

EE3122: Analogue Circuit Fundamentals

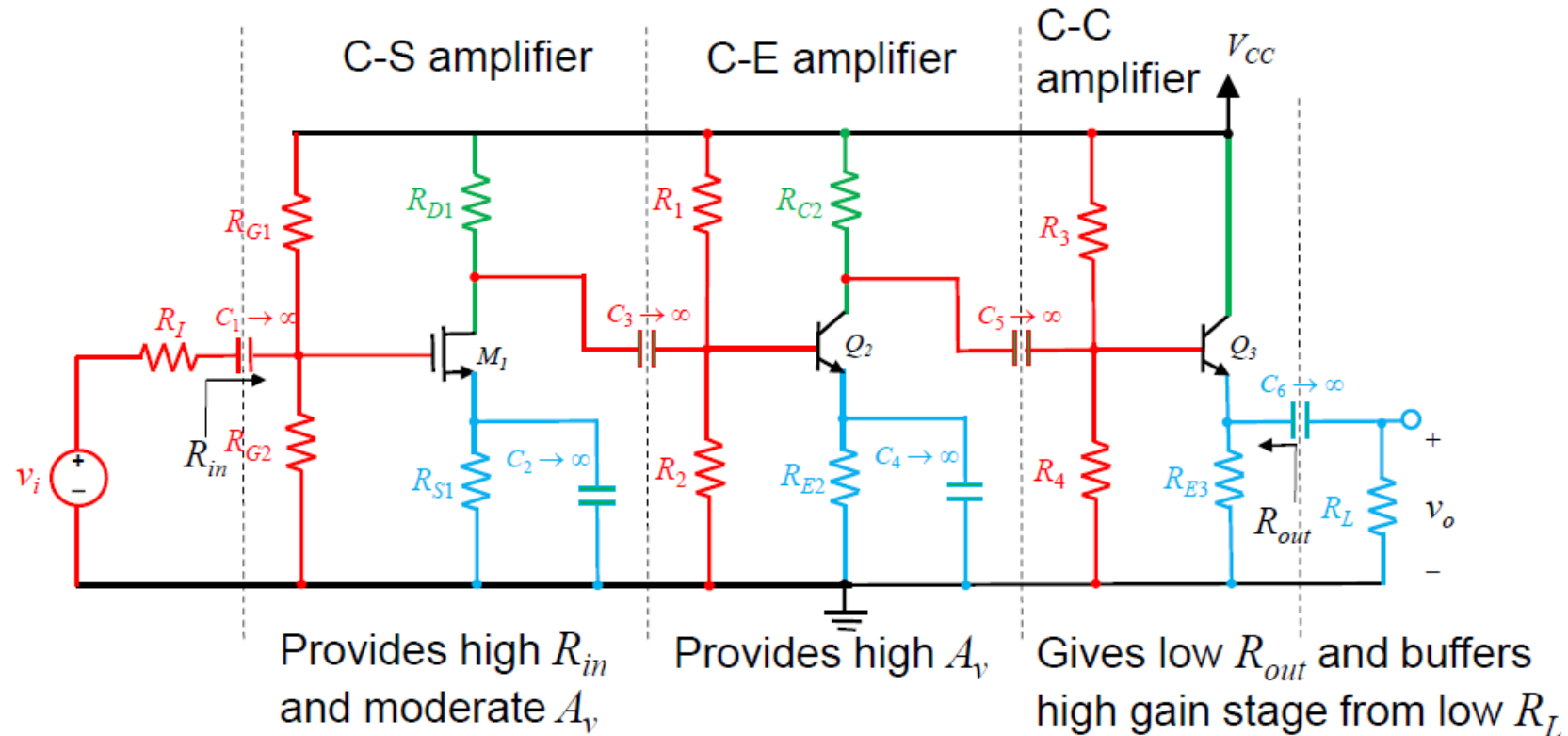
Multiple Transistor Amplifiers

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Example of 3 stage amplifier

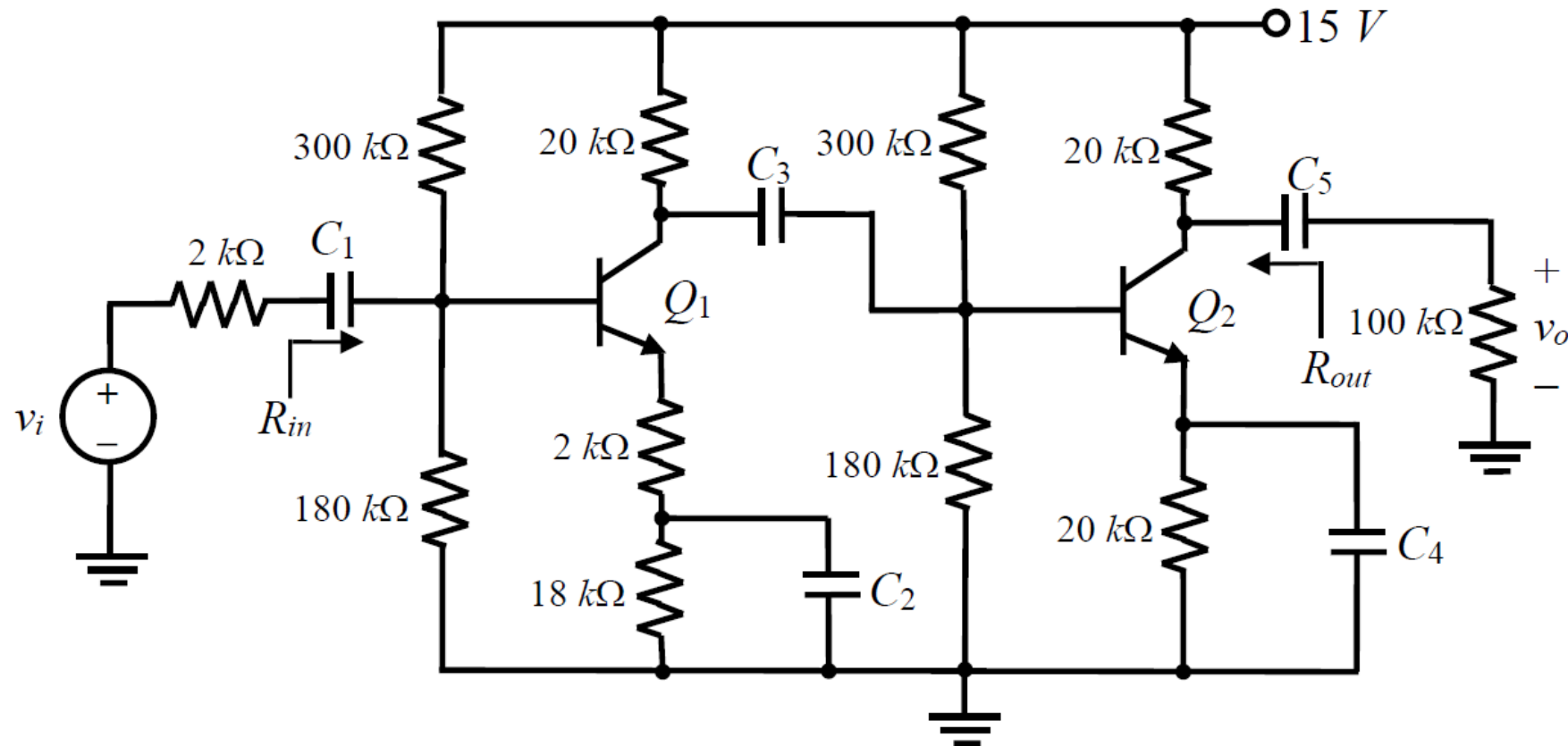


- Input and output of overall amplifier is AC-coupled through capacitors C_1 and C_6 .
- Bypass capacitors C_2 and C_4 are used to get maximum voltage gain from the two inverting amplifiers.

2 stage amplifier: Example

What are the midband voltage gain, input resistance and output resistance of the amplifier in Figure 1? Use $\beta = 100$ and $V_A = 70\text{V}$.

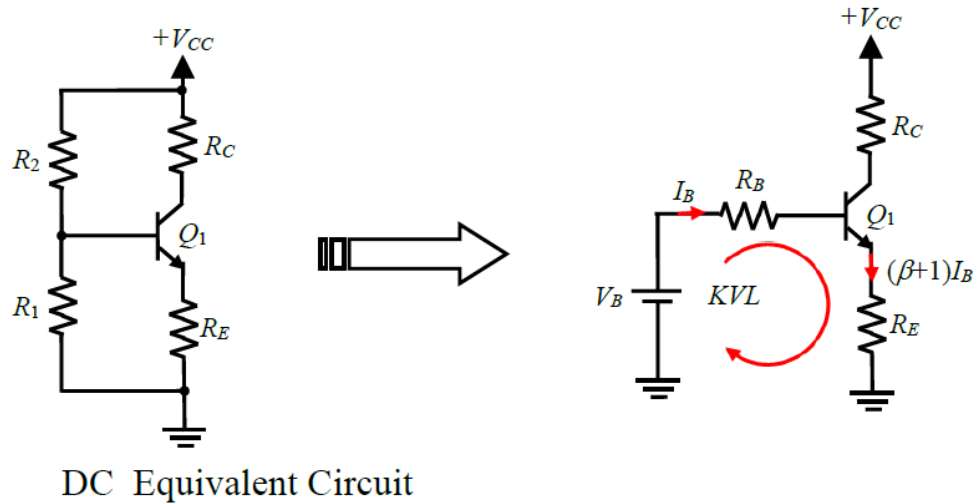
(Ans: $A_v = 444$, $R_{in} = 73.6\text{ k}\Omega$, $R_{out} = 18.8\text{ k}\Omega$)



2 stage amplifier: DC Analysis

DC analysis:

Note that the dc equivalent circuit for Q_1 and Q_2 are identical.



$$V_B = 15 \times \frac{180k}{300k + 180k} = 5.63 V$$

$$R_B = 300k \parallel 180k = 113 k\Omega$$

$$I_B = \frac{5.63 - 0.7}{113k + 101 \times 20k} = 2.31 \mu A$$

$$I_C = \beta I_B = 100 \times 2.31 \mu = 232 \mu A$$

$$I_E = (\beta + 1) I_B = 101 \times 2.31 \mu = 234 \mu A$$

$$V_{CE} = 15 - I_C (20k) - I_E (20k) = 5.71 V$$

2 stage amplifier: AC Analysis

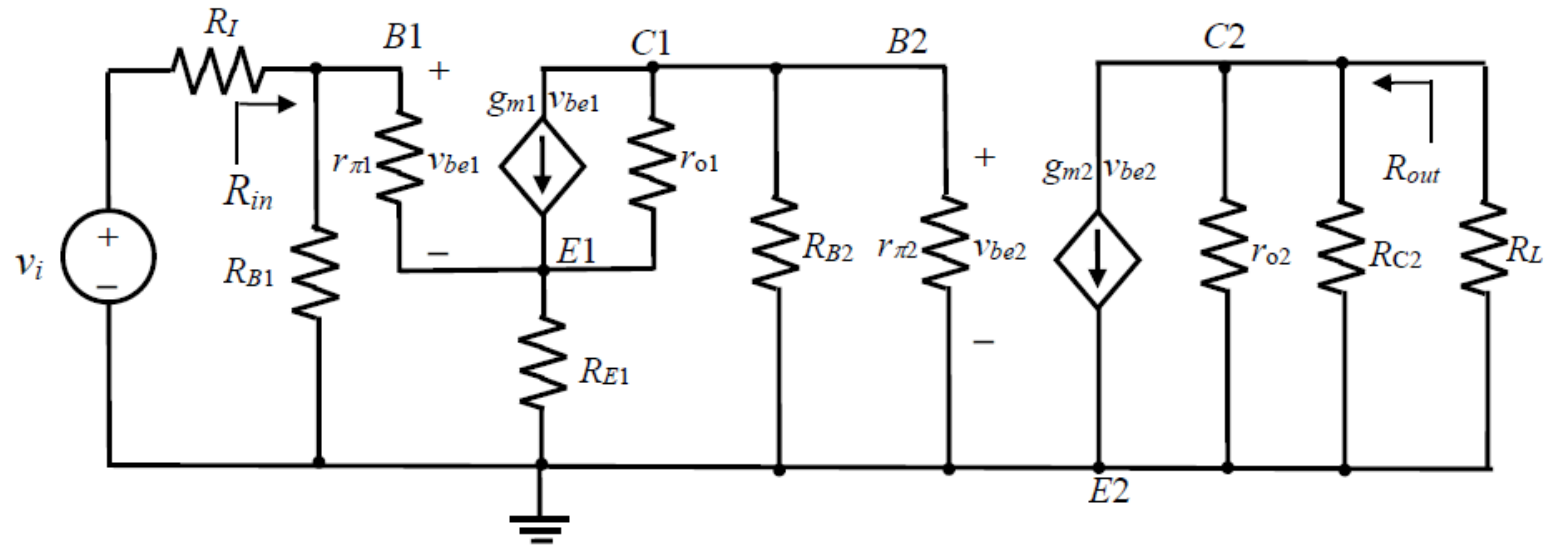
$$g_m = \frac{I_C}{V_T} = \frac{232\mu}{0.025} = 9.28 \text{ mS}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.0928} = 10.8 \text{ k}\Omega$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{70 + 5.71}{232\mu} = 326 \text{ k}\Omega$$

2 stage amplifier: AC Analysis

AC analysis:



$$R_{B1} = 300k \parallel 180k = 112.5 k\Omega$$

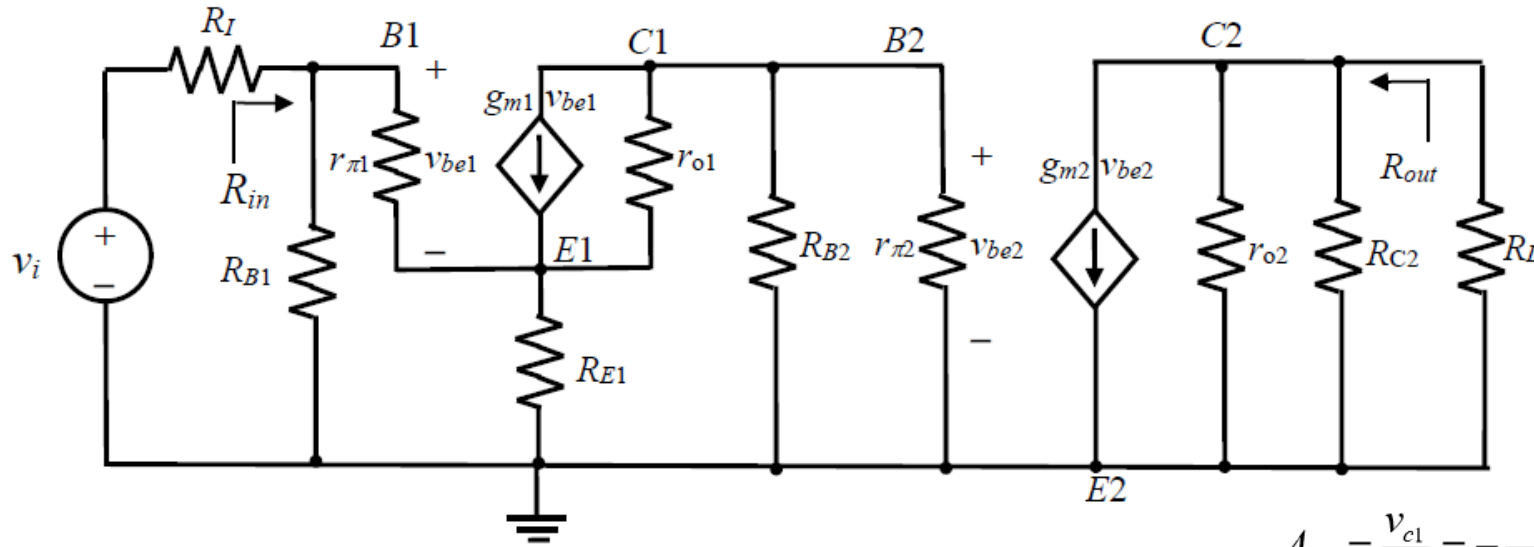
$$R_{B2} = 20k \parallel 300k \parallel 180k = 16.98 k\Omega$$

Input resistance,

$$R_{in} = R_{B1} \parallel (r_{\pi 1} + (\beta + 1) R_{E1}) = 112.5k \parallel (10.8k + (101) 2k) = 73.6 k\Omega$$

2 stage amplifier: AC Analysis

AC analysis:



$$A_v = \left(\frac{R_{in}}{R_I + R_{in}} \right) A_{v1} A_{v2}$$

Stages 1 and 2 are common-emitter amplifier. Note that the emitter resistor, $2k\Omega$ in stage 1 is not bypassed.

$$A_{v1} = \frac{v_{c1}}{v_{b1}} = - \frac{\beta_1 \frac{v_{be1}}{i_{b1}} (R_{B2} \parallel r_{\pi 2})}{\frac{v_{be1}}{i_{b1}} [r_{\pi 1} + (\beta_1 + 1) R_{E1}]} = - \frac{100 (17k \parallel 10.8k)}{10.8k + (101) 2k} = -3.10$$

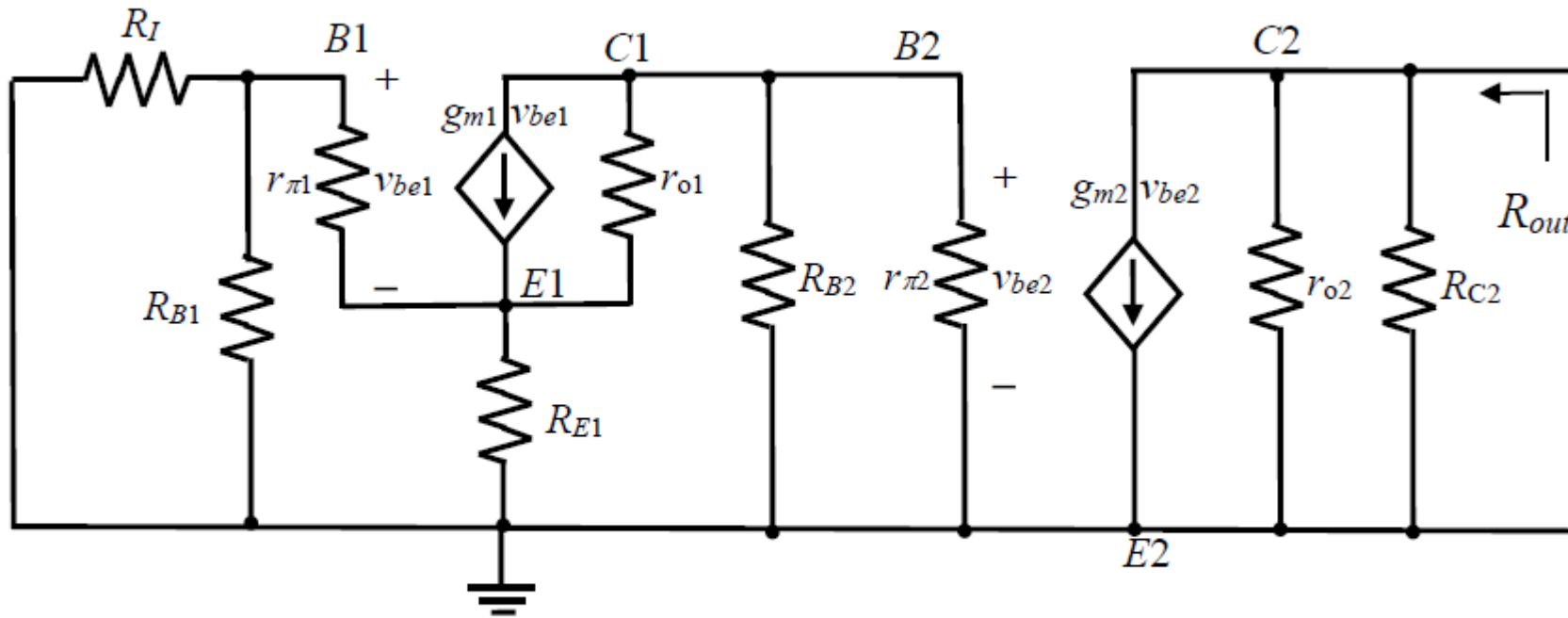
$R_{in} \text{ looking into } b1$

$$A_{v2} = \frac{v_o}{v_{b2}} = \frac{-g_{m2} v_{be2} R_L'}{v_{be2}} = -g_{m2} R_L' = -0.0928 (326k \parallel 20k \parallel 100k) = -147$$

$$A_v = \left(\frac{73.6k}{2k + 73.6k} \right) (-3.10) (-147) = 444$$

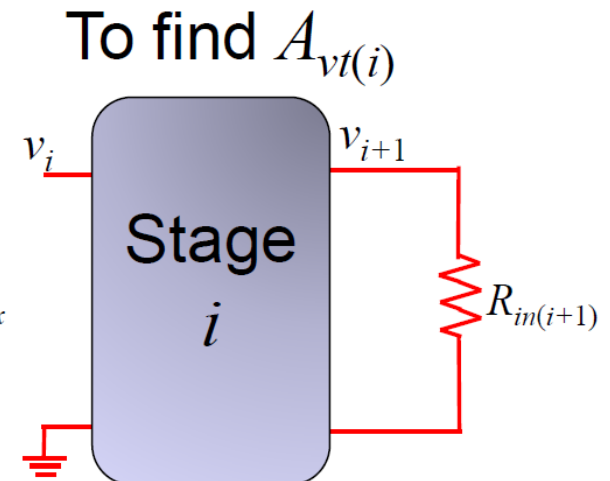
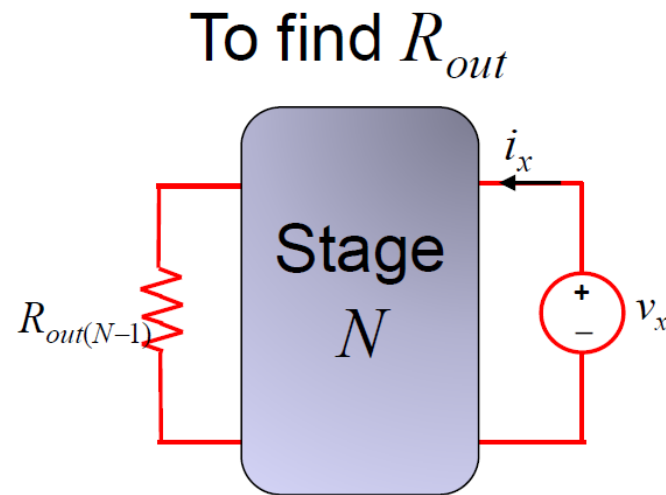
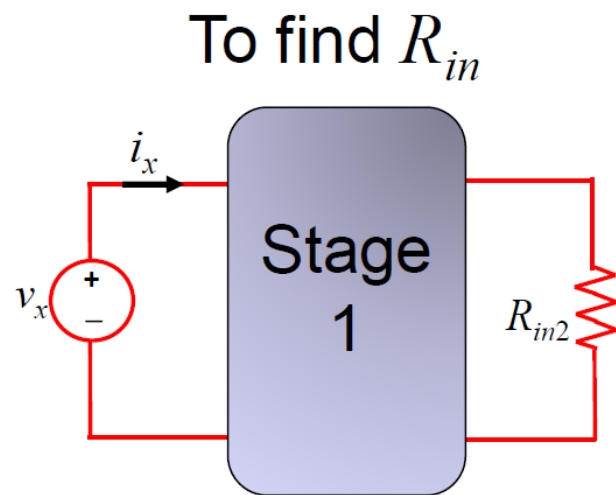
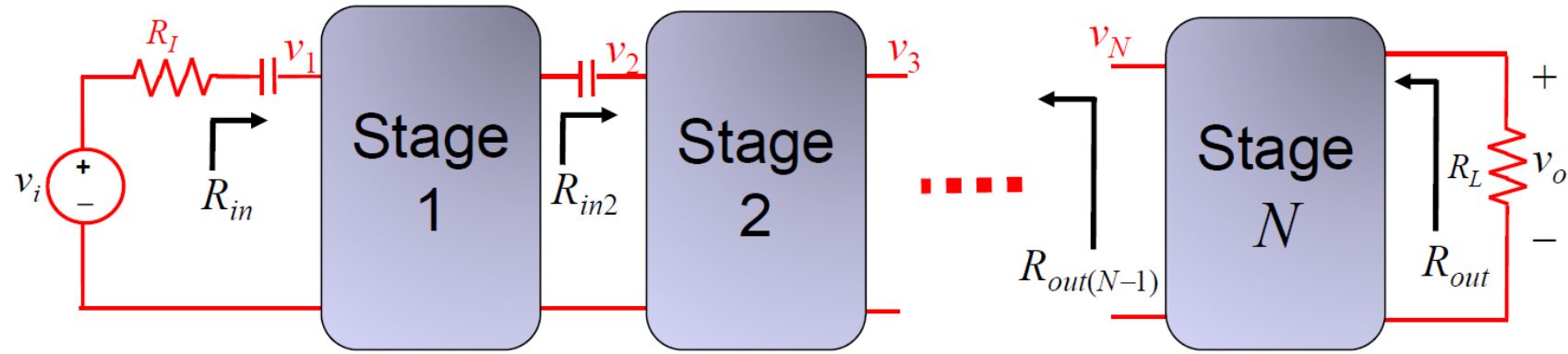
2 stage amplifier: AC Analysis

Output resistance,



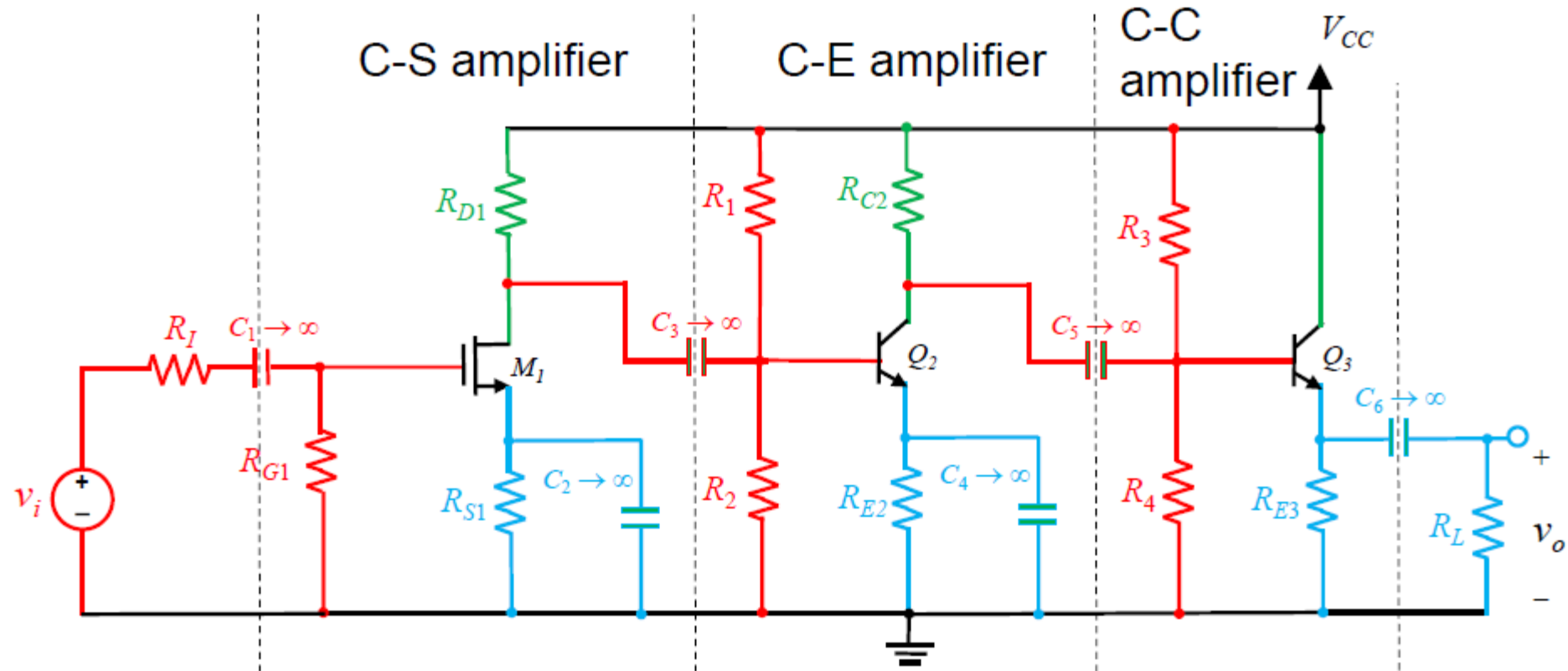
$$R_{out} = 20k \parallel r_{o2} = 20k \parallel 326k = 18.8k\Omega$$

General case



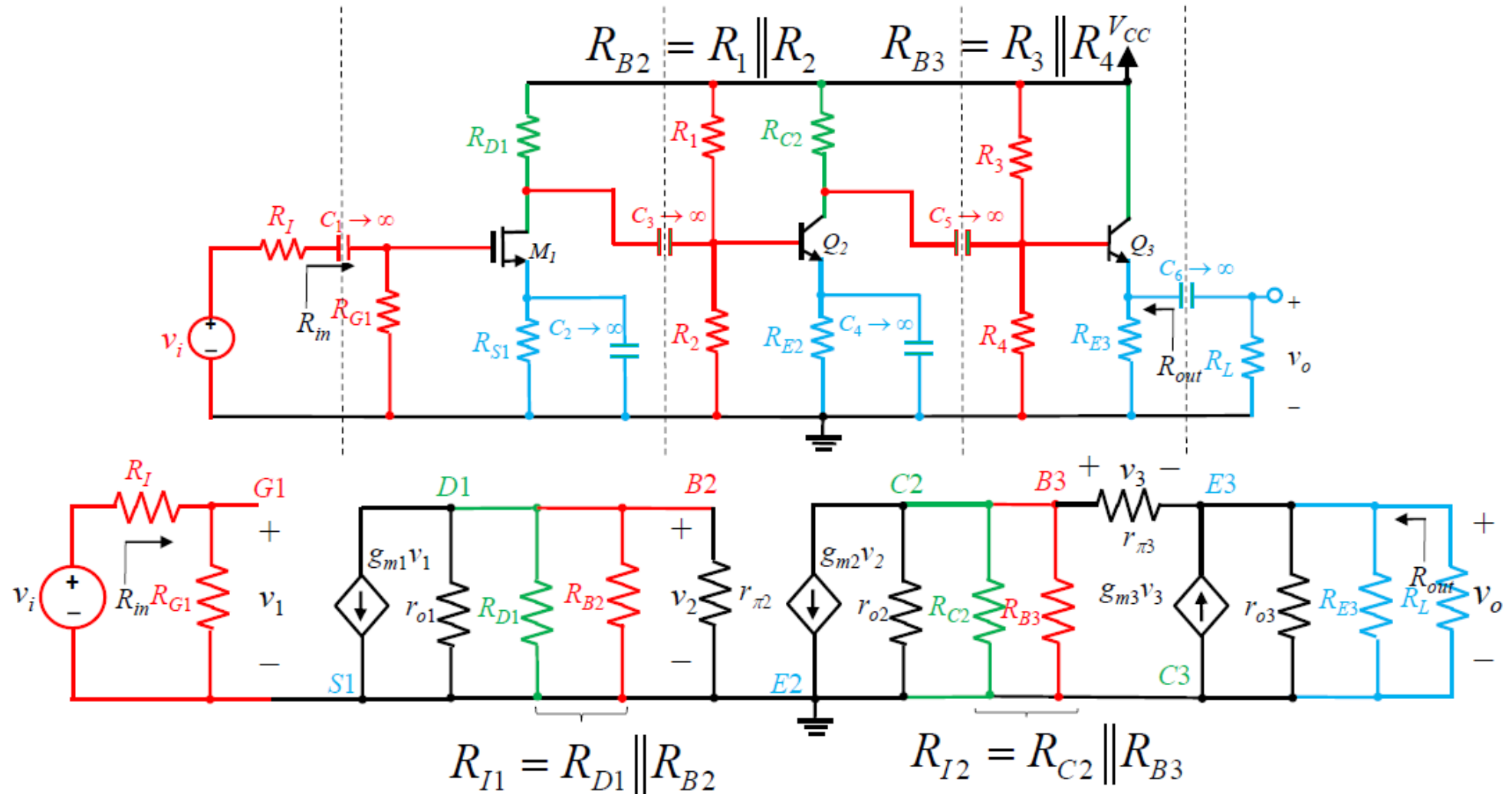
Appendix: Additional Example

3 stage amplifier: DC equivalent

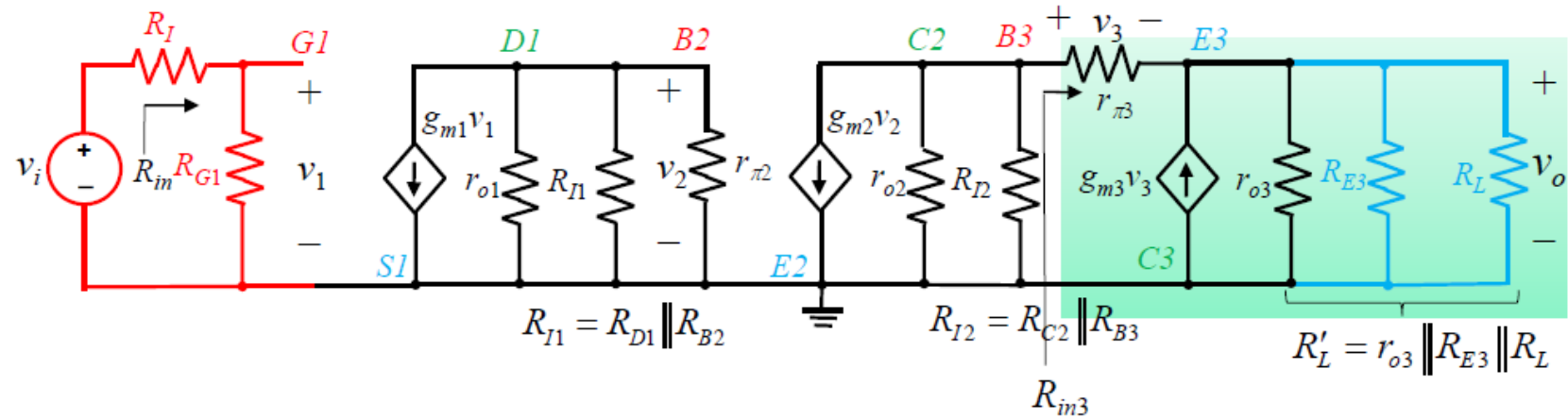


- Inter-stage coupling capacitors allow coupling of AC signals
- For DC analysis, capacitors open $\rightarrow$ DC biasing of each stage is independent. Q point unchanged

3 stage amplifier: AC equivalent



3 stage amplifier: Input resistance & Voltage gain

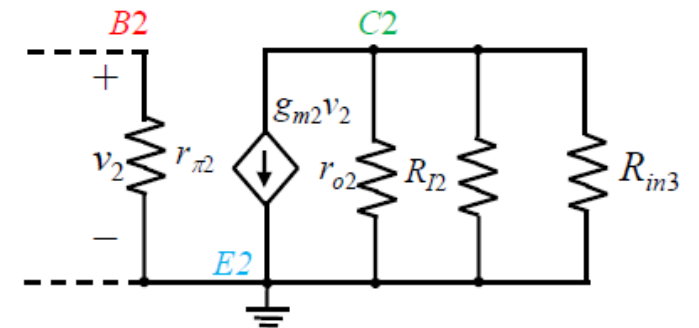


$$R_{in} = R_{G1}$$

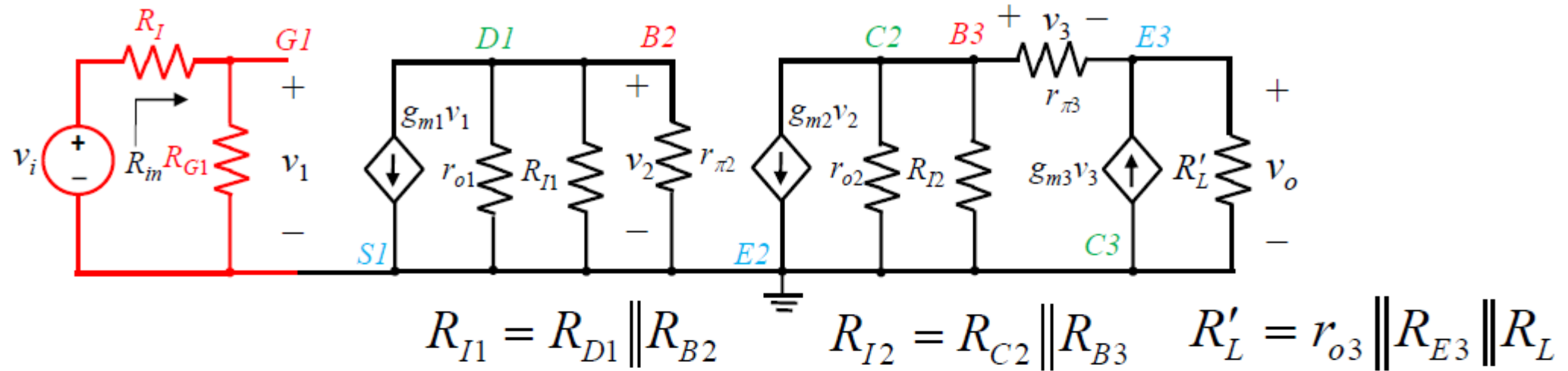
$$A_{vt1} = \frac{v_{d1}}{v_{g1}} = \frac{v_2}{v_1} = \frac{-g_{m1} v_1 (r_{o1} \parallel R_{I1} \parallel r_{\pi 2})}{v_1} = -g_{m1} (r_{o1} \parallel R_{I1} \parallel r_{\pi 2})$$

$$R_{in3} = r_{\pi 3} + (\beta_3 + 1) R'_L$$

$$A_{vt2} = \frac{v_{c2}}{v_{b2}} = \frac{-g_{m2} v_2 (r_{o2} \parallel R_{I2} \parallel R_{in3})}{v_2} = -g_{m2} (r_{o2} \parallel R_{I2} \parallel R_{in3})$$



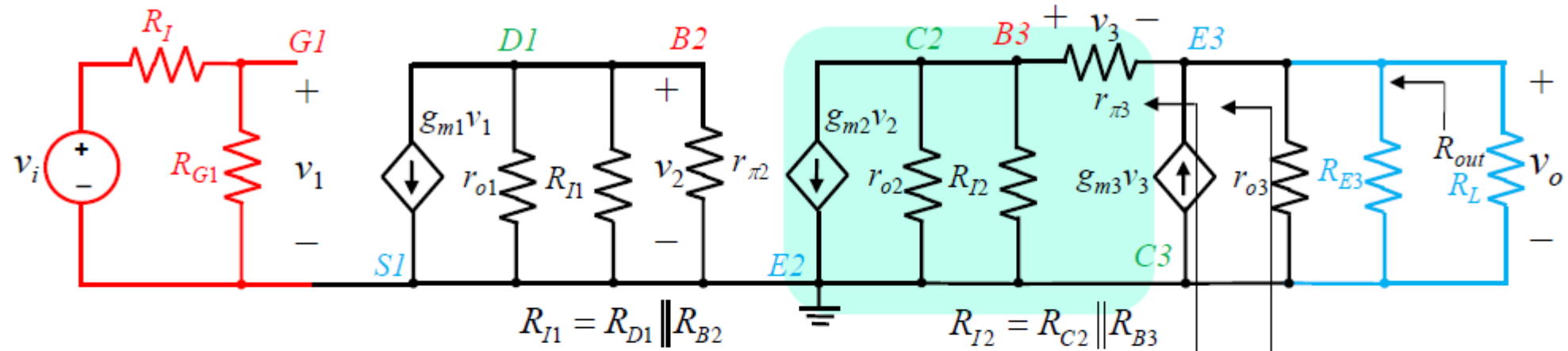
3 stage amplifier: Voltage gain



$$A_{vt3} = \frac{v_{e3}}{v_{b3}} = \frac{g_{m3} v_3 R'_L}{v_3 + g_{m3} v_3 R'_L}$$

$$A_v = \frac{v_o}{v_i} = \frac{v_{g1}}{v_i} \times \frac{v_{d1}}{v_{g1}} \times \frac{v_{c2}}{v_{b2} (= v_{d1})} \times \frac{v_{e3} (= v_o)}{v_{b3} (= v_{c2})} = \left(\frac{R_{in}}{R_I + R_{in}} \right) A_{vt1} A_{vt2} A_{vt3}$$

3 stage amplifier: Output resistance



$$R_{out} = \left(\frac{r_{\pi 3} + r_{o2} \parallel R_{I2}}{\beta_3 + 1} \right) \parallel r_{o3} \parallel R_{E3}$$

$$r_{\pi 3} + r_{o2} \parallel R_{I2}$$

$$\frac{r_{\pi 3} + r_{o2} \parallel R_{I2}}{\beta_3 + 1}$$