Embedded System Interfacing

Lecture 7
ADC

IMT SCHOOL

Introduction

Introduction

We live in an analog world. Every parameter in our life can have infinite possibilities of values. Temperature, pressure, colors , etc. … even between the value 0 and the value 1 there are infinite values.

But in the Embedded System world, we can process only digital values. Therefor, we need a translation unit that can convert any signal from its original analog form, to a digital form that can be processed by the processor.

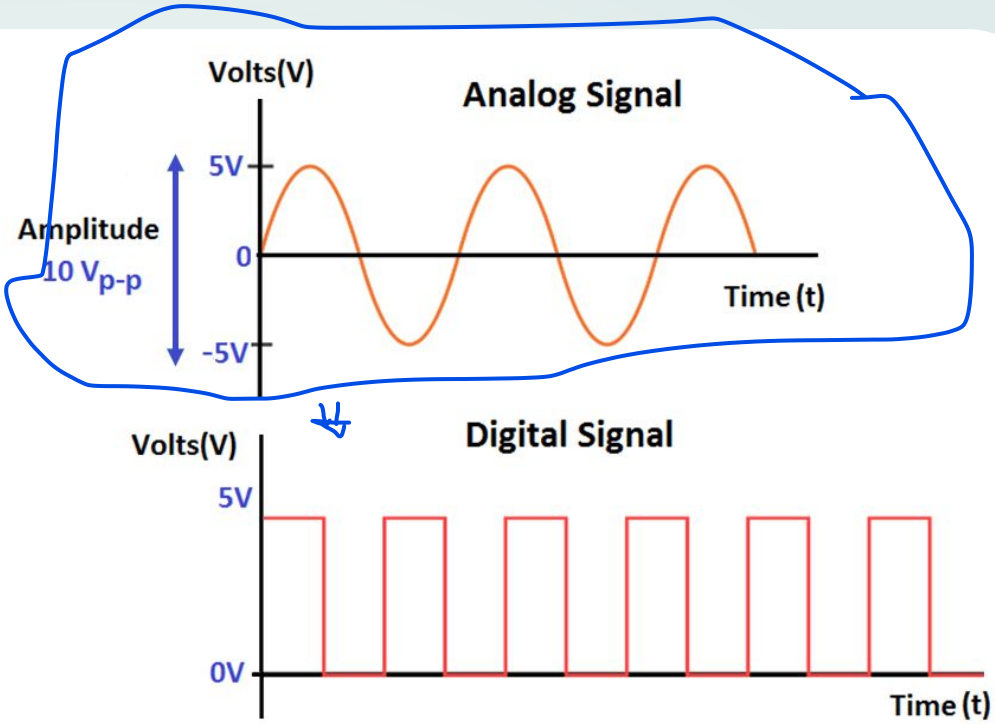
Analog Signal Vs Digital Signal

01
Analog Signal

An analog signal is time-varying and generally bound to a range (e.g. +12V to -12V), but there is an infinite number of values within that continuous range. An analog signal uses a given property of the medium to convey the signal's information, such as electricity moving through a wire.

02
Digital Signal

A digital signal is a signal that represents data as a sequence of discrete values. A digital signal can only take on one value from a finite set of possible values at a given time.



How we Interact with World ?

Looking For An Answer?

IMT SCHOOL

IMT SCHOOL

Transducers

02

Transducers

We have five senses to help us interact with the world - touch, sound, smell, taste and sight. These are *our* sensors. We use them as input devices to gather information. Our body converts the data they receive into chemical and electrical signals which are processed by the brain. We use our hands, feet and voice to manipulate the world ... these are our actuators. Sensors are input devices which gather information and actuators are output devices which manipulate (act on) things.

We have surrounded ourselves with machines and devices that do the same thing. That is, they are able to gather information about the world (sensors) and then interact somehow with the world ... manipulating it (actuator). One can claim that these contraptions do a much better job than humans because they are much more reliable, give more detailed information and are unbiased. In fact, these mechanical devices can detect and measure things which are beyond our human senses. For example, can you tell the strength and orientation of magnetic fields? What is the level of carbon monoxide in your home right now? Which house in your neighborhood is best insulated? Sensors (and actuators) are all around us.

IMT SCHOOL

Transducers

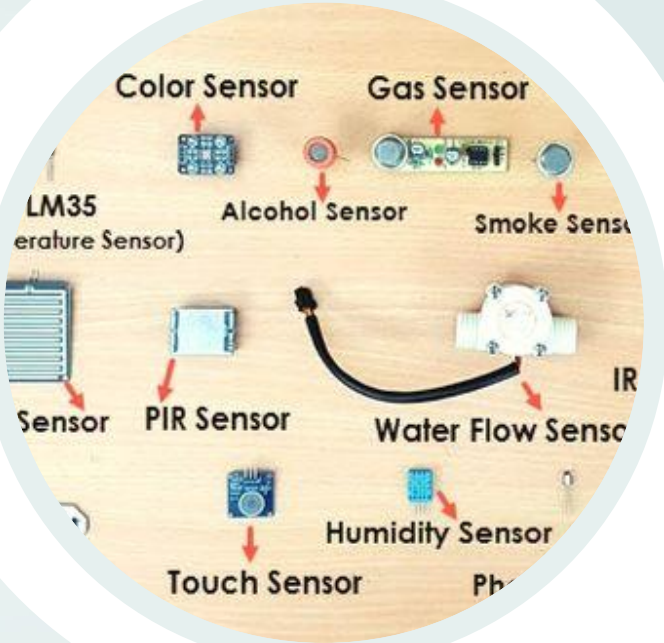
A **transducer** is any device that converts one form of energy into a readable signal. Many transducers have an input that is then converted to a proportional electrical signal. Common inputs include energy, torque, light, force, position, acceleration, and other physical properties.

Transducers Types:

- Sensors
- Actuators

Sensors

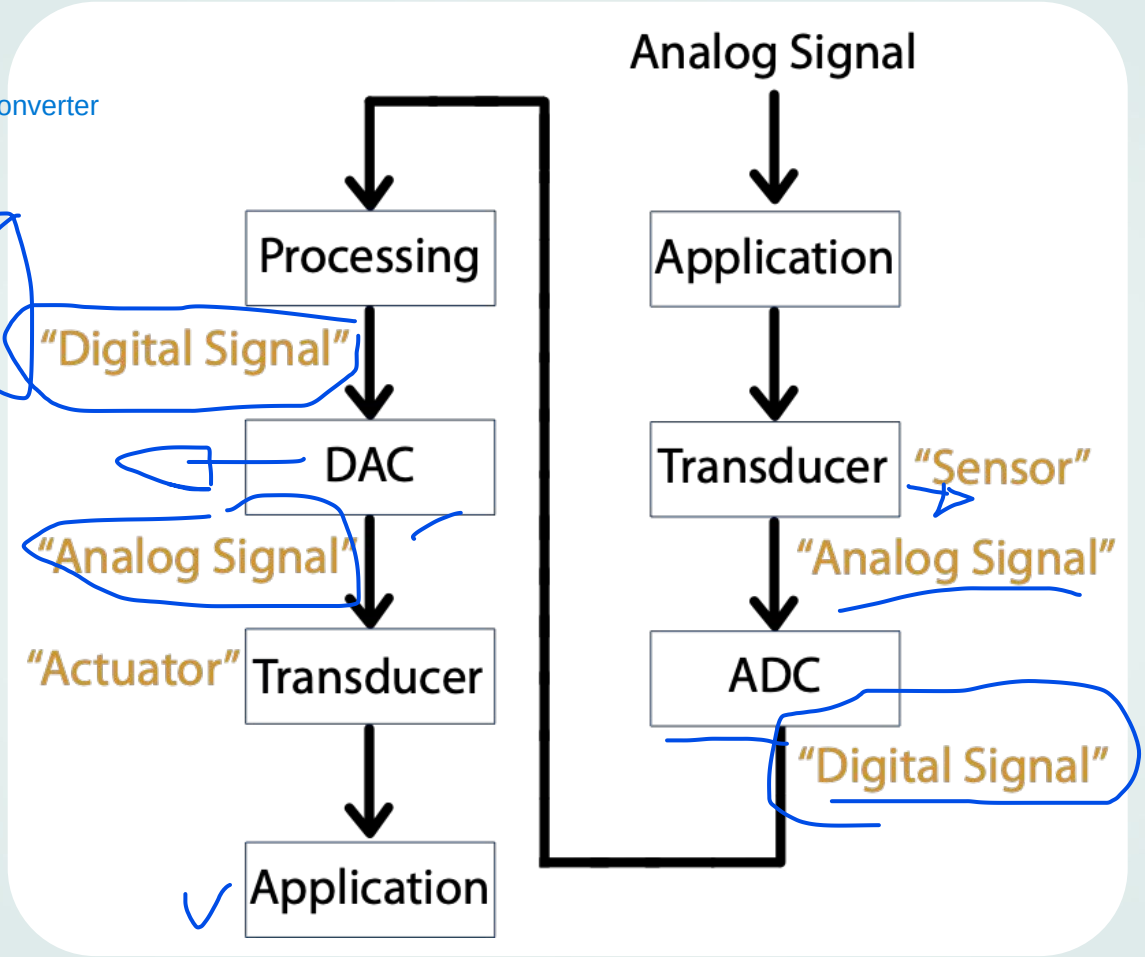
a sensor is a device, module, machine, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. A sensor is always used with other electronics.



Actuators

An *actuator* is a device that is responsible for moving or controlling a mechanism or system. It is controlled by a signal from a control system or manual control. It is operated by a source of energy, which can be mechanical force, electrical current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion.

analog to digital converter



How Sensors Work ?

A sensor consists of three main components:

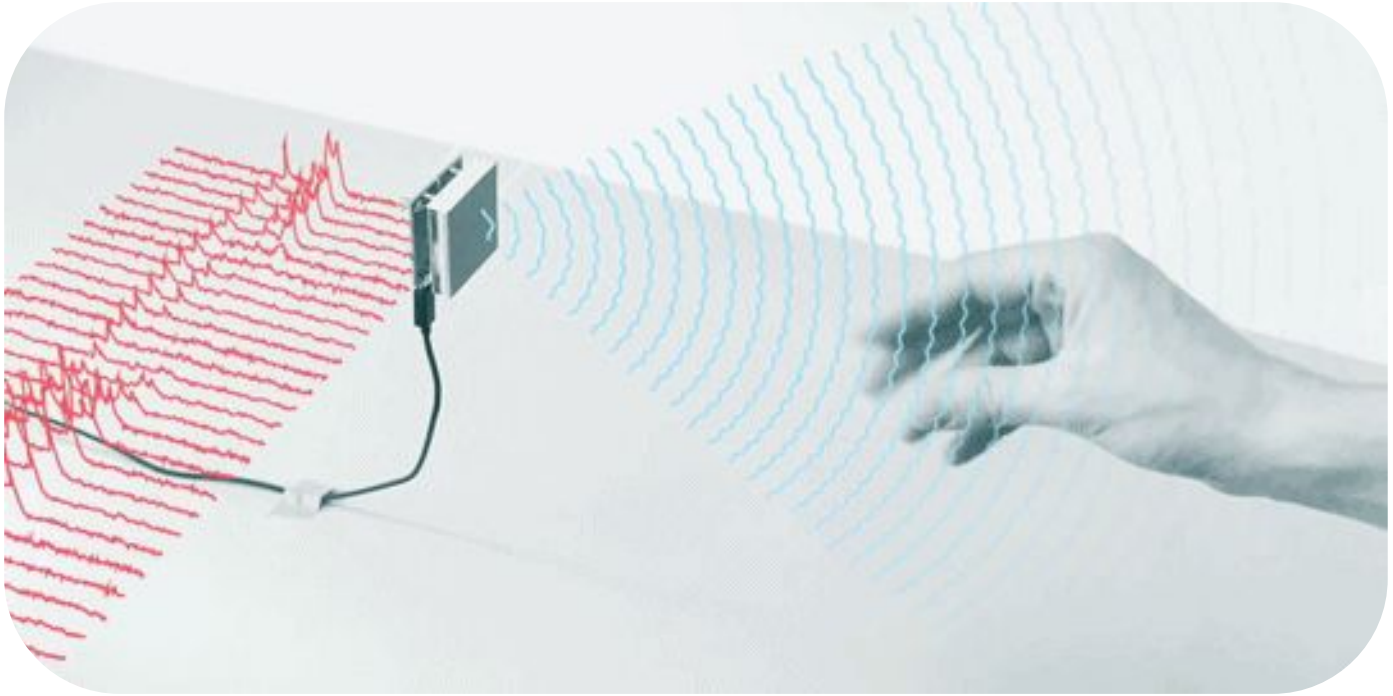
(1) The sensing section contains the sensor itself which is based on a particular technology. The variety of technologies means you can select a sensor technology which fits your application.

(2) The processing circuitry converts the physical variable into an electrical variable.

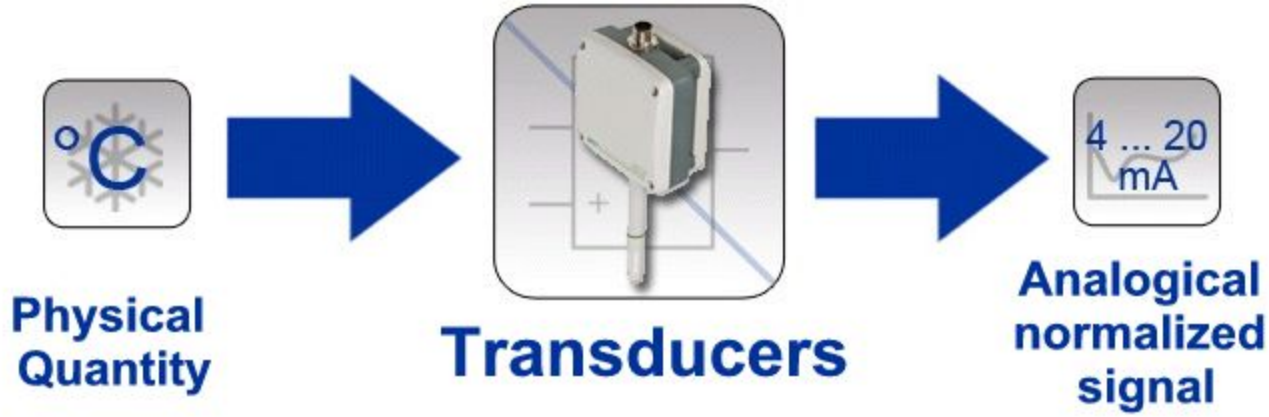
(3) The signal output contains the electronics connected to a control system.

IMT SCHOOL

How Sensors Work ?



How Sensors Work ?



ADC

IMT SCHOOL

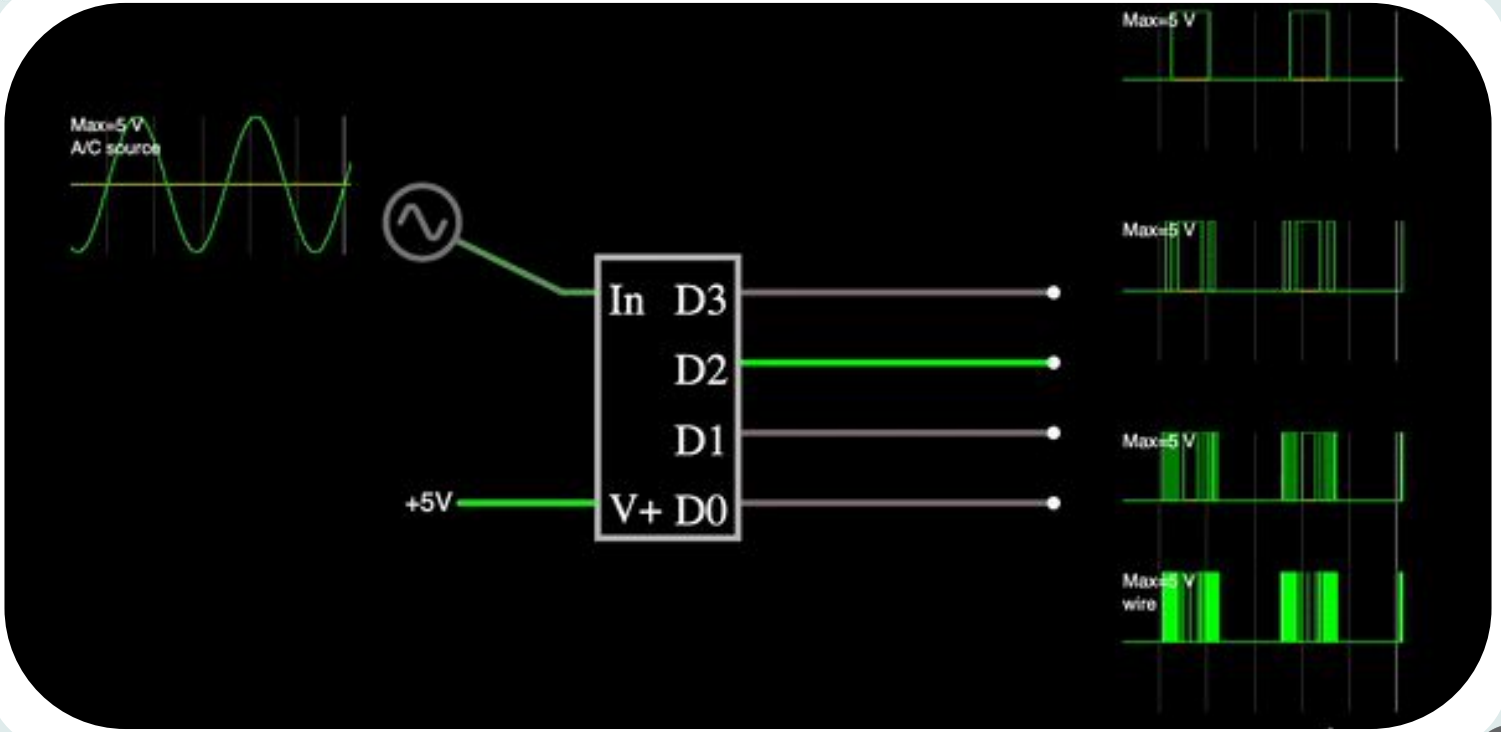
What is an ADC

Analog to Digital Converter, or ADC, is a data converter which allows digital circuits to interface with the real world by encoding an analog signal into a binary code.

(ADCs) allow micro-processor controlled circuits, Arduinos, Raspberry Pi, Atmega and other such digital logic circuits to communicate with the real world. In the real world, analog signals have continuously changing values which come from various sources and sensors which can measure sound, light, temperature or movement, and many digital systems interact with their environment by measuring the analog signals from such transducers.

IMT SCHOOL

ADC


Max=5 V
A/C source
In D3
D2
D1
+5V
V+ D0
Max=5 V
Max=5 V
Max=5 V
Max=5 V
wire

Explanation

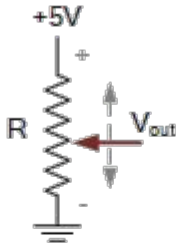
While analog signals can be continuous and provide an infinite number different voltage values, digital circuits on the other hand work with binary signal which have only two discrete states, a logic “1” (HIGH) or a logic “0” (LOW). So it is necessary to have an electronic circuit which can convert between the two different domains of continuously changing analogue signals and discrete digital signals, and this is where *Analogue-to-Digital Converters* (A/D) come in.

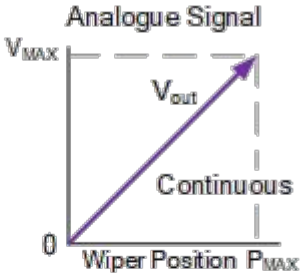
Basically an analog to digital converter takes a snapshot of an analog voltage at one instant in time and produces a digital output code which represents this analog voltage. The number of binary digits, or bits used to represent this analogue voltage value depends on the resolution of an A/D converter.

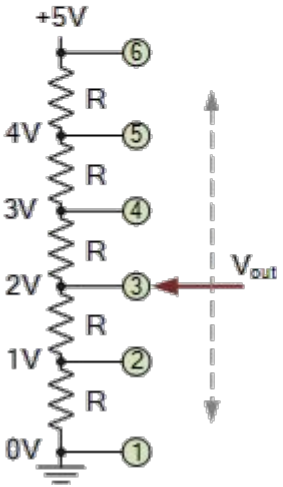
Explanation

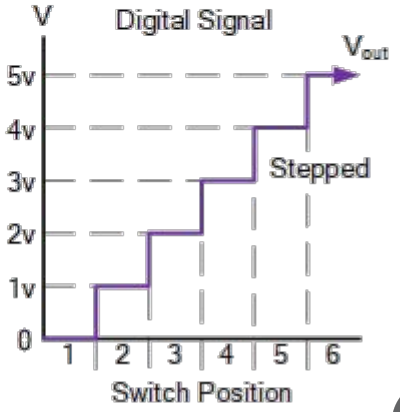
For example a 4-bit ADC will have a resolution of one part in 15, (24 – 1) whereas an 8-bit ADC will have a resolution of one part in 255, (28 – 1). Thus an analogue to digital converter takes an unknown continuous analogue signal and converts it into an "n"- bit binary number of 2n bits.

But first let us remind ourselves of the differences between an analogue (or analog) signal and a digital signal as shown:









Explanation

Here we can see that as the wiper terminal of the potentiometer is rotated between between 0 volts and VMAX, it produces a continuous output signal (or voltage) which has an infinite number of output values relative to the wiper position. As the potentiometers wiper is adjusted from one position to the next, there is no sudden or step change between the two voltage levels thereby producing a continuously variable output voltage. Examples of analogue signals include temperature, pressure, liquid levels and light intensity.

For a digital circuit the potentiometer wiper has been replaced by a single rotary switch which is connected in turn to each junction of the series resistor chain, forming a basic potential divider network. As the switch is rotated from one position (or node) to the next the output voltage, VOUT changes quickly in discrete and distinctive voltage steps representing multiples of 1.0 volts on each switching action or step as shown.

Explanation

So for example, the output voltage will be 2 volts, 3 volts, 5 volts, etc. but NOT 2.5V, 3.1V or 4.6V. Finer output voltage levels could easily be produced by using a multi-positional switch and increasing the number of resistive elements within the potential divider network, therefore increasing the number of discrete switching steps.

Then we can see that the major differences between an analogue signal and a digital signal is that an “Analog” quantity is continuously changing over time while a “Digital” quantity has discrete (step by step) values. “LOW” to “HIGH” or “HIGH” to “LOW”.

So how can we convert a continuously changing signal with an infinite number of values to one which has distinct values or steps for use by a digital circuit.

ADC

The process of taking an analog voltage signal and converting it into an equivalent digital signal can be done in many different ways, and while there are many analog-to-digital converter chips such as the ADC08xx series available from various manufacturers, it is possible to build a simple ADC using discrete components.

One simple and easy way is by using parallel encoding, also known as *flash*, *simultaneous*, or *multiple comparator* converters in which comparators are used to detect different voltage levels and output their switching state to an encoder.

ADC

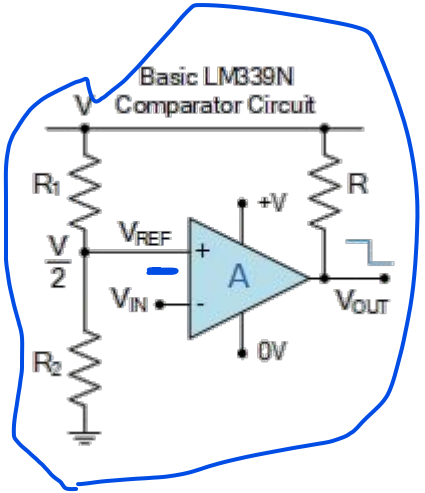
Parallel of “Flash” A/D converters use a series of interconnected but equally spaced comparators and voltage references generated by a series network of precision resistors for generating an equivalent output code for a particular n-bit resolution.

The advantage of parallel or flash converters is that they are simple to construct and do not require any timing clocks as the instant an analogue voltage is applied to the comparator inputs, it is compared against a reference voltage. Consider the comparator circuit below.

Comparator

An analog comparator such as the LM339N which has two analog inputs, one positive and one negative, and which can be used to compare the magnitudes of two different voltage levels.

A voltage input, (VIN) signal is applied to one input of the comparator, while a reference voltage, (VREF) to the other. A comparison of the two voltage levels at the comparator's input is made to determine the comparators digital logic output state, either a "1" or a "0".



Comparator

The reference voltage, VREF is compared against the input voltage, VIN applied to the other input. For an LM339 comparator, if the input voltage is less than the reference voltage, (VIN < VREF) the output is “OFF”, and if it is greater than the reference voltage, (VIN > VREF) the output will be “ON”. Thus a comparator compares two voltage levels and determines which one of the two is higher.

In our simple example above, VREF is obtained from the voltage divider network setup by R1 and R2. If the two resistors are of equal values, that is R1 = R2, then clearly the reference voltage level will be equal to half the supply voltage, or V/2. So for a comparator with an open-collector output, if VIN is less than V/2, the output is HIGH, and if VIN is greater than V/2, the output is LOW acting as a 1-bit ADC.

Comparator

But by adding more resistors to the voltage divider network we can effectively “divide” the supply voltage by an amount determined by the resistances of the resistors. However, the more resistors we use in the voltage divider network the more comparators will be required.

In general, 2n– 1 comparators would be required for conversion of an “n”-bit binary output, where “n” is typically in the range from 8 to 16. In our example above, the single bit ADC used 21– 1, which equals “1” comparator to determine if VIN was greater or smaller than the V/2 reference voltage.

If we now create a 2-bit ADC, then we will need 22– 1 which is “3” comparators as we need four different voltage levels corresponding to the 4 digital values required for a 4-to-2 bit encoder circuit as shown.

ADC Types

But by adding more resistors to the voltage divider network we can effectively “divide” the supply voltage by an amount determined by the resistances of the resistors. However, the more resistors we use in the voltage divider network the more comparators will be required.

In general, 2n– 1 comparators would be required for conversion of an “n”-bit binary output, where “n” is typically in the range from 8 to 16. In our example above, the single bit ADC used 21– 1, which equals “1” comparator to determine if VIN was greater or smaller than the V/2 reference voltage.

If we now create a 2-bit ADC, then we will need 22– 1 which is “3” comparators as we need four different voltage levels corresponding to the 4 digital values required for a 4-to-2 bit encoder circuit as shown.

ADC Performance Factors

We can evaluate ADC performance using several factors, the most important of which are:

ADC Signal-to-noise ratio (SNR): The SNR reflects the average number of non-noise bits in any particular sample (effective number of bits or ENOB).

ADC Bandwidth: We can determine bandwidth by evaluating the sampling rate – the number of times per second the analog source is sampled to generate discrete values.

ADC Types

There are really five major types of ADCs in use today:

- Successive Approximation (SAR) ADC
- Delta-sigma (ΔΣ) ADC
- Dual Slope ADC
- Pipelined ADC
- Flash ADC

ADC Types

ADC Type	Pros	Cons	Max Resolution	Max Sample Rate	Main Applications
Successive Approximation (SAR)	Good speed/resolution ratio	No inherent anti-aliasing protection	18 bits	10 MHz	Data Acquisition
Delta-sigma (ΔΣ)	High dynamic performance, inherent anti-aliasing protection	Hysteresis on unnatural signals	32 bits	1 MHz	Data Acquisition, Noise & Vibration, Audio
Dual Slope	Accurate, inexpensive	Low speed	20 bits	100 Hz	Voltmeters
Pipelined	Very fast	Limited resolution	16 bits	1 GHz	Oscilloscopes
Flash	Fastest	Low bit resolution	12 bits	10 GHz	Oscilloscopes

TO Read More about ADC Click Here

IMT SCHOOL

ADC Terminology

ADC Resolution: Number of the bits that represent the output digital value.

Reference Voltage: Maximum Voltage could be measured by the ADC, at this voltage all bits of the output value shall be 1

ADC Step: The analog value needed to increase the digital value by 1
Step = Reference voltage / (2^ADC Resolution)

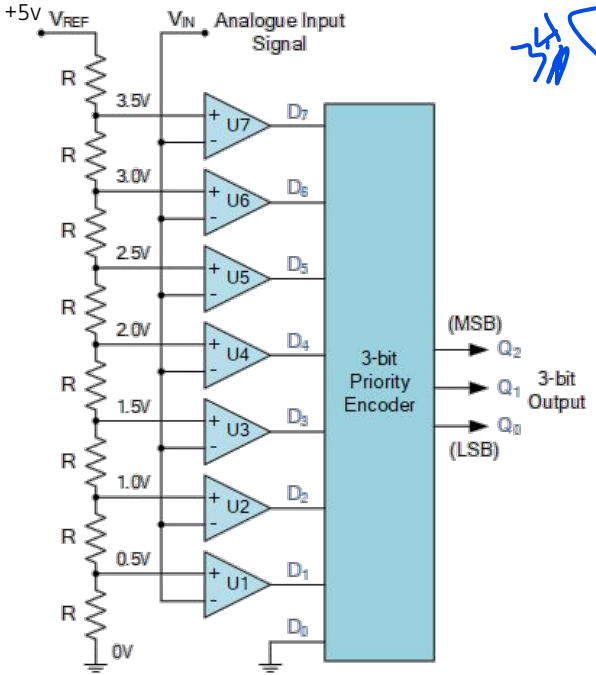
Conversion Time: Time taken by ADC to convert analog signal to digital signal

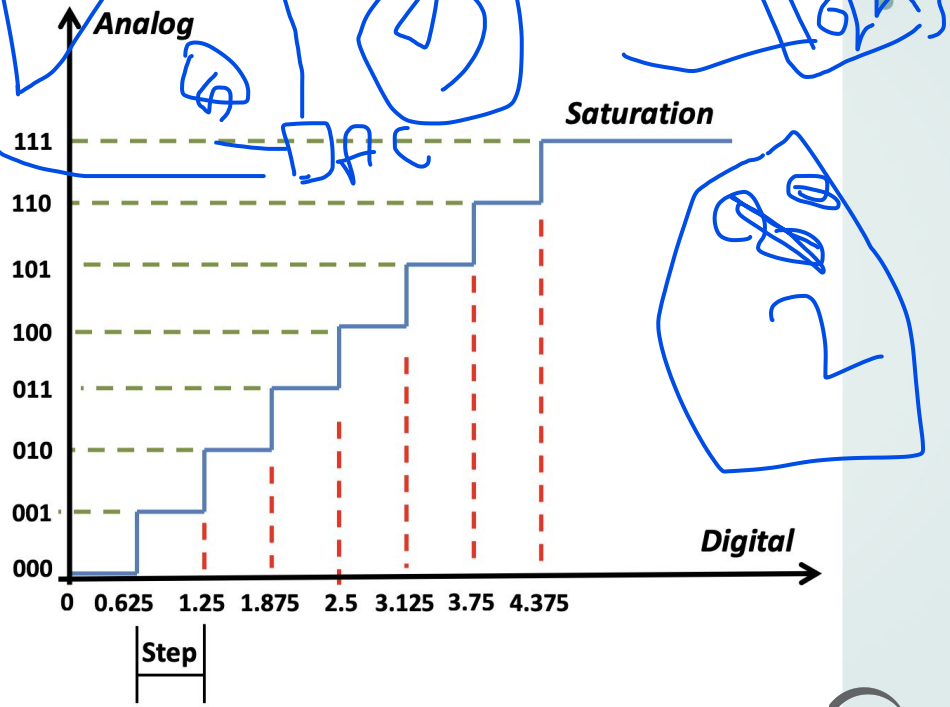
ADC Clock: The input clock to the counter inside the ADC. The higher frequency of the ADC clock, the lower conversion time and higher power consumption.

04

3-bit ADC

3-bit ADC Example





3-bit ADC Example

This graph shows the mapping between the analog values and digital values for 3 bit ADC with reference voltage = 5V. The 3 bit ADC has 8 possible digital values. So, simply the step = 8 / 5 = 0.625v. Important

Note: The ADC saturates at voltage = Reference Voltage – 1 step.

3-bit ADC Example

Analogue Input Voltage (V_{IN})	Comparator Outputs								Digital Outputs		
	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Q_2	Q_1	Q_0
0 to 0.625 **V**	0	0	0	0	0	0	0	**0**	0	0	0
0.625 to 1.25 **V**	0	0	0	0	0	0	**1**	X	0	0	1
1.25 to 1.875 **V**	0	0	0	0	0	**1**	X	X	0	1	0
1.875 to 2.5 **V**	0	0	0	0	**1**	X	X	X	0	1	1
2.5 to 3.125 **V**	0	0	0	**1**	X	X	X	X	1	0	0
3.125 to 3.75 **V**	0	0	**1**	X	X	X	X	X	1	0	1
3.75 to 4.375 **V**	0	**1**	X	X	X	X	X	X	1	1	0
4.375 to 5 **V**	**1**	X	X	X	X	X	X	X	1	1	1

Converting Digital Value to Analog Value

The ADC converts the analog value to digital value. In the code we need to make get back the original analog value to act on it.

$$\text{Analog Value} = \text{Digital Value} \times \text{Step} = \text{Digital Value} \times \frac{\text{Reference Voltage}}{2^{\text{ADC Resolution}}}$$

Important Notes: 1- In C programming, when you have an equation that contains multiplication and division, do the multiplication first

IMT SCHOOL

Important Notes

1- In C programming, when you have an equation that contains multiplication and division, do the multiplication first in brackets ( ), then apply the division. For ex:

Assuming x = 10, y = 20 and z = 30.
Then: result = (x/y) * z = 0 while: result = (x*z) / y = 15

Mathematically, the two previous equations are the same. But in Programing division int by int shall result in int too. So x/y which mathematically = 0.5 in programming it gives 0. To avoid this problem do the multiplication first to increase the numerator and then do the division.

Important Notes

2- To increase the precision, using small units like millivolt in calculations is preferred when comparing to volt. For ex:

Assuming 8 bit ADC, and reference voltage is 5V. To get the analog value for a certain digital value we use the formula:
Analog value = (Digital Value * 5) / 256

The possible values could be obtained from this equation are 0, 1, 2, 3 and 4v although we have 256 digital possible value !
It means that many each 50 digital value will give the same analog Value.

But if we rewrite the equation in terms of milli volt, then:
Analog Value = (Digital Value *5000) / 256.
The output analog value will be in the range from 0 to 4980 approximately

ADC in Atmega 32

The controller has 10 bit ADC, which means we will get digital output 0 to 1023.

i.e. When the input is 0V, the digital output will be 0V & when input is 5V (and Vref=5V), we will get the highest digital output corresponding to 1023 steps, which is 5V.

So controller ADC has 1023 steps and

- Step size with Vref=5V : 5/1023 = 4.88 mV.
- Step size with Vref=2.56 : 2.56/1023 = 2.5 mV.

So Digital data output will be D*out* = Vin / step size.

ATmega16/32 ADC

- It is 10-bit ADC
- Converted output binary data is held in two special functions 8-bit register ADCL (result Low) and ADCH (result in High).
- ADC gives 10-bit output, so (ADCH: ADCL) only 10-bits are useful out of 16-bits.
- We have options to use this 10-bits as upper bits or lower bits.
- We also have three options for Vref. 1. AVcc (analog Vcc), 2. Internal 2.56 v3. External A*ref.* Pin.
- The total conversion time depends on crystal frequency and ADPS0: 2 (frequency devisor)
- If you decided to use AVcc or Vref pin as ADC voltage reference, you can make it more stable and increase the precision of ADC by connecting a capacitor between that pin and GND.

ADC in Atmega 32

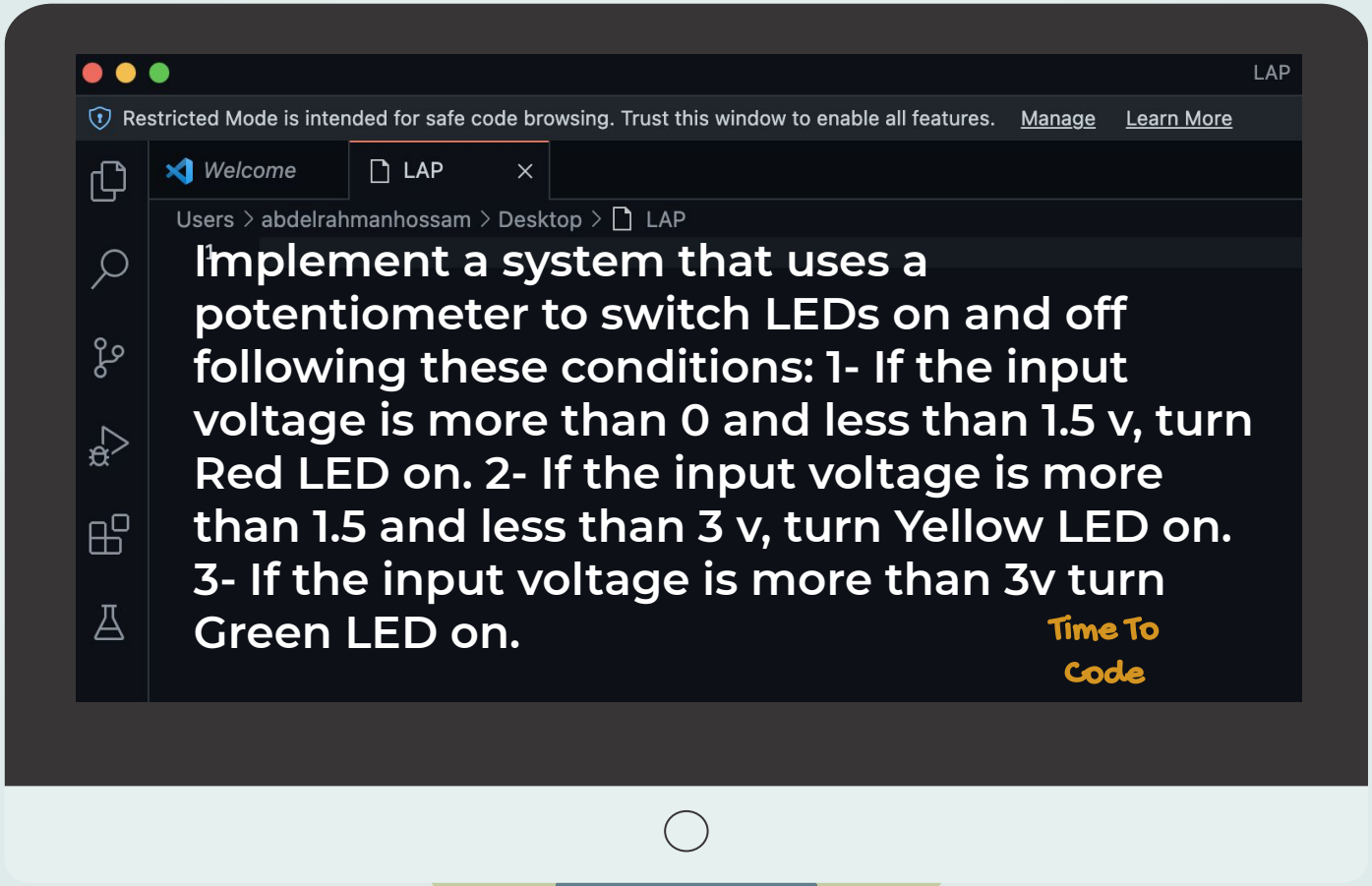
Steps in programming the A/D converter using polling

To program the A/D converter of the AVR, the following steps must be taken:

1. Make the pin for the selected ADC channel an input pin.
2. Turn on the ADC module of the AVR because it is disabled upon power-on reset to save power.
3. Select the conversion speed. We use registers ADPS2:0 to select the conversion speed.
4. Select voltage reference and ADC input channels. We use the REFS0 and REFS1 bits in the ADMUX register to select voltage reference and the MUX4:0 bits in ADMUX to select the ADC input channel.
5. Activate the start conversion bit by writing a one to the ADSC bit of ADCSRA.
6. Wait for the conversion to be completed by polling the ADIF bit in the ADCSRA register.
7. After the ADIF bit has gone HIGH, read the ADCL and ADCH registers to get the digital data output. Notice that you have to read ADCL before ADCH; otherwise, the result will not be valid.
8. If you want to read the selected channel again, go back to step 5.
9. If you want to select another V_{ref} source or input channel, go back to step 4.

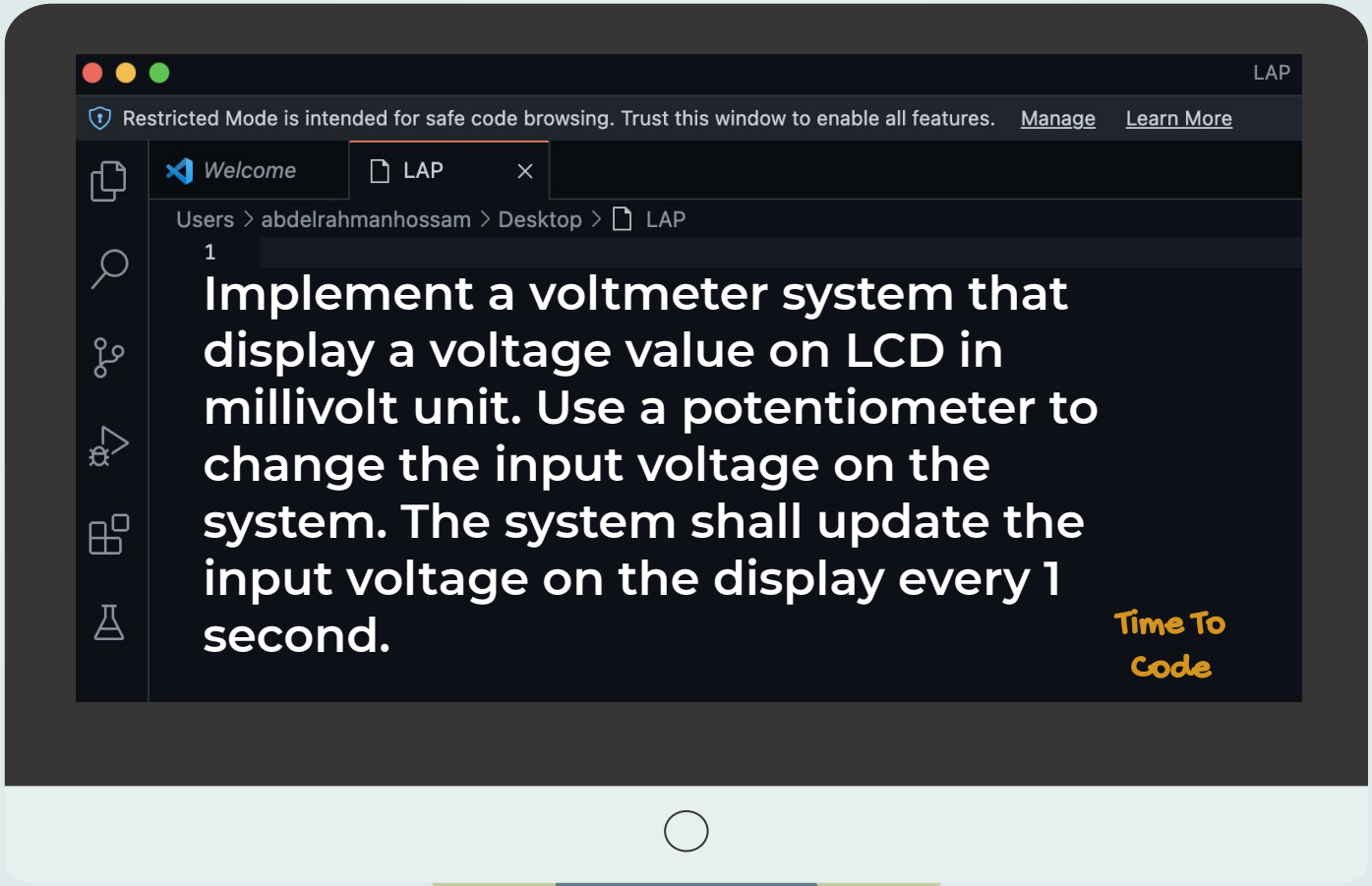
IMT SCHOOL

LAb 1



IMT SCHOOL

LAb 2



IMT SCHOOL

The End

IMT SCHOOL

www.imtschool.com

www.facebook.com/imaketechnologyschool/