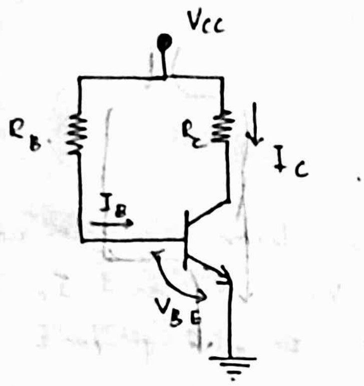
24/11/2021

Module - 1

Biasing

1. Fixed bias circuit



Input Loop:

Applying KVL for input loop.

$$V_{CC} - I_B R_B - V_{BE} = 0$$

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

Once R_B is selected, I_B is fixed.
Hence the name fixed bias circuit

Output Loop:

Applying KVL for output loop.

$$V_{CC} - I_C R_C - V_{BE} = 0$$

$$V_{CE} = V_{CC} - I_C R_C$$

Q point is given by I_C and V_{CE}.

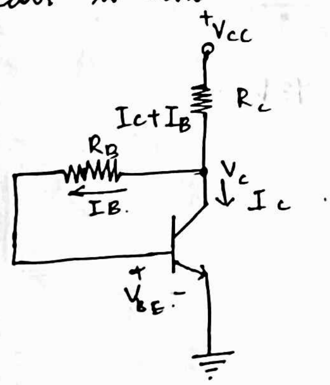
$$V_{CE} = V_C - V_E, \text{ since } V_E = 0$$

$$V_{CE} = V_C$$

$$V_{BE} = V_B - V_E, \text{ since } V_E = 0$$

$$V_{BE} = V_B$$

2. Collector to base bias circuit



Input Loop

Applying KVL.

$$V_{CC} - (I_C + I_B) R_C - I_B R_B - V_{BE} = 0$$

$$V_{CC} - V_{BE} = (\beta I_B + I_B) R_C + I_B R_B$$

$$I_B(\beta + 1) R_C + I_B R_B = V_{CC} - V_{BE}$$

$$I_B = \frac{V_{CC} - V_{BE}}{(1+\beta) R_C + R_B}$$

$$R_B << (1+\beta) R_C$$

$$I_B = \frac{V_{CC} - V_{BE}}{(1+\beta) R_C}$$

$$\beta + 1 \approx \beta$$

$$I_B = \frac{V_{CC} - V_{BE}}{\beta R_C}$$

$\therefore\ I_c \approx \frac{V_{cc} - V_{BE}}{R_c}$

collector current is independent of β.

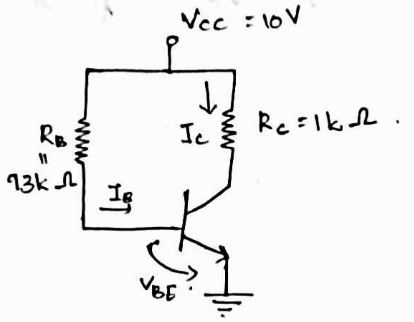
Output loop

Applying KVL.

$$V_{cc} - (I_c + I_B)R_c - V_{CE} = 0$$

$$V_{CE} = V_{cc} - (I_c + I_B)R_c$$

Qn 1) Design a fixed bias circuit using a silicon transistor with $\beta = 50$, $V_{cc} = 10V$, and dc bias conditions are $V_{CE} = 5V$ and $I_c = 5mA$. Also calculate the operating point when $\beta = 25$ and $\beta = 100$.



Input loop apply KVL.

$$V_{cc} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{V_{cc} - V_{BE}}{R_B}$$

$$\therefore R_B = \frac{V_{cc} - V_{BE}}{I_B}$$

Since silicon $V_{BE} = 0.7V$

$V_{cc} = 10V$

$I_c = 5 \times 10^{-3} A$

$\beta = 50$

$$\therefore I_B = \frac{I_c}{\beta} = \frac{5 \times 10^{-3}}{50} = 10^{-4} A$$

$$R_B = \frac{10 - 0.7}{10^{-4}}$$

$$= 93k\Omega$$

Output loop KVL.

$$V_{cc} - I_c R_c - V_{CE} = 0$$

$$V_{cc} - V_{CE} = I_c R_c$$

$$R_c = \frac{V_{cc} - V_{CE}}{I_c} = \frac{10 - 5}{5 \times 10^{-3}} = \underline{\underline{1k\Omega}}$$

when $\beta = 25$

Input KVL. $V_{cc} - I_B R_B - V_{BE} = 0$

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

$$= \frac{10 - 0.7}{93 \times 10^3}$$

$$= \cancel{10^{-4} A \; 100 A} \quad 10^{-4} A$$

$$I_C = \beta I_B = 25 \times 10^{-4}$$

$$= \underline{\underline{2.5 \text{ mA}}}$$

Output KVL.

$$V_{CC} - V_{CE} - I_C R_C = 0$$

$$V_{CE} = V_{CC} - I_C R_C$$

$$= 10 - 2.5 \times 10^{-3} \times 10^3$$

$$= \underline{\underline{7.5 \text{ V}}}$$

when $\beta = 100$

Input KVL

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10 - 0.7}{93 \times 10^3} = 10^{-4} A$$

$$I_C = \beta I_B = 100 \times 10^{-4} = 0.01 \text{ A}$$

Output KVL.

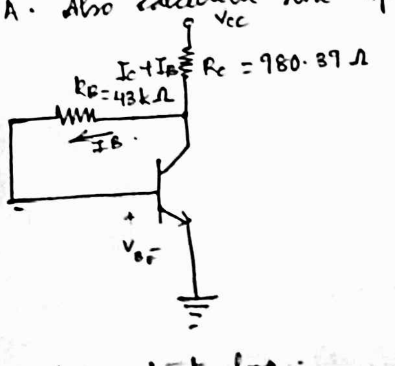
$$V_{CC} - V_{CE} - I_C R_C = 0$$

$$V_{CE} = V_{CC} - I_C R_C$$

$$= 10 - 0.01 \times 10^3$$

$$= \underline{\underline{0 \text{V}}}$$

Qn 2) Design a collector to base bias circuit using a silicon transistor with $\beta = 50$, $V_{CC} = 10V$ and dc bias condition $V_{CE} = 5V$ and $I_C = 5$ mA. Also calculate the operating point when $\beta = 25$ and $\beta = 100$.



$\beta = 50$.

$V_{CC} = 10V$.

$V_{CE} = 5V$

$I_C = 5 \times 10^{-3} A$.

$I_B = \frac{I_C}{\beta} = 10^{-4} A$.

KVL for output loop.

$$V_{CC} - (I_C + I_B) R_C - V_{CE} = 0.$$

$$\frac{V_{CC} - V_{CE}}{I_C + I_B} = R_C$$

$$R_C = \frac{10 - 5}{10^{-4} + 5 \times 10^{-3}} = \frac{5}{10^{-4} + 5 \times 10^{-3}} = 980.39 \, \Omega$$

Input loop KVL.

$$I_B = \frac{V_{cc} - V_{BE}}{R_B + (1+\beta)R_c}.$$

$$10^{-4} = \frac{10 - 0.7}{R_B + 51 \times 980.39}$$

$$10^{-4}(R_B + 50000) = 9.3$$

$$R_B \times 10^{-4} + 5 = 9.3$$

$$R_B = \underline{\underline{43k\Omega}}$$

when $\beta = 25$.

Input

$$I_B = \frac{V_{cc} - V_{BE}}{R_B + (1+\beta)R_c}.$$

$$I_B = \frac{10 - 0.7}{43000 + 26 \times 980.39}$$

$$= \underline{\underline{1.35 \times 10^{-4} A}}$$

$$I_c = \beta I_B = 25 \times 1.35 \times 10^{-4}$$

$$= \underline{\underline{3.394 \times 10^{-3} A}}$$

Output

$$V_{CE} = V_{cc} - (I_B + I_c)R_c$$

$$= 10 - (1.35 \times 10^{-4} + 3.39 \times 10^{-3}) \times 980.39$$

$$= \underline{\underline{6.54\ V}}.$$

When $\beta = 100$

Input

$$I_B = \frac{V_{cc} - V_{BE}}{R_B + (1+\beta)R_c}$$

$$= \frac{10 - 0.7}{43000 + 101 \times 980.39}$$

$$= \underline{\underline{6.54 \times 10^{-5} A}}$$

$$I_c = \beta I_B$$

$$= 100 \times 6.54 \times 10^{-5}$$

$$= \underline{\underline{6.54 \times 10^{-2} A}}.$$

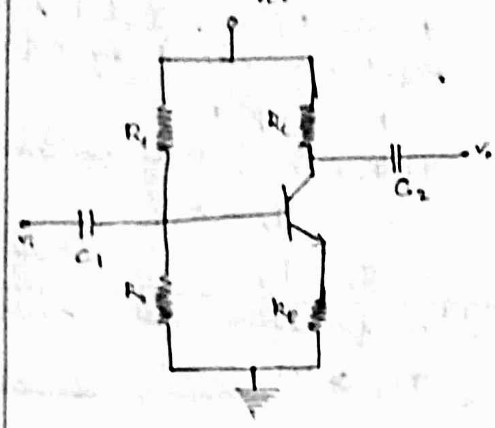
Output.

$$V_{CE} = V_{cc} - (I_B + I_c)R_c$$

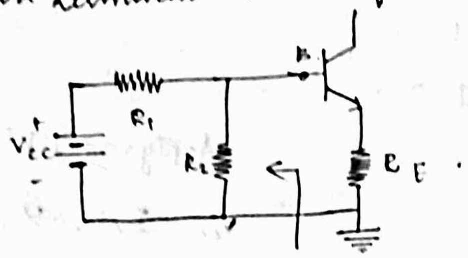
$$= 10 - (6.54 \times 10^{-5} + 6.54 \times 10^{-3}) \times 980.39$$

$$= \underline{\underline{8.515V}}$$

3) Voltage divider biasing

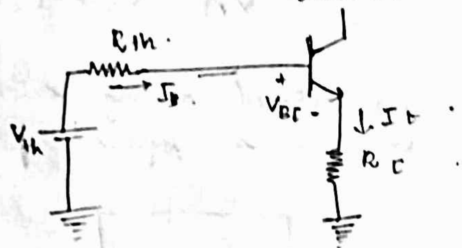


Exact Analysis
The Thevenin equivalent network for the network to the left of the base terminal can be found.

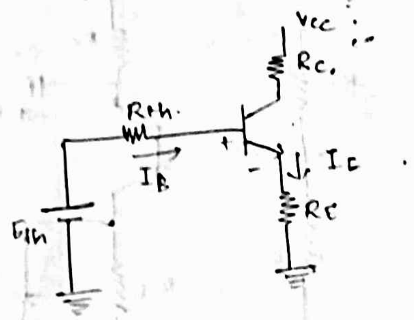


$$E_{Th} = V_{Th} = V_{CC}\frac{R_2}{R_1+R_2}.$$

Thevenin



$$R_{Th} = \frac{R_1 R_2}{R_1+R_2}.$$



Exact analysis

Input loop

Applying KVL

$$E_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

$$E_{Th} - I_B R_{Th} - V_{BE} - (I_C + I_B) R_E = 0$$

$$E_{Th} - I_B R_{Th} - V_{BE} - (\beta I_B + I_B) R_E = 0$$

$$E_{Th} - I_B R_{Th} - V_{BE} - (\beta+1) I_B R_E = 0$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (1+\beta)R_E}$$

$$I_C = \beta I_B$$

Output loop

Applying KVL.

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

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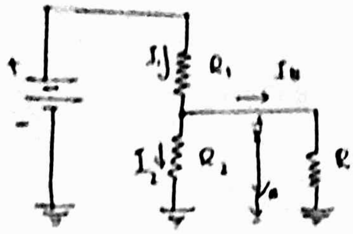


Approximate Analysis

Resistor R_E is reflected back to the input base circuit by a factor $(1+\beta)$

$R_i = (1+\beta) R_E$

If $R_i >> R_2$, then we can approximate $I_B = 0$

$\therefore I_1 = I_2$

$\boxed{\text{condition for approximate analysis} \quad \beta R_E \geq 10 R_2}$

$V_B = V_{CC} \frac{R_2}{R_1 + R_2}$

$V_E = V_B - V_{BE}$

$I_E = \frac{V_E}{R_E}$

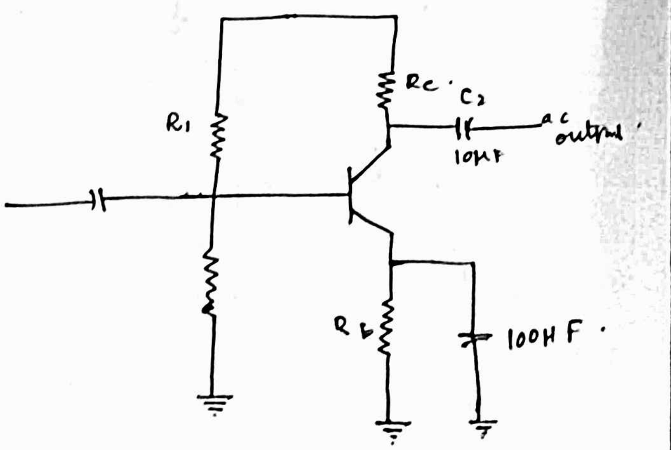
$I_C \cong I_E$

Applying KVL for output loop

$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

$V_{CE} = V_{CC} - I_C (R_C + R_E)$

Qn 1) Design a voltage divider biasing circuit using a supply of 20 V, a transistor with $\beta = 80$ and an operating point $I_C = 10mA$ and $V_{CE} = 8V$

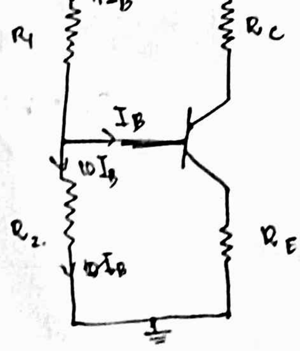


$V_{CC} = 20V$

$\beta = 80$

$I_C = 10 \times 10^{-3} A$

$V_{CE} = 8V$



Let

$V_E = \frac{1}{10} V_{CC}$

$V_E = 2V$

$I_E R_E = V_E$

$(I_C + I_B) R_E = V_E$

$(1+\beta) I_C \cdot R_E = V_E$

$81 \times 10^{-3} \times 10 \; R_E = 2$

$R_E = \frac{2}{81 \times 10^{-3} \times 10}$

$R_E = 2.469\ \Omega$

Using approximation $I_E \approx I_C$

$I_E R_E = 2$

$10^{-2} R_E = 2$

$R_E = \frac{2}{10^{-2}}$

$R_E = 200\ \Omega$

Output KVL

$V_{CC} - I_C R_C - V_{CE} - V_E = 0$

$20 - 10^{-2} R_C - 8 - 2 = 0$

$20 - 10 = 10^{-2} R_C$

$R_C = \frac{10}{10^{-2}}$

$R_C = 10^3\ \Omega = 1k\ \Omega$

Assume current $I_B \neq 0$, current through $R_2 = 10 I_B$

$\therefore$ current through $R_1 = 11 I_B$

$V_B = V_E + V_{BE}$

$= 2 + 0.7$

$= 2.7\ V$

$V_B = 10 I_B R_2$

$= 10 \times \frac{I_C}{\beta} R_2$

$2.7 = 10 \times \frac{10 \times 10^{-3}}{80} R_2$

$2.7 = \frac{10^{-2}}{8} R_2$

$R_2 = \frac{2.7 \times 8}{10^{-2}}$

$R_2 = 2160\ \Omega$

$\frac{V_{CC} - V_B}{R_1} = 11 I_B$

$R_1 = \frac{20 - 2.7}{11 \times 10^{-2}/8}$

$R_1 = 1258.18\ \Omega$

Qn 2) Determine the operating point for the voltage divider bias circuit by a) Exact analysis
b) Approximate analysis

$R_1 = 39k\Omega$

$R_2 = 3.9k\Omega$

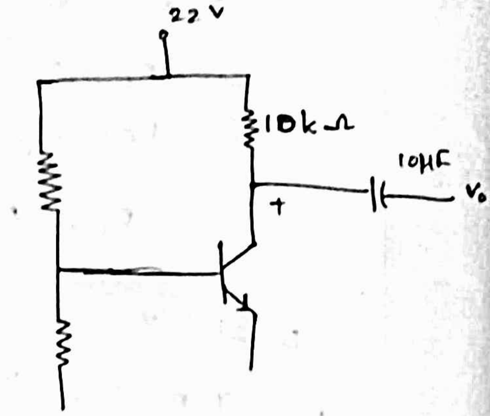
$R_C = 10k\Omega$

~~R_E~~ $1.5k\Omega$

$\beta = 100$

$V_{CC} = 22V$

$R_E = 1.5k\Omega$



a) Exact Analysis

$$E_{Th} = V_{CC}\frac{R_2}{R_1+R_2}$$

$$= 22\left[\frac{3.9\times10^3}{39\times10^3+3.9\times10^3}\right]$$

$$= 22\left(\frac{3.9}{3.9+39}\right)$$

$$= \underline{\underline{2V}}$$

$$R_{Th} = \frac{R_1R_2}{R_1+R_2}$$

$$= \frac{39\times10^3\times3.9\times10^3}{(3.9+39)\times10^3}$$

$$= \underline{\underline{3545.45\,\Omega}}$$

Applying KVL for input loop.

$$E_{Th} - I_BR_{Th} - V_{BE} - R_EI_E = 0$$

$$2 - I_B\times3545.45 - 0.7 - 1.5\times10^3\times(I_B+I_C) = 0$$

$$I_B = \frac{E_{Th}-V_{BE}}{R_{Th}+(1+\beta)R_E}$$

$$= \frac{2-0.7}{3545.45+101\times1.5\times10^3}$$

$$= \underline{\underline{8.384\times10^{-6}\,A}}$$

$$I_C = \beta I_B$$

$$= 100\times8.384\times10^{-6}$$

$$= \underline{\underline{8.3846\times10^{-4}\,A}}$$

KVL for output

$$V_{CC} - I_CR_C - V_{CE} - I_ER_E = 0$$

$$V_{CE} = V_{CC} - I_CR_C - I_ER_E$$

$V_{CE} = 22 - 8.8846\times10^{-4} \times 10\times10^{3} - 8.3846(10^{-6}+10^{-4}) \times 1.5\times10^{3}$

$= \underline{\underline{12.35\ V}}$

b) Approximate analysis

$\beta R_E = 100\times1.5\times10^{3}\ \Omega$

$= 1.5\times10^{5}\ \Omega$

$10R_2 = 10\times3.9\times10^{3}\ \Omega$

$= 3.9\times10^{4}\ \Omega$

$\therefore \beta R_E \geq 10R_2$, $\therefore$ Approximate analysis can be done.

$V_B = V_{CC}\dfrac{R_2}{R_1+R_2}$

$= 22\left[\dfrac{3.9\times10^{3}}{3.9\times10^{3}+39\times10^{3}}\right]$

$= \underline{\underline{2V}}$.

$V_E = V_B - V_{BE}$

$= 2 - 0.7$

$= \underline{\underline{1.3V}}$

$I_E = \dfrac{V_E}{R_E}$

$= \dfrac{1.3}{1.5\times10^{3}} = \underline{\underline{8.667\times10^{-4}\ A}}$.

$I_C \cong I_E$

$\therefore I_C = 8.667\times10^{-4}\ A$

Output KVL.

$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$.

$V_{CE} = V_{CC} - I_C(R_C + R_E)$

$= 22 - 8.667\times10^{-4}(10\times10^{3} + 1.5\times10^{3})$.

$= \underline{\underline{12.03\ V}}$

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Stability factor

$$S(I_{co}) = \left.\frac{dI_c}{dI_{co}}\right|_{V_{BE},\,\beta\ \text{constant}}$$ Stability factor wrt leakage current.

$$S(V_{BE}) = \left.\frac{dI_c}{dV_{BE}}\right|_{I_{co},\,\beta = \text{constant}}$$ SF wrt V_{BE}

$$S(\beta) = \left.\frac{dI_c}{d\beta}\right|_{I_{co},\,V_{BE} = \text{constant}}$$ SF wrt β.

General Expression

$$I_c = \beta I_B + (1+\beta) I_{co}$$

Differentiating wrt I_c

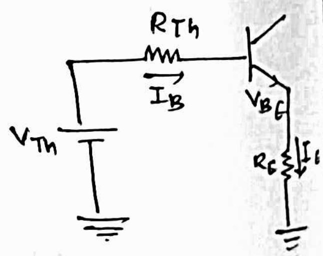
$$1 = \beta\frac{dI_B}{dI_c} + (1+\beta)\frac{dI_{co}}{dI_c} \qquad \frac{dI_{co}}{dI_c} = \frac{1}{S}$$

$$1 = \beta\frac{I_B}{I_c} + \frac{1+\beta}{S}$$

$$1 - \beta\frac{dI_B}{dI_c} = \frac{1+\beta}{S}$$

$$\boxed{S = \frac{1+\beta}{1-\beta\frac{dI_B}{dI_c}}}$$

Voltage ~~biasing~~ divider biasing circuit



$S(I_{co})$

$$V_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

$$V_{Th} - I_B R_{Th} - V_{BE} - (I_c + I_B) R_E = 0$$

Diff wrt I_c

$$0 - R_{Th}\frac{dI_B}{dI_c} - 0 - R_E - R_E\frac{dI_B}{dI_c} = 0$$

$$\frac{dI_B}{dI_c}(-R_{Th} - R_E) = R_E$$

$$\frac{dI_B}{dI_c} = \frac{-R_E}{R_{Th} + R_E}$$

$$\therefore S_{(I_{co})} = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_{Th}+R_E}\right)}$$

$S(V_{BE})$

$$V_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

$$V_{TH} - \frac{I_C}{\beta} R_{Th} - V_{BE} - (1+\beta)\frac{I_C}{\beta} R_E = 0$$

Diff wrt I_C

$$0 - \frac{R_{Th}}{\beta} - \frac{dV_{BE}}{dI_C} - \frac{(1+\beta)}{\beta} R_E = 0$$

$$-\frac{R_{Th}}{\beta} - \frac{(1+\beta)R_E}{\beta} = \frac{dV_{BE}}{dI_C}$$

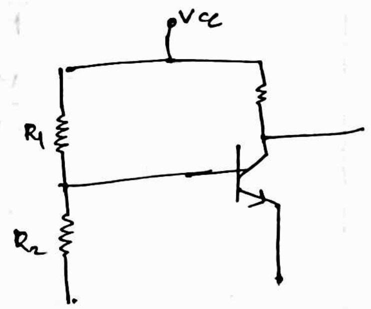
$$\frac{dV_{BE}}{dI_C} = -\frac{(R_{Th} + (1+\beta)R_E)}{\beta}$$

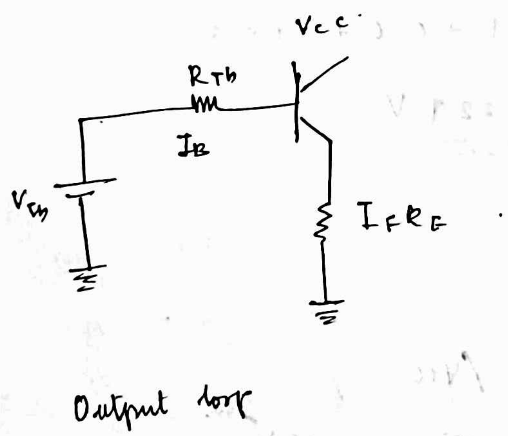
$$\frac{dI_C}{dV_{BE}} = \frac{-\beta}{R_{Th} + (1+\beta)R_E}$$

Qn 1) Design a voltage divider biasing circuit given $\beta = 50$, $V_{BE} = 0.6$, $V_{CC} = 18V$, $R_C = 4.3k\Omega$, & Q point $I_C = 1.5mA$, $V_{CE} = 10V$, SF = 3 ≤ 4.

Exact Analysis

Since R_C is given output loop is taken.





Output loop

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$18 - 1.5\times10^{-3} \times 4.3\times10^{3} - 10 - 1.5\times10^{-3} R_E = 0$$

$$R_E = 1033.33\,\Omega$$

$$R_E = 1k\Omega$$

$$S_{(I_{co})} = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_{Th}+R_E}\right)}$$

$$4 = \frac{1+50}{1+50\left(\frac{1000}{1000+R_{Th}}\right)}$$

$$4 + (50\times4)\frac{1000}{1000+R_{Th}} = 51$$

$$\frac{2\times10^5}{1000+R_{Th}} = 47$$

$$1000+R_{Th} = \cancel{20}\ \frac{2\times10^5}{47}$$

$$R_{Th} = 3255.32\,\Omega \approx 3.3k\,\Omega$$

Input KVL

$$V_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

$$V_{Th} = I_B R_{Th} + V_{EB} + I_E R_E$$

$$= \frac{I_C}{\beta}\times 3.3\times10^3 + 0.6 + (I_C + I_B) R_C$$

$$= \frac{1.5\times10^{-3}}{50}\times 3.3\times10^3 + 0.6 + \left(1.5\times10^{-3} + \frac{1.5\times10^{-3}}{50}\right)1000$$

$$= 0.099 + 0.6 + 1.53$$

$$= 2.229\ V$$

$$V_{Th} = V_{CC}\frac{R_2}{R_1+R_2}$$

$$\frac{R_2}{R_1+R_2} = V_{Th}/V_{CC}$$

$$= \cancel{2.229V}\ 0.1238\ V$$

$$R_{Th} = \frac{R_1 R_2}{R_1+R_2}$$

$$R_{Th} = R_1\times 2.229$$

$$3.3\times10^3 = R_1\times 2.229$$

$$R_1 = 1480.48\,\Omega$$

$\frac{R_2}{1480.48 + R_2} = 2.227$

$R_2 = 2.227 \times 1450.48 + 2.227 R_2$

$R_{Th} = R_1 \times 0.1238$

$R_1 = 26648.7214 \, \Omega$

$= \underline{\underline{26.3 k\Omega}}$

$R_2 = (0.1238)(R_1 + R_2)$

$R_2 = 0.1238 \times 26.3 \times 10^3 + 0.1238 R_2$

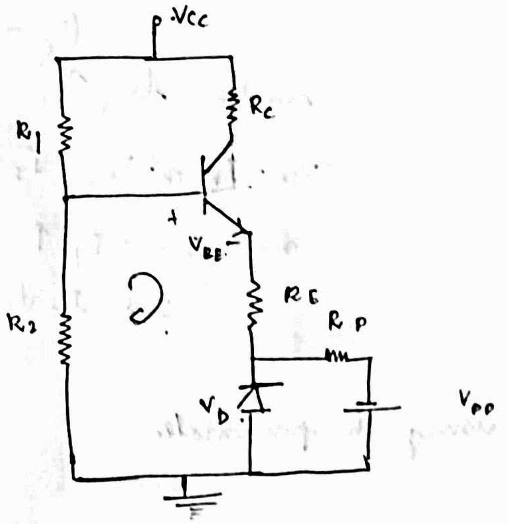
$0.8762 R_2 = 3255.94$

$R_2 = 3715.95 \, \Omega$

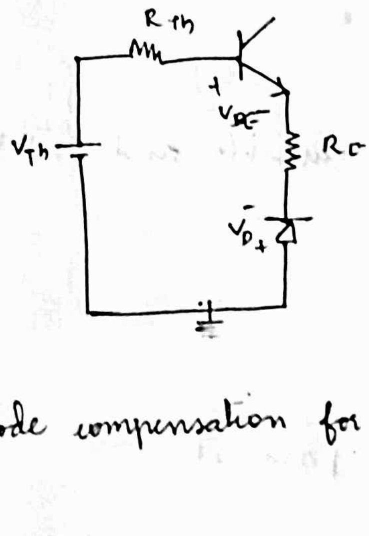
$R_2 = \underline{\underline{2.7 k\Omega}}$

Bias compensation circuits

1) Diode compensation for variation in V_{BE}



Input



$V_{Th} - I_B R_{Th} - V_{BE} - I_C R_E + V_D = 0$

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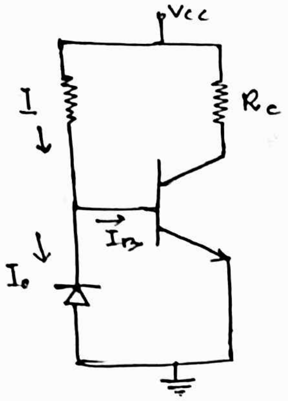
2) Diode compensation for instability due to variation in I_{CO}



I_o - leakage current.

$I_B = I - I_o$

$I_c = \beta I_B + (1+\beta) I_{co}$ $\qquad 1+\beta \approx \beta.$

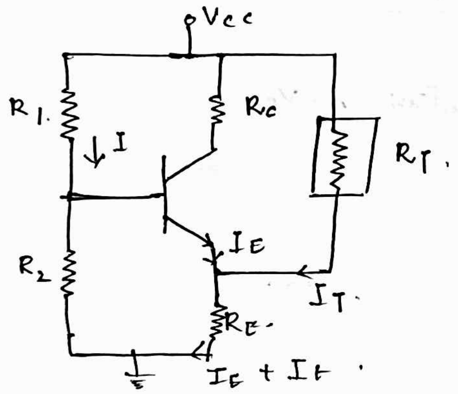
$\therefore I_c = \beta I_B + \beta I_{co}$

$I_c = \beta (I - I_o) + \beta I_{co}$

$I_c = \beta I - \beta I_o + \beta I_{co}.$

The diode & transistor is made of same material, The diode is in the reverse biased condition, so there is a leakage current. Any change in leakage current is compensated by diode leakage current thus I_c remains a constant.

3) Thermistor compensation



Thermistor has -ve temp coefficient

$\therefore$ Temp $\uparrow$ $R_T \downarrow$ $I_T \uparrow$

$\therefore (I_E + I_T) \uparrow$

emitter drop $\uparrow$

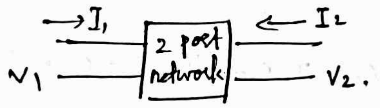
$V_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$

when $I_E + I_t \uparrow$

$I_B \downarrow$ $I_c \downarrow$.

Transistor modelling using h-parameter

h - hybrid



Let V_1 & I_2 be dependent variables and I_1 & V_2 be independent variables.

$V_1 = h_{11} I_1 + h_{12} V_2$

$I_2 = h_{21} I_1 + h_{22} V_2.$

h_{11}, h_{12}, h_{21}, & h_{22} are hybrid-parameters.

$h_{11} = \left.\frac{V_1}{I_1}\right|_{V_2 = 0}$

short circuit input impedance

unit - Ω.

$$h_{12} = \frac{V_1}{V_2}\Big|_{I_1=0}$$

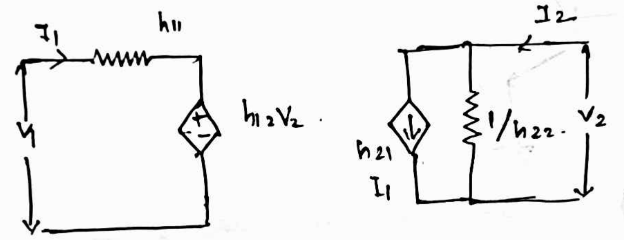
Open circuit reverse voltage gain
No unit

$$h_{21} = \frac{I_2}{I_1}\Big|_{V_2=0}$$

Short circuit forward current gain
No ~~un~~ unit.

$$h_{22} = \frac{I_2}{V_2}\Big|_{I_1=0}$$

Open circuit output admittance
unit - mho.



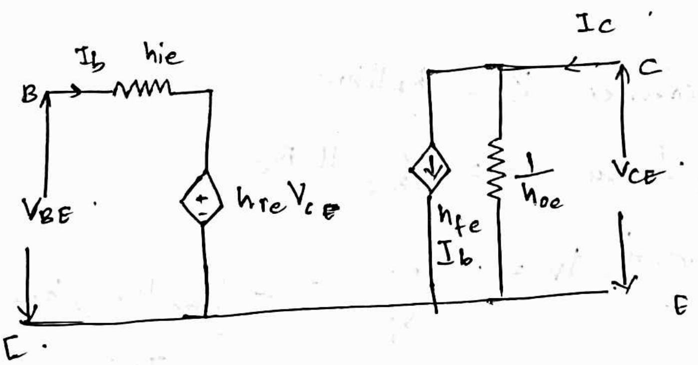
$h_{11} \rightarrow h_i$

$h_{12} = h_r$

$h_{21} = h_f$

$h_{22} = h_o$.

h-parameter model of transistor in CE ~~bias~~ configuration



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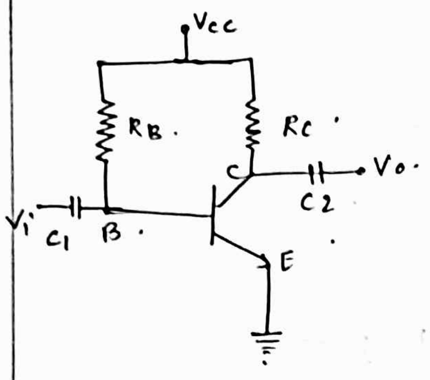
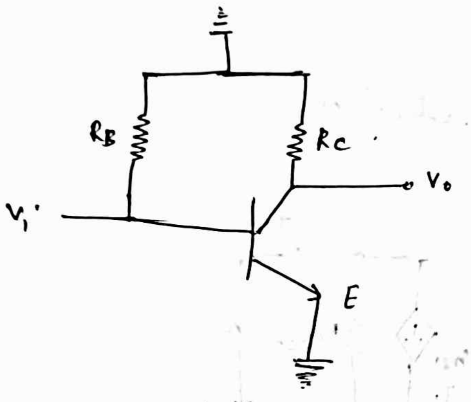
Small signal approximate ac equivalent circuit of CE amplifier

In approximate analysis hre is neglected.

- Ground the dc source V_{cc}.
- short all the capacitors

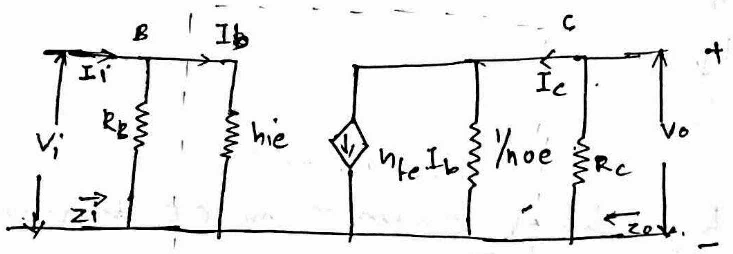




Fixed biasing

h_{re} is neglected

The equivalent is



Input impedance $Z_i = R_B \| h_{ie}$

Output Impedance $Z_o = \frac{1}{h_{oe}} \| R_c$

Voltage gain $A_V = \frac{V_o}{V_i} = \frac{-(\frac{1}{h_{oe}} \| R_c)\, h_{fe} R_b}{I_b h_{ie}}$

$$= -\frac{h_{fe}}{h_{ie}} \left(\frac{1}{h_{oe}} \| R_c\right)$$

The negative sign since the current flows in opposite direction current gain A_i

$$A_i = \frac{I_o}{I_i}, \quad \text{when } R_B >> h_{ie}$$

$$A_i = \frac{I_o}{I_i} = \frac{I_b h_{fe}}{I_b} \approx h_{fe}.$$

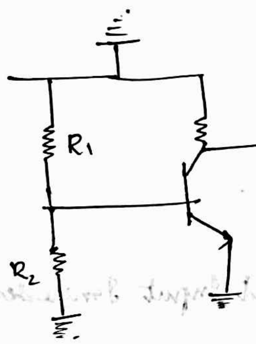
If $R_B \not>> h_{ie}$

$$I_b = \frac{I_i R_B}{R_B + h_{ie}}, \quad \therefore I_i = \frac{I_b (R_B + h_{ie})}{R_B}$$

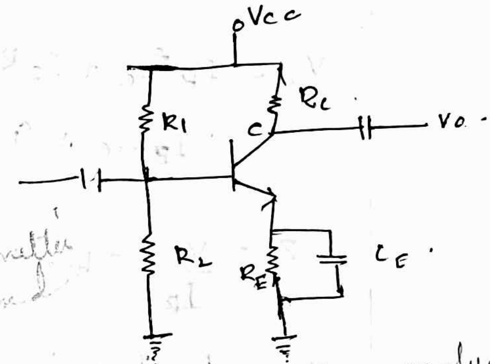
$$A_i = \frac{I_o}{I_i} = \frac{I_b h_{fe} \times R_B}{I_b (R_B + h_{ie})}$$

$$= \frac{h_{fe} R_B}{R_B + h_{ie}}$$

common emitter amplifier circuit using voltage divider drawing

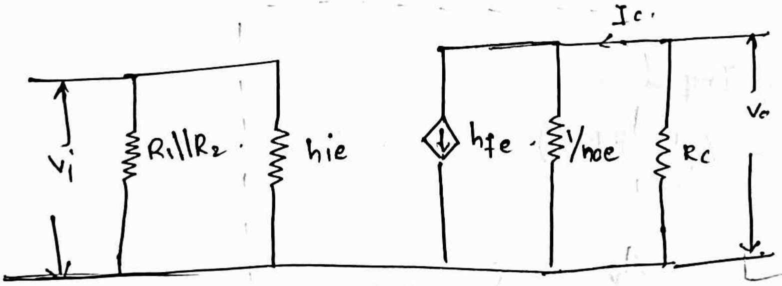


Here the emitter is bypassed



while drawing the ac analysis short all the capacitors & ground all the dc source.

Equivalent is



$\hookrightarrow$ common ground (CE)

$$Z_i = R_1 \| R_2 \| h_{ie}.$$

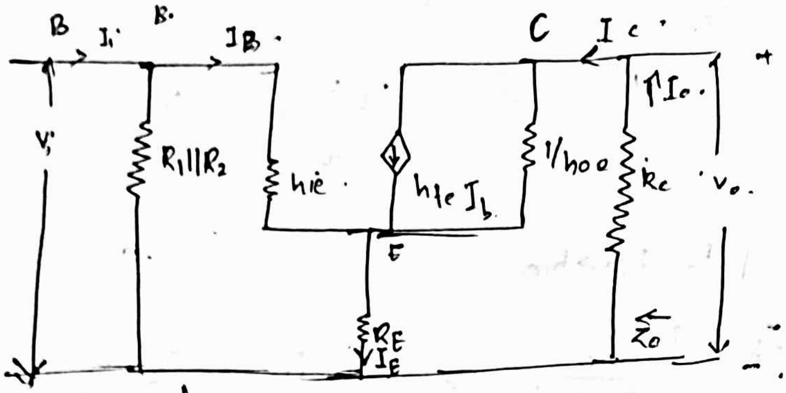
$$Z_o = 1/h_{oe} \| R_C$$

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

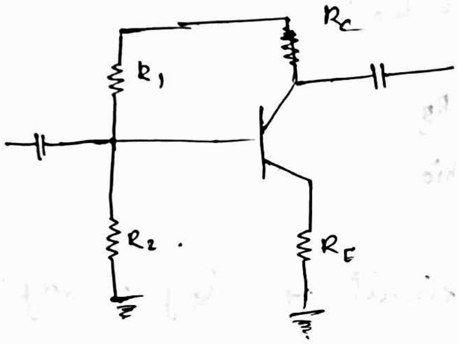
$A_i \approx h_{fe}$ or

$$A_i = \frac{h_{fe} (R_1 \| R_2)}{(R_1 \| R_2) + h_{ie}}$$

when the emitter is unbypassed



The circuit is



$$V_i = I_B h_{ie} + I_C R_E$$
$$= I_B h_{ie} + (1 + h_{fe}) I_B R_E$$

$$Z_i = \frac{V_i}{I_B} = h_{ie} + (1+h_{fe}) R_E$$

Transistor Impedance Z_i' (circuit Input Impedence)

$$Z_i' = (R_1 || R_2) || Z_i$$

Output Impedence

$$Z_o = \left(\frac{1}{h_{oe}} || R_c\right)$$

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Voltage gain $A_v = \dfrac{V_o}{V_i}$

$$V_o = - h_{fe} I_b \left(1/h_{oe} || R_c \right)$$

$$V_i = I_b h_{ie} + (1+h_{fe}) I_b R_E$$

$$V_A = \frac{-h_{fe} I_b \left(1/h_{oe} || R_c \right)}{I_b h_{ie} + (1+h_{fe}) I_b R_E}$$

$$= \frac{-h_{fe}\,(1/h_{oe} \parallel R_c)}{h_{ie} + (1+h_{fe})\,R_c}$$

On Approximating

$$A_v = \frac{-h_{fe} R_c}{h_{fe} R_E} = \frac{-R_c}{R_E}$$

Current gain

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

if $R_1 \parallel R_2 >> h_{ie}$

$$A_i = \frac{I_c}{I_b} = h_{fe}.$$

$$I_b = \frac{I_i \times (R_1 \parallel R_2)}{(R_1 \parallel R_2) + Z_i}$$

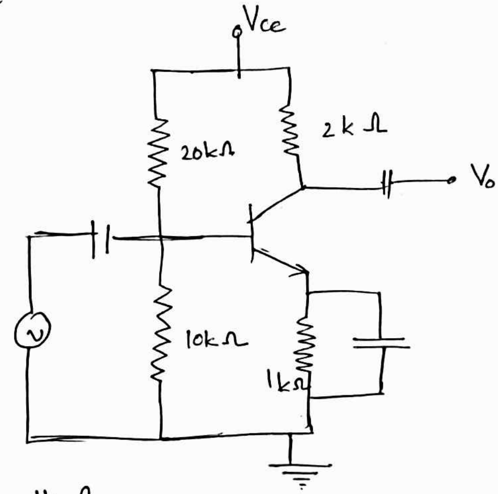
$$I_i = \frac{I_b\,(R_1 \parallel R_2 + Z_i)}{R_1 \parallel R_2}.$$

$$\cancel{A_i = \frac{I_c\, h_{fe} R}{I_b}}$$

$$A_i = \frac{h_{fe}\, I_b\, (R_1 \parallel R_2)}{I_b\, (R_1 \parallel R_2 + Z_i)}$$

$$A_i = \frac{h_{fe}\,(R_1 \parallel R_2)}{(R_1 \parallel R_2) + Z_i}$$

Qn 1) Calculate the input impedence, output impedence, voltage gain and current gain of the given amplifier circuit.

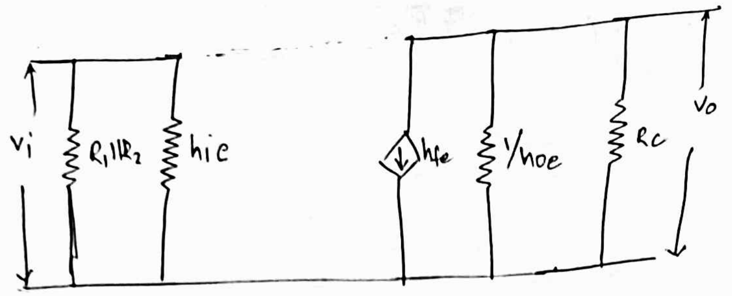


$h_{ie} = 1k\Omega$

$h_{fe} = 100$

$h_{oe} = 25\mu S$

Z_i =



$R_1 = 20k\Omega$

$R_2 = 10k\Omega$.

$$Z_i = R_1 \| R_2 \| h_{ie}$$

$$= 1 \Big/ \frac{1}{20\times10^3} + \frac{1}{10\times10^3} + \frac{1}{1\times10^3}$$

$$= 1 \Big/ \frac{1}{10^3}\left(\frac{1}{20} + \frac{1}{10} + 1\right)$$

$$= \frac{1}{\frac{23}{20}\times10^{3}}$$

$$869.56\ \Omega$$

$$=$$

$$Z_o = \frac{1}{h_{oe}} \| R_C$$

$$= \frac{1}{25\times10^{-6}} \| 2\times10^3$$

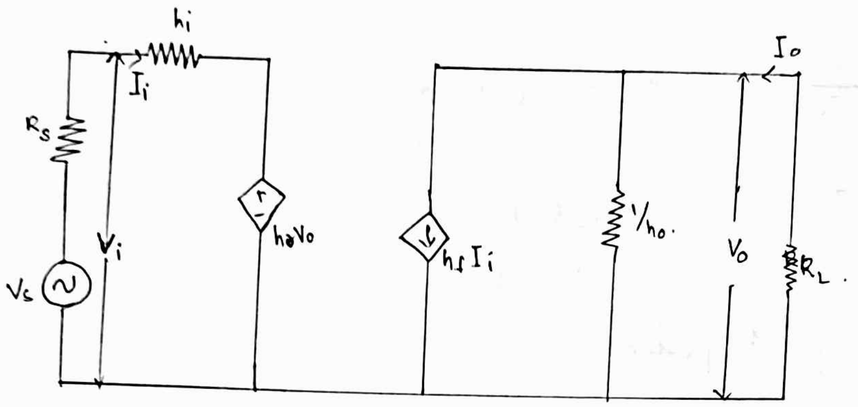
$$= 1 \Big/ 25\times10^{-6} + \frac{1}{2\times10^3}$$

$$A_v = \frac{-h_{fe}}{h_{ie}}\left(\frac{1}{h_{oe}} \| R_c\right)$$

$$A_i = \frac{h_{fe}\,(R_1\|R_2)}{(R_1\|R_2) + h_{ie}}.$$

Exact Equivalent circuit

Small signal analysis of CE amplifier using exact equivalent circuit :



$$V_i = h_i I_i + h_r V_o \quad \text{—①}$$

$$I_o = h_f I_i + h_o V_o \quad \text{—②}$$

Current gain

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

$$I_o = h_f I_i + h_o V_o$$

$$V_o = -I_o R_L$$

$$I_o = h_f I_i - h_o R_L I_o$$

$$h_f I_i = I_o (1 + h_o R_L)$$

$$\boxed{\frac{I_o}{I_i} = \frac{h_f}{1 + h_o R_L}}$$

Voltage gain

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

$$V_i = h_i I_i + h_r V_o$$

$$I_i = \left(\frac{1 + h_o R_L}{h_f}\right) I_o$$

$$I_i = -\left(\frac{1 + h_o R_L}{h_f}\right) \frac{V_o}{R_L}$$

$$V_i = -h_i \frac{V_o}{R_L}\left(\frac{1 + h_o R_L}{h_f}\right) + h_r V_o$$

$$V_i = V_o \left(h_r - \frac{h_i}{R_L h_f}(1 + h_o R_L)\right)$$

$$V_i = V_o \left(\frac{h_r h_f R_L - h_i (1 + h_o R_L)}{R_L h_f}\right)$$

$$A_v = \frac{V_o}{V_i} = \frac{-h_f R_L}{h_i + (h_i h_o - h_r h_f) R_L}$$

Input Impedence :

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

$$V_i = h_i I_i + h_r V_o$$

$$V_o = -I_o R_L$$

$$= \left(-I_i \frac{h_f}{1 + h_o R_L}\right) R_L$$

X_{in}

$$V_i = h_i I_i + h_r \left(- I_i R_L \left(\frac{h_f}{1+h_o R_L} \right) \right).$$

$$V_i = I_i \left(h_i - h_r \left(\frac{R_L h_f}{1+h_o R_L} \right) \right).$$

$$\frac{V_i}{I_i} = h_i - \frac{h_r h_f R_L}{1+h_o R_L}$$

$$Z_i = h_i - \frac{h_r h_f R_L}{1+h_o R_L}$$

Output Impedence

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

$$I_o = h_f I_i + h_o V_o$$

$$I_i = I_o \left(\frac{1+h_o R_L}{h_f} \right)$$

when $V_s = 0$

$$I_i = -\frac{h_r V_o}{h_i + R_s}$$

$$I_o = -h_f \frac{h_r V_o}{h_i + R_s} + h_o V_o.$$

$$I_o = V_o \left(-\frac{h_f h_r}{h_i + R_s} + h_o \right)$$

$$Z_o = \frac{1}{h_o - \left(\frac{h_f h_r}{h_i + R_s} \right)}$$