Spring 2019 Purdue University

ECE 255: L19

Basic Amplifier Configurations

(Sedra and Smith, 7th Ed., Sec. 7.3)

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Announcements

1) LTspice Project 2 due Wed. Feb. 27th by 5:00PM electronically. You should find your assigned your beta value in your grade book.

2) HW6 due Monday 2/25 by 5:00 PM

3) Exam 2 is Tuesday, March 5, 6:30-7:30 PM PHYS 112

Outline

1) T-model

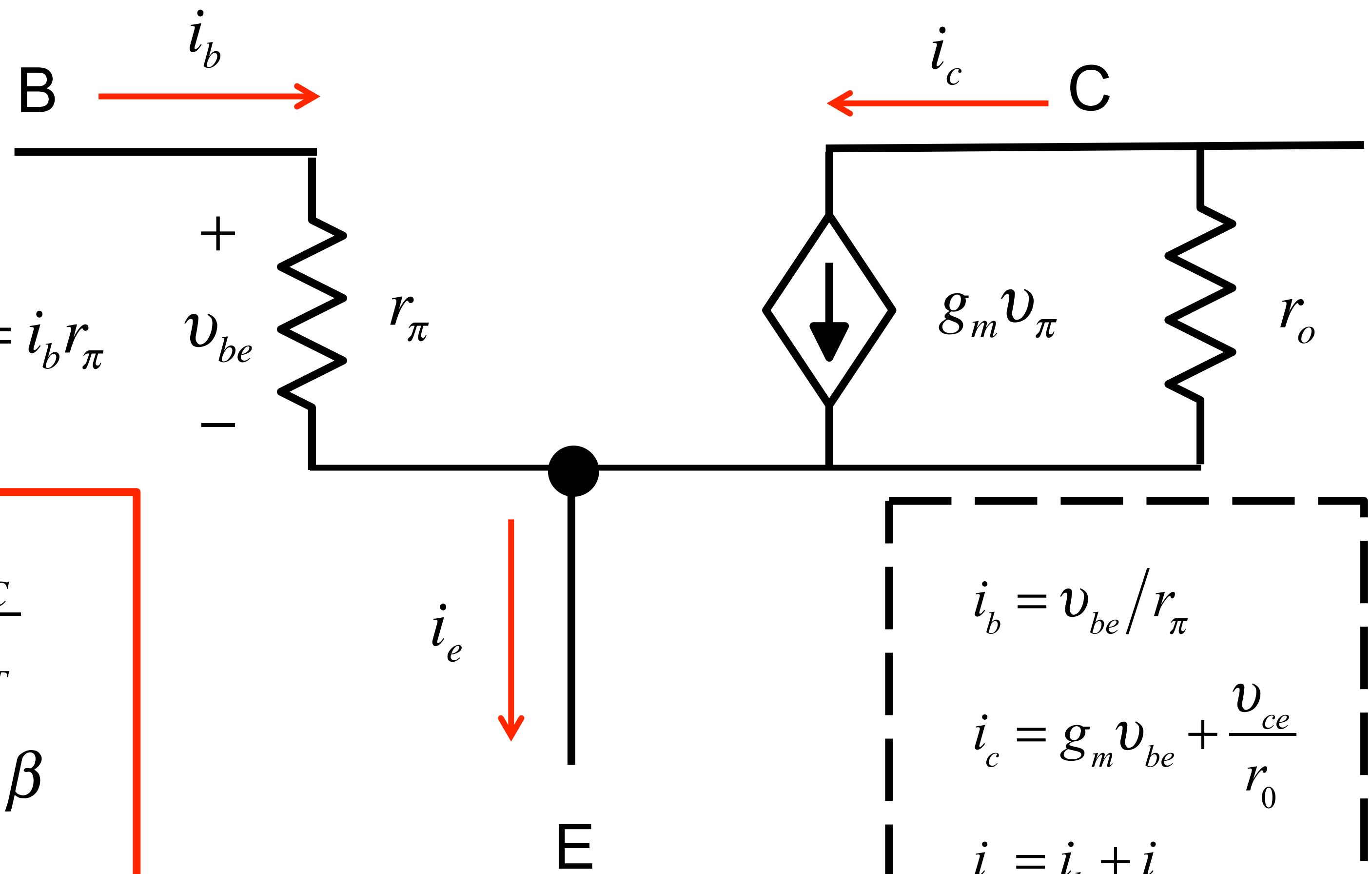
2) Basic amplifier considerations

3) CE

4) CS

Simple hybrid pi model

$$v_{be} = v_\pi = i_b r_\pi$$



$$g_m = \frac{I_C}{V_T}$$

$$g_m r_\pi = \beta$$

$$r_o = V_A / I_C$$

$$i_b = v_{be} / r_\pi$$

$$i_c = g_m v_{be} + \frac{v_{ce}}{r_0}$$

$$i_e = i_b + i_c$$

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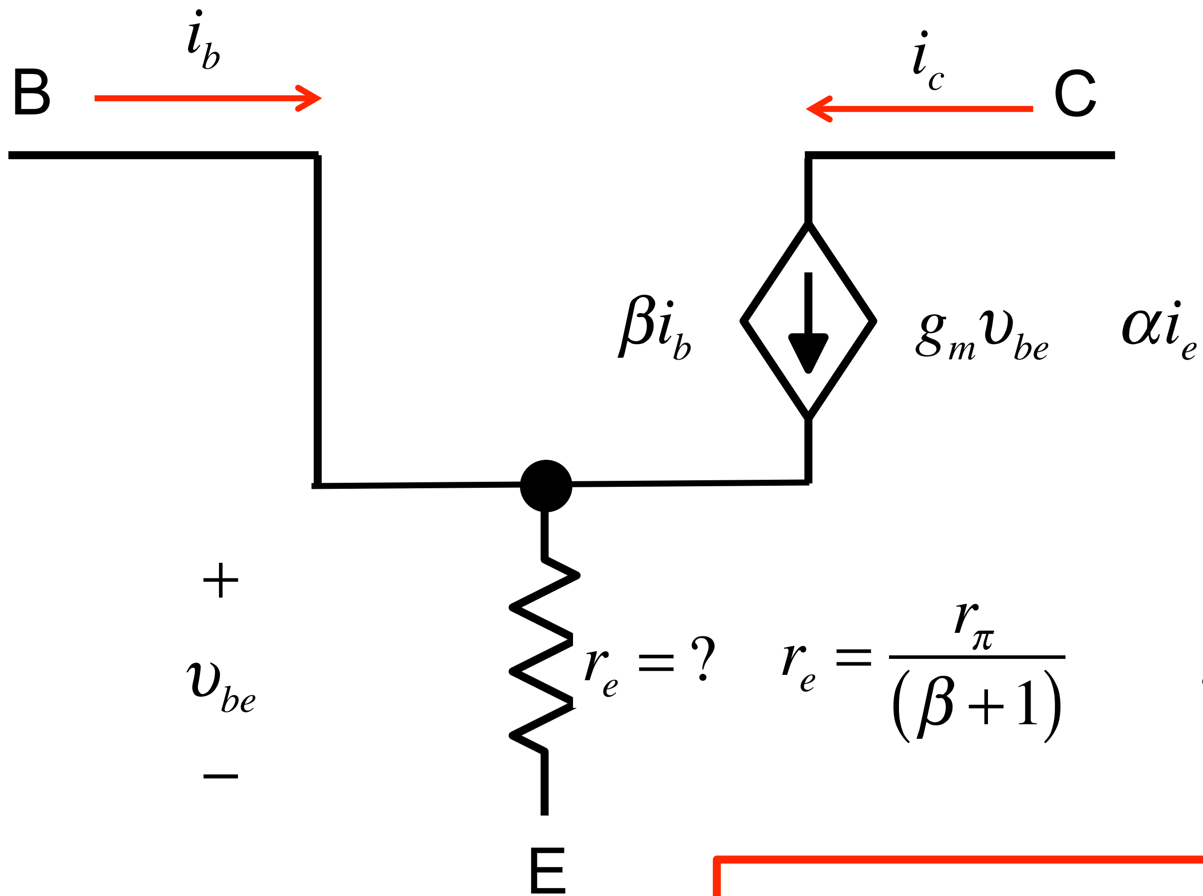
T-model...



$$r_e = \frac{r_\pi}{(\beta + 1)}$$

$$g_m r_\pi = \beta$$

$$\upsilon_{be} = i_b r_\pi = (i_b + \beta i_b) r_e = i_b (\beta + 1) r_e$$

$$r_e = \frac{\alpha}{g_m} \approx \frac{1}{g_m} << r_\pi$$

The "T model" vs. hybrid -pi

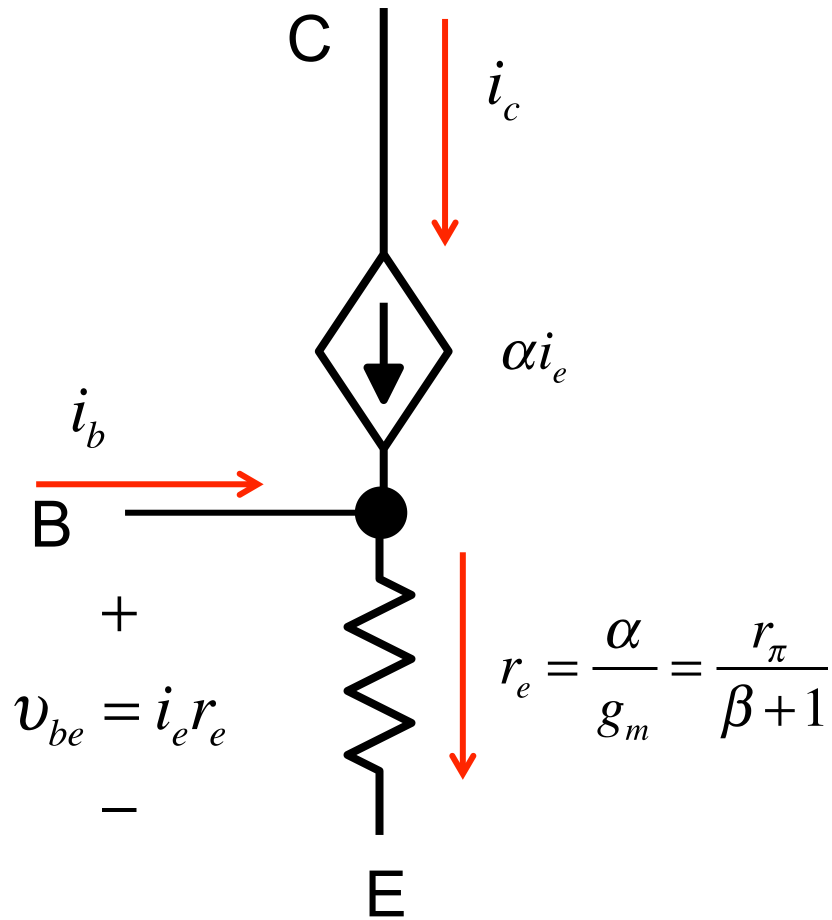
$$i_b = \upsilon_{be}/r_\pi$$

$$i_c = g_m \upsilon_{be}$$

$$i_e = i_b + i_c$$

$$(\beta+1)i_b = \upsilon_{be}(\beta+1)/r_\pi$$

$$i_c = g_m i_e r_e = \alpha i_e$$



The “T model” vs. hybrid -pi

$$I_C = 1.0 \text{ mA}$$

$$\beta = 100$$

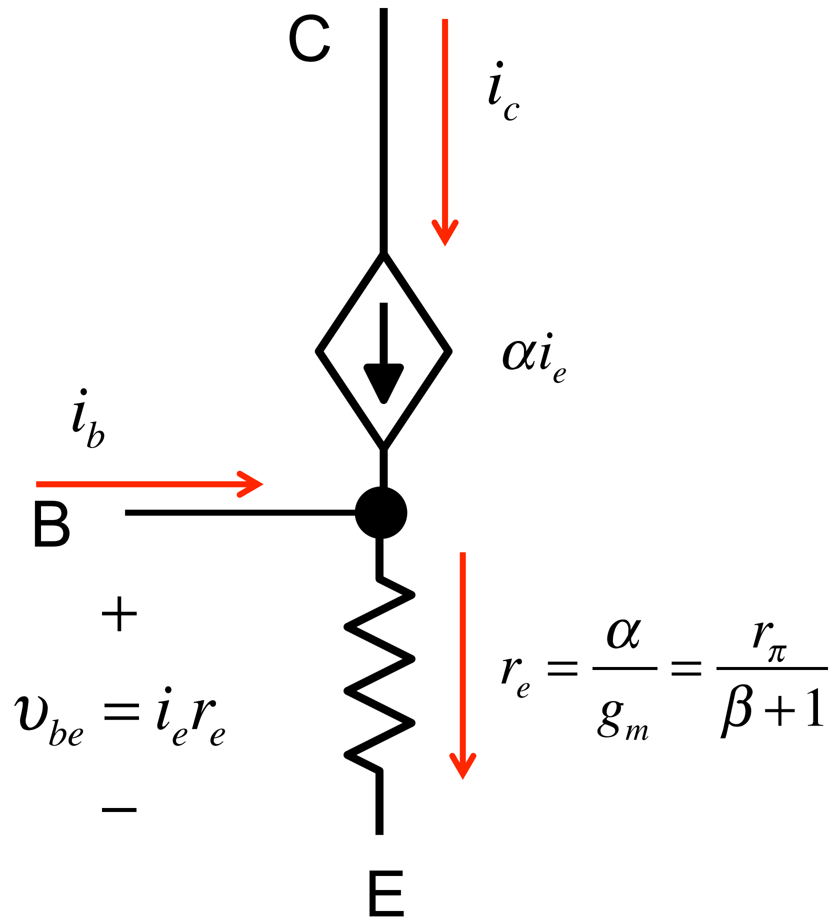
$$g_m = \frac{I_C}{V_T} = 39 \text{ mS}$$

$$g_m r_\pi = \beta$$

$$r_\pi = \frac{\beta}{g_m} = 2.6 \text{ k}\Omega$$

$$\alpha = \frac{\beta}{\beta+1} = 0.99$$

$$r_e = \frac{\alpha}{g_m} = \frac{0.99}{39\times 10^{-3}} = 25\ \Omega$$



Outline

1) T-model

2) Basic amplifier considerations

3) CE

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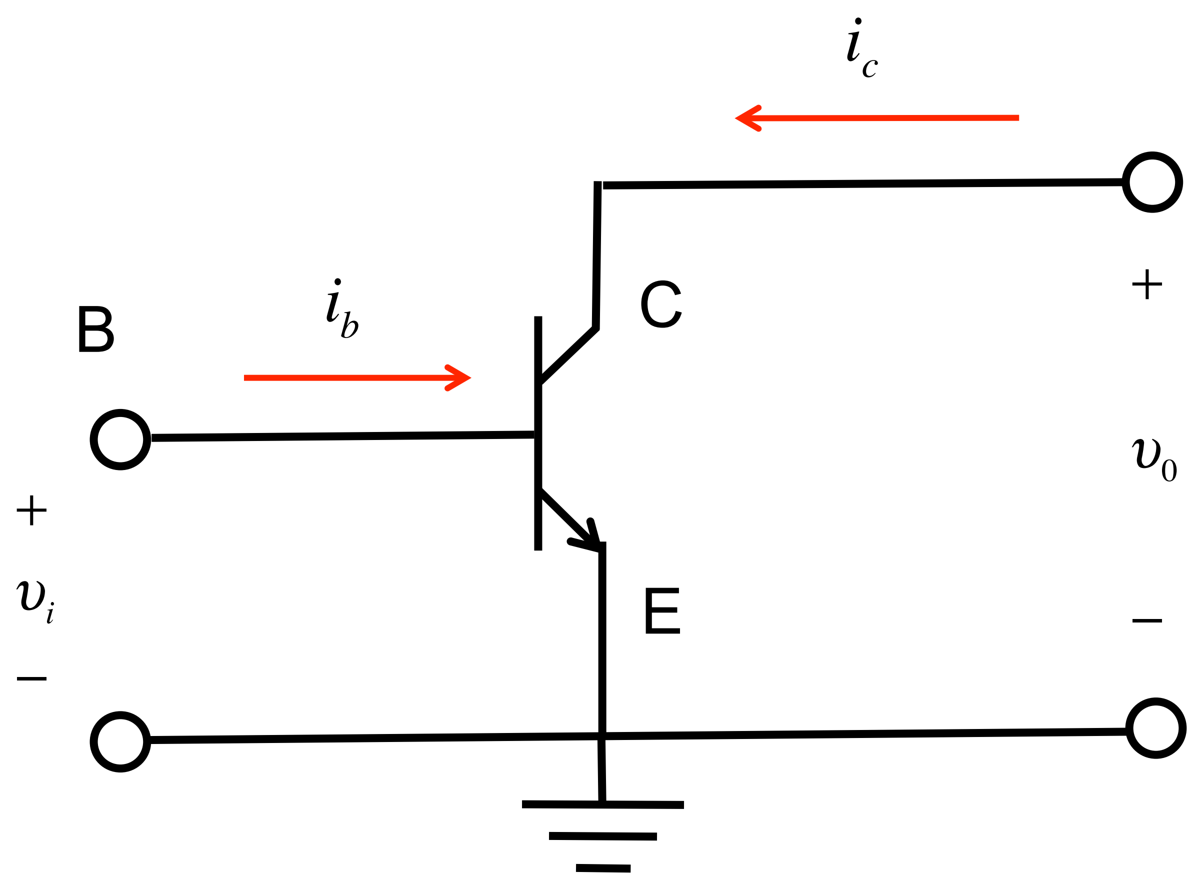
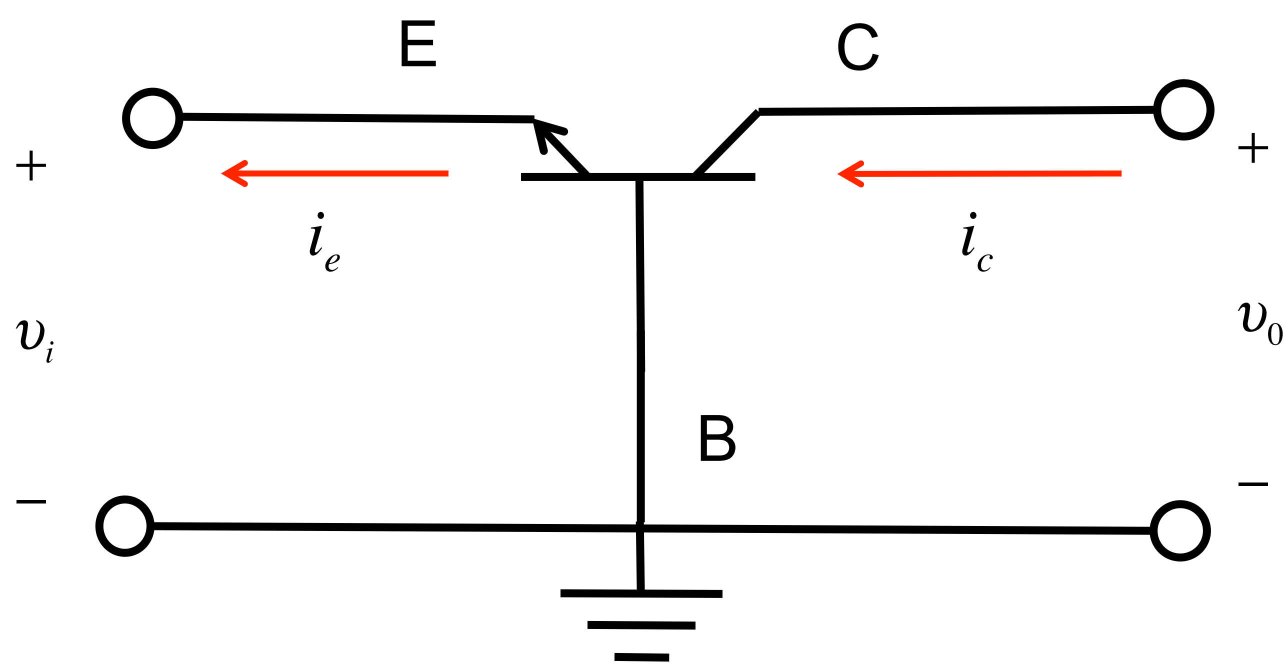
Generic Amplifier (2-port)

Transistors have 3 terminals, so one must be **common** between the input and output.

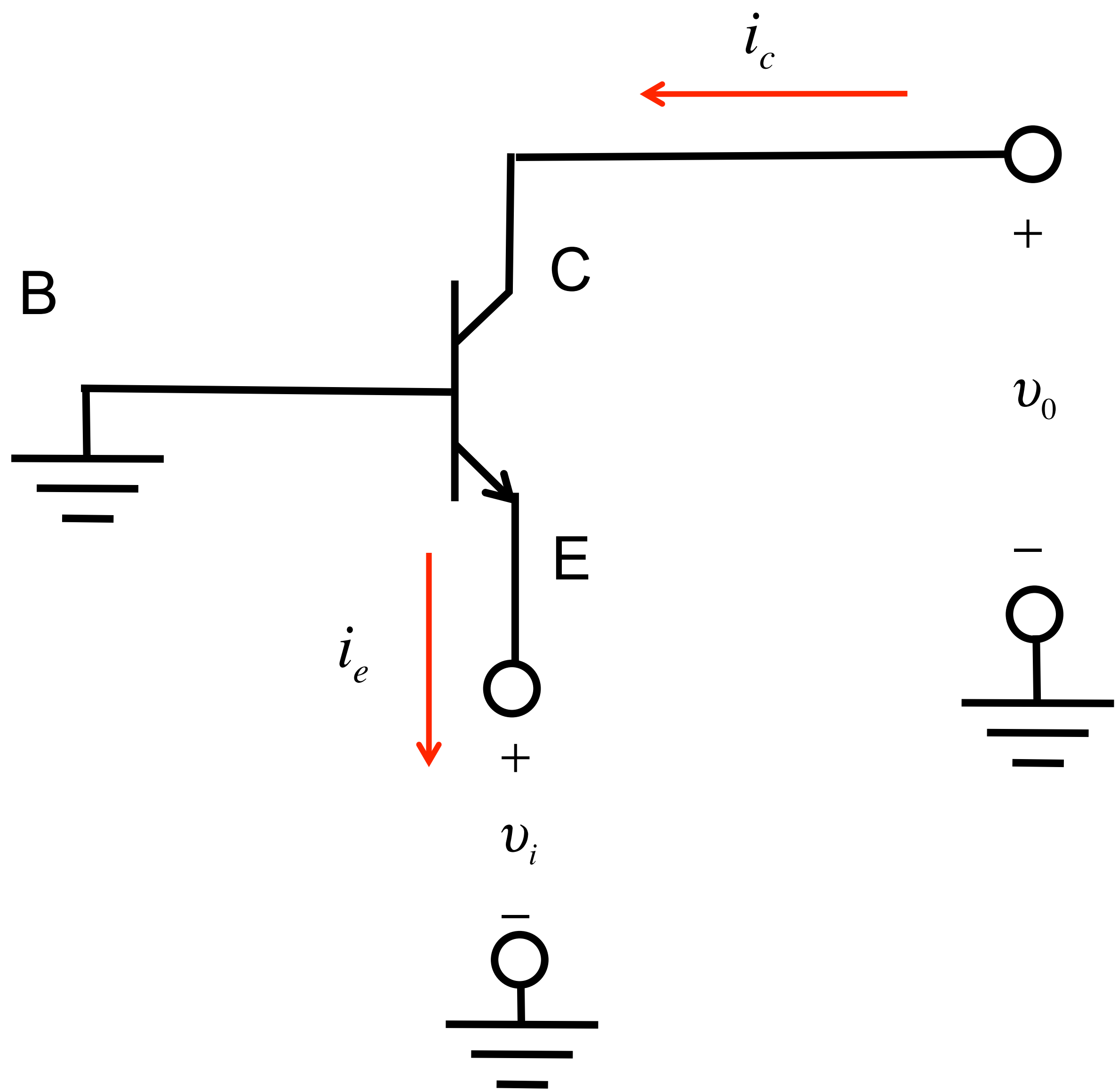
Common emitter



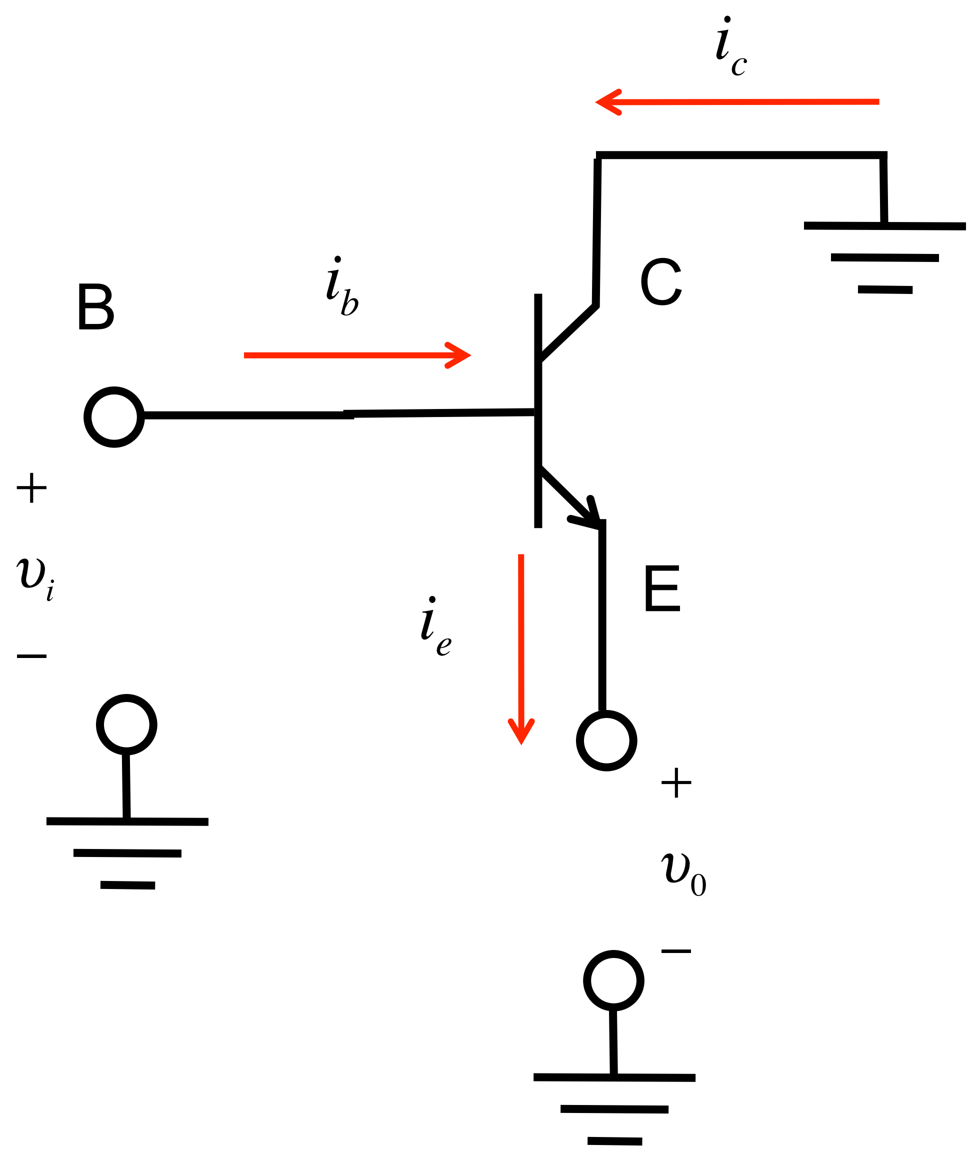
Common base



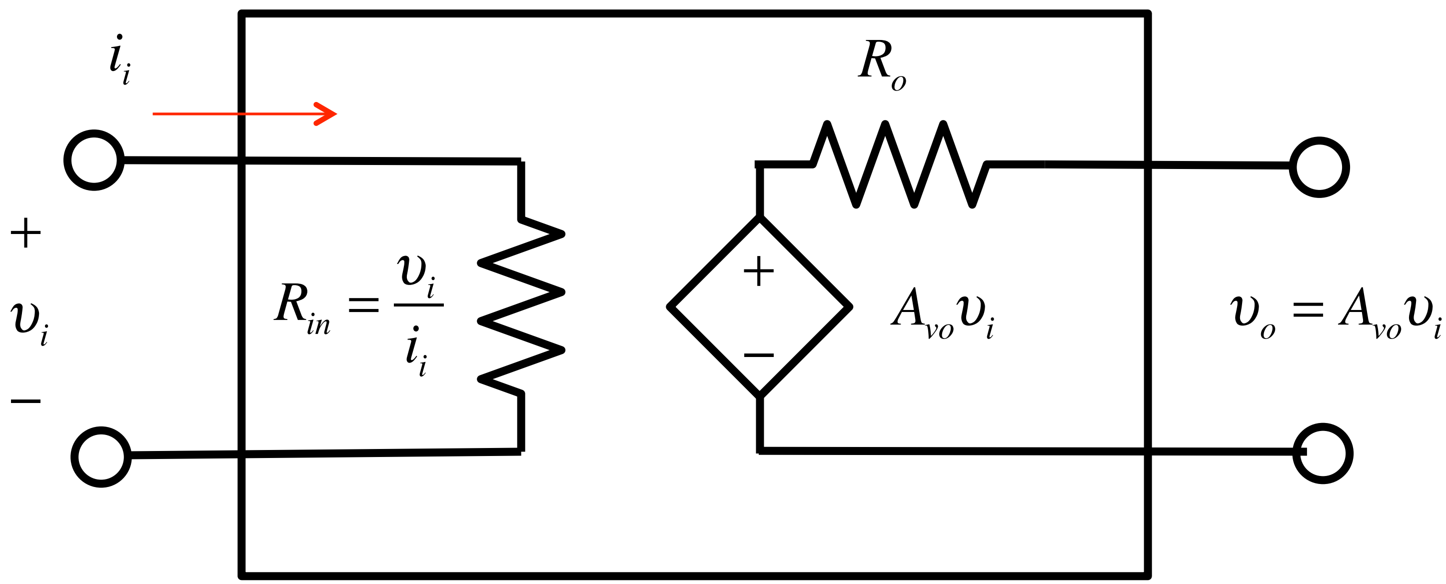
Also common base



Common collector



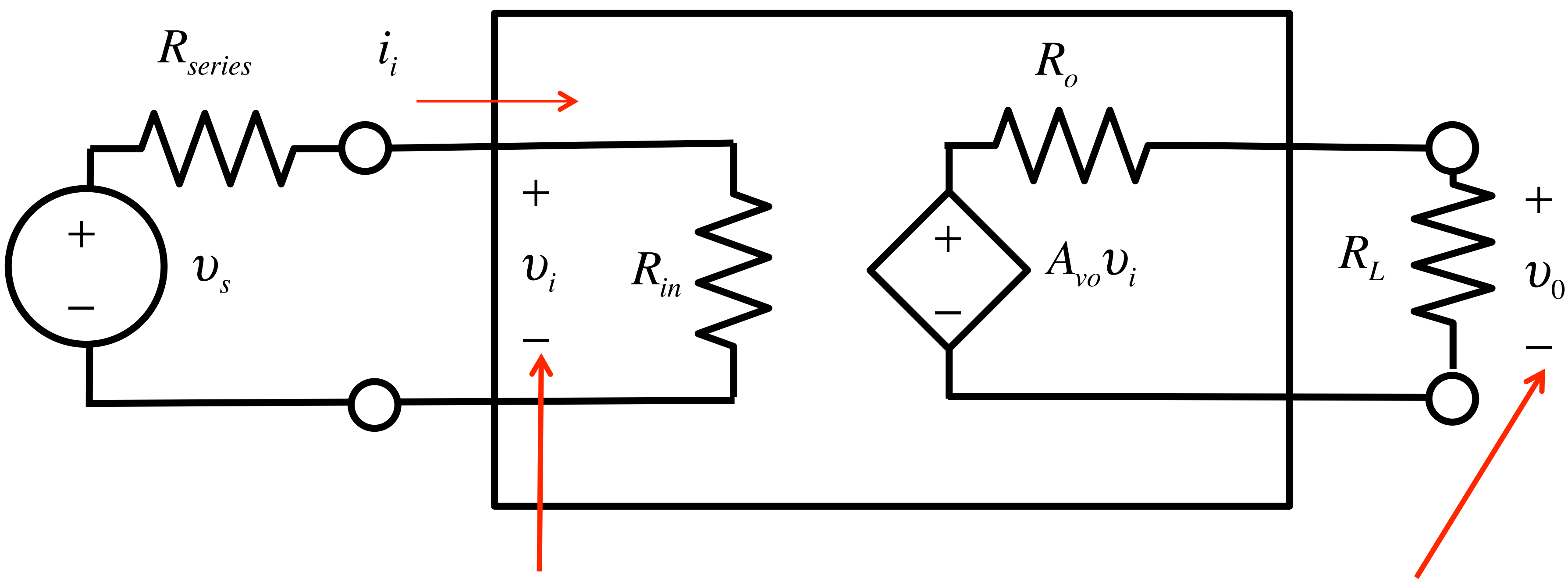
Amplifier model



Open circuit voltage gain $A_{vo} = \left.\frac{\upsilon_o}{\upsilon_i}\right|_{R_L=\infty}$

Amplifier with source and load

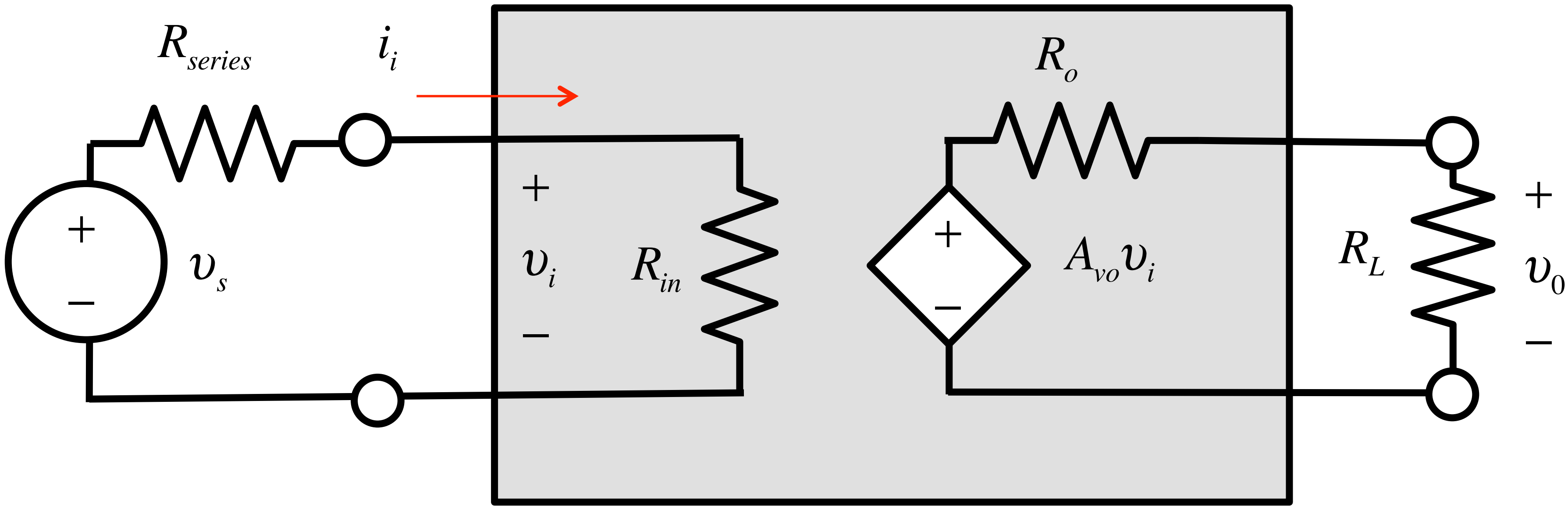
$$G_v = \frac{\upsilon_o}{\upsilon_s} = \frac{R_{in}}{R_{in} + R_s} \times A_{vo} \times \frac{R_L}{R_L + R_o}$$



$$\upsilon_i = \upsilon_s \frac{R_{in}}{R_{in} + R_s}$$

$$\upsilon_o = A_{vo}\upsilon_i \frac{R_L}{R_L + R_0}$$

Amplifier with source and load



$$G_i = \frac{i_o}{i_i} = \frac{\upsilon_o / R_L}{\upsilon_i / R_{in}} = A_{vo} \frac{R_{in}}{R_L}$$

$$G_p = \frac{p_o}{p_i} = \frac{\upsilon_o i_o}{\upsilon_s i_i} = G_v G_i$$

Outline

1) T-model

2) Basic amplifier considerations

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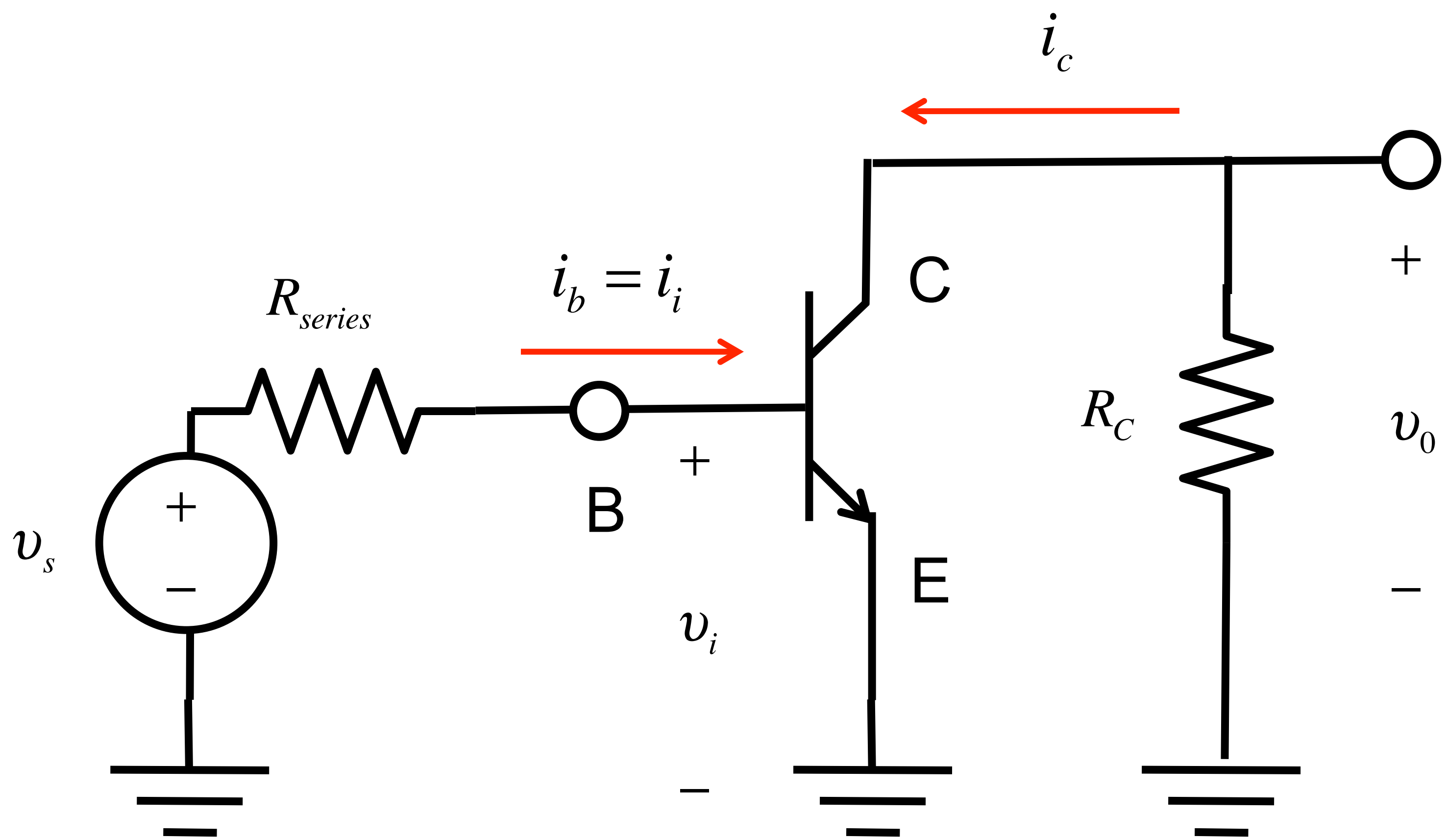
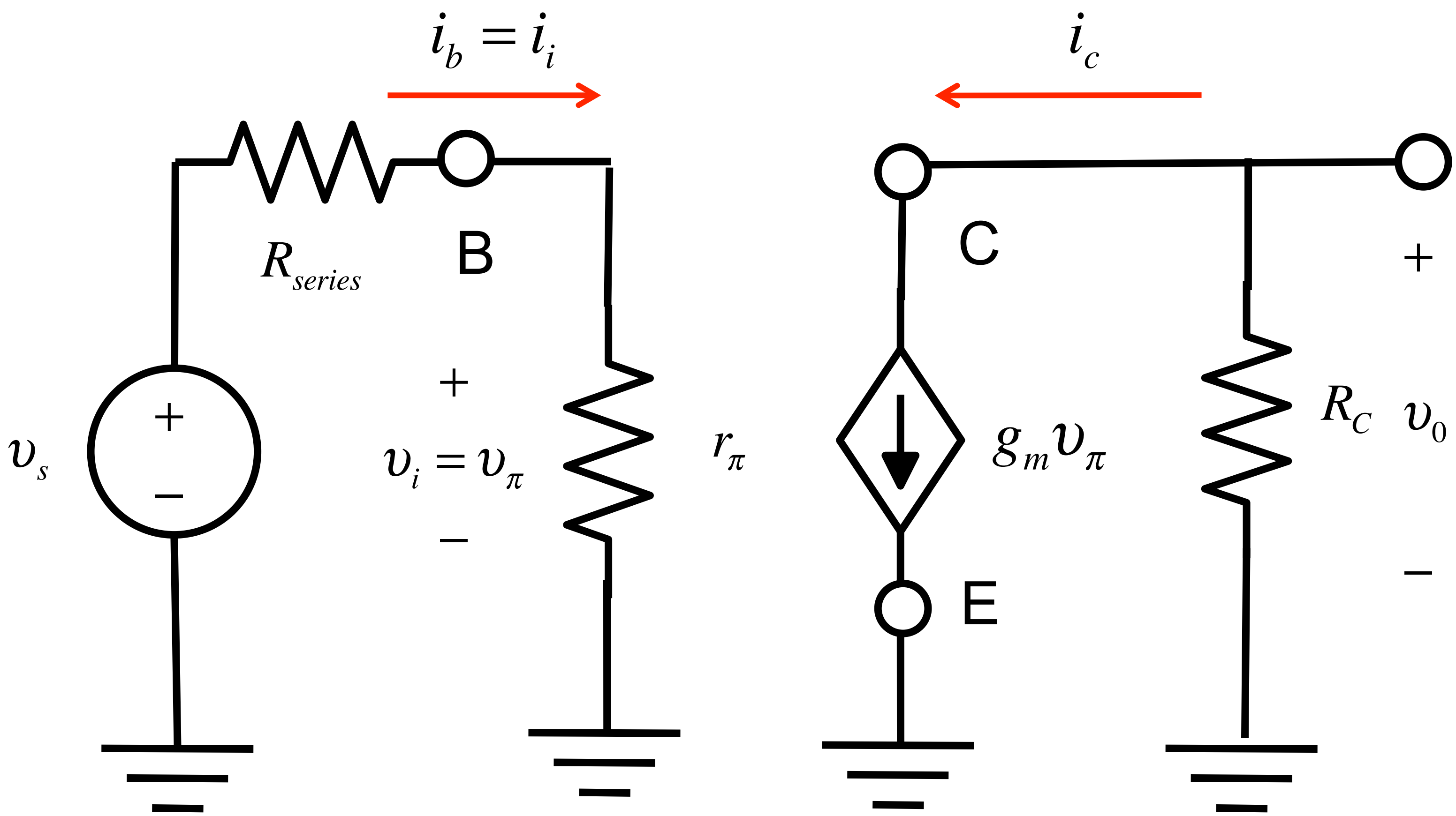
Common emitter



Draw the common emitter s.s. equiv. ckt.

Common emitter s.s. equiv. ckt.



Common emitter analysis

$$A_{v_o} = \frac{v_o}{v_i}$$

$$R_{in} = \frac{v_i}{i_i}$$

$$R_o = \frac{v_o}{i_o}$$

Common emitter analysis

$$\upsilon_o = -g_m \upsilon_\pi R_C = -g_m \upsilon_i R_C$$

$$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = -g_m R_C$$

open circuit voltage gain

$$R_{in} = r_\pi$$

Effect of r_0?

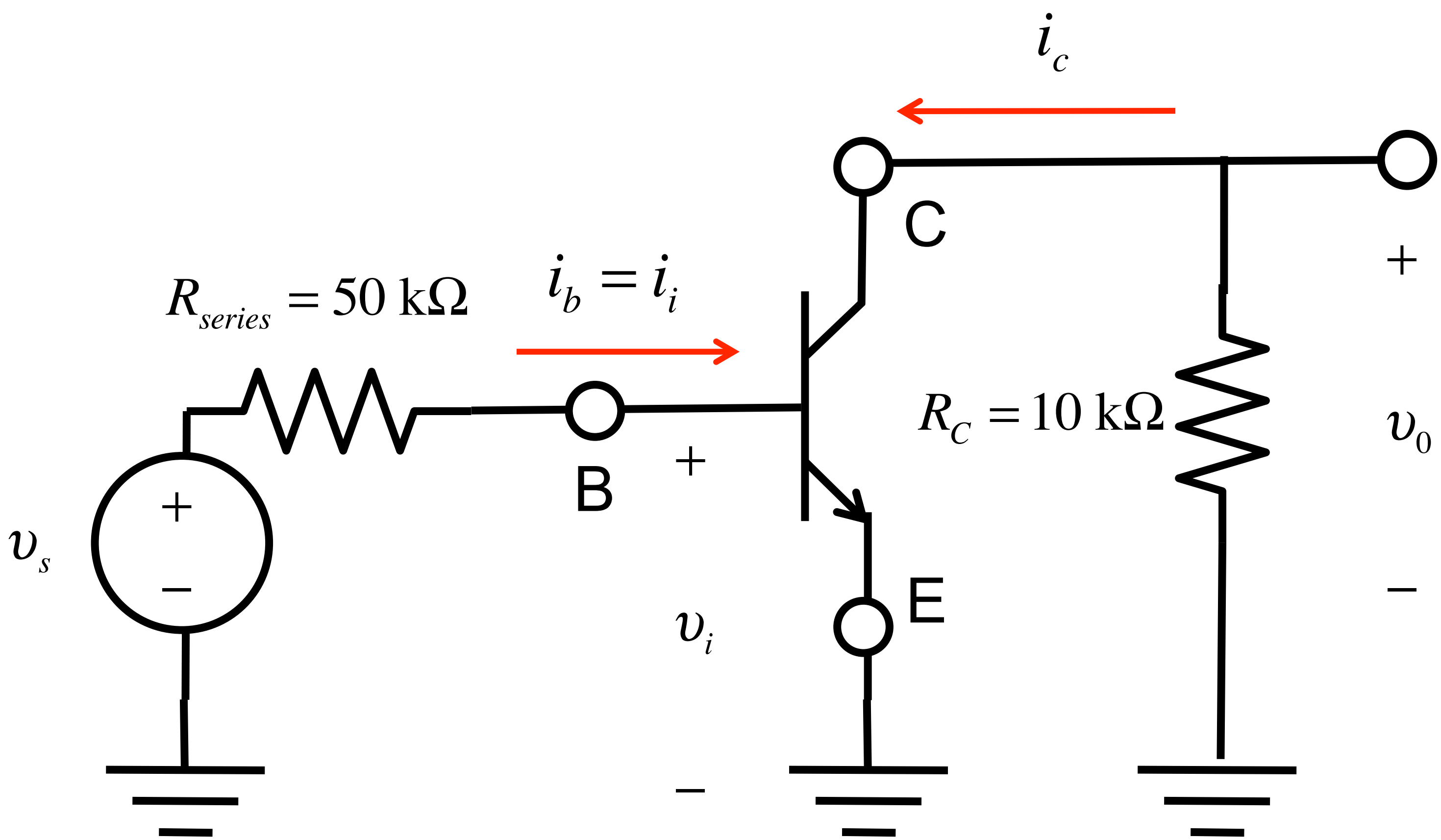
$$R_o = R_C$$

$$A_\upsilon = -g_m \left(R_C \parallel R_L \right)$$

with load attached

$$G_\upsilon = \frac{\upsilon_o}{\upsilon_s} = \frac{\upsilon_i}{\upsilon_s} \frac{\upsilon_o}{\upsilon_i} = -\left(\frac{r_\pi}{r_\pi + R_S} \right) g_m \left(R_C \parallel R_L \right)$$

Common emitter



$I_C = 1\ \text{mA}$ $\beta = 100$ $kT/q = 0.026\ \text{V}$

$V_A = 100\ \text{V}$

Common emitter results

$$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = -g_m R_C$$

$$R_{in} = r_\pi$$

$$R_o = R_C$$

$$A_\upsilon = -g_m \left(R_C \parallel R_L \right)$$

$$G_\upsilon = \frac{\upsilon_o}{\upsilon_s} = -\left(\frac{r_\pi}{r_\pi + R_S} \right) g_m \left(R_C \parallel R_L \right)$$

$$\left(R_L = 5 \text{ k}\Omega \right)$$

$$I_C = 1.0 \text{ mA}$$

$$g_m = I_C / V_T = 39 \text{ mS}$$

$$g_m r_\pi = \beta$$

$$r_\pi = \beta / g_m = 2.6 \text{ k}\Omega$$

$$R_{in} = 2.6 \text{ k}\Omega$$

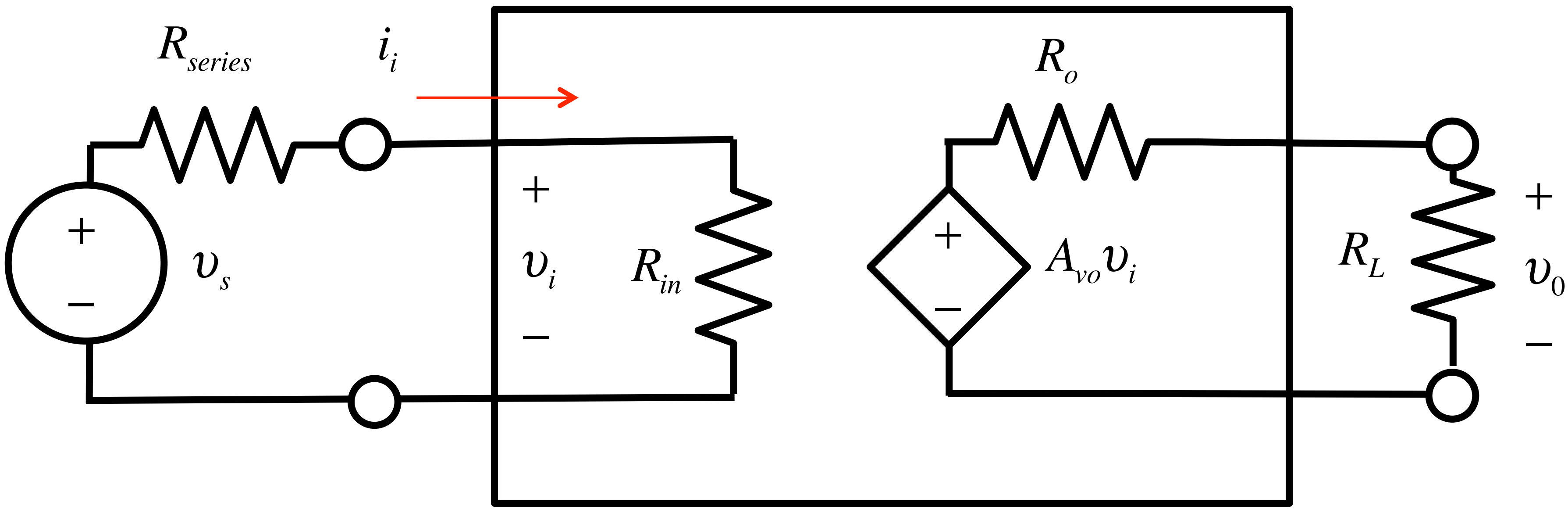
$$R_o = 10 \text{ k}\Omega$$

$$A_{\upsilon_o} = -g_m R_C = -390$$

$$G_\upsilon = -\left(\frac{2.6}{2.6 + 50} \right) 39 \left(10 \parallel 5 \right) = -6.4$$

Alternatively

$$G_v = \frac{\upsilon_o}{\upsilon_s} = \frac{R_{in}}{R_{in} + R_s} \times A_{vo} \times \frac{R_L}{R_L + R_o}$$

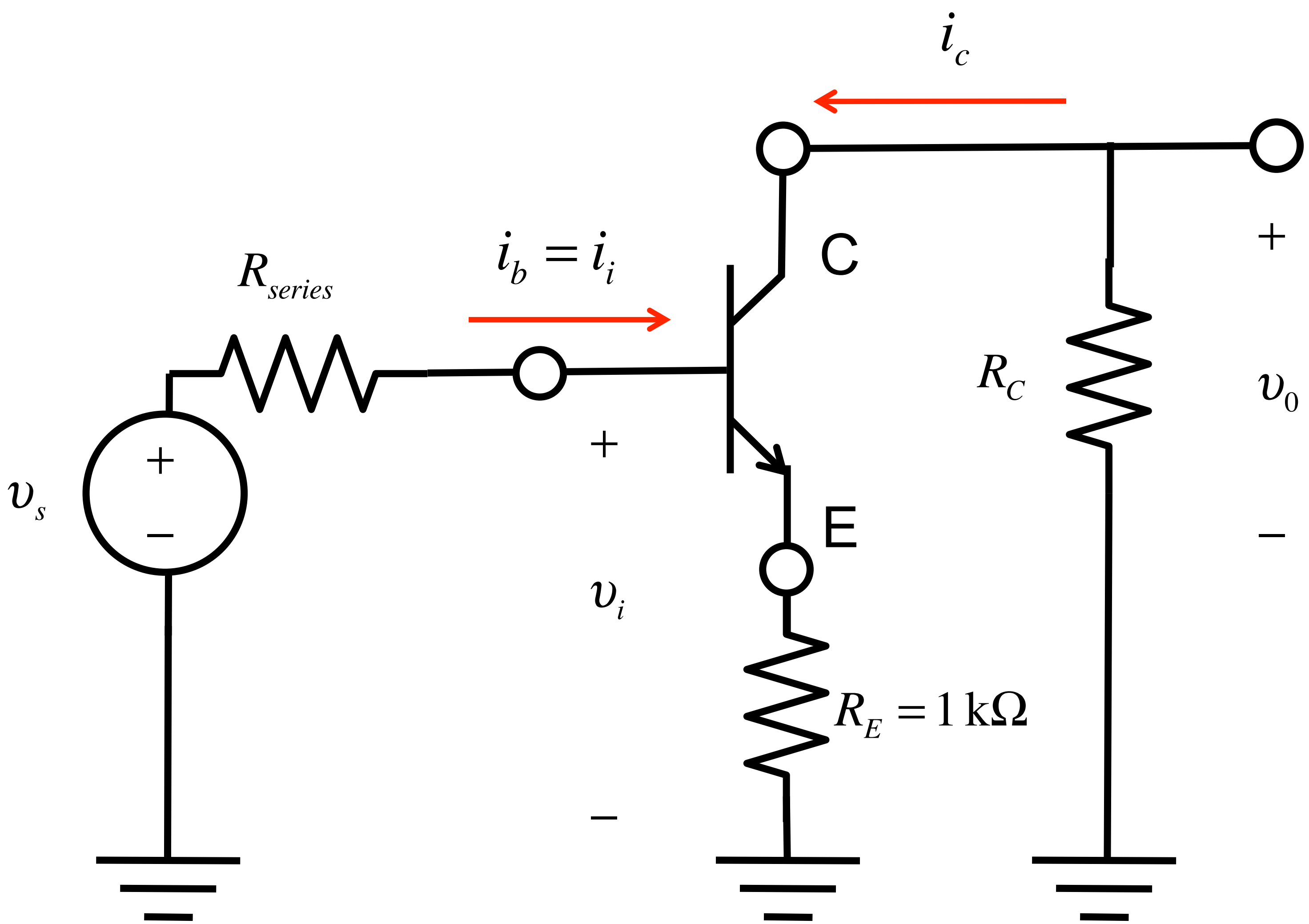


$R_{in} = r_\pi$

$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = -g_m R_C$

$R_o = R_C$

Common emitter with "emitter degeneration"



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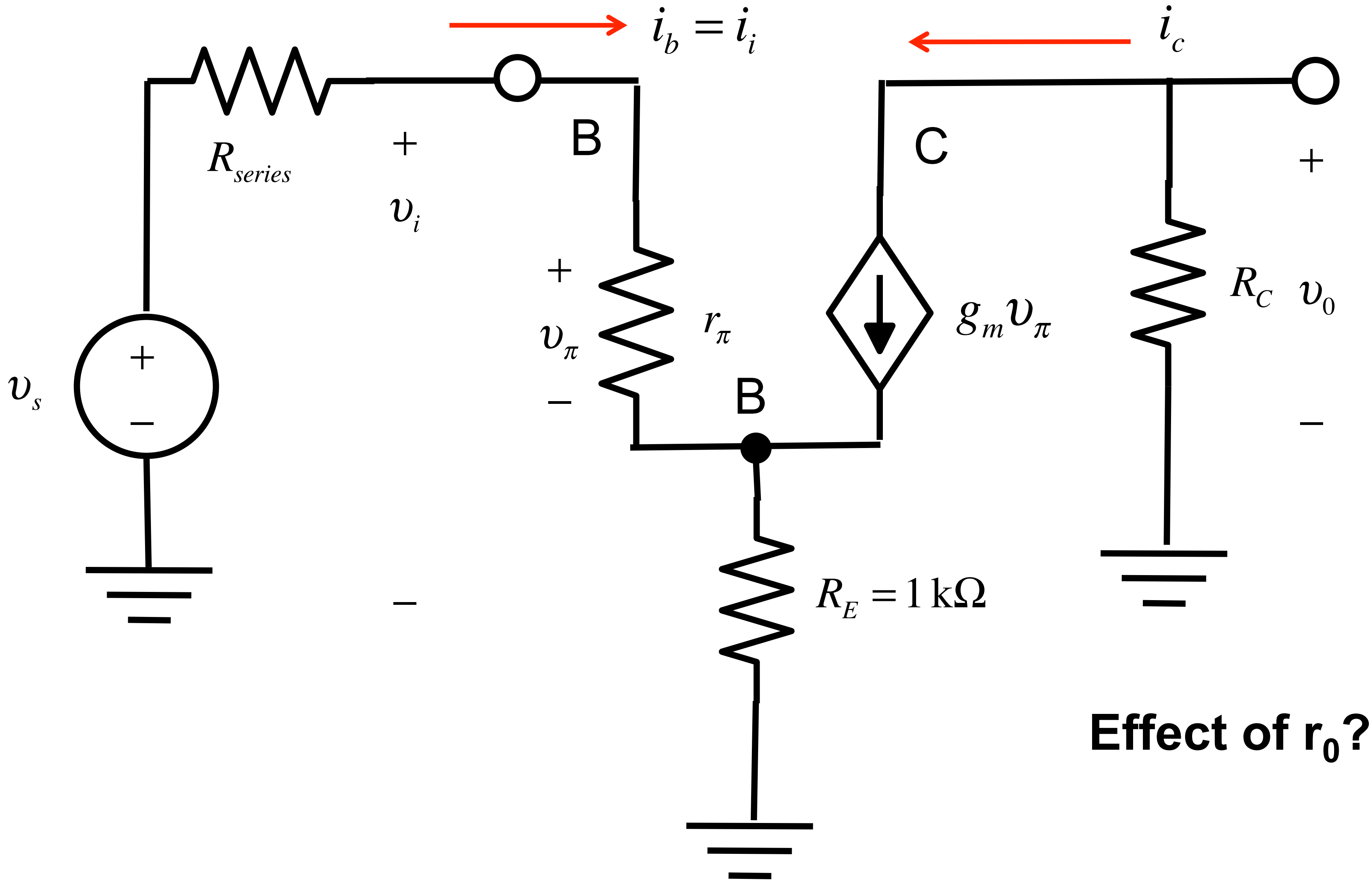
Draw the small signal equiv. ckt.

Small signal equiv. ckt.



Effect of r_0?

Analysis

$$\upsilon_o = -g_m \upsilon_\pi R_C$$

$$\upsilon_i = \upsilon_\pi + \upsilon_{R_E}$$

$$\upsilon_i = \upsilon_\pi + \left(i_b + \beta i_b\right) R_E$$

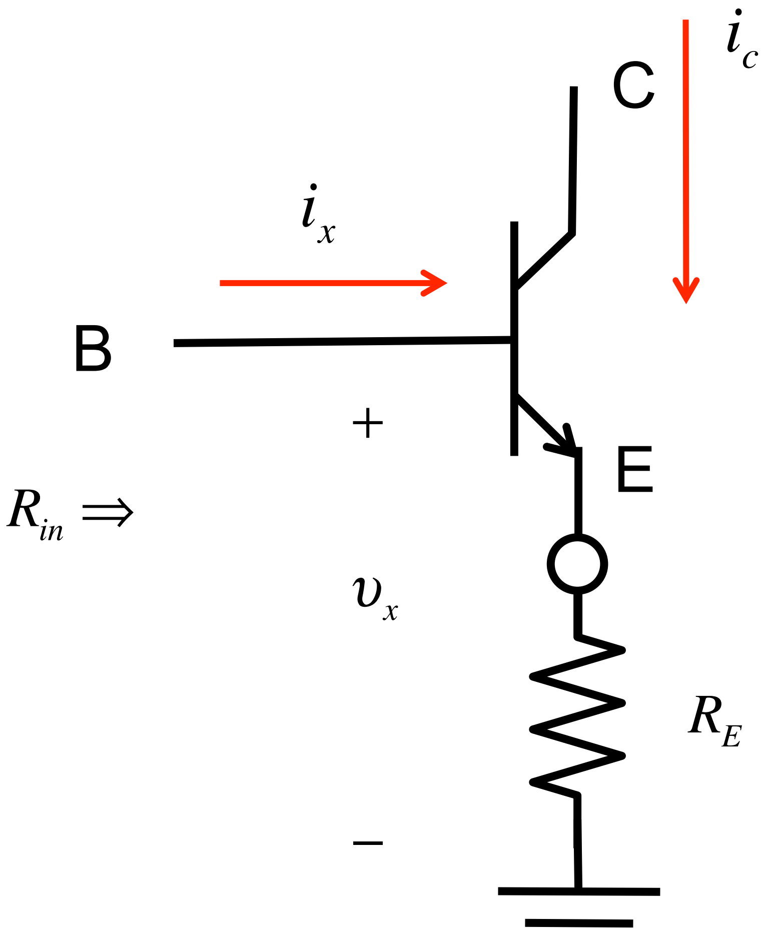
$$\upsilon_i = \upsilon_\pi + \left(\beta + 1\right) \frac{\upsilon_\pi}{r_\pi} R_E$$

$$\upsilon_i = \frac{\upsilon_\pi}{r_\pi}\left(r_\pi + \left(\beta + 1\right) R_E\right)$$

$$\upsilon_\pi = \upsilon_i \frac{r_\pi}{r_\pi + \left(\beta + 1\right) R_E}$$

Do you see how to get this "by inspection"?

“resistance reflection rule”



$$R_{in} = r_\pi + (\beta + 1) R_E$$

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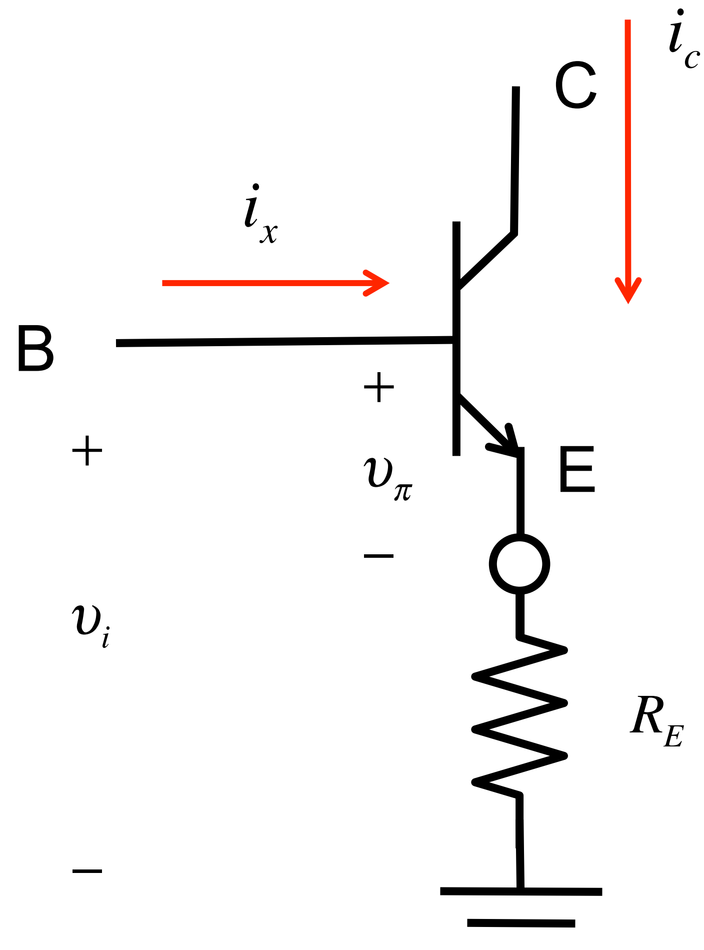
V pi in terms of input voltage



$$\upsilon_\pi = \frac{r_\pi}{r_\pi + (\beta + 1) R_E} \upsilon_i$$

Common emitter with emitter resistor

$$\upsilon_o = -g_m \upsilon_\pi R_C$$

$$\upsilon_\pi = \upsilon_i \frac{r_\pi}{r_\pi + (\beta+1)R_E}$$

$$A_{\upsilon_o} = -\frac{r_\pi}{r_\pi + (\beta+1)R_E}(g_m R_C)$$

$$R_{in} = r_\pi + (\beta+1)R_E$$

$$R_o = R_C$$

$$A_{\upsilon_o} = \frac{2.6}{2.6+(101)1}(-390) = -9.8$$

$$\left(R_E = 0: \quad A_{\upsilon_o} = -390\right)$$

$$R_{in} = 2.6 + (101)1 = 103.6 \text{ k}\Omega$$

$$\left(R_E = 0: \quad R_{in} = 2.6 \text{ k}\Omega\right)$$

$$R_o = 10 \text{ k}\Omega$$

$$\left(R_E = 0: \quad R_o = 10 \text{ k}\Omega\right)$$

"Precision amplifier"

$$A_{v_o} = \frac{r_\pi}{r_\pi + (\beta+1)R_E}(-g_m R_C)$$

$$A_{v_o} \approx -\frac{R_C}{R_E}$$

If:

$$(\beta+1)R_E >> r_\pi$$

$$A_{v_o} \approx -\frac{10}{1} = -10$$

$$A_{v_o} \approx -\frac{g_m r_\pi}{(\beta+1)R_E} R_C = \frac{\beta}{(\beta+1)}\left(-\frac{R_C}{R_E}\right)$$

CE with "emitter degeneration" summary

$$A_{v_o} = \frac{r_\pi}{r_\pi + (\beta+1)R_E}(-g_m R_C) \approx -\frac{R_C}{R_E}$$

$$R_{in} = r_\pi + (\beta+1)R_E$$

$$R_o = R_C$$

Physical reason:

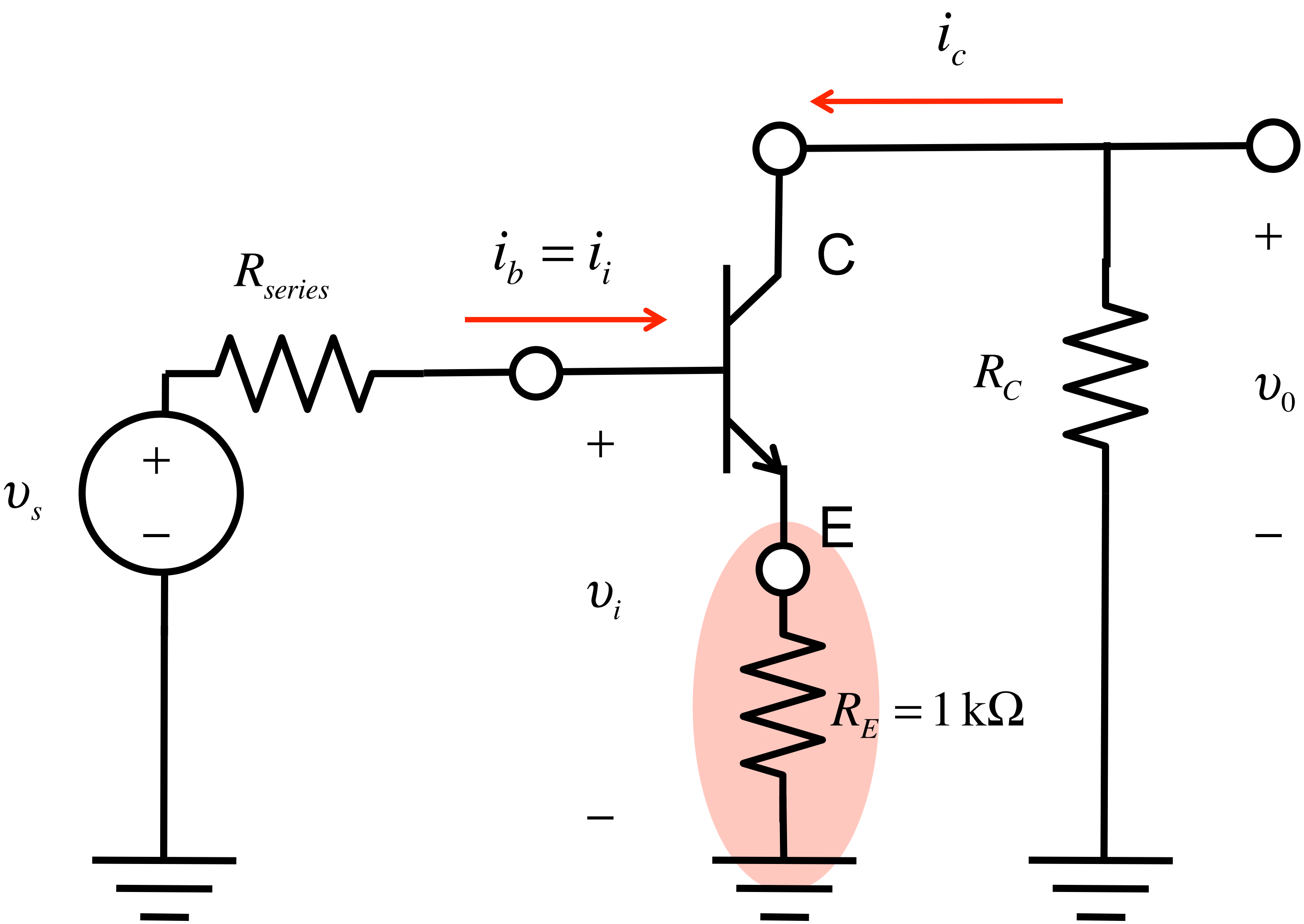
Negative feedback

Effect of R_L?

Compared to the $R_E = 0$ case:

Lower voltage gain
Higher input resistance
Same output resistance

Negative feedback



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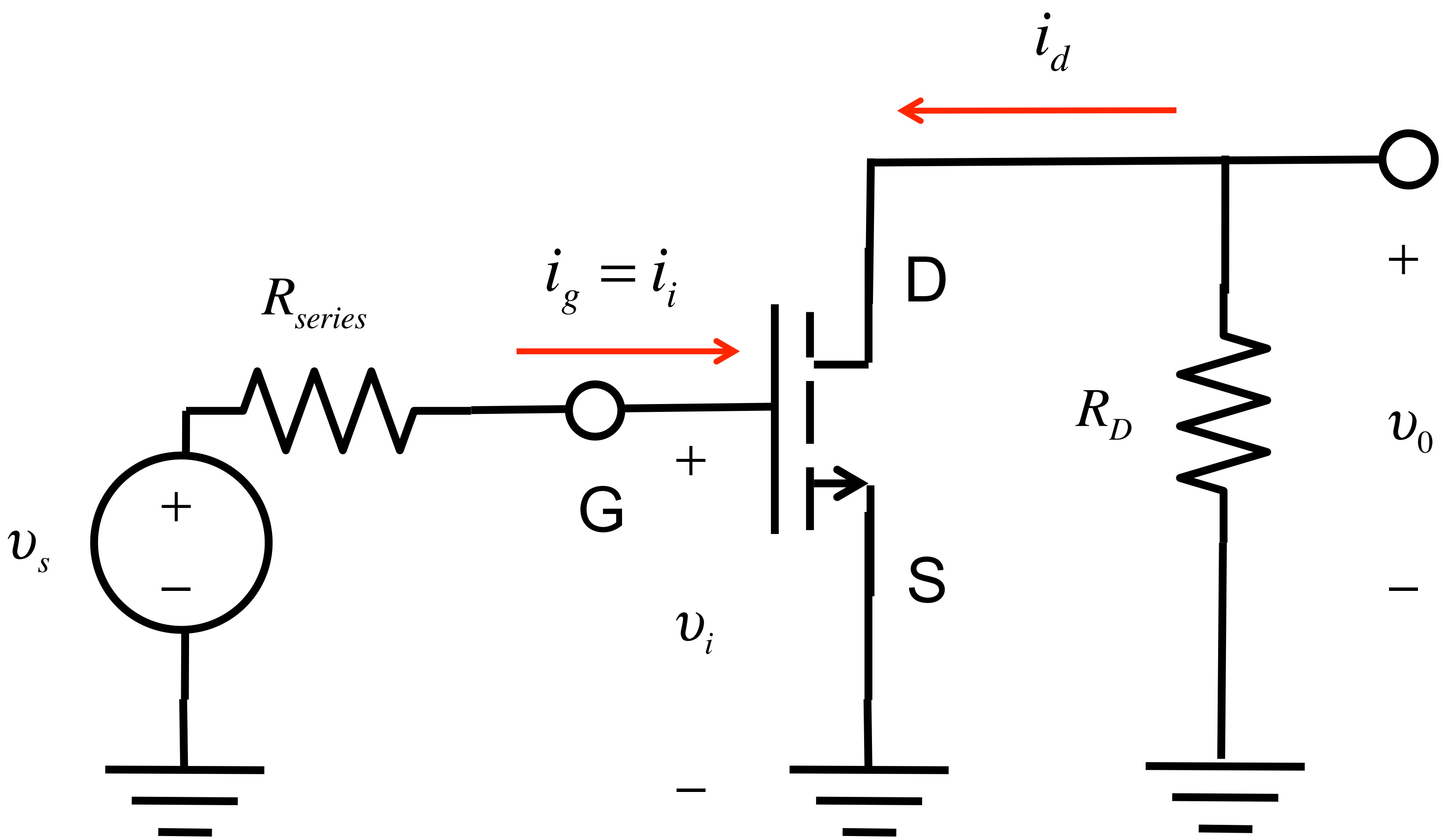
Common source



CE vs. CS

Common Emitter

$$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = -g_m R_C$$

$$R_{in} = r_\pi$$

$$R_o = R_C$$

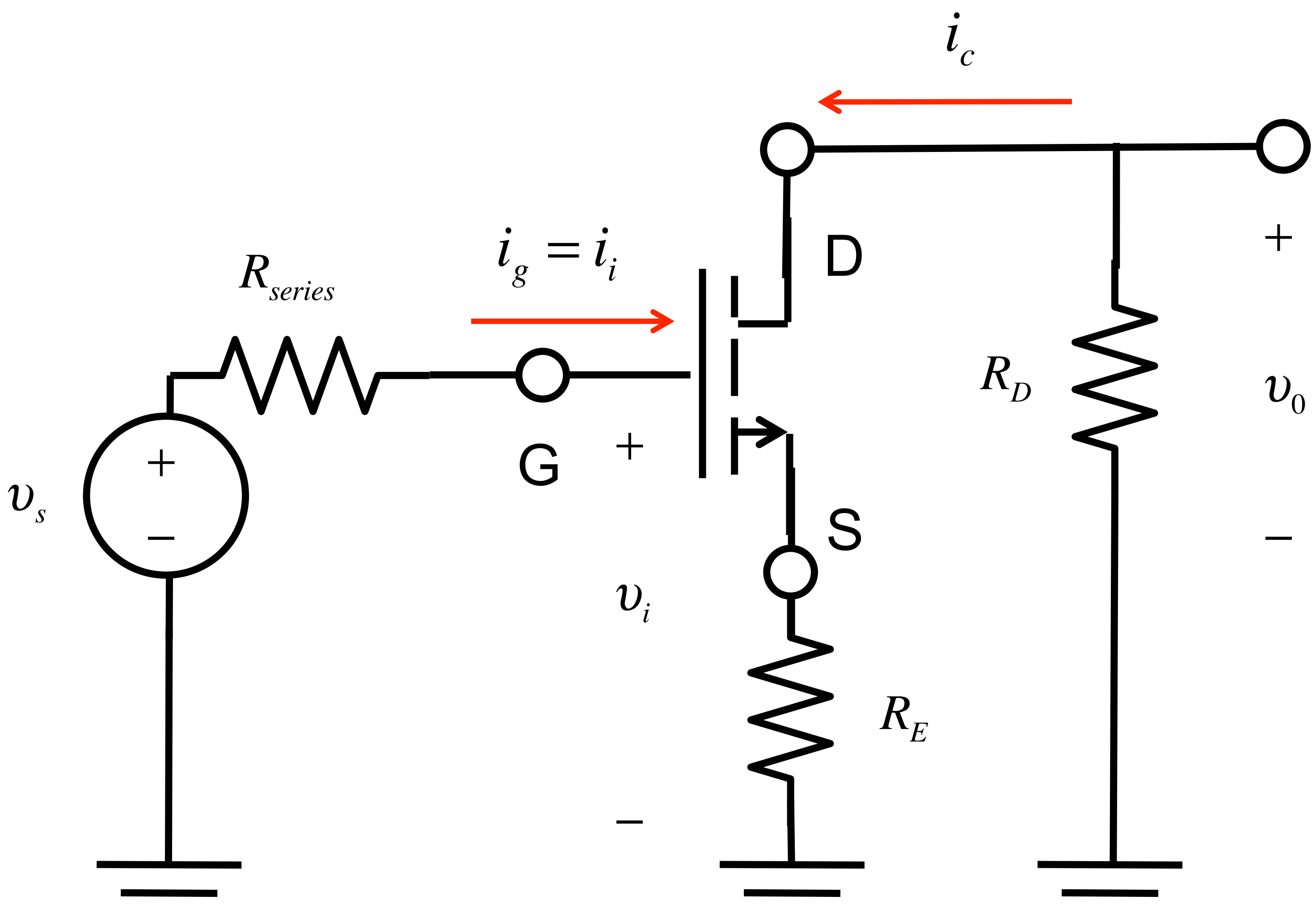
Common Source

$$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = -g_m R_D$$

$$R_{in} = \infty$$

$$R_o = R_D$$

Common source with source degeneration



CE vs. CS with emitter/source degeneration

Common Emitter

$$A_{v_o} = \frac{r_\pi}{r_\pi + (\beta + 1) R_E}(-g_m R_C)$$

$$R_{in} = r_\pi + (\beta + 1) R_E$$

$$R_o = R_C$$

Common Source

CE vs. CS with emitter/source degeneration

Common Emitter

$$A_{\upsilon_o} = \frac{r_\pi}{r_\pi + (\beta + 1) R_E} (-g_m R_C)$$

$$R_{in} = r_\pi + (\beta + 1) R_E$$

$$R_o = R_C$$

Common Source

$$A_{\upsilon_o} = \frac{1}{1 + \frac{(\beta + 1)}{r_\pi} R_S} (-g_m R_D)$$

$$g_m r_\pi = \beta$$

$$A_{\upsilon_o} = \frac{1}{1 + g_m R_S} (-g_m R_D)$$

$$R_{in} = \infty$$

$$R_o = R_D$$

Summary

Amplifiers are characterized in terms of their open-circuit voltage gain, input resistance, and output resistance.

The CE amplifier has high (negative) gain, moderate input impedance and moderate output resistance.

Emitter degeneration ($R_E > 0$) lowers the gain but increases the input impedance.

The CS amplifier has moderate (negative) gain, high input impedance and moderate output resistance.

Basic Amplifier Configurations

1) T-model

2) Basic amplifier considerations

3) CE

4) CS