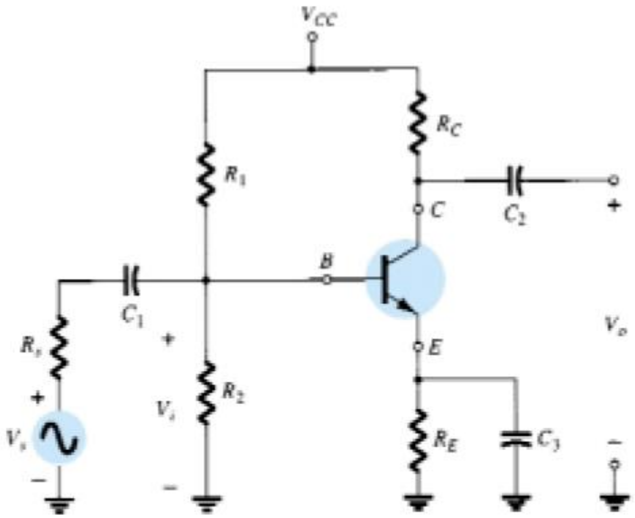
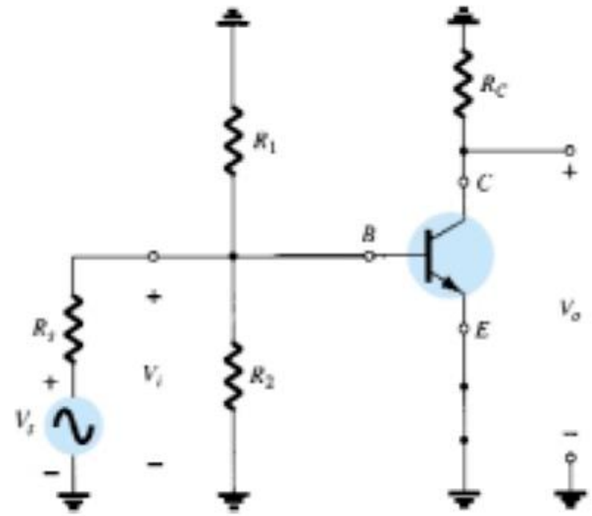
BJT AC ANALYSIS

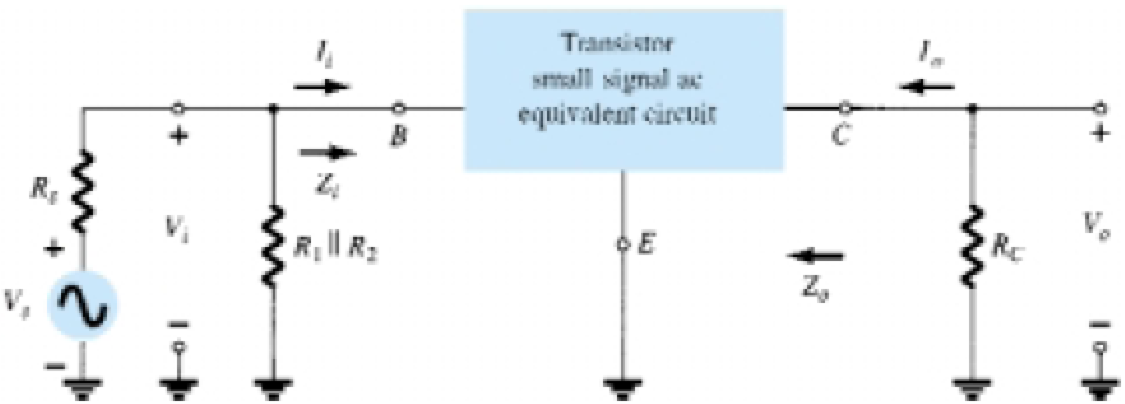
Oleh:
Suwito
mas.suwito@gmail.com
masaji@elect-eng.its.ac.id

Departemen Teknik Elektro
Institut Teknologi Sepuluh Nopember
2009

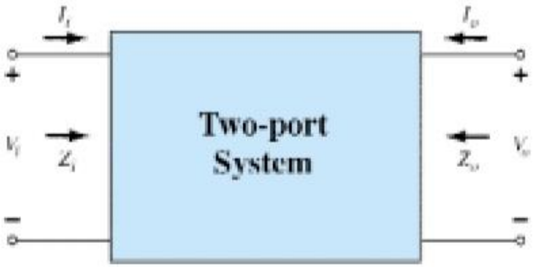
PENGUATAN PADA DOMAIN AC







IMPEDANSI INPUT

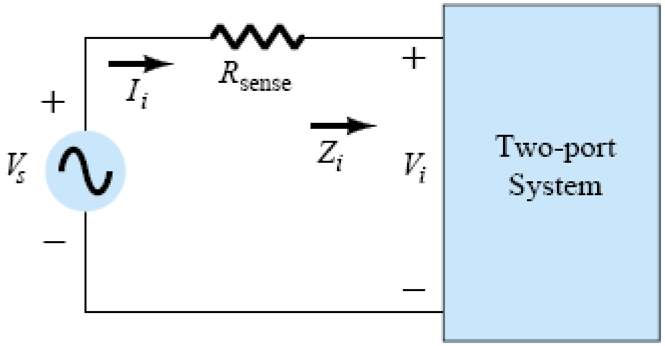


- Rangkaian penguat pada dasarnya merupakan jaringan dengan dua pasang terminal (two-port network).
- Pada sisi input terdapat impedansi input, Zi, yang menurut hukum Ohm adalah:

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

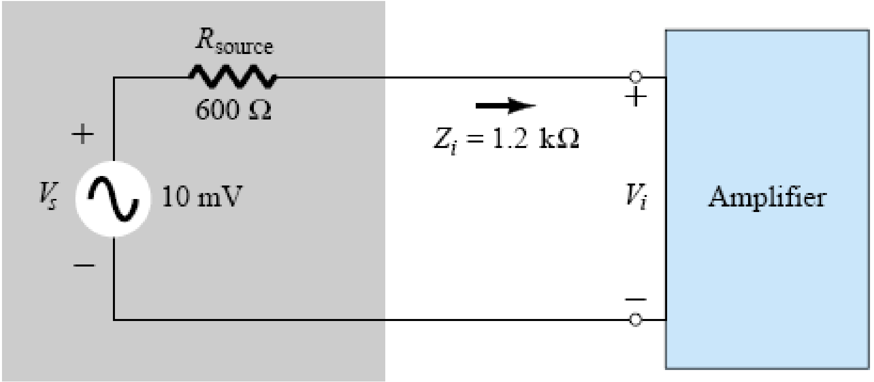
- Pada frekuensi rendah hingga menengah (umumnya kurang dari 100 KHz), impendansi input suatu transistor bipolar adalah resistif murni.
- Nilai resistansinya berkisar antara beberapa Ohm hingga mega Ohm tergantung dari konfigurasi rangkaian transistor yang dipakai.
- Nilai Zi ini tidak bisa diukur dengan Ohmmeter.

MENGUKUR IMPEDANSI INPUT



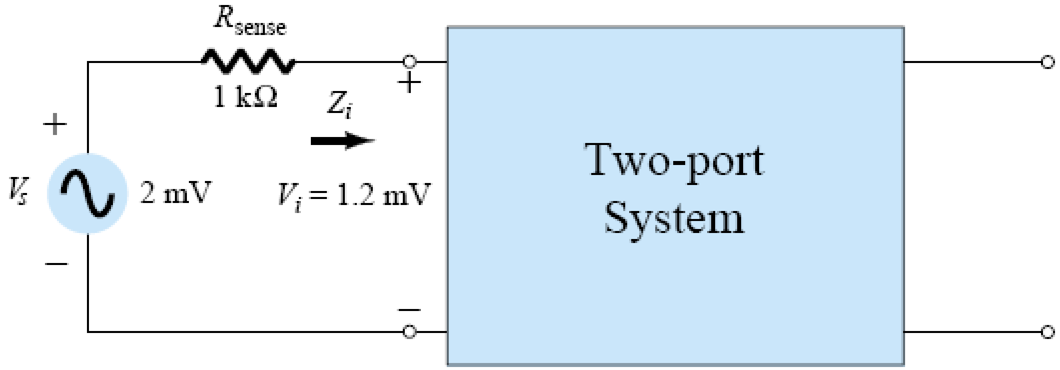
$$I_i = \frac{V_s - V_i}{R_{sense}}$$

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



$$V_i = \frac{Z_i V_s}{Z_i + R_{source}} = \frac{(1.2\ k\Omega)(10\ mV)}{1.2\ k\Omega + 0.6\ k\Omega} = 6.67\ mV$$

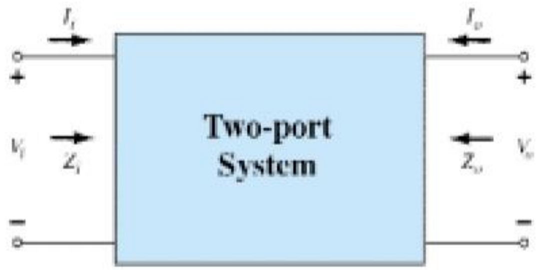
CONTOH



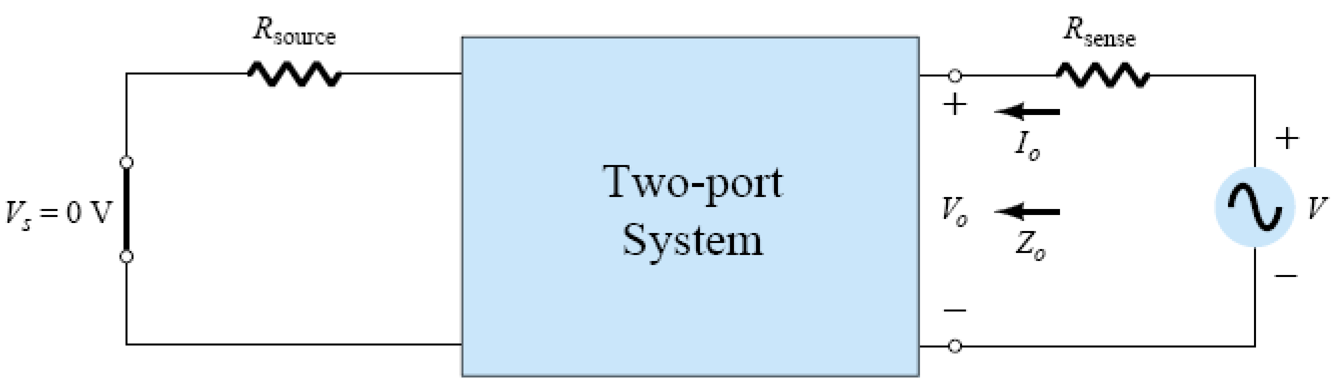
$$I_i = \frac{V_s - V_i}{R_{sense}} = \frac{2\text{ mV} - 1.2\text{ mV}}{1\text{ k}\Omega} = \frac{0.8\text{ mV}}{1\text{ k}\Omega} = 0.8\ \mu\text{A}$$

$$Z_i = \frac{V_i}{I_i} = \frac{1.2\text{ mV}}{0.8\ \mu\text{A}} = \mathbf{1.5\ k\Omega}$$

IMPEDANSI OUTPUT



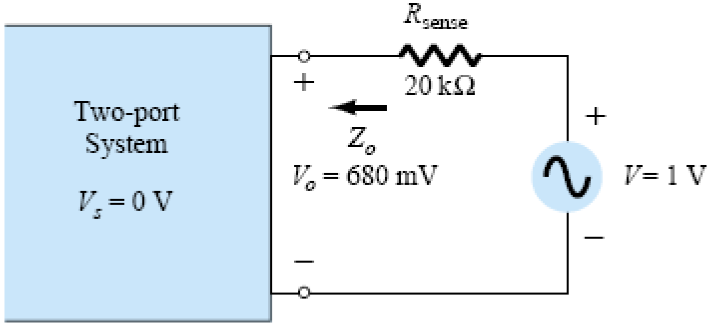
- Impedansi output (Zo) ditentukan pada terminal output melihat belakang ke dalam sistem dengan sinyal input dibuat nol.
- Untuk memperoleh Zo, sumber sinyal diberikan pada terminal output dan sesuai dengan hukum Ohm, yaitu:



$$I_o = \frac{V - V_o}{R_{sense}}$$

$$Z_o = \frac{V_o}{I_o}$$

CONTOH

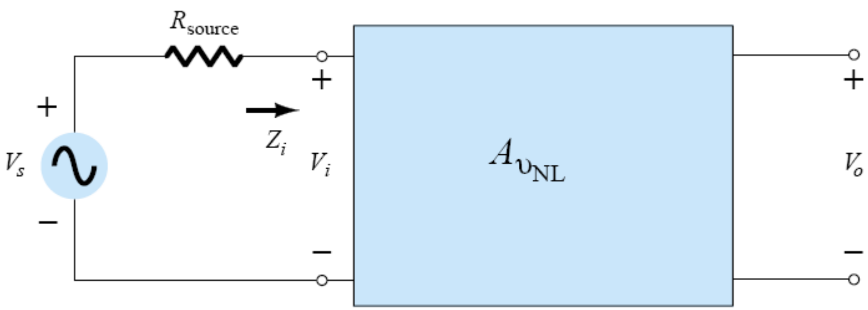


$$I_o = \frac{V - V_o}{R_{sense}} = \frac{1\text{ V} - 680\text{ mV}}{20\text{ k}\Omega} = \frac{320\text{ mV}}{20\text{ k}\Omega} = 16\ \mu\text{A}$$

$$Z_o = \frac{V_o}{I_o} = \frac{680\text{ mV}}{16\ \mu\text{A}} = \mathbf{42.5\ k\Omega}$$

PENGUAT TEGANGAN

$$A_v = \frac{V_o}{V_i}$$



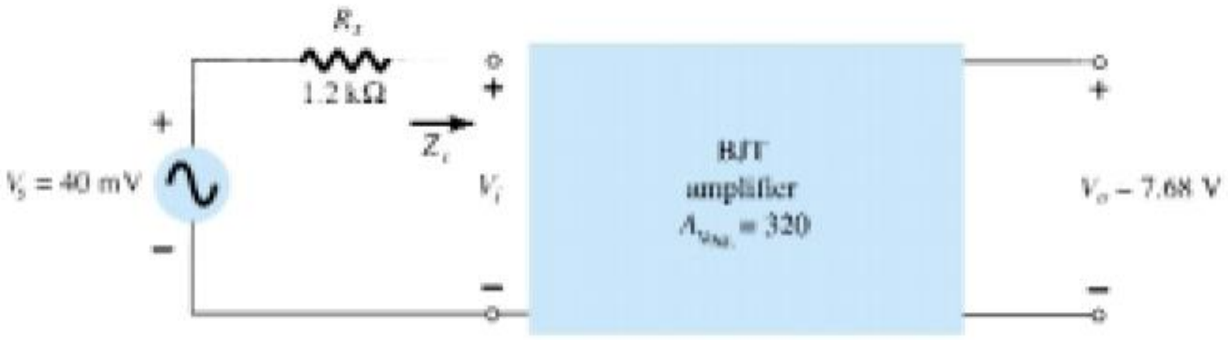
$$A_{v_{\text{NL}}} = \left.\frac{V_o}{V_i}\right|_{R_L = \infty\ \Omega\ \text{(open circuit)}}$$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s}$$

$$A_{v_s} = \frac{V_o}{V_s} = \frac{V_i}{V_s} \cdot \frac{V_o}{V_i}$$

$$A_{v_s} = \frac{V_o}{V_s} = \frac{Z_i}{Z_i + R_s} A_{v_{\text{NL}}}$$

CONTOH



(a) $A_{v_{NL}} = \dfrac{V_o}{V_i}$ and $V_i = \dfrac{V_o}{A_{v_{NL}}} = \dfrac{7.68\text{ V}}{320} = \mathbf{24\ mV}$

(b) $I_i = \dfrac{V_s - V_i}{R_s} = \dfrac{40\text{ mV} - 24\text{ mV}}{1.2\text{ k}\Omega} = \mathbf{13.33\ \mu A}$

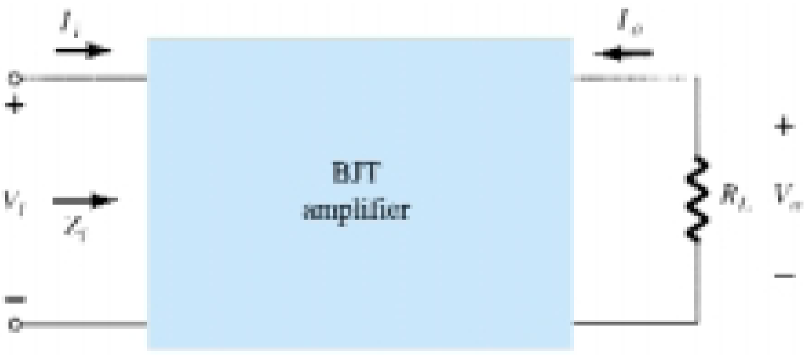
(c) $Z_i = \dfrac{V_i}{I_i} = \dfrac{24\text{ mV}}{13.33\ \mu\text{A}} = \mathbf{1.8\ k\Omega}$

(d) $A_{v_s} = \dfrac{Z_i}{Z_i + R_s} A_{v_{NL}}$

$= \dfrac{1.8\text{ k}\Omega}{1.8\text{ k}\Omega + 1.2\text{ k}\Omega}(320)$

$= \mathbf{192}$

PENGUATAN ARUS



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

$$I_i = \frac{V_i}{Z_i} \qquad I_o = -\frac{V_o}{R_L}$$

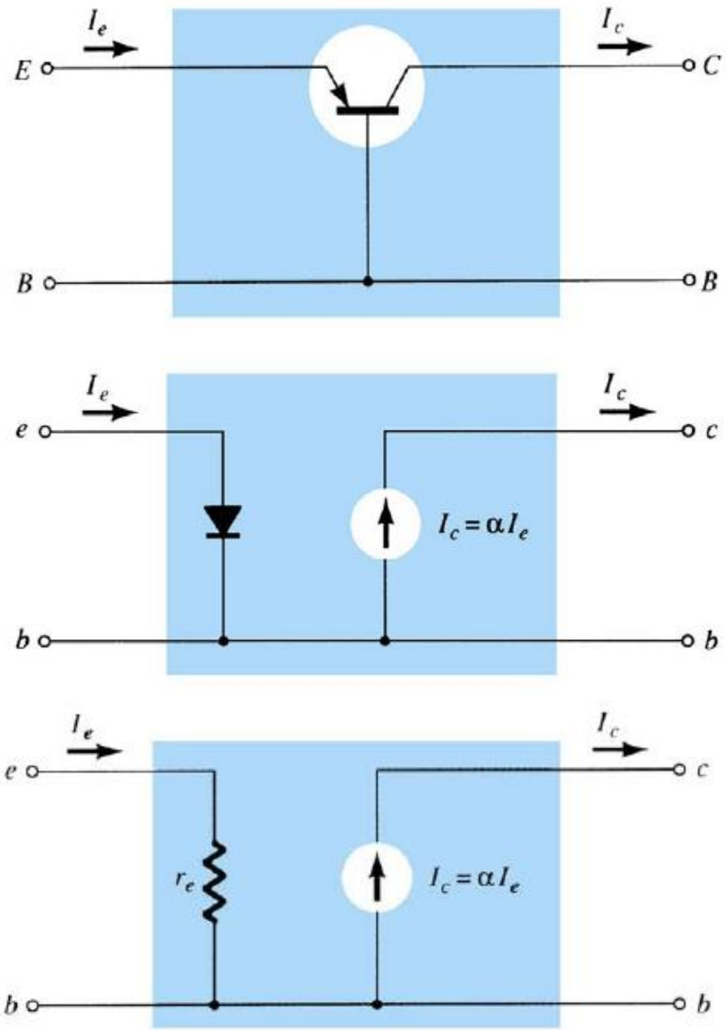
$$A_i = \frac{I_o}{I_i} = -\frac{V_o/R_L}{V_i/Z_i} = -\frac{V_o Z_i}{V_i R_L}$$

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

r_e TRANSISTOR MODEL

- BJTs are basically current-controlled devices, therefore the re model uses a diode and a current source to duplicate the behavior of the transistor. One disadvantage to this model is its sensitivity to the DC level.

r_e MODEL ➔ Common Base Configuration



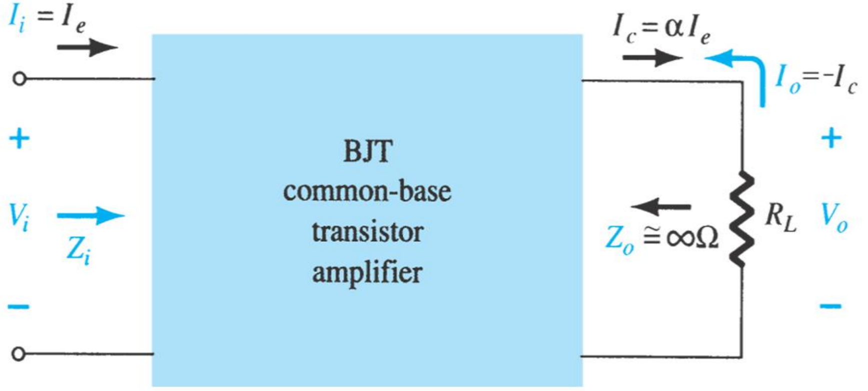
$$r_e = \frac{26 \text{ mV}}{I_E}$$

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

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

- ❑ Pada umumnya CB memiliki Impedansi input yang relatif Rendah dan Impedansi Output yang sangat tinggi.
- ❑ Nilai Impedansi input rata – rata kurang dari 50 Ohm
- ❑ Nilai impedansi Output CB dalam kisaran Mega Ohm.

r_e MODEL ➔ Common Base Configuration



PENGUATAN TEGANGAN

$$V_o = -I_o R_L = -(-I_c) R_L = \alpha I_e R_L$$

$$V_i = I_e Z_i = I_e r_e$$

$$A_v = \frac{V_o}{V_i} = \frac{\alpha I_e R_L}{I_e r_e}$$

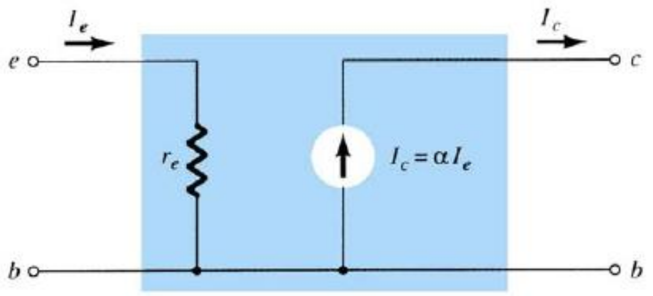
$$\boxed{A_v = \frac{\alpha R_L}{r_e} \cong \frac{R_L}{r_e}} \quad CB$$

PENGUATAN ARUS

$$A_i = \frac{I_o}{I_i} = \frac{-I_c}{I_e} = -\frac{\alpha I_e}{I_e}$$

$$\boxed{A_i = -\alpha \cong -1} \quad CB$$

CONTOH



$I_E = 4$ mA,

$\alpha = 0.98$,

$V_i = 2$ mV

(a) Determine the input impedance.
(b) Calculate the voltage gain if a load of 0.56 kΩ is connected to the output terminals.
(c) Find the output impedance and current gain.

(a) $r_e = \dfrac{26 \text{ mV}}{I_E} = \dfrac{26 \text{ mV}}{4 \text{ mA}} = \mathbf{6.5\ \Omega}$

(b) $I_i = I_e = \dfrac{V_i}{Z_i} = \dfrac{2 \text{ mV}}{6.5\ \Omega} = 307.69\ \mu\text{A}$

$$V_o = I_c R_L = \alpha I_e R_L = (0.98)(307.69\ \mu\text{A})(0.56\text{ k}\Omega) = 168.86 \text{ mV}$$

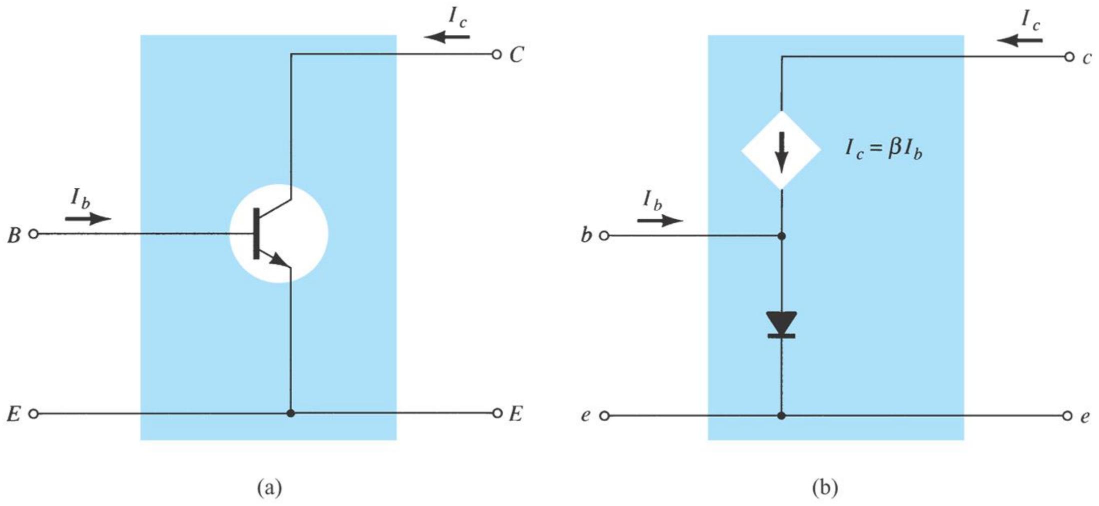
$$A_v = \frac{V_o}{V_i} = \frac{168.86 \text{ mV}}{2 \text{ mV}} = \mathbf{84.43}$$

$$A_v = \frac{\alpha R_L}{r_e} = \frac{(0.98)(0.56\text{ k}\Omega)}{6.5\ \Omega} = \mathbf{84.43}$$

(c) $Z_o \cong \infty\ \Omega$

$$A_i = \frac{I_o}{I_i} = -\alpha = \mathbf{-0.98}$$

r_e MODEL ➔ Common Emitter Configuration



$$\boxed{I_c = \beta I_b}$$

$$I_e = I_c + I_b = \beta I_b + I_b$$

$$\boxed{I_e = (\beta + 1) I_b}$$

$$\boxed{I_e \cong \beta I_b}$$

IMPEDANSI INPUT

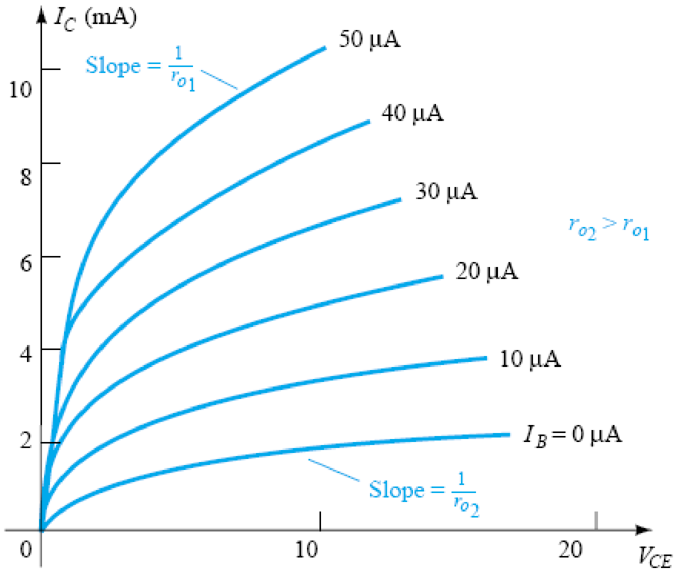
$$Z_i = \frac{V_i}{I_i} = \frac{V_{be}}{I_b} \qquad V_i = V_{be} = I_e r_e \cong \beta I_b r_e$$

$$Z_i = \frac{V_{be}}{I_b} \cong \frac{\beta I_b r_e}{I_b}$$

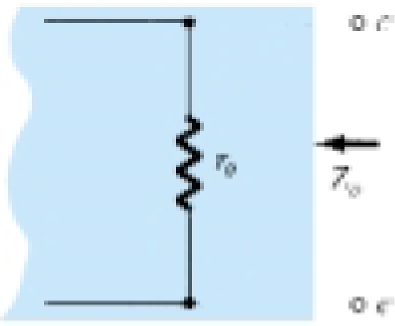
$$\boxed{Z_i \cong \beta r_e}_{CE}$$

- Pada CE, nilai Zi pada umumnya berkisar antara ratusan Ohm hingga Kilo Ohm. Dengan nilai maksimum 6-7 K Ohm.

r_e MODEL ➔ Common Emitter Configuration

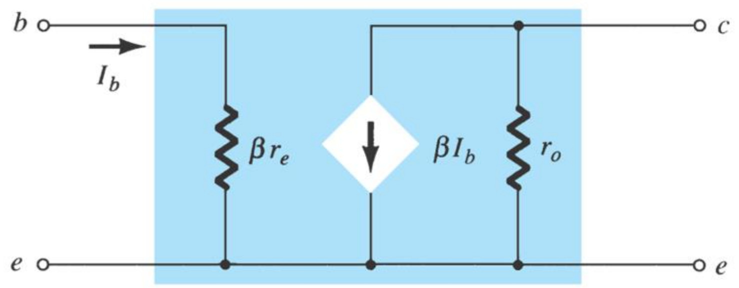


IMPEDANSI OUTPUT

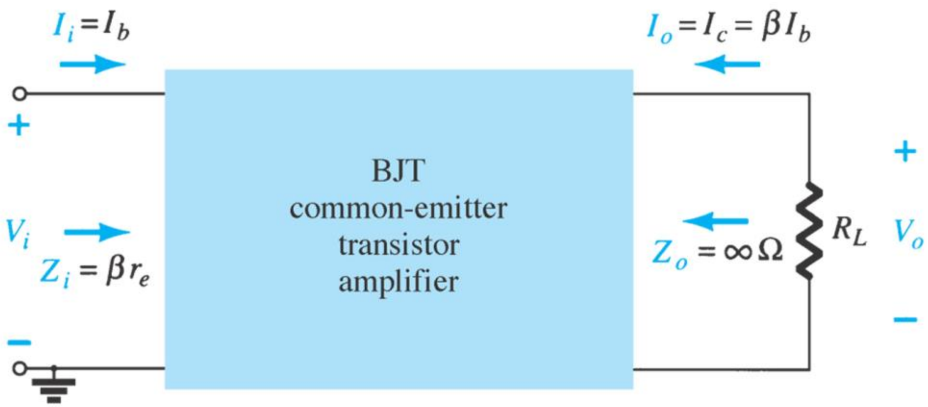


$$\boxed{Z_o = r_o}_{CE}$$

- ❑ Pada CE, nilai Zo pada umumnya berkisar antara 40 Kohm – 50 KOhm



r_e MODEL ➔ Common Emitter Configuration



$$\boxed{A_v = -\frac{R_L}{r_e}}\quad_{CE, r_o = \infty\Omega}$$

PENGUATAN TEGANGAN

$$V_o = -I_o R_L$$

$$V_o = -I_o R_L = -I_c R_L = -\beta I_b R_L$$

$$V_i = I_i Z_i = I_b \beta r_e$$

$$A_v = \frac{V_o}{V_i} = -\frac{\beta I_b R_L}{I_b \beta r_e}$$

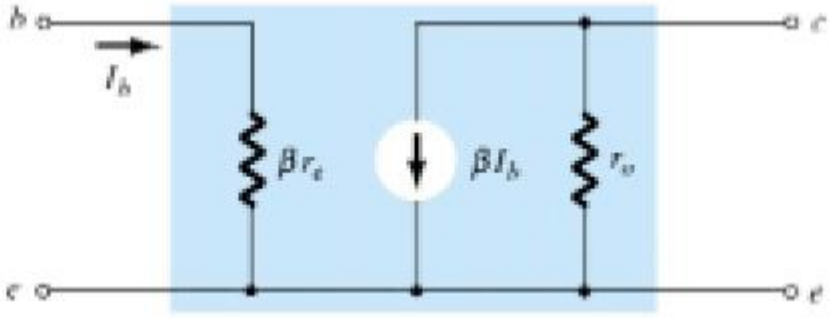
- Tanda minus menunjukkan beda fase antara sinyal input dan output 180^0

PENGUATAN ARUS

$$A_i = \frac{I_o}{I_i} = \frac{I_c}{I_b} = \frac{\beta I_b}{I_b}$$

$$\boxed{A_i = \beta}\quad_{CE, r_o = \infty\,\Omega}$$

CONTOH



$\beta = 120$ and $I_E = 3.2$ mA

$r_o = \infty\ \Omega$.

(a) Z_i.
(b) A_v if a load of 2 kΩ is applied.
(c) A_i with the 2 kΩ load.

(a) $r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{3.2\text{ mA}} = 8.125\ \Omega$

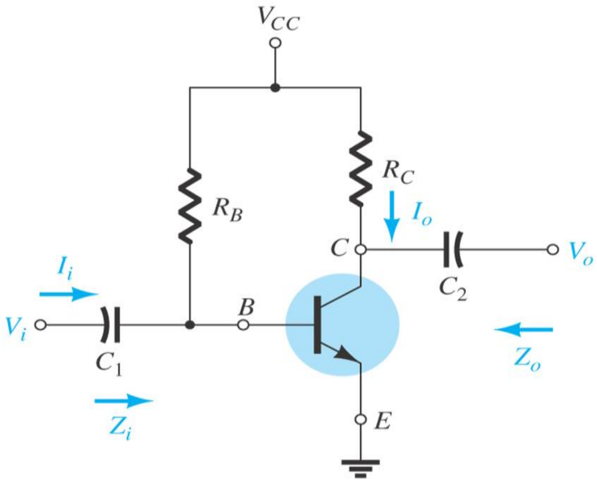
and $Z_i = \beta r_e = (120)(8.125\ \Omega) = \mathbf{975\ \Omega}$

(b) Eq. (7.21): $A_v = -\dfrac{R_L}{r_e} = -\dfrac{2\text{ k}\Omega}{8.125\ \Omega} = \mathbf{-246.15}$

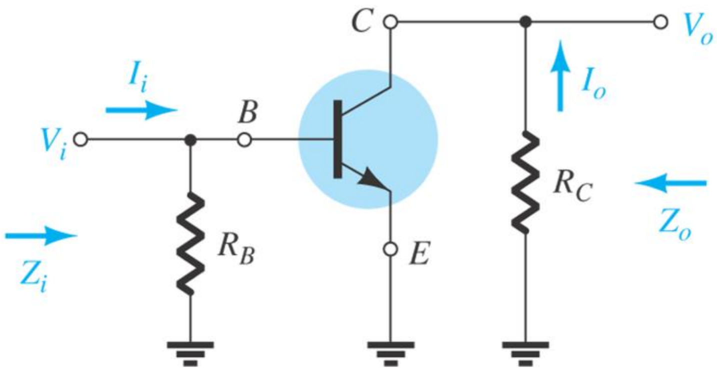
(c) $A_i = \dfrac{I_o}{I_i} = \beta = \mathbf{120}$

mas.suwito@gmail.com

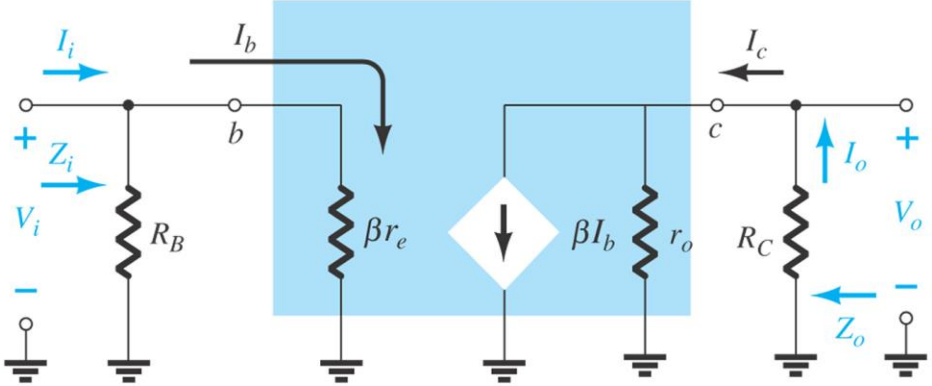
CE FIXED-BIAS CONFIGURATION



Common-emitter fixed-bias configuration.



Removal of the effects of *VCC*, *C*1 and C2



Substituting the *re* model into the network

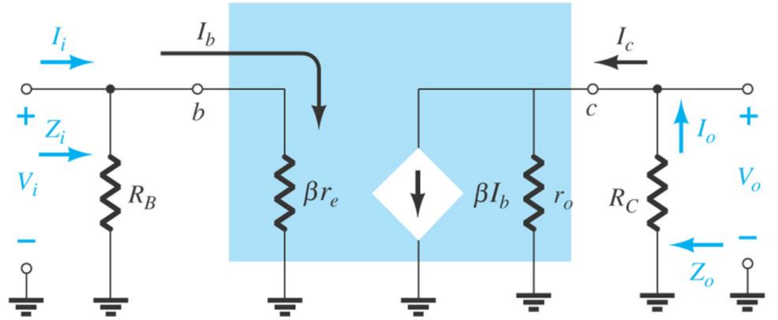
IMPEDANSI INPUT

$$\boxed{Z_i = R_B \| \beta r_e} \quad \text{ohms}$$

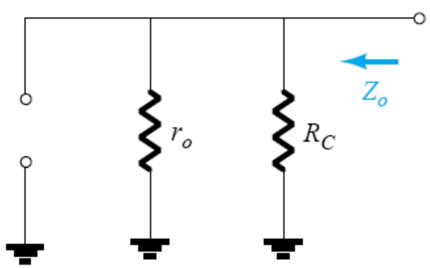
$$\boxed{Z_i \cong \beta r_e}$$

$R_B \geq 10\beta r_e$

CE ➔ IMPEDANSI OUTPUT



IMPEDANSI OUTPUT

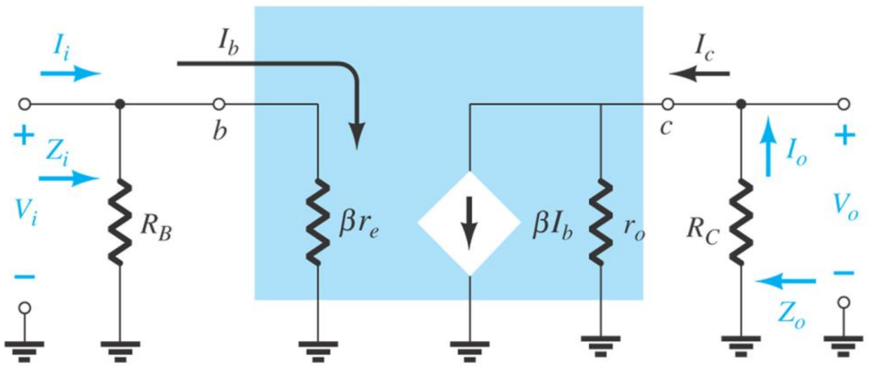


When Vi = 0, Ii = Ib = 0, resulting in an open-circuit equivalence for the current source.

$$\boxed{Z_o = R_C \| r_o} \quad \text{ohms}$$

$$\boxed{Z_o \cong R_C}_{r_o \geq 10R_C}$$

CE ➔ PENGUATAN TEGANGAN (A_V)



The resistors *ro and RC are in parallel.*

$$V_o = -\beta I_b (R_C \| r_o)$$

$$I_b = \frac{V_i}{\beta r_c}$$

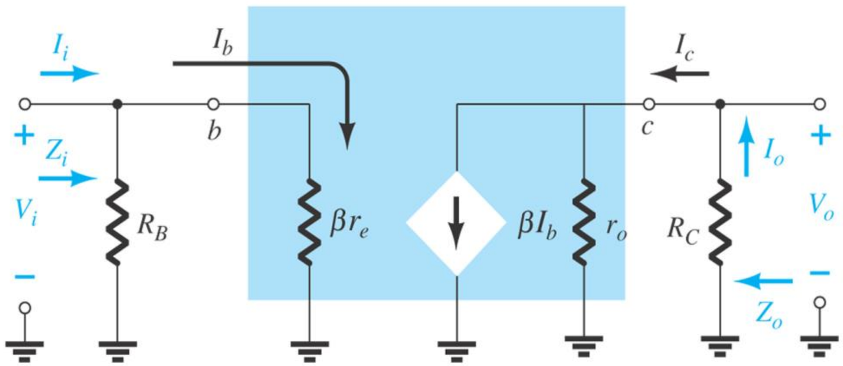
$$V_o = -\beta\left(\frac{V_i}{\beta_{r_e}}\right)(R_C \| r_o)$$

$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{(R_C \| r_o)}{r_e}}$$

If $r_o \geq 10R_C$,

$$\boxed{A_v = -\frac{R_C}{r_e}}_{r_o \geq 10R_C}$$

CE ➔ PENGUATAN ARUS (A_I)



Applying the current-divider rule to the input and output circuits,

$$I_o = \frac{(r_o)(\beta I_b)}{r_o + R_C} \quad \text{and} \quad \frac{I_o}{I_b} = \frac{r_o\beta}{r_o + R_C}$$

$$I_b = \frac{(R_B)(I_i)}{R_B + \beta r_e} \quad \text{or} \quad \frac{I_b}{I_i} = \frac{R_B}{R_B + \beta r_e}$$

$$A_i = \frac{I_o}{I_i} = \left(\frac{I_o}{I_b}\right)\left(\frac{I_b}{I_i}\right) = \left(\frac{r_o\beta}{r_o + R_C}\right)\left(\frac{R_B}{R_B + \beta r_e}\right)$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{\beta R_B r_o}{(r_o + R_C)(R_B + \beta r_e)}}$$

if $r_o \geq 10R_C$ and $R_B \geq 10\beta r_e$,

$$A_i = \frac{I_o}{I_i} \cong \frac{\beta R_B r_o}{(r_o)(R_B)}$$

$$\boxed{A_i \cong \beta}_{\,r_o \geq 10R_C,\ R_B \geq 10\beta r_e}$$

$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{(R_C \| r_o)}{r_e}}$$

$$\boxed{Z_i = R_B \| \beta r_e}$$

➔

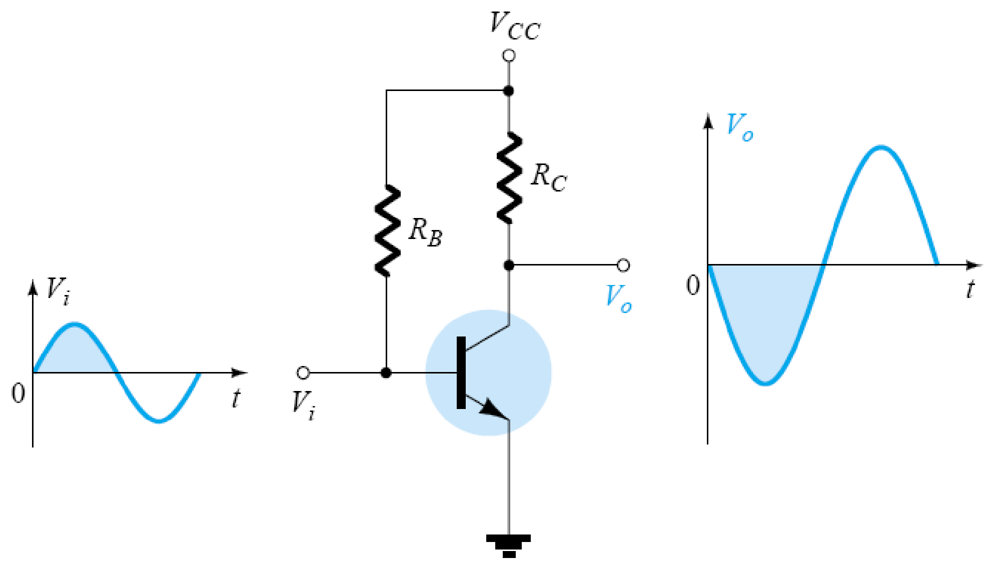
$$\boxed{A_i = -A_v \frac{Z_i}{R_C}}$$

mas.suwito@gmail.com

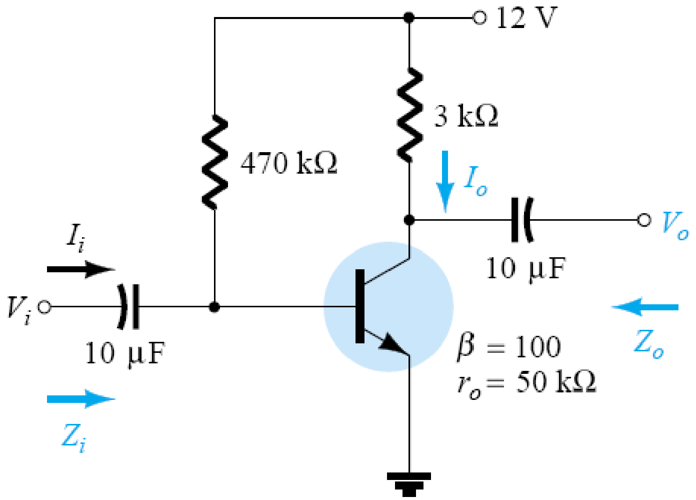
CE ➔ PHASE RELATIONSHIP

$$A_v = \frac{V_o}{V_i} = -\frac{(R_C \| r_o)}{r_e}$$

Tanda minus (-) pada penguatan tegangan berarti antara sinyal input dan output bergeser 180^0



CONTOH



(a) Determine r_e.
(b) Find Z_i (with $r_o = \infty\ \Omega$).
(c) Calculate Z_o (with $r_o = \infty\ \Omega$).
(d) Determine A_v (with $r_o = \infty\ \Omega$).
(e) Find A_i (with $r_o = \infty\ \Omega$).
(f) Repeat parts (c) through (e) including $r_o = 50\ \text{k}\Omega$

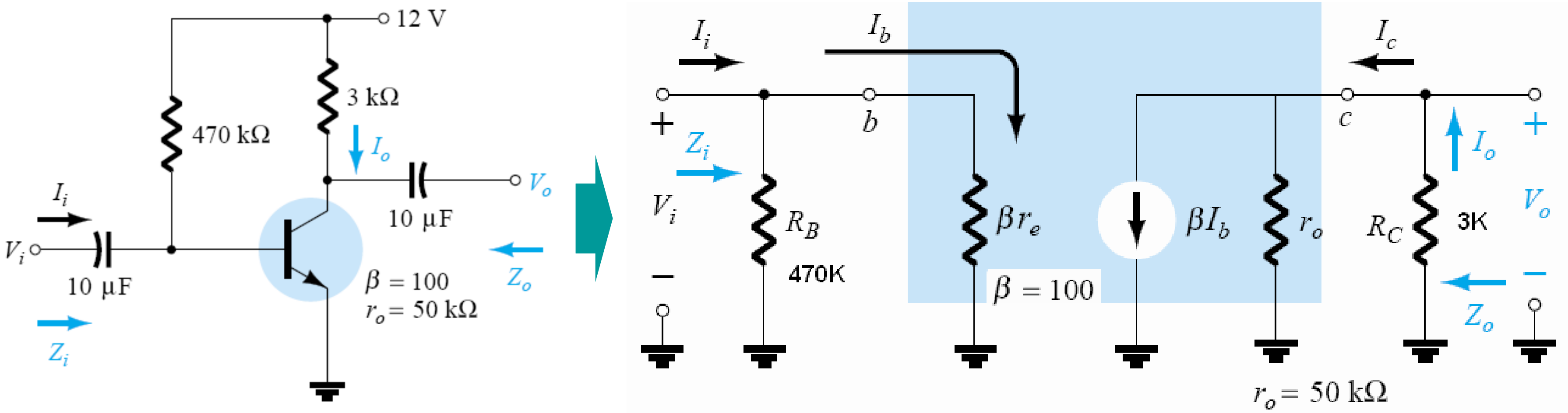
(a) DC analysis:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12\ \text{V} - 0.7\ \text{V}}{470\ \text{k}\Omega} = 24.04\ \mu\text{A}$$

$$I_E = (\beta + 1)I_B = (101)(24.04\ \mu\text{A}) = 2.428\ \text{mA}$$

$$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{2.428\ \text{mA}} = \mathbf{10.71\ \Omega}$$

CONTOH



(b) $\beta r_e = (100)(10.71\ \Omega) = 1.071\ \text{k}\Omega$

$Z_i = R_B \| \beta r_e = 470\ \text{k}\Omega \| 1.071\ \text{k}\Omega = \mathbf{1.069\ k\Omega}$

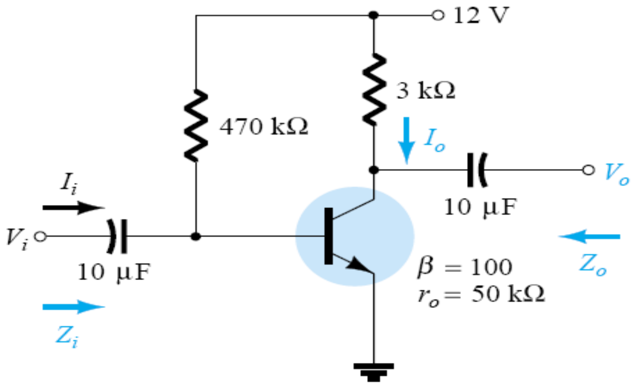
(c) $Z_o = R_C = \mathbf{3\ k\Omega}$

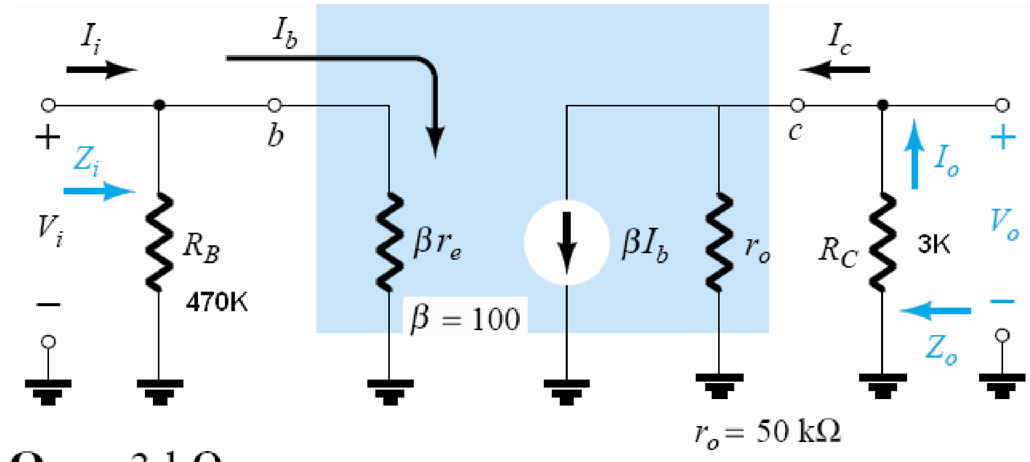
(d) $A_v = -\dfrac{R_C}{r_e} = -\dfrac{3\ \text{k}\Omega}{10.71\ \Omega} = \mathbf{-280.11}$

(e) Since $R_B \geq 10\beta r_e (470\ \text{k}\Omega > 10.71\ \text{k}\Omega)$

$A_i \cong \beta = \mathbf{100}$

CONTOH





(f) $Z_o = r_o \| R_C = 50\text{ k}\Omega \| 3\text{ k}\Omega = \mathbf{2.83\ k\Omega}$ vs. 3 kΩ

$$A_v = -\frac{r_o \| R_C}{r_e} = \frac{2.83\text{ k}\Omega}{10.71\ \Omega} = \mathbf{-264.24} \text{ vs. } -280.11$$

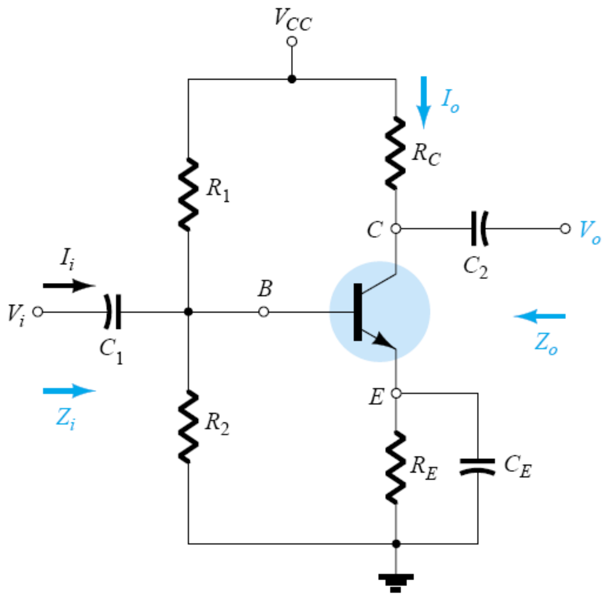
$$A_i = \frac{\beta R_B r_o}{(r_o + R_C)(R_B + \beta r_e)} = \frac{(100)(470\text{ k}\Omega)(50\text{ k}\Omega)}{(50\text{ k}\Omega + 3\text{ k}\Omega)(470\text{ k}\Omega + 1.071\text{ k}\Omega)}$$

$$= \mathbf{94.13} \text{ vs. } 100$$

As a check:

$$A_i = -A_v\frac{Z_i}{R_C} = \frac{-(-264.24)(1.069\text{ k}\Omega)}{3\text{ k}\Omega} = \mathbf{94.16}$$

CE VOLTAGE-DIVIDER BIAS CONFIGURATION



IMPEDANSI INPUT

$$R' = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

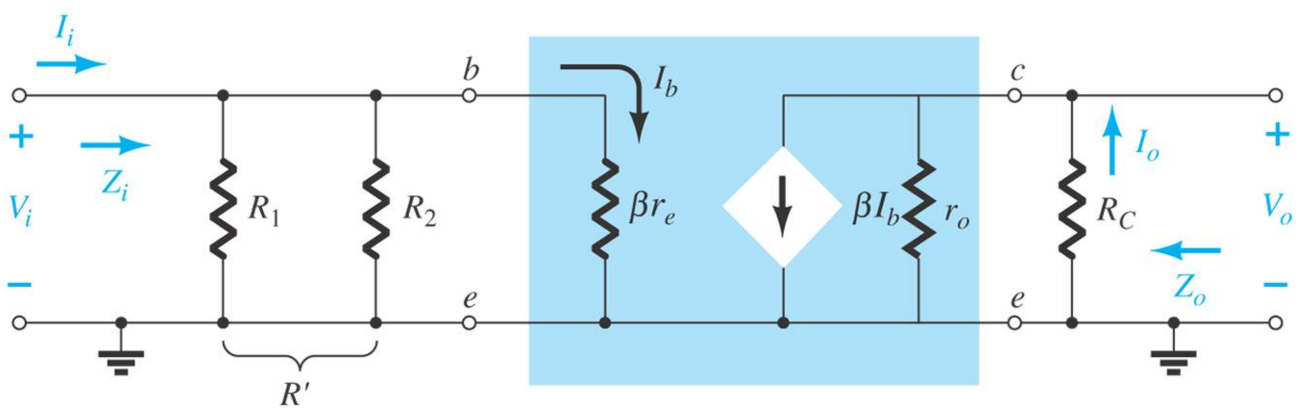
$$Z_i = R' \| \beta r_e$$

IMPEDANSI OUTPUT

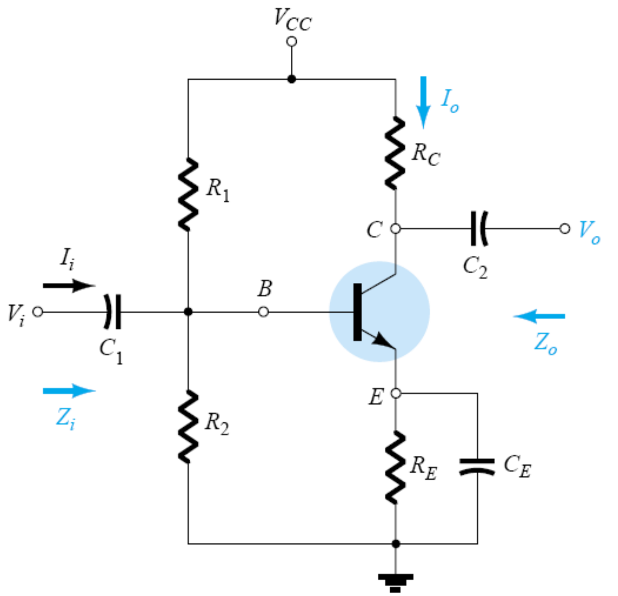
V_i set to 0 V resulting in $I_b = 0\ \mu A$ and $\beta I_b = 0$ mA.

$$Z_o = R_C \| r_o$$

$$Z_o \cong R_C \Big|_{r_o \geq 10R_C}$$



CE VOLTAGE-DIVIDER BIAS CONFIGURATION



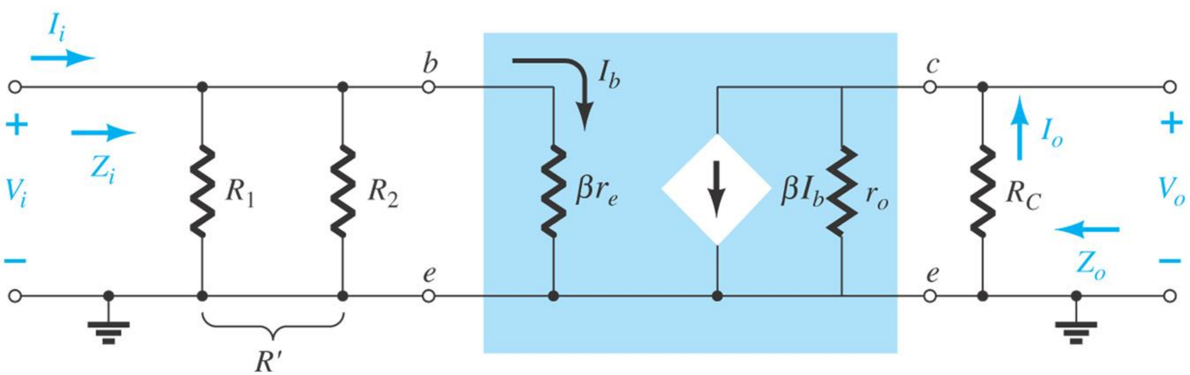
PENGUATAN TEGANGAN

$$V_o = -(\beta I_b)(R_C \| r_o)$$

$$I_b = \frac{V_i}{\beta r_e}$$

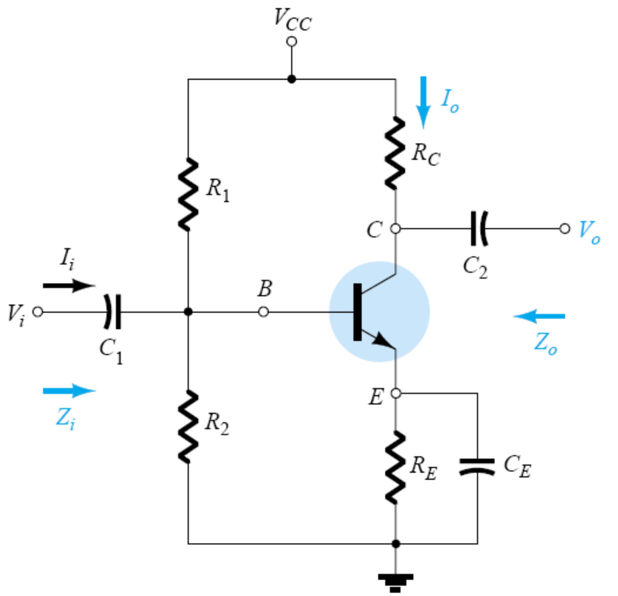
$$V_o = -\beta \left(\frac{V_i}{\beta r_e}\right)(R_C \| r_o)$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{-R_C \| r_o}{r_e}}$$



$$\boxed{A_v = \frac{V_o}{V_i} \cong -\frac{R_C}{r_e}}_{r_o \geq 10R_C}$$

CE VOLTAGE-DIVIDER BIAS CONFIGURATION



PENGUATAN ARUS

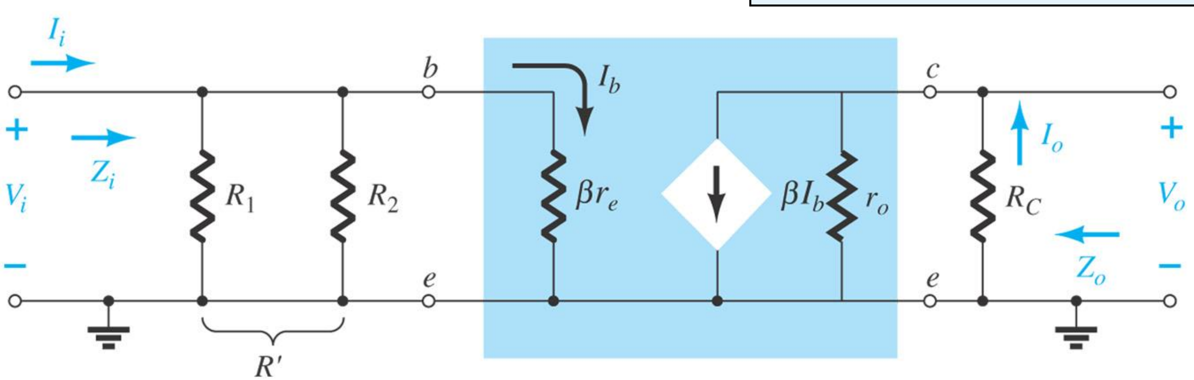
$R' = R_1 \| R_2 = R_B,$

$$I_o = \frac{(r_o)(\beta I_b)}{r_o + R_C} \quad \text{and} \quad \frac{I_o}{I_b} = \frac{r_o \beta}{r_o + R_C}$$

$$I_b = \frac{(R_B)(I_i)}{R_B + \beta r_e} \quad \text{or} \quad \frac{I_b}{I_i} = \frac{R_B}{R_B + \beta r_e}$$

$$A_i = \frac{I_o}{I_i} = \left(\frac{I_o}{I_b}\right)\left(\frac{I_b}{I_i}\right) = \left(\frac{r_o \beta}{r_o + R_C}\right)\left(\frac{R_B}{R_B + \beta r_e}\right)$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{\beta R' r_o}{(r_o + R_C)(R' + \beta r_e)}}$$

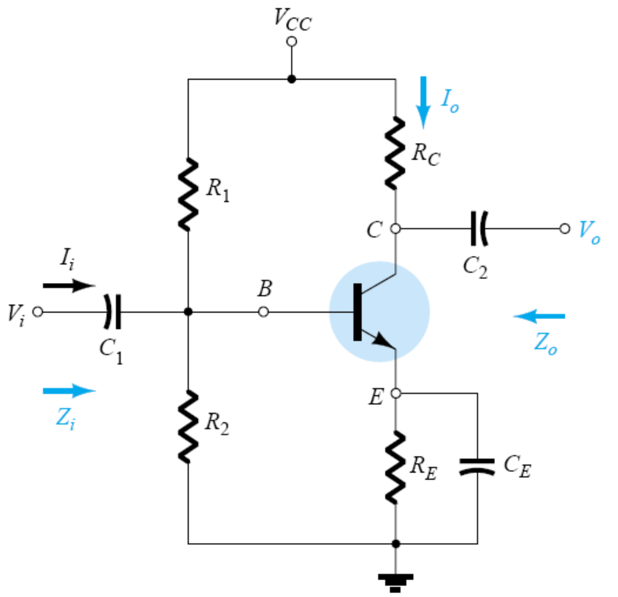


For $r_o \geq 10R_C$,

$$A_i = \frac{I_o}{I_i} \cong \frac{\beta R' r_o}{r_o(R' + \beta r_e)}$$

$$\boxed{A_i = \frac{I_o}{I_i} \cong \frac{\beta R'}{R' + \beta r_e}} \quad r_o \geq 10R_C$$

CE VOLTAGE-DIVIDER BIAS CONFIGURATION



PENGUATAN ARUS

if $R' \geq 10\beta r_e$,

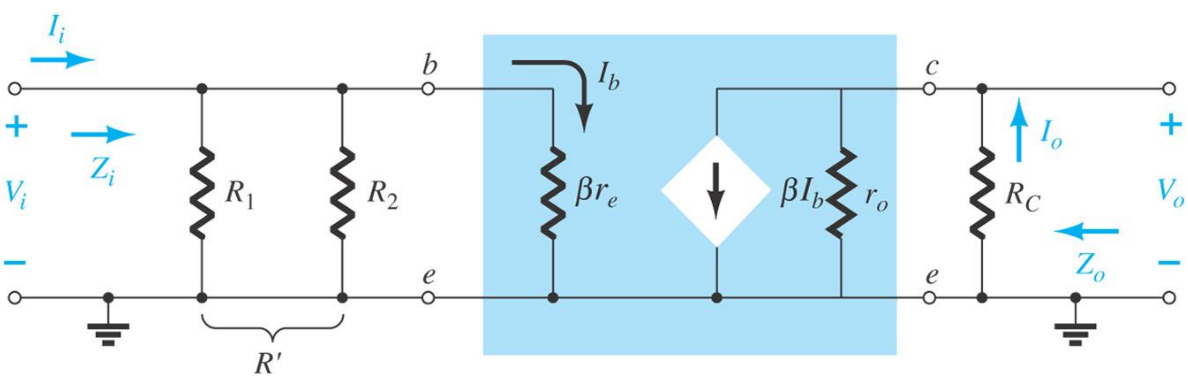
For $r_o \geq 10R_C$,

$$A_i = \frac{I_o}{I_i} = \frac{\beta R' r_o}{(r_o + R_C)(R' + \beta r_e)}$$

$$A_i = \frac{I_o}{I_i} \cong \frac{\beta R'}{R' + \beta r_e} \Bigg|_{r_o \geq 10R_C}$$

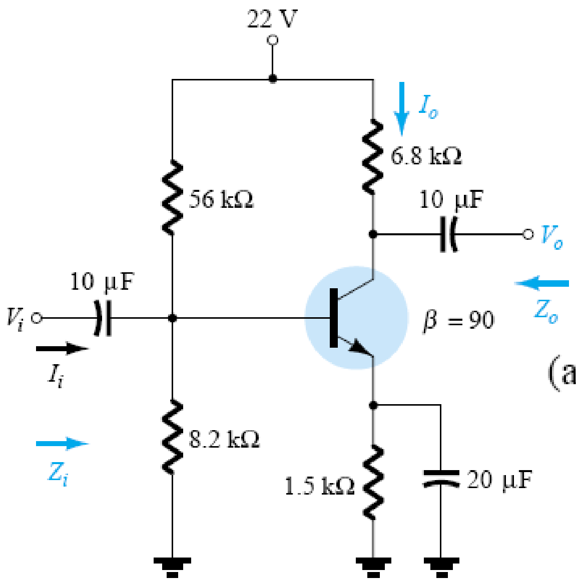
$$A_i = \frac{I_o}{I_i} = \frac{\beta R'}{R'}$$

$$A_i = \frac{I_o}{I_i} \cong \beta \Bigg|_{r_o \geq 10R_C,\ R' \geq 10\beta r_e}$$



$$A_i = -A_v \frac{Z_i}{R_C}$$

CONTOH



(a) r_e.
(b) Z_i.
(c) Z_o ($r_o = \infty\ \Omega$).
(d) A_v ($r_o = \infty\ \Omega$).
(e) A_i ($r_o = \infty\ \Omega$).
(f) The parameters of parts (b) through (e) if $r_o = 1/h_{oe} = 50\ \text{k}\Omega$

(a) DC: Testing $\beta R_E > 10R_2$

$$(90)(1.5\ \text{k}\Omega) > 10(8.2\ \text{k}\Omega)$$

$$135\ \text{k}\Omega > 82\ \text{k}\Omega\ (\textit{satisfied})$$

Using the approximate approach,

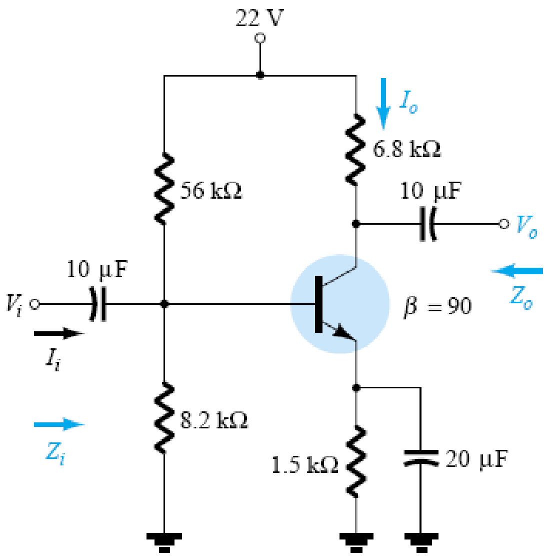
$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{(8.2\ \text{k}\Omega)(22\ \text{V})}{56\ \text{k}\Omega + 8.2\ \text{k}\Omega} = 2.81\ \text{V}$$

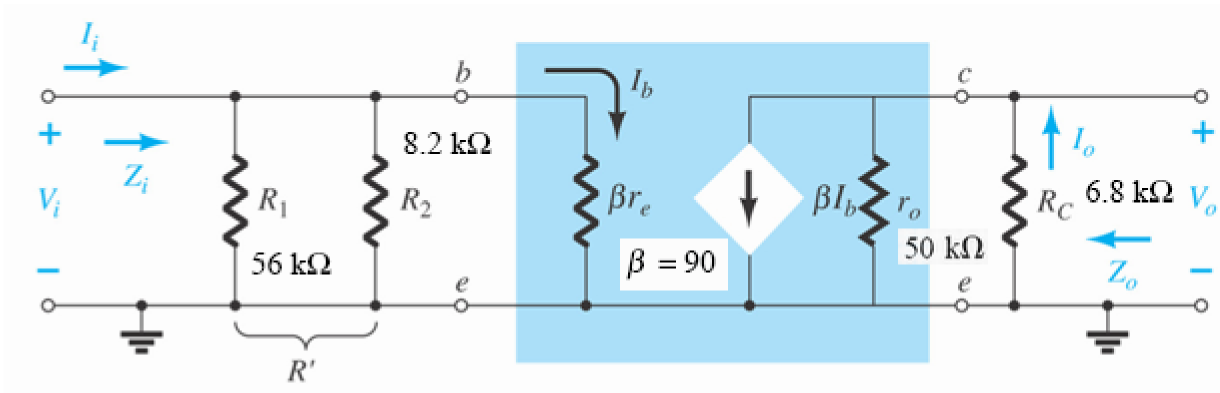
$$V_E = V_B - V_{BE} = 2.81\ \text{V} - 0.7\ \text{V} = 2.11\ \text{V}$$

$$I_E = \frac{V_E}{R_E} = \frac{2.11\ \text{V}}{1.5\ \text{k}\Omega} = 1.41\ \text{mA}$$

$$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{1.41\ \text{mA}} = \mathbf{18.44\ \Omega}$$

CONTOH





$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.41\text{ mA}} = \mathbf{18.44\ \Omega}$$

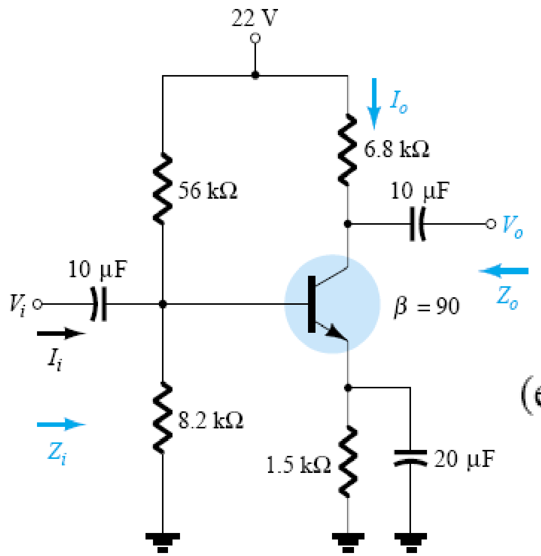
(b) $R' = R_1 \| R_2 = (56\text{ k}\Omega)\|(8.2\text{ k}\Omega) = 7.15\text{ k}\Omega$

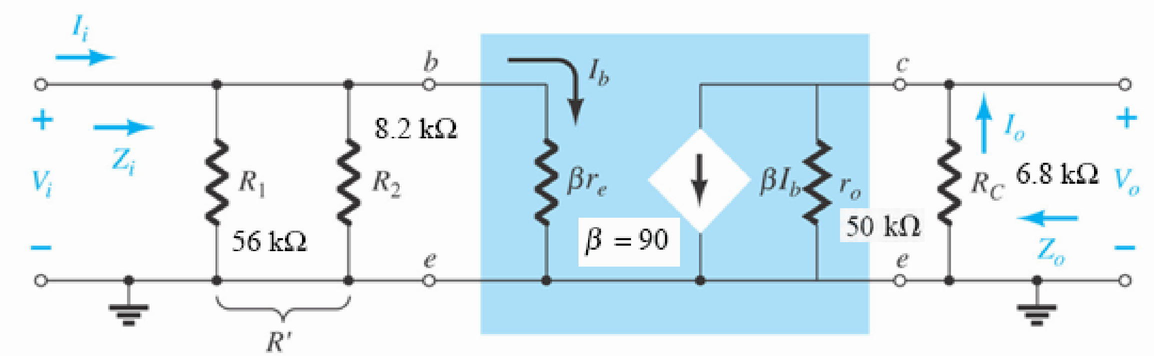
$$Z_i = R' \| \beta r_e = 7.15\text{ k}\Omega \| (90)(18.44\ \Omega) = 7.15\text{ k}\Omega \| 1.66\text{ k}\Omega$$
$$= \mathbf{1.35\ k\Omega}$$

(c) $Z_o = R_C = \mathbf{6.8\ k\Omega}$

(d) $$A_v = -\frac{R_C}{r_e} = -\frac{6.8\text{ k}\Omega}{18.44\ \Omega} = \mathbf{-368.76}$$

CONTOH





(e) The condition $R' \geq 10\beta r_e$ (7.15 kΩ ≥ 10(1.66 kΩ) = 16.6 kΩ is *not* satisfied. Therefore,

$$A_i \cong \frac{\beta R'}{R' + \beta r_e} = \frac{(90)(7.15\ \text{k}\Omega)}{7.15\ \text{k}\Omega + 1.66\ \text{k}\Omega} = \mathbf{73.04}$$

(f) $Z_i = \mathbf{1.35\ k\Omega}$

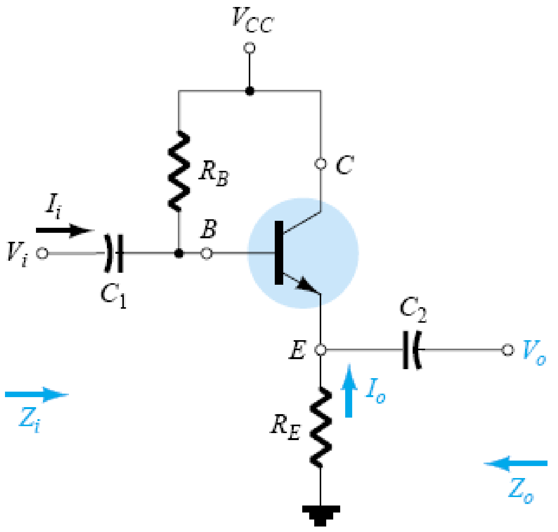
$$Z_o = R_C \| r_o = 6.8\ \text{k}\Omega \| 50\ \text{k}\Omega = \mathbf{5.98\ k\Omega} \text{ vs. } 6.8\ \text{k}\Omega$$

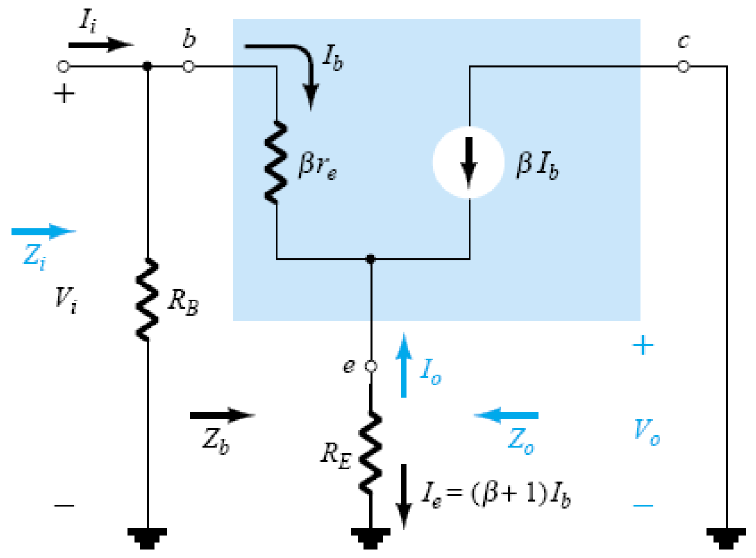
$$A_v = -\frac{R_C \| r_o}{r_e} = -\frac{5.98\ \text{k}\Omega}{18.44\ \Omega} = \mathbf{-324.3} \text{ vs. } -368.76$$

$$A_i = \frac{\beta R' r_o}{(r_o + R_C)(R' + \beta r_e)} = \frac{(90)(7.15\ \text{k}\Omega)(50\ \text{k}\Omega)}{(50\ \text{k}\Omega + 6.8\ \text{k}\Omega)(7.15\ \text{k}\Omega + 1.66\ \text{k}\Omega)}$$

$$= \mathbf{64.3} \text{ vs. } 73.04$$

CC ATAU EMITTER-FOLLOWER CONFIGURATION





IMPEDANSI INPUT

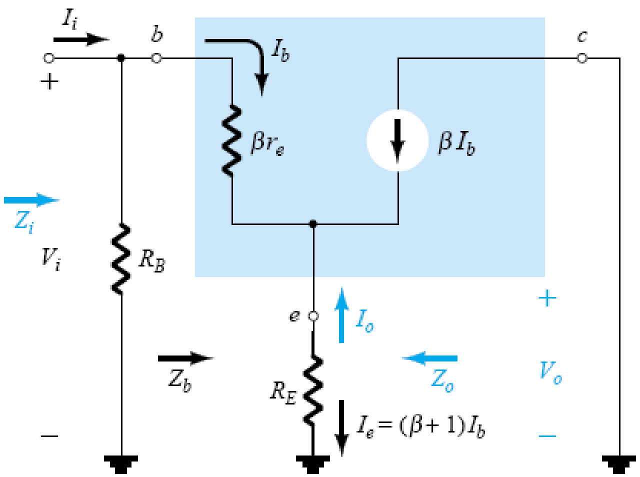
$$Z_i = R_B \| Z_b$$

$$Z_b = \beta r_e + (\beta + 1) R_E$$

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

$$Z_b \cong \beta R_E$$

CE EMITTER-FOLLOWER CONFIGURATION



IMPEDANSI OUTPUT

$$I_b = \frac{V_i}{Z_b}$$

$$I_e = (\beta + 1)I_b = (\beta + 1)\frac{V_i}{Z_b}$$

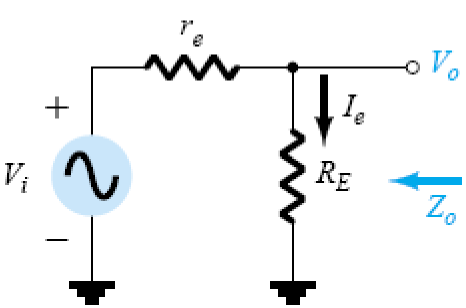
$$I_e = \frac{(\beta + 1)V_i}{\beta r_e + (\beta + 1)R_E}$$

$$I_e = \frac{V_i}{[\beta r_e/(\beta + 1)] + R_E}$$

$$(\beta + 1) \cong \beta$$

$$\frac{\beta r_e}{\beta + 1} \cong \frac{\beta r_e}{\beta} = r_e$$

$$\boxed{I_e \cong \frac{V_i}{r_e + R_E}}$$



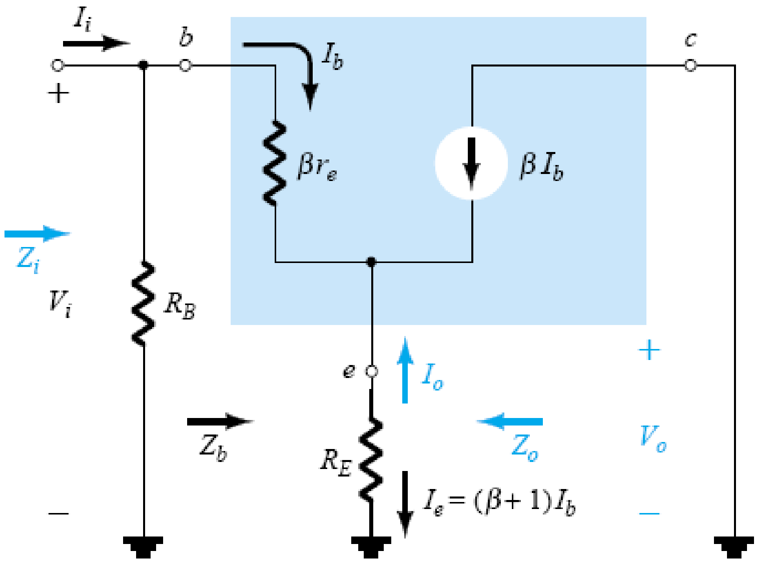
To determine Z_o, V_i is set to zero

$$\boxed{Z_o = R_E \| r_e}$$

Since R_E is typically much greater than r_e,

$$\boxed{Z_o \cong r_e}$$

CE EMITTER-FOLLOWER CONFIGURATION



PENGUATAN TEGANGAN (A_V)

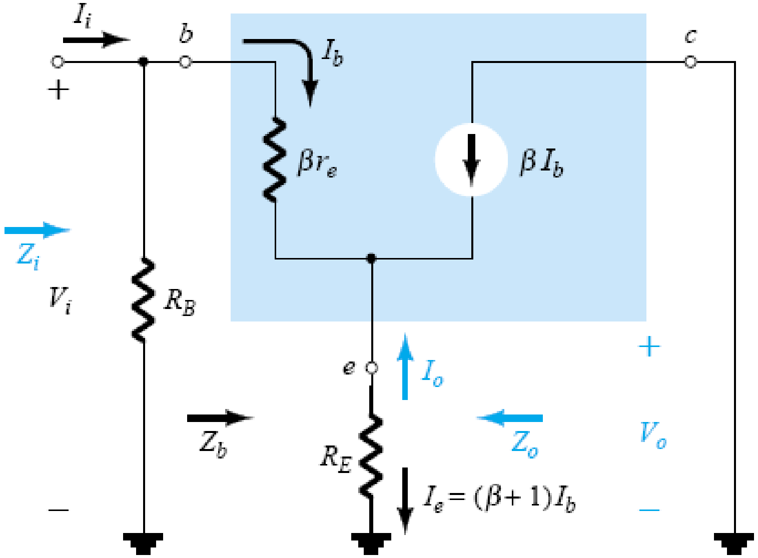
$$V_o = \frac{R_E V_i}{R_E + r_e}$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{R_E}{R_E + r_e}}$$

Since R_E is usually much greater than r_e, $R_E + r_e \cong R_E$

$$\boxed{A_v = \frac{V_o}{V_i} \cong 1}$$

CE EMITTER-FOLLOWER CONFIGURATION



PENGUATAN ARUS (A_I)

$$I_b = \frac{R_B I_i}{R_B + Z_b}$$

$$\frac{I_b}{I_i} = \frac{R_B}{R_B + Z_b}$$

$$I_o = -I_e = -(\beta + 1)I_b$$

$$\frac{I_o}{I_b} = -(\beta + 1)$$

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

$$= -(\beta + 1)\frac{R_B}{R_B + Z_b}$$

$(\beta + 1) \cong \beta,$

$$\boxed{A_i \cong -\frac{\beta R_B}{R_B + Z_b}}$$

$$\boxed{A_i = -A_v \frac{Z_i}{R_E}}$$

CE EMITTER-FOLLOWER CONFIGURATION

EFEK dari r_0

$$Z_b = \beta r_e + \frac{(\beta + 1)R_E}{1 + \dfrac{R_E}{r_o}}$$

If the condition $r_o \geq 10R_E$ is satisfied,

$$Z_b = \beta r_e + (\beta + 1)R_E$$

$$\boxed{Z_b \cong \beta(r_e + R_E)}_{\,r_o \geq 10R_E}$$

$$Z_o = r_o \| R_E \| \frac{\beta r_e}{(\beta + 1)}$$

$\beta + 1 \cong \beta$,

$$Z_o = r_o \| R_E \| r_e$$

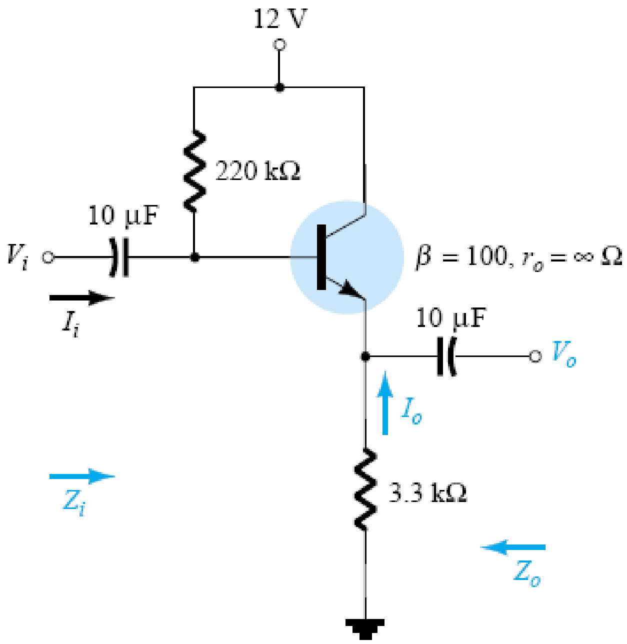
since $r_o \gg r_e$,

$$\boxed{Z_o \cong R_E \| r_e}\ \text{Any } r_o$$

$$A_v = \frac{(\beta + 1)R_E/Z_b}{1 + \dfrac{R_E}{r_o}}$$

$$\boxed{A_v \cong \frac{R_E}{r_e + R_E}}_{\,r_o \geq 10R_E}$$

CONTOH



(a) r_e.
(b) Z_i.
(c) Z_o.
(d) A_v.
(e) A_i.
(f) Repeat parts (b) through (e) with $r_o = 25\ \text{k}\Omega$

(a) $$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E}$$
$$= \frac{12\ \text{V} - 0.7\ \text{V}}{220\ \text{k}\Omega + (101)3.3\ \text{k}\Omega} = 20.42\ \mu\text{A}$$
$$I_E = (\beta + 1)I_B$$
$$= (101)(20.42\ \mu\text{A}) = 2.062\ \text{mA}$$
$$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{2.062\ \text{mA}} = \mathbf{12.61\ \Omega}$$

(b) $$Z_b = \beta r_e + (\beta + 1)R_E$$
$$= (100)(12.61\ \Omega) + (101)(3.3\ \text{k}\Omega)$$
$$= 1.261\ \text{k}\Omega + 333.3\ \text{k}\Omega$$
$$= 334.56\ \text{k}\Omega \cong \beta R_E$$
$$Z_i = R_B \| Z_b = 220\ \text{k}\Omega \| 334.56\ \text{k}\Omega$$
$$= \mathbf{132.72\ k\Omega}$$

CONTOH

(c) $Z_o = R_E \| r_e = 3.3\ \text{k}\Omega \| 12.61\ \Omega$

$$= \mathbf{12.56\ \Omega} \cong r_e$$

(d) $A_v = \dfrac{V_o}{V_i} = \dfrac{R_E}{R_E + r_e} = \dfrac{3.3\ \text{k}\Omega}{3.3\ \text{k}\Omega + 12.61\ \Omega}$

$$= \mathbf{0.996} \cong 1$$

(e) $A_i \cong -\dfrac{\beta R_B}{R_B + Z_b} = -\dfrac{(100)(220\ \text{k}\Omega)}{220\ \text{k}\Omega + 334.56\ \text{k}\Omega} = \mathbf{-39.67}$

versus

$$A_i = -A_v \frac{Z_i}{R_E} = -(0.996)\left(\frac{132.72\ \text{k}\Omega}{3.3\ \text{k}\Omega}\right) = \mathbf{-40.06}$$

CONTOH

(f) Checking the condition $r_o \geq 10R_E$, we have

$$25\ \text{k}\Omega \geq 10(3.3\ \text{k}\Omega) = 33\ \text{k}\Omega$$

which is *not* satisfied. Therefore,

$$Z_b = \beta r_e + \frac{(\beta+1)R_E}{1 + \dfrac{R_E}{r_o}} = (100)(12.61\ \Omega) + \frac{(100+1)3.3\ \text{k}\Omega}{1 + \dfrac{3.3\ \text{k}\Omega}{25\ \text{k}\Omega}}$$

$$= 1.261\ \text{k}\Omega + 294.43\ \text{k}\Omega$$

$$= 295.7\ \text{k}\Omega$$

with $Z_i = R_B \| Z_b = 220\ \text{k}\Omega \| 295.7\ \text{k}\Omega$

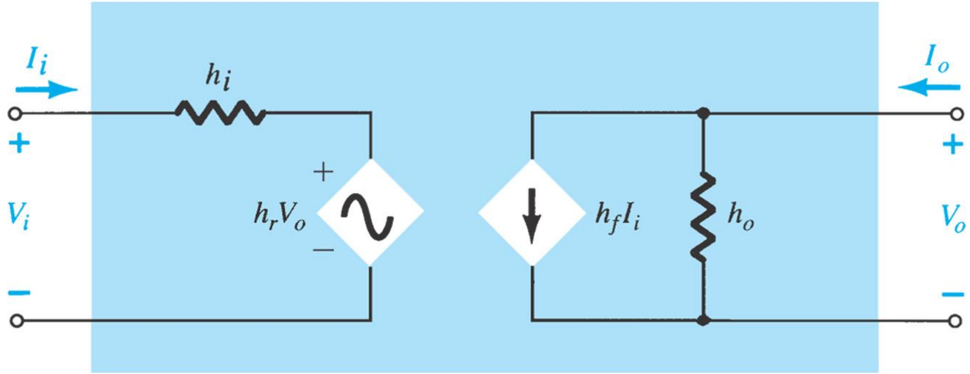
$$= \mathbf{126.15\ k\Omega}\ \text{vs. } 132.72\ \text{k}\Omega \quad \text{obtained earlier}$$

$$Z_o = R_E \| r_e = \mathbf{12.56\ \Omega} \quad \text{as obtained earlier}$$

$$A_v = \frac{(\beta+1)R_E/Z_b}{\left[1 + \dfrac{R_E}{r_o}\right]} = \frac{(100+1)(3.3\ \text{k}\Omega)/295.7\ \text{k}\Omega}{\left[1 + \dfrac{3.3\ \text{k}\Omega}{25\ \text{k}\Omega}\right]}$$

$$= \mathbf{0.996} \cong 1$$

HYBRID TRANSISTOR MODEL



- Pada jaringan dua pasang terminal (two-port network) terdapat empat variabel, yakni: arus input (*Ii*), tegangan input *(Vi)*, arus output *(Io) dan* tegangan output (*Vo*).

$$V_i = h_{11}I_i + h_{12}V_o$$

$$I_o = h_{21}I_i + h_{22}V_o$$

$\mathbf{h}_{11}$ = hi = input resistance

$\mathbf{h}_{12}$ = hr = reverse transfer voltage ratio (Vi/Vo)

$\mathbf{h}_{21}$ = hf = forward transfer current ratio (Io/Ii)

$\mathbf{h}_{22}$ = ho = output conductance

HTM ➔ h_{11}

- Apabila terminal output dibuat hubung singkat (atau *vo = 0),* maka diperoleh h_{11} .
- Perbandingan ini menunjukkan bahwa h_{11} adalah parameter impendansi dengan satuan Ohm. Karena merupakan perbandingan tegangan input dan arus input dengan terminal output dihubung singkat, maka h_{11} disebut dengan impedansi input hubung singkat.

$$\boxed{h_{11} = \left.\frac{V_i}{I_i}\right|_{V_o = 0}} \qquad \text{ohms}$$

HTM → h_{12}

- Apabila terminal input dibuka (atau *Ii = 0),* maka diperoleh h_{12}.
- Parameter h_{12} disebut dengan penguatan tegangan balik rangkaian terbuka. Karena merupakan perbandingan dua level tegangan, maka h_{12} tidak mempunyai satuan.

$$\boxed{h_{12} = \left.\frac{V_i}{V_o}\right|_{I_i = 0}} \qquad \text{unitless}$$

HTM ➔ h_{21}

- Parameter h_{21} diperoleh dengan cara menghubung singkatkan terminal output (atau vo= 0).
- Parameter h21 yang merupakan perbandingan arus output dan arus input dengan terminal output hubung singkat disebut dengan penguatan arus maju hubung singkat. Karena merupakan perbandingan dua level arus, maka h21 tidak mempunyai satuan.

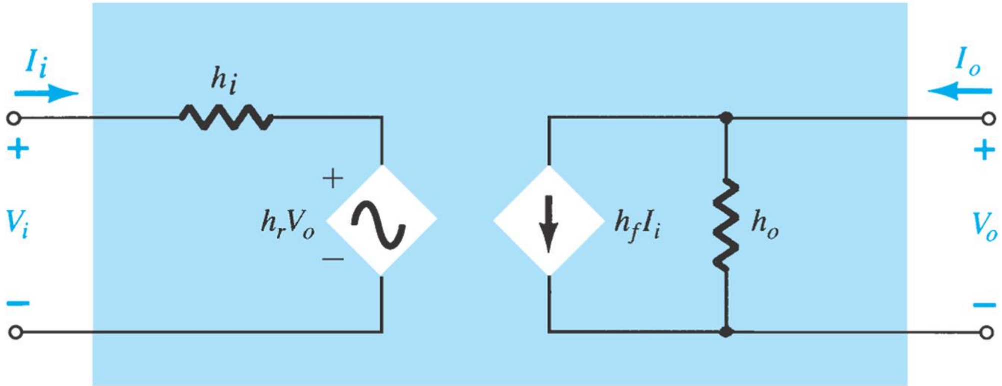
$$h_{21} = \left.\frac{I_o}{I_i}\right|_{V_o=0}$$ unitless

HTM → h_{22}

- Parameter h22 yang diperoleh dengan membuka terminal input (atau Ii= 0),
- Paramater h22 disebut konduktansi output rangkaian terbuka dengan satuan siemen atau mho.

$$\boxed{h_{22} = \left.\frac{I_o}{V_o}\right|_{I_i=0}} \qquad \text{siemens}$$

HYBRID TRANSISTOR MODEL



$$v_i = h_i i_i + h_r v_o$$

$$i_o = h_f i_i + h_o v_o$$

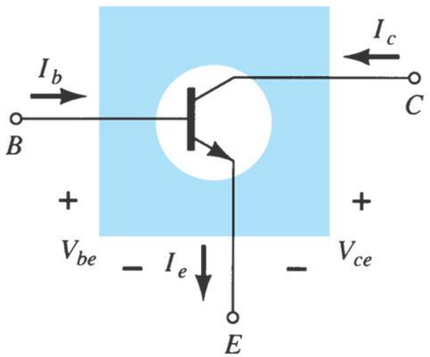
$h_{11} \Rightarrow h_i \Rightarrow$ Resistansi input dari transistor

$h_{12} \Rightarrow h_r \Rightarrow$ Penguatan tegangan balik dari transistor

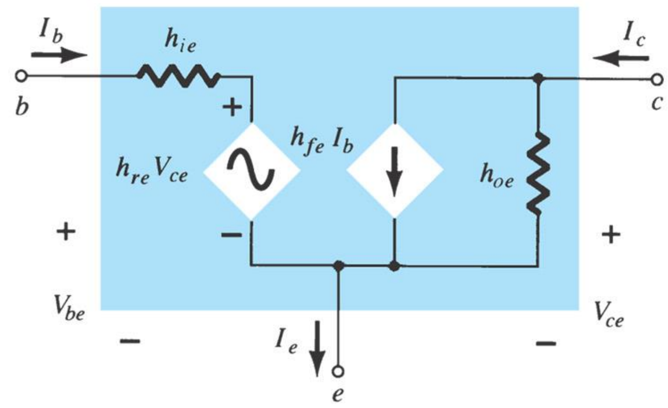
$h_{21} \Rightarrow h_f \Rightarrow$ Penguatan arus maju dari transistor

$h_{22} \Rightarrow h_o \Rightarrow$ Konduktansi output dari transistor

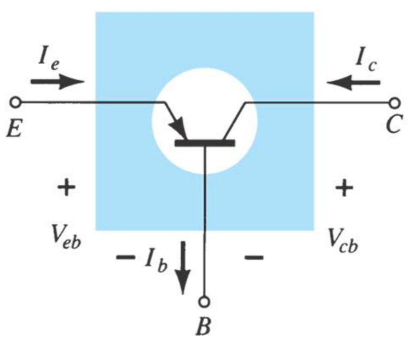
HYBRID TRANSISTOR MODEL



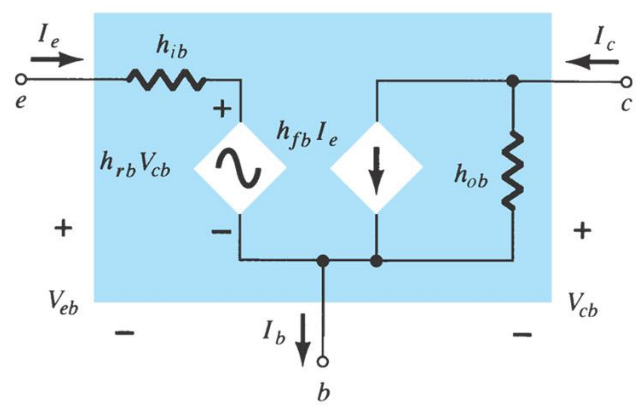
(a)



(b)

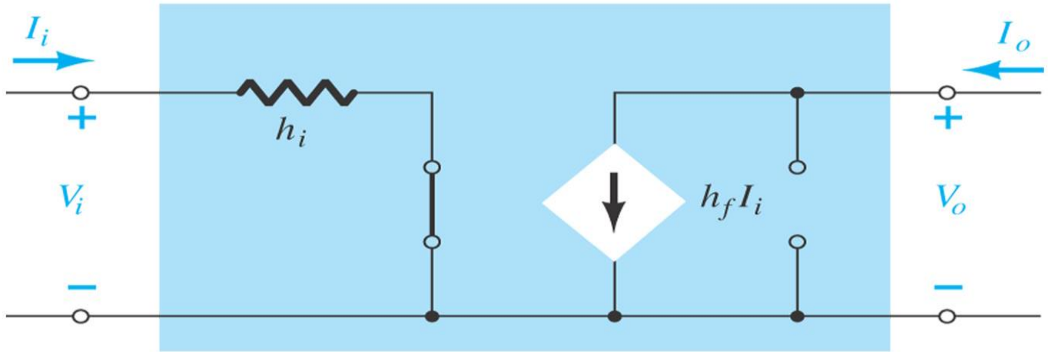


(a)

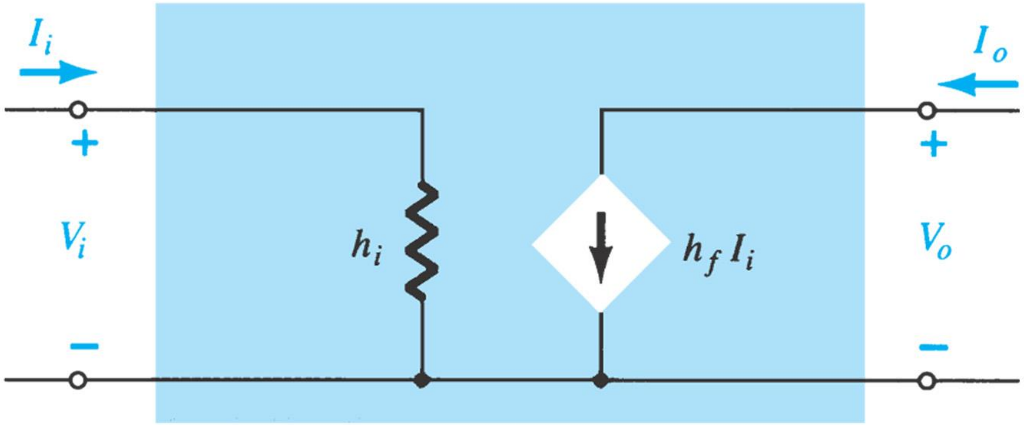


(b)

HYBRID TRANSISTOR MODEL

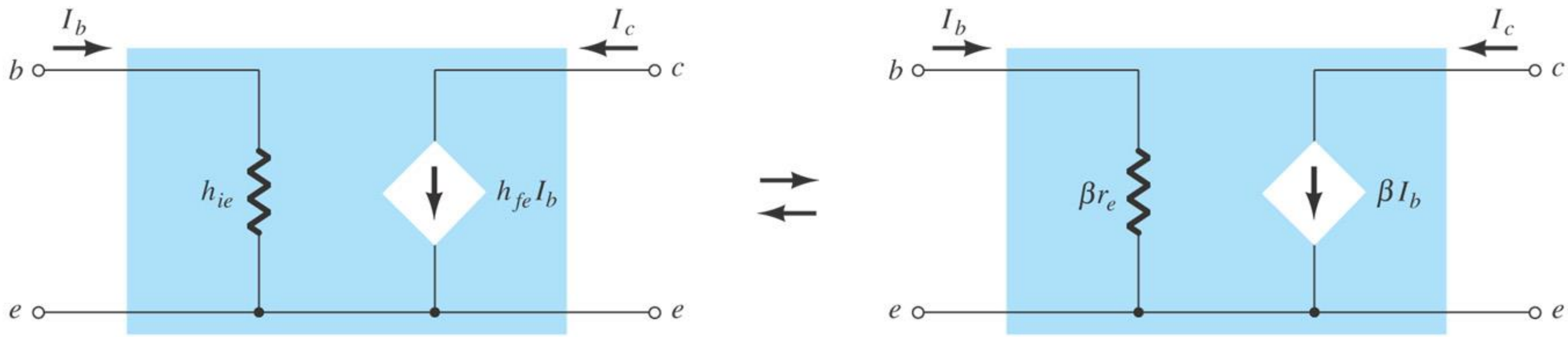


Effect of removing h_{re} and h_{oe} from the hybird equivalent circuit.

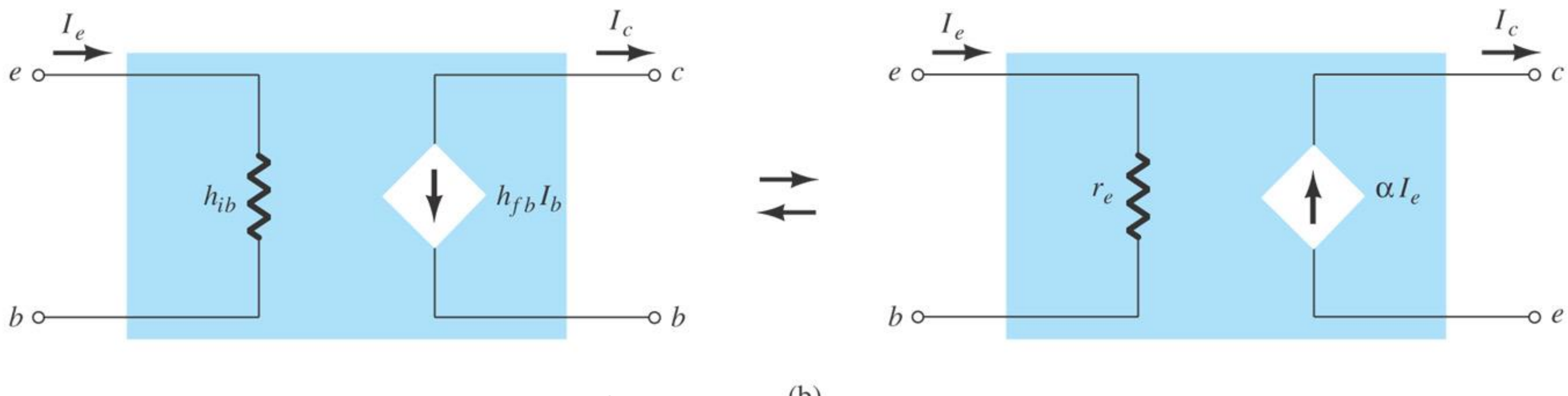


Approximate hybrid equivalent model.

Common-Emitter re vs. h-Parameter Model

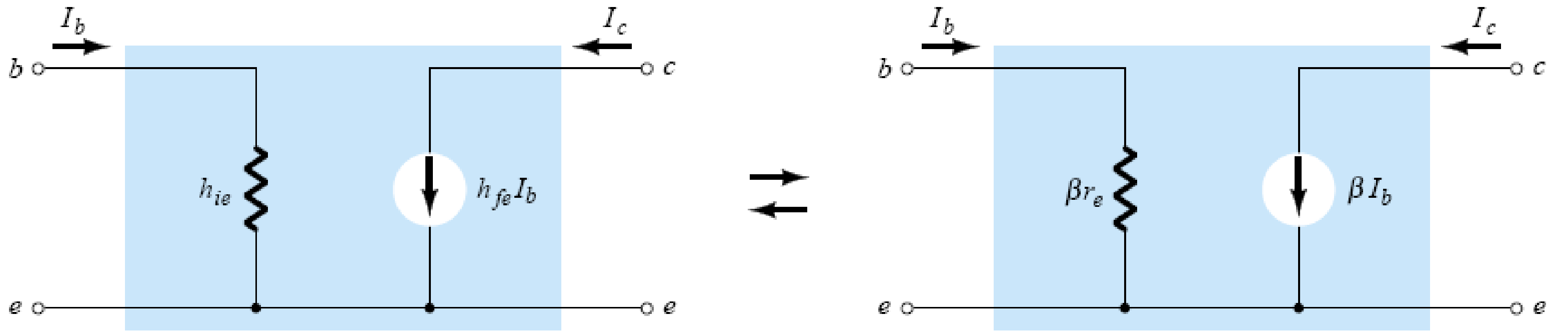


Konfigurasi Common Emitter



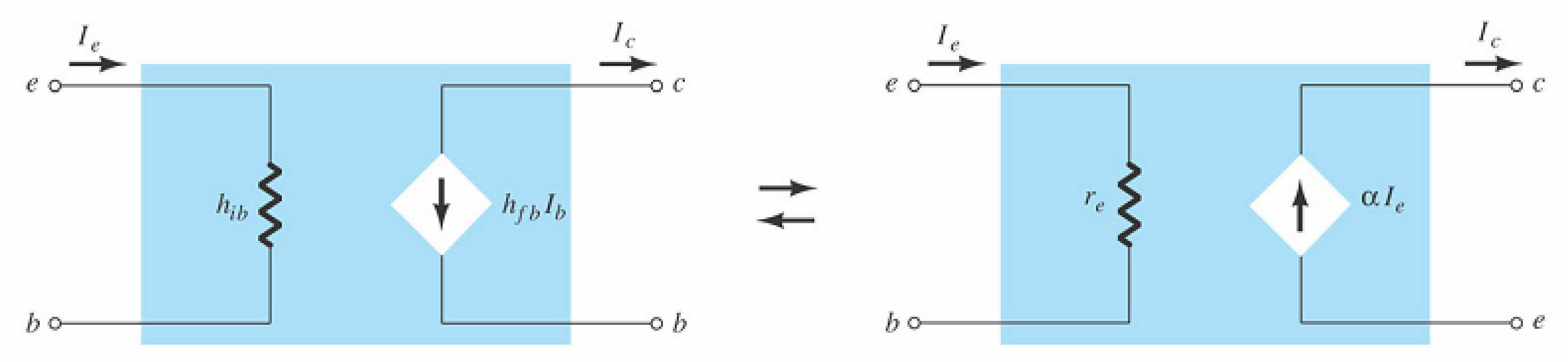
Konfigurasi Common Base

HYBRID TRANSISTOR MODEL



$$h_{ie} = \beta r_e$$

$$h_{fe} = \beta_{ac}$$



$$h_{ib} = r_e$$

$$h_{fb} = -\alpha \cong -1$$

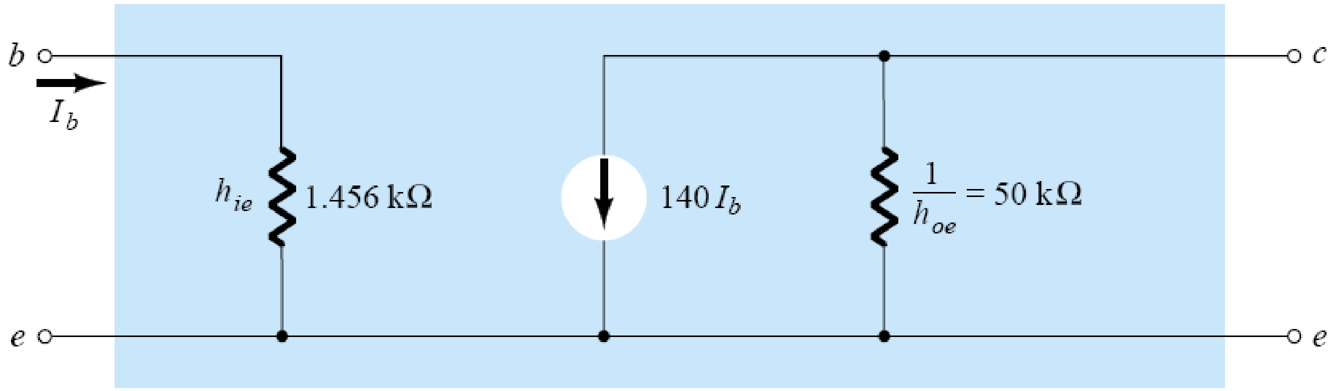
CONTOH

Given $I_E = 2.5$ mA, $h_{fe} = 140$, $h_{oe} = 20\ \mu$S (μmho), and $h_{ob} = 0.5\ \mu$S, determine:
(a) The common-emitter hybrid equivalent circuit.
(b) The common-base r_e model.

$$\text{(a)}\quad r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{2.5\text{ mA}} = 10.4\ \Omega$$

$$h_{ie} = \beta r_e = (140)(10.4\ \Omega) = \mathbf{1.456\ k\Omega}$$

$$r_o = \frac{1}{h_{oe}} = \frac{1}{20\ \mu\text{S}} = 50\text{ k}\Omega$$

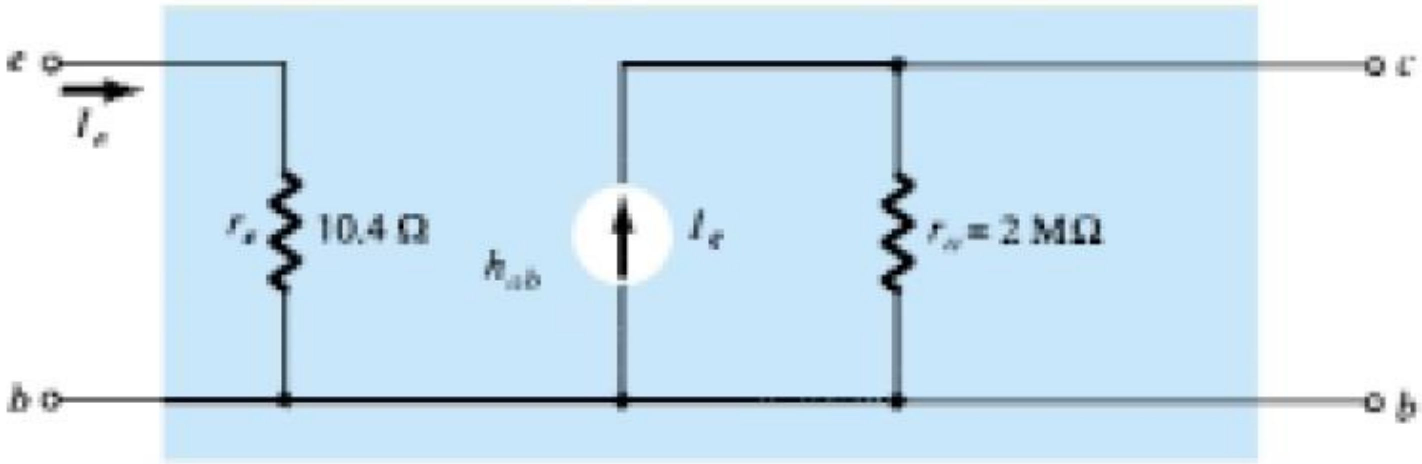


CONTOH

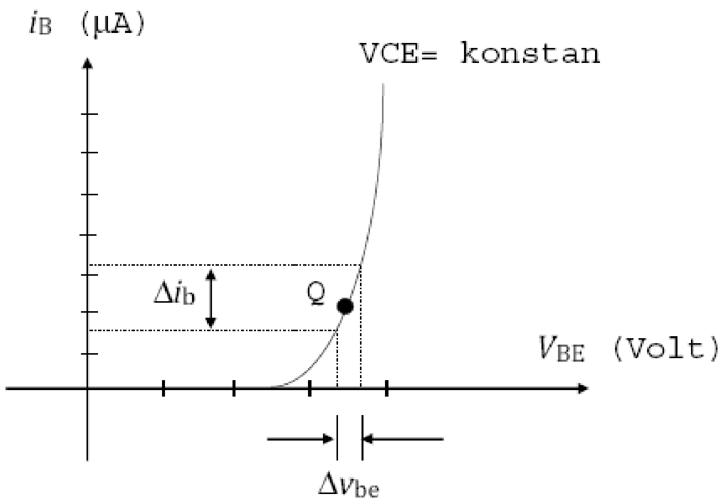
Given $I_E = 2.5$ mA, $h_{fe} = 140$, $h_{oe} = 20\ \mu$S (μmho), and $h_{ob} = 0.5\ \mu$S, determine:
(a) The common-emitter hybrid equivalent circuit.
(b) The common-base r_e model.

(b) $r_e = \mathbf{10.4\ \Omega}$

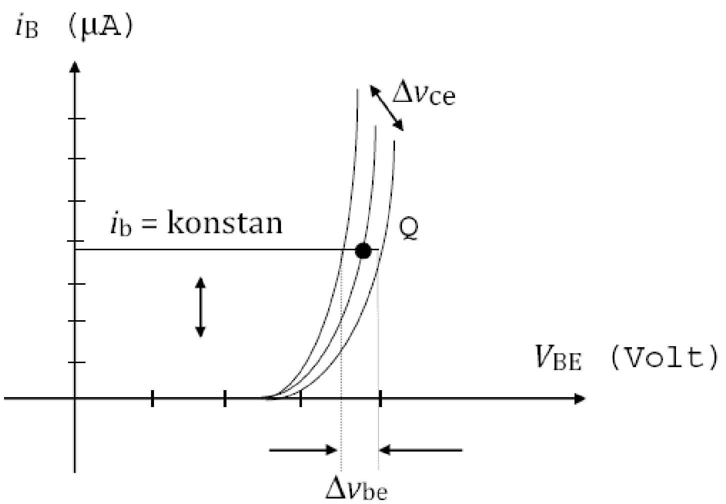
$$\alpha \cong 1, \qquad r_o = \frac{1}{h_{ob}} = \frac{1}{0.5\ \mu\text{S}} = \mathbf{2\ M\Omega}$$



PARAMETER H

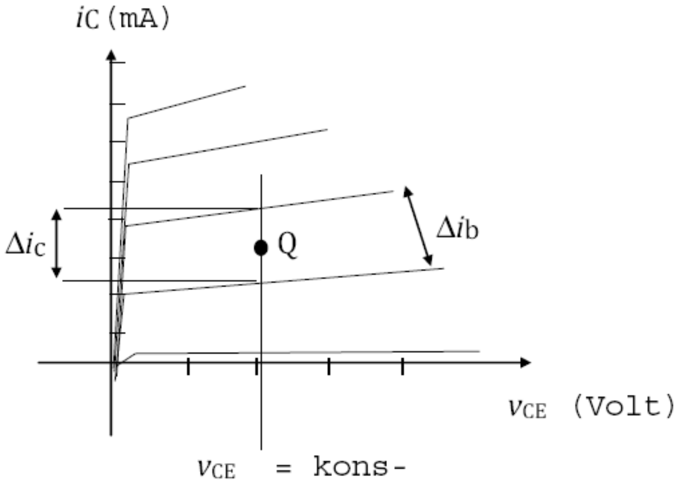


$$h_{ie} \cong \left.\frac{\Delta v_{be}}{\Delta i_b}\right|_{v_{CE}=0} \quad \text{(Ohm)}$$

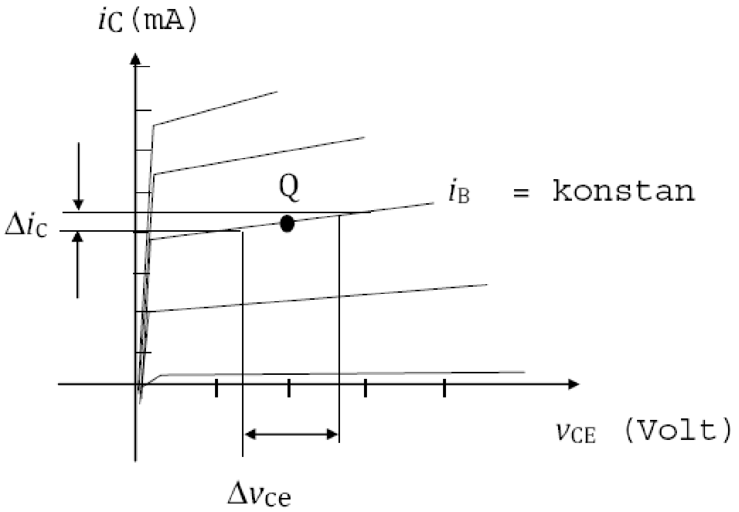


$$h_{re} \cong \left.\frac{\Delta v_{be}}{v_{ce}}\right|_{i_B=0} \quad \text{(tanpa satuan)}$$

PARAMETER H



$$h_{fe} \cong \left.\frac{\Delta i_c}{\Delta i_b}\right|_{v_{CE}=0} \quad \text{(tanpa satuan)}$$



$$h_{oe} \cong \left.\frac{\Delta i_c}{\Delta v_{ce}}\right|_{i_B=0} \quad \text{(Siemen)}$$

PAREMETER H

Parameter	CE	CC	CB
h_i	1 KΩ	1 KΩ	20 Ω
h_r	2.5×10^{-4}	$\cong 1$	3.0×10^{-4}
h_f	50	- 50	- 0.98
h_o	25 μA/V	25 μA/V	0.5 μA/V
$1/h_o$	40 KΩ	40 KΩ	2 MΩ

Parameter hr untuk CE dan CB bernilai sangat kecil, sehingga dalam berbagai analisa praktis parameter hr ini sering diabaikan, yakni dianggap nol.

Parameter ho untuk semua konfigurasi transistor berharga sangat kecil, sehingga dalam berbagai analisa praktis parameter ho ini sering diabaikan atau dianggap nol.

PARAMETER H

Konversi dari CE ke CC

$h_{ic} = h_{ie}$ $\qquad$ $h_{rc} = 1$

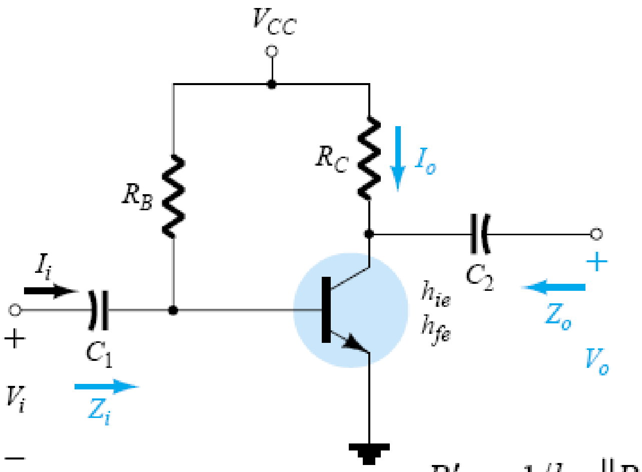
$h_{fc} = -(1 + h_{fe})$ $\qquad$ $h_{oc} = h_{oe}$

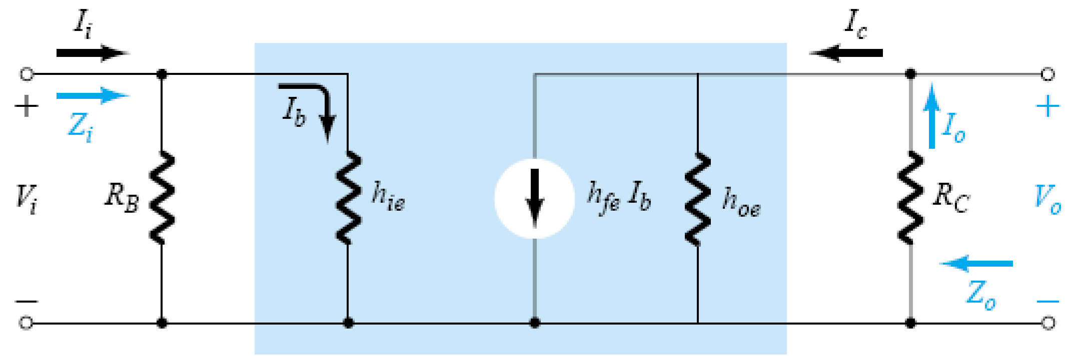
Konversi dari CE ke CB

$$h_{ib} = \frac{h_{ie}}{1 + h_{fe}} \qquad h_{rb} = \frac{h_{ie}\,h_{oe}}{1 + h_{fe}} - h_{re}$$

$$h_{ib} = -\frac{h_{fe}}{1 + h_{fe}} \qquad h_{ob} = \frac{h_{oe}}{1 + h_{fe}}$$

Fixed-Bias Configuration → CE





$$R' = 1/h_{oe} \| R_C,$$

$$R_B \gg h_{ie} \text{ and } 1/h_{oe} \geq 10R_C,$$

$$\boxed{Z_i = R_B \| h_{ie}}$$

$$\boxed{Z_o = R_C \| 1/h_{oe}}$$

$$V_o = -I_o R' = -I_C R'$$
$$= -h_{fe} I_b R'$$
$$I_b = \frac{V_i}{h_{ie}}$$
$$V_o = -h_{fe} \frac{V_i}{h_{ie}} R'$$

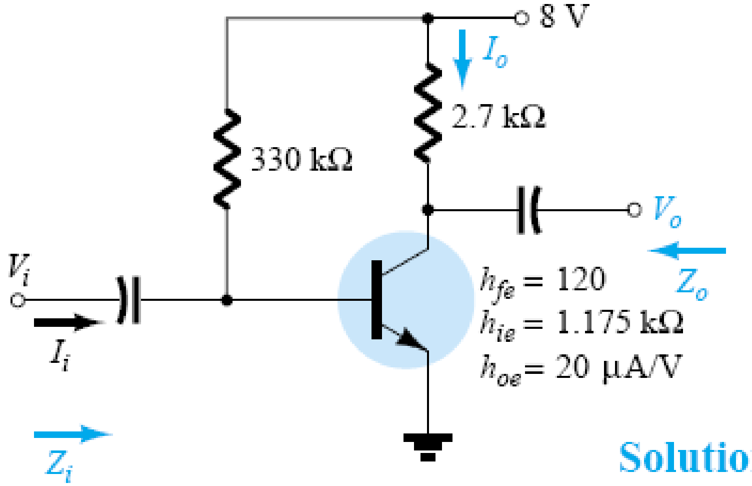
$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{h_{fe}(R_C \| 1/h_{oe})}{h_{ie}}}$$

$$I_b \cong I_i$$

$$I_o = I_c = h_{fe} I_b = h_{fe} I_i$$

$$\boxed{A_i = \frac{I_o}{I_i} \cong h_{fe}}$$

CONTOH



(a) Z_i.
(b) Z_o.
(c) A_v.
(d) A_i.

Solution

(a) $Z_i = R_B \| h_{ie} = 330\ \text{k}\Omega \| 1.175\ \text{k}\Omega$

$\cong h_{ie} = \mathbf{1.171\ k\Omega}$

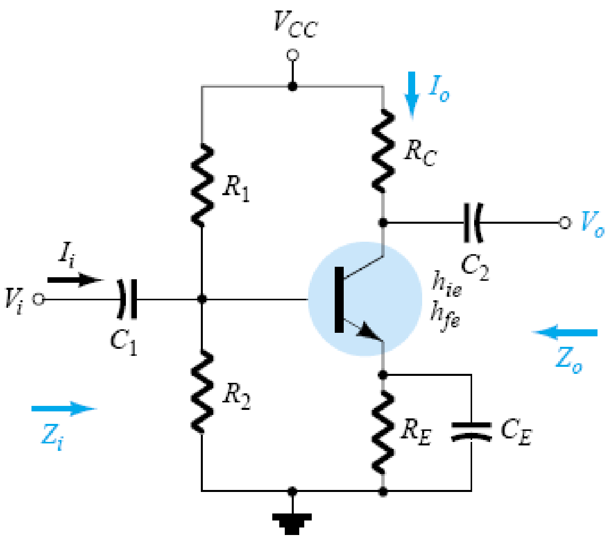
(b) $r_o = \dfrac{1}{h_{oe}} = \dfrac{1}{20\ \mu\text{A/V}} = 50\ \text{k}\Omega$

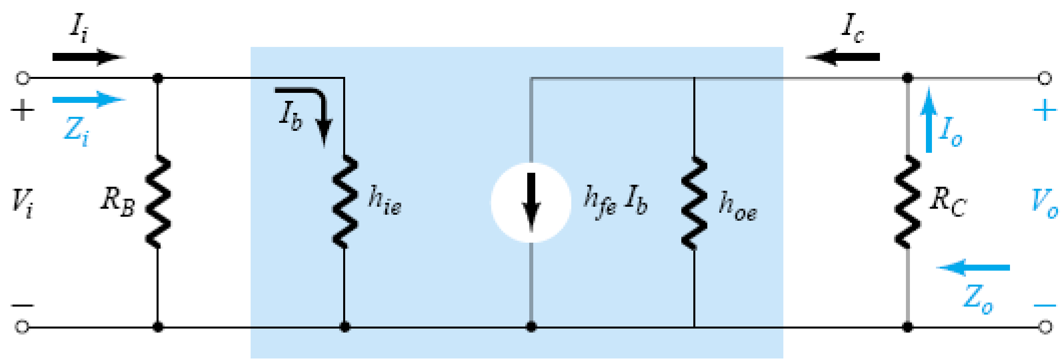
$Z_o = \dfrac{1}{h_{oe}} \| R_C = 50\ \text{k}\Omega \| 2.7\ \text{k}\Omega = \mathbf{2.56\ k\Omega} \cong R_C$

(c) $Av = -\dfrac{h_{fe}(R_C \| 1/h_{oe})}{h_{ie}} = -\dfrac{(120)(2.7\ \text{k}\Omega \| 50\ \text{k}\Omega)}{1.171\ \text{k}\Omega} = \mathbf{-262.34}$

(d) $A_i \cong h_{fe} = 120$

Voltage-Divider Configuration➔ CE





$R_B = R'$,

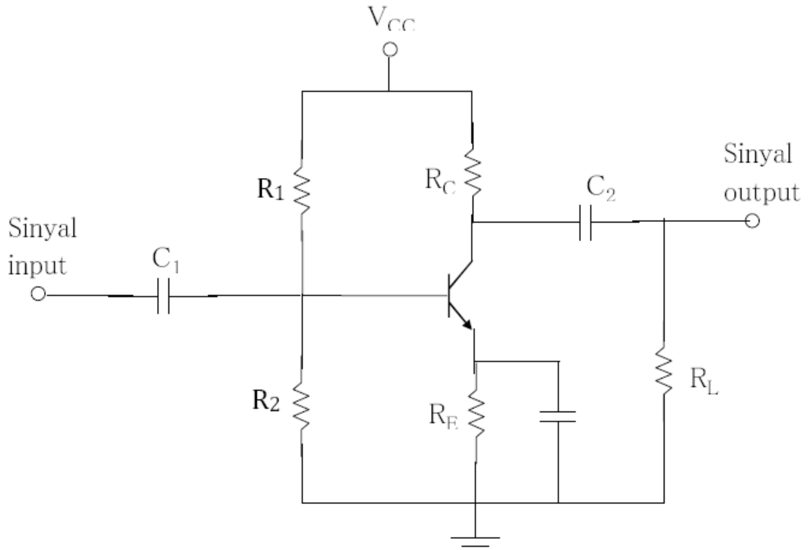
$$\boxed{Z_i = R' \| h_{ie}}$$

$$\boxed{Z_o \cong R_C}$$

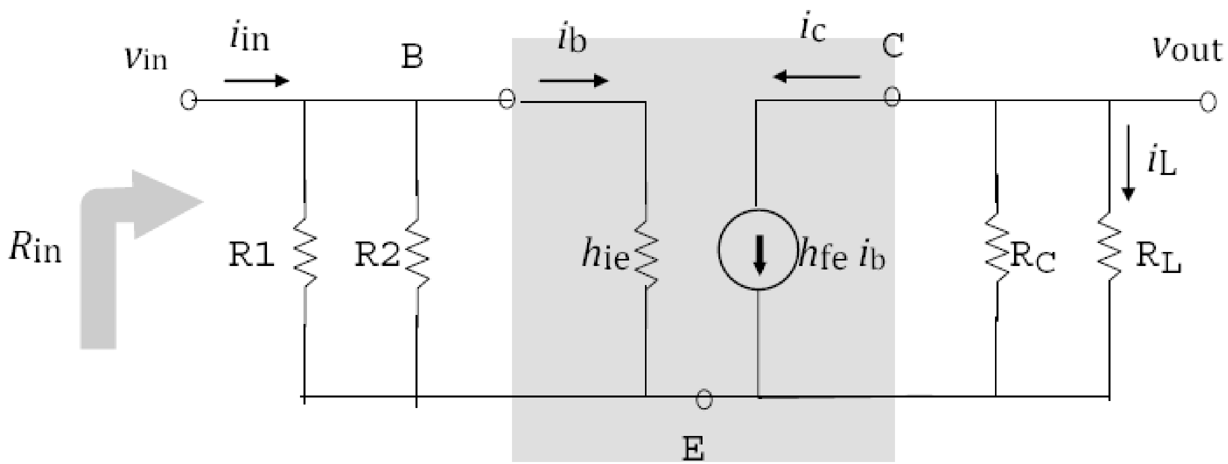
$$\boxed{A_v = -\frac{h_{fe}(R_C \| 1/h_{oe})}{h_{ie}}}$$

$$\boxed{A_i = -\frac{h_{fe} R'}{R' + h_{ie}}}$$

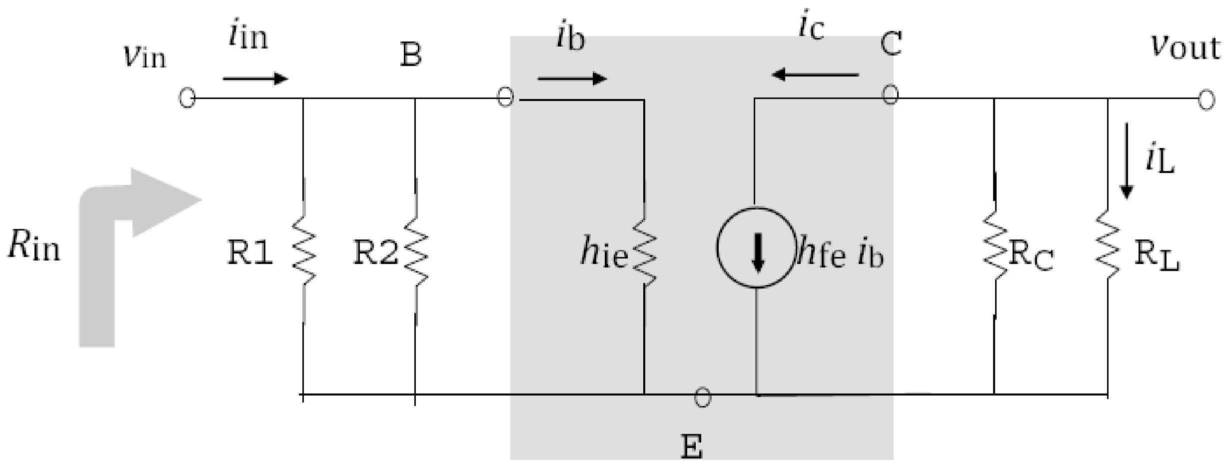
HTM ➔ PENGUAT CE



Harga tipikal parameter hre dan hoe sangat kecil, sehingga dalam berbagai analisa kedua parameter-h tersebut sering diabaikan atau dianggap nol.



HTM ➔ PENGUAT CE



$$R_{in} = \frac{v_{in}}{i_{in}}$$

$$R_{in} = \frac{i_{in}\ (R1 \| R2 \| h_{ie})}{i_{in}}$$

$$R_{in} = (R_B \| h_{ie})$$

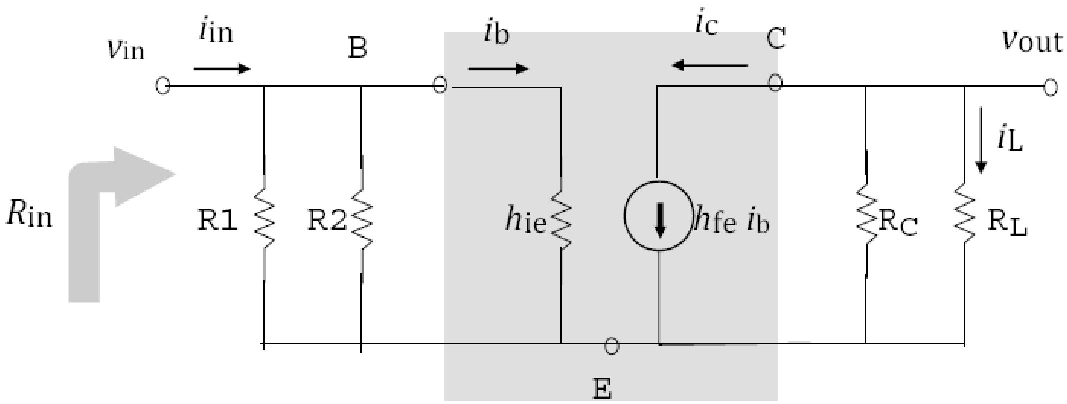
$$A_v = \frac{v_{out}}{v_{in}}$$

$$A_v = \frac{-\ i_c\ (R_C \| R_L)}{i_b\ h_{ie}}$$

$$A_v = \frac{-\ h_{fe}\ i_b\ (R_C \| R_L)}{i_b\ h_{ie}}$$

$$A_v = -\frac{h_{fe}\ (R_C \| R_L)}{h_{ie}}$$

HTM → PENGUAT CE



$$RB = \frac{R1 \cdot R2}{R1 + R2}$$

$$Ai = \frac{i_L}{i_{in}}$$

$$Ai = \frac{-\,i_C\ RC/(RC + RL)}{i_{in}}$$

$$Ai = \frac{-\,i_C\ RC}{i_{in}\,(RC + RL)}$$

$$Ai = \frac{-\,(h_{fe}\, i_b)}{i_{in}} \quad \frac{RC}{(RC + RL)}$$

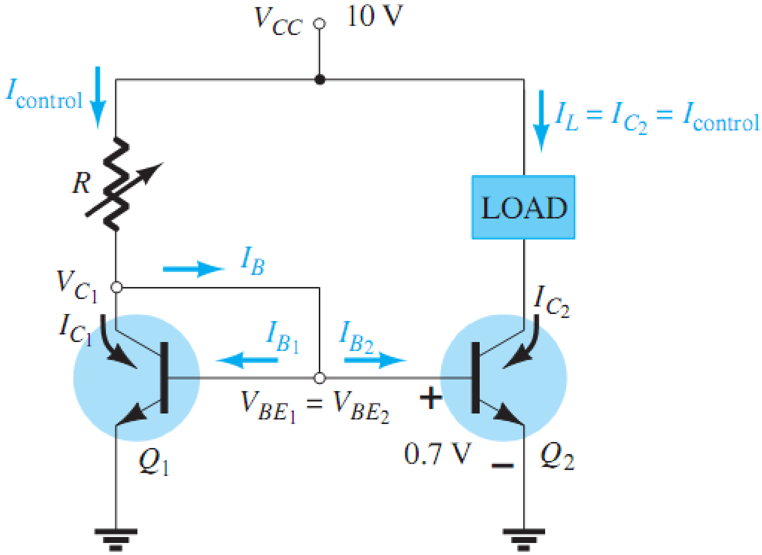
$$i_b = i_{in}\ RB/(RB + h_{ie})$$

$$i_{in} = i_b\ (RB + h_{ie})/RB$$

$$Ai = \frac{-\,(h_{fe}\, i_b)}{i_b\ (RB + h_{ie})/RB} \quad \frac{RC}{(RC + RL)}$$

$$Ai = -\,\frac{h_{fe}\ RB}{(RB + h_{ie})} \quad \frac{RC}{(RC + RL)}$$

CURRENT MIRROR



$$I_{\text{control}} = I_{C_1} + I_B = I_{C_1} + 2I_{B_1}$$

$$I_{C_1} = \beta_1 I_{B_1}$$

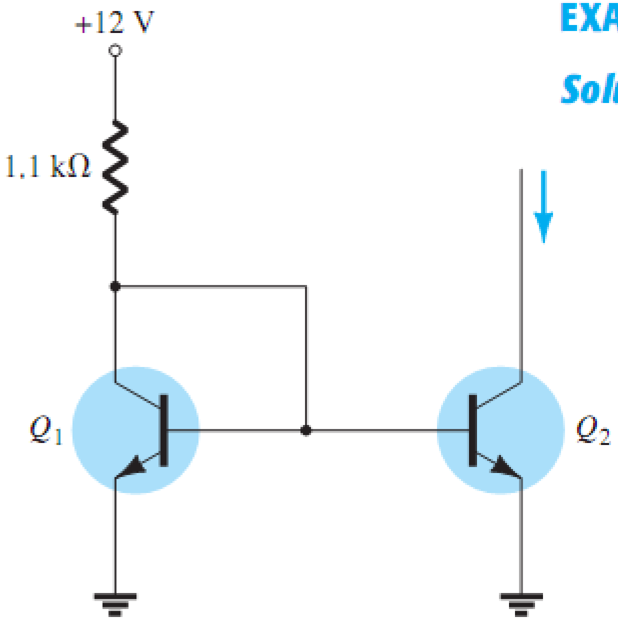
$$I_{\text{control}} = \beta_1 I_{B_1} + 2I_{B_1} = (\beta_1 + 2)I_{B_1}$$

$$I_{\text{control}} \cong \beta_1 I_{B_1}$$

$$\boxed{I_{B_1} = \frac{I_{\text{control}}}{\beta_1}}$$

$$\boxed{I_{\text{control}} = \frac{V_{CC} - V_{BE}}{R}}$$

Contoh



EXAMPLE 4.27 Calculate the mirrored current I in the circuit of Fig. 4.76.

Solution: Eq. (4.75):

$$I = I_{\text{control}} = \frac{V_{CC} - V_{BE}}{R} = \frac{12\text{ V} - 0.7\text{ V}}{1.1\text{ k}\Omega} = \mathbf{10.27\ mA}$$

CONTOH

EXAMPLE 4.28 Calculate the current I through each of the transistor Q_2 and Q_3 in the circuit of Fig. 4.77.

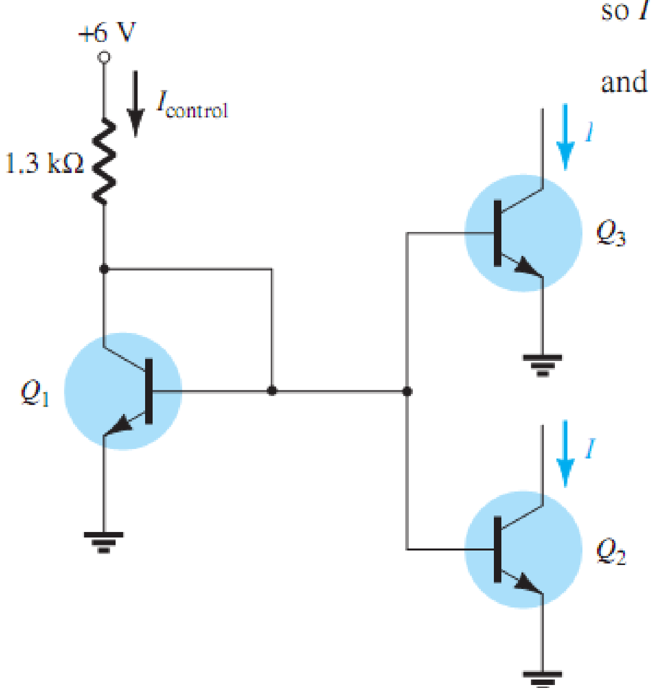
Solution: Since $V_{BE_1} = V_{BE_2} = V_{BE_3}$ then $I_{B_1} = I_{B_2} = I_{B_3}$

Substituting $I_{B_1} = \dfrac{I_{\text{control}}}{\beta}$ and $I_{B_2} = \dfrac{I}{\beta}$ with $I_{B_3} = \dfrac{I}{\beta}$

we have
$$\frac{I_{\text{control}}}{\beta} = \frac{I}{\beta} = \frac{I}{\beta}$$

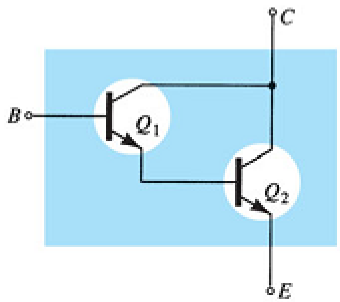
so I must equal I_{control}

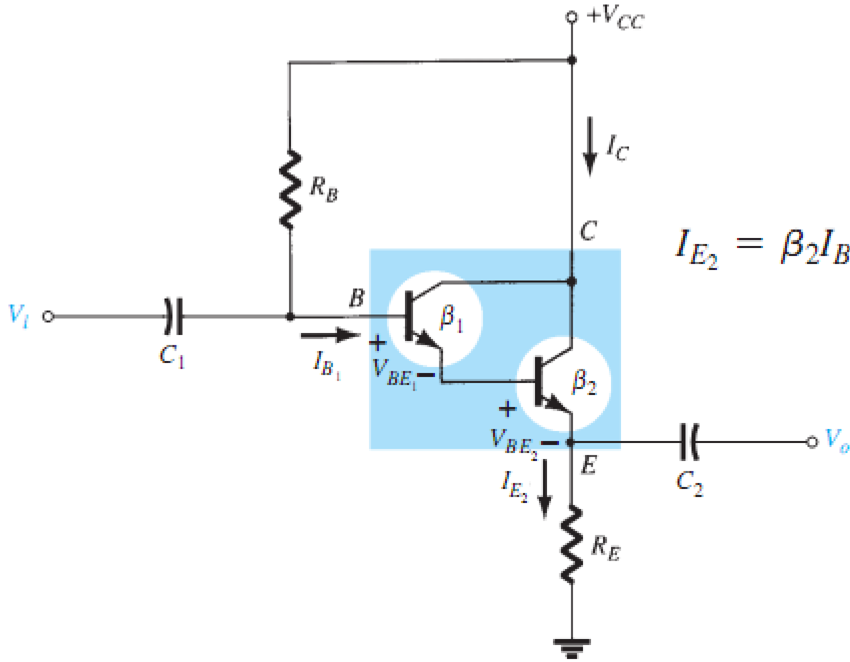
and
$$I_{\text{control}} = \frac{V_{CC} - V_{BE}}{R} = \frac{6\text{ V} - 0.7\text{ V}}{1.3\text{ k}\Omega} = \mathbf{4.08\text{ mA}}$$



DARLINGTON

$$\beta_D = \beta_1 \beta_2$$





$$I_{B_1} = \frac{V_{CC} - V_{BE_1} - V_{BE_2}}{R_B + \beta_D R_E}$$

$$I_{E_2} = \beta_2 I_{B_2} = \beta_2 I_{E_1} = \beta_2(\beta_1 I_{E_1}) = \beta_1 \beta_2 I_{B_1}$$

$$I_{C_2} \cong I_{E_2} = \beta_D I_{B_1}$$

$$V_{C_1} = V_{C_2} = V_{CC}$$

$$V_{E_2} = I_{E_2} R_E$$

$$V_{B_1} = V_{CC} - I_{B_1} R_B = V_{E_2} + V_{BE_1} + V_{BE_2}$$

$$V_{CE_2} = V_{C_2} - V_{E_2} = V_{CC} - V_{E_2}$$