Microcomputer interface – Analog to Digital Conversion

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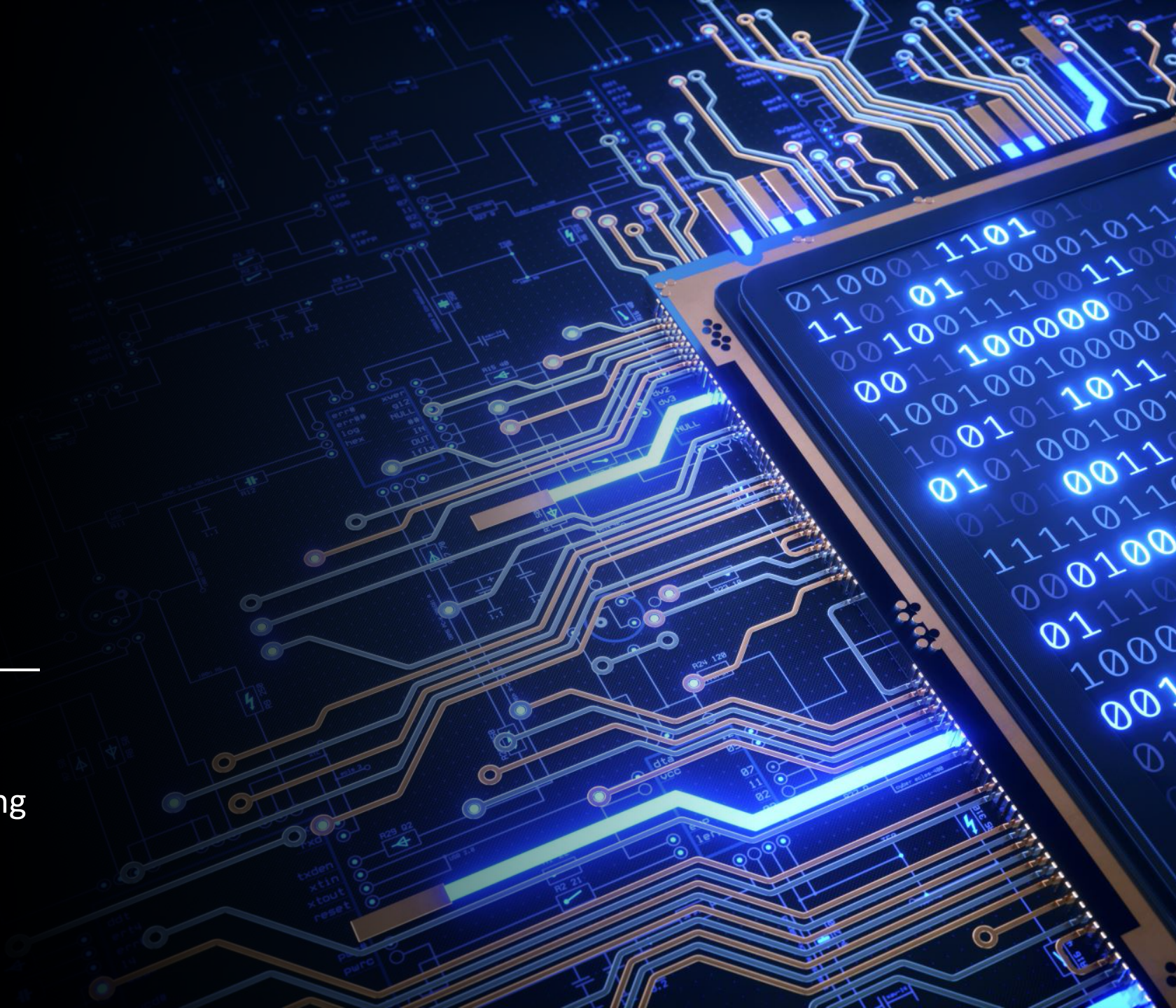
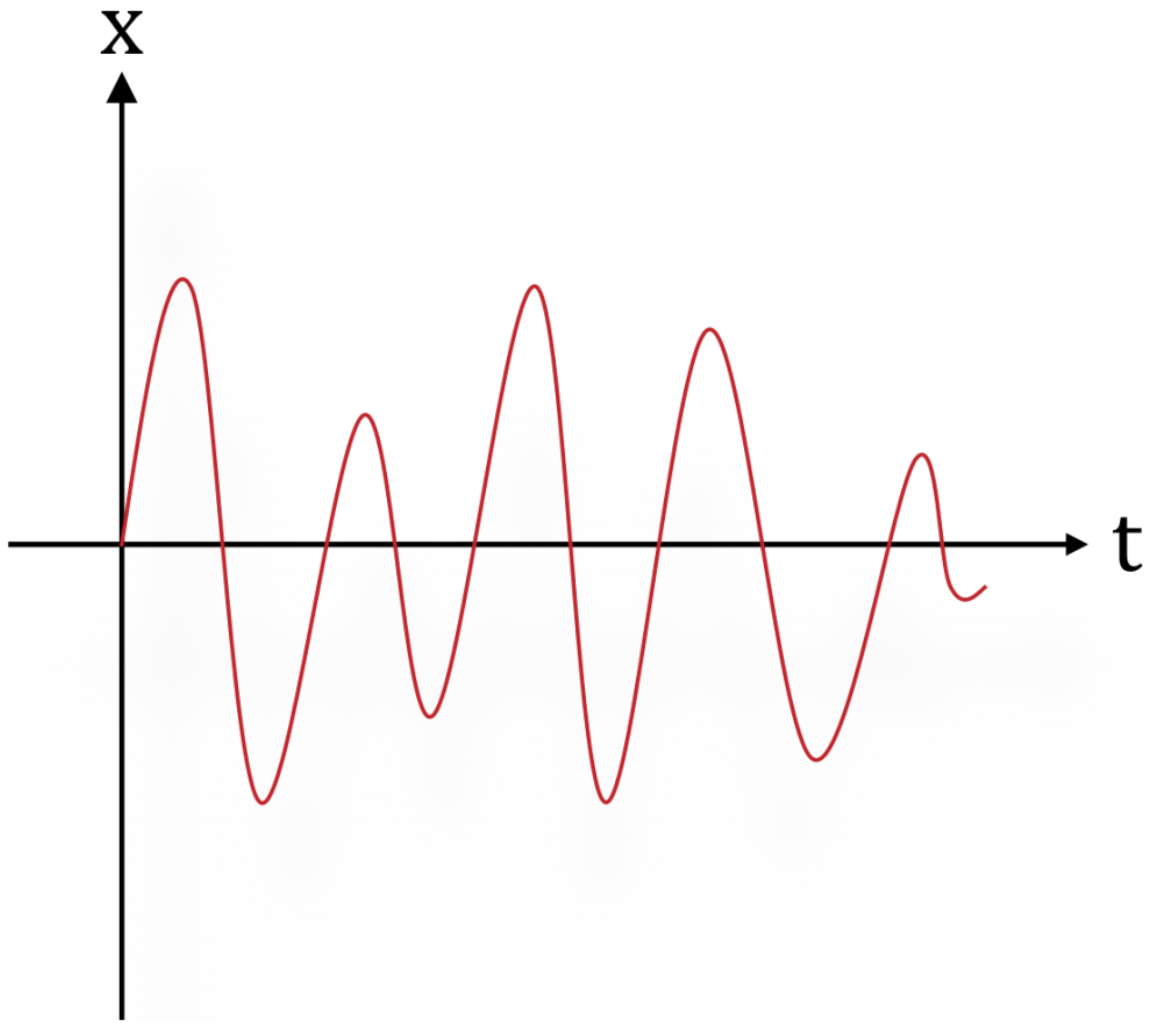


Contents

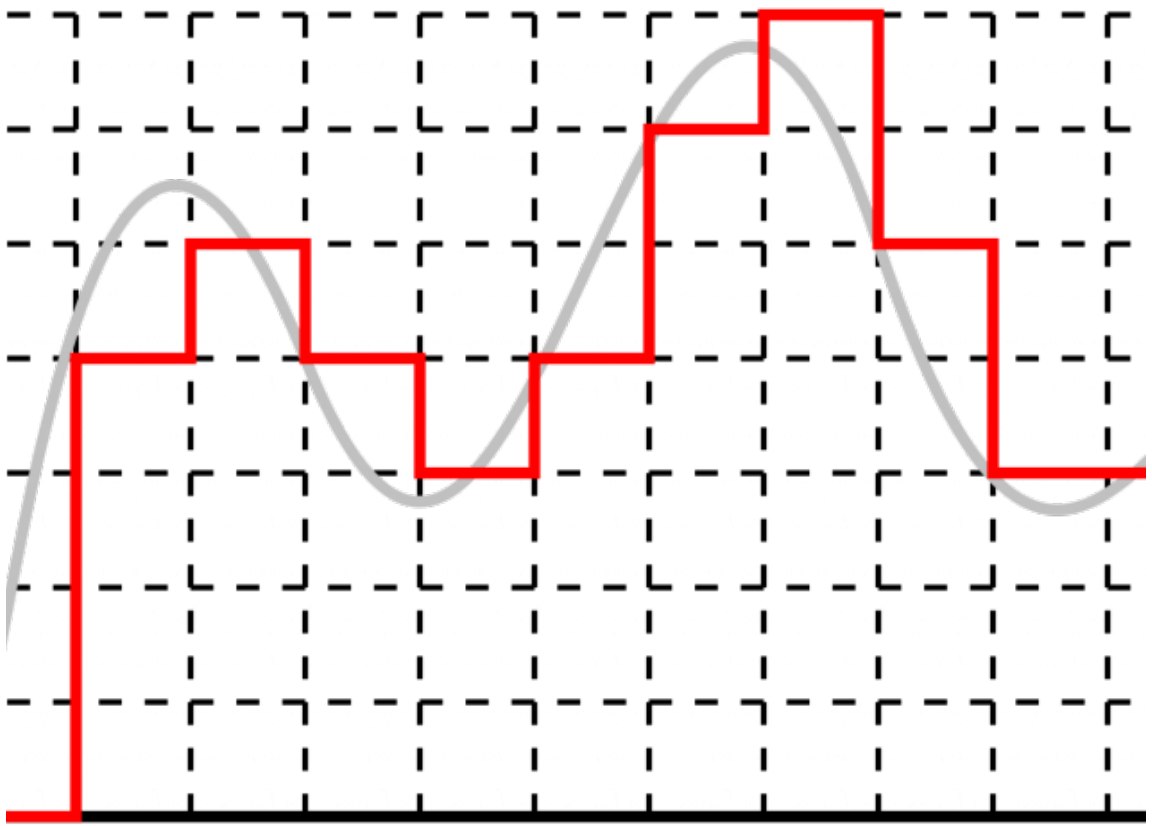
Analog Signals [Revision]

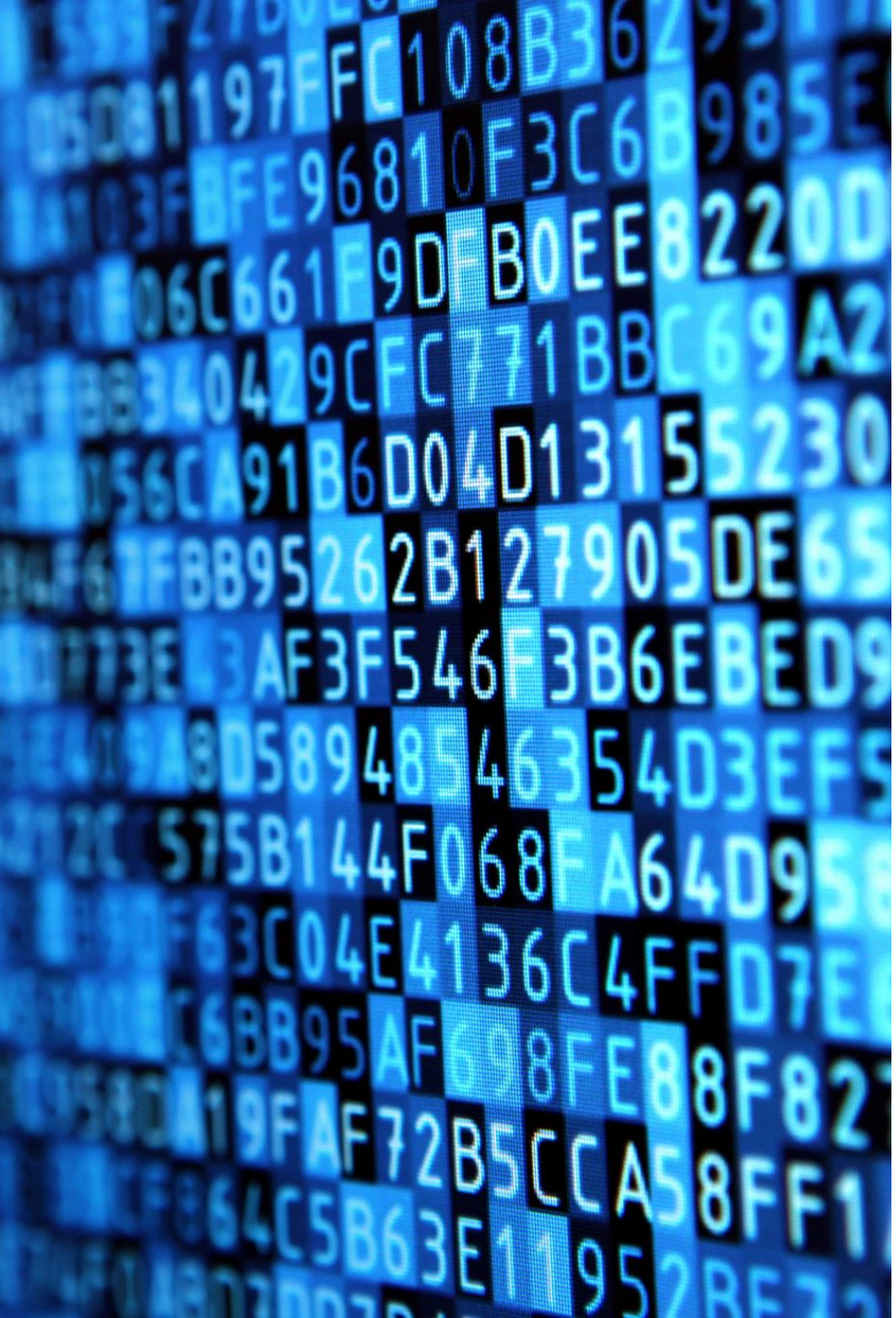
- Voltage of a pin with reference to signal ground (GND)
- What is an analog value?
  - Vary within a range, not in discrete values; Theoretically infinite number of possible values within that range.
- Typically, sensors delivers analog signal. However, some will give discrete levels, such as 0V and 3.3V, or a numerical value.



Digital Signals [Revision]

- Digital signals carry the data although it is a bit different. These signals are discrete or not continuous.
- A digital signal carries the data in the form of binary because it signifies in the bits. [Later, we will discuss in analog to digital conversion.]





Something need to know first

- Relationship between binary, decimal hexadecimal numbers?
- What are analog and digital signals?
- What is analog-to-digital converter?

	2	3	6
Multiplier	10^2	10^1	10^0

Number Representation

- Daily life, we use decimal
  - Each digit is a number from 0 to 9
  - Eg. a number 236d is interpreted in the following way:

Binary Representation

- Similarly, we can have a binary representation
  - Each binary digit (called bit) is either 0 or 1
  - Eg. 110101_b

1	1	0	1	0	1
$2^5=32$	$2^4=16$	$2^3=8$	$2^2=4$	$2^1=2$	$2^0=1$

So, $110101_b = (32+16+4+1)_d = 53_d$

Indicate it is binary

Indicate it is decimal

Hexadecimal Representation

- Also for hexadecimal representation
  - Each digit is from 0-15 (we use A-F to represent 10-15)

Decimal:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Hexadecimal:	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

  - E.g. 13F$_h$

1	3	F
16^2	16^1	16^0

So, 13F $_h$ = $(1x256+3x16+15x1)_d$ = 319$_d$

Indicate it is hexadecimal

Decimal to Binary Conversion

- Decimal to Binary
- $42_d = 101010_b$

- 1 0 1 0 1 0

$2^5 + 2^3 + 2^1 = 32+8+2 = 42$

Long division

$$
\begin{array}{r|l}
2 & 42 \\
2 & 21 \ldots 0 \\
2 & 10 \ldots 1 \\
2 & 5 \ldots 0 \\
2 & 2 \ldots 1 \\
2 & 1 \ldots 0 \\
 & 0 \ldots 1
\end{array}
$$

http://www.wikihow.com/Convert-from-Decimal-to-Binary

Decimal to Hexadecimal Conversion

- Decimal to Hexadecimal: $495_d = 1EF_h$

16| 495

16 |30 …15(F)

16 |1 … 14(E)

0 … 1

$1EF_h$

$1 \times 16^2 + 14 \times 16 + 15 = 495_d$

Binary to Hexadecimal Conversion

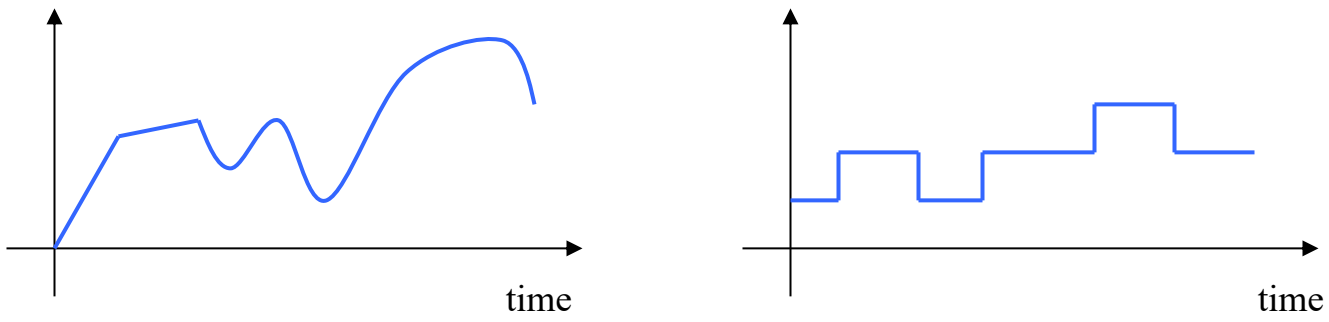
- From Binary to hexadecimal
  - 4 binary bits to 1 hexadecimal digital
  - Eg. 0110 1010 -> 6 A
- From hexadecimal to binary
  - 1 hexadecimal digital to 4 bit
  - Eg. 6 => 0110, A => 1010

  So 6 A -> 0110 1010

4 bits	1 hex
0000	0
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	A
1011	B
1100	C
1101	D
1110	E
1111	F

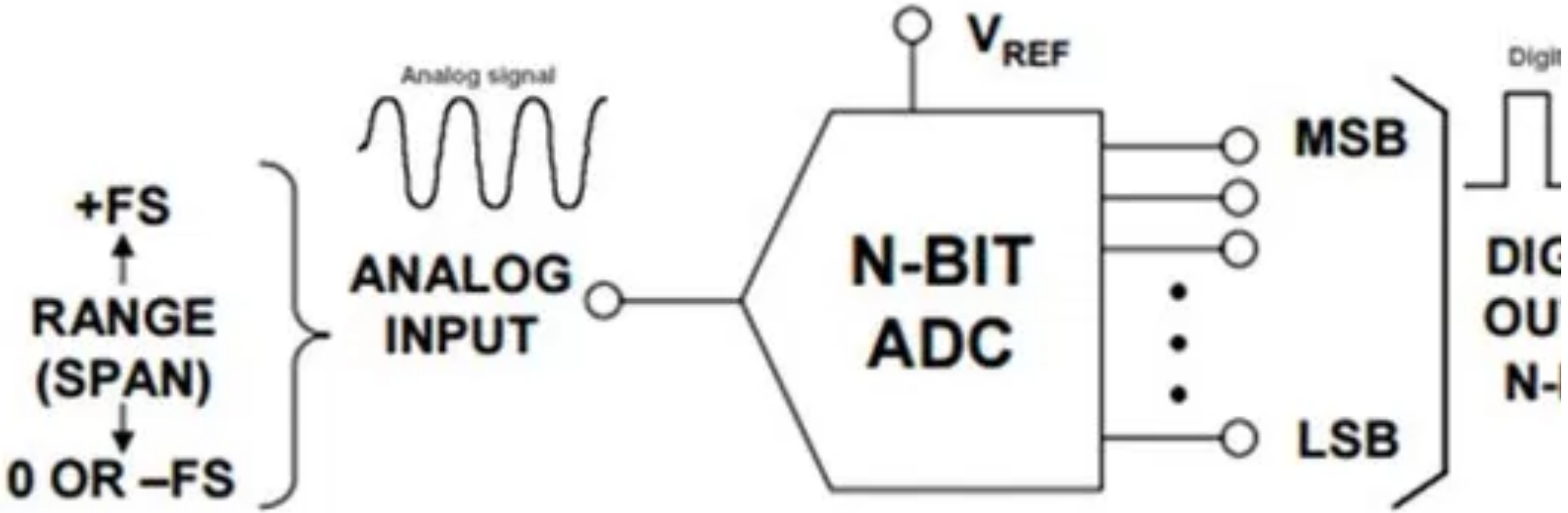
Analog Signal and Digital Value

- analog signal: the signal can have a continuous range of amplitudes.
  - Example: temperature of a room
- Digital signal: the signal is quantized and has finite set of amplitudes.



ADC in Micro:bit

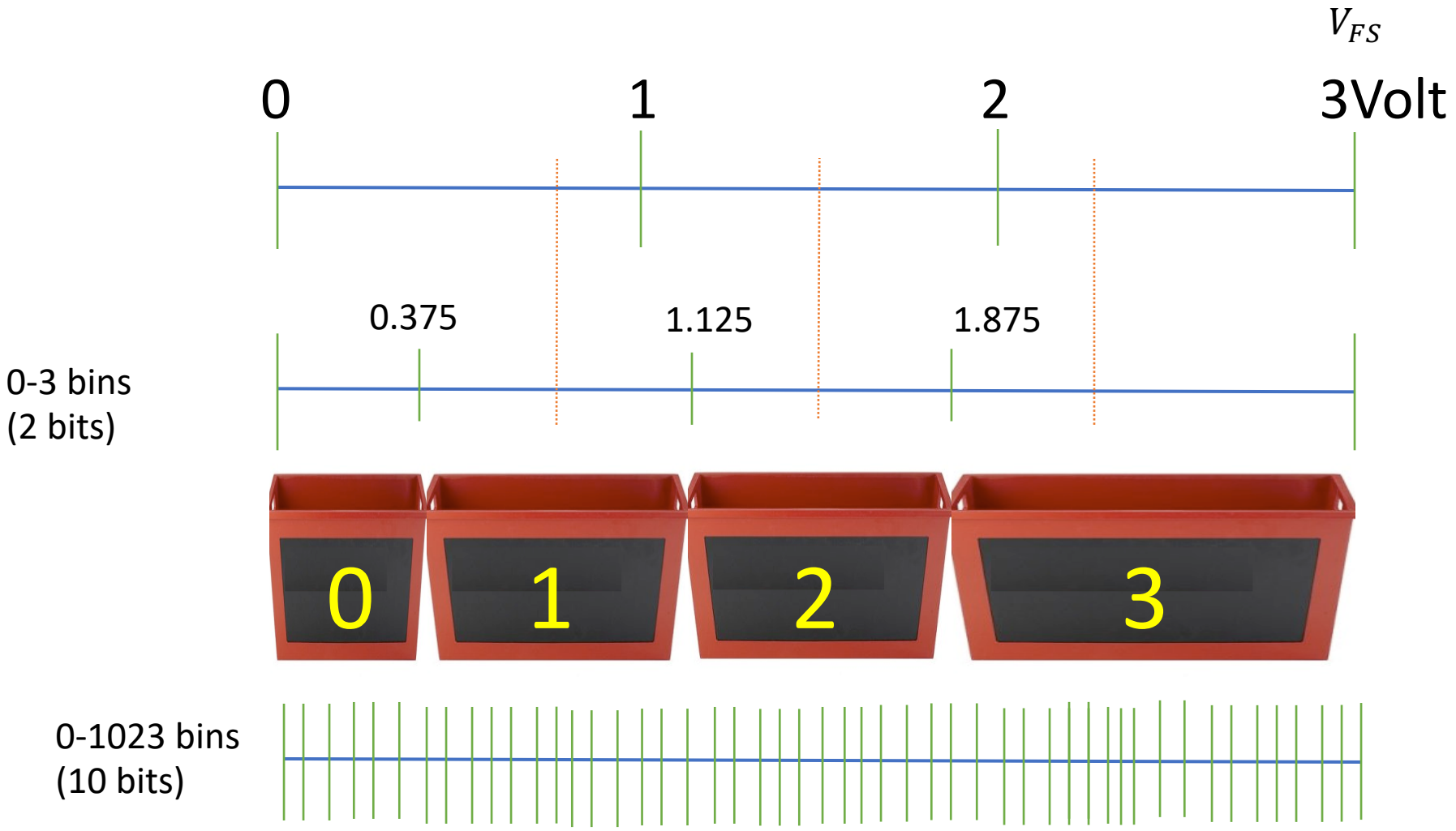
- A device called analog-to-Digital Converter (ADC) is inside the processor of Micro:bit
- ADC converts an analog signal (in voltage) to digital output
- The output is in binary, called as code word
- Resolution measured by number of bits in code word
  - Resolution of micro:bit = 10 bits (N=10 bits)



More Details

- Input: 0 to VFS (full scale voltage)
- Output: 10 bits
  - Smallest: 00000 00000 ⟹ 0
  - Largest: 11111 11111 ⟹ 1023

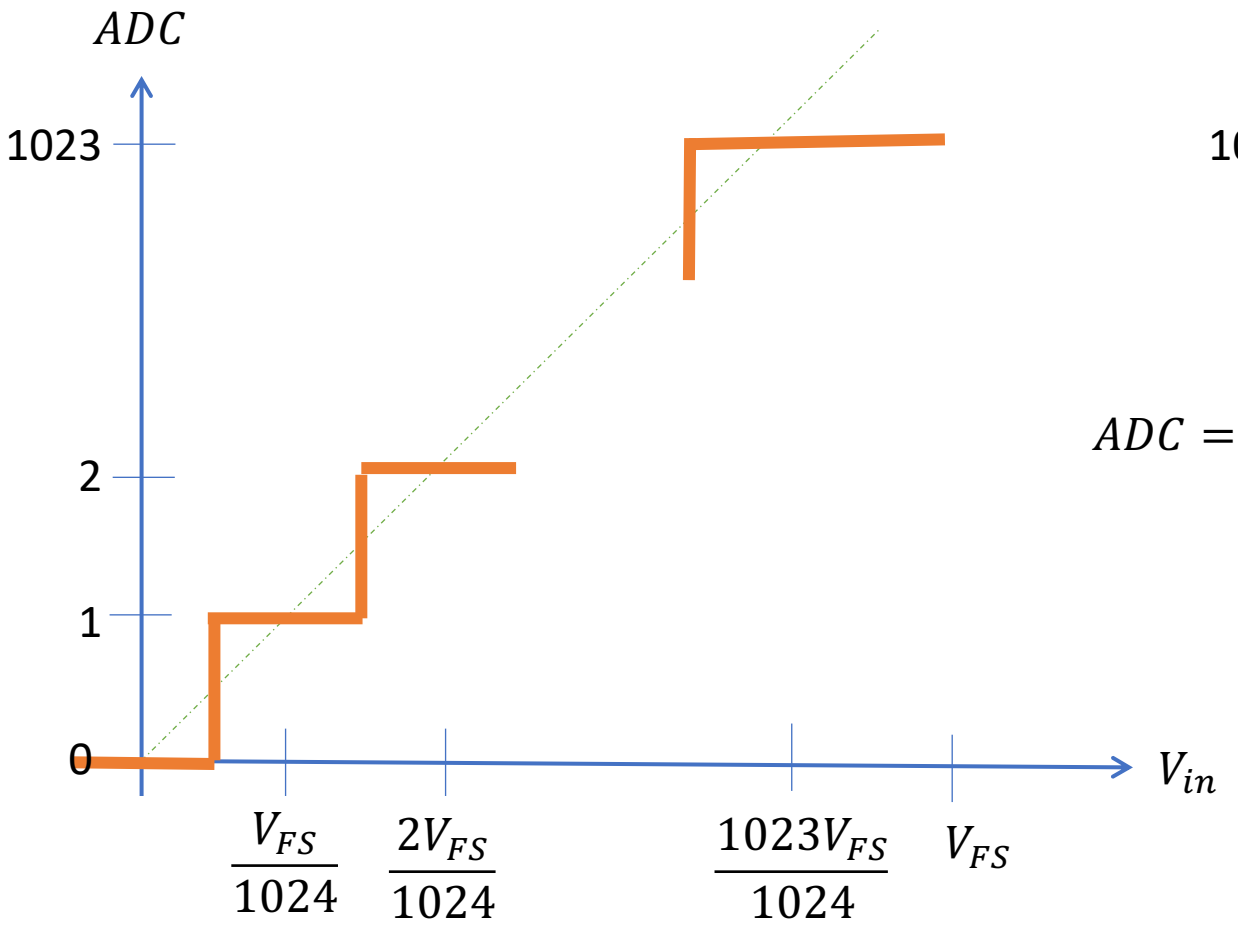
Illustration



1 Least significant bit (LSB) = $\frac{V_{FS}}{2^N}$

Quantization error: (- 0.5 LSB to 0.5LSB)

ADC



10 bits: 0 - 1023

$$ADC = Round\left(\frac{V_{in} \times 1024}{V_{FS}}\right)$$

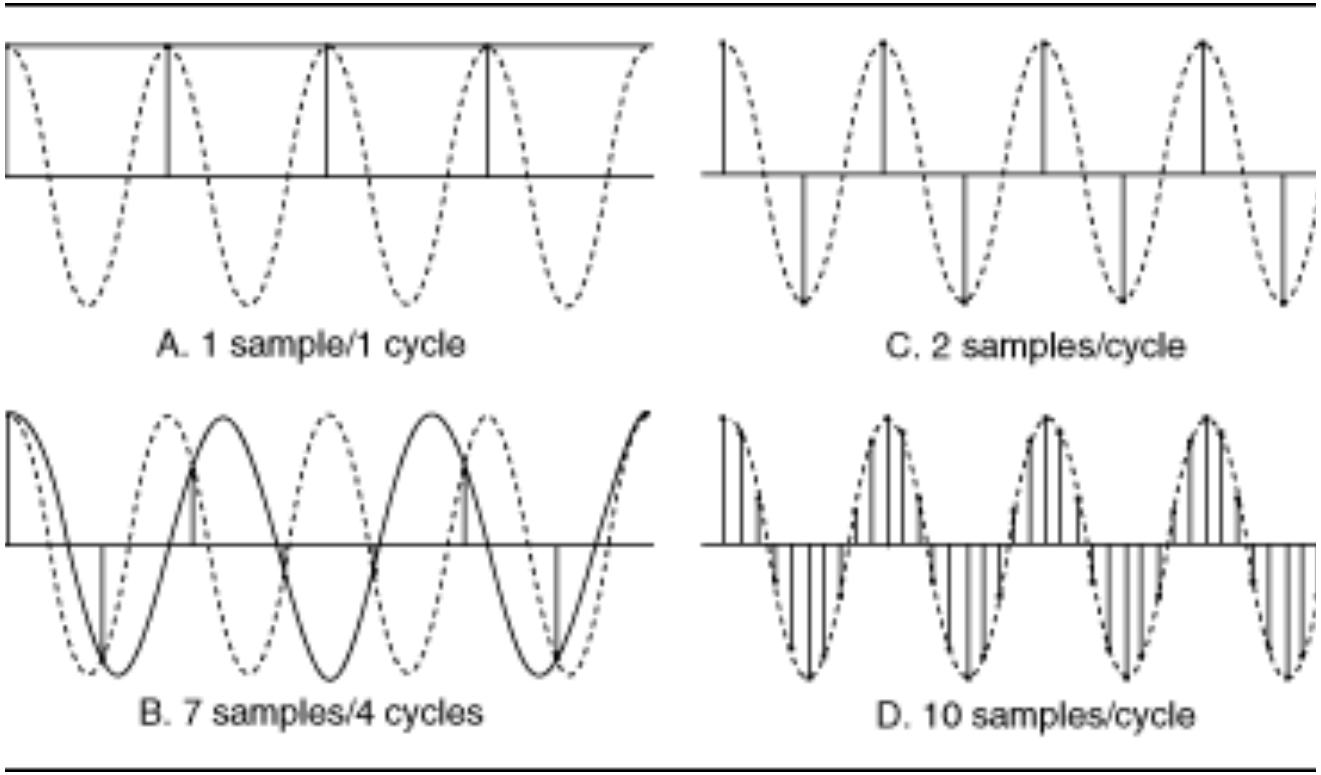
1LSB = $\frac{V_{FS}}{2^{10}} = \frac{V_{FS}}{1024}$

Quantization error: (- 0.5 LSB to 0.5LSB)

Conversion Time

- After sampling the signal, the conversion time is the time required for ADC to complete a single conversion.
- Conversion time for micro:bit takes (typically) 68μs to convert a single sample in 10 bit

Shannon Sampling Theory



According to the sampling theorem (Shannon, 1949), to reconstruct a one-dimensional signal from a set of samples, the sampling rate must be equal to or greater than twice the highest frequency in the signal.

Analog Read

- Perform ADC on the voltage at the pin (eg. P0) and obtain the digital value
- Range of digital value: 0 – 1023 (10 bit ADC)
- Relationship between the digital value and the input:

$$ADC = Round\left(\frac{V_{in} \times 1024}{V_{dd}}\right) \qquad V_{FS} = V_{dd}$$

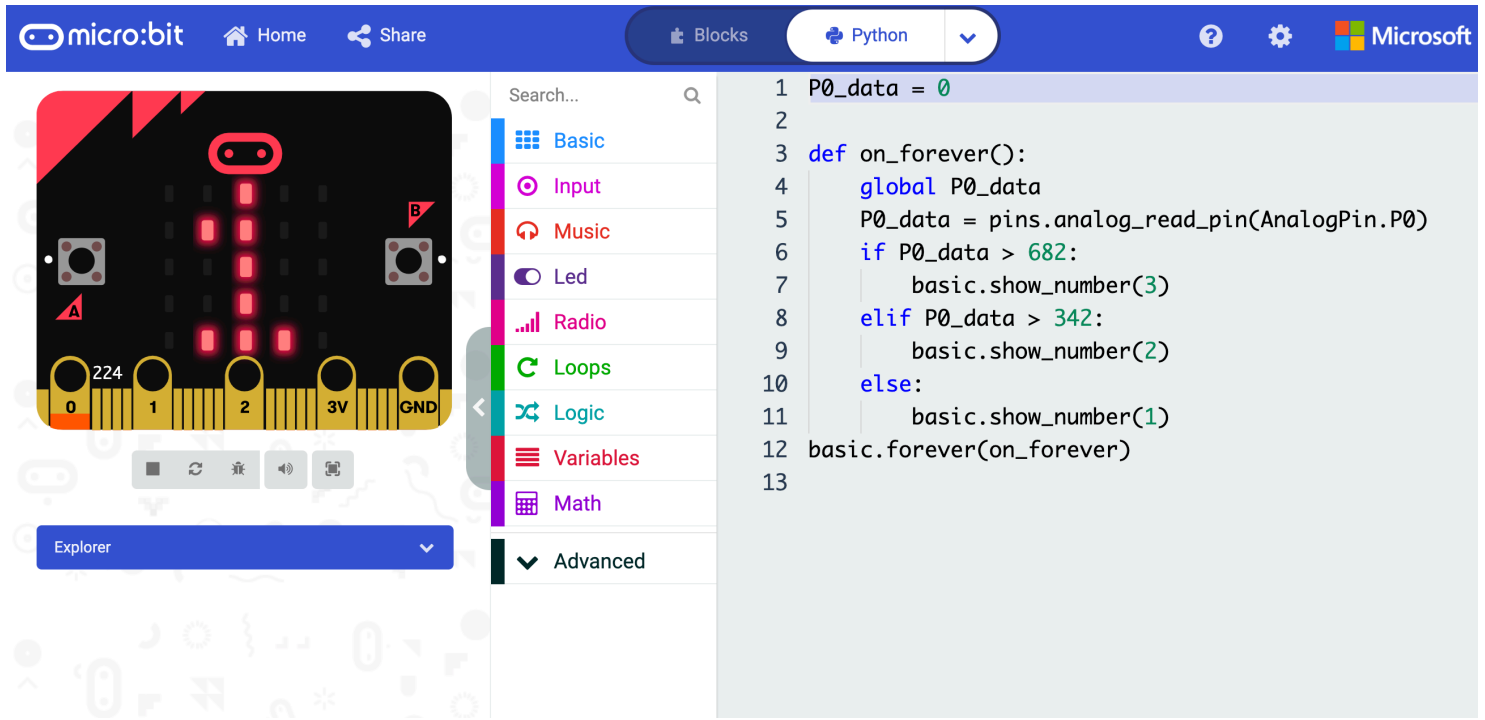
where ADC is the digital value, V_{in} is the analog input.

- Eg. V_{dd} = 3V, V_{in}=1V, we have 341_d (or 0101010101_b)

Note: A GPIO pin must not be exposed to higher voltage than VDD + 0.3 V.

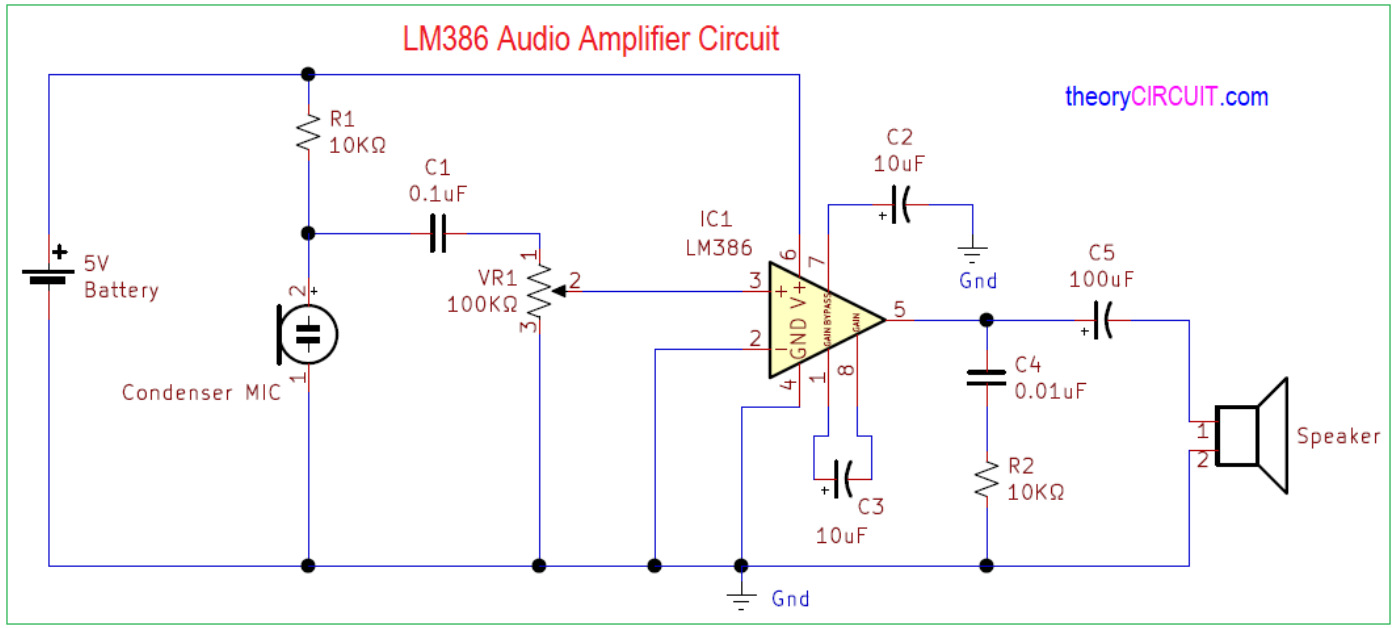
Example

- Analog Input to Microbit



Analog audio amplifier

- The input is an analog signal derived from the condenser microphone
- The output of the audio amplifier – LM 386 is also an analog signal. Preferably, its waveshape is the same as the input analog signal.



Question:

If the input and output waveshape are the same, why is it necessary to use an amplifier?

Digital audio amplifier

- The input can be an analog signal derived from the condenser microphone, or a digital source
- The amplifier consists of a switching stage which generates pulsewidth modulation (PWM) signal. Due to the presence of low-pass filter, the signal applied to the speaker is the same as the source.

Question:

What is PWM? How is it related to the amplitude or frequency of the signal?