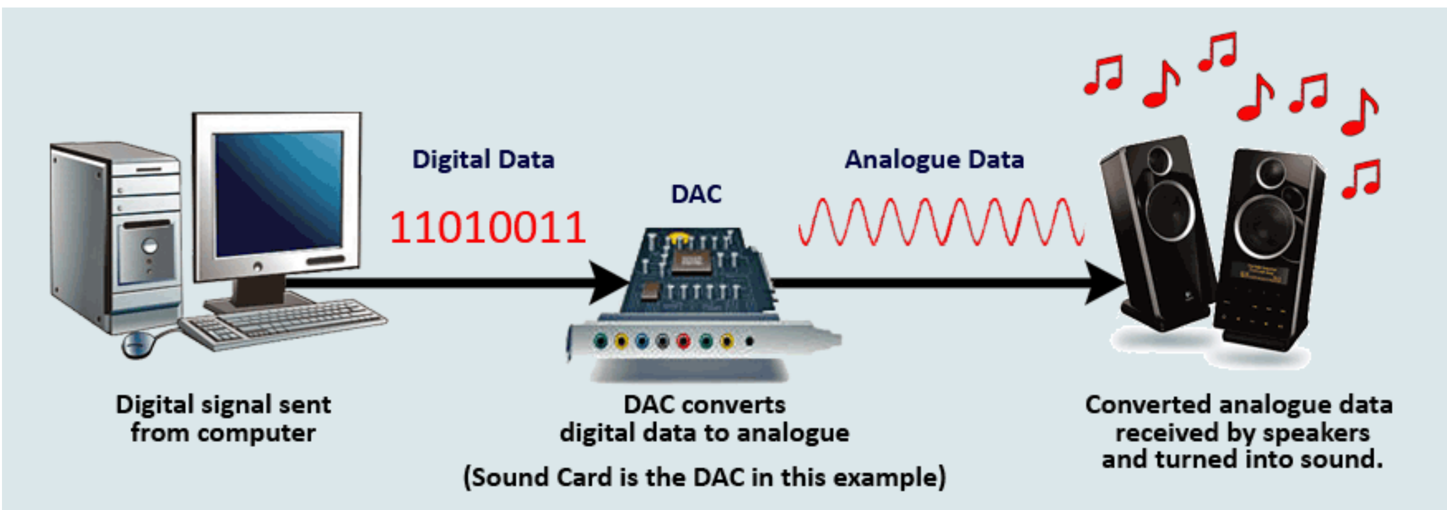
Context

- ADC (analog-to-digital converter)
  - Convert an analog signal into a digital one
- DAC (digital-to-analog converter)
  - Convert a digital signal into an analog one



Analog to Digital, Digital to Analog



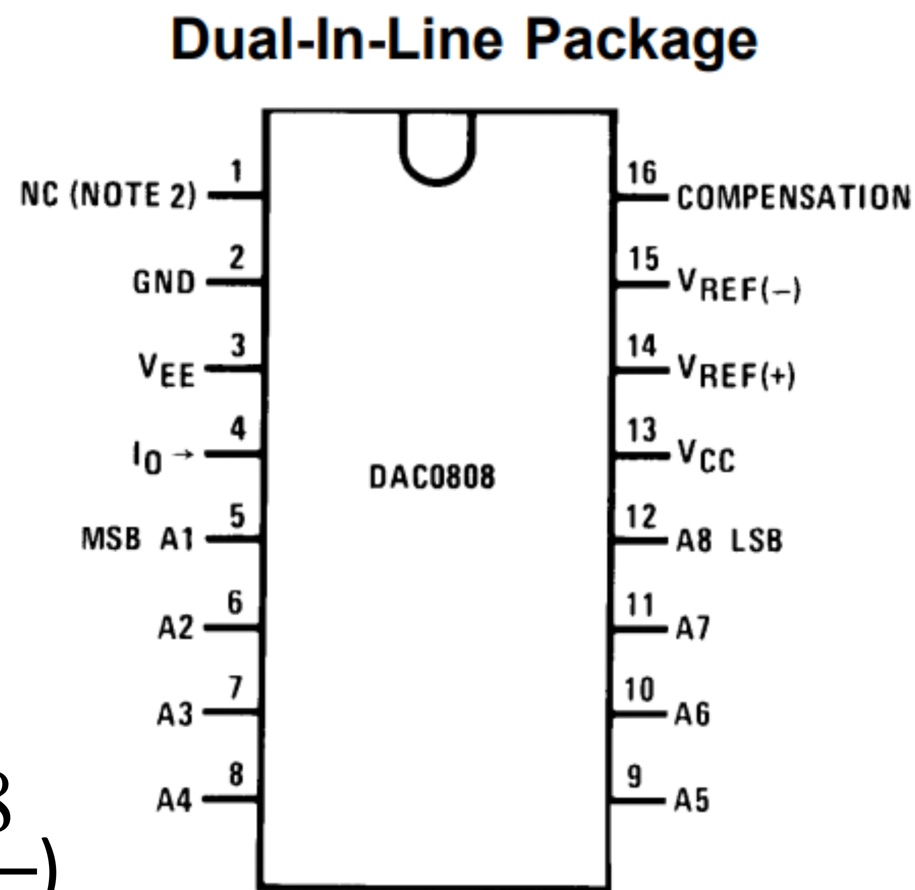


Source: http://samihaandniyatidatahandlingtask.weebly.com/analogue-and-digital-data.html

DAC0808: 8-Bit D/A Converter

- The digital inputs are converted to current (I_{out})
- The total current provided by the I_{out} pin is basically a function of the binary numbers at the input pins A1-A8
- The I_{ref} is the input current. This must be provided into the pin 14 by connecting a resistor. Generally 2.0mA is used as I_{ref}

$$I_{out} = I_{ref}\left(\frac{A1}{2} + \frac{A2}{4} + \ldots + \frac{A8}{256}\right)$$

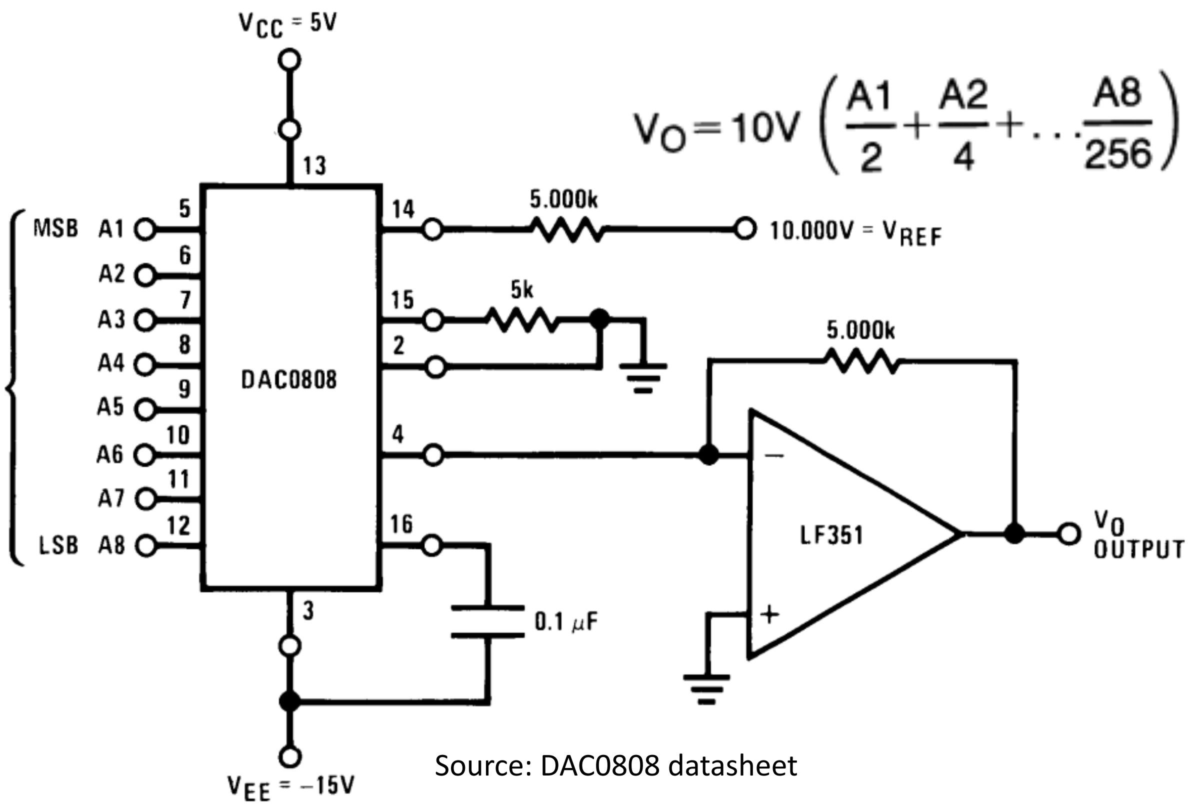


Source: DAC0808 datasheet

Using the DAC

- **The reference pin:**
  - A +10V power source is connected as reference voltage for the device and the negative reference is grounded
  - Reference voltage defines the output voltage range of analog output signal from op-amp output. If Vref=10V, when all inputs are high→ Vout=10V
  - Reference voltage defines the output voltage range of analog output signal from op-amp output

Pin Number	Pin Name	Function
1	NC	No Connection that means not used
2	GND	Power supply ground terminal
3	VEE	Used for external compensation capacitor connection between VEE and Comp pins
4	IOUT	input/output terminal for analog signal
5-12	MSB A1 – LSB A8	These are the eight bits of DAC0808 input. A1 is the first bit or MSB of that input and A8 is the least significant bit of input applied
13	Vcc	Positive Power supply
14	VREF+	Positive reference voltage
15	VREF-	Negative Reference voltage
16	Compensation	COMP is a compensation pin for DAC where we connect an external capacitor

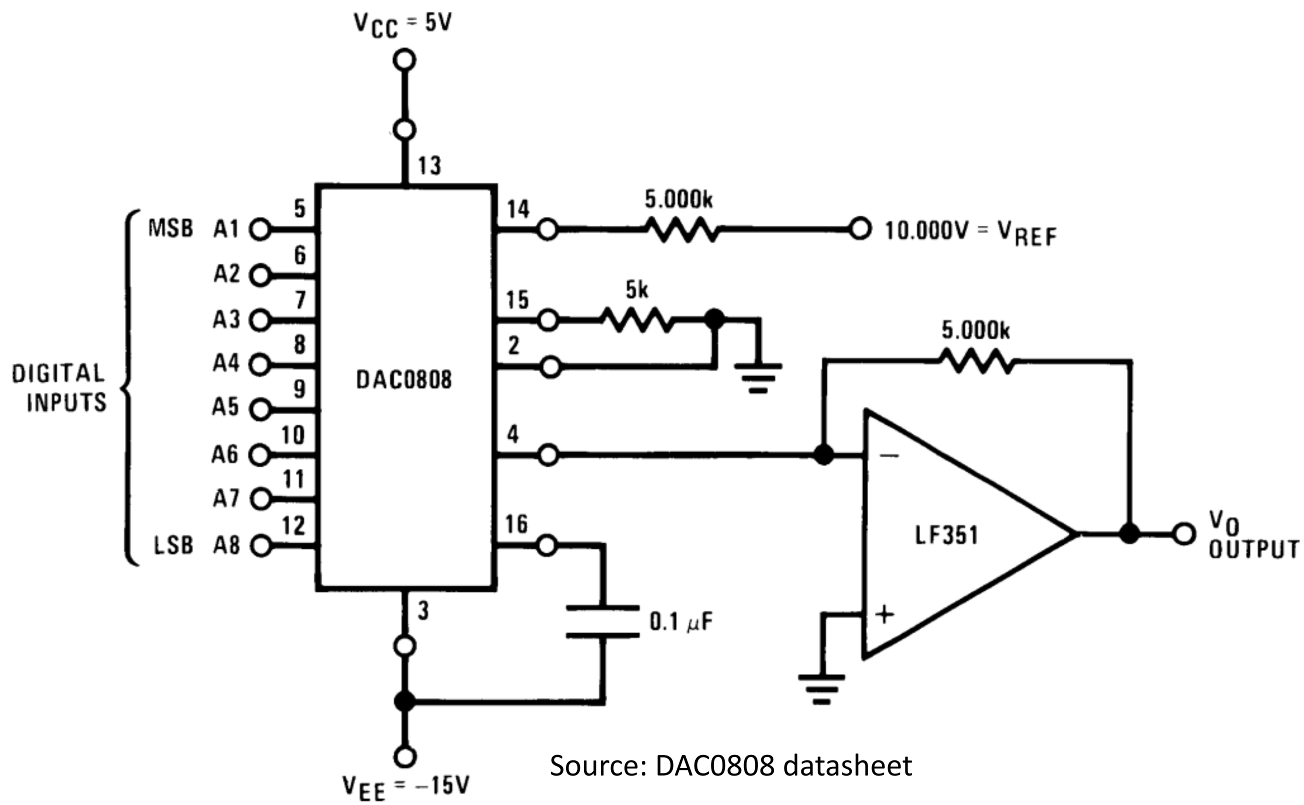


$$V_O = 10V\left(\frac{A1}{2}+\frac{A2}{4}+\ldots\frac{A8}{256}\right)$$

Source: DAC0808 datasheet

Using the DAC

- **The output pin:**
  - The analog output from DAC is a current quantity and this needed to be converted in to voltage parameter for using in applications
  - We connect the I_{out} pin to the op-amp circuit as shown in circuit diagram to convert the current to voltage
  - The output analog voltage from op-amp is in linear relation with input digital value

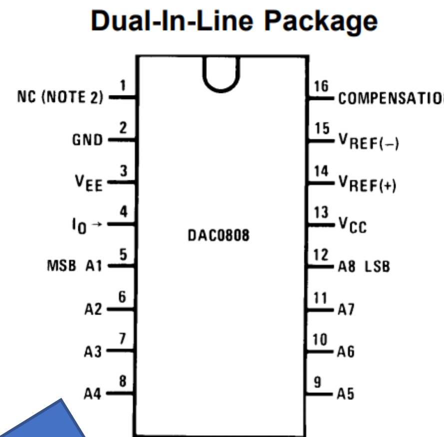


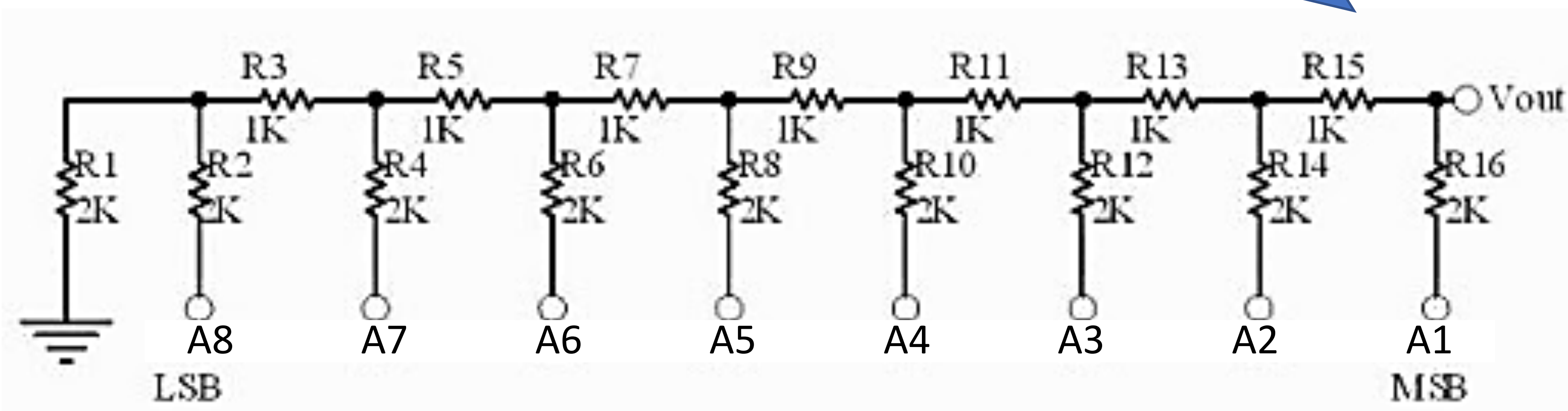
$$V_O = 10V\left(\frac{A1}{2}+\frac{A2}{4}+\ldots\frac{A8}{256}\right)$$

Source: DAC0808 datasheet

Inside DAC 0808

- DAC0808 uses R/2R ladder method.
- The R-2R resistor ladder network directly converts a parallel digital symbol/word into an analog voltage.
- Each digital input (A1, A2, etc.) adds its own weighted contribution to the analog output.
- Example: LSB A8 has less weight (achieved putting more Resistors between Vout and A8.)

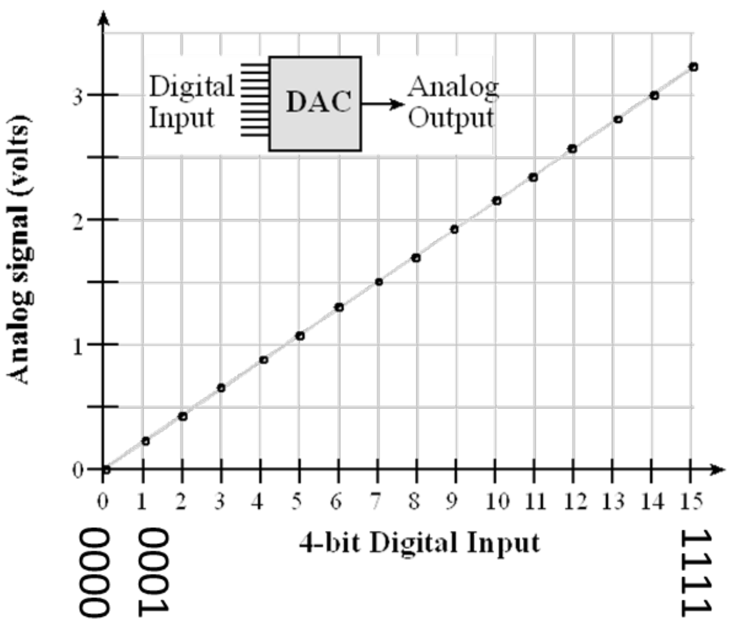




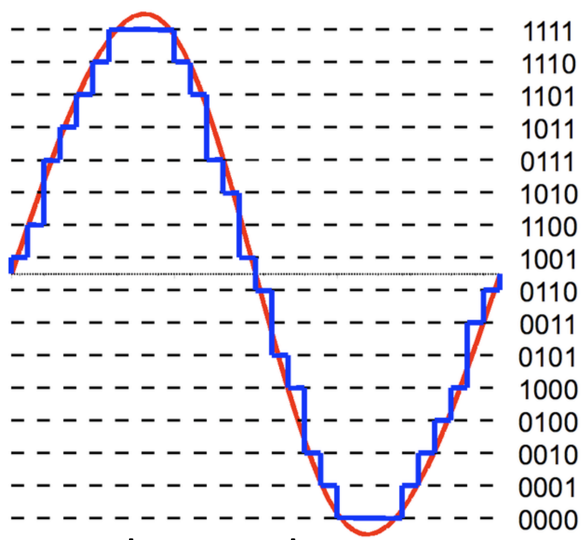
$$I_{out} = I_{ref}\left(\frac{A1}{2} + \frac{A2}{4} + \ldots + \frac{A8}{256}\right)$$

DAC Resolution

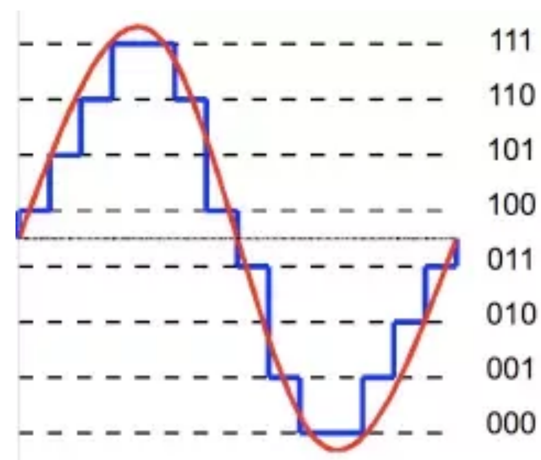
- Number of data inputs decides the resolution of DAC.
- So if there are n digital input pin, there are 2^n analog levels.
- So 8 input DAC has 256 discrete voltage levels.



Input-Output relation for 4-bit DAC



4 bit resolution

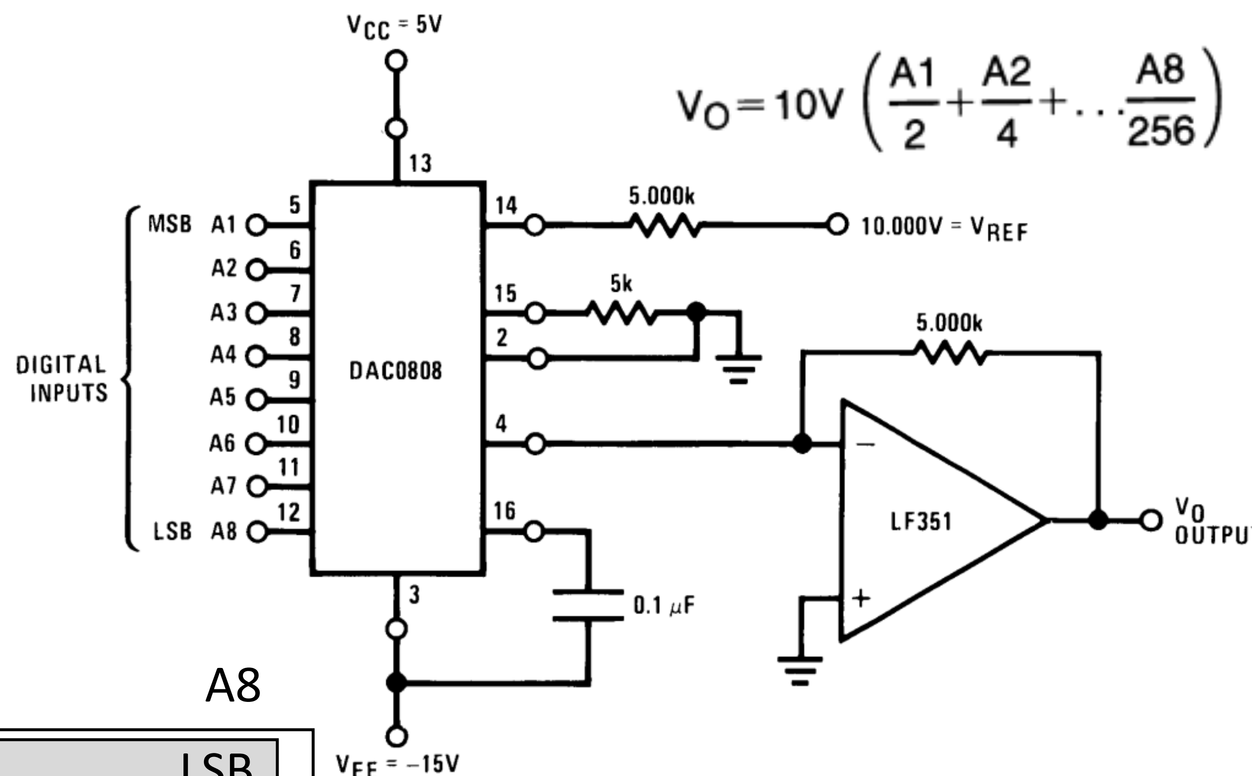


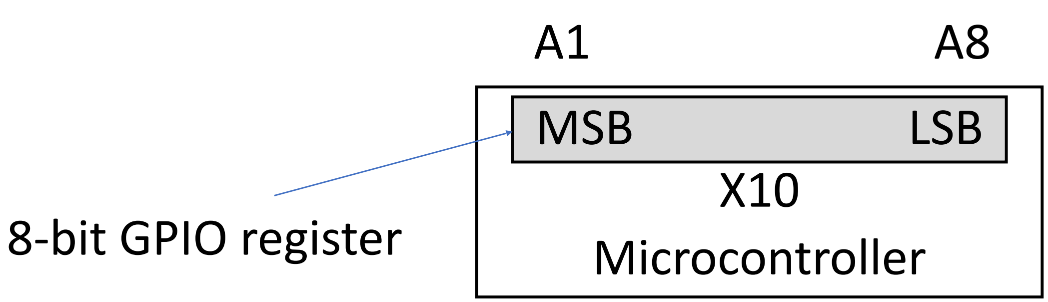
3 bit resolution

In class quiz 5

- Say we are sending data to DAC from 8-bit GPIO register X10
- Considering the following +10V DAC, fill in the table:

X10	Vo (V)
0x00	
0x01	
0x13	
0xF0	
0xFF	





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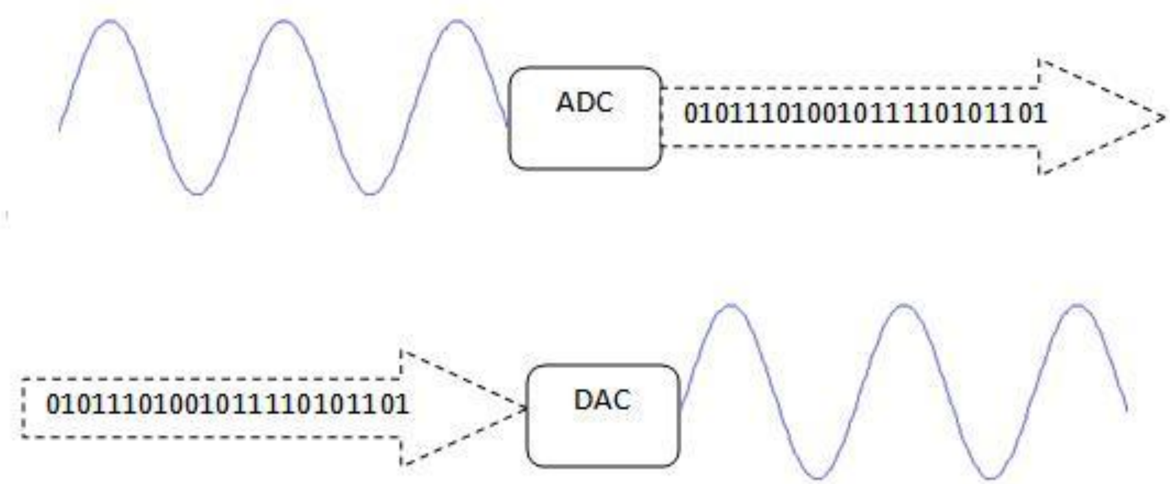


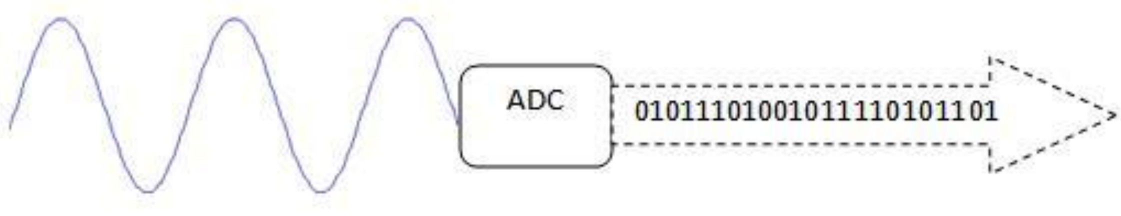
Why Analog to Digital Coverter

- Sensors are a form of transducers that convert a physical parameter like temperature into electrical signals that the microcontroller can understand.
  - Analog Sound Sensors, Analog Pressure Sensors, etc.

- However, analog sensors output data in an analog format which a microcontroller cannot understand.
- Therefore, to convert this analog data to a digital format, Analog to Digital converters or ADCs are used.

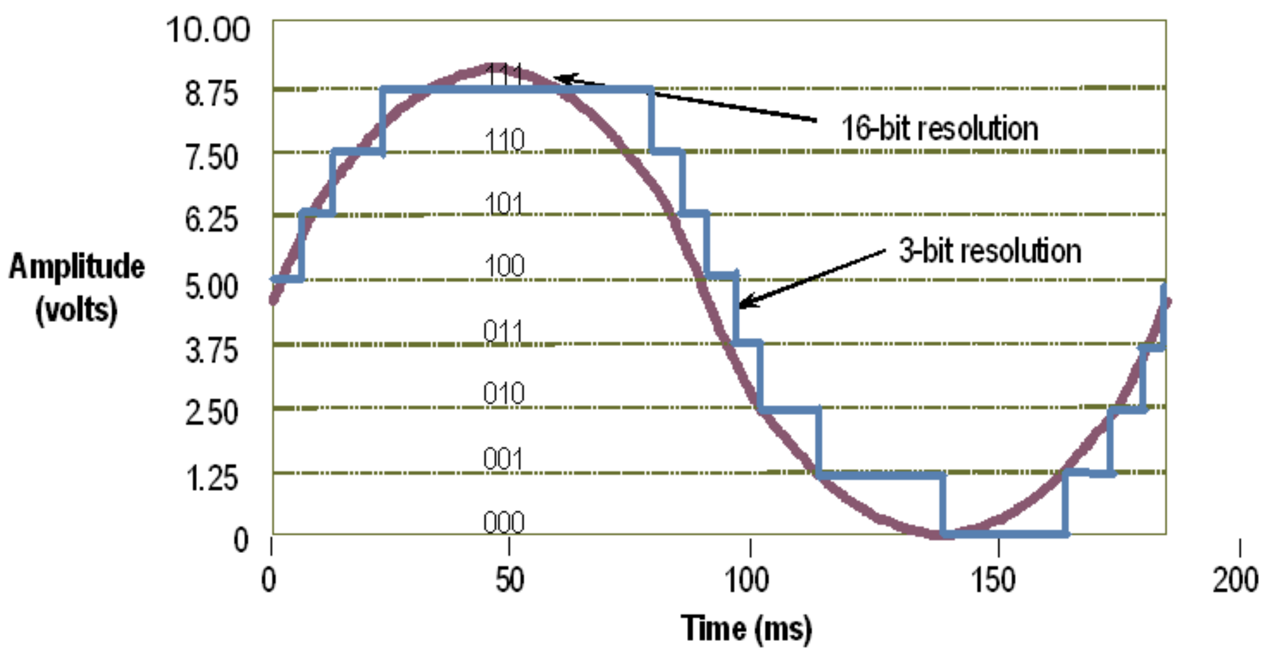
Analog to Digital Convertor

- An analog signal has a continuously changing amplitude with respect to time.
- A digital signal, on the contrary, is a stream of 0s and 1s.
- ADC Periodically samples the analog input and maps analog signals to their binary equivalents
- ADCs use various techniques such as Flash conversion, slope integration, or successive approximation.



Example

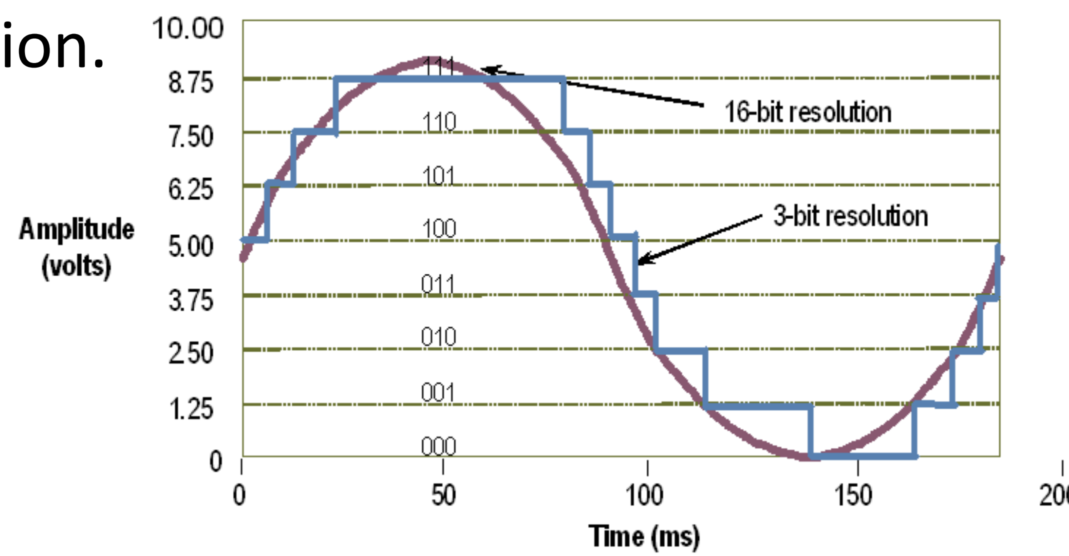
- Let us say we have an input signal which varies from 0 to 10 volt
- we use a 3-bit ADC to convert this signal to binary data.
- A 3-bit ADC can represent 2^3 or 8 different voltage levels using 3 bits of data.



Input voltage	Binary equivalent
0.00-1.24 volt	000B
1.25-2.40 volt	001B
2.50-3.74 volt	010B
.....	.....
8.75-10.0 volt	111B

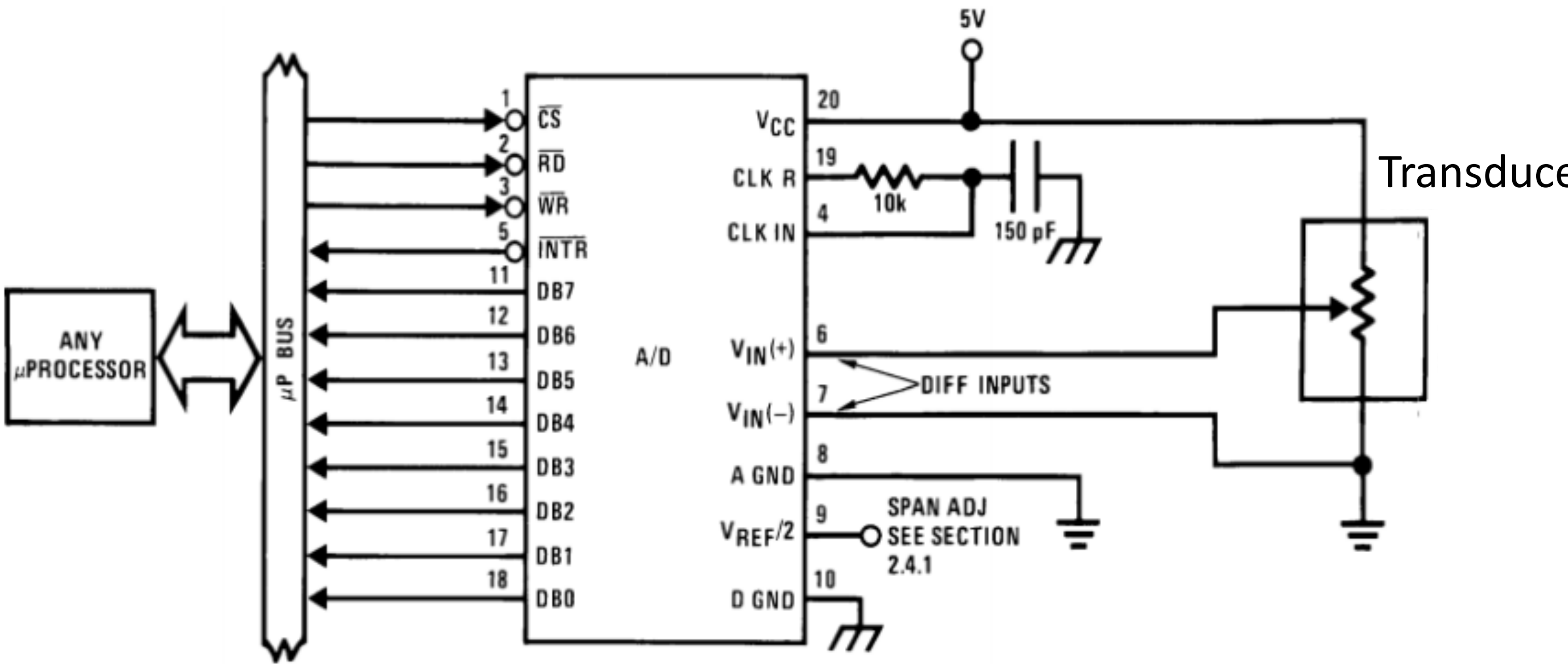
Example

- The minimum change ADC can detect in this example is 1.25 volt.
- If the change is smaller than 1.25 volt, the ADC can't detect it.
- This minimum change that an ADC can detect is known as the **step size of the ADC**.
- Step size=Vmax-Vmin/2n =(10-0)/8=1.25V
- n is the number of bits(resolution) of an ADC
- higher n can detect smaller changes, but this increases the cost of ADC chip production.

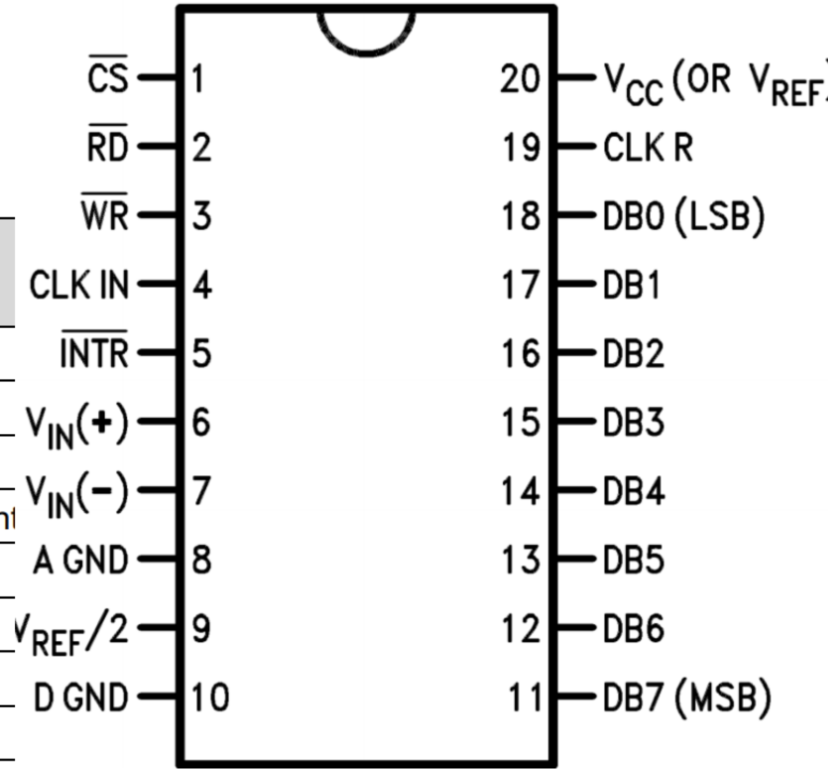


Example: TI ADC080x 8-Bit

- The ADC0801, ADC0802, ADC0803, ADC0804 etc. (all 8 bit input).
- Operates With Processors or as a Stand-Alone Device
- Interface to Temp Sensors, Voltage Sources, and Transducers



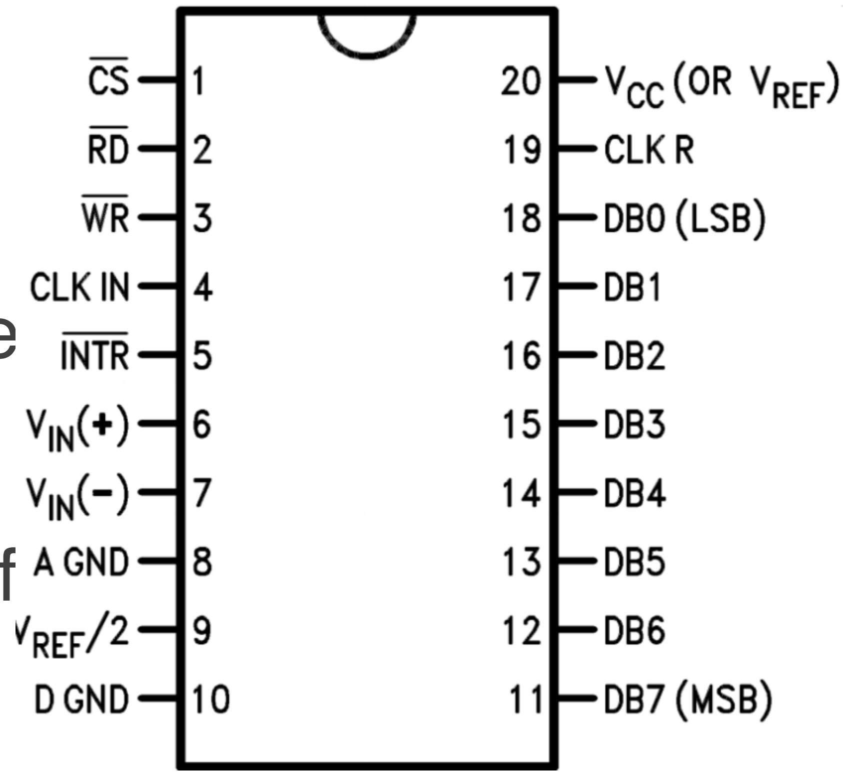
Pin Functions



PIN		I/O	
NO.	NAME		
1	CS	I	Chip Select
2	RD	I	Read
3	WR	I	Write
4	CLK IN	I	External Clock input or use int
5	INTR	O	Interrupt request
6	$V_{IN}(+)$	I	Differential analog input+
7	$V_{IN}(-)$	I	Differential analog input–
8	A GND	I	Analog ground pin
9	$V_{REF}/2$	I	Reference voltage input for adjustment to correct full scale reading
10	D GND	I	Digital ground pin
11	DB7	O	Data bit 7
12	DB6	O	Data bit 6
13	DB5	O	Data bit 5
14	DB4	O	Data bit 4
15	DB3	O	Data bit 3
16	DB2	O	Data bit 2
17	DB1	O	Data bit 1
18	DB0 (LSB)	O	Data bit 0
19	CLK R	I	RC timing resistor input pin for internal clock gen
20	V_{CC} (or V_{REF})	I	+5V supply voltage, also upper reference input to the ladder

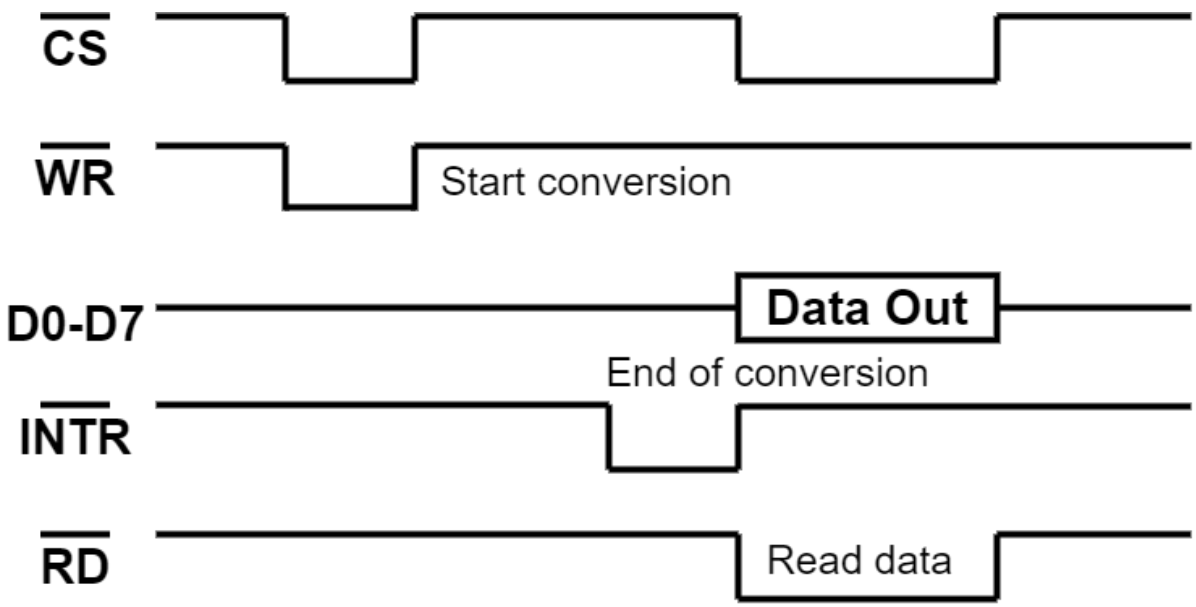
Pin function

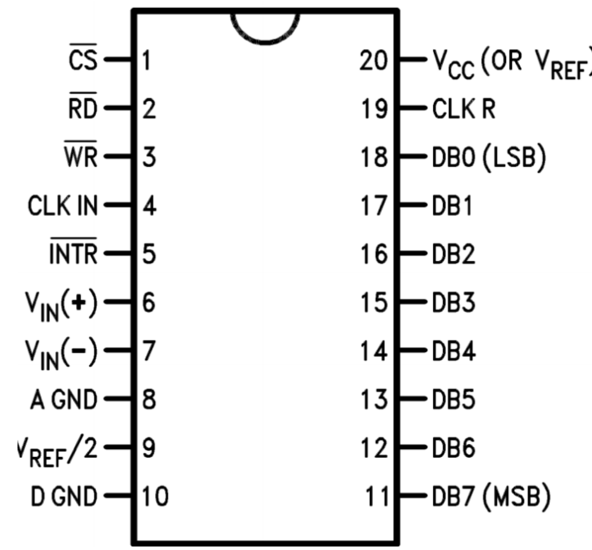
- **VREF (+) and VREF (-)**
- These two pins are used to provide the upper and the lower limit of voltages which determine the step size for the conversion.
- If Vref(+) has an input voltage 5v and Vref(-) has a voltage of 0v then the step size will be
- $5v-0v/2^8$= 15.53 mv.



Timing

- When we decide we need to read from the ADC, we use the processor to assert CS (make CS =0)
- CS: Chip select→ processor enables the ADC (active low)
- At the same time WR must be asserted (WR=0)

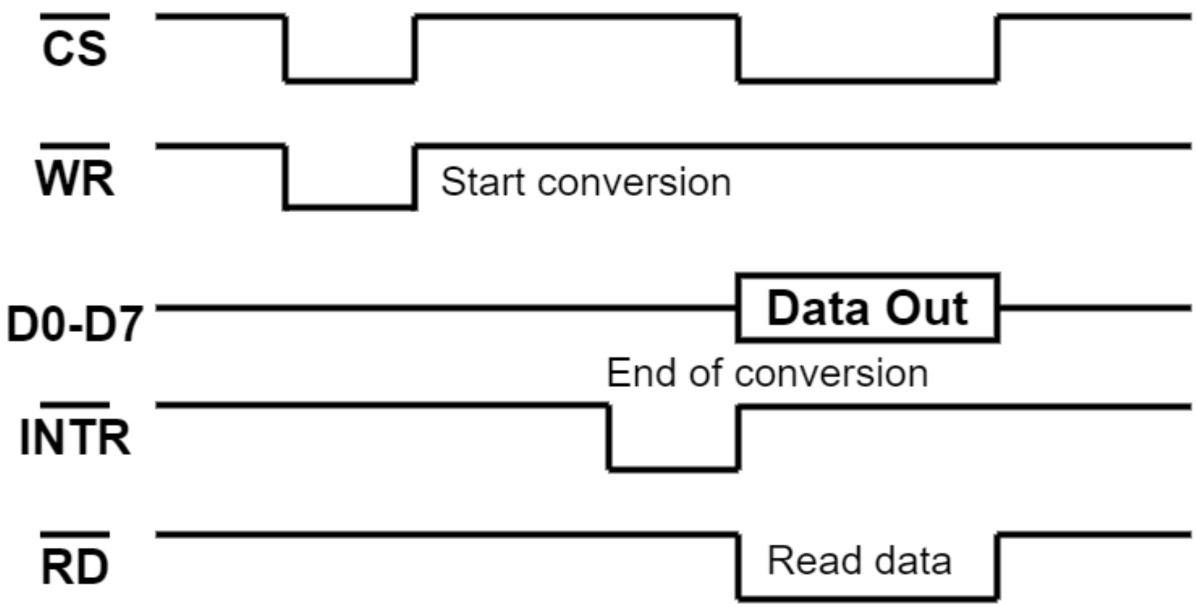


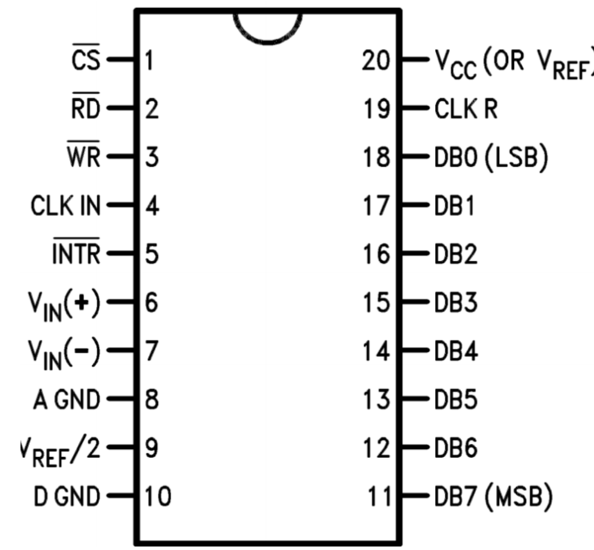


CS: asserted by from uP
RD: asserted by uP
WR: asserted by uP
INTR: sent to uP

Timing

- After receiving the signal from the processor (CS and WR asserted), ADC starts conversions
- Once conversion is done, ADC sends a signal via INTR pin
- This means data can be read now from ADC
- This is called a handshaking protocol





CS: asserted by from uP
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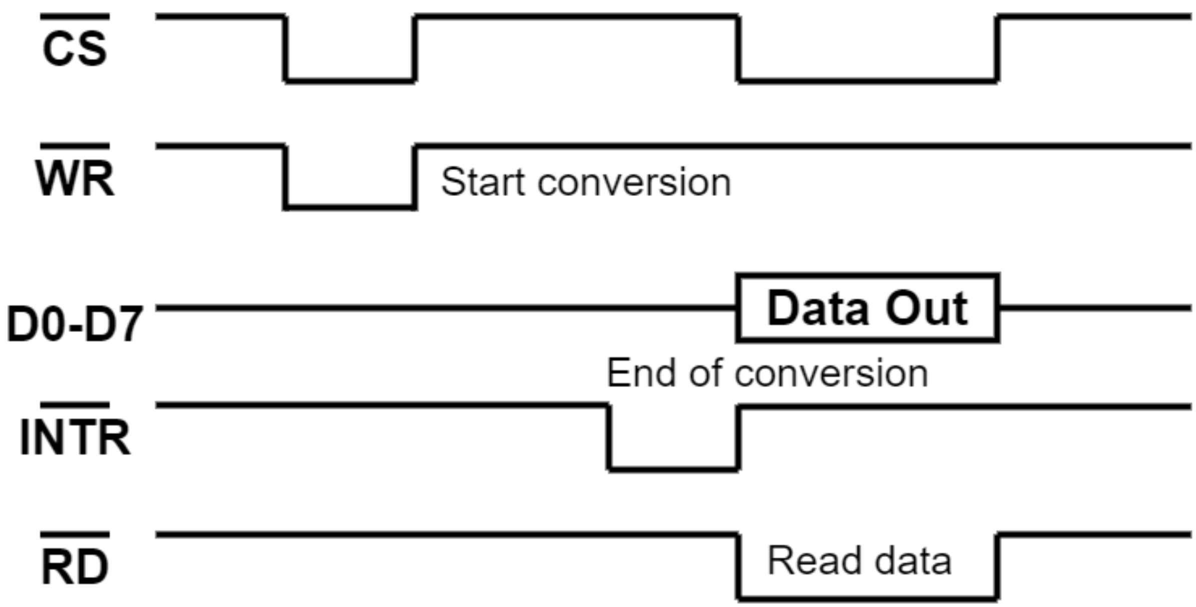
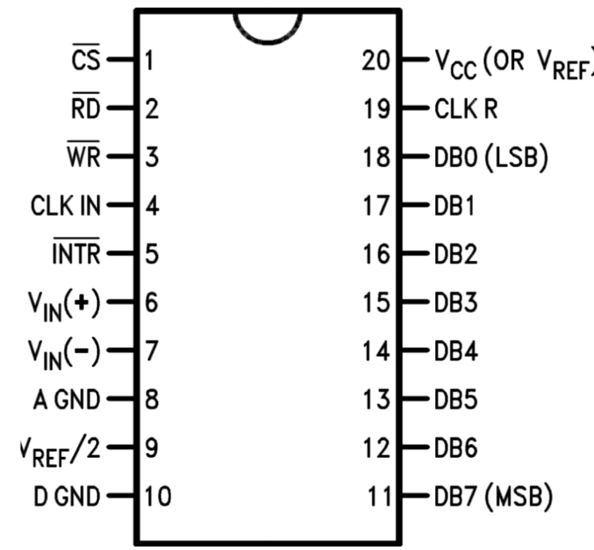
Timing

- Once INTR is asserted (INTR=0), the processor starts reading data from D0-D7
- To do that, the processor asserts the read data signal (RD=0)
- Keep asserted as long as data must be read





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Question

- What signals must be asserted to different GPIO to read from the sensor? Timing of the ADC is shown in the previous slide. Assume that GPIO pins 0 to 8 are already configured as input.