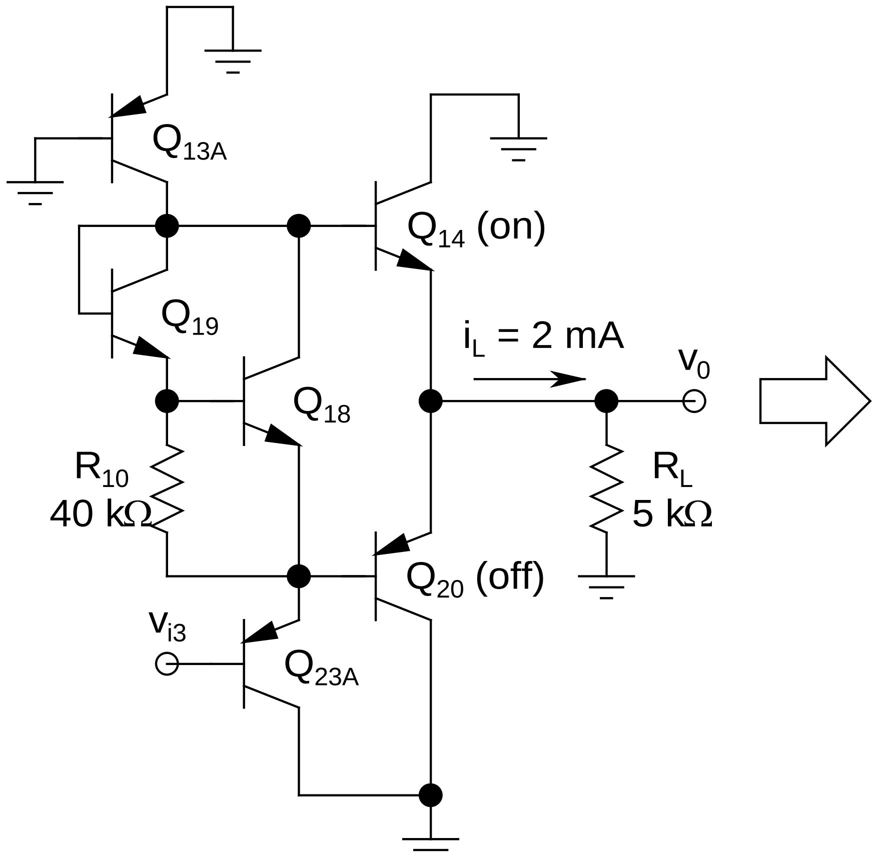
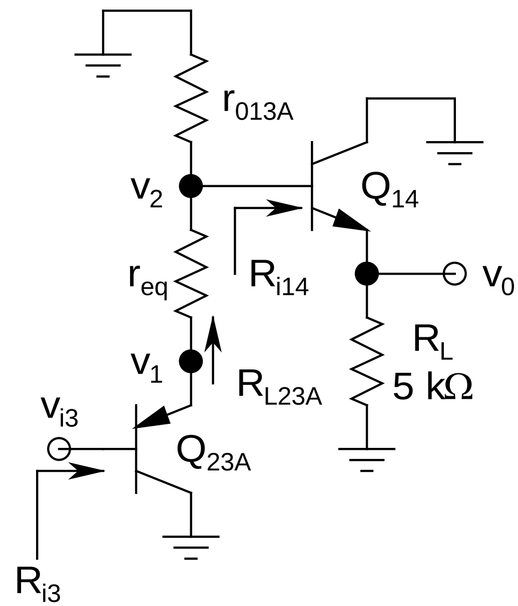
➢ *Output Stage*:



Circuit



Schematic

- ***Analysis slightly different***, since the ***transistors operate with large signal swings***, ***typically from rail-to-rail***, and ***small-signal analysis is not quite valid***
- Will attempt an ***approximate analysis*** under some ***specific assumptions***:
  - v_0 under ***positive excursion***, with Q_{14} ***supplying current to load*** (R_L) and Q_{20} ***off***
  - $R_L = 5\ k\Omega$ and $i_L = 2\ mA$

    $\Rightarrow v_0 = 10\ V$
- ***Ex.***: Show that Q_{18}-Q_{19}-R_{10} ***combination*** effectively appears as a ***resistance*** $r_{eq} = 168.7\ \Omega$
- $r_{E14} = V_T/I_{C14} = 13\ \Omega$
- $r_{013A} = r_{023A} = V_{AP}/I_{C13A} = V_{AP}/I_{C23A} = 272.8\ k\Omega$

- $r_{E23A} = V_T/I_{C23A} = 141.8\ \Omega$
- $r_{\pi 23A} = \beta_{23A} r_{E23A} = 14.2\ k\Omega$
- $R_{i14} = (\beta_{14} + 1)(r_{E14} + R_L) = 1\ M\Omega$
- $R' = r_{013A} || R_{i14} = 214.3\ k\Omega$
- ***Effective load*** of Q_{23A}:

  $R_{L23A} = r_{eq} + R' = 214.5\ k\Omega$
- R_{L23A} appears in ***parallel*** with r_{023A}

  $\Rightarrow R_{eq} = r_{023A} || R_{L23A} = 120.1\ k\Omega$

  $\Rightarrow R_{i3} = r_{\pi 23A} + (\beta_{23A} + 1) R_{eq} = 12.1\ M\Omega$

- Note the ***enormously large input resistance*** of the ***output stage***, primarily due to ***two factors***:
  - ❖ ***Buffering action*** of Q_{23A}, putting its ***entire emitter load to base after multiplying it by*** $\boldsymbol{\beta}$
  - ❖ ***Relatively large value of*** $\boldsymbol{R_L}$
- Thus, the ***choice*** of putting Q_{23A} in the ***signal path*** is obvious
  - ❖ It also provides a ***DC level shift*** of ~ +0.7 V
- Note also that R_{i3} appears as the ***load of the gain stage***, having an ***output resistance*** R_{02} of only 80.9 kΩ

  $\Rightarrow$ ***Negligible loading***

- Since this stage is basically a ***cascade of voltage followers***, hence, it would be ***more prudent*** to find the ***overall voltage gain*** of this stage, rather than the ***short-circuit transconductance***
- Thus:

  $v_1/v_{i3} = R_{eq}/(R_{eq} + r_{E23A}) = 0.9988$

  $v_2/v_1 = R'/(R' + r_{eq}) = 0.9992$

  $v_0/v_2 = R_L/(R_L + r_{E14}) = 0.9974$

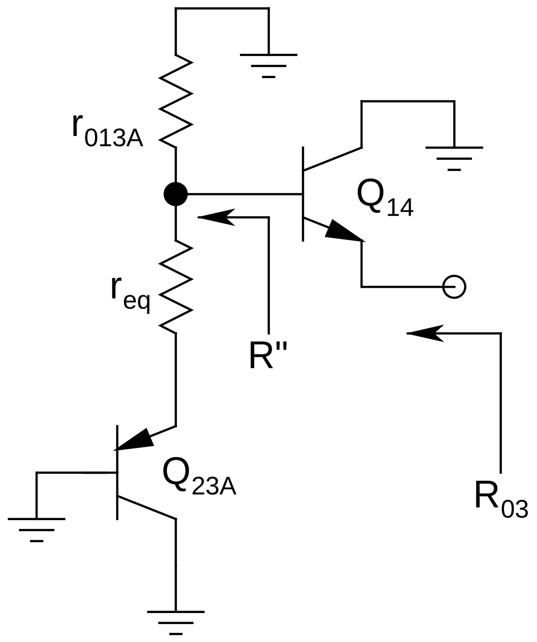
  $\Rightarrow A_{v3} = v_0/v_{i3} = (v_0/v_2) \times (v_2/v_1) \times (v_1/v_{i3})$

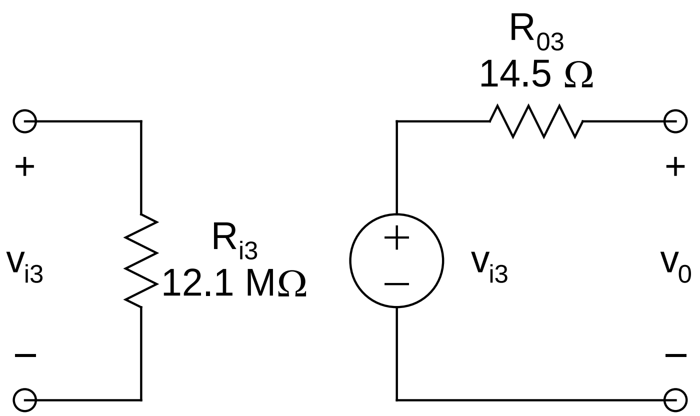
  $= 0.9954 \approx 1$
- Note that in spite of ***keeping*** so many ***significant digits*** after the ***decimal point*** in all the ***intermediate results***, the ***end result*** is still ***extremely close to unity***

- The ***output resistance*** R_{03} can be ***evaluated*** from a ***simple inspection*** of the circuit:

$$R'' = r_{013A} \| (r_{eq} + r_{E23A}) = 310.1\ \Omega$$

$$\Rightarrow R_{03} = r_{E14} + R''/(\beta_{14} + 1) = 14.5\ \Omega$$

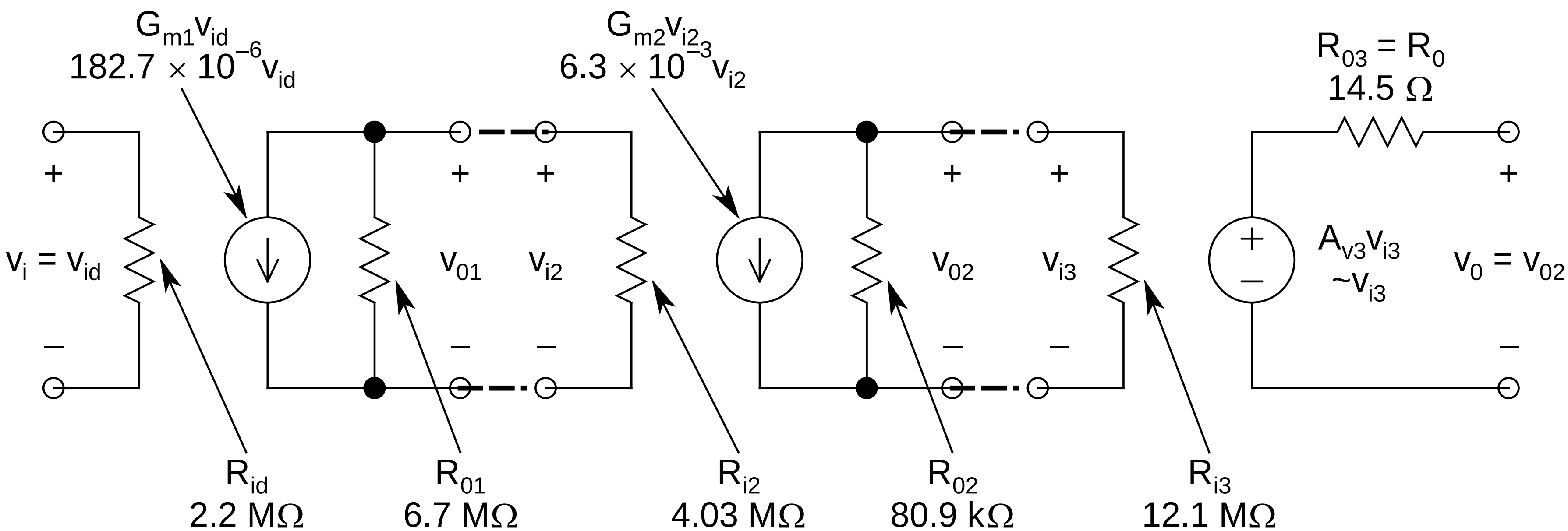




2-Port Equivalent of the Output Stage

➢ *Overall Performance*:

- Just *cascade* the *2-port equivalents* of the *three stages*



Complete 2-Port Representation of 741 Op-Amp