Use of OP AMP as DA Converter (Digital – to – Analog Converter):

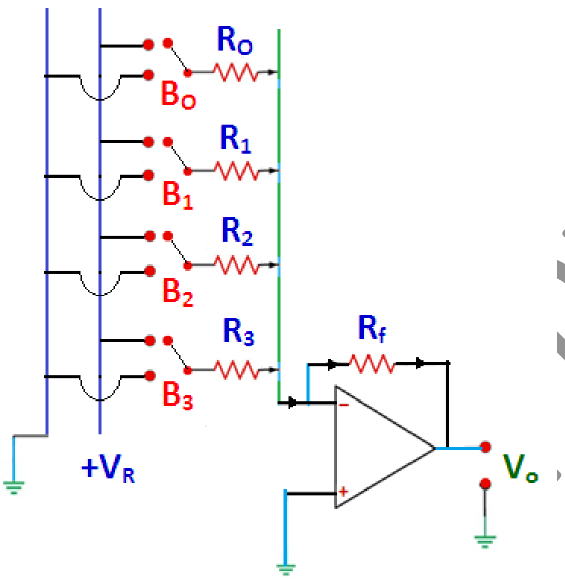
A device that produces an analog output voltage from a given digital input is called a digital-to-analog (DA) converter. We describe below two forms of DA converter using OP AMPs.

(i) The Weighted-Resistor DA Converter:

To start with, we consider the conversion of a 4-bit digital data into an analog form. The decimal equivalent (N) or analog form of a 4-bit digital data $(B_3B_2B_1B_0)$ is

$$N = 2^3B_3 + 2^2B_2 + 2^1B_1 + 2^0B_0 = \sum_{i=3}^{0} 2^iB_i \quad (B_i = 0 \text{ or} 1\ , i = 0, 1, 2, 3)$$

where each bit of the data contributes to the final value with a weight 2^i multiplied by the value of $B_i (i = 0, 1, 2, 3)$. Since B_i is either 0 or 1, the contribution is clearly zero or the bit weight. Here B_0 is the least significant bit (LSB) and B_3 is the most significant bit (MSB).



The conversion circuit is thus required to produce an output signal weighted according to the bit positions and to add them together. A basic 'Weighted Resistor' circuit for the conversion of a 4-bit digital data using an OP AMP is shown in figure. The logic voltages representing the individual bits B_3, B_2, B_1 and B_0 are applied to the resistors of the converter through switches. When the coefficient B_i is 1, the corresponding switch is closed, thus connecting a stabilized voltage source V_R to the converter.

When B_i is 0, the corresponding switch is connected to the ground. The resistors R_0, R_1, R_2 and R_3 in the circuit are weighted so that the successive resistors ratio is 2, i.e. $\frac{R_0}{R_1} = \frac{R_1}{R_2} = \frac{R_2}{R_3} = 2$, and each resistor is inversely proportional to the numerical significance of the appropriate binary bit. Thus, if R is any arbitrary resistance selected to suit the impedance level of the circuit, then

$$R_0 = \frac{R}{2^0} = R;\ R_1 = \frac{R}{2^1} = \frac{R}{2};\ R_2 = \frac{R}{2^2} = \frac{R}{4}; \text{and } R_3 = \frac{R}{2^3} = \frac{R}{8}.$$

The current i to the non-inverting input terminal is $i = V_R\left(\frac{B_3}{R_3} + \frac{B_2}{R_2} + \frac{B_1}{R_1} + \frac{B_0}{R_0}\right)$

Substituting the values of $R_0, R_1, R_2,$ and R_3 we obtain

$$i = \frac{V_R}{R}(2^3B_3 + 2^2B_2 + 2^1B_1 + 2^0B_0)$$

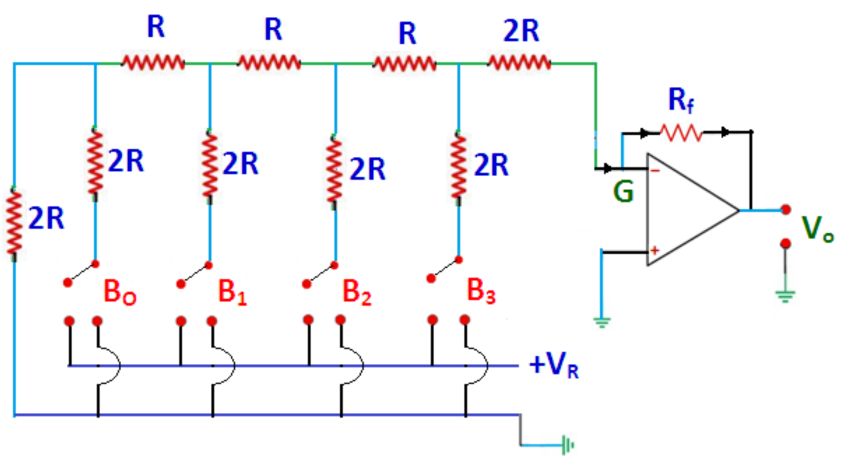
Since G is a virtual ground, we have for the output voltage

$$V_0 = -iR_f = -\frac{V_R}{R}R_f\,(2^3B_3 + 2^2B_2 + 2^1B_1 + 2^0B_0)$$

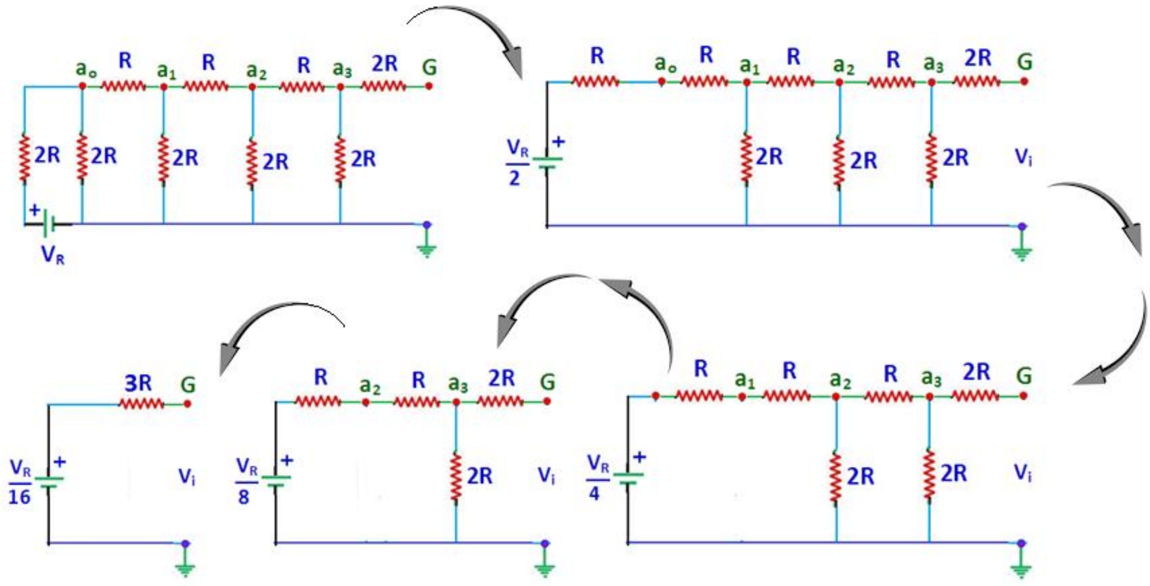
Thus the output voltage is proportional to the numerical value or analog form of the binary input.

(ii) The R-2R Ladder Converter:

A circuit of resistive R-2R ladder converter for a 4-bit digital data is shown in figure. To explain the operation of the circuit and to find the output voltage we have to find the net current flow i through the feedback resistance so that we get the output voltage of OP AMP as $V_0 = -iR_f$. This current flow i can be now obtained by applying the principle of superposition after finding each individual contribution for each applied voltage terminal in accordance with the input digital data. Again here we consider the conversion of input 4-bit digital data $(B_3B_2B_1B_0)$ to its analog form as before.



By the principle of superposition, we now assume that the terminal B_0 is connecter to V_R and all other terminals namely, B_1, B_2 and B_3 are connected to ground. The resulting resistive portion of the ladder is shown in figure. Applying Thevenin's theorem successively to the nodes a_0, a_1, a_2 and a_3 with respect to ground we obtain the equivalent Thevenin networks shown in figure. The final equivalent Thevenin source has a voltage of $\frac{V_R}{16}$ in series with a resistance 3R (as shown in figure)



Again if the terminal B_1 in original figure is connected to the reference V_R and the terminals B_0, B_2 and B_3 are connected to ground, then it can also be shown in similar manner that the above procedure gives an equivalent simple network having the Thevenin voltage $\frac{V_R}{8}$ in series with a resistance 3R connected to the inverting input terminal of the OP AMP.

Similarly when the terminal B_2 is connected to V_R and B_0, B_1 and B_3 be grounded, the corresponding Thevenin equivalent circuit has a voltage $\frac{V_R}{4}$ in series with a resistance 3R.

Lastly when the terminal B_3 is connected to V_R, and B_0, B_1 and B_2 be switched to ground, the equivalent Thevenin source will consist of a voltage source $\frac{V_R}{2}$ in series with a resistance 3R.

The current i obtained by the principle of superposition is $i = i_0 + i_1 + i_2 + i_3$

But usually we have $i_0 = \frac{B_0\left(\frac{V_R}{16}\right)}{3R}$, $i_1 = \frac{B_1\left(\frac{V_R}{8}\right)}{3R}$, $i_2 = \frac{B_2\left(\frac{V_R}{4}\right)}{3R}$, $i_3 = \frac{B_3\left(\frac{V_R}{2}\right)}{3R}$

Thus we get $$i = \frac{V_R}{3R}\left(\frac{B_0}{16} + \frac{B_1}{8} + \frac{B_2}{4} + \frac{B_3}{2}\right).$$

Since G is a virtual ground, we obtain for the output voltage of the OP AMP

$$V_0 = -iR_f = -\frac{R_f}{3R} V_R \left(\frac{B_0}{2^4} + \frac{B_1}{2^3} + \frac{B_2}{2^2} + \frac{B_3}{2^0}\right)$$

Here $B_i = 1$ where the terminal is connected to V_R, and $B_i = 0$ when the terminal is connected to ground $(i = 0, 1, 2, 3)$. Above equation can be rewritten as

$$V_0 = -\frac{R_f V_R}{48R}\left(2^3 B_3 + 2^2 B_2 + 2^1 B_1 + 2^0 B_0\right).$$

Clearly, the output voltage is proportional to the numerical value or analog form of the digital input. Thus digital to analog data conversion is made by this R-2R ladder network.