

ISE 589-006: INTRODUCTION TO MODERN INDUSTRIAL AUTOMATION

LECTURE 004
Fred Livingston, PhD

Course Schedule

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Months



Q1 2023

Q2 2023

Feb

Mar

Apr

May

Lab 1A: Allen Bradley I/O - Sensors | Modern Industrial Automation

Actuators | Modern Industrial Automation

Lab 1B: Allen Bradley I/O - Actuators | Modern Industrial Automation

System Modeling | Modern Industrial Automation

Lab 2: System Modeling (PLC+MATLAB) | Modern Industrial Automation

Module 3: Introduction to Automatic Control

PID (Proportional Integral Derivative Controller) | Modern Industrial Automation

Sequence Control | Modern Industrial Automation

PLC (Programmable Logic Controller) | Modern Industrial Automation

Lab 3A: Application of Sequence Controller | Modern Industrial Automation

Lab 3B: Application of Sequence Controller - Feedback Control | Modern Industrial Automation

Distributive Controllers (Edge-Computing) | Modern Industrial Automation

Industrial Communication (OPC, Modbus, MQTT, DDS) | Modern Industrial Automation

Safety | Modern Industrial Automation

Lab 4: Application of Industrial Communication | Modern Industrial Automation

Lab 5: Application Distributive Control and Safety | Modern Industrial Automation

No Classes; Spring Break | Modern Industrial Automation

Module 4: Manipulators and End-Effectors

Kinematics | Modern Industrial Automation

Universal Robotic Manipulators | Modern Industrial Automation

Lab 6: Application of Industrial Manipulators I | Modern Industrial Automation

Trajectory | Modern Industrial Automation

ABB Robotic Manipulators | Modern Industrial Automation

Lab 7: Application of Industrial Manipulators II | Modern Industrial Automation

Module 5: Design Project

Lab 1A: Allen Bradley I/O - Sensors | Modern Industrial Automation

Actuators | Modern Industrial Automation

Lab 1B: Allen Bradley I/O - Actuators | Modern Industrial Automation

System Modeling | Modern Industrial Automation

Lab 2: System Modeling (PLC+MATLAB) | Modern Industrial Automation

Module 3: Introduction to Automatic Control ● Feb 6 - Mar 17 ● 40 days

PID (Proportional Integral Derivative Controller) | Modern Industrial Automation

Sequence Control | Modern Industrial Automation

PLC (Programmable Logic Controller) | Modern Industrial Automation

Lab 3A: Application of Sequence Controller | Modern Industrial Automation

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Safety | Modern Industrial Automation

Lab 4: Application of Industrial Communication | Modern Industrial Automation

Lab 5: Application Distributive Control and Safety | Modern Industrial Automation

No Classes; Spring Break | Modern Industrial Automation

Module 4: Manipulators and End-Effectors ● Mar 20 - Apr 7 ● 19 days

Kinematics | Modern Industrial Automation

Universal Robotic Manipulators | Modern Industrial Automation

Lab 6: Application of Industrial Manipulators I | Modern Industrial Automation

Trajectory | Modern Industrial Automation

ABB Robotic Manipulators | Modern Industrial Automation

Lab 7: Application of Industrial Manipulators II | Modern Industrial Automation

Module 5: Design Project ● Mar 30 - May 2 ● 34 days

Module 1: Introduction

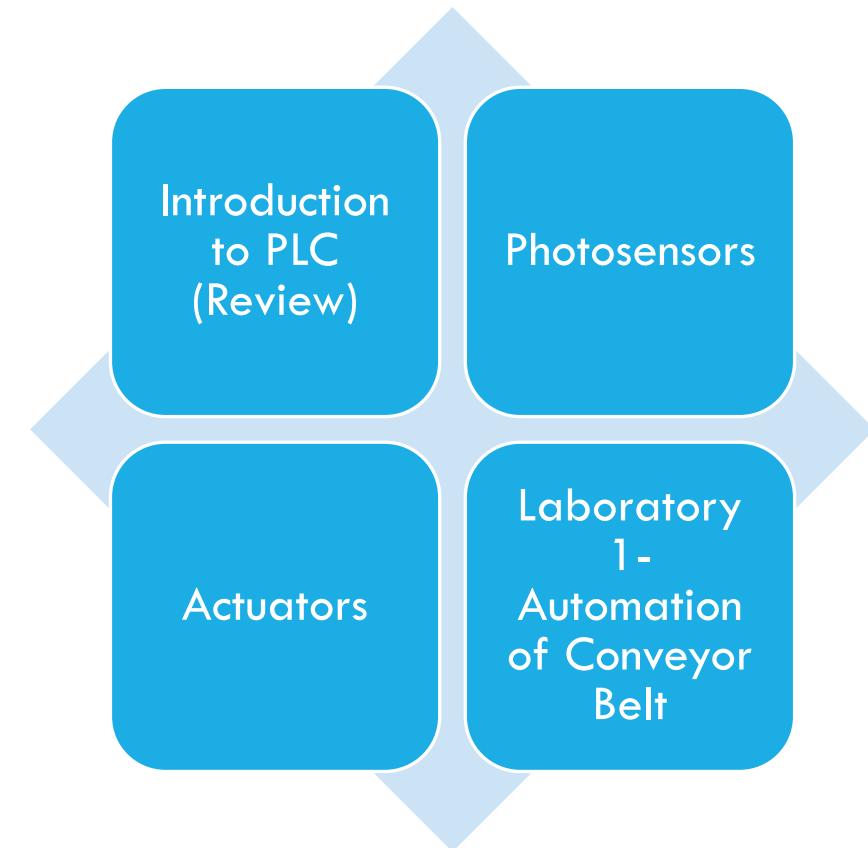
Module 2: Measurement

Module 3: Introduction to Automatic Control

Module 4: Manipulators and End-Effectors

Module 5: Design Project

LECTURE 4: ACTUATORS



HW 1 DUE FEB 5TH 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.

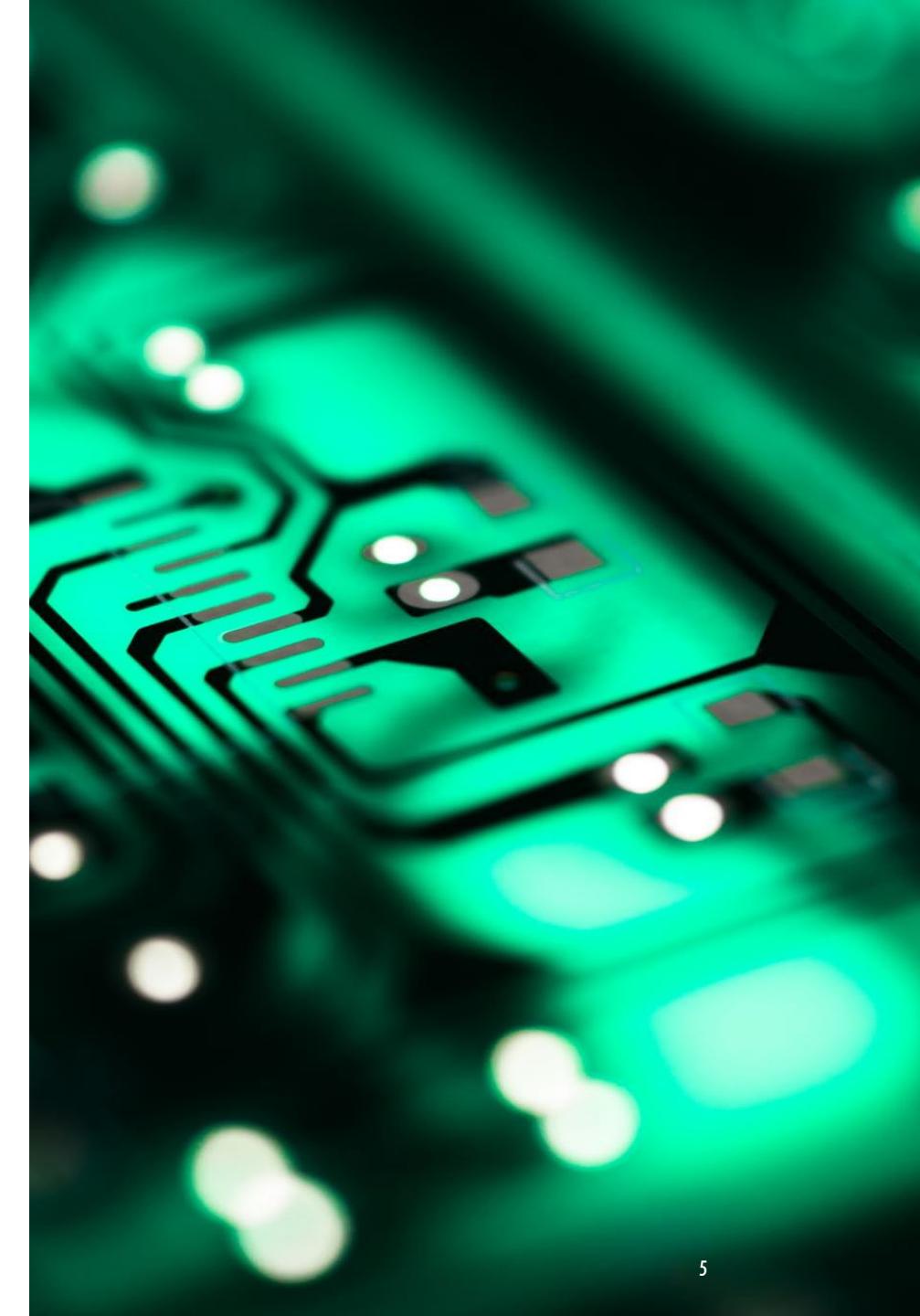
Given a dataset, derive a system model from the response time.

Q4.

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

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.



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

Add Device

Catalog Selection Select existing device...

2080-LC50-24QBB Version: 10

Description:

Micro850 EtherNet/IP Controller, 14 24V DC/AC Input, 10 Source Output, 24V 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

Additional Description:

- Brand Name: Allen-Bradley
- Sub Brand: Micro800
- Type: Controller
- Special Features: 4 HSC, 2 PTO, 3 Plug-In Slots, Max 4 Expansion I/O
- Standard: CE, C-TICK, CUL, KC, UL
- Number Of Channels: 14 Input, 10 Output
- Input Signal: 24V DC/AC
- Output Signal: 24V DC/Source

Select Add To Project

The 'Select' button is highlighted with a red box.

MICRO 850 RESOURCES

The screenshot shows a course page for "MICRO 850 RESOURCES". The left sidebar has sections for "General" (Announcements, Classroom Recordings, Syllabus, Schedule) and "Resources" (Discussion Forum, Article 1, Project Groups). The main content area shows a "Resources" section with items: Discussion Forum (Emerging topics related to robotics and automation), Article 1: Bin Picking for Ship-Building Logistics Using Perception and Grasping Systems, Project Groups, Rockwell Automation Micro Control System, Micro800 Programmable Controllers General Instructions, and Micro800 Plug-in Modules. The last three items are highlighted with a blue border.

NC STATE WolfWare Dashboard My courses Intelliboard Frederick Livingston Edit mode

General

General Course Announcements

Classroom Recordings

Syllabus (Updated: 01-19-2023)

Schedule (Updated: 01-19-2023)

Resources

Discussion Forum (Emerging topics related to robotics and automation)

Article 1: Bin Picking for Ship-Building Logistics Using Perception and Grasping Systems

Project Groups

Rockwell Automation Micro Control System

Micro800 Programmable Controllers General Instructions

Micro800 Plug-in Modules

CONNECTED COMPONENTS WORKBENCH

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

Download Manager

Downloading (1/4) to Folder C:\RA [Open](#) [Change](#) 36.9% Completed

1h 49m 06s remaining at 577.47 KB/s (1.42GB of 3.86GB completed)

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Product Download Status	
Filter:	All ▾
Sort:	Name ▾
Connected Components Workbench English User Manual v21.00.00 - Version 21.00.00	
Completed	
Connected Components Workbench Micro800 Sample Code v21.00.00 - Version 21.00.00	
Completed	
Connected Components Workbench Standard Multiple Languages v21.00.00 - Version 21...	
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1h 49m 06s remaining (1.11GB of 3.54GB completed)	
Remote Access Tool V4.00.01 - Version 21.00.00	
Completed	

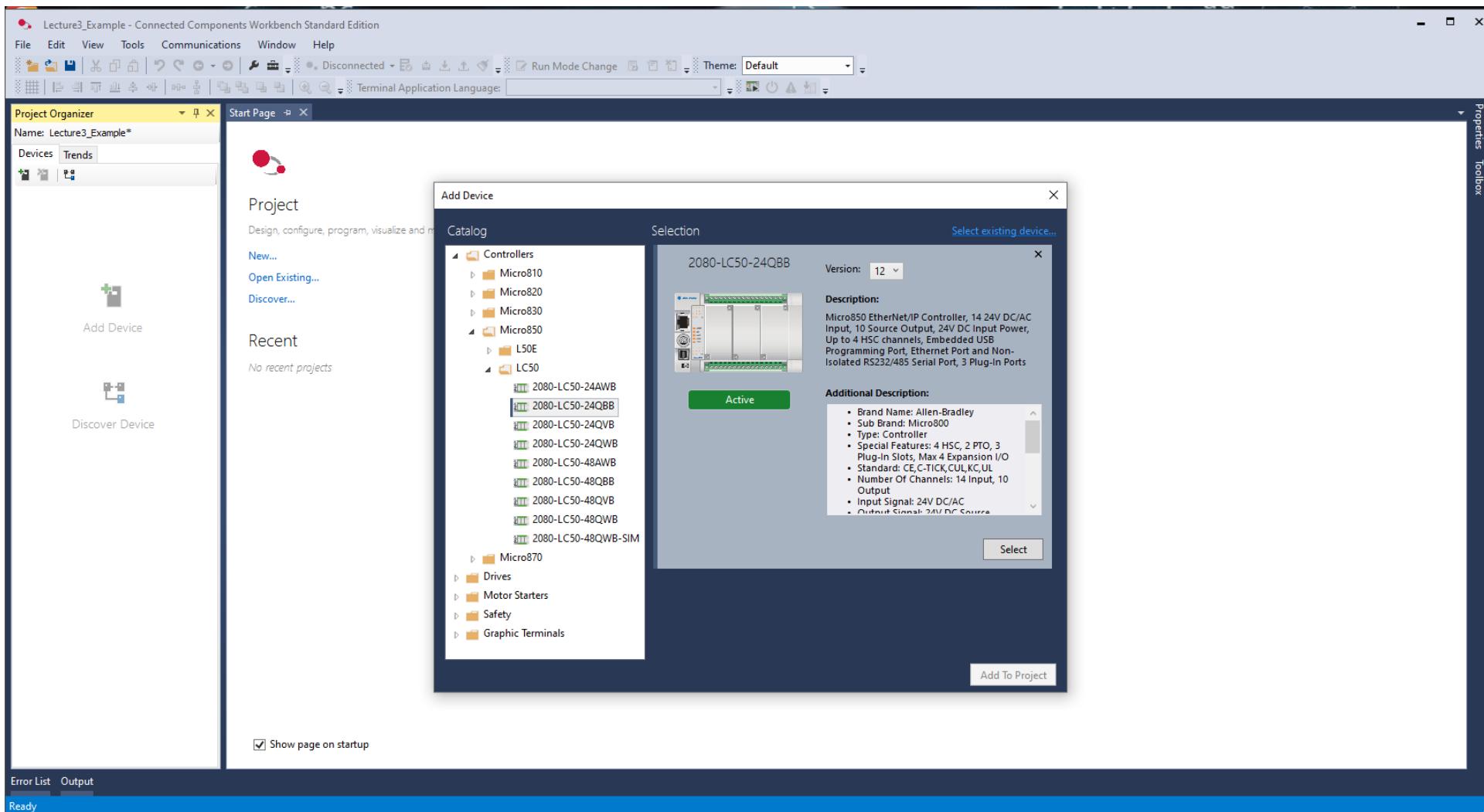
+ Add More to Download

Pause CANCEL

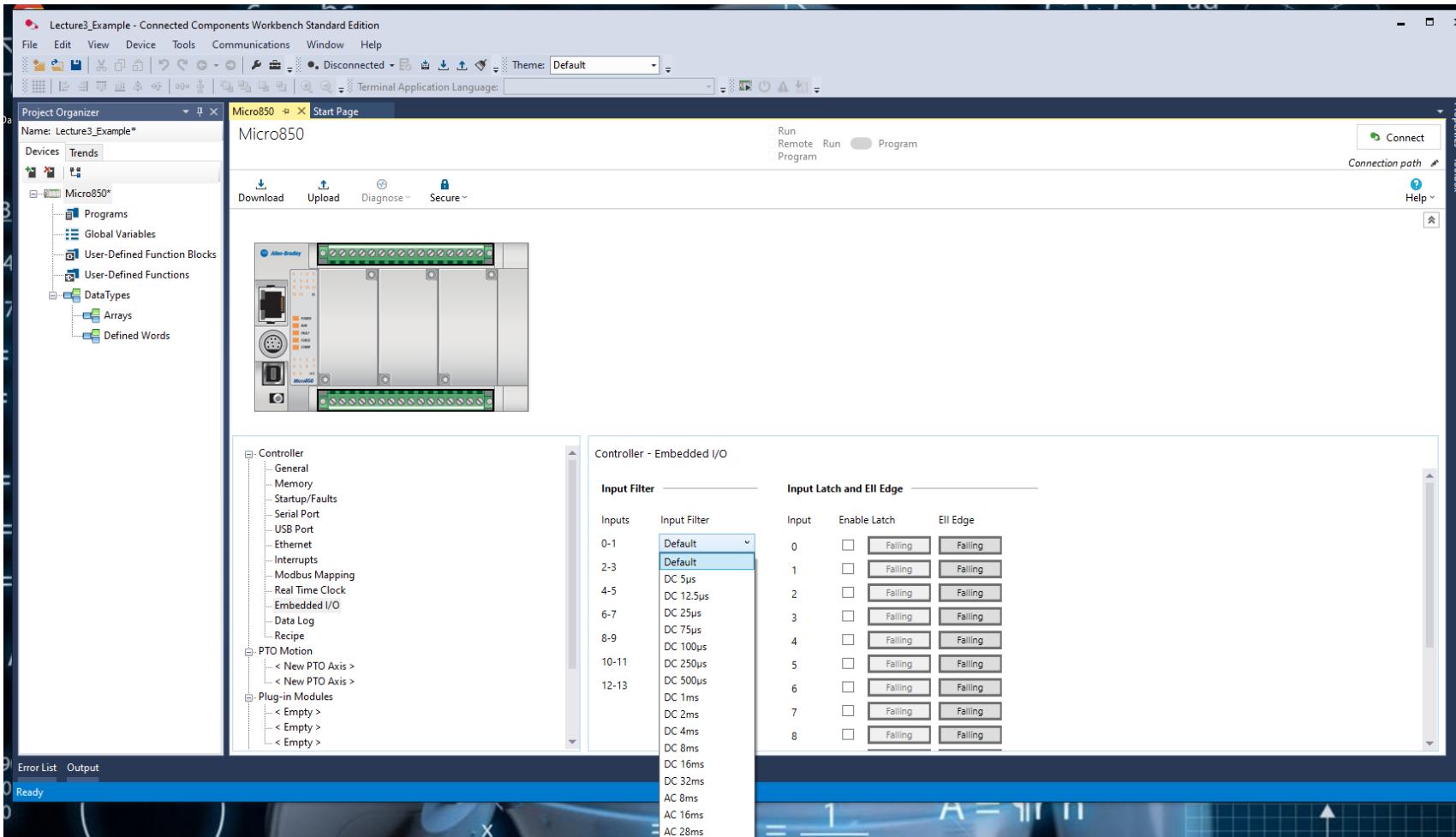
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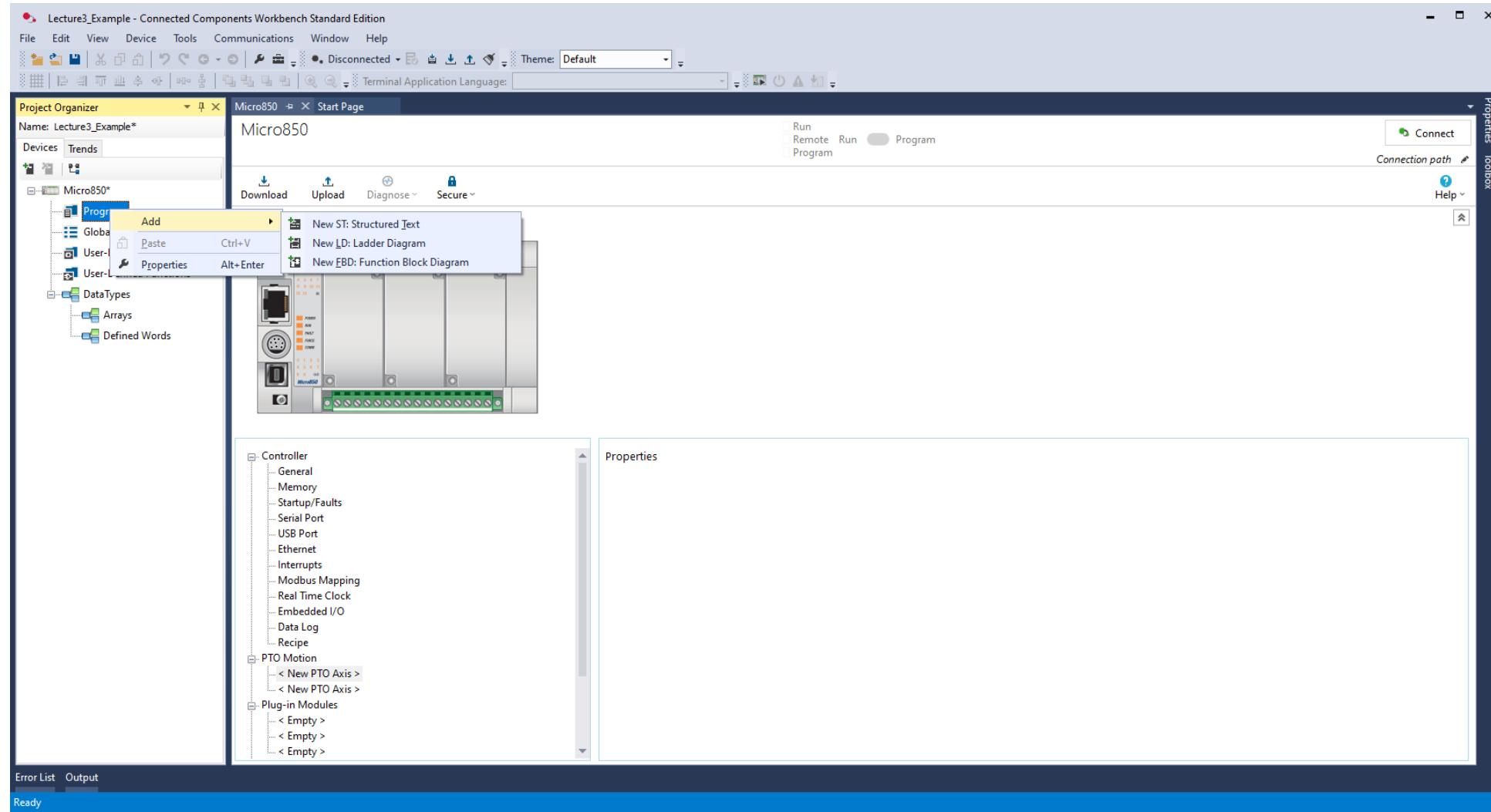
CCW – PROJECT CONFIGURATION



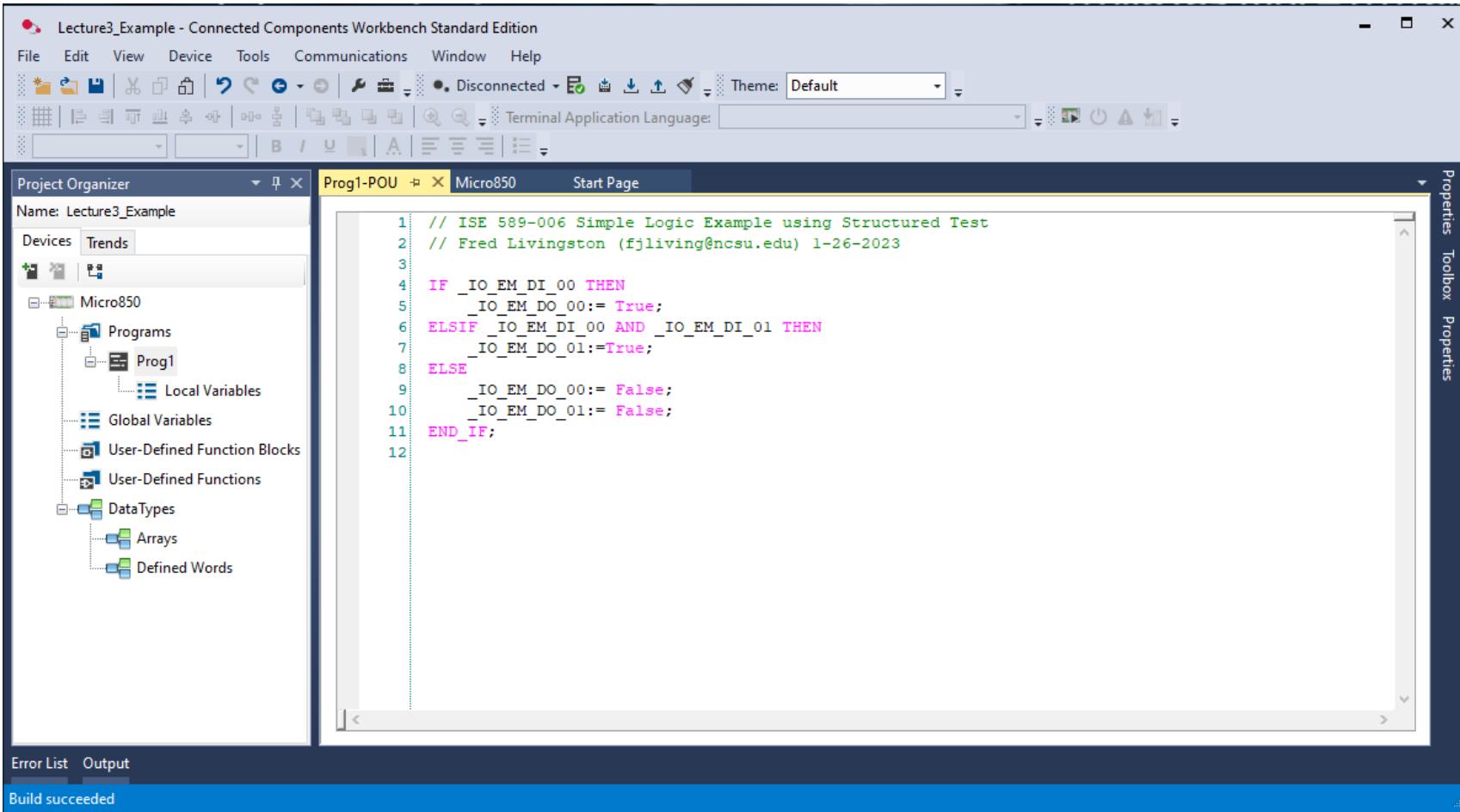
CCW – INPUT FILTERING



CCW – PROGRAMMING TYPES



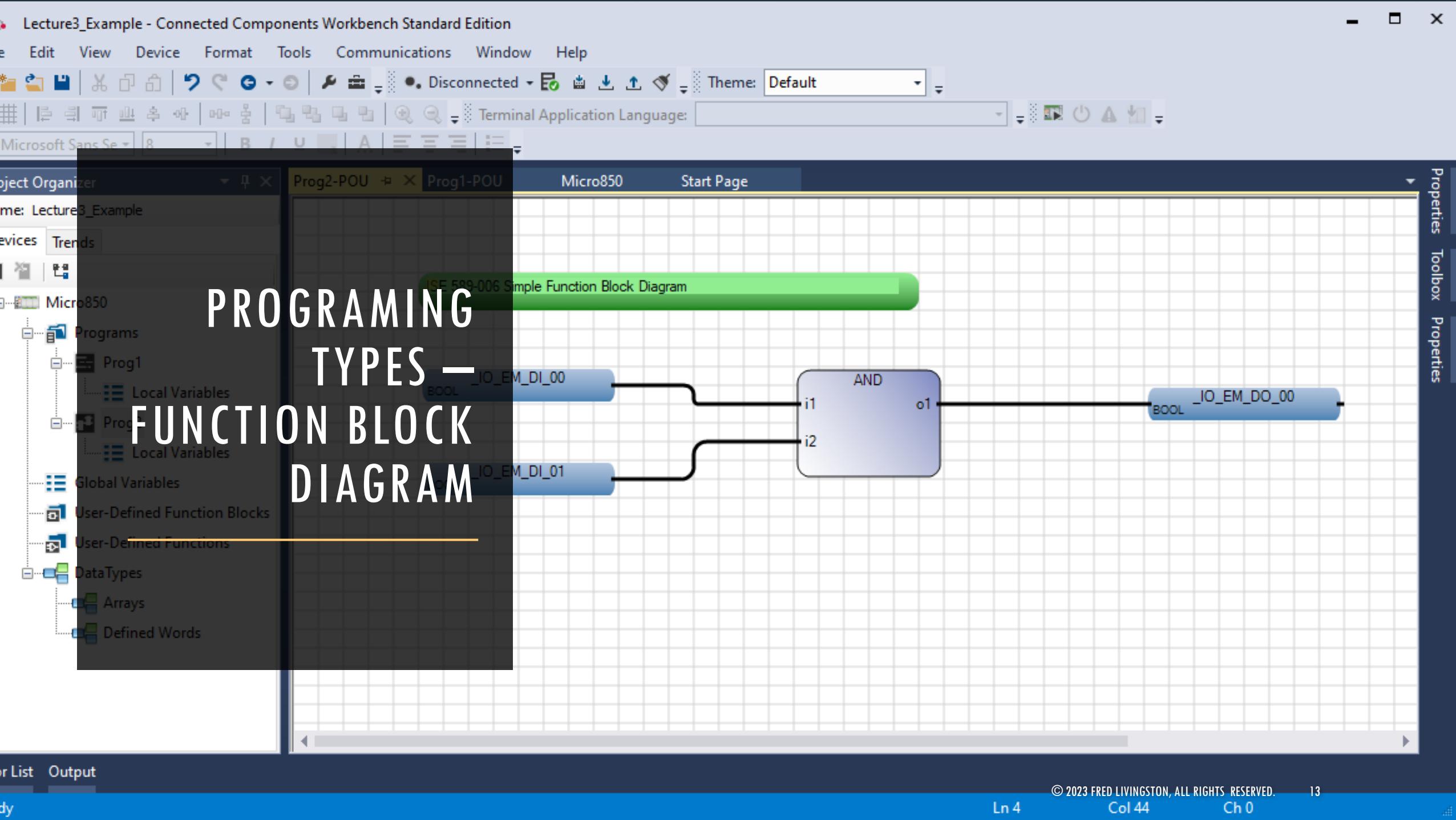
PROGRAMMING TYPES – STRUCTURED TEXT



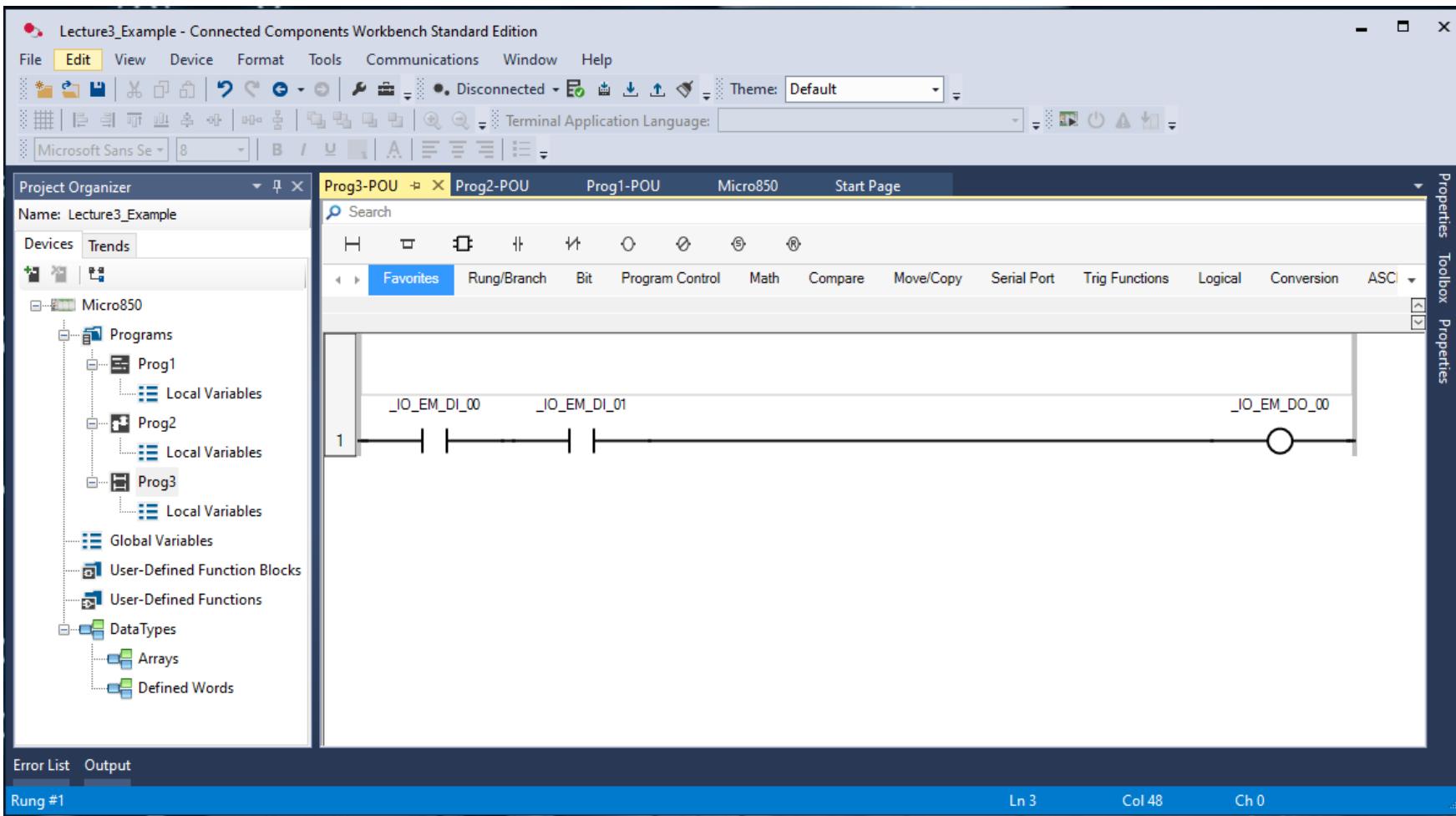
The screenshot shows the Connected Components Workbench Standard Edition interface. The title bar reads "Lecture3_Example - Connected Components Workbench Standard Edition". The menu bar includes File, Edit, View, Device, Tools, Communications, Window, and Help. The toolbar contains various icons for file operations and device management. The Project Organizer on the left shows a project named "Lecture3_Example" with a Micro850 device selected. Inside the Micro850 folder, there are Programs (Prog1), Global Variables, User-Defined Function Blocks, User-Defined Functions, and DataTypes (Arrays, Defined Words). The main workspace displays a Structured Text program titled "Prog1-POU". The code is as follows:

```
1 // ISE 589-006 Simple Logic Example using Structured Text
2 // Fred Livingston (fjliving@ncsu.edu) 1-26-2023
3
4 IF _IO_EM_DI_00 THEN
5     _IO_EM_DO_00:= True;
6 ELSIF _IO_EM_DI_00 AND _IO_EM_DI_01 THEN
7     _IO_EM_DO_01:=True;
8 ELSE
9     _IO_EM_DO_00:= False;
10    _IO_EM_DO_01:= False;
11 END_IF;
```

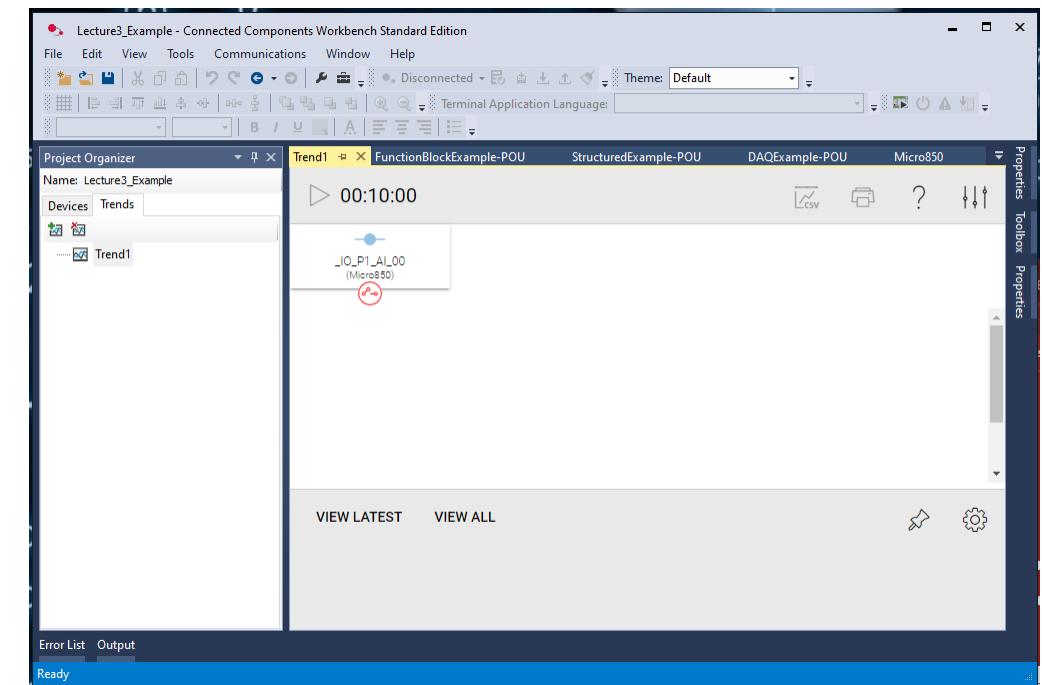
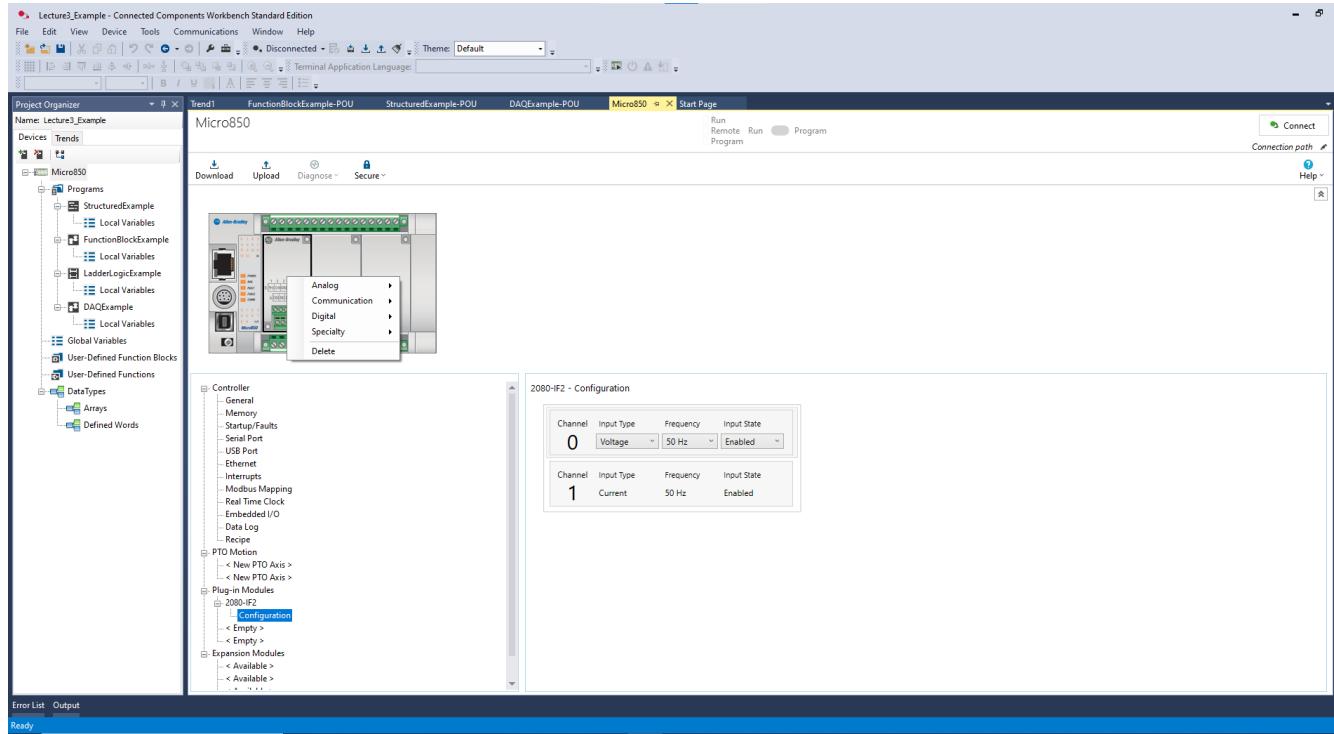
The status bar at the bottom indicates "Build succeeded".



PROGRAMMING TYPES – LADDER LOGIC



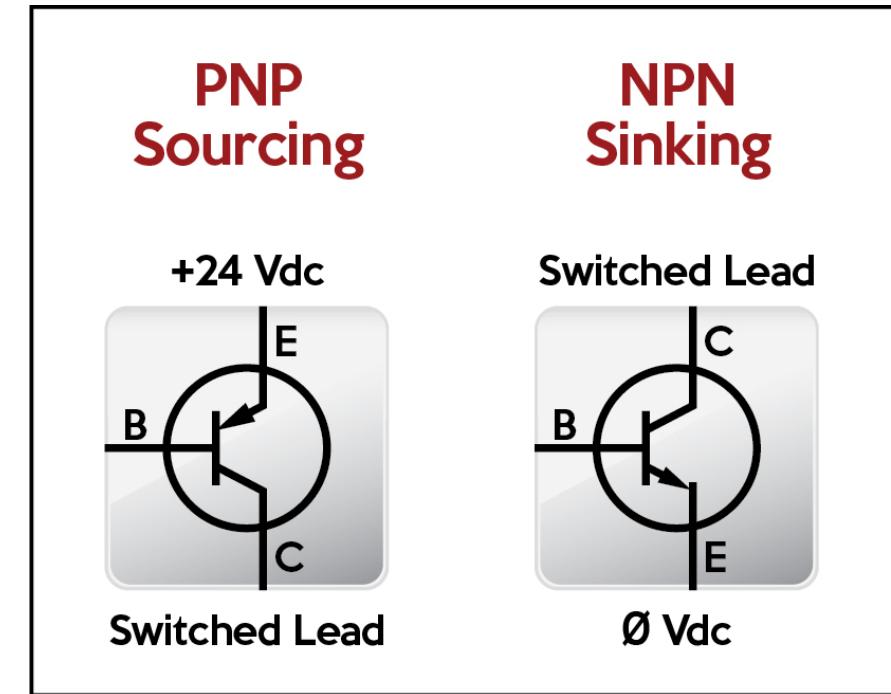
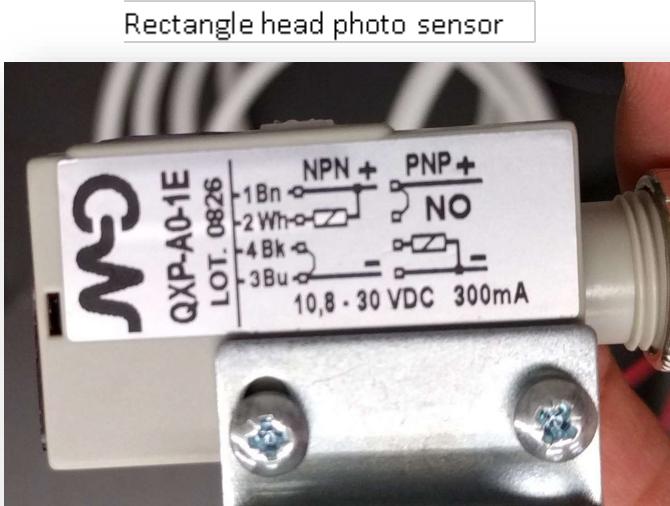
CCW – DATA AQUISTION



CONNECTING SENSORS TO PLC

Two types of 24 VDC sensors; PNP and NPN

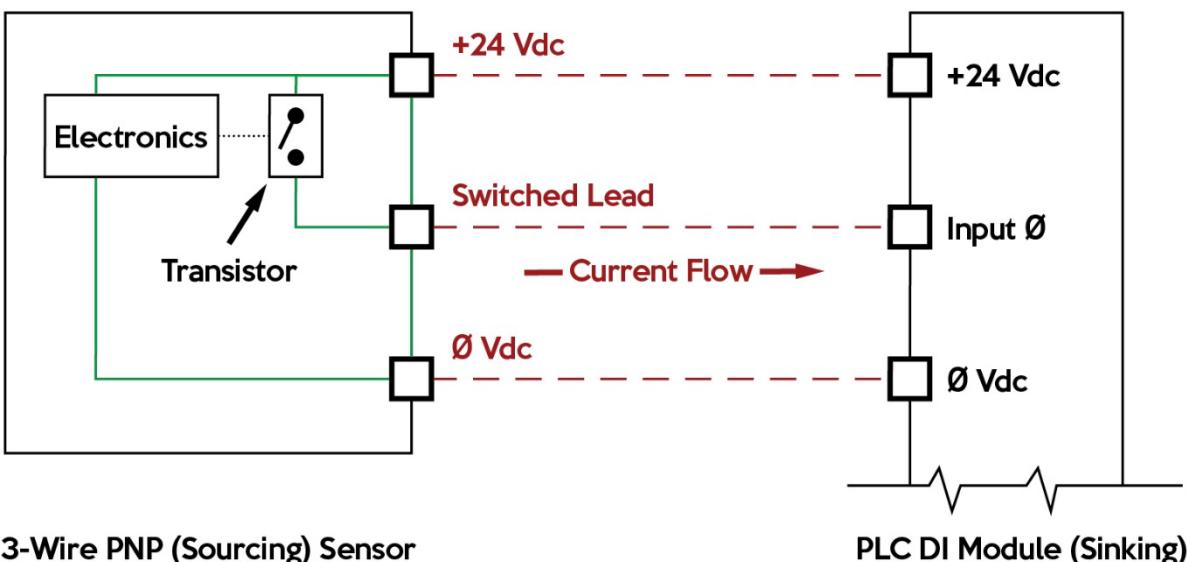
“P” and “N” refer to the arrangement of the semiconductor



SENSOR WIRING

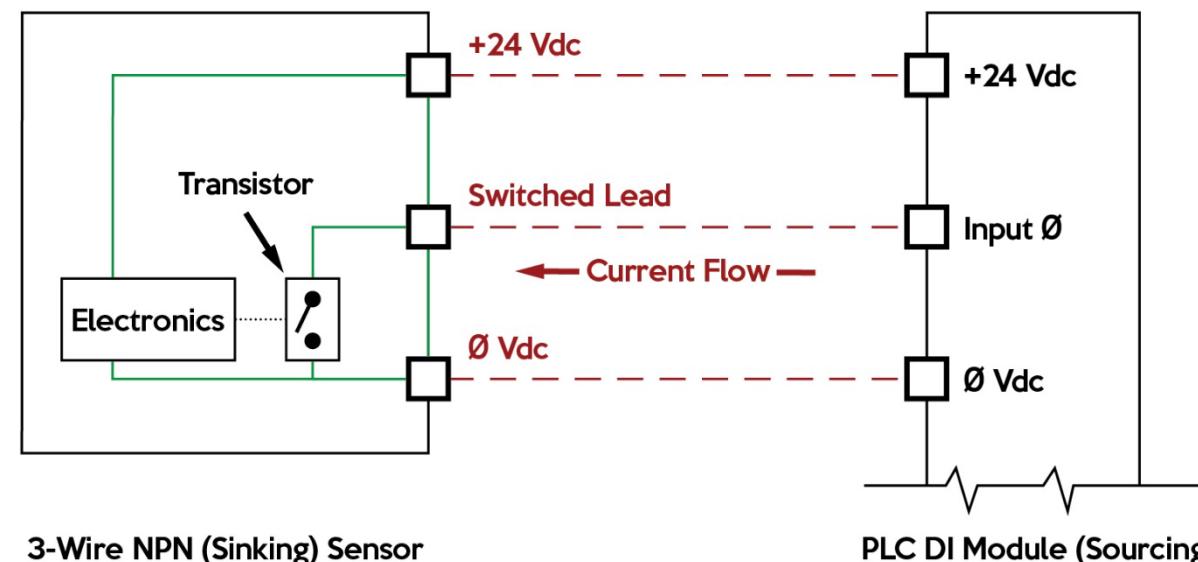
PNP Sensor Wiring

Connects the positive +24 Vdc lead to the switched lead



NPN Sensor Wiring

Connects the negative Ø Vdc lead to the switched lead



3-Wire PNP (Sourcing) Sensor

3-Wire NPN (Sinking) Sensor

SOURCING VS SINKING CIRCUITS

- A sinking PLC DI is suitable for PNP field sensor devices and looks for +24 Vdc on the DI channel coming from the sensor switched lead to indicate a logical true condition.
- A sourcing PLC DI is suitable for NPN field sensor devices and looks for 0 Vdc on the DI channel coming from the sensor switched lead to indicate a logic true condition.

BENEFITS OF PNP VS NPN

- PNP sensors connect +24 Vdc to the switched lead when true, while NPN sensors connect 0 Vdc to the switched lead when true. If a PNP cable is damaged there is a chance the signal could short to ground and damage the sensor. If an NPN cable is damaged there is the chance the signal could short to ground and cause a false true signal, but there would be no damage to the circuit.

BENEFITS OF PNP VS NPN

- Using PNP instead of NPN is the resulting logic because $+24\text{ Vdc} = \text{On} = \text{True}$ is easier for programmers and technicians to use and troubleshoot than $0\text{ Vdc} = \text{On} = \text{True}$.

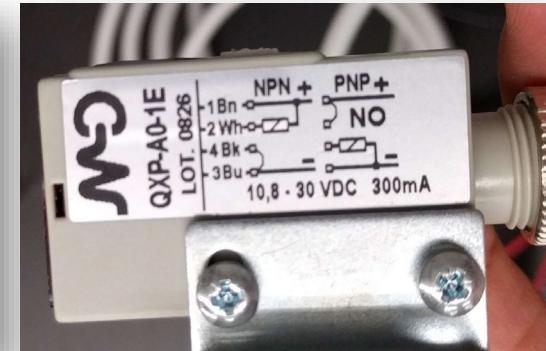
SENSORS



Inductive sensor

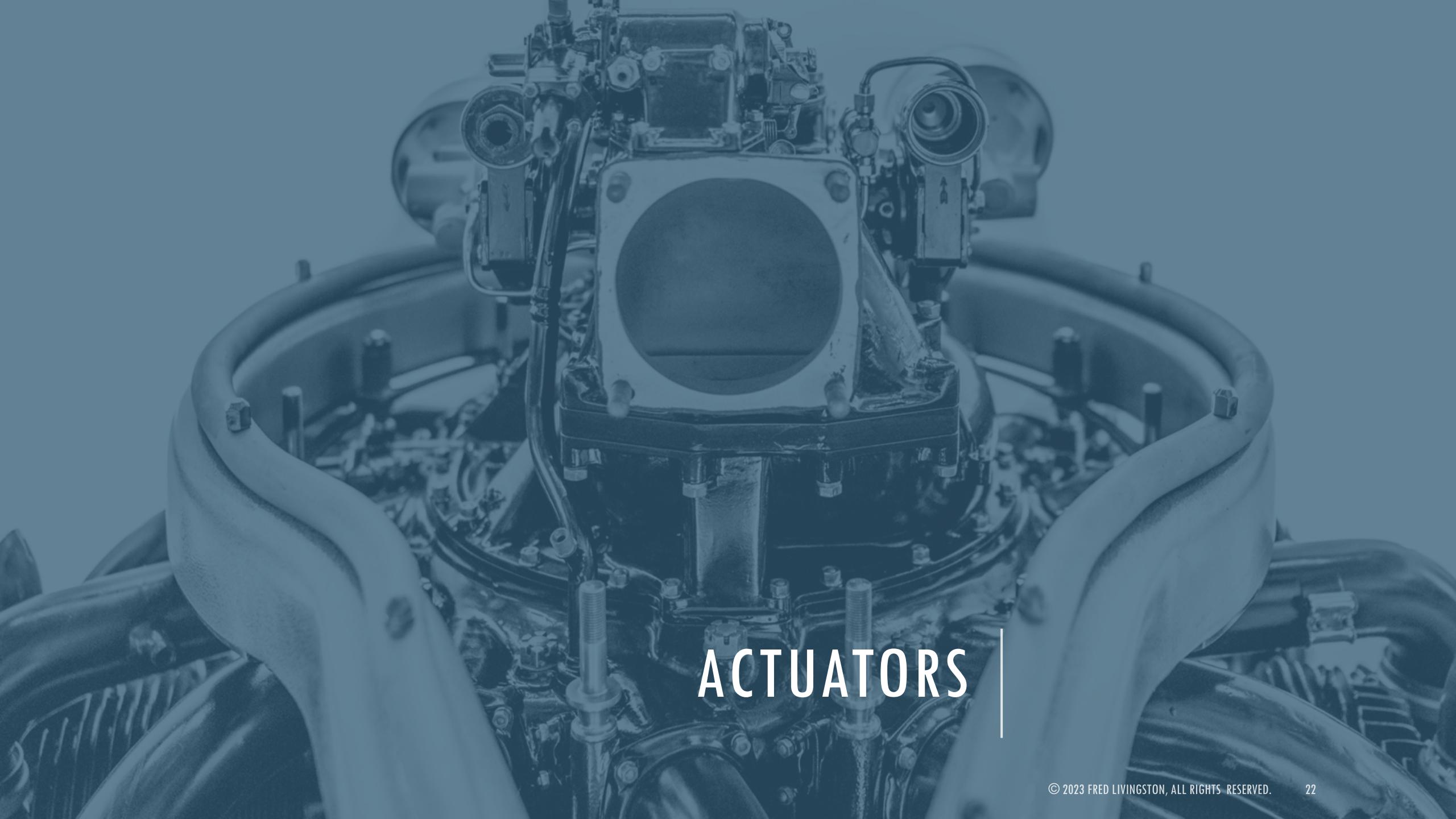


Inductive sensor



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)

A close-up, grayscale photograph of a complex mechanical assembly, likely an actuator. The central component is a cylindrical device with a circular cover, surrounded by various pipes, valves, and sensors. The image has a blue-toned overlay.

ACTUATORS

ACTUATORS

- Actuator is hardware device that usually converts a controller command signal into a change in position or velocity of a mechanical device
- Classification based on the type of power used:
 - Electrical
 - Hydraulic
 - Pneumatic

TYPES OF ACTUATORS

- DC servo motor
- Stepping motor
- Induction motor (rotary)
- Hydraulic piston
- Pneumatic cylinder
- Solenoid
- Relay Switch

ELECTRICAL ACTUATORS

- Most common
- Different Types:
- DC servo motors, stepper motors, AC servomotors, and solenoids
- Electrical actuators include both linear devices (output is linear displacement) and rotational devices (output is rotational displacement or velocity)

SUITABILITY OF ELECTRICAL ACTUATORS

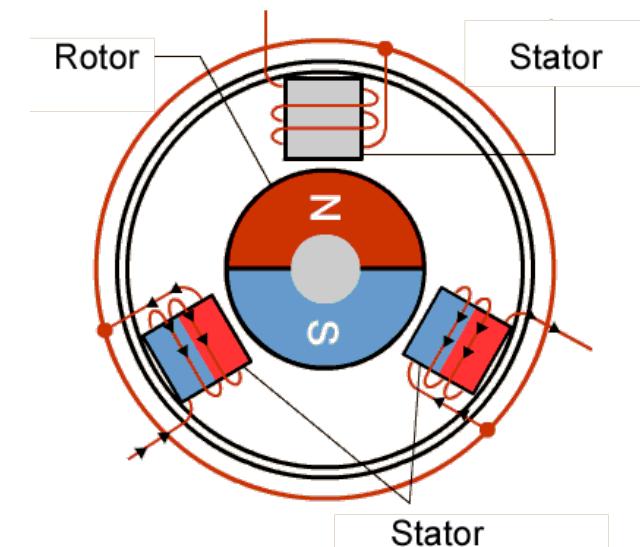
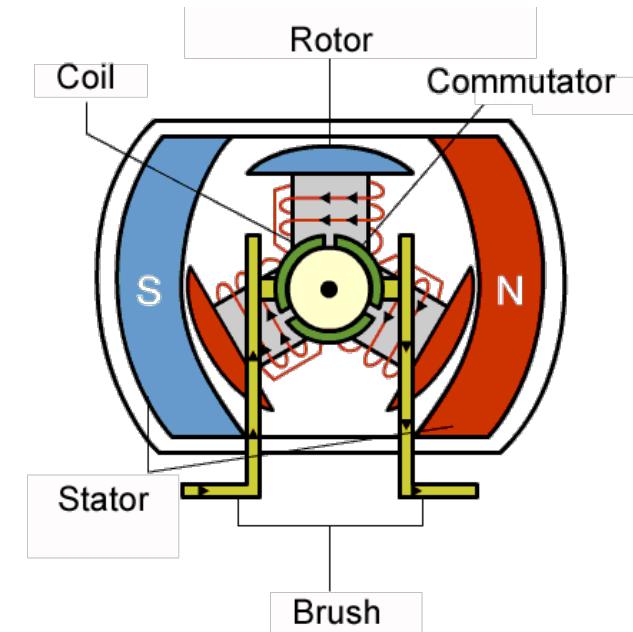
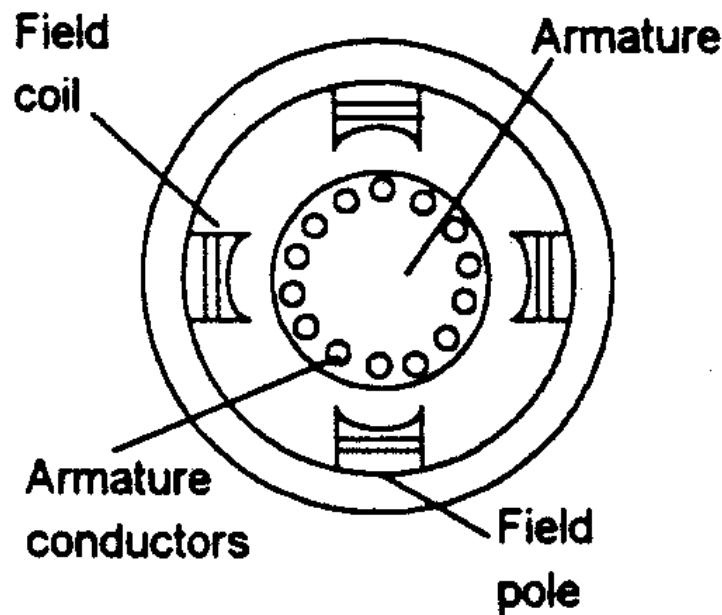
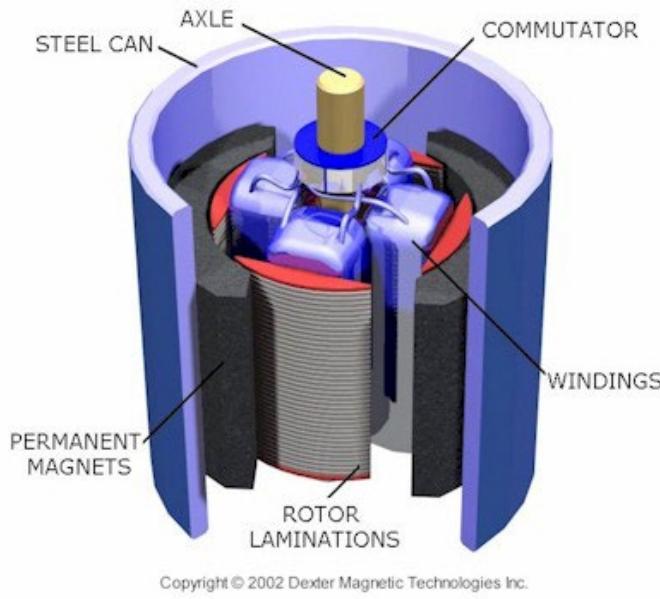
- **Advantages:**

- Best accuracy and repeatability
- Simple to use
- Easy to maintain
- Less expensive and easily available
- possible to apply sophisticated control

- **Disadvantages:**

- Low speed (unless direct drive)
- Low payload
- Usually need to convert for linear axis motion
- Require gear trains or the like to transmit power
- Gear backlash may limit precision

ELEMENTS IN DC MOTOR



ELECTRICAL DC SERVO MOTOR

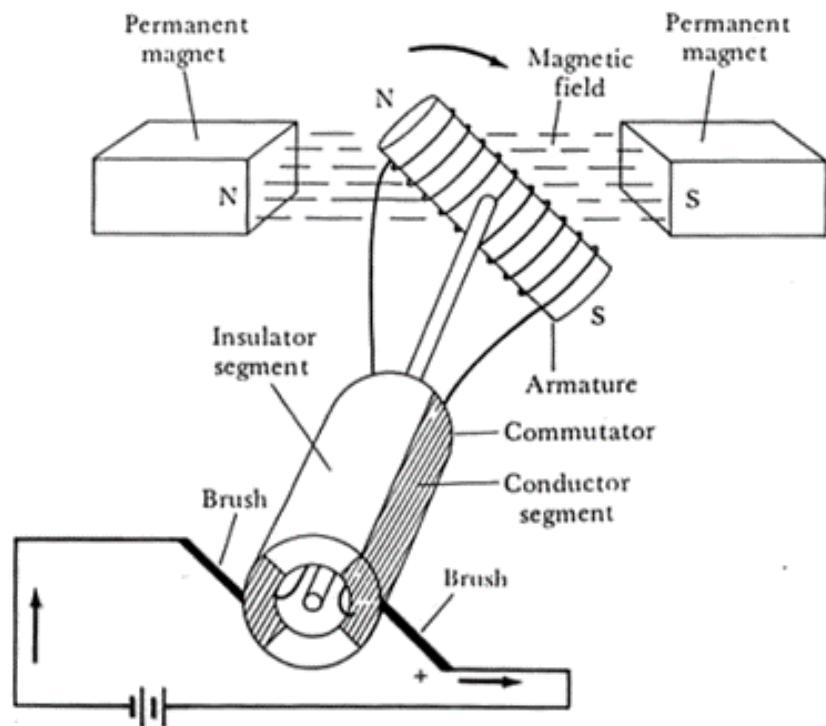
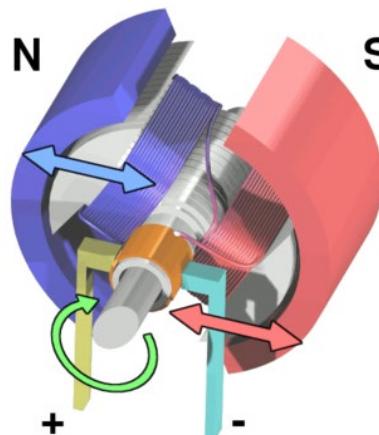


Figure 7–1 Basic Components of a DC Motor

Commutator continuously changes the relative polarity between rotor and stator, so that the magnetic field produces torque to turn the rotor all the time.

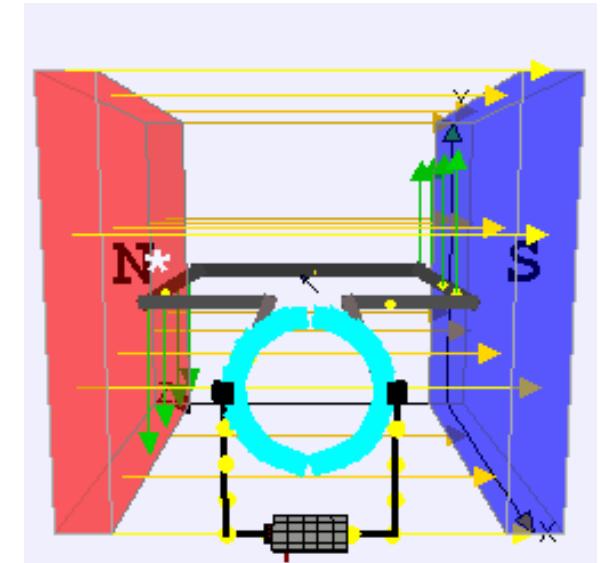
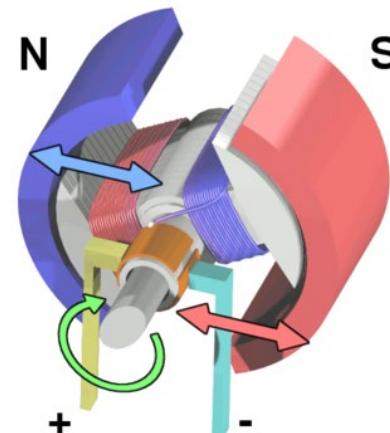
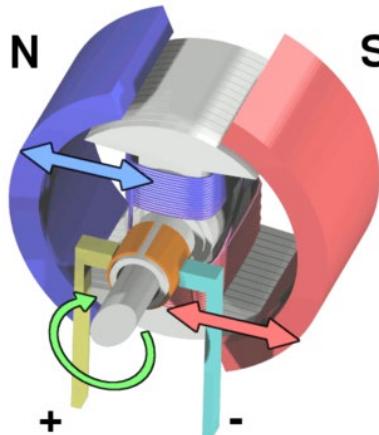
DC MOTOR: HOW IT WORKS

Lorentz law: When the current flows through the coil, the electromagnetic force will be induced



DC Motor

https://en.wikipedia.org/wiki/DC_motor



Brushed DC Electric Motor

https://en.wikipedia.org/wiki/Brushed_DC_electric_motor#Torque_and_speed_of_a_DC_motor

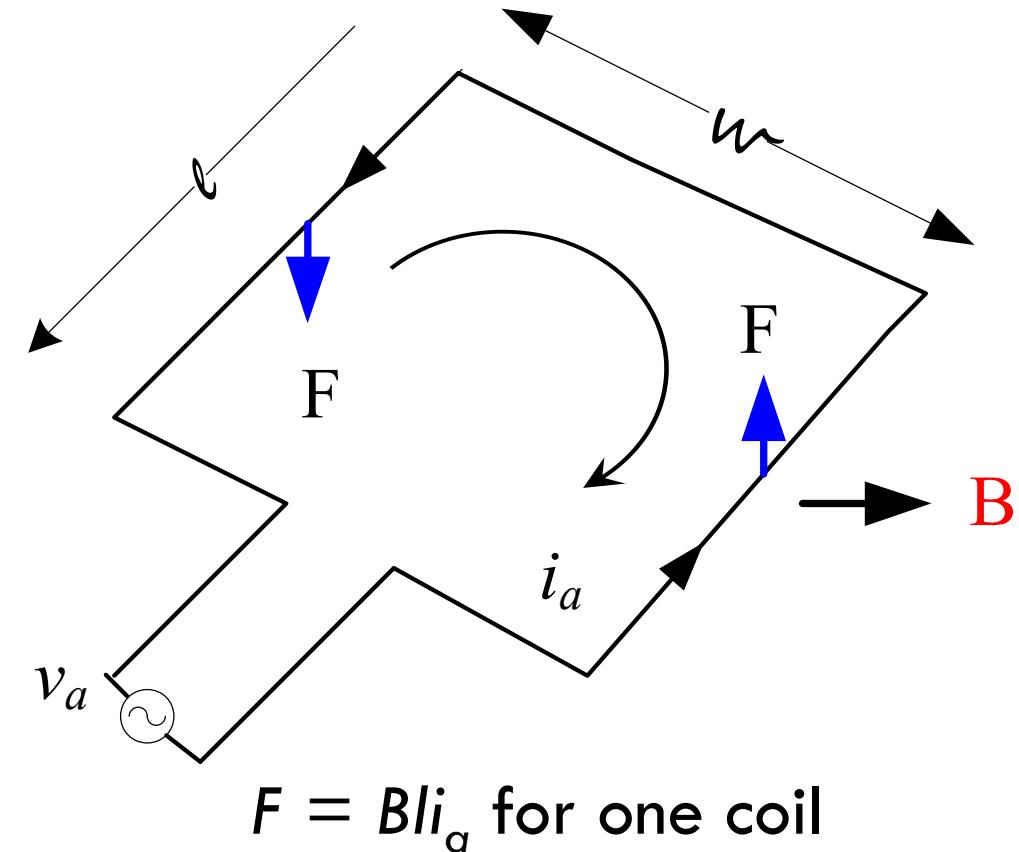
DC MOTOR – ELECTRIC MECHANICAL CONNECTIONS

Electric torque:

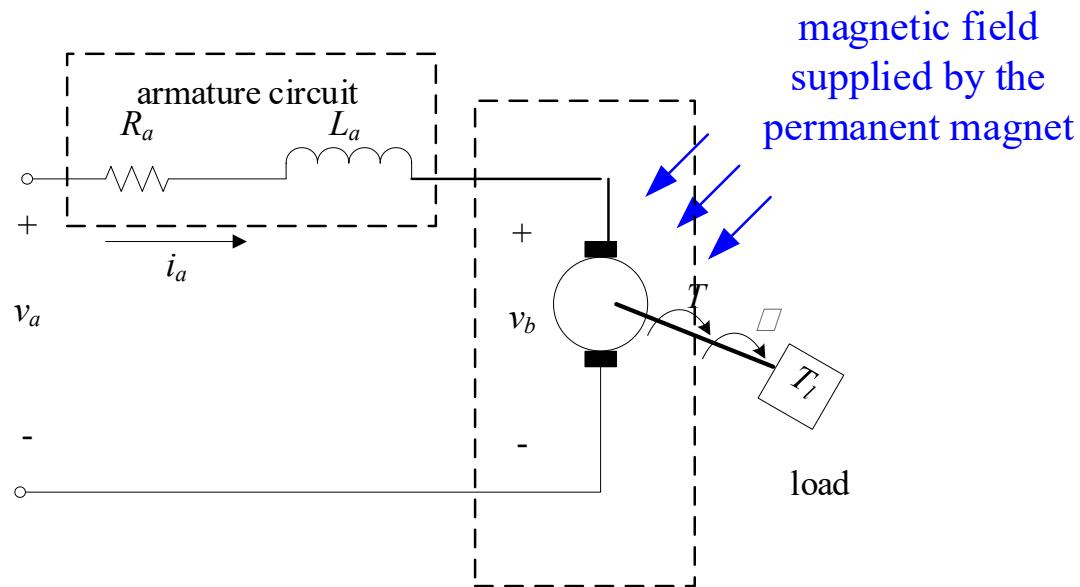
- $T_e = Fw = NBlwi_a = K_e i_a$

Back e.m.f:

- $v_b = k_2 B \omega = K_b \omega$



DC MOTOR DYNAMICS



DC MOTOR DYNAMICS

Armature circuit:

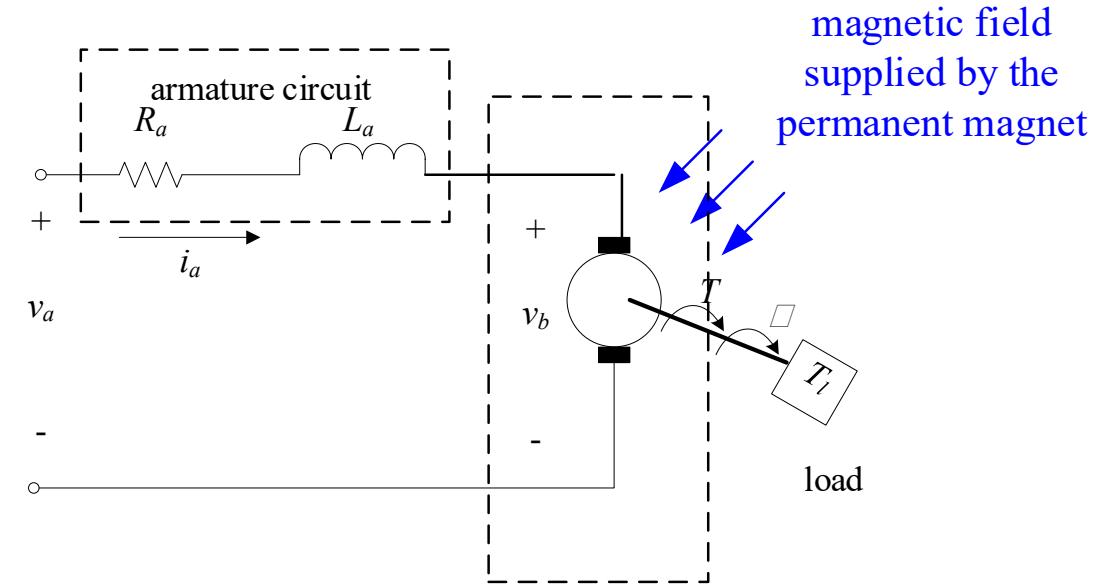
- $v_a - v_b = L_a \frac{di_a}{dt} + R_a i_a$
- $\frac{i_a}{v_a - v_b} = \frac{1}{L_a s + R_a}$

Rotating Motion:

- $J \frac{d\omega}{dt} + B\omega = T_e,$
- $J \frac{d^2\theta}{dt^2} + B \frac{d\theta}{dt} = T_e,$

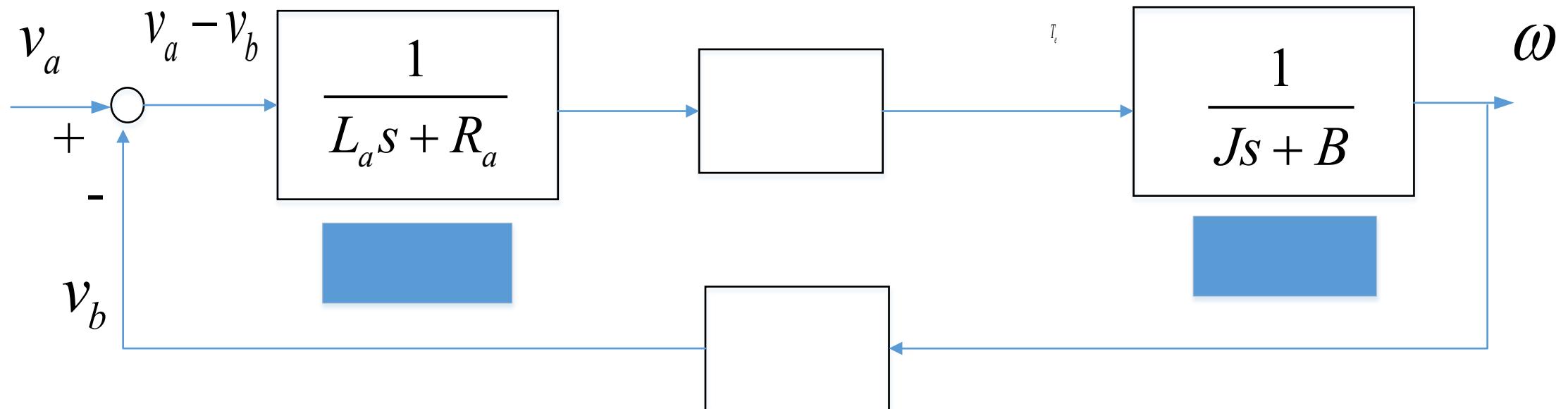
$$\frac{\omega}{T_e} = \frac{1}{Js+B}$$

$$\frac{\theta}{T_e} = \frac{1}{s(Js+B)}$$

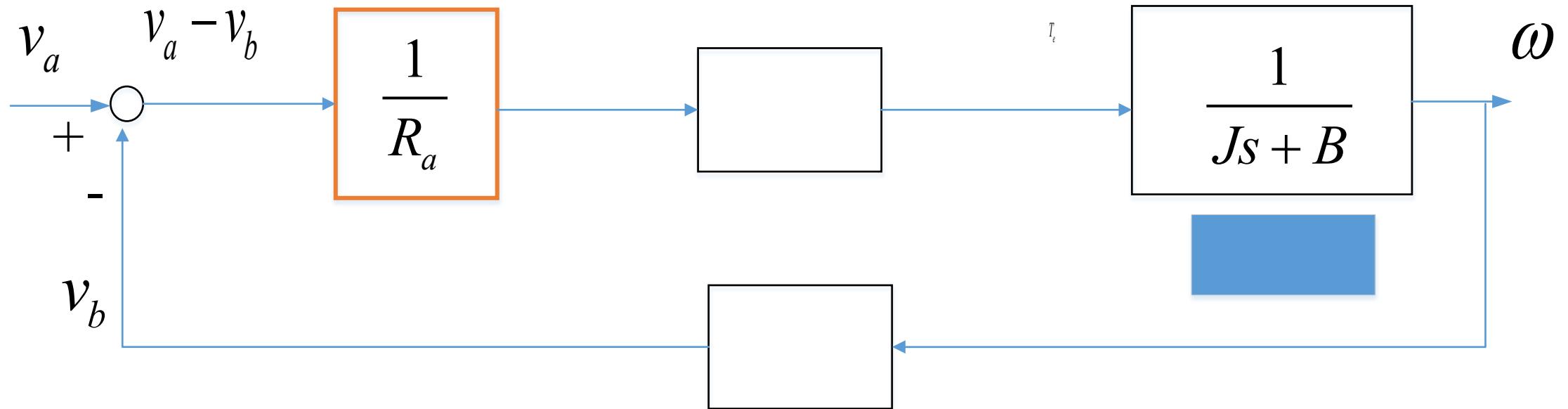


DC MOTOR TRANSFER FUNCTION

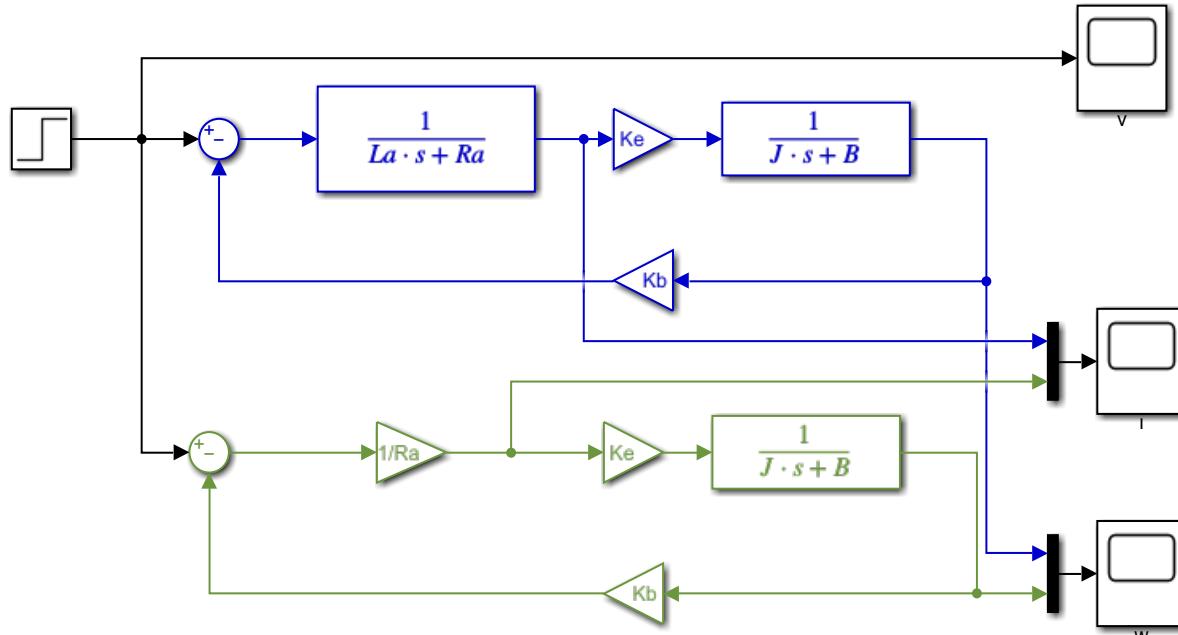
- DC motor dynamic block diagram:



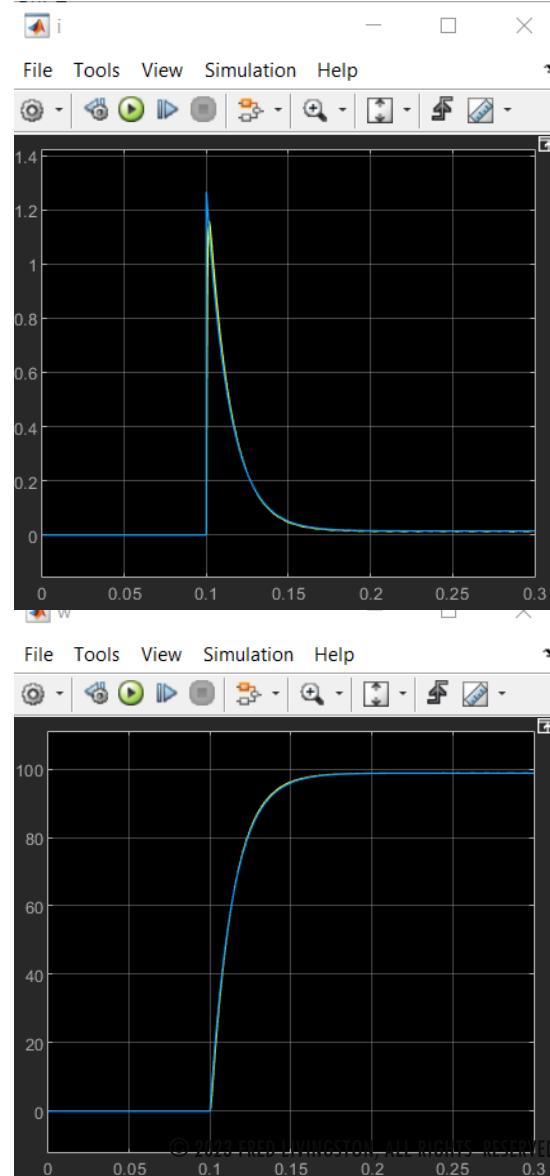
DC MOTOR SIMPLIFIED TRANSFER FUNCTION



DC MOTOR MODEL PERFORMANCE COMPARISON



$L_a = 0.37e-3$ % inductance
 $R_a = 0.79$ % terminal resistance
 $J = 1.62e-6$ % Rotor inertia
 $B = 1.34e-6$ % Viscous damping factor
 $K_e = 0.009$ % Torque constant
 $K_b = 0.01$ % Motor constant

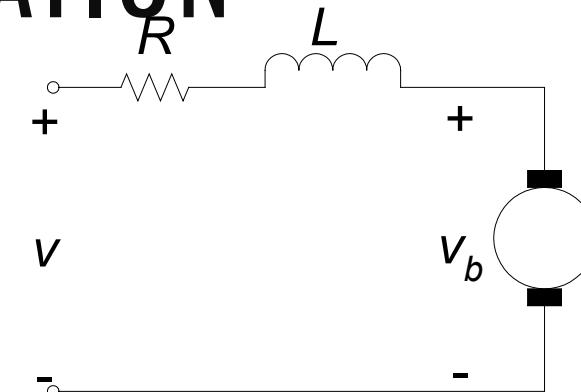
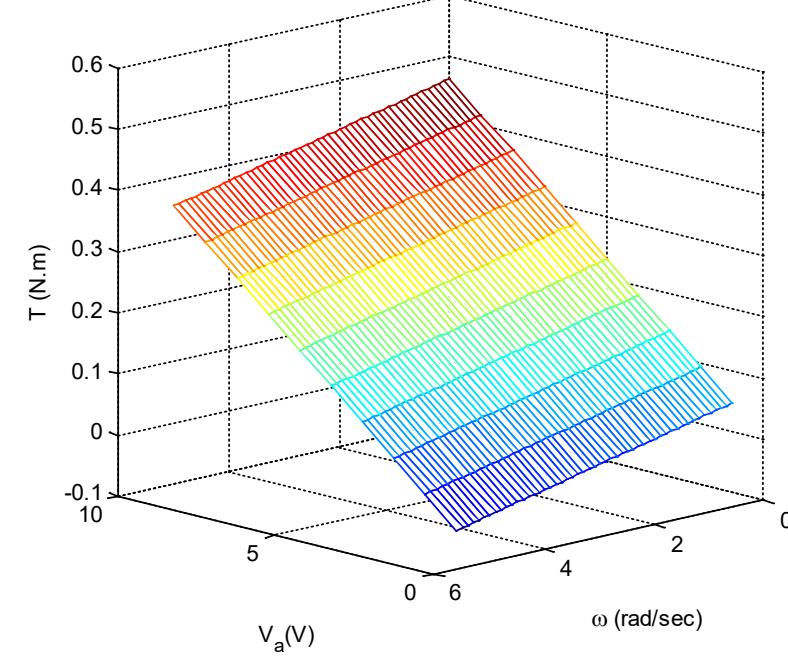


DC MOTOR STEADY-STATE OPERATION

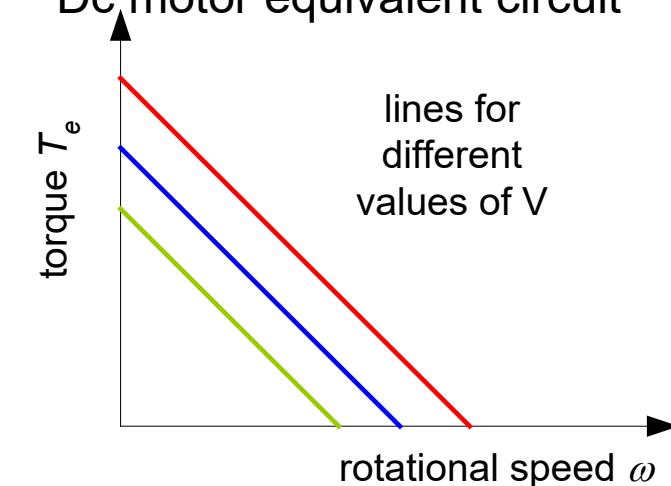
At steady-state: $di/dt = 0$ and $d\omega/dt = 0$

$$\Rightarrow i_a = \frac{v_a - v_b}{R_a} = \frac{v_a - K_b \omega}{R_a}$$

$$T_e = K_e i_a = K_e \frac{(v_a - K_b \omega)}{R_a}$$



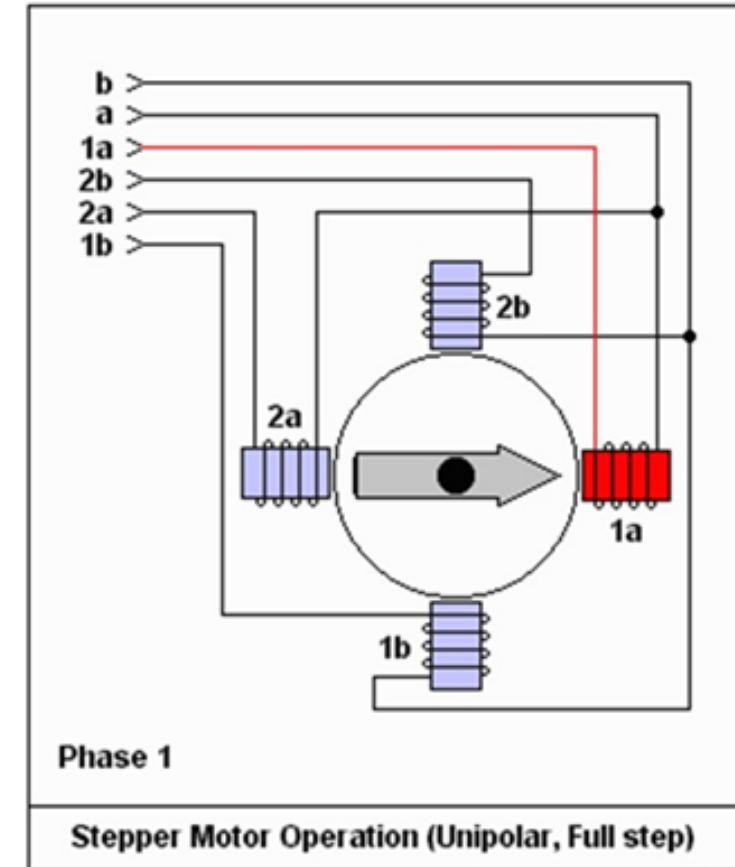
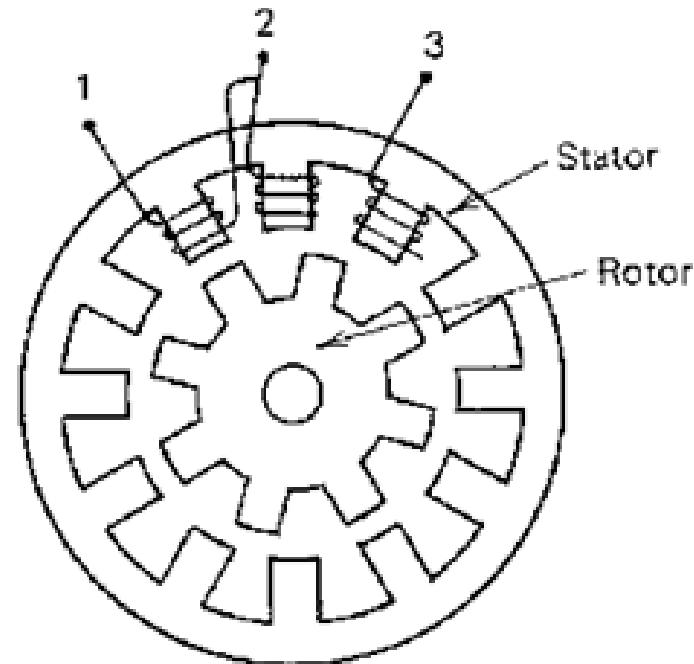
Dc motor equivalent circuit



torque-speed characteristic with different input voltage

STEPPER MOTORS

convert electrical pulses into proportional mechanical motion



STEPPER MOTORS

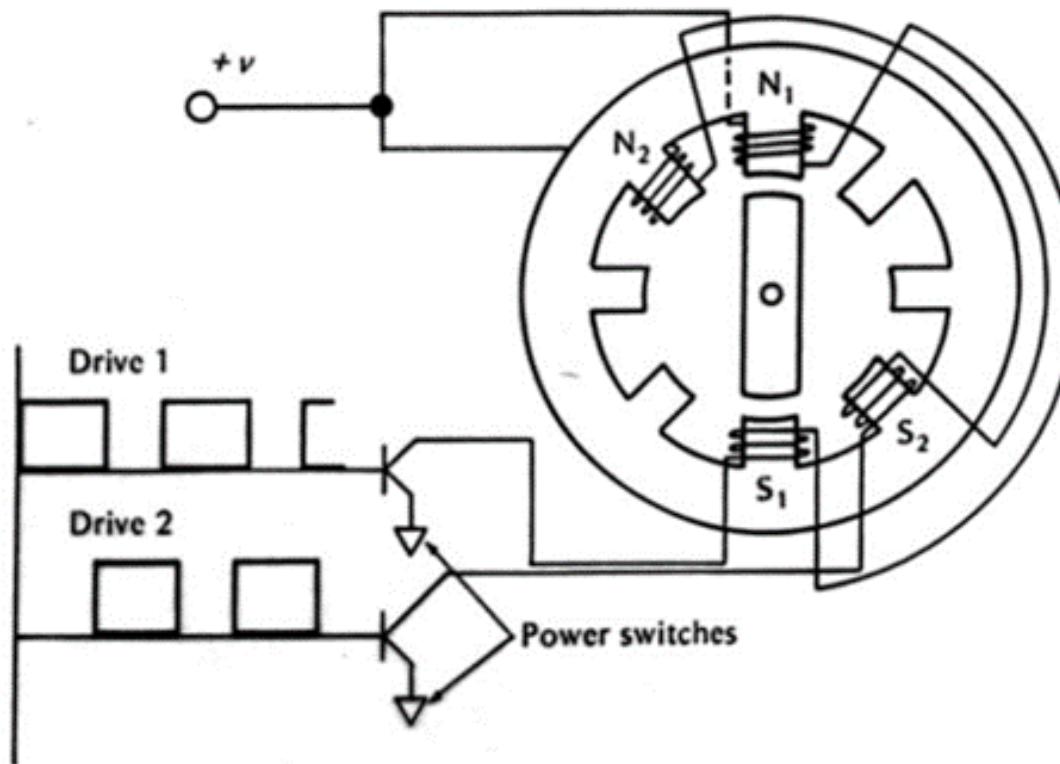
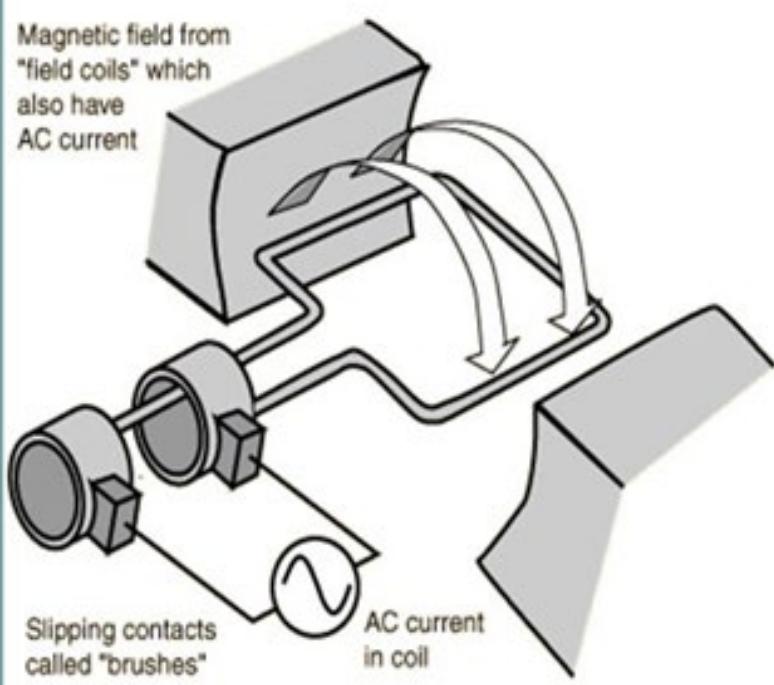


Figure 7-28. Basic operation of a stepper motor.

AC MOTORS



An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field

An inside rotor attached to the output shaft that is given a torque by the rotating field

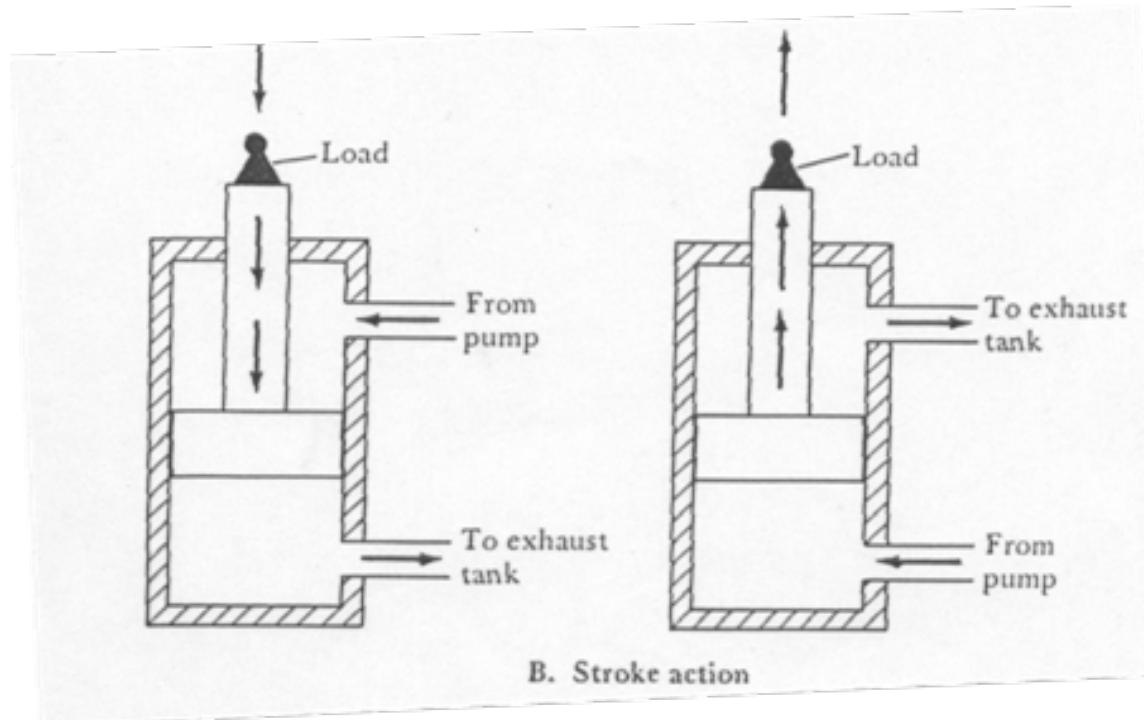
No brushes needed

HYDRAULIC ACTUATORS

- Hydraulic actuators use hydraulic fluid (oil) to amplify the controller command signal.
- The available devices provide both linear and rotational motion.
- Hydraulic actuators are often specified when large forces are required.

HYDRAULIC PISTON

- Piston inside cylinder exerts force and provides linear motion in response to hydraulic pressure.
- High force capability.



HYDRAULIC CYLINDER

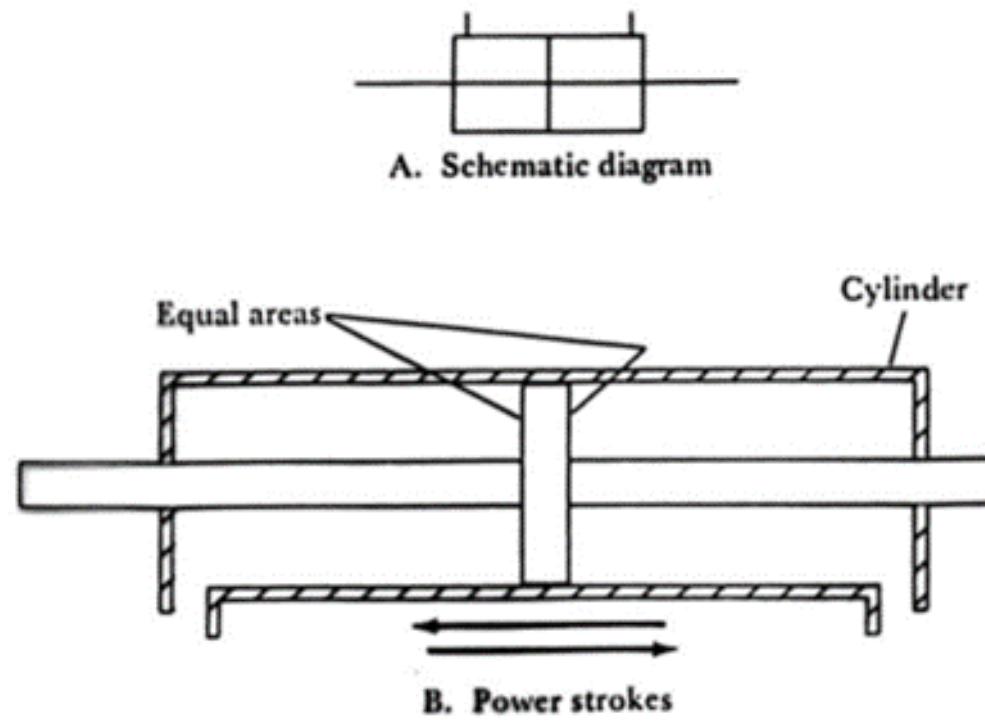
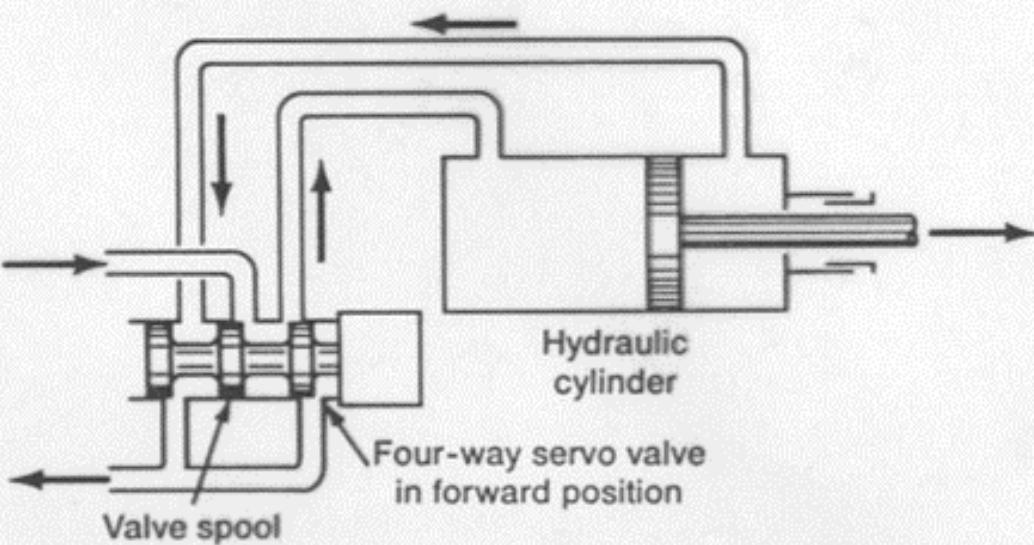


Figure 6–11 Double-Rod Cylinder

HYDRAULIC CYLINDER

Figure 4.1 Simplified diagram of a hydraulic cylinder and servo valve used for control (from Versatran [12]).

Source: Prab Robots, Inc. Used by permission



HYDRAULIC MOTOR

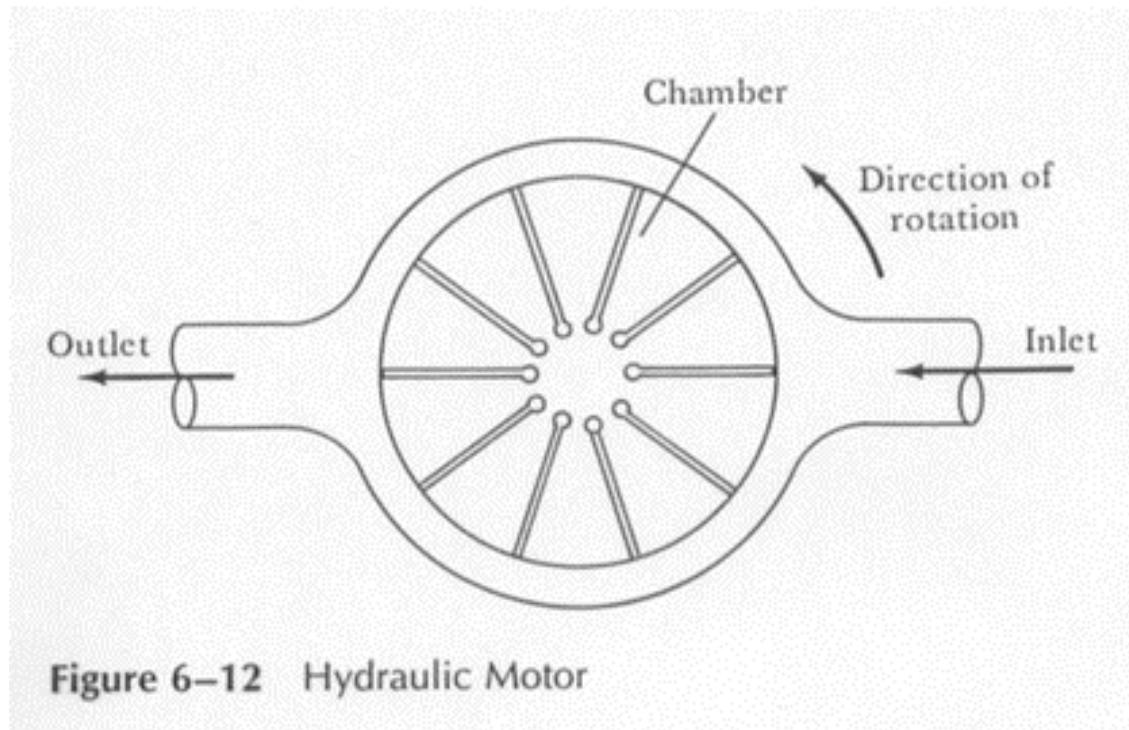


Figure 6–12 Hydraulic Motor

SUITABILITY OF HYDRAULIC ACTUATORS

Advantages

- Mechanical simplicity
- Physical strength
- Moderate speed
- Higher power to weigh ratio
- Accurate Control, compared with pneumatic actuator

Disadvantages

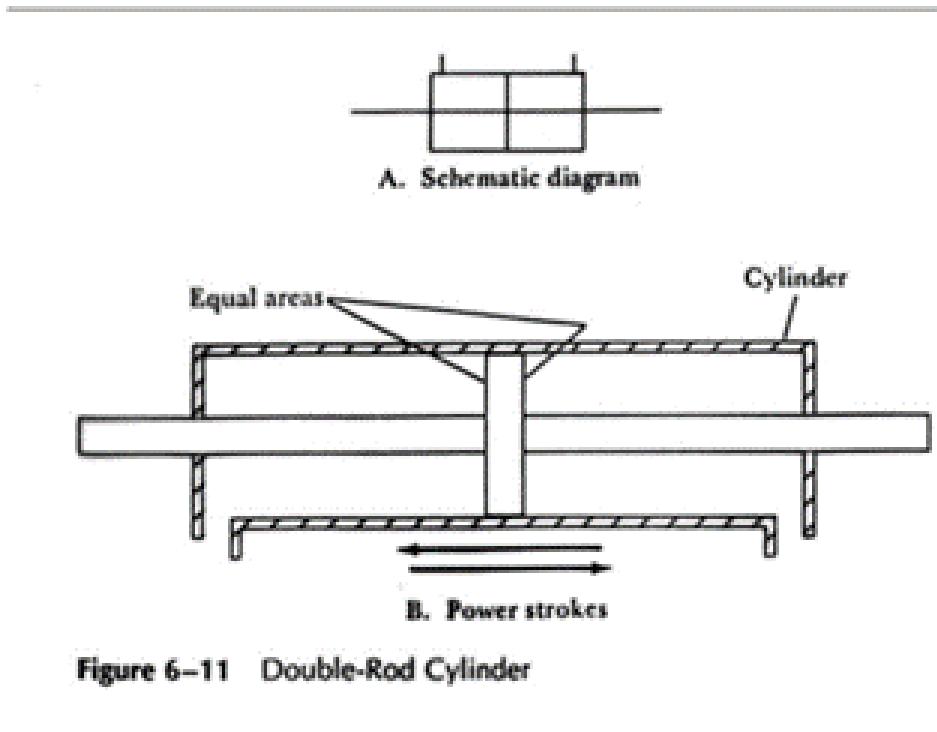
- Hydraulic systems are expensive
- Oscillation in deceleration to a point if used for fast motion
- Extra space for hydraulic pump, tanks, etc.
- High cost of maintenance
- Oil filtering, oil change, hydraulic line rupture, oil leakage,
- Pollution of workplace with oil
- High noise

PNEUMATIC ACTUATORS

- Use compressed air (typically “shop air” in the factory environment) as the driving power.
- Both linear and rotational pneumatic actuators are available.
- Usually limited to relatively low force applications (due to relatively low air pressures) when compared to hydraulic actuators
- Limited servo applications due to the compressibility of air

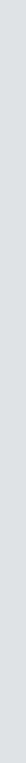
PNEUMATIC CYLINDER

- Piston inside cylinder exerts force and provides linear motion in response to air pressure.



SUITABILITY OF PNEUMATIC ACTUATORS

- Advantages:
 - Low cost of maintenance and operation
 - High speed
- Disadvantages:
 - Compressibility of air, limited accuracy for servo control
 - Air filtering and drying
 - Mostly open loop
 - Very difficult to control position



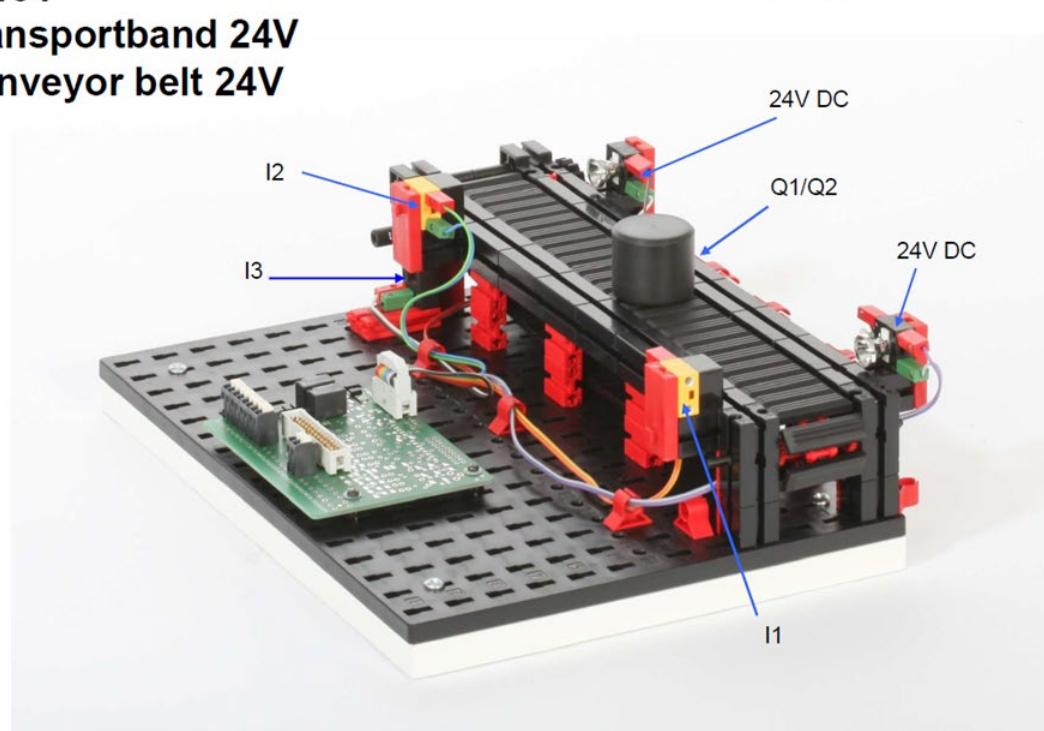
LABORATORY 1

AUTOMATION CONTROL OF CONVEYOR BELT

https://docs.google.com/document/d/1RJWIY5vqn8Hu-hYFN8h5WZ-eERnEdx75JW40znO_JFc/edit?usp=sharing

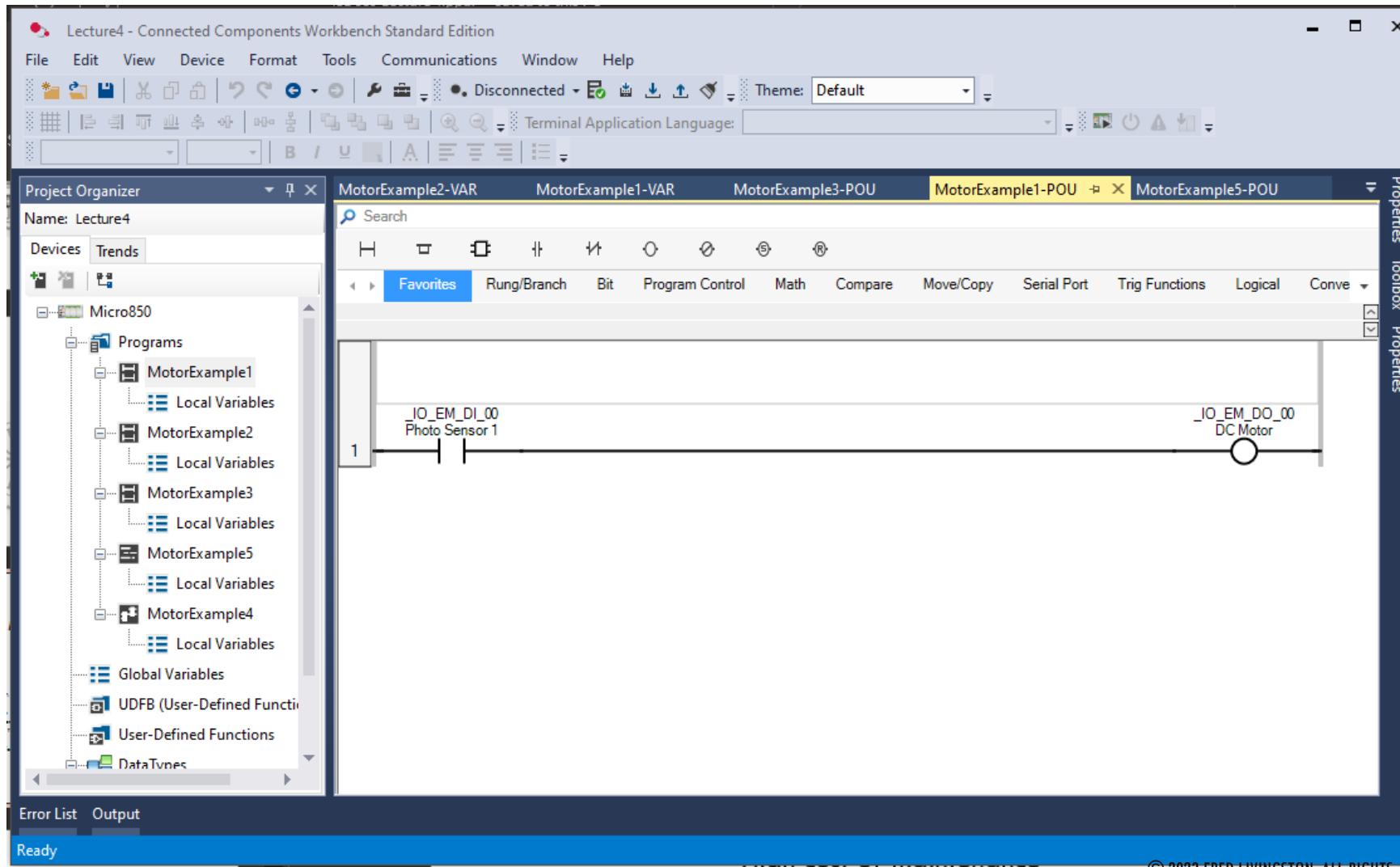
50464
Transportband 24V
Conveyor belt 24V

fischertechnik 

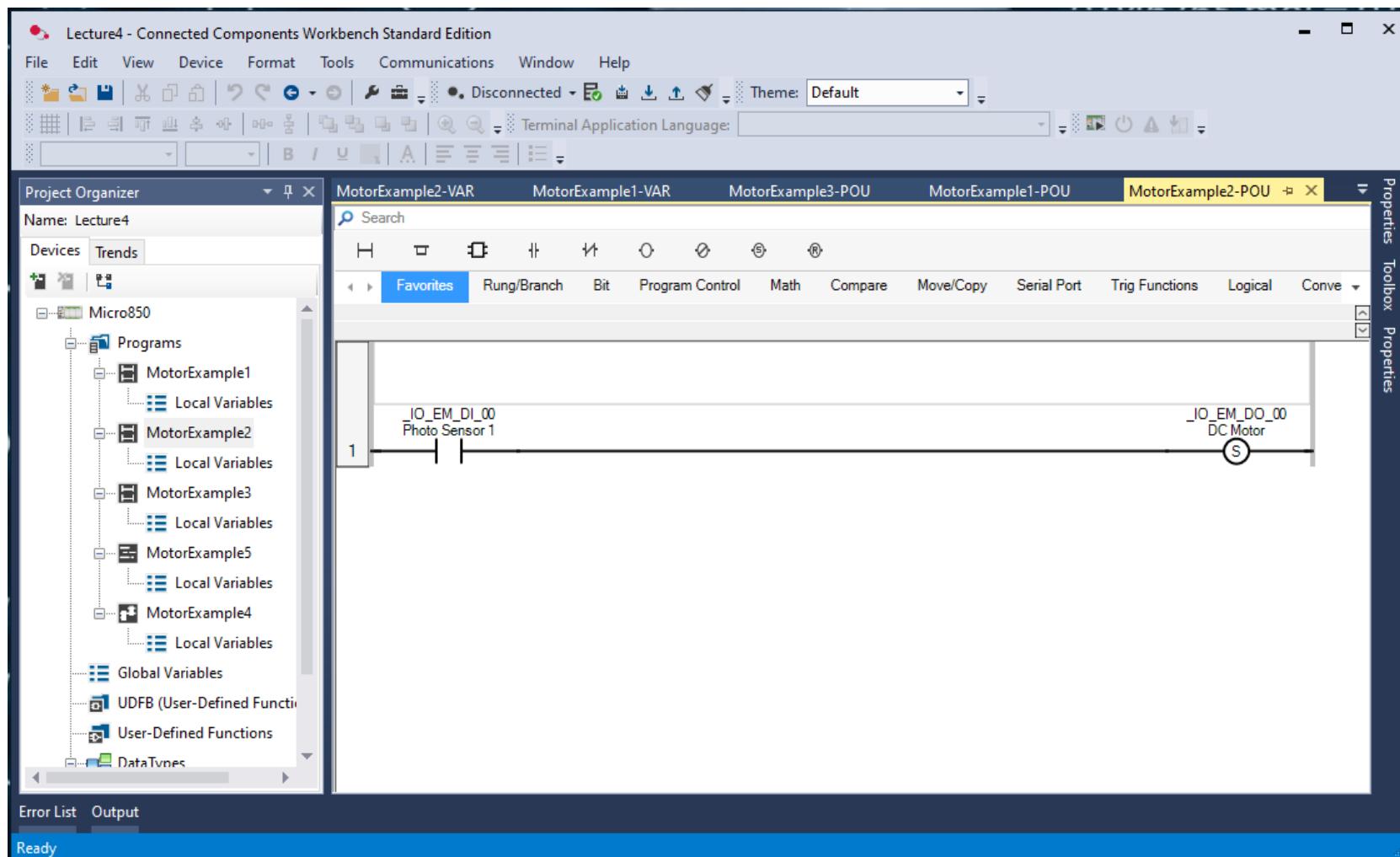


In this laboratory, you will automate and control a conveyor belt system. This system consists of a 24 vDC motor and two NPN phototransistors. The conveyor belt is initially inactivated. After detecting an object, the conveyor belt moves it until a second NPN phototransistor deactivates it. You can demonstrate this using the project using the sensors and actuators found in the Automation Lab or using the 50464 Trainer.

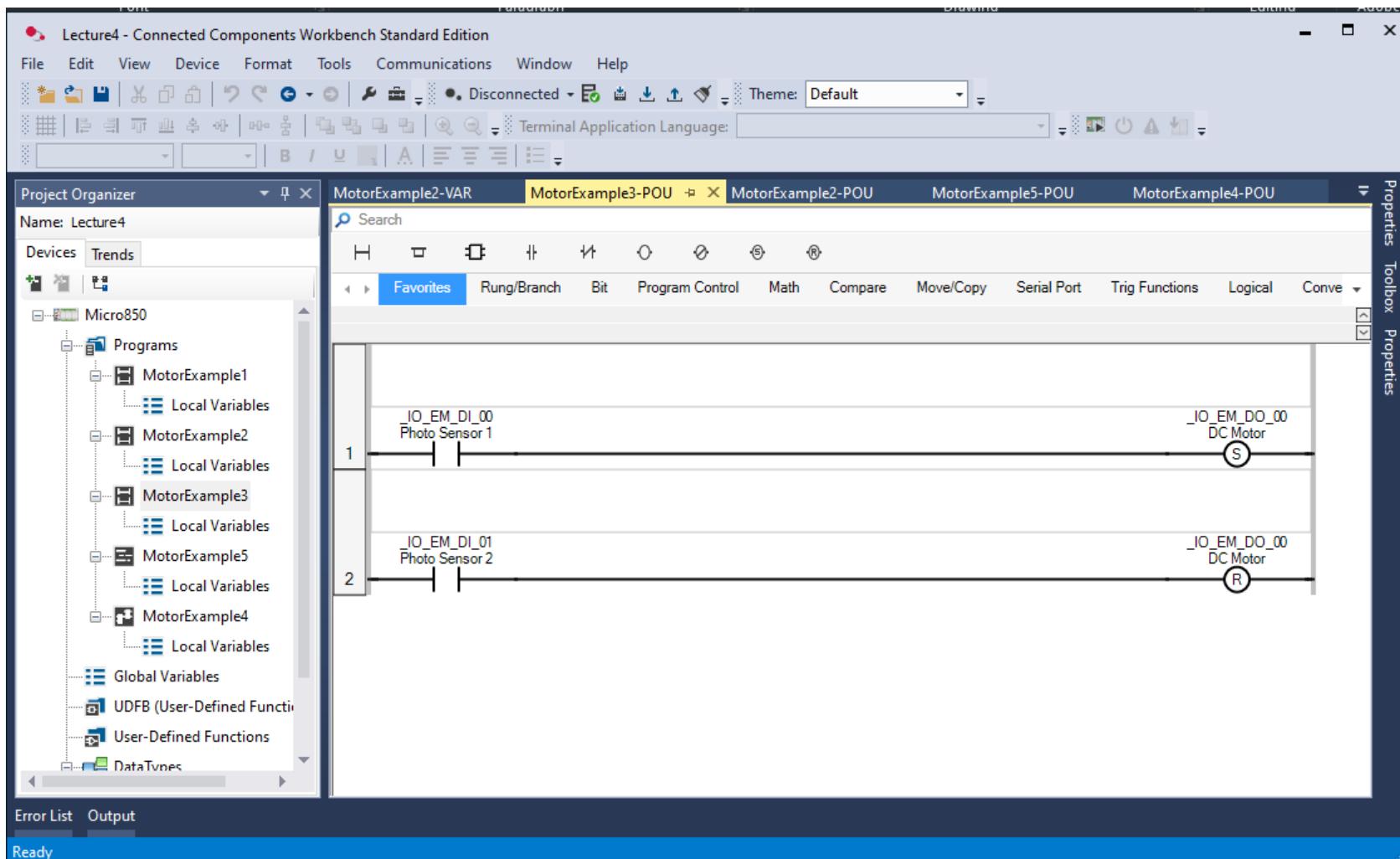
CCW – MOTOR EXAMPLE I



CCW – MOTOR EXAMPLE II



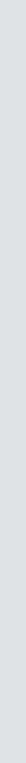
CCW – MOTOR EXAMPLE III



CCW – MOTOR EXAMPLE IV

The screenshot shows the Connected Components Workbench Standard Edition interface with the project 'Lecture4' open. The Project Organizer on the left lists various programs and components under a 'Micro850' device. The main workspace displays a ladder logic program for a motor control example. The code uses structured text (ST) and includes comments explaining the logic. It features a CASE statement that checks for two input conditions: _IO_EM_DI_00 and _IO_EM_DI_01. Depending on the input, it either turns the motor on or off and updates a control state variable.

```
// MotorExample1_Structed
// Fred Livingston (fjliving@ncsu.edu) 2-2-2023
3
4 CASE CONTROL_STATE OF
5
6 0:
7   if _IO_EM_DI_00 then
8     _IO_EM_DO_00:=TRUE; // turn on motor
9     CONTROL_STATE:= 1; // advance to next state
10    END_IF;
11
12 1:
13   if _IO_EM_DI_01 then
14     _IO_EM_DO_00:=FALSE; // turn off motor
15     CONTROL_STATE:=0; // return to previous state
16    END_IF;
17
18 END_CASE;
19
20
21
22
23
```



END OF LECTURE