Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 15: Automation, Robotics and Programmable Logic Controllers (PLCs)

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Design and Operational Characteristics of a PLC System

1.1 System Operational Characteristics

Unitary PLCs

This type of PLC exhibits all the features of a basic system within one compact unit. These may include …

- Power supply
- CPU (central processing unit)
- Outputs
- Inputs

Such compact unitary PLCs are commonly attached to the machine which they are intended to control.

ADVANTAGES

- Compactness
- A complete basic system
- Portability
- Cost effectiveness

DISADVANTAGES

- No scope for system expansion
- Failure often requires total replacement of the PLC
- Only basic functionality is available

Unitary PLCs are often used in applications such as;

- A small machine
- Overhead door control
- Car park access system
- Parts inspection system

Figure 1: *The unitary Micro820 PLC from Allen-Bradley*

Modular PLCs

This type of PLC exhibits more features than a basic system because modules may be slotted together. These modules may include …

- Power supply
- CPU (central processing unit)
- Outputs
- Inputs

Such modular PLCs are commonly expanded with modules to increase the number of inputs and/or outputs available.

ADVANTAGES

- Expansion
- Cost effective replacement of faulty modules

DISADVANTAGES

- More expensive than a typical unitary PLC

Modular PLCs are often used in applications where many inputs and outputs are required, such as process control in the manufacturing sector.

Figure 2: *Modular PLC units available from Siemens*

Rack-mounted PLCs

This type of PLC exhibits more features than both the unitary and modular types. They tend to be of a modular design, but these modules are usually supplied on cards which plug into slots on a rack, housed in a cabinet

ADVANTAGES

- Easy expansion
- Plentiful inputs and outputs
- Communication with other systems
- Direct replacement of faulty cards

DISADVANTAGES

- More expensive than a typical unitary or modular PLC
- Largest power consumption of the three types of PLC

Rack-mounted PLCs are often used in complex applications where many inputs and outputs are required, such as large process control systems in the manufacturing sector.

Figure 3: *Rack-mounted PLC system available from Unico*

Speed

The speed of a PLC is mainly governed by the clock supplied to the CPU (processor). Typical clock speeds can range from 1 MHz up to 1 GHz, and beyond, depending on the sophistication of the system.

Memory

The working program which controls the operation of a PLC is stored in RAM (random access memory). The RAM in a PLC can range anywhere from a few hundred kB up to hundreds of MB, again, depending on the sophistication of the system.

Scan Time

The Scan Time of a PLC is the time taken for it to review and store the data files which contain the statuses of all the inputs and outputs. Again, depending on the sophistication of the system, the scan time can be as long as several hundred milliseconds, or as short as several microseconds (or even less).

Voltage and Current Limits

PLCs can interface with analogue input and output devices. Analogue signals are continuously variable but the range of these signals must be limited to suitable working voltage and current ranges. These will depend upon the PLC you are working with, but a typical voltage range might be 0 to 10 V DC, and a typical current range 4 mA to 20 mA.

Input Devices

There are very many input devices which can be employed with a PLC. Here is a list …

- **mechanical switche for position detection**
- **proximity switch**
- **photoelectric switch**
- **encoder**
- **temperature sensor**
- **pressure sensor**
- potentiometer
- strain gauge
- thermistor
- thermotransistor

Let's have a look at some of the ones highlighted in Bold type;

Mechanical Switch for Position Detection

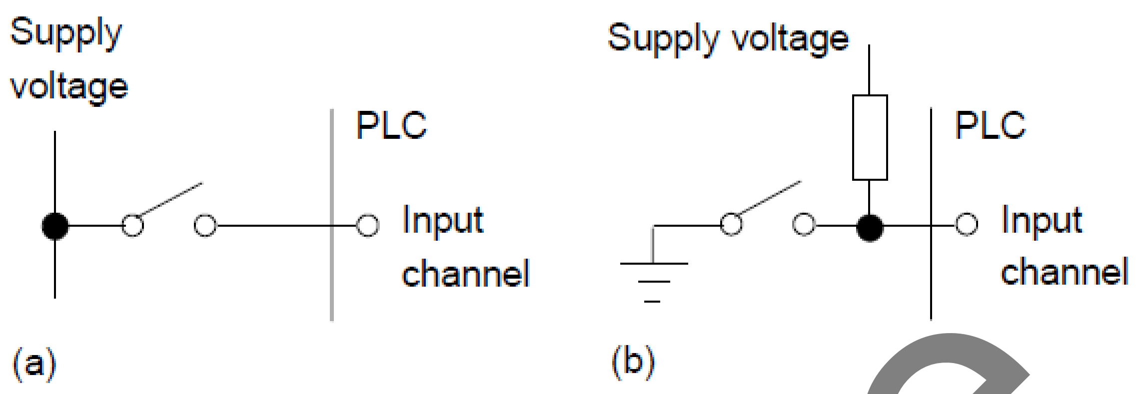

Figure 4: *Switching arrangements for position detection*

A mechanical switch may be closed when the presence of a specimen is detected. Configuration (a) causes a DC voltage to be applied to the PLC input when the specimen is present. Arrangement (b) causes 0V DC (ground) to be applied to the PLC input when the specimen is detected.

Proximity Switch

There are three main types of proximity switch;

EDDY CURRENT TYPE

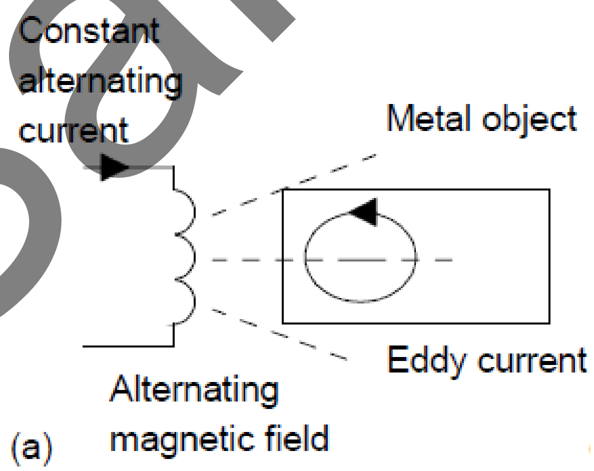

Figure 5: *Proximity switch using eddy currents*

The ac current through the coil produces a constant alternating magnetic field. Eddy currents are induced into any close-by metallic object, causing a back e.m.f. (reverse voltage spike) which influences the ac supply current. An integral transistor circuit can be used to assign logic low or logic high when this occurs.

REED SWITCH TYPE

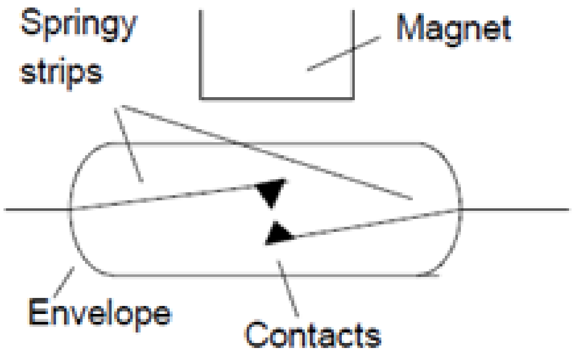

Figure 6: *Proximity switch using Reed contacts*

Reed contacts are normally close, but not touching. The presence of the magnetic field produced by the magnet causes the contacts to touch, completing a circuit. The removal of the magnet causes the contacts to spring back open.

CAPACITIVE TYPE

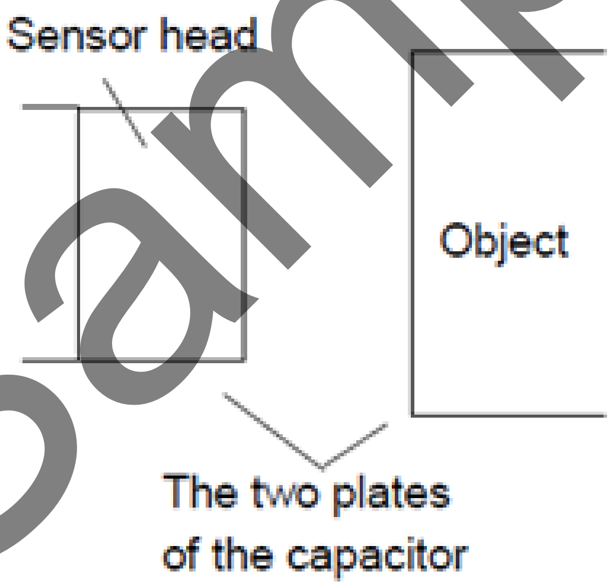

Figure 7: *Proximity switch using capacitor dielectric properties*

An object moving between the plates of a capacitor will change the dielectric's permittivity, and hence the capacitance – a change which can be processed as high or low.

Photoelectric Switch

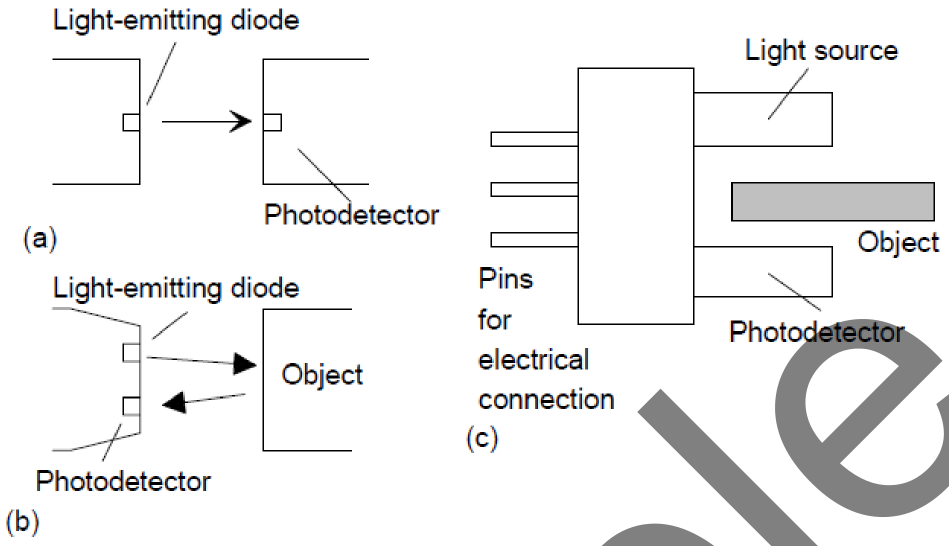

Figure 8: *Object detection using light sources and detectors*

- Transmissive type: detected object breaks a beam of light – (a)
- Reflective type: object reflects a beam of light onto a detector – (b)

In both types the light is emitted by an LED (infrared). The detector could be a photodiode, phototransistor or photo-conductive cell.

Encoder

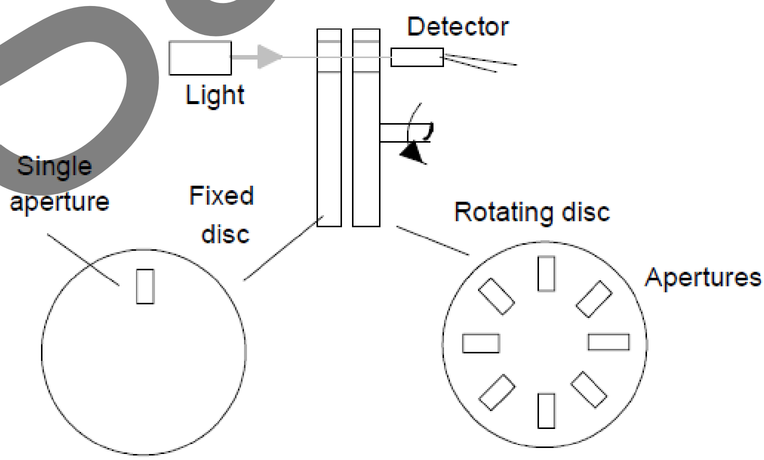

Figure 9: *Angle detection using an encoder*

LED light passes through slots in a disc, and is detected. When the disc is rotated the detected beam is goes and off. Therefore, a pulse is detected for each slot which passes by. The number of pulses is proportional to the angle through which the disc has rotated. With 60 slots then 6 degrees corresponds to moving from one slot to the next (total of 360 degrees, of course). Offset slots can produce much higher resolutions.

Temperature Sensor

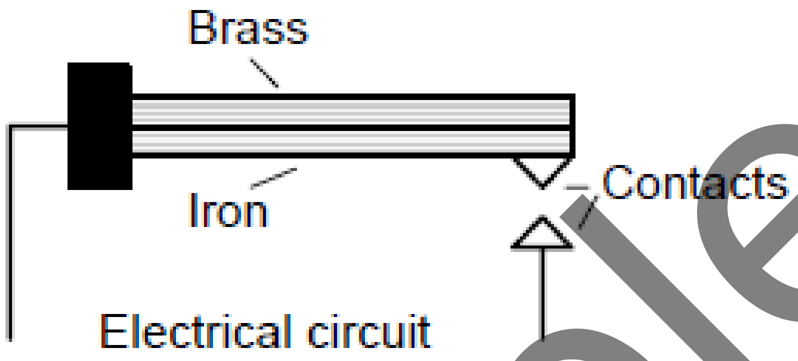

Figure 10: *Temperature detection using bi-metallic strips*

Two metal strips (commonly brass and iron) are bonded together. Each metal expands at different rates when the temperature varies. When the temperature increases the strip curves, causing the contacts to touch. For this to happen we need the metal with the highest expansion (brass) on the outside.

Pressure Sensor

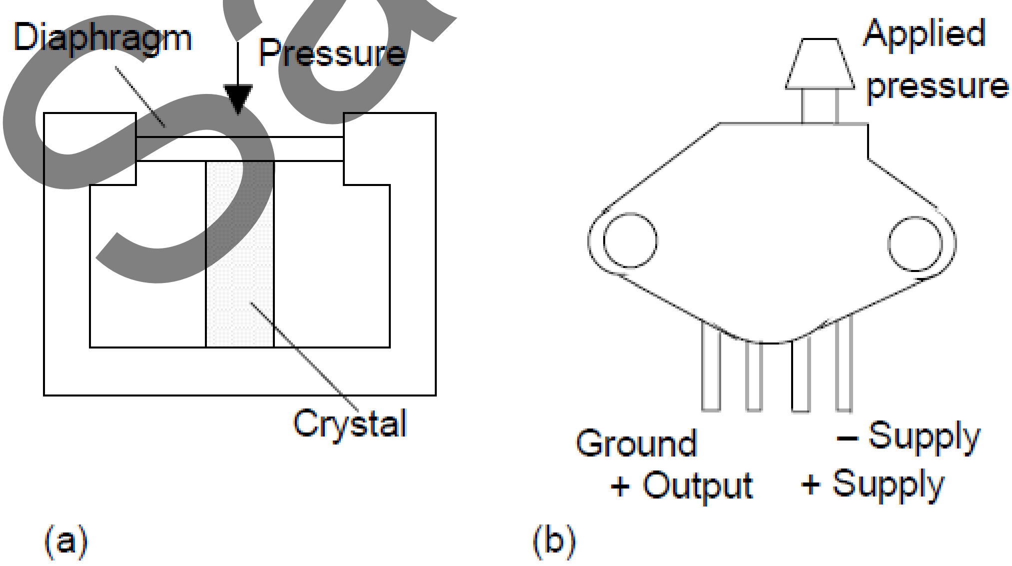

Figure 11: *Pressure detection using a piezoelectric crystal*

Squeezing a piezoelectric crystal displaces charge on it – a voltage appears across it – (a). The Motorola MPX100AP (b) has a vacuum on one side of the diaphragm – it measures absolute pressure.

Many analogue input devices can have their signals digitised using an Analogue-to-Digital Converter (ADC), as in Figure 12;

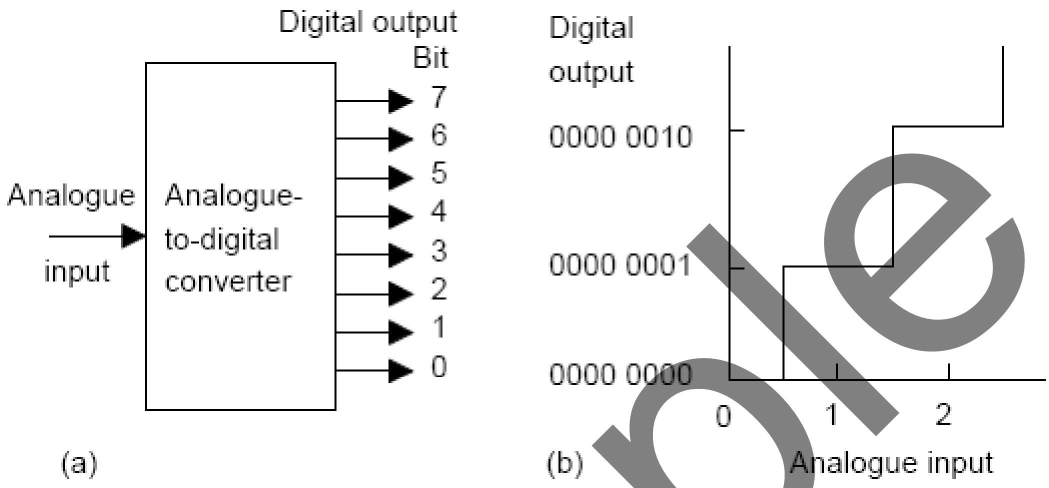

Figure 12: *Digitising an analogue input signal*

The signal from the analogue sensor is presented to the analogue input of the ADC. The ADC then converts the analogue signal into a number of binary digits (8, as shown, or more). This digital representation of the signal is known as a ***word***. With an 8-bit word there are $2^8 = 256$ possible digital values. For example, 00000000 is zero, 00000011 is three, 11111111 is 256. We therefore have what we call 256 ***quantisation levels.***

Output Devices

There are many output devices which can be employed with a PLC. Here is a short list …

- **relay**
- contactor
- solenoid valve
- **motor**

Let's have a look at a couple of these, highlighted in Bold type;

Communication Standards

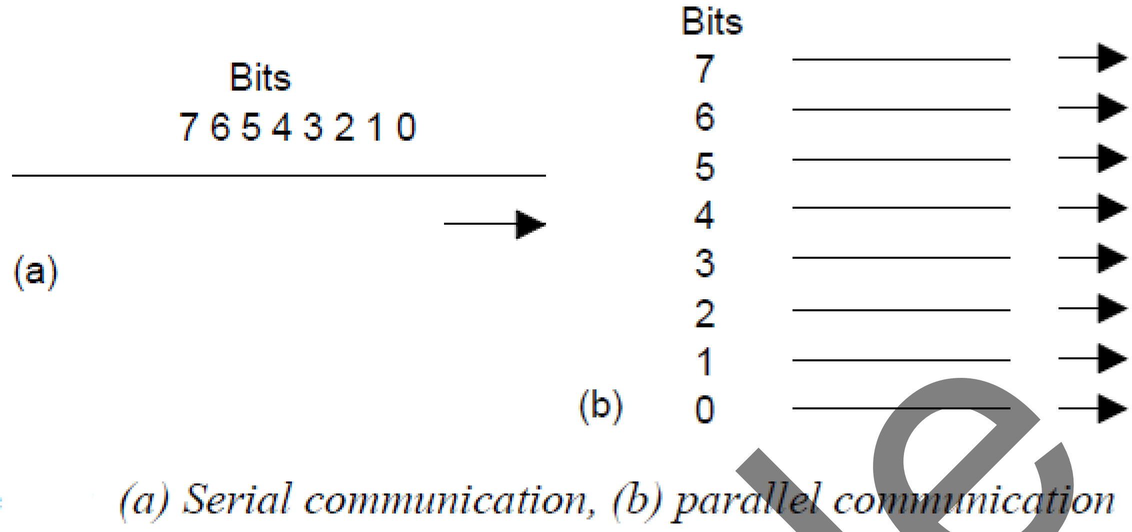

Figure 15: *PLC serial or parallel data*

RS-232

Serial communication – one bit transmitted at a time over a single cable. Serial communication is used for transmitting data over long distances (cheaper). An example serial communications link is between a PLC and a PC, used as a programmer. The most common serial interface is RS-232. The prefix 'RS' stands for 'Recommended Standard'. A UART (universal asynchronous receiver transmitter) is used to convert serial data to parallel data (which the PLC uses internally).

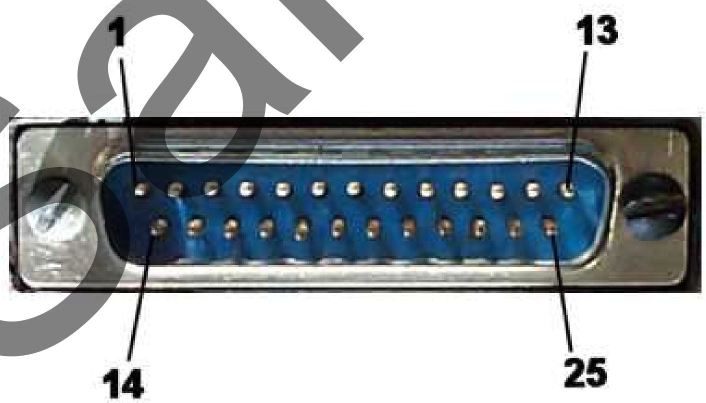

Figure 16: *RS-232 male connector*

Although there are 25 pins in the RS-232 connector, only eight of these are commonly used. The pin assignments and descriptions for these are;

- Pin1: Ground (commonly connected to chassis)
- Pin 2: Transmitted data

newer standards, it is possible to send data beyond 3000 feet, but with increasingly impaired data rate, and quality, with distance.

In a PLC system, it is common for the RS-422 cable to use a 20 mA current loop for signalling, rather than voltage levels. This will improve immunity to electrical noise and increase the potential usable length of the cable.

RS-485

The RS-485 standard is based upon the RS-422 standard. The improvement is that the RS-485 standard allows an output to drive up to 32 receivers. Data rates of 10 Mb/sec are viable, and cable runs of 4000 feet are possible.

RS-485 uses 'three-state logic', meaning that individual transmitters can be turned off. This enables the system to act as a linear bus (i.e. a line) whereby individual devices may be connected along its length. A 120 Ω resistor is recommended to terminate each twisted pair at each end, to minimise noise – fast rising signals will cause less corruption when faced with such a lower impedance. Star or Ring connections are not usually recommended, since signal reflections might cause problems.

Pin 1	TXD-
Pin 2	TXD+
Pin 3	RTS-
Pin 4	RTS+
Pin 5	GND
Pin 6	RXD-
Pin 7	RXD+
Pin 8	CTS
Pin 9	CTS+

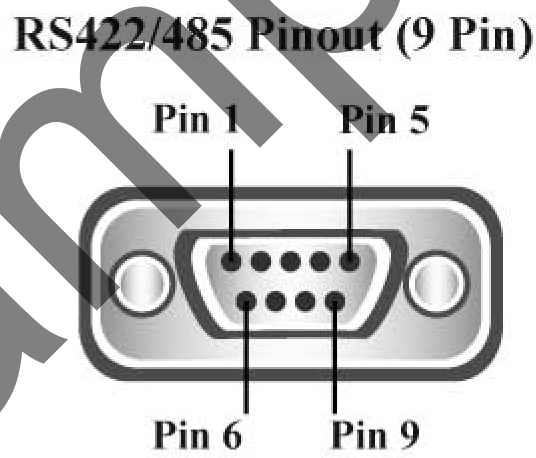

Figure 18: *RS-422/485 pinouts*

Ethernet

Basic Ethernet systems rely on a twisted pair of wires, and are therefore serial systems. However, more modern Ethernet systems use more than one twisted pairs, and are therefore considered to be parallel systems. The original Ethernet standard allowed for a transfer rate of up to 2.94 Mb/sec. More modern Ethernet systems can transfer data beyond 400 Gb/sec.

Internal Architecture

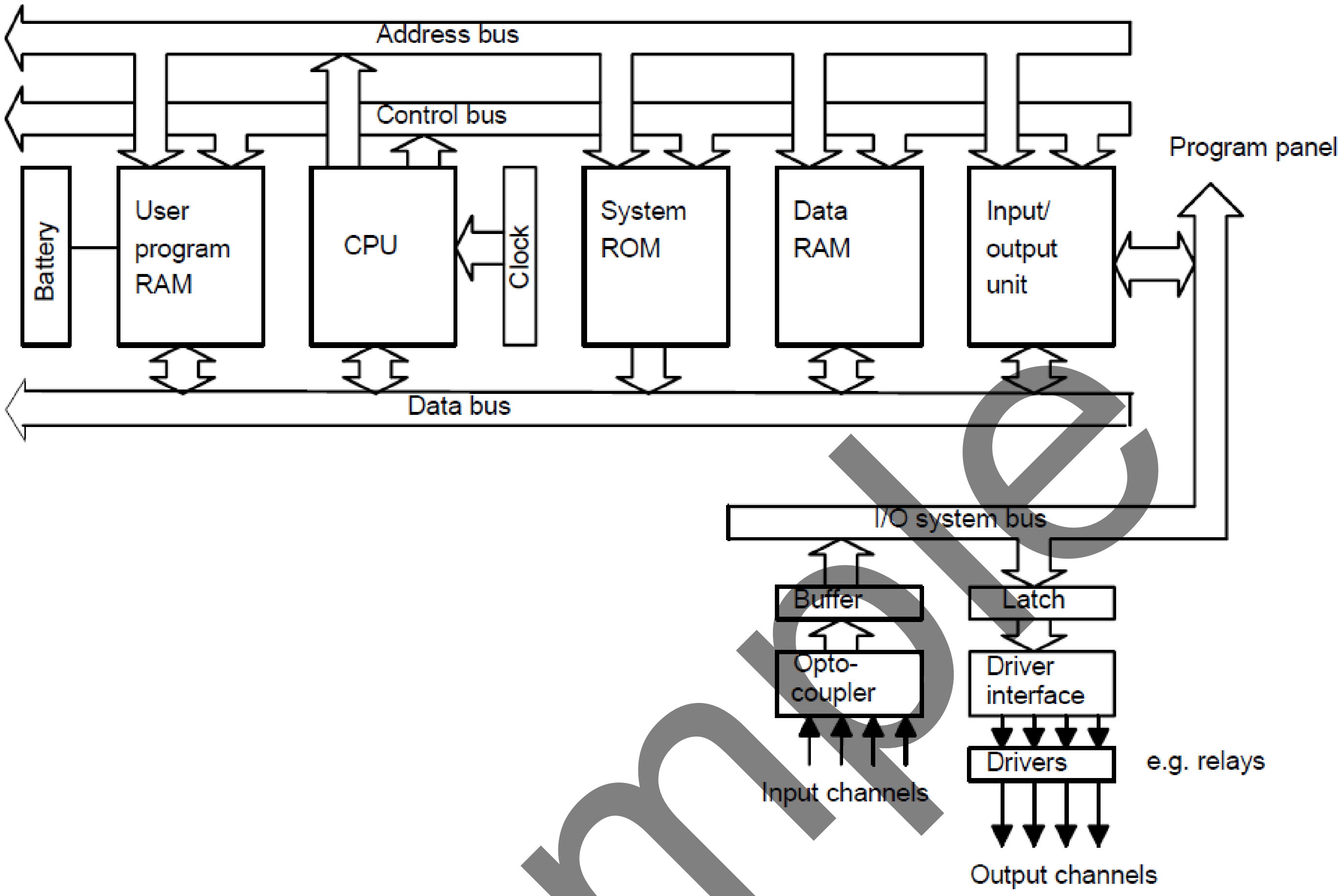

Figure 20: *Typical internal architecture of a PLC*

Figure 20 shows the core internal architecture of a PLC. The CPU (central processing unit) is at the heart of things, of course, and controls all the processes and operations need to maintain functionality. The CPU is time-regulated by a digital clock, which governs the speed at which it executes instructions, and how it synchronises with all other parts of the PLC system.

Signals are carried around the various sub-systems by buses (a group of copper tracks on a pcb, or ribbon cable), which serve to convey parallel information in terms of memory addresses, data to be read or written, control signals, and input/output data.

The CPU contains an ALU (Arithmetic and Logic Unit) which manipulates data, and carries out operations like addition, subtraction, multiplication and division. The ALU will also perform logical operations, as its name suggests, such as; AND, OR, NOT and exlusive-OR. The CPU also contains registers (fast memory) used to hold data when programs execute.

Information is conveyed on the buses in binary form (1's and 0's). Information may be grouped in words – a word could consist of 8 bits (a byte). Each bit of a byte will be carried on its own copper track within the bus.

PLC Programming Languages

The international standard for PLC programming languages (IEC 61131-3) describes a list of languages to be used with a PLC;

- Ladder diagram (LD)
- Sequential Function Charts (SFC)
- Function Block Diagram (FBD)
- Structured Text (ST)
- Mnemonic Instruction List (IL)

A major benefit of this standard is that the program developer can choose which of the languages best fits the particular task.

Ladder Logic

This is by far the main and most common form of programming a PLC. It greatly reduces the amount of training needed by engineers and technicians before they can effectively program a PLC.

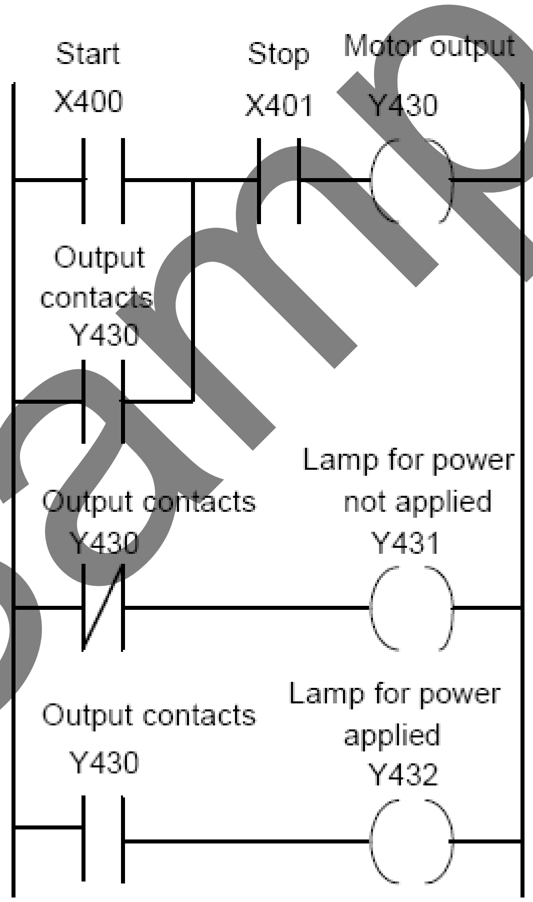

Figure 22: *A basic ladder logic program*

Don't worry at this stage what all the symbols mean in Figure 22. They will all be explained fully in the next workbook. For now, all you need to know is that the two long parallel vertical lines are the rungs of the ladder, the symbols marked X400/X401/Y430 are normally open contacts, the symbol marked Y430 with a diagonal line is a normally closed contact, and the symbols with the curvy lines are a motor/lamp, as indicated. We read the program at the left of the top rung and move right. Once we have reached the far right hand side we move to the left of the second highest rung and move right again etc. Once we have read all rungs we move back to the start (top) and cycle through the instructions in a loop.

Sequential Function Chart

These are used to program more advanced PLCs. They are similar to flowcharts but much more powerful, since one does not need to follow a single path, as in a flowchart.

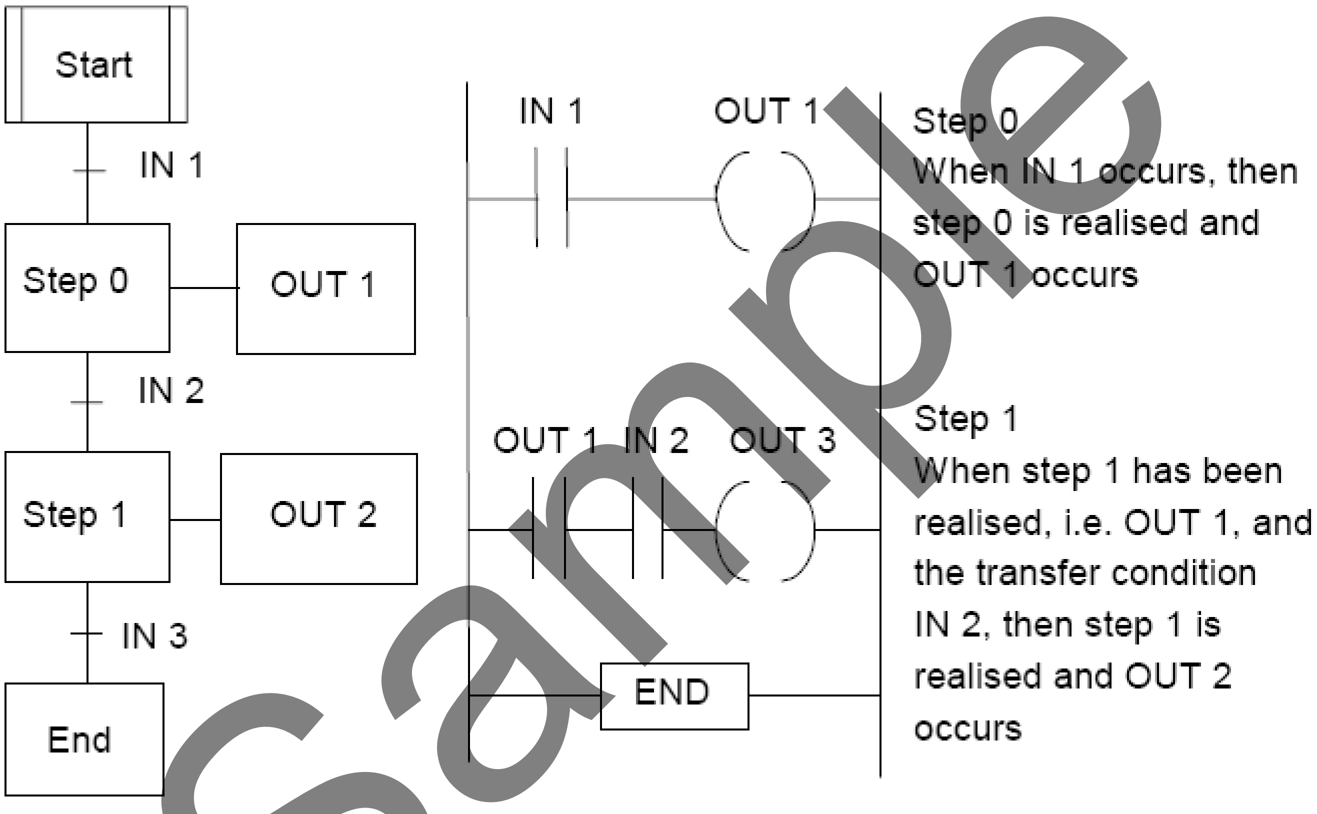

Figure 23: *A sequential function chart (left) with equivalent ladder logic (centre)*