Electronics Circuits Design-1
ELC-1

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CONTENT

1. BJT Amplifier
2. FET Amplifier
3. Frequency Response of Amplifier
4. Operational Amplifier
5. Audio Power Amplifier
6. Linear-Digital ICs
7. Power Supplies

Chapter-1: BJT-Amplifier

1.1 Review of BJT Dynamic Models
1.2 CC & CB Configurations
1.3 Effect of R_L and R_S
1.4 Cascaded System and Amp. Coupling
1.5 Darlington Connection
1.6 Current Mirror and Current Sources
1.7 Approximate Hybrid Equivalent Circuit
1.8 Practical Applications

Review of BJT Dynamic Models

- One of our concerns in the sinusoidal analysis of transistor networks is the magnitude of the input signal:
- 1-Small-signal input ; and
- 2-Large signal input.
- This division leads to the classification of BJT amplifiers :A,B,AB and C…..etc.
- ,which will be considered later.

Review of BJT Dynamic Models

- There are three models commonly used in the small-signal ac analysis of transistor networks:
- 1-r_e model
- 2-The hybrid equivalent model circuit
- 3-The hybrid π model.

Review of BJT Dynamic Models

- Definition of the model.:
- A model is a combination of circuit elements, properly chosen, that best approximates the actual behavior of the semiconductor device under specific operating conditions.

Review of BJT Dynamic Models

- Once the ac equivalent circuit of the BJT is determined, either re model or hybrid model, by the designer, the schematic symbol for the device can be replaced by the equivalent circuit and circuit analysis applied to find out the desired quantities of the network.

Review of BJT Dynamic Models

- In the formative years of transistor network analysis the hybrid equivalent circuit was employed the most frequently. Specification sheets included the parameters in their listing, and the analysis was simply a matter of inserting the equiv.ct with the listed values

Review of BJT Dynamic Models

- The drawback to using this equi.ct ,however is that it is defined for a set of :
- (1)-operating conditions that might not match the actual operating conditions .; i.e.

  $V_{CEQ,spec} \neq V_{CEQ,real} \approx$ but they are very close
- (2)-There is always a variation in actual transistor values and given transistor beta values (β) ,so as an approximate approach it was quite reliable.

Review of BJT Dynamic Models

- Manufacturers continue to specify the hybrid parameter values for a particular operating point on their specification sheets.
- In time , the use of the re model become the more desirable approach because an important parameter of the equi.ct was determined by the actual operating conditions rather than using a data sheet value that in some cases could be quite different .Unfortunately, however,

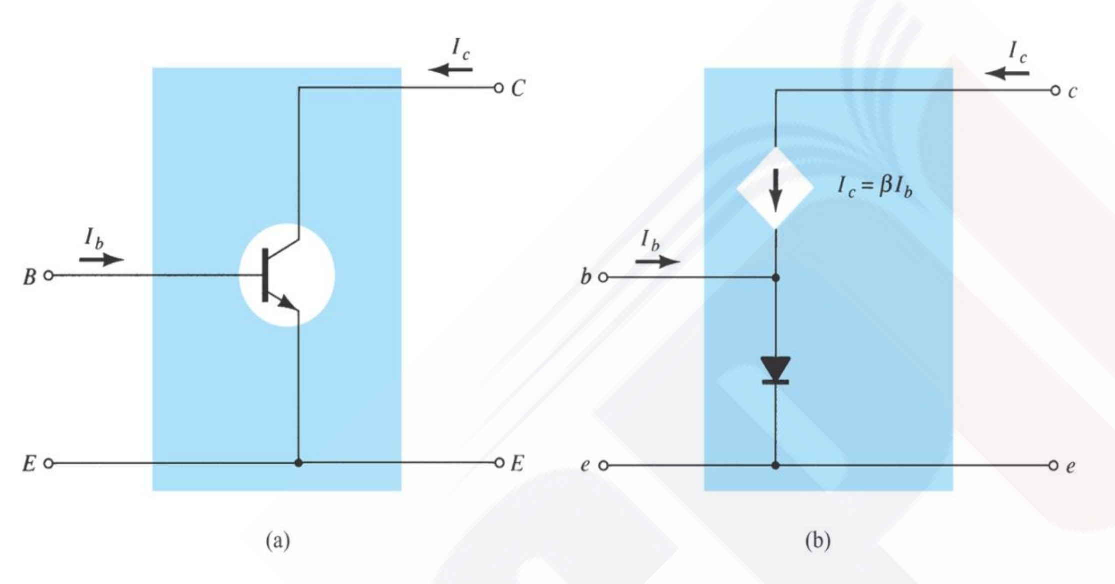
Review of BJT Dynamic Models

- one must still turn to data sheets for some of other parameters of the equi.ct.
- The re model also failed to include a feedback term, which is in some cases can be important ,if not simply troublesome.
- The re model is really a reduced version of hybrid π model used almost exclusively for high-frequency analysis. This model also includes a connection between o/p and i/p to include the FB effect of o/p voltage and i/p quantities.

Review of BJT Dynamic Models

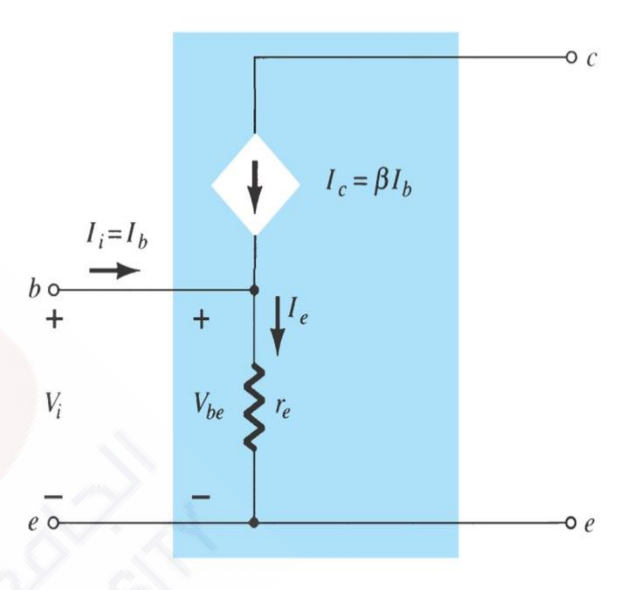
- The following figures show the Common-emitter BJT transistor and approximate model, using re-model.

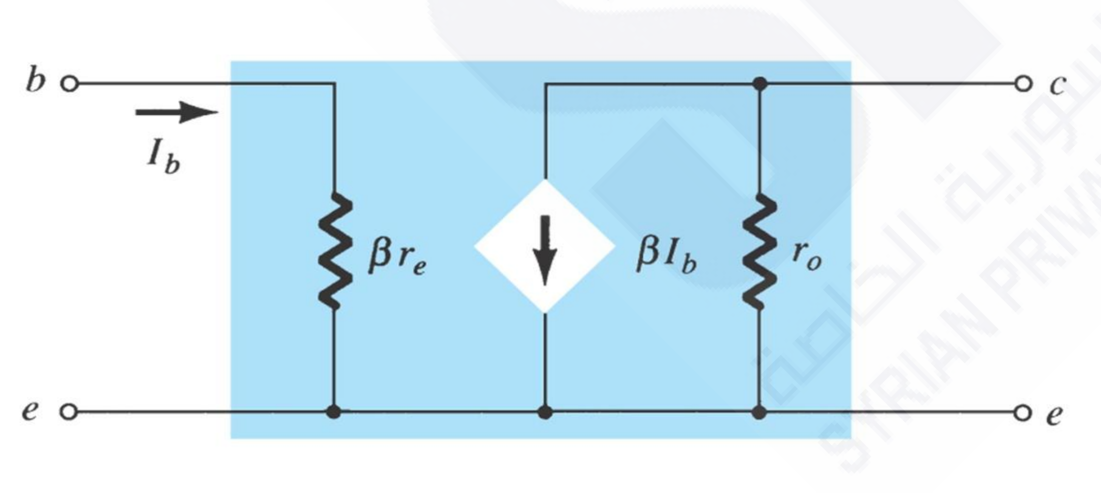
1.1 Review of BJT Dynamic Models

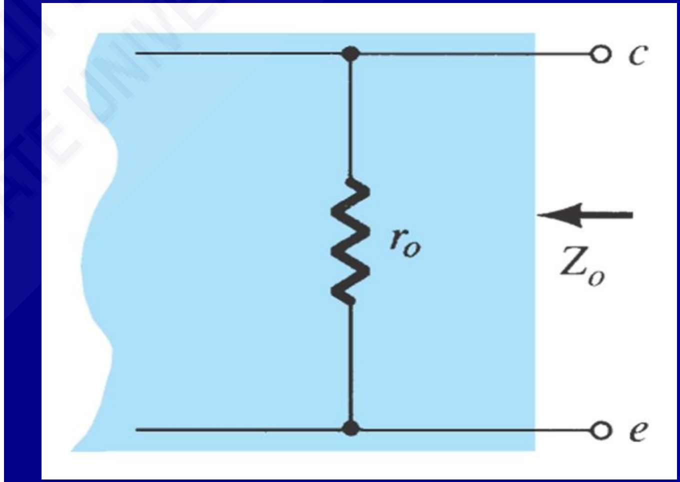


(a)

(b)







Common-emitter BJT transistor and approximate model

A.C Model of the Diode

- When considering an ac-model of the diode, the slope of the device characteristic is important .For the diode equation under significant forward biased, *ignoring the -1 term*, yields:
- $I=I_s(\text{ exp } q.V / k.T)$
- Where q – electronic charge
- =1.602E10-19 (Coulombs)

A.C Model of the Diode

- V-Forward bias (volt)
- K- Boltzmann’s constant=
- =1.38E10-23 (Joules/Kelvin's),and
- T – Absolute temperature (Kelvin)
- =(273+room temperature in Celsius)
- Differentiating w.r.t V,we obtain.:
- $dI/dV= I_s .q / k.T(\exp q.V / k.T)$

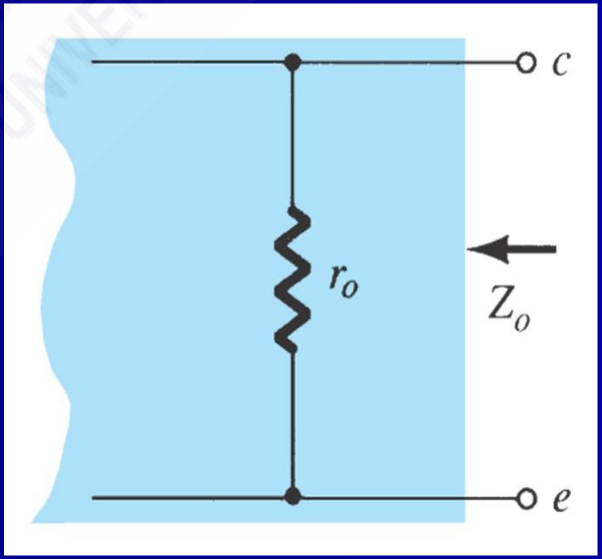
A.C Model of the Diode

- $dI/dV = I\,q. / k.T$, by reversing both sides ,we obtain:
- $dV/dI = K.T/ I.q$,which has a dimension of resistance, and is assigned by a symbol of r_d or r_e in some literature.
- Now K.T/ q =26mV ,hence the forward slope resistance can be expressed as $r_{e} = 26mV / I(mA)$
- Where I is the forward current of the diode In mA.

The Zo :output Resistance

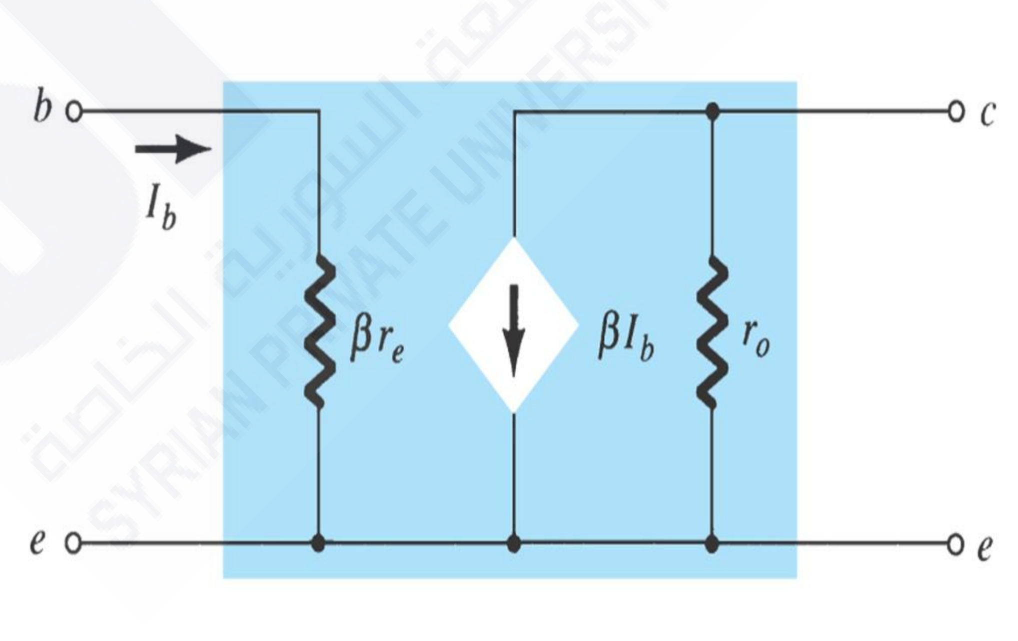
The following figure shows the output impedance(resistance), if we look at CE output terminals which is :

$Z_o = r_o$.



The equivalent r-circuit of CE configuration

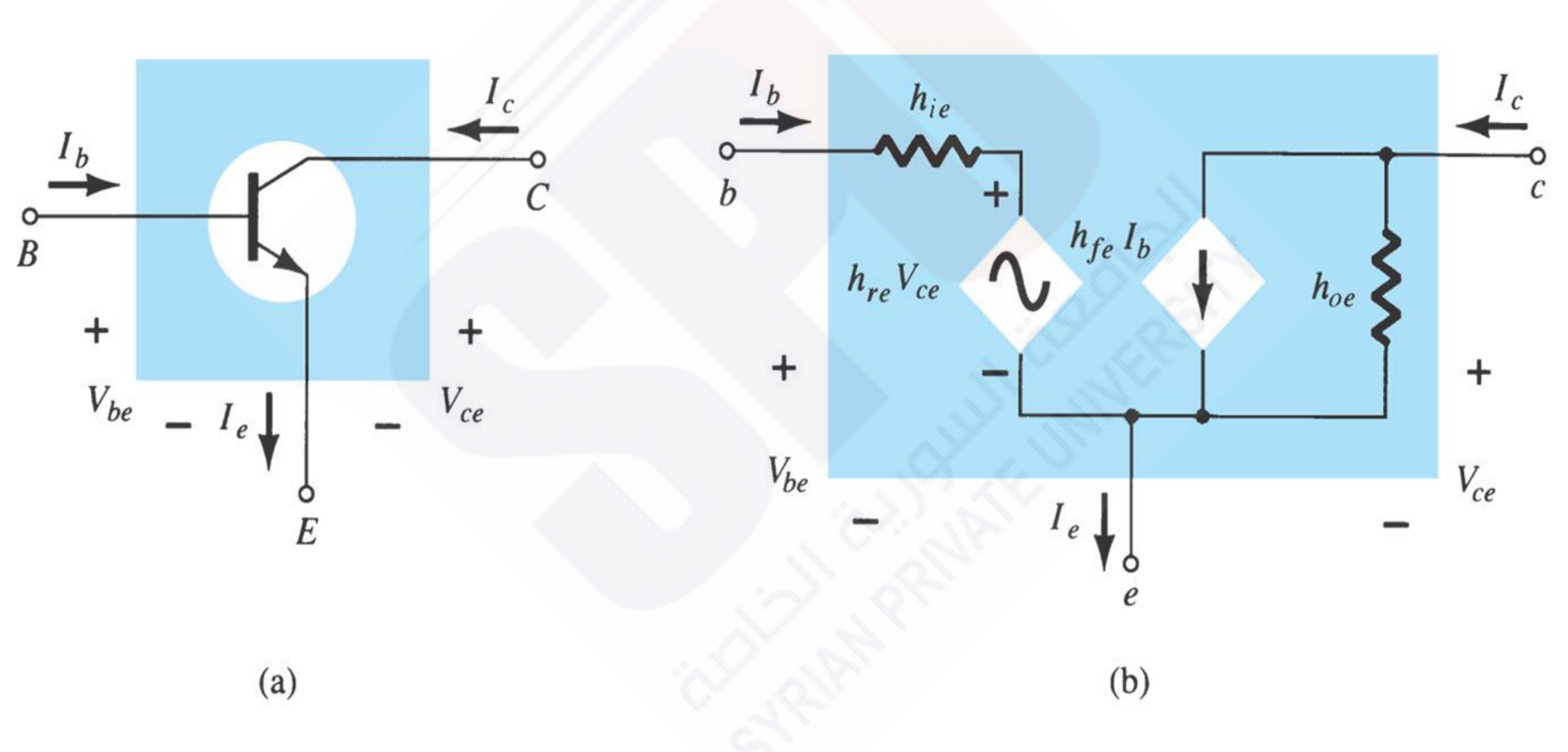
The equivalent circuit using r-parameters is shown , As



The equivalent r-circuit of CE configuration

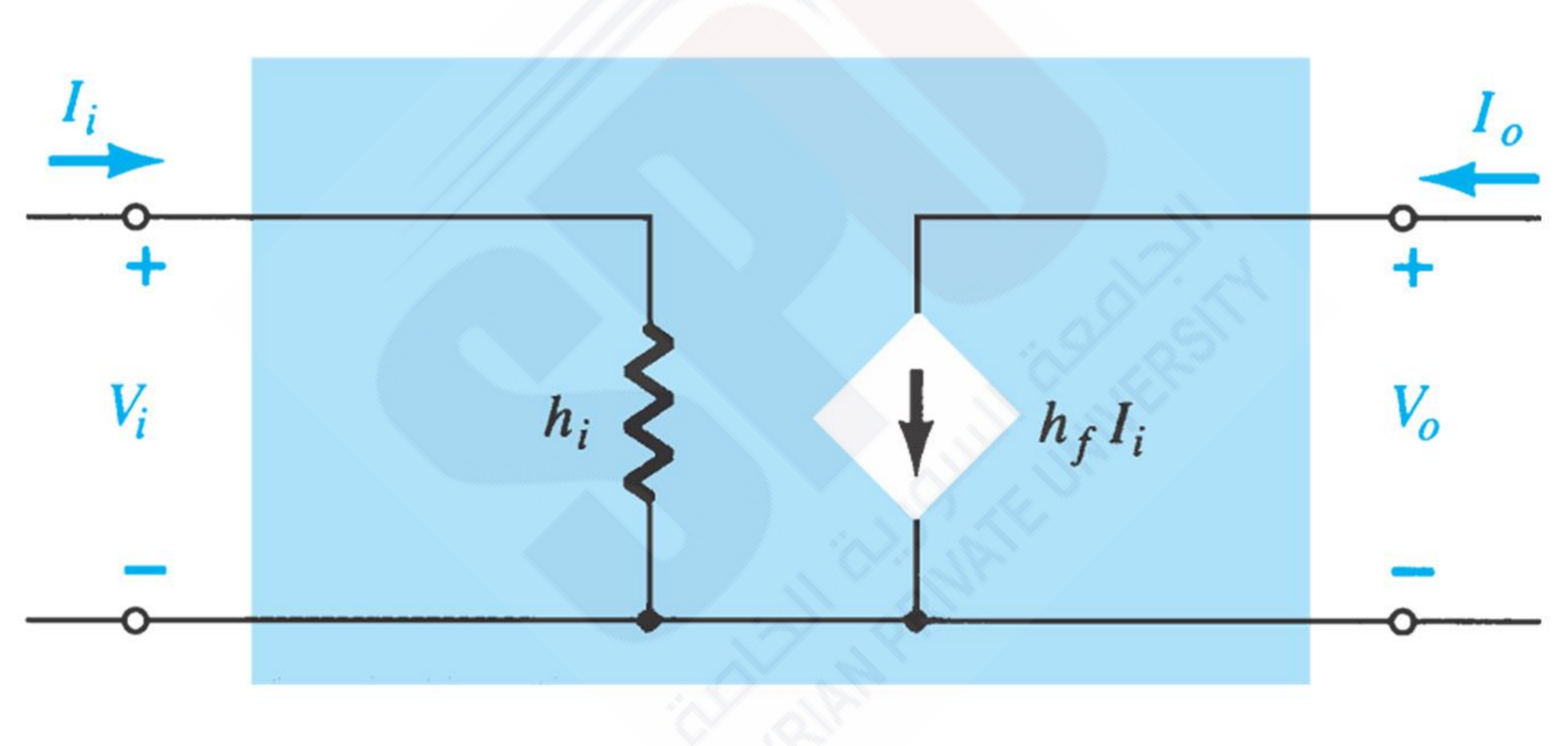
- An equi.ct of the network is obtained by:
- 1-Setting all dc sources to zero and replacing them by a short circuit equivalent.
- 2-Replacing all capacitors by a short circuit equivalent
- 3-Removing all elements bypassed by the sc equivalent introduced by step 1&2.
- 4-Redrawing the network in a more convenient and logical form.

Common-emitter configuration: (a) graphical symbol; (b) hybrid equivalent circuit

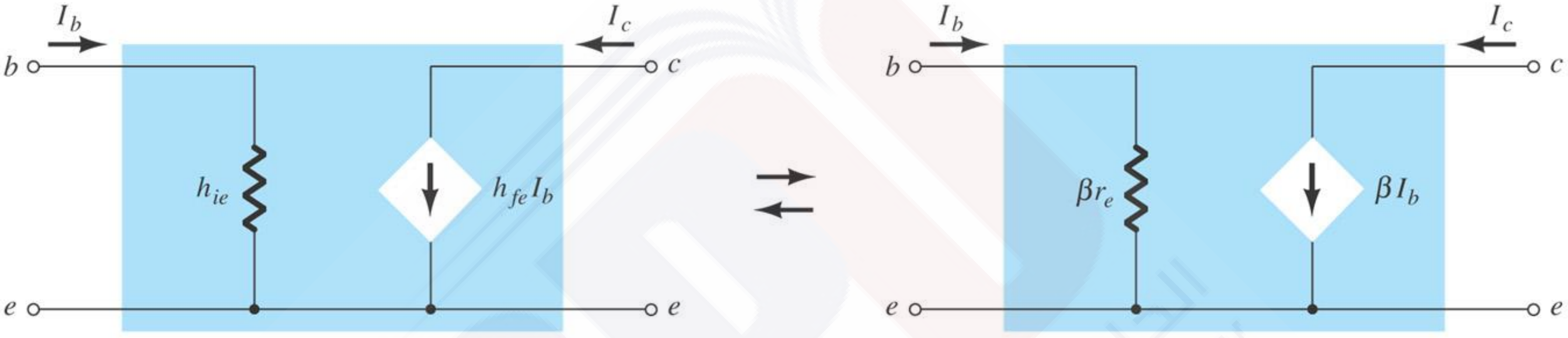


(a) (b)

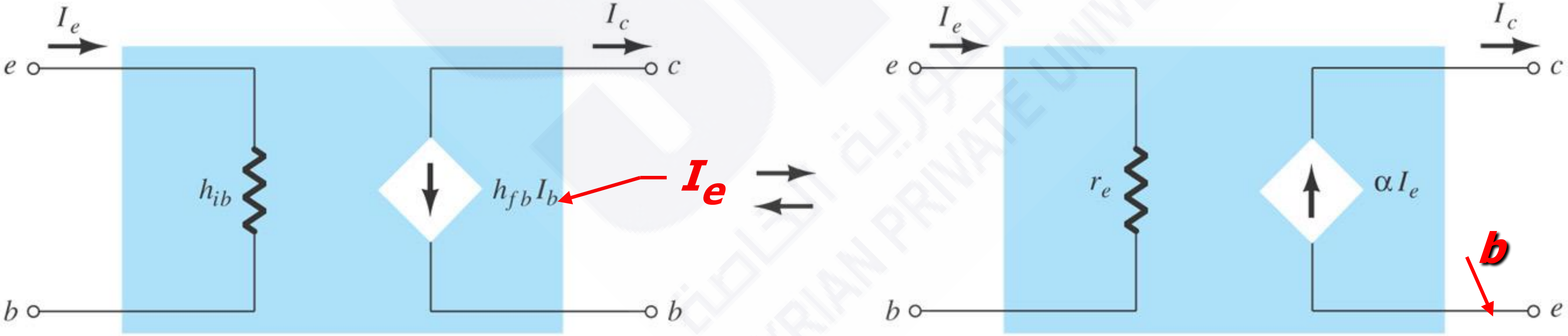
Approximate hybrid equivalent model



Hybrid versus *re* model



common-emitter configuration

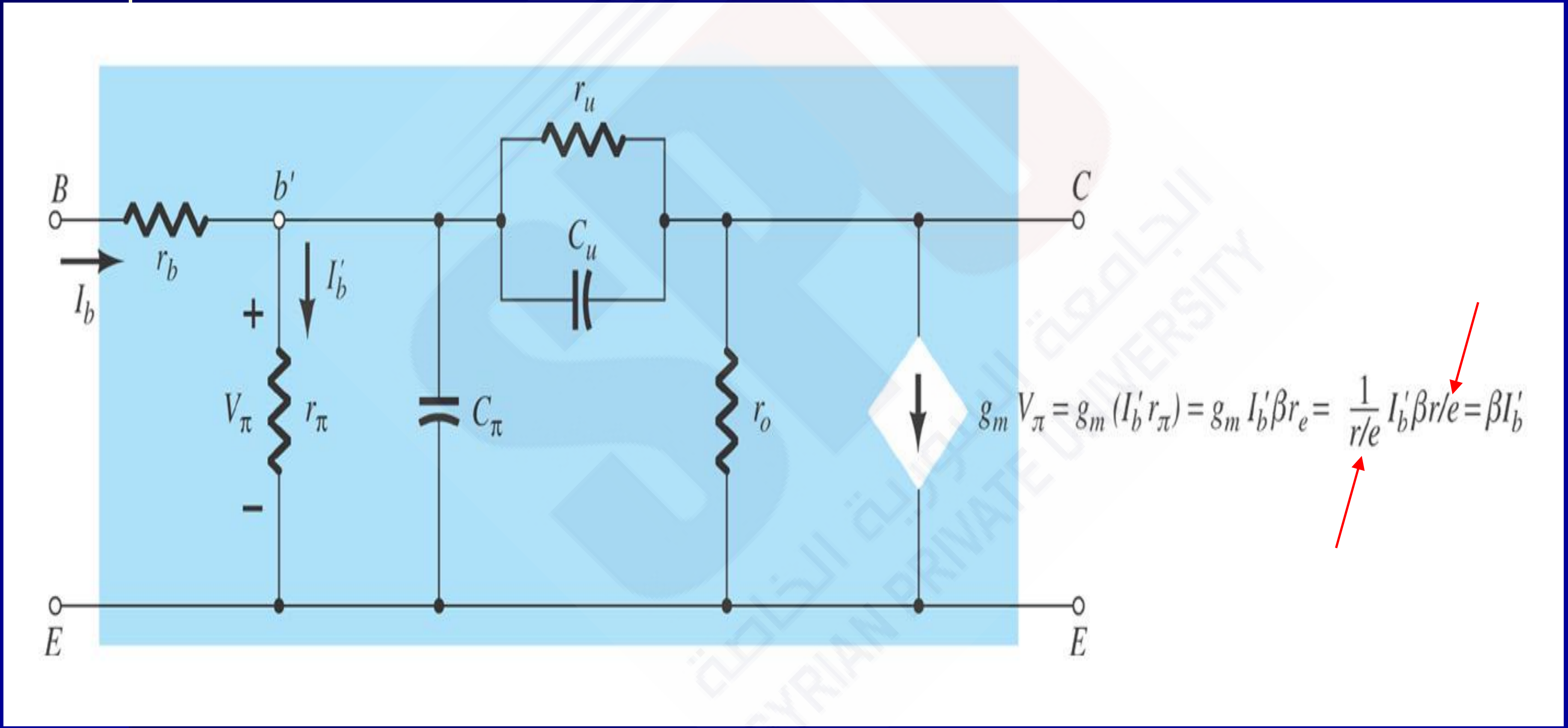


common-base configuration

hybrid π model

- The following Figure shows the hybrid π model ,named as Giacoletto ,for HF transistor small-signal ac equivalent circuit.

Giacoletto (or hybrid π) high-frequency transistor small-signal ac equivalent circuit



$$g_m V_\pi = g_m (I_b' r_\pi) = g_m I_b' \beta r_e = \frac{1}{r/e} I_b' \beta r/e = \beta I_b'$$

hybrid π model

- ***Features OF hybrid π model*** :
- 1-A more accurate mode for HF applications (for full frequency response).
- 2-Include parameters do not appear in other two models.
- 3-C_u & C_π are stray parasitic capacitors ,between various junctions of the device,

  at LF & MF Cu & Cπ ≈ ∞

hybrid π model

- C_u = from several pF to Tens of pF , while
- C_π = from < 1 pF to a few of pF.
- r_u=A very large resistance(union resistance).
- r_b= 2 – 10 Ω , a complex resistance ,consist of :base contact connection ,base bulk resistance from the external terminal to the active region of the Tr. and base spreading resistance within the active region.

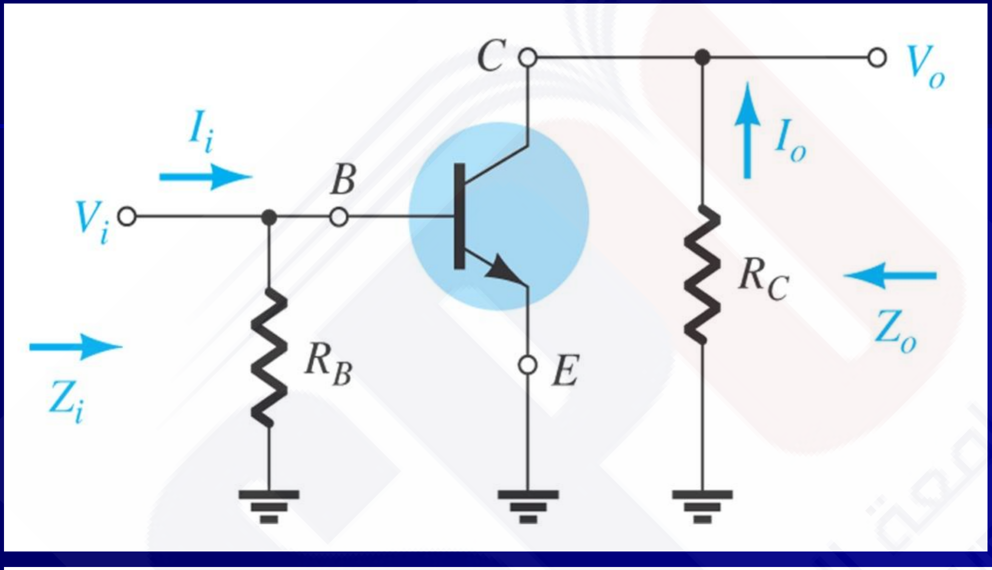
hybrid π model

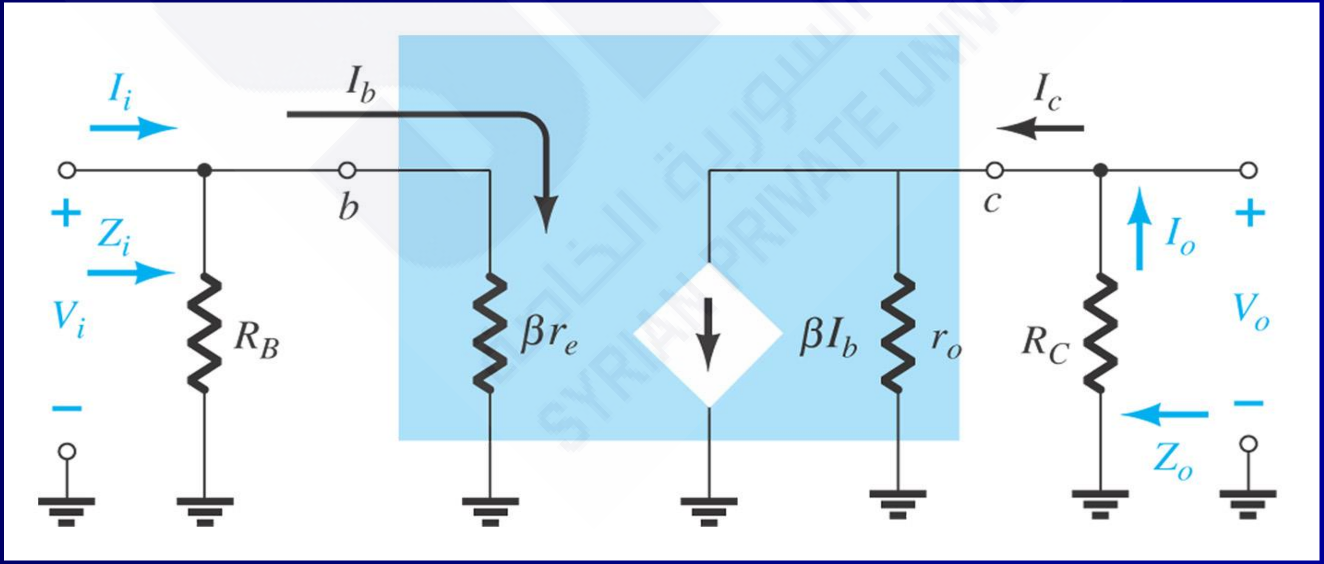
- r_o=(5 – 40) k Ω ,for CE-configuration.
- Note that this hybrid model ,or other Tr. Models can be considered as CCCS or CCVS depending on parameters employed .
- Since the use of the model is totally dependent on finding parameter values for the equivalent network

hybrid π model

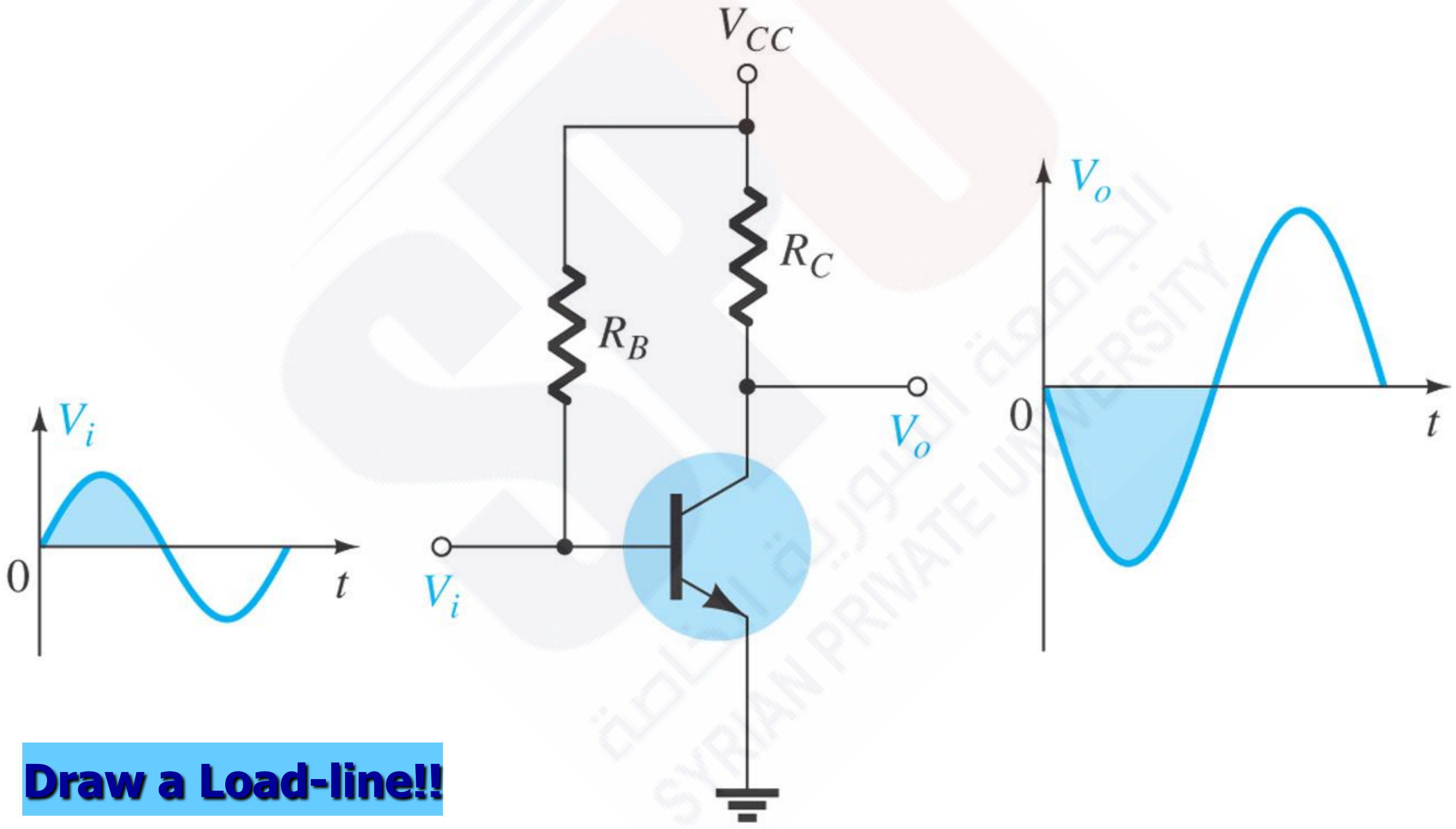
- It is important to be aware of the following relationships to extract the parameter values from the data typically provided.
- $r_\pi = \beta\, r_e$, $g_m = 1 / r_e$
- $r_o = 1 / h_{oe}$,and
- $h_{re} = r_\pi /(r_\pi + r_u) \approx r_\pi / r_u$

Dynamic Drawing and Equivalent Circuit



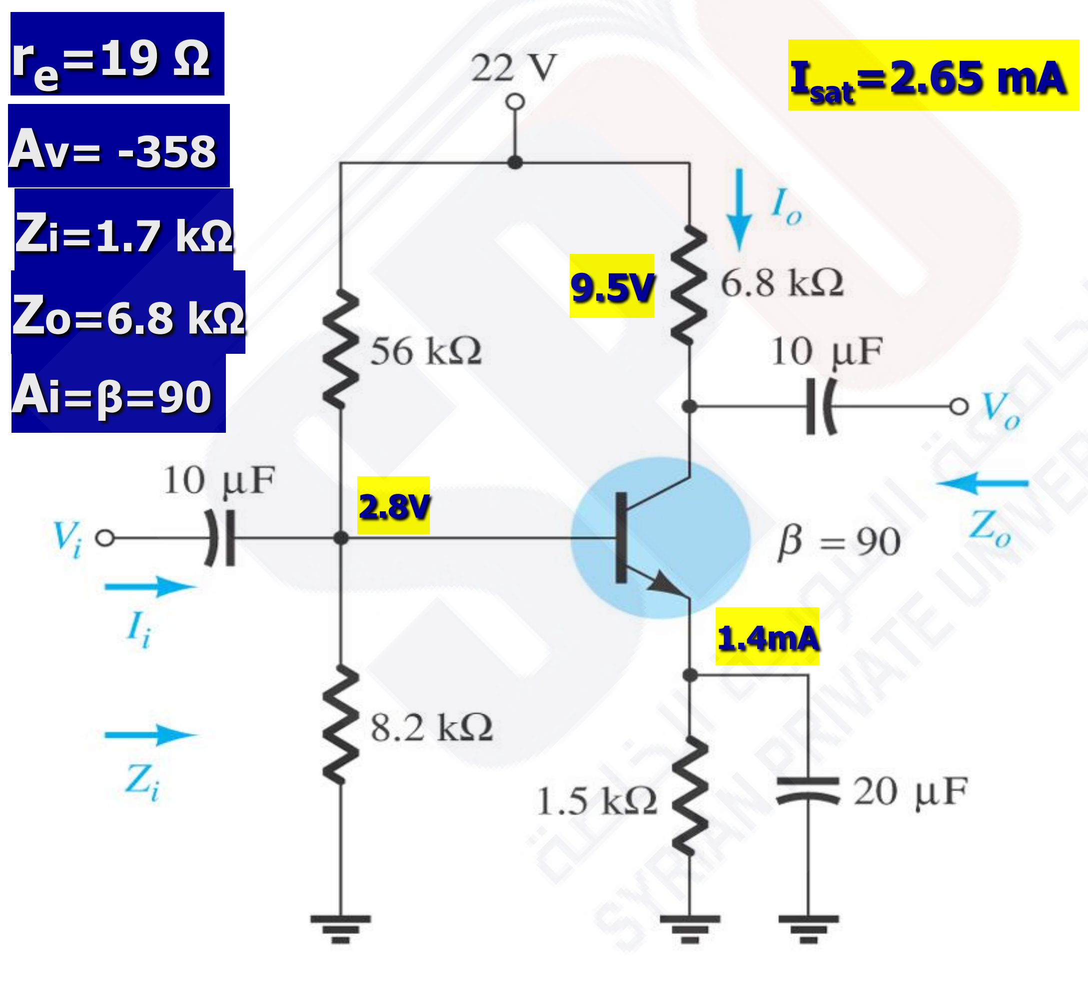


180° phase shift between input and output waveforms



Draw a Load-line!!

Voltage Divider-Bias



r_e=19 Ω

Av= -358

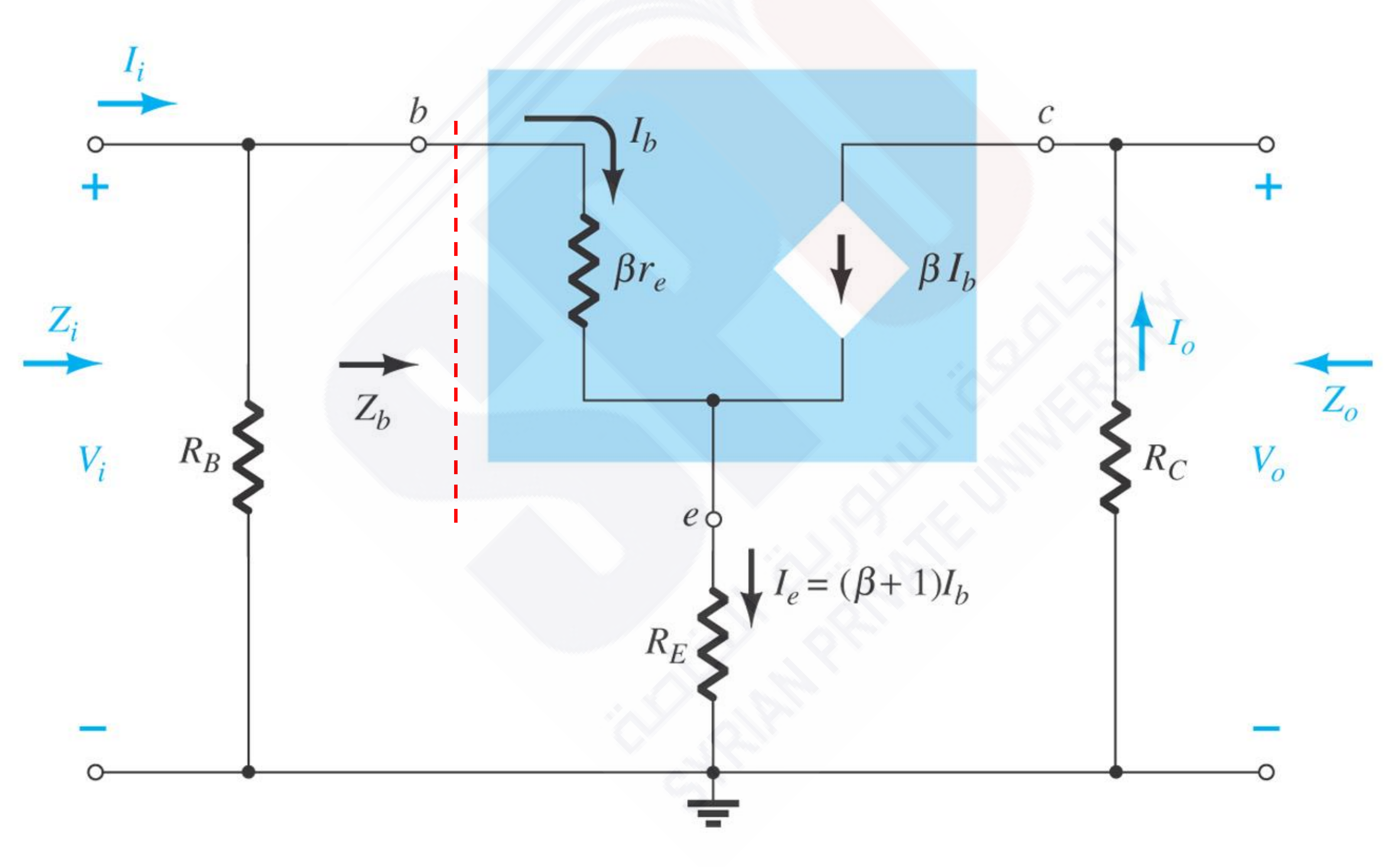
Zi=1.7 kΩ

Zo=6.8 kΩ

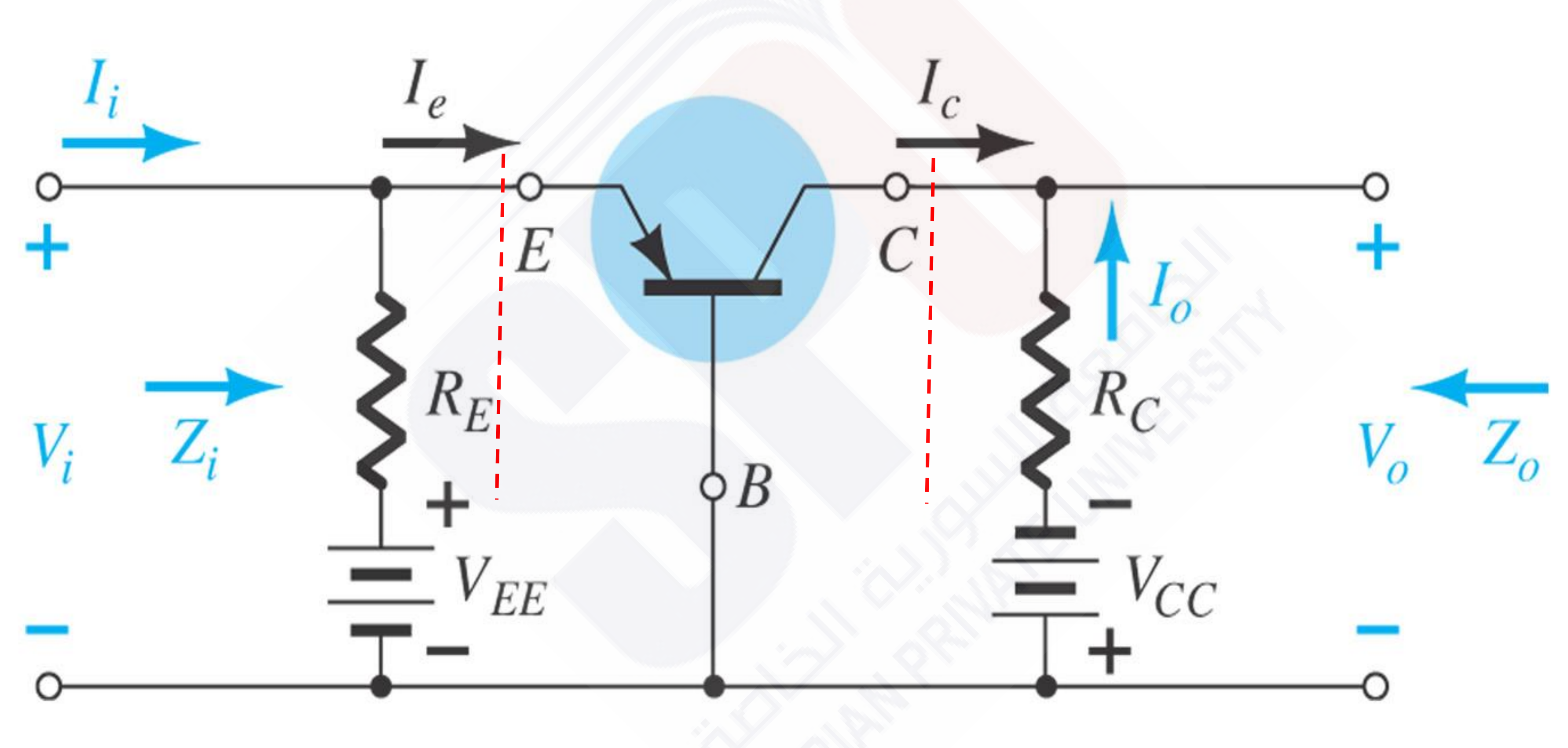
Ai=β=90

I_{sat}=2.65 mA

Equivalent Circuit without C_E

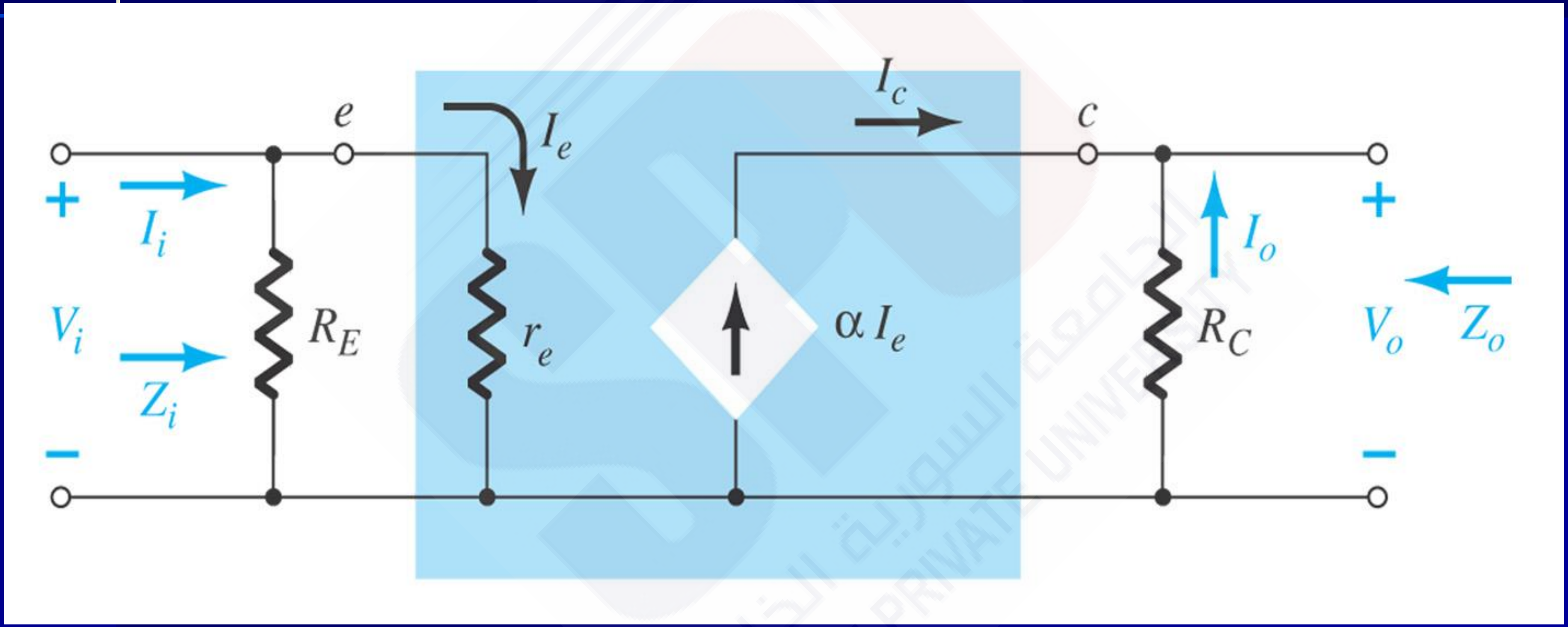


1.2- CC & CB Configurations



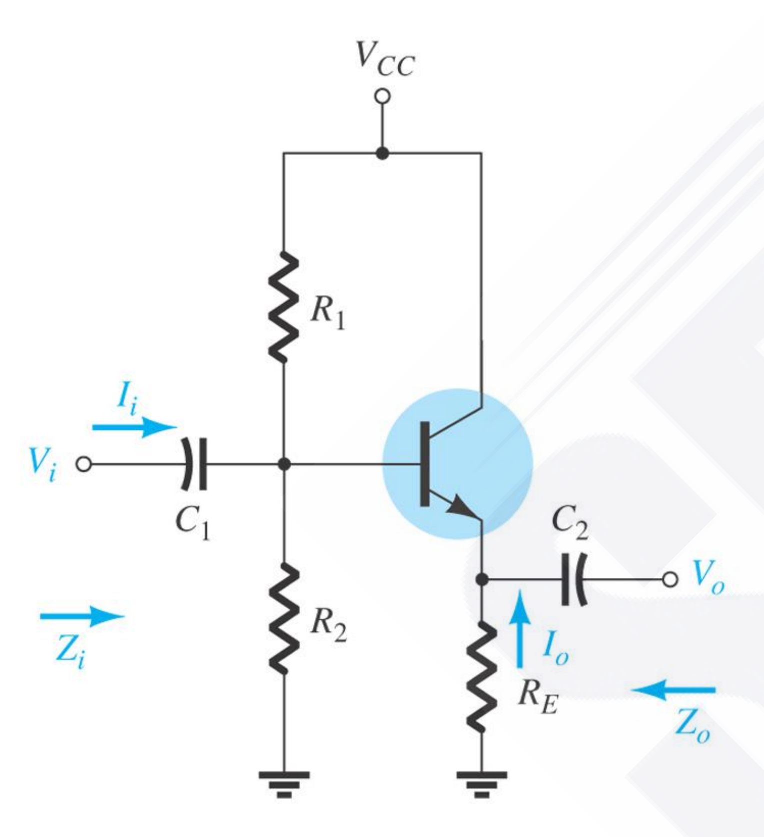
CB-Circuit

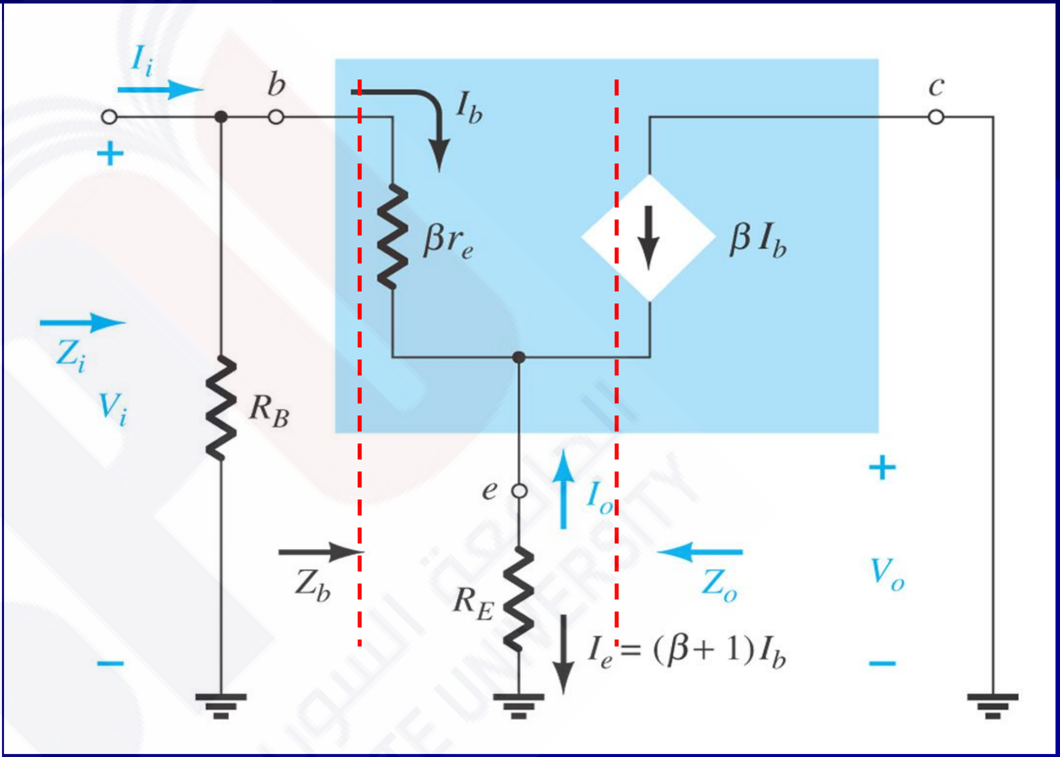
CB Equivalent Circuit



$Z_i=R_E \| r_e$, $Z_o=R_C$, $A_i=\alpha$, $A_v= g_m R_C$

CC- Equivalent Circuit





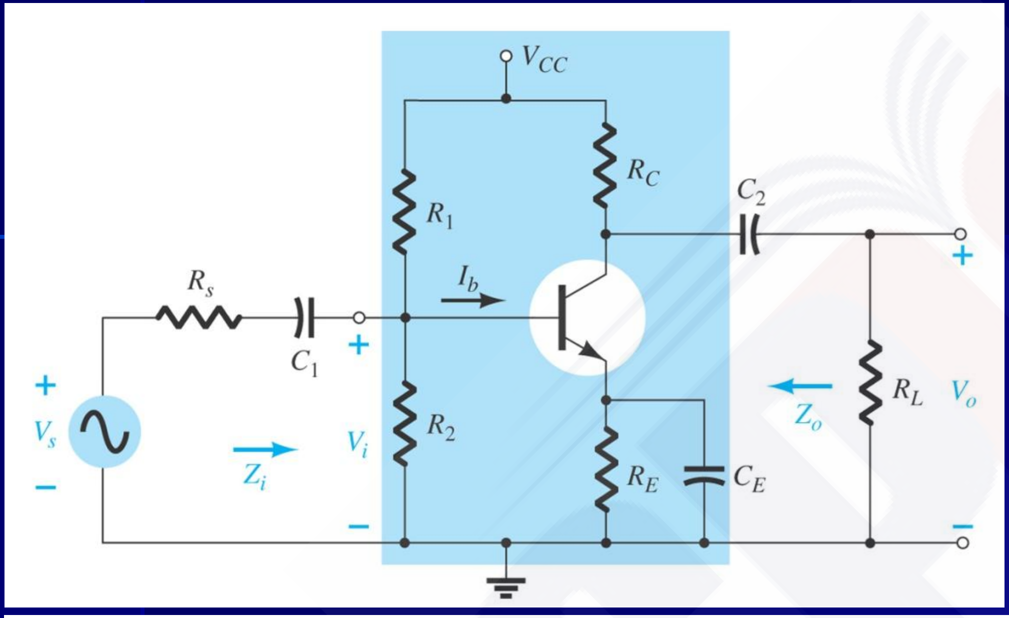
$$Z_i = R_B \parallel Z_b$$

$$Z_b = \beta(r_e + R_E)$$

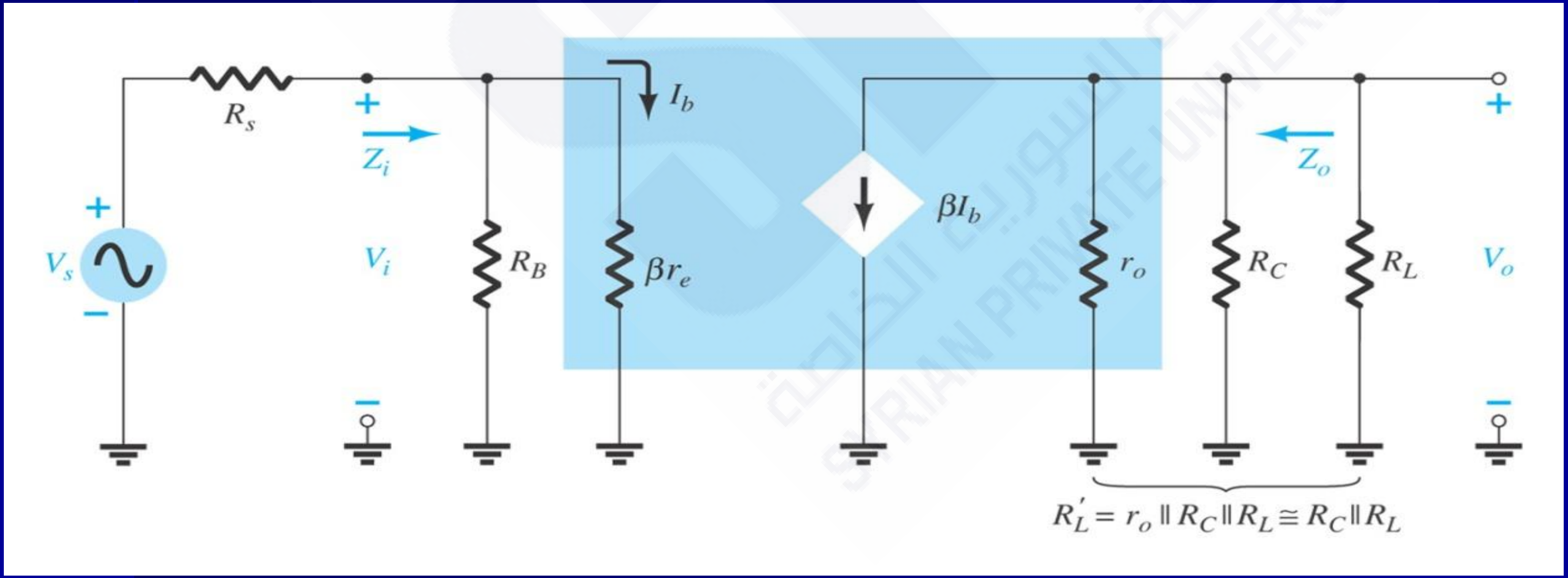
$$Z_o = R_E \parallel r_e$$

$$A_v = \frac{R_E}{r_e + R_E} = 1$$

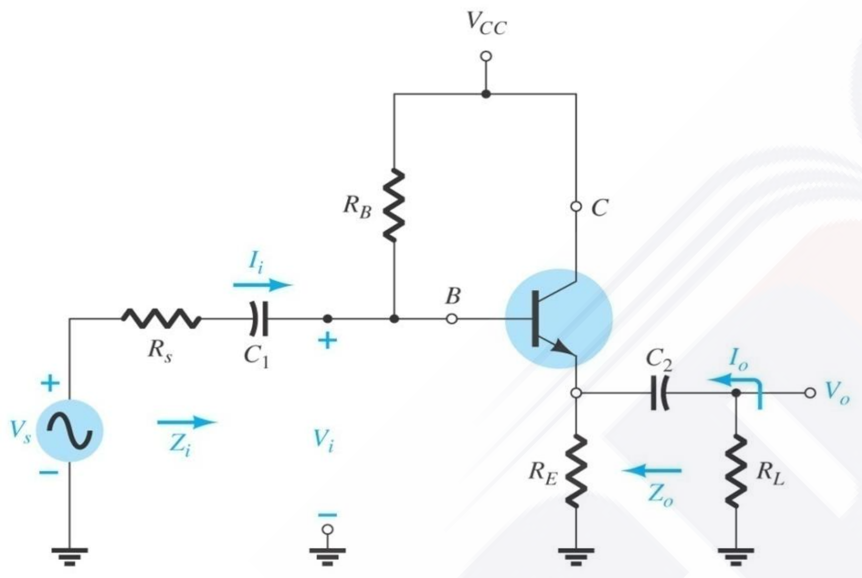
1.3 Effect of RL and RS



A_v: Smaller
Z_o: $R_C \| r_o$
$V_s > V_i$
A_i : Smaller
Z_i : $R_B \| \beta r_e$



Emitter-follower configuration with R_s and R_L



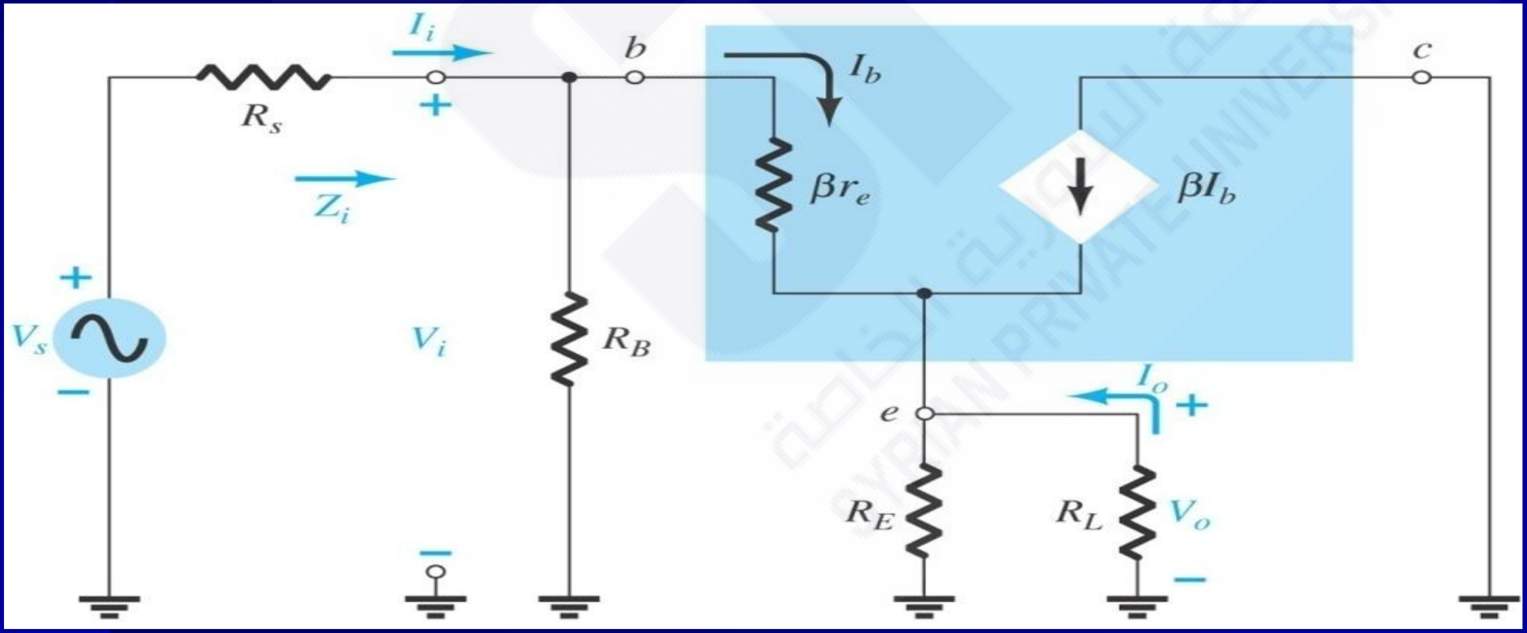
A_v: Smaller

Z_o: $(R_E \parallel r_e)_{\text{for } R_s \ll \beta r_e}$

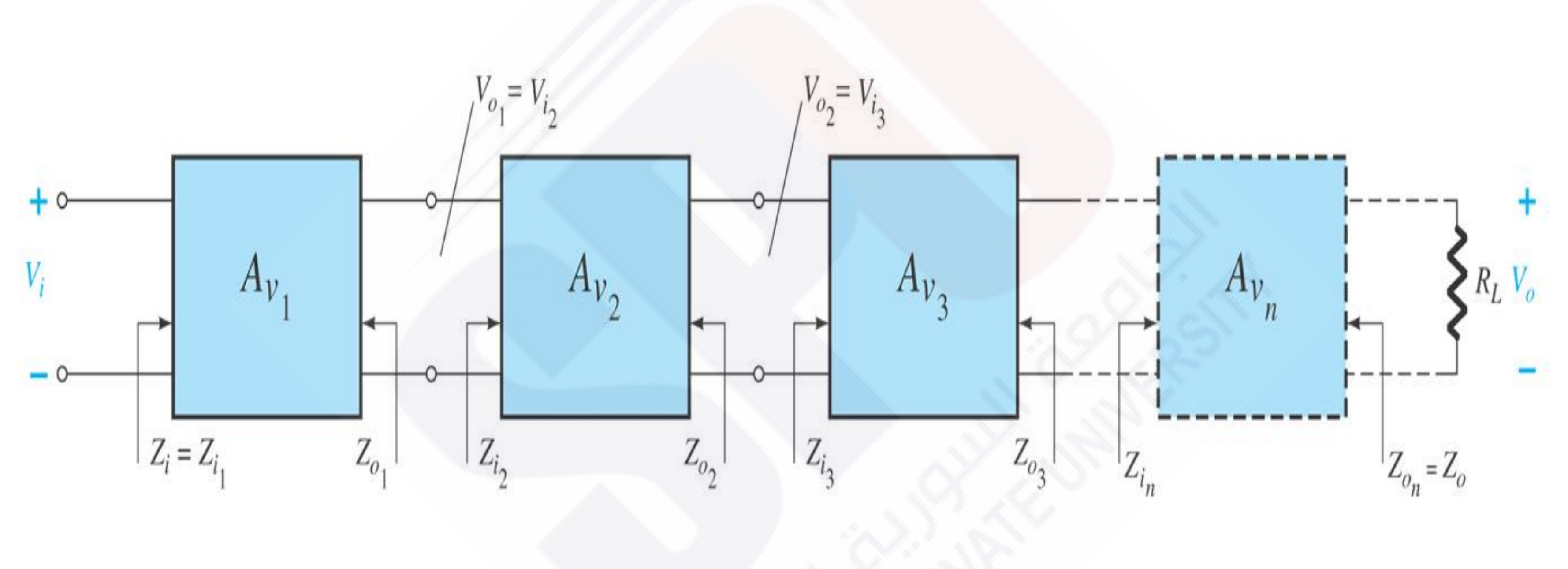
$V_s > V_i$

A_i : Smaller

Z_i : $R_B \parallel \beta(r_e + R_E \parallel R_L)$

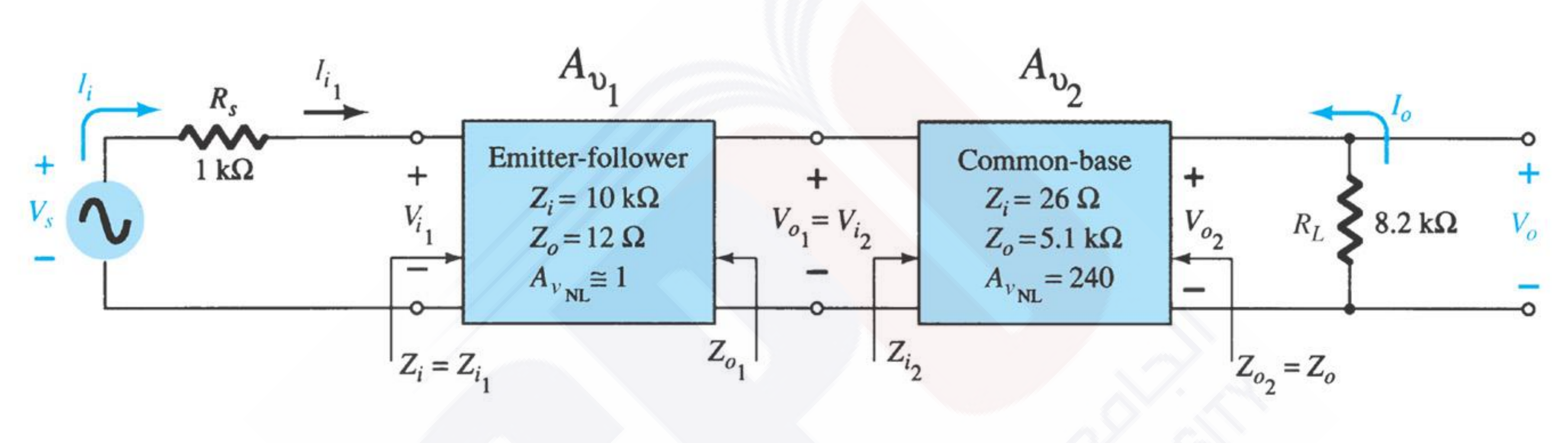


1.4 Cascaded System and Amp. Coupling



Expecting: $A_{vtot} = A_{v1} . A_{v2} .... A_{vn} |_{Z_{ik} : \text{very high}}$

Cascading 2-stages Amplifier



$Z_i = Z_{i1}$, $Z_o = Z_{o2}$

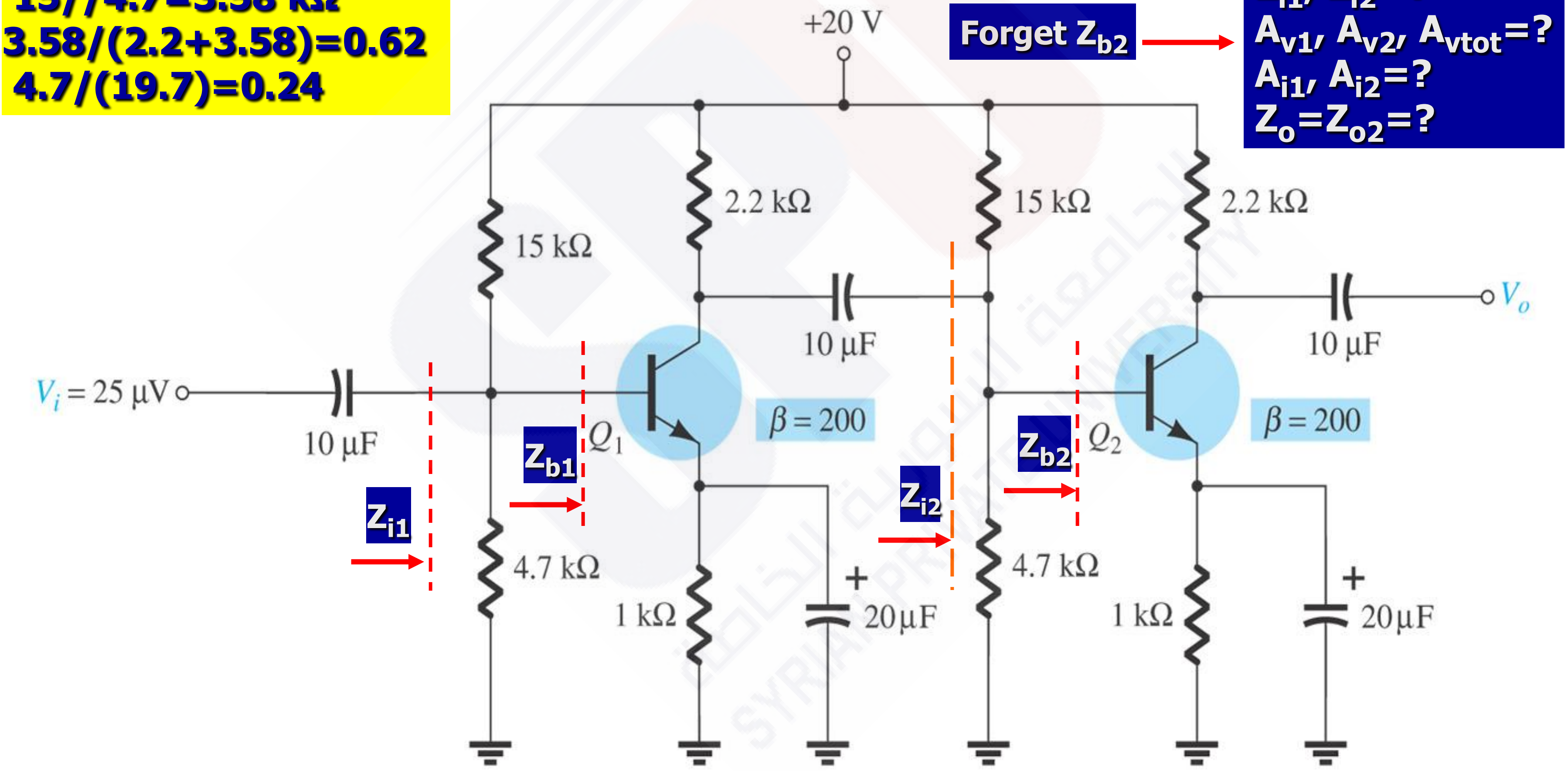
$$A_{vtotal} = \frac{V_{o2}}{V_s} = \frac{V_{o2}}{V_{i2}} \cdot \frac{V_{i2}}{V_{o1}} \frac{V_{o1}}{V_{i1}} \cdot \frac{V_{i1}}{V_s}$$

$$A_{vtotal} = A_{v2NL} \cdot \frac{R_L}{R_L + Z_{o2}} \cdot \frac{Z_{i2}}{Z_{o1} + Z_{i2}} . A_{v1NL} \cdot \frac{Z_{i1}}{R_s + Z_{i1}}$$

$$A_{vtotal} = 240. \frac{R_L}{R_L + Z_{o2}} \frac{Z_{i2}}{Z_{o1} + Z_{i2}} \frac{Z_{i1}}{R_s + Z_{i1}} = 123.4$$

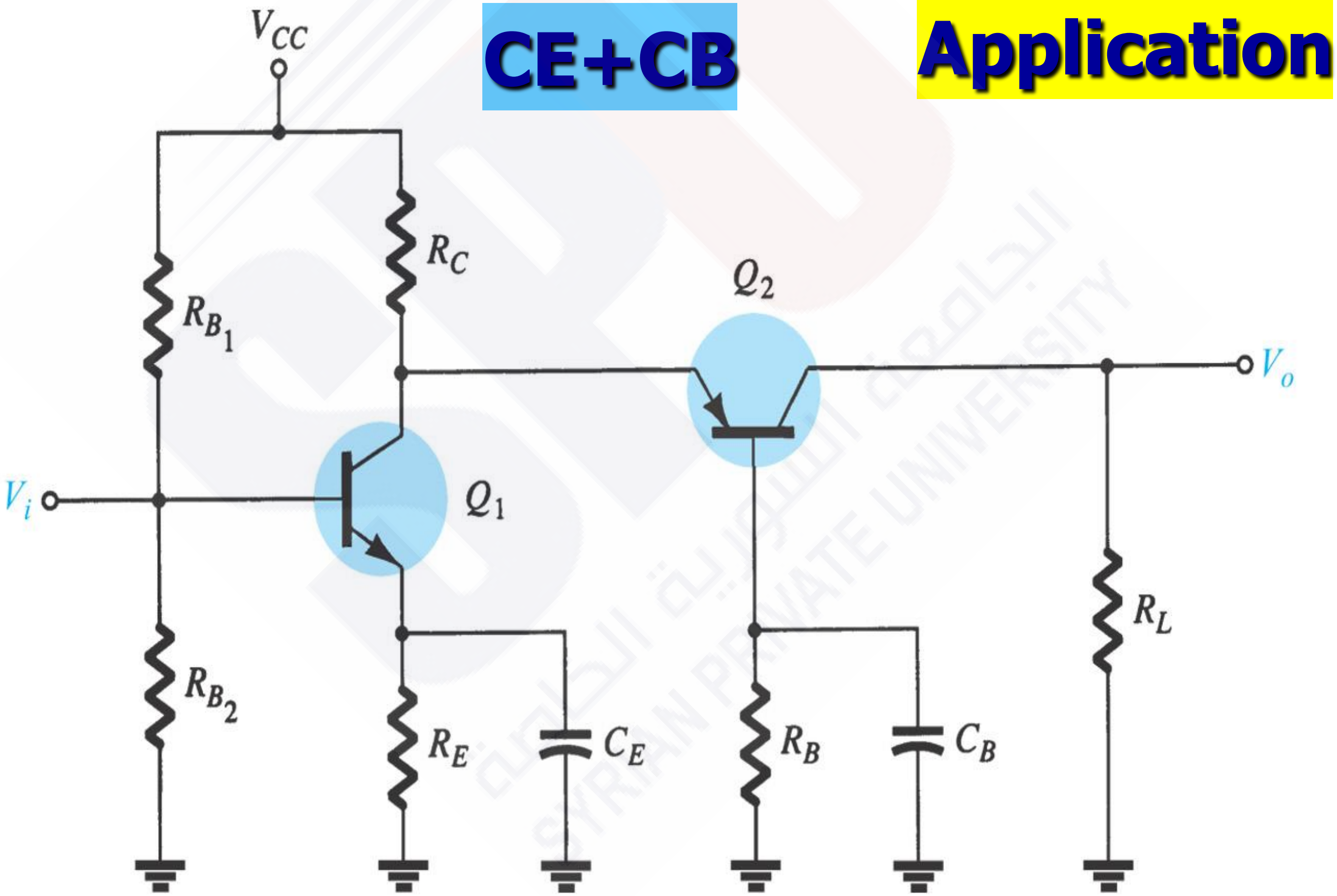
RC-Coupled Amplifiers

$15//4.7=3.58\ k\Omega$
$3.58/(2.2+3.58)=0.62$
$4.7/(19.7)=0.24$



$r_e=6$
$Z_{i1}, Z_{i2}=?$
$A_{v1}, A_{v2}, A_{vtot}=?$
$A_{i1}, A_{i2}=?$
$Z_o=Z_{o2}=?$

Cascade configuration

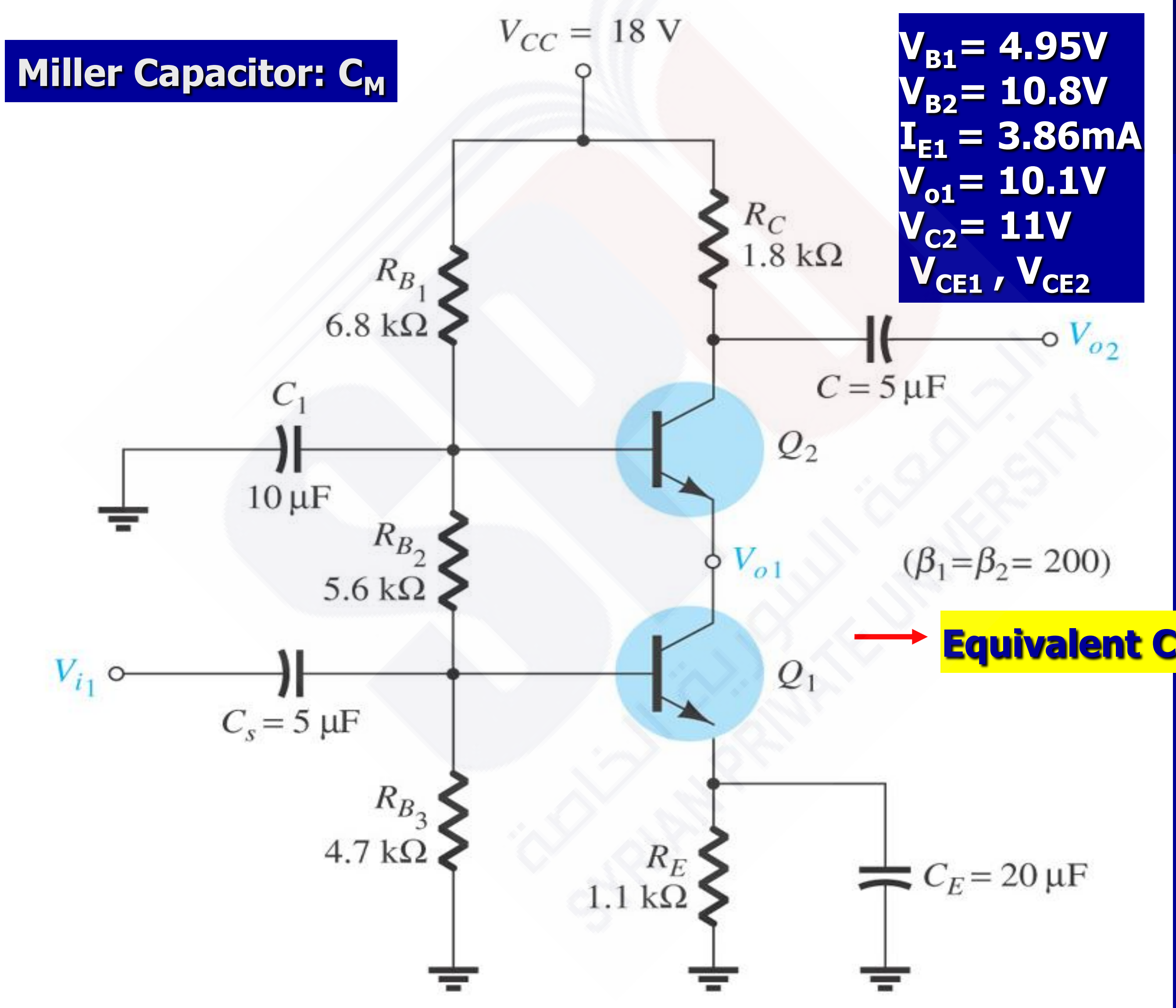


CE+CB

Application

Practical cascade circuit

Miller Capacitor: C_M



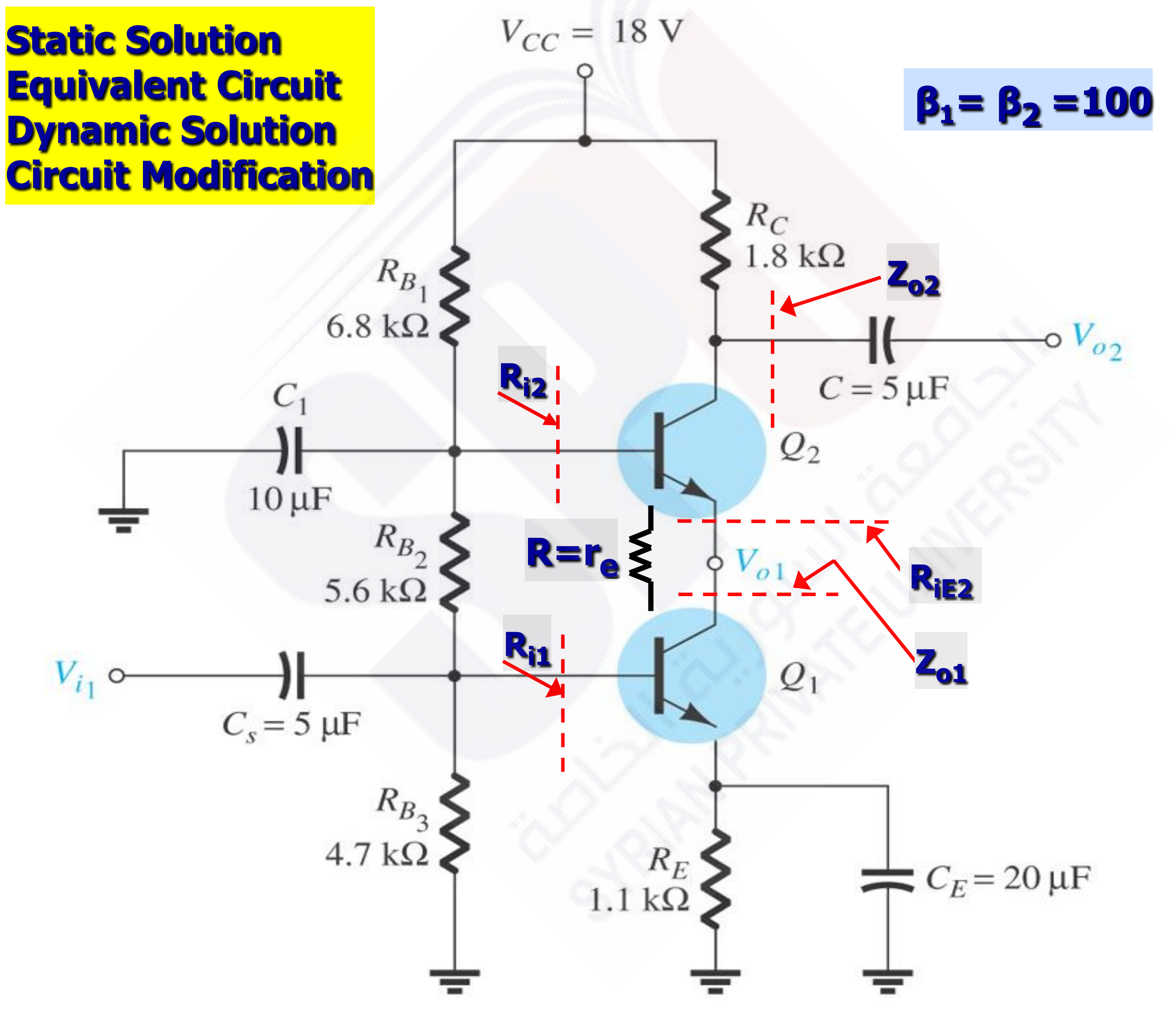
$V_{B1} = 4.95V$
$V_{B2} = 10.8V$
$I_{E1} = 3.86mA$
$V_{o1} = 10.1V$
$V_{C2} = 11V$
V_{CE1} , V_{CE2}

→ **Equivalent Circuit**

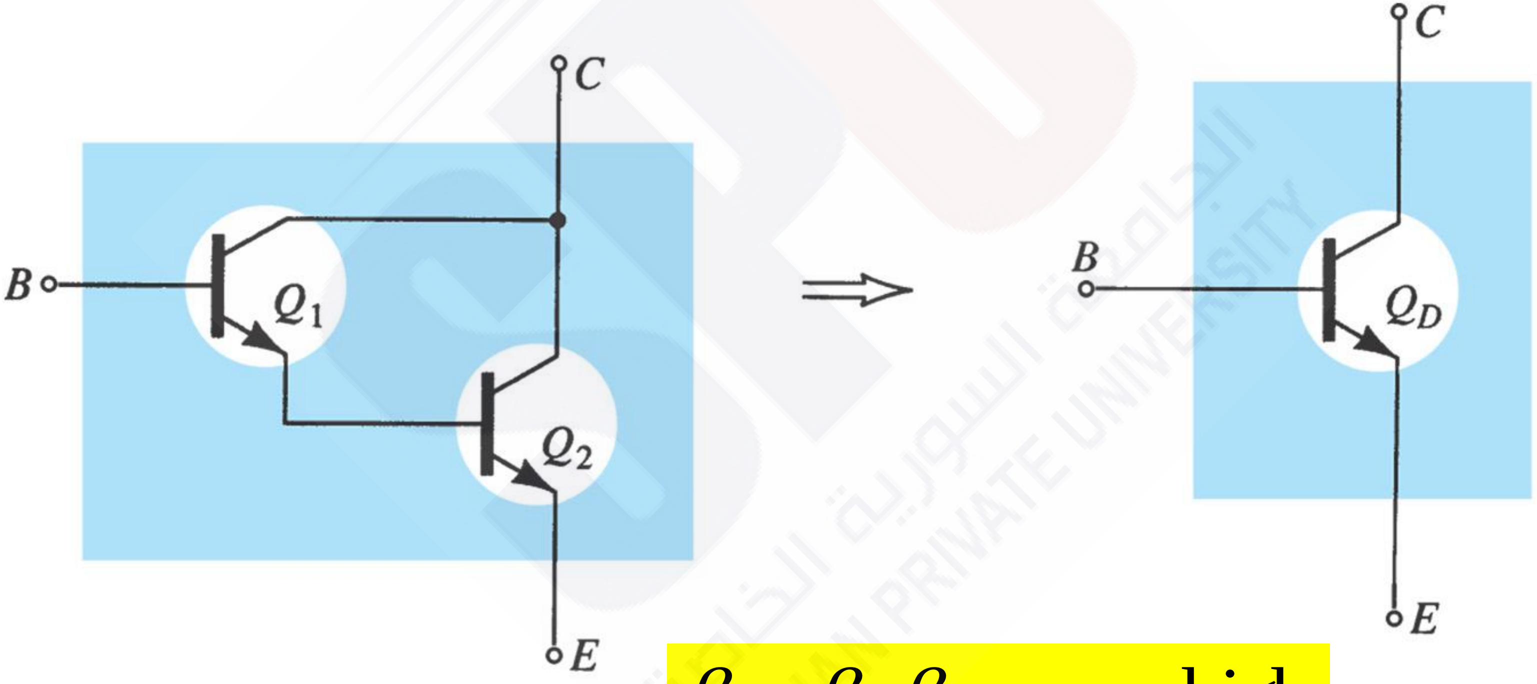
Example

Static Solution
Equivalent Circuit
Dynamic Solution
Circuit Modification

$\beta_1 = \beta_2 = 100$

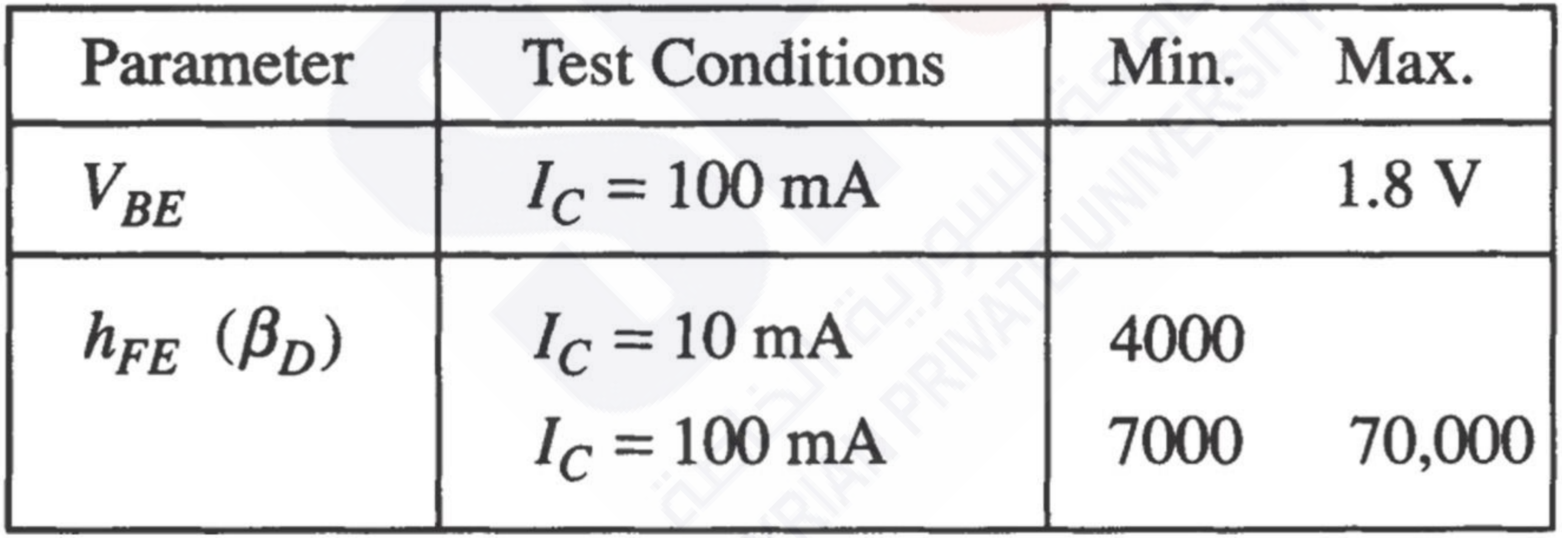


1.5 Darlington Pair Connection



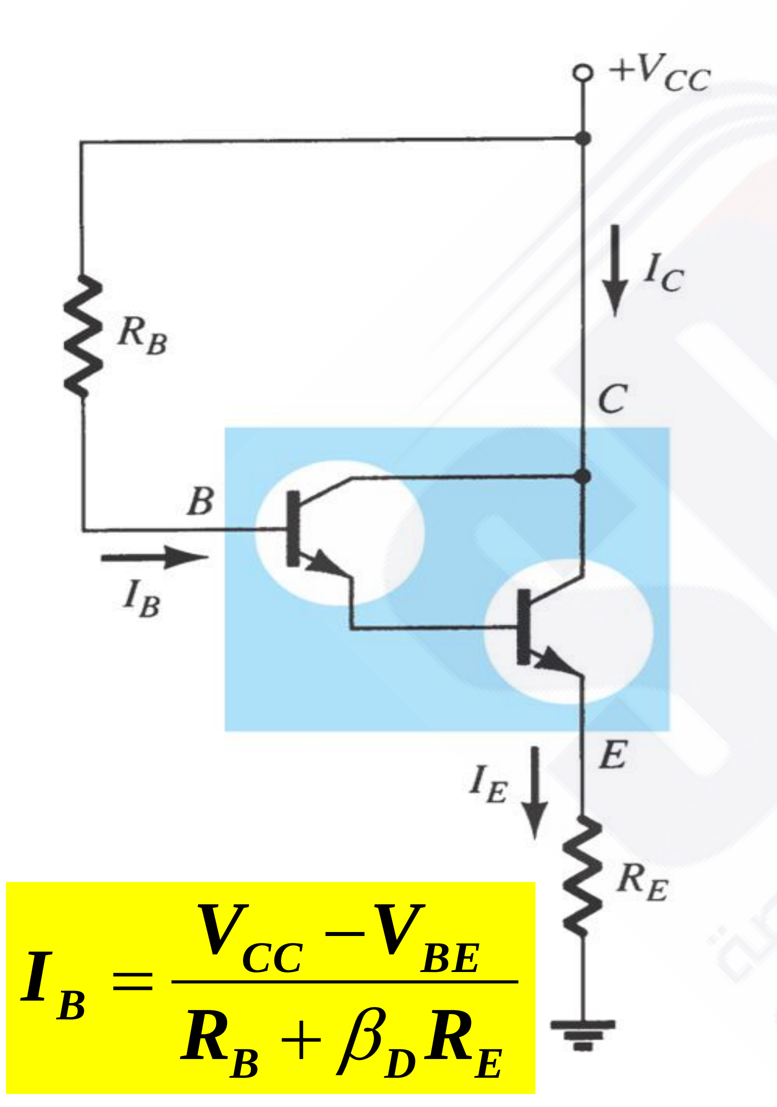
$\beta = \beta_1 . \beta_2$: very high

Specification of a Darlington npn transistor 2N999

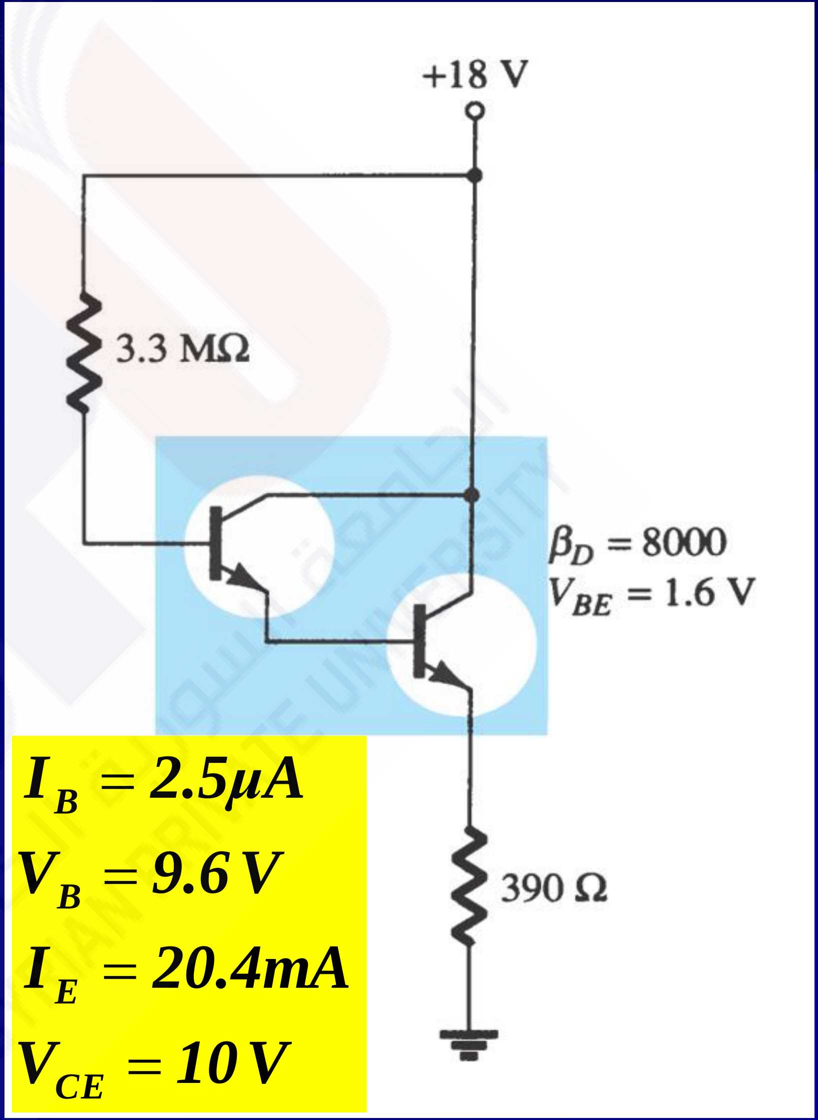


Parameter	Test Conditions	Min.	Max.
V_{BE}	$I_C = 100$ mA		1.8 V
h_{FE} (β_D)	$I_C = 10$ mA	4000	
	$I_C = 100$ mA	7000	70,000

Darlington Circuit



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta_D R_E}$$



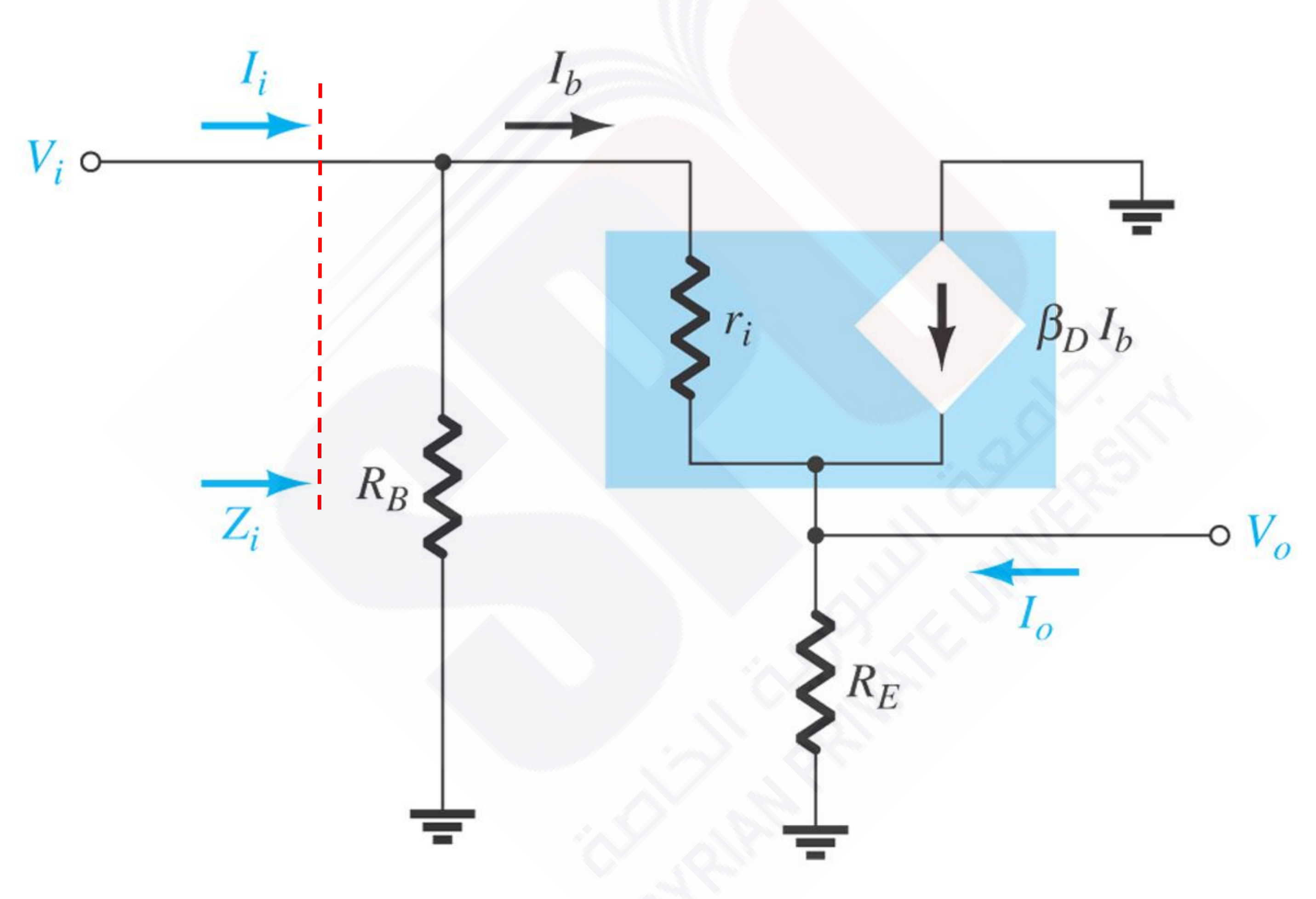
$I_B = 2.5\mu A$

$V_B = 9.6\,V$

$I_E = 20.4mA$

$V_{CE} = 10\,V$

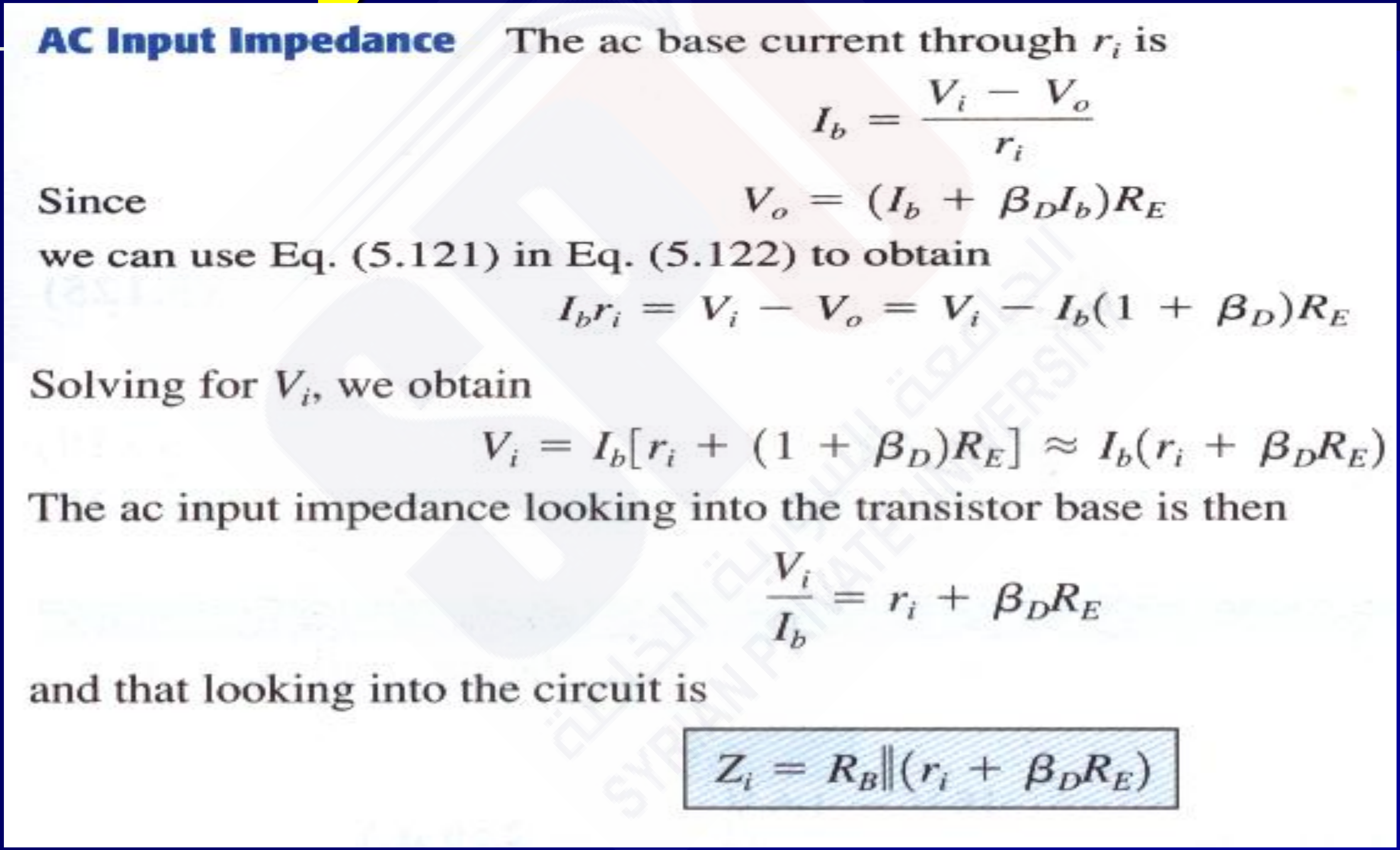
AC Equivalent Circuit of Darlington Emitter-Follower



$$Z_i = R_B // (r_i + \beta_D R_E)$$

$$r_i = \beta_1 r_{e1} + \beta_D r_{e2}$$

AC Equivalent Circuit of Darlington Emitter-Follower



AC Input Impedance The ac base current through r_i is

$$I_b = \frac{V_i - V_o}{r_i}$$

Since

$$V_o = (I_b + \beta_D I_b)R_E$$

we can use Eq. (5.121) in Eq. (5.122) to obtain

$$I_b r_i = V_i - V_o = V_i - I_b(1 + \beta_D)R_E$$

Solving for V_i, we obtain

$$V_i = I_b[r_i + (1 + \beta_D)R_E] \approx I_b(r_i + \beta_D R_E)$$

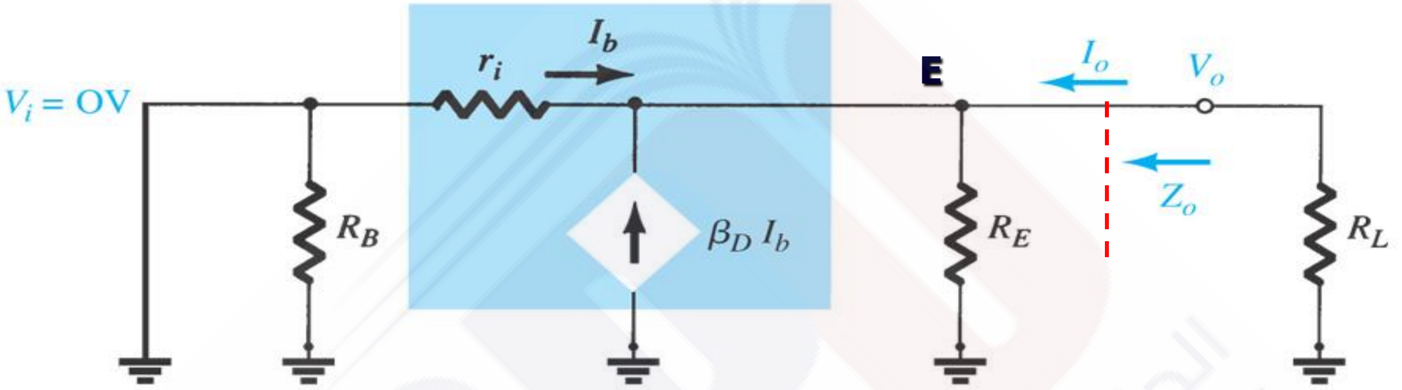
The ac input impedance looking into the transistor base is then

$$\frac{V_i}{I_b} = r_i + \beta_D R_E$$

and that looking into the circuit is

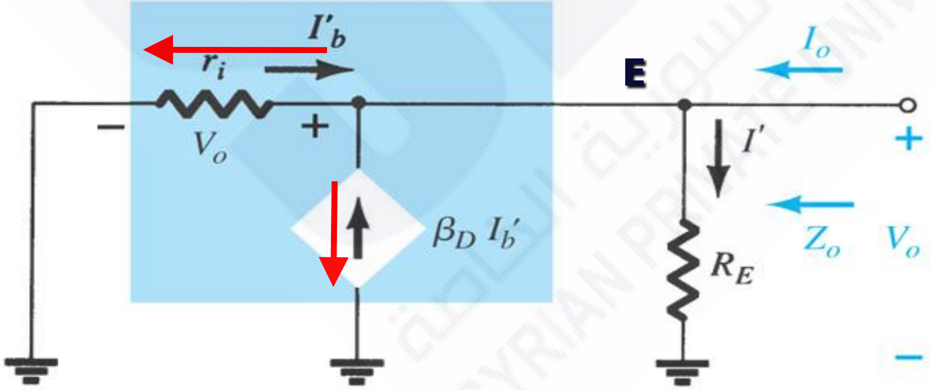
$$\boxed{Z_i = R_B \| (r_i + \beta_D R_E)}$$

AC equivalent circuit for determining Z_o



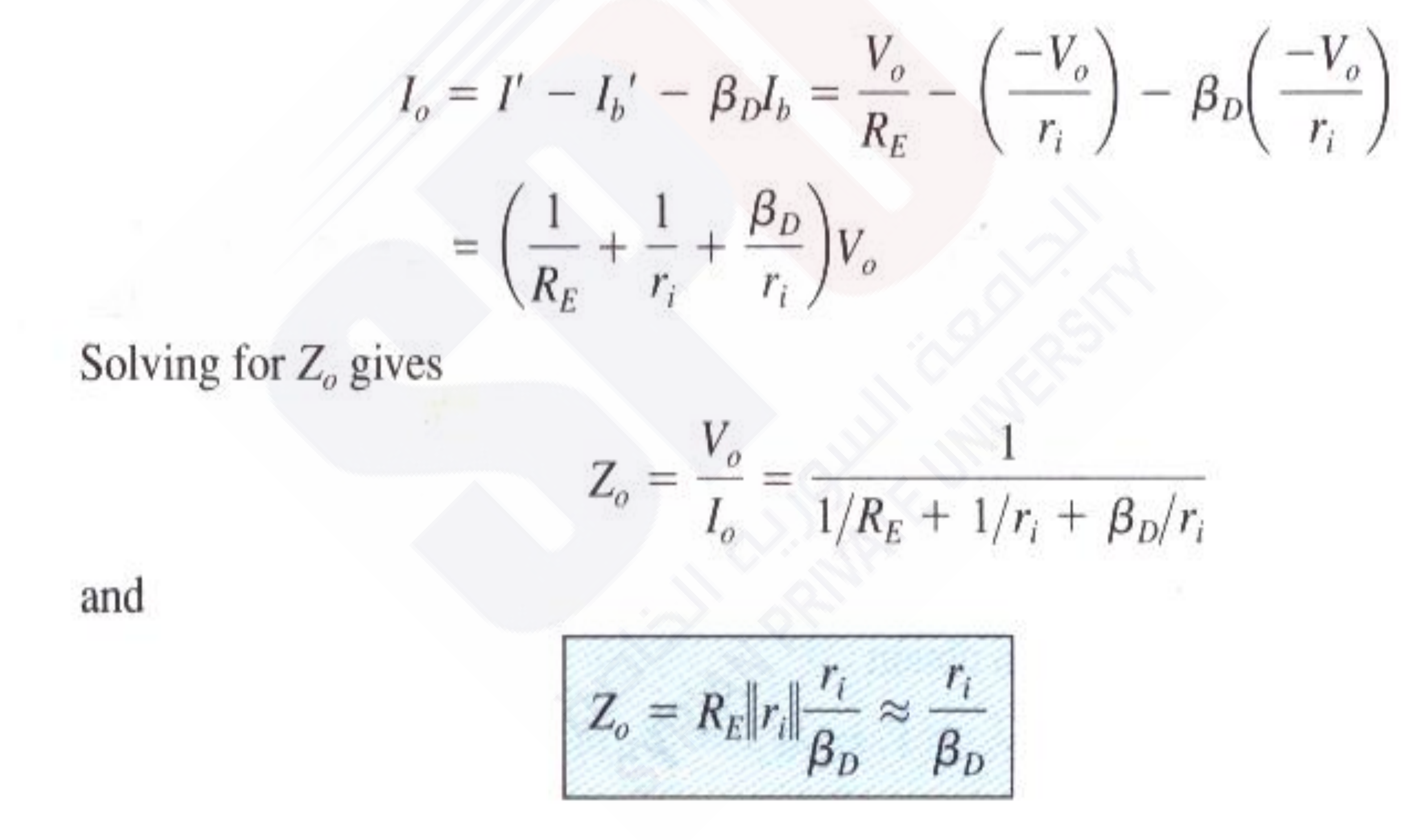
(a)

$$\frac{r_i + (R_B = 0)}{\beta_D} \| R_E = Z_o \cong r_i / \beta_D$$



(b)

AC equivalent circuit for determining *Zo*



$$I_o = I' - I_b' - \beta_D I_b = \frac{V_o}{R_E} - \left(\frac{-V_o}{r_i}\right) - \beta_D\left(\frac{-V_o}{r_i}\right)$$

$$= \left(\frac{1}{R_E} + \frac{1}{r_i} + \frac{\beta_D}{r_i}\right)V_o$$

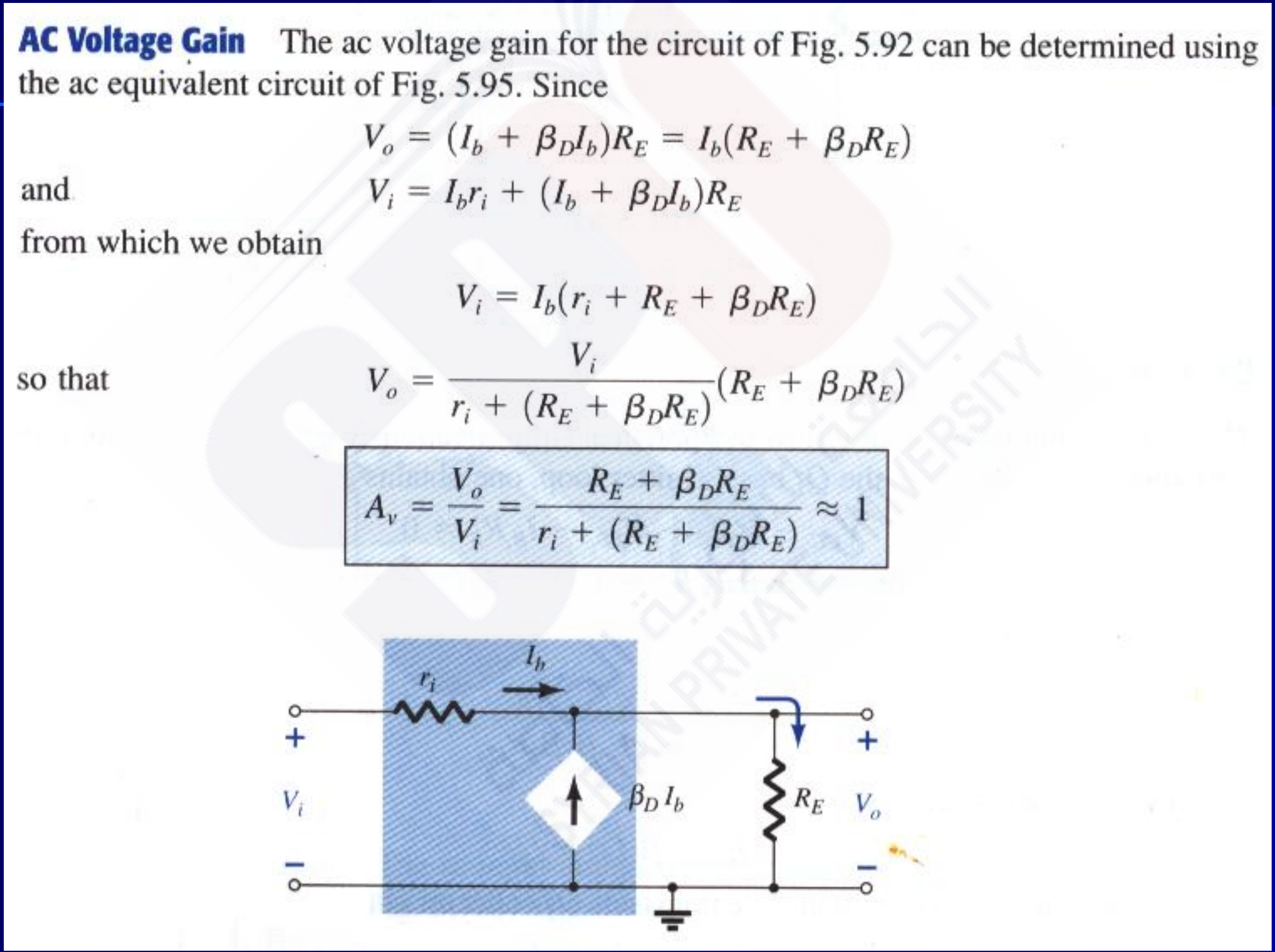
Solving for Z_o gives

$$Z_o = \frac{V_o}{I_o} = \frac{1}{1/R_E + 1/r_i + \beta_D/r_i}$$

and

$$\boxed{Z_o = R_E \| r_i \| \frac{r_i}{\beta_D} \approx \frac{r_i}{\beta_D}}$$

AC Voltage Gain



AC Voltage Gain The ac voltage gain for the circuit of Fig. 5.92 can be determined using the ac equivalent circuit of Fig. 5.95. Since

$$V_o = (I_b + \beta_D I_b)R_E = I_b(R_E + \beta_D R_E)$$

and

$$V_i = I_b r_i + (I_b + \beta_D I_b)R_E$$

from which we obtain

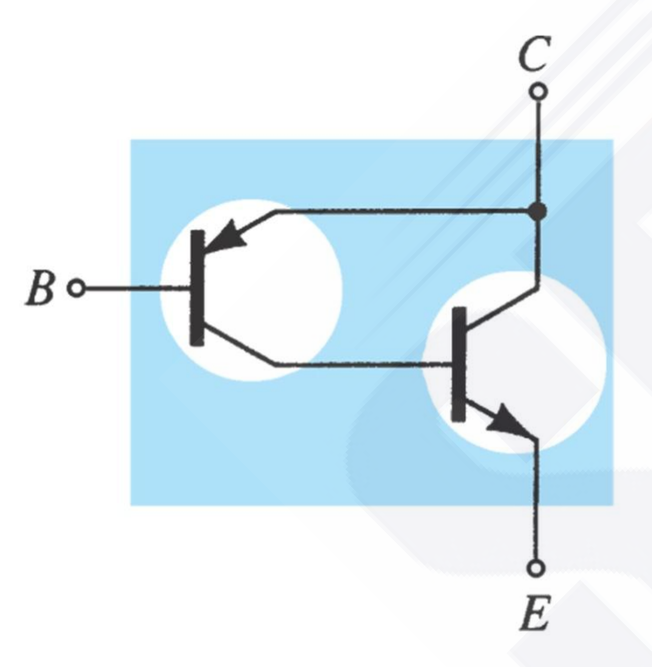
$$V_i = I_b(r_i + R_E + \beta_D R_E)$$

so that

$$V_o = \frac{V_i}{r_i + (R_E + \beta_D R_E)}(R_E + \beta_D R_E)$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{R_E + \beta_D R_E}{r_i + (R_E + \beta_D R_E)} \approx 1}$$

Feedback Pair



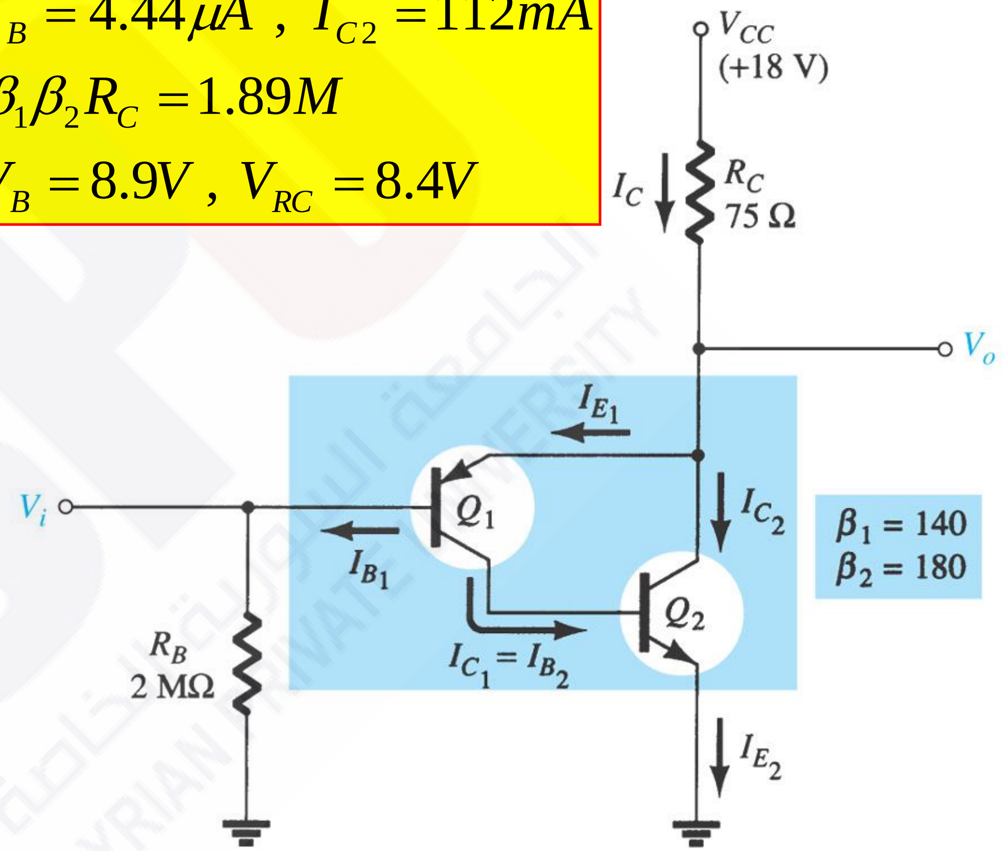
$$I_C = I_{C2} + I_{E1} \approx I_{C2}$$

$$V_B = \frac{V_{CC} - V_{BE1}}{R_B + \beta_1\beta_2 R_C} R_B$$

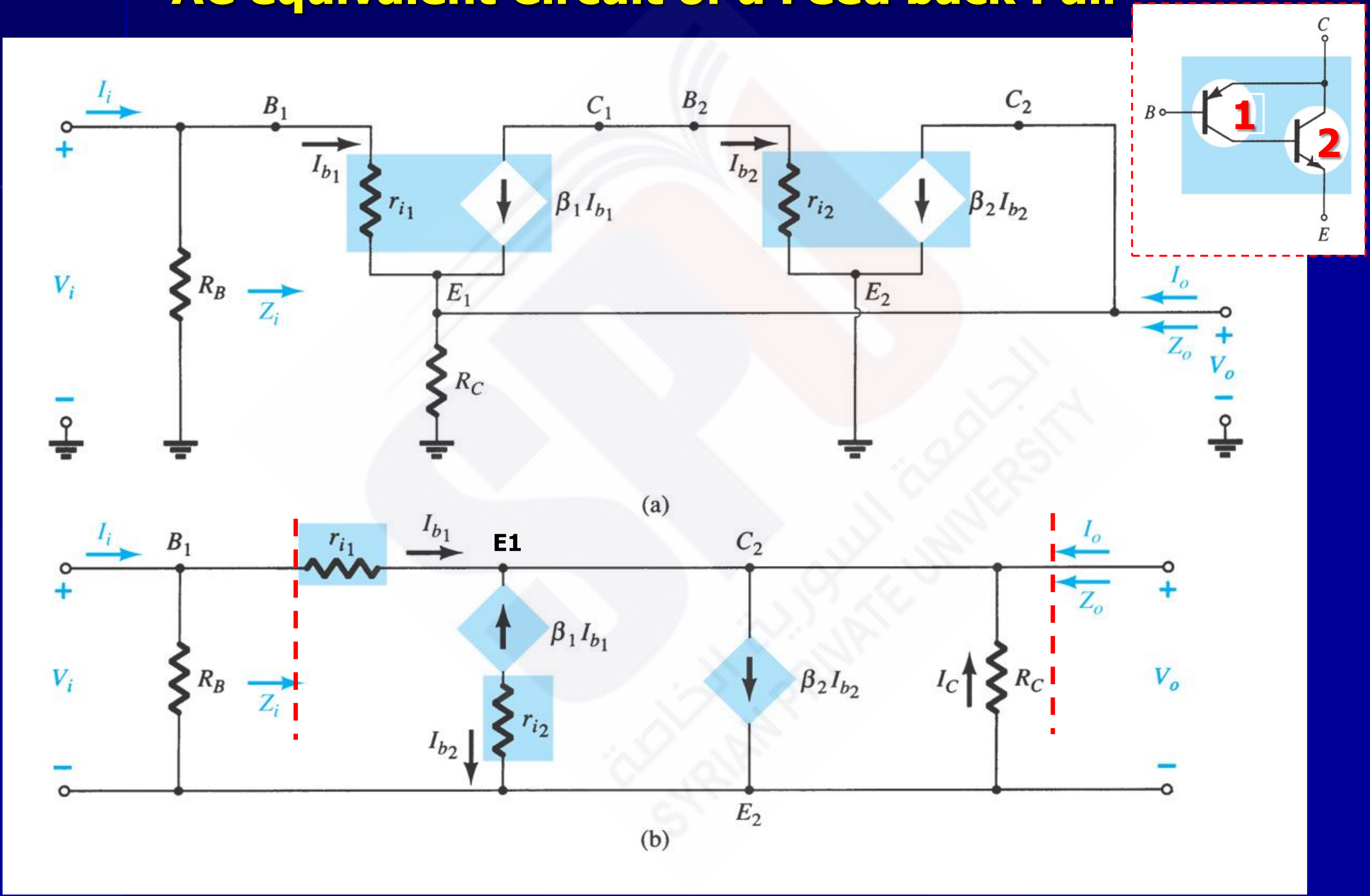
$$I_B = 4.44\mu A \ , \ I_{C2} = 112mA$$

$$\beta_1\beta_2 R_C = 1.89M$$

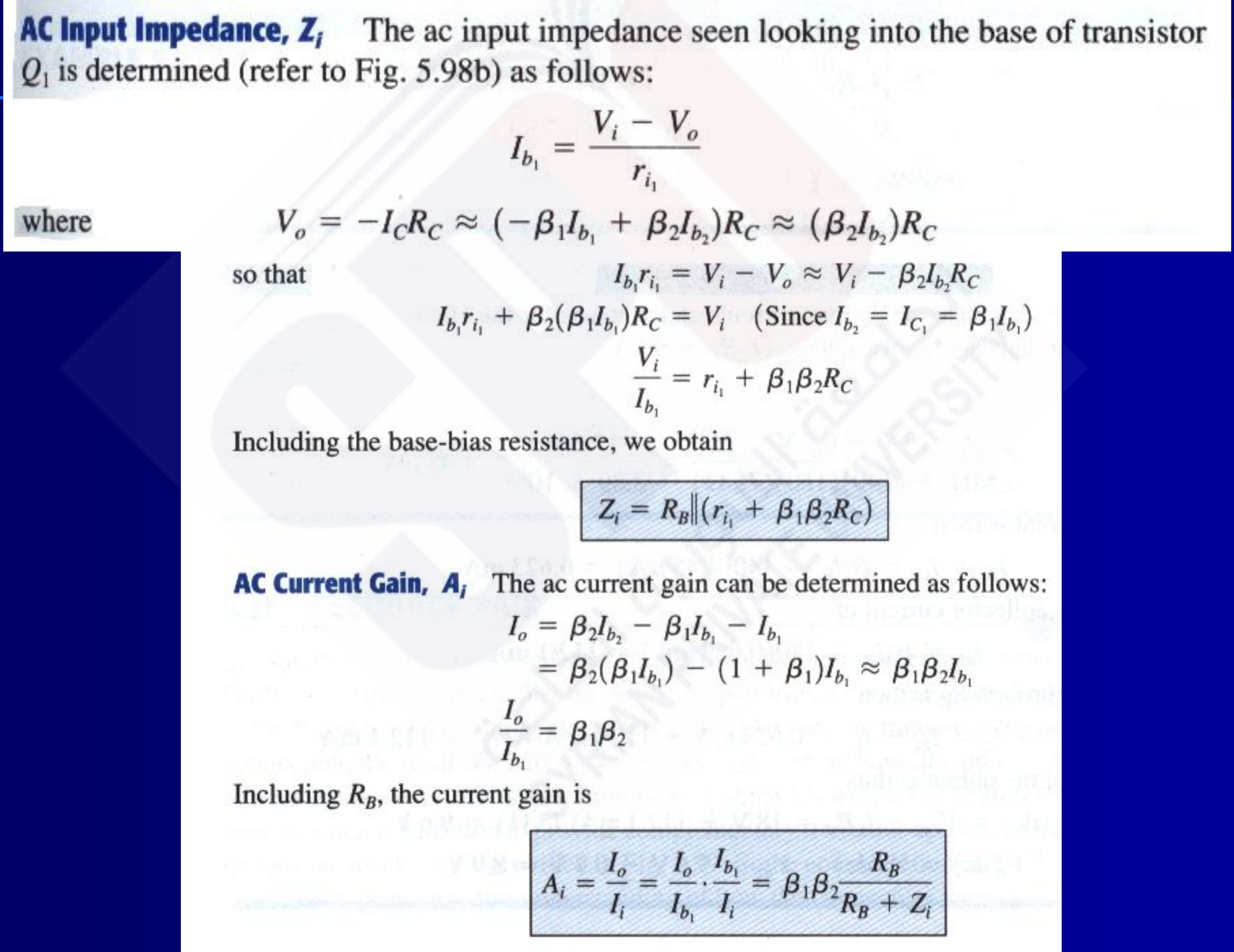
$$V_B = 8.9V \ , \ V_{RC} = 8.4V$$



AC equivalent Circuit of a Feed back Pair



AC input resistance



AC Input Impedance, Z_i The ac input impedance seen looking into the base of transistor Q_1 is determined (refer to Fig. 5.98b) as follows:

$$I_{b_1} = \frac{V_i - V_o}{r_{i_1}}$$

where $$V_o = -I_C R_C \approx (-\beta_1 I_{b_1} + \beta_2 I_{b_2}) R_C \approx (\beta_2 I_{b_2}) R_C$$

so that $$I_{b_1} r_{i_1} = V_i - V_o \approx V_i - \beta_2 I_{b_2} R_C$$

$$I_{b_1} r_{i_1} + \beta_2(\beta_1 I_{b_1}) R_C = V_i \quad (\text{Since } I_{b_2} = I_{C_1} = \beta_1 I_{b_1})$$

$$\frac{V_i}{I_{b_1}} = r_{i_1} + \beta_1 \beta_2 R_C$$

Including the base-bias resistance, we obtain

$$\boxed{Z_i = R_B \| (r_{i_1} + \beta_1 \beta_2 R_C)}$$

AC Current Gain, A_i The ac current gain can be determined as follows:

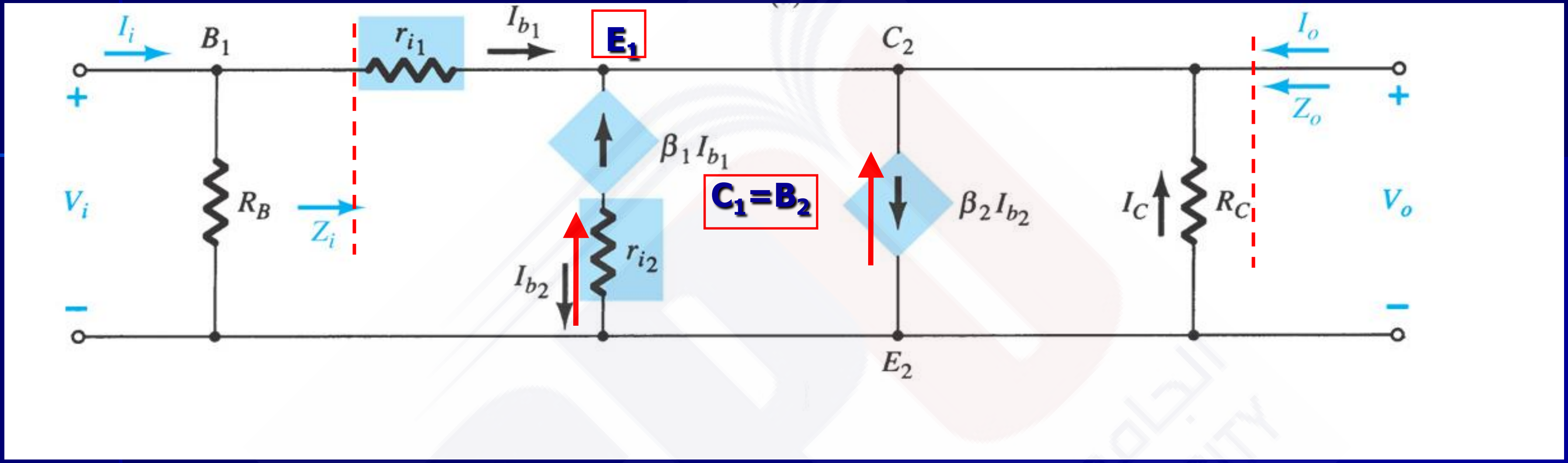
$$\begin{aligned} I_o &= \beta_2 I_{b_2} - \beta_1 I_{b_1} - I_{b_1} \\ &= \beta_2(\beta_1 I_{b_1}) - (1 + \beta_1) I_{b_1} \approx \beta_1 \beta_2 I_{b_1} \end{aligned}$$

$$\frac{I_o}{I_{b_1}} = \beta_1 \beta_2$$

Including R_B, the current gain is

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{I_o}{I_{b_1}} \cdot \frac{I_{b_1}}{I_i} = \beta_1 \beta_2 \frac{R_B}{R_B + Z_i}}$$

AC equivalent Circuit of a Feed back Pair



$$V_i = I_{b1} r_{i1} + R_C[(\beta_1+1)I_{b1} - \beta_2 I_{b2}] = I_{b1} r_{i1} + R_C[(\beta_1+1)I_{b1} + \beta_2\beta_1 I_{b1}]$$

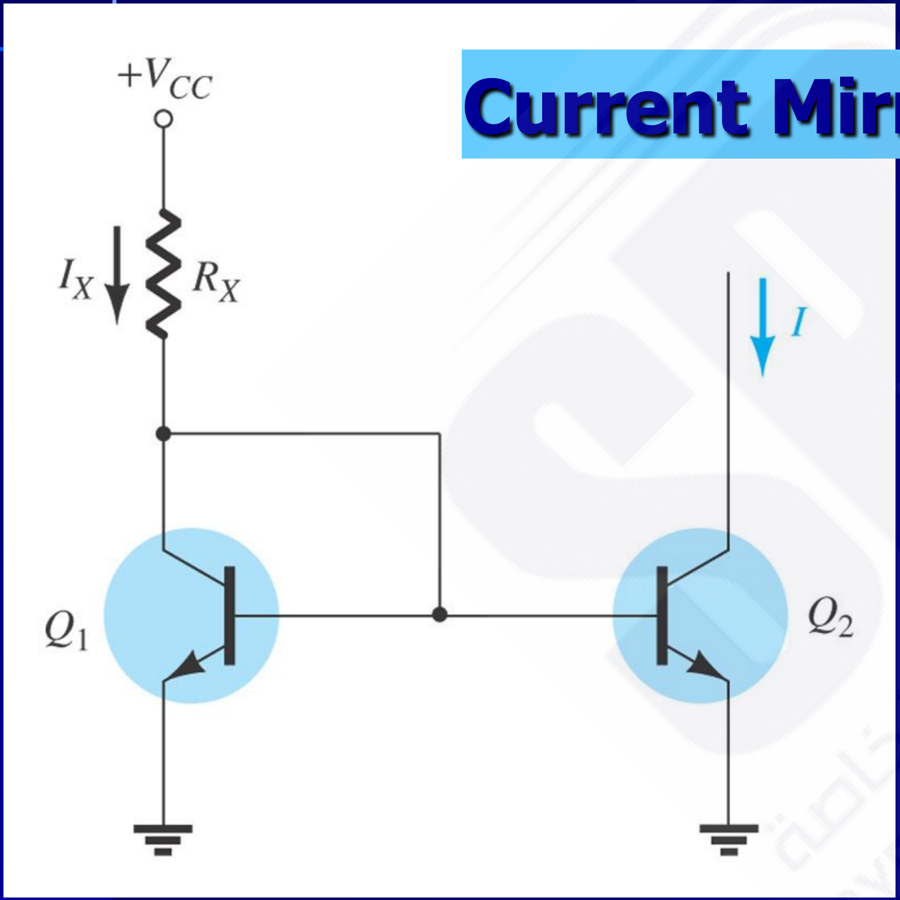
$$Z_i = r_{i1} + R_C[(\beta_1+1) + \beta_2\beta_1] \cong \beta_2\beta_1 R_C$$

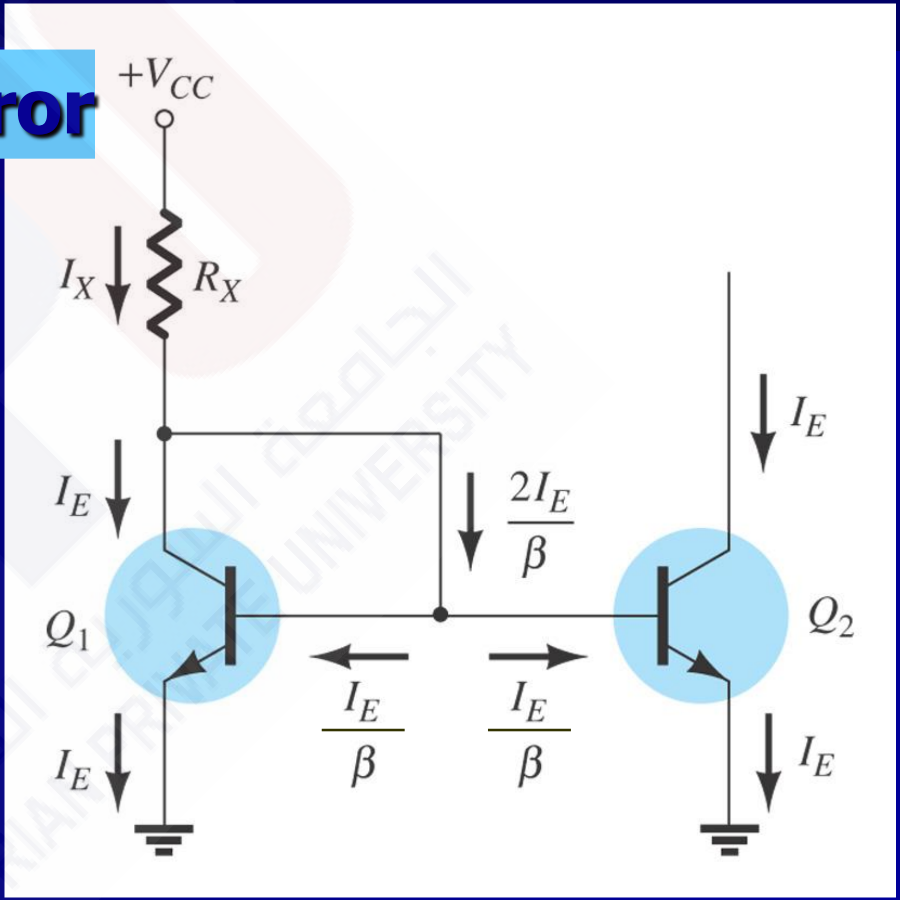
$$Z_o = r_{i1} \| R_C \| \frac{r_{i1}}{\beta_1} \| \frac{r_{i1}}{\beta_2\beta_1}] \cong \frac{r_{i1}}{\beta_2\beta_1}$$

$$V_o = V_i - I_{b1} r_{i1} = V_i - \frac{V_o r_{i1}}{\beta_2\beta_1 R_C} \Rightarrow \quad A_v = \frac{\beta_2\beta_1 R_C}{\beta_2\beta_1 R_C + r_{i1}}$$

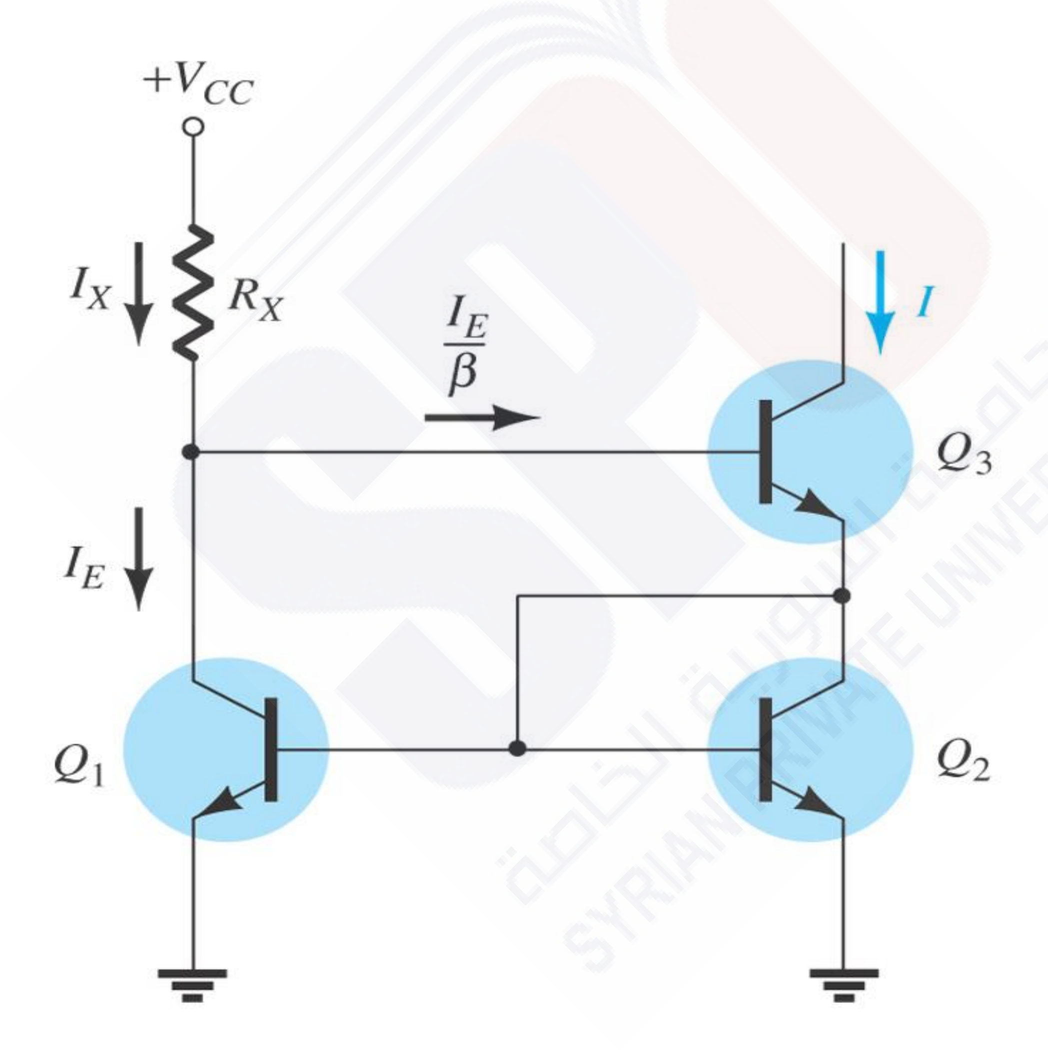
1.6 Current Mirror and Current Sources

Current Mirror

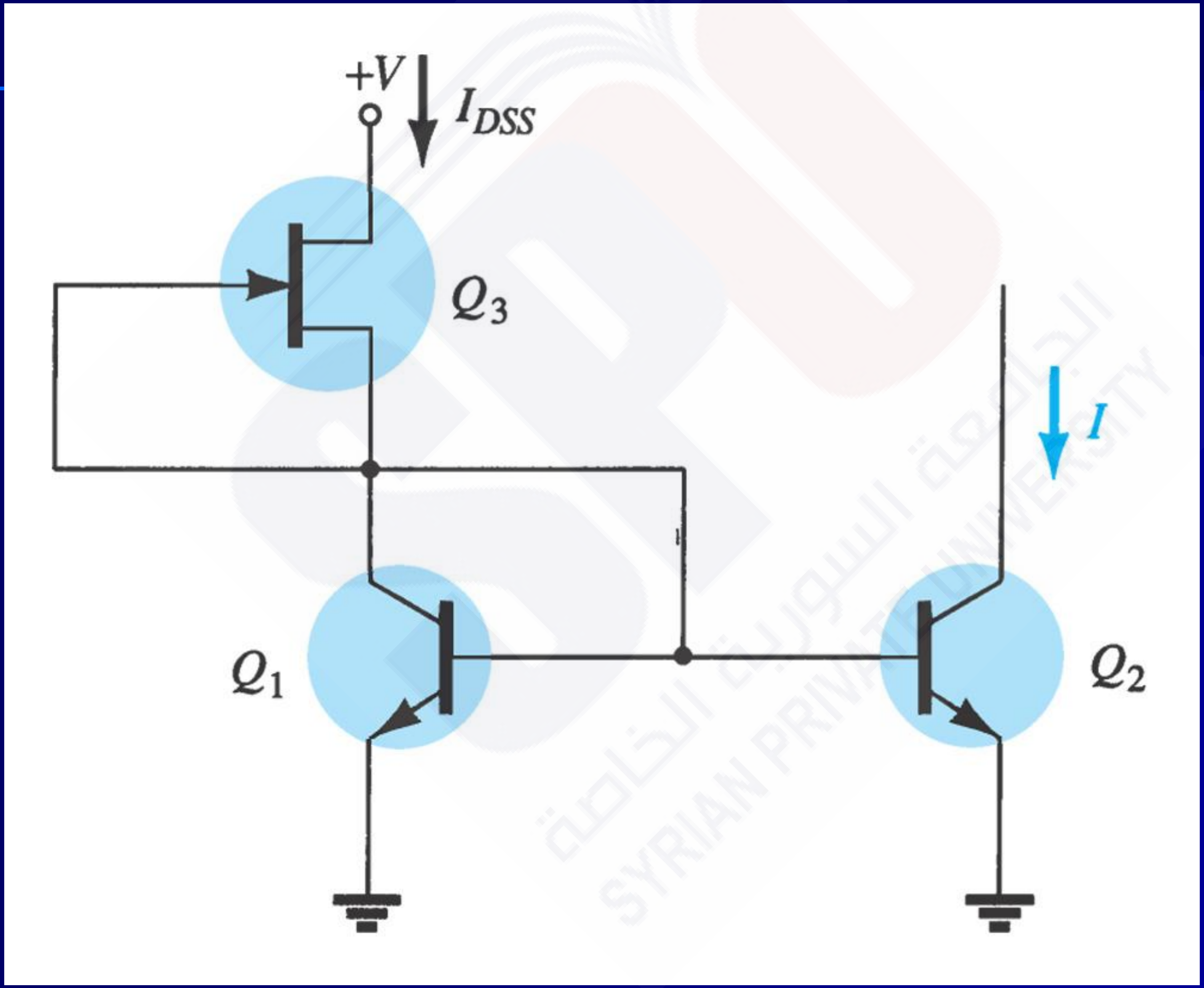




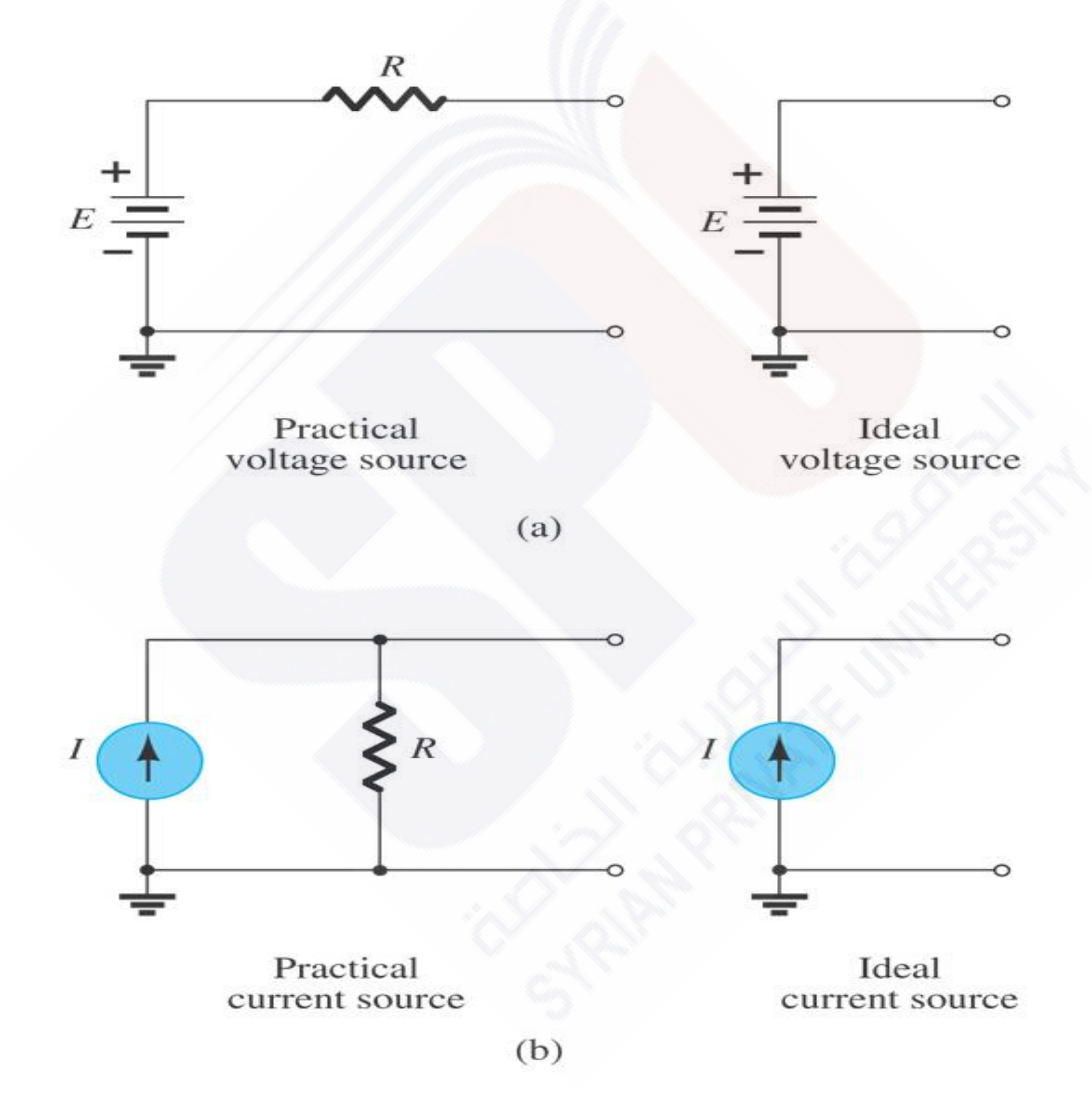
Current mirror circuit with higher output impedance



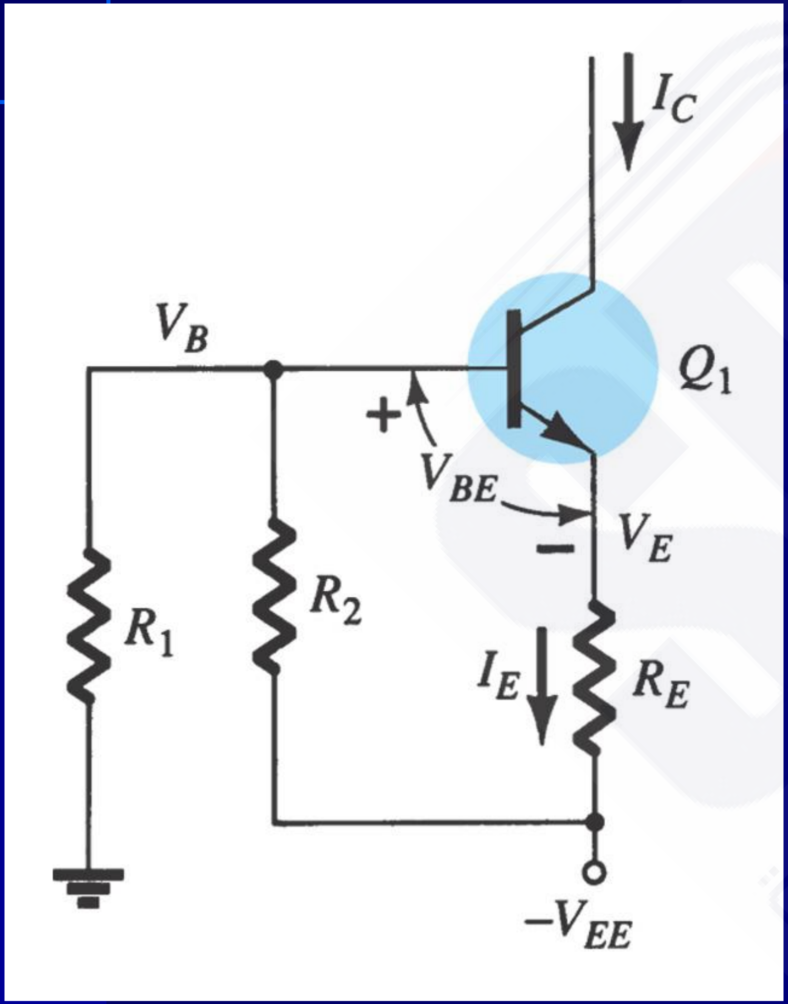
Current mirror connection

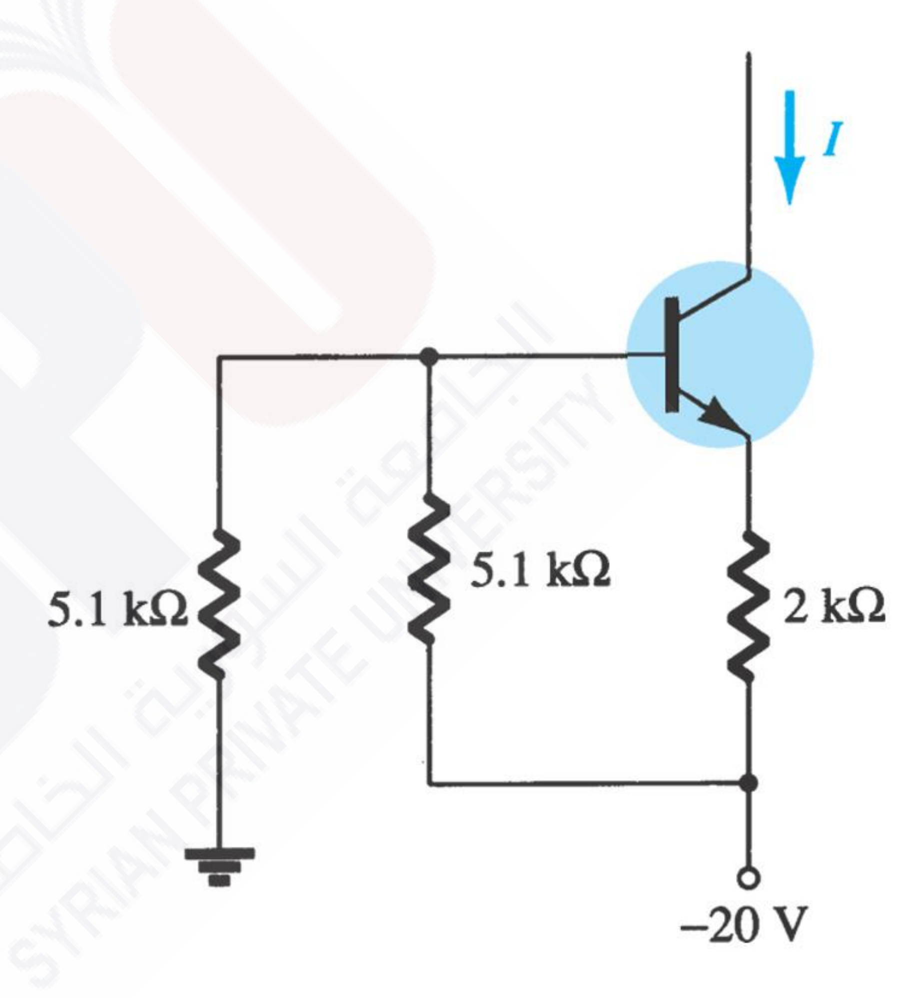


Voltage and current sources

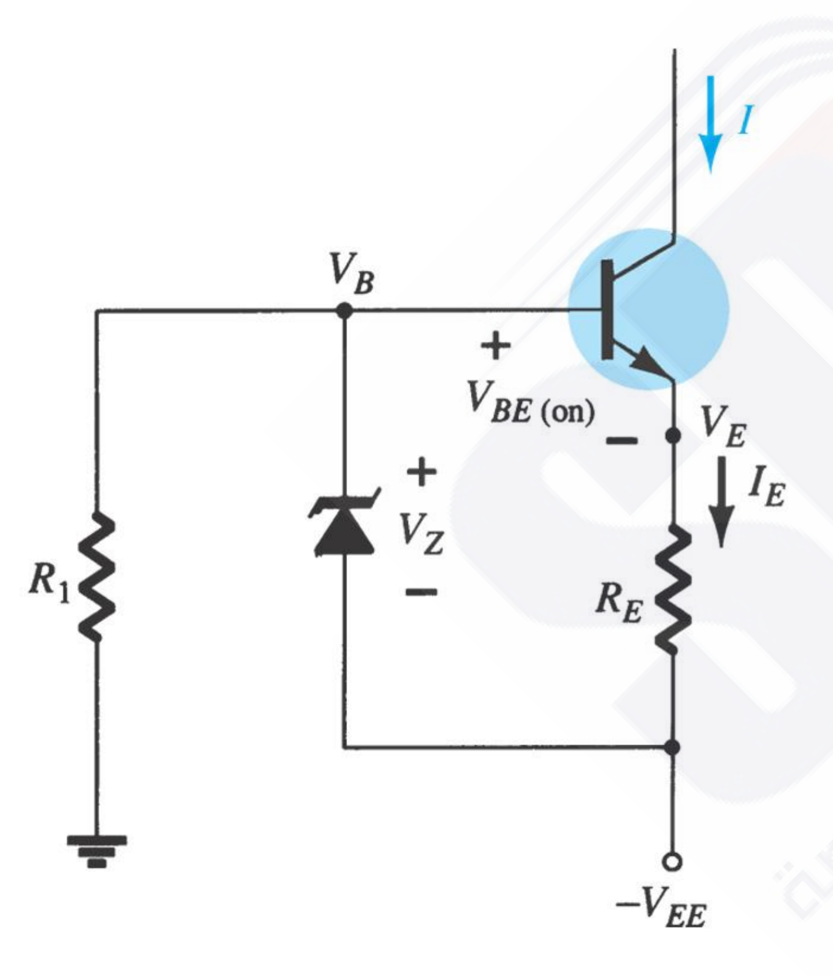


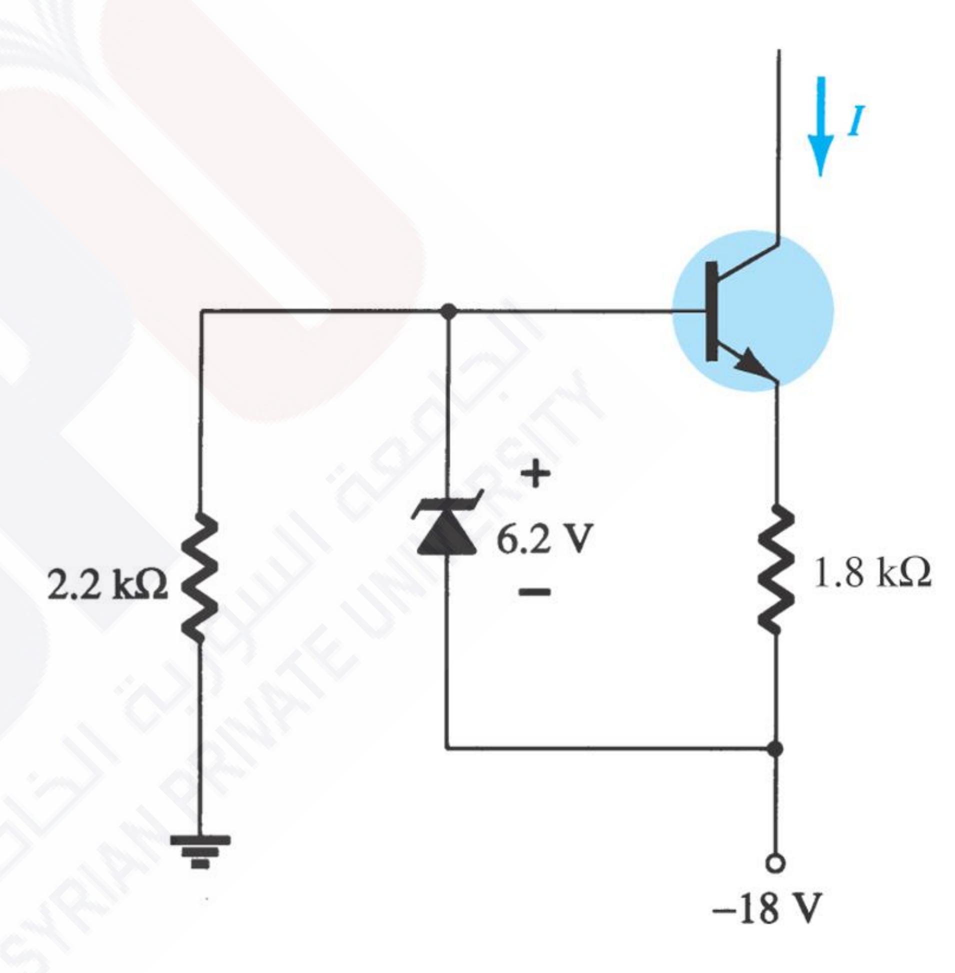
Discrete constant-current source



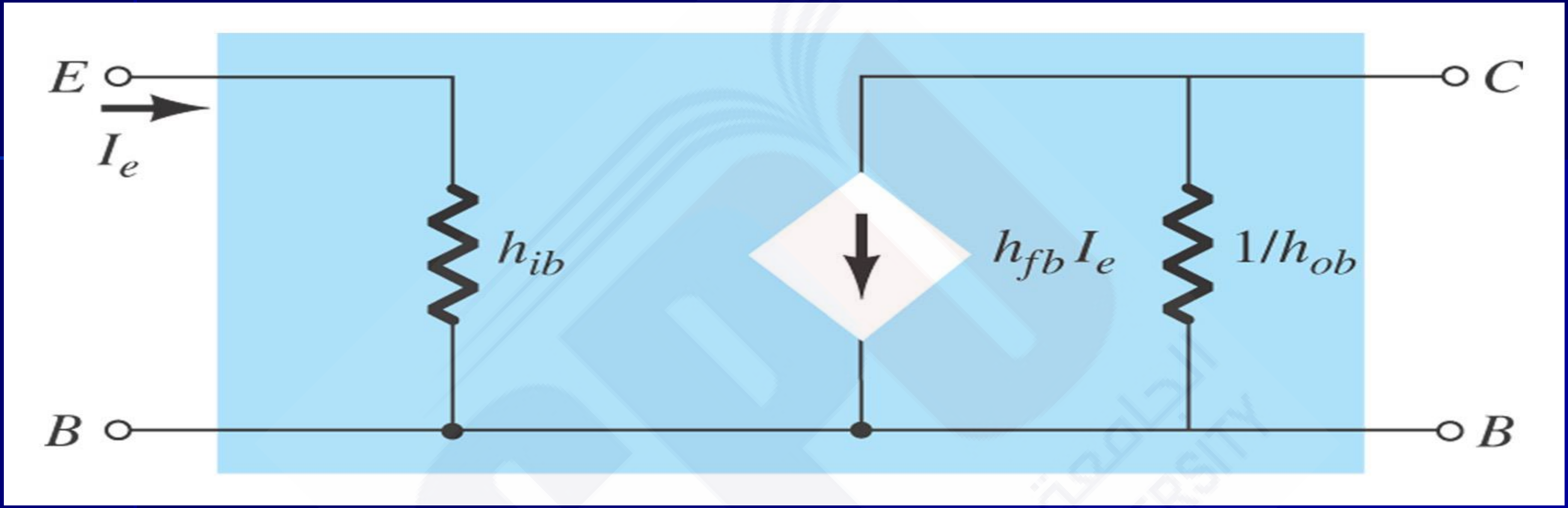


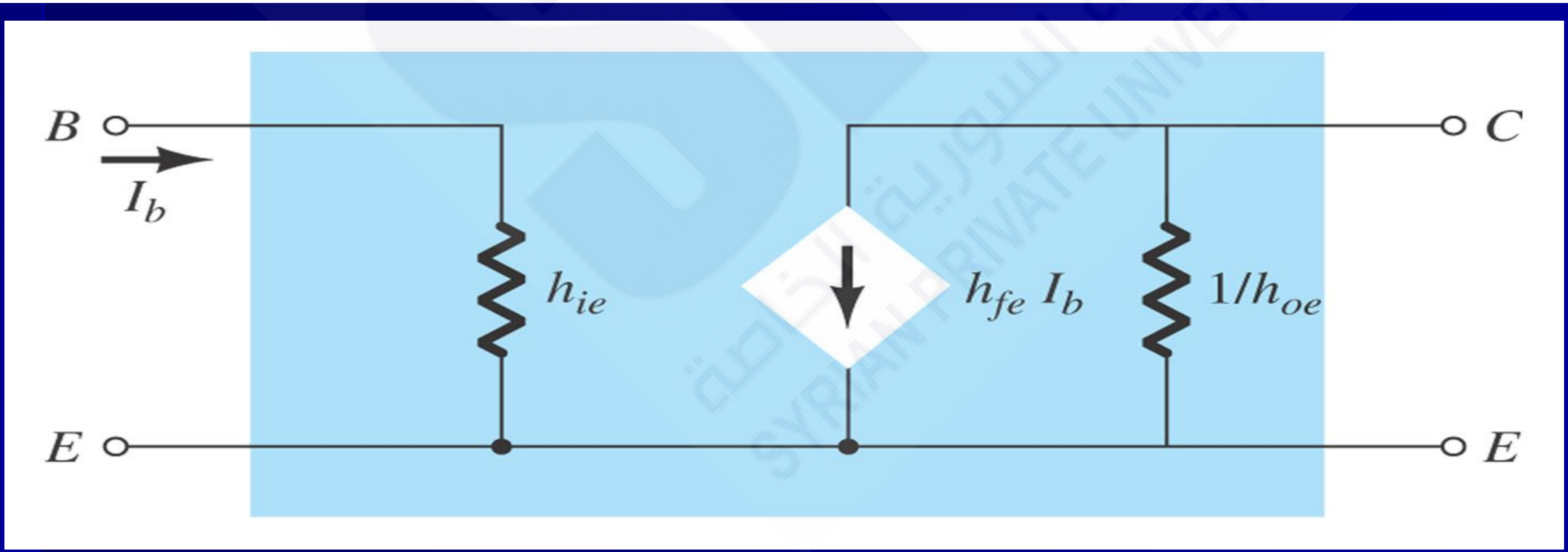
Constant-current circuit: Example



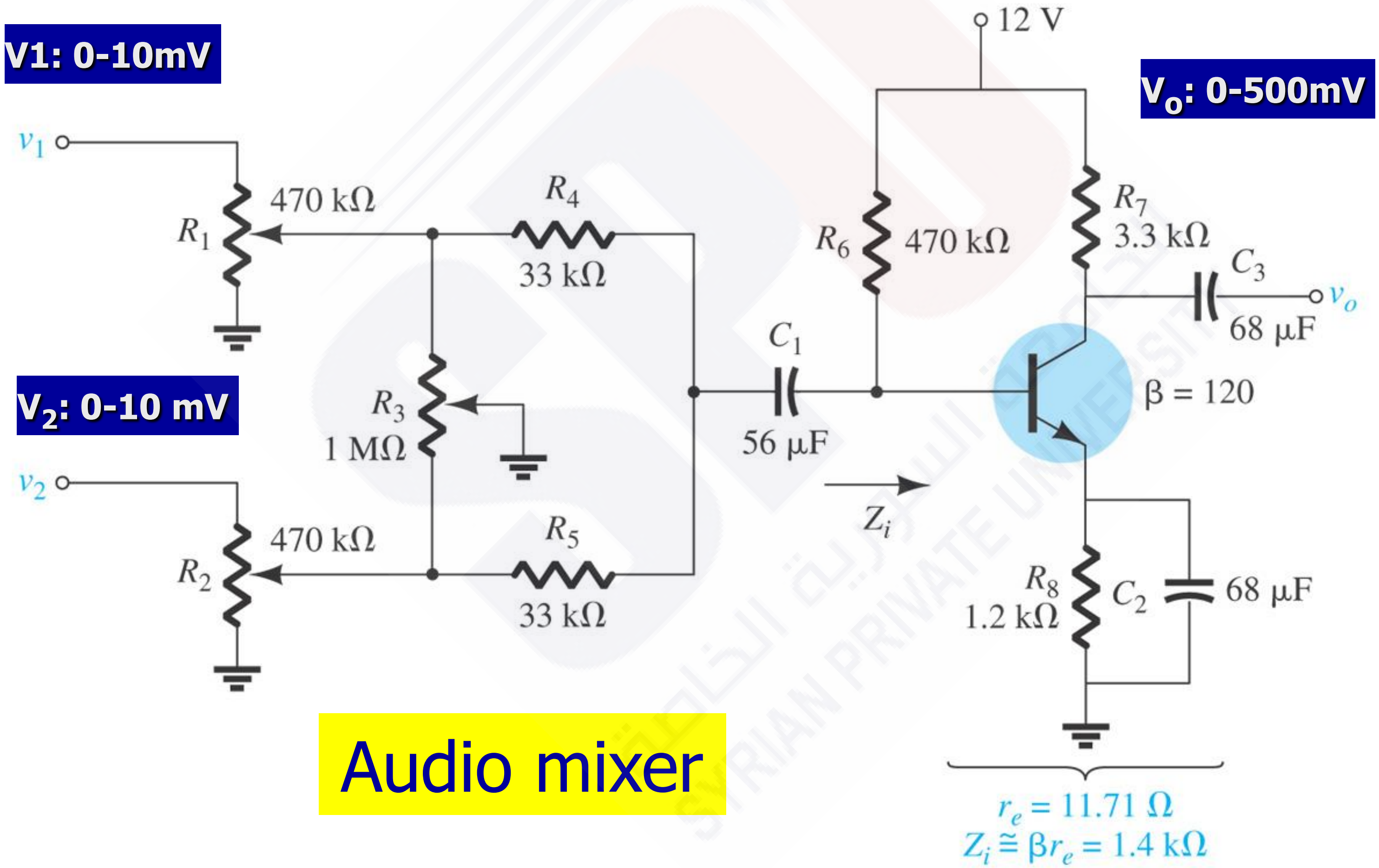


1.7 Approximate Hybrid Equivalent Circuit



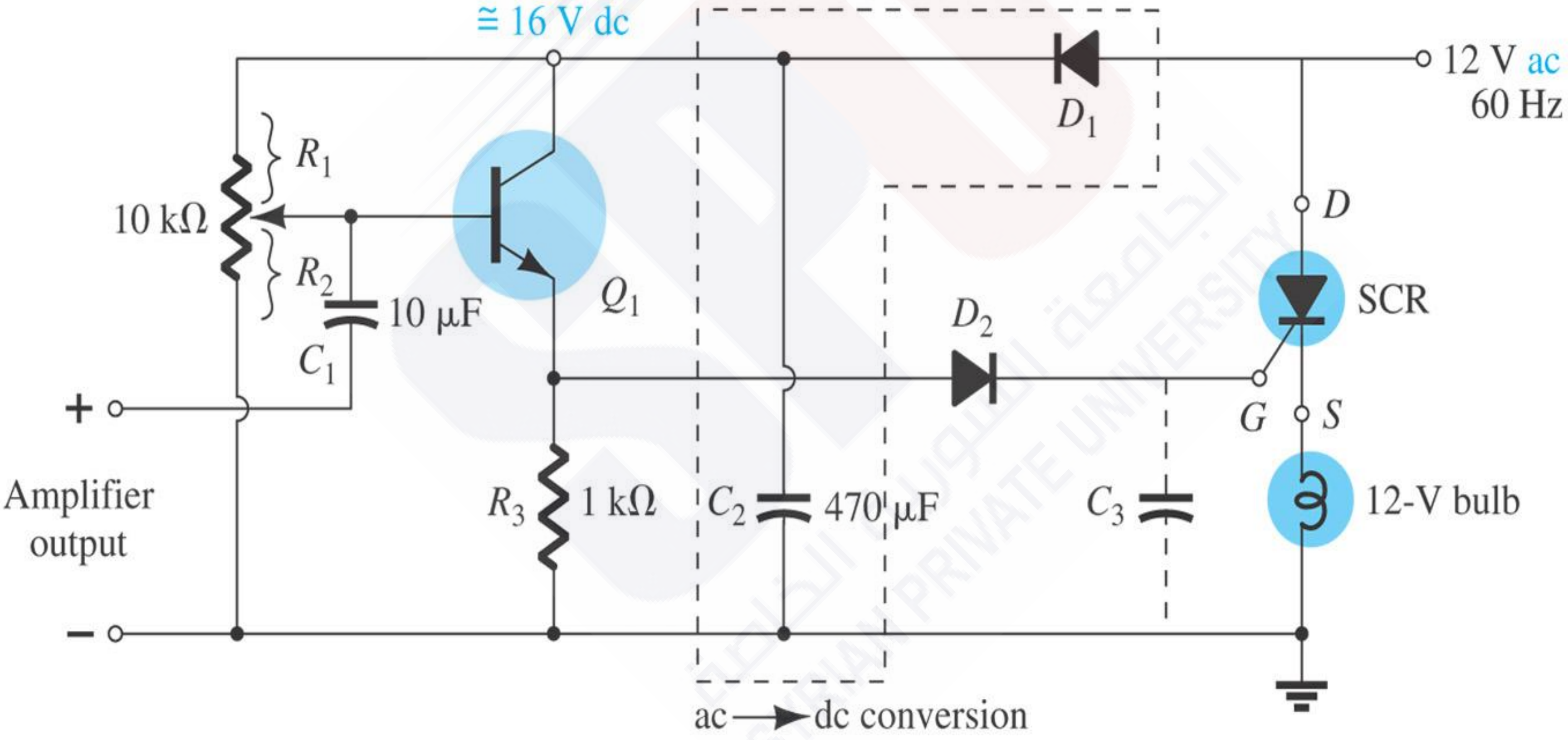


1.8 Practical Applications



Audio mixer

Sound-modulated light source
Silicon-controlled Rectifier



White-and pink-noise generator