ECET 4530

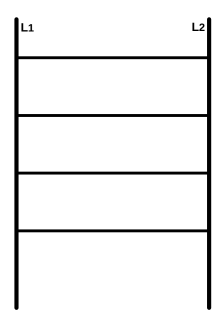
Industrial Motor Control

Introduction to Ladder Diagrams

Ladder Diagrams

Ladder Diagrams are a special type of schematic diagrams that are often used to depict industrial control systems.

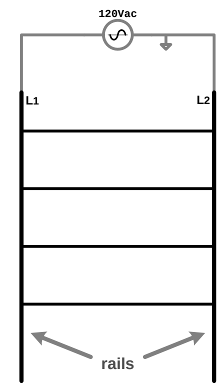
They are called “ladder” diagrams because they look like a ladder, having two vertical rails and multiple horizontal rungs.



Ladder Diagram Components

The vertical <u>rails</u> of the ladder provide a connection to the control system's power supply (voltage source).

The rails may be labeled "L_1" and "L_2" where:
L_1 is the energized conductor, and
L_2 is the grounded (neutral) conductor.

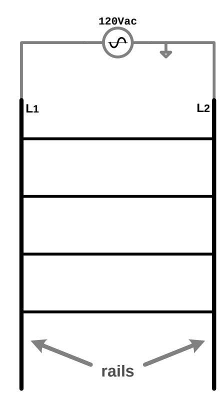


Source Voltages

The choice of the supply voltage can depend on may different factors including:

- Safety
- Convenience/Availability
- Component Size

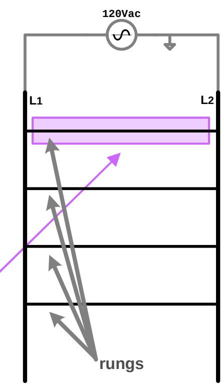
Typical voltages include: $120V_{AC}$, $24V_{AC}$, $24V_{DC}$

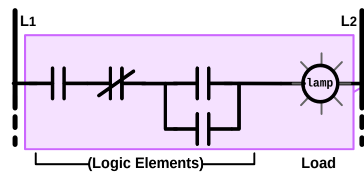


Ladder Diagram Components

The horizontal <u>rungs</u> represent the individual circuits or functional elements used within the control system.

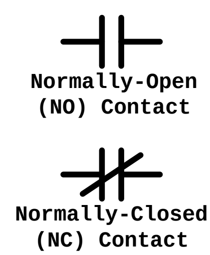
A typical rung contains a single output device or load (lamp, field coil, etc.) along with all of the logic elements (contacts, pushbuttons, etc.) that determine its operation.



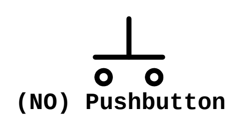


Logic Elements

A ladder's fundamental logic element is a contact, which may be either normally-open (NO) or normally-closed (NC).



Even though some logic elements may be represented by a different symbol, such as that for a pushbutton, their operation can typically be reproduced by a contact.

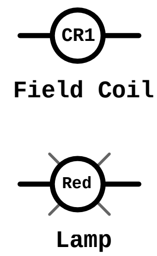


Output Devices / Loads

A variety of output devices (loads) may appear in a ladder diagram, such as:

- Field Coils
- Indicator Lamps
- Timers

Despite their fundamental differences, they are often represented by similar symbols, such as a circle for a contactor's field coil or a circle with diagonal whiskers for an indicator lamp.

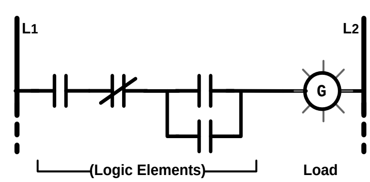


Standard Device Location on Rungs

Standard Device Placement

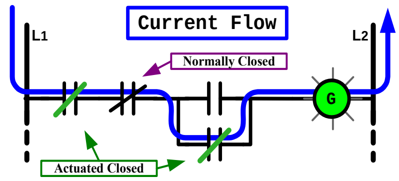
Loads are typically placed on the right-hand side of the rung, closest to the (grounded) supply rail L_2.

All of the logic elements that govern the operation of the loads are placed to the left of the load.

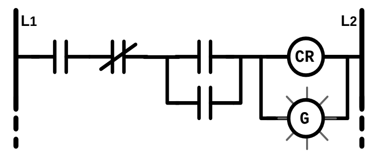


Rung Operation

The load is energized when the state of the logic elements allows current to flow from L_1 to L_2 through the load.



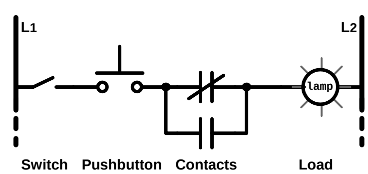
Note that two or more loads may be connected in parallel on one rung when their operation is based on the same conditional logic.



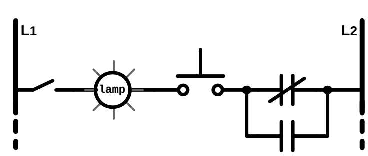
Proper Device Location on Rungs

Although placement of the logic elements to the right of the load will not affect the load's operation under normal conditions, <u>proper placement can affect both the load's operation and system safety under abnormal conditions</u>, such as during the occurrence of a fault (short circuit) within the control system.

Standard Device Placement



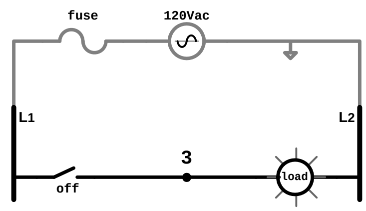
Improper Device Placement



Proper/Safe Device Placement

Safe Placement Example

During normal operation, there will be no voltage potential present at either terminal of the load while the switch is "off" (in the "open" position).



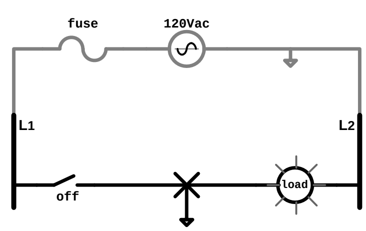
If the load is a lamp, it could be removed from its socket and replaced without risk of shock while the switch is "off".

Proper/Safe Device Placement

Safe Placement Example:

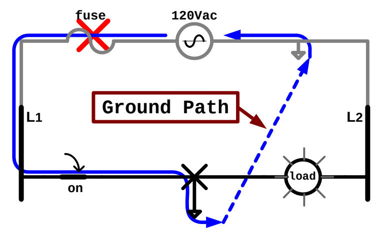
If the switch is "off" and a ground-fault occurs on the wire connecting the switch to the load, then:

- **no current will flow in the rung**
- **the load will remain de-energized since both of its terminals are grounded**



Proper/Safe Device Placement

<u>Safe Placement Example</u>:

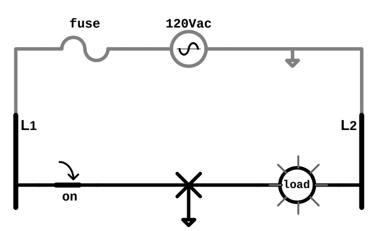


If the switch is flipped "on" after the ground-fault occurs, or if the ground-fault occurs after the switch is flipped "on", then:

- L_1 will be shorted to ground, creating or maintaining a zero-volt potential across the load (i.e. – the load will either remain or be de-energized)
- the resultant fault current will blow the fuse, shutting down the entire system

Proper/Safe Device Placement

<u>Safe Placement Example</u>:



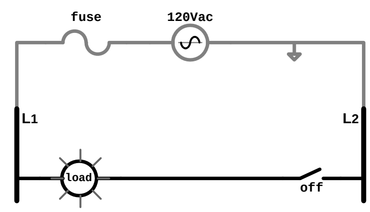
The presence of the ground fault will <u>always</u> cause the fuse to blow when the rung is energized, which will shut down the entire control system.

In this manner, the fault will always be detected and the system will never remain operation in an unsafe manner.

Unsafe Load Placement Example

<u>Unsafe Placement Example</u>

During <u>normal operation</u> while the switch is “off”, there will be a voltage potential present at both terminals of the load even though the load is de-energized.



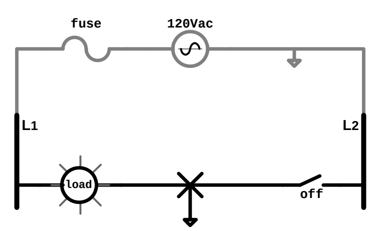
If the load is a lamp, there is a risk of shock during lamp replacement even while the switch is “off”.

Unsafe Load Placement Example

<u>Unsafe Placement Example</u>:

If the switch is “off” and a ground-fault occurs on the wire connecting the switch to the load, then:

- <u>the load will energize</u> even though the switch is still open
- the <u>fuse will not blow</u> because the load will still limit the current
- <u>the load can no longer be controlled by the switch</u>!

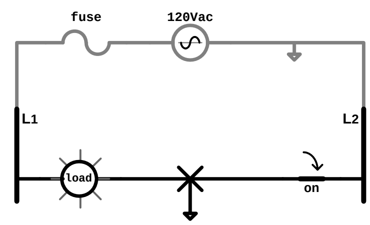


Unsafe Load Placement Example

Unsafe Placement Example:

If the switch is flipped "on" after the ground-fault occurs, then:

- since the ground fault already energized the load while the switch was "off", flipping the switch to "on" has no additional effect on the load or the fuse

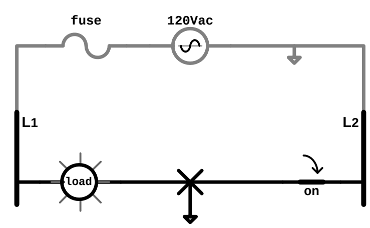


Unsafe Load Placement Example

Unsafe Placement Example:

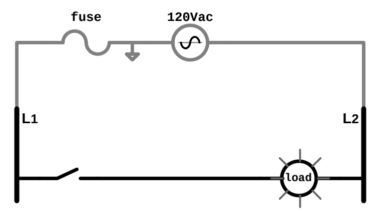
If the ground-fault occurs after the switch is flipped "on", then:

- since the switch already energized the load before the fault occurred, there will be no noticeable change in the system's operation at the time of the fault
- the fuse will still not blow



Unsafe Load Placement Example

Unsafe Placement Example:

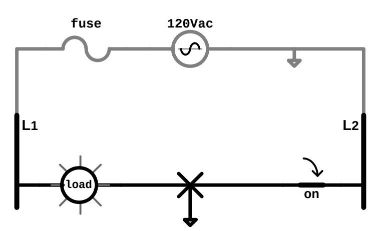


Note that the same situation may occur even if the load is correctly placed next to rung L_2, but L_1 is grounded instead of L_2.

Careful attention to detail is important, both during the design and the implementation of the system, because what might appear as either a simple error on paper or a simple wiring error in practice can result in a dangerous situation.

Safe Operation is Critically Important

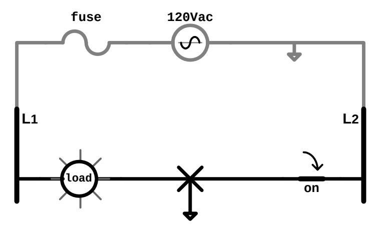
Unsafe Placement



Although the presence of a voltage potential at the terminals of the load under normal (non-fault) conditions while the switch is "off" provides a risk of shock, the hazardous situation that occurs due to the potentially uncontrolled start-up and the loss of control during the ground-fault is of primary concern.

Safe Operation is Critically Important

Unsafe Placement

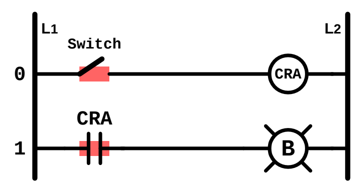


The possibility that a load becomes energized due to a ground fault is quite dangerous, especially if the load unexpectantly provides power to an industrial machine without warning to the operators.

To make matters worse, once the ground fault occurs, the switch is no longer able to de-energize the load! And, if the fault occurs after the load was already energized, there will be no indication of the fault until an attempt is made to shut down the load!

Logic Element Fundamentals

Given the ladder diagram to the right:



- Rung-0 contains a switch and the field coil of control relay "CRA"
- Rung-1 contains a normally-open contact "CRA" and a blue light

If the switch on rung-0 is initially open, CRA's field coil will be de-energized, and CRA's NO contact on rung-1 will be in its "normal" position (i.e. – open).

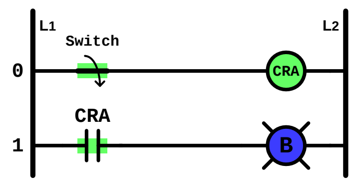
The colored bars behind both the switch and the NO contact denotes their current conductive states: ≡ open (non-conductive) ≡ closed (conductive)

If CRA's NO contact is open, the blue light will be OFF.

Logic Element Fundamentals

Given the ladder diagram to the right:

- Rung-0 contains a switch and the field coil of control relay “CRA”
- Rung-1 contains a normally-open contact “CRA” and a blue light

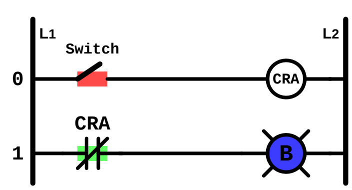


But, when the switch on rung-0 closes, CRA’s field coil will be energized, in-turn actuating CRA’s NO contact on rung-1.

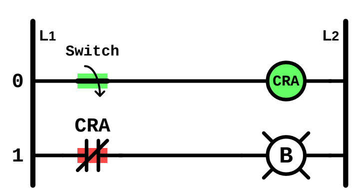
When CRA’s NO contact actuates, it closes, in-turn energizing the blue light.

Logic Element Fundamentals

But, what if the contact on rung-1 is replaced with a NC contact?



If the switch is open, CRA’s field coil will be de-energized, CRA’s NC contact will be in its “normal” (closed) position, and the blue light will be ON.



If the switch is closed, CRA’s field coil will be energized, CRA’s NC contact will actuate (open), in-turn de-energizing the blue light.

Ladder/Digital Logic Equivalents

In the case of a control relay, a digital logic equivalency can be determined for its contact's operational states.

Since a contact only has two positions, we can represent the contact's <u>positional state</u> by either a "0" or a "1":

0 – the contact in its "normal" position
1 – the contact in its actuated position

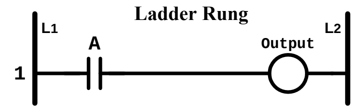
We can also represent the contact's <u>current conductive state</u> by either a "0" or a "1":

0 – the contact is currently non-conductive (OPEN) (FALSE)
1 – the contact is currently conductive (CLOSED) (TRUE)

Ladder/Digital Logic Equivalents

If there's a single contact on a rung, then the <u>state of the load</u> directly relates to the contact's <u>current conductive state</u>.

Ladder Rung

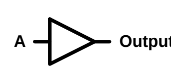


Thus, for the case of a single <u>NO contact</u>, the following truth table can be used to define the rung's operation:

A	Output
0	0
1	1

which is equivalent to that which defines the operation of a digital <u>gate</u>.

Digital Logic Equivalent



$$Output = A$$

A	Output
0	0
1	1

Ladder/Digital Logic Equivalents

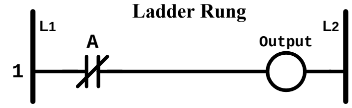
If there's a single contact on a rung, then the state of the load directly relates to the contact's current conductive state.

Thus, for the case of a single NC contact, the following truth table can be used to define the rung's operation:

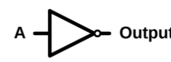
A	Output
0	1
1	0

which is equivalent to that which defines the operation of an inverting gate.

Ladder Rung



Digital Logic Equivalent



$Output = \overline{A}$

A	Output
0	1
1	0

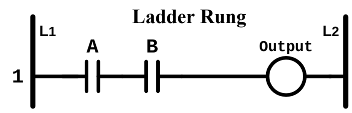
Ladder/Digital Logic Equivalents

Complex logic statements may be realized using multiple contacts.

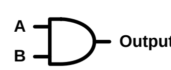
For example, the AND function can be constructed using two series-connected NO contacts.

A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1

Ladder Rung



Digital Logic Equivalent



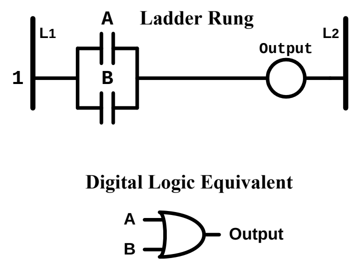
$Output = A \cdot B$ A and B

Ladder/Digital Logic Equivalents

Complex logic statements may be realized using multiple contacts.

Similarly, the <u>OR</u> function can be constructed using two parallel-connected NO contacts.

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1



$Output = A + B$

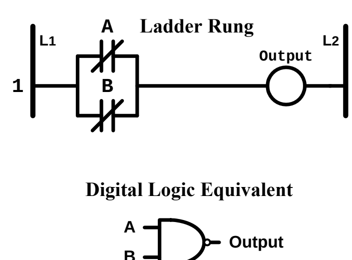
A <u>or</u> B

Ladder/Digital Logic Equivalents

Complex logic statements may be realized using multiple contacts.

The <u>NAND</u> function can be realized using two parallel-connected NC contacts.

A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0



$Output = \overline{A \cdot B}$

$= \overline{A} + \overline{B}$

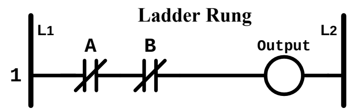
NOT (A <u>and</u> B)

Ladder/Digital Logic Equivalents

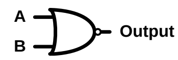
Complex logic statements may be realized using multiple contacts.

The <u>NOR</u> function can be realized using two series-connected NC contacts.

A	B	Output
0	0	1
0	1	0
1	0	0
1	1	0



Digital Logic Equivalent



$$Output = \overline{A + B}$$
$$= \overline{A} \cdot \overline{B}$$

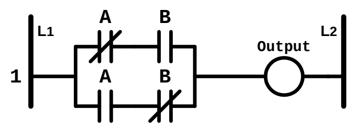
NOT (A <u>or</u> B)

Ladder/Digital Logic Equivalents

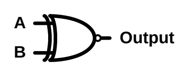
Complex logic statements may be realized using multiple contacts.

The <u>XOR</u> (Exclusive OR) function can be realized using multiple NO & NC contacts.

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0



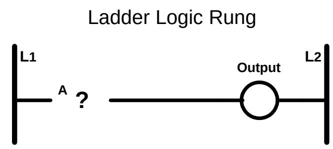
Digital Logic Equivalent



$$Output = A \oplus B$$
$$= \overline{A} \cdot B + A \cdot \overline{B}$$

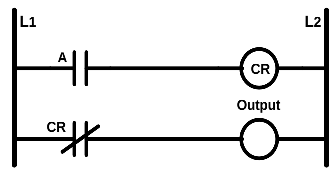
Other Issues

At times, the correct type of contact (NO or NC) may not be available for use on a device utilized in the control system.



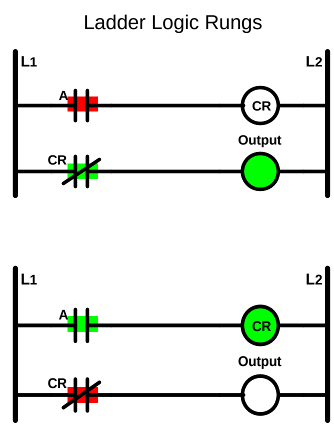
For example: a relay has a spare NO contact available, but a NC contact is needed to implement the required logic.

The logical function of a contact may be inverted using a second relay that contains the opposite type of contact.



Other Issues

The logical function of a contact (or statement) may be inverted using an additional relay that contains a NC contact.



When A is <u>open</u>, CR is closed, and the Output is "on".

When A is <u>closed</u>, CR is open, and the Output is "off".

$$Output = \overline{A}$$