EMEM 280: Measurements, Instrumentation, & Controls

MIC Fundamentals:
Analog Input Essentials

Part I: A/D Conversion & Amplification

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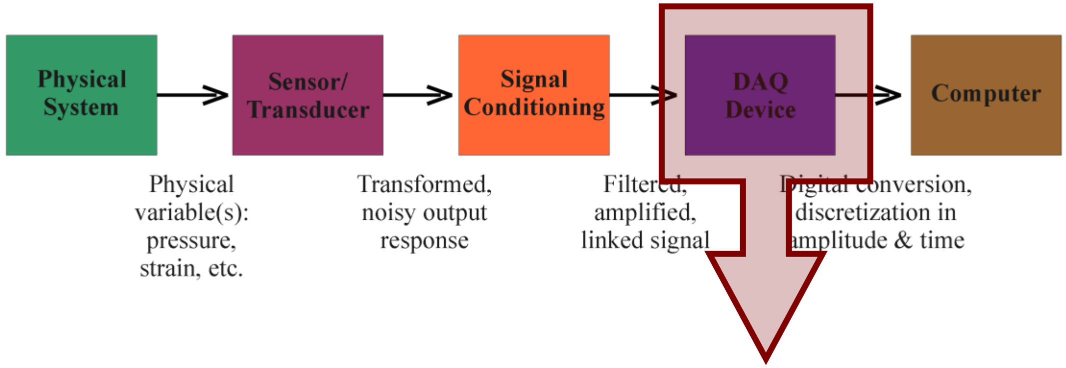
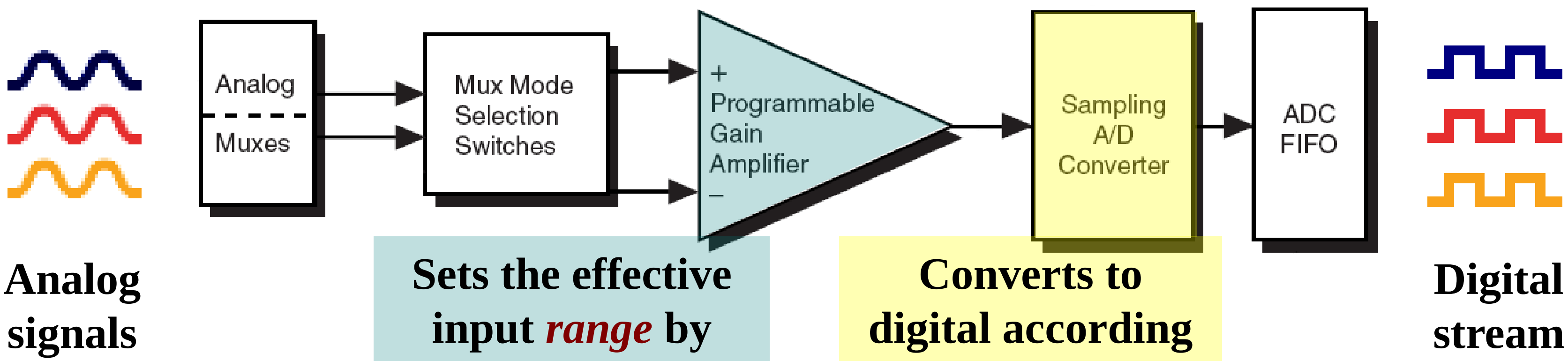
Recall Analog Input "Flow Path"





Sets the effective input *range* by adjusting the *gain*

Converts to digital according to *bit resolution*, driven at some *sampling rate*

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A/D Conversion

Reference Voltage

Precision value that the input voltage is compared against

Clock Signal

Conversion “driver” that determines how frequently to convert samples

Input = analog voltage to convert

Sampling A/D Converter

Splits the reference voltage range (unipolar or bipolar) into 2^N discrete “bins”, where N is the bit resolution, and places the supplied voltage into one of them

Output = “binary counts” = integer value representing discrete position within the reference limits (which bin?)

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A/D Conversion

EXAMPLE: 5V reference, bipolar operation, 4-bit A/D

4 bits $\Rightarrow 2^4 = 16$ bins, numbered 0 – 15

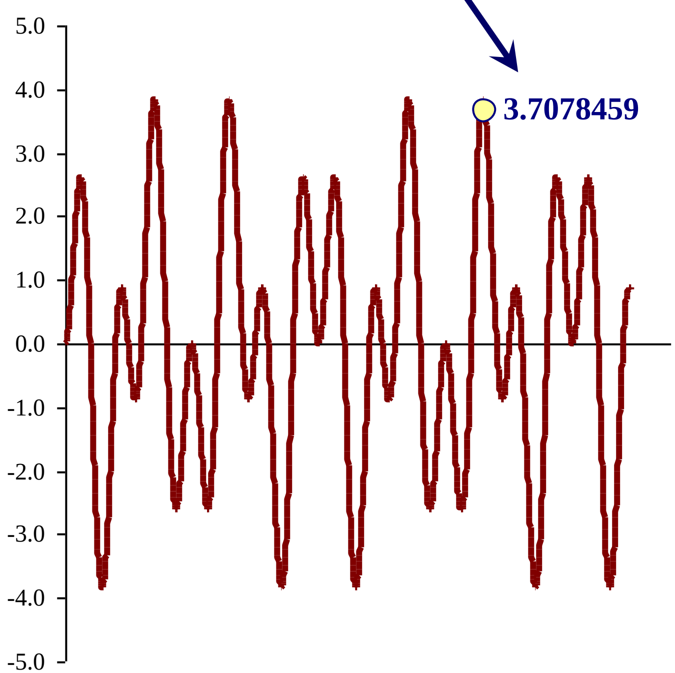
Bipolar 5V $\Rightarrow$ discretize -5V to 5V with the 16 bins

The "size" of each bin is 10V/16 = 0.625V: this is referred to as the *resolution* of the device

A/D Conversion

EXAMPLE: 5V reference, bipolar operation, 4-bit A/D converter

Single sample at 3.7078459V if exact



Analog	Digital
5.000 4.375	15
4.375 3.750	14
3.750 3.125	13
3.125 2.500	12
2.500 1.875	11
1.875 1.250	10
1.250 0.625	9
0.625 0.000	8
0.000 -0.625	7
-0.625 -1.250	6
-1.250 -1.875	5
-1.875 -2.500	4
-2.500 -3.125	3
-3.125 -3.750	2
-3.750 -4.375	1
-4.375 -5.000	0

Discretized as 13

When later "translated" by the software interface, we only know that the value is somewhere in the range 3.125V to 3.750V, and therefore off by as much as 0.625V

A/D Conversion

As shown in the example, the resolution determines how well an input voltage can be measured by the given device. Consider the same bipolar 5V operation for these other conditions (appropriate values in V):

# Bits	8	12	16	24
# Bins	256	4,096	65,536	16,777,216
Resolution	0.03906	0.00244	0.00015	5.96E-07

In practice, however, the actual measurement is always worse because of reference voltage inaccuracy, drift, gain errors, settling time errors, etc.

So…

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A/D Conversion

The *true error* is defined as the difference between the exact measured value and the digitized representation. *Accuracy* refers to the magnitude of the true error—more accurate readings have smaller true errors. Thus, the resolution determines the minimum true error that can be expected, but in practice the true error is always higher (the accuracy is always worse).

Resolution ≠ Accuracy

Still, better resolution leads to better accuracy. For a given DAQ device, with a fixed number of A/D bits, one way to improve resolution is to amplify the signal before conversion.

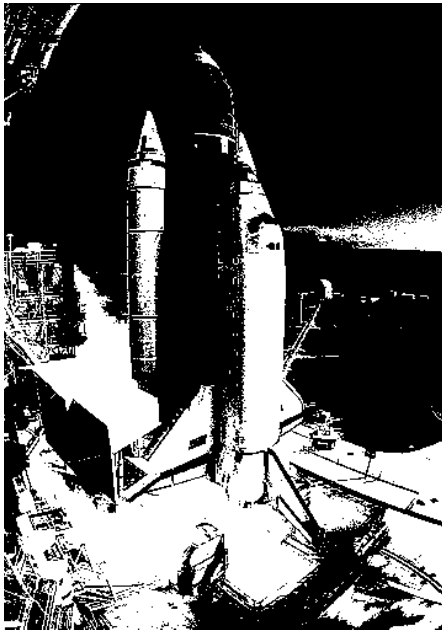
An Analogy: Color Depth

126,026 colors

256 colors (8-bit)

16 colors (4-bit)

2 colors (1-bit)



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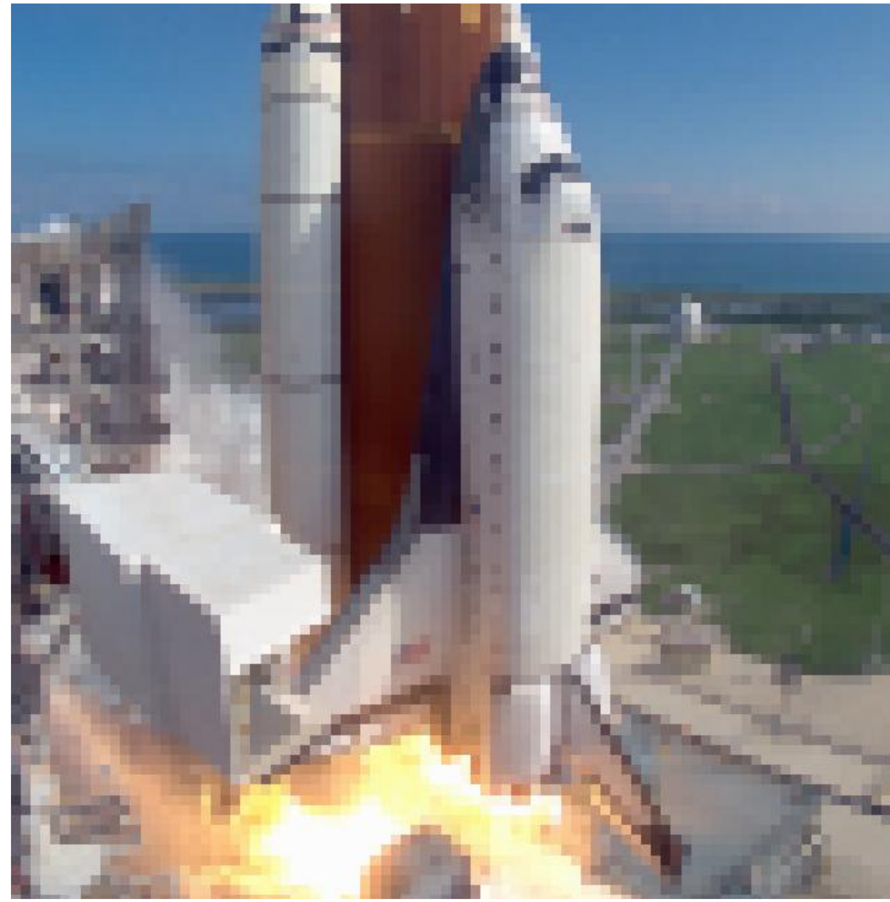
A Better Analogy: Pixel Resolution

900 x 900 pixels

90 x 90 pixels



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Instrumentation Amplifier

Conceptually, the purpose of the amplifier is very simple: to scale up (amplify), or sometimes reduce (attenuate), an input voltage to better match the A/D converter's reference voltage range. So, for example, a signal that is known to always be in the range ±1V should be amplified 5 times to match a bipolar 5V A/D.

The amplification factor is called the *gain*. A *programmable gain instrumentation amplifier (PGIA)* has a fixed selection of gains that can be programmatically selected in software by the DAQ driver.

Instrumentation Amplifier

Why does this help?

In the previous example of a 4-bit bipolar 5V A/D, the "straight" resolution of the converter itself is 0.625V. The *effective resolution* on a signal that was scaled up 5 times is actually 0.625V ÷ 5 = 0.125V, because it is the latter voltage value that can be distinguished overall. There is a price to pay, however: for this scenario, the input voltage must stay within the *effective range* of ±1V.

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An Analogy: Image Magnification

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Instrumentation Amplifier

Consider bipolar 5V operation for these other conditions:

12-bit Converter with Amplifier

Gain	Effective Resolution (mV)	Effective Range (±V)
0.5	4.88	10
1	2.44	5
2	1.22	2.5
4	0.61	1.25
5	0.488	1
10	0.244	0.5
25	0.0976	0.2
50	0.0488	0.1
100	0.0244	0.05
200	0.0122	0.025
1000	0.00244	0.005

16-bit Converter with Amplifier

Gain	Effective Resolution (mV)	Effective Range (±V)
0.5	0.3	10
1	0.15	5
2	0.075	2.5
4	0.0375	1.25
5	0.03	1
10	0.015	0.5
25	0.006	0.2
50	0.003	0.1
100	0.0015	0.05
200	0.00075	0.025
1000	0.00015	0.005

Instrumentation Amplifier

Note that, in all cases, the *relative* resolution is the same. In other words, the ratio of effective resolution to effective range is the same for all gains.

So, while amplification does allow smaller signals to be detected, a higher bit resolution is still better than higher amplification. With more bits, it is possible to detect the same small signal changes even when superposed on larger signals.

Witness: a 24-bit A/D converter with no amplification can achieve the same effective resolution as a 16-bit converter with amplification of 250x, but without the corresponding reduction of effective range.