TTE Training Ltd.

Phase 2

Electrical Course Notes

E2-CN-014

Programmable Logic Controllers

PLC HARDWARE

Topics:

- PLC hardware configurations
- Input and output types
- Electrical wiring for inputs and outputs
- Relays
- Electrical Ladder Diagrams

Objectives:

- Be able to understand and design basic input and output wiring.
- Be able to produce industrial wiring diagrams.

1 INTRODUCTION

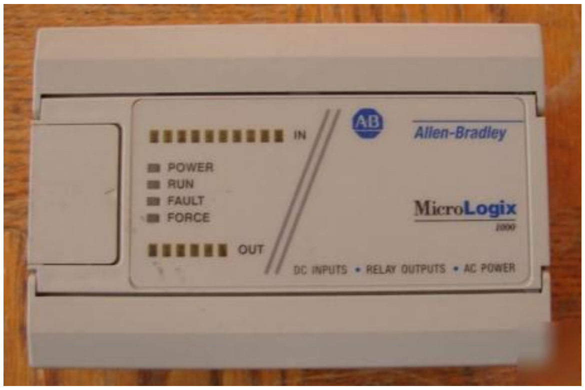
Many PLC configurations are available, even from single vendor, but in each of these there are common components and concepts. The most essential components are:

Power Supply - This can be built into the PLC or be external unit. Common voltage levels required by the PLC (with and without the power supply) are 24Vdc, 120Vac, 220Vac.

CPU (Central Processing Unit) – This is a computer where ladder logic is stored and processed. I/O (Input/Output) – A number of input/output terminals must be provided so that the PLC can monitor the process and initiate actions.

Indicator lights – These indicate the status of the PLC including power on, program running, and a fault. These are essential when diagnosing problems.

The configuration of the PLC refers to the packaging of the components. Typical configurations are listed below from smallest to largest as shown on next page.



Micro – These units can be small as a deck of cards. They tend to have fixed quantities of I/O and limited abilities, but costs will be the lowest.

Mini – These are smaller full-sized PLC racks but can have the same IO capacity.

Rack - A rack is often large (up to 18” by 30” by 10”) and can hold multiple cards. When necessary, multiple racks can be connected together. These tend to be the highest cost, but also the most flexible and easy to maintain.

2 INPUTS AND OUTPUTS

Inputs to, and outputs from, a PLC are necessary to monitor and control a process. Both inputs and outputs can be categorized into two basic types: logical or continuous. Consider the example of a light bulb. If it can only be turned on or off, it is logical control. If the light can be dimmed to different levels, it is continuous. Continuous values seem more intuitive, but logical values are preferred because they allow more certainty and simplify control. As a result, most controls applications (and PLCs) use logical inputs and outputs for most applications. Hence, we will discuss logical I/O and leave continuous I/O for later.

Outputs to actuators allow a PLC to cause something to happen in a process. A short list of popular actuators is given below in order of relative popularity.

Solenoid Valves – logical outputs that can switch a hydraulic or pneumatic flow.

Lights – logical outputs that can often be powered directly from PLC output boards.

Motor Starters - motors often draw a large amount of current when started, so they require motor starters, which are basically large relays.

Servo Motors – a continuous output from the PLC can command a variable speed or position.

Outputs from PLCs are often Relays but they can also be solid state electronics such as transistors for DC outputs or Triac’s for AC outputs. Continuous outputs require special output cards with digital to analogue converters.

Inputs come from sensors that translate physical phenomena into electrical signals. Typical examples of sensors are listed below in relative order of popularity.

Proximity Switches – use inductance, capacitance, or light to detect an object logically.

Switches – mechanical mechanisms will open or close electrical contracts for a logical signal.

Potentiometer – measures angular positions continuously, using resistance.

LVDT (linear variable differential transformer) – measures linear displacement continuously using magnetic coupling.

Inputs for a PLC come in a few basic varieties, the simplest are AC and DC inputs. Sourcing and sinking inputs are also popular. This output method dictates that a device does not supply any power. Instead, the device only switches current on or off, like a simple switch.

Sinking – When active the output allows current to flow to common ground. This is best selected when different voltages are supplied. *e.g., Allen-Bradley SLC500 Input Card*

Sourcing – When active, current flows from a supply, through the output device and to ground. This method is best used when all devices use a single supply voltage. *e.g., Allen-Bradley SLC500 Output Card*

This is also referred to as NPN (sinking) and PNP (sourcing). PNP is more popular. This will be covered in detail in the chapter on sensors.

3. Inputs

In smaller PLCs the inputs are normally built in and are specified when purchasing the PLC. For larger PLCs the inputs are purchased as modules, or cards, with 8 or 16 inputs of the same type of each card. For discussion purposes we will discuss all inputs as if they have been purchased as cards. The list below shows typical ranges for input voltages and is roughly in order of popularity.

12-24 Vdc
100-120 Vac
10-60 Vdc
12-24 Vac/dc
5 Vdc (TTL)
200-240 Vac
48 Vdc
24 Vac

PLC input cards rarely supply power, this means that an external power supply is needed to supply power for the inputs and sensors.

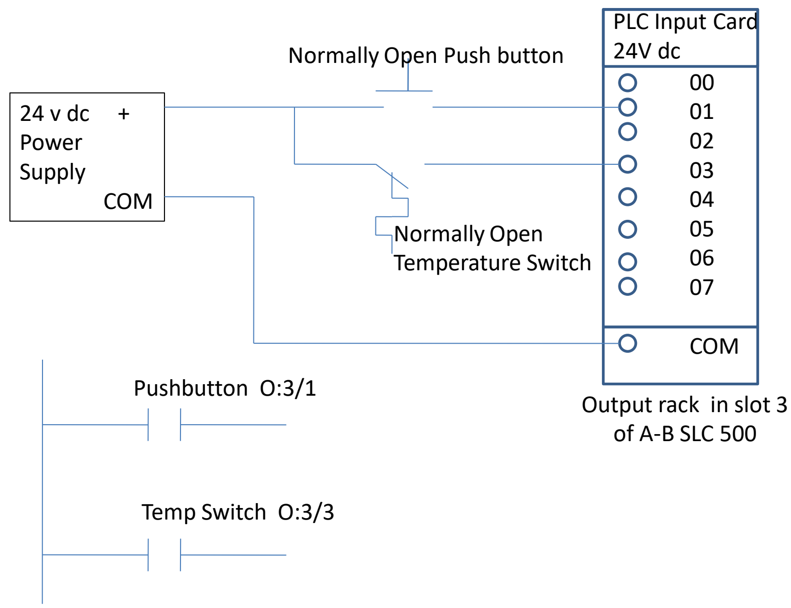


*Figure 2: A DC Input Card and Ladder Logic - **Sinking***

In the example there are two inputs, one is a normally open push button, and the second is a temperature switch, or thermal relay. Both of the switches are powered by the positive output of the 24Vdc power supply. Power is supplied to the left side of both of the switches. When the switches are open there is no voltage passed to the input card. If either of the switches are closed power will be supplied to the input card. In this case inputs 1 and 3 are used – notice that the inputs start at 0. The input card compares these voltages to the common. If the input voltage is within a given tolerance range the inputs will switch on. Ladder logic is shown in the figure for the inputs.

NOTE: The design process will be much easier if the inputs and outputs are planned first.

Many beginners become confused about where connections are needed in the circuit above. The key word to remember is circuit, which means that there is a full loop that the voltage must be able to follow. In Figure 2 we can start following the circuit (loop) at the power supply. The path goes through the switches, through the input card, and back to the power supply where it flows back through to the start. In a full PLC implementation, there will be many circuits that must each be complete.

A second important concept is the common. Here the negative on the power supply is the common, or reference voltage. In effect we have chosen this to be our 0V reference, and all other voltages are measured relative to it.

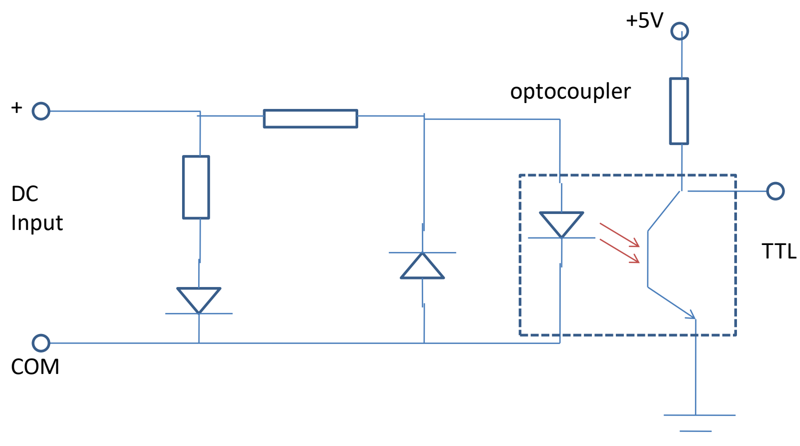
Remember – Don't mix up the ground and common. Don't connect them together if the common of your device is connected to a common on another device.

One final concept that tends to trap beginners is that each input card is isolated. This means that if you have connected a common to only one card, then the other cards are not connected. When this happens, the other cards will not work properly. You must connect a common for each of the output cards.

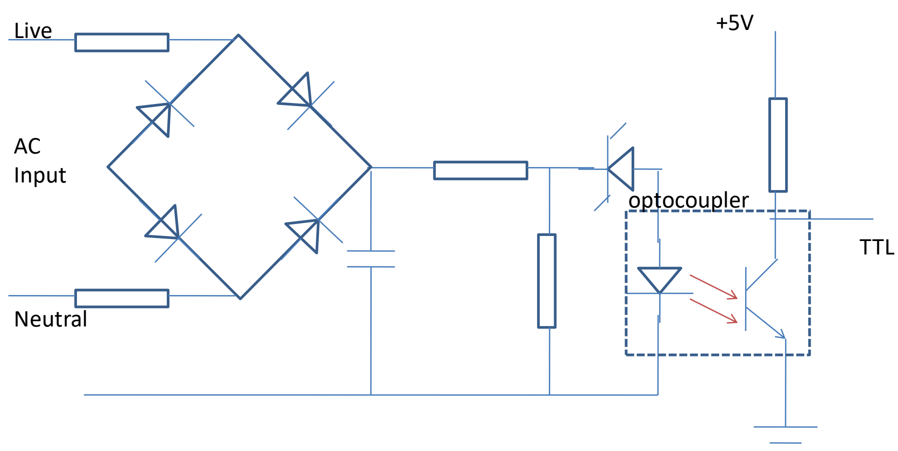
There are many trade-offs when deciding which type of input cards to use.

- DC voltages are usually lower, and therefore safer (i.e., 12-24V)
- DC inputs are very fast, AC inputs require a longer on-time. For example, a 50Hz wave may require up to 1/50secs for reasonable recognition.
- DC voltages can be connected to larger variety of electrical systems.
- AC signals are more immune to noise than DC, so they are suited to long distances, and noisy (magnetic) environments.
- AC power is easier and less expensive to supply to equipment.
- AC signals are very common in many existing automation devices.

NOTE: PLC inputs must convert a variety of logic levels to the 5Vdc logic levels used on the data bus. This can be done with circuits similar to those shown below. Basically, the circuits condition the input to drive an optocoupler. This electrically isolates the external electrical circuitry from the internal circuitry. Other circuit components are used to guard against excess or reversed voltage polarity.



PLC Input Circuits



4 Output Modules

WARNING – ALWAYS CHECK RATED VOLTAGES AND CURRENTS FOR PLC'S AND NEVER EXCEED!

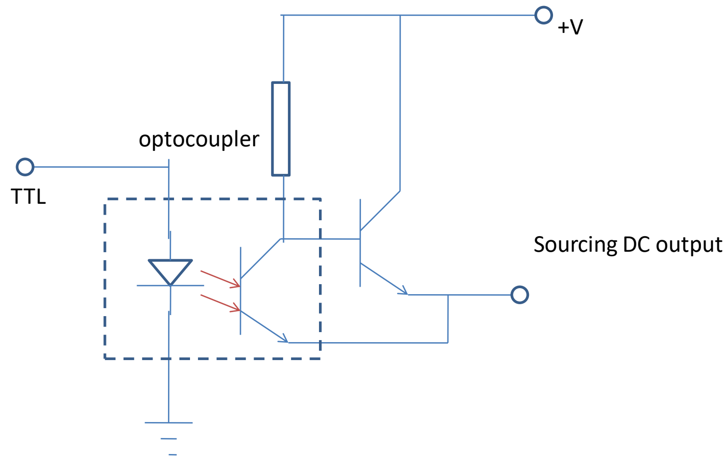
As with input modules, output modules rarely supply any power, but instead act as switches. External power supplies are connected to the output card and the card will switch the power on or off for each output. Typical output voltages are listed below.

120 Vac
24 Vdc
12-48Vac
5Vdc
230 Vac

These cards typically have 8 to 16 outputs of the same type and can be purchased with different current ratings. A common choice when purchasing output cards is relays, transistor or Triac's. Relays are the most flexible output devices. They are capable of switching both AC and DC outputs. But they are slower (about 10ms switching is typical), they are bulkier, they cost more. And they will wear out after millions of cycles. Transistors are limited to DC outputs, and Triac's are limited to AC outputs. Transistor and Triac outputs are called switched outputs.

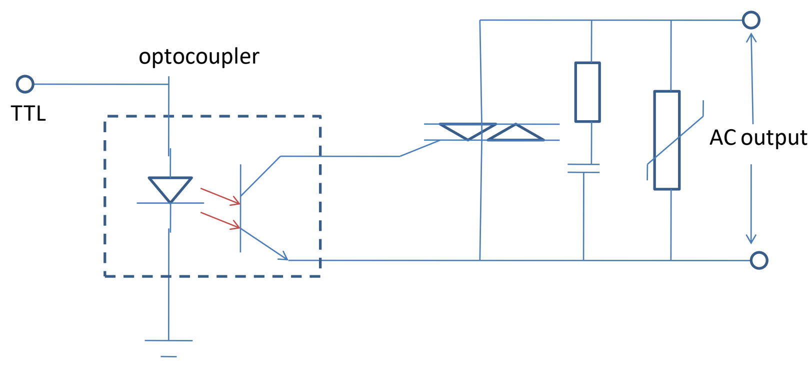
Relay contacts – a separate relay is dedicated to each output. This allows mixed voltages (AC or DC and voltage levels up to maximum), as well as isolated outputs to protect other outputs and the PLC. Response times are often greater than 10ms. This method is the least sensitive to voltage variations and spikes.

Switched outputs – a voltage is supplied to the PLC card, and the card switches it to different outputs using solid state circuitry (transistors, Triacs, etc.) Triacs are well suited to AC devices requiring less than 1A. Transistor outputs use NPN or PNP transistors up to 1A typically. Their response time is well under 1ms.

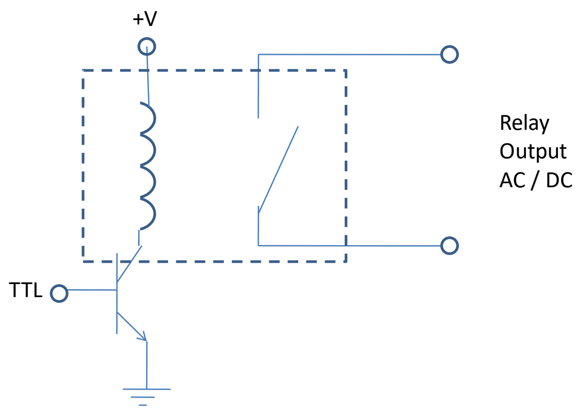


PLC output circuit

NOTE: PLC outputs must convert the 5Vdc logic levels on the PLC data bus to external voltage levels. This can be done with circuits similar to those shown below. Basically, the circuits use an optocoupler to switch external circuitry. This electrically isolates the external electrical circuitry from the internal circuitry. Other circuit components are used to guard against excess or reversed voltage polarity.



PLC output circuit



PLC output circuit

Figure 4: PLC Output Circuits

Caution is required when building a system with both AC and DC outputs. If AC is accidentally connected to a DC transistor output, it will only be on for the positive half of the cycle and appear to be working with a diminished voltage. If DC is connected to an AC Triac output it will turn on and appear to work, but you will not be able to turn it off without turning off the entire PLC.

A major issue with outputs is mixed power sources. It is good practice to isolate all power supplies and keep their commons separate, but this is not always feasible. Some output modules, such as relays, allow each output to have its own common. Other output cards require that multiple, or all, outputs on each card share the same common. Each output card will be isolated from the rest, so each common will have to be connected. It is common for beginners to only connect the common to one card and forget the other cards – then only one card seems to work!

The output card shown in Figure 5 is an example of a 24Vdc output card that has a shared common. This type of output card would typically use transistors for the outputs.

In this example the outputs are connected to a low current light bulb (lamp) and a relay coil. Consider the circuit through the lamp, starting at 24Vdc supply. When the output 07 is on, current can flow in 07 to the COM, thus completing the circuit, and allowing the light to turn on. If the output is off the current cannot flow, and the light will not turn on. The output 03 for the relay is connected in a similar way. When the output 03 is on, current will flow through the relay coil to close the contacts and supply 120Vac to the motor. Ladder logic for the outputs is shown in the bottom right of the figure.

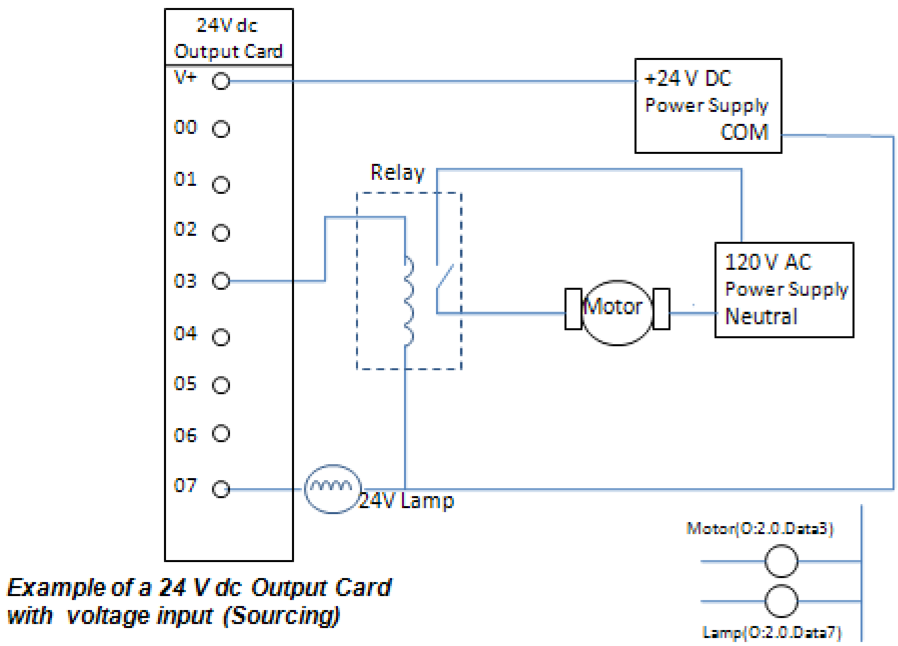


Figure 5: An example of a 24Vdc Output Card with a voltage input (Sourcing) as per Allan Bradley SLC500 plc

In this example the positive terminal of the 24Vdc supply is connected to the output card directly. When an output is on power will be supplied to the output. For example, if output 07 is on them the supply voltage will be output to the lamp. Current will flow through the lamp and back to the common on the power supply. The operation is very similar for they relay switching the motor. With this type of output card only one power supply can be used.

Basic Ladder Logic Programming

Ladder Logic is the primary programming language of programmable logic controllers. Since the PLC was developed to replace relay logic control systems, it was only natural that the initial language closely resembles the diagrams used to document the relay logic. By using this approach, the engineers and technicians using the early PLCs did not need retraining to understand the program. To introduce ladder logic programming simple switch circuits are converted to relay logic and then to PLC ladder logic.

In all ladder logic examples used in this chapter symbols are used for all inputs, outputs, and internal memory in the examples to avoid having to deal with input/output addressing. This addressing is generally different for each PLC manufacturer.

Example 1 OR circuit.

Two switches labelled A and B are wired in parallel controlling a lamp as shown on the next page. Implement this function as PLC ladder logic where the two switches are separate inputs.

Solution. The switch circuit action is described as. 'The lamp is **on** when switch A is **on** (closed), or switch B is **on** (closed).' All possible combinations of the two switches and the consequent lamp action can be shown as a truth table. *Individual exercise, produce a Truth Table*

To implement this function using relays, the switches A and B are not connected to the lamp directly but are connected to relay coils labelled AR and BR which are normally – open.

The switches, A and B, are the inputs to the circuit. When either switch A and B is closed, the corresponding relay coil AR or BR is energized, closing a contact and supplying power to the lamp.

The output (lamp in this case) is driven by the LR relay to provide voltage isolation from the relays implementing the logic. The switches, A and B, control relay coils (AR and BR) isolate the inputs from the logic. Also, with this arrangement, the one switch connection to an input relay can be used multiple times in the logic. A typical industrial control relay can have up to 12 poles, or sets of contacts, per coil. For example, if the AR relay has six poles (only one shown), then the other five poles are available for use in the relay logic without requiring five other connections to switch A.

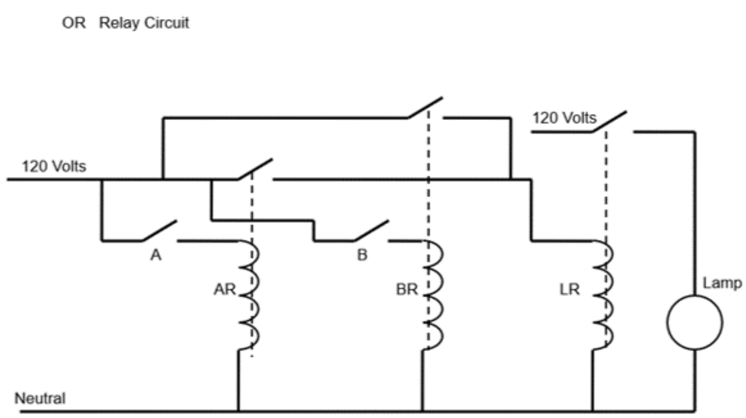
Before the PLC was developed, engineers had already developed a graphical electrical circuit shorthand notation for the relay circuit. This notation was called a *relay ladder logic diagram*, shown. The switches are shown as their usual symbol, the circles indicate the relay coils, and the NO *(normally open)* relay contacts are shown as the vertical parallel bars.

The PLC *ladder logic* notation is shortened from the relay wiring diagram to show only the third line, the relay contacts and the coil of the output relay. The PLC ladder logic notation assumes that the inputs (switches in this example) are connected to discrete input channels (equivalent to the relay coils AR and BR). Also, the actual output (lamp) is connected to a discrete output channel (equivalent to the normally open contacts of LR in) controlled by the coil. The label shown above a contact symbol is not the contact label, but the control for the coil that drives the contact. Also, the output for the rung occurs on the extreme right side of the rung and power is assumed to flow from left to right. The PLC ladder logic run is interpreted as: 'When input (switch) A is **on** OR input (switch) B is **on** then the lamp is **on**,' which is the same as the statement describing the switch circuit in.

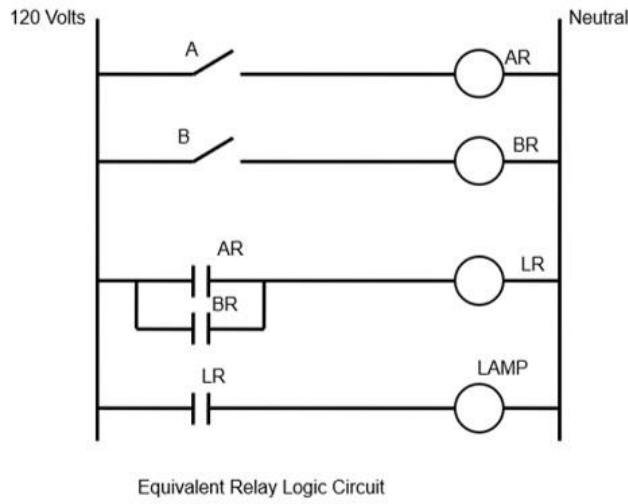
Notice that the original description of the switch circuit,

The lamp is **on** when switch A is **on,** or switch B is **on.**

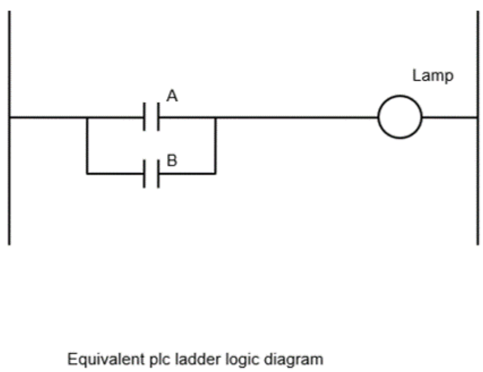
Translates into a relay circuit described as a parallel connection of **normally open contacts,** which describes the PLC ladder logic.



(a)



(b)



(c)

Parallel switch relay and ladder logic circuits i.e., OR function: (a) equivalent relay circuit; (b) equivalent relay ladder logic circuit; (c) equivalent PLC ladder logic.

Example 2 AND Circuit*.*

Two switches labelled A and B are wired in series controlling a lamp as shown. Implement this function as PLC ladder logic where the two switches are separate inputs.

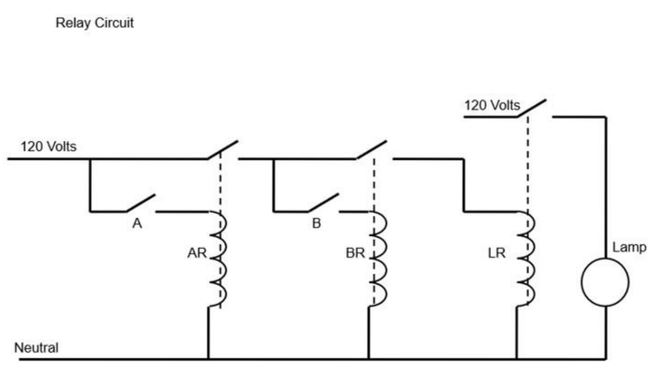
Solution. The switch circuit action is described as, 'The lamp is **on** (closed) ***and*** switch B is **on** (closed).' All possible combinations of the two switches and the consequent lamp action are shown as a truth table. *Individual exercise, produce a Truth Table*

To implement this function using relays, the only change from OR circuit example is to wire the normally open contacts of control relays AR and BR in series to control the light, the wiring of switches A and B and the wiring of the lamp do not change. The relay circuit diagram, shown in below is different from the previous OR circuit only in the third line. As for OR circuit, the PLC ladder logic notation is shortened from the relay wiring diagram to show only the third line, the relay contacts, and the coil of the output relay. The PLC ladder logic rung is interpreted as: 'When input (switch) A is **on** AND input (switch) B is **on** then the lamp is **on**'.

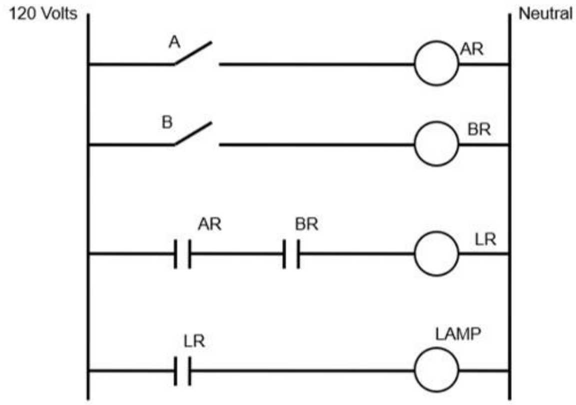
Notice that the original description of the switch circuit.

The lamp is **on** when switch A is **on,** and switch B is **on.**

Translates into a relay circuit described as a series connection of **normally – open contacts,** which describes the PLC ladder logic.

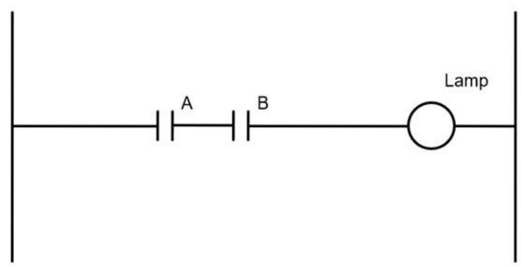


(a)



Equivalent Relay Logic Circuit

(b)



Equivalent plc ladder logic diagram

(c)

AND function ladder logic circuits; (a) equivalent relay circuit; (b) equivalent relay ladder (c) equivalent PLC ladder logic.

Example 3 NOT circuit.

As third example, consider the implementation of a logical NOT functions. Suppose a lamp needs to be turned **on** when switch A is **on** (closed) and switch B is **off** (open). Implement this function as PLC ladder logic where two switches are separate inputs.

Solution. Fig *Individual exercise produce a Truth Table The diagrams below show the* relay implementation and ladder logic for this example. The only difference between the relay implementation previously is the wiring of the relay BR contacts. The logical NOT for switch B is accomplished with the normally closed (NC) contact of relay BR. The PLC ladder logic rung in the NOT circuit is different from the AND circuit only in the second contact symbol. The PLC ladder logic is interpreted as: 'When input (switch) A is **on** (closed) and input (switch) B is **off** (open) then the lamp is **on.'**

Notice that the original description of the NOT circuit, the lamp is **on** when switch A is **on** and switch B is **off** translating into a relay circuit described as a series connection of a **normally open contact** and a **normally closed contact,** which describes the PLC ladder logic below.

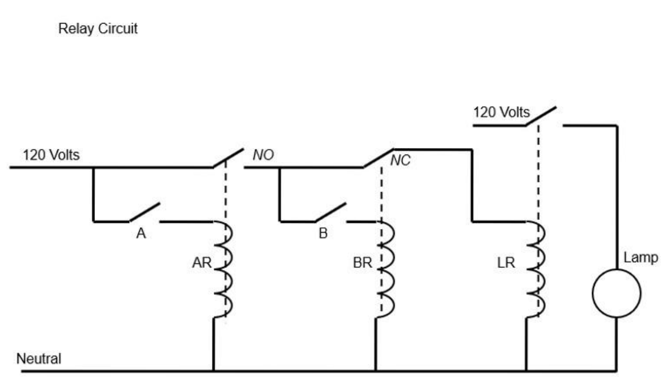
Summarizing these three examples, one should notice that key words in the description of the operation translate into certain aspects of the solution:

And - series connection of contacts

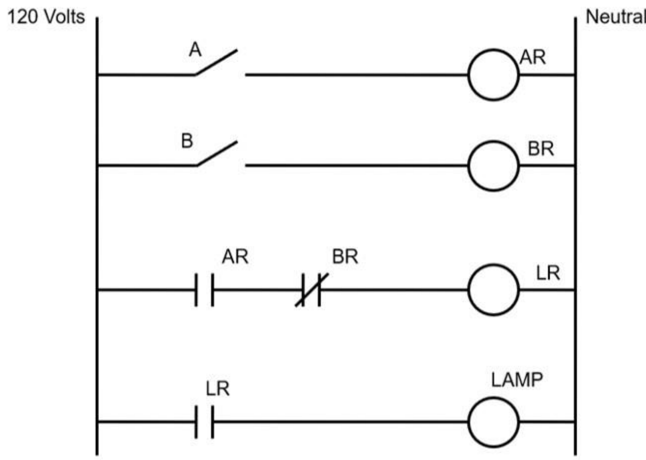
or - parallel connection of contacts

On – normally-open contact

Off – normally-closed contact

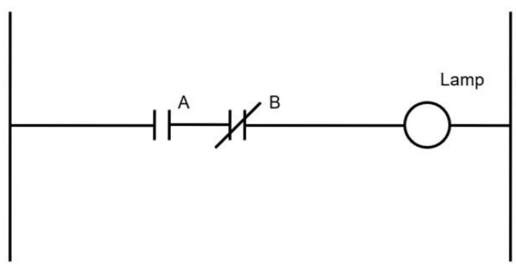


(a)



Equivalent Relay Logic Circuit

(b)



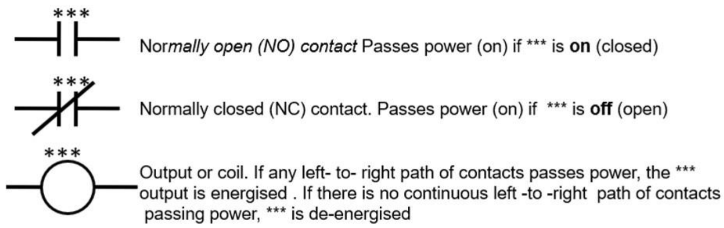
Equivalent plc ladder logic diagram

(c)

NOT function ladder logic circuits; (a) equivalent relay circuit; (b) equivalent relay ladder (c) equivalent PLC ladder logic.

BASIC LADDER LOGIC SYMBOLS

At this point, one should start interpreting ladder logic directly and not think of its implementation with relays. As introduced by the examples in the previous section, the basic ladder logic symbols are:



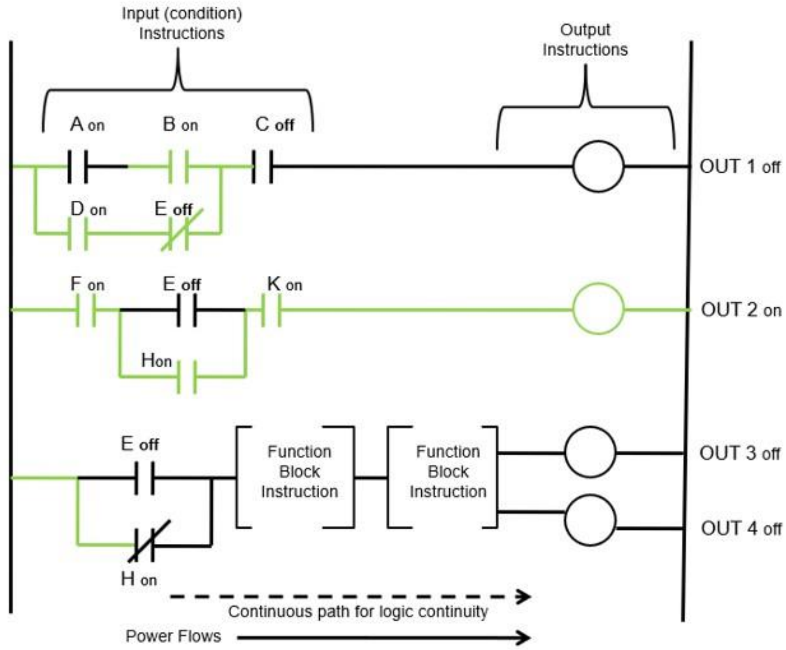
LADDER LOGIC DIAGRAM

An example PLC ladder logic diagram appears below. The vertical lines on the left and right are called the power rails. The contacts are arranged horizontally between the power rails, hence the term *rung*. The ladder diagram on below has three rungs.

The example diagram is what you would expect to see if monitoring (usually with a laptop computer) the running program in the PLC. The coloured lines indicate continuity, and the state **(on/off)** of the inputs and outputs is shown next to the tag. Regardless of the contact symbol, if the contact is closed (continuity through it), it is shown as coloured lines. If the contact is open, it is shown as thin lines. In a relay ladder diagram, power flows from left to right. In PLC ladder logic, there is no real power flow, but there still must be a continuous path through closed contacts in order to energize an output.

In the example the output on the first rung is **off** because the contact for C is open, blocking continuity through the B and E contacts. Also notice that the E input is **off,** which means the NC contact in the first rung is closed and the NO contact in the second rung is open.

This example also introduces the concept of *function block instructions.* Any instruction that is not a contact or a coil is called a function block instruction because of its appearance in the ladder diagram. The most common function block instructions are timer, counter, comparison, and computation operations. More advanced function block instructions include sequencer, shift register, and first-in-first out operations.



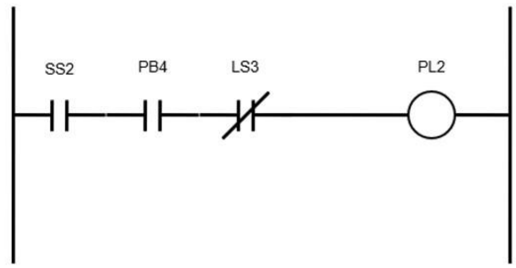
Example 4 – Draw a ladder diagram that will cause the output, pilot light PL2, to be **on** when selector switch SS2 is **closed**, push-button PB4 is **closed** and limit switch LS3 is **not open** (Note: no, I/O addresses yet)

Solution: the first question to answer is 'what is the output'? The output is PL2, so the coil labelled as PL2 is put on the right side of the rung. Secondly, consider the type of connection of contacts to use. Since **all** three switches must be in a certain position to turn on the pilot light, a series connection is needed. Thirdly, the type of contact is determined by the switch position to turn the pilot light.

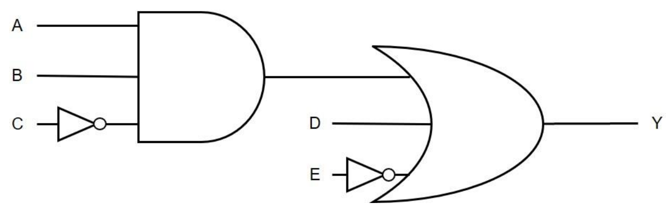
Putting all the pieces together, only one rung of ladder logic is needed, as shown below.

Design Tip

The concept of placing the output on the rung first and then 'looking back' to determine the input conditions is very important. Because of the way the diagram is configured, one tends to consider the input conditions first and then position the output coil as the last step. As will be shown later, the coil or negated coil instruction referring to a particular output coil first and the conditions for which is active (on) will avoid repeating coils.



Solution to Pilot Light output



Example 5 – Draw a ladder diagram that is equivalent to the digital logic diagram shown above, which is the same as the following descriptions.

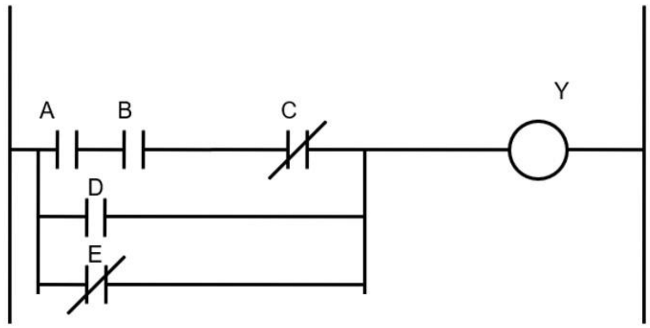
In words: Y is **on** when (A is **on** and B is **on,** and C is **off**.) or D is **on,** or E is **off**

Boolean logic equation:

$Y = AB\overline{C} + D + \overline{E}$

Solution

First answer, 'what is the output?' The output is Y, so the coil labelled as Y is put on the right side of the rung. Secondly, consider the type of connection of contacts to use. For this problem, there is more than one type of connection. The three inputs A, B and C within the AND gate are connected with 'and', so a <u>series</u> connection is required for these three contacts. The other two inputs (D and E) are connected with the three series contacts by 'or' (the OR gate inputs), so a parallel connection is required. Thirdly, the type of contact is determined by the input state that turns **on** the output, Y. Putting all the parts together, only one rung of ladder logic is needed, as shown.

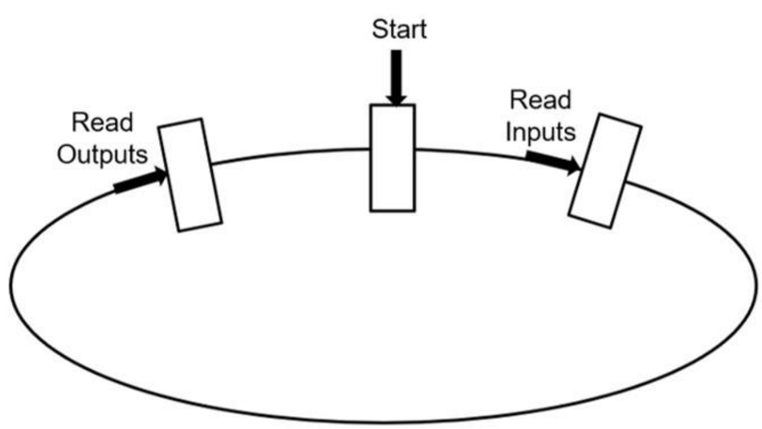


PLC PROCESSOR SCAN

In addition to scanning the ladder logic, the PLC processor must also read the state of its physical inputs and set the state of the physical outputs. These three major tasks in a PLC processor scan are executed in the following order:

- Read the physical inputs.
- Scan the ladder logic program.
- Write the physical outputs.

The processor repeats these tasks as long as it is running, as shown below. The time required to complete these three tasks is defined as the scan time and is typically 1-200 milliseconds, depending on the length of the ladder logic program. For very large ladder logic programs, the scan time can be more than one second.



Program (ladder Logic) Execution