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
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: \(2^2\)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>ON</td>
<td>ON</td>
<td>ON</td>
</tr>
</tbody>
</table>

Simple Ladder Logic
OR Operation
Relay Circuit

- 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
  - Relay coil LR gets energized
  - Power is transmitted to the Light bulb
- Power is transmitted to the Light bulb
**OR Operation**

**Relay Ladder Logic Circuit**

![Relay Ladder Logic Circuit Diagram](image)

**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**

**AND Truth Table**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>ON</td>
<td>ON</td>
<td>ON</td>
</tr>
</tbody>
</table>

**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?

---

**Simple Ladder Logic**

**AND Operation**

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

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

---

**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

NOT Operation

PLC Ladder Logic

Simple Ladder Logic

NOT Operation

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

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>

NOT Truth Table

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

NAND Truth Table

Simple Ladder Logic

NAND Operation

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

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>

NAND Truth Table
### NAND Operation

**Relay Circuit**

![Relay Circuit Diagram]

**Ladder Logic Circuit**

![Ladder Logic Diagram]

### 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 - Examine If Open

- **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:
  - $\rightarrow$ = on = Closed = True = 1
  - $\rightarrow\leftarrow$ = 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)

### Digital Logic Gates

- **AND**
  - $A \cdot B$
- **OR**
  - $A + B$
- **NAND**
  - $\overline{A \cdot B}$
- **NOR**
  - $\overline{A + B}$
- **NOT**
  - $\overline{A}$

### 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

---

### 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**

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

   - SS2 closed  
   - PB4 closed  
   - LS3 open

---

### 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

**Thought Process**

1. Identify the output: Y → Coil Y appears on rhs of rung
2. 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
3. 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 - Correction

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

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

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**

- Read Inputs
- Execute Ladder Logic
- Update Outputs

**Scan Time**

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

The processor must read the state of the physical inputs and set the state of the physical outputs.

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

**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 is the significance of the input and output data tables?
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 (0).
When rung 2 is scanned → PL2 is still off (0). 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 still 1 → 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 5 and 6: Nothing Changes.

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

At the end of scan 10 the values in Output data table are copied to the Physical Output Devices: PL 1 turns on.

I/O Terminal: -------
I/O Data Table:

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 still 1 → 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).

Scan Timing Diagram

Scan 1
Scan 2
Scan 3
Scan 4
Scan 5
Scan 6
Scan 7
Scan 8
Scan 9
Scan 10

I/O Terminal: -------
I/O Data Table:

Assume rungs are scanned from top - down

Physical Input: PB1
Physical Output: PL1
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.

Scan 3: 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.

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.