Handout 2 for EE-203

Bipolar Junction Transistor (BJT)

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(Ref: Text book and KFUPM Online course of EE-203)

(Remember to solve all the related examples, exercises problems as given in the Syllabus)
Chapter 5: Bipolar Junction Transistor (BJT)

Text book: “Microelectronic Circuits by Sedra and Smith

5.1: Device Structure and Physical Operation

- BJT is a three terminal device that can operate as “Amplifier” or as “Switch”
- Voltage between the two terminals is used to control the current in the third terminal
- BJT consist of three semiconductor regions: NPN or PNP

Table 5.1: BJT Modes of operation

<table>
<thead>
<tr>
<th>Application</th>
<th>Mode</th>
<th>EBJ</th>
<th>CBJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplifier</td>
<td>Active</td>
<td>Forward</td>
<td>Reverse</td>
</tr>
<tr>
<td>Switch</td>
<td>Cutoff</td>
<td>Reverse</td>
<td>Reverse</td>
</tr>
<tr>
<td></td>
<td>Saturation</td>
<td>Forward</td>
<td>Forward</td>
</tr>
</tbody>
</table>

Figures from text book

Symbols: NPN and PNP
Active Mode of Operation of an NPN transistor:

**N-Type material:** Arsenic, Antimony and Phosphorus (group V materials)

**P-Type material:** Aluminum, Boron and Gallium (group III materials)

**Fig 5.3:** Forward current flow in an *NPN* transistor biased to operate in the active mode (Very small reverse current, due to drift of thermally generated minority carriers, are not shown.)
• The EMITTER is heavily doped and have high density of electrons. But the base is thin, lightly doped and has low density of holes. So, the current flow \((i_E)\) between the forward biased emitter-base junction is mainly due to electronics flowing from emitter to base. This process emits free electrons into the base.

• Among the emitted electrons in BASE, around 5% **recombines** with available holes and escapes into external base lead as \(i_{B2}\), \((i_B=i_{B1}+i_{B2} \rightarrow i_{B1}\) is due to majority holes\) Remaining 95% base electrons acts as a minority carriers and are swept away to collector region by the electric field of reverse biased collector-base junc. (fig)

• These electrons are then collected by more positive collector terminal that constitute collector current \((i_c)\). **THUS:** \((i_E) = (i_B) + (i_C)\)
The Collector Current \( (i_C) \):

\[
i_C = I_S \cdot e^{\frac{V_{BE}}{V_T}}
\]

Base Current \( (i_B) \):

\[
i_B = \frac{i_C}{\beta} = \frac{I_S \cdot e^{\frac{V_{BE}}{V_T}}}{\beta}
\]

Emitter Current \( (i_E) \):

\[
i_E = i_C + i_B
\]

- Here, \( n = 1 \); Saturation current, \( 10^{-12} > I_S > 10^{-14} \) A and thermal voltage, \( V_T = 25 \) mV
- Note that \( i_C \) is independent of \( V_{CB} \), for \( V_{CB} \geq 0 \). So collector behaves as an ideal constant current source where the current is determined by \( V_{BE} \). (fig 2nd slide)
- Since, \( i_C = \alpha i_E \); \( i_C = \beta i_B \) and \( \alpha = \beta / (\beta + 1) \),
  where “\( \beta \)” is common emitter current gain constant for a particular BJT
  “\( \alpha \)” is common base current gain

So the Emitter Current is given by:

\[
i_E = i_C + i_B = \frac{\beta + 1}{\beta} \cdot I_S \cdot e^{\frac{V_{BE}}{V_T}}
\]

**Exercise BJT-1:** For an NPN transistor having \( I_S = 10^{-11} \) A,
\( \beta = 100 \) & \( V_T = 25 \) mV (at room temperature)
Calculate \( V_{BE} \) for \( i_C = 1.5 \) A

(Solution: 0.643 V)
The PNP Transistor operation in Active mode:

Note that the PNP transistors have $V_{EB}$; whereas the NPN transistors has $V_{BE}$. 
Summary of the BJT relationships in active & saturation modes

**Active Mode**

\[ i_C = I_S e^{\frac{v_{BE}}{V_T}} \]

\[ i_E = \frac{\beta + 1}{\beta} i_C \]

\[ i_C = \beta i_B \]

\[ i_E = i_C + i_B \]

\[ \alpha = \frac{\beta}{\beta + 1} \]

**Saturation Mode**

\[ i_C = I_S e^{\frac{v_{BE}}{V_T}} \]

\[ i_C \neq \beta i_B \quad \text{but} \quad i_C < \beta i_B \]

\[ i_E = i_C + i_B \]

\[ v_{CE} \approx 0.2V \]

For the pnp transistor, replace \( v_{BE} \) with \( v_{EB} \).
5.2.3: Dependence of current, voltage, temperature and the Early Effect:

- The collector current $i_C$ without the early voltage effect is given by $i_C = I_S e^{v_{BE}/V_T}$.
- Increase in $V_{CE}$ causes the base width to decrease due to increased reverse biasing on the collector-base junction.
- Since $I_S$ is inversely proportional to the base width, it increases with the decrease in base width.
- $i_C$ is directly proportional to $I_S$ and therefore increase in $I_S$ also increases the collector current.

This is called the early voltage effect and the new equation for $i_C$ is given by

$$i_C = I_S e^{v_{BE}/V_T} \left(1 + \frac{v_{CE}}{V_A}\right)$$

$$I_S = \frac{A_E q D_n r_i^2}{N_A W}$$

- Therefore the output resistance seen into the collector is defined and is given by

$$r_O = \left[\frac{\partial i_C}{\partial v_{CE}}\right]_{v_{CE} \text{ constant}}^{-1} \Rightarrow r_O \approx \frac{V_A}{I_C}$$

Exercise BJT-2: If a BJT has $V_A=100\text{v}$ and $I_C=1\text{mA}$, find $r_0$.
5.3.3: **Q-point/Biasing point:** Location of biasing point affects maximum allowable signal swing

Limited + swing of $v_{ce}$ as Q-point ($i_C$ & $v_{CE}$) is close to $v_{CC}$ (this case is for Low $R_c$)

(See figure 5.26)

5.4: **How to solve NPN or PNP BJT-DC circuits**

- If not specified, assume that the transistor is working in active mode.
- Use the simple constant-$V_{BE}$ model that is used for diode, i.e. take $V_{BE} = 0.7V$ for forward biased base-emitter junction.
- Analyze the circuit using current-voltage relationships for active mode operation.
- Check if the initial assumption of active mode operation was correct by verifying that the base-collector junction is reverse biased.
- If the active mode assumption was wrong than use the saturation mode current-voltage relationships for analysis.
Calculate $I_c$, $I_b$, $I_e$, $V_C$, $V_B$ of the following 'nnp' circuit. $\beta = 200$

Assume Active mode

$\{\text{CBJ} \rightarrow \text{RB} \}$
$\{\text{EBJ} \rightarrow \text{FB}\}$

Solution:

Base current is found as

$$-4 + I_B R_B + V_{BE} = 0$$

$$\Rightarrow I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{4 - 0.7}{220} = 15\mu A$$

Collector current is found as

$$I_C = \beta I_B = (200)(15\mu A) = 3mA$$

Emitter current is found as

$$I_E = I_B + I_C = (\beta + 1)I_B = 3.02mA$$

Collector voltage is calculated as

$$V_{CC} - V_C - I_C R_C = 0 \Rightarrow V_C = V_{CC} - I_C R_C$$

$$V_C = 4V$$

Since $V_C > V_B \Rightarrow \text{Base-Collector junction is reverse biased}$

$V_B = V_{BE} = 0.7V$

TRANSISTOR IN ACTIVE MODE
Find $I_C$, $I_B$, $I_E$, $V_C$, $V_E$ of the following 'n-p-n transistor' circuit. $\beta = 200$

Assume Active Mode

- Initial assumption was correct

Assume Cutoff

Find the bias point detail of the following n-p-n circuit, take $\beta = 100$

- Assume Active Mode

  of operation $\Rightarrow V_{BE}=0.7$

  $V_{CC}=5V$

  $R_C=0.5k\Omega$

  $I_B = \frac{I_C}{\beta} = 42.6\mu A$

  $I_C = \frac{\beta}{\beta + 1}$

  $I_E = \alpha I_E = 4.26mA$ \hspace{1cm} (Step 3)

  $R_E=1k\Omega$

  $I_E = \frac{V_E - V_{EE}}{R_E} = -\frac{0.7 - (-5)}{1k} = 4.3mA$ \hspace{1cm} (Step 2)

  $V_{EE} = -5V$

  $V_C = V_{CC} - I_C R_C = 2.87V$ \hspace{1cm} (Step 4)

  $V_E = -0.7V$ \hspace{1cm} (Step 1)

Solve examples 5.4 to 5.12

- Since CBJ is RB,
- Initial assumption was correct
5.5: Biasing single stage BJT Amplifiers: - Operating point or Q-point ($i_C$ and $v_{CE}$)

Find the dc bias point (operating point) of the following circuit

Voltage Divider Biasing

Applying KVL around the base emitter loop

$$V_{BB} = I_B R_B + V_{BE} + I_E R_E$$  Since $I_E = \frac{V_{BB} - V_{BE}}{R_E + [R_B/(\beta + 1)]]}$

$$I_E = \frac{1.29\text{mA}}{1.29\text{mA}} = 1.29\text{mA}$$

Now $I_B = \frac{I_E}{\beta + 1} = 0.0128\text{mA}$

Now $I_C = \beta I_B = 1.28\text{mA}$

$V_B = V_{BE} + I_E R_E = 4.57\text{V}$

$V_C = V_{CC} - I_C R_C = 8.6\text{V}$
Find the bias point detail of the following npn circuit, take $\beta = 100$

**Two supply Biasing**

$$V_{CC} = 5V$$

$$V_{CE} = 3.57V$$

$$R_C = 0.5k\Omega$$

$$(\text{Step 5})$$

$$I_B = \frac{I_C}{\beta} = 42.6\mu A$$

$$V_C = V_{CC} - I_C R_C = 2.87V$$

$$(\text{Step 4})$$

$$R_E = 1k\Omega$$

$$I_E = \frac{V_E - V_{EE}}{R_E} = \frac{-0.7 - (-5)}{1k} = 4.3mA$$

$$(\text{Step 2})$$

$$V_{EE} = -5V$$

**Exercises BJT-3**

**Design pnp BJT circuit such that $V_{EC} = 2.5V$. Take $\beta = 60$**

Applying KVL around the emitter collector loop

$$V_{CC} = I_E R_E + V_{EC}$$

$$\Rightarrow I_E = 1.25mA$$

$$I_C = \frac{\beta}{\beta + 1} I_E = \alpha I_E = 1.23mA$$

$$I_B = \frac{I_C}{\beta} = 20.5\mu A$$

Applying KVL around the emitter base loop

$$V_{CC} = I_E R_E + V_{EB} + I_B R_B + V_{BB}$$

$$\Rightarrow R_B = 190k\Omega$$
Solve the given circuit to find
(a) $I_C$, $I_E$ and $I_B$

(b) Prove that the transistor is working in active mode.

(Hint: Find $V_C$ and $V_B$ and if $V_C > V_B$, the transistor is working in active mode)

Answer: $I_E = 3.21 \text{mA}$

$I_C = 3.178 \text{mA}$

$I_B = 31.78 \mu\text{A}$

For the collector feedback circuit, the BJT used is specified to have $\beta$ values in the range of 20 to 200. For the two extreme values of $\beta$ ($\beta = 20$ and $\beta = 200$) find $I_E$, $V_E$ and $V_B$.

(Hint: Apply KVL in the loop starting from $V_{CC}$ to $R_F$ to $V_{BE}$ to $R_E$ to ground)

Answer: For $\beta = 20$

$I_E = 1.44 \text{mA}$

$V_E = 1.44 \text{V}$

$V_B = 2.14 \text{V}$

For $\beta = 200$

$I_E = 5.54 \text{mA}$

$V_E = 5.54 \text{V}$

$V_B = 6.24 \text{V}$

Exercises BJT-3:

Exercises BJT-4:

Solve example 5.13 & related exercises
5.6: BJT Amplifiers, Small-Signal Operation and Models:

- In linear amplifier the output signal is equal to the input signal multiplied by a constant. The value of this constant is usually greater than unity.
- To operate as an amplifier, the transistor must be biased in the active mode.
- The biasing problem is that of establishing a proper value of constant dc current in the emitter or collector of transistor.
- The operation of transistor as an amplifier is highly influenced by the value of the bias current also called operating point.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_C, V_{CE}$</td>
<td>DC values</td>
</tr>
<tr>
<td>$i_c, v_{ce}$</td>
<td>Instantaneous ac values</td>
</tr>
<tr>
<td>$i_C, v_{CE}$</td>
<td>Total instantaneous values</td>
</tr>
</tbody>
</table>

**DC Analysis**

\[
I_C = I_s e^{V_{BE}/V_T} \\
I_E = \frac{I_C}{\alpha} \\
I_B = \frac{I_C}{\beta} \\
V_C = V_{CE} = V_{CC} - I_C R_C
\]
The total base current is therefore given by

\[ i_B = \frac{i_C}{\beta} + \frac{1}{\beta} \cdot \frac{i_C}{V_T} \cdot v_{be} \]

DC bias current \( I_B \)  
ac signal current \( i_b \)

Thus, \( i_b = \frac{1}{\beta} \cdot \frac{i_C}{V_T} \cdot v_{be} = \frac{g_m}{\beta} \cdot v_{be} = \frac{1}{r_\pi} \cdot v_{be} \)

where \( r_\pi \) is the small signal input resistance between base and emitter, looking into the base

The total emitter current is therefore given by

\[ i_E = \frac{i_C}{\alpha} + \frac{1}{\alpha} \cdot \frac{i_C}{V_T} \cdot v_{be} \]

DC bias current \( I_E \)  
ac signal current \( i_e \)

Thus, \( i_e = \frac{1}{\alpha} \cdot \frac{i_C}{V_T} \cdot v_{be} = \frac{g_m}{\alpha} \cdot v_{be} = \frac{1}{r_e} \cdot v_{be} \)

where \( r_e \) is the small signal input resistance between base and emitter, looking into the emitter

Since \( \alpha \approx 1 \) \( \Rightarrow r_e \approx \frac{1}{g_m} \)
Two different versions of simplified **hybrid-Π model** for the small-signal operation of the BJT. **(a)** represents the BJT as a voltage-controlled current source (a transconductance amplifier) **(b)** represents the BJT as a current-controlled current source (a current amplifier).

Two slightly different versions of what is known as the **T model** of the BJT. The circuit in **(a)** is a voltage-controlled current source representation and that in **(b)** is a current-controlled current source representation. These models explicitly show the emitter resistance $r_e$ rather than the base resistance $r_{\Pi}$ featured in the hybrid-π model.

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**Solve example 5.14**
5.7.3: Common emitter Amplifier: **DC analysis** to find $I_B$, $I_C$, $I_E$, $V_B$, $V_C$ and $V_E$

Let's assume the BJT is operating in Active Mode. Thus, $I_C = \alpha.I_E$, $I_C = \beta.I_B$ and $\alpha = \beta/(\beta+1)$

Since $I_E = I$ mA ; $I_B = I_E / (\beta+1)$ mA ; $V_B = 0 - I_B.R_B$ ; $V_E = V_B - 0.7$ ;

Now $I_C = \alpha.I_E = (\beta.I_E) / (\beta+1)$ ; $V_C = V_{CC} - I_C.R_C$ and if CBJ remains RB then assumption is OK

**Exercise-5:** Find the operating point if $V_{CC}=V_{EE}=10V$, $R_C=8 \text{ k}\Omega$, $R_B=100 \text{ k}\Omega$, $I=1\text{ mA}$ & $\beta=100$

**Solution:** $Q$ or operating point is, $I_C=0.99$ mA ; $V_{CE}=0.3$ v \,(as \, V_B = -1v, \, V_C = 2v, \, V_E = -1.7v)$
5.7.3: Common emitter Amplifier: **AC analysis** to find Gain, Input & output Impedances

**Exercise-6:** Find $R_{in}, R_{out}, A_v, G_v$ if $R_{sig}=R_L=5k\Omega, R_B=100k, R_C=8k; I_C=1mA, I_B=0.01mA, V_A=100V, V_T=25mV$

**Solution:** $R_i=2.43\ k\Omega; R_{out}=7.4\ k\Omega; A_v=-119\ V/V, G_v=-39\ V/V$ (as $r_\pi=2.5K, g_m=40\ mA/V, r_0=100k$)
Exercises-7:

**DC analysis:** O/C capacitors 
& find $I_B$, $I_C$, $I_E$, $V_B$, $V_C$, $V_E$

*Find model parameters* ($r_\pi$, $r_e$, $g_m$)

**S/C DC voltage source**
**O/C DC current source**

**AC analysis:** S/C capacitors 
& find $\Re_{in}$, $\Re_{out}$, $A_V$, $A_i$

---

The transistor shown has $\beta=100$ and $V_A=100\,\text{V}$.

(a) Find the dc voltages at the base, emitter, and collector.

(b) Find $g_m$, $r_\pi$, and $r_o$.

(c) Draw the small signal equivalent circuit using hybrid-$\pi$ model (with $r_o$) and find the voltage gain.

(d) Neglect $r_o$ and again find the voltage gain and find the percentage error between (c) and (d).

**Hint:** When performing dc analysis open circuit all the capacitors. Notice that $I_E=I=1\,\text{mA}$. When performing small signal analysis short circuit all the capacitors and open circuit the dc current source $I$.

**Answer:** (a) -0.1V, -0.8V, +2V (b) 40mA/V, 2.5k$\Omega$, 100k$\Omega$ (c) -77 (d) -80 $+$3.9%
The transistor shown has $\beta=100$ and $V_{A}=100\text{V}$.

(a) Find the dc voltages at the base, emitter, and collector.

(b) Find $g_m$, $r_\pi$, and $r_e$

(c) Draw the small signal equivalent circuit using hybrid-$\pi$ model and find the voltage gain $A_v=v_o/v_i$.

**Answer:** (a) $0.7\text{v}$, $0\text{v}$, $3.1\text{v}$, (b) $92\text{ mA}/\text{v}$, $1.09 \text{ K}\Omega$, $10.8\text{ \Omega}$ (c) $-3.04$

### 5.7.4: Common emitter Amplifier with $R_e$ (emitter resistor):

Controlled voltage amp

**Exercises-8:**

- **DC Analysis**

**Exercise-9:** Find the operating point if $V_{CC}=V_{EE}=10\text{V}$, $R_C=8\ \text{k}\Omega$, $R_B=100\ \text{k}\Omega$, $I=1\text{mA}$ & $\beta=100$

**Solution:** operating point, $I_C=0.99\text{ mA}$ ; $V_{CE}=3.7\text{v}$ (as $I_E=1mA$ ; $V_B=-1v$, $V_C=2v$, $V_E=-1.7v$)
AC analysis

Remember, \( r_e = \frac{V_T}{I_E} \) & Resistance reflection rule \( R_{\text{base}} = (\beta+1)R_{\text{emitter}} \)

- input resistance at the base, \( R_{ib} \equiv \frac{v_i}{i_b} \), where \( i_b = \frac{i_e}{\beta+1} \), and \( v_i = i_e(r_e + R_e) \)

Thus, \( R_{ib} = (\beta+1)(r_e + R_e) \), **Remember**, \( r_e = \frac{V_T}{I_E} \) & Resistance reflection rule \( R_{\text{base}} = (\beta+1)R_{\text{emitter}} \)

- input resistance looking into base is \((\beta+1)\) times the total resistance in emitter.

Thus, \( \frac{R_{ib} \text{ (with } R_e \text{ included)}}{R_{ib} \text{ (without } R_e)} = \frac{(\beta+1)(r_e + R_e)}{(\beta+1)r_e} = 1 + \frac{R_e}{r_e} \equiv 1 + g_m R_e \); **Remember**, \( g_m = \frac{I_C}{V_T} \)

The output resistance \( R_{\text{out}} = R_C \) (as \( r_o \) of T-model is neglected to ease solution process)
5.7.3: Common Emitter (CE) with Emitter Resistance ($R_e$): AC analysis (cont’d…)

The voltage gain $A_v \equiv \frac{v_o}{v_i} = \frac{-i_c(R_C || R_L)}{i_e(r_e + R_e)} = -\frac{\alpha i_e(R_C || R_L)}{i_e(r_e + R_e)} = -\frac{\alpha(R_C || R_L)}{r_e + R_e}$

$$A_v \approx -\frac{R_C || R_L}{r_e + R_e}, \quad \text{if} \quad \alpha \equiv 1$$

The current gain $A_{is} = \frac{i_{os}}{i_i} = \frac{-\alpha i_e}{v_i/R_{in}} = -\frac{\alpha R_{in} i_e}{v_i} = -\frac{\alpha(R_B || R_{ib})}{r_e + R_e}$

$$A_{is} = -\beta, \quad \text{if} \quad R_B \gg R_{ib}, \alpha \equiv 1 \text{ and } R_{ib} = (\beta + 1)(r_e + R_e)$$

The overall voltage gain $G_v = \frac{v_i}{v_{sig}} \cdot A_v = -\frac{R_{in}}{R_{sig} + R_{in}} \frac{\alpha(R_C || R_L)}{r_e + R_e}$

The resistance $R_e$ in the emitter introduce a negative feedback ⇒ see pg 474

1. The input resistance $R_{ib}$ is increased by the factor $(1 + g_m R_e)$.
2. The voltage gain from base to collector, $A_v$, is reduced by factor $(1 + g_m R_e)$.
3. For the same nonlinear distortion, the input signal $v_i$ can be increased by the factor $(1 + g_m R_e)$.
4. The overall voltage gain is less dependant on the value of $\beta$.

**Exercise-10:** if $I_E=1\text{mA}$, $I_C=0.99\text{mA}$, $R_e=225\Omega$, $R_B=100k\Omega$, $R_C=8k\Omega$, $R_{sig}=R_L=5k\Omega$, $\beta=100$, $V_T=25\text{mV}$, Neglect $r_o$ to FIND $R_{in}$, $R_{out}$, $A_v$, $G_v$ ⇒ **Sol:** $R_{in}=20.16 \text{k}\Omega$; $R_{out}=8 \text{k}\Omega$, $A_v=-12.18\text{V/V}$, $G_v=-9.76\text{v/v}$
5.7.5: Common Base (CB) Amplifier: Unity-gain-current-amplifier or Current-buffer

**DC analysis**

Lets assume Active Mode.

\[ V_B = 0 \; ; \; V_E = V_B - 0.7 \; ; \]

\[ I_E = I \; mA \; ; \; I_B = I_E / (\beta+1) \; mA; \]

\[ I_C = \alpha.I_E = (\beta.I_E) / (\beta+1) \; ; \]

\[ V_C = V_{CC} - I_C.R_C \; \text{and} \]

if CBJ remains RB

then assumption is OK

---

**AC analysis:** For the AC equivalent circuit given in the figure in the next page,

The input resistance \( R_{in} = r_e \) and output resistance \( R_{out} = R_C \) (with \( r_o \) neglected)

The low \( R_{in} \) cause the input signal to be severely attenuated,

\[ \frac{v_i}{v_{sig}} = \frac{R_i}{R_{sig} + R_i} = \frac{r_e}{R_{sig} + r_e} \]
5.7.5: Common Base (CB) Amplifier: Low $Z_{\text{in}}$ makes it not good voltage amplifier

The voltage gain $A_v \equiv \frac{v_o}{v_i}$ as $v_o = -\alpha i_e (R_C \parallel R_L)$ and $v_i = -i_e \cdot r_e$

$$A_v \equiv \frac{v_o}{v_i} = \frac{\alpha}{r_e} (R_C \parallel R_L) = g_m (R_C \parallel R_L)$$

and the overall voltage gain $G_v = \frac{r_e}{R_{\text{sig}} + r_e} g_m (R_C \parallel R_L) = \frac{\alpha (R_C \parallel R_L)}{R_{\text{sig}} + r_e}$

Finally, a very significant application of the CB circuit is as a unity-gain current amplifier or **current buffer**: It accepts an input
**Exercise-11:** Determine the voltage gain of the circuit given in figure (a)

Hints: Draw the DC and AC (using T-model) equivalent circuits (as shown in figure)

The DC solutions are also shown in figure (b).  
Calculated \( r_e = 27 \, \Omega \)

The Gain of the circuit, calculated from figure (c) is, \( A_v = \frac{v_o}{v_i} = 183.3 \, \text{V/V} \)
5.7.5: Common Collector (CC) Amplifier: Emitter Follower

**DC analysis**

Assume Active Mode.

\[ I_E = I \text{ mA}; \ I_B = I_E / (\beta + 1) \text{ mA} \]

\[ V_B = 0 - (I_B)(R_B) \]

\[ V_E = V_B - 0.7 \]

\[ I_C = \alpha . I_E = (\beta . I_E) / (\beta + 1) \]

\[ V_C = V_{CC} \]

if CBJ remains RB
then assumption is OK

**AC analysis**

**Figures from text book**
AC analysis

Emitter to Base:
*Figures from text book*

\[
R_{\text{in}} = R_B/(\beta + 1)(r_e + (r_o//R_L))
\]

\[
G_v = \frac{v_o}{v_{\text{sig}}} = \frac{R_B}{R_{\text{sig}} + R_B} \frac{(\beta + 1)(r_o//R_L)}{(\beta + 1)(r_e + (r_o//R_L))}
\]

Base to Emitter

\[
G_v = \frac{v_o}{v_{\text{sig}}} = \frac{R_B}{R_{\text{sig}} + R_B} \frac{(r_o//R_L)}{(r_o//R_L) + r_e + (r_o//R_L)}
\]

\[
R_{\text{out}} = r_o \parallel \left( r_e + \frac{R_{\text{sig}}//R_B}{\beta + 1} \right)
\]
Consider the CB amplifier shown in the figure. To what value must current source 'I' be set in order that the input resistance at emitter 'Ri' is equal to that of the source (namely 50Ω)? What is the resulting voltage gain from the source to the load? Assume $\alpha=1$ and neglect early voltage effect.

**Hint**: Since $\alpha=1$, therefore $I_E=I_C=I$. Using T-model, it's easy to see that $R_i=r_e$. Find $r_e$ in terms of $I$ and put it equal to 50 to find $I$.

Find the voltage gain $A_v=v_o/v_s$ from the T-model. **Answer**: $I = 0.5\, \text{mA} \quad ; \quad A_v = 50$

In the CC amplifier shown, the BJT used is specified to have β values in the range of 20 to 200 (a distressing situation for the circuit designer). For the two extreme values of β ($\beta=20$ and $\beta=200$), find

(a) the input resistance, $R_i$
(b) the overall voltage gain, $G_v$

The result will show why electronic engineers want to design biasing circuits that are independent of variations in β.

**Answer**: $\beta=20 \quad G_v = v_o/v_s = 0.478 \quad ; \quad R_i = 9.8\, \text{kΩ}$

$\beta=200 \quad G_v = v_o/v_s = 0.827 \quad ; \quad R_i = 50.3\, \text{kΩ}$
Exercise-14: For the following circuits, find the expressions for $R_{in}$, $R_{out}$, $A_v$.

Assignment Problems: 5.21, 5.26, 5.72, 5.83(b), 5.130, 5.134, 5.135, 5.143, and 5.141 ➔ Due on next week.
Design Criteria of a BJT Amplifier (review):

**Figures from text book**
Simulation Examples using the Spice software: