Spring 2019 Purdue University

ECE 255: L20

Basic Amplifier Configurations: II

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

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Announcements

1) There is no HW due Monday, but HW7 (Practice Problems for Exam 2) will be discussed in class on Monday.

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

3) Professor Janes will hold a help session on Tuesday in ME 1061 at 1:30 PM.

4) No class on Friday, March 8

Announcements

For Exam 2, you should be prepared on: (HW5- HW7)

1) DC analysis / design of 4-resisitor bias circuit

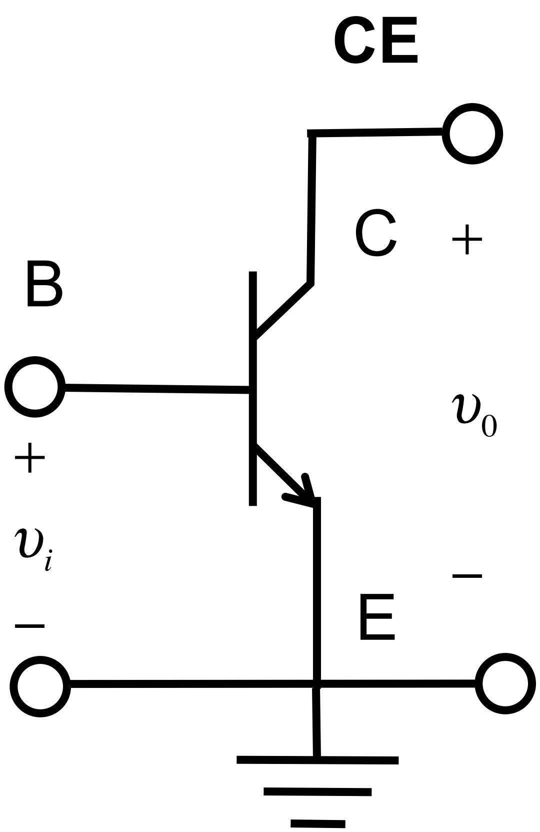
2) Small signal models

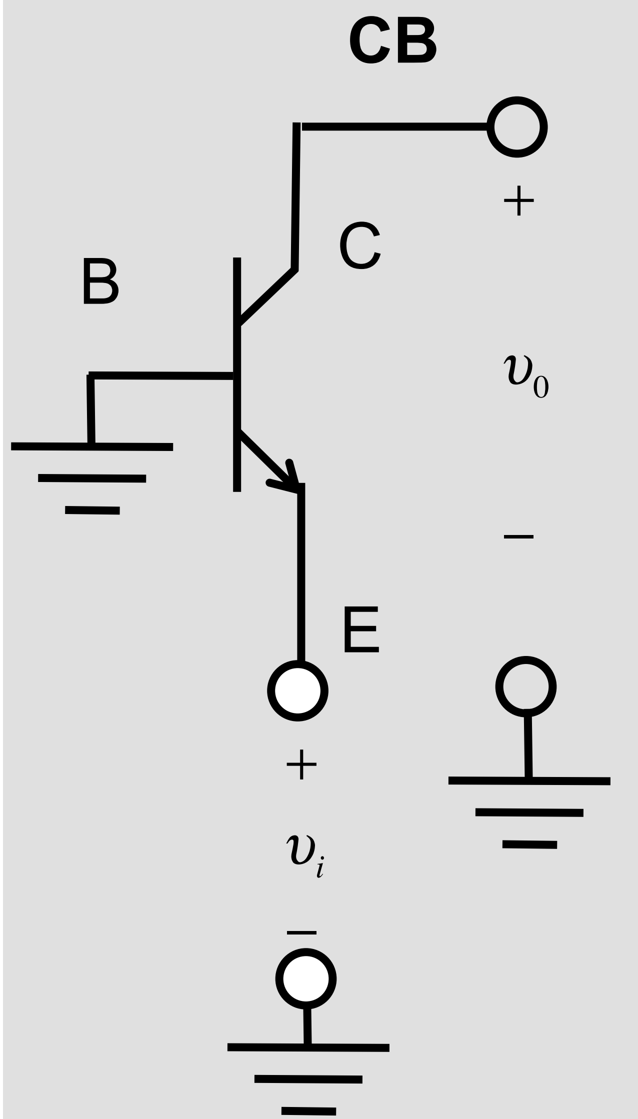
3) Reducing a circuit diagram to a s.s. equiv. circuit

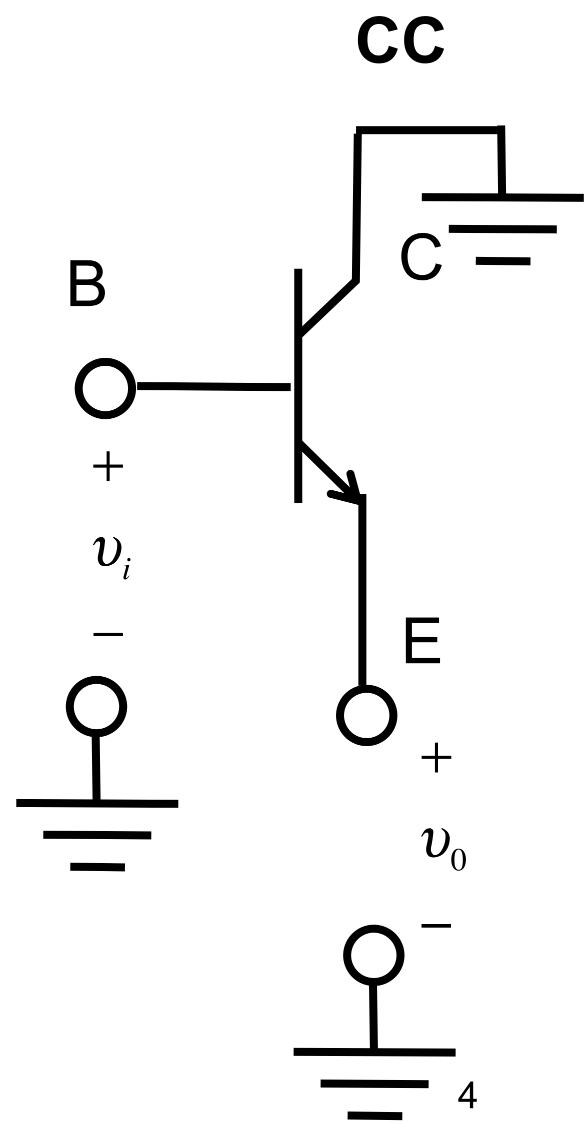
3) Amplifier configurations

4) CE and CS in detail

Three basic BJT amplifiers

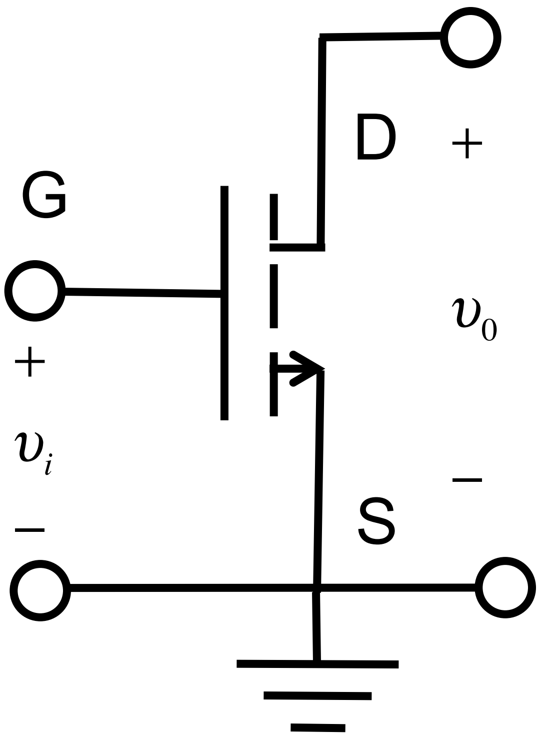




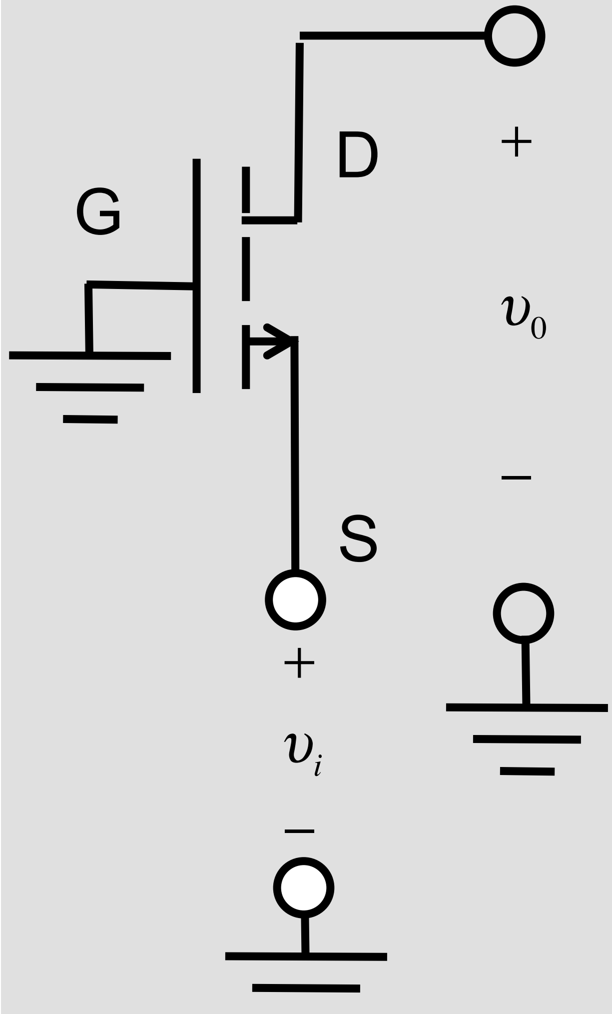


Three basic MOS amplifiers

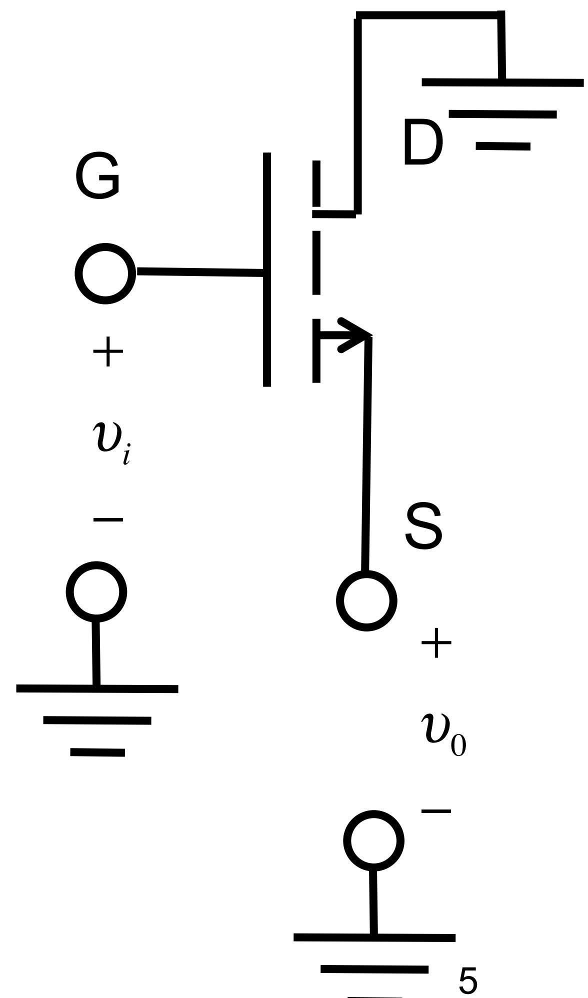
CS



CG



CD



Outline

1) Basic amplifier considerations

2) CE / CS

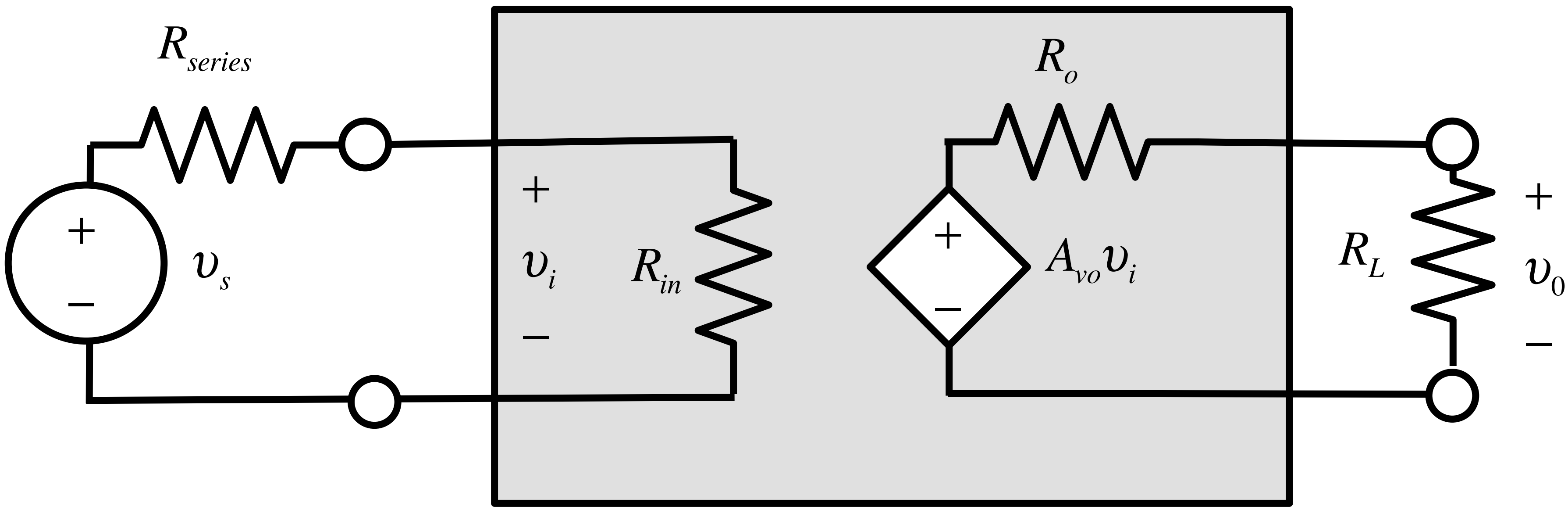
3) CB / CG

4) Common base example

5) CC (emitter follower) / CD (source follower)

Amplifier with source and load

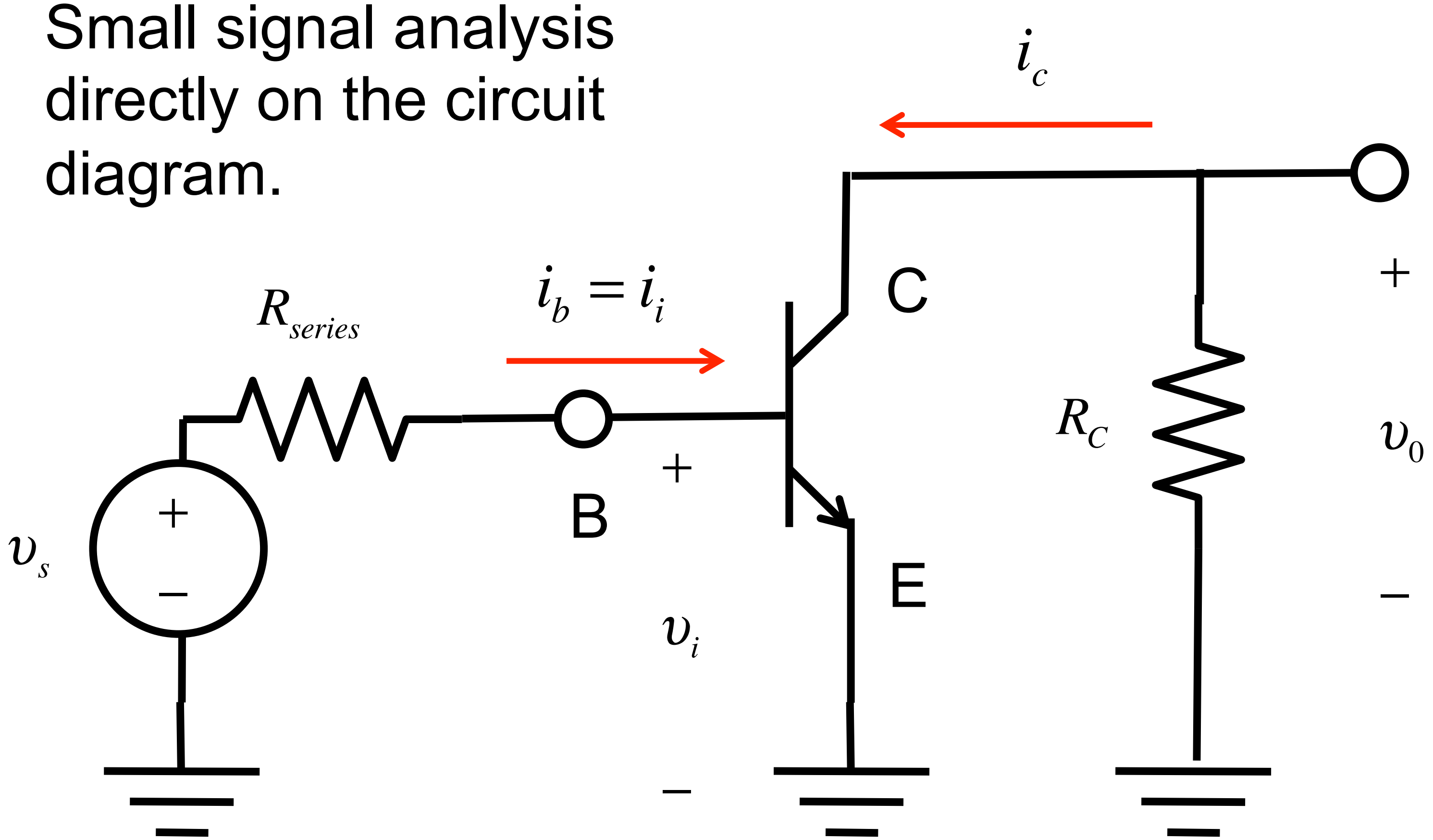
A_{vo} R_{in} R_o



$$G_v = \frac{R_{in}}{R_{in}+R_{series}} \times A_{vo} \times \frac{R_L}{R_L+R_o} \qquad G_i = A_{vo}\frac{R_{in}}{R_L} \qquad G_p = G_v G_i$$

Common emitter

Small signal analysis directly on the circuit diagram.



Common emitter results

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

open circuit voltage gain

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

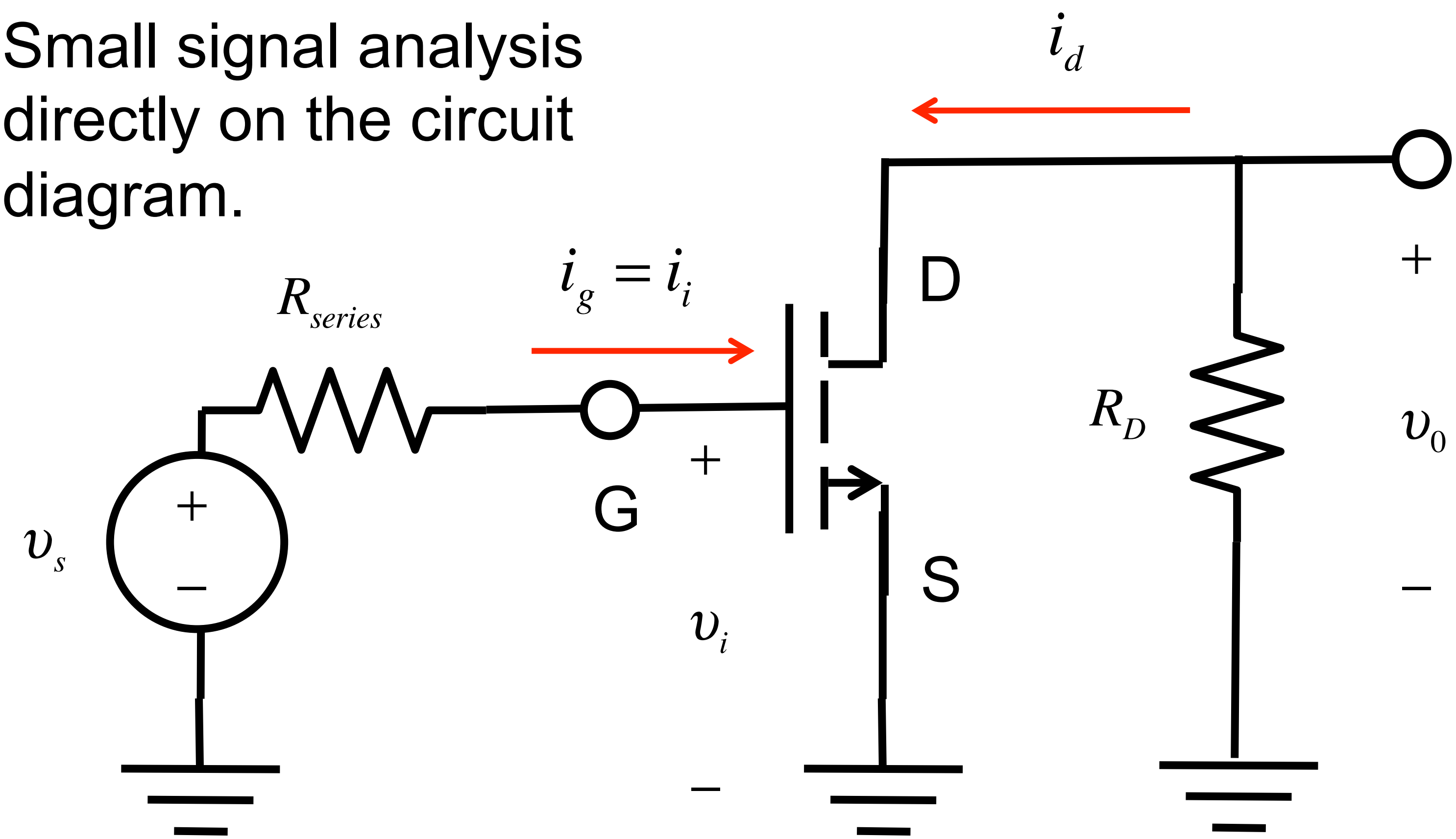
with load attached

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

$$R_o = R_C \parallel r_o$$

Common source

Small signal analysis directly on the circuit diagram.



Common source results

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

open circuit voltage gain

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

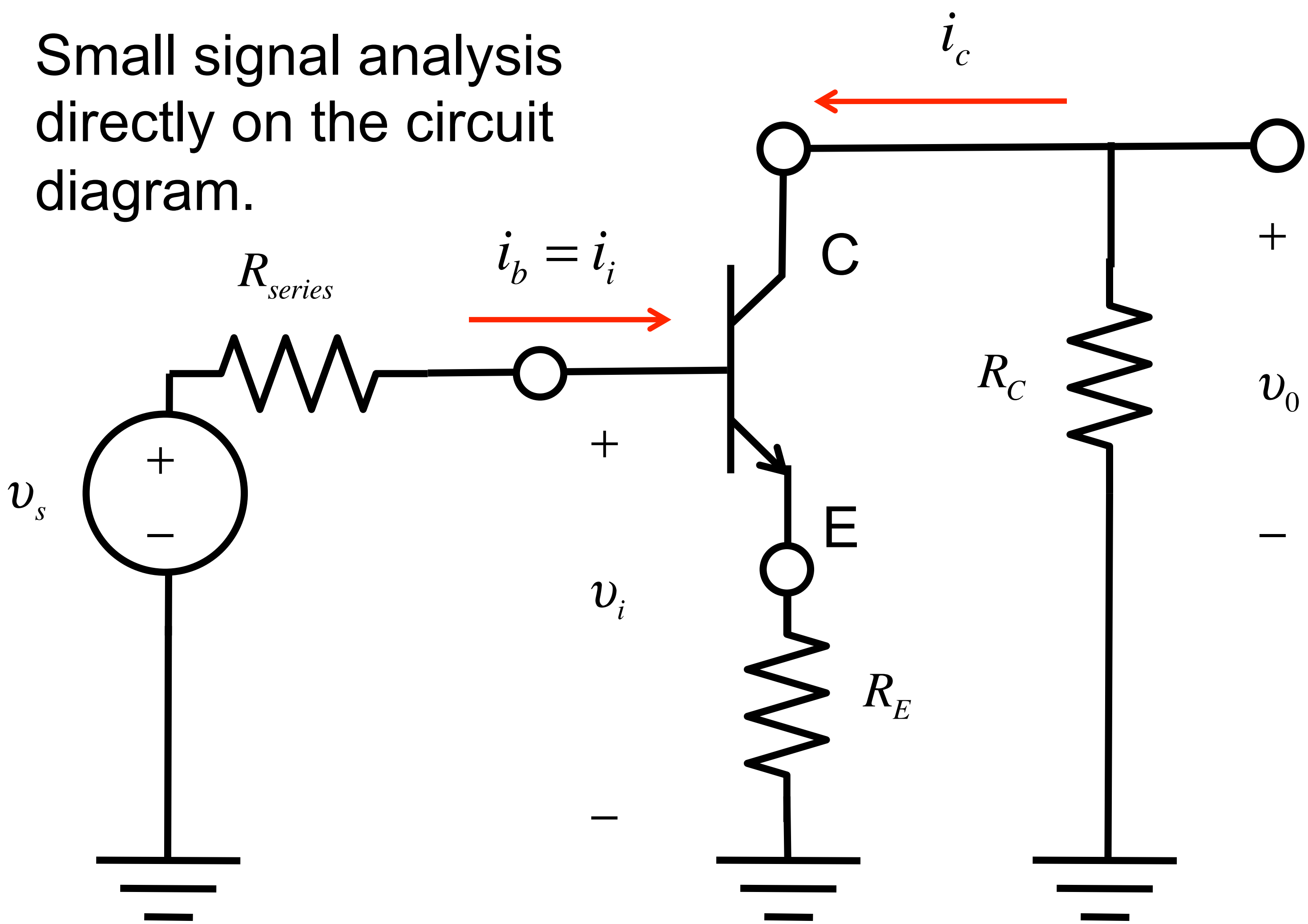
with load attached

$$R_{in} = \infty$$

$$R_o = R_D \parallel r_o$$

Common emitter with “emitter degeneration”

Small signal analysis directly on the circuit diagram.



Common emitter with emitter resistor

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

open circuit voltage gain

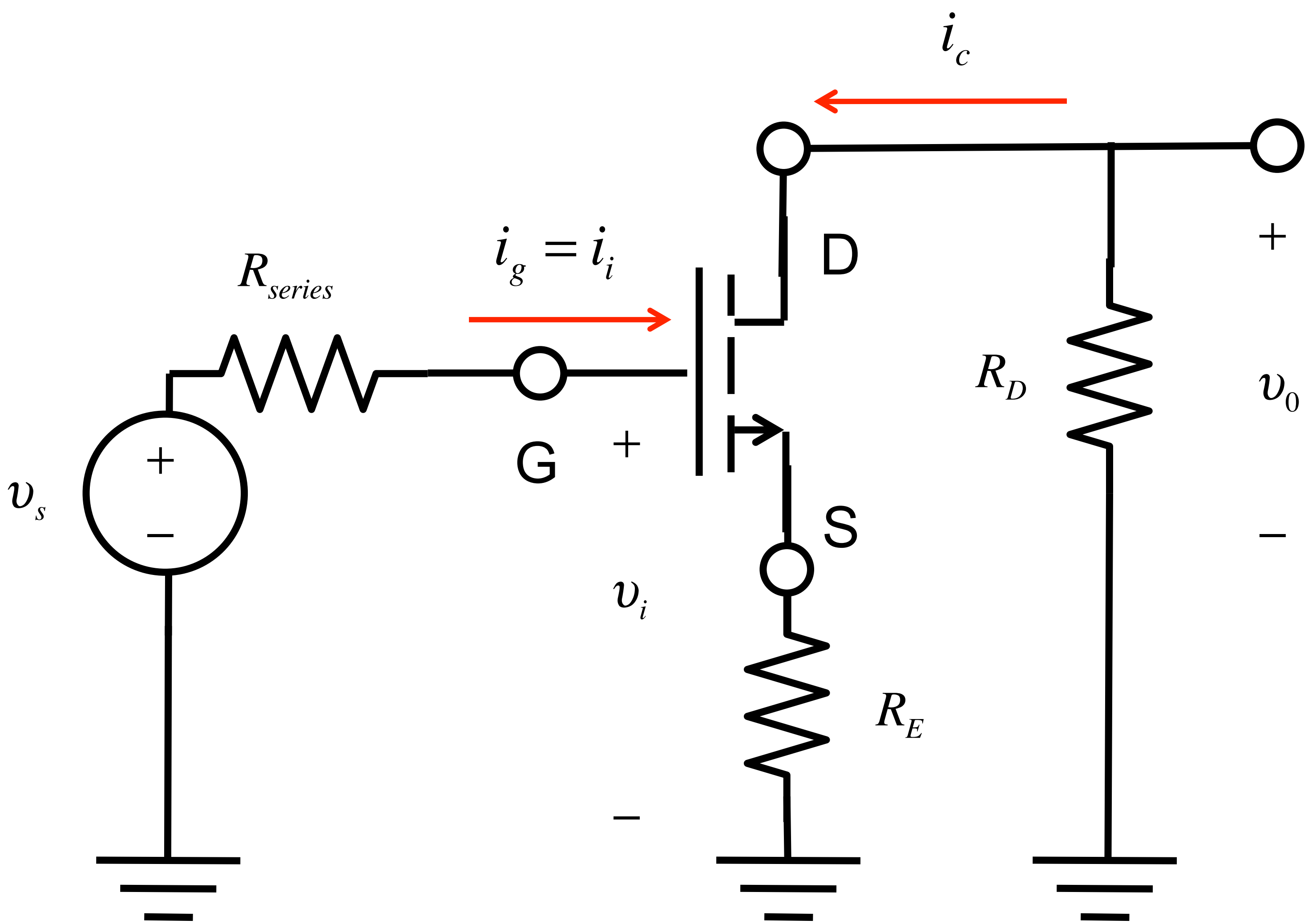
$$A_{v_o} = -\frac{r_\pi}{r_\pi + (\beta+1)R_E}(g_m R_C \parallel R_L)$$

with load attached

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

$$R_o = R_C$$

Common source with source degeneration



Common source with source resistor

$$r_\pi \rightarrow \infty \qquad \beta \rightarrow \infty$$

$$A_{v_o} = -\frac{1}{1+g_m R_S}\left(g_m R_D\right)$$ open circuit voltage gain

$$A_{v_o} = -\frac{1}{1+g_m R_S}\left(g_m R_D \parallel R_L\right)$$ with load attached

$$R_{in} = \infty$$

$$R_o = R_D$$

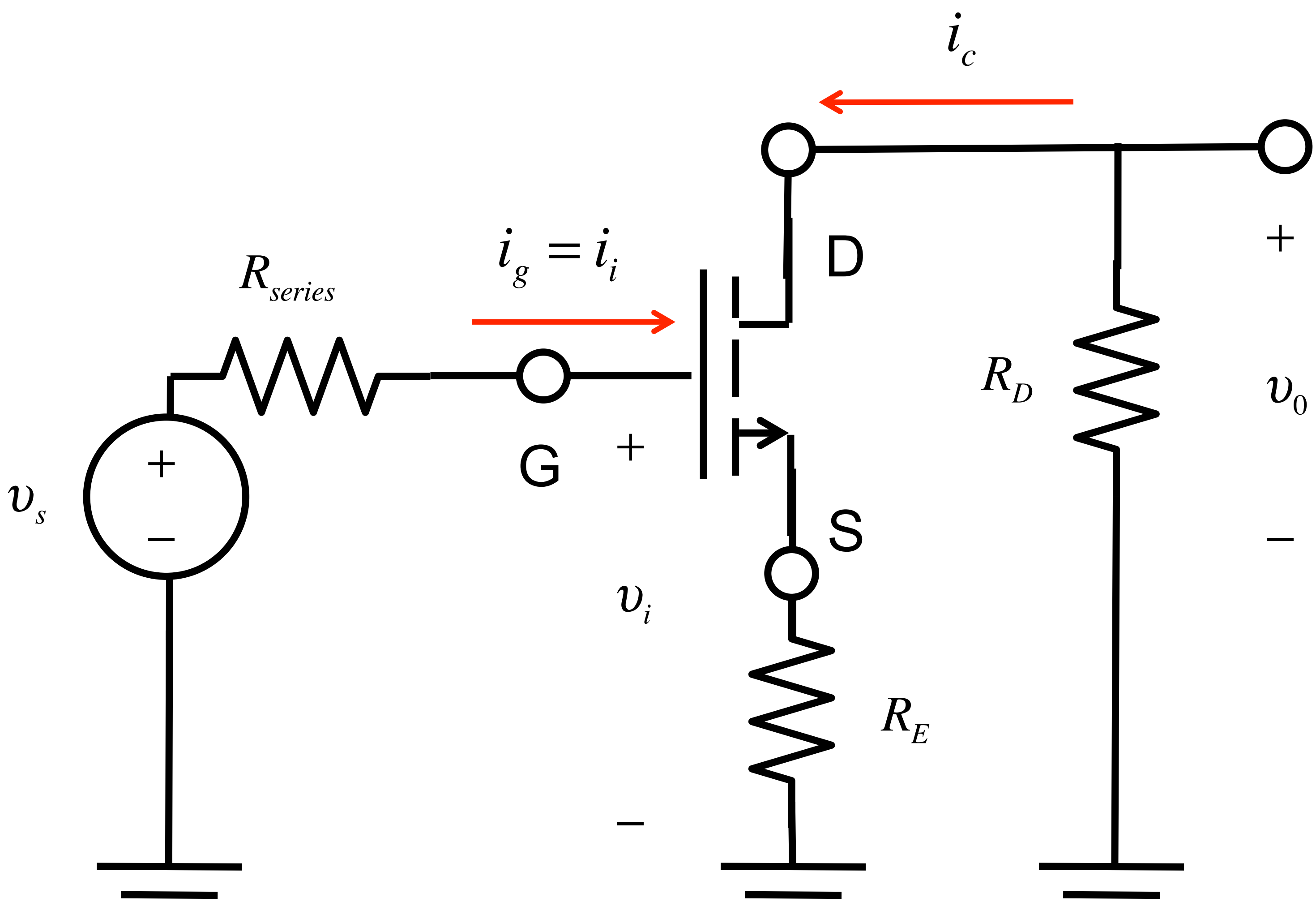
Aside: taking limits

$$r_\pi \to \infty \qquad \beta \to \infty$$

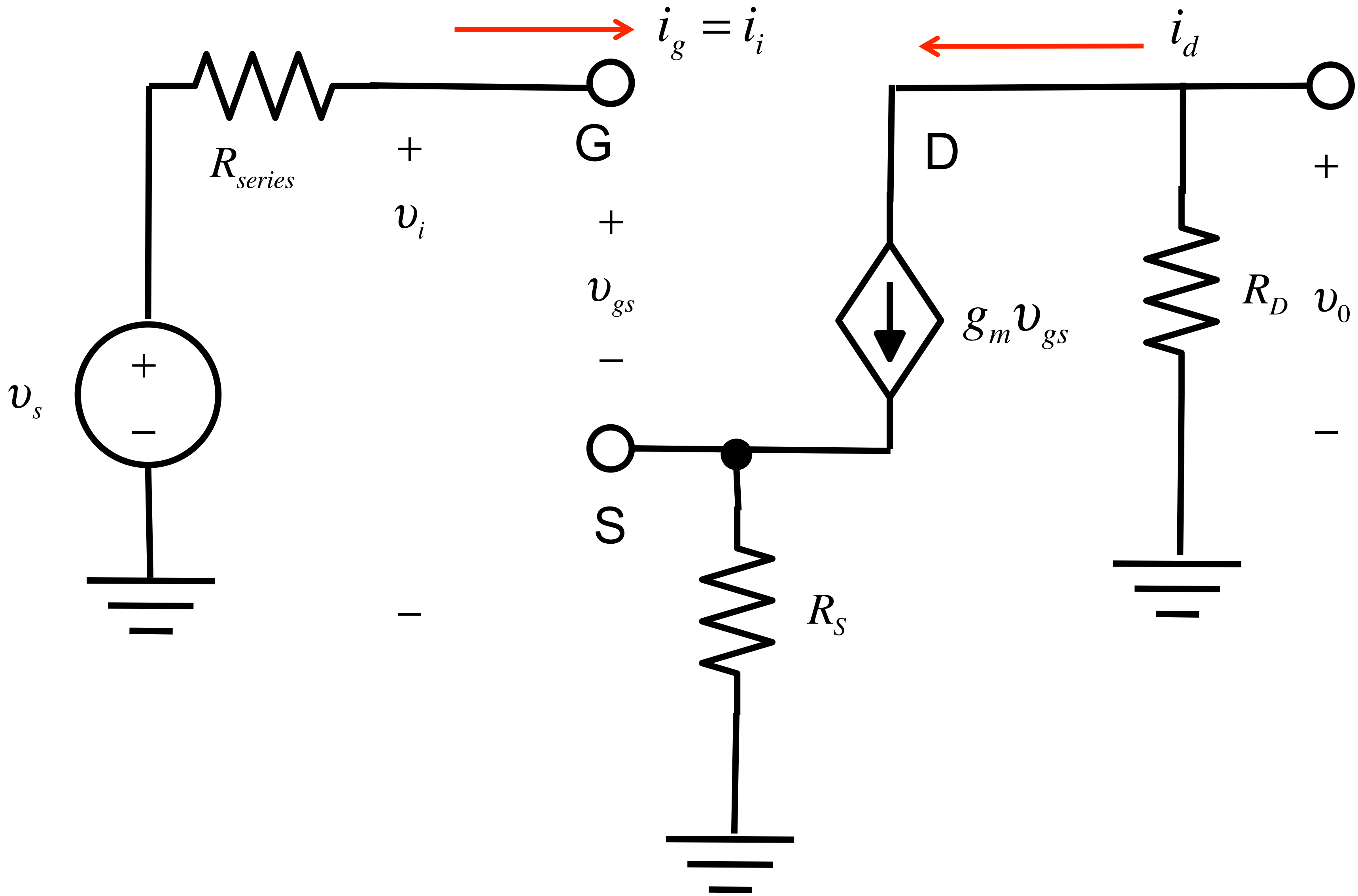
$$A_{\upsilon_o} = -\frac{r_\pi}{r_\pi + (\beta + 1) R_E} (g_m R_C)$$

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

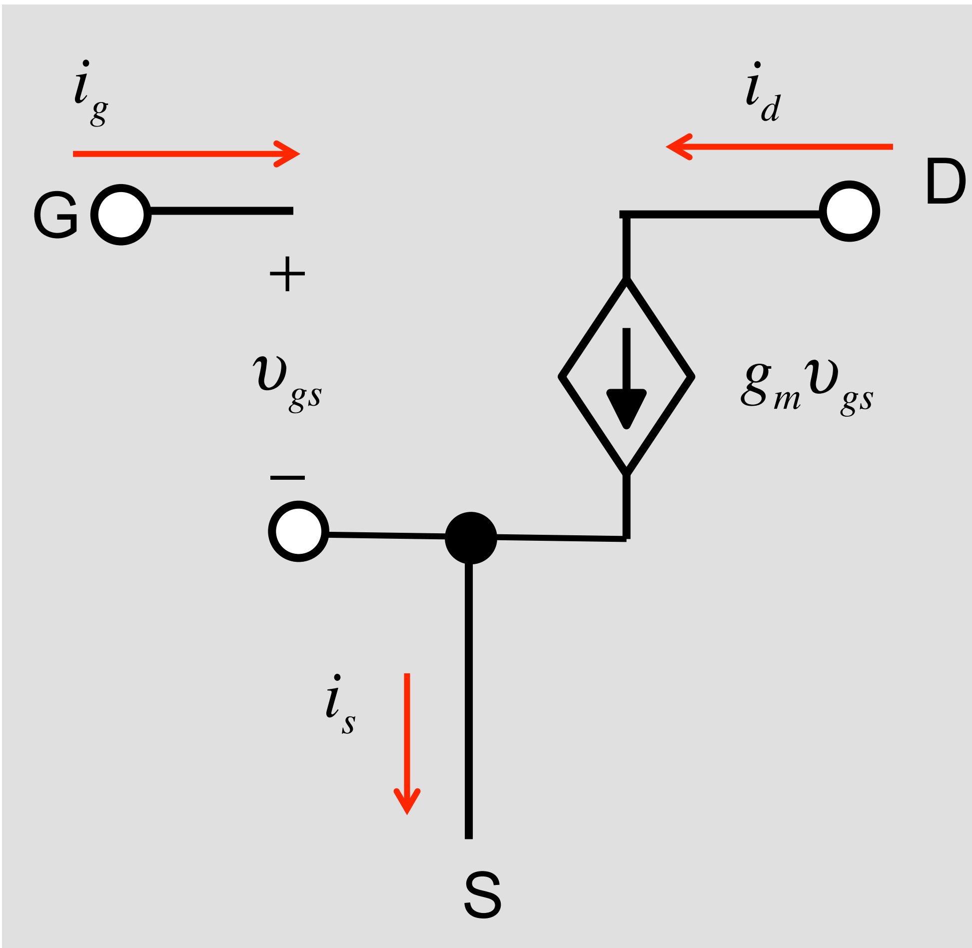
CS analysis with equivalent circuits

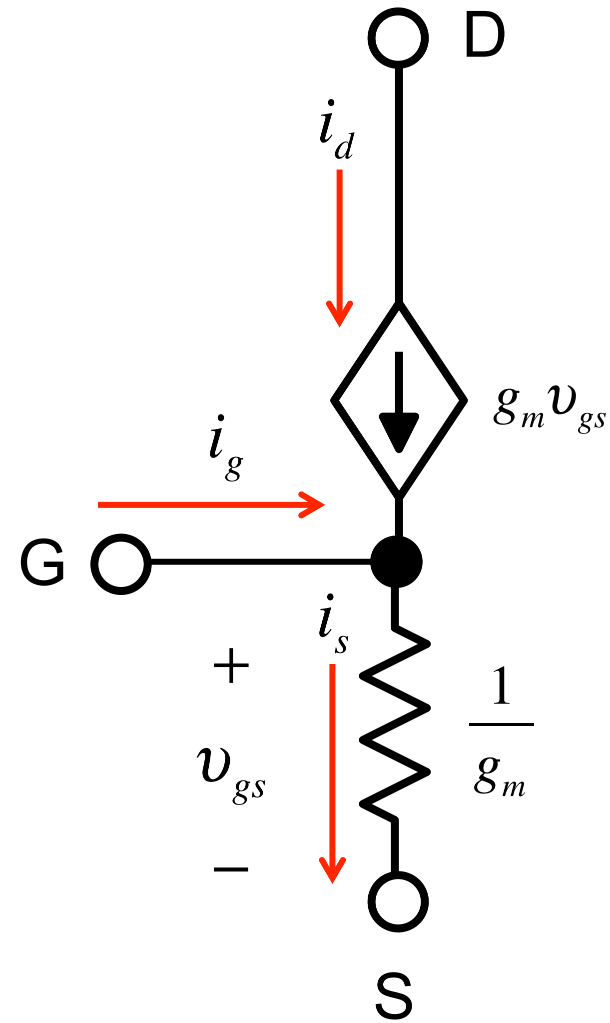


1) CS with hybrid-pi model

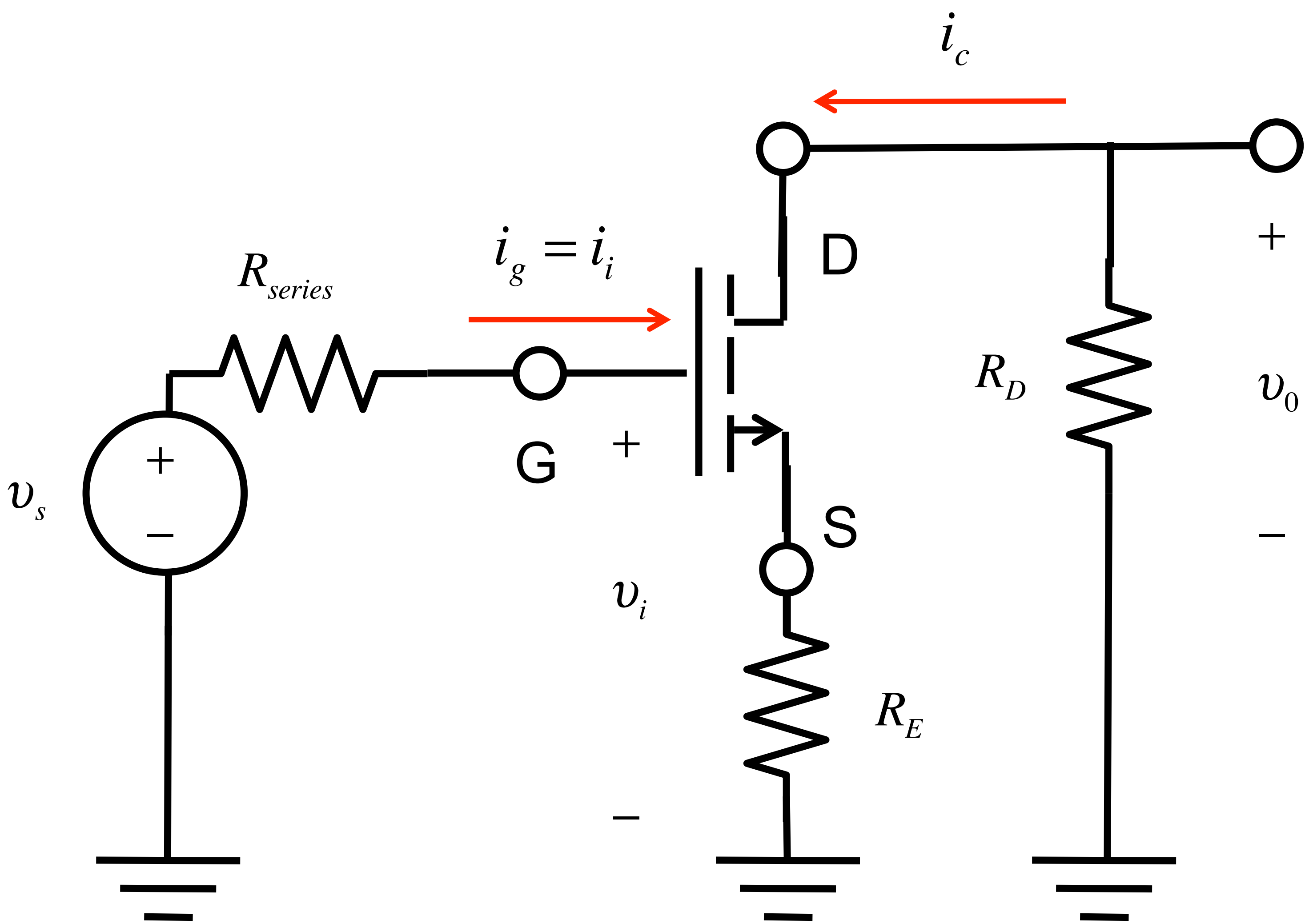


Hybrid pi vs. T-model

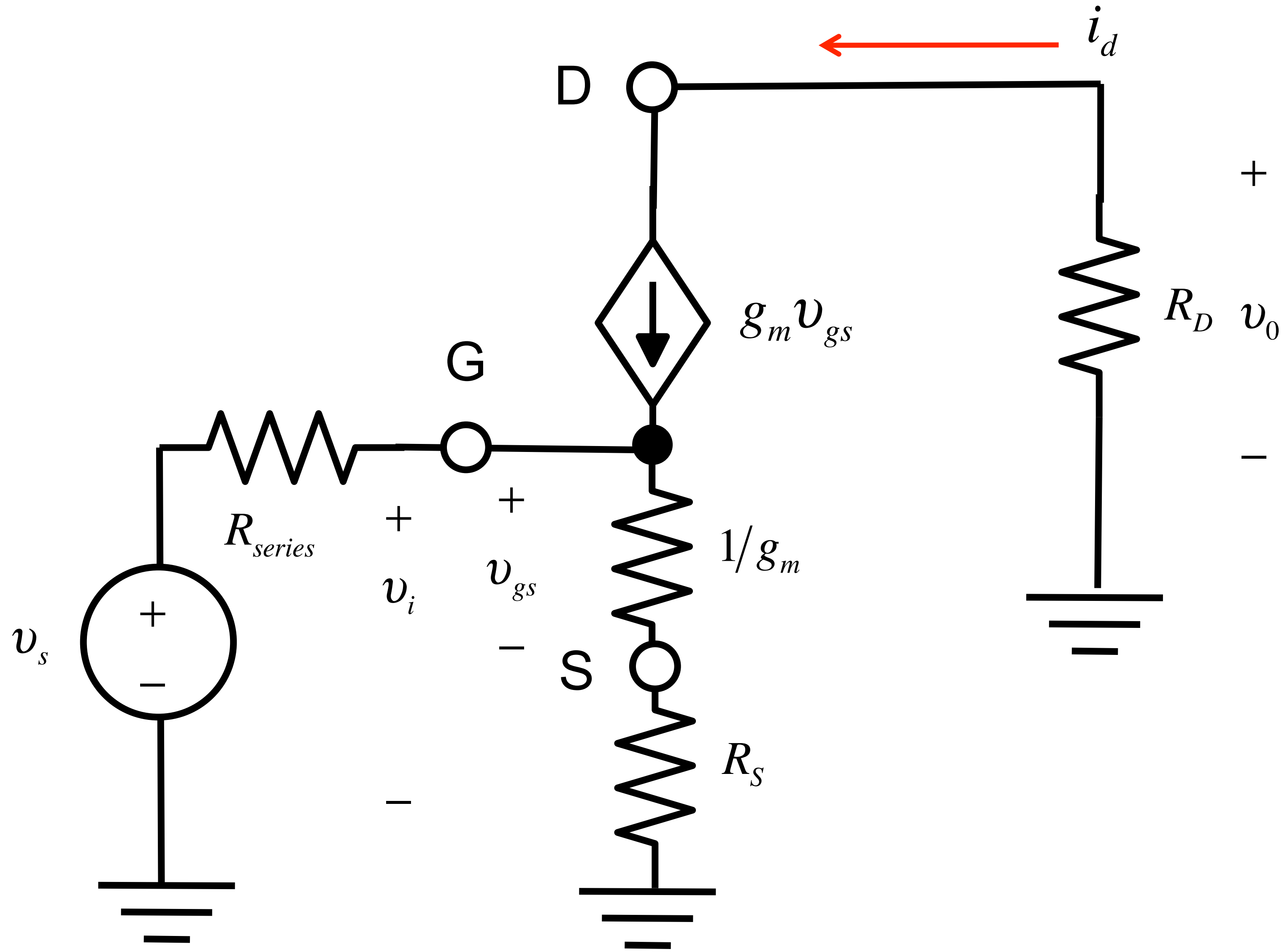




Draw the s.s. model using T-model



Common source with source resistor



Common source with source resistor

$$A_{v_o} = -\frac{1}{1+g_m R_S}\left(g_m R_D\right)$$ open circuit voltage gain

$$A_{v_o} = -\frac{1}{1+g_m R_S}\left(g_m R_D \parallel R_L\right)$$ with load attached

$$R_{in} = \infty$$

$$R_o = R_D$$

Outline

1) Basic amplifier considerations

2) CE / CS

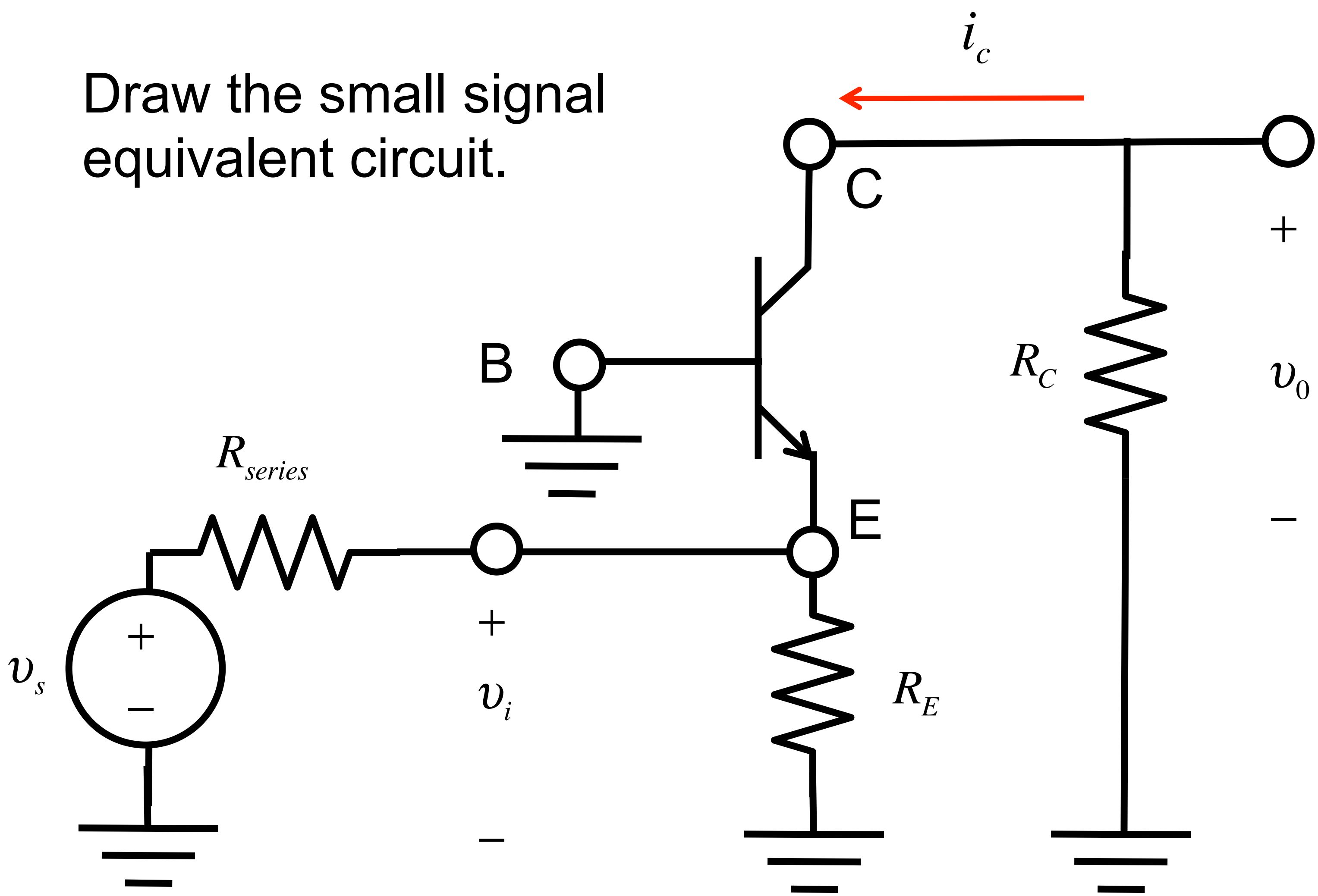
3) CB / CG

4) Common base example

5) CC (emitter follower) / CD (source follower)

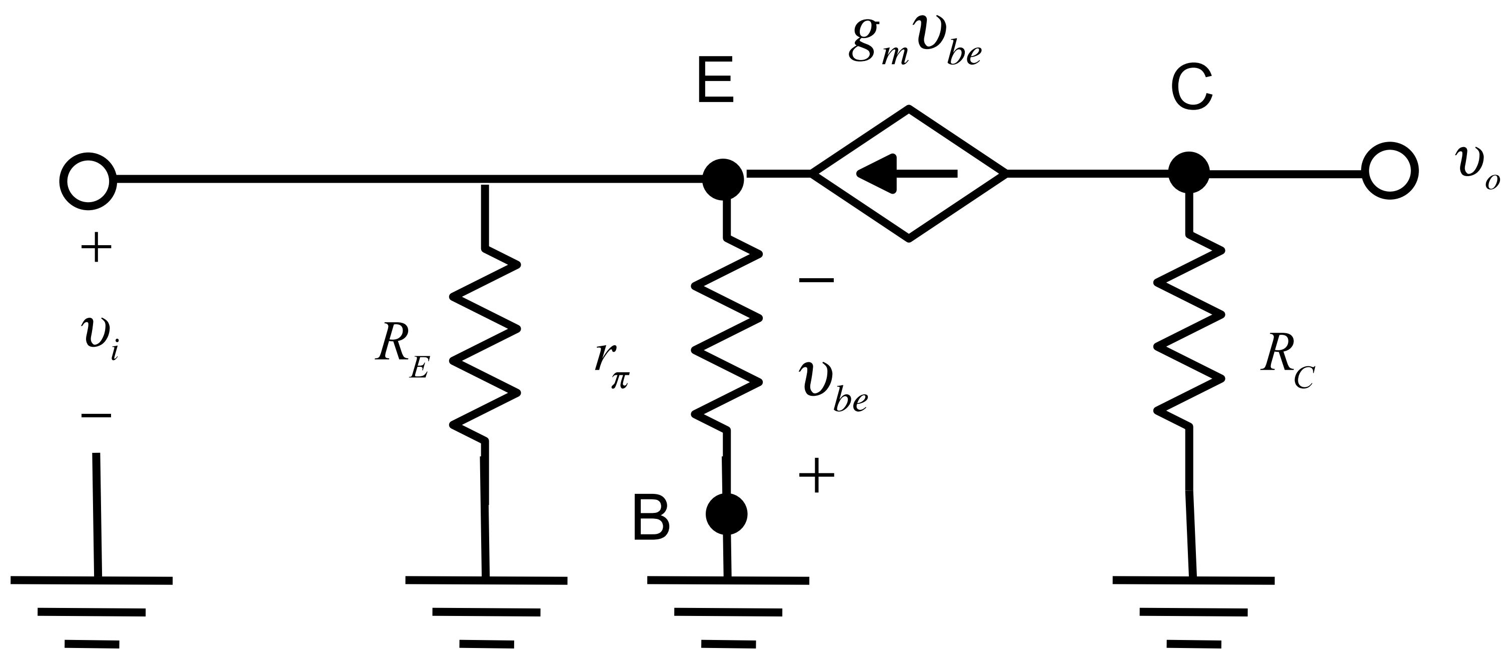
Common base

Draw the small signal equivalent circuit.



Common base amplifier

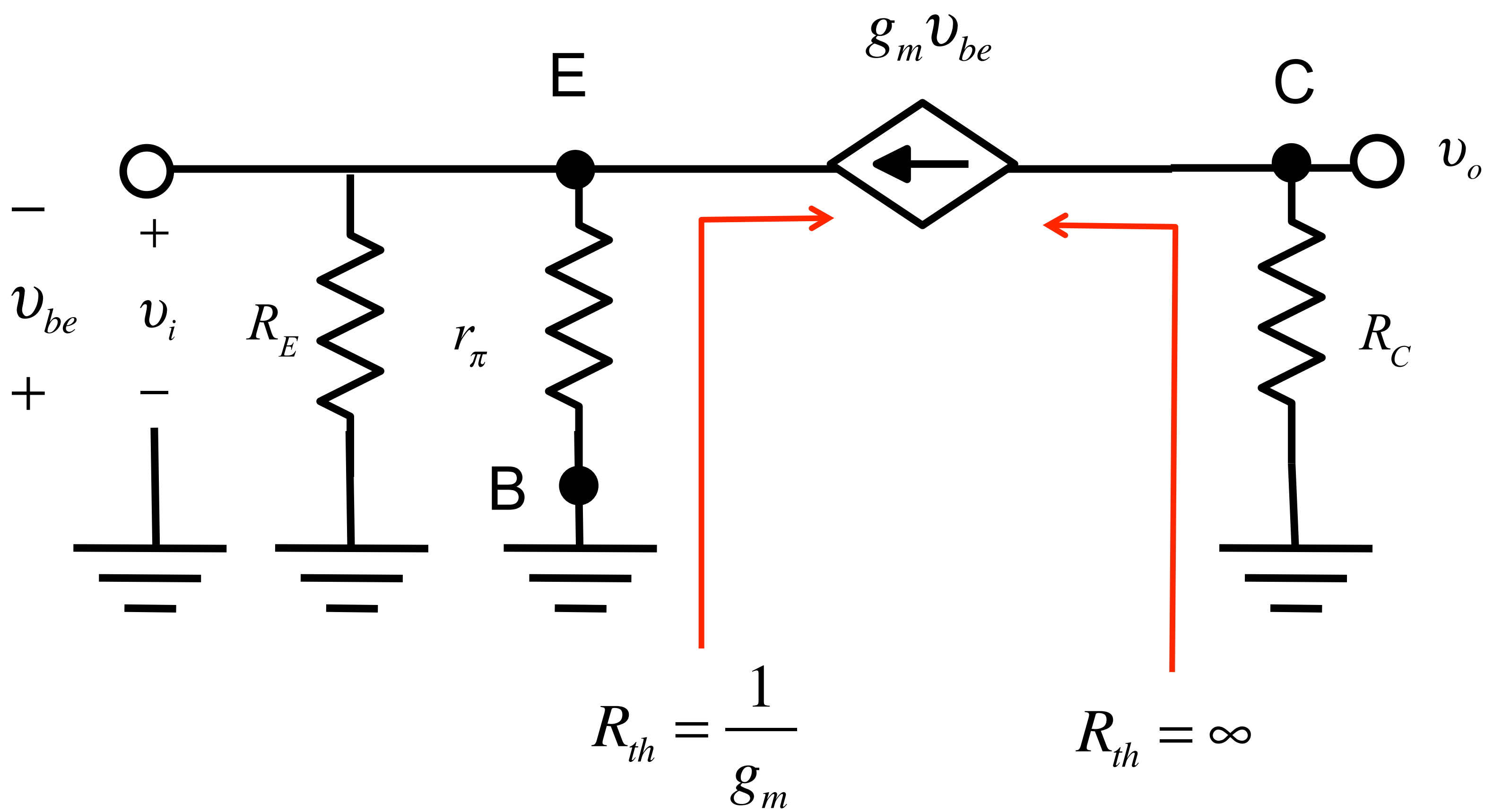
Effect of r_0?



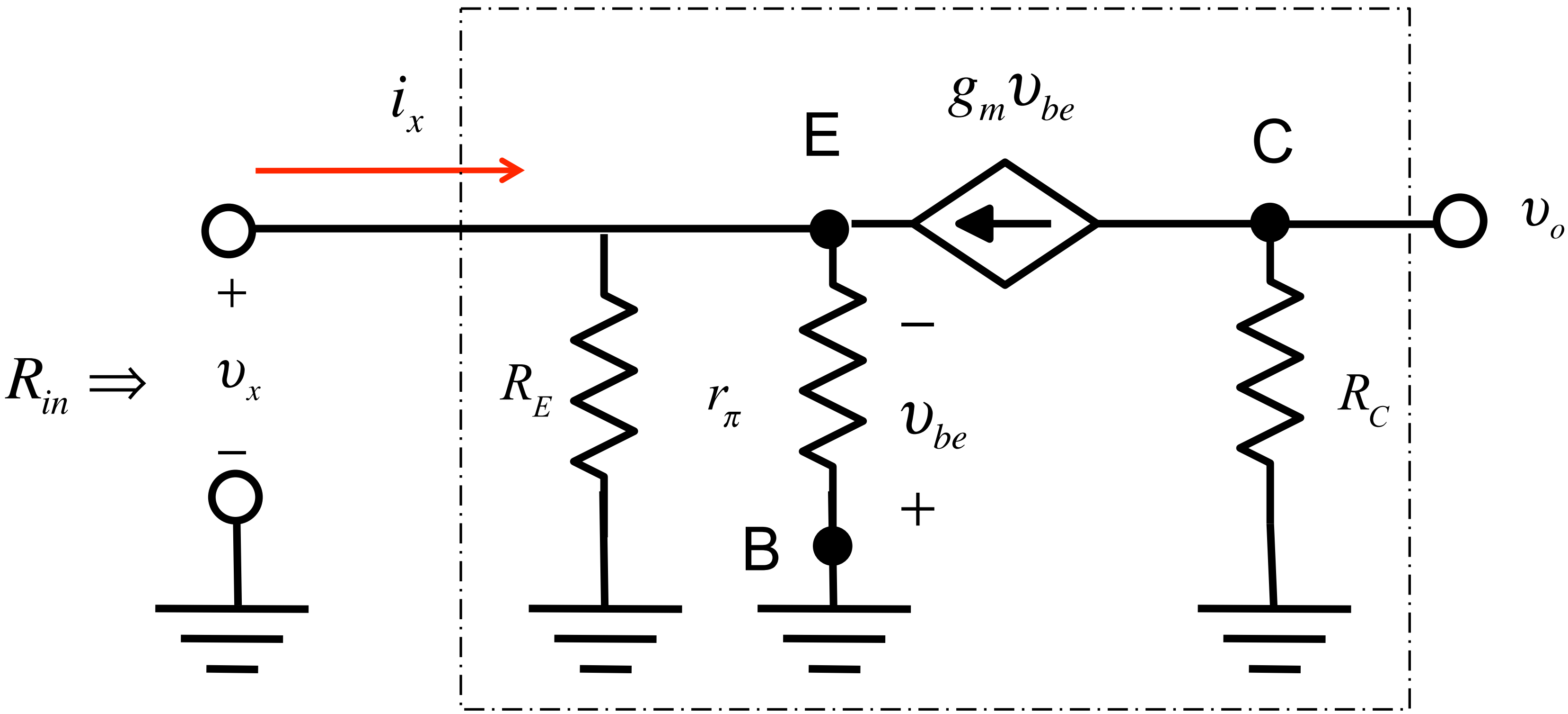
$$v_o = -g_m v_{be} R_C \qquad v_o = +g_m v_i R_C \qquad R_o = R_C$$

$$v_{be} = -v_i \qquad A_v = \frac{v_o}{v_i} = +g_m R_C \qquad R_{in} = ?$$

Looking into current sourse

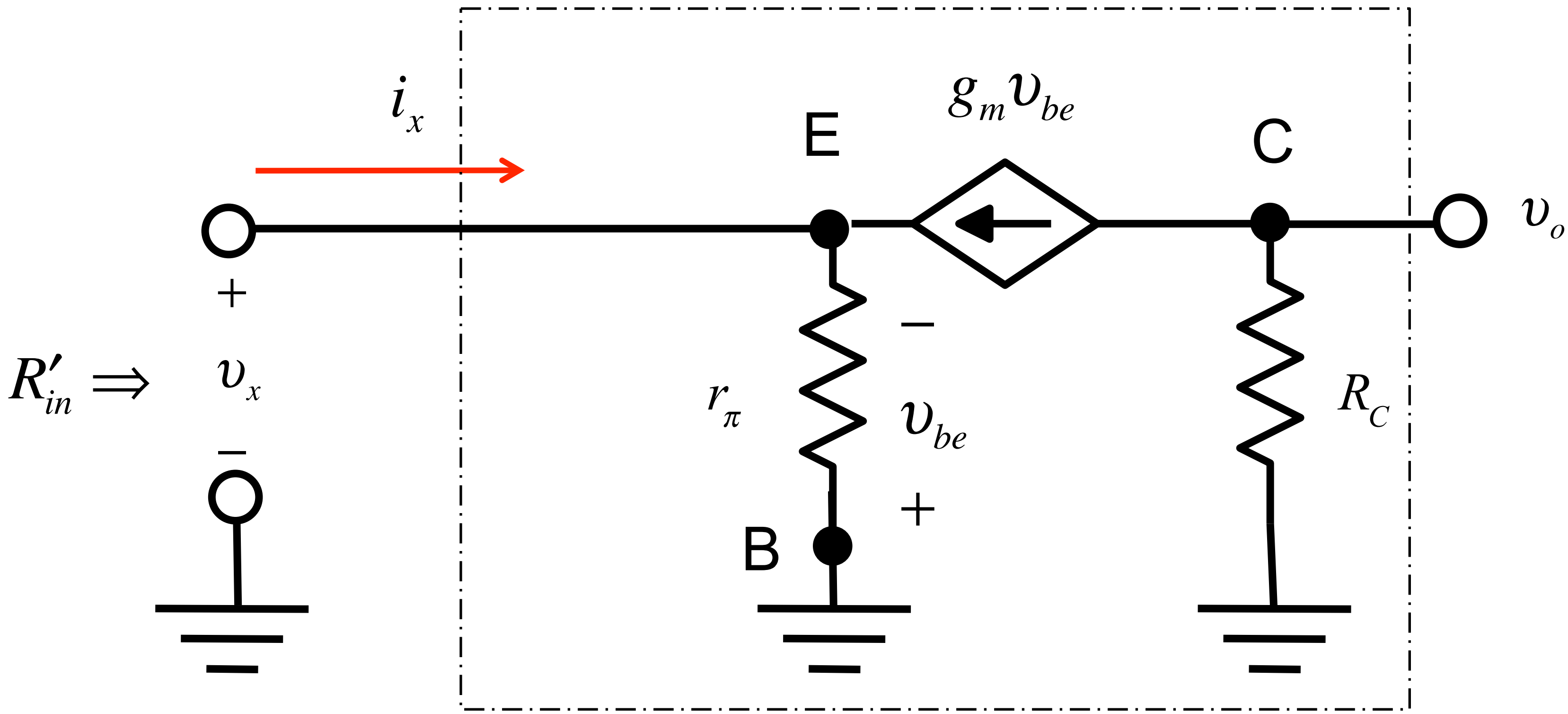


CB input resistance



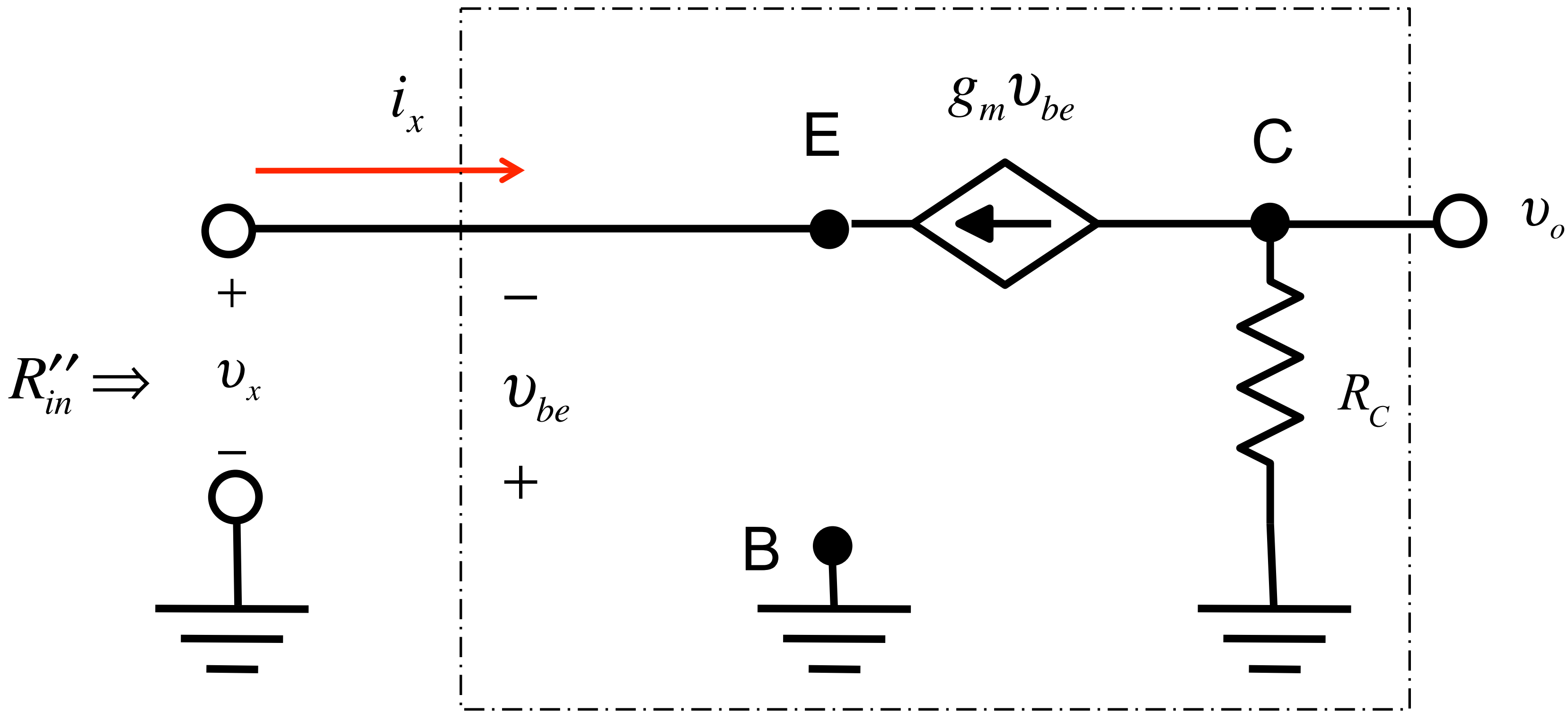
$$R_{in} = R_E \parallel ?$$

CB input resistance (ii)



$$R_{in} = R_E \parallel r_\pi \parallel ?$$

CB input resistance (iii)



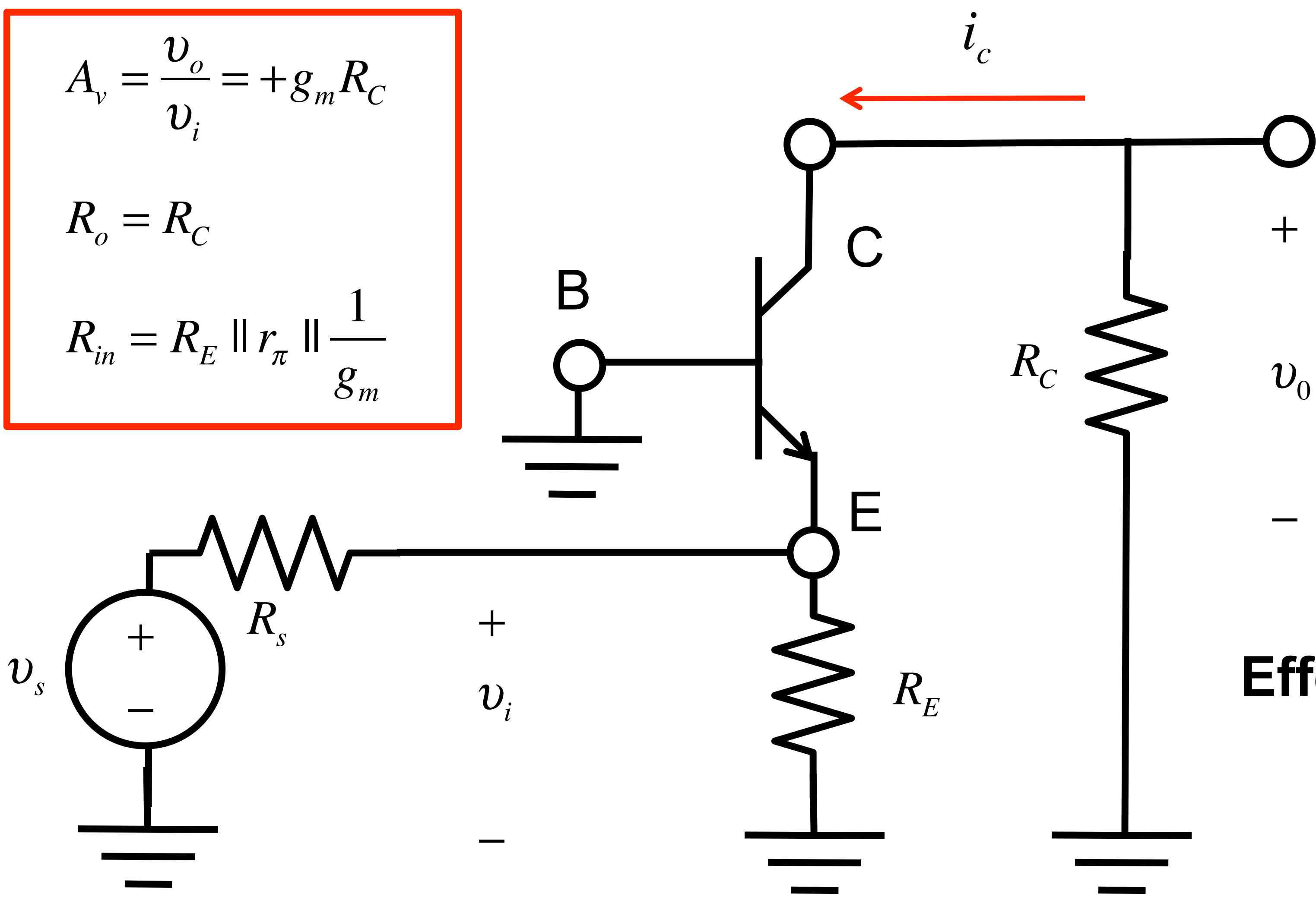
$$R_{in} = R_E \parallel r_\pi \parallel ? \qquad R''_{in} = \frac{\upsilon_x}{i_x} = \frac{\upsilon_x}{g_m \upsilon_x} = \frac{1}{g_m}$$

Common base

$$A_v = \frac{\upsilon_o}{\upsilon_i} = +g_m R_C$$

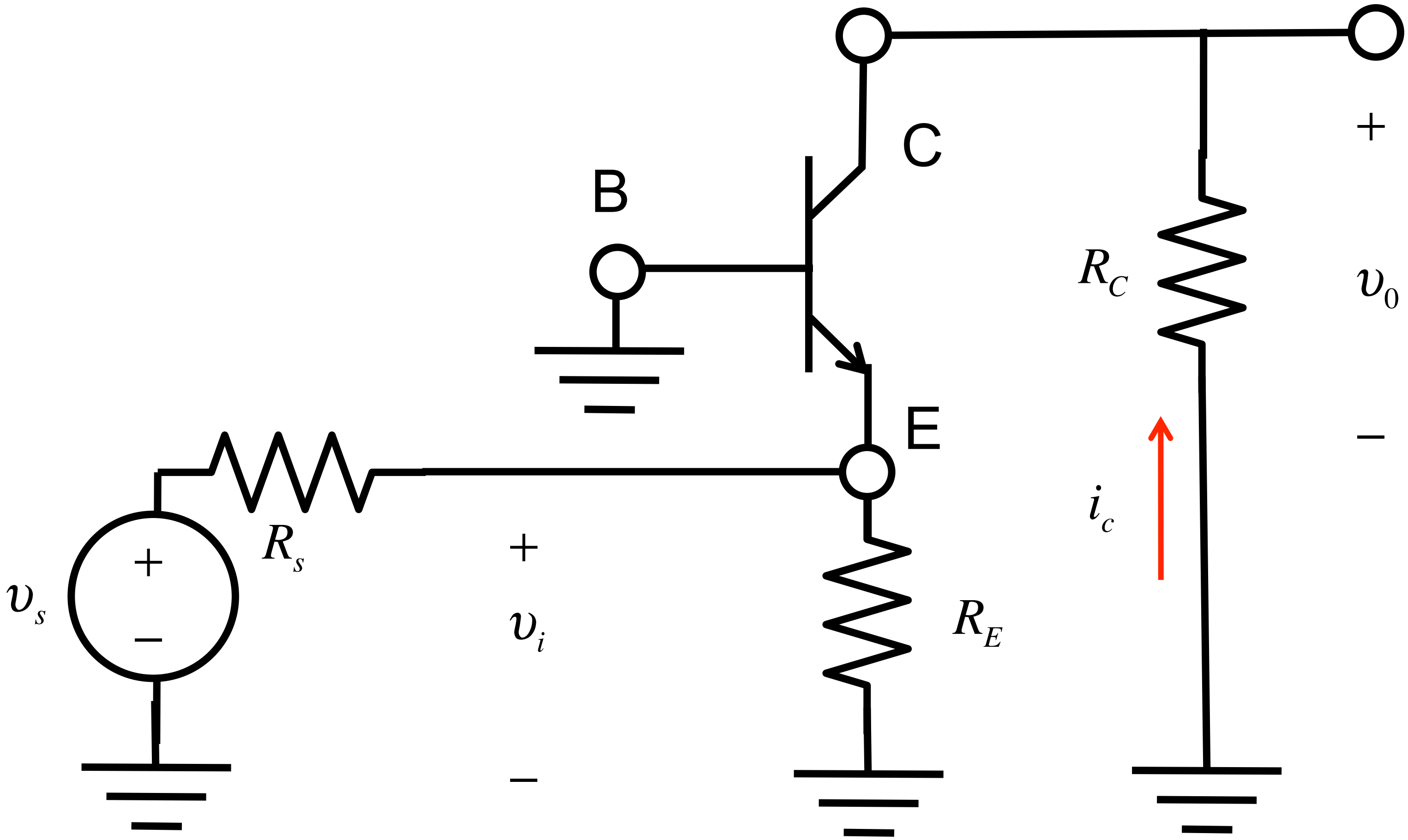
$$R_o = R_C$$

$$R_{in} = R_E \parallel r_\pi \parallel \frac{1}{g_m}$$



Effect of R_L?

CB analysis on the circuit diagram



Common base: results

$$A_v = \frac{\upsilon_o}{\upsilon_i} = +g_m R_C$$

$$R_o = R_C$$

$$R_{in} = R_E \parallel r_\pi \parallel \frac{1}{g_m}$$

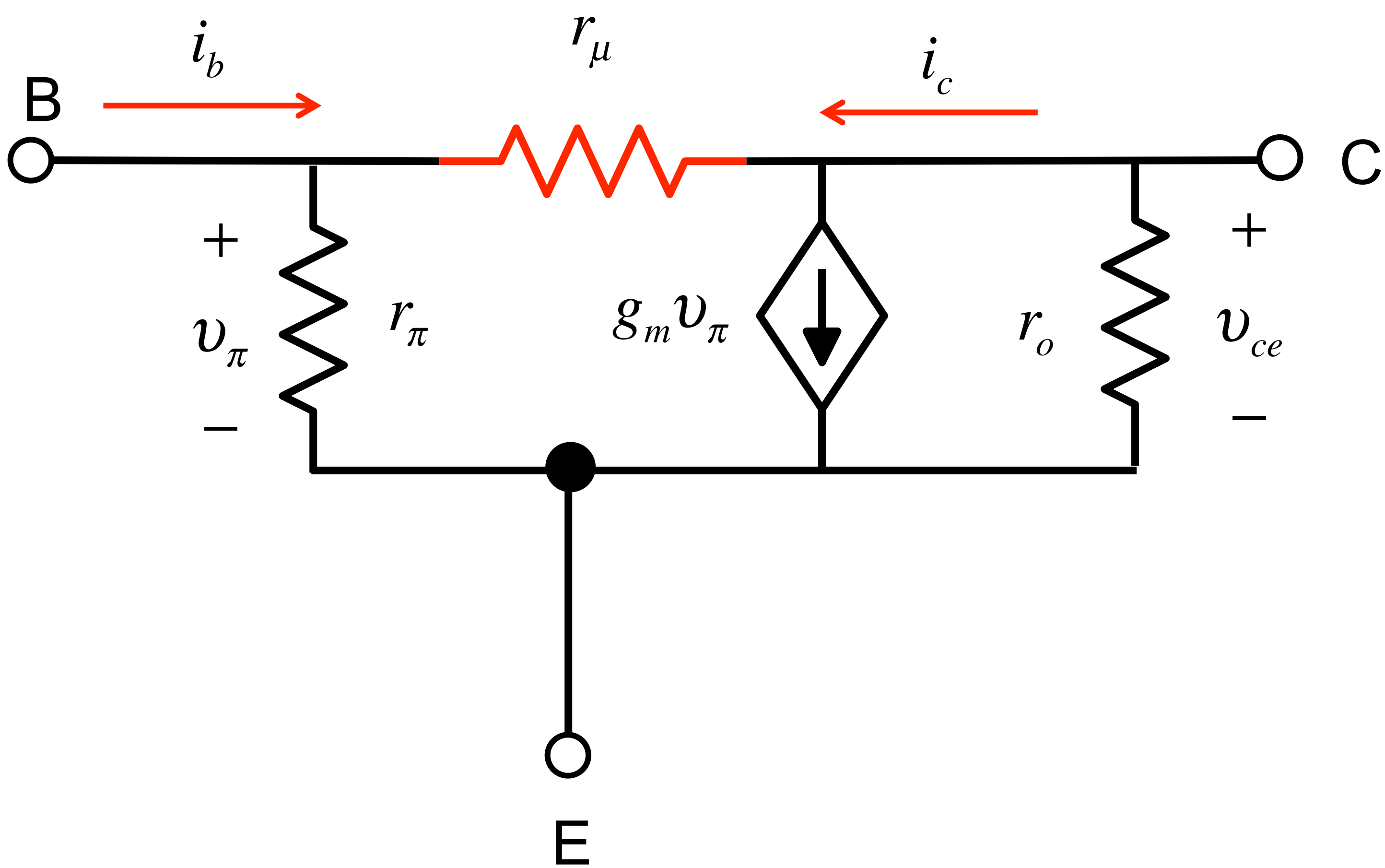
$$A_v = \frac{\upsilon_o}{\upsilon_i} = +g_m R_C$$

$$R_o = R_C$$

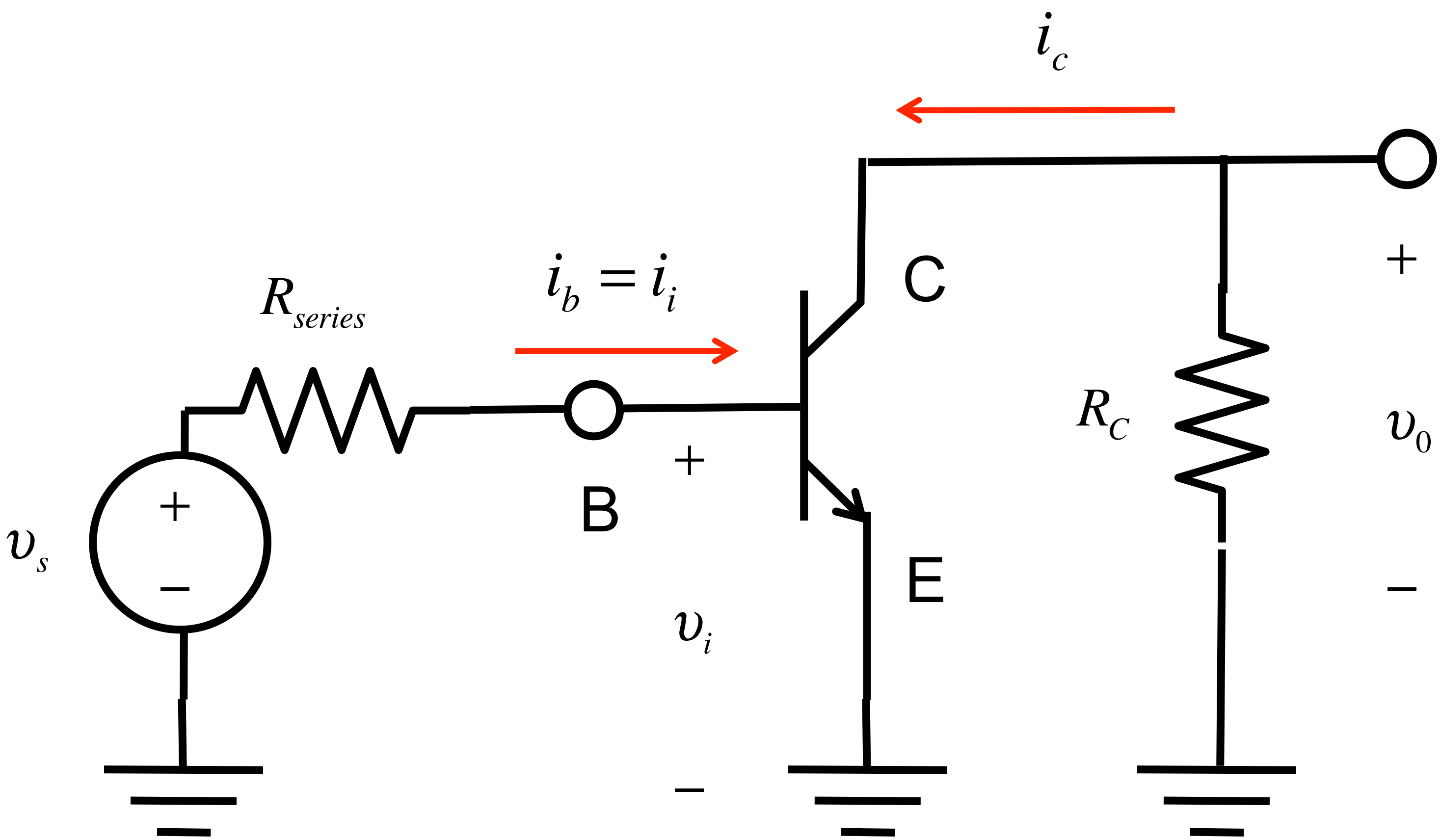
$$R_{in} = R_E \parallel \frac{r_\pi}{\beta + 1}$$

$$r_\pi \parallel \frac{1}{g_m} = \frac{r_\pi}{\beta + 1}$$

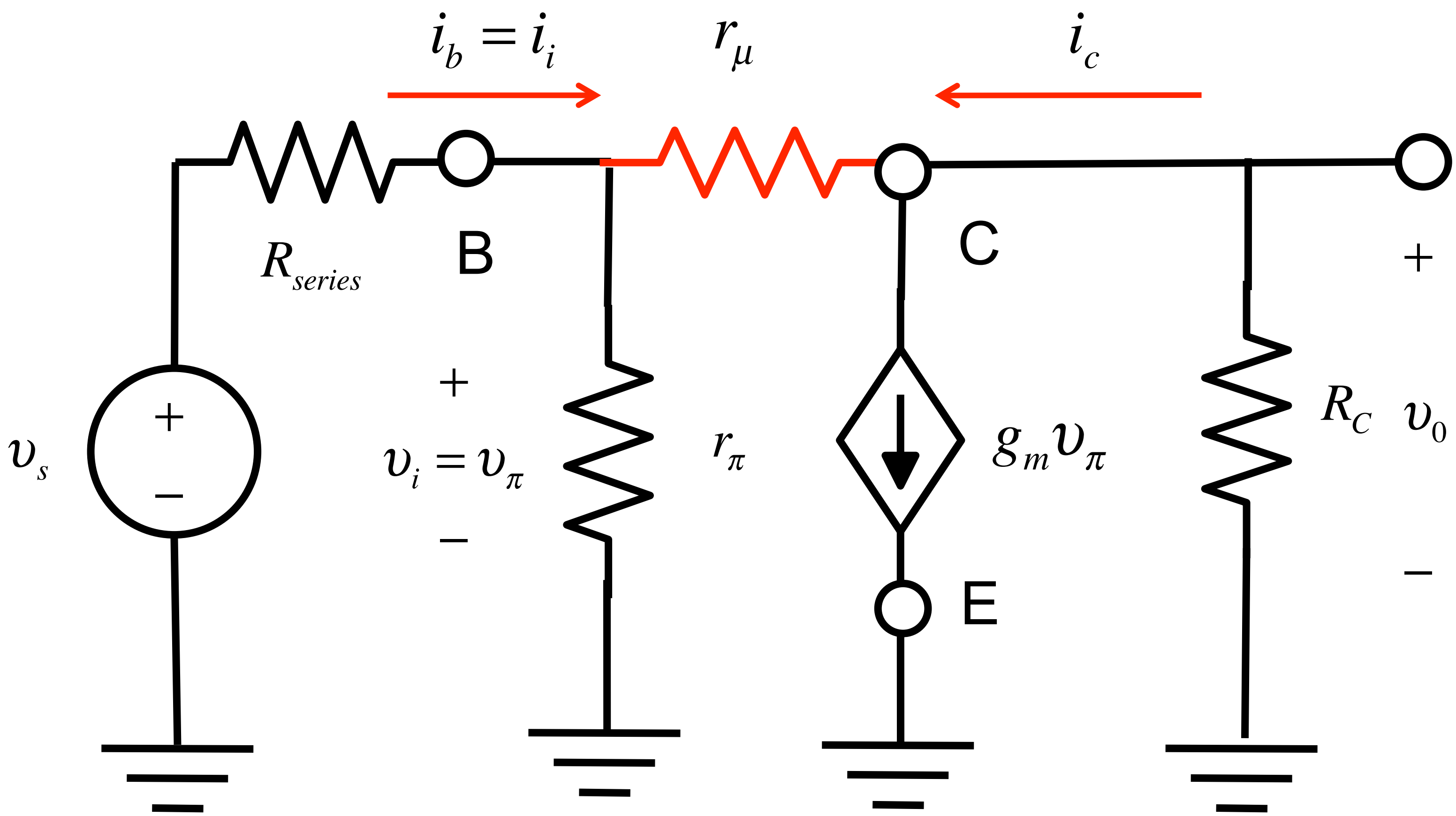
When can we not do problems by inspection?



Common emitter amplifier



Small signal equivalent circuit



Lundstrom: 2019

Result

$$A_v = -g_m R_C$$

$$R_o = R_C$$

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

$$A_v = -g_m R_C \left[\frac{1 - 1/(g_m r_\mu)}{1 + R_C/r_\mu} \right]$$

$$R_o = R_C \parallel r_\mu$$

$$R_{in} = r_\pi \parallel \left[\frac{r_\mu + R_C}{1 + g_m R_C} \right]$$

Sedra and Smith, problem 7.63

Common base numbers

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

$R_E = 1\ \text{k}\Omega$

$I_C = 1.0\ \text{mA}$

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

$g_m r_\pi = \beta \qquad \beta = 100$

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

$A_v = +g_m R_C = +390$

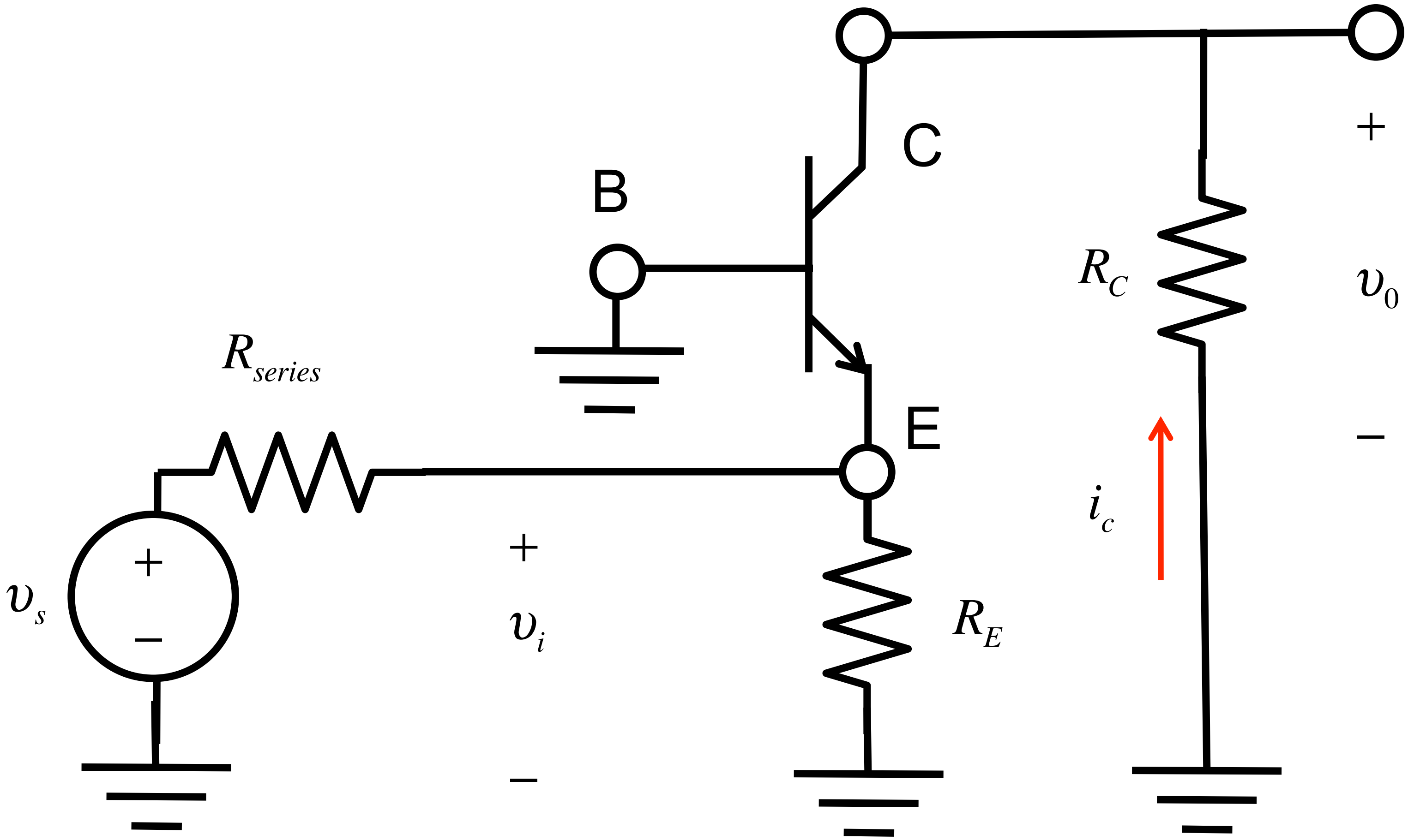
$R_o = R_C = 10\ \text{k}\Omega$

$$R_{in} = R_E \parallel r_\pi \parallel \frac{1}{g_m}$$

$$\frac{1}{g_m} = \frac{1}{39}\ \text{k}\Omega = 26\ \Omega$$

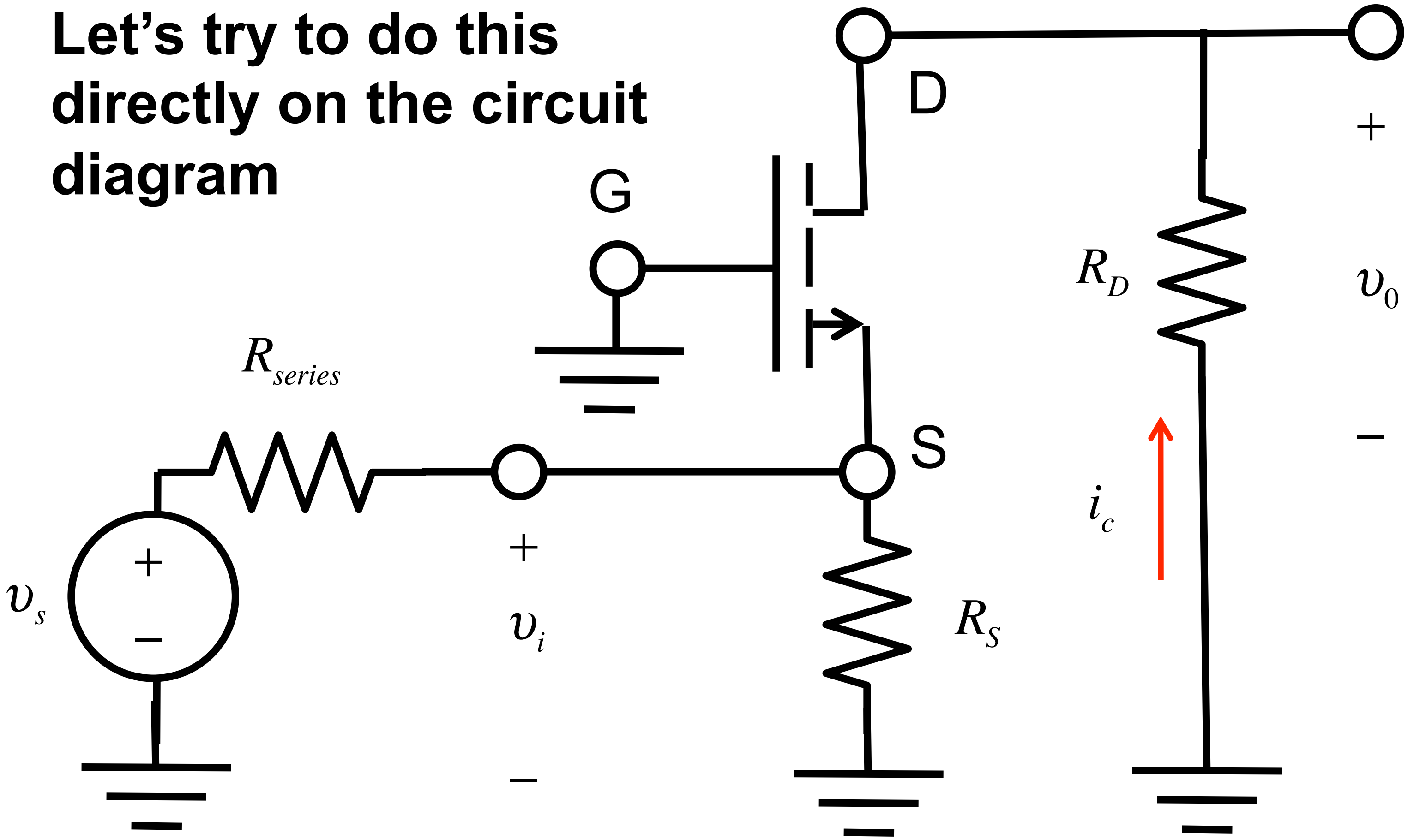
$R_{in} = 25\ \Omega$

Common base to common gate



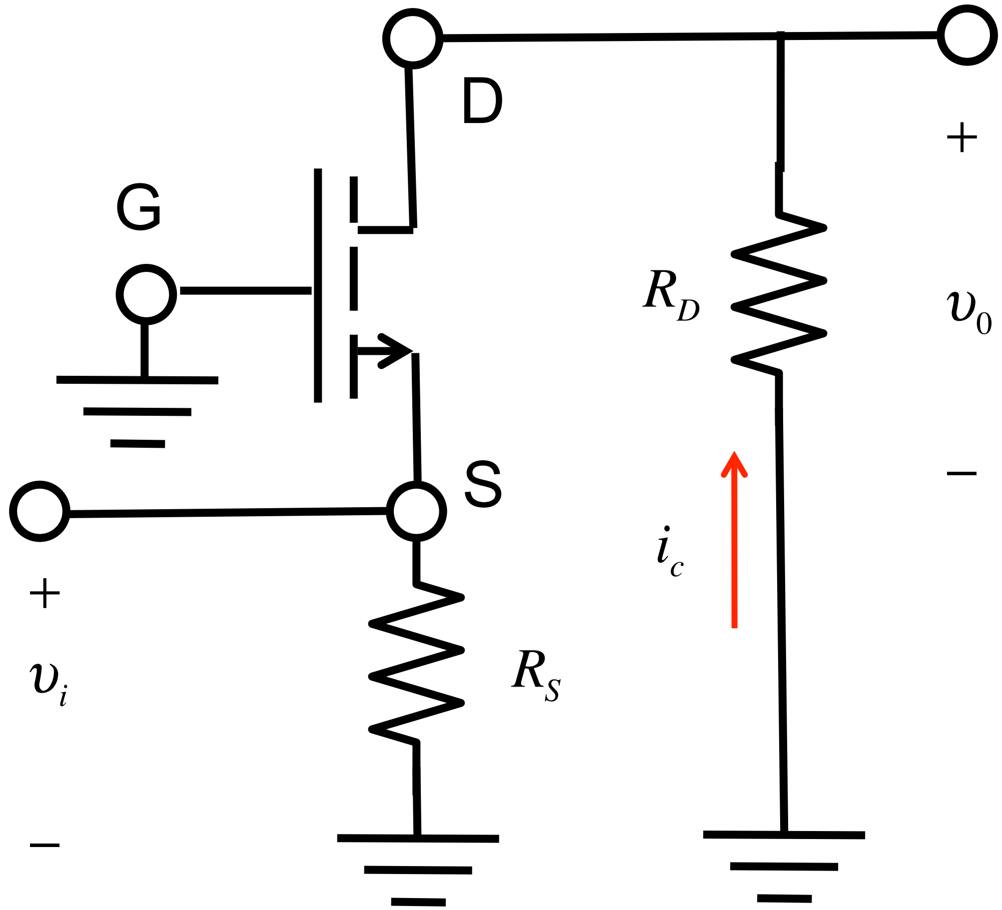
Common gate

Let's try to do this directly on the circuit diagram

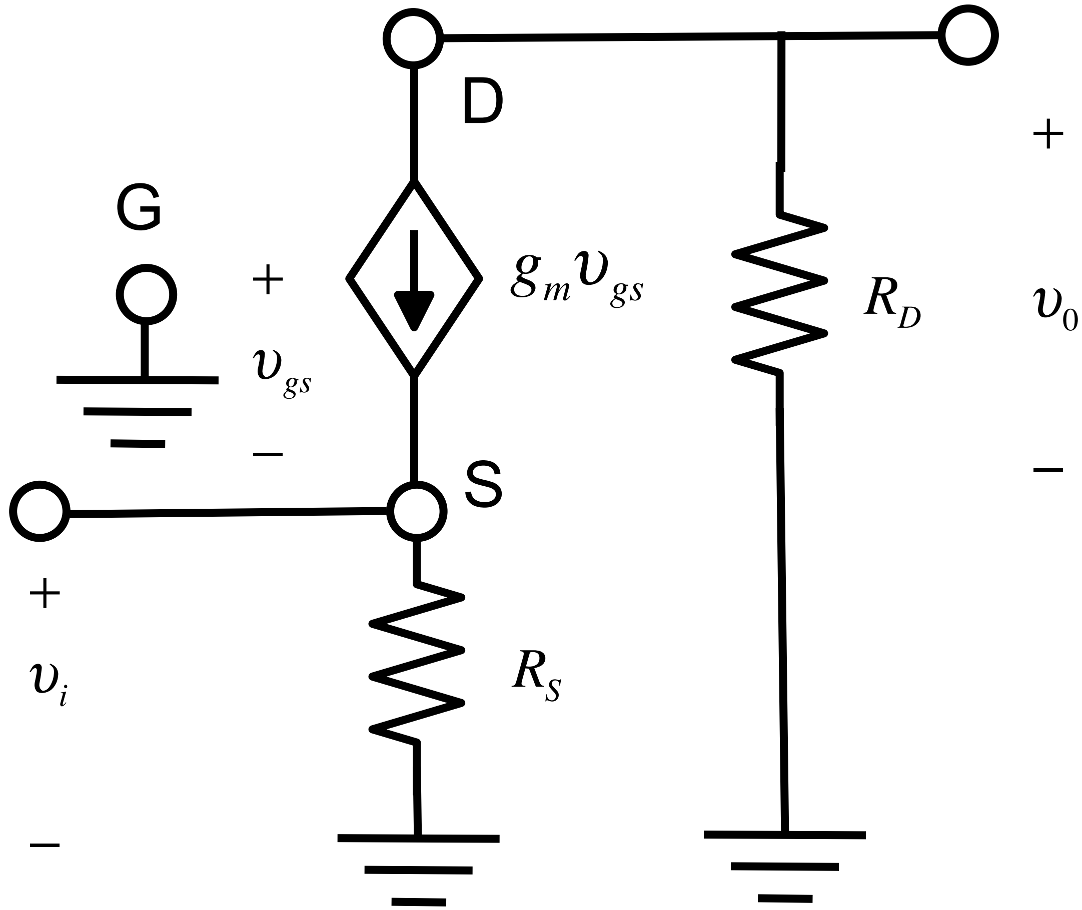


Input resistance

$R_{in} \Rightarrow$



Input resistance (ii)



$R_{in} \Rightarrow$

$R_{in} = R_S \parallel ?$

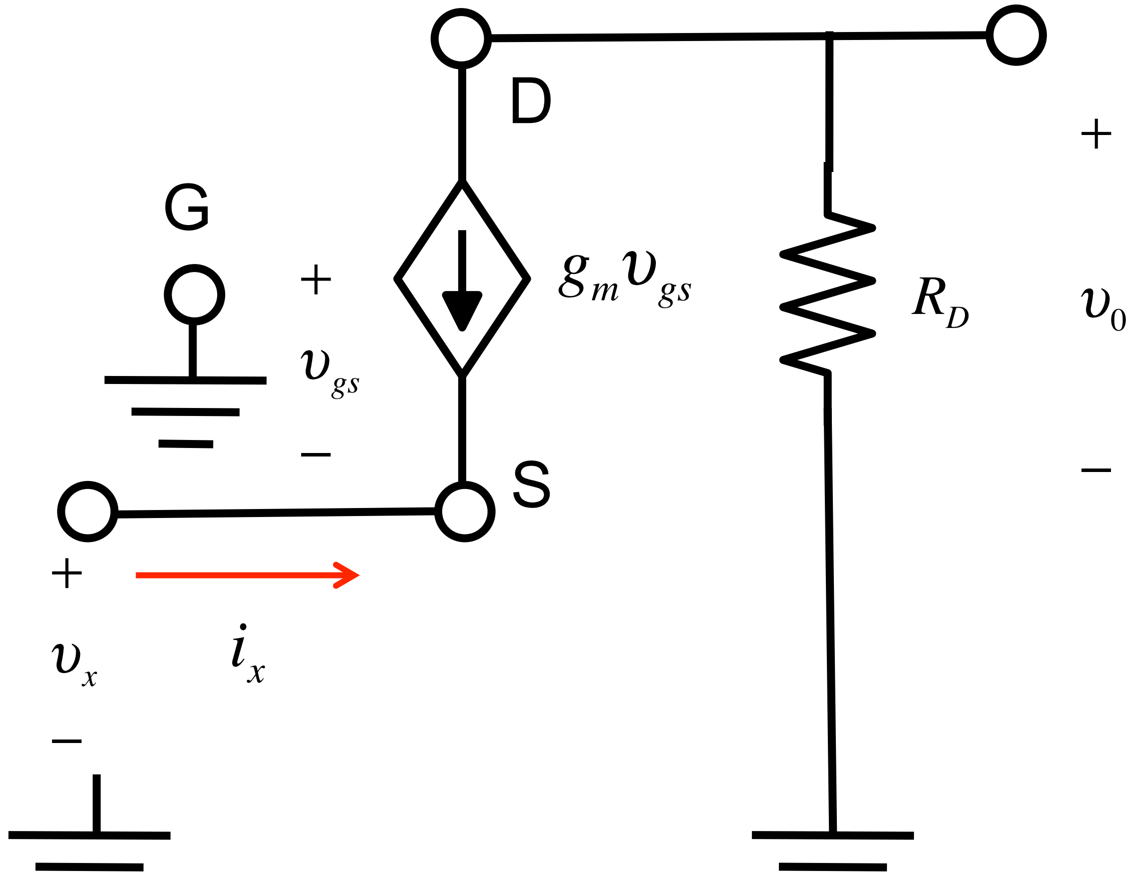
Input resistance (iii)

$$i_x = -g_m \upsilon_{gs}$$

$$i_x = +g_m \upsilon_x$$

$$R_{th} = \frac{\upsilon_x}{i_x} = \frac{1}{g_m}$$

$$R_{th} \Rightarrow$$



Common base vs. common gate

CB

$$A_v = \frac{v_o}{v_i} = +g_m R_C$$

$$R_o = R_C$$

$$R_{in} = R_E \parallel r_\pi \parallel \frac{1}{g_m}$$

$$r_\pi \parallel \frac{1}{g_m} = \frac{r_\pi}{\beta + 1}$$

CG

$$A_v = \frac{v_o}{v_i} = +g_m R_D$$

$$R_o = R_D$$

$$R_{in} = R_S \parallel \frac{1}{g_m}$$

Outline

1) Basic amplifier considerations

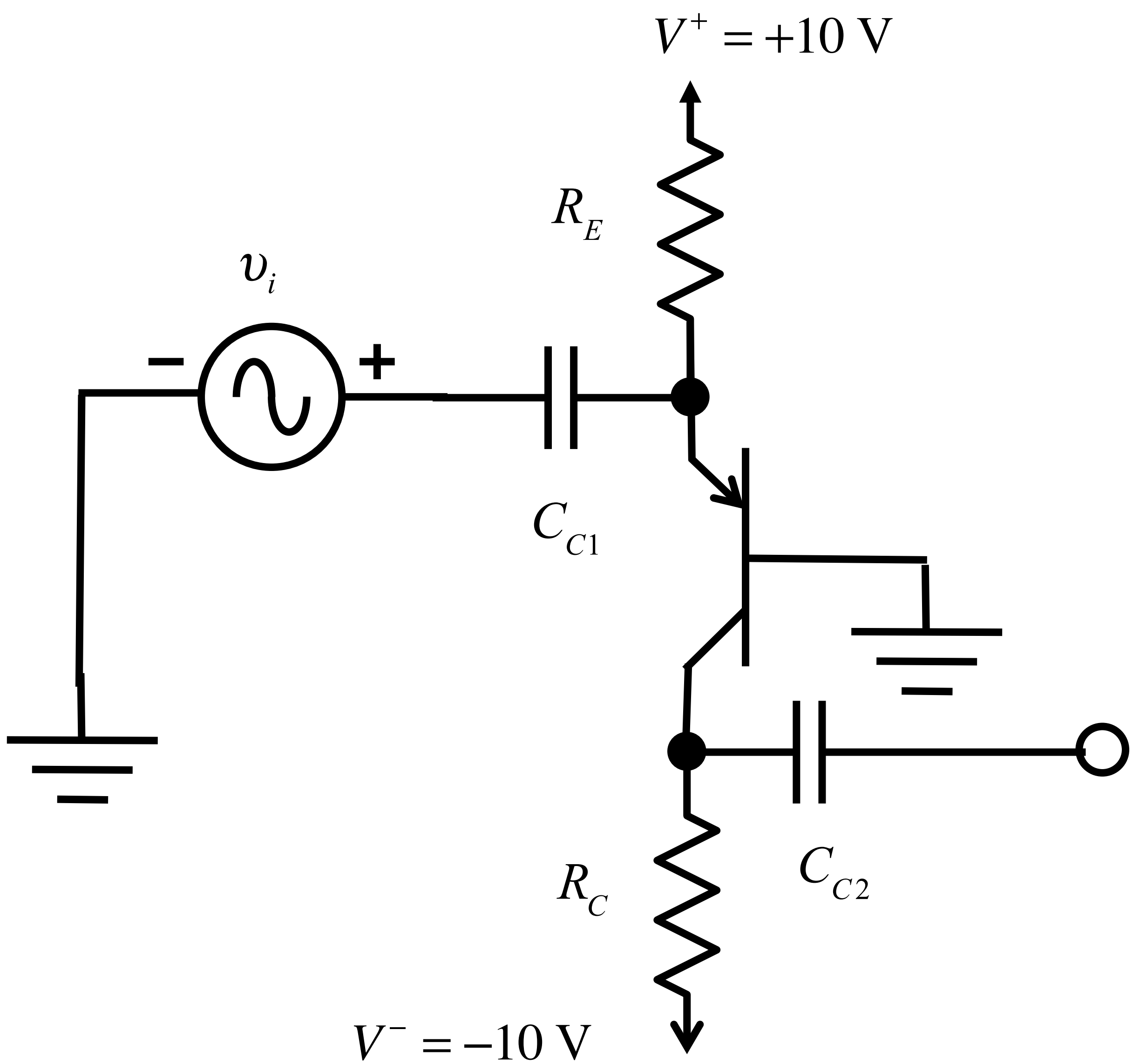
2) CE / CS

3) CB / CG

4) Common base example

5) CC (emitter follower) / CD (source follower)

Realistic Common base amplifier



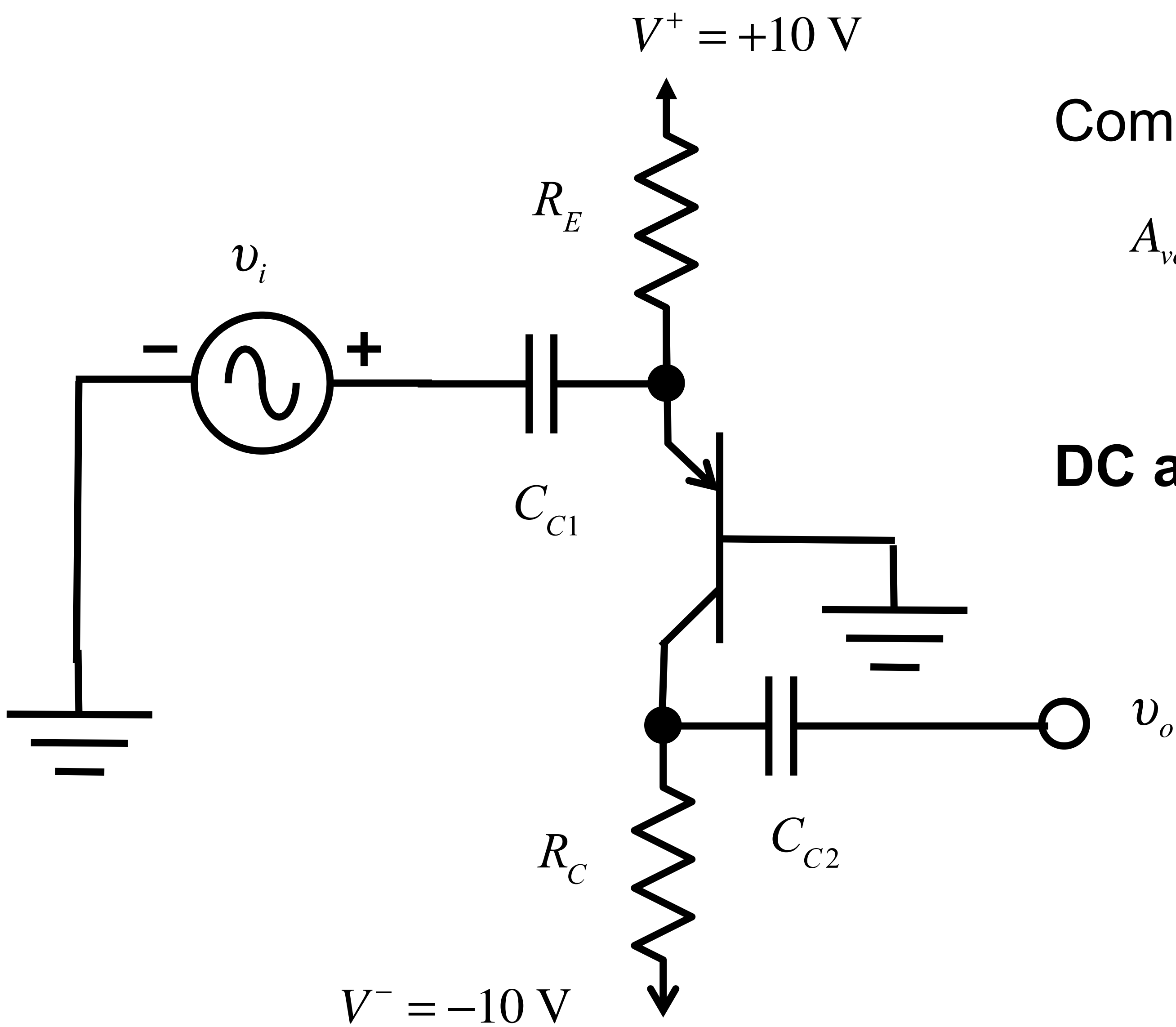
Compute:

A_{vo} R_{in} R_o

Size of Capacitors?

Audio frequencies: 20 – 20,000 Hz

Realistic Common base amplifier

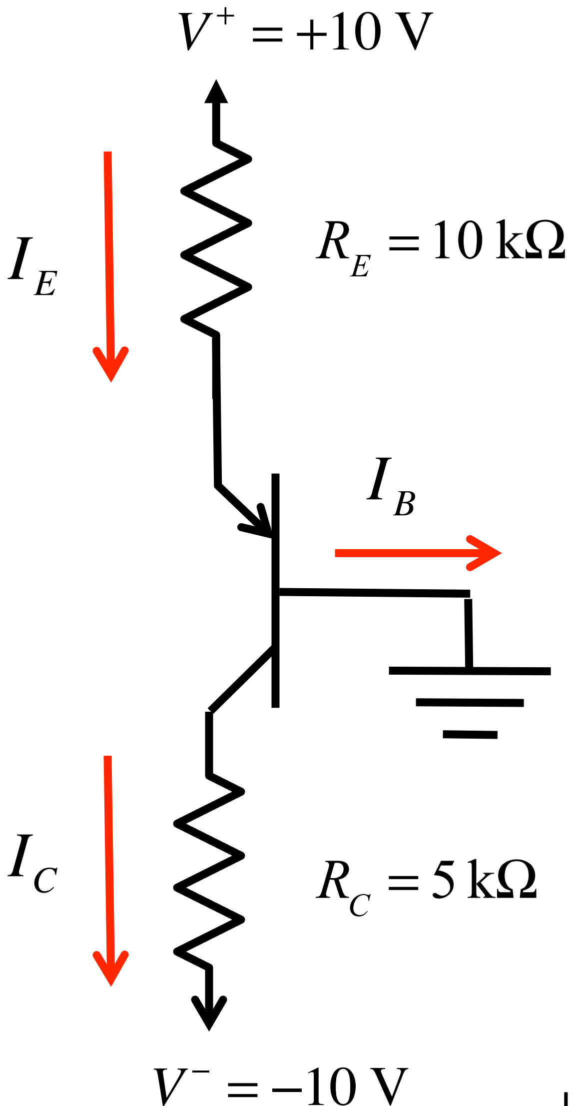


Compute:

A_{vo} R_{in} R_o

DC analysis first

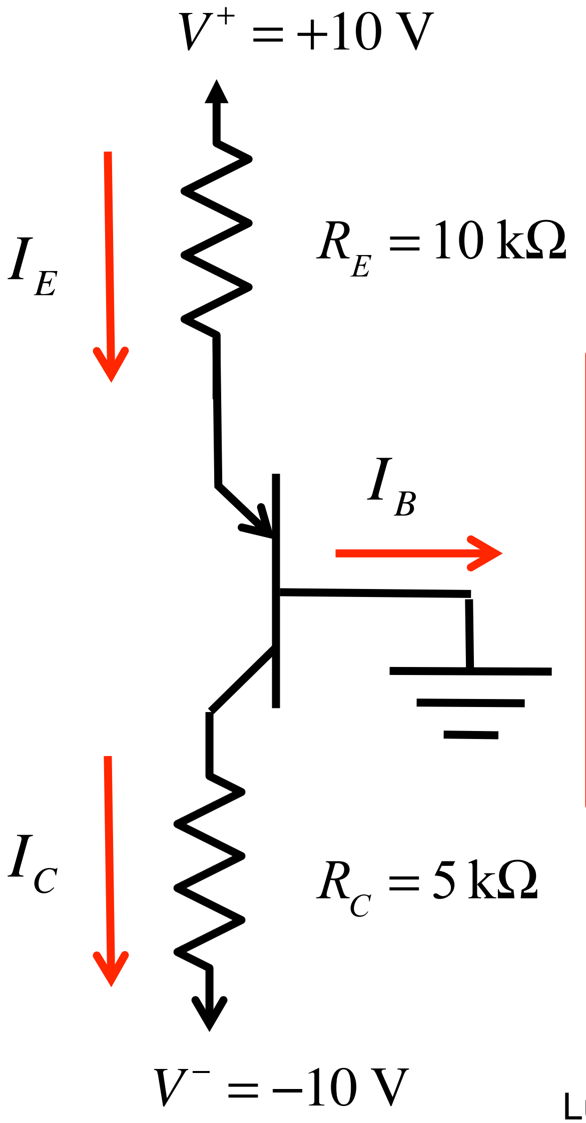
DC analysis



$\beta = 100$

$V_{BE} \approx 0.7$ V

DC analysis



$$g_m = \frac{I_C}{V_T} = 35.4\text{ mS}$$

$$r_\pi = \frac{\beta}{g_m} = 2.8\text{ k}\Omega$$

$\beta = 100$

$V_{BE} \approx 0.7\text{ V}$

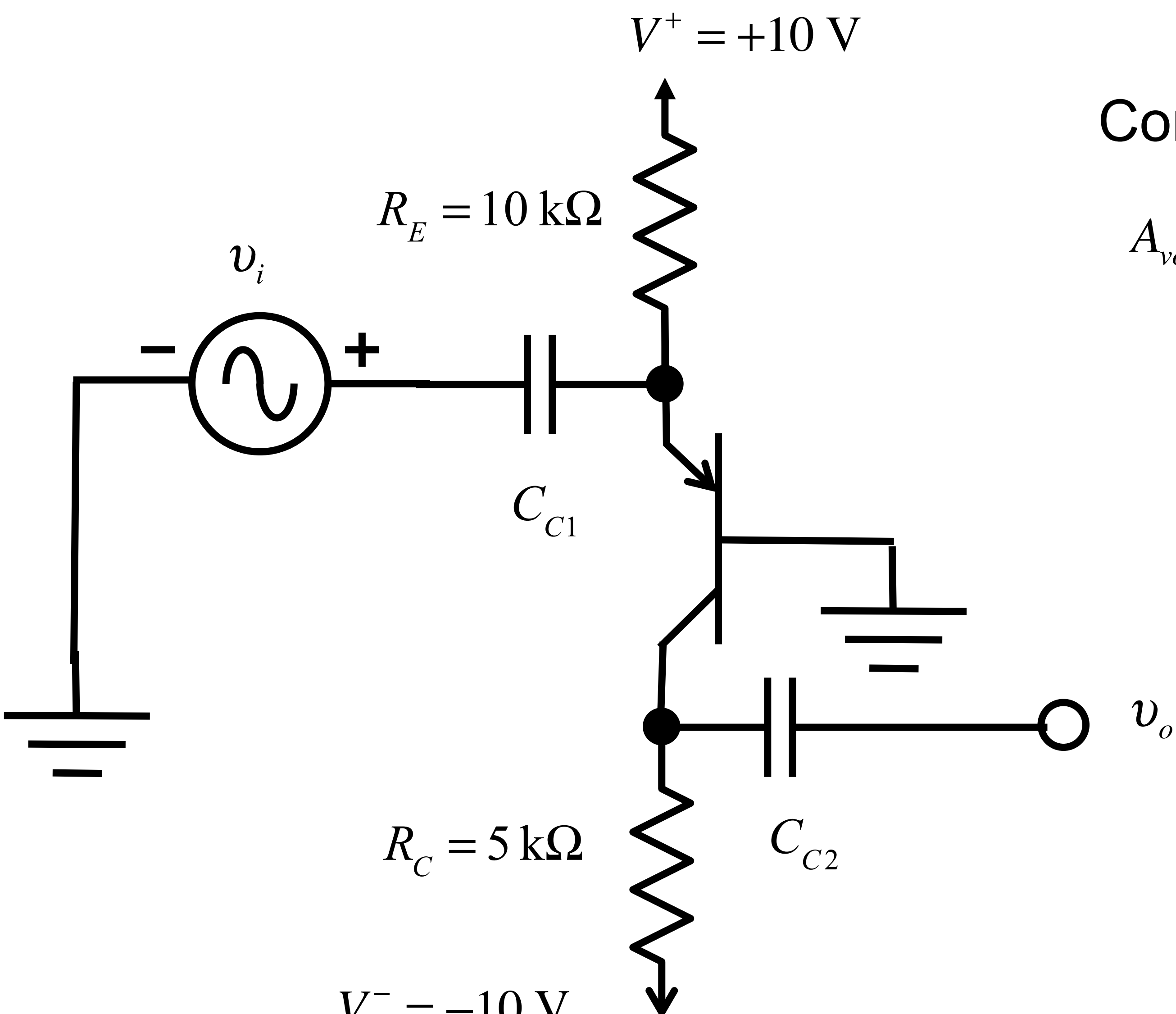
$I_E = 0.93\text{ mA}$

$I_C = 0.92\text{ mA}$

$V_C = -5.4\text{ V}$

$V_E = +0.7\text{ V}$

Realistic Common base amplifier



Compute:

A_{vo} R_{in} R_o

Outline

1) Basic amplifier considerations

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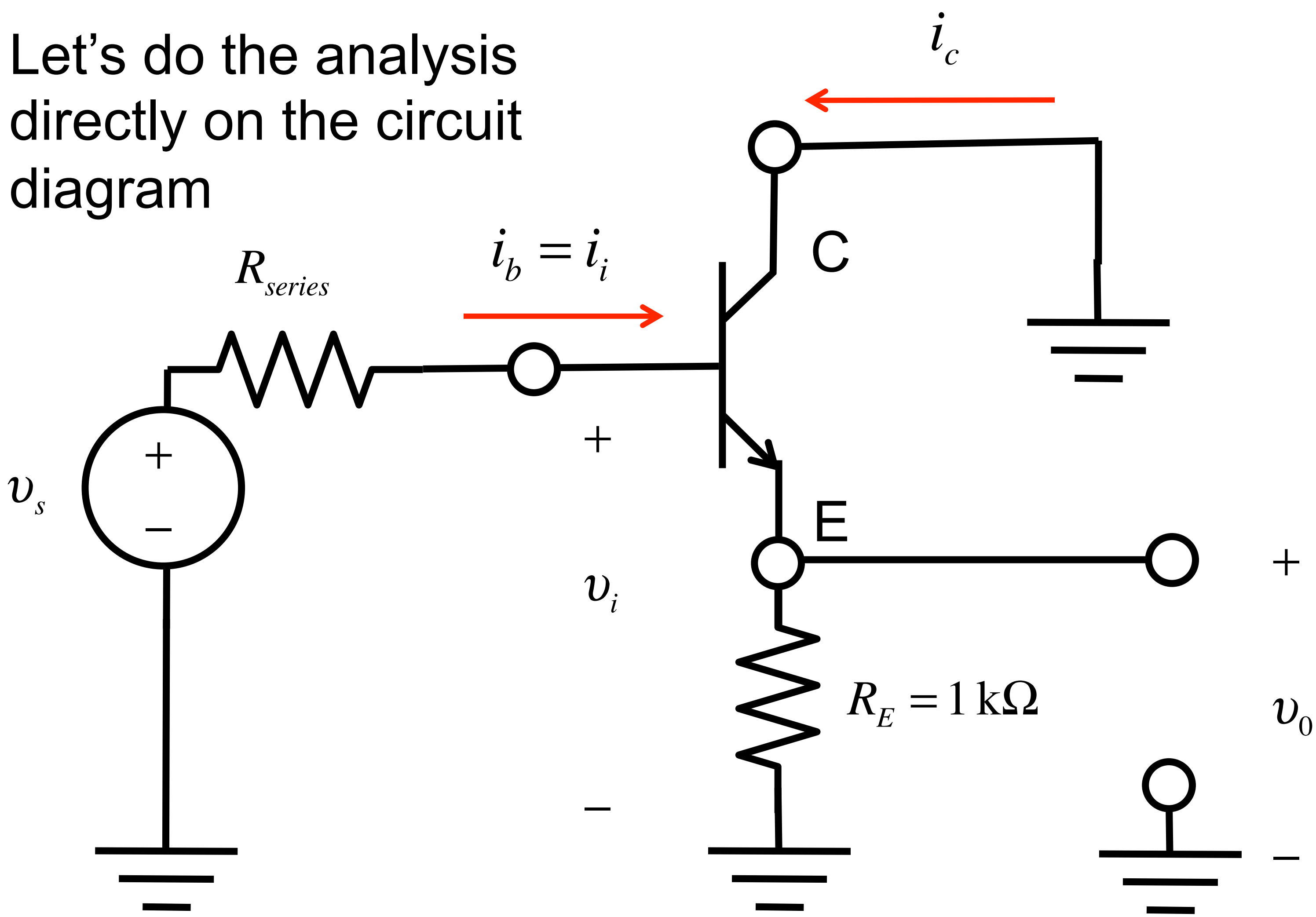
Common collector (emitter follower)

Let's do the analysis directly on the circuit diagram



CC by inspection

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

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

$$R_o = R_E \parallel \left(\frac{r_\pi + R_{series}}{\beta+1}\right)$$

$$A_{v_o} \approx 1$$

Emitter follower

CC is not a unilateral amplifier

CC by inspection

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

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

$$R_o = R_E \parallel \left(\frac{r_\pi + R_{series}}{\beta+1} \right)$$

Hybrid pi model

$$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = +\frac{R_E}{\frac{r_\pi}{\beta+1} + R_E} = \frac{R_E}{r_e + R_E}$$

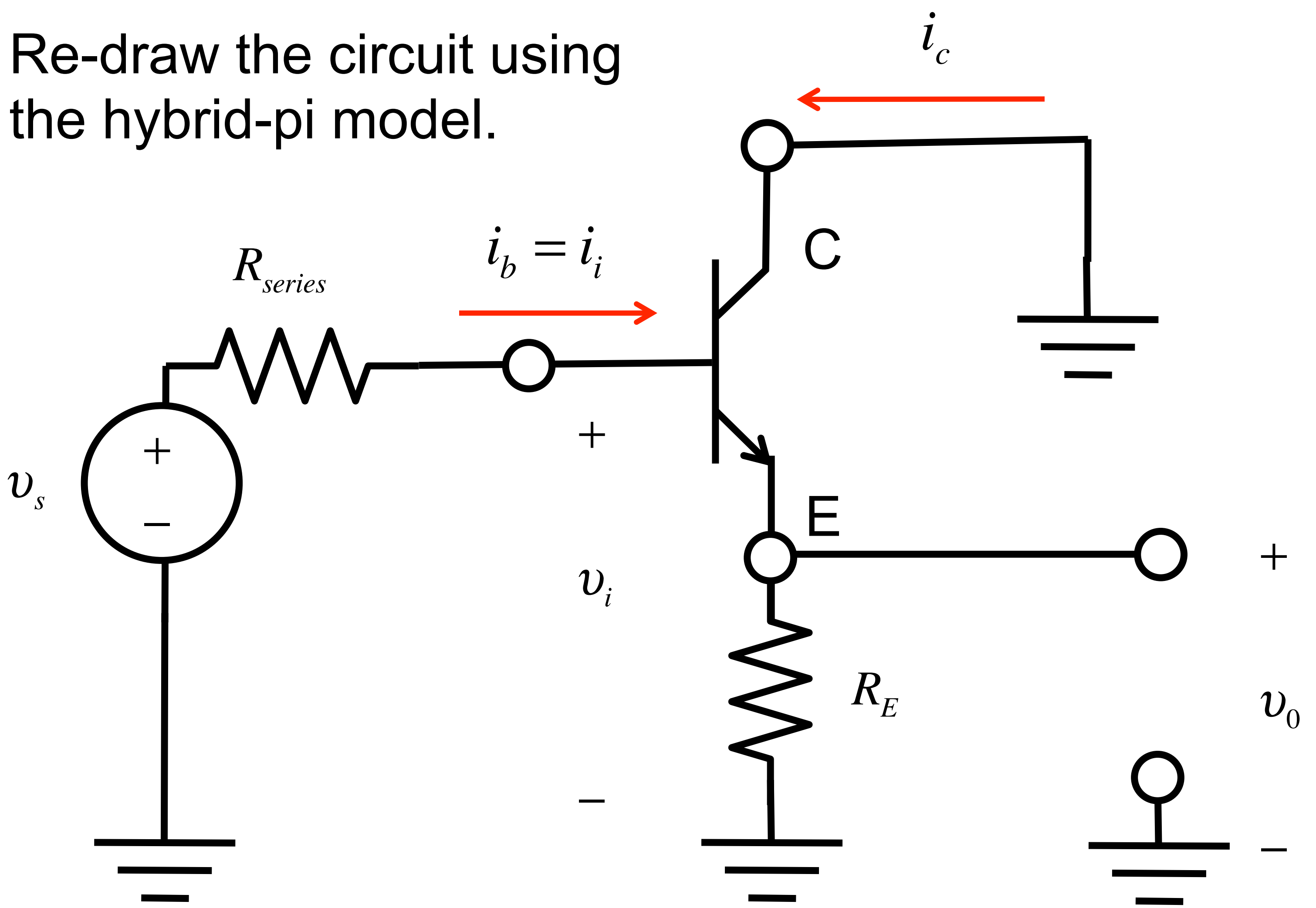
$$R_{in} = r_\pi + (\beta+1)R_E = (\beta+1)(r_e + R_E)$$

$$R_o = R_E \parallel \left(r_e + \frac{R_{series}}{\beta+1} \right)$$

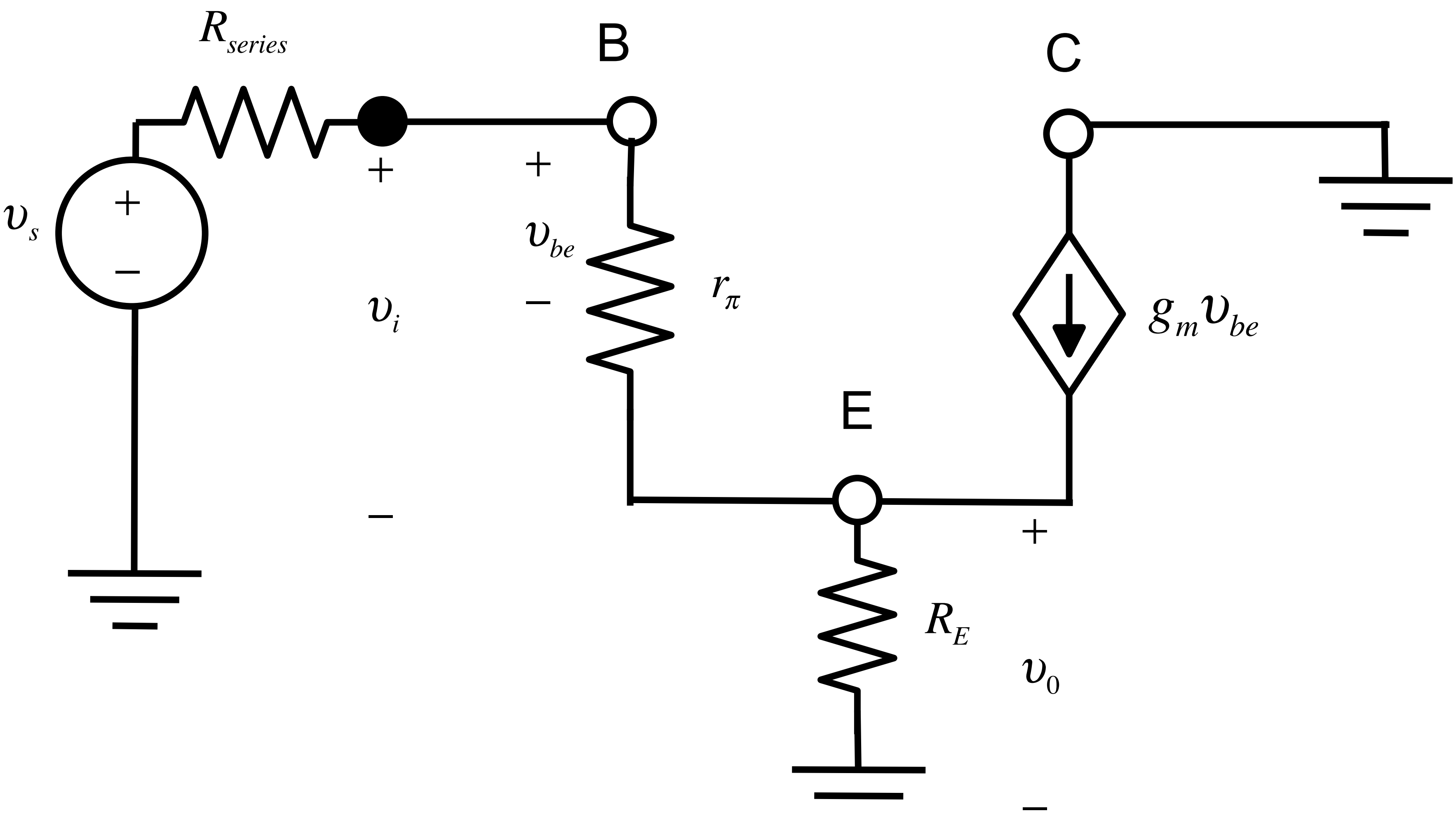
T model

Common collector analysis with hybrid-pi model

Re-draw the circuit using the hybrid-pi model.



Small signal equivalent circuit



Small signal analysis

$A_{\upsilon_o} = ?$

$R_{in} = ?$

$R_E = 1\ \mathrm{k}\Omega$

$R_o = ?$

CC numbers

"emitter follower"

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

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

$$R_o = R_E \parallel \left(\frac{r_\pi}{\beta+1}\right) \approx R_E \parallel \left(\frac{1}{g_m}\right)$$

$$A_{\upsilon_o} = \frac{(101)1}{2.6+(101)1} = +0.98$$

$$R_{in} = 2.6\text{ k}\Omega + (101)1\text{ k}\Omega = 104\text{ k}\Omega$$

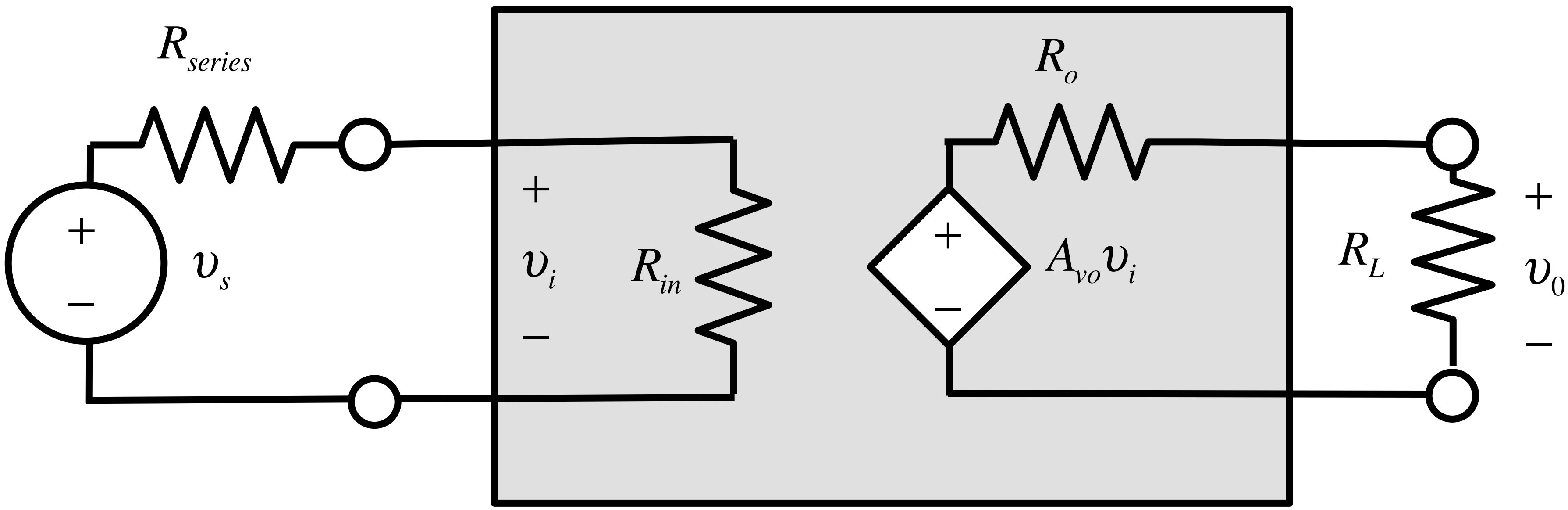
$$R_o = 1\text{ k}\Omega \parallel \frac{2.6\text{ k}\Omega}{101} = 25\ \Omega$$

$$\frac{1}{g_m} = \frac{1}{39}\text{ k}\Omega = 26\ \Omega$$

$I_C = 1.0\text{ mA}$ $\beta = 100$ $g_m = 39\text{ mS}$ $r_\pi = 2.6\text{ k}\Omega$

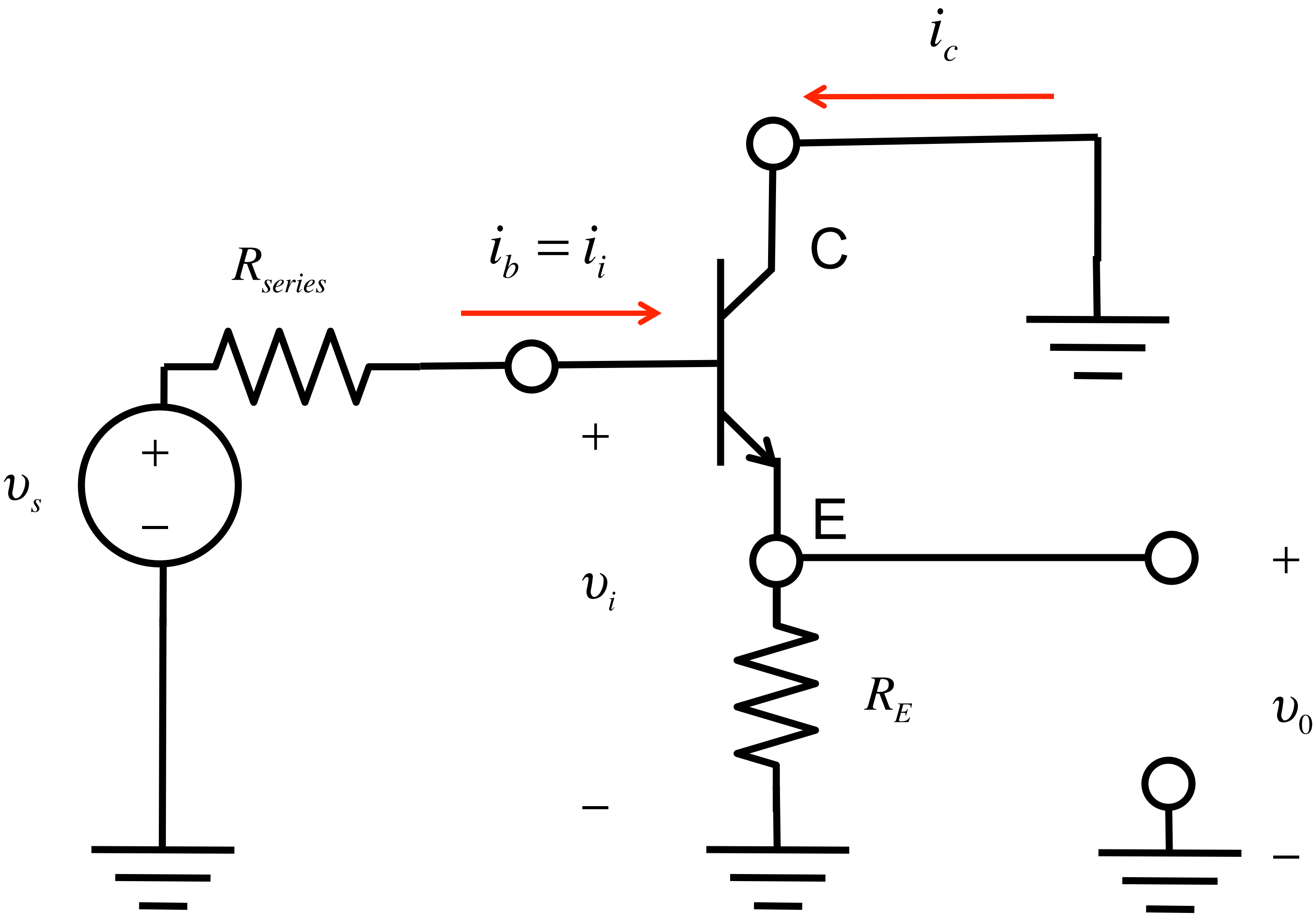
CC is a “voltage buffer”

A_{vo} R_{in} R_o



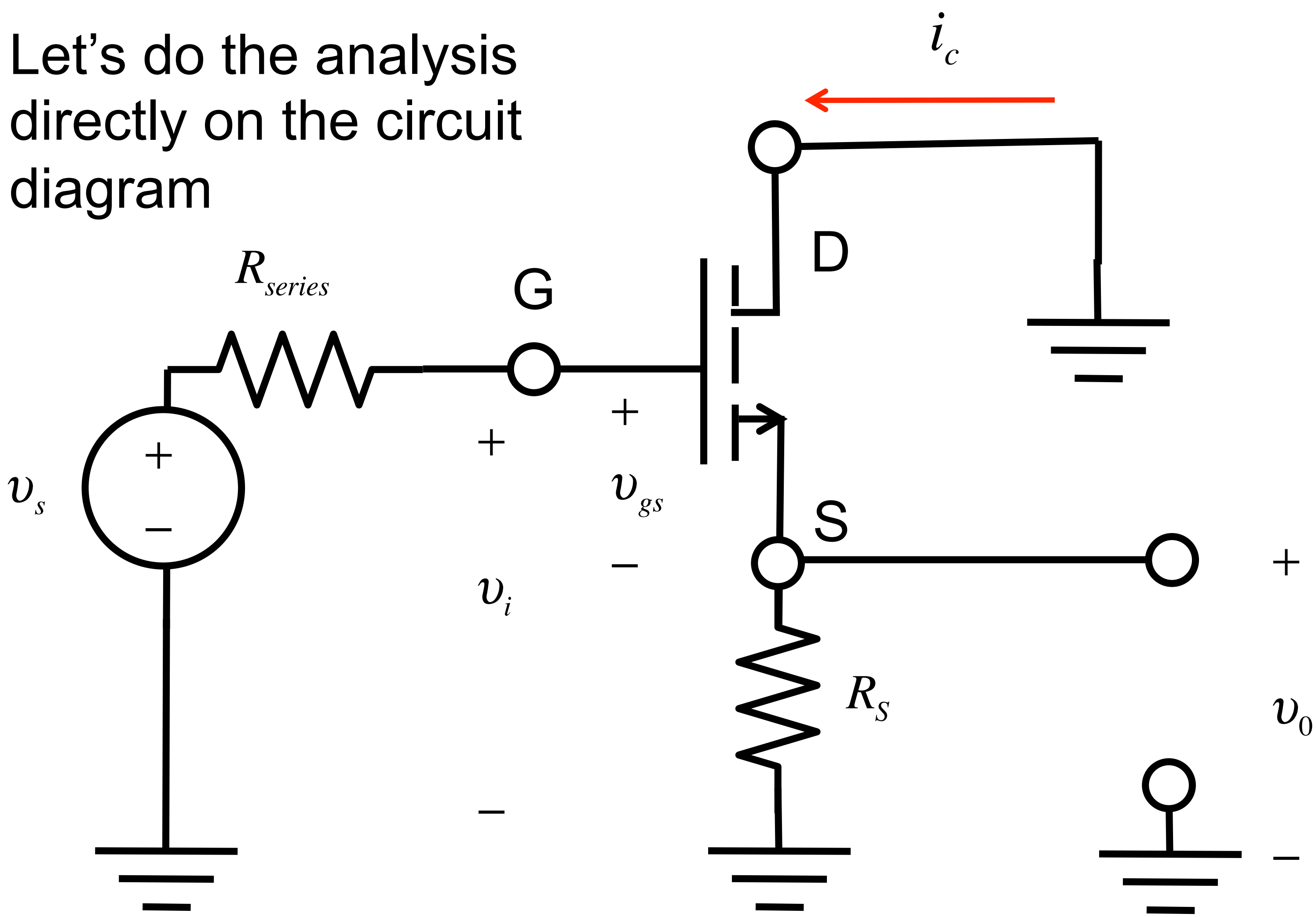
$$G_v = \frac{R_{in}}{R_{in} + R_{series}} \times A_{vo} \times \frac{R_L}{R_L + R_o} \qquad G_i = A_{vo}\frac{R_{in}}{R_L} \qquad G_p = G_v G_i$$

CC to CD



Common Drain (Source follower)

Let's do the analysis directly on the circuit diagram



CC vs. CD

source follower

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

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

$$R_o = R_E \parallel \left(\frac{r_\pi}{\beta+1}\right) \approx R_E \parallel \left(\frac{1}{g_m}\right)$$

$$A_{v_o} = \frac{v_o}{v_i} = +\frac{g_m R_S}{1 + g_m R_S}$$

$$R_{in} = \infty$$

$$R_o = R_S \parallel \left(\frac{1}{g_m}\right)$$

Outline

1) Basic amplifier considerations

2) CE / CS

3) CB / CG

4) Common base example

5) CC (emitter follower) / CD (source follower)

BJT Amplifier summary

Common emitter	Common base	Common collector
$A_{v_o} = -g_m R_C$	$A_{v_o} = +g_m R_C$	$A_v = \dfrac{(\beta+1)R_E}{r_\pi + (\beta+1)R_E}$
< 0, | high |	**>0, | high |**	**~1**
$R_{in} = r_\pi$	$R_{in} = R_E \parallel \dfrac{r_\pi}{\beta+1}$	$R_{in} = r_\pi + (\beta+1)R_E$
moderate	**low**	**high**
$R_o = R_C$	$R_o = R_C$	$R_o = R_E \parallel \left(\dfrac{r_\pi}{\beta+1}\right)$
moderate	**moderate**	**low**

BJT Amplifier summary

Common emitter with R_E

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

< 0 , |moderate|

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

high

$$R_o = R_C$$

moderate

MOS Amplifier summary

Common source **Common gate** **Common drain**

Summary

The **Common Emitter** amplifier has a voltage gain that is large in magnitude and with a **negative** sign. It has moderate input and output resistance.

The **Common Source** amplifier has a voltage gain that is moderate in magnitude and with a **negative** sign. It has a high input resistance and moderate output resistance.

The **Common Base** amplifier has a voltage gain that is large in magnitude and with a **positive** sign. It has low input resistance and moderate output resistance.

The **Common Gate** amplifier has a voltage gain that is lmoderate in magnitude and with a **positive** sign. It has fairly low input resistance and moderate output resistance.

Summary

The **Common Collector (emitter follower) amplifier** has a voltage gain of about one, It has high input resistance and a very low output resistance.

The **Common Drain (source follower) amplifier** has a voltage gain of a little less than one, It has a very high input resistance and a moderately low output resistance.

Basic Amplifier Configurations: II

1) Basic amplifier considerations

2) CE / CS

3) CB / CG

4) Common base example

5) CC (emitter follower) / CD (source follower)