

Module 4

Programmable Logic Control Systems

Lesson 22

The PLC Hardware Environment

Instructional Objectives

After learning the lesson students should be able to

- A. Describe the physical organization of hardware in the PLC
- B. State typical components and functionality of the main types of modules
- C. Describe typical Function modules used in PLC systems

Introduction

In Lesson 18 the architecture of a PLC system has been presented. In this lesson the hardware characteristics of the components of a PLC system and their physical organization are discussed in some detail. PLC systems are available in many hardware configurations, even from a single vendor, to cater to a variety of customer requirements and affordability. However, there are some common components present in each of these. These components are:

- A. Power Supply - This module can be built into the PLC processor module or be an external unit. Common voltage levels required by the PLC are 5Vdc, 24Vdc, 220Vac. The voltage lends are stabilized and often the PS monitors its own health.
- B. Processor - This is the main computing module where ladder logic and other application programs are stored and processed.
- C. Input/Output - A number of input/output modules must be provided so that the PLC can monitor the process and initiate control actions as specified in the application control programs. Depending on the size of the PLC systems the input-output subsystem can either span across several cards or even be integrated on the processor module. Some of there input-output

Input/output cards generates/accept TTL level, clean signals. Output 'modules' provide necessary power to the signals. Input 'modules' converts voltage levels, cleans up RF noise and isolates it from common mode voltages. I/O modules may also prevent over voltages to reach the CPU or low level TTL.
- D. Indicator lights - These indicate the status of the PLC including power on, program running, and a fault. These are essential when diagnosing problems.
- E. Rack, Slot, Backplane – These physically house and connect the electronic components of a PLC.

In addition there may be

- A. Communication processors that realize remote and network i/o for PLCs
- B. Programming and man-machine interface devices for PLCs.

Figure 22.1 shows the typical subsystems found on a PLC system.

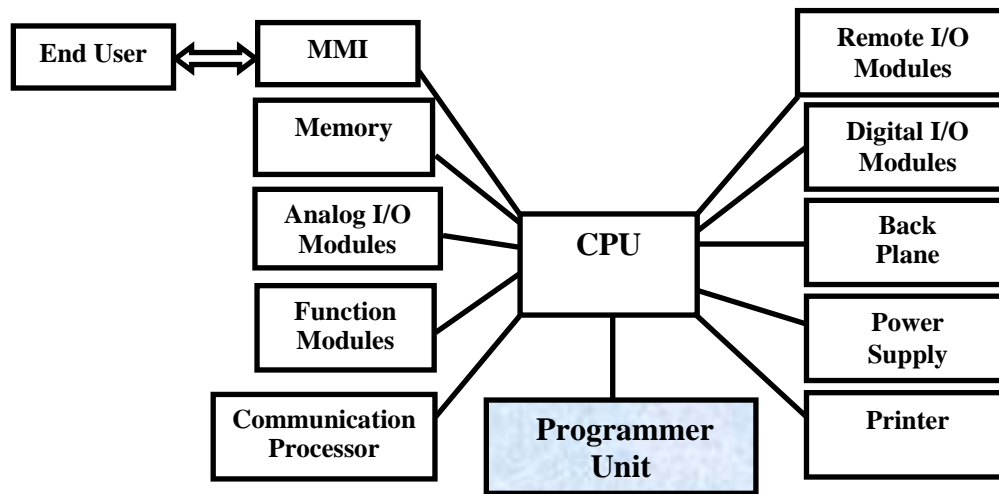


Fig. 22.1 Typical Subsystems for a PLC system

Point to Ponder: 1

- A. *What is remote i/o? How is it different from the other kinds of i/o?*
- B. *What are the functions of the blocks named MMI and Programmer?*

The configuration of the PLC refers to the physical organization of the components. Typical configurations are listed below from largest to smallest.

- A. **Rack** - A rack is often large and can hold multiple cards. These cards, which realize the CPU, power, communication, i/o and special function modules, are connected by a bus, often called a backplane. When necessary, multiple racks can be connected together by bus extenders. Each channel in a card can be addressed by a rack – slot – channel addressing scheme, which varies from vendor to vendor. These tend to be of highest cost, but also the most flexible and easy to maintain. The functional architecture of such a rack mounted PLC system is shown in Fig. 22.2. The figure shows the various types of functional subsystems, which may or may not be on the same board, connected through a backplane. However this does not reflect the physical organization the various modules that make a PLC system. This is shown, distributed over a number of racks along with bus extension system shown in Fig. 22.3. The figure shows that while direct connection may be possible for extension over small distances of a few meters. For extension over longer distances special bus extension units are needed to provide the necessary drives for reliable signal transmission over a distance.

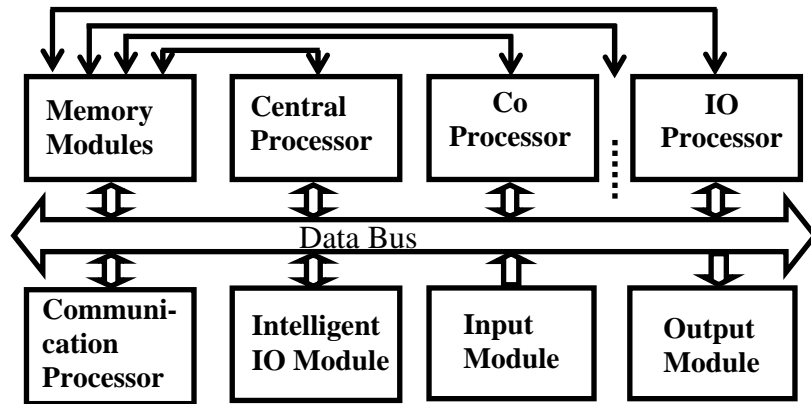


Fig. 22.2 Functional hardware organization of a PLC System

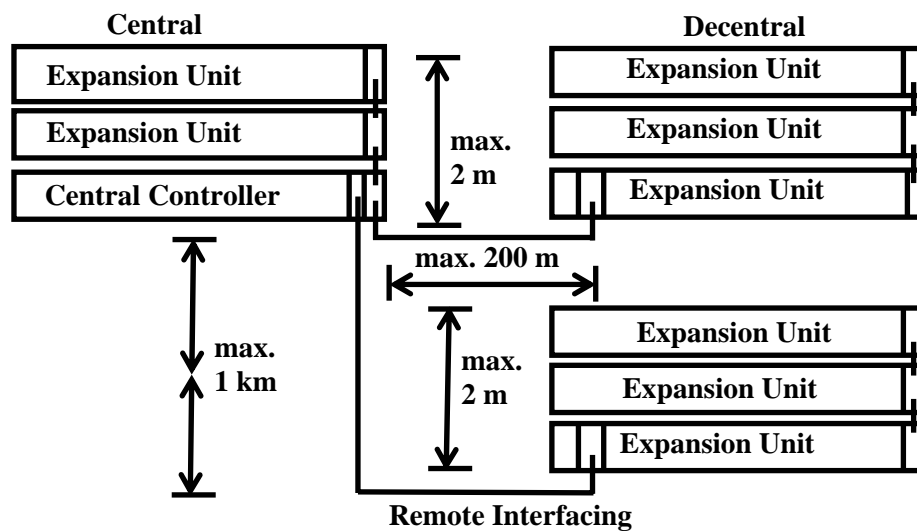


Fig. 22.3 Physical layout and Bus extension System for PLCs

- B. Mini - These are similar in function to PLC racks, but about half the size. Photograph of one such PLC system is shown in Fig. 22.4. These generally are situated completely at one place and do not use an extended bus. Floor mounted or wall mounted.



Fig. 22.4 A mini PLC System

- C. Compact - A compact, all-in-one unit (about the size of a shoebox) that has limited expansion capabilities. Lower cost, and compactness make these ideal for small applications. Usually wall mounts.
- D. Micro - These units can be as small as a deck of cards suitable for wall mounted or table top. They tend to have fixed quantities of I/O and limited abilities, but costs will be the lowest. Used for simple embedded applications. Often not suitable for industrial applications.
- E. Software - A software based PLC requires a general purpose computer, like a PC, with an interface card. The software, utilizes the operating system resources of the computer to realize control, logic and i/o functions. An advantage of such a configuration is that it allows the PLC to be connected to sensors, other similar PLCs or to other computers across a general purpose network, such as the ethernet. The PLC can also function concurrently with other PC-based applications like a visualization software.

Point to Ponder: 2

- A. Name one application each for which a mini PLC may be appropriate. Provide justifications for your choice.
- B. Why is a special bus extender unit needed for extending the bus over long distances?

Processor Module

A wide range of processor modules, scalable in terms of performance and capacity, are available to meet the different needs of users. Processors manage the whole PLC station consisting of discrete input/output modules, analog modules and application-specific function modules (counting, axis control, stepper control, communication, etc.) located on one or more racks connected to the backplane. In terms of hardware, besides a CPU and possible co-processor, each processor module typically includes:

- a protected internal RAM memory which can take the application program and can be extended by memory extension cards (RAM or Flash EPROM)
- a realtime clock
- ports for connecting several devices simultaneously for purposes such as programming, human-machine interface etc.
- communication cards for various industrial communication standards such as, Modbus+ or Fieldbus, as well as serial links and Ethernet links
- Display block with LEDs, RESET button, used to activate a cold restart of the PLC system.

Typical specifications for a high end and a low end PLC processor module for a rack-based PLC system are given below.

Features	Low end	High end
No. of racks	6	24
No. of module slots	21	87
In-rack discrete I/O	512	2048

In-rack analog I/O	24	256
Application specific function modules	8	64
Process control loops	-	60
Process control channels	-	20
Network connection: TCP/IP, Modbus +, Ethernet	1	4
Fieldbus connection	0	2
Internal memory (16-bit words)	32K	176K
Memory extension (16-bit words)	64K	512K

Table 22.1 Typical Features of high end and low-end processor modules

Processor modules contain function block libraries, which can be configured to work with other modules, to realize various automation related functionality, such as,

- Counting up to 10 – 100 KHz
- PID Control with algorithms realized in different forms
- Controlled positioning for manufacturing by CNC machines with stepper / servo drives, and features such as rapid traverse / creep speed for high accuracy positioning of point to point axes, interpolation and multi axis synchronization for contouring axes
- Input/output: These may be categorized as digital / analog depending on the nature of the signal or as local/remote/networked, depending on the interface through which it is acquired. These are described in detail below.

Input Module

Input modules convert process level signals from sensors (e.g. voltage face Contacts, 0-24v Dc, 4 – 20mA), to processor level digital signals such as 5V or 3.3 V. They also accept direct inputs from thermocouples and RTDs in the analog case, and limit switches or encoders in the digital case. Naturally, therefore these modules include circuitry for galvanic isolation, such as those using optocouplers.

Galvanic isolation-

Analog input modules

Analog input modules convert analog process level signals to digital values, which are then processed by the digital electronic hardware of the programmable controller. A set of typical parameters that define an analog input module are shown in Table 22.2. The analog modules sense 8/16 analog signals in the range ± 5 V, ± 10 V or 0 to 10 V. Each channel can either be single-ended, or differential. For single ended channels only one wire is connected to a channel terminal. The analog voltage on each channel terminal that is sensed is referred to a common ground. In the case of differential channels, each channel terminal involves two wires and the voltage between the pair of wires is sensed. Thus both the wires can be at different voltages and only their difference is sensed and converted to digital. Differential channels are more accurate but consume more electronic resources of the module for their processing. Often these modules

also house channels that output analog/digital signals, as well as excitation circuitry for sensors such as RTDs.

An analog module typically contains:

- Analog to digital (A/D) converters
- Analog multiplexers and simultaneous sample-and-hold (S/H)
- Analog Signal termination
- PLC bus ports
- Synchronisation



Fig. 22.5 Analog IO Module

Module Parameter	Type/Number/Typical Value
Number of input	8/16 voltage/current/Pt 100/ RTD
Galvanic isolation	Yes /No
Input ranges	± 50 mV to ± 10 V; ± 20 mA; Pt 100
Input impedance for various ranges (ohm)	± 50 mV: > 10 M ; ± 10 V: > 50 k; ± 20 mA : 25; Pt 100 : > 10 M
Types of sensor connections	2-wire connection; 4-wire connection for Pt 100
Data format	11 bits plus sign or 12 bit 2's complement
Conversion principle	Integrating /successive approximation
Conversion time	In ms (integrating) , μ s (successive approx.)

Table 22.2 Typical Parameters for an Analog Input Module

Digital Input Modules

The digital inputs modules convert the external binary signals from the process to the internal digital signal level of programmable controllers. Digital input channel processing involves isolation and signal conditioning before inputting to a comparator for conversion to a 0 or a 1. The typical parameters that define a digital input module are shown in tabular form along with typical values in Table.

Module Parameter	Typical Values
Number of input	16/32
Galvanic isolation	yes
Nominal input voltage	+ 24 V DC
Input voltage range - “0” signal - “1” signal	-33...+7V +13...+33V
Input current	Typically in mA
Delay	Typically in μ s
Maximum cable length	Typically within 1000m

Table 22.3 Typical Parameters for an Digital Input Module

Point to Ponder: 3

- Why so many types of analog inputs have been provided for?*
- How to select between integrating and successive approximation converters?*
- What is the significance of the input ranges for digital input modules?*

Output Modules

Outputs to actuators allow a PLC to cause something to happen in a process. Common actuators include:

1. Solenoid Valves - logical outputs that can switch a hydraulic or pneumatic flow.
2. Lights - logical outputs that can often be powered directly from PLC boards.
3. Motor Starters - motors often draw a large amount of current when started, so they require motor starters, which are basically large relays.
4. Servo Motors - a continuous output from the PLC can command a variable speed or position to a servo motor drive system.

The outputs from these modules may be used to drive such actuators. Consequently, they include circuitry for current / power drive using solid-state electronics such as transistors for DC outputs or triacs for AC outputs. Continuous outputs require output cards with D/A converters. Sometimes they also provide potential free relay contacts (NO/NC), which may be used to drive higher power actuators using a separate power source. Since these modules straddle across the processor and the output power circuit, these must provide isolation. However, most often, output modules act as modulators of the actuator power, which is actually applied to the equipment, machine or plant. 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 120V ac, 24V dc, 12-48V ac/dc, 5V dc (TTL) or 230V ac. 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, transistors or triacs. 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 wear out after a large number of cycles. Relays can switch high DC and AC voltage levels while maintaining isolation. Transistors are limited to DC outputs, and triacs are limited to AC outputs. Transistor and triac outputs are called switched outputs. In this case, 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.

Analog Output Module

Analog output modules convert digital values from the PLC processor module into an analog signal required by the process. These modules therefore require a D/A converter for providing analog outputs. However, typically, servo-amplifiers for power amplification, required for driving high current loads directly, are not integrated on-board. Front connectors are used for terminating the signal cables. Modules and front connectors may be inserted and removed under power. The output signals can be disabled by means of an enable input. The last value then remains latched. Typical parameters that define an analog output module are shown in Table 22.4 along with typical values.

Digital Output Module

Digital output modules convert internal signal levels of the programmable controllers into the binary signal levels required externally by the process. Output can be DC or AC. Up to 16 outputs can be connected in parallel. Indication for short-circuits, fuse blowing etc. are often provided.

Number of outputs	8 voltage and current output
Galvanic isolation	yes
Output ranges (rated values)	$\pm 10 \text{ V}$; $0 \dots 20 \text{ mA}$
Load resistance	
- for voltage outputs min.	3.3 k
- for current outputs max.	300
Digital representation of the signal	11 bits plus sign
Conversion time	In μs
Short-circuit protection	yes
Short-circuit current approx.	25 mA (for a voltage output)
Open-circuit voltage approx.	18 V (for a current output)
Linearity in the rated range	$\pm 0.25\% + 2 \text{ LSB}$
Cable length max.	200 m

Table 22.4 Typical Parameters for an Analog Output Module

The typical parameters that define a digital output module are shown in Table 22.5 along with typical values.

Module Parameter	Typical Value
1.Number of outputs	16/32
2.Galvanic isolation	yes
Rated value of Supply voltage Permissible range	+ 24 V DC 20-30 V
Max. output current for “1” signal	0.5 A
Short-circuit protection	Yes
Max. switching frequency for resistive loads, lamps, inductive loads, respectively, in Hz.	100/11/2 Hz (at 0.3 A)
“0” signal level max “1” signal level max.	+3V V _{pp} 1.5 V
Max. cable length (unshielded)	400 m

Table 22.5 Typical Parameters for an Digital Output Module

Point to Ponder: 4

- A. *Determine the significance of the following specifications for an analog output module:*
 - a. Load resistance
 - b. Linearity
 - c. Conversion time
- B. *Determine the significance of the following specifications for a digital output module:*
 - a. Max. switching frequency
 - b. Short circuit protection

Function Modules

For high speed i/o tasks such as one required to measure speed by counting pulses from shaft angle encoders, or for precision position control applications, independent i/o modules that execute tasks independently of the central processor are required to meet the timing requirements of the i/o. The signal preprocessing “intelligent” I/O- modules make it possible to count fast impulse trains, to acquire and process travel increments, speed and time measure etc., i.e. they take on the critical timing control tasks which normally can’t be carried out fast enough by the central processor with its programmable logic control, as well as its primary logic control functions. These modules not only relieve the central processor of additional tasks, they also provide fast and specialized solutions to some common control problems. The processing of the signals is carried out primarily by the appropriate I/O- modules, which frequently operate with their own processor. Below we discuss two such modules, which are used with PLCs to handle specific high performance automation functions.

- A. **A Count Module** is employed where pulses at high frequency have to be counted, i.e. when machines run fast. It can also be applied to output fast pulse trains or realize accurate timing signals.
- B. **A Loop Controller Module** is primarily used where high speed closed loop control is required, such as with controlled drives. The preprogrammed, parameterized functions available with the module (e.g. for ramp-function generation, speed regulation, signal limit monitoring) can be easily parameterized via graphical interfaces by a programmer.

Count Module

A count module senses fast pulses, from sources such as shaft angle encoders, through several input ports. Counting frequency can be as high as 2 MHz and a typically, a counter of length 16 bit or more can count up and down. Counter modules can often also be applied for time and frequency measurement and as a frequency divider.

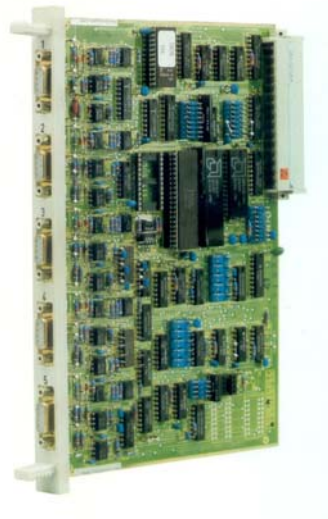


Fig. 22.6 A high speed counter module

Typical counter module hardware contains, among possible other things, an interface to the processor through the system bus, a counter electronics block, a quartz controlled frequency generator and a frequency divider. For example, it may contain, say, 5 counters with, say, 16 bits, each of which are cascadable. In this way, up to 80 bit can be counted in various codes. Thus, decimals up to about 10^{24} can be counted. Each port input can be switched on to the counter at random. It is possible to place a frequency divider from 1 to 16, between the port input and the counter. The frequency of an internal frequency generator can be directed either straight to a counter or via the frequency divider to a port input. On reaching the terminal count, the counter outputs a level or edge signal.

For each counter there are a number of different operating modes, which can be set by a user program. With a comparator and an alarm register, a number of count values can be compared and under defined conditions configured to turn on a process alarm.

A counter can be programmed in many ways, such as:

- Count mode binary or BCD coded
- Count once or cyclically
- Count on rising or falling edge
- Count up or down
- Counting of internal clock or external pulses

Loop Controller Module

A loop controller module is suitable for solving fast control loop problems. A typical module can process several control loops with sampling times varying between a few milliseconds to several seconds. The process output values are measured via analog input ports and are compared with the set point values. The power circuits of the actuator units are driven through analog output ports. Such a module contains a microprocessor, which controls the sensing and processing of the process output and set point values and computes the control law and outputs the manipulated variables. The operating configurations of the loop controller module are assigned with a programmer and committed to memory located on the module. The central controller provides set point values, parameters and control commands and reads the output values.

The application software for the module can be structured in terms of standard close loop functions (e.g. ramp function generator, speed controller, etc.). These standard functions can be interconnected to a closed loop structures with the aid of a programmer interface and are the resulting control code automatically compiled and downloaded to memory on the module. The microprocessor executes the standard functions in accordance with the designed closed loop structure for an application such as a motor drive or a standard cascade process control loop. A drive loop controller would comprise all necessary functions for the control of a drive, while a cascade loop controller would consist of a cascade of two control loops. The outer loop controller can, for an instant, be used for closed loop position control, while the inner loop for control of rotational speed control. Each loop controller can be equipped with P, D, PI, PD or PID algorithms. As additional functions there may exist limit monitoring indicators limit monitoring indicators, which for example, can monitor the actual armature current value, for thermal supervision of the drive.

Point to Ponder: 5

- A. *Name two advantages and two disadvantages of using a function module for an automation application*
- B. *Based on the illustrative figures given for the counter module, determine the maximum possible timing interval that can be programmed on the counter module.*
- C. *Describe the meaning of the various counting modes of a counter module*
- D. *Consider a position control application. Describe the options for receiving feedbacks for the loop controller for this application*

Lesson Summary

In this lesson, the following topics related to PLC System hardware have been discussed.

- A. Introduction to typical PLC hardware subsystems
- B. Physical organization of the PLC hardware subsystems
- C. Typical features of Processors Modules
- D. Typical features of analog and digital input modules
- E. Typical features of analog and digital output modules
- F. Two function modules : High Speed Counter and Loop Controller

Answers, Remarks and Hints to Points to Ponder

Point to Ponder: 1

A. What is remote i/o? How is it different from the other kinds of i/o?

Ans: Local i/o, as contrasted with remote i/o is where the field terminals of the PLC i/o modules are connected directly to the field devices. Each channel carries data that is not multiplexed. On the other hand for remote i/o, multiplexed data for several field channels is sent in multiplexed form to a remote i/o device that demultiplexes and transmits data for each field device to it, with or without data conversion and signal conditioning. Local i/o may be analog or digital. Remote i/o is always digital. Remote i/o is used to mainly to save on cabling of individual data channels from the device to the PLC rack.

B. What are the functions of the blocks named MMI and Programmer?

Ans: MMI is an acronym for Man Machine Interface. Generally PLC modules do not have facilities for visualization. However, if needed, one can connect a special MMI device like a terminal or a printer and visualization of process outputs and their transitions. Similarly, a programmer is another device which facilitates easy development, debugging and monitoring of programs through graphical interfaces. The developed programs can be compiled and downloaded into the PLC memory. Programmers are available in table-top PC based as well as handheld versions.

Point to Ponder: 2

A. Name one application each for which a mini PLC may be appropriate. Provide justifications for your choice.

Ans: A typical example would be a CNC machining Centre. Typical i/o requirements for such a centre would be less than 100 channels. The number of channels are going to be more or less fixed. Communication, visualisation and programming requirements are non trivial but not extensive either. Therefore, neither a full PLC rack, nor a compact PLC is suitable.

B. Why is a special bus extender unit is needed for extending the bus over long distances?

Ans: That is because for long distances, the capacitive loading of connecting cables increases significantly. A much higher value of capacitance therefore needs to be charged and discharged at a high rate, without causing signal voltage degradations. This requires much higher current driving capability and thus necessitates a separate driver module.

Point to Ponder: 3

A. Why so many types of analog inputs have been provided for?

Ans: So that the user need not face the trouble of signal conditioning for most of the common sensing devices, such as those providing voltage or current outputs, resistance sensors, thermocouples. These can be easily interfaced with the input modules directly.

B. How to select between integrating and successive approximation converters

Ans: For integrating ADCs conversion is the slowest with conversion times in the range of several milliseconds but can be very accurate. Successive approximation types are a thousand times faster, are now available with good accuracies and therefore are suited to most applications and are popular too.

C. What is the significance of the input ranges for digital input modules?

Ans: The wide input voltage ranges and the wide separation of the ranges for 0 and 1 signal levels has been designed to ensure reliable data transmissin in possibly very noisy industrial environments. Obviously power levels for signals drivers have to be very high to maintain these levels but is not a concern here.

Point to Ponder: 4

*A. Determine the significance of the following specifications for an analog output module:
a. Load resistance b. Linearity c. Conversion time*

Ans: The significance of the specifications are described below.

- Load Resistance: Decides the current drive capacity that needs to be provided on the output module
- Linearity: Basically works like an accuracy specification between the digital value and the analog field level output.
- Conversion time: Added to the control computation time, decides the lower bound on sampling time that can be used for control.

B. Determine the significance of the following specifications for a digital output module: a. Max. switching frequency b. Shrot circuit protection

- Maximum switching frequency: Decides the speed of the control application. However, for inductive loads, the switching frequency depends on the power sourcing and sinking capabilities provided on the module.
- Short circuit protection: Since the load being driven may be shorted, this feature is essential to protect the module from damage.

Point to Ponder: 5

A. Name two advantages and two disadvantages of using a function module for an automation application

Ans: First advantage is that the main processor computational burden is reduced significantly. For example, for a control function, that main processor only has to supply the set point and not compute the control input every sampling time. The second advantage is that the application program developer does not need to be concerned with the fine details of a control algorithm for a specific application such as a precision positioning. One of the disadvantages is the additional cost of such a module. The second disadvantage may be that the functional module may prove to be a constraint if one is interested in using a different control algorithm for the application.

E. Based on the illustrative figures given for the counter module, determine the maximum possible timing interval that can be programmed on the counter module.

Ans: The maximum timing interval that can be programmed on counter, for the data of 5 cascaded 16 bit counters, is, the half clock period divided by 2^{80} .

F. Describe the meaning of the various counting modes of a counter module

Ans: The meanings of the modes are described below.

- Count mode binary or BCD coded: Refers to the code using which the count values propagate. Codes may be chosen depending on requirements of other software/hardware modules that interface to it.
- Count once or cyclically: Refers to whether the counter should stop after reaching terminal count or would reload the initial count and restart counting.
- Count on rising or falling edge: Refers to the edge that increments/decrements count value.
- Count up or down : Self explanatory
- Counting of internal clock or external pulses: If the counter increments by internal clock, it becomes a timer. It would generate output after a fixed time interval which depends on the clock frequency and the number of bits in the counter. With external pulses it counts the number of pulse events in the field.

G. Consider a position control application. Describe the options for receiving feedbacks for the loop controller for this application

Ans: The options for feedback depend on the sensors used in the drive. If the position sensor used is analog, like a resolver, a potentiometer or an LVDT, then an analog input channel has to be used. On the other hand, if the sensor used is a shaft angle encoder, then either a digital input channel is to be used, in which case, the pulse counting has to be done by the module. Else the encoder channel can be interfaced to a counter function module and the count value read from it via the bus. Similar arguments apply for the speed feedback input, if any.