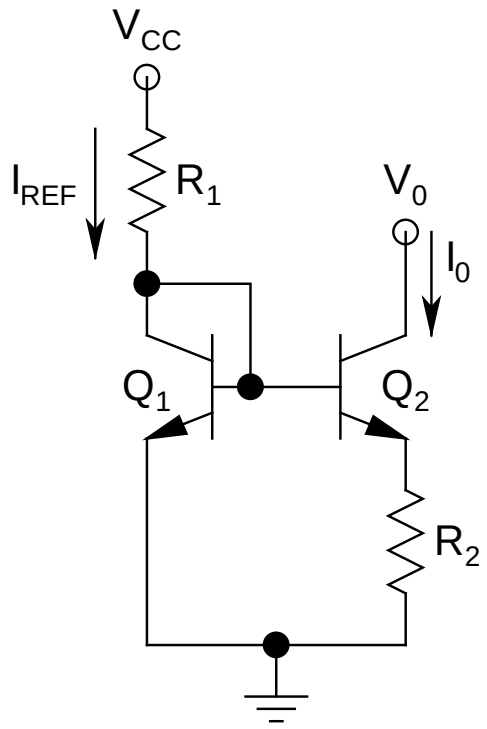
- ***Widlar Current Source***:
  - ***Q_1-Q_2 matched pair***
  - $I_{REF} = (V_{CC} - V_{BE1})/R_1$
  - If $I_0 = I_{REF}$, then $V_{BE1} = V_{BE2}$
    - ***No drop across R_2***!

      $\Rightarrow I_0 \neq I_{REF}$
  - ***Actually, the difference between V_{BE1} and V_{BE2} drops across R_2***



- ***KVL around Q_1-Q_2 BE loop***:

$$V_{BE1} = V_{BE2} + I_0 R_2$$

$$\Rightarrow I_0 = \frac{V_{BE1} - V_{BE2}}{R_2} = \frac{V_T}{R_2} \ln\left(\frac{I_{REF}}{I_0}\right)$$

(***since $I_{S1} = I_{S2}$***)

- ***Transcendental equation in I_0***
- ***If I_0 is known***, ***finding R_2 is absolutely easy***!
- On the other hand, ***if R_2 is given***, ***to find I_0***, ***need to iterate***, ***but the solution will converge rapidly*** (***Why***?)

- ***The ln function compresses a large difference between I_{REF} and I_0 into a small range***
  - For I_{REF} ~ mA, I_0 ~ μA, with R_1 ~ few kΩs and R_2 ~ few 10s of kΩ

    ⇒ ***Significant flexibility***!
- $V_{0,min} = V_{CE2}(SS) + I_0R_2$

  ~ ***0.3-0.4 V for practical values of I_0 and R_2***
- ***R_0 can be obtained by sheer inspection of the circuit by noting that the base of Q_2 is approximately at ac ground***
- Also, $r_{\pi 2} >> R_2$ (***Why***?)

- Thus,

  $R_0 \approx r_{02}(1 + g_{m2}R_2)$

- ***Note***: ***To approximate this as $g_{m2}r_{02}R_2$, first make sure that $g_{m2}R_2 >> 1$*** (***may not be***!)
- ***Actual expression***:

  $R_0 \approx r_{02}(1 + g_{m2}R_{eff})$ with $R_{eff} = R_2 \| r_{\pi 2}$

- ***During further simplification***, ***always check the validity of your assumption/approximation***
  - ***Otherwise it may lead to large errors***!
- ***Counterpart of this circuit in MOS technology does not exist*** (***Why***?)

DC Voltage References

- ***Along with current sources/sinks*, *also need stable and precise DC voltage references***
- ***Provides DC bias voltages at specific points of the circuit***
- ***Should be independent of power supply and temperature***
- ***Can range from –ve to +ve power supplies***
- ***On-Chip*: *Generated within the chip itself***

- ***In ICs**, diodes are not fabricated as such*
  - ***BJTs/MOSFETs are used as diodes by shorting their B/G and C/D terminals***
- ***Various Voltage References**:*
  - ***Single Diode Reference***
  - ***Multiple Diode Reference***
  - ***V_{BE} (or V_D) Multiplier***
  - ***Saturated Transistor***
  - ***NMOS Voltage Reference***