Digital Signal Conditioning

Digital signal conditioning in process control indicates the method of representing analog information related to a process in digital format.

Example: If Temperature is to be controlled using digital devices like computer, temperature has to be converted to digital format first.

Why digital signal conditioning?

The controllers used nowadays are mainly digital devices like computer. The information obtained from measurement system is analog in nature. In-order to communicate analog data to a digital device, it has to be processed accordingly. Similarly, the signal to be applied to the actuators or final control elements is also analog in nature. Hence digital signal conditioning becomes relevant, when we use digital controllers together with analog devices like sensors and actuators.

Note: Accuracy is lost when analog data is converted to digital format.

Why are computers relevant in process control?

1. A computer can control process involving several variables
2. Nonlinearities in process can be linearized by the computer
3. Complicated control equations can be solved quickly using computer
4. A large process plant can be controlled using a network of computers

Digital information

Digital signals are simply two-state (binary) levels. It can be two voltages, two currents or two frequencies. The two states are a high state (H or 1) or a low state (L or 0).

Example: A 0 V indicates Low state (0) and a 5 V indicates High state (1).

Conversion of binary number into decimal number: Refer Note book

Application of Boolean Algebra in a practical Problem (Alarm annunciating circuit)

Consider a mixing tank in which there are three variables: liquid level, pressure, and temperature. We must signal an alarm when certain combinations of conditions occur among these variables. We denote level by A, pressure by B, and temperature by C. The alarm will be triggered when the Boolean variable D goes to the logic true state. The alarm conditions are,

1. Low level with high pressure

2. High level with high temperature

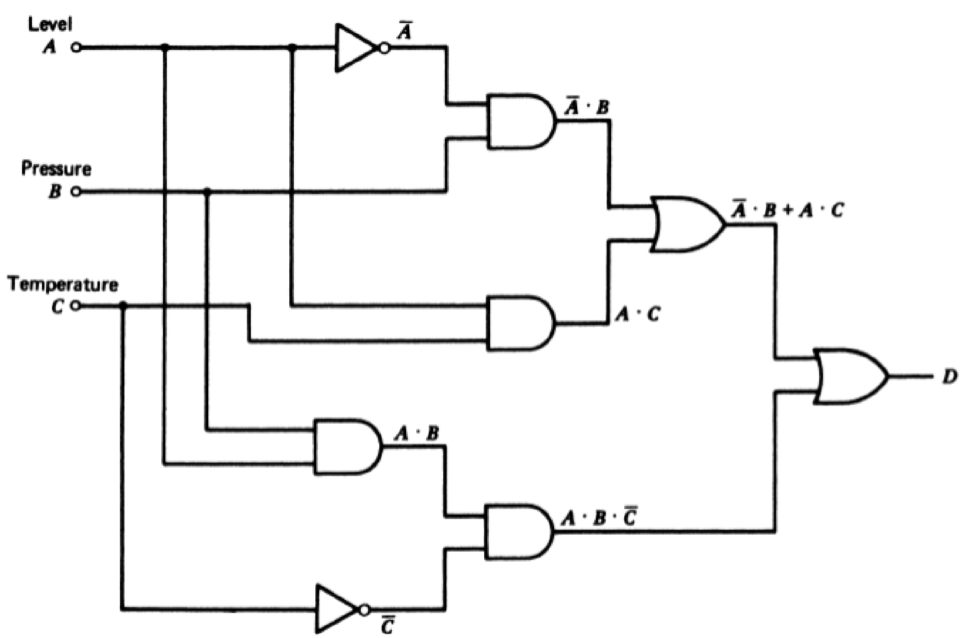
3. High level with low temperature and high pressure

1. $D = \overline{A} \cdot B$ will give $D = \mathbf{1}$ for condition 1.
2. $D = A \cdot C$ will give $D = \mathbf{1}$ for condition 2.
3. $D = A \cdot \overline{C} \cdot B$ will give $D = \mathbf{1}$ for condition 3.

The final logic equation results from combining all three conditions. If any of the above condition is true, the alarm will sound. This is done with the OR (+) operation.

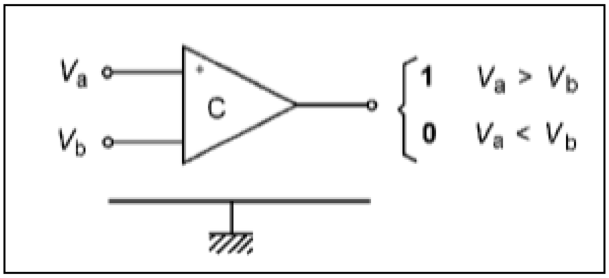
$$D = \overline{A} \cdot B + A \cdot C + A \cdot \overline{C} \cdot B$$

This alarm condition can be implemented using logic-gates as shown here:



Comparators

A comparator is used to produce alarm signals in process control. It is an important part of Analog to Digital Converters (ADCs) and Digital to Analog Converters (DACs).

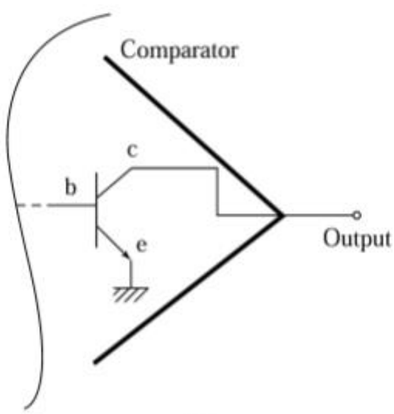


A comparator compares two analog voltages at its input and gives a digital signal (High or Low) as the output. Here two voltages V_a and V_b are compared. In this V_a is a variable voltage that indicates the process variable (Obtained from sensors). The other voltage V_b is fixed and it indicates the setpoint voltage. The fixed voltage is also known as trip or trigger or reference voltage.

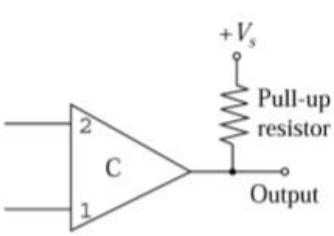
If $V_a > V_b$ output is High (1). Otherwise if $V_a < V_b$ output is Low (0).

There are two types of comparators: Open collector comparator and Hysteresis comparator.

1. Open collector comparator



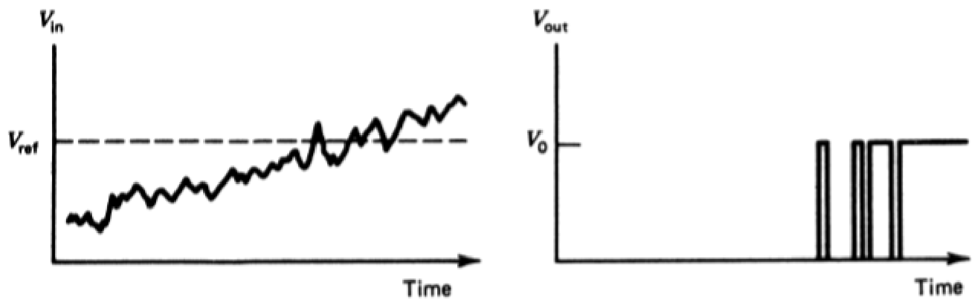
(a)



(b)

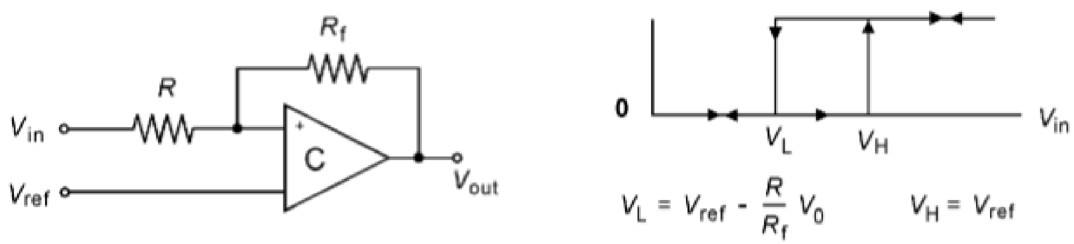
In open collector comparator, the output terminal of the comparator is connected internally to the collector of a transistor, which is inside the opamp. An external resistor is connected from the output to a power supply. This resistor is called a collector pull-up resistor. The output terminal will show either a 0 (0 V) if the internal transistor is ON or 1 if the internal transistor is OFF.

The use of open collector comparator has one demerit. If there is noise in the process variable, it will approach the reference voltage very slowly. As a result, the comparator output will toggle between High and Low values. The comparator output will be mostly connected to some other circuits like an alarm circuit. If there are fluctuations in the comparator output, it will affect the working of the circuit to which it is connected. In-order to overcome this problem, a hysteresis comparator can be used.



Input and output graphs with an open-collector comparator

2. <u>Hysteresis Comparator</u>



a) Hysteresis comparator circuit

b) Hysteresis comparator input-output relationship and equations

A hysteresis comparator can be realized by using an opamp with positive feedback. This comparator is used to overcome the fluctuations in the output of a comparator.

In this type of comparator, there are two reference voltages, a low reference voltage V_L and a high reference voltage V_H. Initially, let the input voltage is increasing. The output voltage changes from Low to High only when the input voltage is greater than $V_{H.}$ Now let the input voltage is decreasing. The output voltage will switch back from High state to Low state only when the input voltage is less than V_L. By this arrangement, the fluctuations in the output signal of a comparator can be eliminated (avoided).

For this circuit, V_H is V_{ref} and V_L is V_{ref}-(R_f/R) V_{out}.

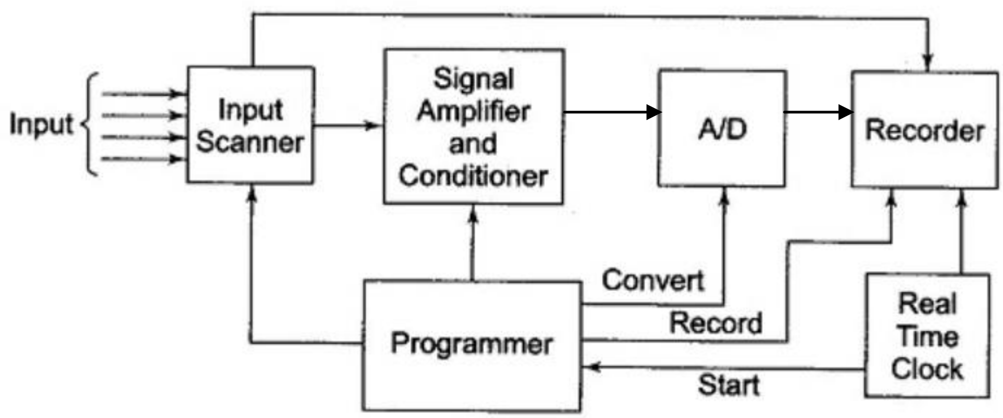
Thus,

When $V_{in} > V_H$, V_{out} = High

And

When $V_{in} < V_L$, V_{out} = Low.

Data Logger

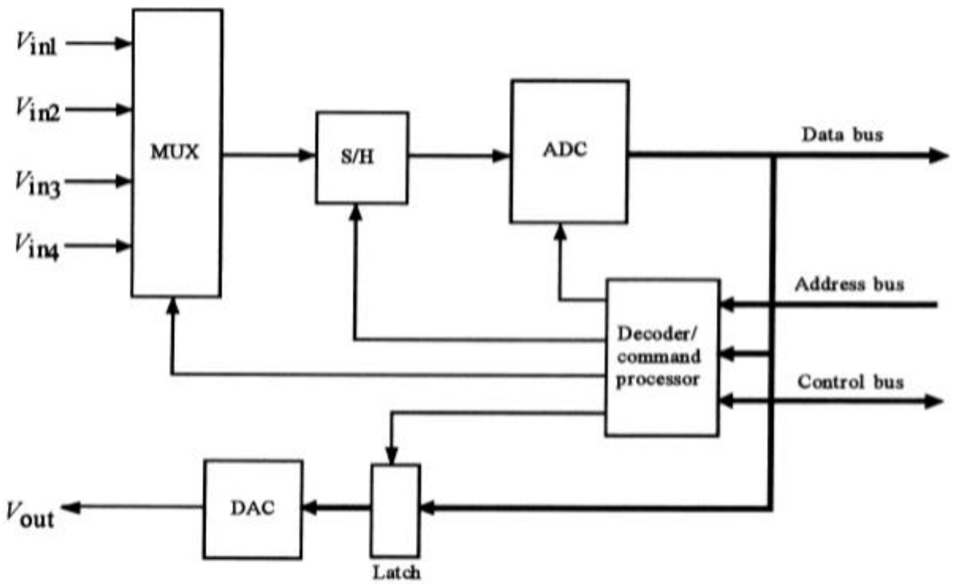


Block Diagram of a Data Logger

A data logger is an electronic device that records or displays data from a process plant over a period of time. The data recorded includes the variable type (Temperature, pressure etc), value of the variable, its min and max ranges and time of recording in seconds, minutes or hours. It consists of the following blocks:

1. Input Scanner: This block scans the inputs from various sensors. The inputs can be of different nature, like, a high level input from a pressure transducer or a low level input from a thermocouple or ON/OFF inputs from switches. The input scanner acts like a MUX and only one from the several inputs is passed onto the signal conditioning unit.
2. Signal Amplifier and Conditioner: This unit performs the following functions:
    - Amplification of low level signals
    - Filtering of signals with noise
    - Linearizing the nonlinear inputs
3. Analog to Digital Converter: This is used to convert the analog data from the Signal Conditioning unit to digital data, for displaying on the screen or for storing in the data logger memory.
4. Recorder: The data saved using a data logger can be either displayed on a screen or can be printed on a strip chart or paper.
5. Programmer: This block controls the operation of all other blocks.
    - It sets high and low alarm limits
    - It selects the input channel that is to be scanned
    - It fixes the amplifier gain
    - It initiates the A/D conversion
    - It resets the logger, when necessary
6. Real Time Clock: A real time clock is used to control the timing of the programmer.

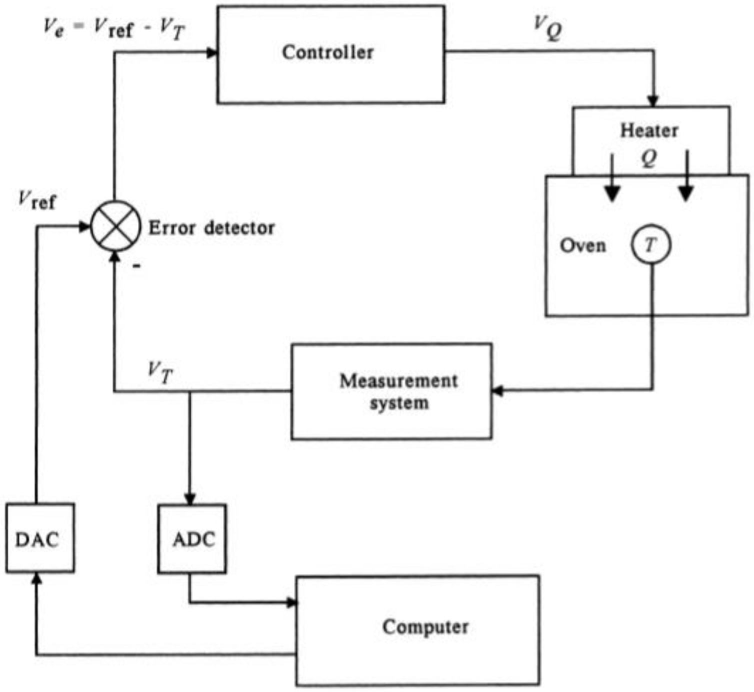
Data Acquisition System



A data acquisition system is a system that consists of subsystems for collection, conversion, processing, display and transmission of data. It is used for interfacing a process plant with a computer for controlling or monitoring purposes. It consists of the following blocks:

1. Multiplexer (MUX): Multiplexer is used to select data one at a time, from a number of input channels. This is used when there are several sensors at the input, from which information is to be passed onto a computer.
2. S/H and ADC: S/H is the Sample and Hold circuit. It samples the continuously varying analog signal and holds it at a constant value for some period. The analog signal from sensors is to be converted into digital signal before sending it to the computer. For this purpose, a high speed successive approximation type ADC (Analog to Digital Converter) is used.
3. Decoder/Command Processor: This block controls the operation of all other blocks in the Data Acquisition System.
    - It chooses the input channel that is to be scanned
    - The address bus has address of the channel that is to be read.
    - The data bus contains the information to be send to the computer and the control signal received from the computer, both in digital format.
    - The signals on the control bus decide the direction in which data transfer has to take place (to computer or from computer).
    - It tells ADC when to start the Analog to Digital Conversion
4. Latch and DAC: Latch is for temporarily storing the information received from a computer before passing it onto DAC. The information from computer is digital in nature. It has to be converted to analog signal before applying it to the actuators in a plant. For this, a Digital to Analog Converter is used.

Supervisory Control

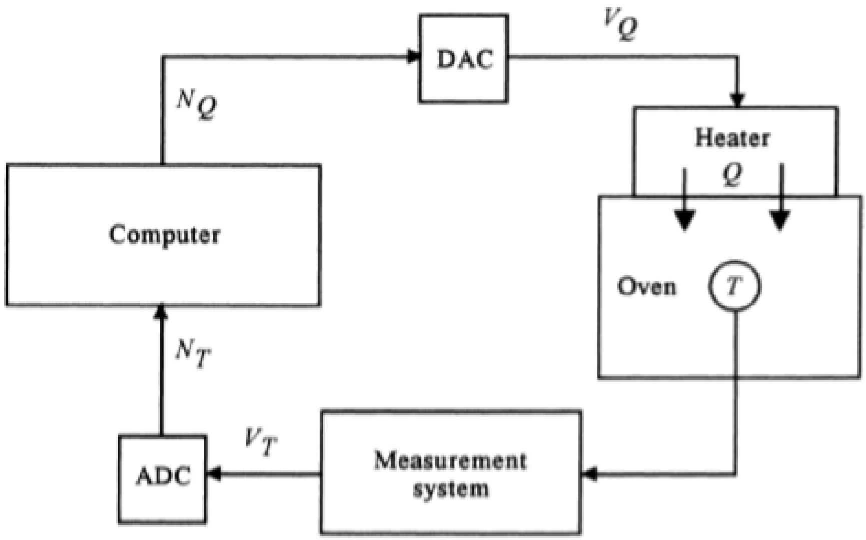


During early times, use of computers in process control was not reliable due to frequent failure of computers. As a result, computers were used only to monitor other analog controllers and determine the set points. This type of control is known as Supervisory Control. The actual controllers used were analog controllers, which are opamp based controllers. In the figure, the computer is used to determine or fix the set point in a temperature control process. It is determine to keep the temperature inside the oven as a constant. Temperature is measured using a measurement system. In order to communicate the measured value with computer, an Analog to Digital Converter is used. The computer calculates the set point and gives it to the DAC. The DAC converts it into analog voltage. Based on the set point, the analog controller adjusts the heat input to the oven. Even if the supervisory computer fails, the analog controller can still run the process loop.

Features of supervisory control

- The role of computers is to monitor or supervise the function of analog or specialized controllers
- Computers calculate the set point for analog controllers (opamp based)
- Even if computers fail, analog controllers can manage the process
- Computers are kept far away from the process
- Set point calculation for more than one process can be done by a single computer.

Direct Digital Control (DDC)

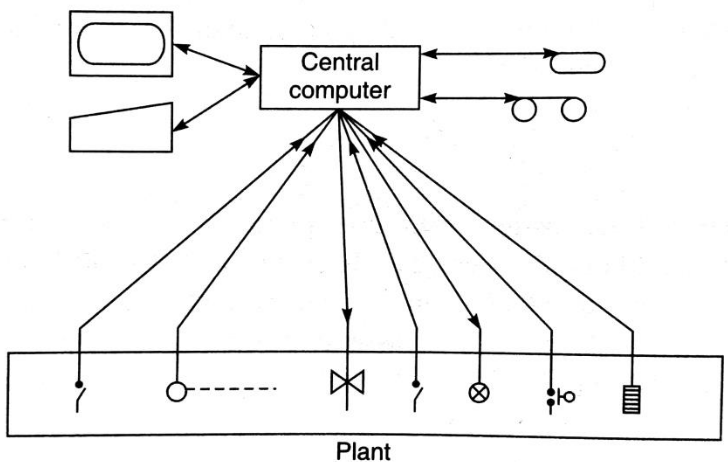


In Direct Digital Control, the computer is interfaced directly with the process for monitoring and control. The method involves use of hardware like signal conditioning units, ADC (to get measurement from sensor), DAC (to send signal to actuator) etc for interfacing process data with computer. The computer used in DDC should have necessary memory and arithmetic capability to execute P, PI or PID control strategy. If there are more than one sensors, a MUX is used for input selection. In the above example, the computer receives measurement information from oven through ADC, makes decision according to the control method (P, Pi PID etc) and gives control signal to the heater through a DAC.

Features of Direct Digital Control

- The computer itself works as the controller.
- No use of outdated analog controllers.
- They are comparatively fast and inexpensive.
- Failure of computer will affect the running of the process
- Computers are kept directly at the plant site.
- If a whole plant is to be controlled, DDC units are placed on a LAN network.

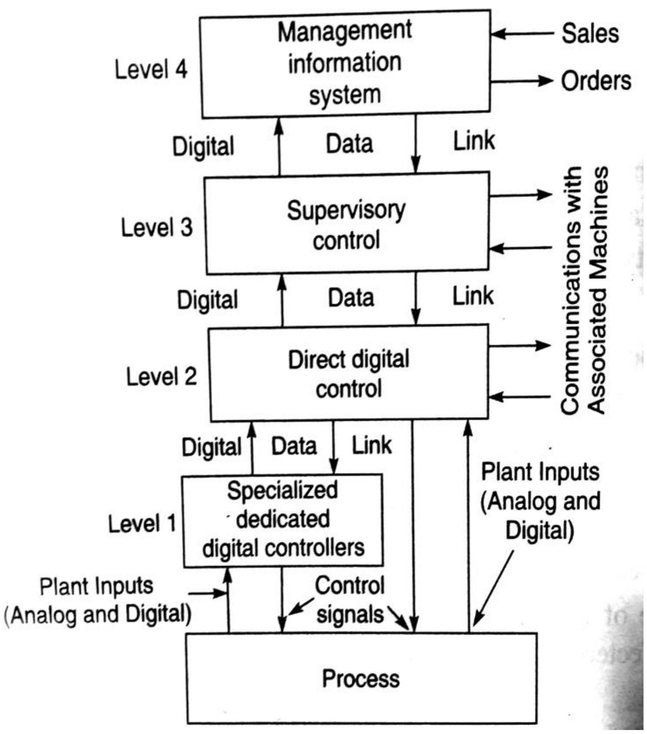
Centralized Computer Control



In centralized computer control, a single large computer is used for the control of a whole plant. Earlier, the cost of computers and its peripherals (input/output devices) were high. Hence it was necessary to use the available computing power efficiently and it led to the use of Centralized computer control. The following are the features of centralized computer control.

- The computer is located in a central room and the plat under control is at a distant location
- Large mainframe computers are used, which are expensive
- Only one set of peripherals is used (discs, printers, plotters etc) because they are also expensive
- The cost of interfacing the computer with the process is high because large cables are needed to send information from plant to the computer.
- Overall co-ordination and optimization is possible because,
    - It is easy to analyze earlier data since all are saved in the same computer.
    - Solution of complex equations need data from different parts of the plant.
- This type of control is not reliable – If the computer fails, it will affect the working of entire plant, sometimes it will lead to shut down of the plant.
- During shut down, a stand-by computer may used, but buying another large mainframe computer is also expensive.
- It is easy to introduce Centralized computer control in an existing plant because only the opamp based analog controllers has to be replaced with computer. The interfacing cables will be there already.
- If a new plant is to be started, the initial cost will be very high in Centralized control because a large number of interfacing cables have to be bought to interface the computer with the plant.

Distributed Control System



A distributed Control system has a layered structure. Each layer has specific functions.

Layer 1 – Field Level

- This level is controlled by Plant Operator. The type of computer used is a simple microprocessor.
- This level consists of specialized digital controllers
- It performs lowest level of functions like detecting emergency condition and shut down. During emergency situation, that area should be isolated.
- This level should be easy to handle – in either manual or automatic modes

Layer 2 – Area Control Level

- This level is maintained by a maintenance engineer. A micro computer is used at this level.
- The level performs Direct Digital Control – like control of Temperature, Pressure, Level etc
- If there is any damage, repair is done without complete plant shut down.
- The level takes care of monitoring of messages and alarm signals
- The type of control can be open loop control or closed loop control

Layer 3 – Plant Level Control

- This level is maintained by a Design and Development engineer. A medium scale computer is used.
- This level performs supervisory control – means set point calculation or adaptive control
- This level takes care of expansion of the system – like adding new controllers
- Design of new control algorithms are done at this level

Layer 4 – Plant Management Level

- This level is managed by a manager. Large Computer is used.
- This level controls plant operation as a whole and includes planning of production.
- The history of plant operation, maintenance details etc are saved.
- This level takes care of training of Plant employees

General features of Distributed Control System

1. The Control system structure is hierarchical (in different levels).
2. The functions of each level are distributed according the hierarchy.
3. There are specialized devices for performing signal conditioning and protection of equipments.
4. There is a bus system for exchange of data.
5. There are special operator stations for process monitoring
6. There is record (log) of data which has details about operator interventions and alarms
7. The failure of one device will not affect the working of other devices
8. If there is failure in one loop, only that loop is disconnected (single loop principle)

Advantages of Distributed Control System

1. Use of several small computers is less expensive compared to use of large main frame computer.
2. Upgrading cost is also less because it is easy to install new small computers compared to mainframe computers
3. Cost of interfacing with the process is less as only small cables are required.
4. It is more reliable than Centralized control. Back up is easy.
5. It is more flexible – easy to make any changes in the system.
6. Management is simplified
7. Data loss and error are minimized because large cables are not used for interfacing