

# EE105 – Fall 2014

## Microelectronic Devices and Circuits

Prof. Ming C. Wu

wu@eecs.berkeley.edu

511 Sutardja Dai Hall (SDH)

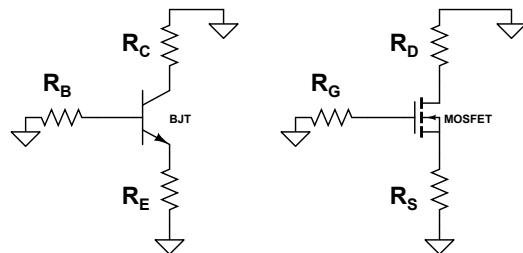


Lecture19-Review of Single Transistor  
Amplifiers

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### Terminal Resistance of Generally Loaded Transistors



$$R_e = \frac{r_\pi + R_B}{(\beta+1)} \approx \frac{1}{g_m} + \frac{R_B}{(\beta+1)}$$

$$R_s = \frac{1}{g_m}$$

$$R_b = r_\pi + (\beta+1)R_E$$

$$R_g = \infty$$

$$R_c = r_o(1 + g_m R_E)$$

$$R_d = r_o(1 + g_m R_S)$$



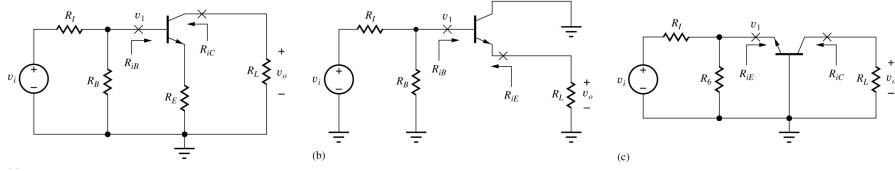
Lecture19-Review of Single Transistor  
Amplifiers

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## Single-Stage Amplifiers

### “Terminal Gain and I/O Resistances of BJT Amplifiers”



$$A_{V,I} = -\frac{g_m R_L}{1 + g_m R_E}$$

$$R_i = r_\pi + (\beta + 1) R_E$$

$$R_o = [r_o(1 + g_m R_E)]$$

$$A_{I,I} = \beta$$

Without degeneration:

Simply set  $R_E = 0$

$$A_{V,I} = \frac{R_L}{\frac{g_m}{1 + g_m R_L} + R_L}$$

$$R_i = r_\pi + (\beta + 1) R_L$$

$$R_o = \frac{r_\pi + R_{th}}{1 + \beta} \approx \frac{1}{g_m} + \frac{R_{th}}{\beta}$$

$$A_{I,I} = \beta + 1$$

$$A_{V,I} = g_m R_L$$

$$R_i = \frac{1}{g_m}$$

$$R_o = [r_o(1 + g_m R_E)]$$

$$A_{I,I} \approx 1$$

For the gain,  $R_i$ ,  $R_o$  of the whole amplifier, you need to include voltage/current dividers at input and output stages



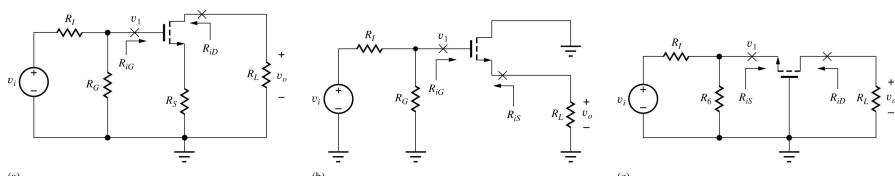
Lecture19-Review of Single Transistor Amplifiers

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## Single-Stage Amplifiers

### “Terminal Gain and I/O Resistances of MOS Amplifiers”



$$A_{V,I} = -\frac{g_m R_L}{1 + g_m R_S}$$

$$R_i = \infty$$

$$R_o = [r_o(1 + g_m R_E)]$$

$$A_{I,I} = \infty$$

Without degeneration:

Simply set  $R_S = 0$

$$A_{V,I} = \frac{R_L}{\frac{g_m}{1 + g_m R_L} + R_L}$$

$$R_i = \infty$$

$$R_o = \frac{1}{g_m}$$

$$A_{I,I} = \infty$$

$$A_{V,I} = g_m R_L$$

$$R_i = \frac{1}{g_m}$$

$$R_o = [r_o(1 + g_m R_E)]$$

$$A_{I,I} \approx 1$$

For the gain,  $R_i$ ,  $R_o$  of the whole amplifier, you need to include voltage/current dividers at input and output stages



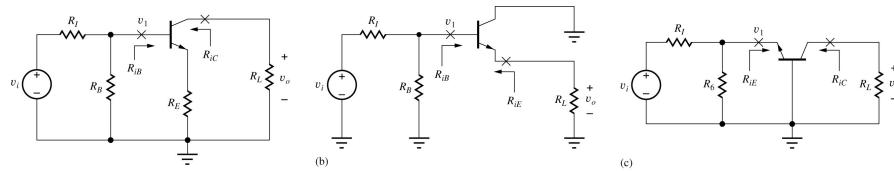
Lecture19-Review of Single Transistor Amplifiers

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# Single-Stage Amplifiers

## Simplified Characteristics of BJT Amplifiers

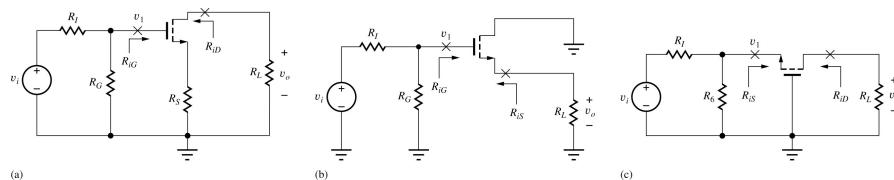


	COMMON-EMITTER ( $R_E = 0$ )	COMMON-EMITTER WITH EMITTER RESISTOR $R_E$	COMMON- COLLECTOR	COMMON-BASE
Terminal voltage gain	$-g_m R_L \cong -10V_{CC}$	$-\frac{R_L}{R_E}$	1	$+g_m R_L \cong +10V_{CC}$
$A_{vI} = \frac{v_o}{v_I}$	(high)	(moderate)	(low)	(high)
Input terminal resistance	$r_\pi$ (moderate)	$\beta_o R_E$ (high)	$\beta_o R_L$ (high)	$1/g_m$ (low)
Output terminal resistance	$r_o$ (moderate)	$\mu_f R_E$ (high)	$1/g_m$ (low)	$\mu_f (R_L \  R_4)$ (high)
Current gain	$-\beta_o$ (moderate)	$-\beta_o$ (moderate)	$\beta_o + 1$ (moderate)	1 (low)



# Single-Stage Amplifiers

## Simplified Characteristics of FET Amplifiers



	COMMON-SOURCE ( $R_S = 0$ )	COMMON-SOURCE WITH SOURCE RESISTOR $R_S$	COMMON-DRAIN	COMMON-GATE
Terminal voltage gain	$-g_m R_L \cong -V_{DD}$	$-\frac{R_L}{R_S}$	1	$+g_m R_L \cong +V_{DD}$
$A_{vt} = \frac{v_o}{v_i}$	(moderate)	(moderate)	(low)	(moderate)
Input terminal resistance	$\infty$ (high)	$\infty$ (high)	$\infty$ (high)	$1/g_m$ (low)
Output terminal resistance	$r_o$ (moderate)	$\mu_f R_S$ (high)	$1/g_m$ (low)	$\mu_f (R_I \  R_6)$ (high)
Current gain	$\infty$ (high)	$\infty$ (high)	$\infty$ (high)	1 (low)



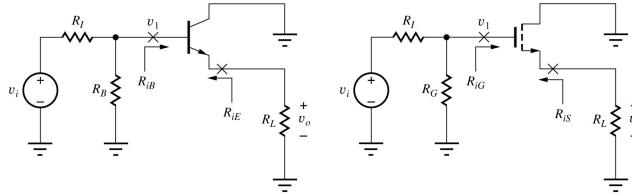
## Inverting Amplifiers: C-E and C-S Amplifier Review

**TABLE 14.3**  
Common-Emitter/Common-Source Amplifier Design Summary

	COMMON-EMITTER (C-E) AMPLIFIER	COMMON-SOURCE (C-S) AMPLIFIER
Terminal voltage gain	$A_{vt}^{CE} = \frac{v_o}{v_i} = -\frac{g_m R_L}{1 + g_m R_E}$	$A_{vt}^{CS} = \frac{v_o}{v_i} = -\frac{g_m R_L}{1 + g_m R_S}$
Signal source voltage gain	$A_v^{CE} = \frac{v_o}{v_i} = A_{vt}^{CE} \frac{R_B \  R_{iB}}{R_I + R_B \  R_{iB}}$	$A_v^{CS} = \frac{v_o}{v_i} = A_{vt}^{CS} \frac{R_G}{R_I + R_G}$
Rule-of-thumb estimate for $g_m R_L$	$10(V_{CC} + V_{EE})$	$(V_{DD} + V_{SS})$
Input terminal resistance	$R_{iB} = r_\pi(1 + g_m R_E)$	$R_{iG} = \infty$
Output terminal resistance	$R_{iC} = r_o(1 + g_m R_E)$	$R_{iD} = r_o(1 + g_m R_S)$
Amplifier input resistance	$R_{in}^{CE} = R_B \  R_{iB}$	$R_{in}^{CS} = R_G$
Amplifier output resistance	$R_{out}^{CE} = R_C \  R_{iC}$	$R_{out}^{CS} = R_D \  R_{iD}$
Input signal range	$0.005(1 + g_m R_E) \text{ V}$	$0.2(V_{GS} - V_{TN})(1 + g_m R_S)$
Terminal current gain	$\beta_o$	$\infty$



## Follower Circuits Summary

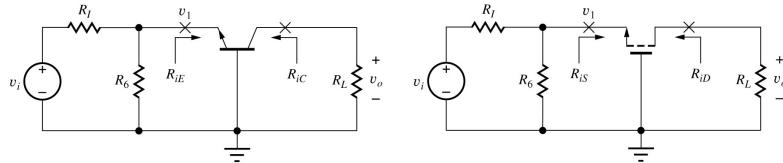


**TABLE 14.5**  
Common-Collector/Common-Drain Amplifier Design Summary

	COMMON-COLLECTOR (C-C) AMPLIFIER	COMMON-DRAIN (C-D) AMPLIFIER
Terminal voltage gain	$A_{vt}^{CC} = \frac{v_o}{v_i} = +\frac{g_m R_L}{1 + g_m R_L} \cong 1$	$A_{vt}^{CD} = \frac{v_o}{v_i} = +\frac{g_m R_L}{1 + g_m R_L} \cong 1$
Signal source voltage gain	$A_v^{CC} = \frac{v_o}{v_i} = A_{vt}^{CC} \frac{R_B \  R_{iB}}{R_I + R_B \  R_{iB}}$	$A_v^{CD} = \frac{v_o}{v_i} = A_{vt}^{CD} \frac{R_G}{R_I + R_G}$
Rule-of-thumb estimate for $g_m R_L$	$10(V_{CC} + V_{EE})$	$(V_{DD} + V_{SS})$
Input terminal resistance	$R_{iB} = r_\pi(1 + g_m R_L)$	$R_{iG} = \infty$
Output terminal resistance	$R_{iE} \cong \frac{1}{g_m} + \frac{R_{th}}{\beta_o}$	$R_{iS} = \frac{1}{g_m}$
Input signal range	$0.005(1 + g_m R_L) \text{ V}$	$0.2(V_{GS} - V_{TN})(1 + g_m R_L)$
Terminal current gain	$\beta_o + 1$	$\infty$



## C-B and C-G Amplifiers Summary

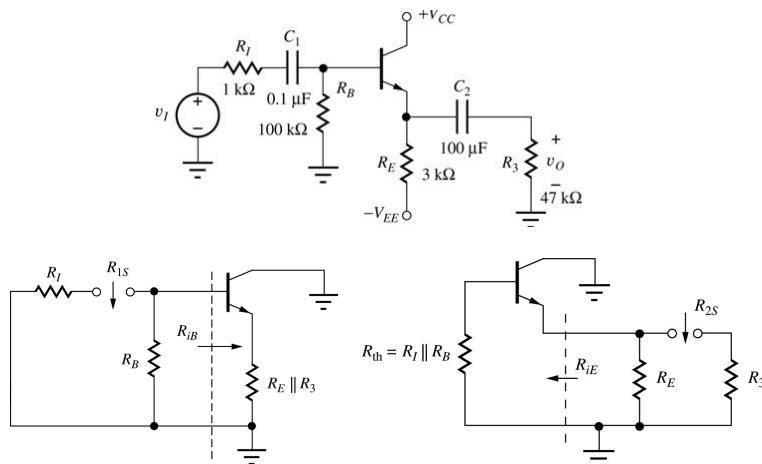


**TABLE 14.8**  
Common-Base/Common-Gate Amplifier Summary

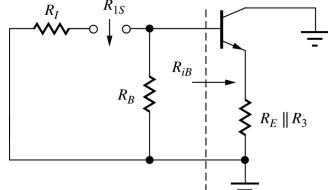
	C-B AMPLIFIER	C-G AMPLIFIER
Terminal voltage gain $A_{vt} = \frac{v_o}{v_i}$	$+g_m R_L$	$+g_m R_L$
Signal-source voltage gain $A_v = \frac{v_o}{v_i}$	$\frac{g_m R_L}{1 + g_m R_{th}} \left( \frac{R_6}{R_I + R_6} \right)$	$\frac{g_m R_L}{1 + g_m R_{th}} \left( \frac{R_6}{R_I + R_6} \right)$
Input terminal resistance	$\frac{1}{g_m}$	$\frac{1}{g_m}$
Output terminal resistance	$r_o(1 + g_m R_{th}) = r_o + \mu_f R_{th}$	$r_o(1 + g_m R_{th}) = r_o + \mu_f R_{th}$
Input signal range	$0.005(1 + g_m R_{th})$	$0.2(V_{GS} - V_{TN})(1 + g_m R_{th})$
Terminal current gain	$\alpha_o \cong +1$	$+1$



## Lower Cutoff Frequency ( $\omega_L$ ) The SCTC Estimate: C-C Amplifier



## Lower Cutoff Frequency ( $\omega_L$ ) The SCTC Estimate: C-C Amplifier (cont.)



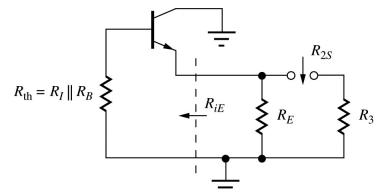
Using the SCTC method:

For  $C_1$ :

$$R_{1S} = R_I + (R_B \parallel R_{iB})$$

$$R_{1S} = R_I + R_B \left[ r_\pi + (\beta_o + 1) (R_E \parallel R_3) \right]$$

For  $C_2$ :



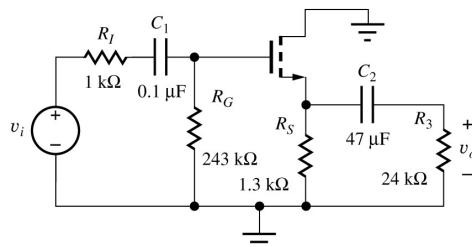
$$R_{2S} = R_3 + (R_E \parallel R_{iE}) = R_3 + R_E \frac{r_\pi + R_{th}}{\beta_o + 1}$$

$$f_L \cong \frac{1}{2\pi} \left( \frac{1}{R_{1S}C_1} + \frac{1}{R_{2S}C_2} \right)$$



## Lower Cutoff Frequency ( $\omega_L$ ) The SCTC Estimate: C-D Amplifier

Using the SCTC method:



For  $C_1$ :

$$R_{1S} = R_I + (R_G \parallel R_{iG}) = R_I + R_G$$

For  $C_2$ :

$$R_{2S} = R_3 + (R_S \parallel R_{iS}) = R_3 + \left( R_S \parallel \frac{1}{g_m} \right)$$

$$f_L \cong \frac{1}{2\pi} \left( \frac{1}{R_{1S}C_1} + \frac{1}{R_{2S}C_2} \right)$$

