- ***Differential-mode input resistance***:

$$R_{id} \triangleq \frac{v_{id}}{i_i} = 2 \times \frac{v_{id}/2}{i_i} = 2(\beta_1 + 1)(r_{E1} + r_{E3}) \simeq 4\beta_1 r_{E1}$$

$$= \frac{4\beta_1 V_T}{I_{C1}} = 2.2\ \text{M}\Omega$$

- This is also the ***input resistance*** R_i of the ***op-amp***
- The ***output resistance*** can be ***calculated*** by following our ***standard procedure*** of ***nulling the independent sources***, ***exciting the output by a test voltage source***, and ***finding the current drawn from it***

- ***Base*** of Q_6 can be considered to be at a ***fixed DC potential***, and thus, ***ac ground***
- ***By inspection***:

$R_{04} = r_{04}[1 + g_{m4}(r_{\pi 4}||r_{E2})]$

$R_{06} = r_{06}[1 + g_{m6}(r_{\pi 6}||R_2)]$

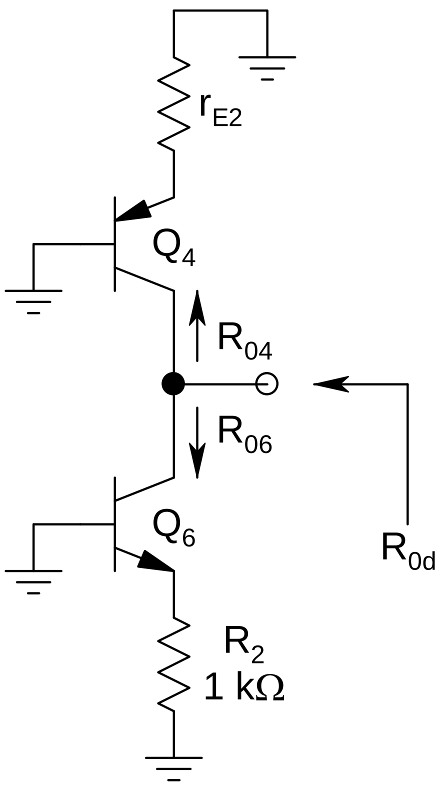
$r_{04} = V_{AP}/I_{C4} = 5.26\ M\Omega$

$g_{m4} = I_{C4}/V_T = 365\ \mu A/V$

$r_{\pi 4} = \beta_4/g_{m4} = 273.7\ k\Omega$

$r_{E2} = V_T/I_{C2} = 2.74\ k\Omega$

$\Rightarrow R_{04} \approx 2r_{04} = 10.5\ M\Omega$



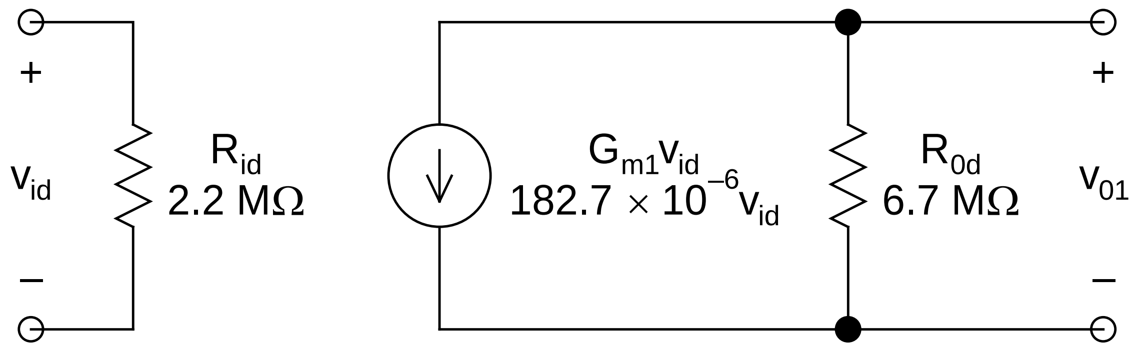
$r_{06} = V_{AN}/I_{C6} = 13.7\ \text{M}\Omega$

$g_{m6} = I_{C6}/V_T = 365\ \mu\text{A/V}$

$r_{\pi 6} = \beta_6/g_{m6} = 547.9\ \text{k}\Omega$

$\Rightarrow R_{06} \approx r_{06}(1 + g_{m6}R_2) = 18.7\ \text{M}\Omega$

$\Rightarrow R_{0d} = R_{04}||R_{06} = 6.7\ \text{M}\Omega$



2-Port Equivalent of the Input Stage

➢ *Gain Stage*:

- $r_{E16} = V_T/I_{C16} = 1.45\ k\Omega$

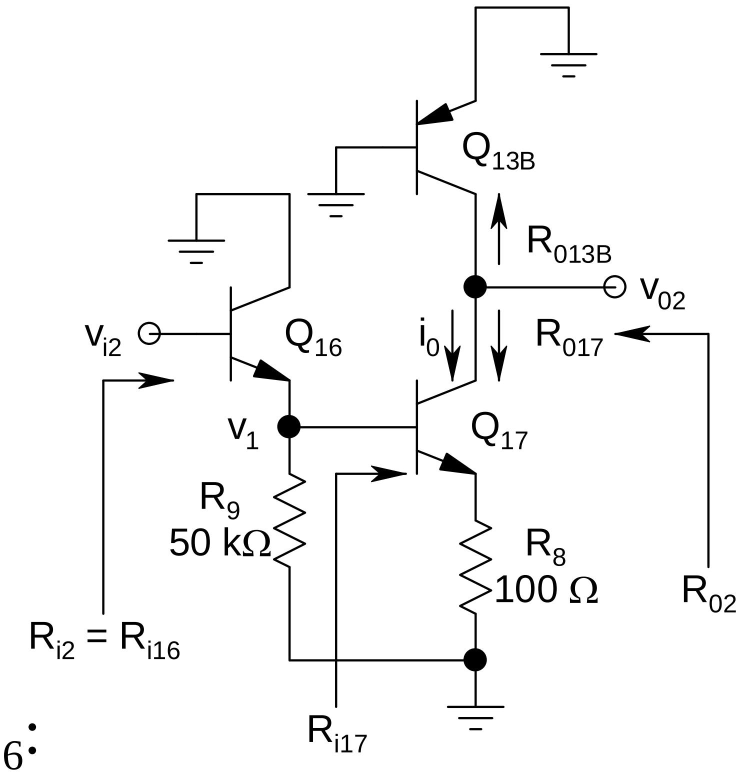
  $r_{\pi16} = \beta_{16} r_{E16} = 290.5\ k\Omega$

  $r_{E17} = V_T/I_{C17} = 47.3\ \Omega$

  $r_{\pi17} = \beta_{17} r_{E17} = 9.45\ k\Omega$

  $\Rightarrow R_{i17} = r_{\pi17} + (\beta_{17} + 1)R_8$

  $= 29.6\ k\Omega$



- ***Effective load resistance*** of Q_{16}:

  $R_{L16} = R_9 || R_{i17} = 18.6\ k\Omega$

- Thus, the ***input resistance*** of the ***gain stage***:

  $R_{i2} = R_{i16} = r_{\pi16} + (\beta_{16} + 1)R_{L16} = 4.03\ M\Omega$

- Next, we have to ***calculate*** the ***short-circuit transconductance*** G_{m2} (= i_0/v_{i2}), with the ***output terminal shorted to ground***
- ***Voltage gain*** of Q_{16}:

  $v_1/v_{i2} = R_{L16}/(R_{L16} + r_{E16}) = 0.93$
- ***Overall transconductance*** of Q_{17}-R_8 combination (***emitter degenerated stage***):

  $G_{m17} = i_0/v_1 = g_{m17}/(1 + g_{m17}R_8) \approx 1/(r_{E17} + R_8)$
  $= 6.8$ mA/V

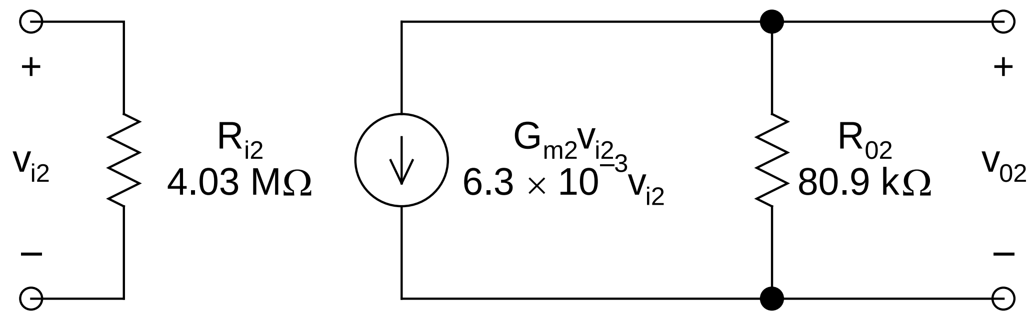
  $\Rightarrow G_{m2} = i_0/v_{i2} = (i_0/v_1) \times (v_1/v_{i2}) = 6.3$ mA/V
- Next is the ***output resistance*** R_{02}
- ***From inspection***: $R_{02} = R_{013B}||R_{017}$

- $R_{013B} = r_{013B} = V_{AP}/I_{C13B} = 90.9\ k\Omega$
- $r_{017} = V_{AN}/I_{C17} = 236.4\ k\Omega$
- Since ***base*** of Q_{17} can be considered to be at ***ac ground***, and $r_{\pi 17} >> R_8$:

$$R_{017} \approx r_{017}(1 + g_{m17}R_8) = r_{017}(1 + R_8/r_{E17})$$
$$= 736.2\ k\Omega$$

- Thus:

$$R_{02} = R_{013B}||R_{017} = 80.9\ k\Omega$$



2-Port Equivalent of the Gain Stage