DIGITAL TO ANALOG CONVERTER

The task of a D/A converter is to transform a digital input into an analog output.

Input: **A binary word.**
Output: **Analog signal representing the weighted sum of the non- zero bits in the word.**

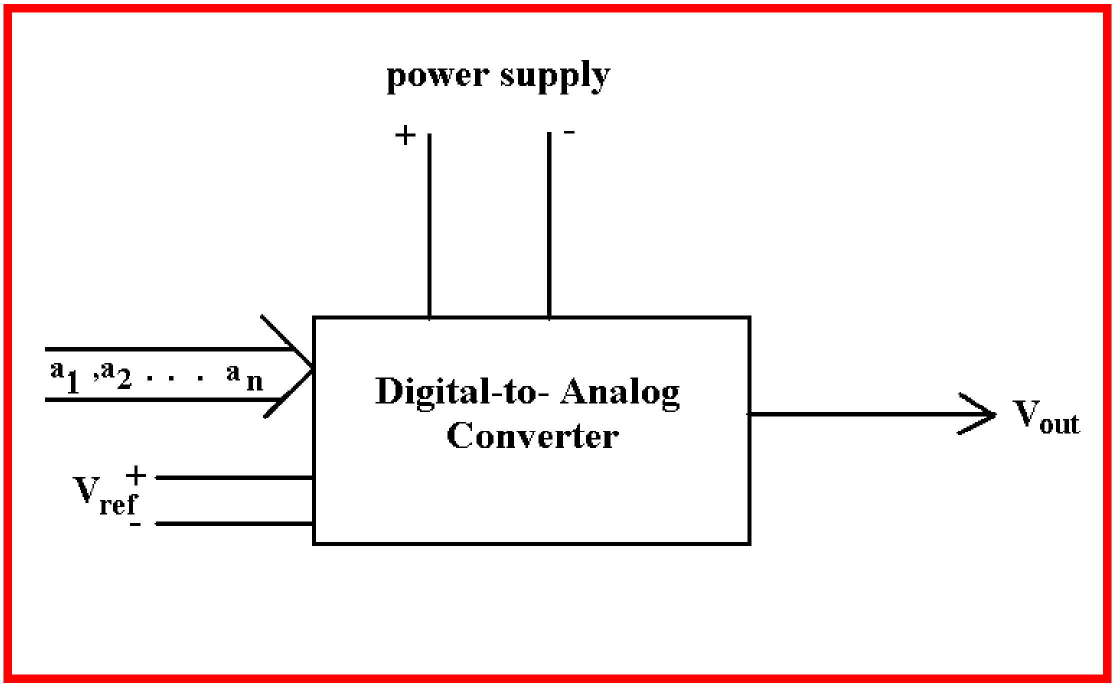


FIG. Block diagram of D/A Converter

The output of n-bit D/A converter is given by

$$V_{out} = V_{ref}(a_1 2^{-1} + a_2 2^{-2} + \cdots \ldots + a_n 2^{-n})$$
$$= V_{fs} \sum_{i=1}^{n} a_i 2^{-i}$$

Where, V_{out} = Output voltage, V_{fs} = full scale output voltage
V_{ref} = reference voltage. Usually V_{ref} and V_{fs} are same.
a_1, a_2, a_n = n bit digital input word, a_1= Most Significant Bit(MSB), a_n= Least Significant Bit (LSB).

Example:

Input : $110_2 = (6_{10})$, V_{ref} = 8 volts
Output : $(1*2^{-1} + 1*2^{-2})V_{ref}$ = 6 volts

Types of DAC's
- **Binary Weighted Resistor Network**
- **R-2R Ladder Network**

Binary Weighted Resistor Network

➢ **Utilizes weighted resistor network and summing amplifier to form the weighted sum of all non-zero bits in the input word.**

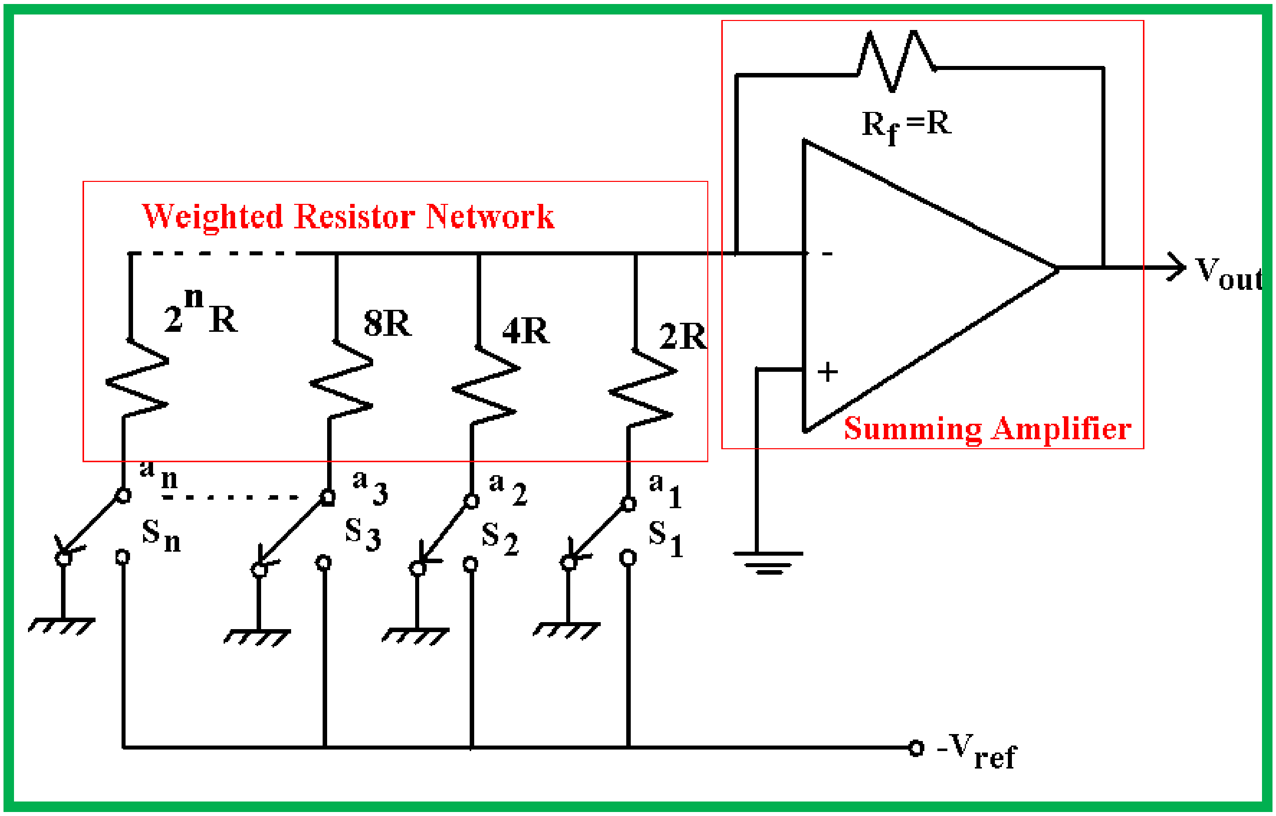


Fig. Weighted Resistor Network DAC

BWRN Equations:

$$V_{out} = -\frac{R_f}{R} * V_{ref}\left(\frac{a_1}{2^1} + \frac{a_2}{2^2} + \cdots \ldots \ldots + \frac{a_n}{2^n}\right)$$

Where $R_f = is\ the\ feedback\ resistance$

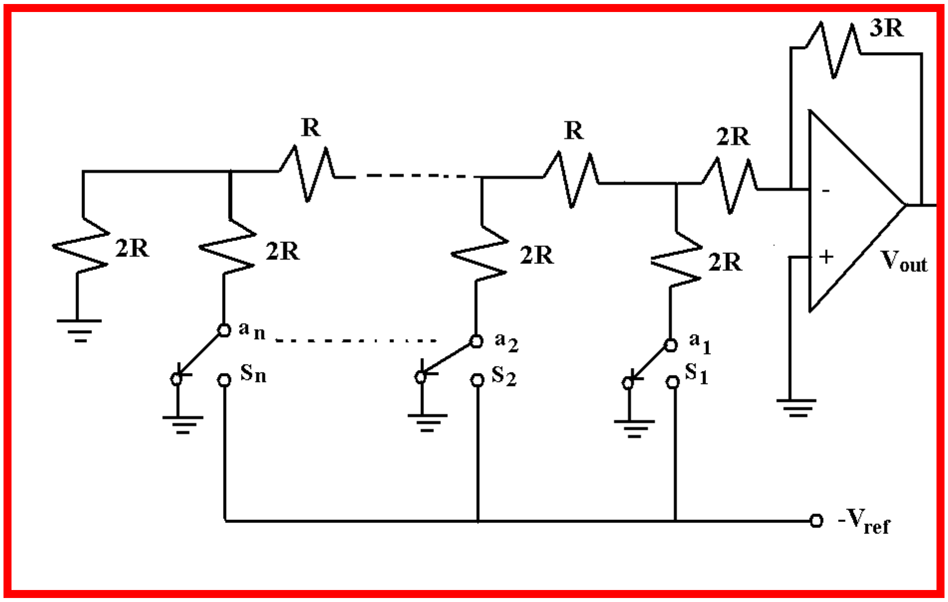
a_i = is the value of the i^{th} bit (1 or 0)

Problems of BWRN?

- **Wide range of resistor values required with great accuracy**
- **Current drawn from V_{ref} varies with input binary word value.**
- **Problem of varying power dissipation in resistor network.**

R-2R Ladder Network

- **Constructed with resistors that have only two values R and 2R and thus overcomes one of the problems of the weighted resistor network type DAC.**



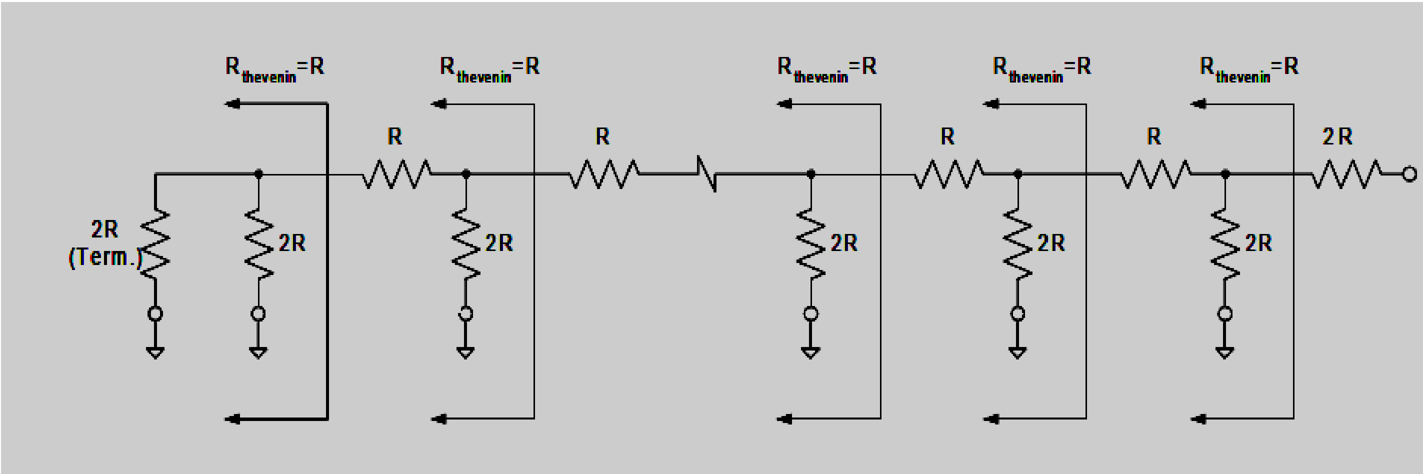


Fig. Binary R-2R Ladder type DAC

DAC Specification

- **Resolution**
- **Accuracy**
- **Monotonicity**
- **Settling Time**
- **Errors**

Resolution :

The resolution of a DAC is defined as the smallest observable change in the analog output that can be affected by a single step change in the digital input.

$$\text{Resolution} = V_{LSB} = \frac{V_{\text{Ref}}}{2^n}$$

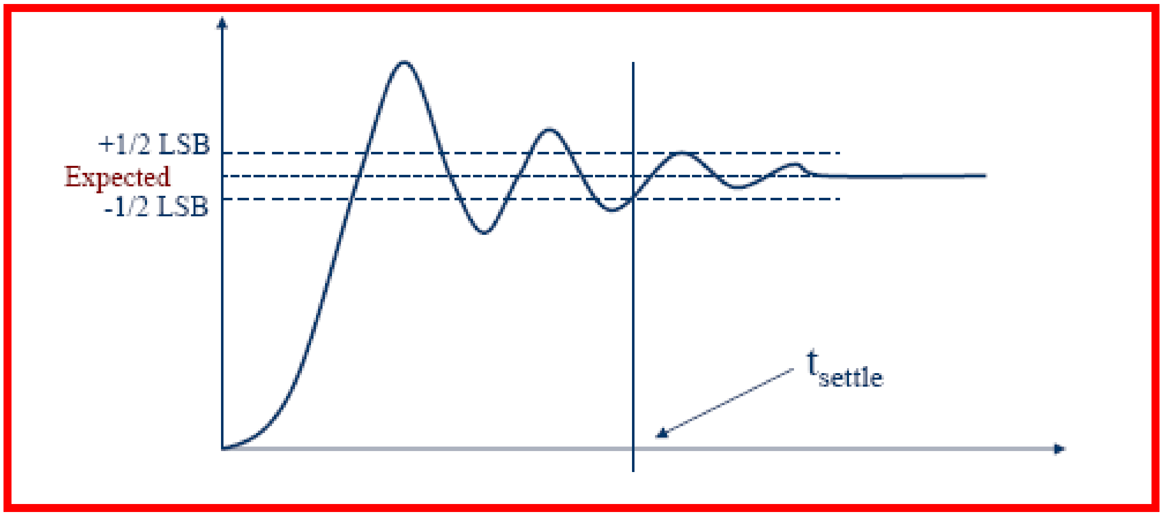
Accuracy:

Accuracy is a measure of how close the actual output is to the theoretical output. Accuracy of the DAC is depend upon the accuracy of the resistors used and the accuracy of the reference voltage used.

Example : If a DAC is specified with a theoretical 10V output and actually produces 9.9V, the it is 99% accurate and 1% inaccurate. Another way of saying it is that the converter has an error of 1%.

Settling Time:

This is the time it takes a DAC to settle within +/- 1/2 of a LSB of its final value when a change occurs in the input digital code.



Monotonicity

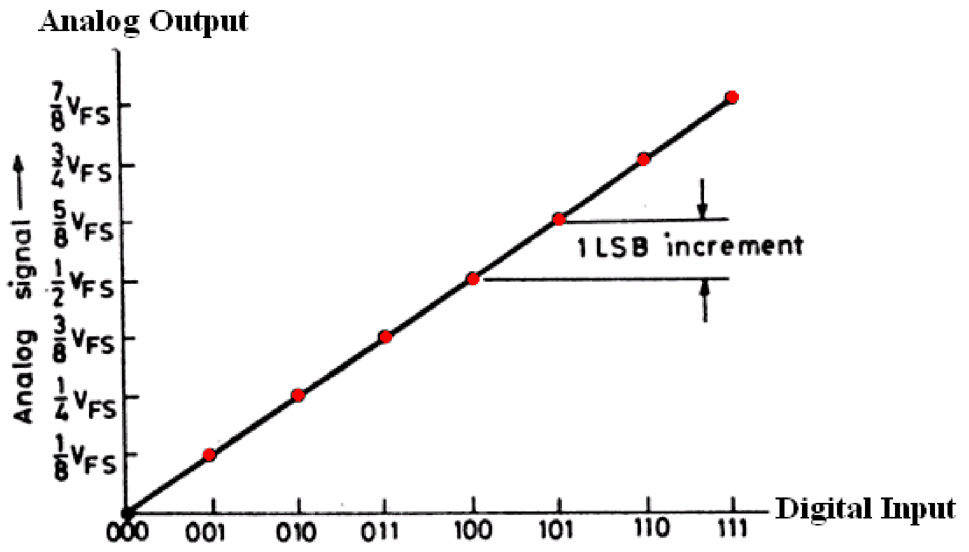
A DAC is said to be monotonic if its output either increase or remain same for correspondingly increasing input. When such a converter skips or misses an output by decreasing in output for a corresponding increasing input, it is said to be non-monotonic. This refers to the ability of a DAC's analog output to move only in the direction that the digital input moves (i.e., if the input increases, the output doesn't dip before asserting the correct output.)

DAC Errors

- **Offset Error**
- **Gain Error**
- **Linearity Error**

The ideal relationship between the digital input code and the analog output voltage for an ideal 3-bit DAC is shown in Fig. below. The dots in the Fig. represent the eight possible output voltages ranging from 0 to 0.875 V_{FS}. The output voltage never reaches a value equal to V_{FS}. The maximum output is always one LSB smaller than V_{FS}. <u>Due to the errors the actual transfer function curve deviates from the ideal one. All these errors are temperature dependent.</u>

$$V_{o/p\max} = V_{FS}\left(\frac{2^n - 1}{2^n}\right)$$



The Ideal Transfer Function curve of DAC

Offset Error

If the analog outputs that are on a straight line are uniformly shifted by an equal amount for each digital input value, the DAC is said to have an offset error. In other words it is the voltage offset from zero when all input bits are low.
Fig. below shows all output points are offset from the ideal output by an equal amount.

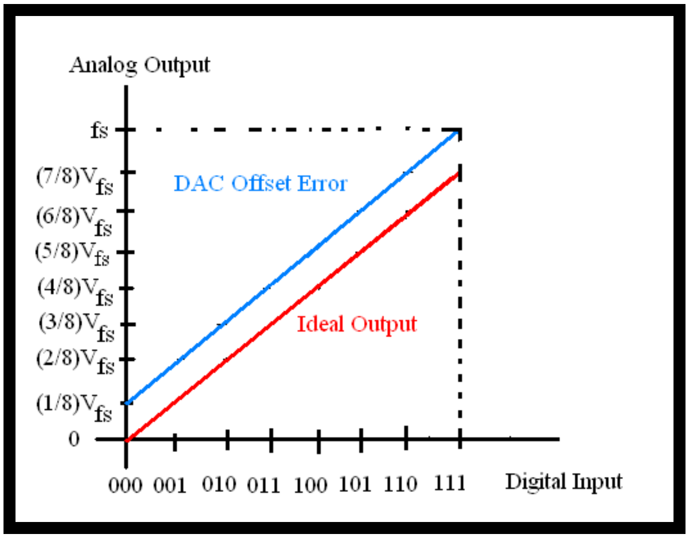


Fig. DAC (3-bit) with an offset error of 1LSB.

Gain Error

If the difference between the actual analog outputs and their corresponding ideal analog outputs increase linearly for increase in the digital inputs, the DAC is said to have a gain error, i.e. Slope deviates from ideal gain.

- **Low Gain Error: Step Amplitude Less than Ideal**.
- **High Gain Error: Step Amplitude Higher than Ideal**.

Gain Temperature Coefficient (Full Scale Temperature Coefficient): **Change in gain error divided by change in temperature. Usually expressed in parts per million per degree Celsius (ppm/°C).**

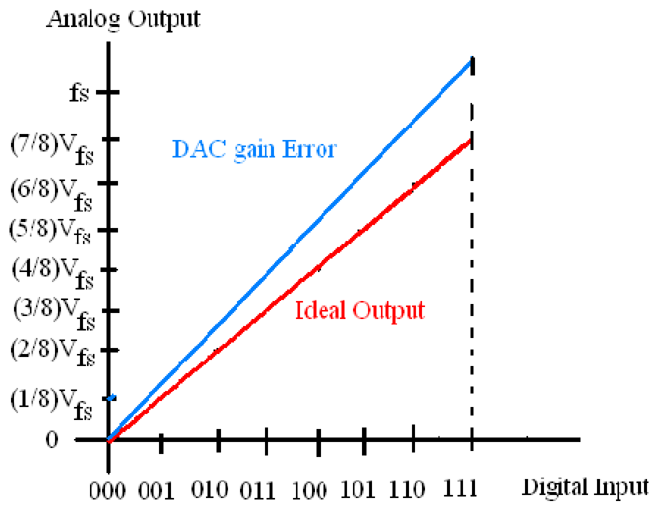


Fig. DAC (3-bit) with high gain error

Linearity Error

The actual outputs for possible digital inputs are unevenly distributed instead of being on a straight line, the DAC is said to have linearity error.
A good DAC exhibits a linearity error of less than 0.5 LSB.

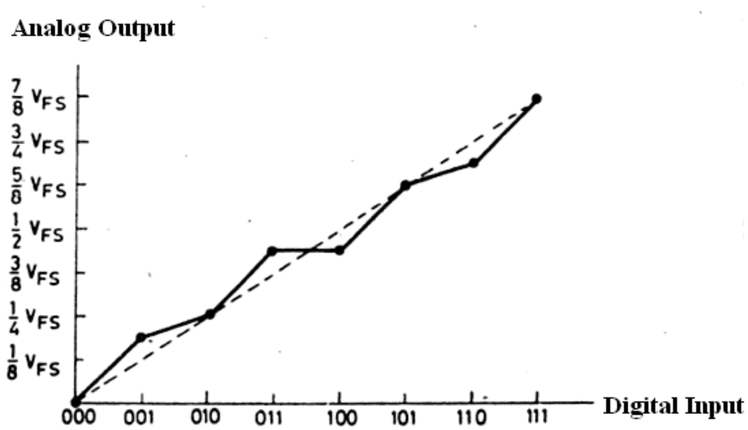


Fig. Linearity Error for 3-bit DAC

Linearity Error is of two types:

- **Differential non-linearity**
- **Integral non-linearity**

Differential non-linearity (DNL) is the maximum deviation of an analog output from the ideal output of +1LSB between two adjacent input codes.

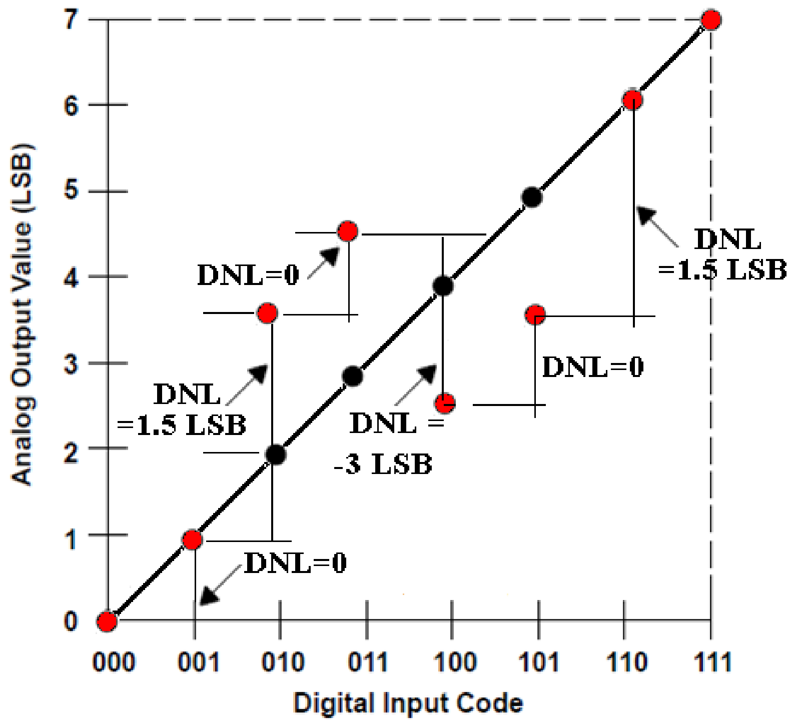


Fig. DNL Error for 3-bit DAC

Integral non-linearity (INL) is the deviation of the values on the actual transfer function from a straight line. This straight line can be a line drawn between the end points of the transfer function once the gain and offset errors have been nullified. This method is called <u>end-point linearity</u>.

For DAC, INL is measured at each step. The name integral nonlinearity is derived from the fact that the summation of the differential nonlinearities from the bottom up to a particular step, determines the value of the integral nonlinearity at that step.

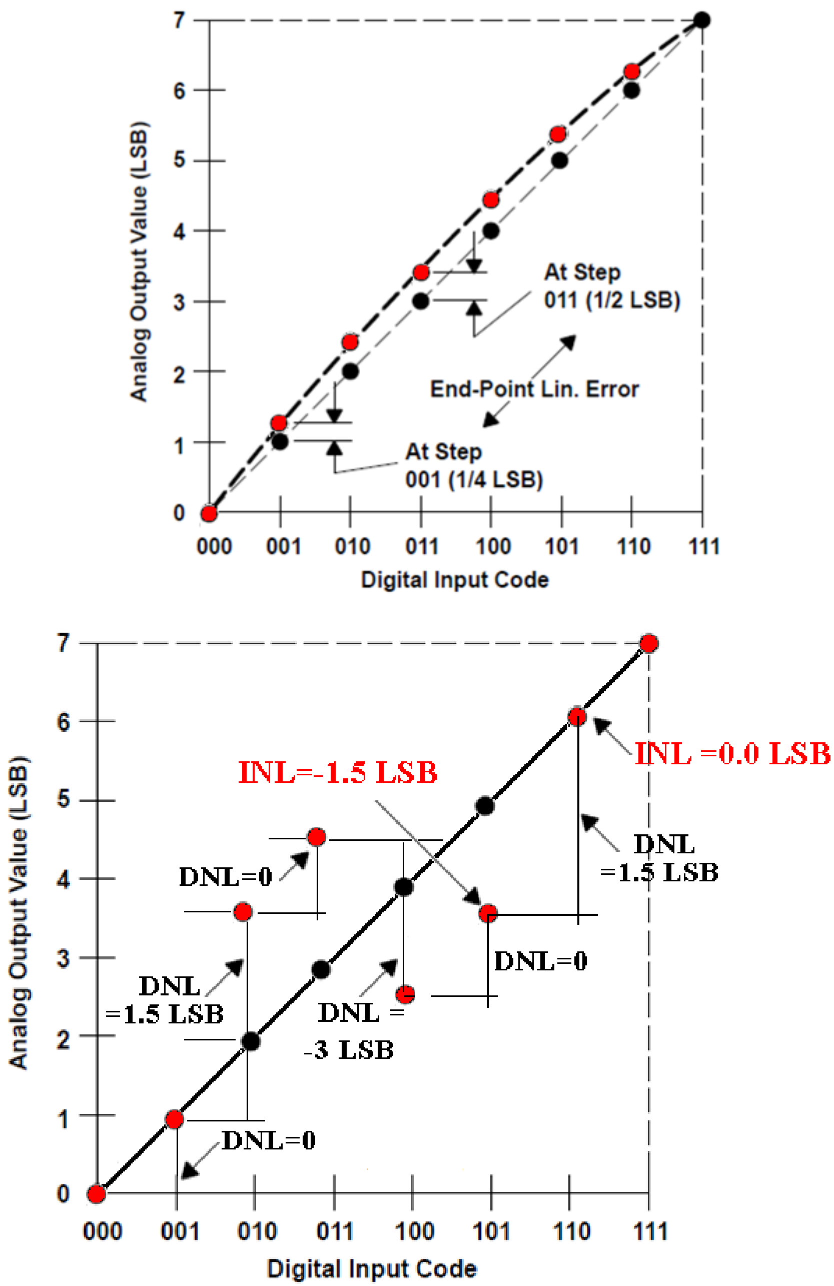


Fig. INL Error for 3-bit DAC