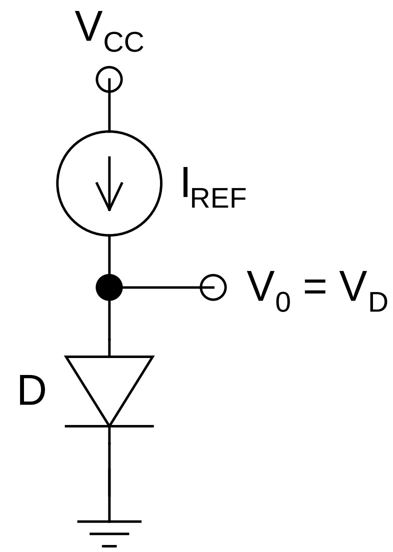
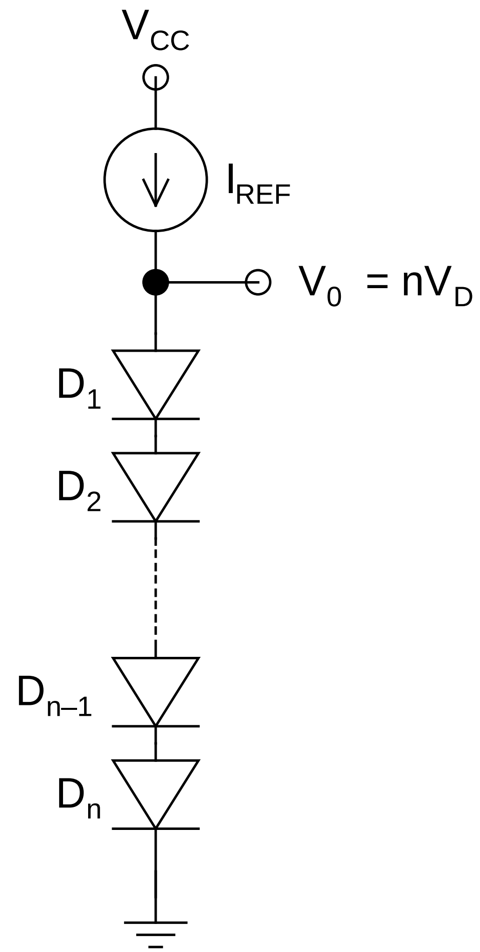
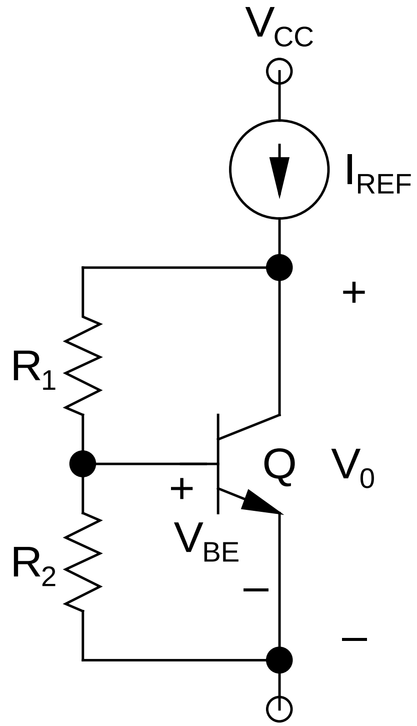
- ***Single Diode Reference***:
  - I_{REF}: ***DC Bias Current***
  - ***Creates a voltage drop of V_D (or V_{BE}) across the diode of ~ 0.7 V***
  - ***Known as V_{BE} (or V_D) Reference***
  - ***Precision quite poor***
  - ***Thermal tracking poor***



- ***Multiple Diode Reference***:
  - ***Putting multiple diodes in series***
  - ***DC bias current I_{REF} pushed through them***
  - ***Each diode creates a drop of V_D across it***
  - ***Has same problems as Single Diode Reference***
  - ***Note***: ***n can only be an integer***



- ***V_{BE} (or V_D) Multiplier Circuit*:**
  - ***Previous two circuits provide $V_0 = nV_D$, with n being an integer ≥ 1***
  - ***For any arbitrary value of n (≥ 1), this circuit becomes useful***
  - ***Immensely popular because of its simplicity and effectiveness***
  - ***Biased by a DC current source I_{REF}***



- ***Neglecting base current***:

$$V_{BE} = \frac{R_2}{R_1 + R_2} V_0$$

$$\Rightarrow V_0 = \left(1 + \frac{R_1}{R_2}\right) V_{BE}$$

$\Rightarrow$ ***V_{BE} Multiplier*** with ***multiplication factor $(1 + R_1/R_2)$***

- ***Any arbitrary ratio of R_1 and R_2 can be used***, ***but the multiplication factor is always ≥ 1***

- ***Least possible $V_0 = V_{BE}$*** [***$R_1 = 0$*** (***short-circuit***) and ***$R_2 \to \infty$*** (***open-circuit***)]

  $\Rightarrow$ ***Diode-Connected BJT***

- ***Has excellent thermal tracking***, ***since TC_F of R_1 and R_2 cancel each other***, ***but the TC_F of V_{BE} remains***

- ***So far, we have got voltage references having $V_0 \geq V_{BE}$***

- ***How to have a voltage reference having $V_0 < V_{BE}$?***

- ***Saturated Transistor***:
  - ***Neglecting base current***:

    $$V_0 = V_{BE} - I_{REF}R$$
  - ***Note***: ***V_0 is actually V_{CE}***, ***which is < V_{BE}***

    $\Rightarrow$ ***Q saturated***

    $\Rightarrow$ ***Analysis highly approximate***, ***since base current can't be neglected in saturation***
  - ***Typical range of V_0 ~ 0.2-0.7 V***