AC Analysis of BJT and MOSFET Voltage Followers

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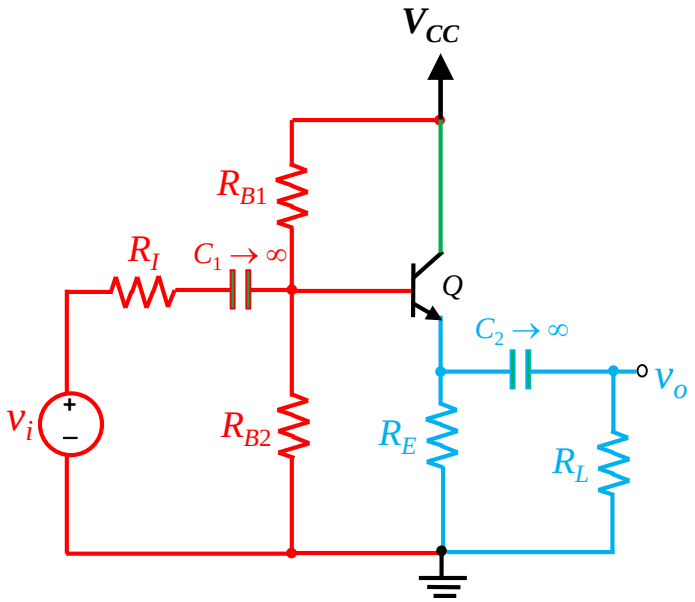
EE2002 Analog Electronics

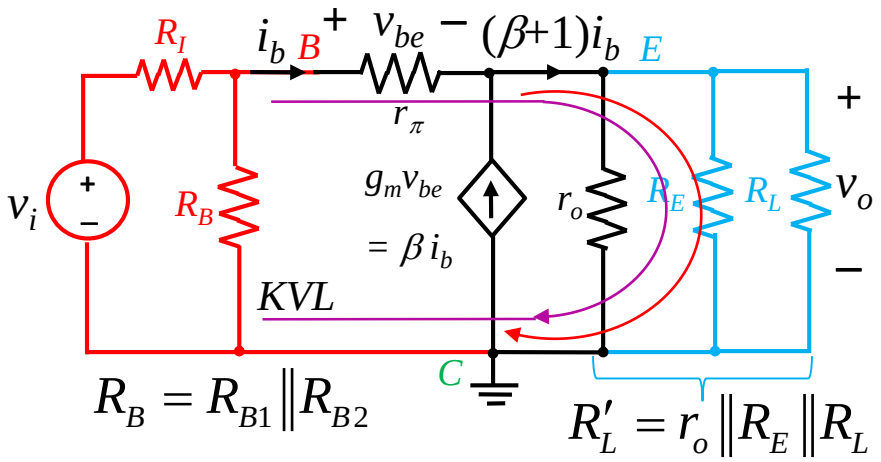
Lesson Objectives

At the end of this lesson, you should be able to:

- Identify BJT and MOSFET voltage follower circuits
- Draw small-signal AC equivalent circuits of C-C and C-D amplifiers
- Calculate the following performance characteristics of C-C and C-D amplifiers
  - Voltage gain
  - Input resistance
  - Output resistance

C-C Amplifier (Voltage Follower): Terminal Voltage Gain

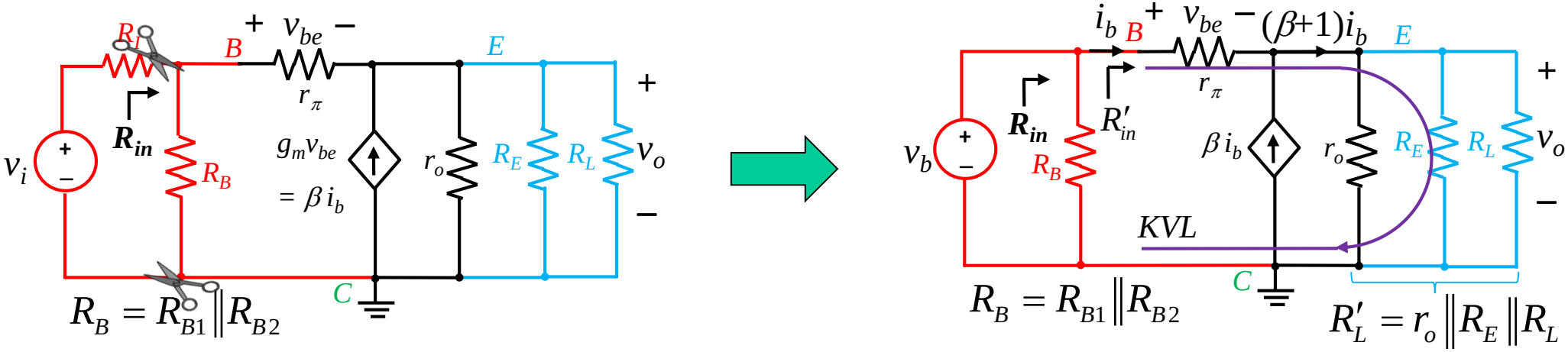




$$A_{vt} = \frac{v_e}{v_b} = \frac{(\beta+1) i_b R'_L}{i_b r_\pi + (\beta+1) i_b R'_L} = \frac{(\beta+1) R'_L}{r_\pi + (\beta+1) R'_L} \approx \frac{g_m R'_L}{1 + g_m R'_L}$$

If $g_m R'_L \gg 1$, $A_{vt} \approx 1 \Rightarrow v_o \approx v_b$.

C-C Amplifier (Voltage Follower): Input Resistance

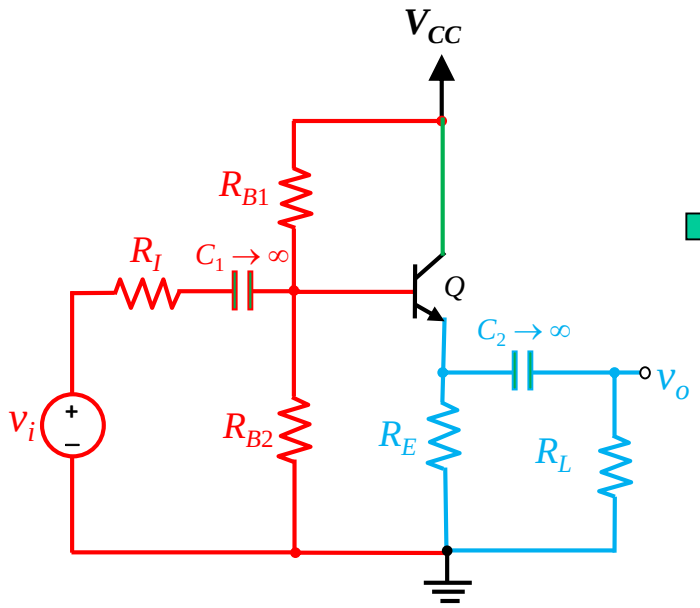


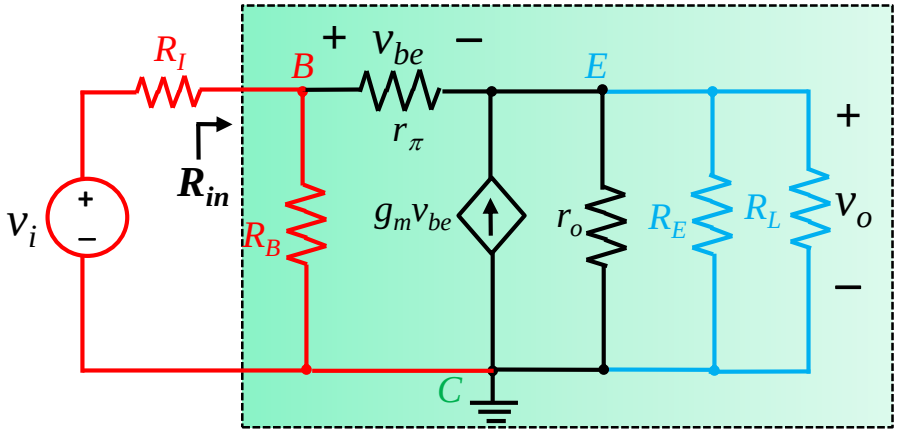
$$v_b = i_b r_\pi + (\beta + 1) i_b R'_L$$

$$R'_{in} = \frac{v_b}{i_b} = r_\pi + (\beta + 1) R'_L$$

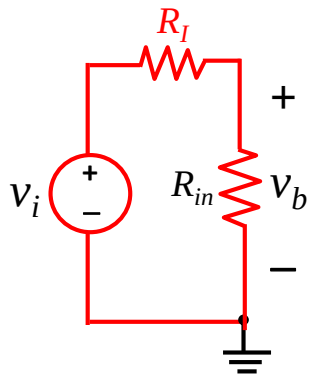
$$R_{in} = R'_{in} \| R_B$$

C-C Amplifier (Voltage Follower): Overall Voltage Gain



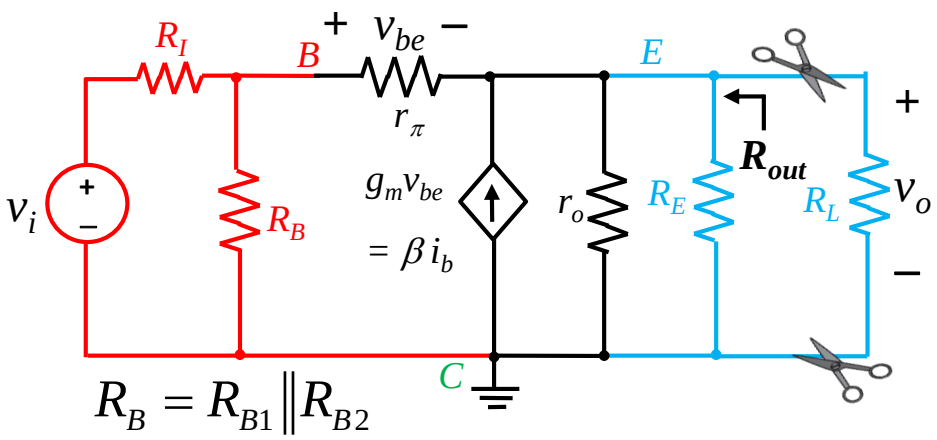


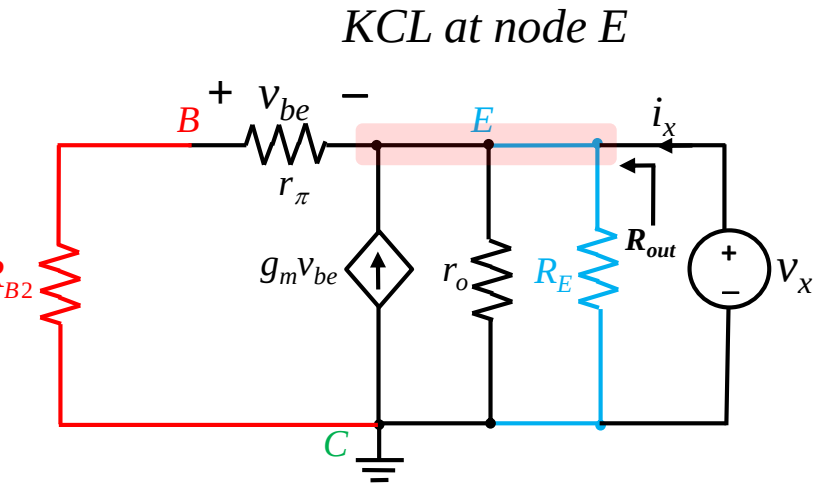
$$R_B = R_{B1} \| R_{B2}$$



$$A_v = \frac{v_o}{v_i} = \frac{v_o}{v_b} \times \frac{v_b}{v_i} = A_{vt} \times \frac{R_{in}}{R_I + R_{in}}$$

C-C Amplifier (Voltage Follower): Output Resistance





$$R_{th} = R_I \| R_{B1} \| R_{B2}$$

$$i_x = \frac{v_x}{R_E} + \frac{v_x}{r_o} - g_m v_{be} + \frac{v_x}{r_\pi + R_{th}}$$

$$v_{be} = -\left(\frac{r_\pi}{r_\pi + R_{th}}\right) v_x$$

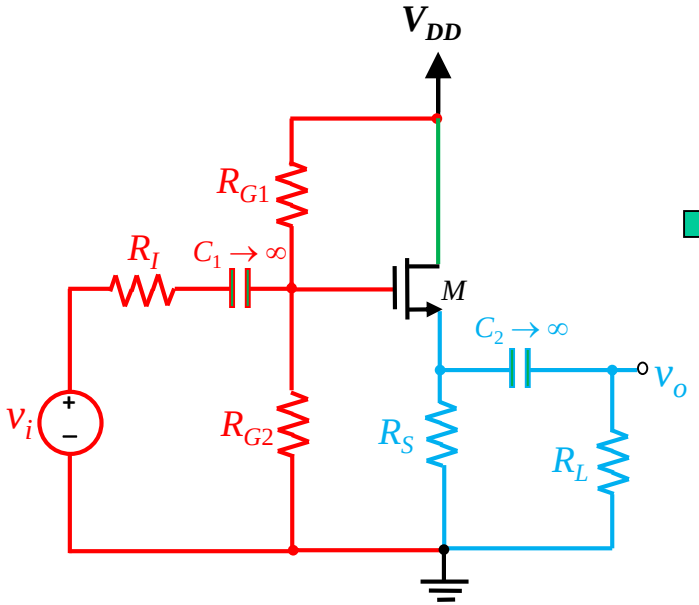
$$i_x = \frac{v_x}{R_E} + \frac{v_x}{r_o} + \frac{g_m r_\pi v_x}{r_\pi + R_{th}} + \frac{v_x}{r_\pi + R_{th}}$$

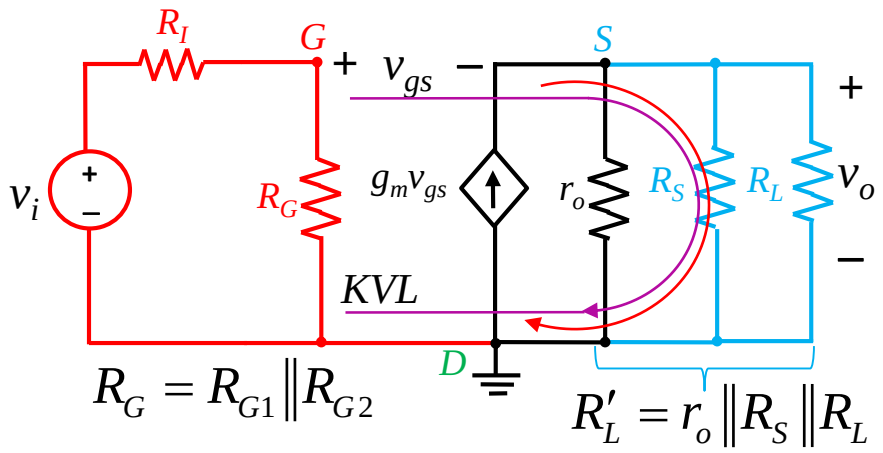
$$= \left(\frac{1}{R_E} + \frac{1}{r_o} + \frac{\beta}{r_\pi + R_{th}} + \frac{1}{r_\pi + R_{th}}\right) v_x$$

$$R_{out} = \frac{v_x}{i_x} = \left(\frac{1}{R_E} + \frac{1}{r_o} + \frac{\beta + 1}{r_\pi + R_{th}}\right)^{-1}$$

$$= R_E \left\| r_o \right\| \left(\frac{r_\pi + R_{th}}{\beta + 1}\right)$$

C-D Amplifier (Voltage Follower): Terminal Voltage Gain

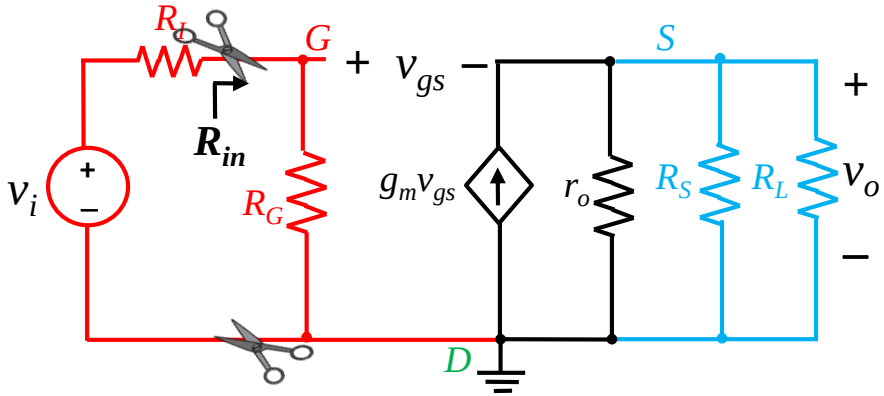




$$A_{vt} = \frac{v_s}{v_g} = \frac{g_m v_{gs} R'_L}{v_{gs} + g_m v_{gs} R'_L} = \frac{g_m R'_L}{1 + g_m R'_L}$$

If $g_m R'_L \gg 1$, $A_{vt} \approx 1 \Rightarrow v_o \approx v_g$.

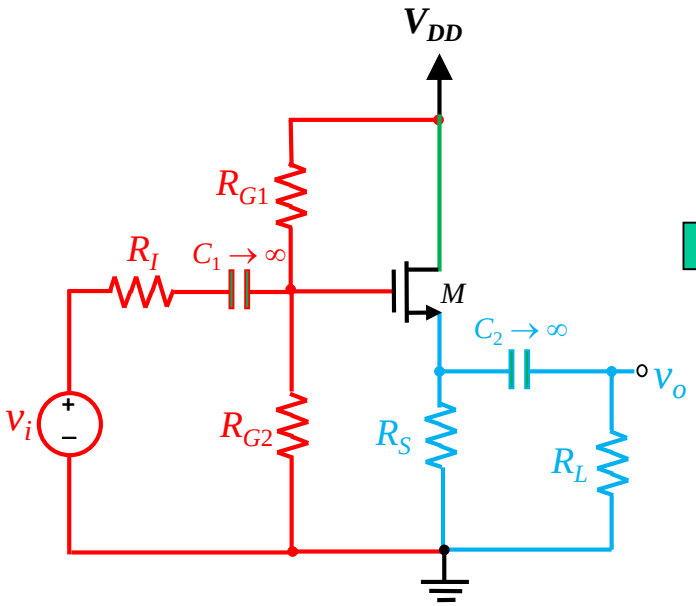
C-D Amplifier (Voltage Follower): Input Resistance

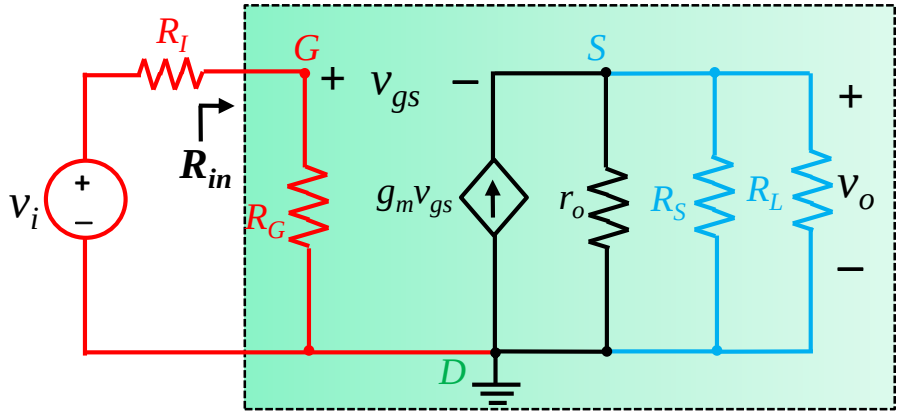


$$R_G = R_{G1} \| R_{G2}$$

$$R_{in} = R_G$$

C-D Amplifier (Voltage Follower): Overall Voltage Gain

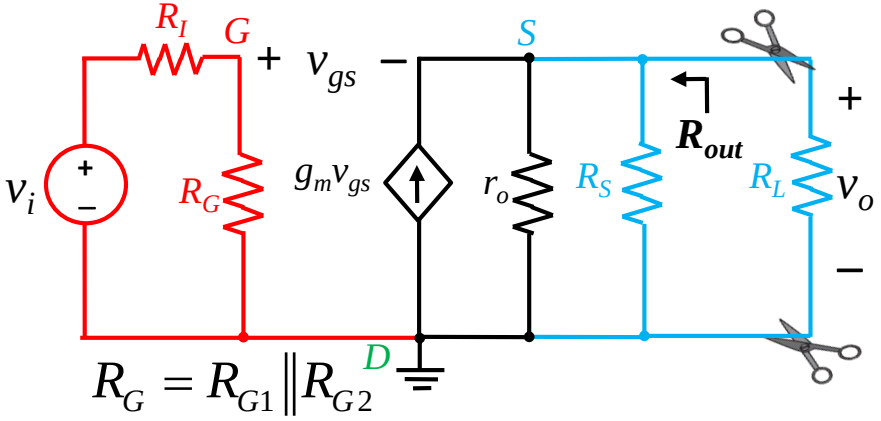


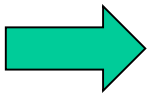


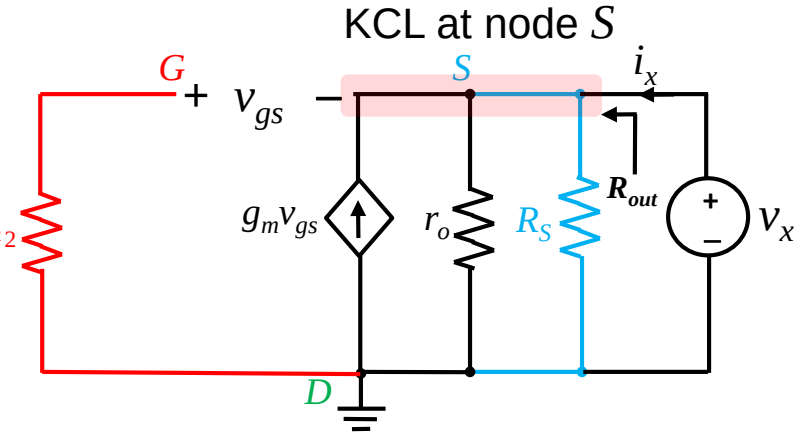
$$R_G = R_{G1} \| R_{G2}$$

$$A_v = \frac{v_o}{v_i} = \frac{v_o}{v_g} \times \frac{v_g}{v_i} = A_{vt} \times \frac{R_G}{R_I + R_G}$$

C-D Amplifier (Voltage Follower): Output Resistance







$$i_x = \frac{v_x}{R_S} + \frac{v_x}{r_o} - g_m v_{gs}$$

$$v_{gs} = -v_x$$

$$i_x = \frac{v_x}{R_S} + \frac{v_x}{r_o} + g_m v_x = \left(\frac{1}{R_S} + \frac{1}{r_o} + g_m \right) v_x$$

$$R_{out} = \frac{v_x}{i_x} = \left(\frac{1}{R_S} + \frac{1}{r_o} + g_m \right)^{-1}$$

$$= R_S \left\| r_o \right\| \frac{1}{g_m}$$