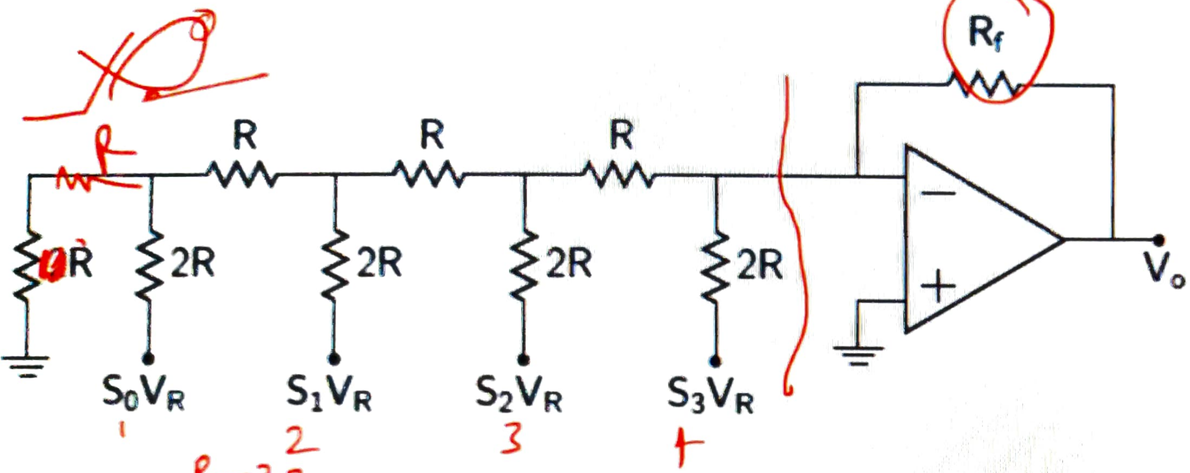
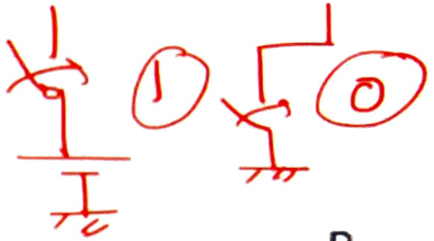
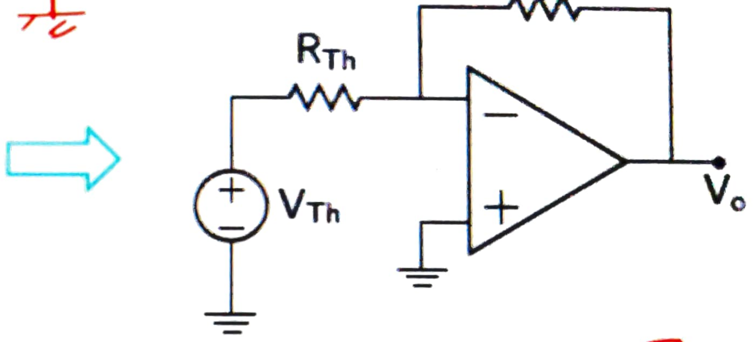
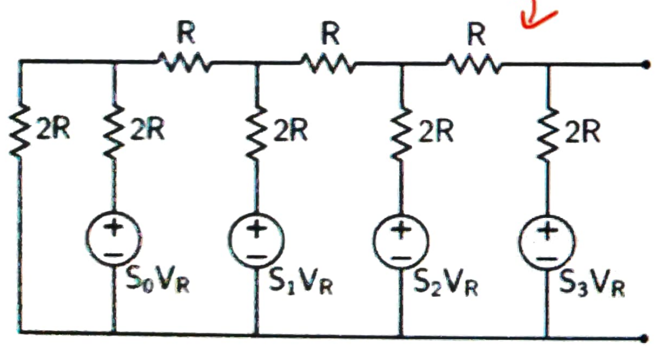
# DAC with R-2R Ladder




The ~~original~~ R-2R network is equivalent to




Thevenin's → R
→ V

S → represents status of switch

→ 0 (or) 1

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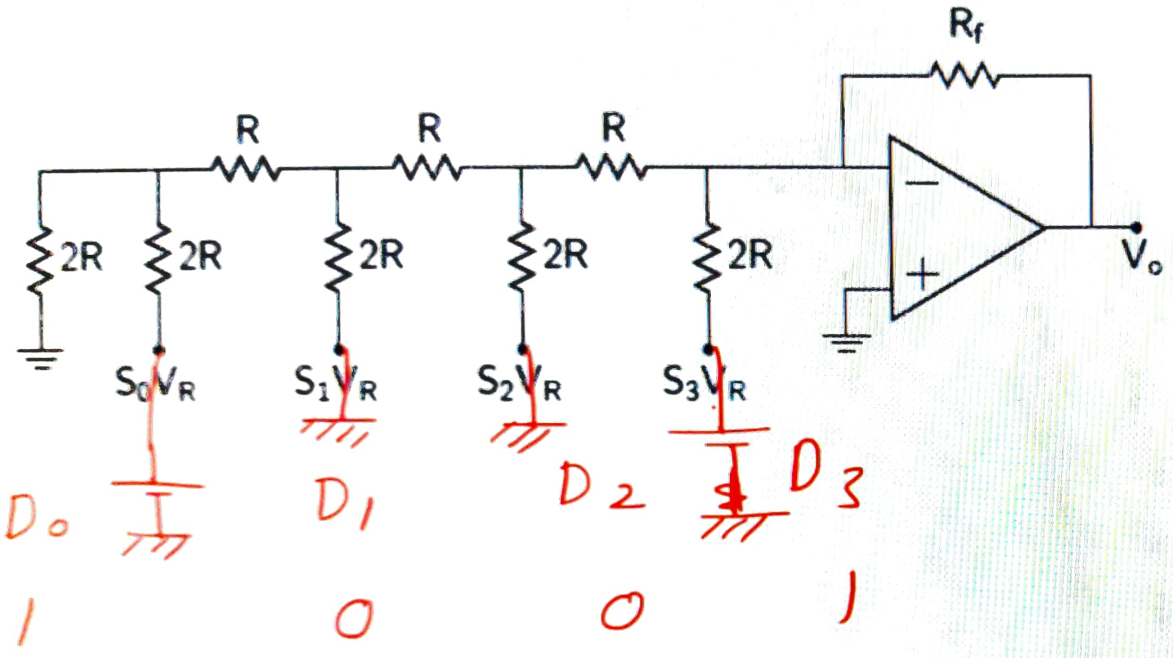
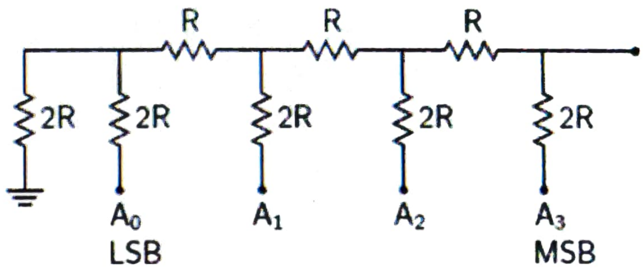


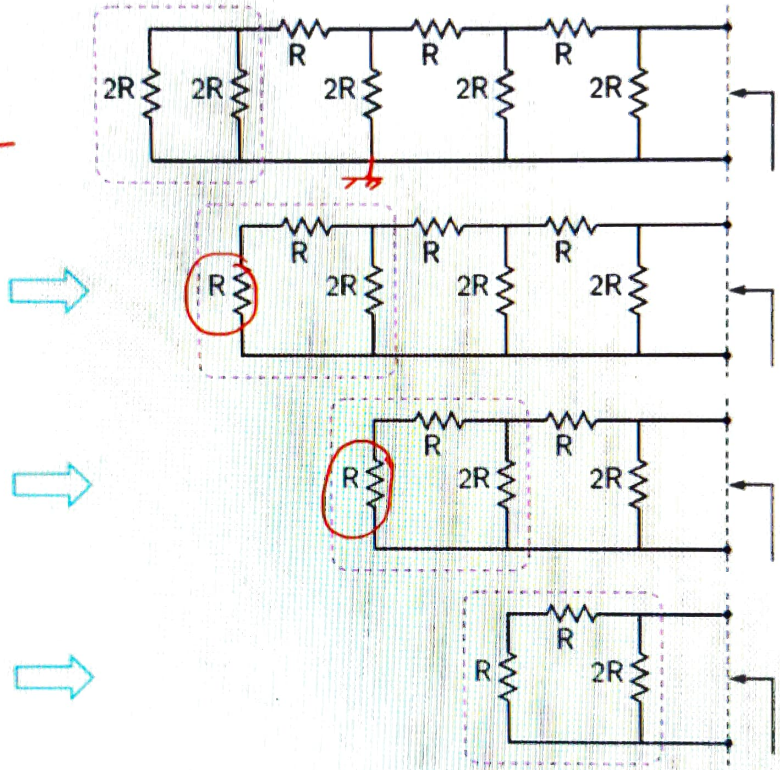

Node $A_k$ is connected to $V_R$ if input bit $S_k$ is 1; else, it is connected to ground.

# R-2R Ladder Network: Equivalent resistance

If all the inputs are grounded.

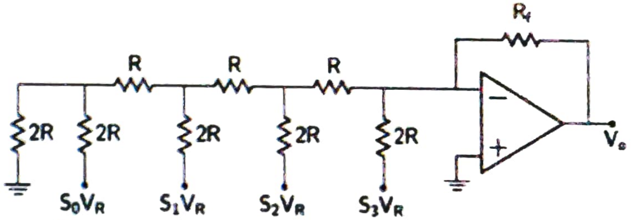
$\frac{\cancel{2}R}{\cancel{2}} = R$

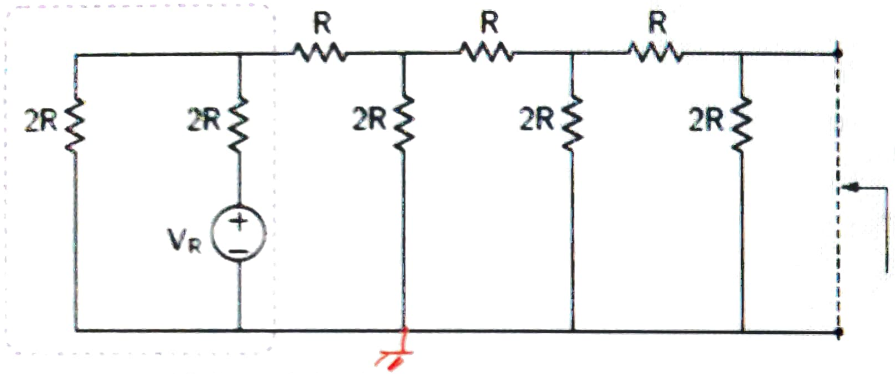
$R_{eq} = \frac{R}{2}$

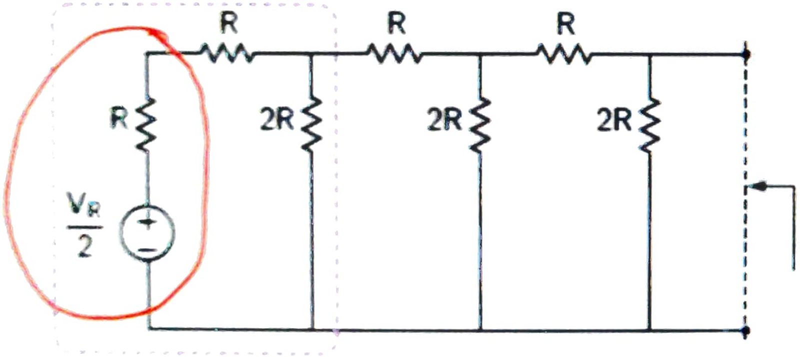


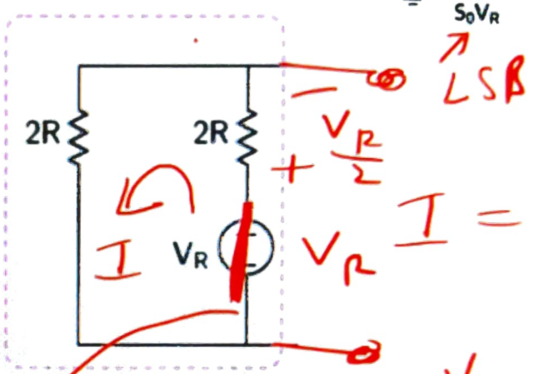

$R_{Th} = R$

# R-2R ladder network: $V_{Th}$ for $S_0 = 1$



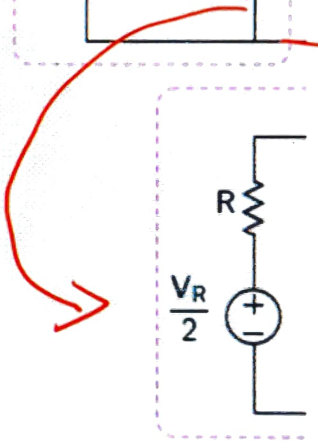



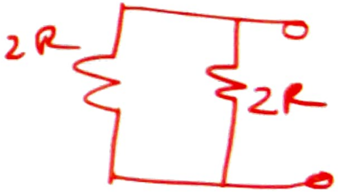




$$I = \frac{V_R}{4R}$$

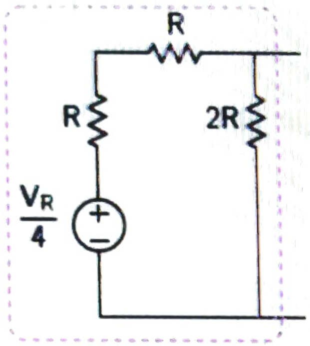
$$V_{2R} = \frac{V_R}{4R} 2R$$

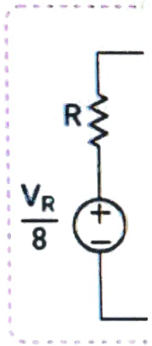
$$= \frac{V_R}{2}$$

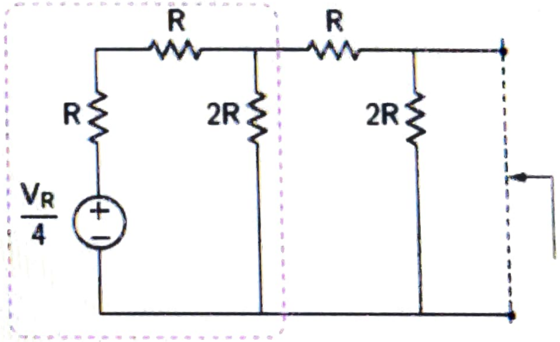


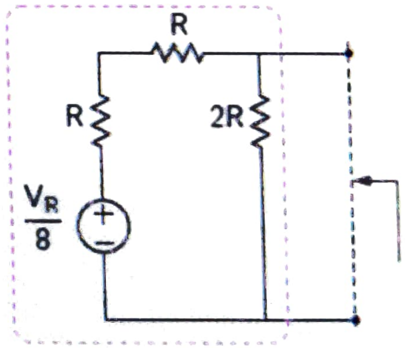



# R-2R ladder network: $V_{Th}$ for $S_0$ =1

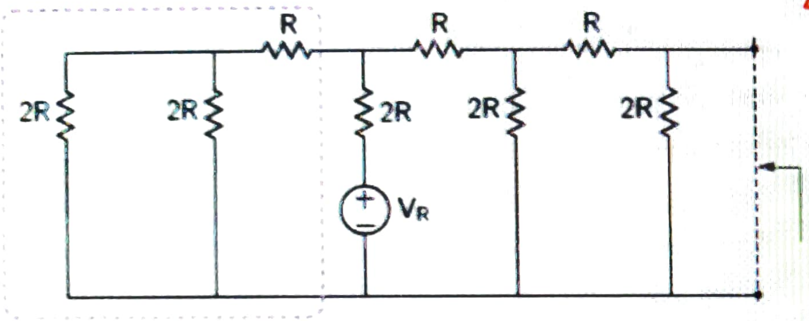


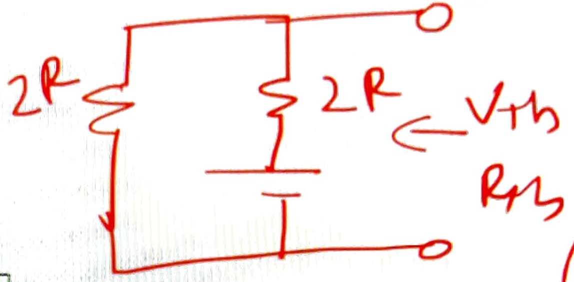



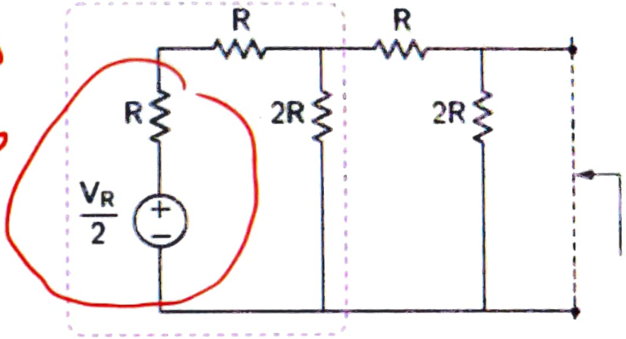



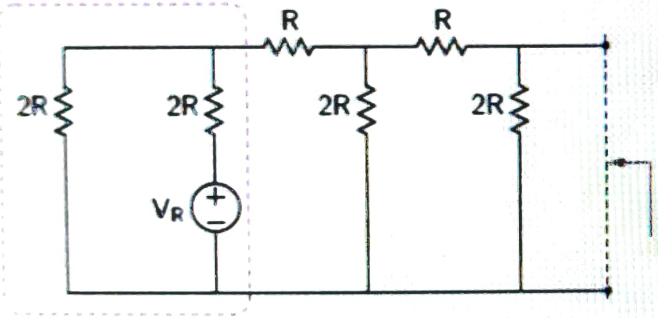



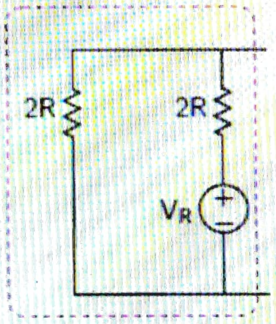
# R-2R ladder network: $V_{Th}$ for $S_1$ =1

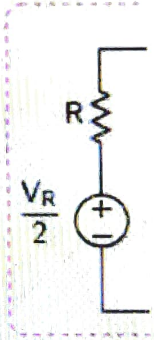


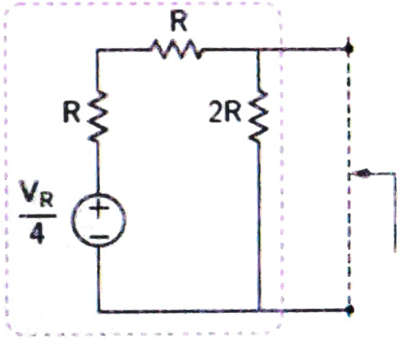



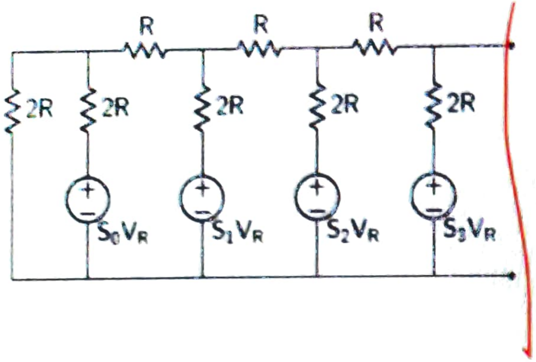



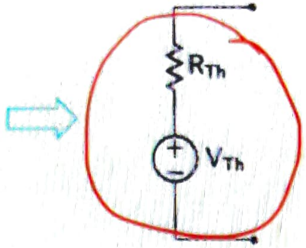





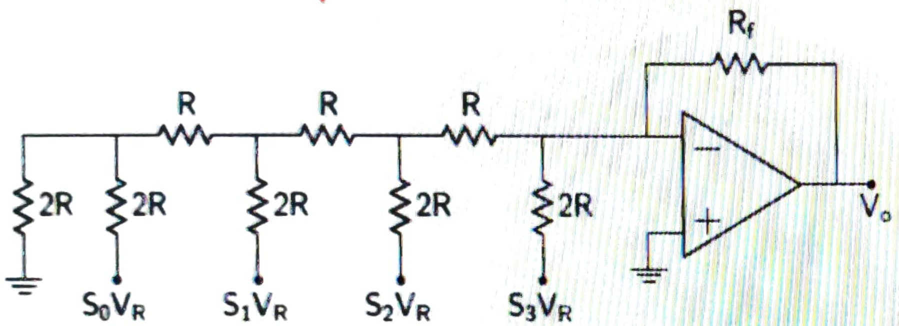



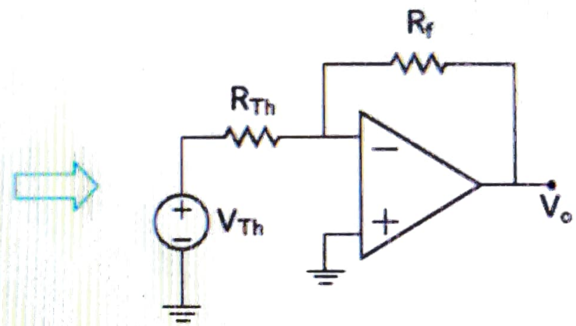

$$R_{Th} = R$$

$$V_{Th} = V_{Th}^{(S0)} + V_{Th}^{(S1)} + V_{Th}^{(S2)} + V_{Th}^{(S3)}$$

$$= \frac{V_R}{16}\left[S_0\,2^0 + S_1\,2^1 + S_2\,2^2 + S_3\,2^3\right]$$

We can use the $R$-$2R$ ladder network and an Op Amp




$$V_o = -\frac{R_f}{R_{Th}}\,V_{Th} = -\frac{R_f}{R_{Th}}\,\frac{V_R}{16}\left[S_0\,2^0 + S_1\,2^1 + S_2\,2^2 + S_3\,2^3\right]$$

For an N-bit DAC, $V_o = -\frac{R_f}{R_{Th}}\,V_{Th} = -\frac{R_f}{R_{Th}}\,\frac{V_R}{2^N}\sum_{0}^{N-1} S_k\,2^k$ .

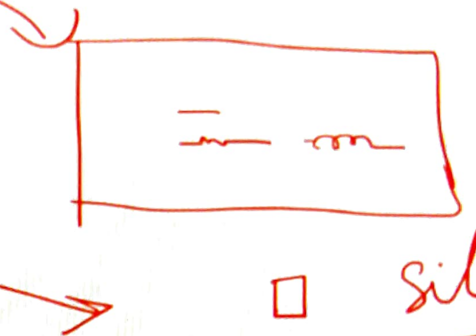
6- to 20-bit DACs based on the R-2R ladder network are commercially available in monolithic form (single chip)

# R-2R Ladder

- Design a 3 bit R-2R ladder DAC, and determine Vo for the following input sequences, (a) 010 (b) 011 (c) 100, and (d) 101.

For an N-bit DAC, $V_o = -\frac{R_f}{R_{Th}} V_{Th} = -\frac{R_f}{R_{Th}} \frac{V_R}{2^N} \sum_{0}^{N-1} S_k 2^k$.

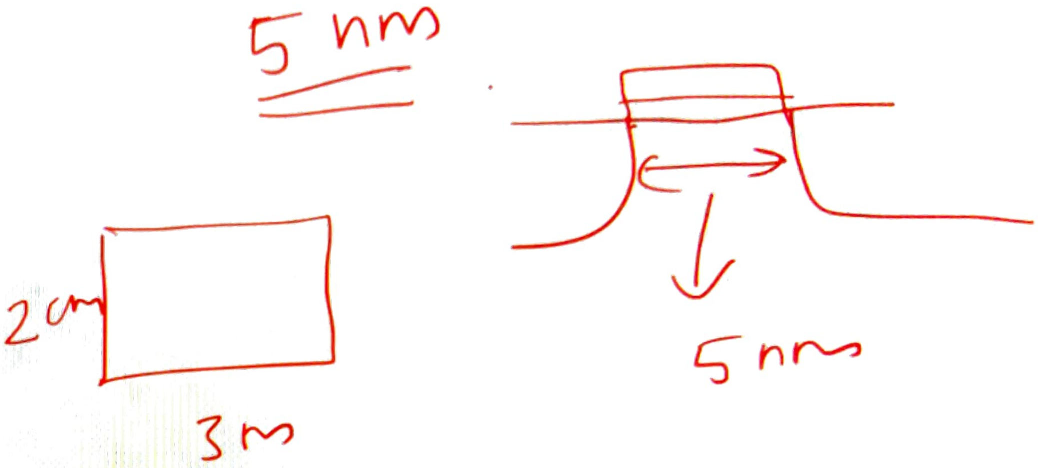
# Integrated Circuits



silicon

- How are they made
  - Diodes
  - BJTs
  - MOSFETs
- Material
  - Silicon
- Size
  - Micrometer ($10^{-6}$ m), nm ($10^{-9}$m)
- Where they are made
  - Microfabrication unit (Specialized units)

# Integrated Circuits

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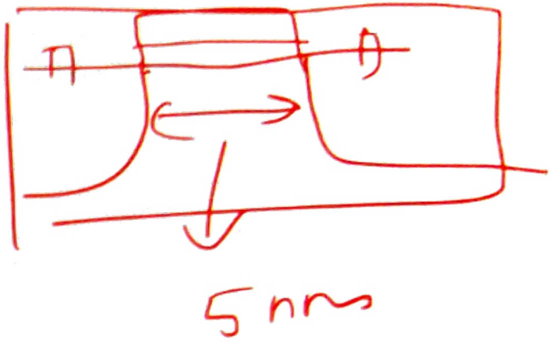
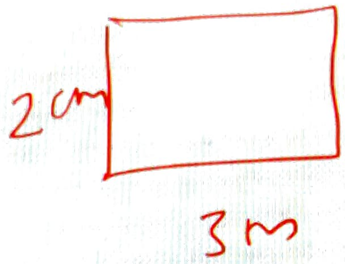
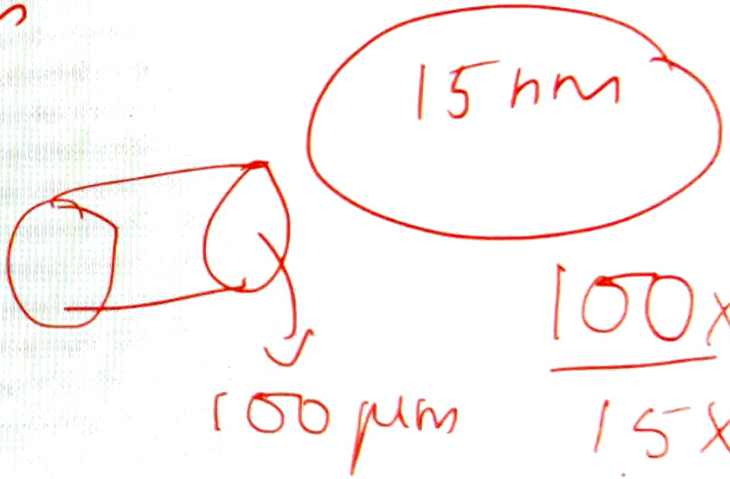
5 nm




$$\frac{100\times10^{-6}}{15\times10^{-9}} = 7000$$

# How do they look like