CHAPTER 5

BJT MODELING

SMALL SIGNAL RESPONSE

re-Model

hybrid equivalent

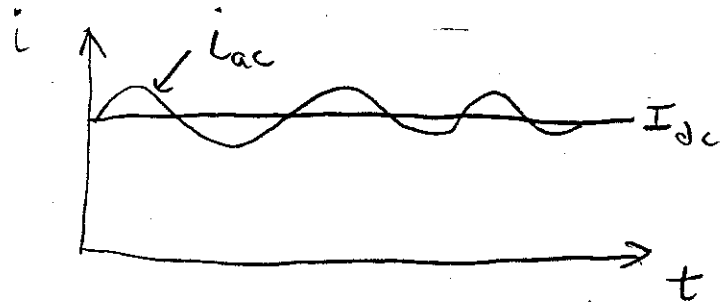
$P_o < P_{in}$ efficiency $\eta = \dfrac{P_{o\,ac}}{P_{i\,dc}}$

where

$P_{i_{dc}}$ = DC Power in

$P_{o_{ac}}$ = ac power to the load.

use superposition ac + dc



MODEL – COMBINATION OF CIRCUIT ELEMENTS THAT BEST APPROXIMATES ACTUAL BEHAVIOR OF A SEMICONDUCTOR DEVICE UNDER SPECIFIC CONDITIONS

Figure 7.3 TRANSISTOR CIRCUIT UNDER EXAMINATION IN THIS INTRODUCTORY DISCUSSION.

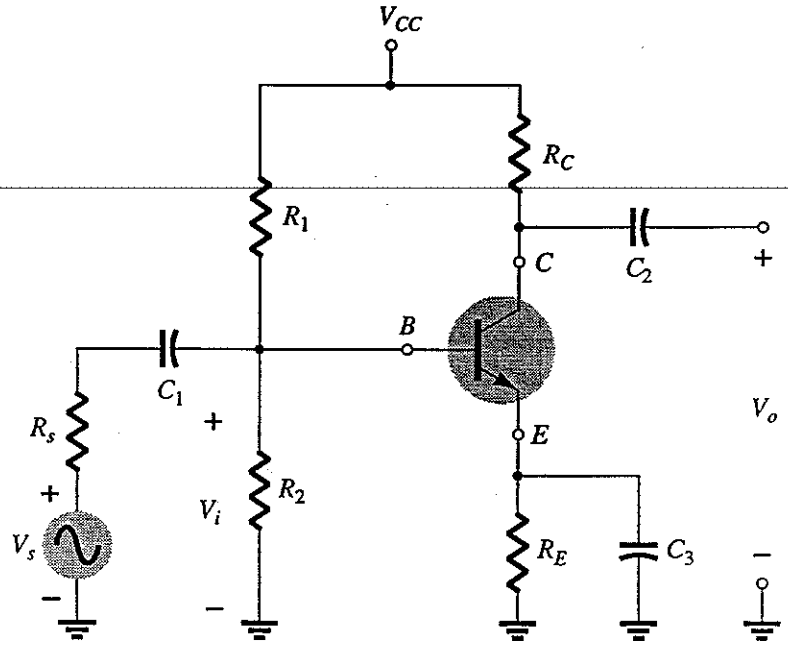


Figure 7.4 THE NETWORK OF FIG. 7.3 FOLLOWING REMOVAL OF THE DC SUPPLY AND INSERTION OF THE SHORT-CIRCUIT EQUIVALENT FOR THE CAPACITORS.

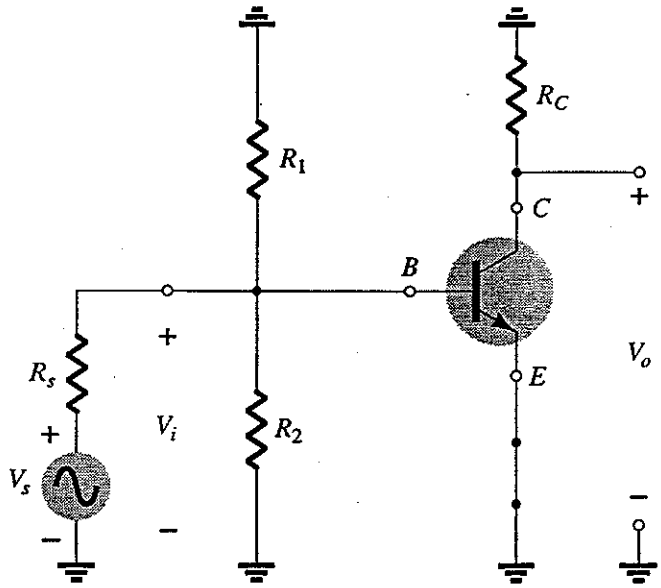


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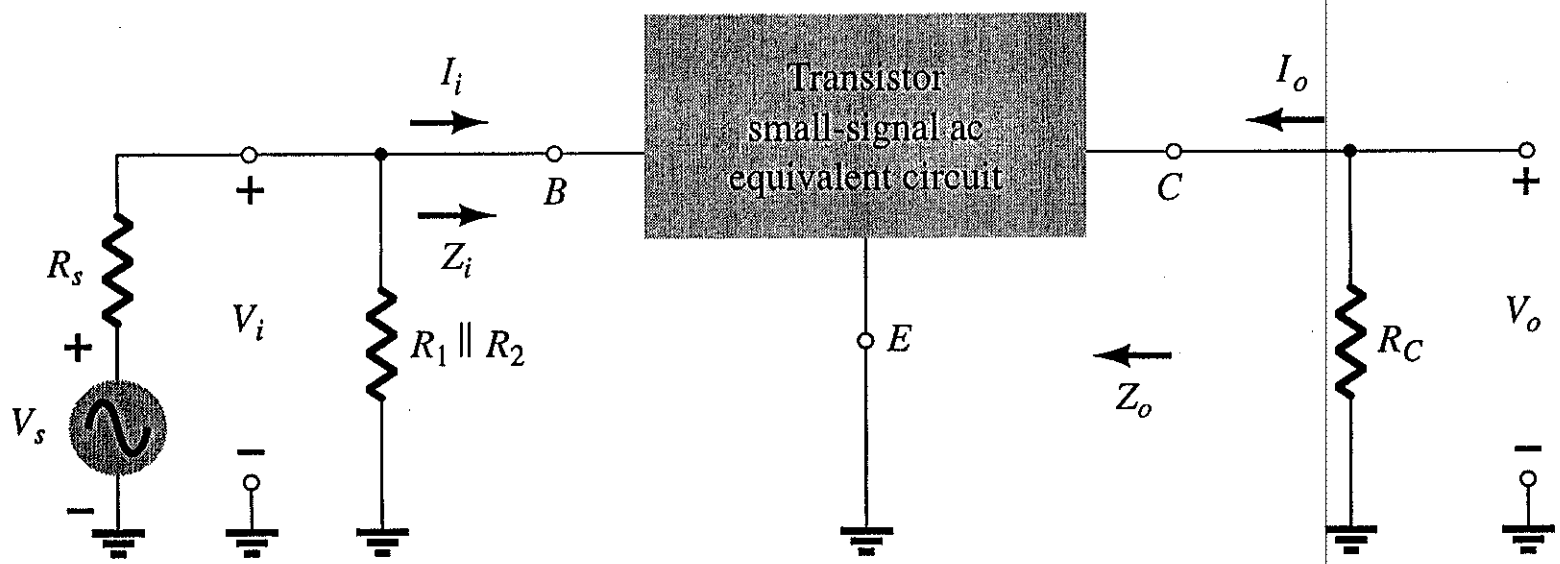
Figure 7.5 CIRCUIT OF FIG. 7.4 REDRAWN FOR SMALL-SIGNAL AC ANALYSIS.



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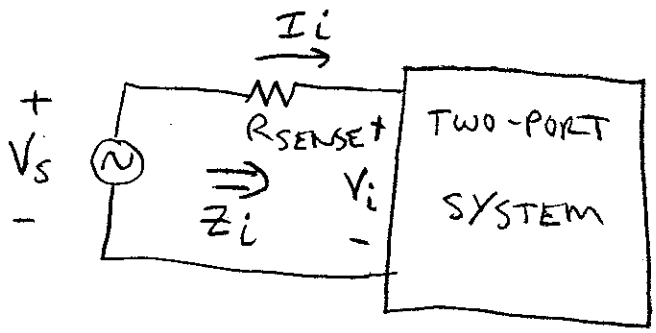
INPUT IMPEDANCE, Z_i

$$\boxed{Z_i = \frac{V_i}{I_i}}$$

Z_i of a BJT is purely resistive - Few OHMS $\leq Z_i \leq$ MΩ's

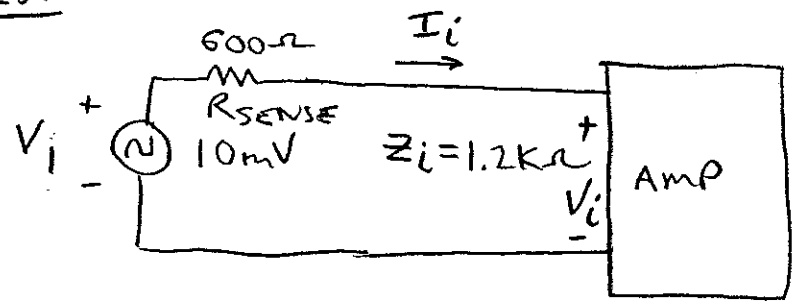
DC BIASING CONDITIONS CAN APPROXIMATE Z_i FOR $f \leq 100$ KHZ (TYP)



$$\boxed{I_i = \frac{V_s - V_i}{R_{SENSE}}}$$

$$\boxed{Z_i = \frac{V_i}{I_i}}$$

EX



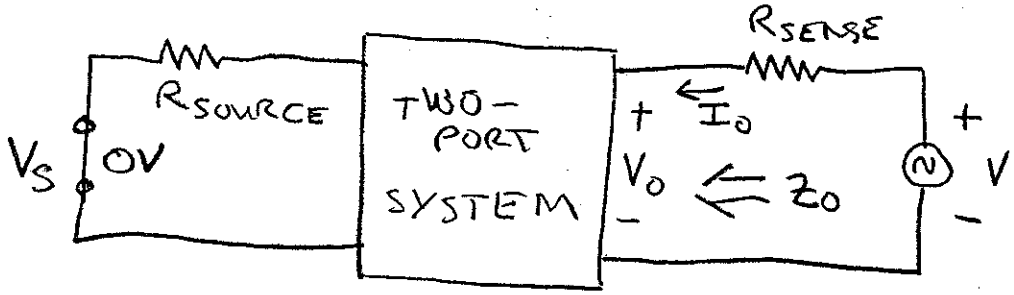
Using voltage divider rule

$$V_i = V_1 \frac{Z_i}{Z_i + R_{SENSE}}$$

$$V_i = \frac{1.2K\Omega}{1.2K\Omega + 600\Omega}(10mV) = \boxed{6.67mV}$$

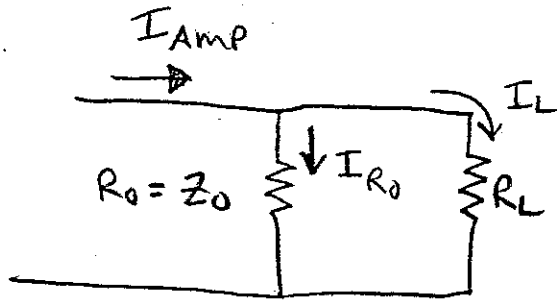
Output Impedance Z_o

Output impedance – IMPEDANCE @ THE OUTPUT LOOKING INTO THE SYSTEM WITH APPLIED INPUT SIGNAL SET TO ZERO



FOR $f \leq 100\,kHz$, Z_o purely resistive in nature

Few Ω's $\leq Z_o < 2M\Omega$ (OR GREATER)



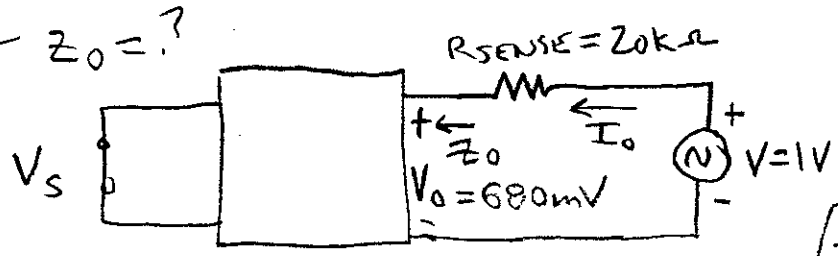
for $R_o >> R_L$

$I_L >> I_{R_o}$

FOR SIGNIFICANT CURRENT GAIN

Z_o frequently $>> R_L$ $\therefore$ Z_o replaced with 'open circuit'

EX $Z_o = ?$



$$I_o = \frac{V - V_o}{20k\Omega} = \underline{16\mu A}$$

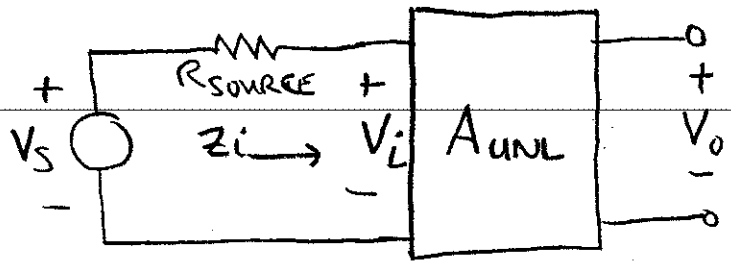
$$\boxed{Z_o = \frac{V_o}{I_o} = 42.5k\Omega}$$

Voltage Gain, A_V

$$\boxed{A_V = \frac{V_o}{V_i}}$$

NO LOAD VOLTAGE GAIN

$$A_{V_{NL}} > A_V$$



USING VDR, $V_i = \dfrac{Z_i \, V_S}{Z_i + R_{SOURCE}}$ OR $\dfrac{V_i}{V_S} = \dfrac{Z_i}{Z_i + R_{SOURCE}}$

$$\boxed{A_{V_S} = \frac{V_o}{V_S} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_S} = \frac{Z_i}{Z_i + R_{SOURCE}} A_{V_{NL}}}$$

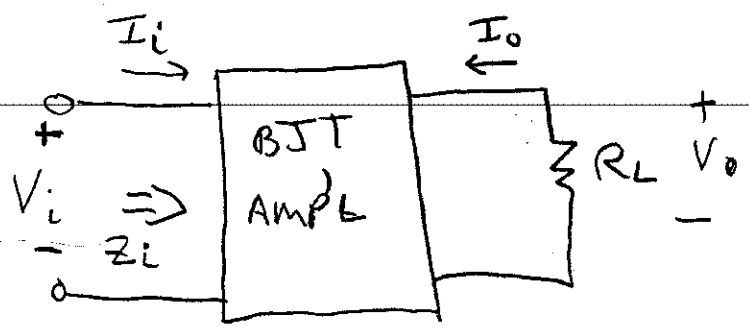
Single-Stage loaded amplifier

less than 1 $\leq A_{V_L} \leq$ Few hundred

CURRENT GAIN A_i

$$\boxed{A_i = \frac{I_o}{I_i}}$$

$\approx 1 < A_i < 100$ may exceed



LOADED CONDITION

$$I_i = \frac{V_i}{Z_i}$$

$$I_o = -\frac{V_o}{R_L}$$

$$A_i = \frac{I_o}{I_i} = -\frac{V_o/R_L}{V_i/Z_i} = -\frac{V_o}{V_i}\left(\frac{Z_i}{R_L}\right)$$

$$\boxed{A_i = -A_V \frac{Z_i}{R_L}}$$

Phase

INPUT & OUTPUT FOR BJT AMP.

USUALLY IN PHASE OR 180° OUT OF PHASE

(IGNORING REACTIVE ELEMENTS)

r_e Transistor Model

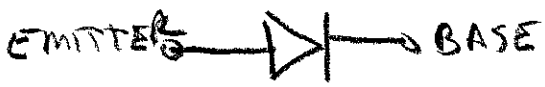
COMPRISED OF DIODE & CONTROLLED CURRENT SOURCE

BJT AMPLIFIER IS A CURRENT-CONTROLLED DEVICE.

COMMON BASE CONFIGURATION FIG 7.16

USING A PNP TRANSISTOR, A MODEL REPLACES THE TRANSISTOR - APPROXIMATES THE BEHAVIOR AT AN OPERATING REGION.

A DIODE-EQUIVALENT MODEL REPLACES THE 'BE' JUNCTION

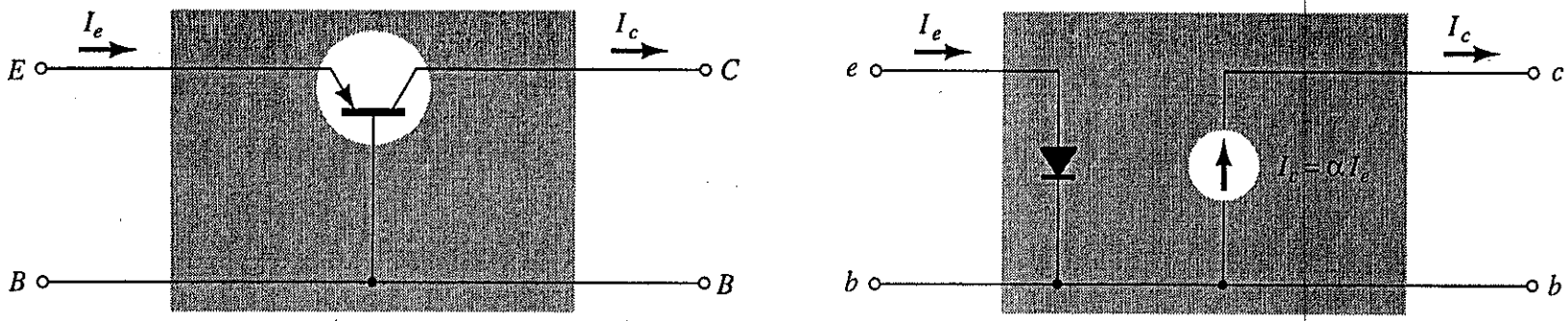


A CURRENT-CONTROLLED CURRENT SOURCE REPLACES B-C JUNCTION

$$I_C = \alpha I_E$$

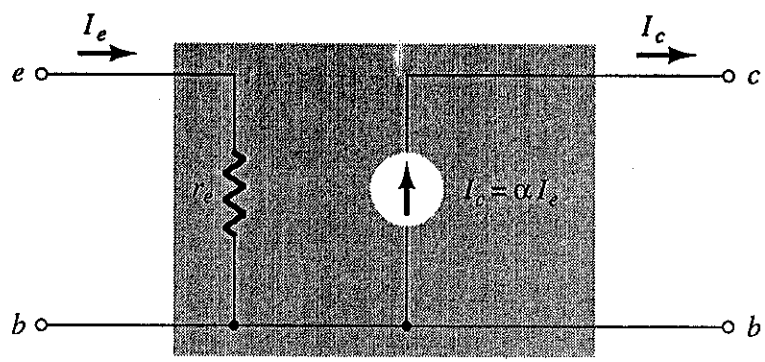
FOR THE RANGE OF VALUES OF VCE

Figure 7.16 (A) COMMON-BASE BJT TRANSISTOR; (B) r_e MODEL FOR THE CONFIGURATION OF FIG. 7.16A.



(a) (b)

Figure 7.17 COMMON-BASE r_e EQUIVALENT CIRCUIT.



the ac resistance of a diode is

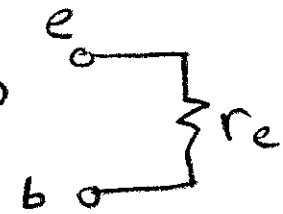
$$r_{ac} = \frac{26\,mV}{I_E} = r_e$$

r_e USED BECAUSE THE DC LEVEL OF I_E DETERMINES r_{ac}

FIG 7.16 (b) can be rewritten as FIG 7.17.

<u>INPUT IMPEDANCE</u> (COMMON BASE)

$$\boxed{Z_i = r_e}_{CB} \Rightarrow$$



$50 > Z_i >$ few ohms

<u>OUTPUT IMPEDANCE</u>, Z_o

setting the signal to 0, $I_e = 0$, $I_c = 0$ } OPEN CKT

$$\boxed{Z_o \cong \infty\,\Omega}_{CB}$$

GRAPHICALLY $\frac{\Delta V_{CB}}{\Delta I_C}$

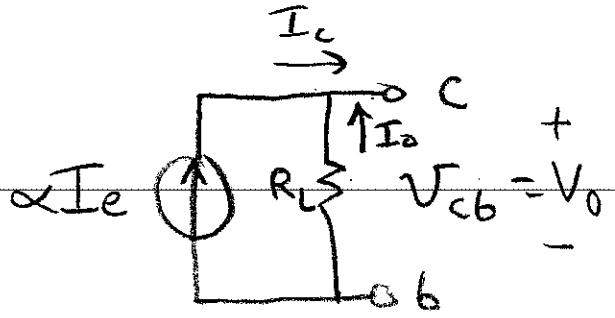
Z_o (MΩ range)

Typ: <u>1 - 2 MΩ</u>

COMMON BASE

INPUT IMPEDANCE Z_i SMALL

OUTPUT IMPEDANCE Z_o HIGH

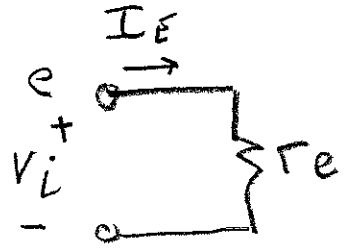


OUTPUT

$$V_o = -I_o R_L$$

$$= +I_c R_L$$

$$\boxed{V_o = +\alpha I_E R_L}$$



$$\boxed{V_i = I_e r_e}$$

INPUT

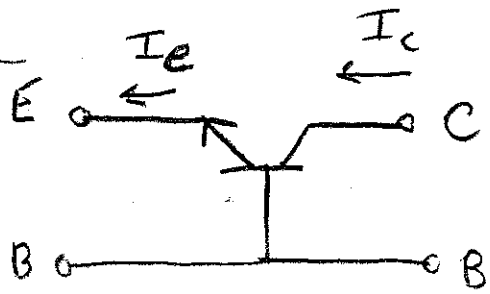
$$A_V = \frac{V_o}{V_i} = \frac{\alpha I_E R_L}{I_E r_e}$$

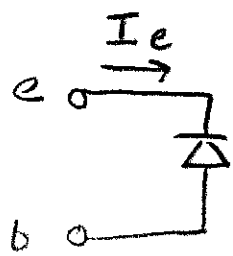
$$\boxed{A_V = \frac{\alpha R_L}{r_e}}$$

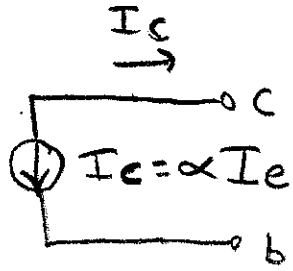
$$A_i = \frac{I_o}{I_i} = \frac{-\alpha I_e}{I_e} = \boxed{-\alpha \cong -1 = A_i}$$

CB

NPN







COMMON BASE

COMMON EMITTER CONFIGURATION

FIG 7.21

$I_e \cong \beta I_B$ 'bc' junction

'be' junction is DIODE

$[I_c = \beta I_B \quad I_e = (\beta+1) I_B]$

$$Z_i = \frac{V_i}{I_i} = \frac{V_{be}}{I_b}$$

$V_{be} = I_e r_e \cong \beta I_b r_e$

by subst $\boxed{Z_i = \beta r_e}$ CE 6-7 kΩ range

$\boxed{Z_o = r_o}$ IGNORED IN re model

Figure 7.21 (A) COMMON-EMITTER BJT TRANSISTOR; (B) APPROXIMATE MODEL FOR THE CONFIGURATION OF FIG. 7.21A.

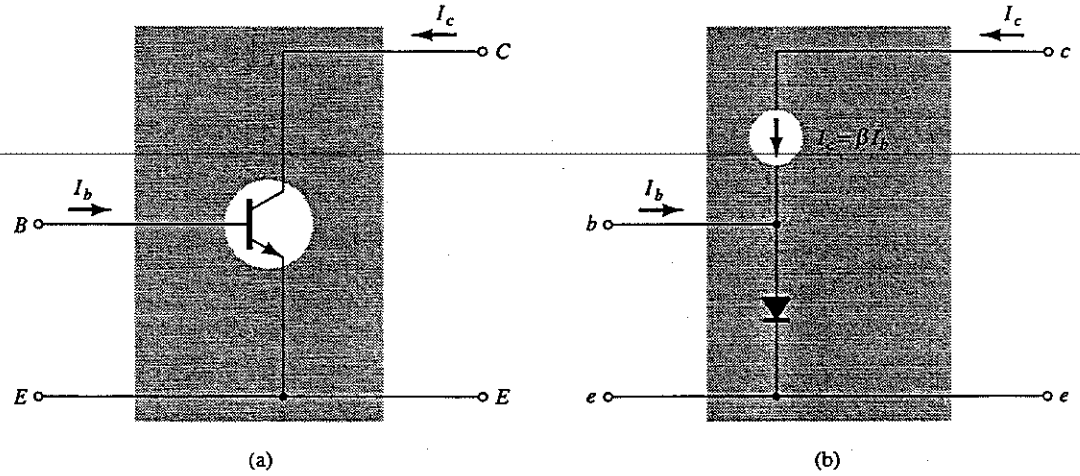


Figure 7.22 DETERMINING Z_i USING THE APPROXIMATE MODEL.

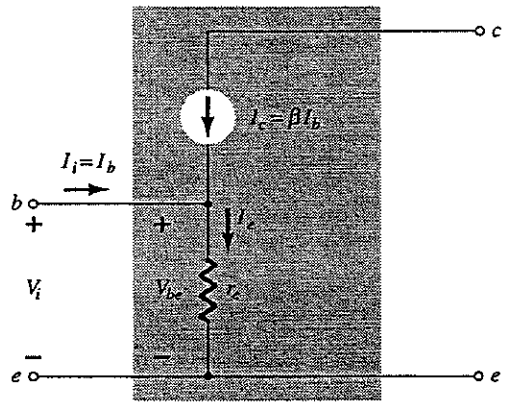
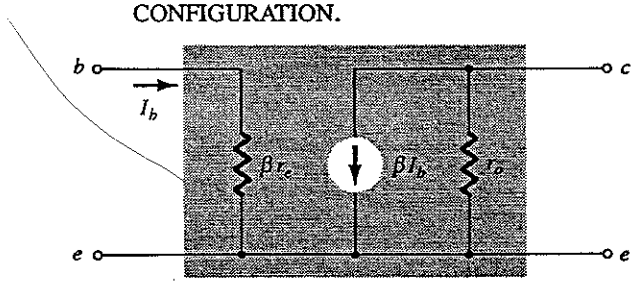


Figure 7.27 r_e MODEL FOR THE COMMON-EMITTER TRANSISTOR CONFIGURATION.



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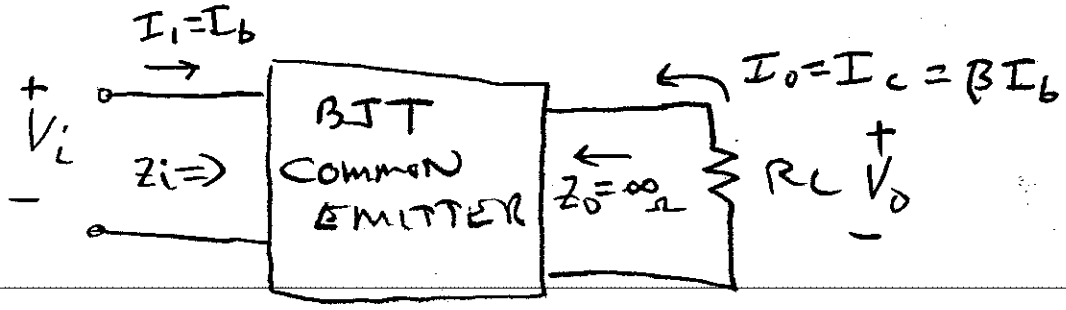
VOLTAGE GAIN COMMON EMITTER



$Z_i = \beta r_e$

$$V_o = -I_o R_L = \boxed{-\beta I_b R_L = V_o}$$

$$\boxed{V_i = I_b(\beta r_e)}$$

$$A_V = \frac{V_o}{V_i} = \frac{-I_b \beta R_L}{I_b \beta r_e} = \boxed{\frac{-R_L}{r_e} = A_V}_{CE}$$

for $r_o = \infty$

CURRENT GAIN

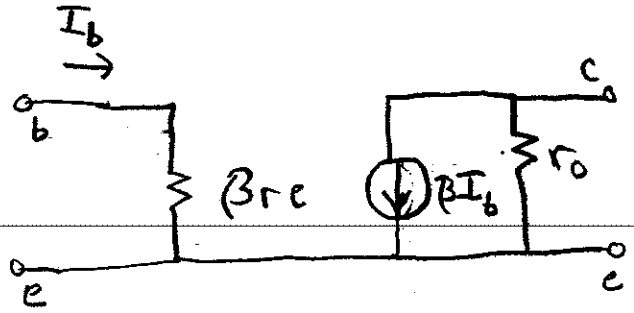
$$A_i = \frac{I_o}{I_i} = \frac{\beta I_b}{I_b} = \boxed{\beta = A_i}_{CE}$$

for $r_o = \infty$

COMMON COLLECTOR –

USE COMMON EMITTER MODEL

EXAMPLE OF COMMON EMITTER
(r_e MODEL)



GIVEN

$\beta = 120$

$I_E = 3.2\,mA$

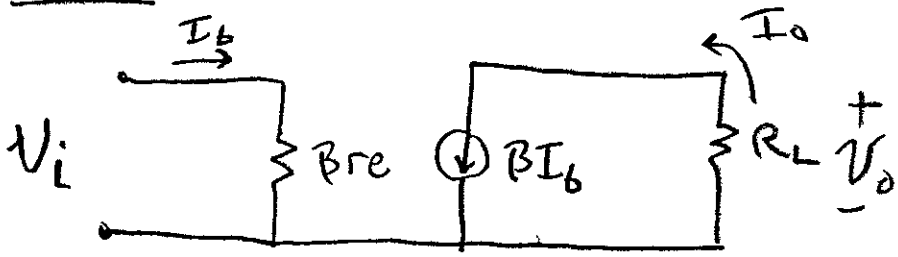
$r_o = \infty\,\Omega$

ⓐ $Z_i = ?$

$$r_e = \frac{26\,mV}{I_E} = \frac{26\,mV}{3.2\,mA} = 8.125\,\Omega$$

$$Z_i = \beta r_e = 120(8.125\,\Omega) = \boxed{975\,\Omega}$$

ⓑ A_v for $R_L = 2K\Omega$



$$\frac{V_o}{V_i} = -\frac{\beta I_b R_L}{I_b \beta r_e} = -\frac{R_L}{r_e} = \frac{-2K\Omega}{8.125\,\Omega} = \boxed{-246.15}$$

ⓒ A_i WITH $2K\Omega$ load

$$A_i = \frac{I_o}{I_i} = \beta = \boxed{120}$$