Dr. Norbert Cheung's Series
in
Electrical Engineering

Level 4 Topic no: 09

Introduction to Digital Control

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Reference:

"Modern Digital Control Systems, 2nd edition" Raymond G. Jacquot, Longman.

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1. Introduction to Systems and Control

The topic with which we deal in this book is that of the control of a dynamic system, the plant, by employing feedback which incorporates a digital computer in the control loop. A dynamic system is one that is described by differential equations, and as such the output variables will not exactly track the reference input variables.

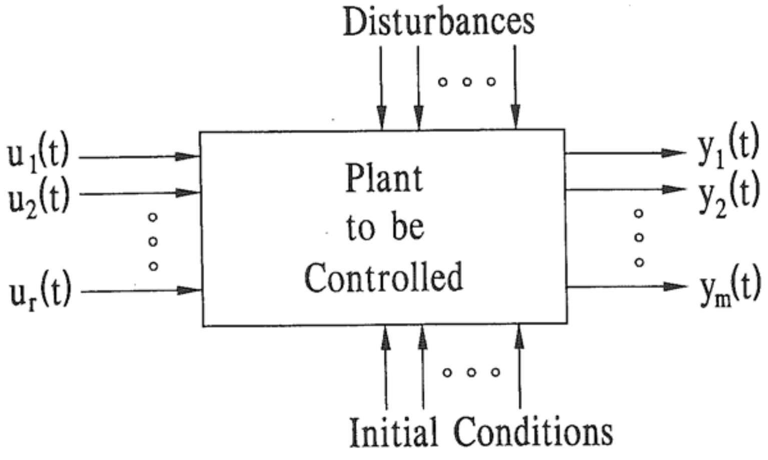

Figure 1.1. Open-loop-controlled plant.

Because of uncertainties in the system model and initial conditions and because of disturbances there is a better way to accomplish the control task. This technique involves using sensors to measure the behavior of

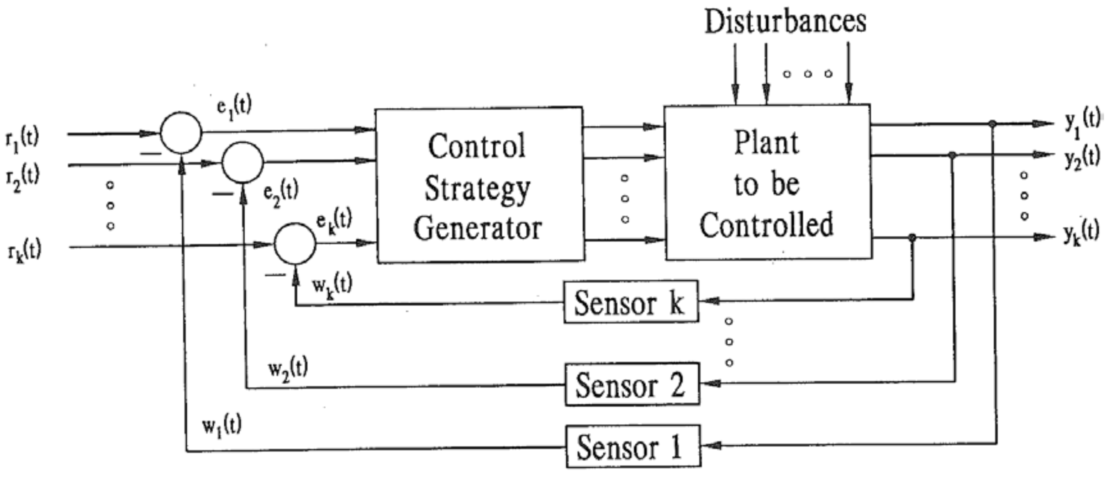

Figure 1.2. Feedback-controlled multivariable system with sensors.

some subset of the output variables (those we want to control) $y_1(t), \ldots,$ $y_k(t)$ $(k \leq m)$ and, after measurement, comparing them with what we would like each of them to be at time t and calling the difference between the desired value $r_i(t)$ and the measured value $w_i(t)$ the *error*. Using the errors in each of the variables, we can generate the control efforts so as to drive the errors toward zero. This situation, depicted in Fig. 1.2, is referred to as *feedback control*.

Difference between analogue control and digital control:

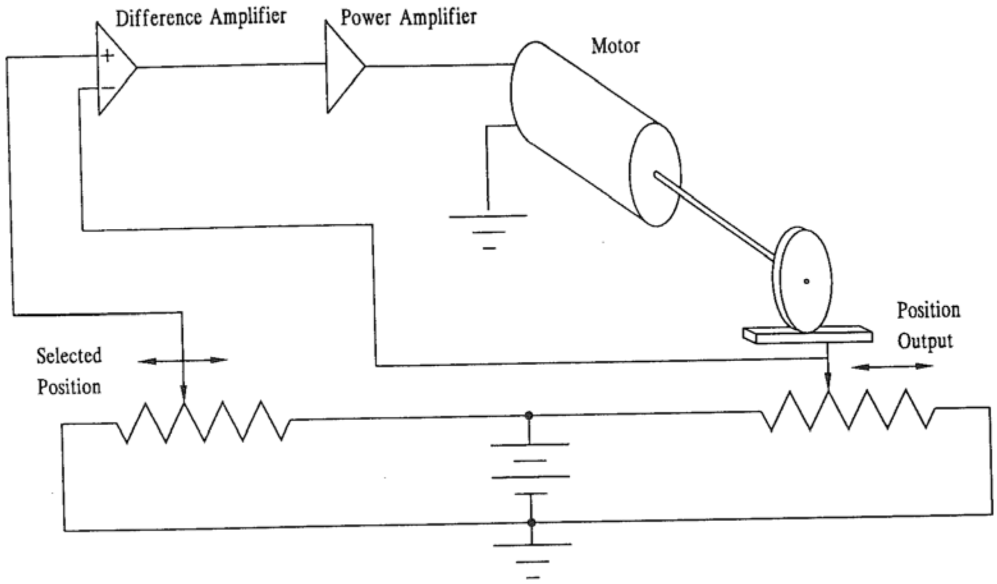

Figure 1.3. Position servomechanism with continuous signals.

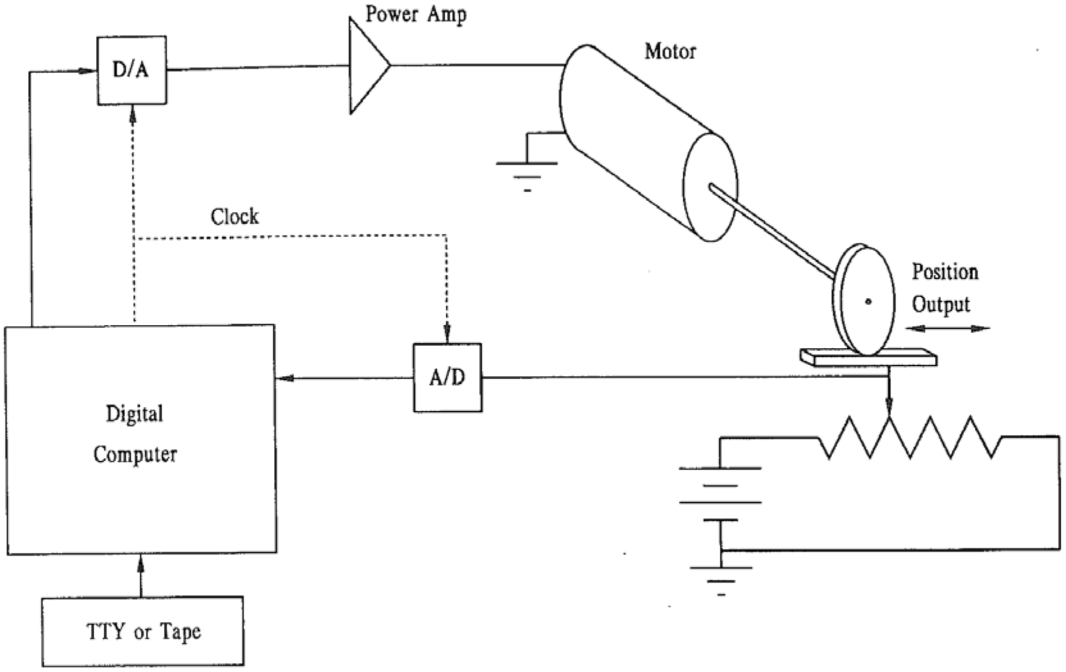

Figure 1.4. Digitally controlled positioning system.

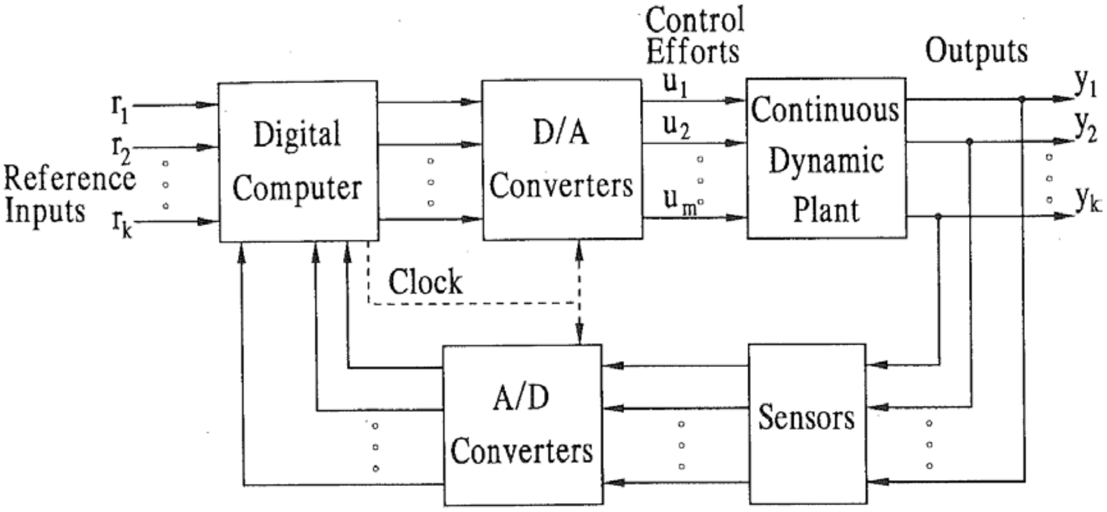

Figure 1.5. Digitally controlled multivariable system.

A single loop digital control system

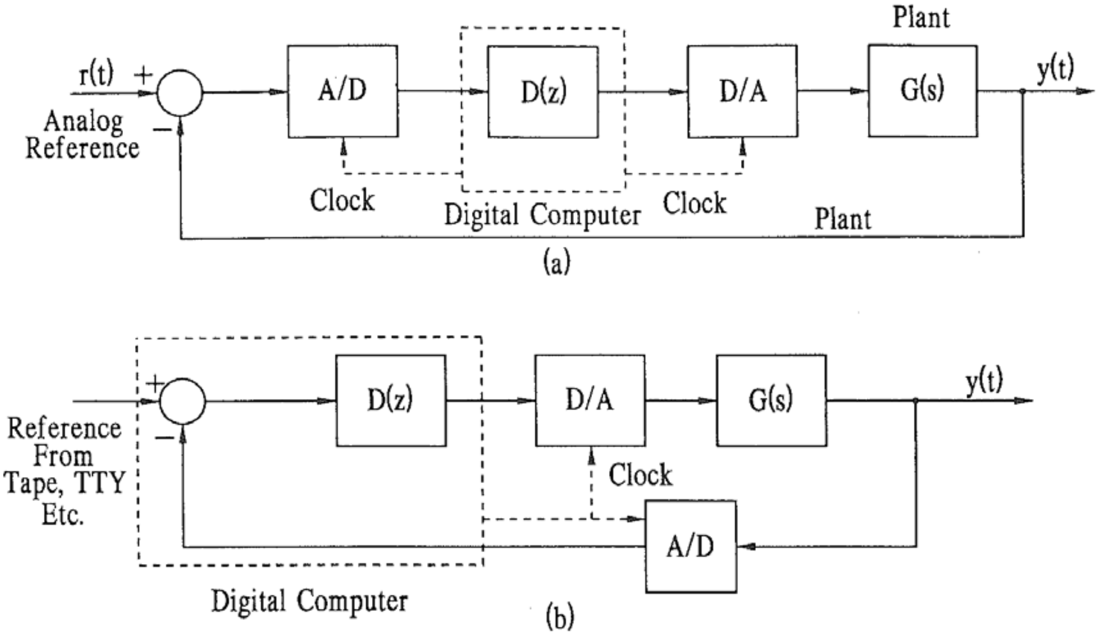

Figure 1.6. Several configurations of a digital control system.

Why use digital instead of analogue?

- More stable performance, environmentally robust
- Lower component cost, less setup and adjustment effort
- Software Programmable
- Can easily include more intelligent control functions
- More space saving.
- Easy interface with other systems

2. Digital Control Components

Solid state switch (analogue channel connection)

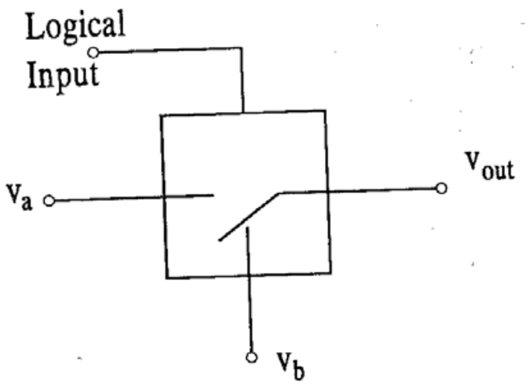

Figure 1.8. Solid-state switch.

Summing digital-to-analogue converter

$$v_o = 5\left(B_3 + \frac{B_2}{2} + \frac{B_1}{4} + \frac{B_0}{8}\right) \quad \text{volts} \qquad (1.5.1)$$

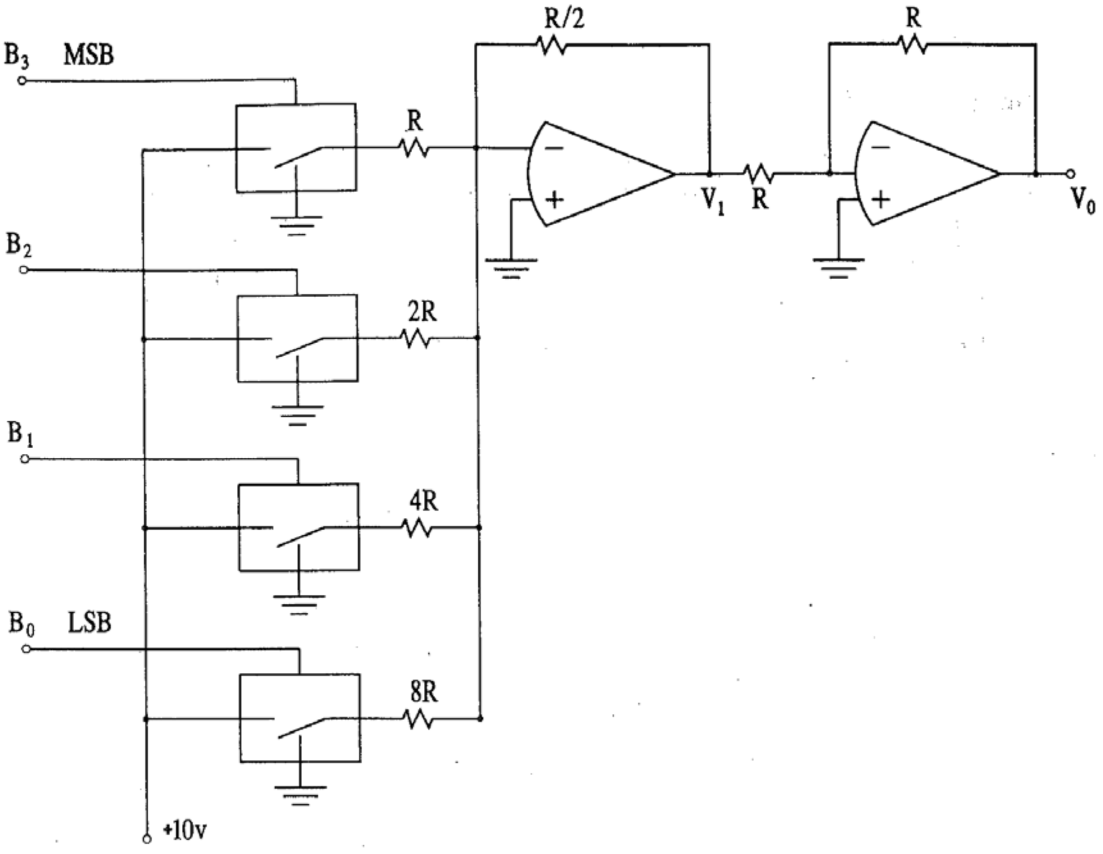

Figure 1.9. Summing digital-to-analog converter.

Ladder digital to analogue converter

For arbitrary inputs the output may be calculated by the method of superposition for each bit of input, although the calculations are quite tedious for the lower bits. The input–output relation is

$$v_o = 5\left(B_3 + \frac{B_2}{2} + \frac{B_1}{4} + \frac{B_0}{8}\right) \qquad \text{volts} \qquad (1.5.2)$$

This design eliminates the need to have a wide range of resistances by having only two values, and only the ratio of these must be controlled in the manufacturing process.

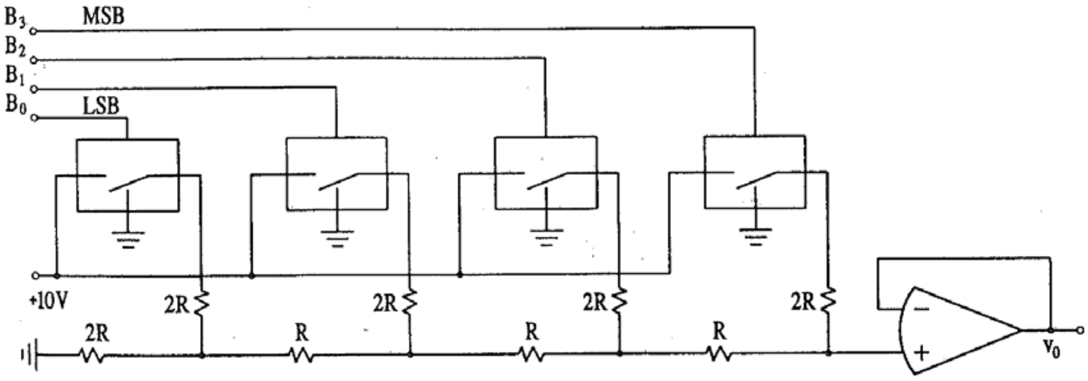

Figure 1.10. R–$2R$ ladder D/A converter.

Sample and hold (SOH) circuit

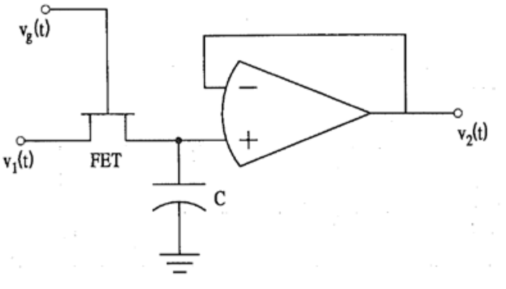

Figure 1.11. Sample-and-hold circuit.

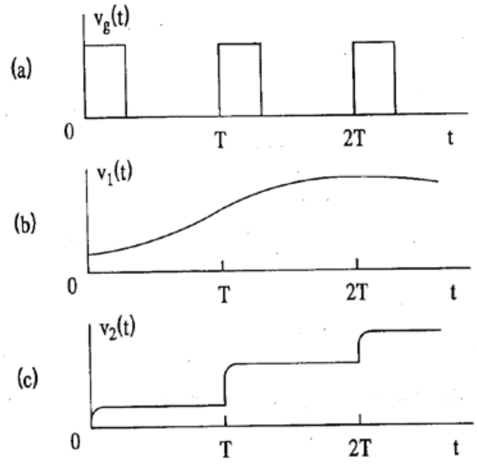

Figure 1.12. Typical voltages for the sample-and-hold circuit.

Types of Analogue-to Digital Converters

- Successful approximation
- Tracking
- Flash

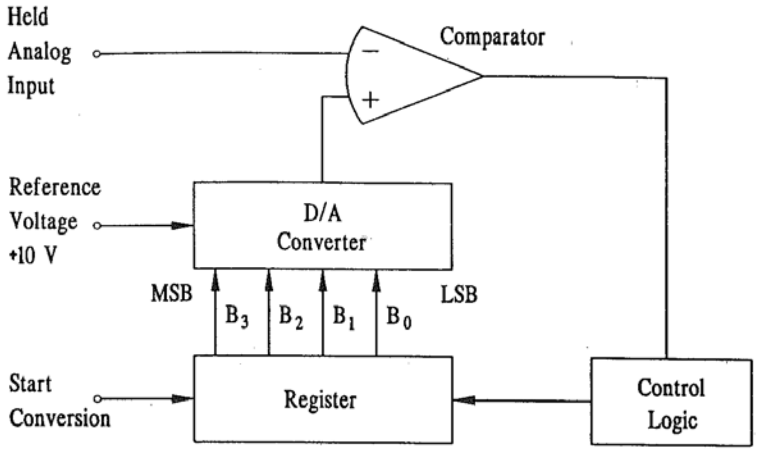

Figure 1.13. Successive approximation analog-to-digital converter.

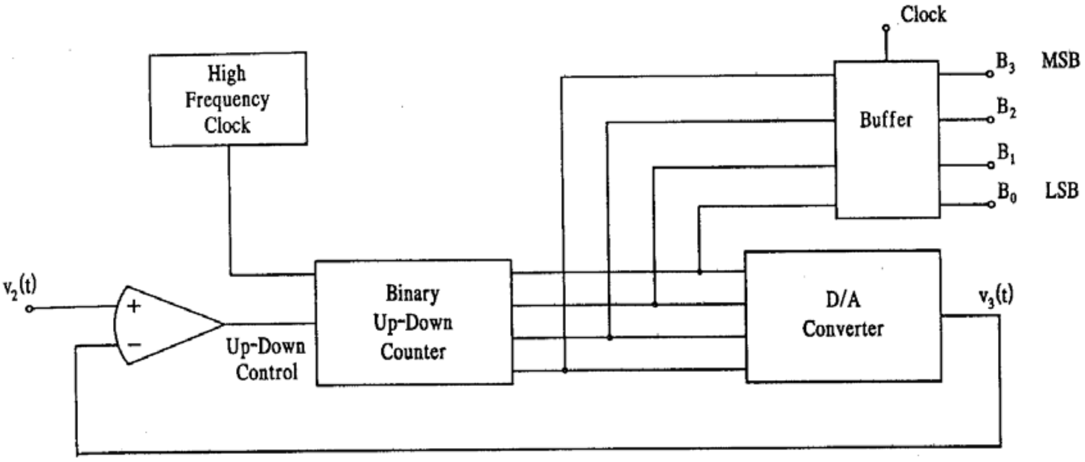

Figure 1.14. Tracking analog-to-digital converter.

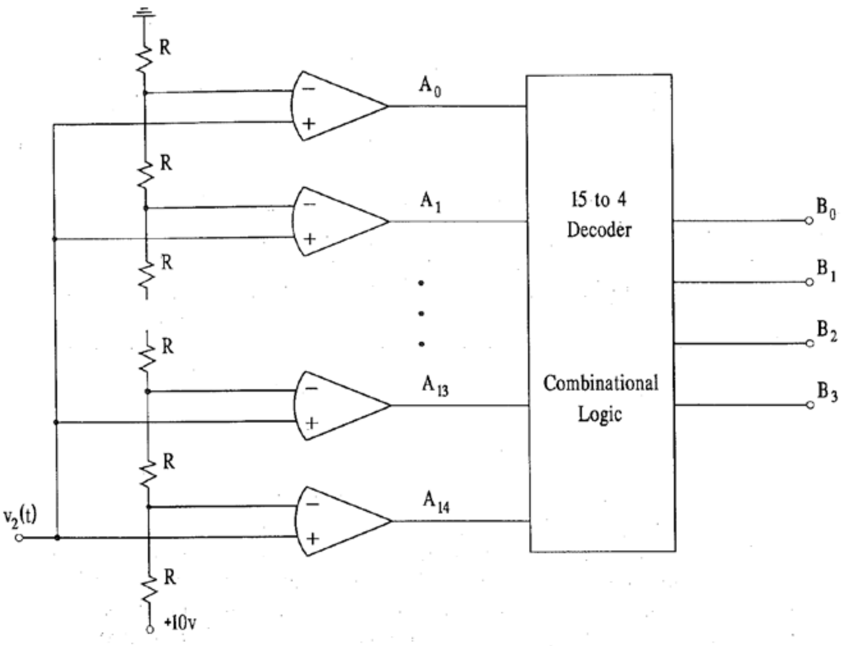

Figure 1.15. Flash analog-to-digital converter.

Digital Computing Hardware

Micro-controller (embedded processor), features:

- All interface on a chip
- Less computing power
- Low cost and high volume applications

Digital Signal Processor (DSP), features:

- Highly parallel architecture for signal processing
- Include multiplier and barrel shifter hardware
- May include high speed interface for parallel processing

3. Example of a Microprocessor based Thermal Controller

As an example of how a digital processor might be used to control a physical process, consider the bacterial growth chamber of Fig. 1.16, in which it is desired to control the temperature to be somewhat higher than room temperature. The chamber is subject to changing environmental temperature $T_e(t)$.

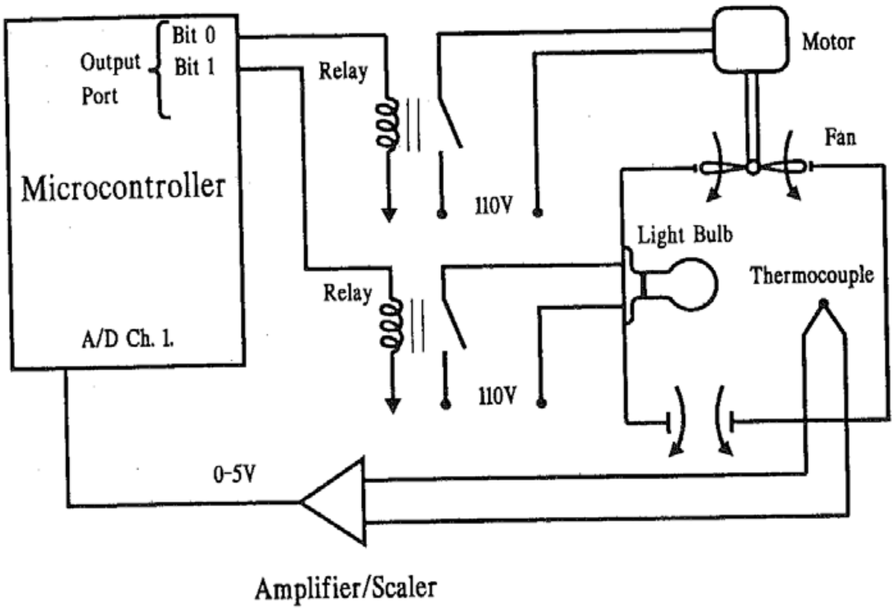

Figure 1.16. Bacterial growth chamber control problem.

The temperature in the chamber is measured by a thermocouple and some associated amplifying and scaling circuitry. The voltage output from the amplifier is then converted by the on-board analog-to-digital converter of the microcontroller. If the temperature exceeds some predetermined value, bit 0 of the output port will be driven high and the fan will be turned on to bring in cool external air. When the temperature gets below a predetermined value, bit 1 of the output port will turn on the light to heat the air in the chamber. The predetermined values for light on and fan on need not be the same. It is even conceivable that both the fan and light could be on at the same time.

This example has many of the features of the types of systems in which we are interested. These features are:

1. The output variable (temperature) is measured periodically and converted to a binary number.
2. The resulting number is used to decide what control strategy will be used (fan on, light on, both on, both off).
3. There are actuators (the light and fan) to provide the controlling action.

The on–off nature of the actuation in this problem will make it such that the precision of the control will not be too great, as the temperature will tend to "hunt" because there is no way to decrease the heat addition as the system nears the temperature desired.

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