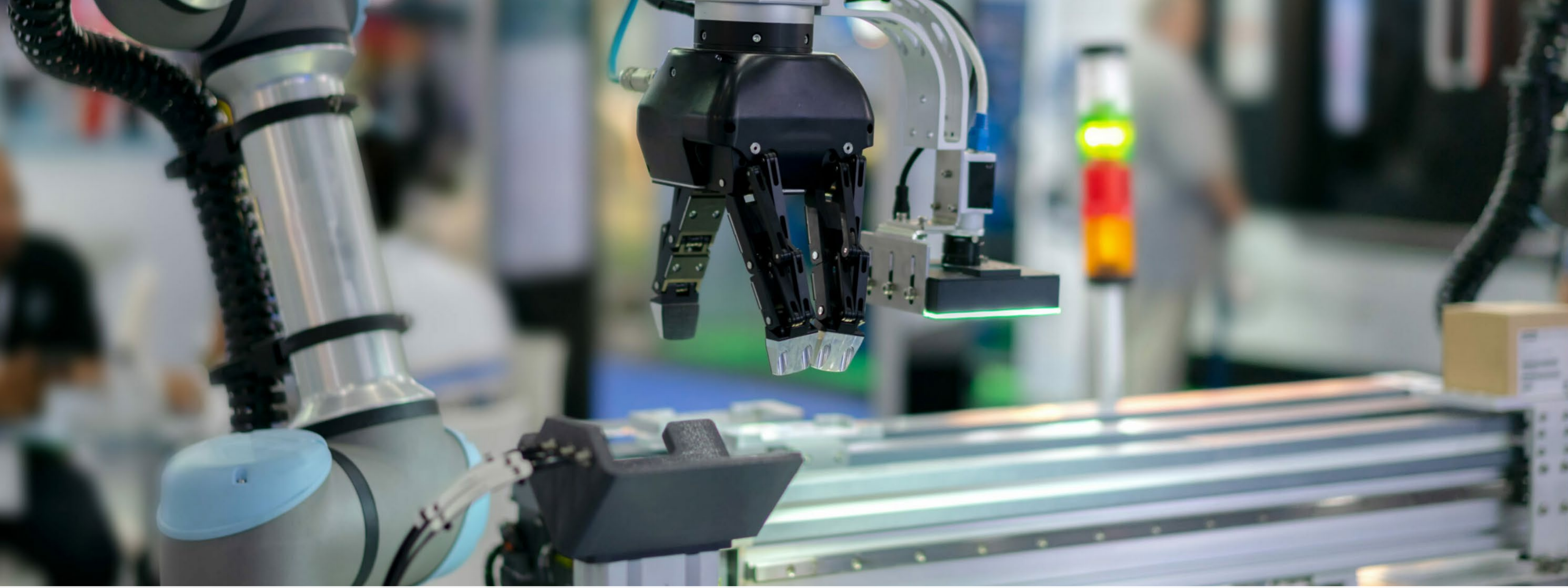
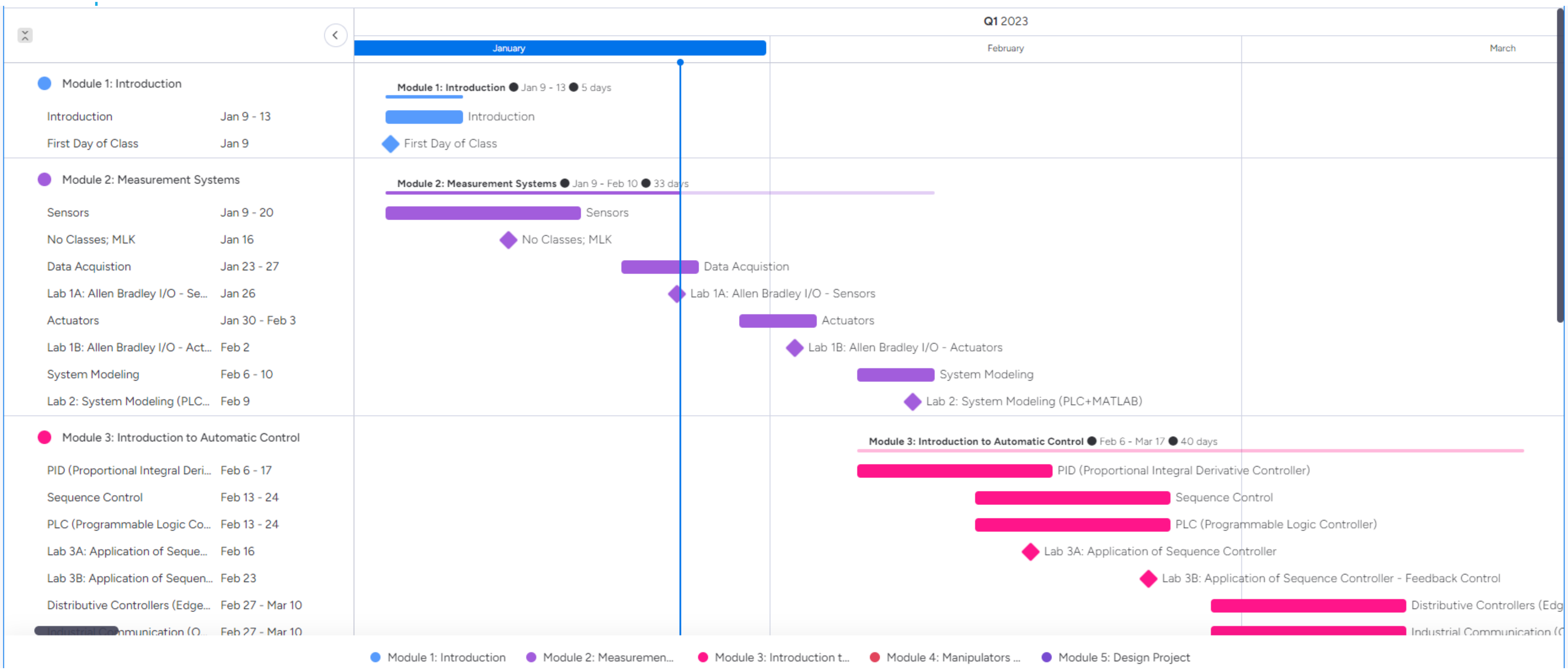


ISE 589-006: INTRODUCTION TO MODERN INDUSTRIAL AUTOMATION

LECTURE 003

Fred Livingston, PhD


Q1 2023
January
February
March
Module 1: Introduction
Introduction Jan 9 - 13
First Day of Class Jan 9
Module 2: Measurement Systems
Sensors Jan 9 - 20
No Classes; MLK Jan 16
Data Acquistion Jan 23 - 27
Lab 1A: Allen Bradley I/O - Se... Jan 26
Actuators Jan 30 - Feb 3
Lab 1B: Allen Bradley I/O - Act... Feb 2
System Modeling Feb 6 - 10
Lab 2: System Modeling (PLC... Feb 9
Module 3: Introduction to Automatic Control
PID (Proportional Integral Deri... Feb 6 - 17
Sequence Control Feb 13 - 24
PLC (Programmable Logic Co... Feb 13 - 24
Lab 3A: Application of Seque... Feb 16
Lab 3B: Application of Sequen... Feb 23
Distributive Controllers (Edge... Feb 27 - Mar 10
Industrial Communication (O... Feb 27 - Mar 10
Module 1: Introduction • Jan 9 - 13 • 5 days
Introduction
First Day of Class
Module 2: Measurement Systems • Jan 9 - Feb 10 • 33 days
Sensors
No Classes; MLK
Data Acquistion
Lab 1A: Allen Bradley I/O - Sensors
Actuators
Lab 1B: Allen Bradley I/O - Actuators
System Modeling
Lab 2: System Modeling (PLC+MATLAB)
Module 3: Introduction to Automatic Control • Feb 6 - Mar 17 • 40 days
PID (Proportional Integral Derivative Controller)
Sequence Control
PLC (Programmable Logic Controller)
Lab 3A: Application of Sequence Controller
Lab 3B: Application of Sequence Controller - Feedback Control
Distributive Controllers (Edg
Industrial Communication (
Module 1: Introduction
Module 2: Measuremen...
Module 3: Introduction t...
Module 4: Manipulators ...
Module 5: Design Project

LECTURE 3: DATA ACQUISITION

Homework 1

Data Acquisition

Computer Process Control

Introduction Programming Control Logic

HW 1 DUE FEB 2ND 2023

Q1. Given the following desired task

1. Detecting the presence of the part
2. Detecting the location and orientation of the part
3. Detect the velocity of the workspace

Determine the best sensors for completing each of the above tasks—things to consider contact vs. non-contact, material properties, performance, and accuracy.

Q2.

This robot contains a numbers of sensors for detecting an object. Given the following data, determine the best sensor suitable for the task.

Q3.

Given a dataset, derive a system model from the response time.

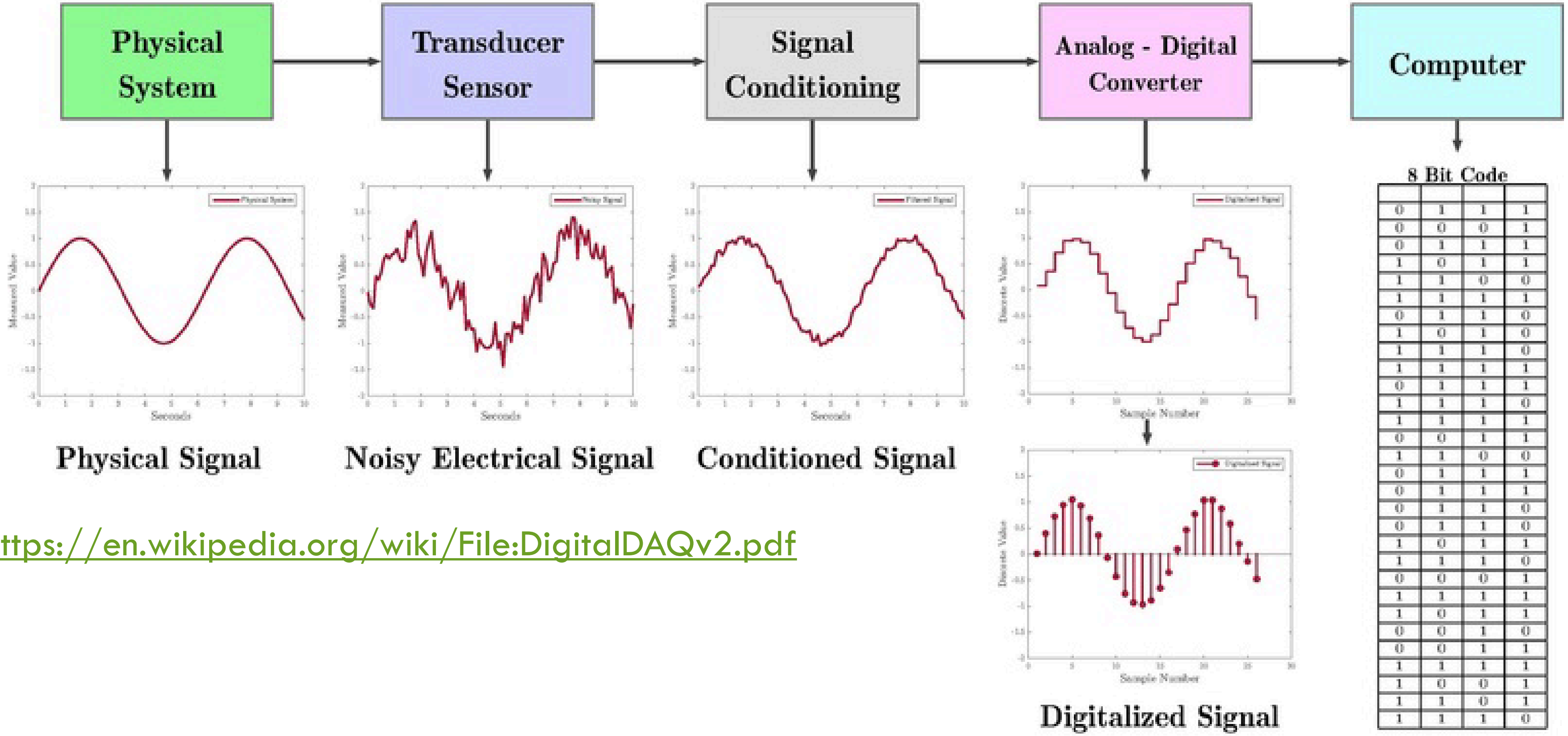
Q4.

Describe the sensor technologies in the article; ***Bin picking for ship-building logistics using perception and grasping systems***

SIGNAL CONDITIONING AND DATA ACQUISITION SYSTEMS

Purpose: Process the output signal from the sensor of a measurement system in some way to make it suitable for the next stage of the operation.

A TYPICAL DIGITAL DATA ACQUISITION PROCESS



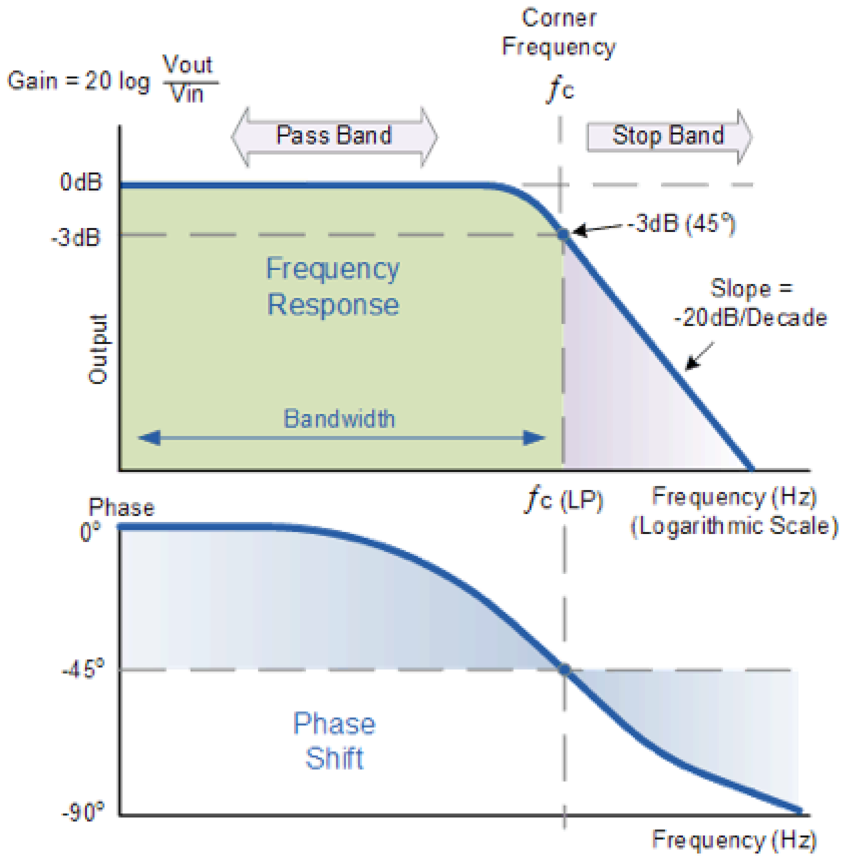
https://en.wikipedia.org/wiki/File:DigitalDAQv2.pdf

LOW PASS FILTER (LPF) DESIGN

Cut off frequency: $f_c = \frac{1}{2\pi RC}$.

First order filter transfer function – $\frac{1}{\frac{1}{\omega_c}s+1}$, $\omega_c = 2\pi f_c = 1/RC$.

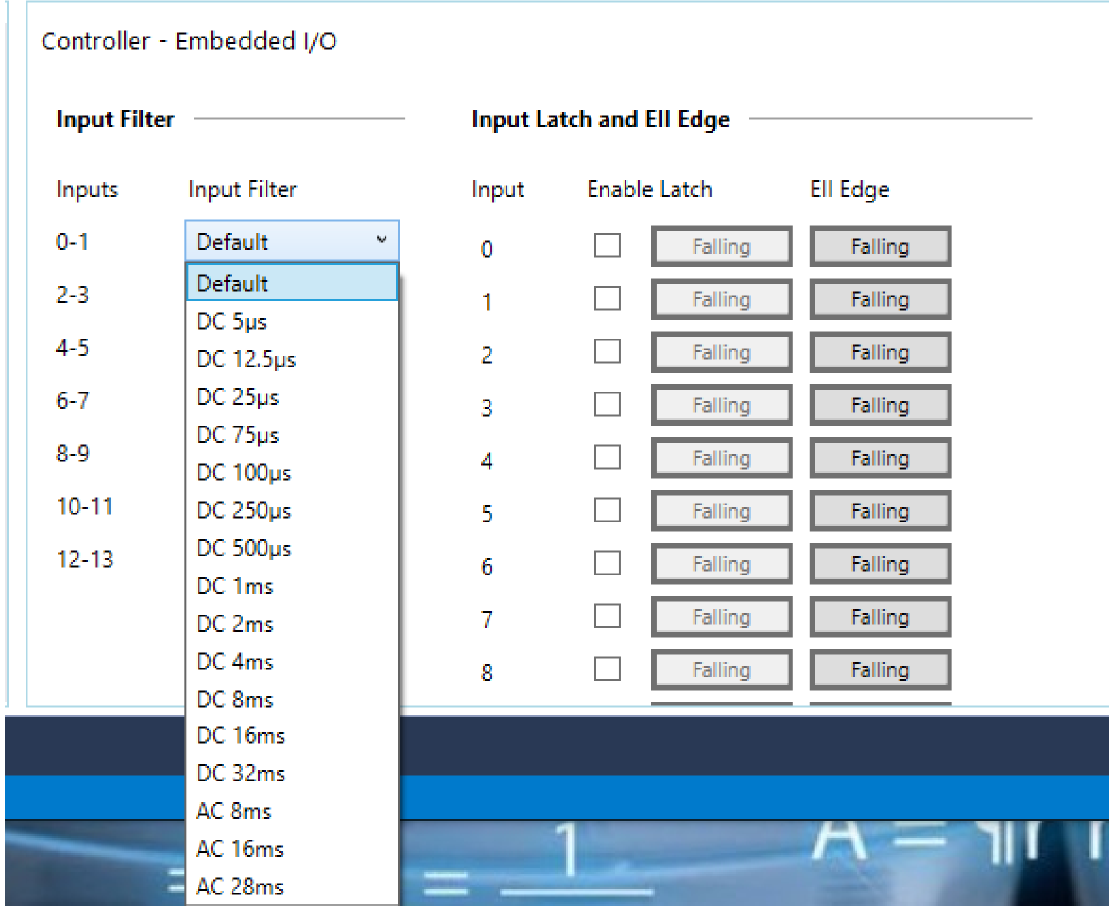
Convert to Discrete domain using Backward Euler Method or c2d() in MATLAB



TIME AVERAGING FILTERING

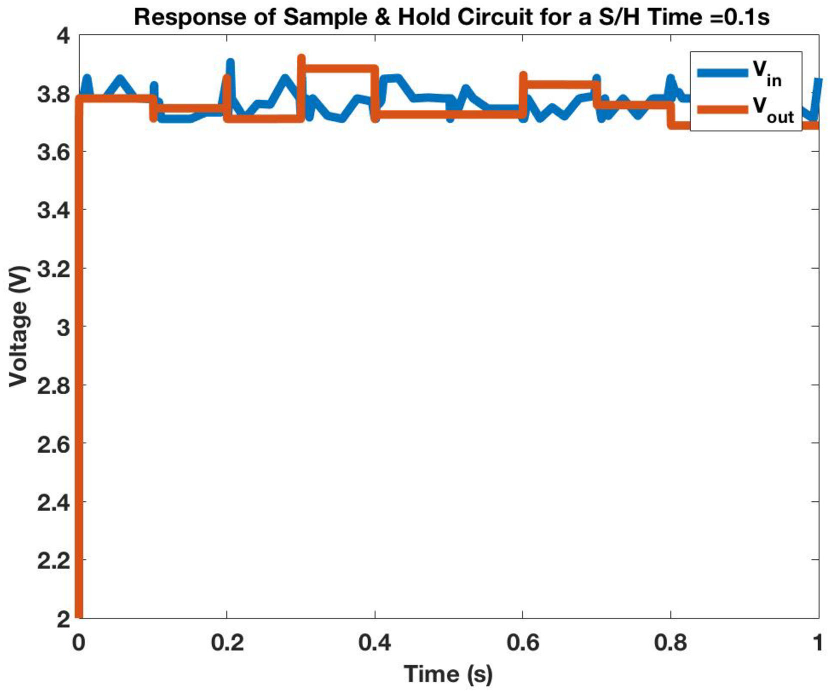
The moving average filter operates by averaging a number of points from the input signal to produce each point in the output signal. In equation form, this is written:

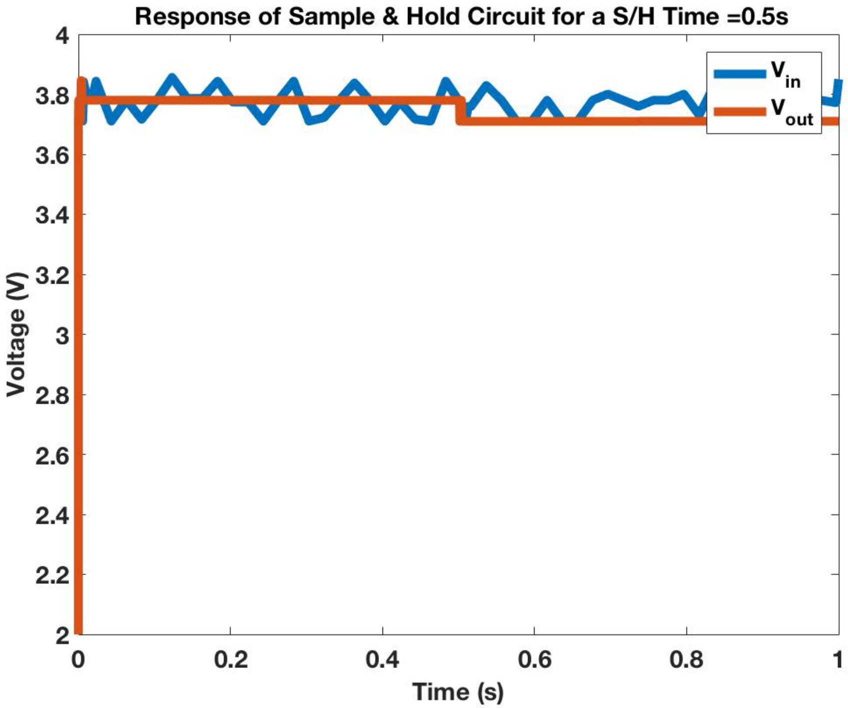
$$y[i] = \frac{1}{M} \sum_{j=0}^{M-1} x[i+j]$$



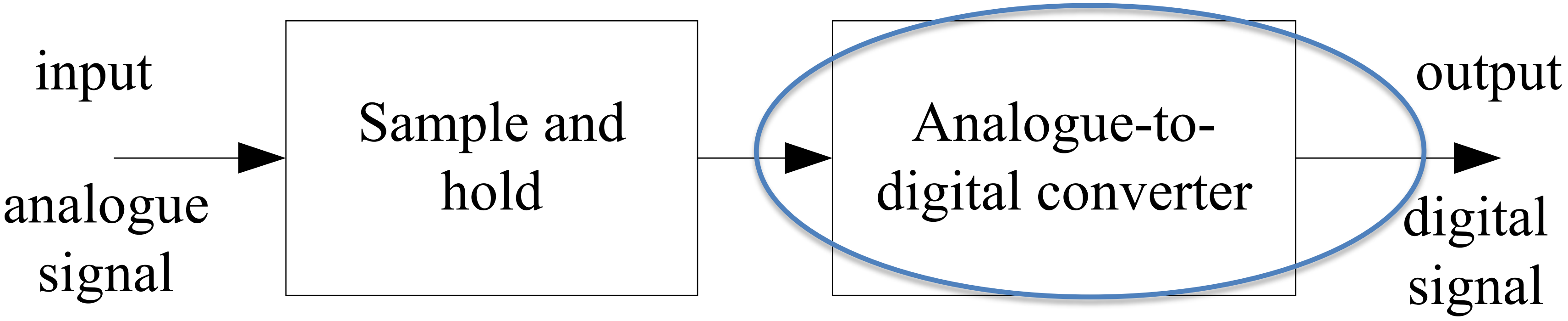
SAMPLE AND HOLD AMPLIFIERS

V_{out} = sampled version of V_{in}





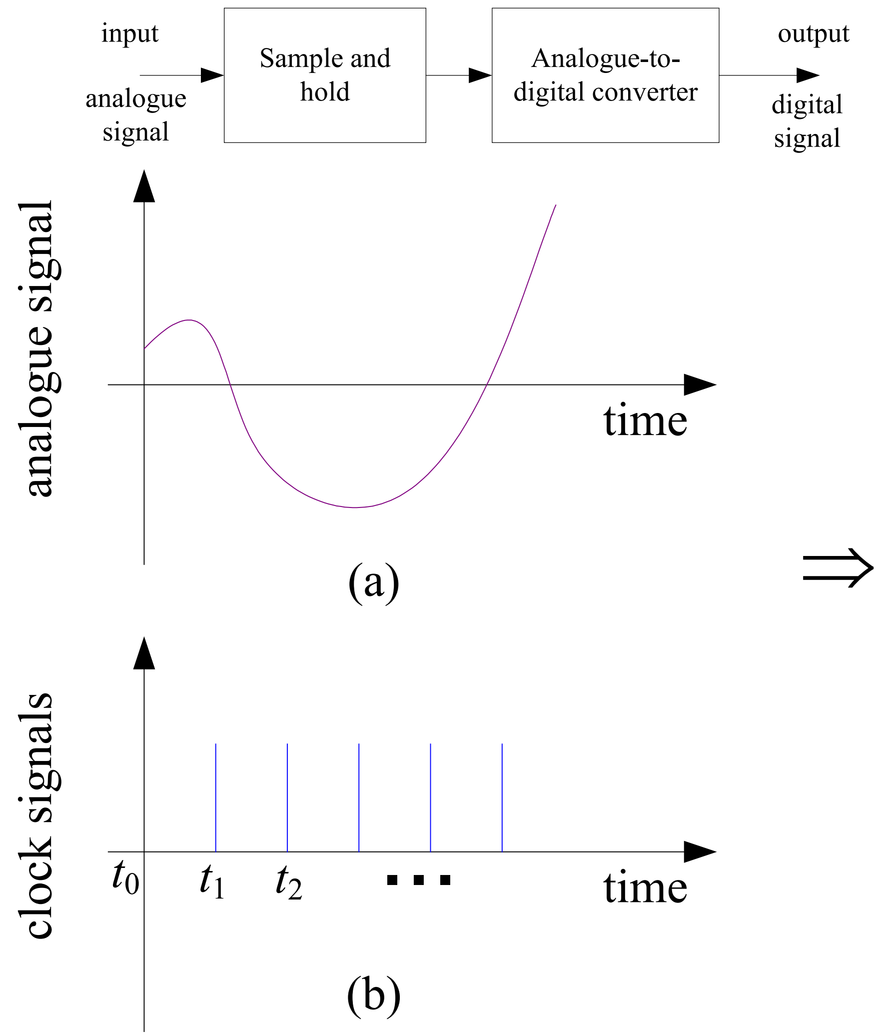
DIGITAL SIGNALS



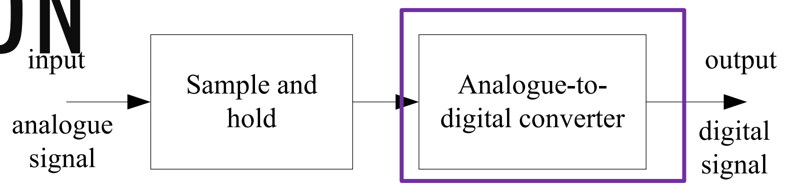
- Binary system: {0,1}
- Example:
  - the decimal number 14 is $1 \cdot 2^3 + 1 \cdot 2^2 + 1 \cdot 2^1 + 0 \cdot 2^0 = 1110$ in the binary system

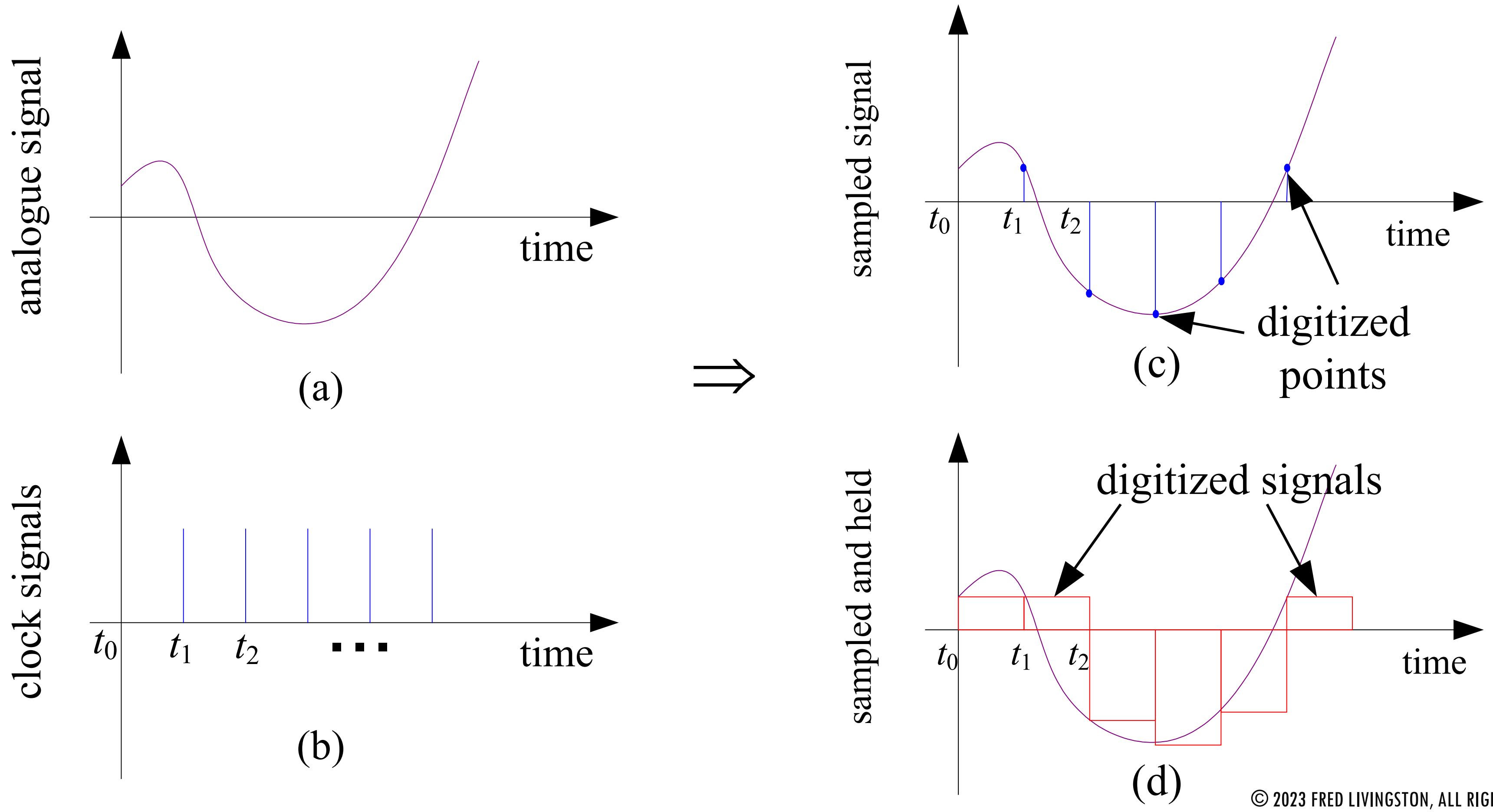
bit 3 bit 0

ANALOGUE-TO-DIGITAL CONVERSION

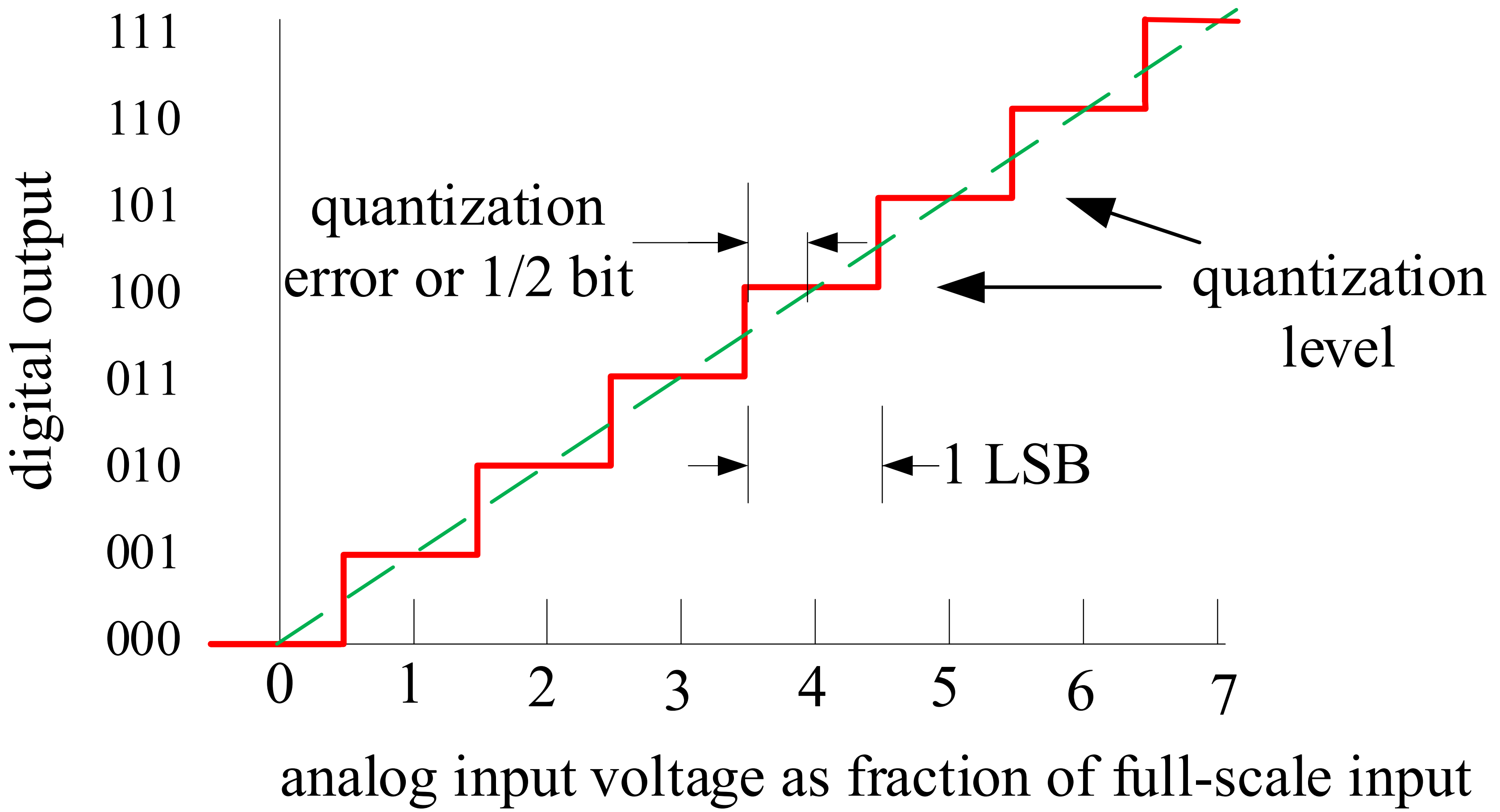


ANALOGUE-TO-DIGITAL CONVERSION





(UNIFORM) QUANTIZATION - EXAMPLE



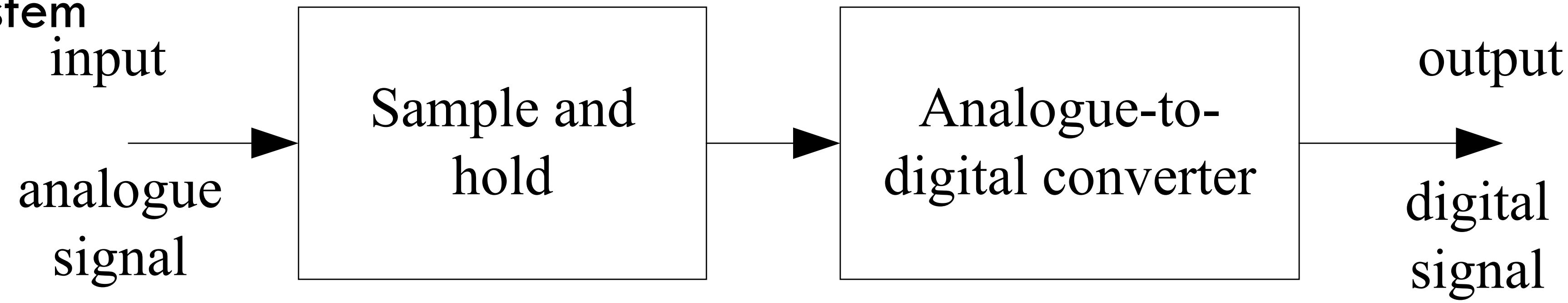
DIGITAL SIGNALS

Binary system: {0,1}

bit 3 bit 0

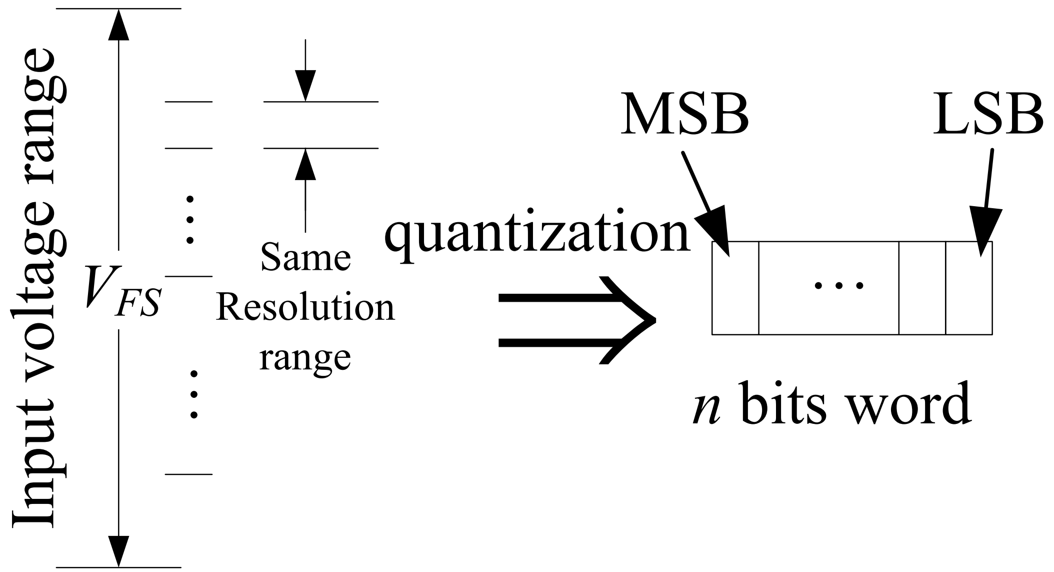
Example:

- the decimal number 14 is $1\cdot2^3 + 1\cdot2^2 + 1\cdot2^1 + 0\cdot2^0 = 1110$ in the binary system



QUANTIZATION RESOLUTION

Given: n bit word and the full-scale analogue input: V_{FS}



The minimum change in input that can be detected (thus) the resolution:

$$\frac{V_{FS}}{2^n}$$

QUANTIZATION RESOLUTION VS QUANTIZATION ERROR

Quantization Resolution

- Defines the minimum change in input that causes a change in the output
- Remains constant for a given ADC
- Independent of input

Quantization Error

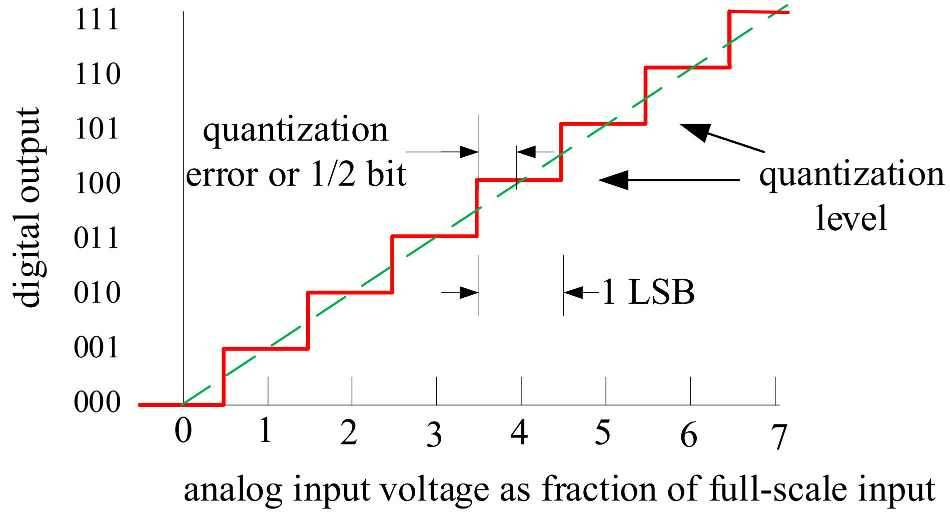
- Is the error between the quantized value and the true input value
- Depends on the quantization resolution i.e. number of bits and ADC input range
- Can vary between 0 and 0.5*LSB based on the input
- Maximum quantization error $= 0.5 * LSB$

RESOLUTION EXAMPLE:

Question: The analogue output voltage (0 ~ 10V) from a sensor can be quantized into 12 bits

- What is the range of the discretization/quantization?
- What is the quantized value for an input of 5.4 V?
- What is the quantization error?
- What is the maximum quantization error of the ADC?

RESOLUTION EXAMPLE:



Answer

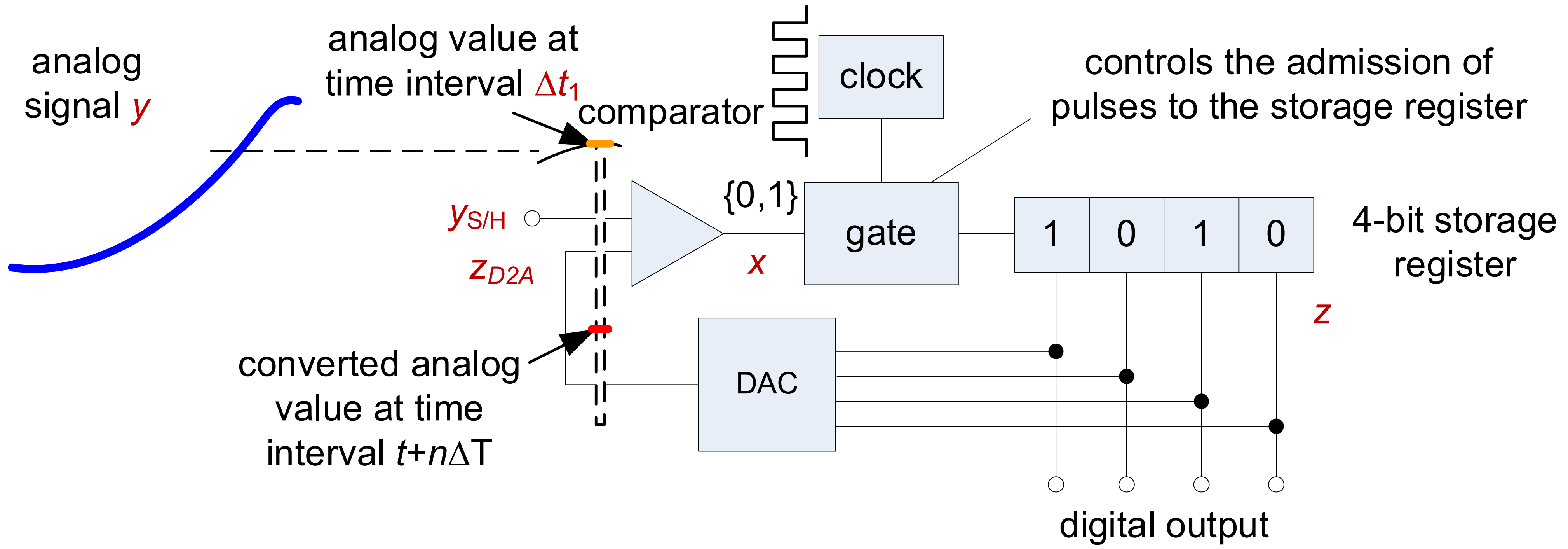
- A 12-bit word is needed ($2^{12} = 4096$, $n = 12$)
- The resolution is: $\frac{V_{FS}}{2^n} = \frac{10}{4096} V = 2.441mV$
- quantization error $= \frac{LSB}{2} = \frac{2.441mV}{2} = 1.22mV$
- If $V_{in} = 5.4V, V_{quant} = \boldsymbol{floor}\left(\frac{V_{in}}{2.441m}\right) * 2.441mV = 5.39796V$
- Quantization error = 5.4-5.39796 = 0.00205V = 2.05mV
- If $V_{in} = 5.4V, V_{quant} = ciel\left(\frac{V_{in}}{2.441m}\right) * 2.441mV = 5.40039V$
- Quantization error = 5.4-5.4003 = 0.0003906V = 0.39mV

ANALOGUE-TO-DIGITAL CONVERTERS

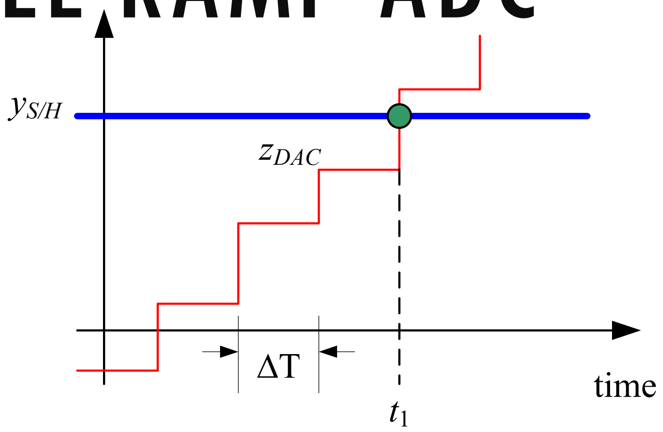
Different type of A/D converters

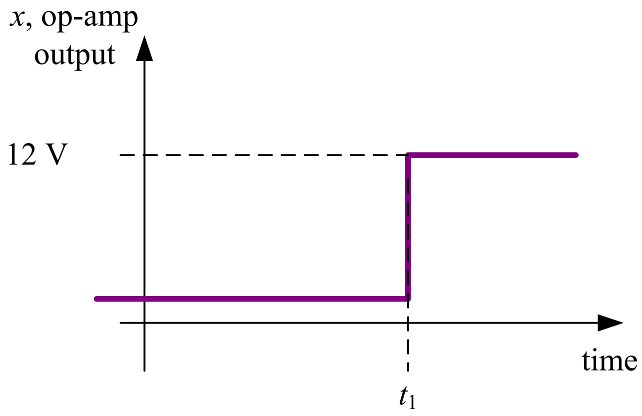
1. **Single ramp (integrating) converter**
2. **Successive approximations converter**
3. Dual ramp (integrating) converter
4. Flash A/D converter
5. .....

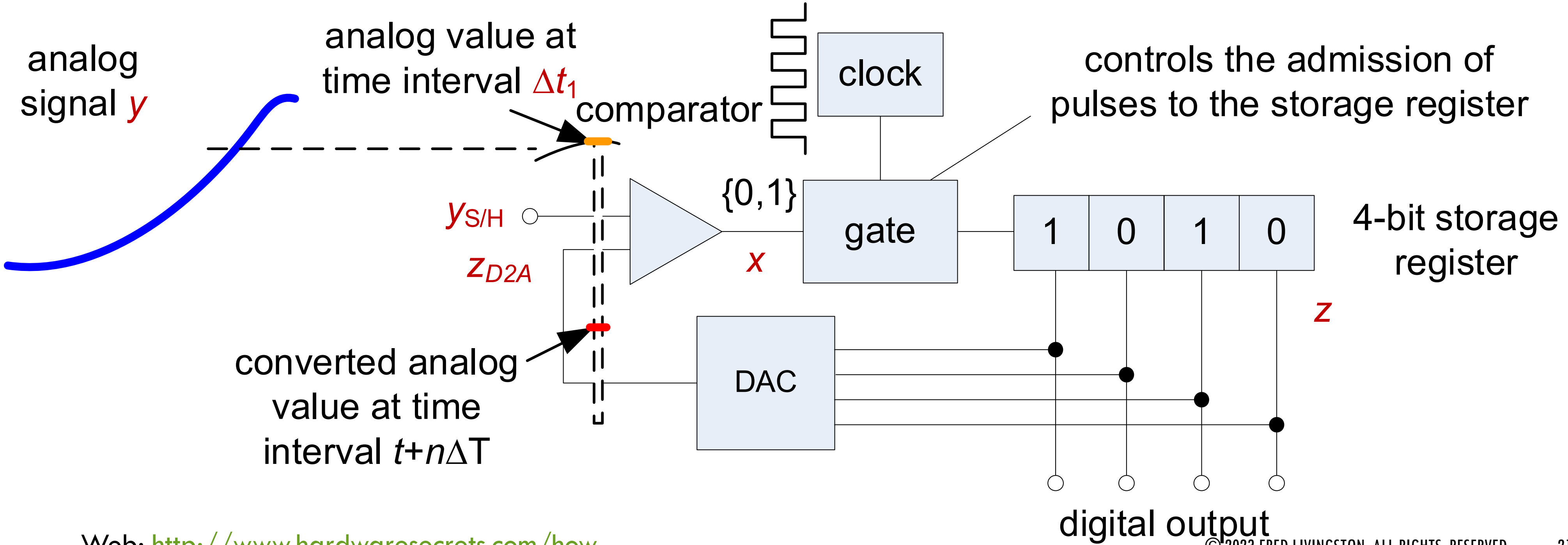
SINGLE RAMP ADC



SINGLE RAMP ADC



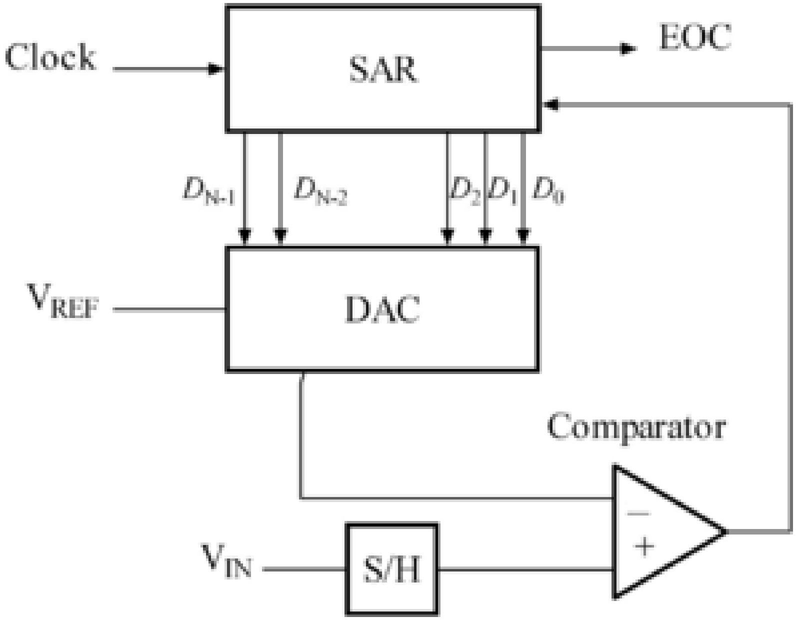




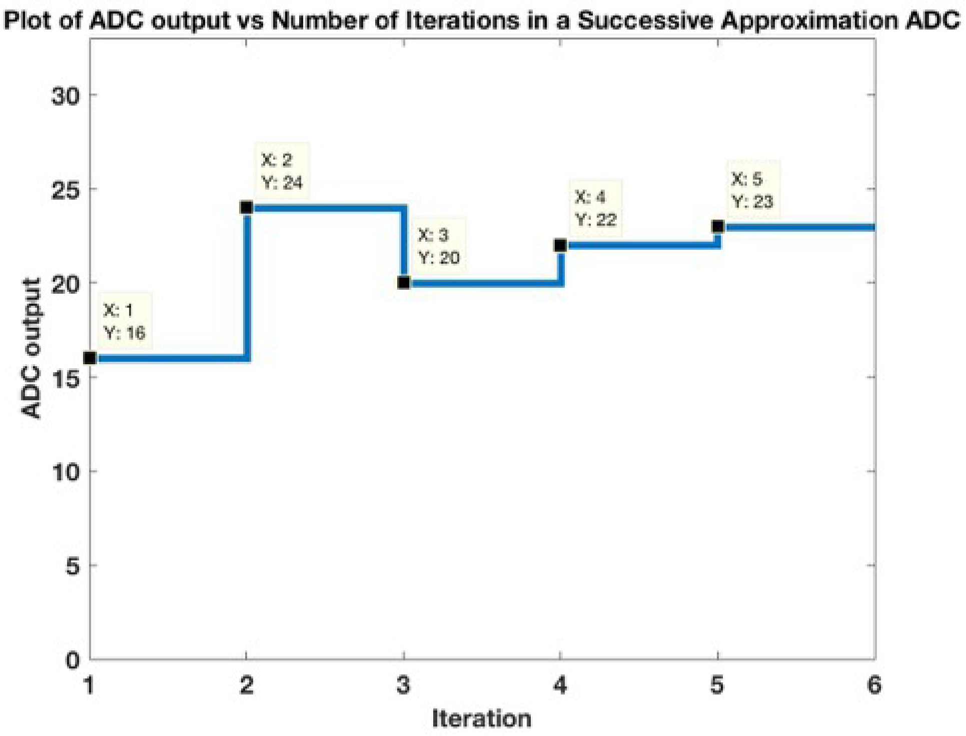
Web: http://www.hardwaresecrets.com/how-analog-to-digital-converter-adc-works/7/

SUCCESSIVE APPROXIMATION ADC

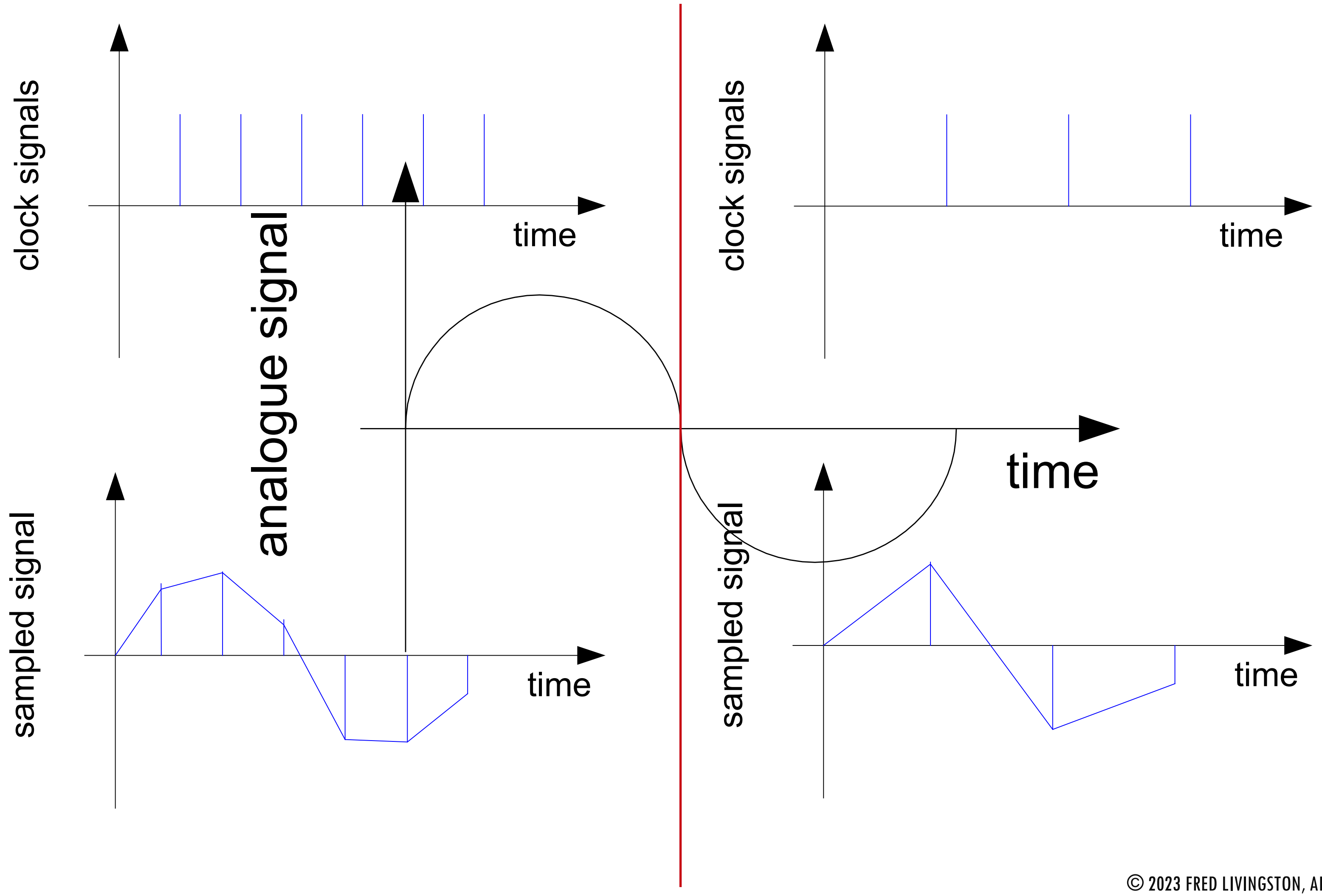
- Loops between comparator and $\mathrm{V}_{\mathrm{REF}}$ update
- When $\mathrm{V}_{\mathrm{REF}} \sim V_{IN}$ or ADC has reached the LSB – terminates conversion
- SAR - Successive Approximation Register



Web: https://en.wikipedia.org/wiki/Successive_approximation_ADC



SAMPLING THEOREM



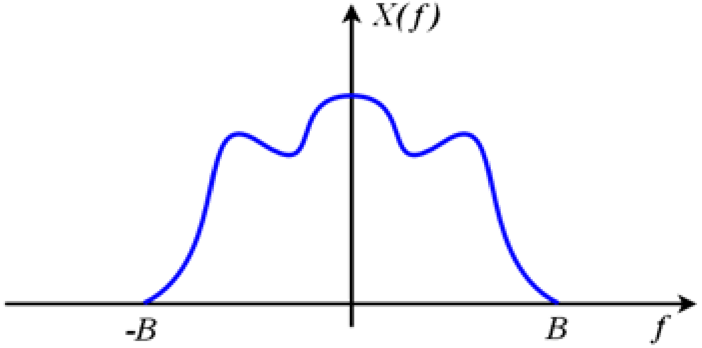
NYQUIST CRITERION

Nyquist criterion or *Shannon's sampling theorem*

- Sample at least twice the highest frequency of the analogy signal

$$f_s > 2 f_{\max}$$

$$\Delta t = \frac{1}{f_s}$$



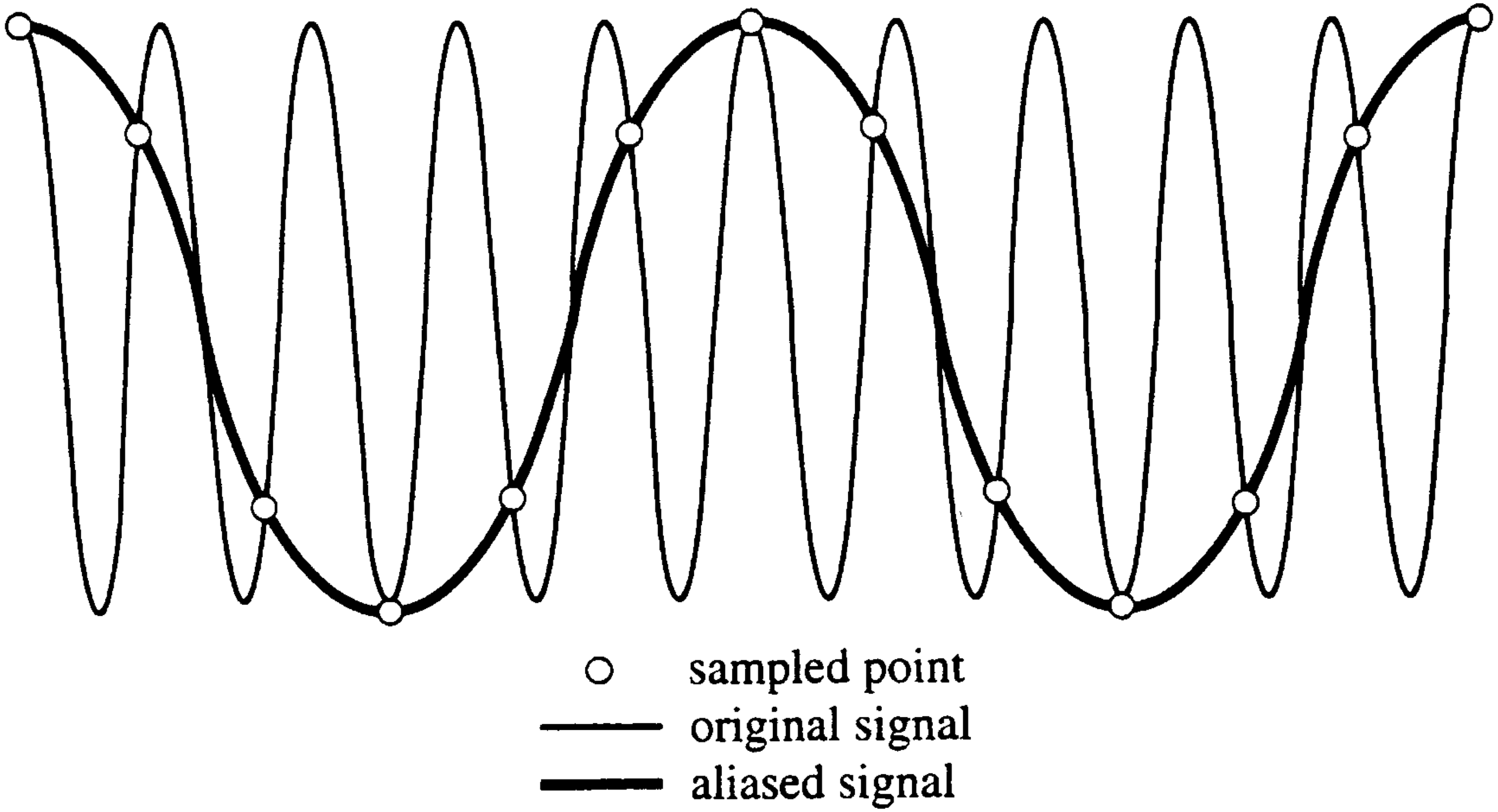
E.g. signal *F*(*t*) is well approximated by its Fourier series:

$$F(t) = C_0 + \sum_{n=1}^{N} A_n \cos(n\omega_0 t) + \sum_{n=1}^{N} B_n \sin(n\omega_0 t)$$

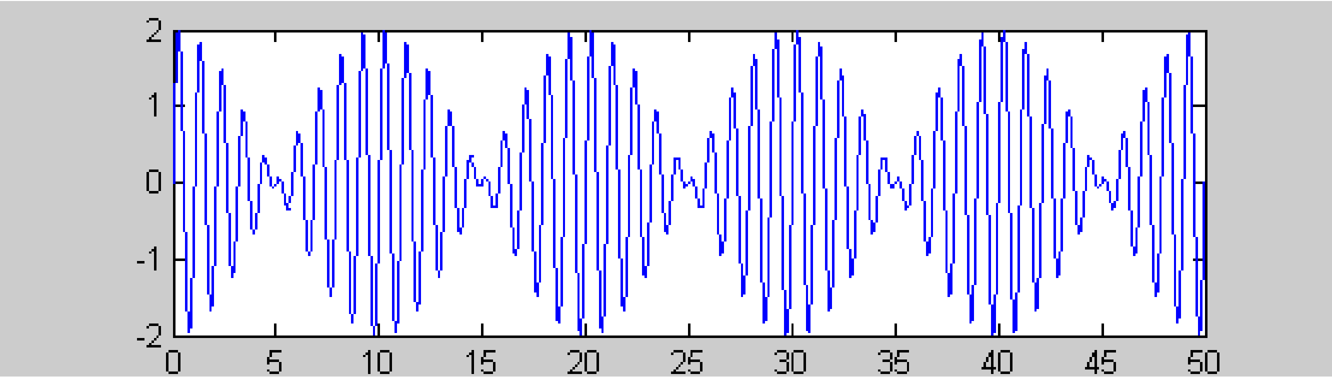
$$f_{\max} = \frac{N\omega_0}{2\pi}\,\mathrm{Hz}$$

Harry Nyquist.

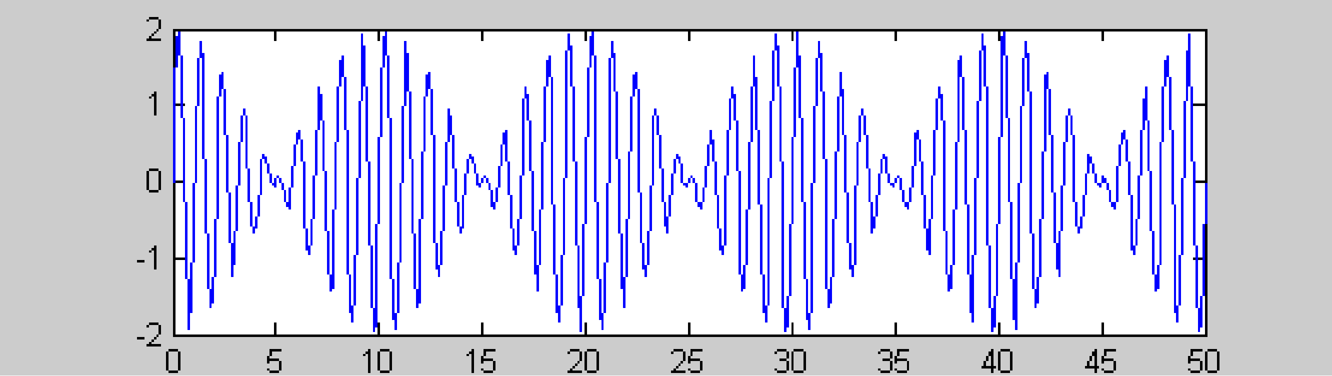
ALIASING



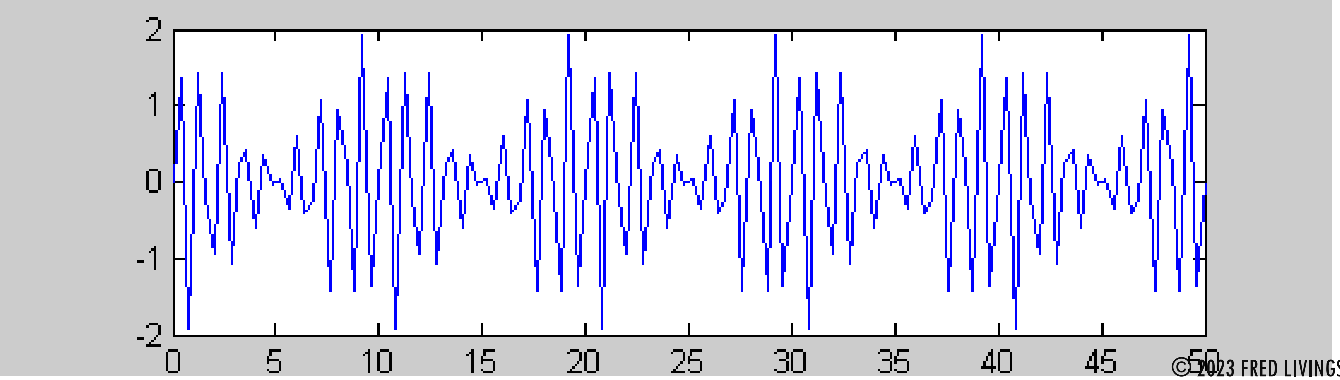
BEAT FREQUENCY EXAMPLE



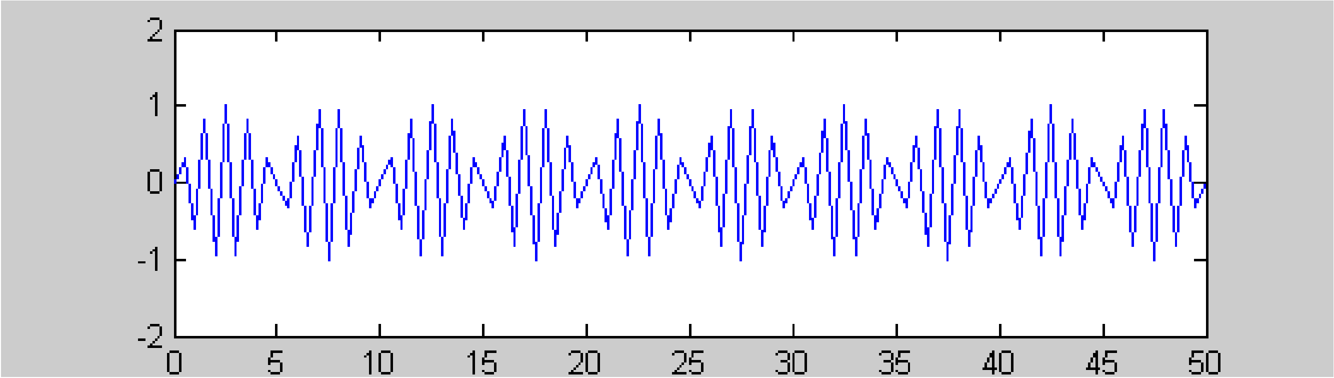
Original signal



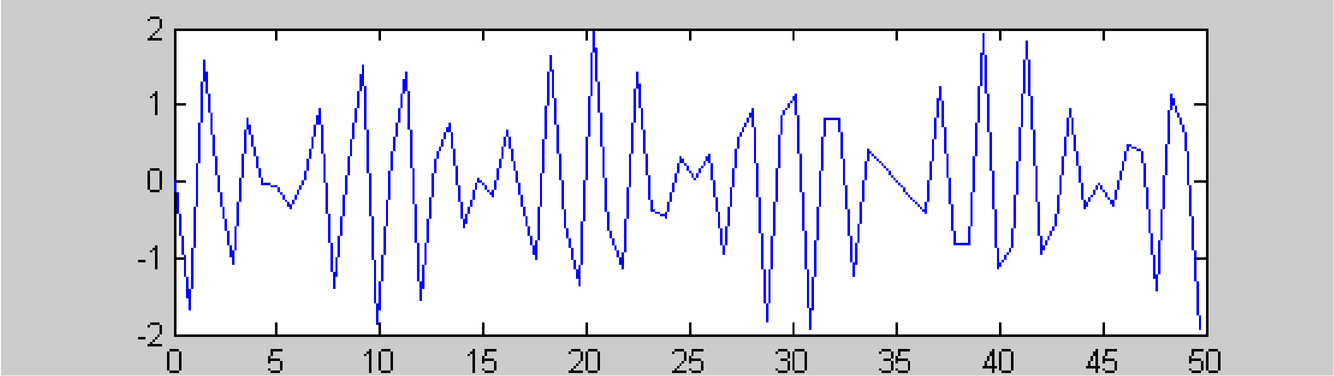
Δt=0.1 sec (10 Hz), which is greater than the Nyquist frequency 2Hz. (Note, linear interpolation is used between samples)



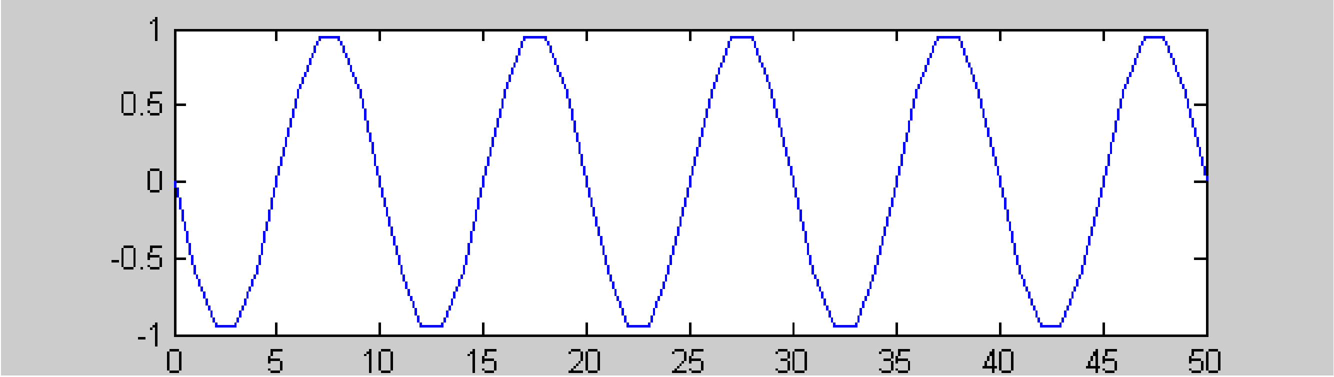
Δt=0.4 sec (2.5 Hz), which is greater than the maximum frequency 2.5 Hz, which is close to the Nyquist frequency.



$\Delta t=0.5$ sec
(2 Hz), which is at the Nyquist frequency.

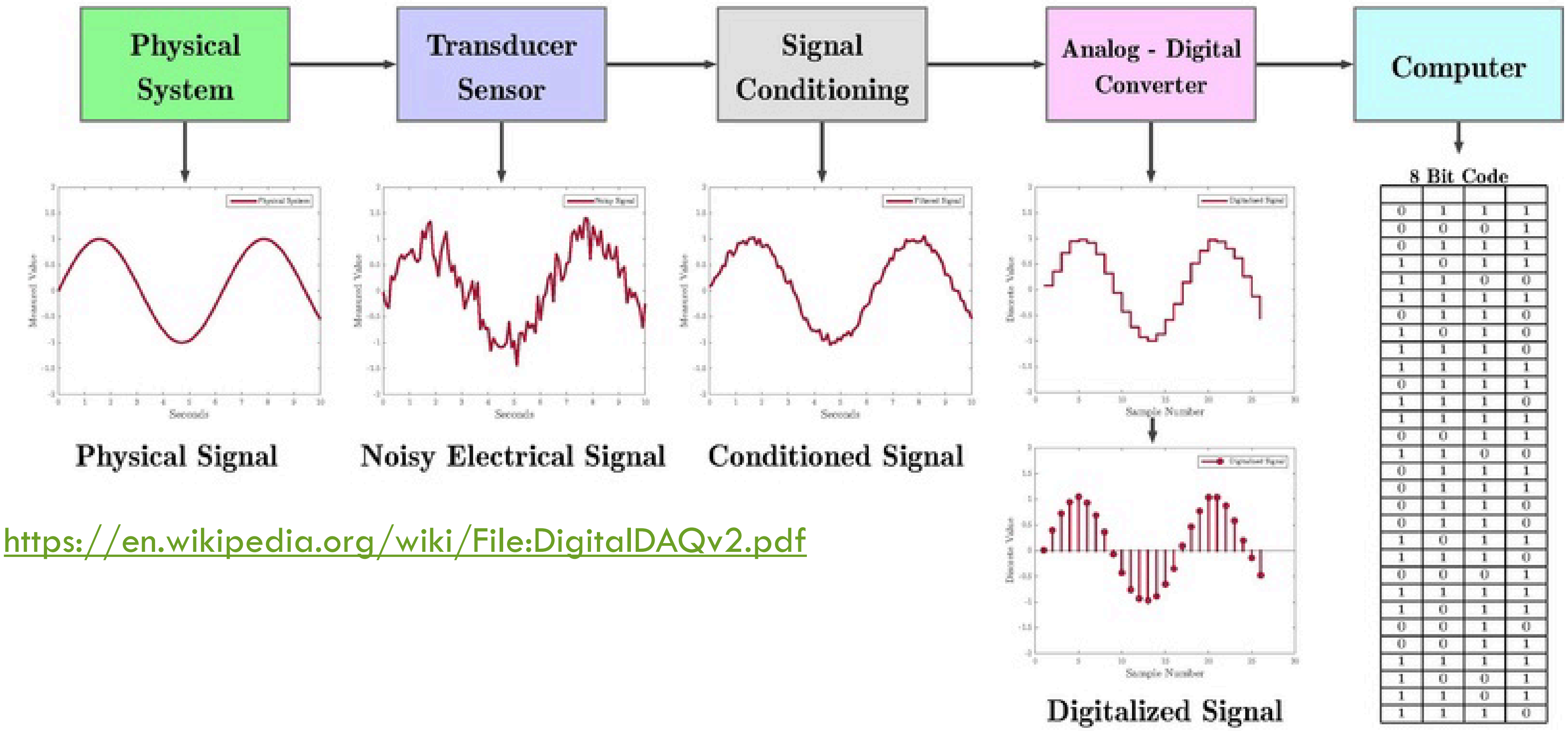


$\Delta t=0.7$ sec
(1.43 Hz), which is below the Nyquist frequency.



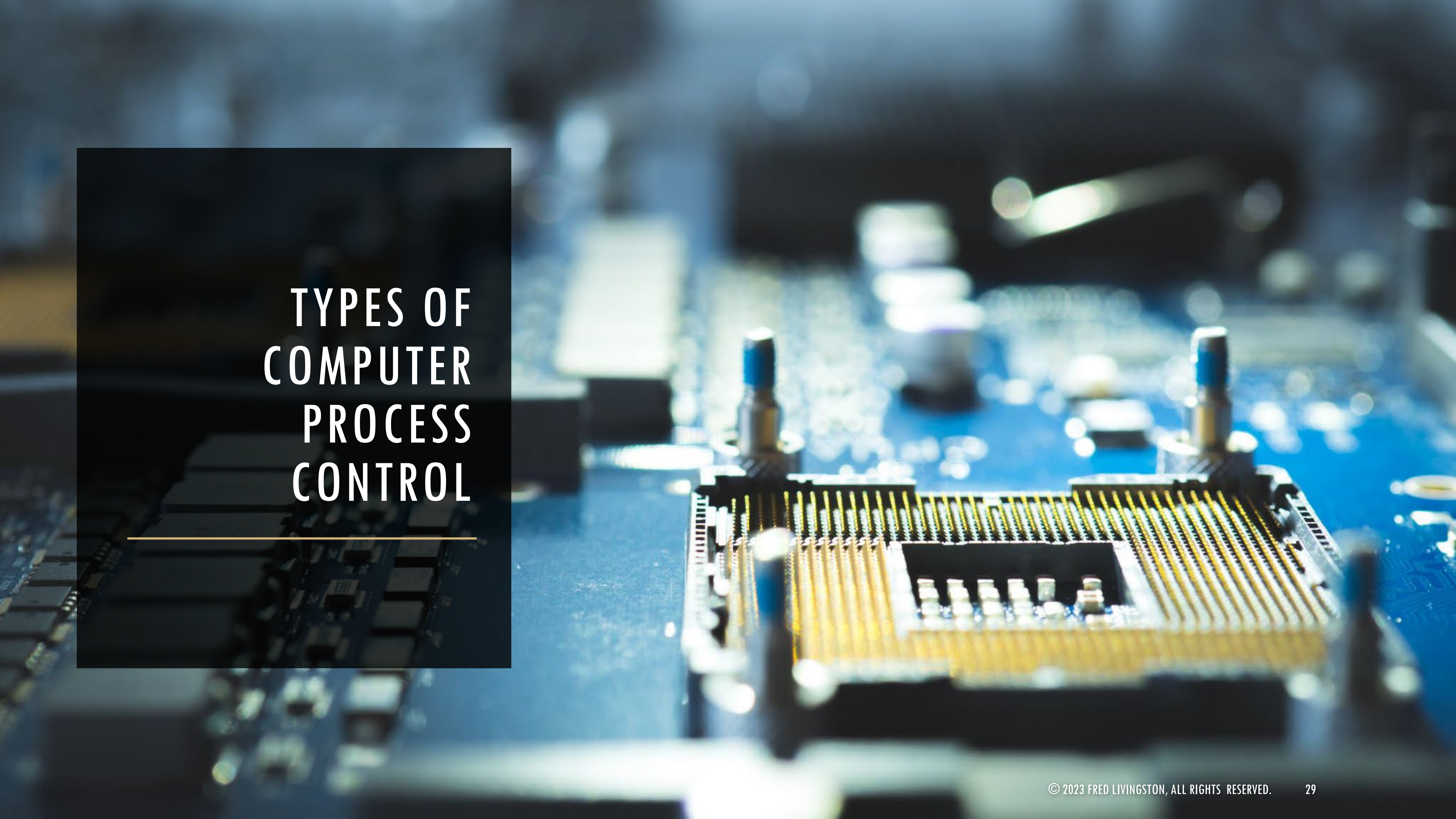
$\Delta t=1$ sec which is below the Nyquist frequency. Even worse, the frequency is a sub-integer of the Nyquist frequency and cause misleading signals.

A TYPICAL DIGITAL DATA ACQUISITION PROCESS



https://en.wikipedia.org/wiki/File:DigitalDAQv2.pdf

TYPES OF COMPUTER PROCESS CONTROL



FORMS OF COMPUTER PROCESS CONTROL

There are various ways in which computers can be used to control a process

Process monitoring

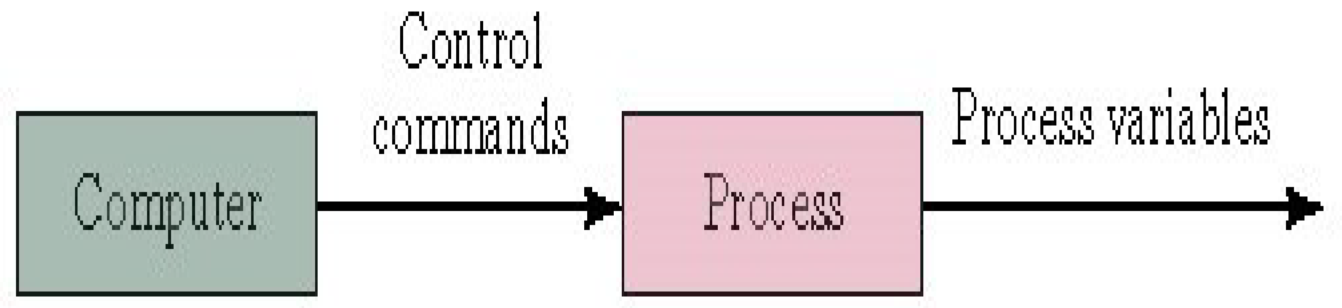
- The computer is used to simply collect data from the process

FORMS OF COMPUTER PROCESS CONTROL

Process control

- The computer regulates the process

Process control can be open-loop that requires no feedback data to be collected from the process

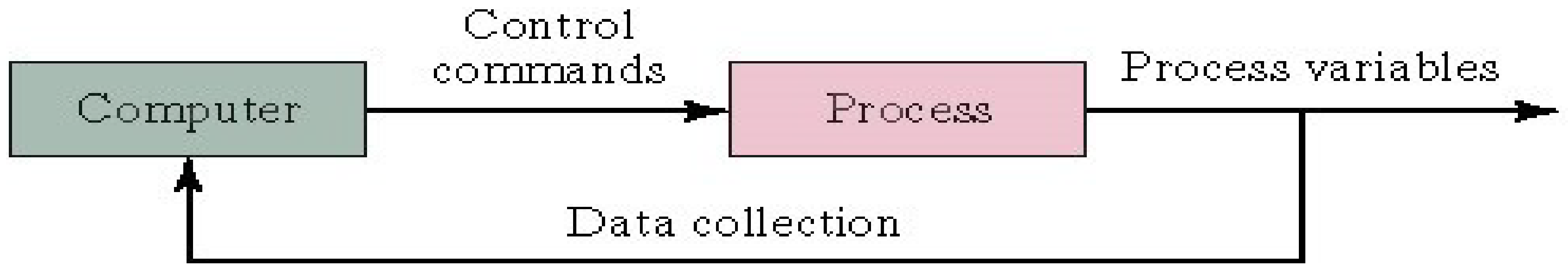


FORMS OF COMPUTER PROCESS CONTROL

Process control

- The computer regulates the process

Closed-loop in which some form of feedback or interlocking is required to ensure that the control instructions have been properly carried out



FORMS OF COMPUTER PROCESS CONTROL

Process monitoring

Process Control

- Open-Loop
- Closed-Loop
- Direct Digital Control (DDC)
- Numerical Control (NC)
- Programmable Logic Controller
- Supervisory Control
- Distributed Control Systems

COMPUTER PROCESS MONITORING

Computer observes process and associated equipment, collects and records data from the operation

The computer does not directly control the process

Types of data collected:

- Process data – input parameters and output variables
- Equipment data – machine utilization, tool change scheduling, diagnosis or malfunctions
- Product data – to satisfy government requirements

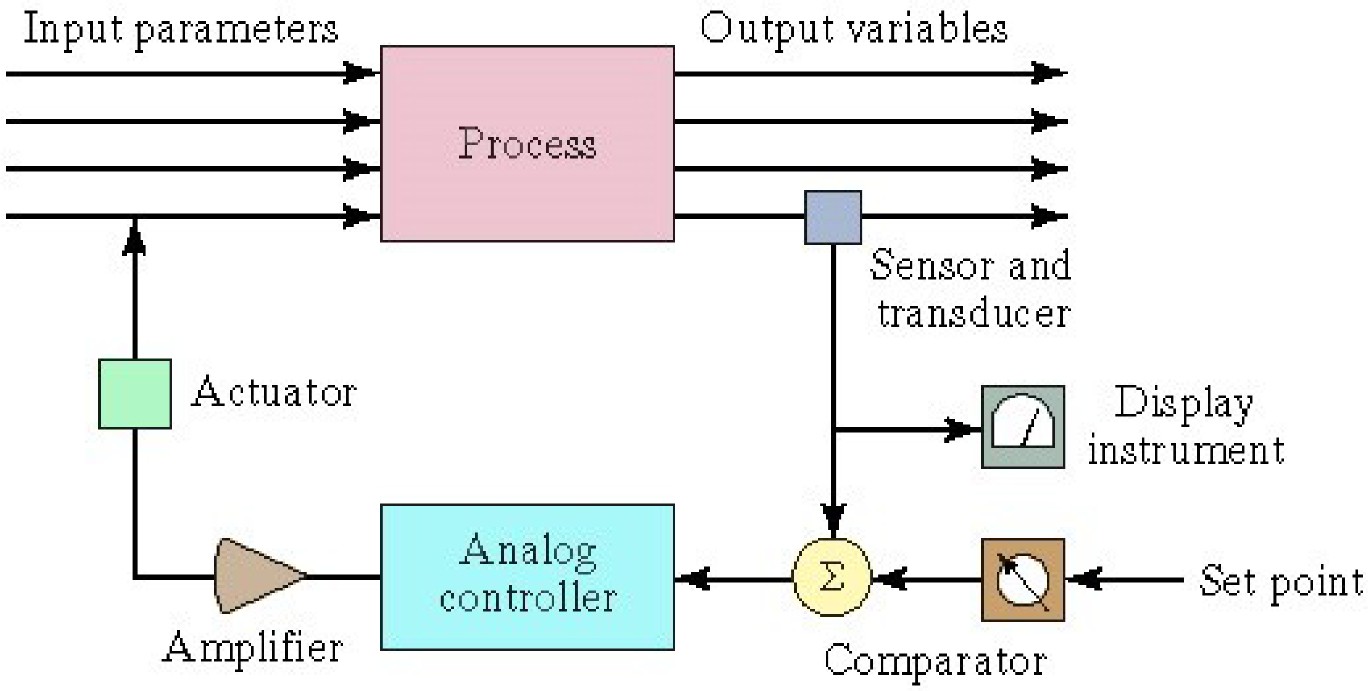
DIRECT DIGITAL CONTROL

Direct digital control (DDC) is a computer process control system in which certain components in a conventical analog control system are replaced by a digital device

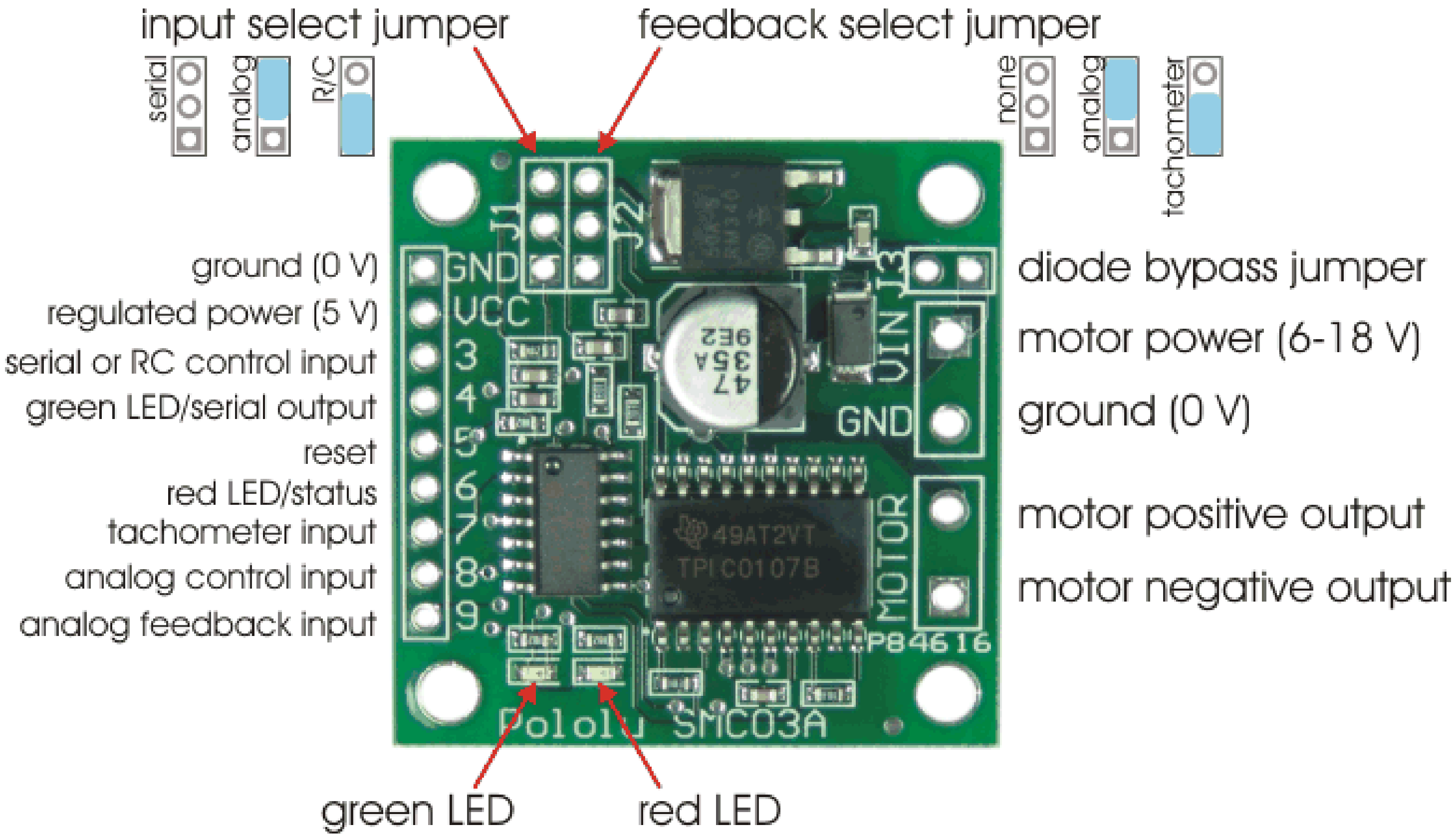
The computer calculates the desired value of the input parameters and set points, and these values are applied through a direct link to the process

- Accomplished on a time-shared, sampled-data basis rather than continuously by dedicated components
- Components remaining in DDC: sensors and actuators
- Components replaced in DDC: analog controllers, recording and display instruments, set point dials

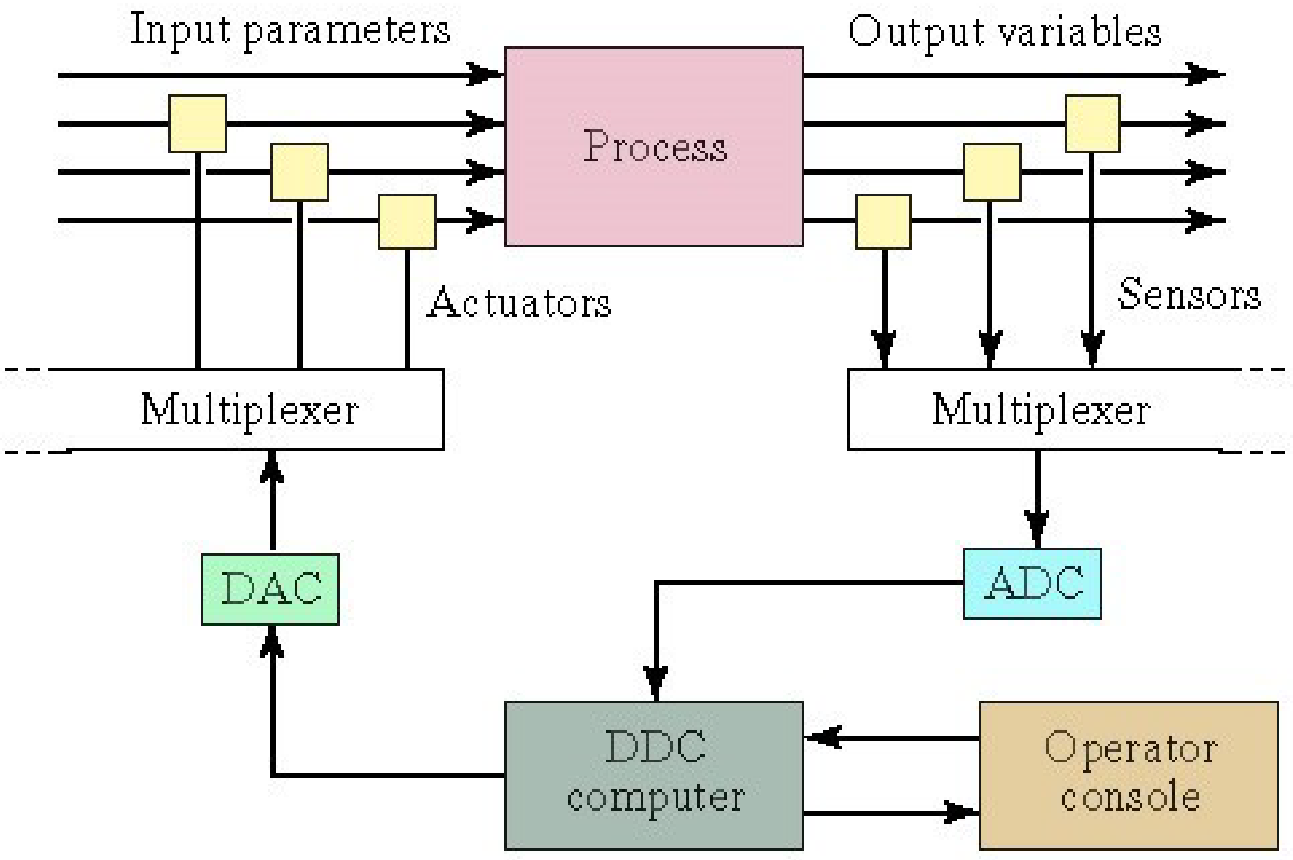
A TYPICAL ANALOG CONTROL LOOP



A TYPICAL ANALOG CONTROLLER



DIRECT DIGITAL CONTROL SYSTEM



PROGRAMMABLE LOGIC CONTROLLERS

A modern programmable logic controller is a microprocessor-based controller that uses stored instructions in programmable memory to implement logic, sequencing, timing, counting, and arithmetic control functions for controlling machines and processes.

Perform both discrete and continuous control in both process industries and discrete product industries

Introduced around 1970 to replace electromechanical relay controllers in discrete product manufacturing

NUMERICAL CONTROL

Numerical control (NC) is another form of industrial computer control.

For a machine tool

- Computers direct a machine tool through a sequence of processing steps to control position between tool and workpart

SUPERVISORY CONTROL

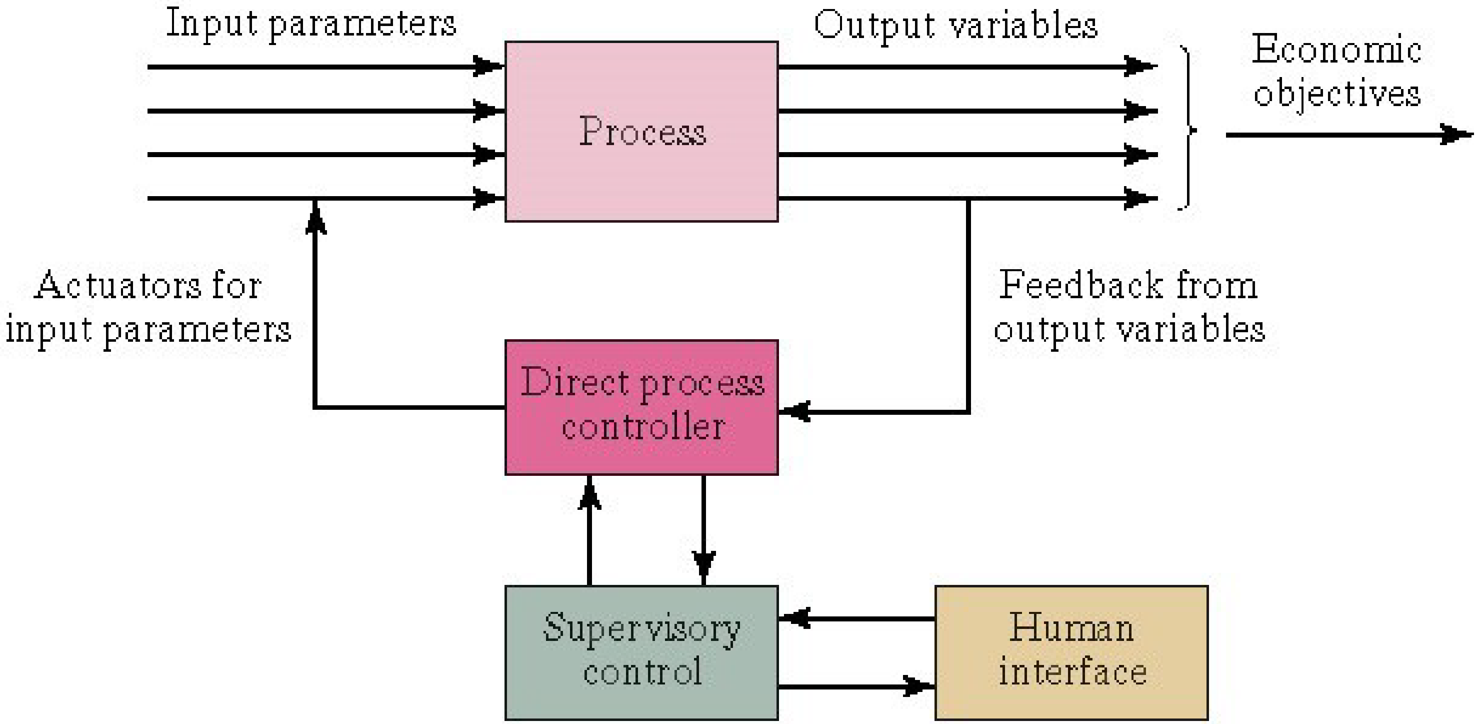
Supervisory control represents a higher level of control than the preceding forms of process control (DDC, NC and PLCs).

- DDC, NC and PLCs are interfaced directly to the process.
- Supervisory control is often superimposed on these process- level control systems and directs their operations.

In process industries: a control system that manages the activities of a number of integrated unit operations

In discrete manufacturing: control system that directs and coordinates the activities of several interacting pieces of equipment in a manufacturing cell or system,

- Example: a group of machines interconnected by a material handling system.



SUPERVISORY CONTROL

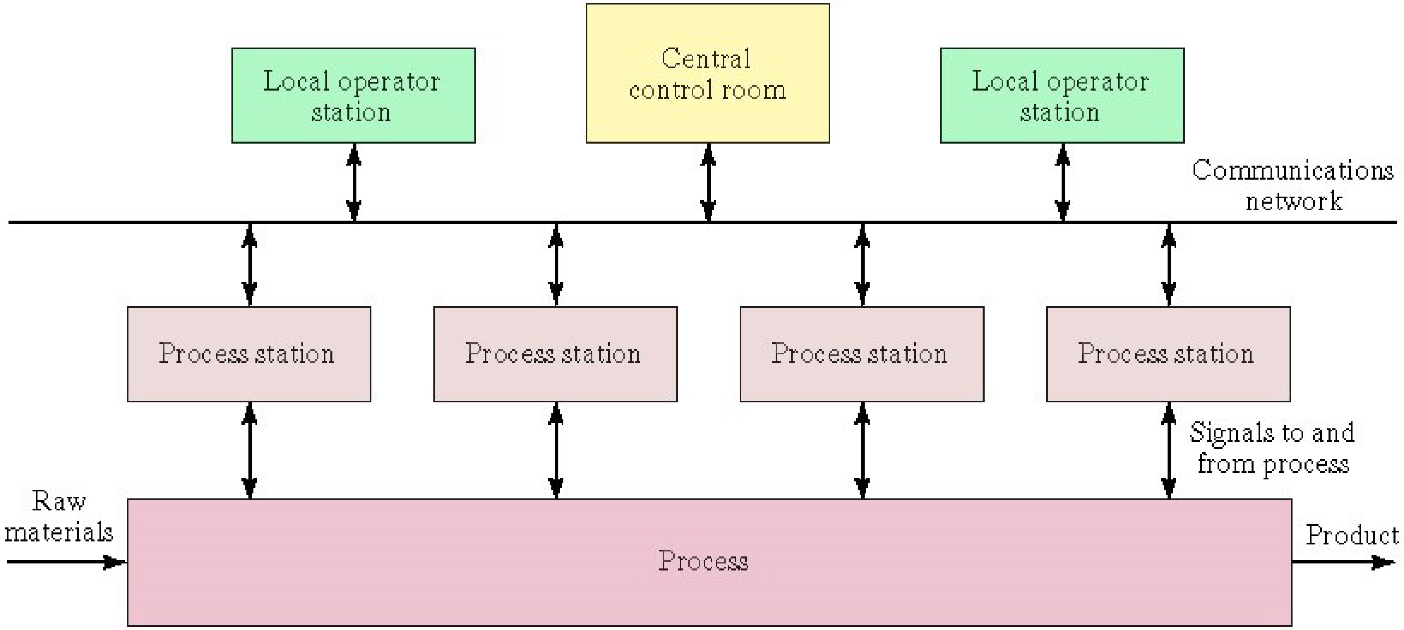
DISTRIBUTED CONTROL SYSTEMS

Multiple microcomputers connected together to share and distribute the process control workload through a common communications network

Features:

- Multiple process control stations to control individual loops and devices
- Central control room where supervisory control is accomplished
- Local operator stations for redundancy
- Communications network (data highway)

DISTRIBUTED CONTROL SYSTEMS



EDGE-COMPUTING IN PROCESS CONTROL

Two categories of edge-computing applications in process control:

Operator interface – PC is interfaced to one or more PLCs or other devices that directly control the process

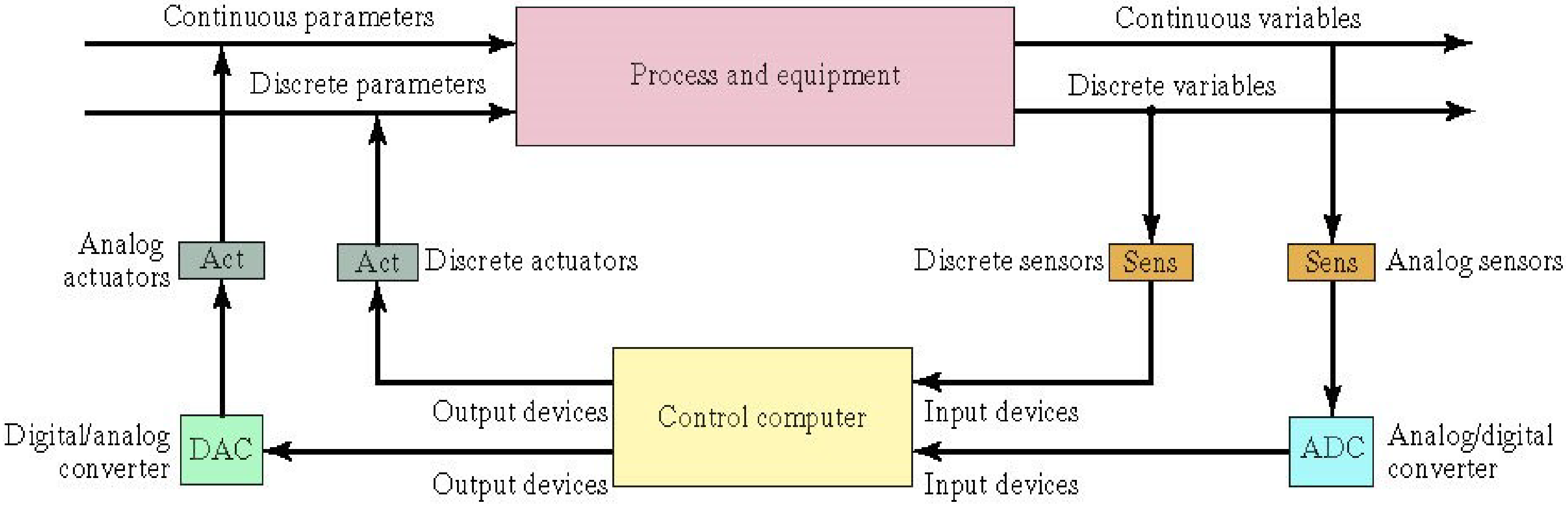
Edge-computing performs certain monitoring and supervisory functions, but does not directly control process

Direct control – edge-computing is interfaced directly to the process and controls its operations in real time

Traditional thinking is that this is risky

New hardware and real time software developments gradually enable real-time control

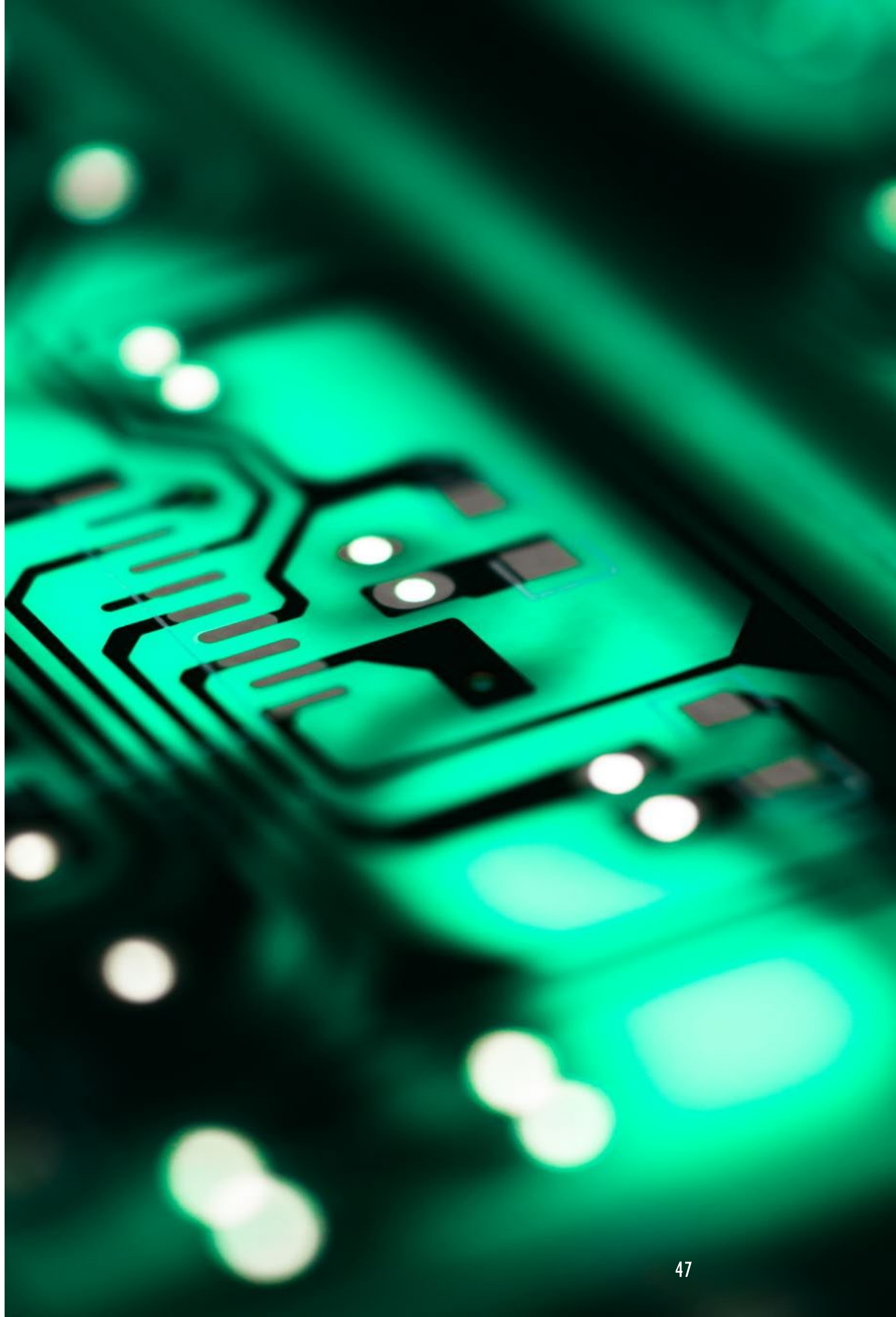
EDGE-COMPUTING IN PROCESS CONTROL



- Sensors to measure process variables
- Actuators to drive process parameters
- Devices for ADC(analog to digital converter) and DAC
- Digital I/O devices for discrete data

INTRODUCTION TO PROGRAMMABLE LOGIC CONTROLLER

Programmable controller is a digital electronic apparatus with a programmable memory for storing instructions to implement specific functions such as logic, sequencing, timing, counting, and arithmetic, to control machines and processes.



PLC FUNCTION

To examine the status of a set of input devices and based on their status, regulate a set of output addresses controlling a process.

Combination of input and output responses reflect the control plan or program logic in the PLC.

BASIC COMPONENTS OF PLC

Basic Controller Hardware

I/O Modules (Peripheral interface adapters)

Programming Hardware

PROCESSOR /CPU

Brain of the PLC

- Controls the operations of the entire system and executes the program

Types

- Special purpose logic circuits used for CPU
- Microprocessor- Increased logical and control capabilities of PLC
- Multi-Processors: Task are divided

FUNCTIONS OF CPU

Scan

- Read input
- Execute the program
- Write output

Communications

- Information exchange between CPU and I/O system

Error Checking

- To monitor the function of memory, communication links between subsystems and peripherals

CPU Diagnostics (self tests)

MEMORY

Stores instructions and data

Types

- ROM- Read-Only Memory
- RAM- Random-Access Memory
- PROM- Programmable ROM
- EAROM- Electronically Alterable ROM
- EPROM- Erasable PROM
- EAPROM- Electronically Erasable PROM

INPUT/OUTPUT

A set of modular plug-in peripherals that allow acceptance of signals from a variety of external devices

Each I/O location is assigned a specific memory location

CPU accesses input by loading contents of a specific memory location into storage registers

CPU writes outputs by writing to the mapped memory addresses

TYPES OF I/O MODULES

Analog I/O

Digital I/O

Special Purpose:

- A/D and D/A
- Strain gage amplifiers
- Stepper motor output- series of pulses

AC Voltage- 110 , 240, etc.

DC voltage- 5, 12, 24, etc.

etc.

BENEFITS OF PLC

Flexibility; programmable

Setup Speed

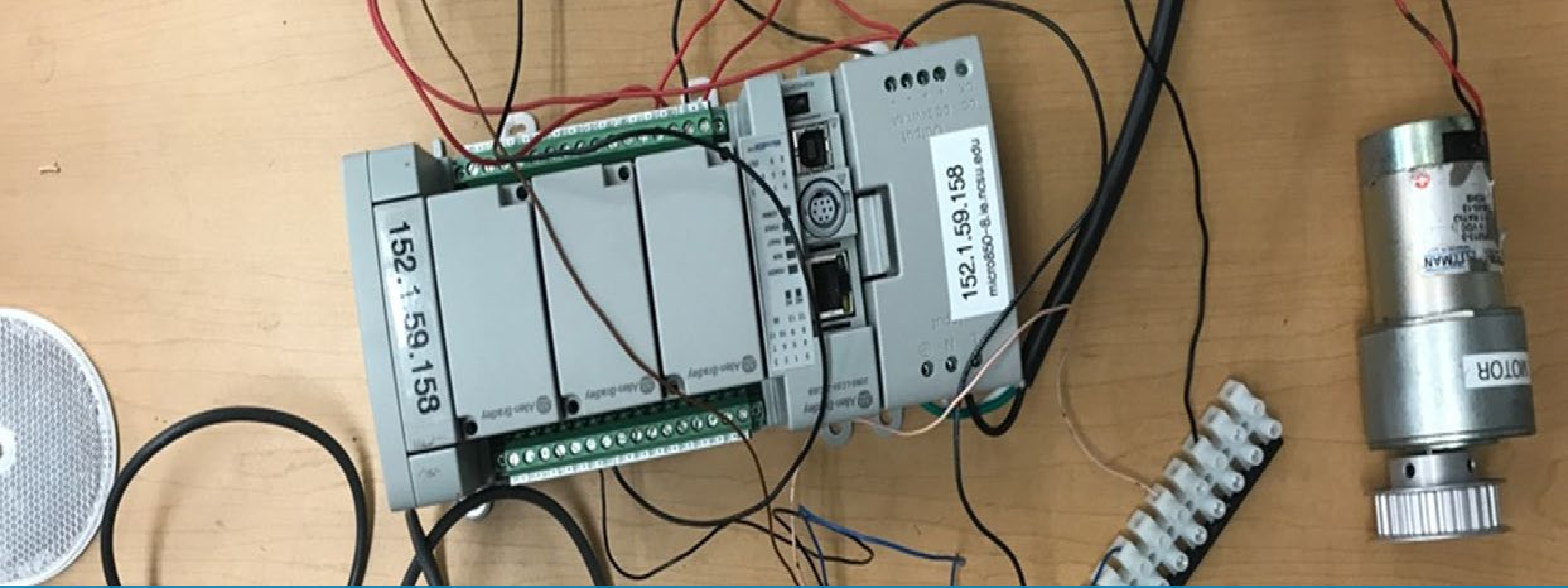
Reliability

Maintenance

Data Collection Capabilities

I/O Options

Cost



A TYPICAL PLC SETUP

Products that enable the Micro Control System

Micro800 controllers

The Allen-Bradley® Micro800 programmable logic controller (PLC) family, together with Connected Components Workbench software, sets a new global standard for ease of use, while providing enough control capability to match your application requirements. With a wide range of network protocols, finding the right controller to fit your communication needs is easy.

With greater flexibility in mind, Micro800 plug-in and expansion I/O modules extend the functionality of embedded I/O without increasing the footprint of your controller. You can buy only the functionality you need to scale your control and use plug-in modules to customize the system for your specific application needs. The controllers offer a scalable Micro Control solution for smart machine development.

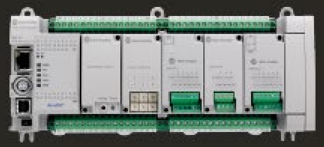
Start smart. Enable Micro800 controllers for cloud connectivity. Watch now.

Micro810® controller
Smart relay

Micro820® controller
Remote automation

Micro830® controller
Simple motion

Micro850® controller
3 axes of motion support



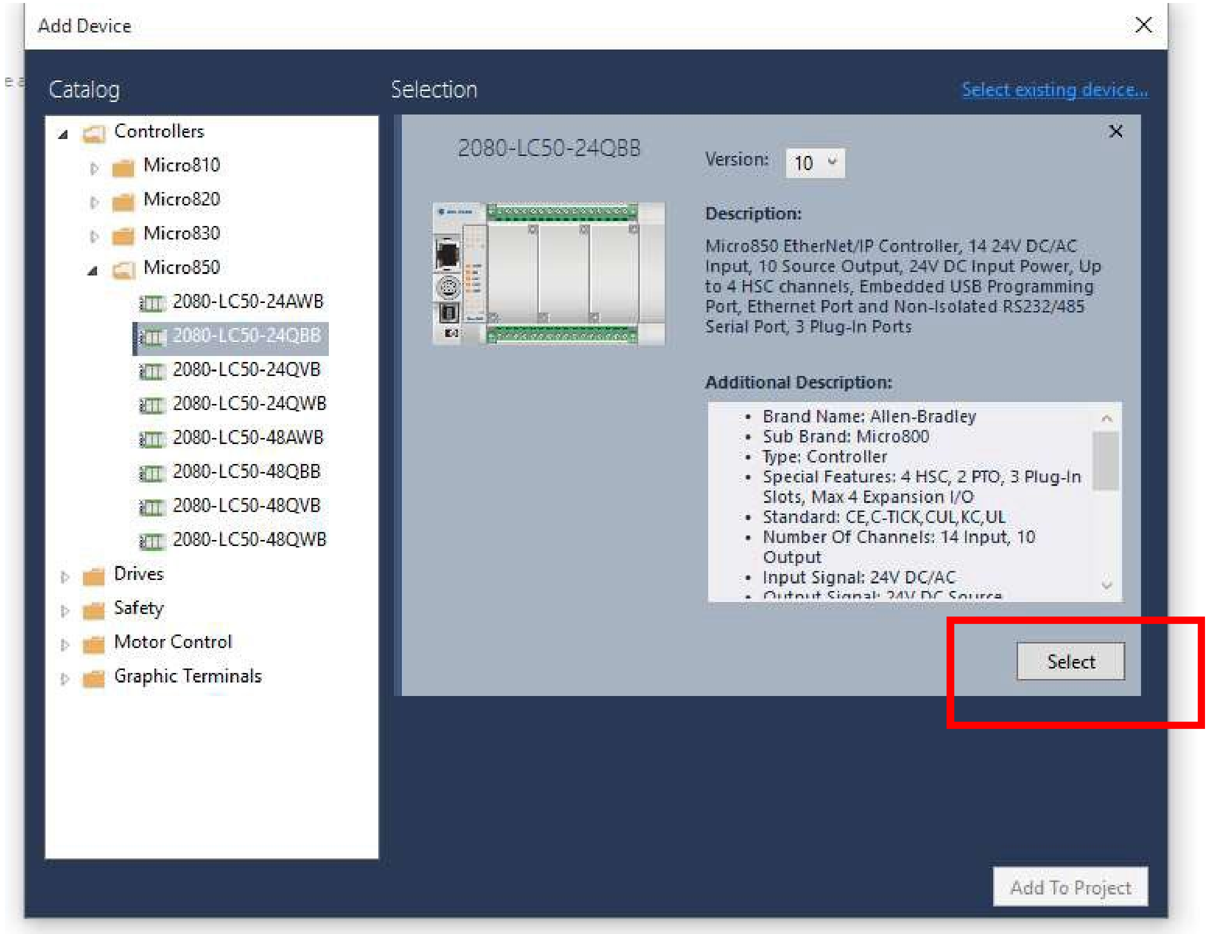
Micro870® controller
Highest memory and I/O

Each controller is **optimized for performance and customization**

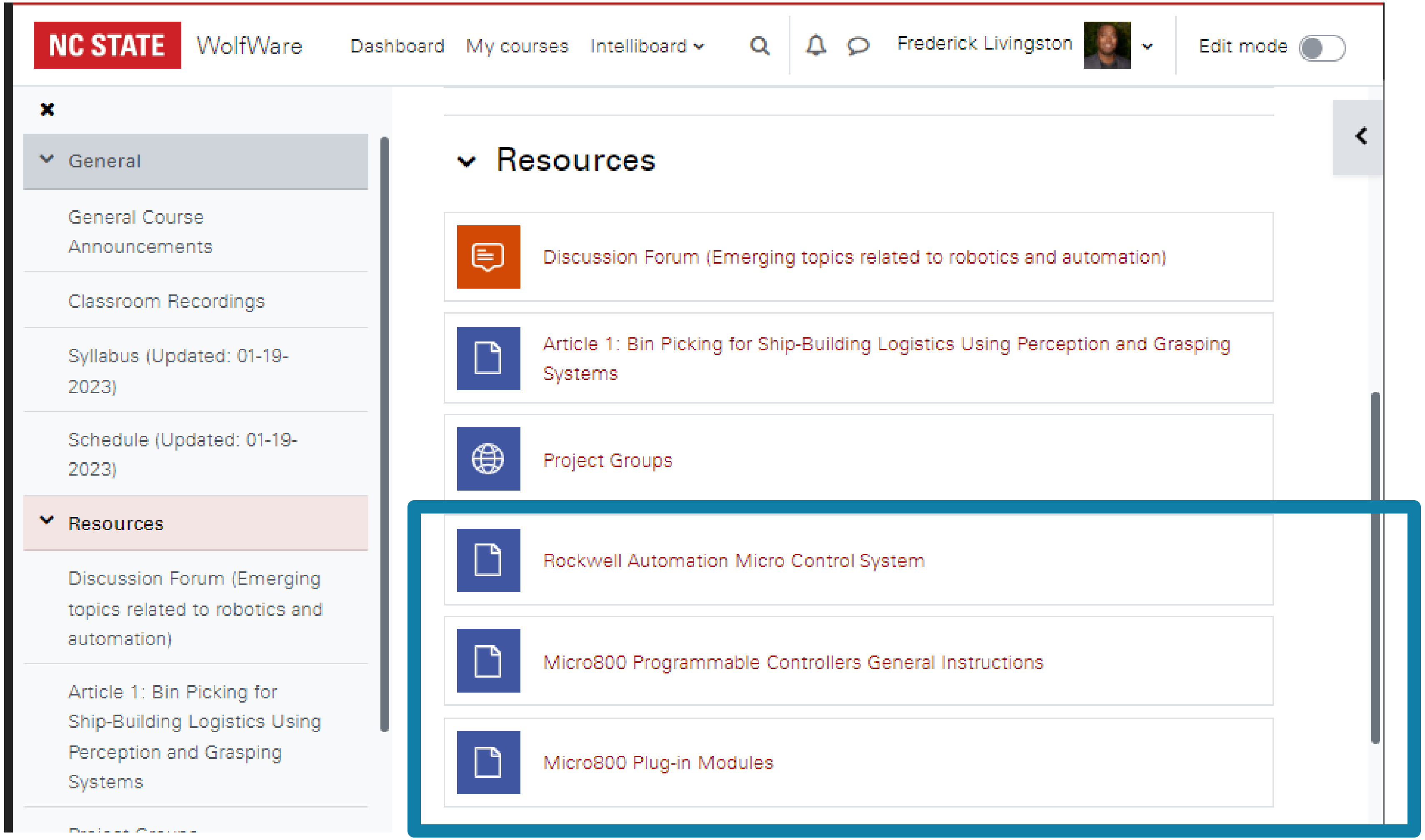
MICRO 850 (2080-LC50-24QBB)

https://www.rockwellautomation.com/en-us/products/details.2080-LC50-24QBB.html

Micro850 EtherNet/IP Controller, 14 24 VDC/VAC Inputs, 10 Source Output, 24 DC Input Power, Up to 4 HSC channels, Embedded USB Programming Port, Ethernet Port and Non-Isolated RS232/485 Serial Port, 3 Plug-In Ports



MICRO 850 RESOURCES



MICRO 850 PLUGINS

Plug-in Slots on Micro800 Controllers

Controller	Number of Plug-in Slots
Micro810	0
Micro820	2
Micro830	2 (10/16 points) 3 (24 points) 5 (48 points)
Micro850	3 (24 points) 5 (48 points)
Micro870	3

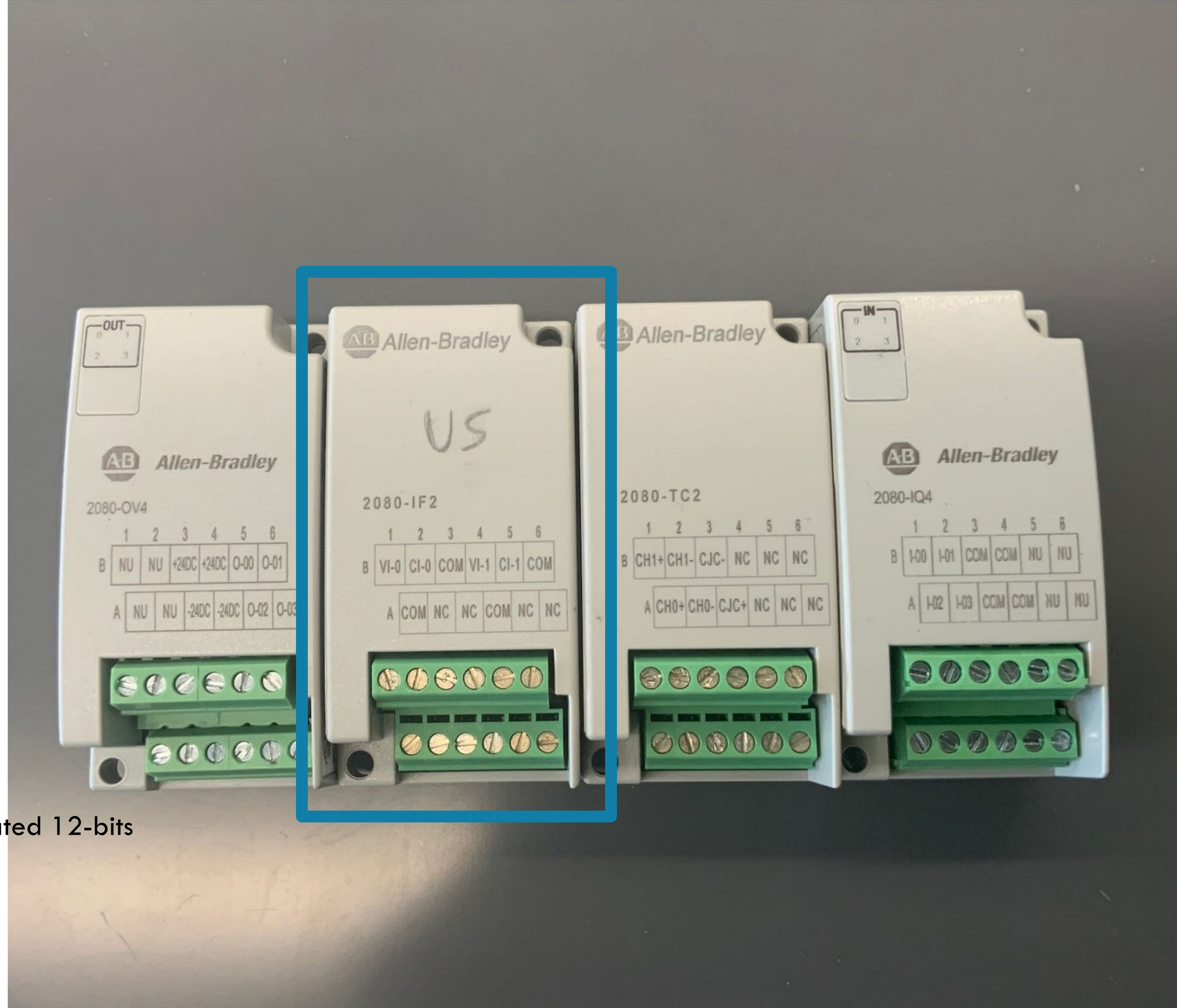
PLUGINS

2080-OV4 4-pt Digital Output, 12/24VDC, Sink

2080-IF2 2-ch Analog Input, 0-20 mA, 0-10V, non-isolated 12-bits

2080-TC2 2-ch TC, non-isolated, ±1.0 °C

2080-IQ4 4-pt Digital Input, 12/24 VDC, Sink/Source



2080-IF2

2080-IF2 2-ch Analog Input, I1,2 0-20 mA, V1,2 0-10V, non-isolated 12-bits

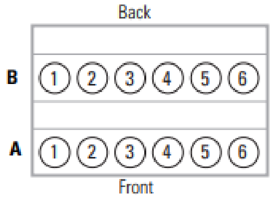
Input Specifications – 2080-IF2, 2080-IF4

Attribute	2080-IF2	2080-IF4
Number of inputs, single ended	2	4
Analog normal operating ranges	Voltage: 0…10V DC Current: 0…20 mA	
Resolution, max.	12 bits unipolar, with software selected option for 50 Hz, 60 Hz, 250 Hz, 500 Hz	
Data range	0…65535	
Input impedance	Voltage Terminal: > 220K Ω, Current Terminal: 250 Ω	
Overall accuracy[1]	Voltage Terminal: ±1% full scale @ 25°C Current Terminal: ±1% full scale @ 25°C	
Non-linearity (in percent full scale)	± 0.1%	
Repeatability[2]	± 0.1%	
Module error over full temperature range, -20…65°C (-4…149°F)	Voltage: ± 1.5% Current: ± 2.0%	
Input channel configuration	Through configuration software or the user program	
Field input calibration	Not required	
Update time	180 ms per enabled channel	

Wiring

The following plug-in modules have 12-pin female terminal blocks:

- 2080-IQ4,
- 2080-IQ4OB4, 2080-IQ4OV4
- 2080-OB4, 2080-OV4, 2080-OW4I
- 2080-IF2, 2080-IF4
- 2080-TC2, 2080-RTD2



Twelve-pin Female Terminal Block

Pin Designations for 12-Pin Female Terminal Block Modules

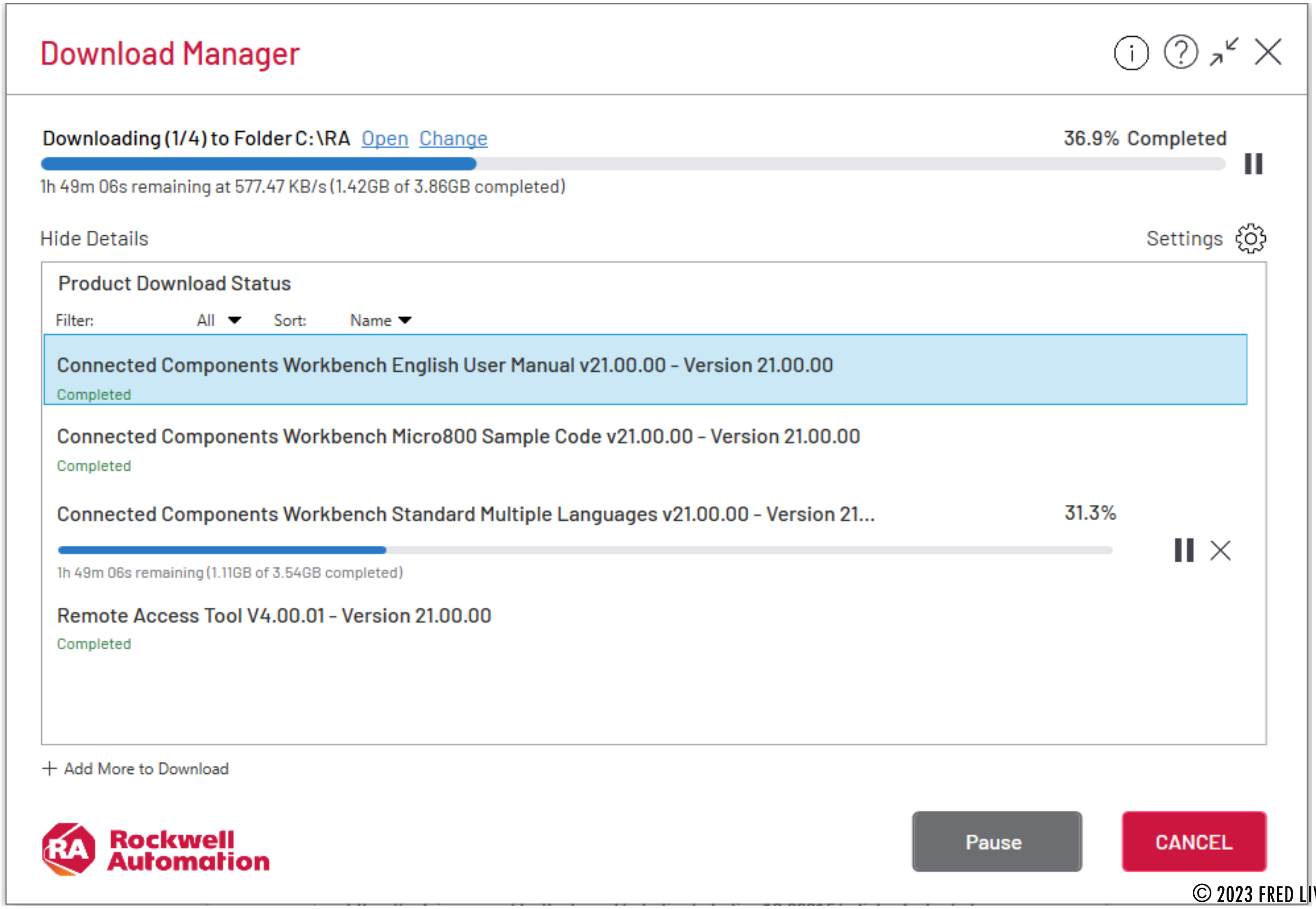
Pin	2080-IQ4	2080-IQ4OB4, 2080-IQ4OV4	2080-OB4, 2080-OV4	2080-OW4I	2080-IF2	2080-IF4	2080-TC2	2080-RTD2
A1	I-02	I-02	Not used	COM3	COM	COM	CH0+	CH0+
A2	I-03	I-03	Not used	O-3	Not used	VI	CH0-	CH0-
A3	COM	COM	-24V DC	Not used	Not used	CI	CJC+	CH0L (Sense)
A4	COM	-24V DC	-24V DC	Not used	COM	COM	Not used	Not used
A5	Not used	O-02	O-02	Not used	Not used	VI	Not used	Not used
A6	Not used	O-03	O-03	Not used	Not used	CI	Not used	Not used
B1	I-00	I-00	Not used	COM0	VI-0	VI	CH1+	CH1+
B2	I-01	I-01	Not used	O-0	CI-0	CI	CH1-	CH1-
B3	COM	COM	+24V DC	COM1	COM	COM	CJC-	CH1L (Sense)
B4	COM	+24V DC	+24V DC	O-1	VI-1	VI	Not used	Not used
B5	Not used	O-00	O-00	COM2	CI-1	CI	Not used	Not used
B6	Not used	O-01	O-01	O-2	COM	COM	TH	Not used

AUTOMATION IP TABLE

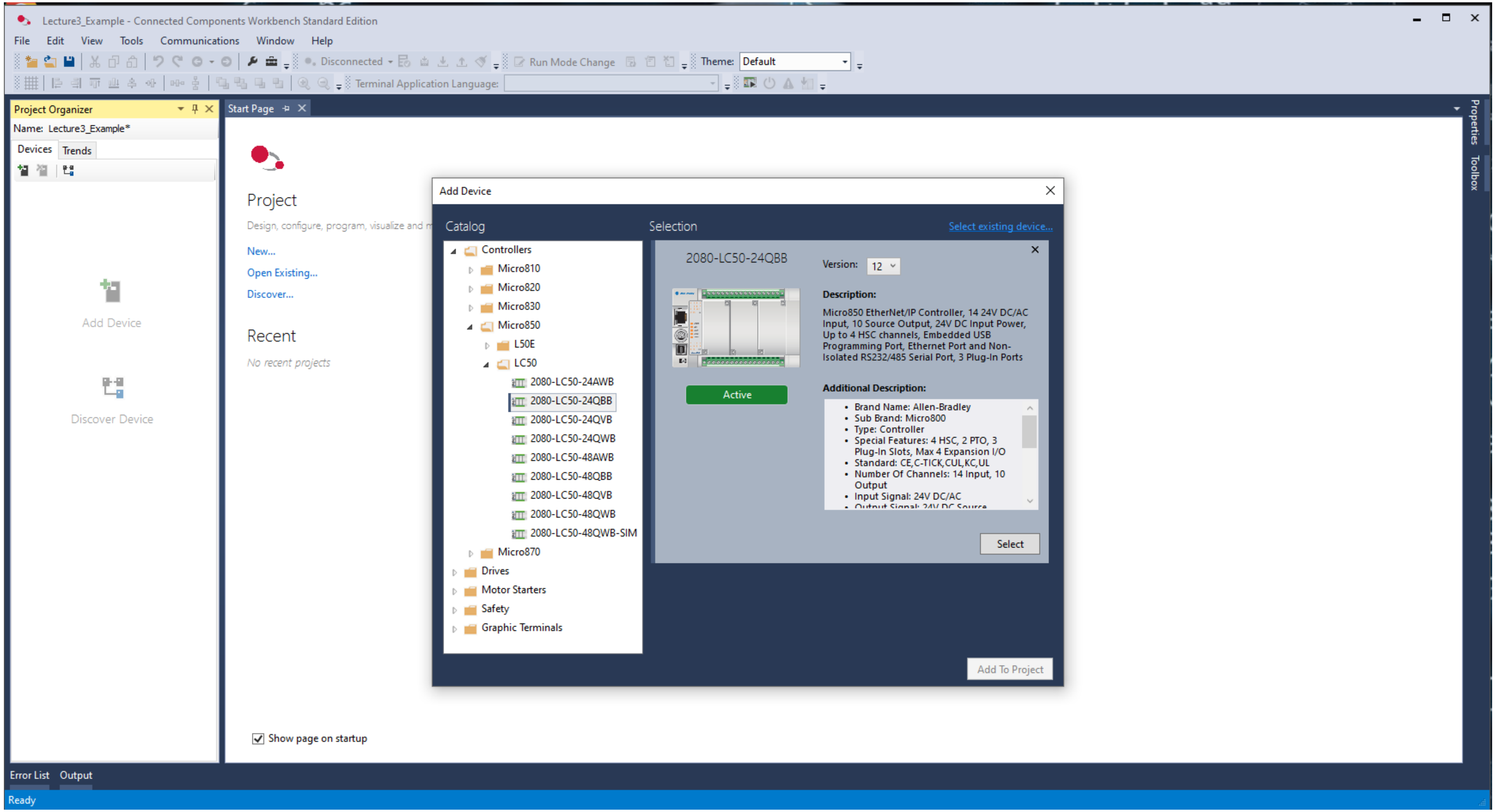
PLC	IP	HOST
1	10.76.152.223	micro850-3.ie.ncsu.edu
3	10.76.152.224	micro850-4.ie.ncsu.edu
4	10.76.152.228	micro850-8.ie.ncsu.edu
7	10.76.152.221	micro850-1.ie.ncsu.edu
9	10.76.152.229	micro850-9.ie.ncsu.edu
10	10.76152.230	micro850-10.ie.ncsu.edu
12	10.76.152.227	micro850-7.ie.ncsu.edu

CONNECTED COMPONENTS WORKBENCH

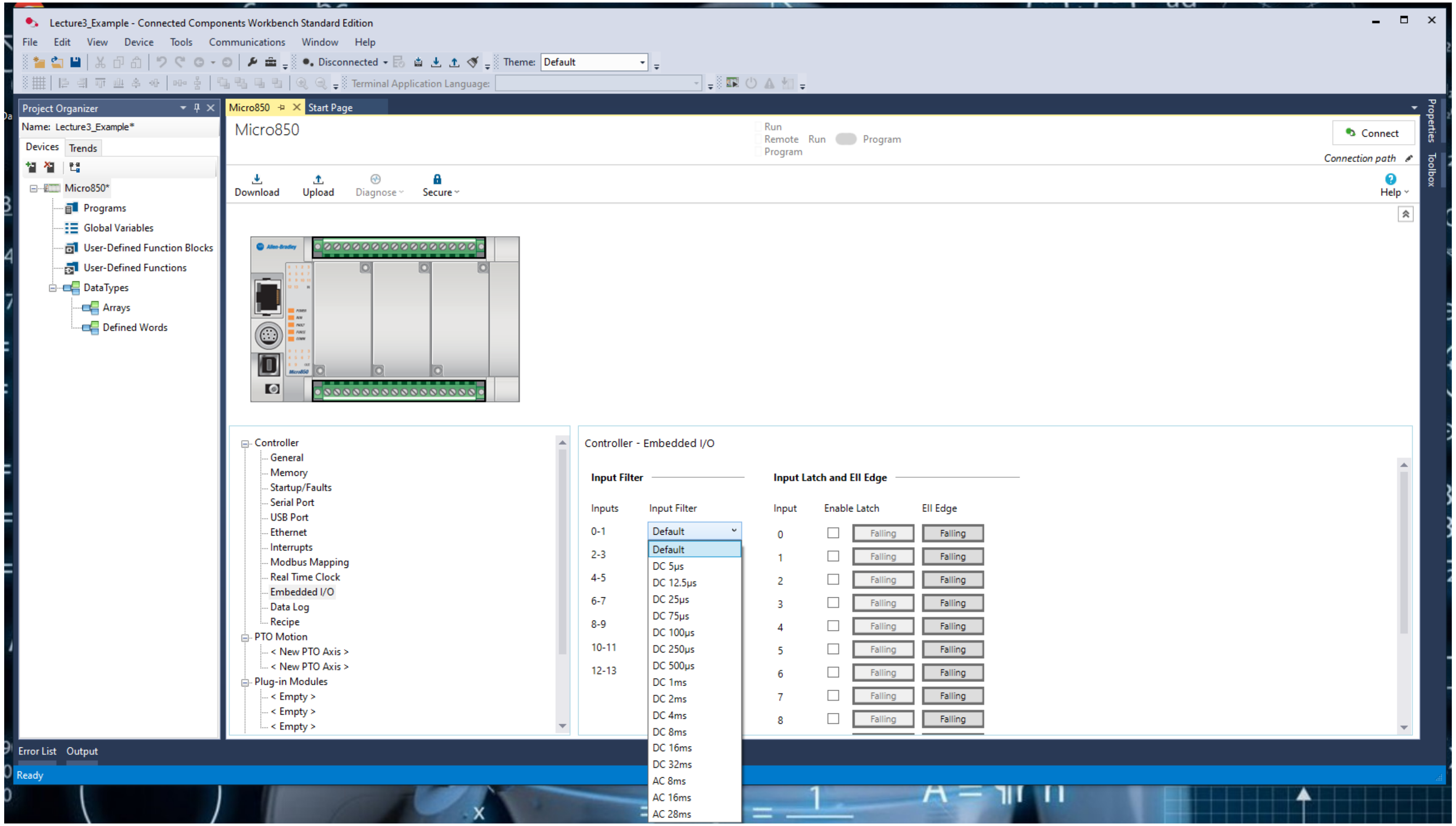
https://www.rockwellautomation.com/en-us/capabilities/industrial-automation-control/design-and-configuration-software.html



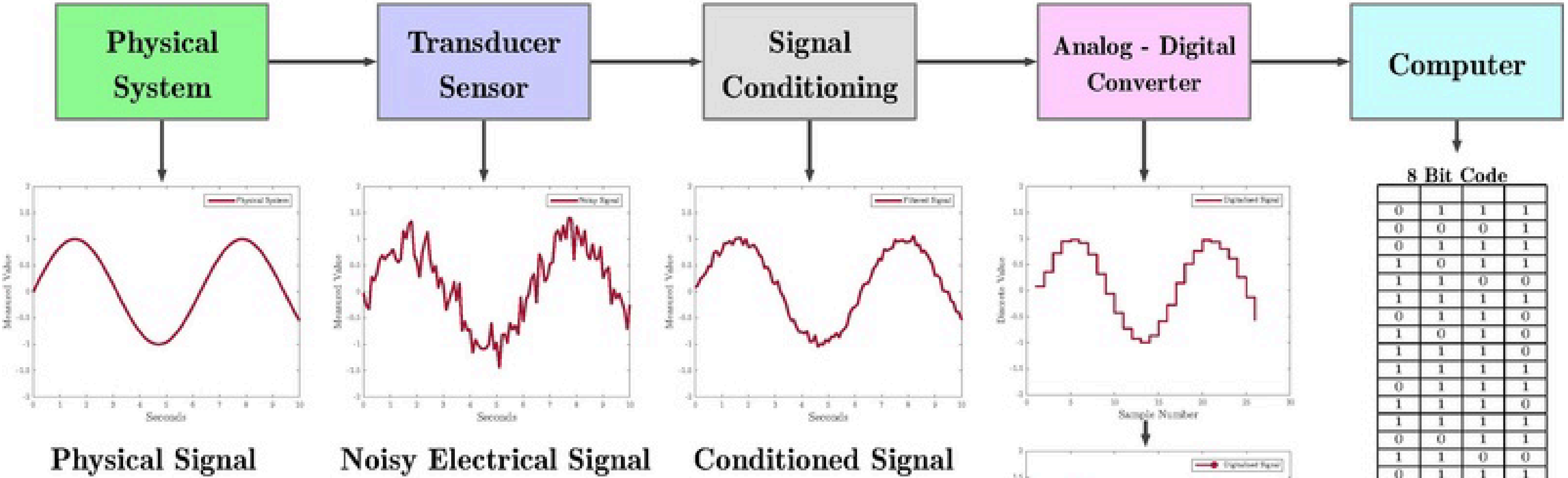
CCW – PROJECT CONFIGURATION



CCW – INPUT FILTERING



A TYPICAL DIGITAL DATA ACQUISITION PROCESS



0	1	1	1
0	0	0	1
0	1	1	1
1	0	1	1
1	1	0	0
1	1	1	1
0	1	1	0
1	0	1	0
1	1	1	0
1	1	1	1
0	1	1	1
1	1	1	0
1	1	1	1
0	0	1	1
1	1	0	0
0	1	1	1
0	1	1	1
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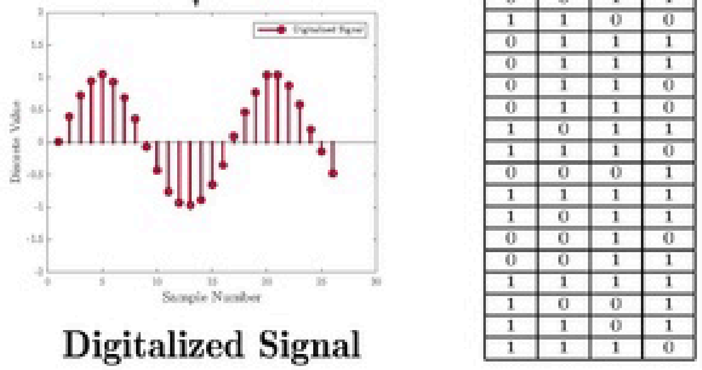
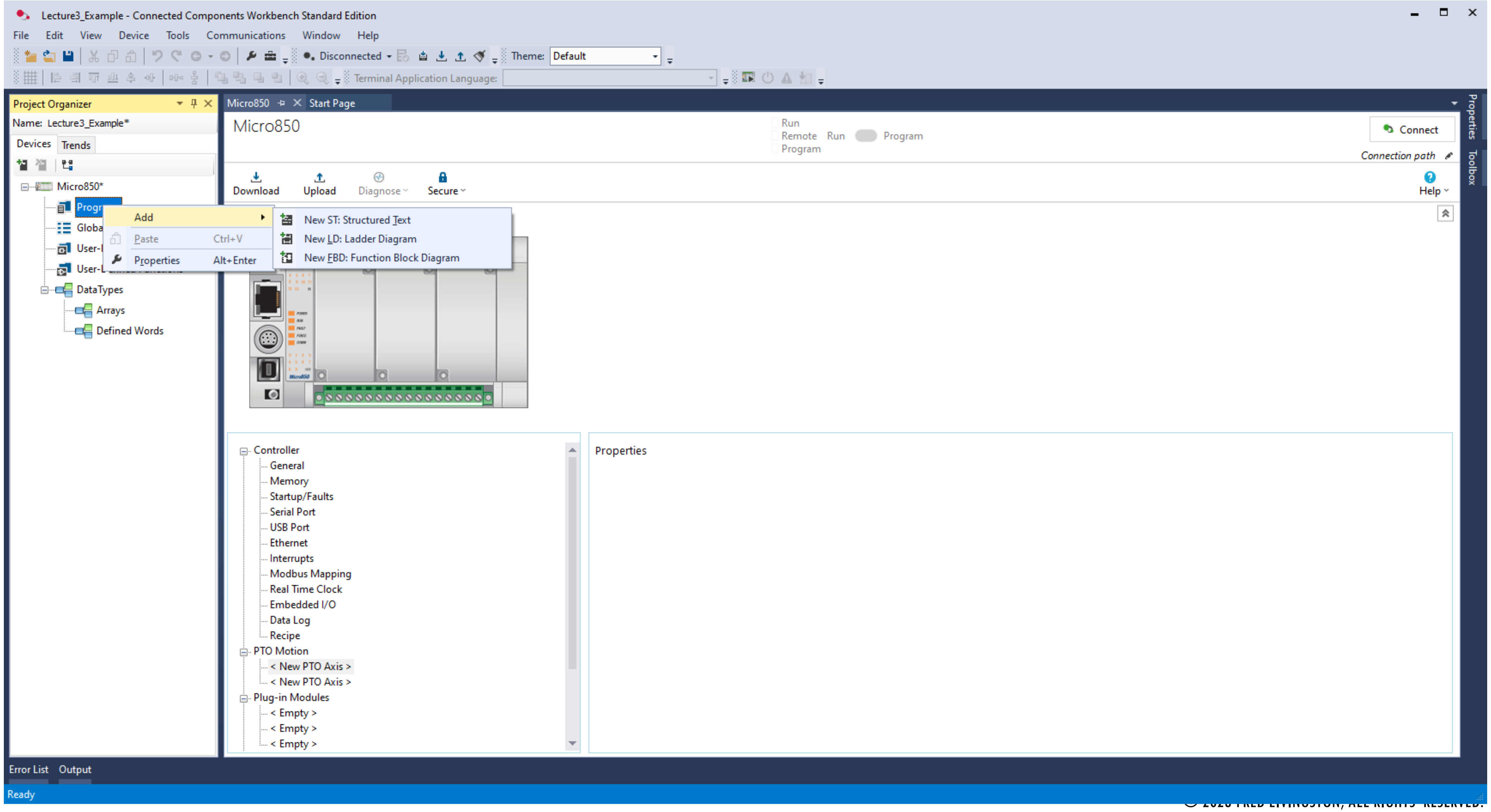
1	1	1	0
0	0	0	1
1	1	1	1
1	0	1	1
0	0	1	0
0	0	1	1
1	1	1	1
1	0	0	1
1	1	0	1
1	1	1	0

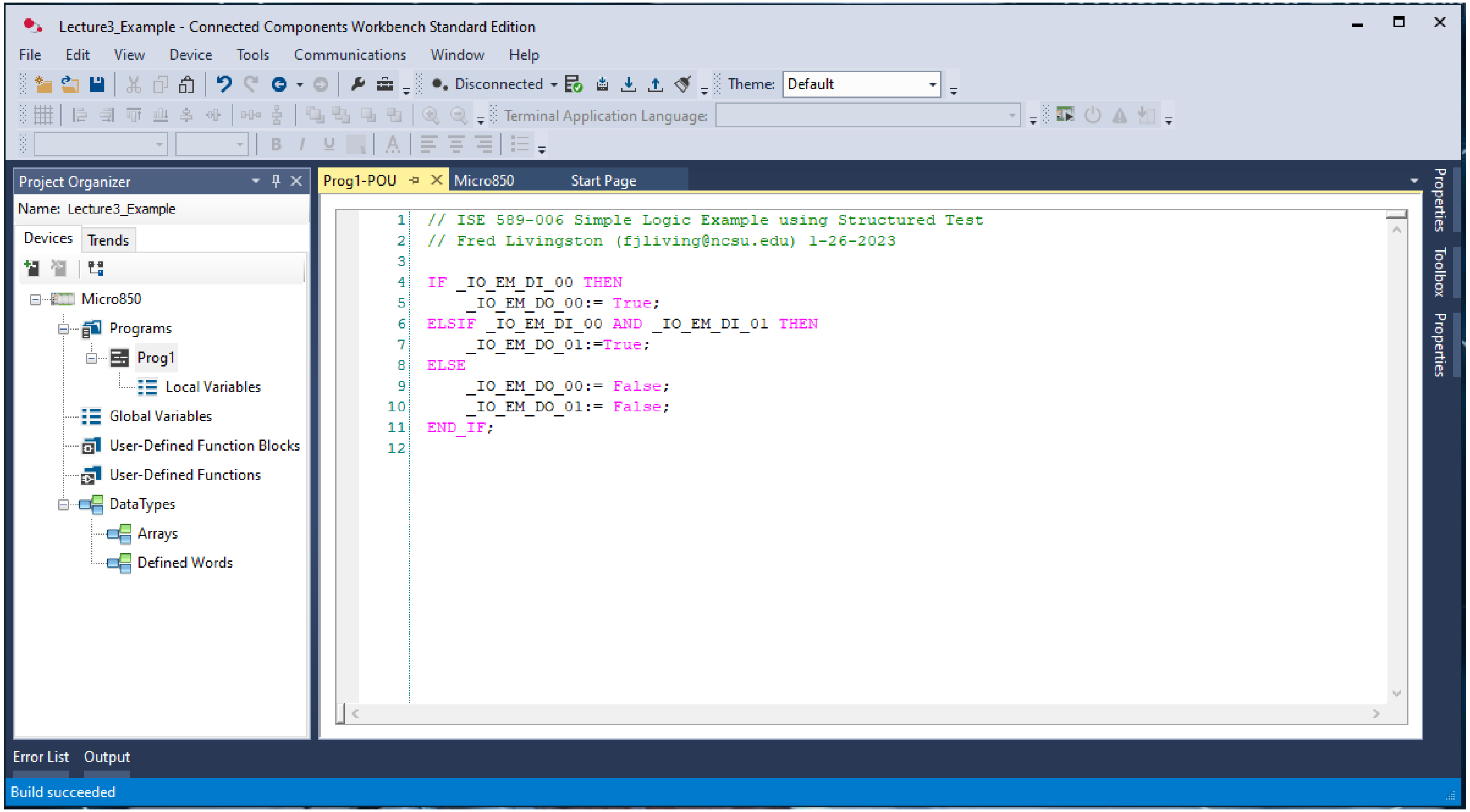
https://en.wikipedia.org/wiki/File:DigitalDAQv2.pdf



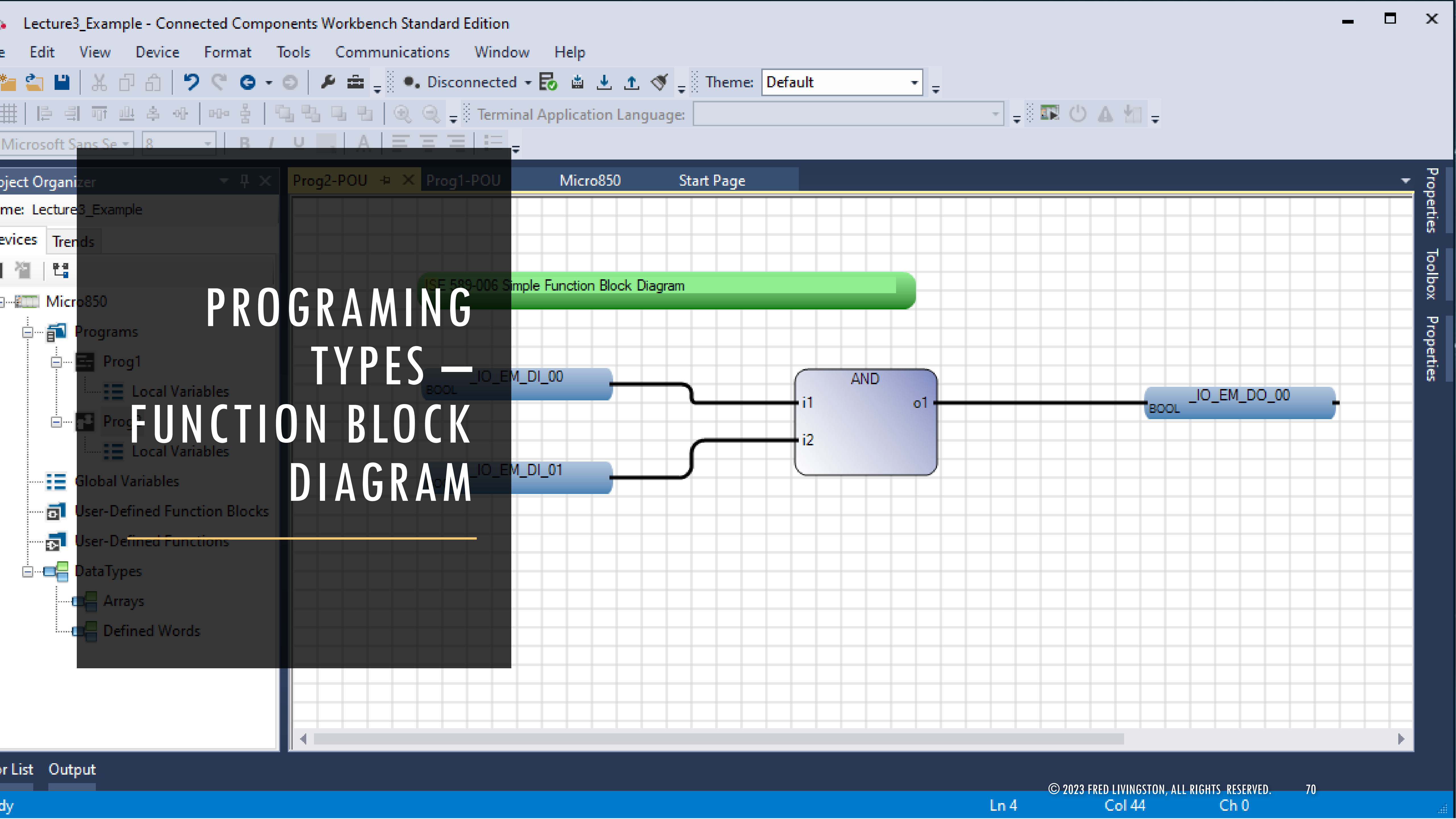
CCW – PROGRAMING TYPES



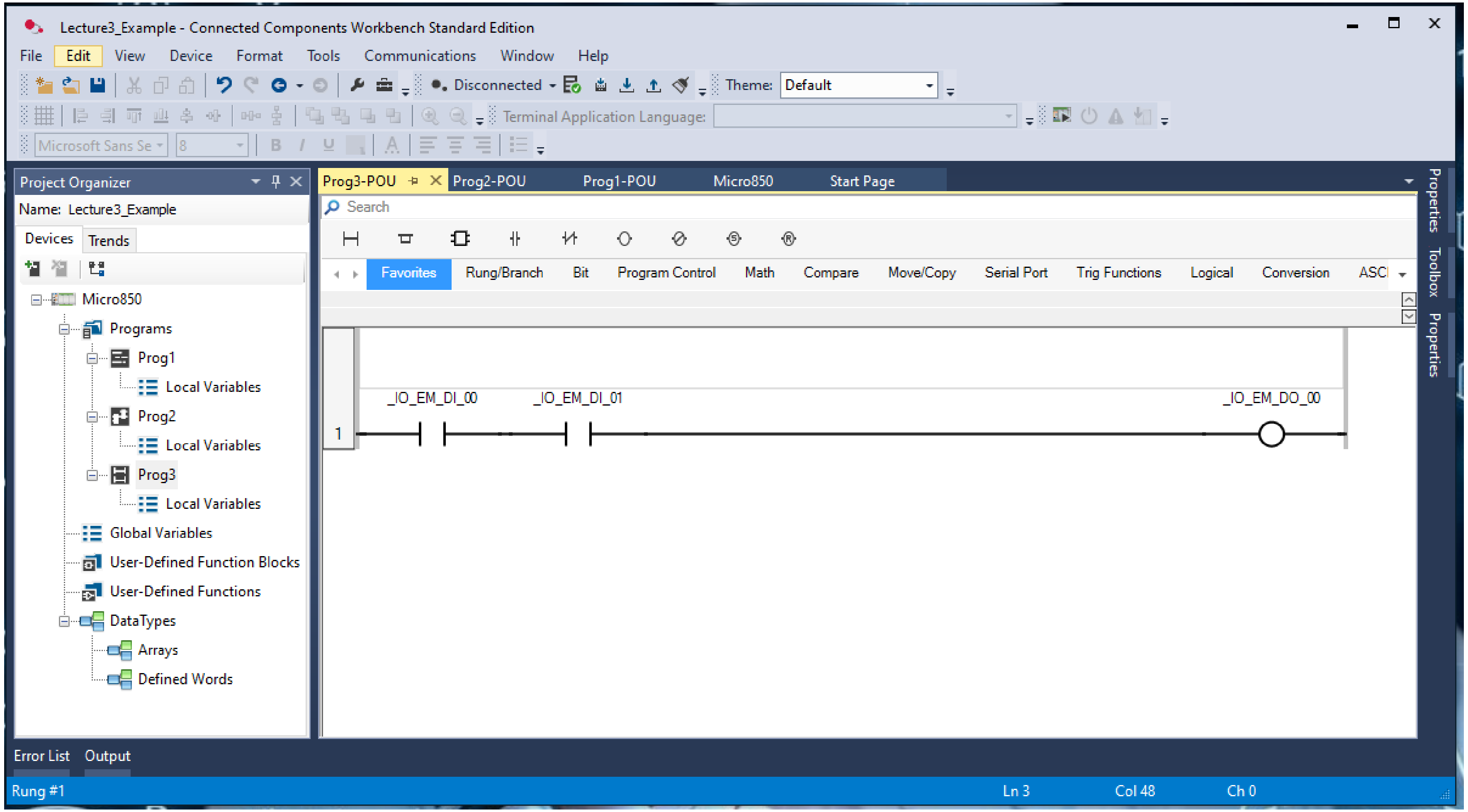
PROGRAMING TYPES – STRUCTURED TEXT



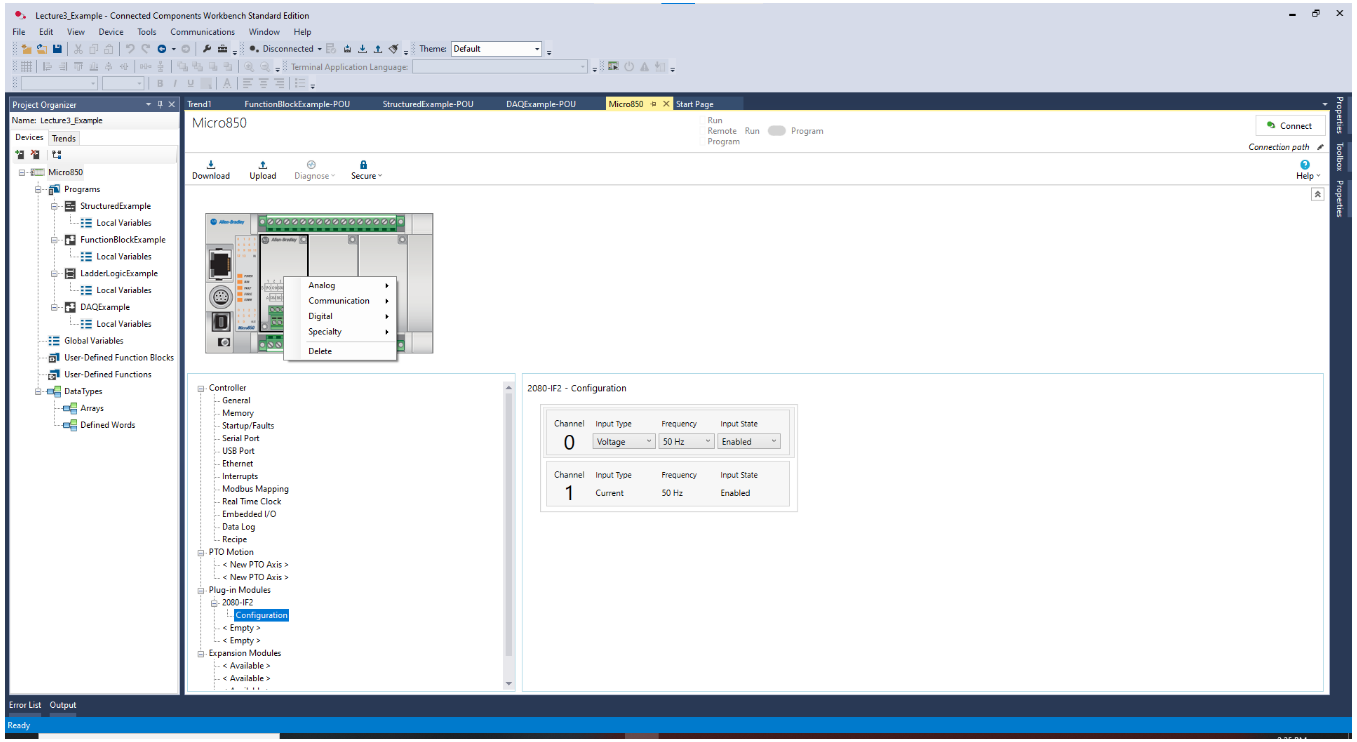
PROGRAMING TYPES — FUNCTION BLOCK DIAGRAM

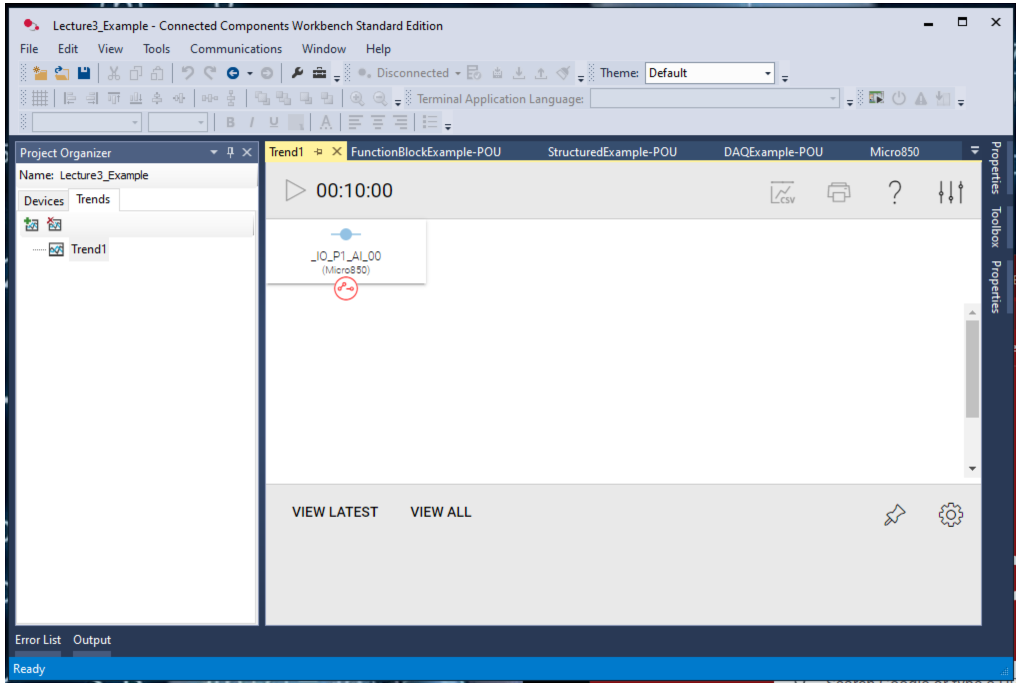


PROGRAMING TYPES – LADDER LOGIC



CCW – DATA AQUISTION





2080-IF2

12bit A/D (Voltage)

- A 12-bit word is needed $(2^{12} = 4096, n = 12)$
- The resolution is: $\frac{V_{FS}}{2^n} = \frac{10}{4096}V = 2.441mV$
- If $V_{in} = 5.4V, V_{quant} = floor\left(\frac{V_{in}}{2.441m}\right) * 2.441mV = 5.3971V$
- Quantization error = 5.4-5.3971 = 0.002929V = 2.9mV
- Maximum quantization error = $\frac{LSB}{2} = \frac{2.441mV}{2} = 1.22mV$

LAB 1A – INTRODUCTION TO MICRO850 PLC

LAB 1 PREVIEW (MORE SOON)

Data Acquisition of a photo sensor.

Using a PLC; connect and monitor the output of a photo sensor to determine the following: range, noise, etc.

Describe the effects of the filter function on the signal.

Create a circuit and program that performs the following function:

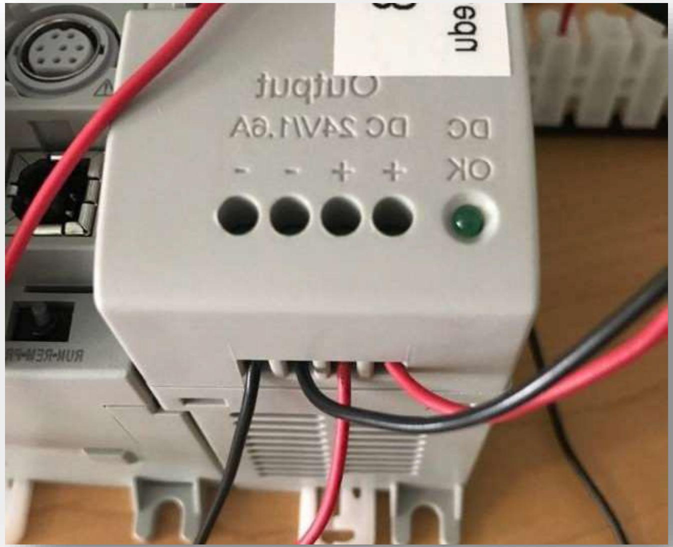
photo sensor will de-energize a 24v DC motor

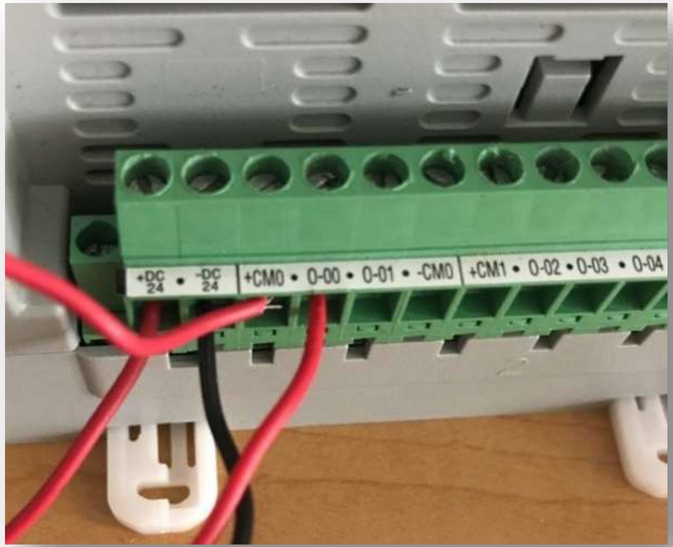
TODAYS'S OBJECTIVE

- Become familiar with the most basic functions of a PLC, including wiring, programming, downloading, and interfacing with input and output devices.
- Become familiar with the behavior of a photo sensor and accomplishing automation.

SENSOR EVALUATIONS

1. Before using any group of Input or output channels, they have to be powered through the COM0 or COM1 for input channels, and CM0, CM1 for output channels.

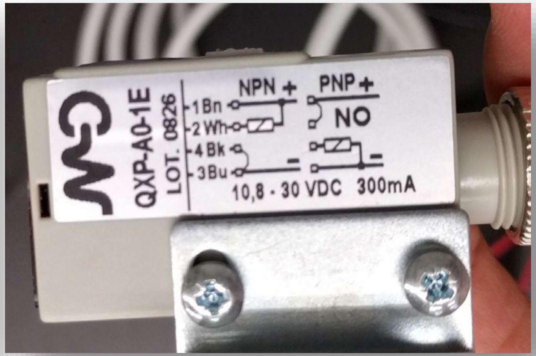




SENSORS

Inductive sensor


Inductive sensor



Rectangle head photo sensor

- If you are using an inductive sensor, connect the black wire to the PLC's Input0 (I-00), connect the brown wire the positive terminal block and connect he blue wire the negative terminal block.
- If connecting a photo sensor with a round head, connect the blue and pink wires to the negative terminal block. Connect the brown wire to the positive terminal block. Connect the black wire to the PLC's Input0 (I-00).
- If connecting a photo sensor with a rectangle head, connect the blue and black wires to the negative terminal block. Connect the brown wire to the positive terminal block. Connect the white wire to the PLC's Input0 (I-00)

END OF LECTURE