Digital to Analog Converters

The data converters convert one form of data into another form. Real world processes produces analog signals which carry information pertaining to process variables such as voltage, current, charge, temperature and pressure. The rate of flow of such information may be very slow or very fast. It is difficult to store, manipulate, compare, calculate and retrive such data with good accuracy using purely analog technology.

However, computers can perform storing, manipulation, comparison and calculation operations quickly and efficiently using digital technique. Therefore it is necessary to convert the analog signals from various transducers into its equivalent digital data, which act as the input for digital system. Thus the requirement for converting analog signal into digital data emerged. The computer also need to communicate with people and physical processes through the use of analog signals, which necessiated the process of digital to analog conversion

A D/A converter or DAC converts digital

data into its equivalent analog data.

An A/D converter or ADC converts analog data into its equivalent digital data i.e binary data.

13.3 SPECIFICATIONS OF D/A CONVERTER

The important specifications, namely, accuracy, offset voltage, monotonicity, resolution and settling time of D/A converter are discussed below.

Accuracy

The components in D/A converter circuits are prone to mismatches, drift, ageing, noise and other sources of errors. These factors lead to degradation in conversion performance.

Absolute accuracy defines the maximum deviation of the output from the ideal value and it is expressed in fractions of 1 LSB. The D/A converter manufacturers follow different ways of specifying accuracy. The D/A converter errors are classified as *static* and *dynamic errors*.

Offset Voltage

The simplest kind of static errors are *offset error* and *gain error*. Ideally, the output of a D/A converter is 0V when all the bits of binary input word are 0s. In practice, however, there is a very small output voltage called *offset voltage* or *offset error* as depicted in Fig. 13.2(a). The offset error is nullified by translating the actual A/D converter characteristics up or down so that it goes through the origin as shown in Fig. 13.2(b). The gain error shown in Fig. 13.2(b) is compensated by adjusting the scale factor *K*.

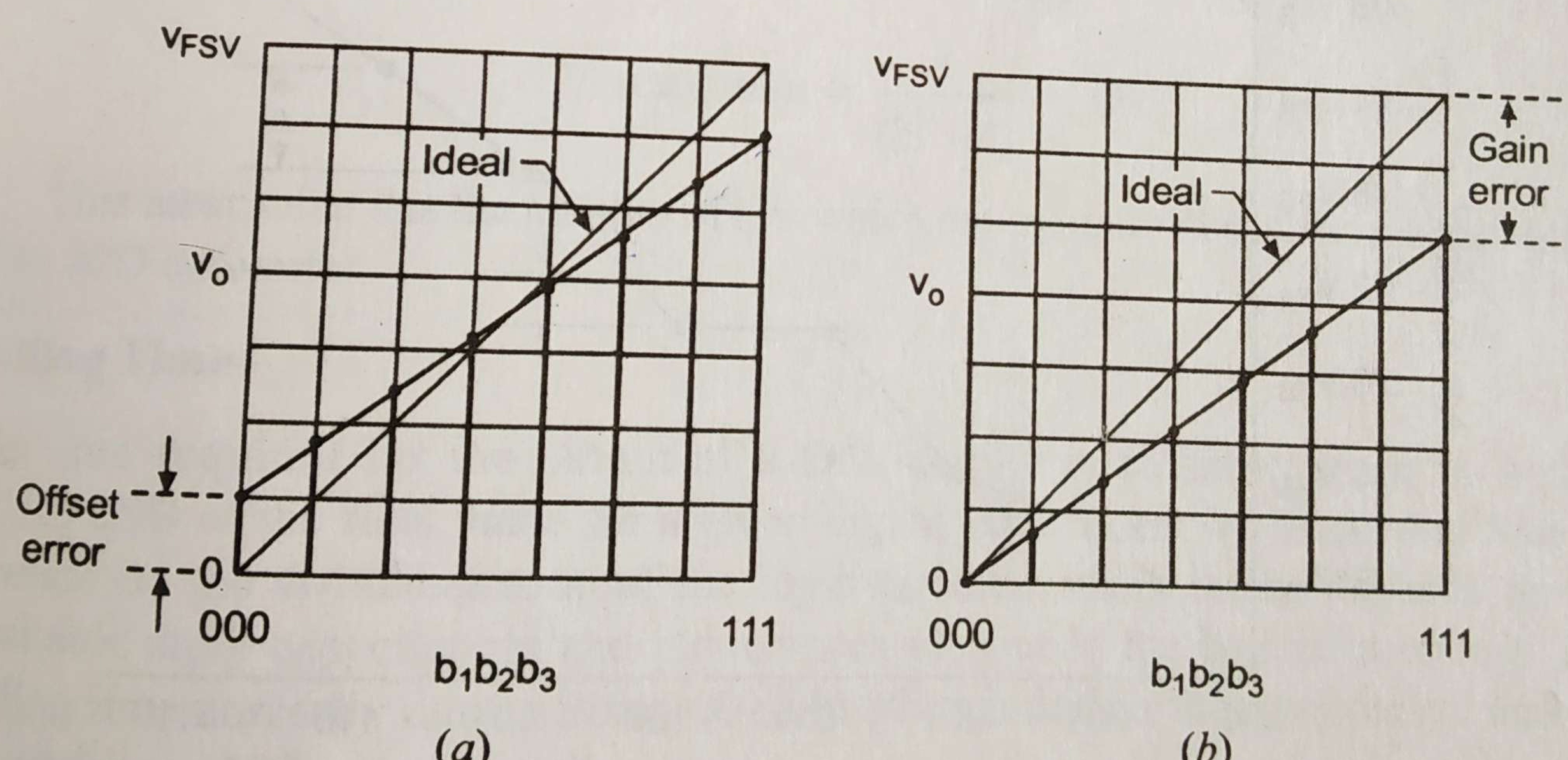

***Fig. 13.2** (a) D/A converter offset and gain errors; (b) Nullifying the errors*

Linearity

The most common dynamic errors are *full-scale error* and *linearity error*. *Full-scale error* is the maximum deviation of the output value from its expected or *ideal* value, expressed in percentage of full-scale. *Linearity error* is the maximum deviation in step size from the ideal step size. More expensive D/A converters have full-scale and linearity errors as low as 0.001% of full-scale. General purpose D/A converters have accuracies in the range of 0.01 to 0.1%.

The linearity of a D/A converter is defined as the precision with which the digital input is converted into analog output. An ideal D/A converter produces equal increments in analog output for equal increments in digital input as shown in dotted line curve of the transfer characteristics of Fig. 13.3. However, in an actual D/A converter, the gain and offset errors due to resistors introduce non-linearity as shown by the solid line of the transfer characteristics of Fig. 13.3.

The linearity error measures the deviation of the output from the fitted straight line which passes through the measured output points. It is represented by $\in/\Delta$ as shown in Fig. 13.3. Commonly, the linearity of D/A converter is specified as less than ± 1/2 *LSB* meaning that $|\in| < (1/2)\Delta$.

Differential nonlinearity (DNL) error: For a D/A converter, the DNL error is the difference between the ideal and the measured output responses for successive D/A converter codes. An ideal D/A converter response would have analog output values exactly one code (1 LSB) apart (DNL = 0). A DNL specification of greater than or equal to 1 LSB guarantees monotonicity.

Integral nonlinearity (INL) error: For data converters, INL is the deviation of an actual transfer function from a straight line. After nullifying offset and gain errors, the straight line is either a best-fit straight line or a line drawn between the end points of the transfer function. The INL is often called *relative accuracy*.

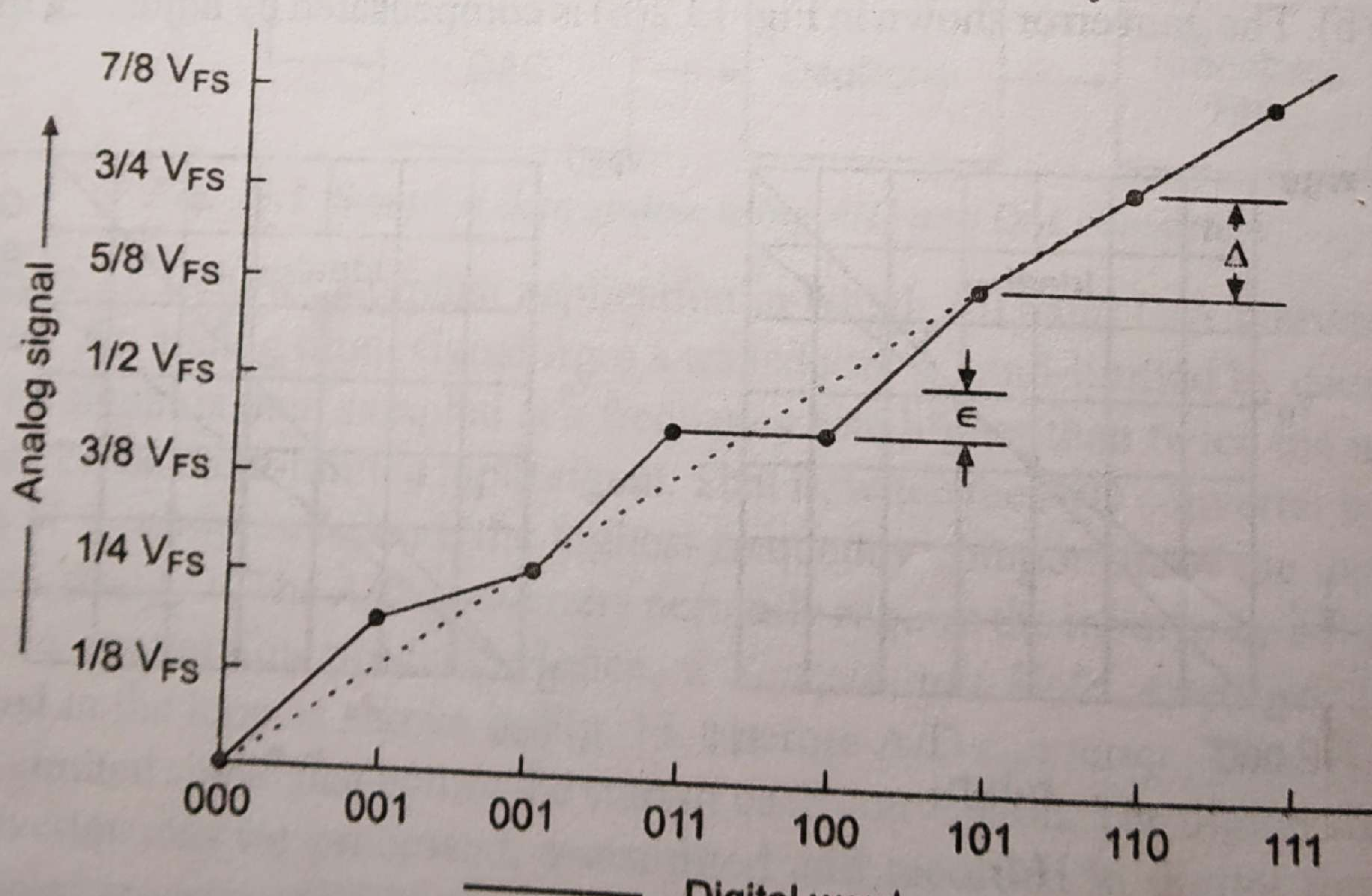

Fig.13.3 Linearity error of a 3-bit D/A converter

Monotonicity

A D/A converter is monotonic if its output value increases as the binary inputs are incremented from one value to the next. That is, the staircase output can have no downward step as the binary input is incremented. Figure 13.3 shows the transfer curve for a non-monotonic D/A converter. The output decreases when the input word changes from 011 to 100.

The monotonic characteristic is important in control applications, without which, oscillations will result. If a D/A converter is identified to be monotonic, the error must be less than ± (1/2) *LSB* at each output level. Hence all the D/A converter ICs are designed to have linearity error of less than ± (1/2) *LSB* always.

Resolution (Step Size)

Resolution of D/A converter is defined as the smallest change that can occur in the analog output as a result of a change in the digital input. The resolution is always equal to the weight of the LSB and is also known as the step size, since it is the amount of V_o that will change when the digital input data goes from one step to the next.

Although resolution can be expressed as the amount of voltage or current per step, it is more useful to express it as a percentage of the full-scale output. The percentage resolution is given by

$$\text{Percentage resolution} = \frac{\text{step size}}{\text{full scale}} \times 100 \tag{13.1}$$

Percentage resolution can also be calculated as

$$\%\,\text{resolution} = \frac{1}{\text{total number of steps}} \times 100 \tag{13.2}$$

For an n-bit digital input, the total number of steps is $(2^n - 1)$. Then,

$$\%\,\text{resolution} = \frac{1}{(2^n - 1)} \times 100$$

This means that it is the number of bits which determines the percentage resolution of an A/D converter.

Settling Time

The time required for the output of a D/A converter to settle down to within ± (1/2) LSB of the final value for a given digital input is known as *settling time*. It depends on the switching time of the logic circuits, which inturn depends on the inevitable stray capacitances and inductances present in the converter circuit. The settling time normally ranges from 100 ns to 10 µs based on the word length and the conversion technique employed.

Temperature Sensitivity

For a fixed digital input, the analog input varies with temperature, normally from ± 50ppm/°C to ± 1.5ppm/°C. This is introduced due to the temperature sensitivity of the reference voltages, the resistors used in the converters, the op-amp and its offset voltage. Therefore, this factor determines the stability of D/A converter.

There are various types of D/A converters, namely, (i) weighted resistor type, (ii) R-2R ladder type, (iii) voltage mode R-2R ladder type, and (iv) inverted or current mode R-2R ladder type.