Solution: Assume for ward active

a) \( I_c = \frac{V_{CC} - V_{CE}}{R_c} \)

\[ I_c = \frac{10V - 3.2V}{6.8k\Omega} \]

\[ I_c = 1mA \]

\( I_c = \frac{I_s \exp \left( \frac{V_{BE}}{V_T} \right)}{1mA} \)

Solve using given values.

\[ V_{BE} = 690.8\text{mV} \]

b) \( V_{CE} = 0.3V \)

\[ i_c = \frac{10 - 0.3V}{6.8k\Omega} = 1.617mA \]

To increase \( i_c \) from 1mA to 1.617mA

\( V_{BE} \) must increase

\[ \Delta V_{BE} = V_T \ln \left( \frac{1.617}{1mA} \right) = 12\text{mV} \]

d) \( V_0 = 0.99 \) \( V_{CC} = 9.9V \)

\[ i_c = \frac{10 - 9.9V}{6.8k\Omega} = 0.0147mA \]

To decrease \( i_c \) from 1mA to 0.0147mA

\( V_{BE} \) changes by

\[ \Delta V_{BE} = V_T \ln \left( \frac{0.0147V}{1V} \right) = -105.5\text{mV} \]
Ex 6.4

Analyze circuit to determine all node voltages and currents

Assume NPN is forward biased.

1) $V_B = 4\, \text{V}$  $V_E = \text{ground through } R_E$
   
   Assume $V_{BE} = 0.7\, \text{V}$

   $V_E = 4\, \text{V} - V_{BE} = 4 - 0.7\, \text{V} = 3.3\, \text{V}$

2) $I_E = \frac{3.3\, \text{V} - 0\, \text{V}}{3.3\, \text{k}\Omega} = 1\, \text{mA}$

3) It is possible that $V_C > V_B$ (Collector connected to 10V power supply)
   
   Needed for active mode. Assume active mode & check later

   $I_C = \alpha I_E$

   $\alpha = \frac{B}{(B+1)} = \frac{100}{101} = 0.99$
Ex 6.4 (contin)

1) $I_c = (0.99 \times 1\text{mA}) = 0.99\text{mA}$

4) $V_c = 10 - I_cR_c = 10 - (0.99\text{mA}) (4.7\text{k})$
   \[= +5.3\text{V}\]

   Check $V_B = 4\text{V} \Rightarrow V_c > V_B \Rightarrow$ reverse biased

   so forward active assumption good

5) $I_B = \frac{I_E}{B+1} = \frac{1\text{mA}}{101} = 0.01\text{mA}$

Ex 6.5

- Same as 6.4
  - EXCEPT
    1) Base @ 6V
    2) $B \geq 50$

Reminder = DC problems

1) Determine or assume regime of operation
   2) $V_{BE}$, $I_{CE} = 0.7\text{V}$
   3) $V_{CE}$ edge of sat = 0.3V
      $V_{CE}$ sat = 0.2V

1) $V_B = 6\text{V}$
   $V_E = ?$
   Assume forward bias
\[ V_E = 6V - V_{BE} \]
\[ = 6 - 0.7V = 5.3V \]
\[ I_E = \frac{5.3V}{3.3k} = 1.6mA \]

2) \[ I_C = \alpha I_E = I_E \]

\[ V_C = 10V - (4.7k\Omega)(1.6mA) = 2.48V \]

3) \[ V_C < V_B \Rightarrow \text{not active mode} \]

- transistor in saturation!

a) \[ V_E \& I_E \text{ are correct} \]

\[ V_E = 5.3V \quad I_E = 1.6mA \]

b) \[ V_C = V_E + V_{cesat} = 5.3V + 0.2V = 5.5V \]

c) \[ I_C = \left( \frac{10-5.5V}{4.7k\Omega} \right) = 0.96mA \]

d) \[ I_B = I_E - I_C = 1.6mA - 0.96mA = 0.64mA \]

\[ B_{F(urd)} = \frac{I_C}{I_B} = \frac{0.96mA}{0.64mA} = 1.5 < 50 \]

\[ \Rightarrow \text{saturate} \]
Example 4.8

Analyze the circuit to determine voltages at all nodes and currents in branches. \( B = 100 \)

1. Assume BE is forward biased.
   \[ I_B = \frac{5 - V_{BE}}{R_B} = \frac{5 - 0.7V}{100k} = 0.043mA \]

2. Assume active mode.
   \[ I_C = B I_B = 100 \times 0.043mA = 4.3mA \]

3. \( V_C = 10 - I_C R_C = 10V - (4.3mA)(2k) = 1.4V \)

3b) \( I_E = \frac{I_C}{\alpha} = 4.349mA \)

4. \( V_B = V_{BE} = 0.7V \)

\( V_C > V_B \), CB is reverse biased and active mode assumption is correct.
Collector & emitter currents depend critically on B.

If B is 10% higher, transistor would be saturated ⇒ bad design

Ex 6.10

Simplify with

Thevenin theorem

\[ V_{BB} = \frac{15R_{B2}}{R_{B1} + R_{B2}} = 5V \]

\[ R_{BB} = R_{B1} \parallel R_{B2} = 33.3k\Omega \]

\[ V_{BB} = I_B R_B + V_{BE} + I_E R_E \]

Assume active mode operation
Replace \( I_B \) with \( I_E / (B+1) \)

\[
I_E = \frac{V_{BB} - V_{BE}}{R_E + \frac{B\cdot V_{BB}}{B+1}}
\]

\[
I_E = \frac{(5 - 0.7V)}{3 + 33.3/101} = 1.29 \text{ mA}
\]

\[
I_B = \frac{1.29}{101} = 0.0128 \text{ mA}
\]

\[
V_B = V_{BE} + I_E R_E
\]

\[
= 0.7V + (1.29 \text{ mA})(3k) = 4.57V
\]

\[
I_C = \alpha I_E = 0.99 (1.29 \text{ mA}) = 1.28 \text{ mA}
\]

\[
V_C = 15 - I_C R_C = 5 - (1.29 \text{ mA})(5k)
\]

\[
= 8.16V
\]

\( V_C > V_B \) \text{ so active mode assumption is correct}
Q1 Part of circuit identical to example 6.10 assume Q1 in active mode and use values from previous example

\[ V_{B1} = +4.57 \, \text{V} \quad I_{E1} = 1.29 \, \text{mA} \]
\[ I_{B1} = 0.0128 \, \text{mA} \quad I_{C1} = 1.28 \, \text{mA} \]

> However \( V_{C1} \) will be different
> Assume \( I_{B2} < I_{C1} \) & current through \( R_{C1} \approx I_{C1} \)
> \( V_{C1} \approx 15 - I_{C1} R_{C1} = 4.5V - (1.28 \, \text{mA})(5 \, \text{k}\Omega) \)
  \[ = 8.16 \, \text{V} \]

\[ \Rightarrow \text{Thus Q1 in active mode} \Rightarrow V_{C1} > V_{B1} \]

Q2 \[ V_E > V_B \Rightarrow \text{forward biased} \]
\[ V_{E2} = V_{C1} + 0.7V = 8.16V + 0.7V = 9.3V \]
\[ I_{E2} = \frac{15 - V_{E2}}{R_{E2}} = \frac{15 - 9.3V}{2\,\text{k}\Omega} = 2.85 \, \text{mA} \]
Assume active mode
\[ I_{C2} = I_{E2} \times 0.99 \times 2.85 \, \text{mA} \]
\[ = 2.82 \, \text{mA} \]

\[ V_{C2} = I_{C2} R_2 = (2.82 \, \text{mA})(2.4 \, \text{k}\Omega) \]
\[ = 7.012 \, \text{V} \]
\[ V_{C2} < V_{B2} \Rightarrow \text{active mode assumption is fine} \]
Find error in calculations from neglecting $I_{B2}$.

\[ I_{B2} = \frac{I_{E2}}{B+1} = \frac{2.85 \text{mA}}{101} = 0.028 \text{mA} \]

$I_{B2} \ll I_{c1}$

If include $I_{B2}$ in calculations (iterate once more):

\[ I_{RC1} = I_{c1} - I_{B2}, \text{ assume } I_{B2} = 0.028 \text{mA} \]

\[ = 1.28 \text{mA} - 0.0028 \text{mA} = 1.252 \text{mA} \]

\[ V_{c1} = 15 - (5 \text{k} \Omega)(1.252 \text{mA}) = 8.74 \text{V} \]

\[ V_{E2} = 8.74 \text{V} + 0.7 \text{V} = 9.44 \text{V} \]

\[ I_{E2} = \frac{15 \text{V} - 9.44 \text{V}}{2k} = 2.78 \text{mA} \]

\[ I_{c2} = 0.99(2.78 \text{mA}) = 2.75 \text{mA} \]

\[ V_{c2} = (2.75 \text{mA})(2.7 \text{k}\Omega) = 7.43 \text{V} \]

\[ I_{B2} = \frac{2.78 \text{mA}}{101} = 0.00275 \text{mA} \]

**7.1.0.2 Obtaining a voltage amplifier**

BJT as amplifier, voltage (VBE) controlled current source.
Voltage transfer characteristic

For small \( U_{BE} \) (i.e. \( U_{BE} < 0.5V \))

\[ i_c = 0 \quad \text{and} \quad V_o = V_{cc} \ (X-Y \ \text{segment}) \]

For \( U_{BE} > 0.5V \), BE forward biased and initial \( V_o \) to large active mode

\[ V_o = V_{cc} - R_c I_s \exp\left(\frac{V_i}{V_T}\right) \quad \text{Y-Z segment} \]

When \( V_o < V_i - 0.4V \)

\( \Rightarrow \) saturation (point Z)

\( V_o \) is almost constant

\[ V_o = \frac{V_i}{V_{ce \ \text{sat}}} \quad I_{c \ \text{sat}} = \frac{V_{cc} - V_{cesat}}{R_c} \]
7.1.4 Amplifier Gain

Amplifier is in active mode from circuit above

1) Bias at point \( Q \) quiescent point

2) Superimpose small signal on top of \( U_{BE} \)

I) DC Bias point
\[
I_C = I_S \exp \left( \frac{U_{BE}}{V_T} \right)
\]
\[
U_{CE} = V_{CC} - R_C I_C
\]

II) Superimpose small signal on top of \( U_{BE} \)

Amplifier gain determined by slope of transfer characteristics
\[
A_V = \left. \frac{\Delta V_O}{\Delta V_I} \right|_{V_I = U_{BE}} = -\frac{1}{V_T} I_S \exp \left( \frac{U_{BE}}{V_T} \right) R_C
\]
\[ Av = -\frac{IcRc}{VT} = -\frac{V_{RC}}{VT} \]

where \( V_{RC} = V_{CC} - V_{CEO} \)

- \( Av < 0 \Rightarrow \text{inverting amplifier} \)
- \( \uparrow Av \text{ when } \uparrow V_{RC} \Rightarrow \text{need larger } Ic \Rightarrow \text{need larger } U_{BE} \)
- Pushing Q too close to Y lowers gain & clips off positive peak
- Theoretical max \( Av \) occurs at z point

\[ Av = -\frac{(V_{CC} - V_{CE\text{sat}})}{VT} \approx -\frac{V_{CC}}{VT} \]

\[ \text{Example} \]

V\(_{CC} = 10V\]

\[ Ic = 1mA \]
\[ Av = -320V/V \]

1. Find value of \( R_c \) corresponding to this

\[ Ic = \frac{V_{CC} - V_{CE}}{RC} \]
\[ Av = -\frac{IcRc}{VT} \Rightarrow R_c = \frac{AvVT}{Ic} \]
\[ R_c = \frac{(-320V/V) (0.025V)}{1mA} = 8k\Omega \]
What is the largest negative signal allowed at output 
\( V_{ce} \geq 0.3V \)

\[
V_{ce} \mid i = 1mA, R_c = 8k\Omega = 2V
\]

largest swing allowed = 1.7V

2. Corresponding signal amplitude

\[
A_v = \frac{V_o}{V_i}
\]
\[
\Delta V_i = \frac{\Delta V_o}{A_v} = \frac{1.7V}{320V/V} = 5.3mV
\]

Can use graphical analysis to determine voltage transfer function

7.2.2 Small Signal operation & model

Valid for active mode!

1. DC analysis

\[
V_{be} = 0
\]
\[
I_C = I_S \exp \left( \frac{V_{BE}}{V_T} \right)
\]
\[
I_E = I_C / \alpha
\]
\[
V_{CE} = V_{CC} = V_{CC} - I_C R_C
\]
2. Add $V_{be}$ (small signal)

$$V_{BE} = V_{BE} + V_{be}$$

$$i_c = I_s \exp \left( \frac{V_{BE}}{V_T} \right)$$

$$= I_s \exp \left( \frac{V_{BE}}{V_T} \right) \exp \left( \frac{V_{be}}{V_T} \right)$$

$$= I_c \exp \left( \frac{V_{be}}{V_T} \right)$$

$$i_c \approx I_c \left( 1 + \frac{V_{be}}{V_T} \right)$$  \quad V_{be} \ll V_T$$

Valid for $V_{be} < 10 \text{mV}$, small signal approximation

**Small signal approximation**

$$i_c = I_c + i_c$$  \quad \text{where } i_c = \frac{I_c}{V_{be}}$$

$$i_c = g_m V_{be}$$

$$g_m = \frac{I_c}{V_T} \quad \text{transconductance}$$

For constant $g_m$, need constant $I_c$

$g_m$ of BJT tends to be higher than that of MOSFET

$$g_m = \frac{\delta i_c}{\delta V_{BE}} \mid i_c = I_c$$

Small signal approx keeps signal amplitude small so that restricted to almost linear portion of
Input resistance at base (forward active)

\[ i_B = \frac{i_C}{B} = \frac{I_C}{B} + \frac{I_c}{B} \left( \frac{U_{be}}{V_T} \right) \]

\[ i_B = I_B + i_b \]
\[ i_b = \frac{I_C}{B} \frac{U_{be}}{V_T} = \frac{g_m}{B} U_{be} \]

Small signal resistance looking between B & E, looking into base

\[ R_{TI} = \frac{U_{be}}{i_b} = \frac{B}{g_m} = \frac{BV_T}{I_C} = \frac{V_T}{I_B} \]

Input resistance at emitter

\[ i_E = \frac{i_C}{\alpha} = \frac{I_C}{\alpha} + \frac{i_c}{\alpha} \Rightarrow i_E = I_E + \frac{i_c}{\alpha} \]

\[ I_E = \frac{I_C}{\alpha} \]
\[ i_e = \frac{i_c}{\alpha} \]
\[ i_e = \frac{I_C}{\alpha} \frac{V_{be}}{\alpha V_T} \]
\[ U_{be} = \frac{I_E}{V_T} U_{be} \]

Input signal resistance looking back into emitter

\[ R_e = \frac{U_{be}}{i_e} = \frac{1}{I_E} \Rightarrow U_{be} I_E = \frac{I_C}{\alpha} \]

\[ R_e = \frac{\alpha}{g_m} = \frac{1}{g_m} \]

\[ g_m = \frac{I_C}{V_T} \]
relationship between $\beta \pi$ and $R_e$

$V_{be} = i_{b0}$

$\beta \pi = i_e R_e$ (added)

$\beta \pi = (\beta + 1) R_e$

Voltage gain

$V_o = V_c = V_{cc} - i_c R_c$

$= V_{cc} - (i_c + i_e) R_c$

Signal component

$V_c = -i_c R_c$

$= -g_m V_{be} R_c$

$= (-g_m R_c) V_{be}$

Voltage gain

$A_v = \frac{V_c}{V_{be}} = -g_m R_c = \frac{-i_c R_c}{V_T}$

Hybrid $\pi$ model

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

$\beta \pi = \frac{B}{g_m}$
Obvious

\[ i_c = g_m V_{be} \quad i_b = \frac{V_{be}}{r_{\pi}} \]

Not so obvious

\[ i_e = \frac{V_{be}}{r_{\pi}} + g_m V_{be} = \frac{V_{be}}{r_{\pi}} \left( 1 + g_m r_{\pi} \right) \]

Alternate version

\[ g_m V_{be} = g_m \left( i_b r_{\pi} \right) = B i_b \]

I model

> Hybrid \( \Pi \) is most popular

\[ g_m = \frac{I_c}{V_T} \]

\[ r_e = \frac{V_T}{I_e} \]
Alternative

\[ i_b = \frac{U_{be}}{R_e} - Gm U_{be} \]
\[ = \frac{U_{be}}{R_e} (1 - Gm R_e) \]
\[ = \frac{U_{be}}{R_e} (1 - \alpha) \]
\[ = \frac{U_{be}}{R_e} \frac{1}{1 + B} = \frac{U_{be}}{R_{\Pi}} \]

\[ Gm U_{be} = Gm i_e R_e = \alpha i_e \]

PNP is same as NPN \( \Rightarrow \) no change with polarity

Small signal analysis

1) DC analysis \( \Rightarrow \) Find all node voltages and currents

2) Calculate small signal parameters
\[ Gm / R_{\Pi} / R_e \]

3) Eliminate all DC sources, replace BJT with equivalent circuit model

4) Analyze equivalent circuit, find voltage gain, \( R_{in} \) and \( R_{out} \)
Determine voltage gain of amplifier

1. DC analysis
   \( V_i = 0 \)
   \[
   I_B = \frac{3 - 0.7V}{100k} = 0.023mA
   \]

   Amplifier \( \Rightarrow \) Assume forward active
   \[
   I_C = B \times I_B = 21.3mA
   \]
   \[
   V_C = 10V - (3k\Omega)(21.3mA) = 3.1V
   \]
   \( V_C > V_B \Rightarrow \) Forward active!

2. Small signal parameters
   \[
   R_e = \frac{V_T}{I_T} = \frac{0.025V}{(I_C/I_d)}
   \]
   \[
   = \frac{6.025V}{(21.3mA/0.99)} = 10.85k\Omega
   \]
   \[
   R_{\pi} = \frac{B}{g_m} = \frac{100}{92mA/V} = 1.09k\Omega
   \]
3. Draw small signal model

\[ V_{be} = \frac{V_i \cdot \frac{1}{R_T}}{R_T + 100k\Omega} = V_i \left( \frac{1.09k\Omega}{1.09k\Omega + 100k\Omega} \right) \]

\[ V_{be} = 0.011V_i \]

Output voltage \( V_0 = -g_m V_{be}(3k\Omega) \)

\[ \frac{V_0}{V_i} = -\left(9.2 \text{ mA/V}\right)\left(0.011\right)\left(3k\Omega\right) \]

\[ = -3.04 \text{ V/V} \]

7.3 3 Basic types amplifier

CE (Common emitter)  CB (Common base)
7.5.2 Common Emitter with biasing

Signal ground established by $C_e$ (μF) bypass cap $\Rightarrow$ acts like short for signal

Coupling caps $C_{c1}$ & $C_{c2}$ block DC, act like short for AC signal
\[ R_{in} = \frac{V_i}{i_i} = R_B \parallel R_T \approx R_T \quad \text{when } R_B \gg R_T \]

\[ R_{in} \sim \text{few kΩ} \quad \text{low} \rightarrow \text{moderate} \]

\[ V_i = V_{sig} \frac{R_{in}}{R_{in} + R_{sig}} = V_{sig} \left( \frac{R_B \parallel R_T}{R_{sig} + R_B \parallel R_T} \right) \]

\[ V_i = V_T \]

\[ V_o = -g_m V_T \left( R_0 \parallel R_C \parallel R_L \right) \]

\[ A_V = \frac{V_o}{V_i} = -g_m \left( R_0 \parallel R_C \parallel R_L \right) \]

\[ A_{V0} = \frac{V_o}{V_i} \bigg|_{R_L=\infty} = -g_m \left( R_0 \parallel R_C \right) \]

Effect \( R_0 \) \( \Rightarrow \) reduce gain

\[ A_V = A_{V0} \left( \frac{R_L}{R_L + R_0} \right) \]

Typically, \( R_0 \gg R_C \)
reduce \( A_V \)
slightly.

\[ R_0 \gg R_C \]
\[ A_V \approx -g_m R_C \]
Overall voltage gain:

\[ G_v = \frac{- (R_{B11} R_{T1})}{(R_{B11} R_{T1}) + R_{sig}} G_m \left( R_{o11} R_{ch11} R_{L} \right) \]  

when \( R_B \gg R_{T1} \):

\[ G_v \approx \frac{-B \left( R_{c11} R_{ch11} R_{o} \right)}{R_{T1} + R_{sig}} j R_{B11} R_{T1} R_{T1} \]

If \( R_{sig} \gg R_{T1} \), \( B \times B \) not desirable as wide variation in \( B \)

If \( R_{sig} \ll R_{T1} \), \( G_v = -G_m \left( R_{c11} R_{ch11} R_{o} \right) = A \nu \)

\( G_v \& A \nu \) can reach few hundred (significant gain)

Short circuit current gain:

\[ i_{os} \mid R_L=0 = -G_m V_{T1} \]

\[ V_{T1} = V_i = i; R_{in}; A_{is} = \frac{i_{os}}{i_{is}} = -G_m R_{in} \]

Limited by high frequency.

If \( R_B \gg R_{T1} \), \( A_{is} = -G_m \left( R_{T1} \| R_B \right) \)

\[ \alpha = -G_m R_{T1} = B \]
Common emitter with emitter resistance
Small Signal Model

\[ R_{in} = R_B \parallel R_{ib} \]
\[ R_{ib} = \frac{V_i}{i_b} \quad \text{(Input resistance)} \]

\[ i_{ib} = (1 - \alpha) i_e = \frac{i_e}{B+1} \]
\[ i_e = \frac{V_i}{(R_e + R_e)} \]
\[ R_{ib} = \frac{V_i}{i_e} (B+1) = \frac{V_i}{(R_e + R_e)} (B+1) \]

* Resistance reflection rule because \[ i_e = (B+1) i_b \]

Inclusion of \( R_e \) substantially increases \( i_b \)

- Can use \( R_e \) to control \( R_{in} \) if \( R_B \) is dominated by \( R_{ib} \) (\( i_e R_B \gg R_{ib} \))

At output \[ V_o = -i_e (R_{ch} R_L) = -\alpha i_e (R_{ch} R_L) \]

Since \[ i_e = \frac{V_i}{(R_e + R_e)} \]
\[ V_o = \frac{-\alpha (R_{ch} R_L)}{R_e + R_e} V_i \]

\[ A = \frac{-\alpha (R_{ch} R_L)}{R_e + R_e} \]
\[ A_v = \frac{-\alpha R_C}{Re + Re} \]

\[ Re = \frac{\alpha}{g_m} \quad A_v = \frac{-g_m R_C}{1 + Re/Re} = \frac{-g_m R_C}{1 + (g_m R_C / \alpha)} \]

\[ R_o = R_C; \text{ the only resistance in output} \]

To find \( A_{in} \)

\[ i_{os} = -\alpha i_e \]
\[ i_i = \frac{V_i}{R_{in}} \]
\[ A_{is} = -\alpha \frac{R_{in} i_e}{V_i} \]

Since \( i_e = \frac{V_i}{Re + Re} \) \quad \( R_{in} = R_B || R_{ib} \)

\[ A_{is} = -\alpha \left( \frac{R_B || R_{ib}}{Re + Re} \right) \]

When \( R_B > R_{ib} \Rightarrow A_{is} \approx -\alpha \frac{R_{ib}}{Re + Re} \)

\[ A_{is} \approx -\alpha \frac{(R_B+1)(Re + Re)}{(Re + Re)} \]

\[ A_{is} \approx -B \]

Overall voltage gain

\[ G_v = \frac{V_i}{V_{sy}} \quad A_v = \left( \frac{-R_{in}}{R_{sy} + R_{in}} \right) \left( \frac{\alpha R_C || R_{ib}}{Re + Re} \right) \]

If \( R_B > R_{ib} \Rightarrow R_{in} \approx R_{ib} = (1+B)(Re + Re) \)

\[ G_v \approx \frac{-B (R_C || R_{ib})}{R_{sy} + (B+1)(Re + Re)} \]
Gain is lower than common emitter amplifier \(\text{w}10\text{ Re}, \text{but less sensitive to B}\)

- Common emitter amplifier \(\text{w}1\text{ Re}\) can also handle large input signal up to distortion \(\text{b/c only a fraction of } V_i \text{ appears across base/emitter}\)

\[
\frac{V_{\pi}}{V_i} = \frac{R_e}{R_e + R_e} = \frac{1}{1 + g_m R_e}
\]

Summary of Common Emitter amplifier

\(\text{w}1\text{ Re} \text{ compared w/ CE w/o Re}\)

1) \(R_h\) increased by \((1+g_m R_e)\)

2) \(A_v\) reduced by \((1+g_m R_e)\)

3) For same NL distortion \(V_i\) can be increased by \((1+g_m R_e)\)

4) \(G_v\) less sensitive to B

5) High frequency response better

6) Negative feedback

\[+ i_c \Rightarrow + u_e \Rightarrow - V_i\]
7.5.4 Common Base Amplifier

\[ Vcc \]
\[ \begin{array}{c}
Rc \\
\end{array} \]
\[ V_0 \]
\[ \begin{array}{c}
R_L \\
\end{array} \]
\[ R_0 \]
\[ \text{Ignore } R_0 \]
\[ \text{Use } T \text{ model} \]

Small Signal Model

\[ R_{in} = R_e \sim \text{a few ohms}, R_{in} \text{ very low} \]

\[ V_0 = -\alpha V_i (R_c + R_L) \]

\[ i_e = -\frac{V_i}{R_e} \]
\[ AV = \frac{V_0}{V_i} = \frac{\alpha}{R_e} (R_c + R_L) \]
\[ A_v = G_m (R_c || R_L) \]

* non inverting, otherwise same as CE

\[ A_v = G_m \frac{R_c}{R_L} \quad \text{Same as CE} \]

\[ R_o = R_c \quad \text{same as CE} \]

\[ A_{is} = \frac{-X_{ie}}{i_i} = \frac{-X_{ie}}{-ie} = \alpha \quad \text{common base current gain} \]

\[ G_v = \frac{R_e}{R_g + R_e} \quad G_m (R_c || R_L) \]

\[ G_v = \frac{\alpha (R_c || R_L)}{R_g + R_e} \approx \frac{R_c || R_L}{R_g + R_e} \]

- \( G_v \) proportional to ratio of resistance in collector to that of emitter \( \Rightarrow \) not dependent on \( B \) \( \Rightarrow \) very desirable

- \( R_g \approx R_c \& R_L \) gain very small

- Boax, cubic amplifier - need low Rin for min reticron

- Current buffer (unity gain current amplifier) delivers same current from low input R to high R output circuit
Summary of Common Base Amplifier

- Low input R
- Open circuit gain = 1/|CE|
- High output R (Rc)
- Low overall voltage gain

7.5.5 Emitter follower or common collector (Section 7.8.5, letted)

Use T model
Apply resistance reflection rule

\[ i_b = (1 - \alpha) i_e = \frac{i_e}{B+1} \]

\[ R_{ib} = \text{input resistance} = (B+1) \left[ R_e + R_{11RL} \right] \]

\[ R_{in} = R_B \parallel R_{ib} \]

Emitter follower presents increased resistance to source. To fully realize RB

\[ R_B \text{ must be high} \]

\[ A_V = \frac{R_{L11R_0}}{R_{011RL} + R_e} \]

\[ A_{V0} = A_V \bigg|_{R_L = \infty} \approx 1 \]

\[ G_V = \left( \frac{R_{b11R_{ib}}}{R_{b11R_{ib}} + R_{sg}} \right) \left( \frac{R_{L11R_0}}{R_{011RL} + R_e} \right) \]

\[ G_V = \left( \frac{R_B (B+1) \left[ R_e + R_{11RL} \right]}{R_B (B+1) \left[ R_e + R_{11RL} + R_{sg} \right]} \right) \left( \frac{R_{L11R_0}}{R_{011RL} + R_e} \right) \]

\[ G_V < 1 ! \]

Simplifying, for \( R_B \gg R_{sg} \) & \( R_e \gg R_L \)

\[ \frac{V_o}{V_{sg}} = \frac{R_L}{R_{sg} + R_e + R_L} \]

\[ G_V \rightarrow 1 \text{ when } R_{sg} \ll (B+1) R_L \]
Butterfly action $\Rightarrow$ short circuit current gain approaches $B+1$

\[ G_{vo} = G_v \left|_{RL=\infty} \right. \approx \left( \frac{R_B}{R_S + R_B} \right) \left( \frac{R_o}{R_S + R_B + r_o + r_e} \right) \]

\[ R_o \left|_{vi=0} \right. = R \parallel r_e \]

**Emitter follower**
- $R_{in}$ high, $R_o$ low, $G_v \approx 1$

**Summary**

<table>
<thead>
<tr>
<th>Amplifier Type</th>
<th>$R_{in}$</th>
<th>$R_{out}$</th>
<th>$A_v / G_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
<td>moderate</td>
<td>large</td>
<td>Large</td>
</tr>
<tr>
<td>CE w/Re</td>
<td>increase $R_{in}$</td>
<td>large</td>
<td>Smaller</td>
</tr>
<tr>
<td>CB</td>
<td>small</td>
<td>large</td>
<td>$\text{large } A_v$ Small $G_v$ unity gain current amp.</td>
</tr>
<tr>
<td>CE emitter follower</td>
<td>high</td>
<td>low</td>
<td>$A_v \approx 1$, voltage buffer connect high $R$ source to low $R$ load.</td>
</tr>
</tbody>
</table>