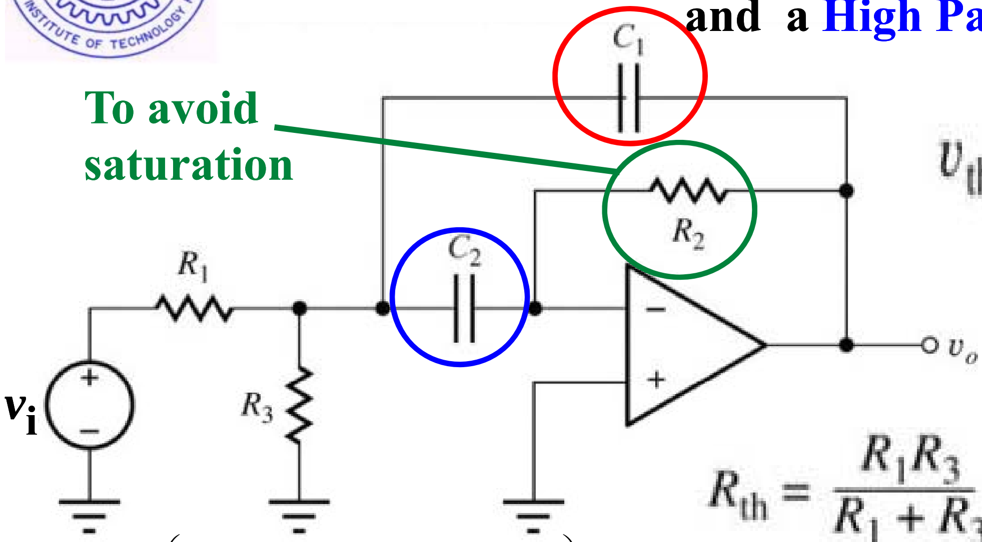
ESc201, Lecture 26: Operational Amplifier

Band Pass Filter (Combination of a Low Pass and a High Pass Filter):

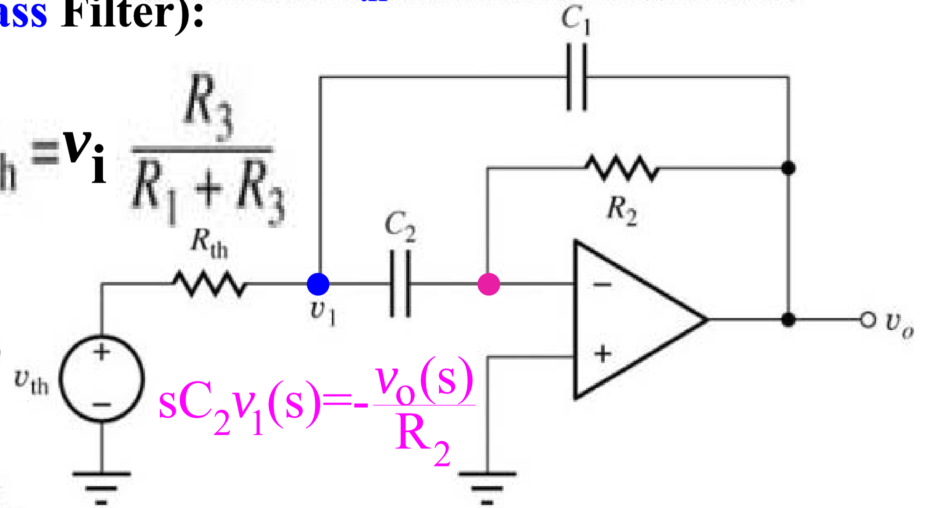
$$\frac{v_{th}-v_1(s)}{R_{th}}=sC_1\left(v_1(s)-v_o(s)\right)+sC_2v_1(s)$$

To avoid saturation



$$v_{th}=v_i\frac{R_3}{R_1+R_3}$$

$$R_{th}=\frac{R_1R_3}{R_1+R_3}$$



$$sC_2v_1(s)=-\frac{v_o(s)}{R_2}$$

$$\frac{v_{th}}{R_{th}}=\left(s\left(C_1+C_2\right)+\frac{1}{R_{th}}\right)v_1(s)-sC_1v_o(s)=s\left[-\left(C_1+C_2\right)\frac{v_o(s)}{sC_2R_2}-C_1v_o(s)\right]+\frac{v_o(s)}{R_{th}sC_2R_2}$$

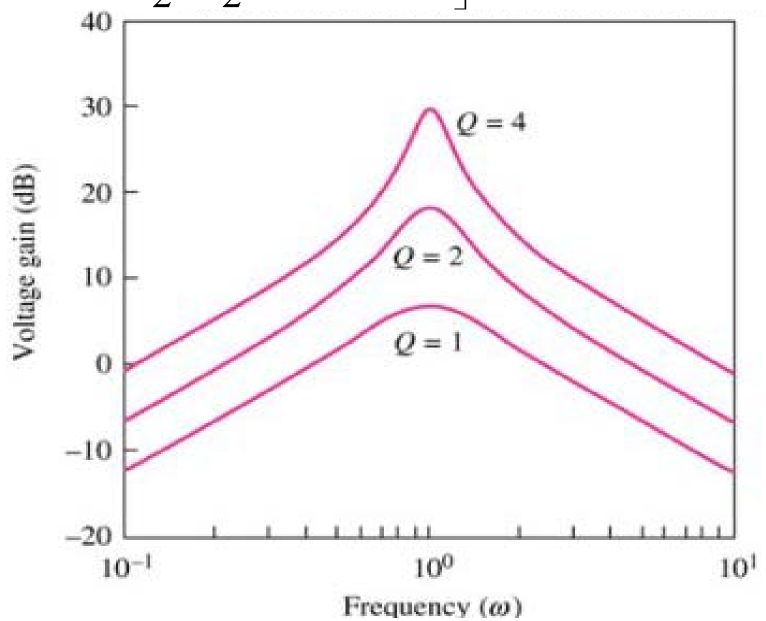
$$\omega_o=\frac{1}{\sqrt{R_{th}R_2C_1C_2}}\qquad Q=\sqrt{\frac{R_2}{R_{th}}}\frac{\sqrt{C_1C_2}}{C_1+C_2}$$

$$A_{BP}(s)=\frac{v_o(s)}{v_{th}(s)}=-\sqrt{\frac{R_3}{R_1+R_3}\frac{R_2C_2}{R_1C_1}}\frac{s\omega_o}{s^2+s\frac{\omega_o}{Q}+\omega_o^2}$$

$1/\sqrt{R_2}$

For $C_1 = C_2 = C$, and $\omega_o=\dfrac{1}{C\sqrt{R_{th}R_2}}$ $\quad Q=\sqrt{\dfrac{R_2}{R_{th}}}$

$$BW=\frac{2}{R_2C}\qquad \frac{\omega_o}{Q}\propto\frac{1}{R_2},\ \text{and}\ \omega_o^2\propto\frac{1}{R_2}$$



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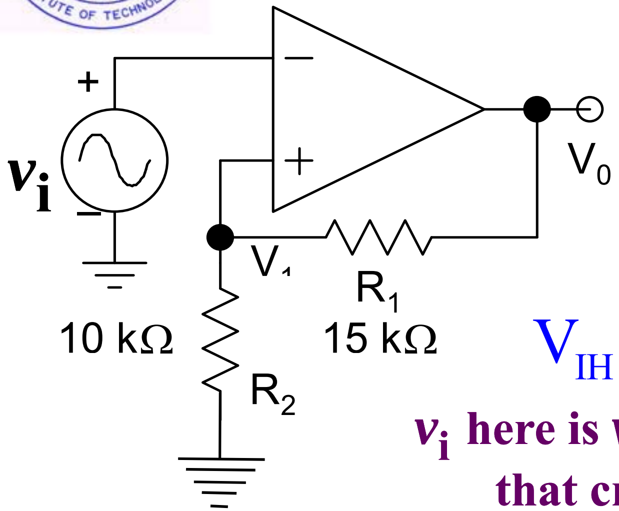
Schmitt Trigger:

Positive Feedback – Inverting input



$$v_o = A_v\,(v_+ - v_-)$$

$$v_- > v_+ \Rightarrow v_o = -V_{sat}$$

$$v_- < v_+ \Rightarrow v_o = +V_{sat}$$

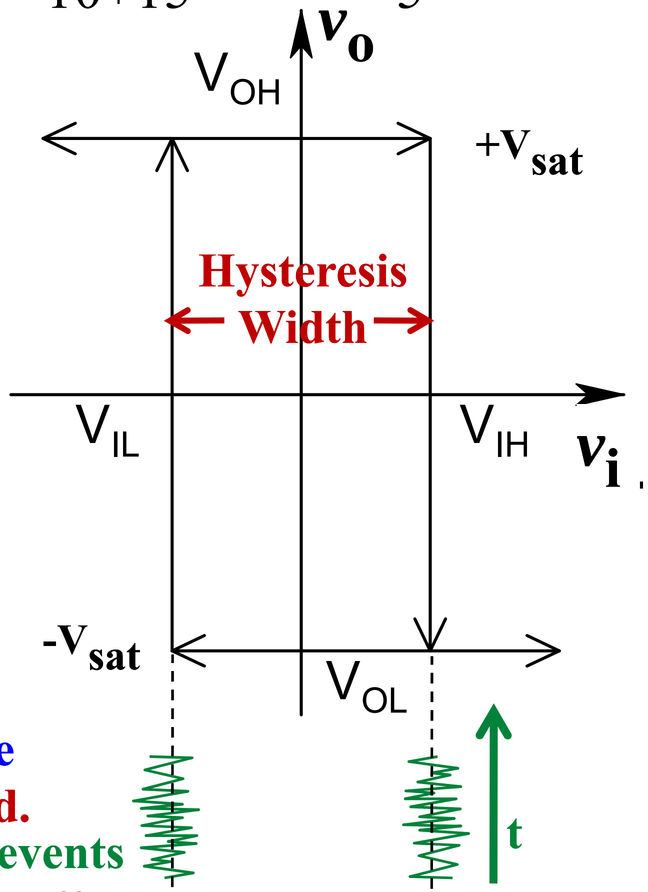
$$v_+ = v_o\,\frac{R_2}{R_1+R_2}$$

Let R_2=10k, V_{CC}=+12V, V_{EE}=-12V,

$$v_+ = \pm V_{sat}\,\frac{10}{10+15} = \pm\,12\times\frac{2}{5} = \pm\,4.8\text{V}$$

$$V_{IH} = +\,4.8\text{V},\ V_{IL} = -\,4.8\text{V}$$

v_i here is $v_{trigger}$ the Trigger Signal that creates change of state.



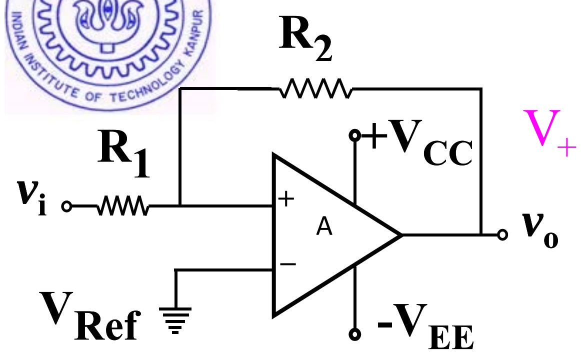
Let the output be high (+12V) and hence input has to be low (≤ - 4.8V). As v_i increases, nothing happens till v_i reaches 4.8V, when the output toggles from +12V to -12V. So the toggling from V_{OH} to V_{OL} does not happen at the same input. The loop formed is called Hysteresis.

Thus, the circuit has <u>two stable states</u>, giving the name <u>“bistable circuit”</u>. For a change of state at the output, an appropriate trigger signal needs to be applied at the input.

Within the Hysteresis width (V_{IH} - V_{IL}), the output is indeterminate and depends on the direction of change of the Trigger input. Is Hysteresis good or bad? Usually unwanted.

But imagine the input has noise added. Then Hysteresis prevents the output from chattering - good. ***Schmitt Trigger acts as an Effective Noise Suppressor***

ESc201, Lecture 26: Operational Amplifier –Non-Inverting Schmitt Trigger



By Superposition

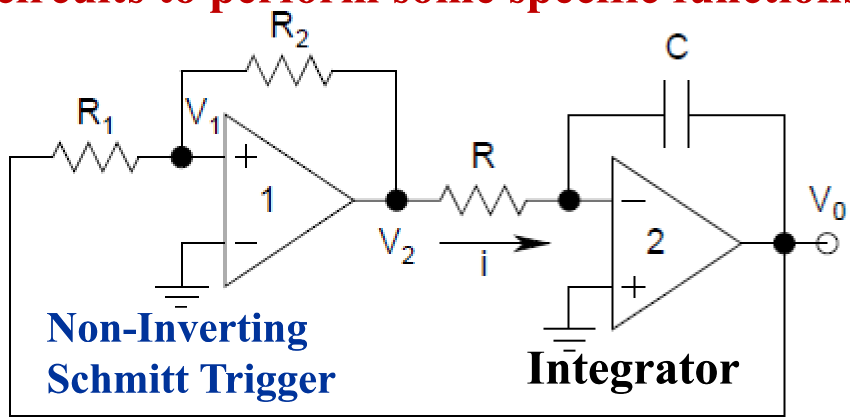
$$V_+ = \frac{R_1}{R_1+R_2} v_i + \frac{R_2}{R_1+R_2} v_o$$

Due to *positive feedback*, the output v_o will be at V_{+sat} for $V_+ > V_-$, and at $-V_{sat}$ for $V_- > V_+$. For $V_- = 0$, if v_o is at V_{+sat}, then no positive of V_i can change the state of the output.

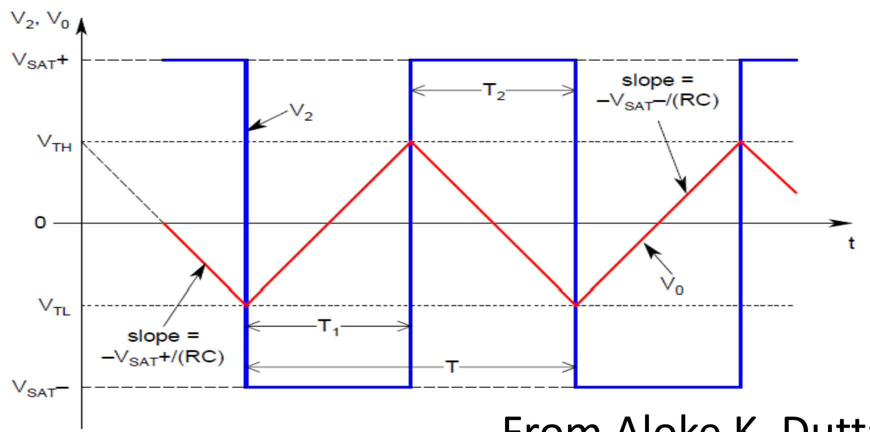
To switch v_o to V_{-sat}, V_+ must be pulled below ground, (which is the potential of V_-) and it would be possible only if v_i goes below $-(R_1/R_2)V_{+sat}$. This corresponds to the Threshold Low (V_{TL}) of the circuit.

Similarly when V_o is at V_{-sat}, to cause a change in the state of the output V_i must be more positive than $-(R_1/R_2)V_{-sat}$. This corresponds to the Threshold High (V_{TH}) of the circuit. ($V_{TH} - V_{TL}$) is then the Hysteresis width.

This non-inverting Schmitt Trigger circuit is not much used unless it is followed by other circuits to perform some specific functions, for example:

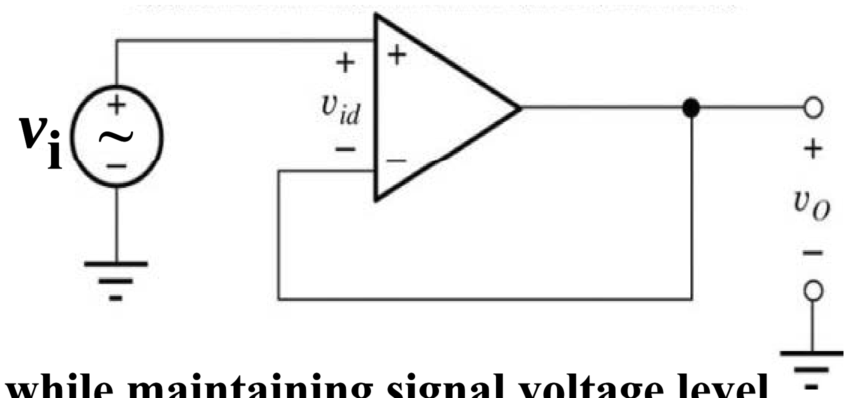


Triangular Wave Generator



From Aloke K. Dutta

ESc201, Lecture 26: Operational Amplifier - Other Applications

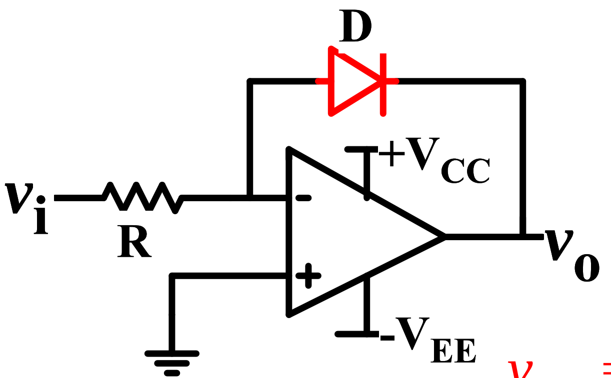


A special case of non-inverting amplifier, also called Voltage Follower with infinite R_1 and zero R_2. Hence $A_v = 1$.

Provides excellent impedance-level transformation while maintaining signal voltage level. Ideal voltage buffer does not require any input current and can drive any desired load resistance without loss of signal voltage. Unity-gain buffer is used in may sensor and data acquisition systems.

Log Amplifier or Temperature Sensor:

$$I_i = I_D = I_S(e^{V_D/V_T} - 1) \quad ; V_T = \frac{k_B T}{q}$$



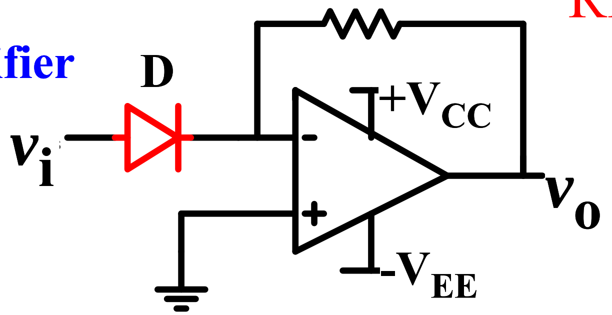
$$\therefore \frac{v_i}{R} = I_S(e^{-v_O/V_T} - 1) \qquad \frac{v_i}{I_S R} + 1 = e^{-v_O/V_T}$$

$$\text{which gives} \quad -v_O = V_T \times \ln\left(1 + \frac{v_i}{RI_S}\right) \cong V_T \times \ln\left(\frac{v_i}{RI_S}\right)$$

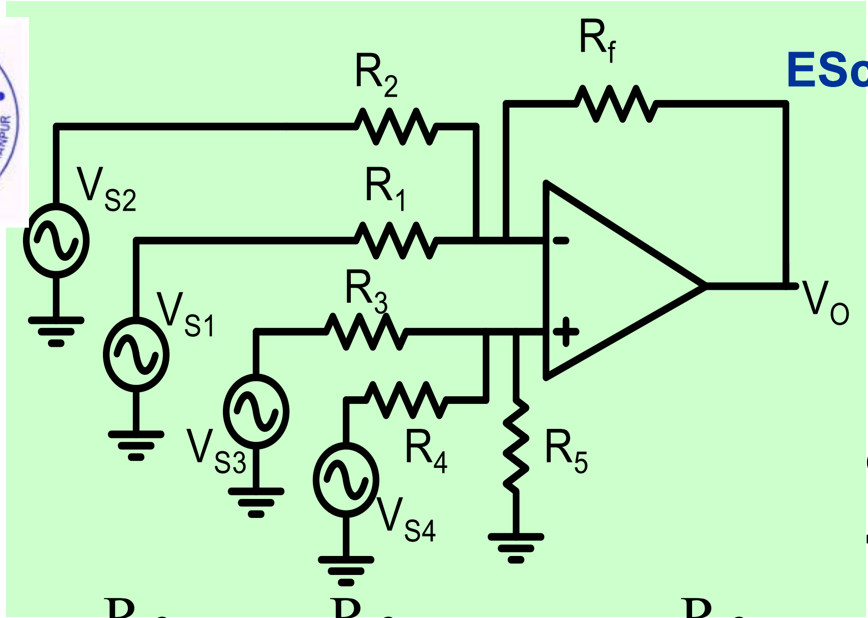
$$v_O = -V_T \times \ln\left(\frac{v_i}{RI_i}\right)$$

But $I_i = I_S$ for $i_- = 0$, where the diode saturation current I_S is a function of temperature also.

Antilog Amplifier



$$v_O = -RI_S(e^{v_i/V_T} - 1) \cong -RI_S \times e^{v_i/V_T}$$



Example of summer/subtractor

$$v_o = -10v_{s_1} - 4v_{s_2} + 5v_{s_3} + 2v_{s_4}$$

$$R_P = R_3 \| R_4 \| R_5$$

Choose : $R_f = 10K$

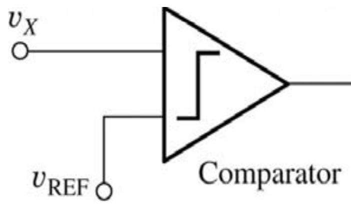
Then by Superposition:

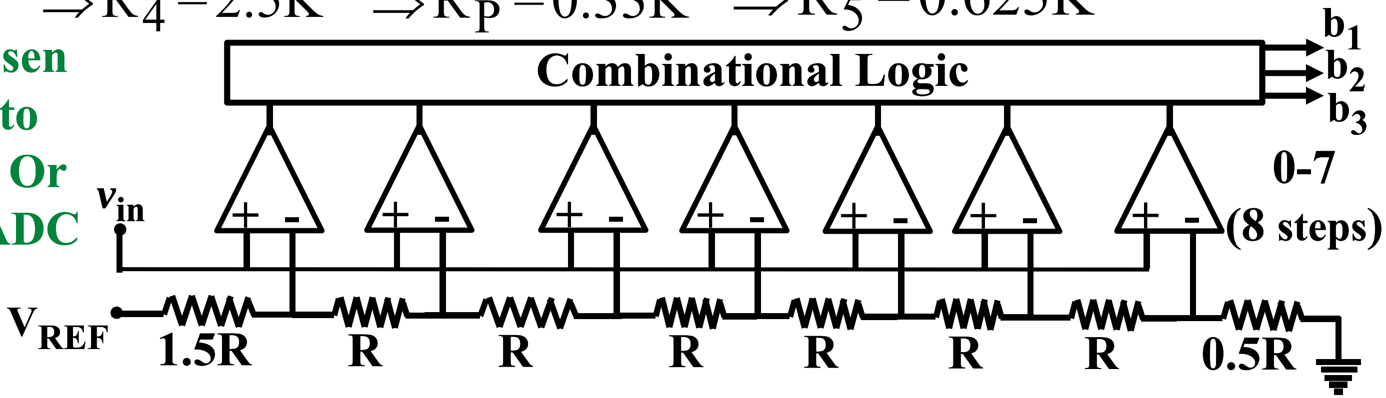
$$v_o = -\left(\frac{R_f}{R_1}\right)v_{s_1} - \left(\frac{R_f}{R_2}\right)v_{s_2} + \left(1+\frac{R_f}{R_1\|R_2}\right)\times\frac{R_P}{R_3}v_{s_3} + \left(1+\frac{R_f}{R_1\|R_2}\right)\times\frac{R_P}{R_4}v_{s_4}$$

$$\Rightarrow R_1 = 1K \qquad \Rightarrow R_2 = 2.5K \qquad \Rightarrow \frac{R_P}{R_3} = 0.33 \qquad \Rightarrow \frac{R_P}{R_4} = 0.133 \qquad \Rightarrow \frac{R_4}{R_3} = 2.5$$

Now choose : $R_3 = 1K \quad \Rightarrow R_4 = 2.5K \quad \Rightarrow R_P = 0.33K \quad \Rightarrow R_5 = 0.625K$

The ratios can be so chosen that one gets an Analog to digital converter (ADC) Or simply a flash (fastest) ADC using a comparator is:





Requires 2^n-1 comparators and reference voltages for n-bit conversion.

Other types are Counting ADC, D-S, Successive Approximation, Single-Ramp, Dual-Ramp, etc.

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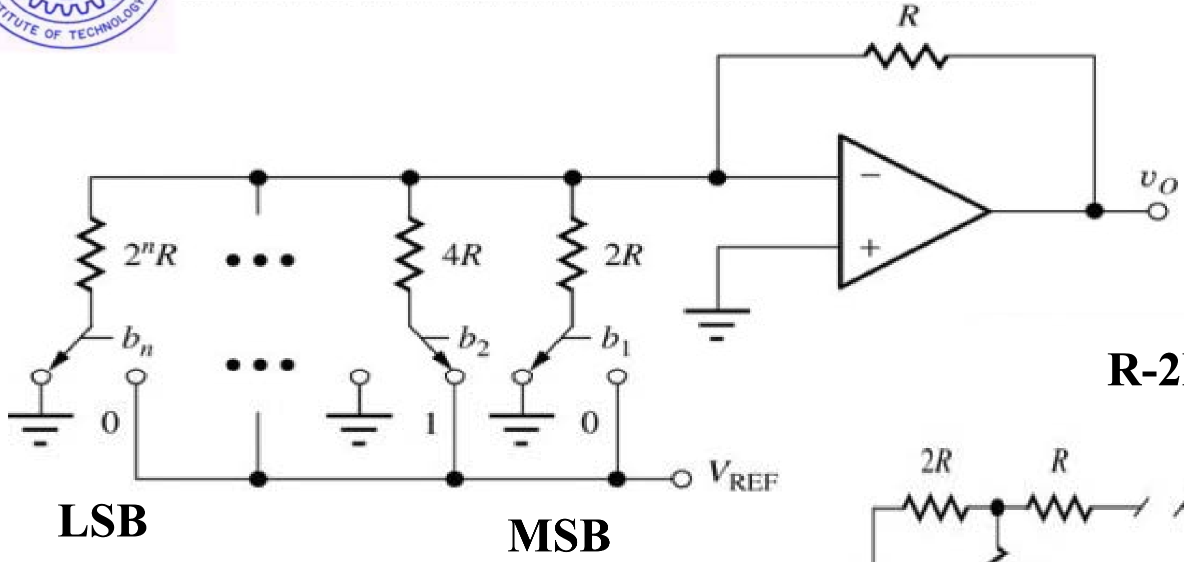
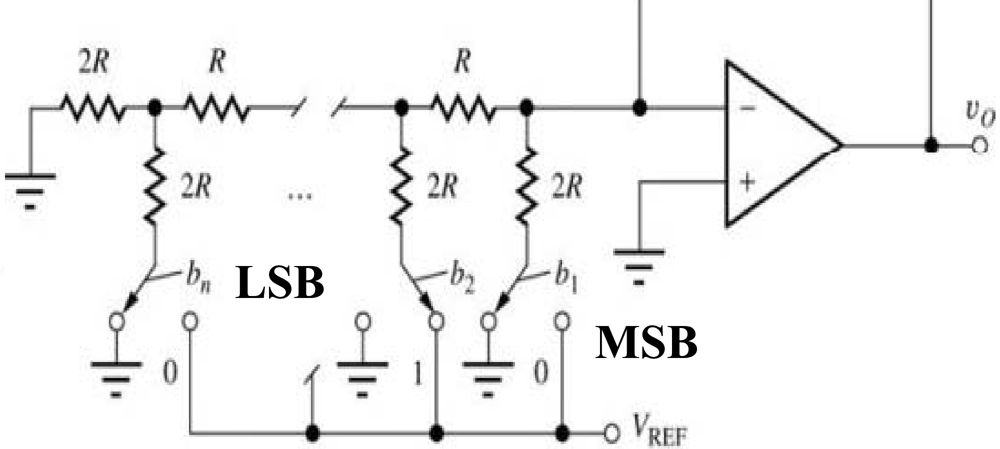
Digital to Analog Converters : (DAC)

$v_o = V_{REF}(b_1 2^{-1} + b_2 2^{-2} + ... + b_n 2^{-n})$



R-2R Ladder



Inverted R-2R Ladder