Input Signal Range of BJT and MOSFET

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EE2002 Analog Electronics

Lesson Objectives

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

- Derive the small signal operation criterion for BJT and MOSFET
- Analyse the input signal range of BJT and MOSFET

Small-Signal Operation of BJT

$$i_C \approx I_S \exp\left(\frac{v_{BE}}{V_T}\right) = I_S \exp\left(\frac{V_{BE} + v_{be}}{V_T}\right)$$

$$\therefore i_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)\exp\left(\frac{v_{be}}{V_T}\right) = I_C\left[1+\frac{v_{be}}{V_T}+\frac{1}{2!}\left(\frac{v_{be}}{V_T}\right)^2+\frac{1}{3!}\left(\frac{v_{be}}{V_T}\right)^3+\cdots\right]$$

$$i_c = i_C - I_C = I_C\left[\frac{v_{be}}{V_T}+\frac{1}{2}\left(\frac{v_{be}}{V_T}\right)^2+\frac{1}{6}\left(\frac{v_{be}}{V_T}\right)^3+\cdots\right]$$

For linearity, i_c should be proportional to v_{be}.

$$\frac{1}{2}\left(\frac{v_{be}}{V_T}\right)^2 \ll \frac{v_{be}}{V_T} \Rightarrow |v_{be}| \ll 2V_T = 0.05\,V \Rightarrow |v_{be}| \leq 0.005\,V$$

C-E Amplifier Input Signal Range

For BJT small-signal operation, $|v_{be}| \le 5$ mV.

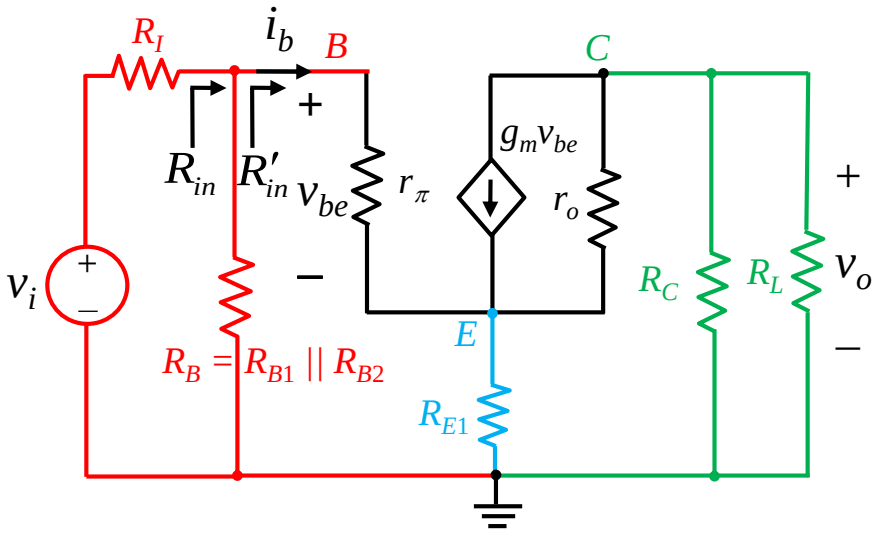
$$|v_{be}| = i_b r_\pi = \frac{|v_b| r_\pi}{R'_{in}} = \frac{|v_b| r_\pi}{r_\pi + (\beta+1) R_{E1}}$$

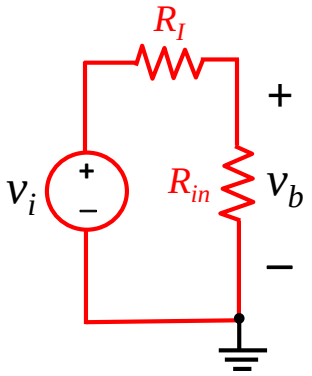
$$|v_{be}| \le 0.005$$

$$\Rightarrow |v_b| \le 0.005 \left(\frac{r_\pi + (\beta+1) R_{E1}}{r_\pi} \right)$$

$$\because \beta + 1 \approx \beta = g_m r_\pi, \ |v_b| \le 0.005 (1 + g_m R_{E1})$$

$$\because v_b = \left(\frac{R_{in}}{R_I + R_{in}} \right) v_i \Rightarrow |v_i| \le 0.005 (1 + g_m R_{E1}) \left(\frac{R_I + R_{in}}{R_{in}} \right)$$



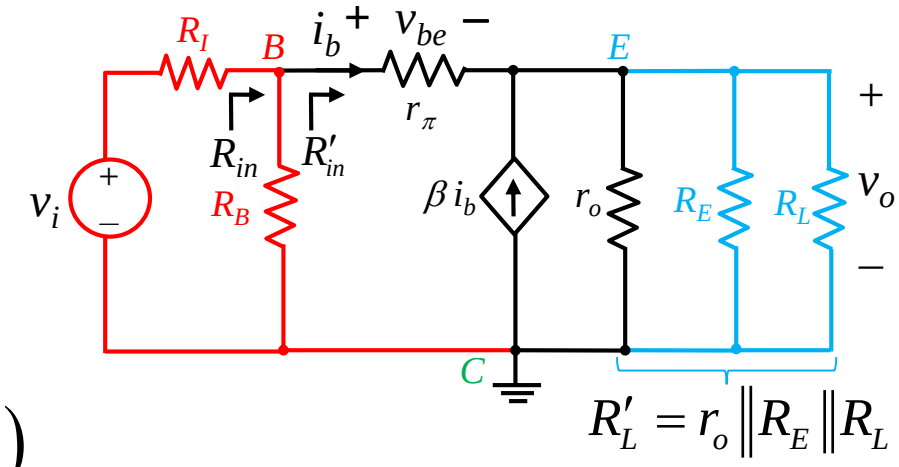


C-C Amplifier Input Signal Range

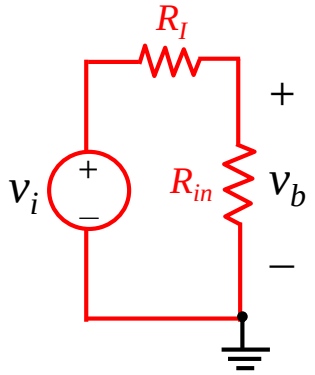
For BJT small-signal operation, $|v_{be}| \le 5\ \text{mV}$.

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

$$\Rightarrow |v_b| \le 0.005\left(\frac{r_\pi + (\beta+1)R'_L}{r_\pi}\right) \approx 0.005(1 + g_m R'_L)$$



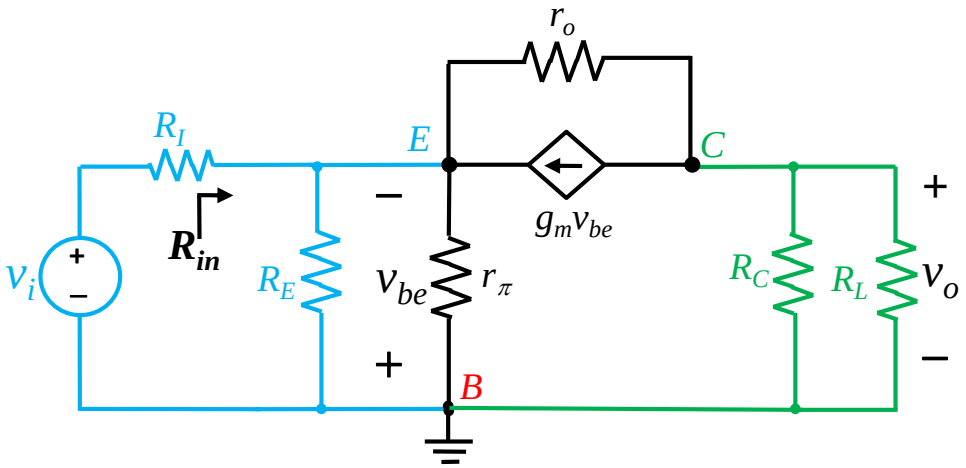
$$\because v_b = \left(\frac{R_{in}}{R_I + R_{in}}\right) v_i \Rightarrow |v_i| \le 0.005(1 + g_m R'_L)\left(\frac{R_I + R_{in}}{R_{in}}\right)$$



C-B Amplifier Input Signal Range

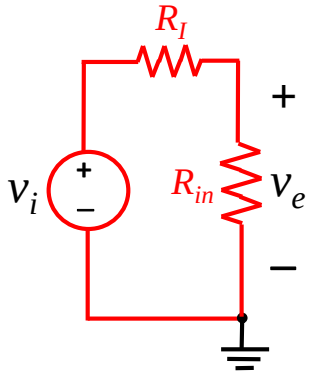
For BJT small-signal operation, $|v_{be}| \le 5$ mV.

$$v_{be} = -v_e = -\left(\frac{R_{in}}{R_I + R_{in}}\right) v_i$$



$$|v_{be}| \le 0.005$$

$$\Rightarrow |v_i| \le 0.005\left(\frac{R_I + R_{in}}{R_{in}}\right)$$



Small-Signal Operation of MOSFET

$$i_D = \frac{K_n}{2}\left(v_{GS} - V_{TN}\right)^2 \text{ for } v_{DS} \geq v_{GS} - V_{TN}$$

$$i_D = \frac{K_n}{2}\left(V_{GS} + v_{gs} - V_{TN}\right)^2 = \frac{K_n}{2}\left[\left(V_{GS} - V_{TN}\right)^2 + 2v_{gs}\left(V_{GS} - V_{TN}\right) + v_{gs}^2\right]$$

$$i_d = i_D - I_D = \frac{K_n}{2}\left[2v_{gs}\left(V_{GS} - V_{TN}\right) + v_{gs}^2\right]$$

For linearity, i_d should be proportional to v_{gs}.

$$\left|v_{gs}\right| \ll 2\left(V_{GS} - V_{TN}\right) \Rightarrow \left|v_{gs}\right| \leq 0.2\left(V_{GS} - V_{TN}\right)$$

C-S Amplifier Input Signal Range

For MOSFET small-signal operation, $|v_{gs}| \le 0.2(V_{GS} - V_{TN})$.

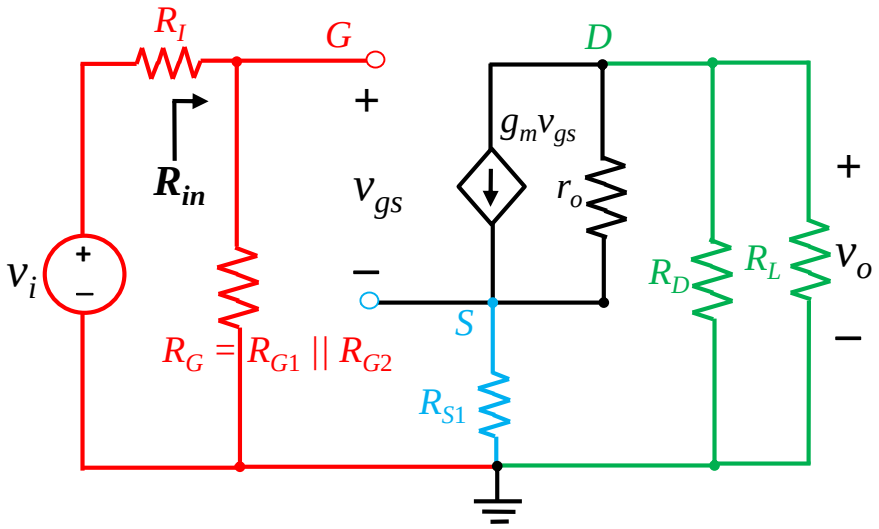
$$v_g \approx v_{gs} + g_m v_{gs} R_{S1} = v_{gs}\left(1 + g_m R_{S1}\right)$$

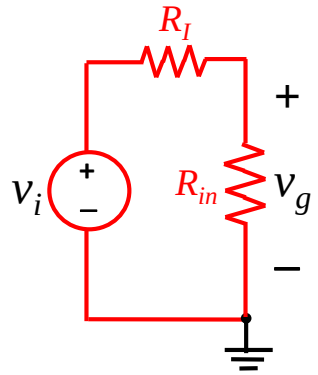
$$v_{gs} = \frac{v_g}{1 + g_m R_{S1}}$$

$$\frac{|v_g|}{1 + g_m R_{S1}} \le 0.2\left(V_{GS} - V_{TN}\right)$$

$$\Rightarrow |v_g| \le 0.2\left(V_{GS} - V_{TN}\right)\left(1 + g_m R_{S1}\right)$$

$$\because v_g = \left(\frac{R_{in}}{R_I + R_{in}}\right) v_i \Rightarrow |v_i| \le 0.2\left(V_{GS} - V_{TN}\right)\left(1 + g_m R_{S1}\right)\left(\frac{R_I + R_{in}}{R_{in}}\right)$$





C-D Amplifier Input Signal Range

For MOSFET small-signal operation, $|v_{gs}| \le 0.2(V_{GS} - V_{TN})$.

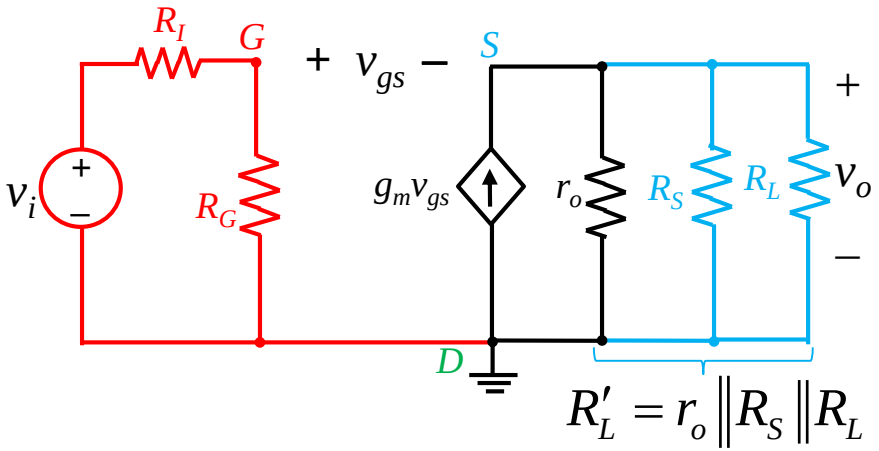
$$v_g \approx v_{gs} + g_m v_{gs} R_L'$$

$$v_{gs} = \frac{v_g}{1 + g_m R_L'}$$

$$\frac{|v_g|}{1 + g_m R_L'} \le 0.2(V_{GS} - V_{TN})$$

$$\Rightarrow |v_g| \le 0.2(V_{GS} - V_{TN})(1 + g_m R_L')$$

$$\because v_g = \left(\frac{R_G}{R_I + R_G}\right) v_i \Rightarrow |v_i| \le 0.2(V_{GS} - V_{TN})(1 + g_m R_L')\left(\frac{R_I + R_G}{R_G}\right)$$



C-G Amplifier Input Signal Range

For MOSFET small-signal operation, $|v_{gs}| \le 0.2(V_{GS} - V_{TN})$.

$$v_{gs} = -v_s = -\left(\frac{R_{in}}{R_I + R_{in}}\right) v_i$$

$$|v_{gs}| \le 0.2(V_{GS} - V_{TN})$$

$$\Rightarrow |v_i| \le 0.2(V_{GS} - V_{TN})\left(\frac{R_I + R_{in}}{R_{in}}\right)$$