ELC1408- Level 1
Analog Electronics

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Lecture #1

Course Introduction

➢ Course Details

Course Code	ELC 1408
Course Name	Analog Electronics
Coordinating Unit	Electronics and Communications Engineering Department, Faculty of Engineering, Helwan University
Term	Semester 2 (Spring)
Level	Undergraduate -Level 1

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➢Course Staff

➢ Instructor

- Dr. Eman Farouk

➢ Teaching Assistant

- Eng. Eman Hasan
- Eng. Mohamed Hassan Elarabawy

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الفصل الدراســى الثـانى

كود المقرر	اسـم المقـرر	عدد الساعات الأسبوعية				توزيـع الدرجـات			عدد ساعات الامتحان التحريرى	مجموع درجات المقرر	الساعات المعتمدة
		محاضرة	تطبيقـات		مجموع	أعمال سنة	عملى وشفوى	تحريرى			
			تمرين	معمل							
عام 1407	الرياضيات الهندسية (4)	2	2	-	4	30	-	70	3	100	3
إلك 1408	الإلكترونيات التناظرية	2	1	1	4	30	20	100	3	150	2
إلك 1409	مقدمة الاتصالات	3	1	1	5	30	20	100	3	150	3
حاس1410	برمجة الحاسب	2	-	2	4	20	30	100	3	150	3
إلك 1411	دوائر المنطق	2	1	1	4	20	20	60	3	100	2
عام 1412	الكتابة التقنية	2	-	-	2	30	-	70	2	100	2
إجمالى عدد الساعات الأسبوعية		**13**	**5**	**5**	**23**	**عدد الساعات المعتمدة**					**15**
						المجموع الكلى للدرجات				**1500**	

- تدريب صيفى بورش الإلكترونيات بالكلية لمدة ثلاثة أسابيع بعد امتحانات الفصل الدراسى الثانى للفرقة الأولى ترصد نتيجته (ناجح أو راسب فقط وبدون درجات) فى الفصل الدراسى الأول للفرقة الثانية.

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➢ Textbooks

- Sedra/Smith, "*Microelectronic circuits*", Sixth edition.
- Floyd, "*Electronic Devices*", 9th-edition.

ELC 1708: Course outlines

The main contents of the course are:

- Introduction
  - Amplifiers
- Frequency response of amplifiers
  - Low-Frequency Response of the CS and CE Amplifiers
  - High-Frequency Response of the CS and CE Amplifiers
  - The High-Frequency Model of the MOSFET and the BJT

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ELC 1708: Course outlines

The main contents of the course are:

- Differential Amplifiers
- Multistage amplifiers
  - RC coupling
  - Direct coupling
  - transformer coupling

Introduction

- Semiconductors
- Diodes
- Transistors

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Types of Transistors

- There are two major types of three-terminal semiconductor devices:
  - **The bipolar junction transistor (BJT)**
  - **Field Effect Transistor (FET)**
    - **the metal-oxide semiconductor field-effect transistor (MOSFET)**

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Uses of Transistors

- Electrically controlled switch (digital circuits/computers)
- Amplifier
- Resistor with value electrically controlled

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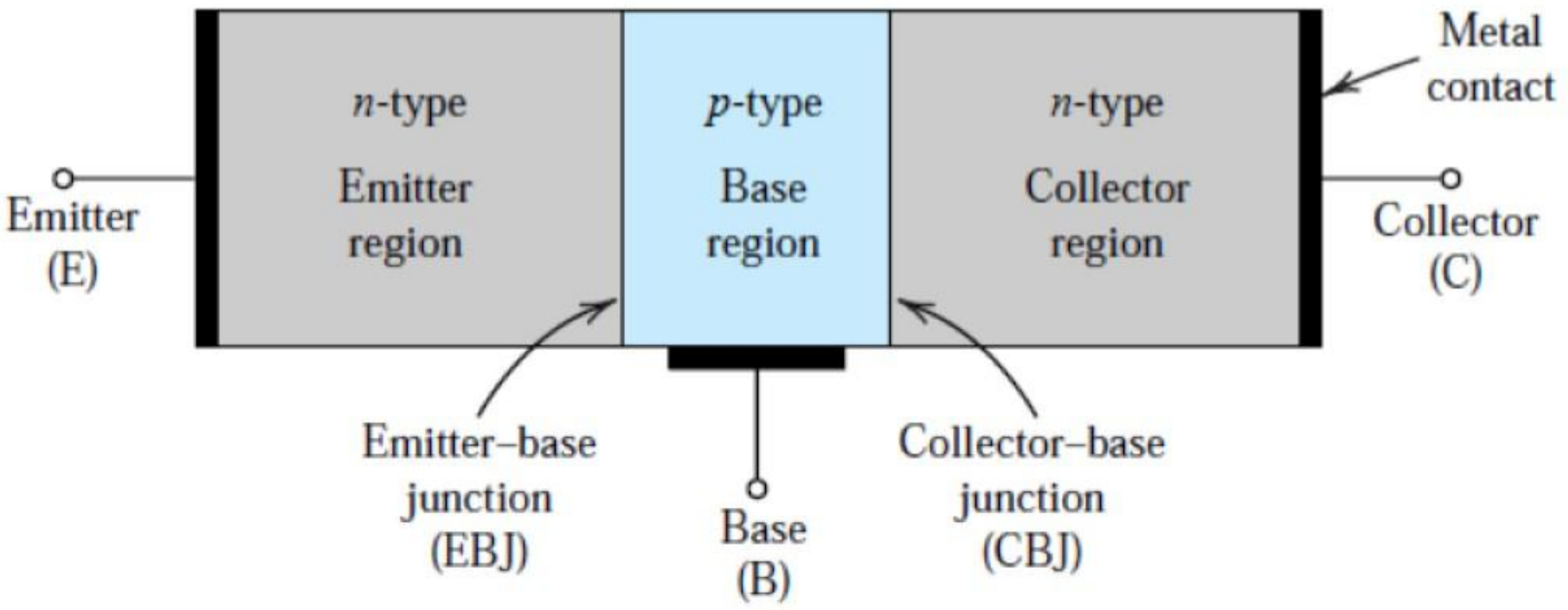
The bipolar junction transistor (BJT)

Structure of Bipolar Junction Transistor



A simplified structure of the *npn* transistor.

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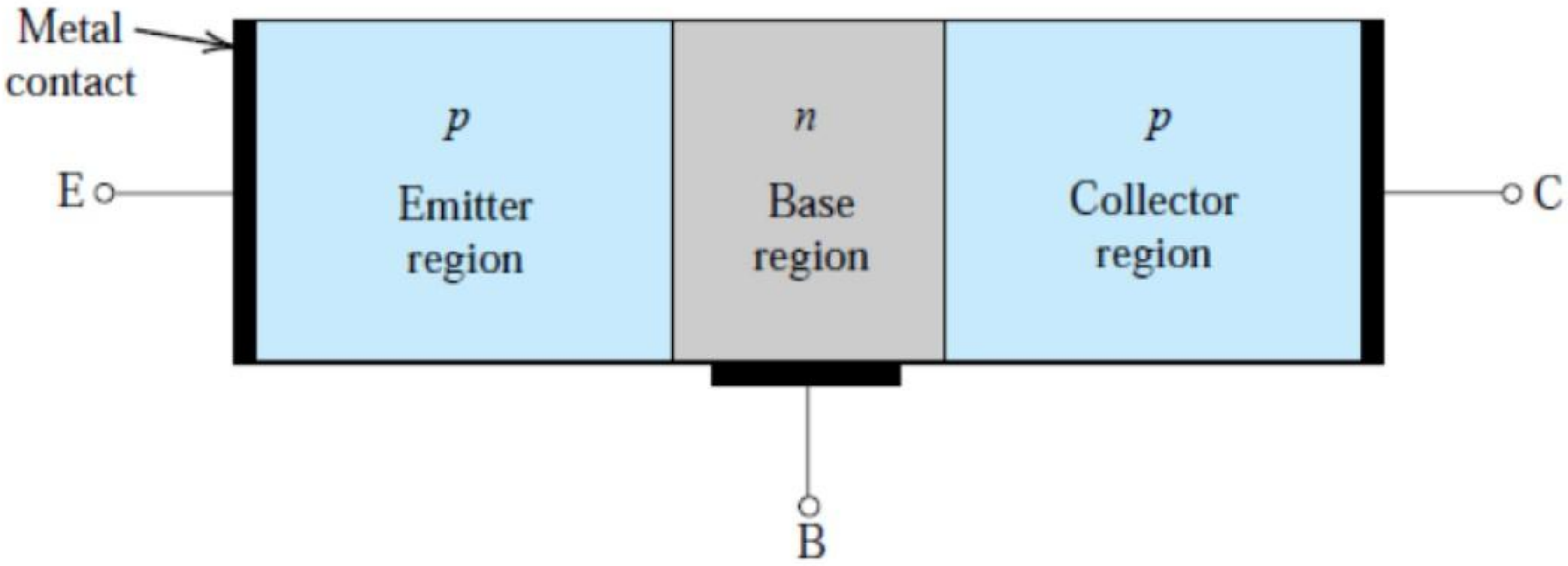
Structure of Bipolar Junction Transistor



A simplified structure of the *pnp* transistor.

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Regions of Operation

Emitter-Base junction	Collector-Base juncion	Mode of operation	Applications
Reverse	Reverse	Cutoff mode	Electronic Switch
Forward	Forward	Saturation mode	
Forward	Reverse	Active mode	Amplifier

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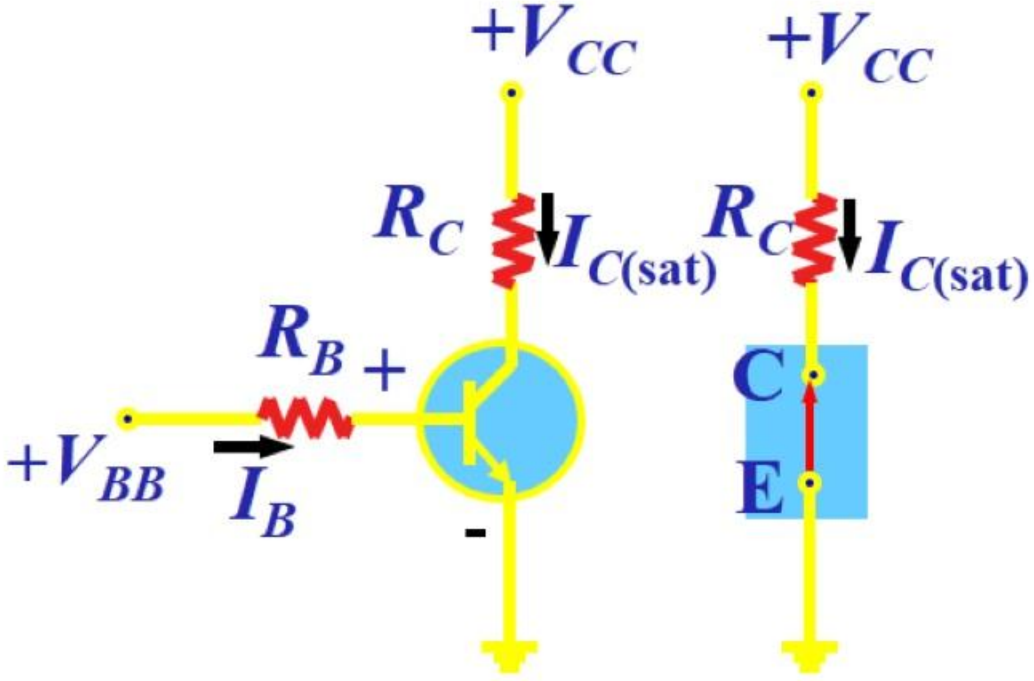
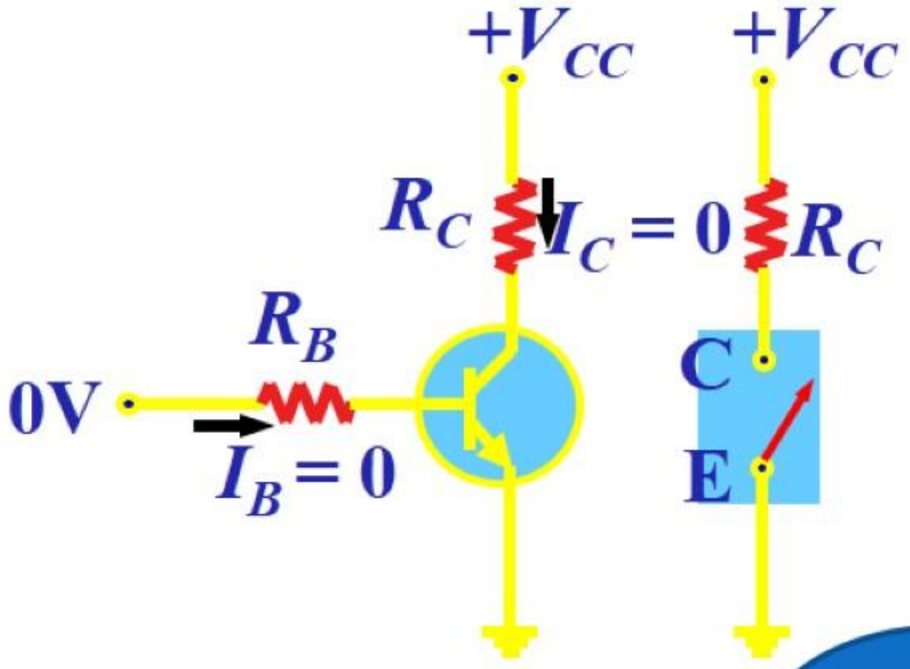
Transistor Applications

The Bipolar Transistor as a Switch

When used as an electronic switch, a transistor is normally operated alternately in cutoff and saturation.



Saturation –Closed switch



Cutoff – open switch

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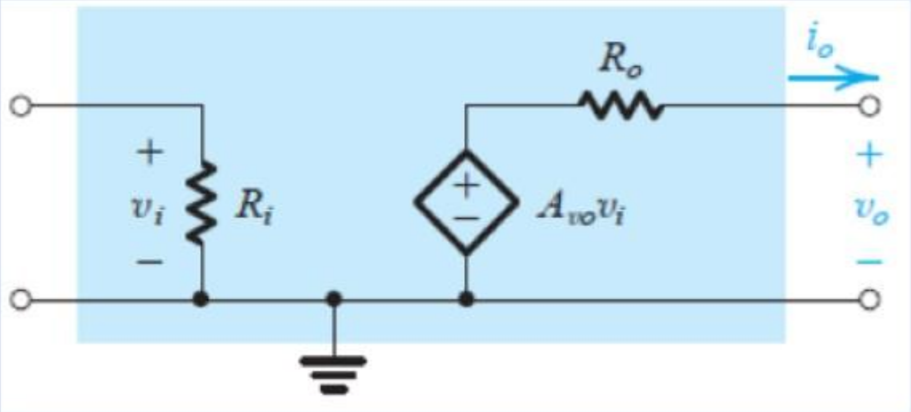
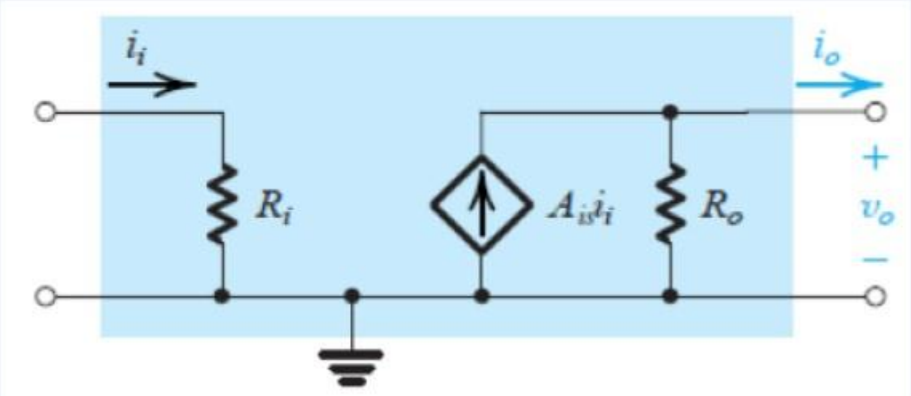
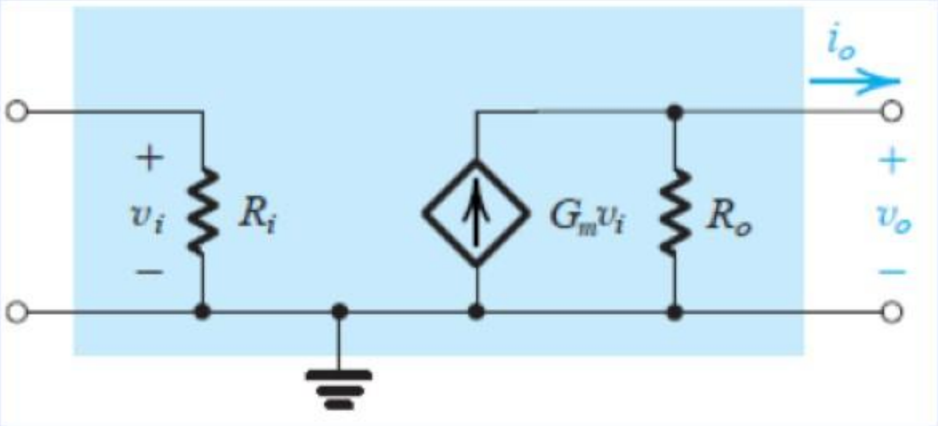
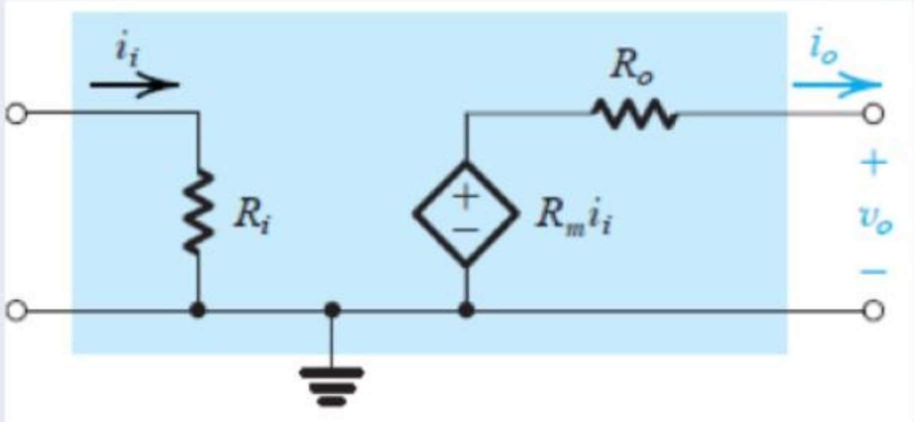
The BJT as an Amplifier

The Four Amplifier Types:

Type	Circuit Model	Gain Parameter	Ideal Characteristics
Voltage amplifier		Open circuit voltage gain $=A_{vo} = \frac{v_o}{v_i}\Big\vert_{i_o=0}$ (V/V)	$R_i = \infty$, $R_o = 0$
Current amplifier		Short circuit current gain $=A_{is} = \frac{i_o}{i_i}\Big\vert_{v_o=0}$ (A/A)	$R_i = 0$, $R_o = \infty$

The Four Amplifier Types:

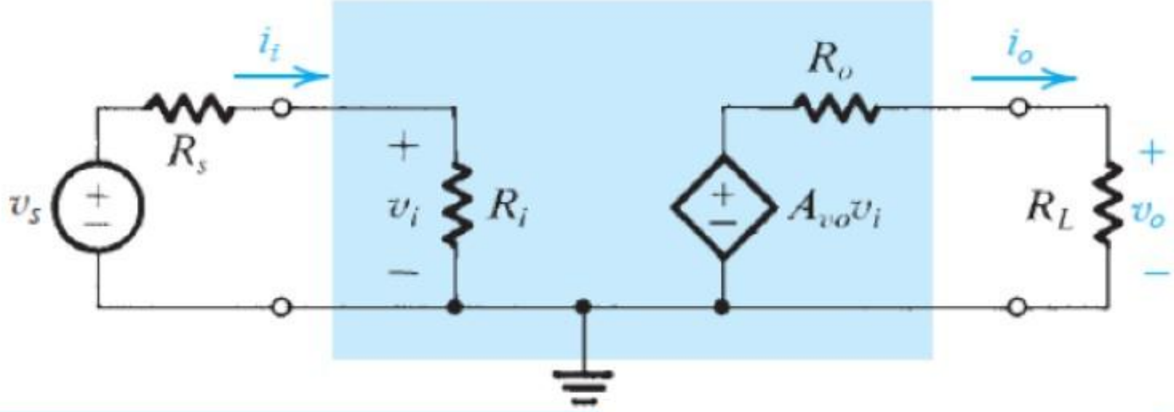
Type	Circuit Model	Gain Parameter	Ideal Characteristics
Transconductance amplifier		Short circuit Transconductance $= G_m = \left.\frac{i_o}{v_i}\right\|_{v_o=0}$ (A/V)	$R_i = \infty$, $R_o = \infty$
Transresistance amplifier		Open circuit Transresistance $= R_m = \left.\frac{v_o}{i_i}\right\|_{i_o=0}$ (V/A)	$R_i = 0$, $R_o = 0$

Objective

- Implementing a voltage amplifier Circuit on the transistor level
- <u>**What are the Specifications for an Ideal Voltage Amp.?**</u>
  - Infinite Input Resistance: R_{in}
  - Infinite **open circuit voltage gain.**: A_{vo}
  - Finite Output Resistance (Short Circuit): R_{out}

$$A_{vo} \equiv \left.\frac{v_o}{v_i}\right|_{R_L=\infty}$$

$$A_v = \frac{v_o}{v_i} = A_{vo}\,\frac{R_L}{R_L + R_o}$$



The overall voltage gain $G_v = \frac{v_o}{v_s} = A_{vo}\,\frac{R_L}{R_L+R_o}\,\frac{R_i}{R_i+R_s}$

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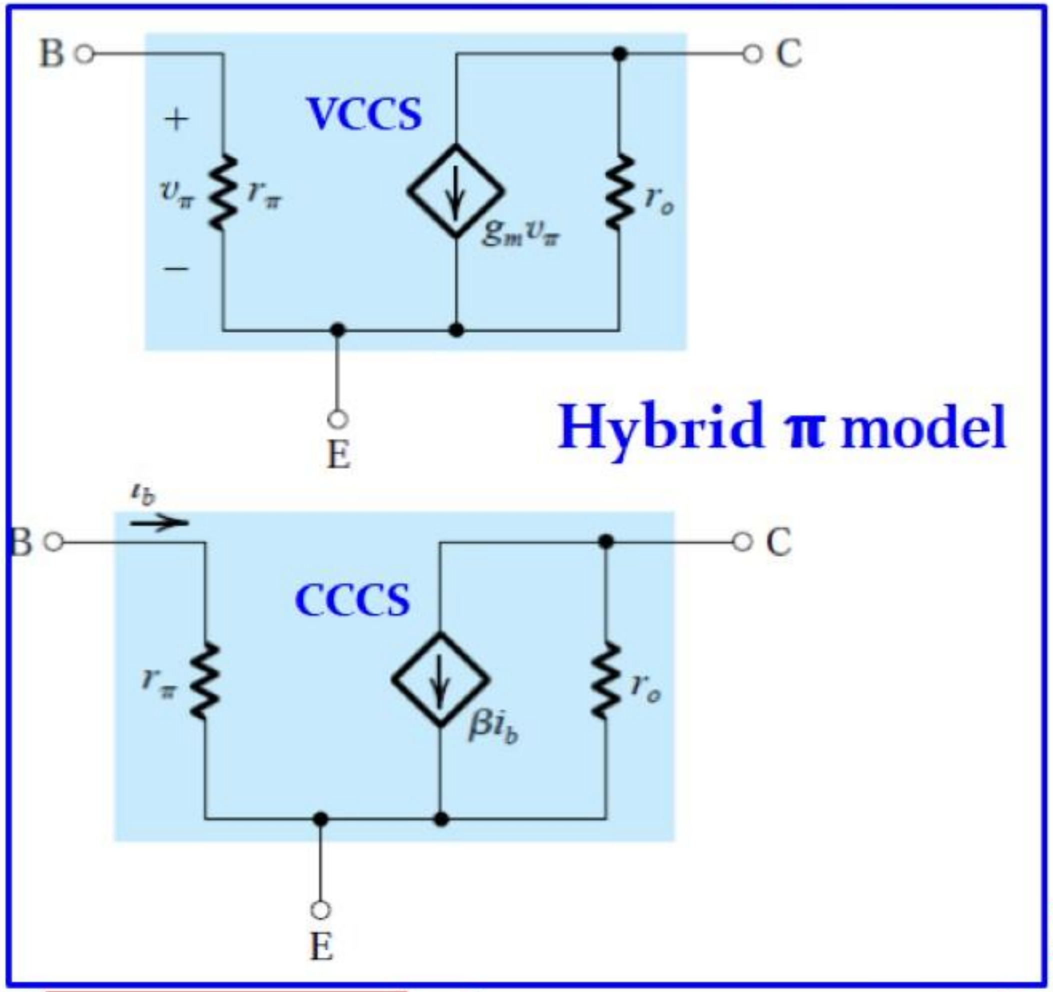
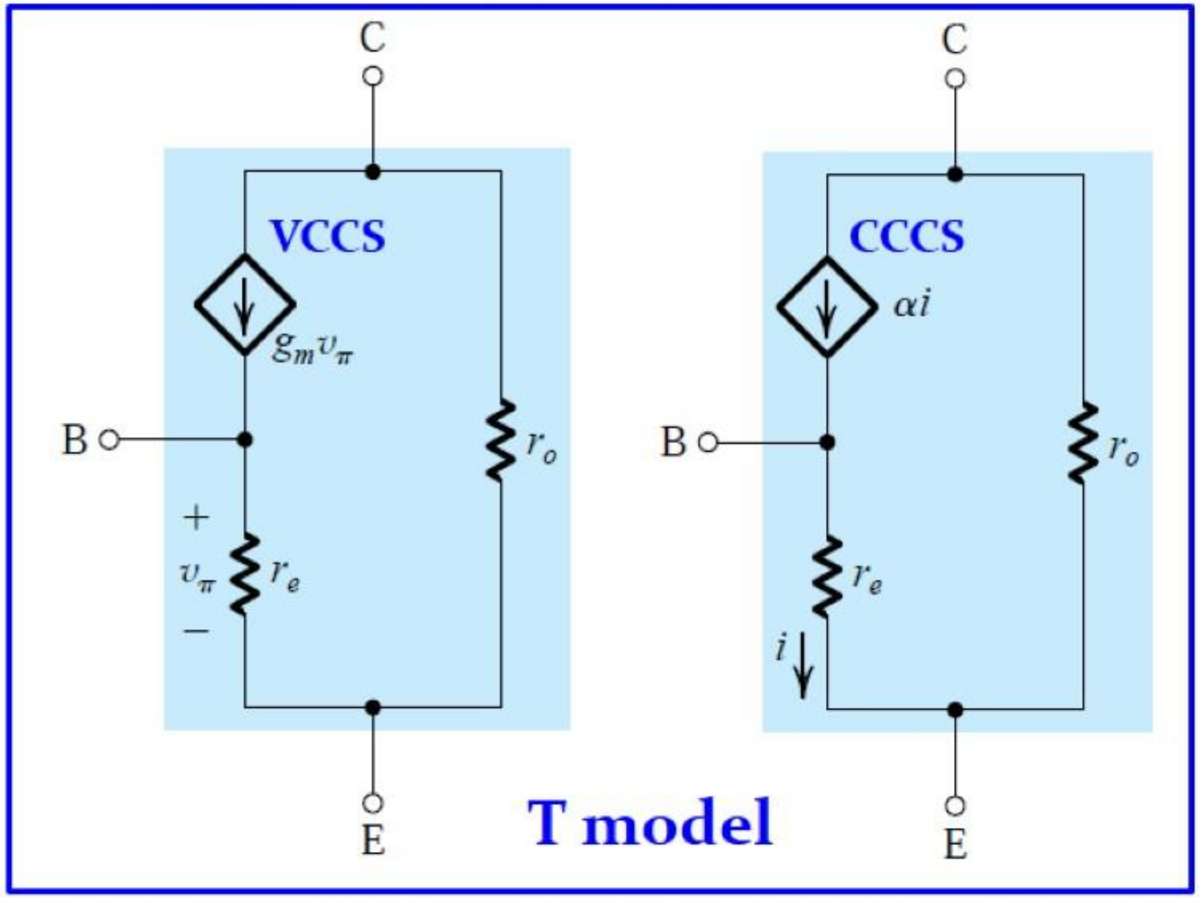
BJT Amplifiers Configurations

Summary of the Small Signal Models of BJT





Model Parameters in Terms of DC Bias Currents

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

$$r_\pi = \frac{V_T}{I_B} = \beta \frac{V_T}{I_C}$$

$$r_e = \frac{V_T}{I_E} = \alpha \frac{V_T}{I_C} = \frac{\alpha}{g_m}$$

$$r_o = \frac{|V_A|}{I_C}$$

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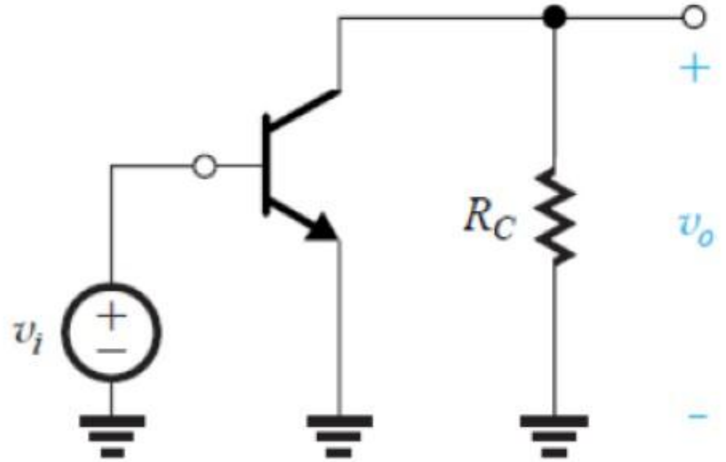
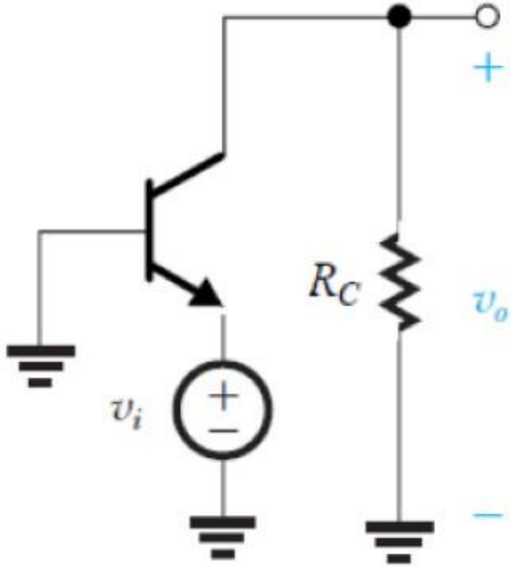
Basic Configurations of BJT Amplifiers

➢ There are three basic configurations for connecting the BJT as an amplifier. Each of these configurations is obtained by connecting one of the three BJT terminals to ground, thus creating a two-port network with the grounded terminal being *common* to the input and output ports.

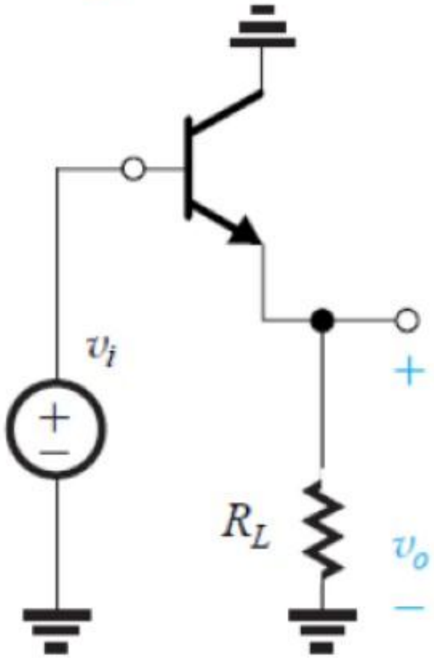


Common emitter

It is the mostly used configuration



Common Base



Common collector

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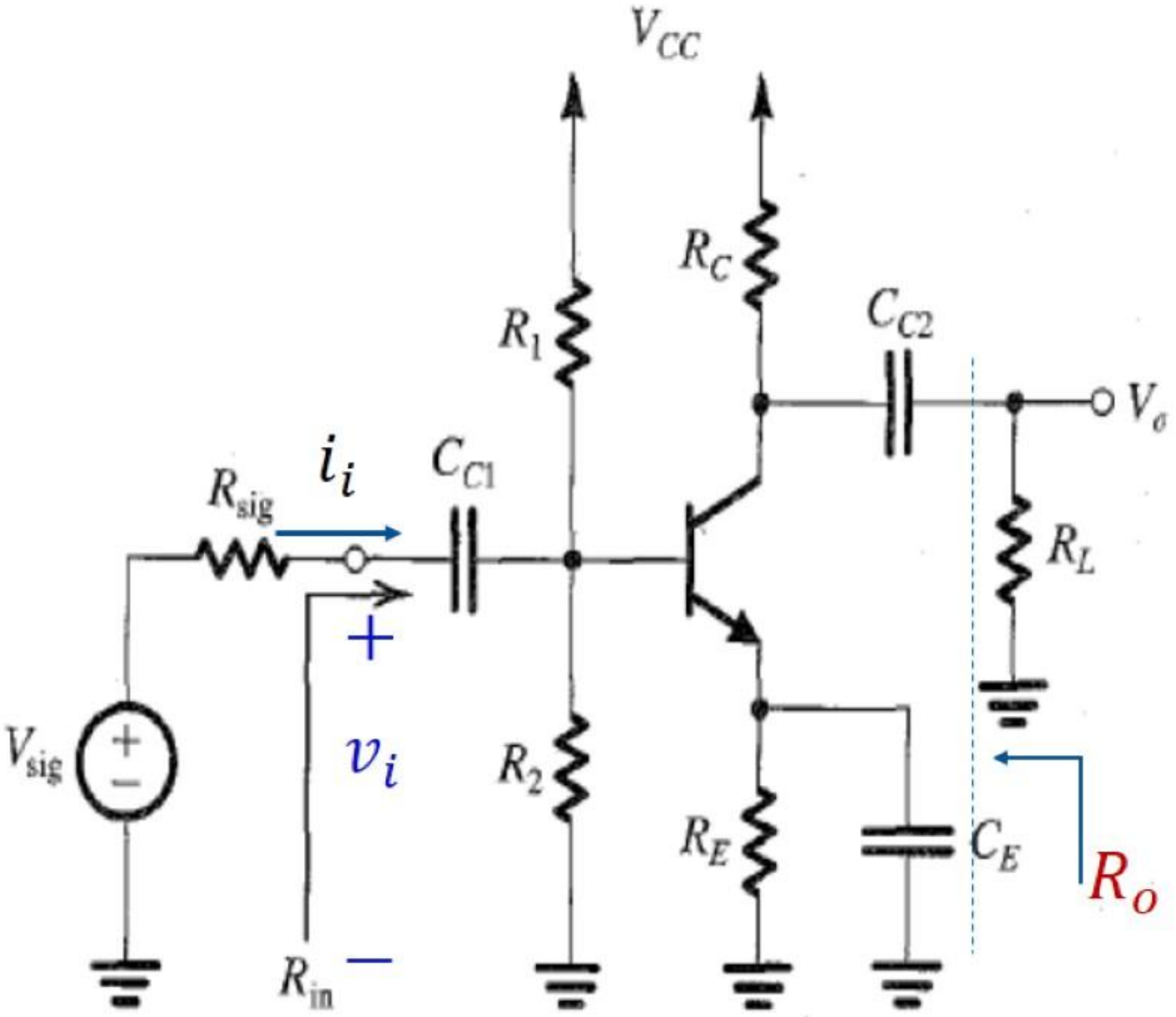
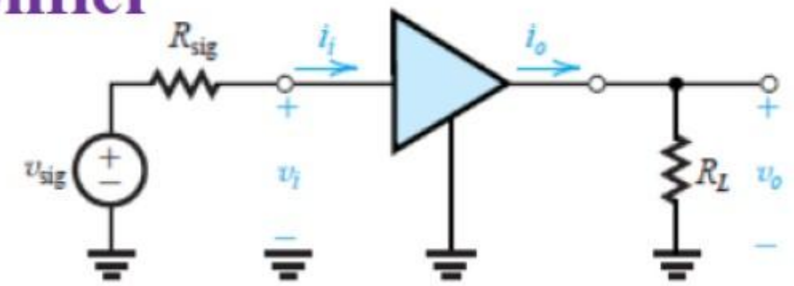
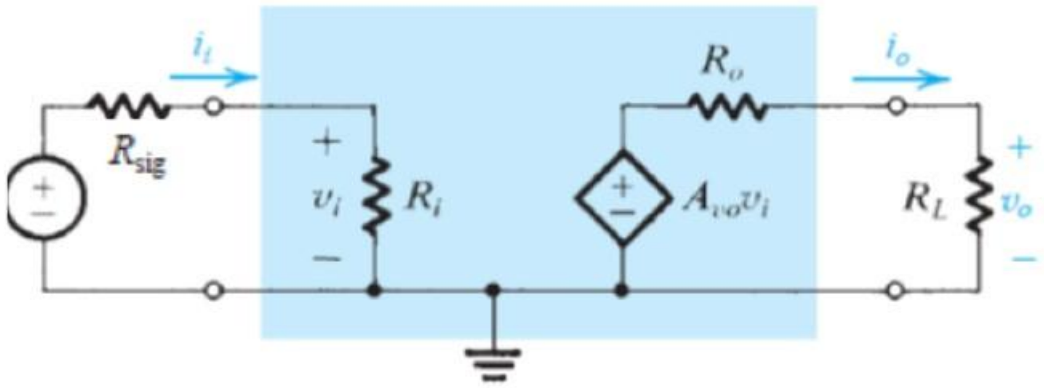
The Common Emitter Amplifier







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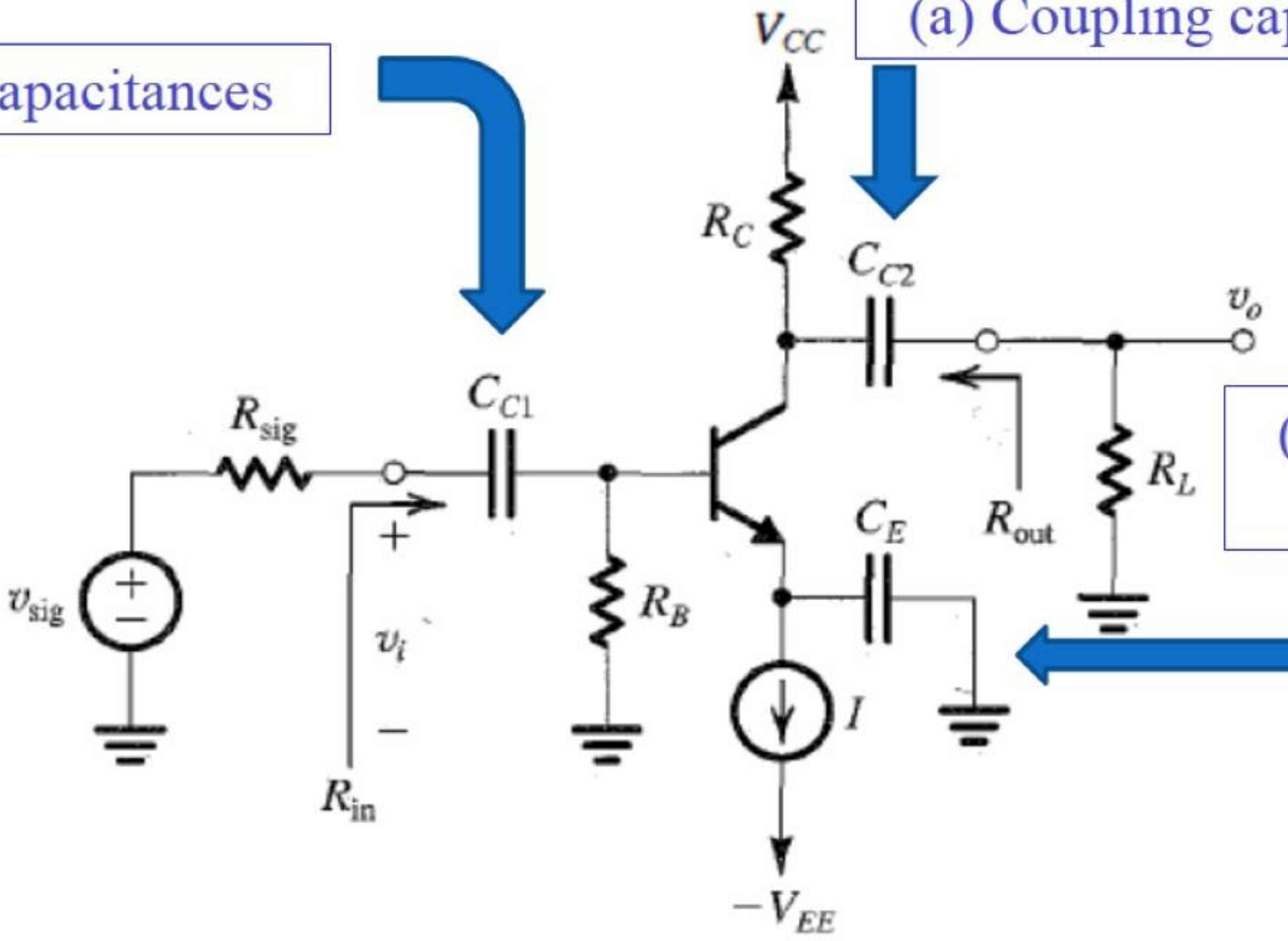
The Common Emitter Amplifier

Example:

(a) Coupling capacitances

(a) Coupling capacitances

(b) Bypassing capacitors



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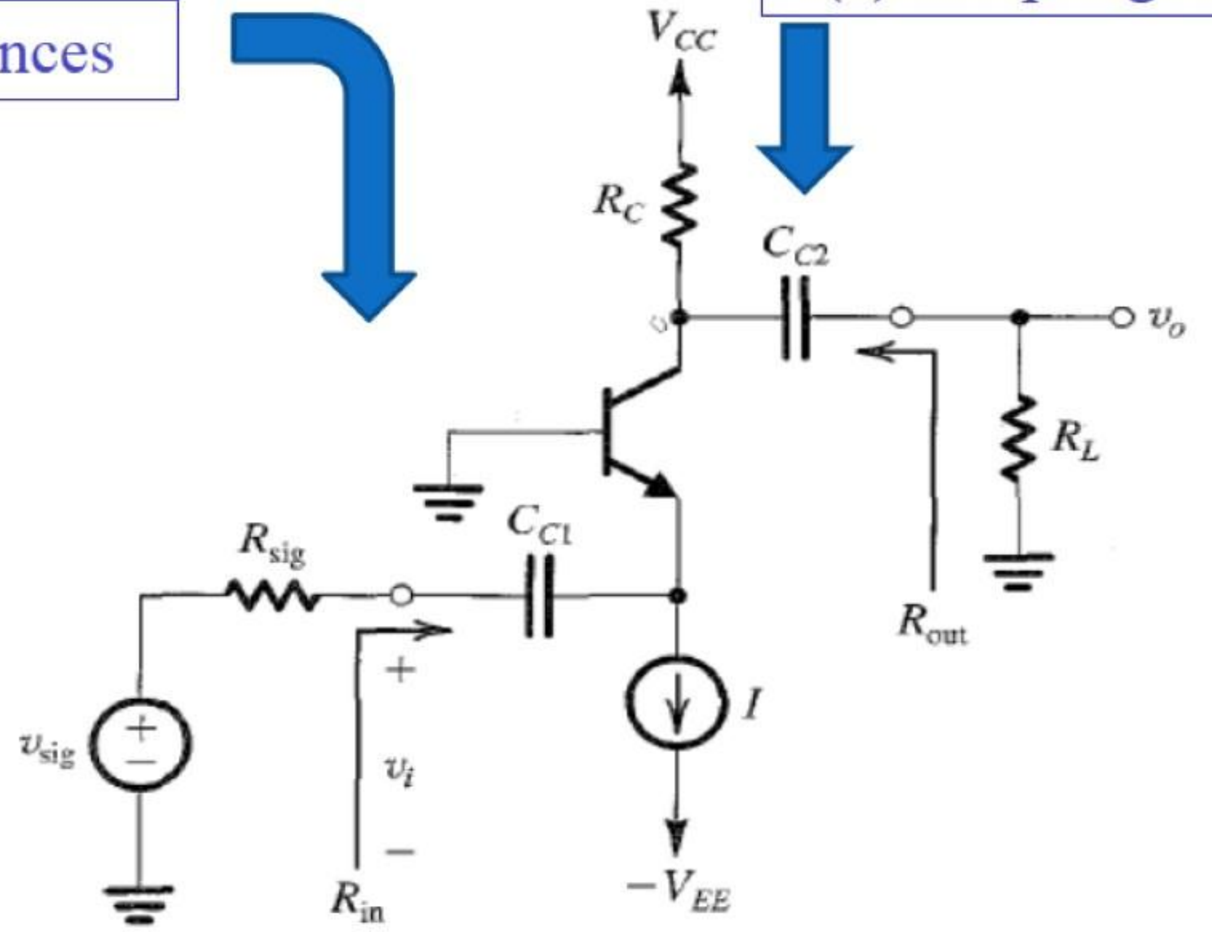
The Common Base Amplifier

(a) Coupling capacitances

(a) Coupling capacitances



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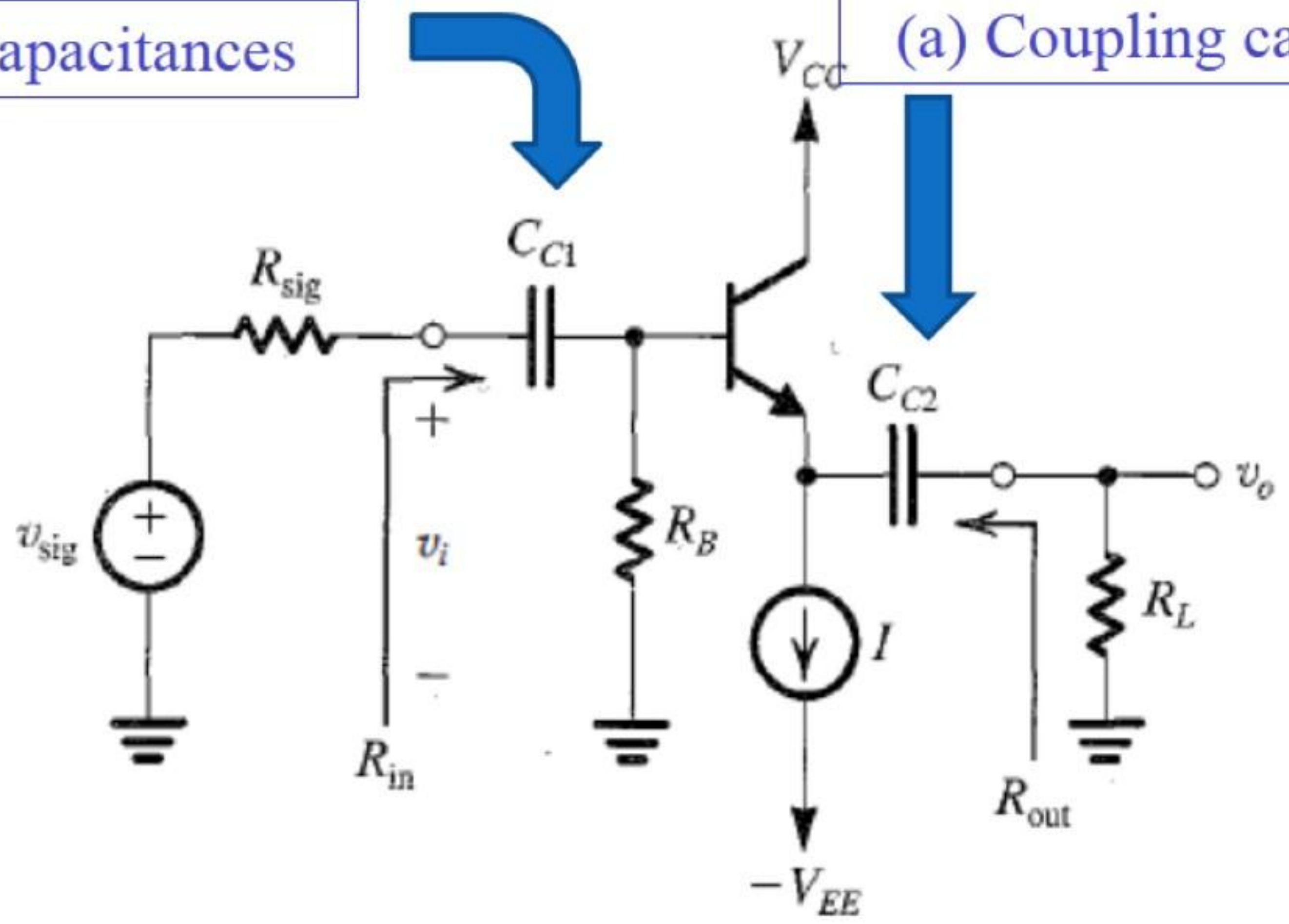
Common Collector Amplifier or Emitter Follower

The Common Collector, CC, or Emitter follower Amplifier

(a) Coupling capacitances

(a) Coupling capacitances



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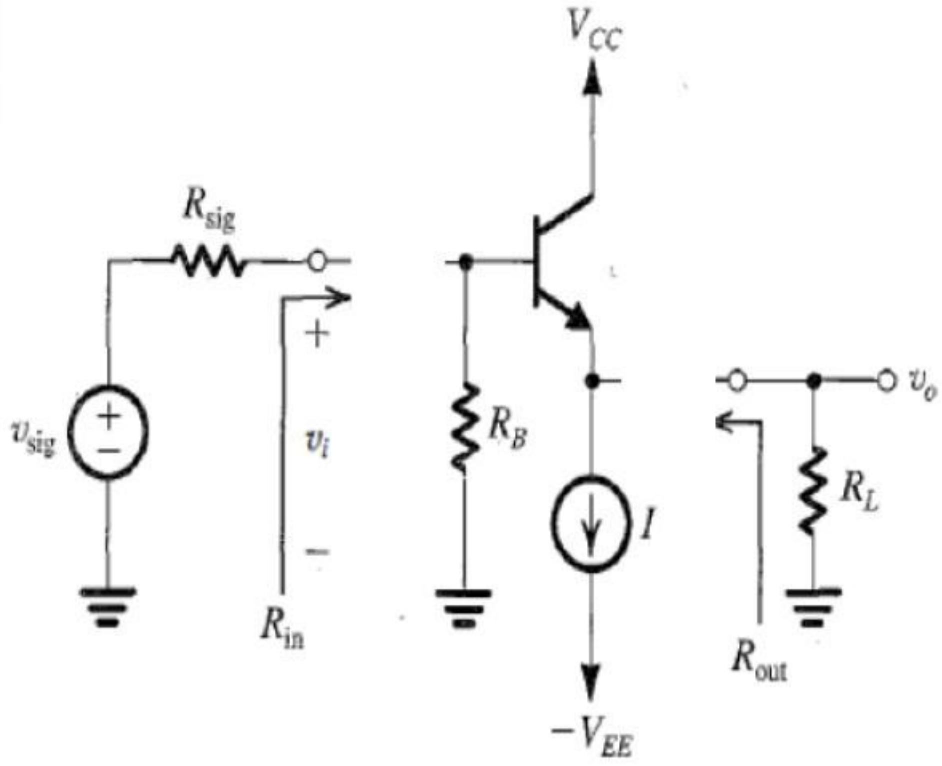
DC analysis

- To find the DC operating point (I_B, I_C, I_E, …, and mode of operation).
- **To Calculate g_m, r_π, r_e, r_0 using:**



- f=0

$$Z_C = \frac{1}{SC} = \frac{1}{j2\pi fC} \cong \infty$$

all **capacitors** are **open circuit**

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DC analysis

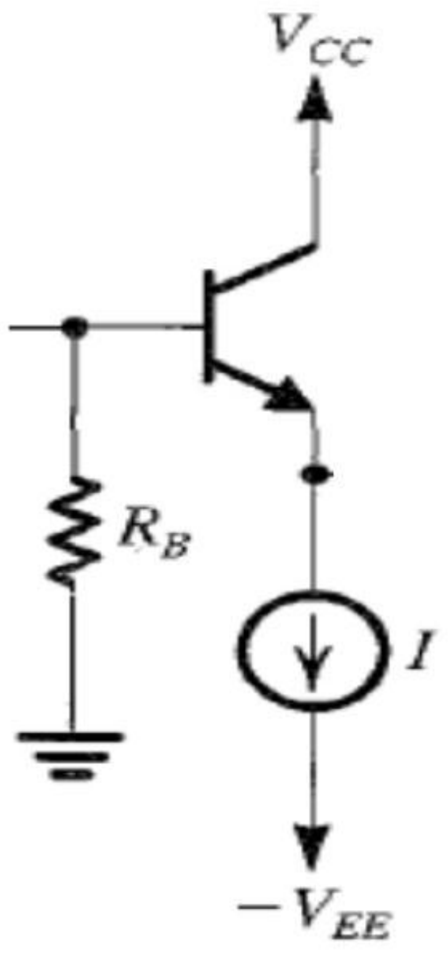
$I_E = I$

$$r_e = \frac{V_T}{I_E} = \alpha\frac{V_T}{I_C} = \frac{\alpha}{g_m}$$

$g_m = I_C/V_T$

$r_\pi = V_T/I_B = \beta/g_m$

$$r_o = \frac{|V_A|}{I_C} = \frac{|V_A|}{\beta I_B}$$



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AC analysis

- To find the R_i, R_o, A_{Vo}, A_V, G_V.

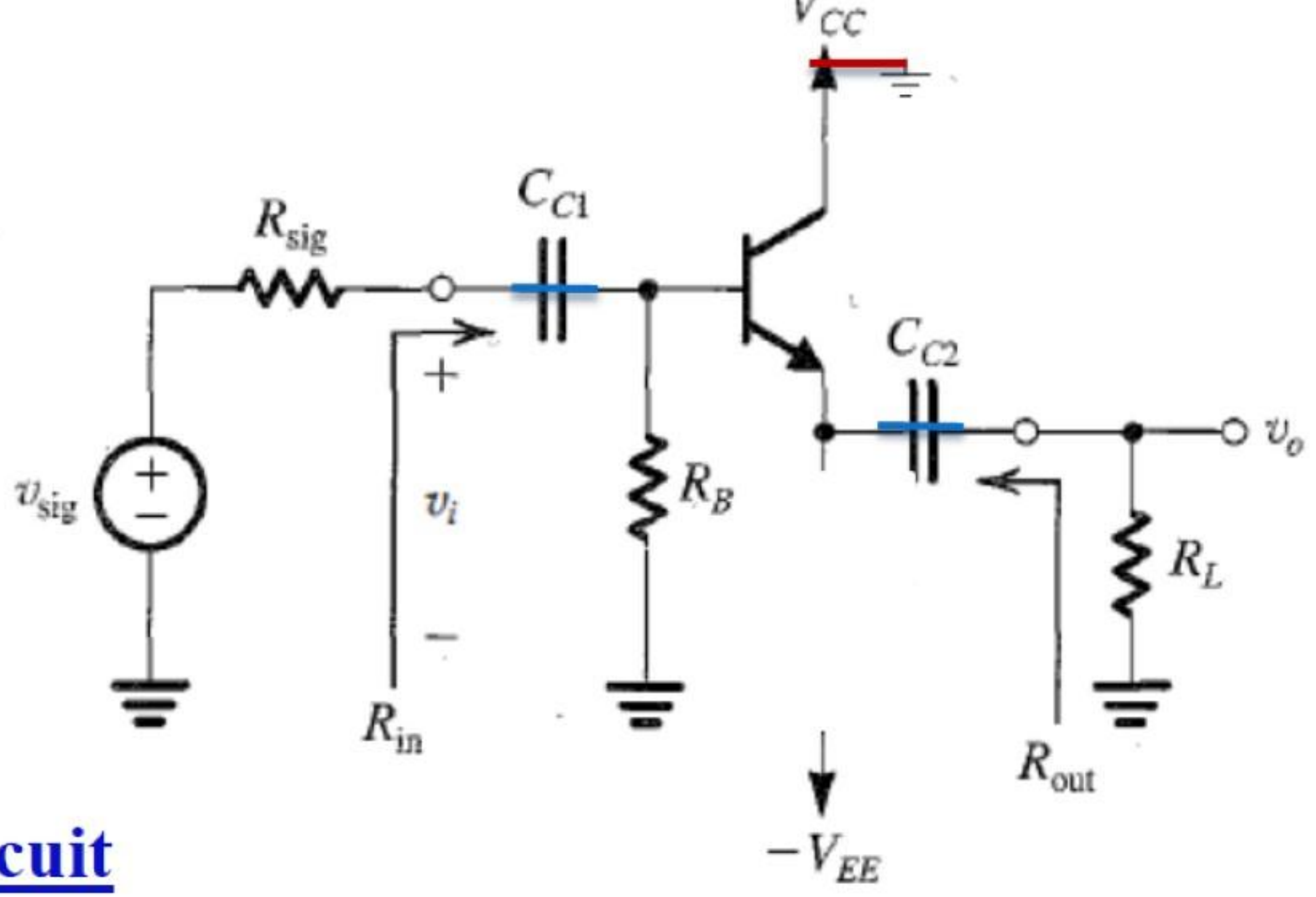
$$Z_{Cext} = \frac{1}{SC} = \frac{1}{j2\pi f C} \cong 0$$

all **capacitors** are **short circuit**

all **DC sources** ➡ **neglected**

Voltage **DC sources >>Short circuit**

Current **DC sources >>open circuit**



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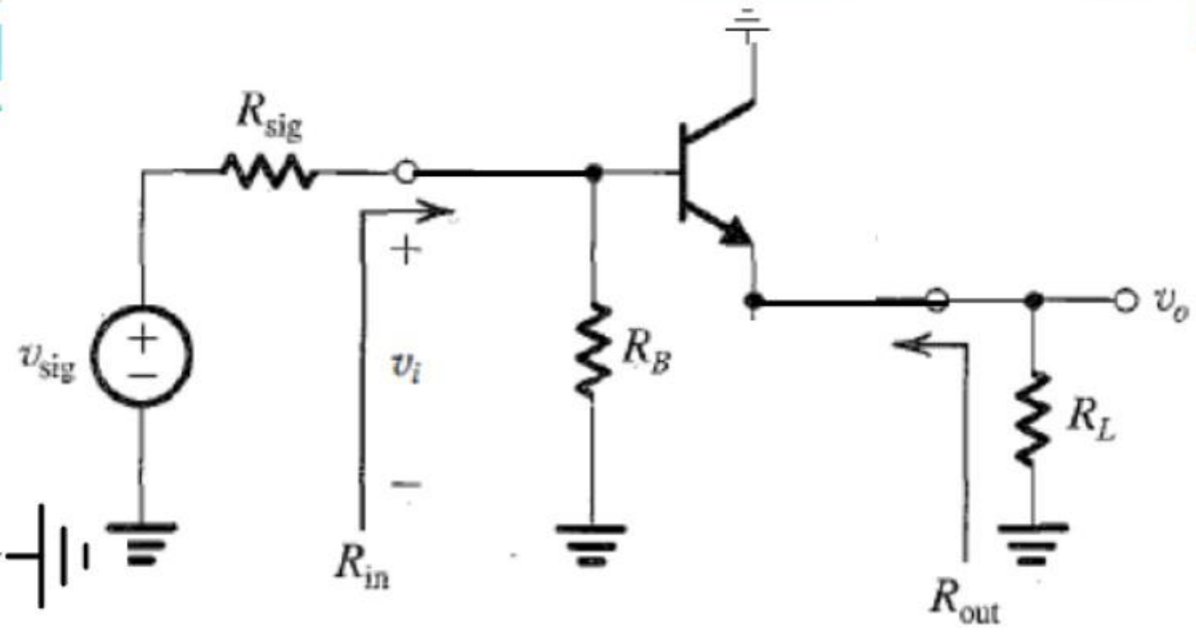
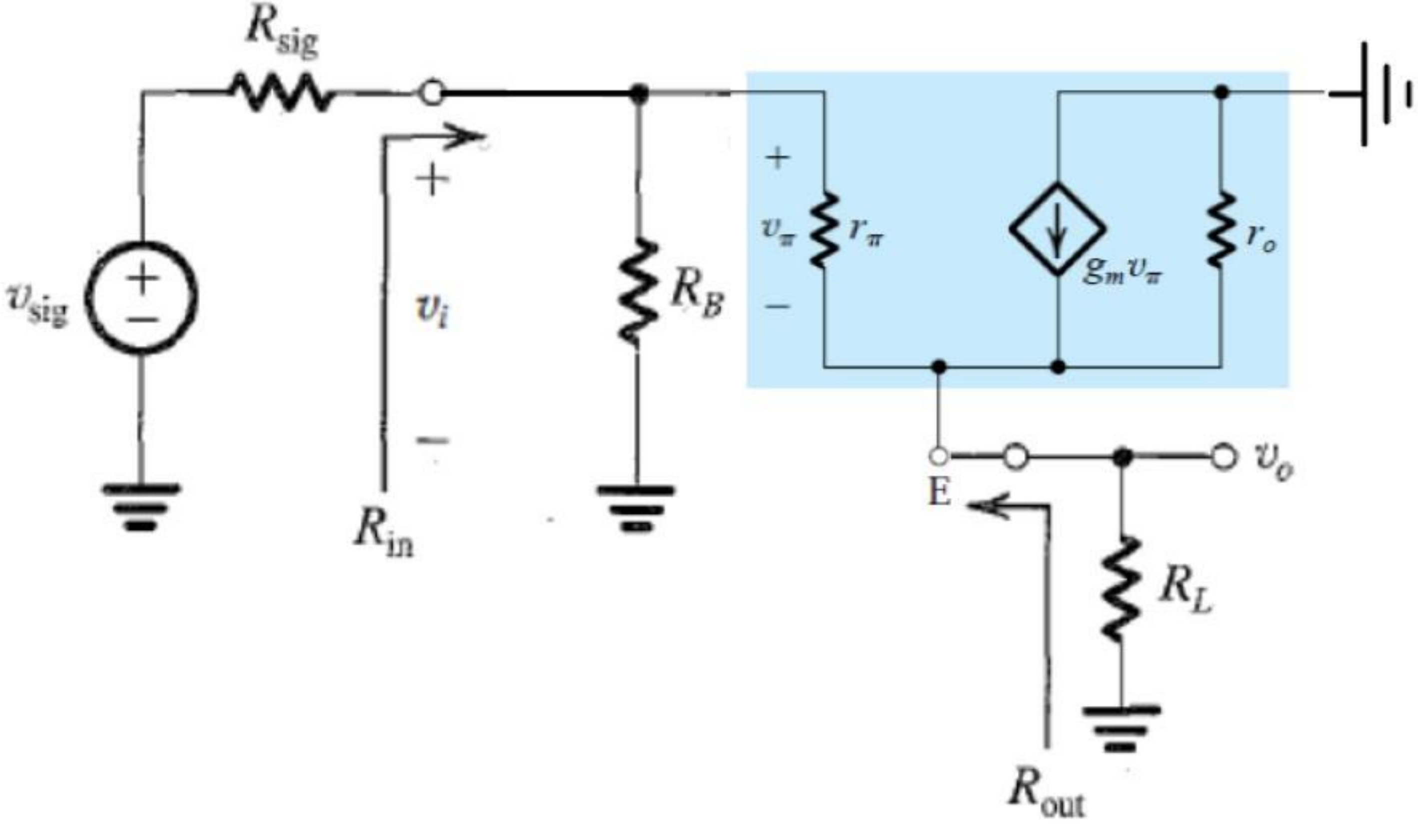
AC analysis





The AC (small-signal) equivalent circuit

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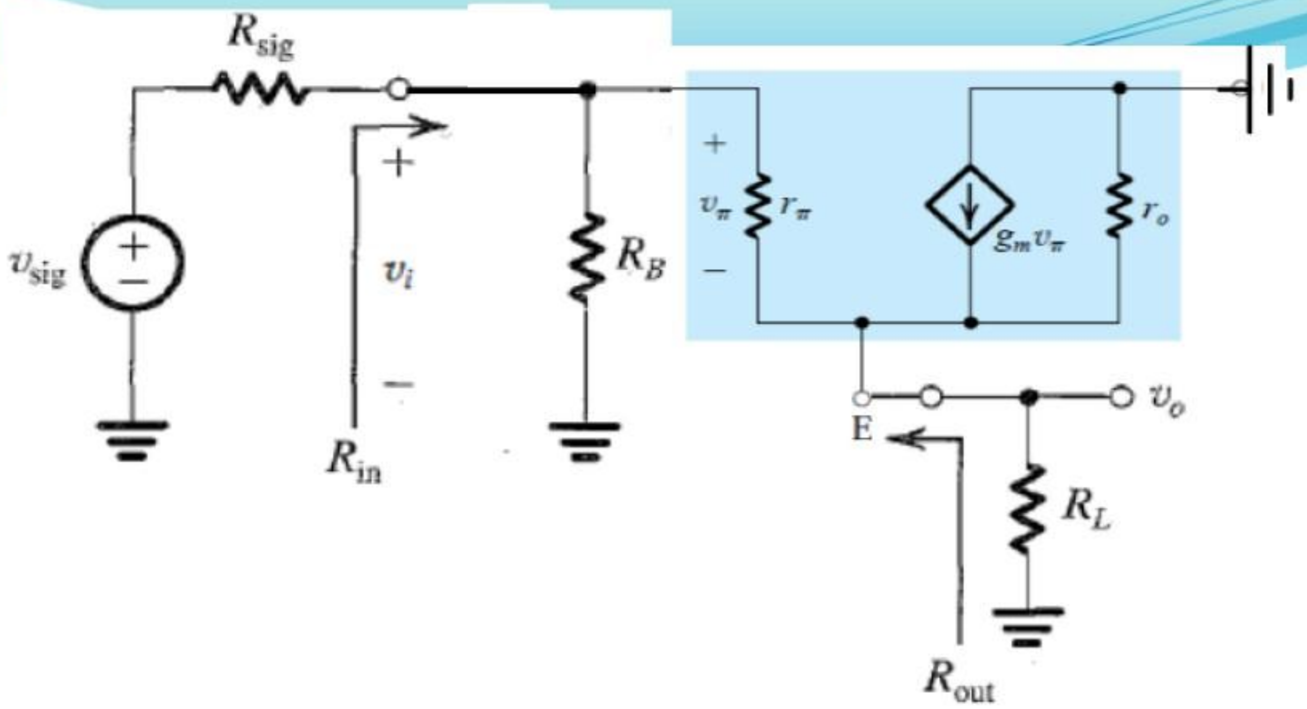
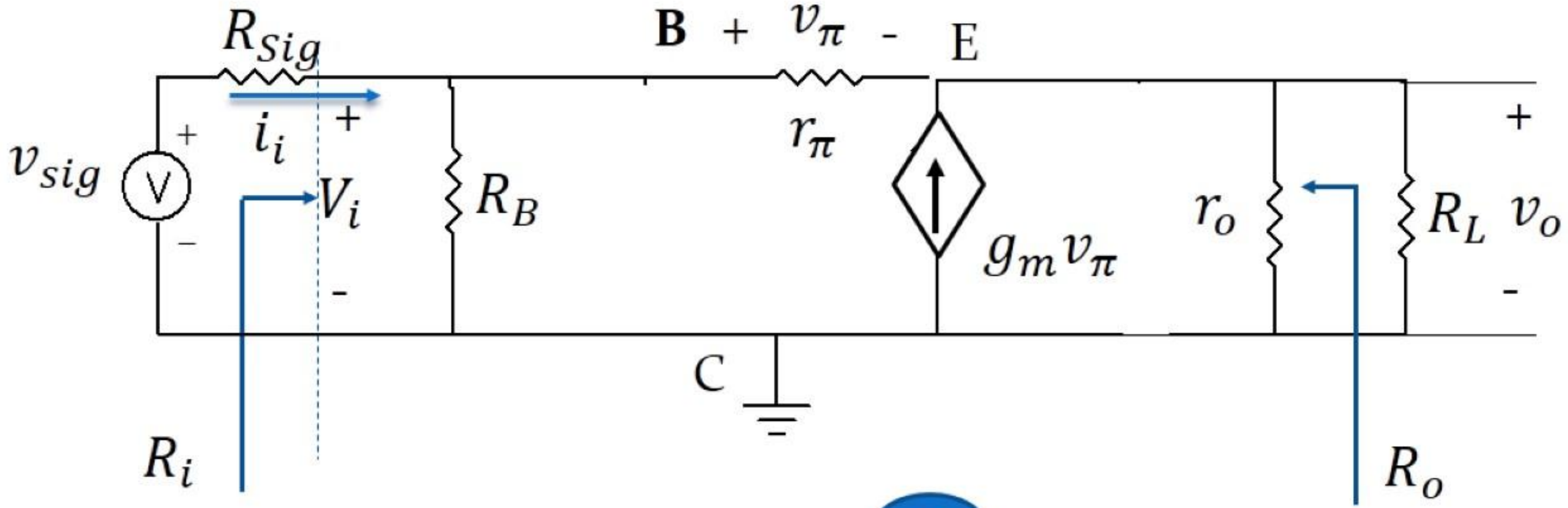
AC analysis





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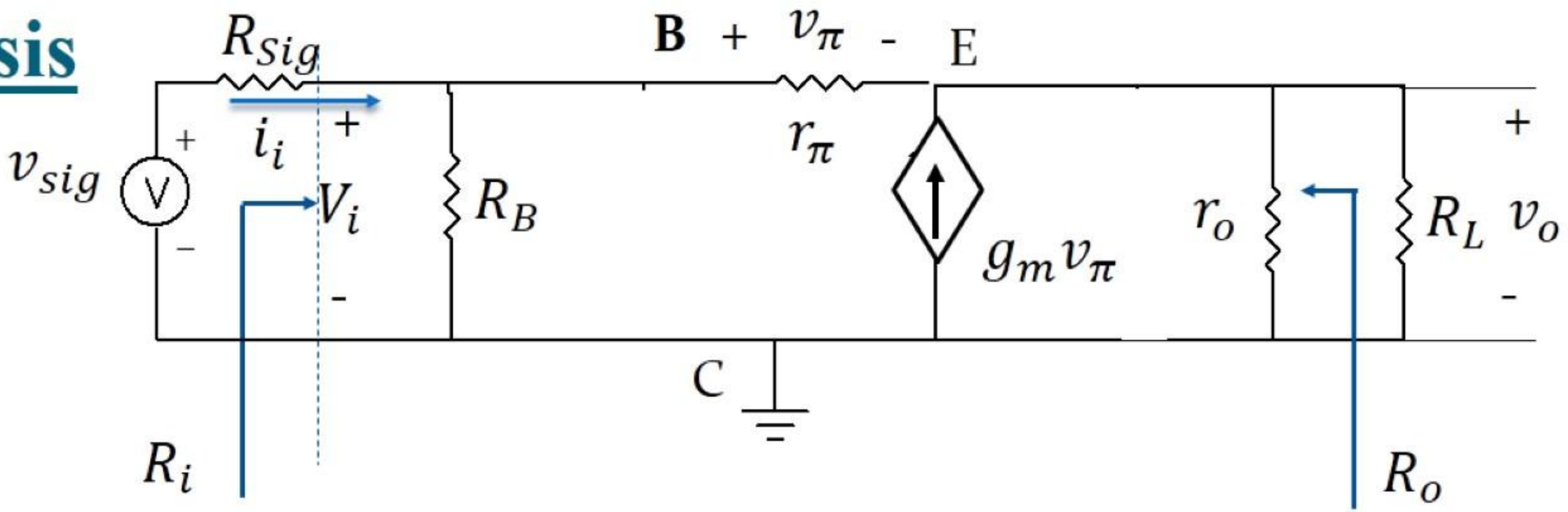
AC analysis



$$v_i = v_o + v_\pi$$

$$v_o = (r_o||R_L)\left(g_m v_\pi + \frac{v_\pi}{r_\pi}\right) = \frac{v_\pi}{r_\pi}(r_o||R_L)(g_m r_\pi + 1) = \frac{v_\pi}{r_\pi}(r_o||R_L)(\beta + 1)$$

$$v_i = v_o + \frac{v_o r_\pi}{(r_o||R_L)(\beta + 1)}$$

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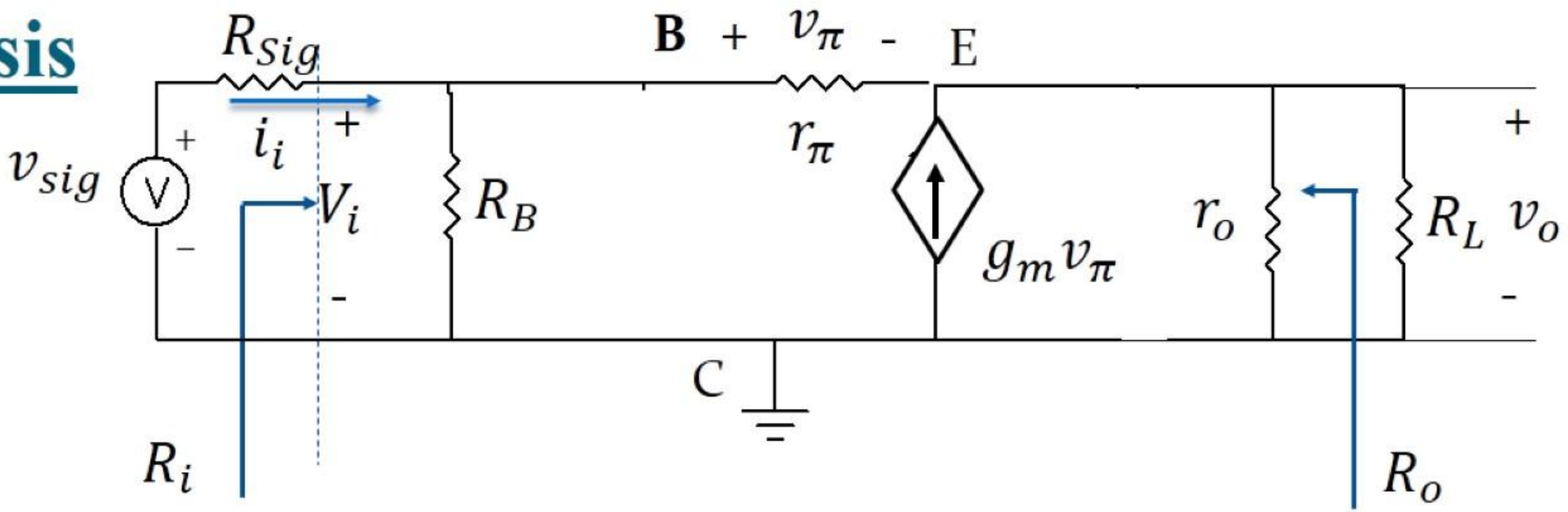
AC analysis



$$A_v = \frac{v_o}{v_i} = \frac{(r_o||R_L)(\beta+1)}{(r_o||R_L)(\beta+1) + r_\pi} = \frac{(r_o||R_L)}{(r_o||R_L) + r_e} < 1$$

$$A_{vo} = A_v \Big|_{\text{At } R_L = \infty} \cong 1$$

- A_{vo}=1 means that the signal voltage at the emitter follows that at the base, this why it is called emitter follower.

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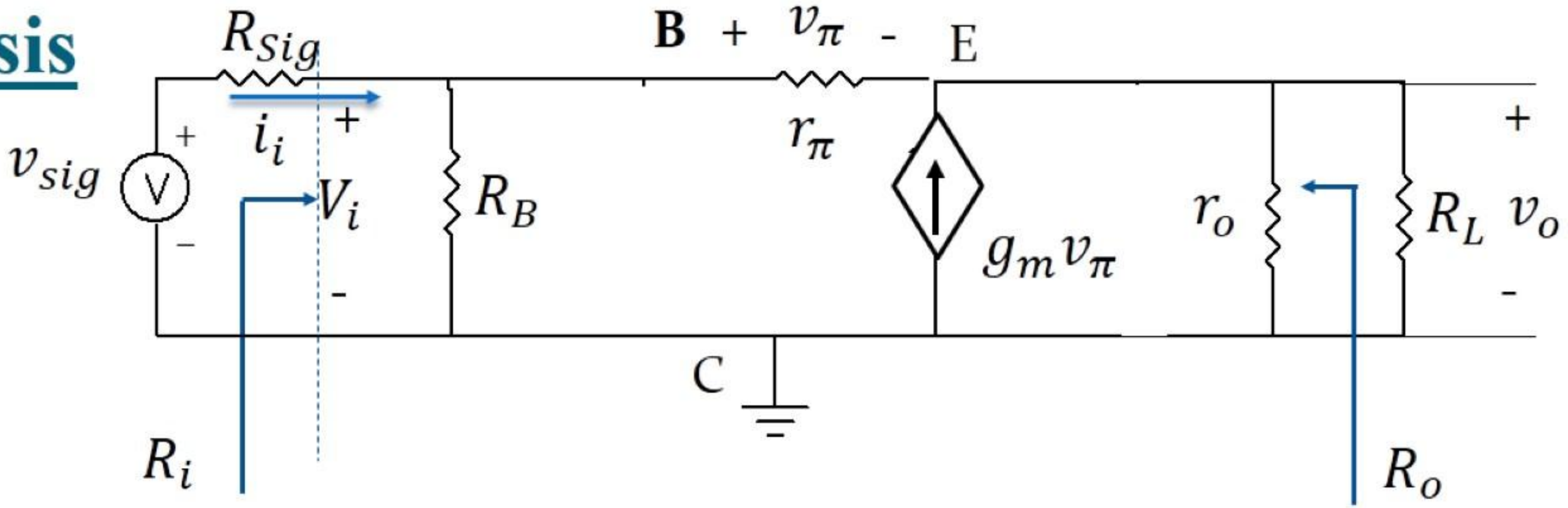
AC analysis



overall gain: $G_v = \frac{v_o}{v_{sig}} = \frac{v_i}{v_{sig}} x A_v = \frac{R_{in}}{R_{in}+R_{sig}} x A_v$

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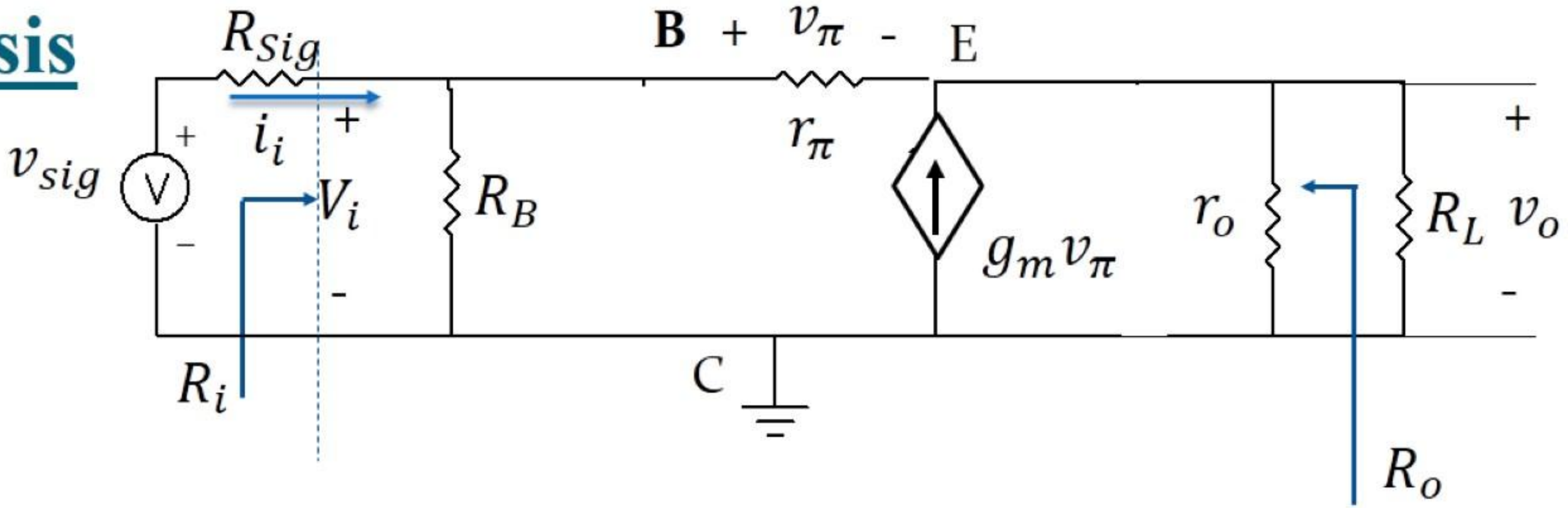
AC analysis



$$\boldsymbol{i_i = \frac{v_i}{R_B} + \frac{v_\pi}{r_\pi}}$$

$$v_i = v_o + v_\pi = \frac{v_\pi}{r_\pi}\,(r_o \| R_L)(\beta + 1) + v_\pi = \frac{v_\pi}{r_\pi}[(r_o \| R_L)(\beta + 1) + r_\pi]$$

$$\boldsymbol{i_i = \frac{v_i}{R_B}} + \frac{v_i}{[(r_o \| R_L)(\beta + 1) + r_\pi]}$$

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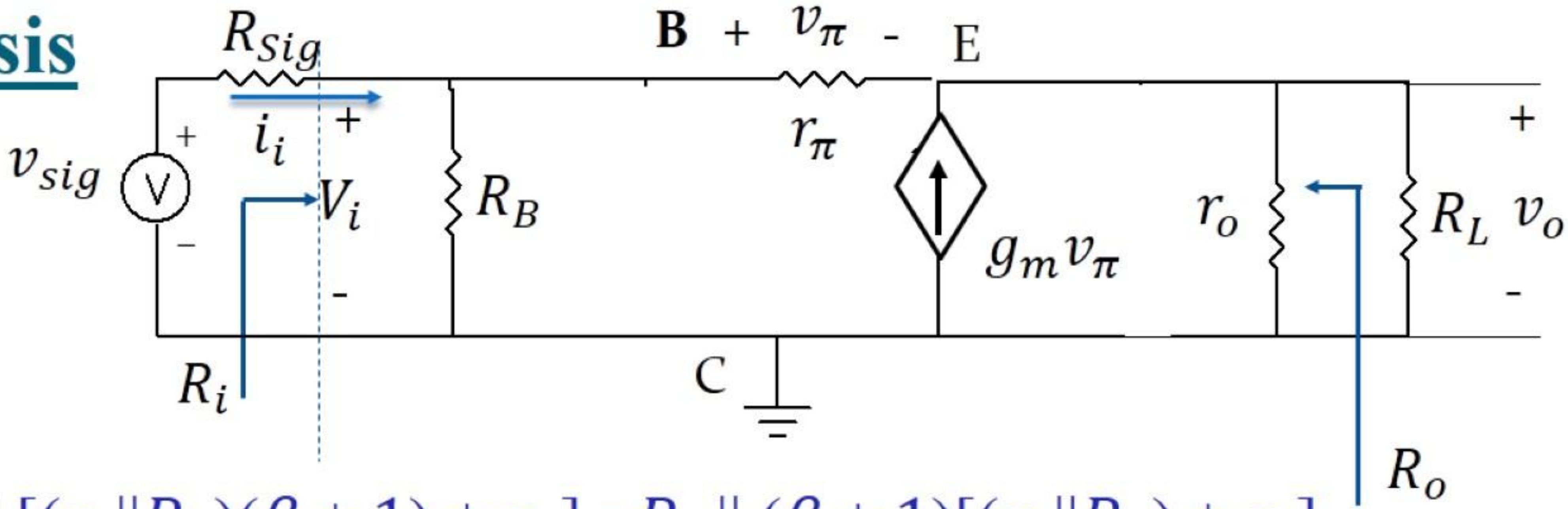
AC analysis



$$\boldsymbol{R_i = \frac{v_i}{i_i}} = R_B \| \left[(r_o \| R_L)(\beta + 1) + r_\pi\right] = R_B \| (\beta + 1)\left[(r_o \| R_L) + r_e\right]$$

➢ Note that as expected the emitter follower takes the low load resistance and reflects it to the base side, after increasing its value by a factor (β+1). It is this impedance transformation property of the emitter follower that makes it useful in connecting a low resistance load to a high-resistance source, that is, to implement a buffer amplifier.

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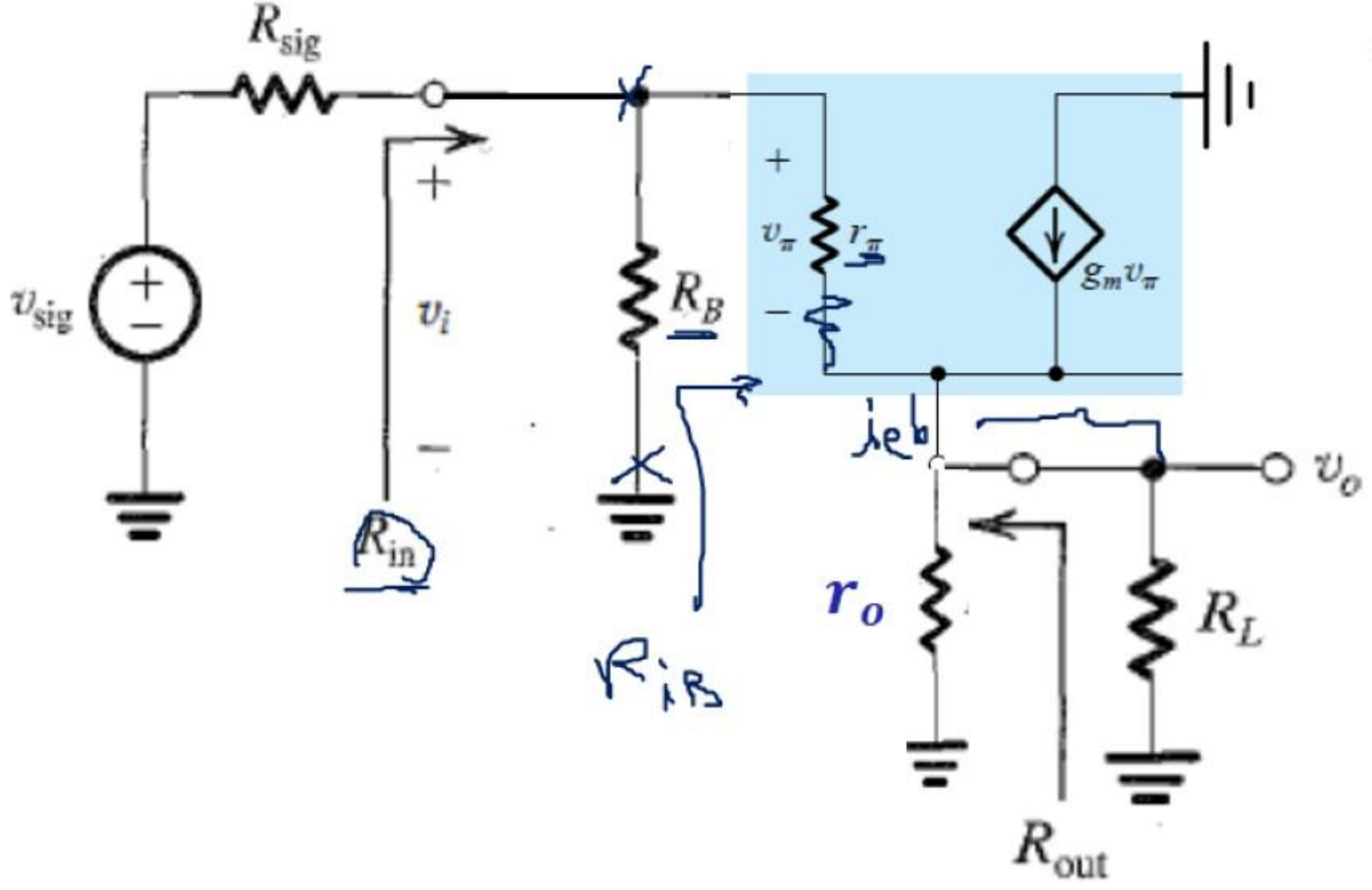
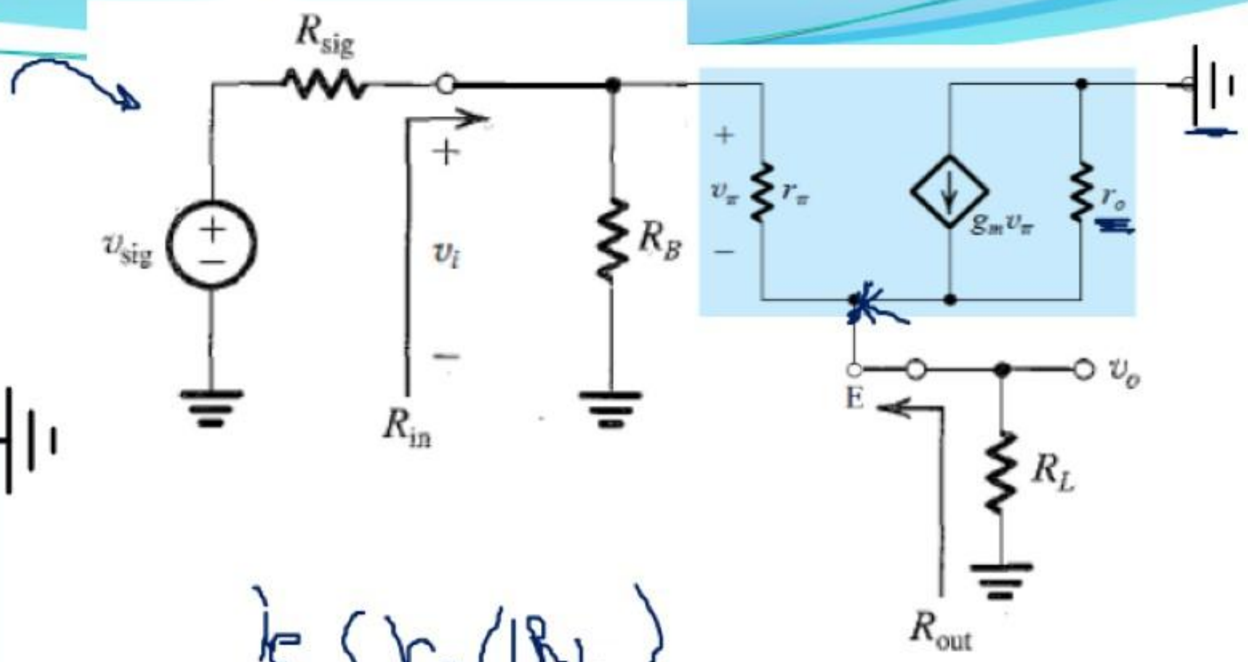
AC analysis





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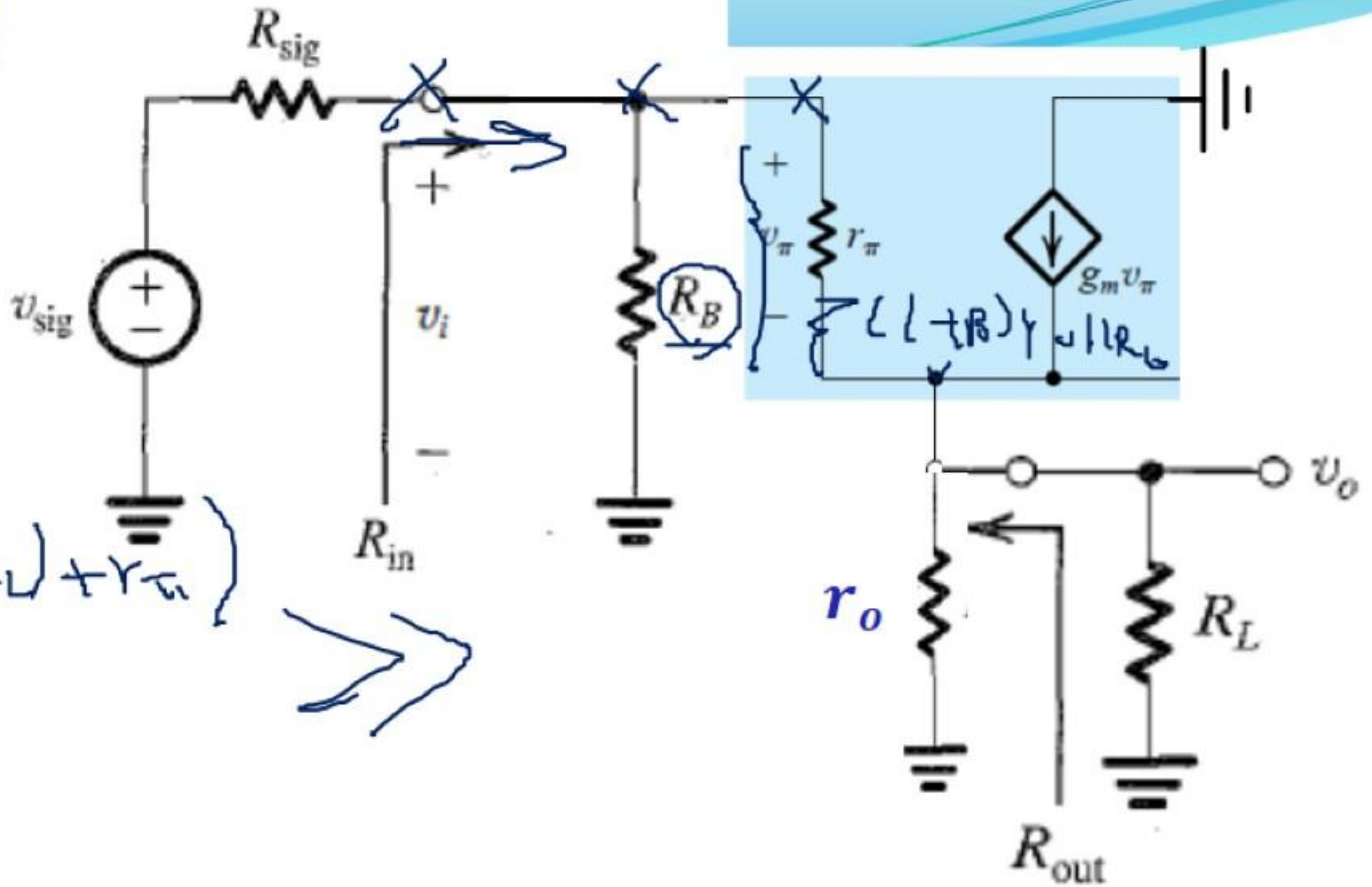
AC analysis

$$R_i = R_B \| (\beta + 1)[(r_o \| R_L) + r_e]$$

$$R_i = R_B \,//\, \left((1+\beta)(r_o \| R_L) + r_\pi \right)$$



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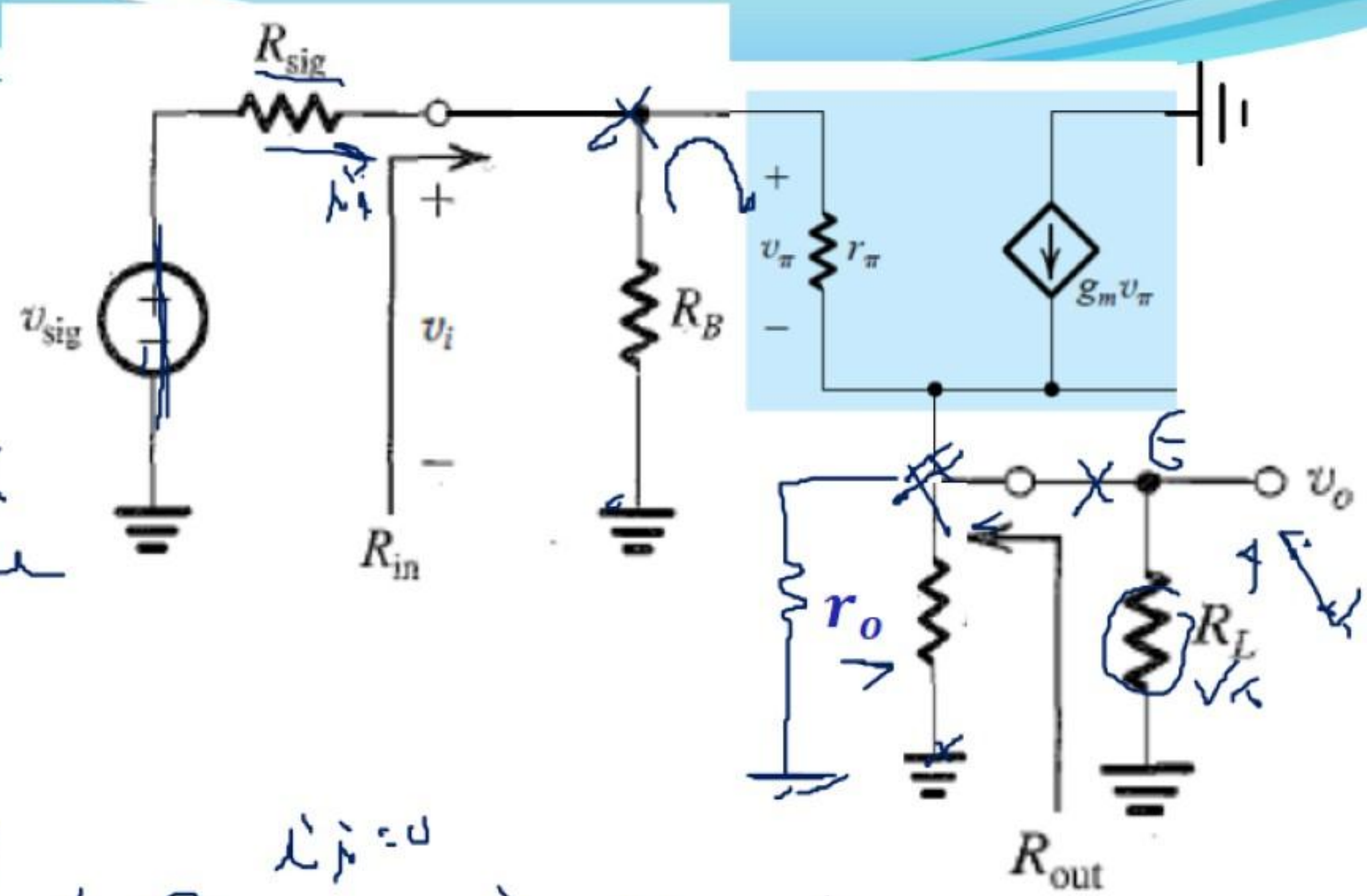
AC analysis

$$R_{out} = r_o \| \left[r_e + \frac{R_{sig} \| R_B}{\beta + 1} \right]$$



$i_i = 0$

$$r_o \| \left(\frac{(R_{sig} \| R_B) + r_\pi}{1 + \beta} \right)$$

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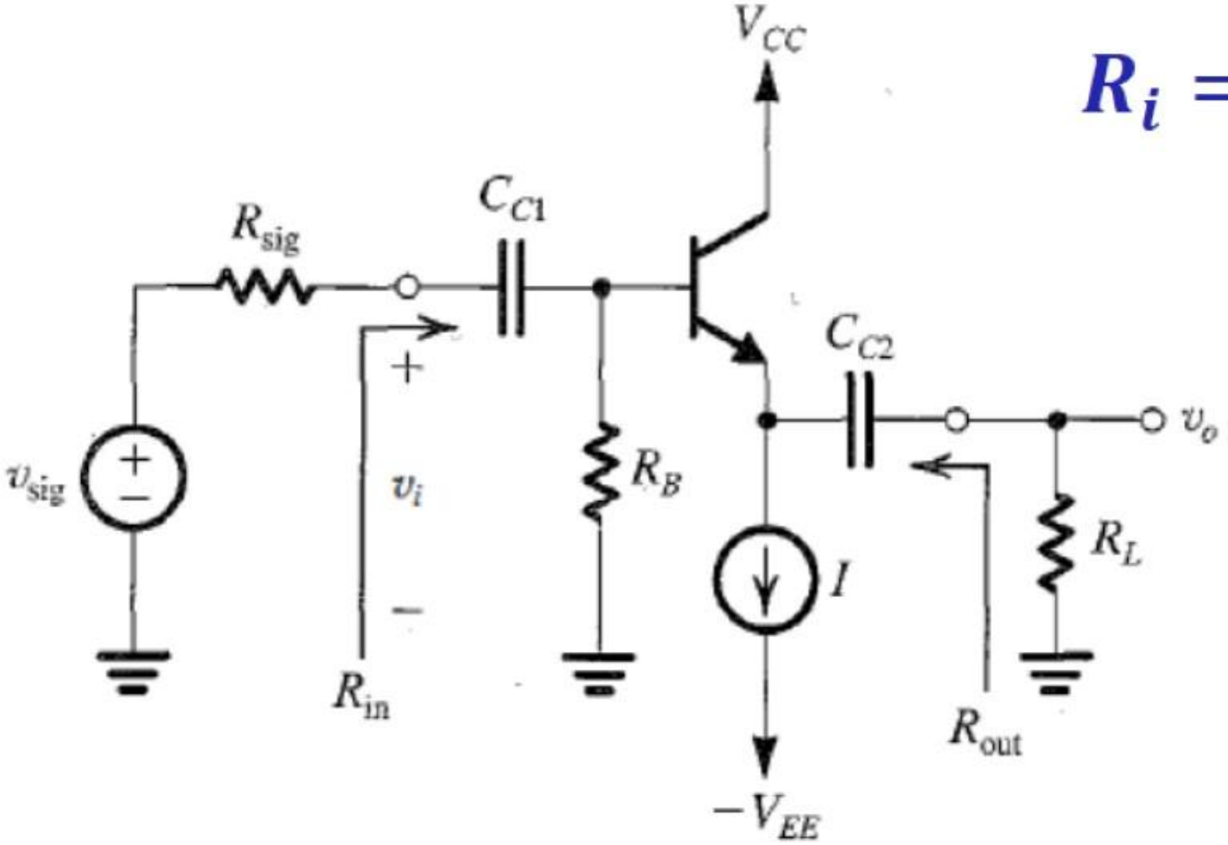
Common Collector or Emitter Follower



Non-Inverting Amplifier

$$\boldsymbol{R_i} = R_B \| (\beta + 1)[(r_o \| R_L) + r_e] \quad >>$$

$$\boldsymbol{A_v} = \frac{(r_o \| R_L)}{(r_o \| R_L) + r_e} \quad < \boldsymbol{1}$$

$$R_{out} = r_o \| \left[r_e + \frac{R_{sig} \| R_B}{\beta + 1} \right] \quad <<$$

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Summary and Comparisons

1. The CE configuration is the one best suited for realizing the bulk of the gain required in an amplifier. Depending on the magnitude of the gain required, either a single stage or a cascade of two or three stages can be used.
2. Including a resistor in the emitter lead of the CE stage provides a number of performance improvements at the expense of gain reduction.
3. The low input resistance of the CB amplifier makes it useful only in specific applications. It has a much better high-frequency response than the CE amplifier. This superiority will make it useful as a high-frequency amplifier, especially when combined with the CE circuit.

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Summary and Comparisons

4. The emitter follower (CC) finds application as a voltage buffer for connecting a high resistance source to a low-resistance load and as the output stage in a multistage amplifier, where its purpose is to equip the amplifier with a low output-resistance.

	CE	CB	CC
Voltage gain, A_v	High	High	Low $\cong 1$
Current gain, A_i	High	Low $\cong 1$	High
Power gain, A_p	Very high $\cong A_v A_i$	High $\cong A_v$	High $\cong A_i$
Input resistance, $R_{in}(max)$	moderate to low	Very low	High
Output resistance, R_{out}	moderate to high	High	Very low
ϕ	180	0	0

Thank You

???

Have a Wonderful Semester