Chapter 2: Basic Ladder Logic Programming

Ladder Logic
Learning objectives

- **Understand basic ladder logic symbol**
- **Write ladder logic for simple applications**
- **Translate relay ladder logic into PLC ladder logic**

Simple Ladder Logic

Ladder Logic:

- **Primary Programming Language for PLCs.**
- **Visual and Graphical language unlike textual high-level, such as C, C++, Java…**
- **Derived from relay logic diagrams**
- **Primitive Logic Operations:**
  - **OR**
  - **AND**
  - **NOT**

Simple Ladder Logic
OR Operation

- Control Behavior: The light should be on when either switch A is on (i.e., closed) or switch B is on (closed). Otherwise it should be off

- Task: Implement this behavior using
  - Relay circuit
  - PLC Ladder Logic

Simple Ladder Logic

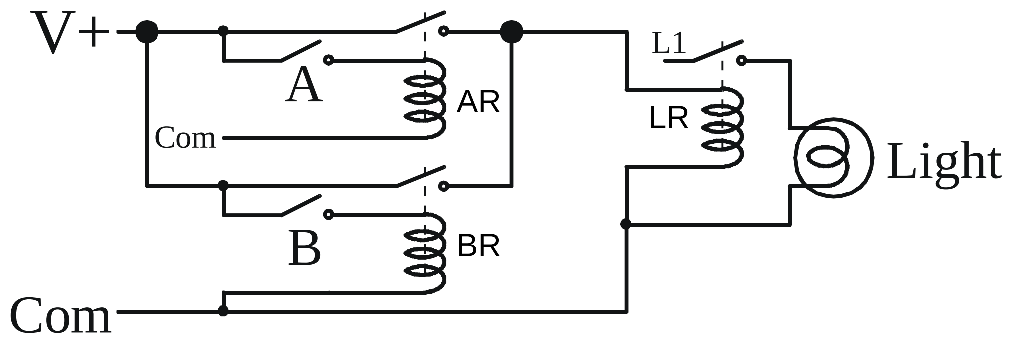
OR Operation

- Possible Combinations of the 2 Switches: (2^2)

OR Truth Table

A	B	Light
OFF	OFF	OFF
OFF	ON	ON
ON	OFF	ON
ON	ON	ON

OR Operation
Relay Circuit

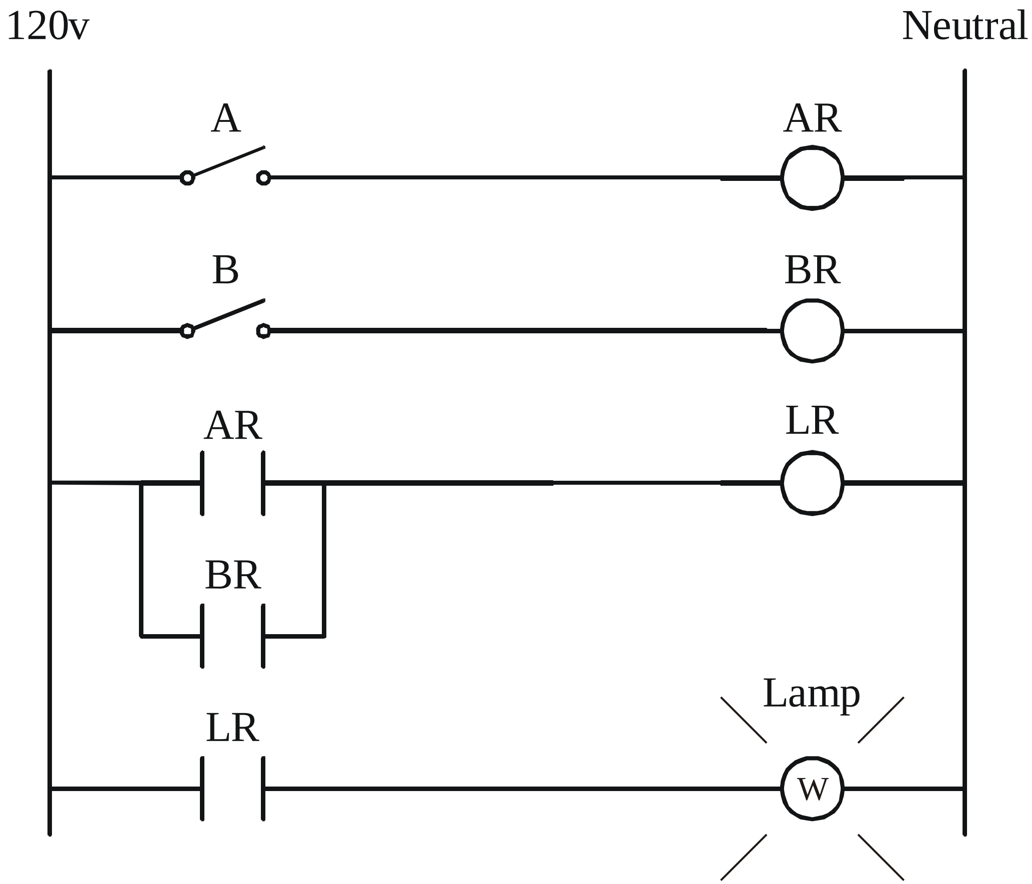


A typical coil can have up to12 contacts

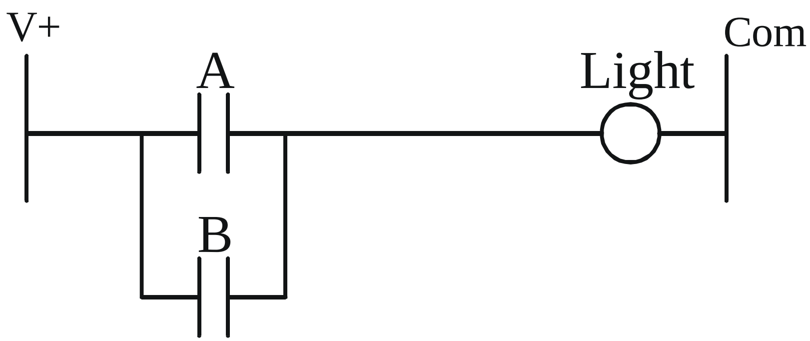
- Switches A and B are connected in parallel to relay coils AR & BR resp.
- When switch A (or switch B) is closed relay coil AR (or BR) gets energized
  - The *Normally Open (NO)* contact AR (or BR) gets closed
    - Power is transmitted to coil LR
      - Relay coil LR gets energized
        - The *NO* contact LR gets closed
        - **Power is transmitted to the Light bulb**

OR Operation

Relay Ladder Logic Circuit



OR Operation
PLC Ladder Logic



- Append above to the leading two rungs of relay ladder logic diagram
- Switch A and Switch B are connected to discrete input channels of the PLC
- Light is connected to discrete output channel (actuator) of the PLC

When input switch A (or switch B) is on
the light is on

Simple Ladder Logic
AND Operation

- Control Behavior: The light should be on when switch A is on (i.e., closed) <u>and</u> switch B is on (closed). Otherwise it should be off

- Task: Implement this behavior using
  - Relay circuit
  - PLC Ladder Logic

Simple Ladder Logic
AND Operation

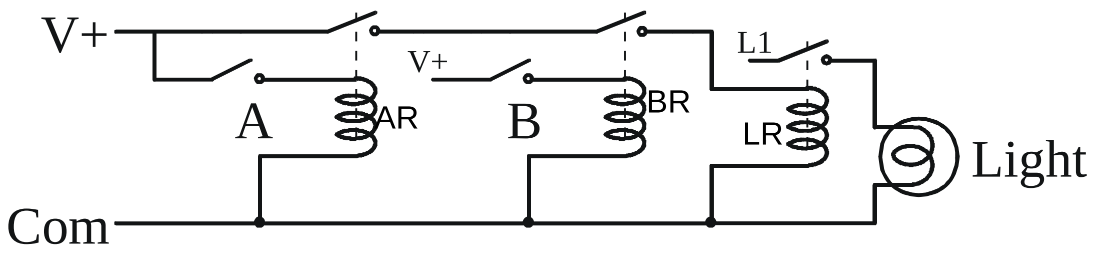
- Possible Combinations of the **2** Switches: (2^2)

AND Truth Table

A	B	Light
OFF	OFF	OFF
OFF	ON	OFF
ON	OFF	OFF
ON	ON	ON

AND Operation

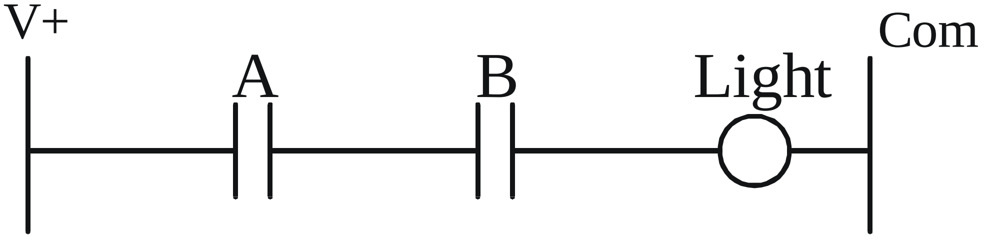
Relay Circuit



- Switches A and B are connected in series to relay coils AR & BR resp.
- When switch A is closed relay coil AR gets energized
  - The *Normally Open (NO)* contact AR gets closed
    - Power flows to *Normally Open (NO)* contact BR, where it terminates until BR is energized
      - Subsequently, when BR gets energized, LR is energized, which causes the *NO* contact LR to close
        - **Power is transmitted to the Light bulb**

What happens if BR is energized before AR?

AND Operation
PLC Ladder Logic Circuit



Simple Ladder Logic

NOT Operation

- Control Behavior: The light comes on only when switch A is on (i.e., closed) and switch B is off (open). Otherwise it should be off

- Task: Implement this behavior using
  - Relay circuit
  - PLC Ladder Logic

Simple Ladder Logic

NOT Operation

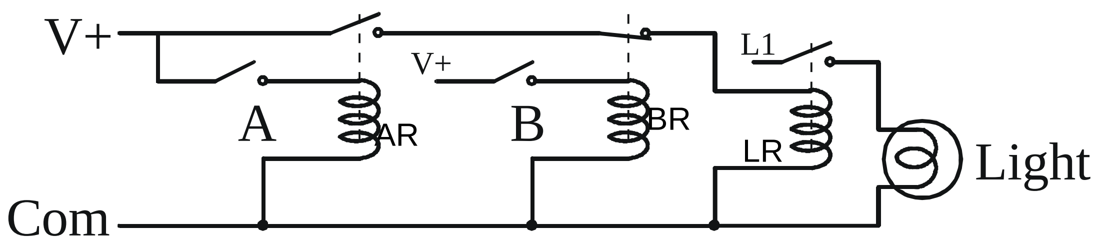
- Possible Combinations of the 2 Switches: (2^2)

NOT Truth Table

A	B	Light
OFF	OFF	OFF
OFF	ON	OFF
ON	OFF	ON
ON	ON	OFF

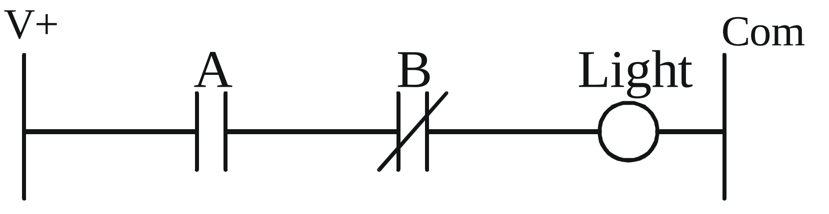
NOT Operation

Relay Circuit



- Switches A and B are connected to relay coils AR & BR resp.
- When switch A is closed relay coil AR gets energized
- When switch B is off (on) relay coil BR is not energized (energized) and BR contact is normally-closed (normally-open)
  - ……

NOT Operation
PLC Ladder Logic



Simple Ladder Logic

NAND Operation

NAND (NOT AND)

- Control Behavior: The light comes on only when switch A is off and switch B is off. Otherwise it should be off

- Task: Implement this behavior using
  - Relay circuit
  - PLC Ladder Logic

Simple Ladder Logic

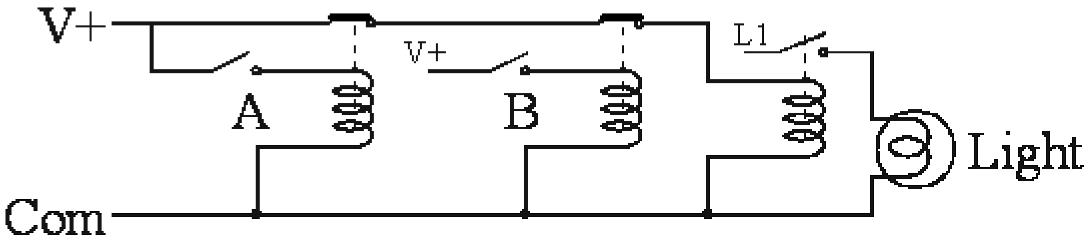
NAND Operation

- Possible Combinations of the **2** Switches: (2^2)

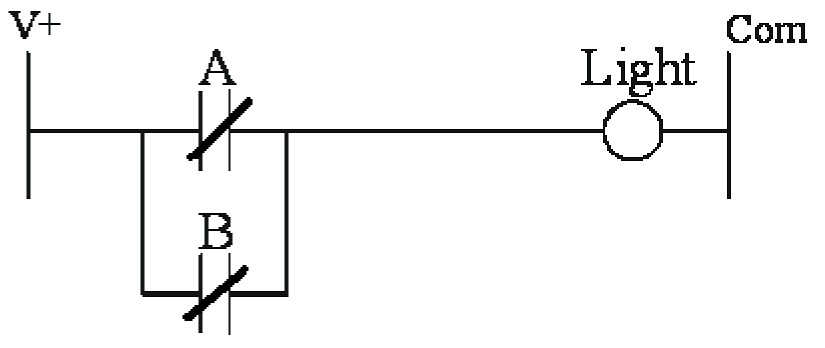
NAND Truth Table

A	B	Light
OFF	OFF	ON
OFF	ON	ON
ON	OFF	ON
ON	ON	OFF

NAND Operation
Relay Circuit



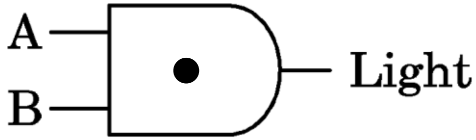
NAND Operation
Ladder Logic Circuit



Digital Logic

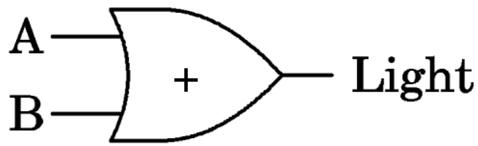
Gates

AND



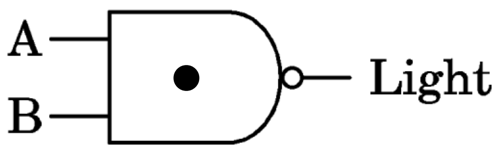
$A \bullet B$

OR



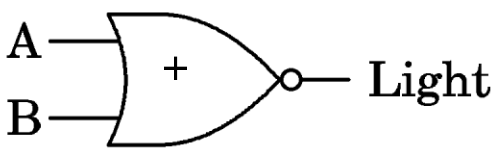
$A + B$

NAND



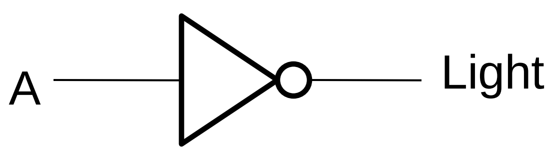
$\overline{A \bullet B}$

NOR



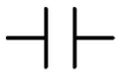
$\overline{A + B}$

NOT

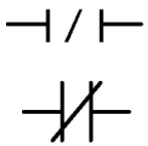


$\overline{A}$

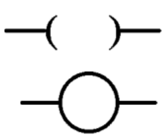
Basic Ladder Logic Symbol



Normally open contact
Passes power (ON) if coil driving the contact is ON (closed)
Allen-Bradley calls it **XIC** - eXamine If Closed

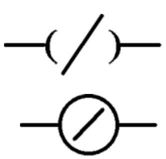


Normally closed contact
Passes power (ON) if coil driving the contact is off (open)
Allen-Bradley calls it **XIO** - e**X**amine **If** **O**pen



Output or coil

If any left-to-right path of inputs passes power, output is energized
Allen-Bradley calls it OTE - OuTput Energize



Not Output or coil

If any left-to-right path of inputs passes power, output is de-energized

The IEC 61131-3 standards describe the complete list of ladder logic contact and coil symbols. **See also section 2.3.1**

PLC Ladder Logic

Symbols

- The symbols are ladder logic instructions
- The PLC scans (executes) the symbols:

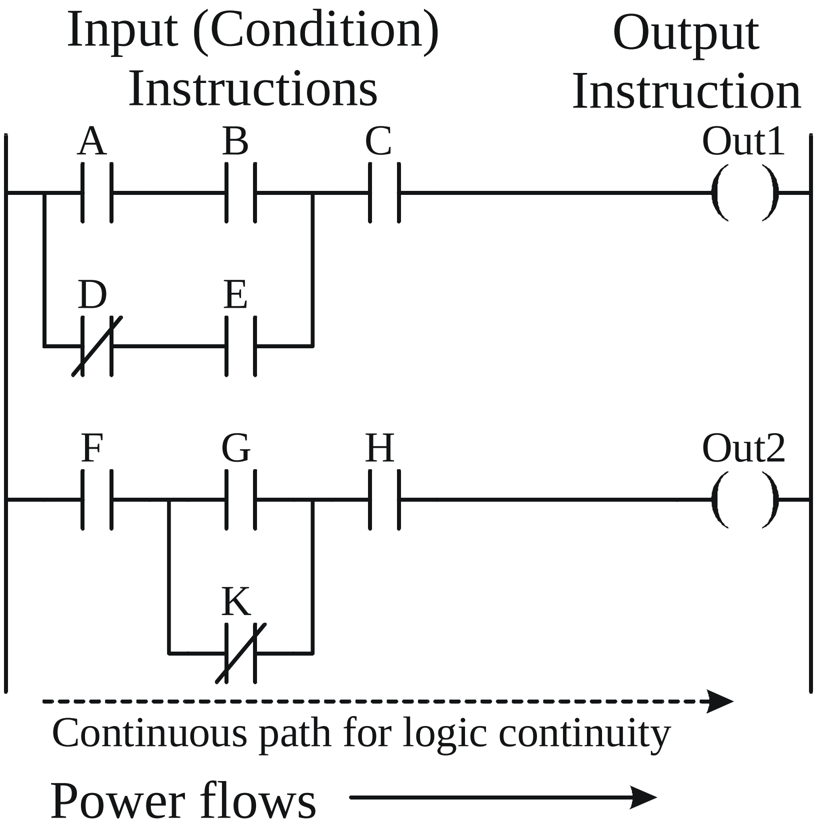
—| |— = on = Closed = True = 1

—|/|— = off = Open = False = 0

- Every PLC manufacturer uses instruction symbols
- Industry trend is based on IEC 61131-3
  - Variations in symbols by Manufacturers
- Allen-Bradley ControlLogix symbols slightly different (Refer 2.3.3)

Ladder Logic Diagram

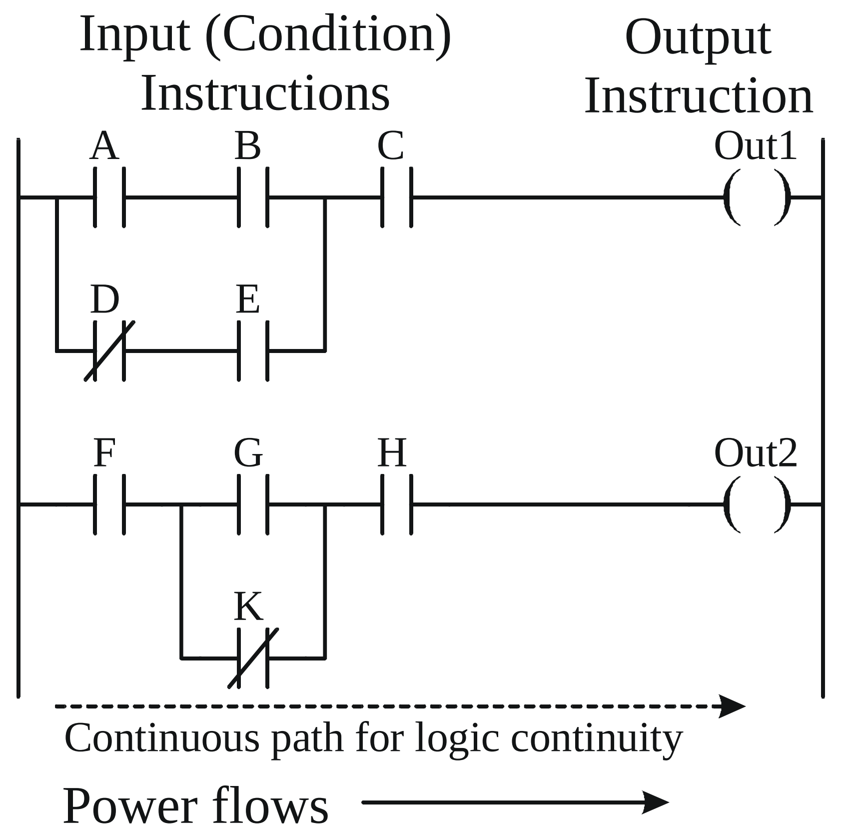
- ❑ Power Rails - Pair of Vertical Lines
- ❑ Rungs - Horizontal Lines
- ❑ Contacts A, B, C, D… arranged on rungs
- ❑ Note in PLC Ladder Logic:
  - • No Real Power Flow (like in relay ladder)
  - • There must be continuous path thru' the contacts to energize the output



Ladder Logic Diagram Instructions

Two Classes of Ladder Logic Instructions

- **Output:** Appears on extreme RHS of rung always – Out1, Out2
- **Input:** Any instruction that can replace a contact

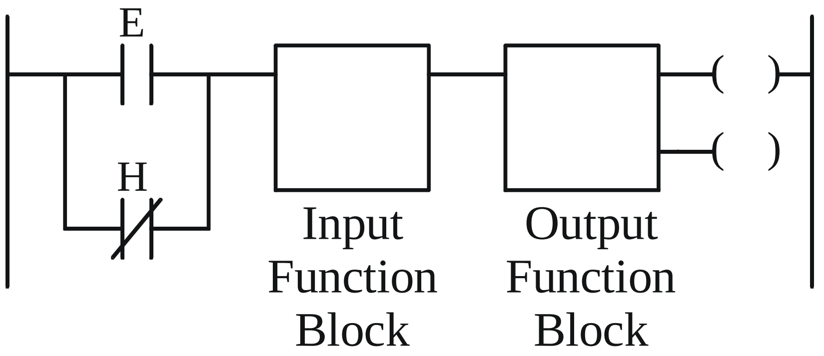


Can contacts appear on the RHS of a coil?

Ladder Logic Diagram
Function Block Instructions

Function Block Instructions

- Any non-contact instruction:
  - Timer Instruction
  - Counter Instruction
  - Comparison Instruction



Ladder Logic Diagram
Example 1

Task:

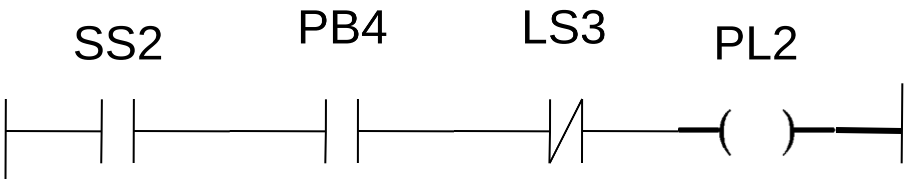
Draw a ladder diagram that will cause the output, pilot light PL2, to be on when selector switch SS2 is closed, push button PB4 is closed and limit switch LS3 is open. (Note: no I/O addresses yet.)

Thought Process

- ❑ Identify the output: PL2 → PL2 appears on rhs of rung
- ❑ What is the behavior (type of connection to use): sequential operation of all switches → series connection
- ❑ Type of contacts to implement output:

SS2 closed ┤ ├   PB4 closed ┤ ├   LS3 open ┤ / ├

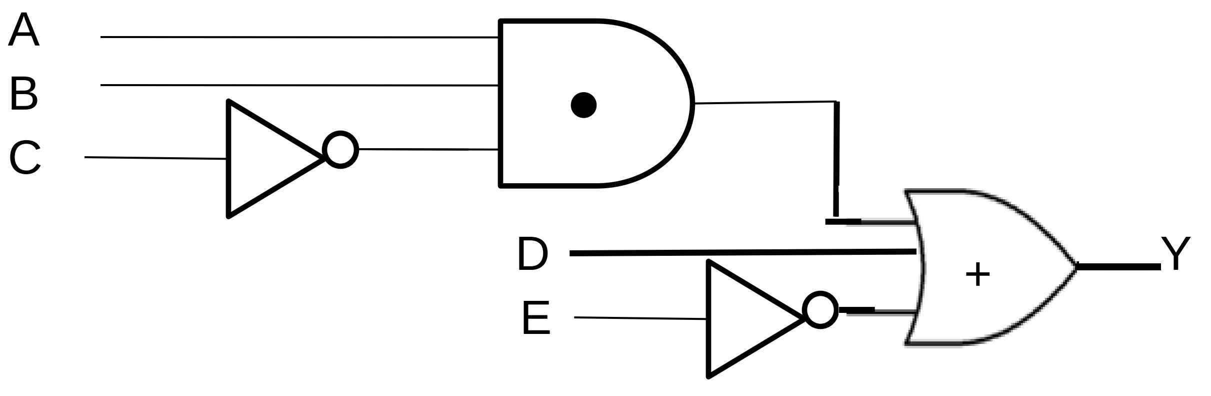
Ladder Logic Diagram
Example 1



Ladder Logic Diagram
Example 2

Task:

Draw a ladder diagram that is equivalent to the following digital logic diagram



Y is on when (A is on, B is on and C is off) or D is on, or E is off

What is the Boolean logic expression?

Ladder Logic Diagram
Example 2

Thought Process

- Identify the output: Y → Coil Y appears on rhs of rung
- What is the behavior (type of connection to use):
  - The inputs A, B, C for AND gate will be connected in series
  - The D, E inputs for OR gate will be connected in parallel with the output of AND gate
- Type of contacts to implement output (review the expected behavior again to determine contact types):

A is on: ⊣ ⊢

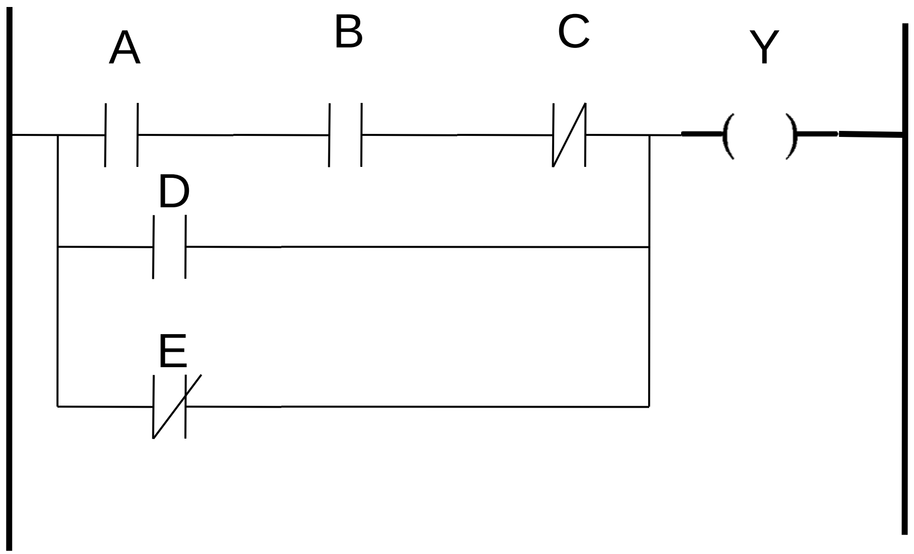
B is on: ⊣ ⊢

C is off: ⊣ / ⊢

D is on: ⊣ ⊢

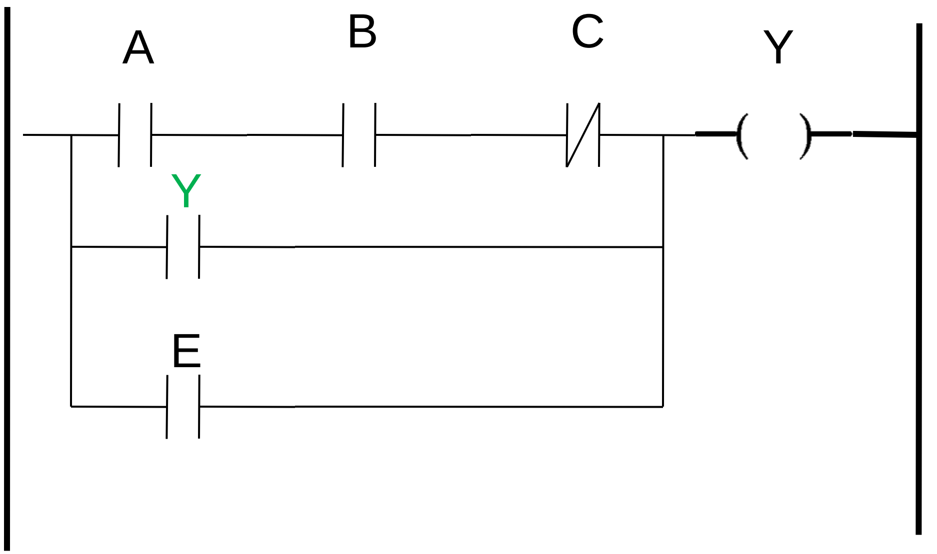
E is off: ⊣ / ⊢

Ladder Logic Diagram
Example 2



What happens if the D contact refers to Y?

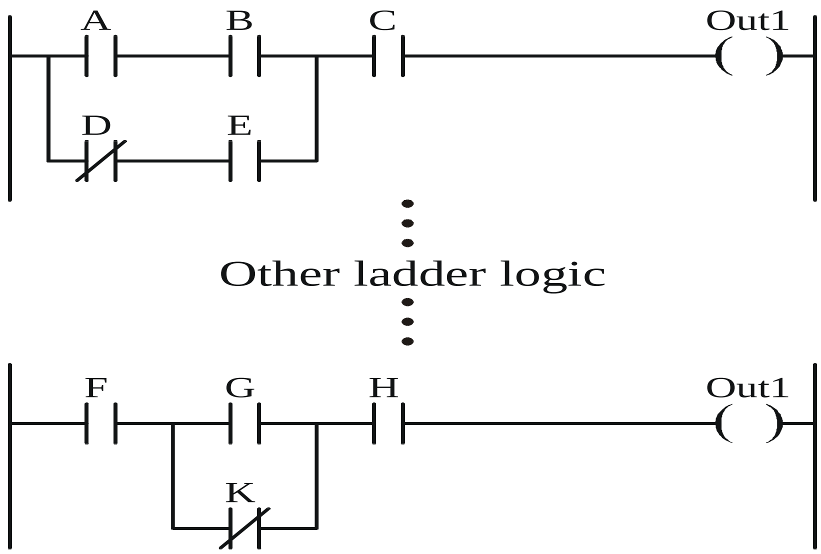
Ladder Logic Diagram
Sealing an output



Output Y is set (latched) indefinitely

Ladder Logic Diagram Dangers
Repeated Output

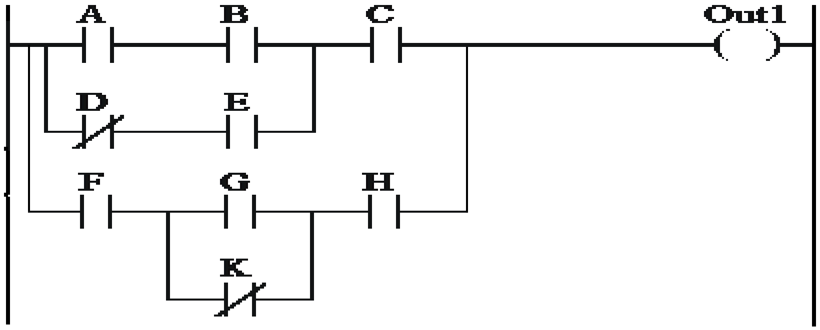
- Do not repeat normal output coils that refer to the same address



- The coils for first and second rung refer to Out1
  - Second rung overrides the logic in first rung

Ladder Logic Diagram Dangers
Repeated Output - Correction

- First consider the output
  - Next, consider ALL the conditions that drive the output (Out1) (Implement the conditions in parallel)

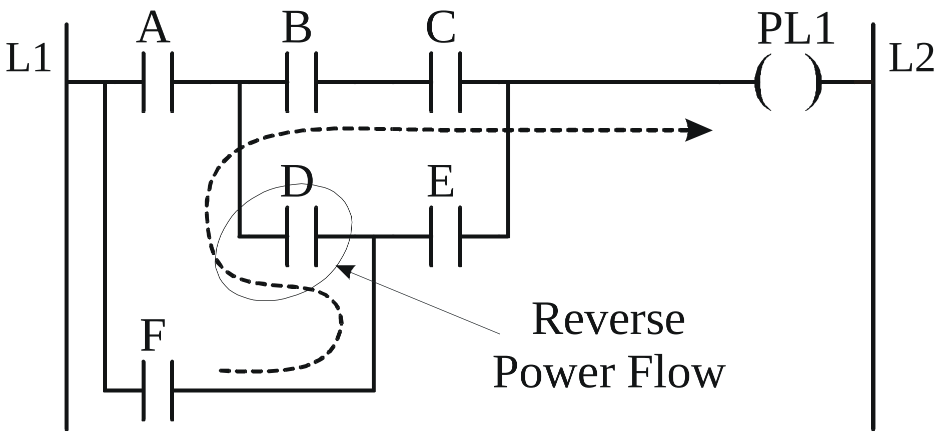


Ladder Logic Diagram Dangers

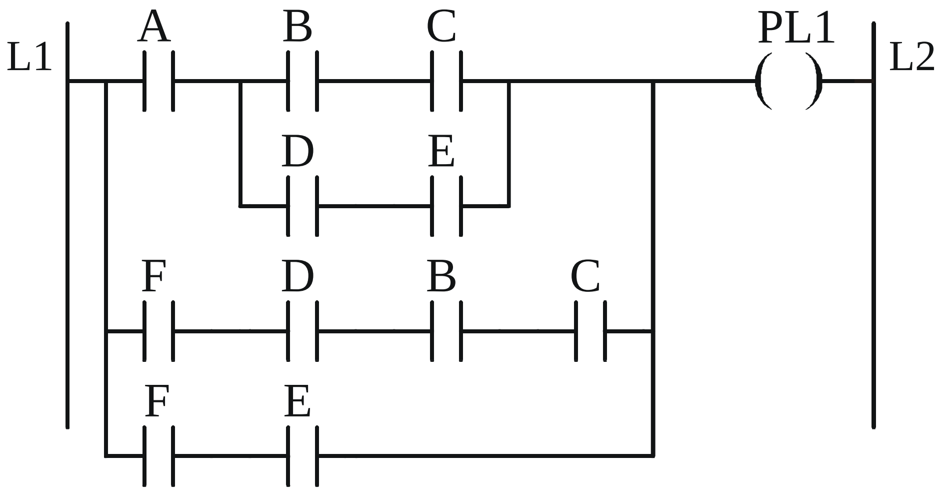
- Use set/seal (latch) and reset (unlatch) together:
  - If a set coil refers to an output there should be a reset coil for that output
  - Reverse power flow in contact matrix is not allowed
    - Power flow one way left to right (solid state relays)

Ladder Logic Diagram Dangers
Reverse Power Flow

- This is not allowed:

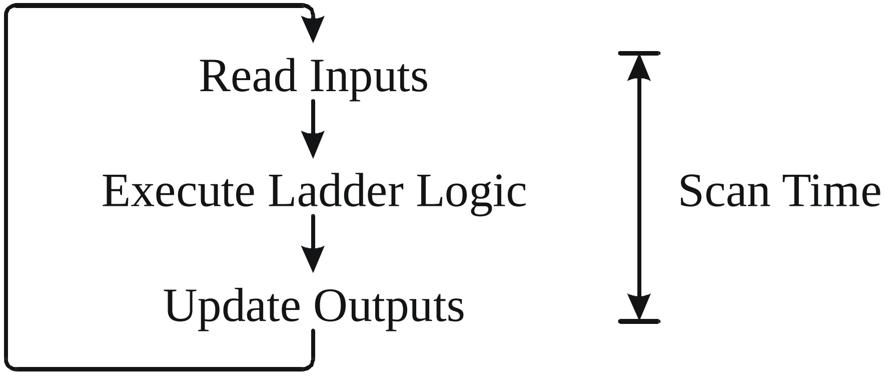


- If the reverse power flow path is truly needed, then put it as a separate path, where the power flows from left to right:



Typical PLC Processor Scan

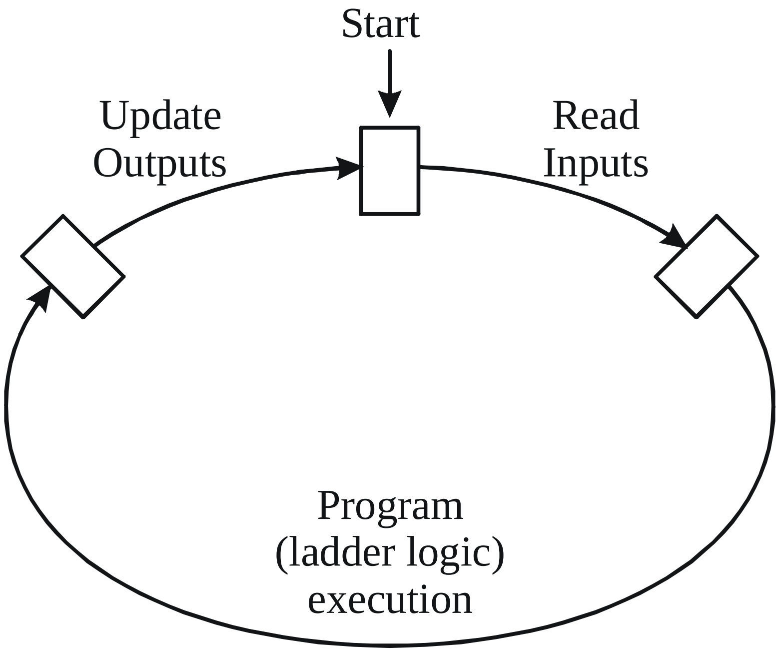
- Major tasks in a scan



- Processor must read the state of the physical inputs and set the state of the Physical outputs

Typical PLC Processor Scan

- Order of PLC Processor Scan
  - Read Physical Inputs
  - Scan ladder logic program
  - Write the physical outputs

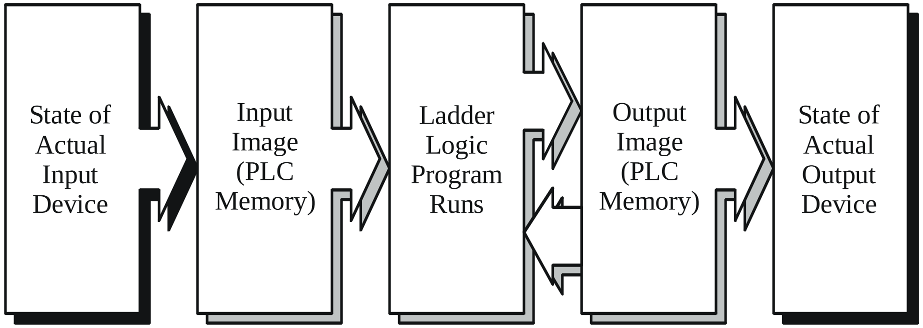


- Scan Time
  - Time to complete above cycle
  - Order of 1-200 milliseconds

What could happen if scan time exceeds more than 200 milliseconds?

Typical PLC Processor Scan
Scenario 2

- The state of actual input devices are copied to an area of the PLC Memory, input data table **before** the ladder logic program executes



  - As the ladder logic program is scanned, it reads the input data table then writes to a portion of PLC memory - the output data, table as it executes

  - The output data table is copied to the actual output devices **after** the ladder logic has been scanned.

What is the significance of the input and output data tables?

Typical PLC Processor Scan
Allen-Bradley RSLogix 5000

The execution of PLC Processor controlled by processor mode (Refer to lab 1)

- Run Mode:
  - Physical Input, Physical Outputs and Ladder logic all get scanned
- Remote Mode
  - Down load ladder logic to PLC Processor; and initiate scan from the remote terminal
- Program Mode
  - Ladder logic not scanned

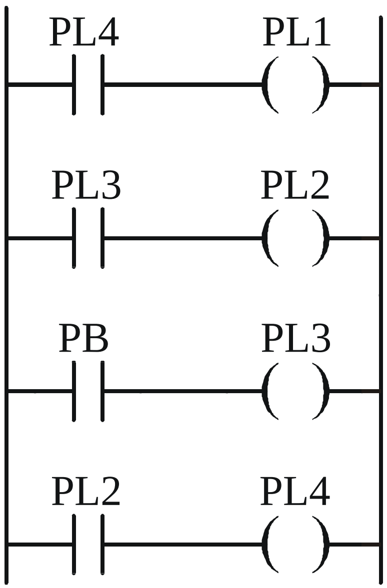
Ladder Logic Evaluation

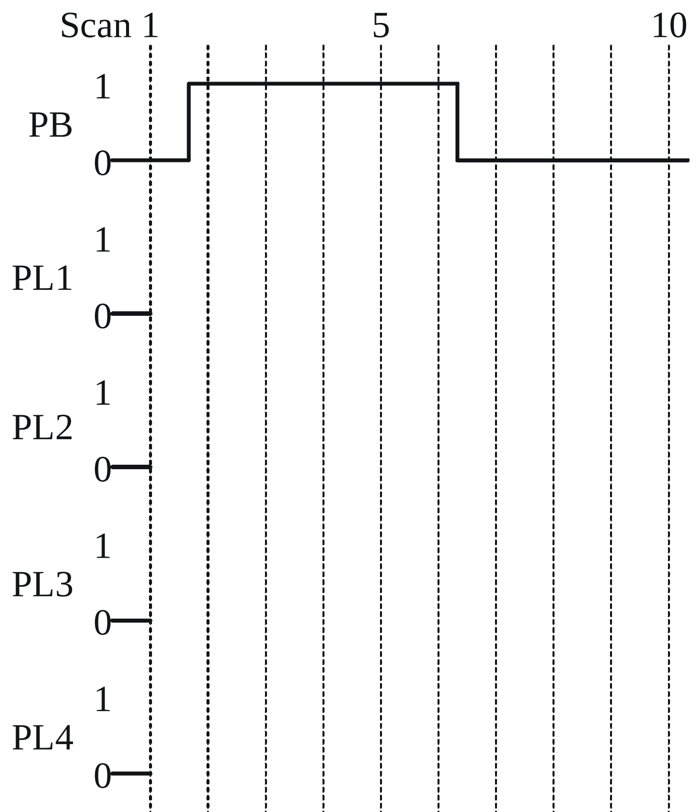
- For most PLC's, the ladder scan starts at the top of the ladder and proceeds to the bottom of the ladder, examining each rung from left to right.
  - Once a rung is examined, it is not examined again until the **next** scan.
  - The rungs are not examined in reverse order.
- The JMP instruction may be used to jump back up the ladder and execute earlier rungs.
  - Use of JMP not recommended Why?

Ladder Logic Evaluation

Push Button (PB)

Start PB:





Physical Input: PB

Physical Outputs: PL1, PL2, PL3 and PL4

Start of PLC scans

State of PLC image memory for I/O devices:

Ladder Logic Evaluation

Push Button (PB)

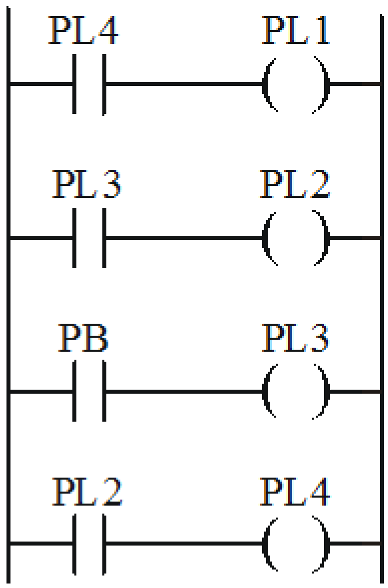
Scan 1: Only the state of PB changes to ON (**1**)
during the scan

Scan 2:
The ON state of PB is copied into Input data table
before Ladder logic is scanned

When rung 1 is scanned → PL1 is still off (o)
When rung 2 is scanned → PL2 is still off (o) Why?
What is the value of PL4 and PL3 in Output Data table?

When rung 3 is scanned the Value of PL3 in the output data table changes to 1 Why?

When rung 4 is scanned, the Value of PL4 in the output data table remains at off (0). Why?



At the end of scan 2 the values in Output data table are copied to the Physical Output Devices. PL 3 turns on

Ladder Logic Evaluation

Push Button (PB)

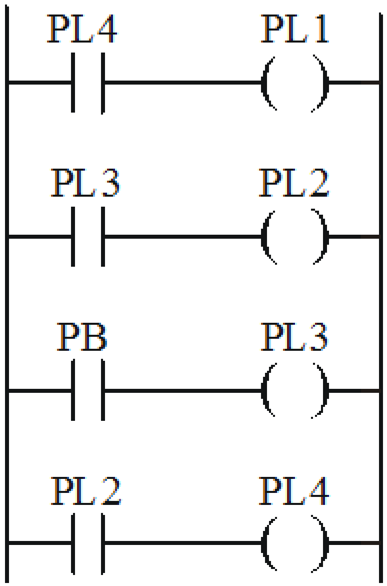
Scan 3:

When rung 1 is scanned the value of PL4 in output data table is still 0 → PL1 in output data table remains 0

When rung 2 is scanned the value of PL3 in Output Data table is currently 1 → value of PL2 in Output Data table changes to 1

When rung 3 is scanned the Value of PB in the input data table is still1 → Value of PL3 in Output data table remains at 1

When rung 4 is scanned Value of PL2 in the output data table is now 1 so the value of PL4 in the Output Data table changes to 1



At the end of scan 3 the values in Output data table are copied to the Physical Output Devices:
PL2 and PL4 turn on simultaneously
(PL3 remains on)

Ladder Logic Evaluation

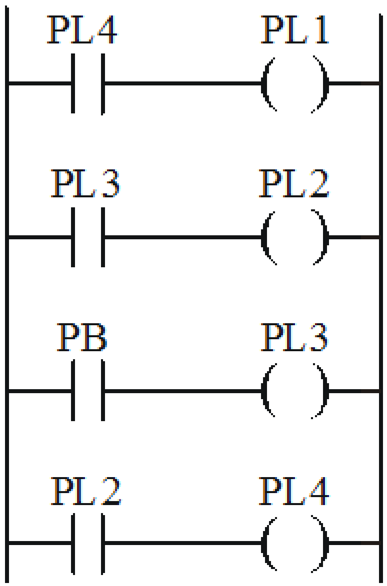
Push Button (PB)

Scan 4:

When rung 1 value of PL4 in output data table is now 1
→ value of PL1 in output data table changes to 1
When rung 2 is scanned the value of PL3 in Output Data table is still 1 → value of PL2 in Output Data table remains at 1

When rung 3 is scanned the Value of PB in the input data table is still1 → Value of PL3 in Output data table remains at 1

When rung 4 is scanned Value of PL2 in the output data table is still 1 so the value of PL4 in the Output Data table remains at 1

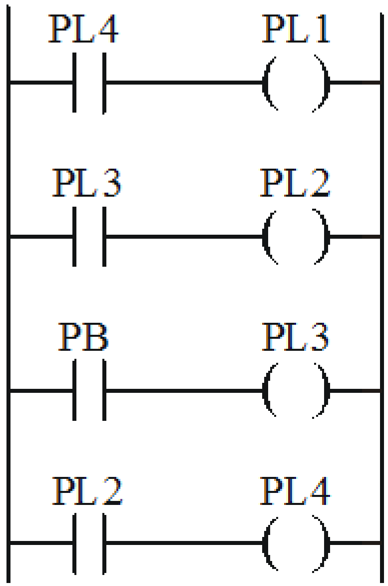


At the end of scan 4 the values in Output data table are copied to the Physical Output Devices:
PL1 turns on
(PL2, PL3 and PL4 remain on)

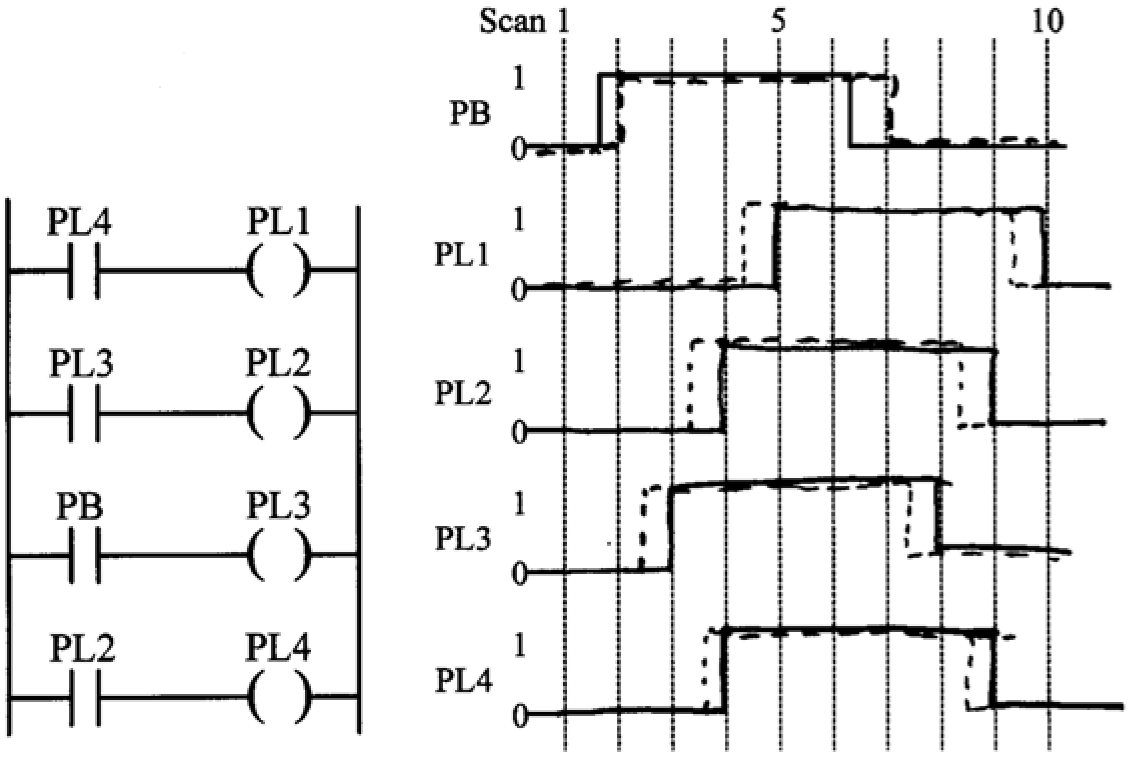
Ladder Logic Evaluation
Push Button (PB)

Scans 5 and 6: Nothing Changes

Scans 7 – 9 : Similar to Scans 2 – 4 except that state changes from 1 (on) to 0 (off)



Ladder Logic Evaluation
Push Button (PB) Scan Timing Diagram



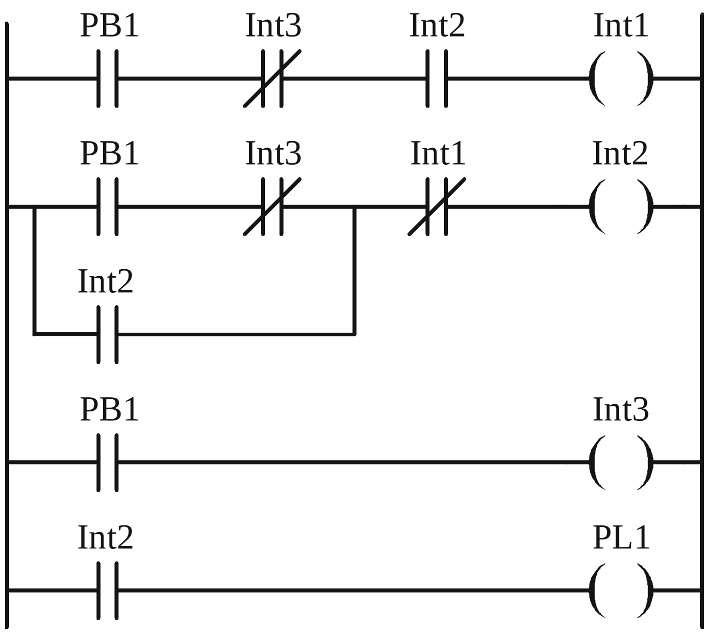
I/O Terminal: -------

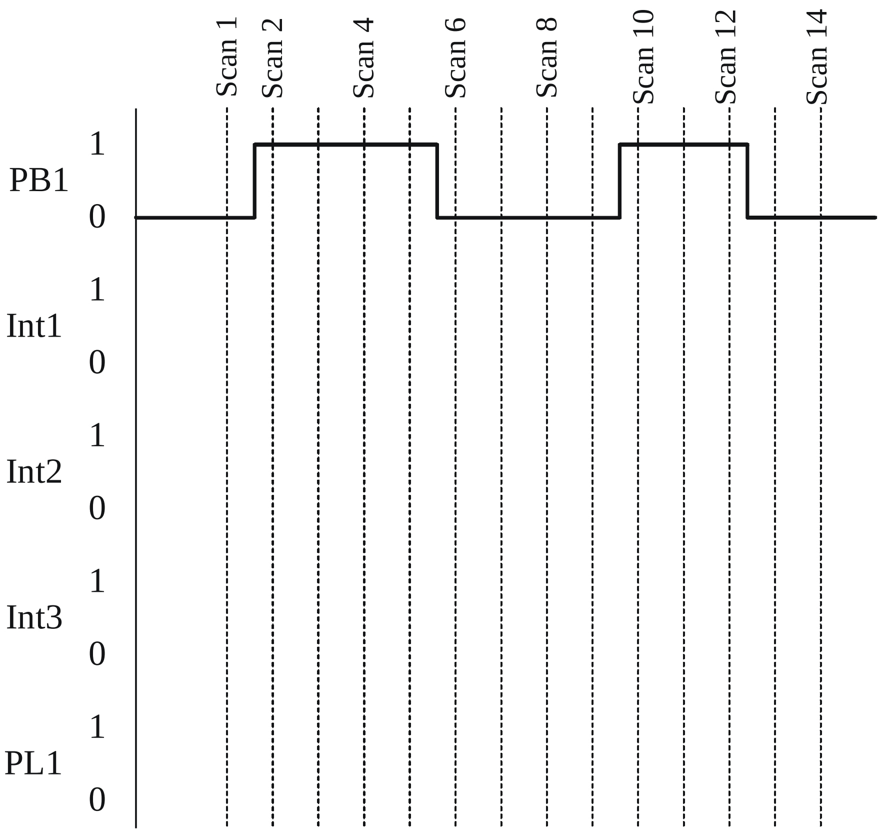
I/O Data Table: ▬▬▬

Ladder Logic Evaluation

Push Button (PB1)

Assume rungs are scanned from top - down



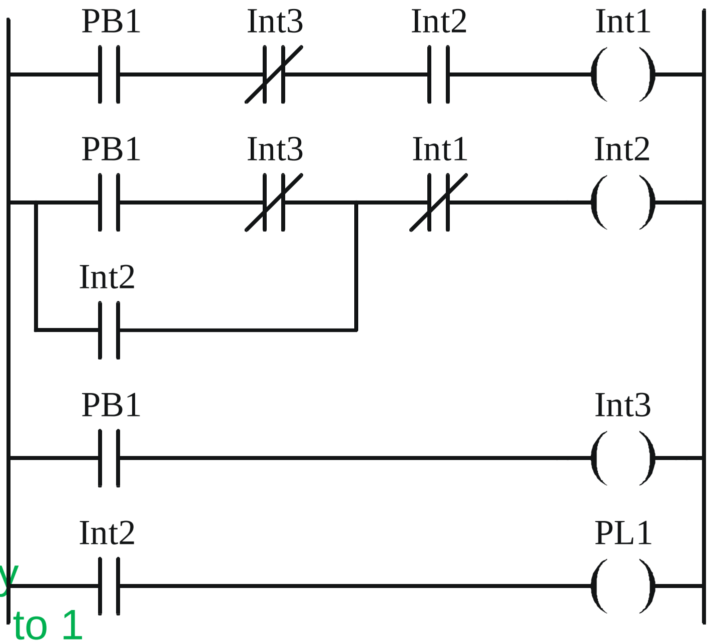


Physical Input: PB1

Physical Output: PL1

Ladder Logic Evaluation

Push Button (PB1)



Scan 1: Only the state of PB1 changes to ON (**1**) during the scan, new state copied at next scan

Scan 2:

The ON state of PB1 is copied into Input data table before Ladder logic is scanned

When rung 1 is scanned, PB1 is ON, Int3 is off so power goes to Int2, But Int2 is off→ Int1 is off (0)

When rung 2 is scanned PB1 is ON, Power goes thru' Int3 and Int1 → Int2 is On

When rung 3 is scanned the Value of PB1 in the input data table is now 1 so Int3 is energized and Int3 contact is ON

When rung 4 is scanned, the Value of Int2 in the PLC memory is now 1 so the value of PL1 in the Output data table changes to 1

At the end of scan 2 the values in Output data table are copied to the Physical Output Devices. PL1 turns on

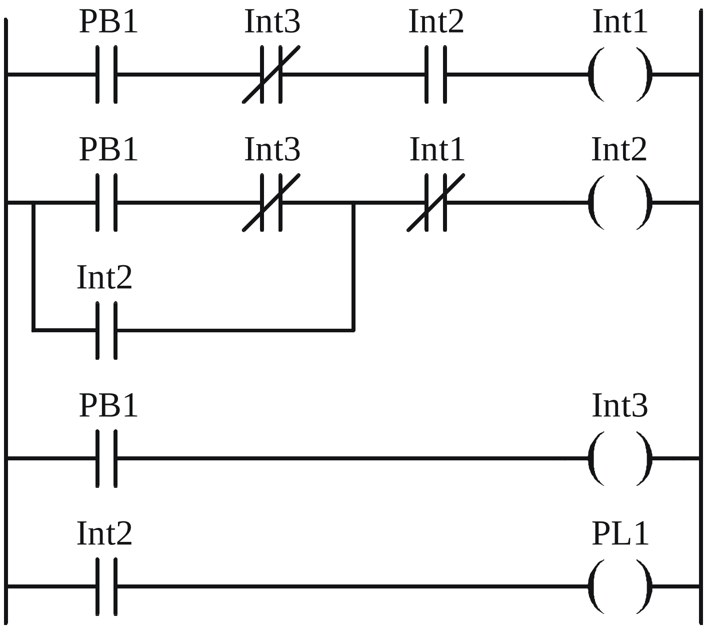
Ladder Logic Evaluation

Push Button (PB1)

<u>Scan 3</u>: No change in the rung output coils

When rung 1 is scanned There is continuity thru' PB1 and Int2 but not Int3

When rung 2 is scanned – no continuity thru' top branch But continuity thru' lower branch → Int2 remains ON



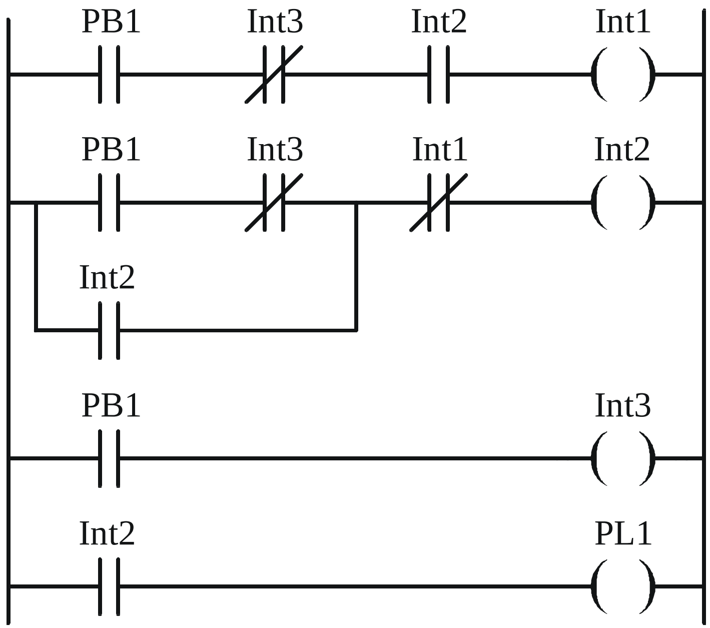
At the end of scan 3 the values in Output data table are copied to the Physical Output Devices. PL1 remains on

Ladder Logic Evaluation

Push Button (PB1)

Scans 4 - 5:

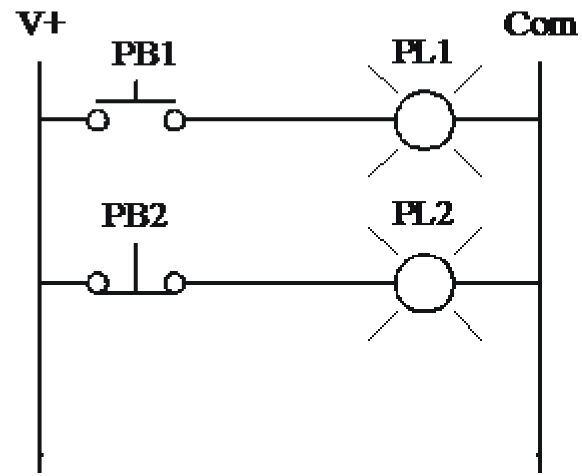
No change in the rung output coils because there is no change in the contacts



At the end of scans 4 and 5 the values in Output data table are copied to the Physical Output Devices. PL1 remains on

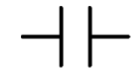
Discrete Input/Output

- An actual PLC has connections to the “real" world, and is not just ladder logic.

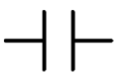


An example hard-wired ladder circuit

Programming with NC Contacts

- If you want “action" (turn ON) when switch is closed (relay energized), use . 
- If you want “action" (turn ON) when switch is open (relay de-energized), use . 
-

In the rungs, think of the contact as a symbol,

 = ON = CLOSED = TRUE = 1

 = OFF = OPEN = FALSE = 0

Note: this is probably the most confusing concept in ladder logic