Starting with the input, we have the normally open symbol | | for the input contacts. There are no other input devices and the line terminates with the output, denoted by the symbol ( ). When the switch is closed, i.e. there is an input, the output of the motor is activated. Only while there is an input to the contacts is there an output. If there had been a normally closed switch |/| with the output (Figure 5.5(b)), then there would have been an output until that switch was opened. Only while there is no input to the contacts is there an output.

In drawing ladder diagrams the names of the associated variable or addresses of each element are appended to its symbol. Thus Figure 5.6 shows how the ladder diagram of Figure 5.5(a) would appear using (a) Mitsubishi, (b) Siemens, (c) Allen-Bradley, (d) Telemecanique notations for the addresses. Thus Figure 5.6(a) indicates that this rung of the ladder program has an input from address X400 and an output to address Y430. When wiring up the inputs and outputs to the PLC, the relevant ones must be connected to the input and output terminals with these addresses.

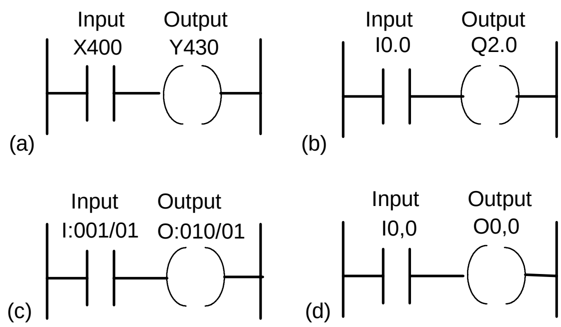

Figure 5.6 *Notation: (a) Mitsubishi, (b) Siemens, (c) Allen-Bradley, (d) Telemecanique*

5.2 Logic functions

There are many control situations requiring actions to be initiated when a certain combination of conditions is realised. Thus, for an automatic drilling machine (as illustrated in Figure 1.1(a)), there might be the condition that the drill motor is to be activated when the limit switches are activated that indicate the presence of the workpiece and the drill position as being at the surface of the workpiece. Such a situation involves the AND logic function, condition A and condition B having both to be realised for an output to occur. This section is a consideration of such logic functions.

5.2.1 AND

Figure 5.7(a) shows a situation where an output is not energised unless two, normally open, switches are both closed. Switch A and switch B have both to be closed, which thus gives an AND logic situation. We can think of this as representing a control system with two inputs A and B (Figure 5.7(b)). Only when A and B are both on is there an output. Thus if we use 1 to indicate an on signal and 0 to represent an off signal, then for there to be a 1 output we must have A and B both 1. Such an operation is said to be controlled by a *logic gate* and the relationship between the inputs to a logic gate and the outputs is tabulated in a form known as a *truth table*. Thus for the AND gate we have:

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

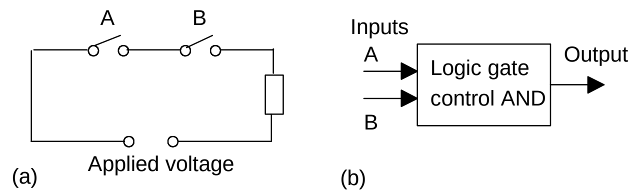

Figure 5.7 *(a) AND circuit, (b) AND logic gate*

An example of an AND gate is an interlock control system for a machine tool so that it can only be operated when the safety guard is in position and the power switched on.

Figure 5.8(a) shows an AND gate system on a ladder diagram. The ladder diagram starts with | |, a normally open set of contacts labelled input A, to represent switch A and in series with it | |, another normally open set of contacts labelled input B, to represent switch B. The line then terminates with O to represent the output. For there to be an output, both input A and input B have to occur, i.e. input A and input B contacts have to be closed (Figure 5.8(b)). In general:

> *On a ladder diagram contacts in a horizontal rung, i.e. contacts in series, represent the logical AND operations.*

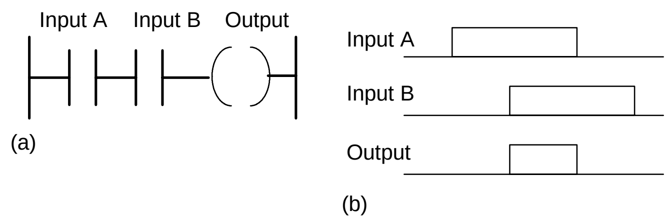

Figure 5.8 *AND gate with a ladder diagram rung*

5.2.2 OR

Figure 5.9(a) shows an electrical circuit where an output is energised when switch A <u>or</u> B, both normally open, are closed. This describes an OR logic gate (Figure 5.9(b)) in that input A <u>or</u> input B must be on for there to be an output. The truth table is:

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

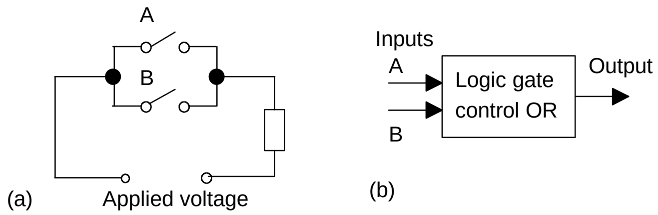

Figure 5.9 *(a) OR electrical circuit, (b) OR logic gate*

Figure 5.10(a) shows an OR logic gate system on a ladder diagram, Figure 5.10(b) showing an equivalent alternative way of drawing the same diagram. The ladder diagram starts with | |, normally open contacts labelled input A, to represent switch A and in parallel with it | |, normally open contacts labelled input B, to represent switch B. Either input A or input B have to be closed for the output to be energised (Figure 5.10(c)). The line then terminates with O to represent the output. In general:

Alternative paths provided by vertical paths from the main rung of a ladder diagram, i.e. paths in parallel, represent logical OR operations.

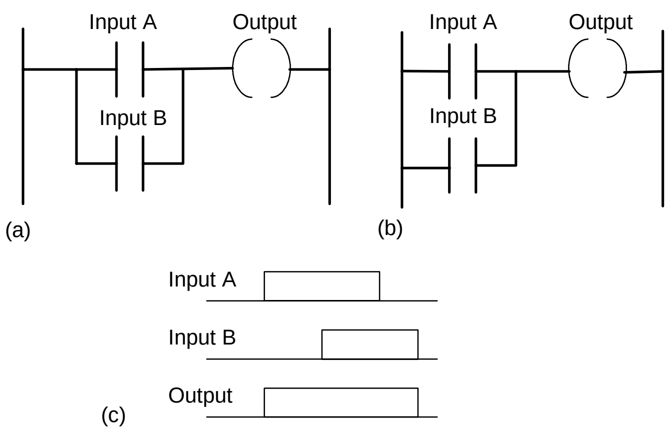

Figure 5.10 *OR gate*

An example of an OR gate control system is a conveyor belt transporting bottled products to packaging where a deflector plate is activated to deflect bottles into a reject bin if either the weight is not within certain tolerances or there is no cap on the bottle.

5.2.3 NOT

Figure 5.11(a) shows an electrical circuit controlled by a switch that is normally closed. When there is an input to the switch, it opens and there is then no current in the circuit. This illustrates a NOT gate in that there is an output when there is no input and no output when there is an input (Figure 5.11(c)). The gate is sometimes referred to as an *inverter*. The truth table is:

Input A	Output
0	1
1	0

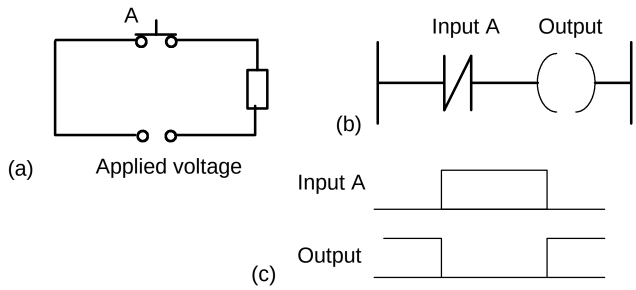

Figure 5.11 *(a) NOT circuit, (b) NOT logic with a ladder rung, (c) high output when no input to A*

Figure 5.11(b) shows a NOT gate system on a ladder diagram. The input A contacts are shown as being normally closed. This is in series with the output ( ). With no input to input A, the contacts are closed and so there is an output. When there is an input to input A, it opens and there is then no output.

An example of a NOT gate control system is a light that comes on when it becomes dark, i.e. when there is no light input to the light sensor there is an output.

5.2.4 NAND

Suppose we follow an AND gate with a NOT gate (Figure 5.12(a)). The consequence of having the NOT gate is to invert all the outputs from the AND gate. An alternative, which gives exactly the same results, is to put a NOT gate on each input and then follow that with OR (Figure 5.12(b)). The same truth table occurs, namely:

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

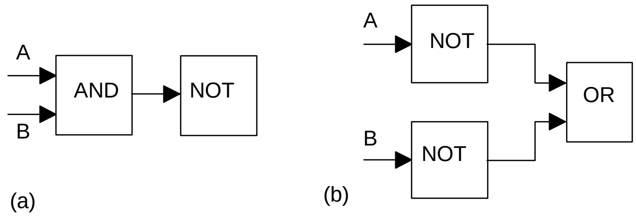

Figure 5.12 *NAND gate*

Both the inputs A and B have to be 0 for there to be a 1 output. There is an output when input A and input B are not 1. The combination of these gates is termed a NAND gate.

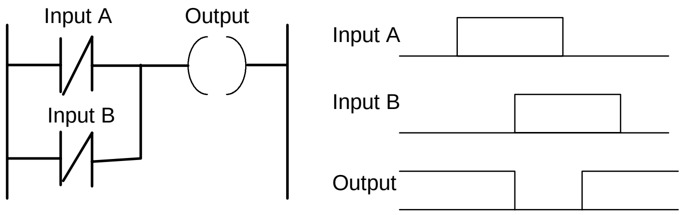

Figure 5.13 *A NAND gate*

Figure 4.18 shows a ladder diagram which gives a NAND gate. When the inputs to input A and input B are both 0 then the output is 1. When the inputs to input A and input B are both 1, or one is 0 and the other 1, then the output is 0.

An example of a NAND gate control system is a warning light that comes on if, with a machine tool, the safety guard switch has not been activated and the limit switch signalling the presence of the workpiece has not been activated.

5.2.5 NOR

Suppose we follow an OR gate by a NOT gate (Figure 5.14(a)). The consequence of having the NOT gate is to invert the outputs of the OR gate. An alternative, which gives exactly the same results, is to put a NOT gate on each input and then an AND gate for the resulting inverted inputs (Figure 5.14(b)). The following is the resulting truth table:

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

The combination of OR and NOT gates is termed a NOR gate. There is an output when neither input A or input B is 1.

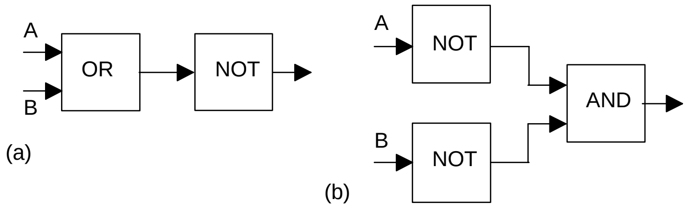

Figure 5.14 *NOR gate*

Figure 5.15 shows a ladder diagram of a NOR system. When input A and input B are both not activated, there is a 1 output. When either X400 or X401 are 1 there is a 0 output.

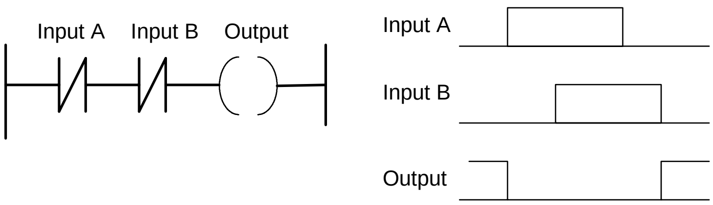

Figure 5.15 *NOR gate*

5.2.6 Exclusive OR (XOR)

The OR gate gives an output when either or both of the inputs are 1. Sometimes there is, however, a need for a gate that gives an output when either of the inputs is 1 but not when both are 1, i.e. has the truth table:

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

Such a gate is called an *Exclusive* OR or XOR gate. One way of obtaining such a gate is by using NOT, AND and OR gates as shown in Figure 5.16.

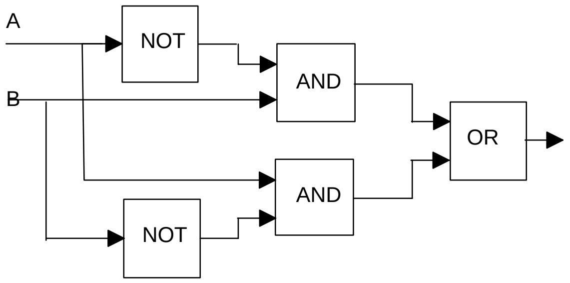

Figure 5.16 *XOR gate*

Figure 5.17 shows a ladder diagram for an XOR gate system. When input A and input B are not activated then there is 0 output. When just input A is activated, then the upper branch results in the output being 1. When just input B is activated, then the lower branch results in the output being 1. When both input A and input B are activated, there is no output. In this example of a logic gate, input A and input B have two sets of contacts in the circuits, one set being normally open and the other normally closed. With PLC programming, each input may have as many sets of contacts as necessary.

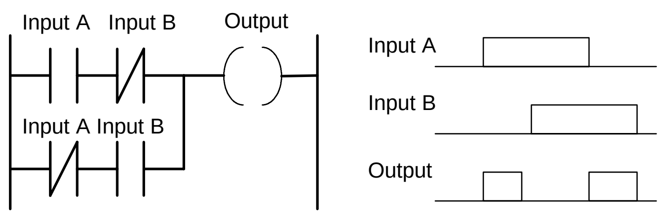

Figure 5.17 *XOR gate*

5.3 Latching

There are often situations where it is necessary to hold an output energised, even when the input ceases. A simple example of such a situation is a motor which is started by pressing a push button switch. Though the switch contacts do not remain closed, the motor is required to continue running until a stop push button switch is pressed. The term *latch circuit* is used for the circuit used to carry out such an operation. It is a self-maintaining circuit in that, after being energised, it maintains that state until another input is received.

An example of a latch circuit is shown in Figure 5.18. When the input A contacts close, there is an output. However, when there is an output, another set of contacts associated with the output closes. These contacts form an OR logic gate system with the input contacts. Thus, even if the input A opens, the circuit will still maintain the output energised. The only way to release the output is by operating the normally closed contact B.

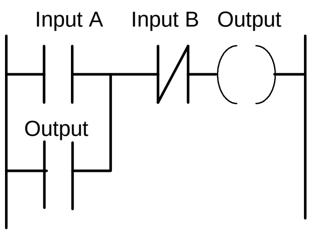

Figure 5.18 *Latched circuit*

As an illustration of the application of a latching circuit, consider a motor controlled by stop and start push button switches and for which one signal light must be illuminated when the power is applied to the motor and another when it is not applied. Figure 5.19 shows the ladder diagram with Mitsubishi notation for the addresses.

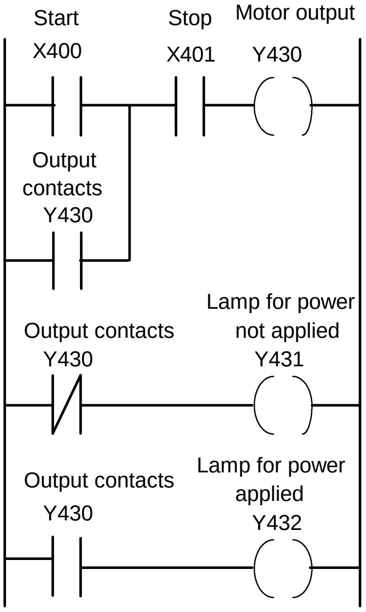

Figure 5.19 *Motor on-off, with signal lamps, ladder diagram. Note that the stop contacts X401 are shown as being programmed as open. If the stop switch used is normally closed then X401 receives a start-up signal to close. This gives a safer operation than programming X401 as normally closed.*

X401 is closed when the program is started. When X400 is momentarily closed, Y430 is energised and its contacts close. This results in latching and also the switching off of Y431 and the switching on of Y432. To switch the motor off, X401 is pressed and opens. Y430 contacts open in the top rung and third rung, but close in the second rung. Thus Y431 comes on and Y432 off.

Latching is widely used with start-ups so that the initial switch on of an application becomes latched on.

5.4 Multiple outputs

With ladder diagrams, there can be more than one output connected to a contact. Figure 5.20 shows a ladder program with two output coils. When the input contacts close both the coils give outputs.

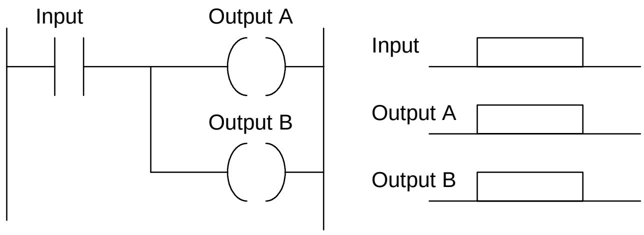

Figure 5.20 *Ladder rung with two outputs*

For the ladder rung shown in Figure 5.21, output A occurs when input A occurs. Output B only occurs when both input A and input B occur.

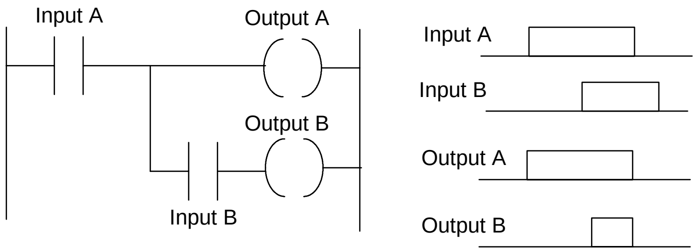

Figure 5.21 *Ladder rung with two inputs and two outputs*

Such an arrangement enables a sequence of outputs to be produced, the sequence being in the sequence with which contacts are closed. Figure 5.22 illustrates this with the same ladder program in Mitsubishi and Siemens notations. Outputs A, B and C are switched on as the contacts in the sequence given by the contacts A, B and C are being closed. Until input A is closed, none of the other outputs can be switched on. When input A is closed, output A is switched on. Then, when input B is closed, output B is switched on. Finally, when input C is closed, output C is switched on.

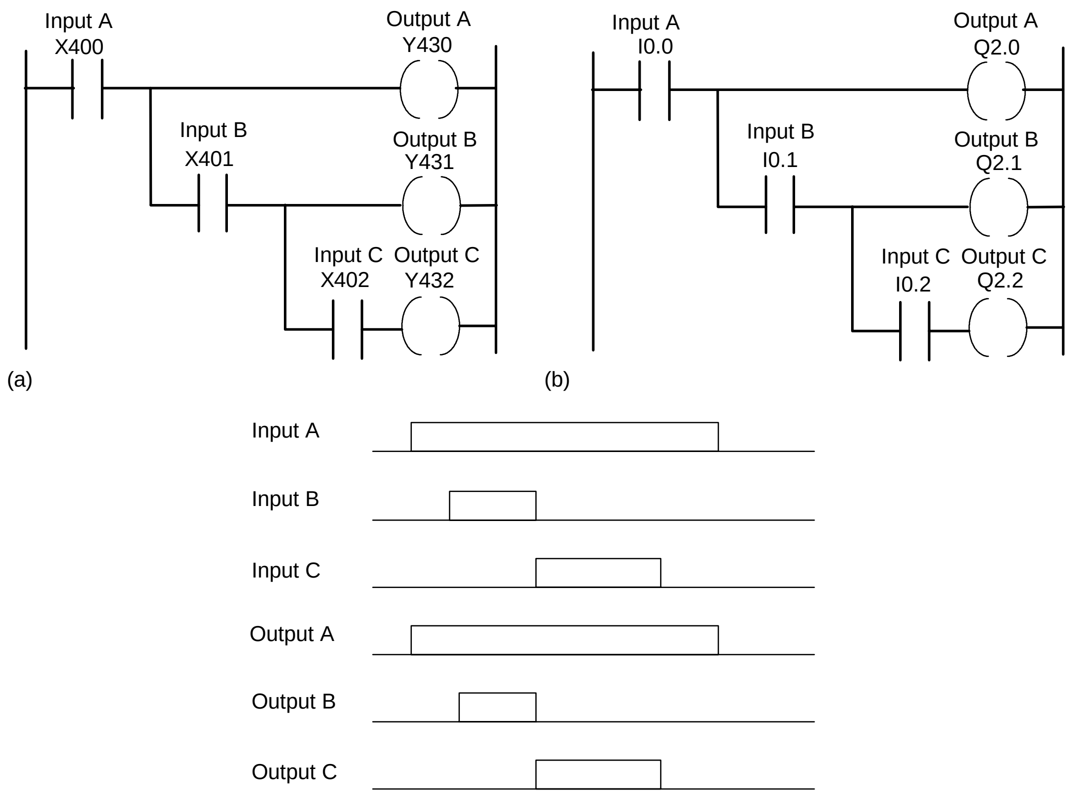

Figure 5.22 *Sequenced outputs*