Key educational goals:

Develop the basic principle of operation of a BJT. Classify the different types of BJTs and analyze their applications.

Reading/Preparatory activities for class


ii) Power-point file: BJT

Questions to guide your reading and to think about ahead of time.

1. Why is the rationale for different symbols for NPN and PNP BJT?
2. What are the three different modes of operation of a BJT?
3. What are the three reasons for a BJT to go into saturation?
4. Why should the bias point of a BJT be invariant to temperature, $\beta$ etc. changes?
5. What is the difference between a large signal BJT model and a small signal BJT model?
6. In what mode (active, cutoff and saturation) do amplifiers operate?
7. What type of an amplifier is a BJT based voltage regulator and why is it better than a zener diode based voltage regulator?
8. Which type of BJT is more convenient to use for current source application and why?
Introduction
Chapter 1: Introduction and Chapter 2: Resistive circuits

The main concepts for the module

1. Analyze how a BJT conducts in active region even though the base collector junction is reverse biased.
2. Evaluate physically how a BJT can get into saturation following the fluid-jet controlled valve models.
3. Develop the concept of a load line to determine an operating point in a BJT circuit.
4. Analyze how the transistor $\beta$ variation can drive a BJT from active to saturation region and vice-versa.
5. Evaluate the position of the bias point for the best possible amplifier operation.
6. Analyze the need for a common emitter amplifier to be different from emitter follower amplifier?
5. Identify an application area where BJTs are made to work in saturation region.
Summary

The knowledge gained from this module will be useful for designing amplifiers for increasing transducer signals, voltage regulators for supplying regulated dc voltage and simple logic circuits (known as TTL or transistor transistor logic).

For next time

We will next look into the Metal Oxide Junction Field effect transistor (MOSFET) which works like a voltage controlled current source.

Sample test/exam questions/problems to help you study:

1. Is Q1 in the next slide (Fig. 1) in saturation or active region? The manufacturer suggest an active region $\beta$ of 200. See flowchart on slide 5 to solve.

2. In Fig. 2 (next slide) if $V_1 = 15V$, $R_1 = 9.1 \, k\Omega$, $R_2 = 3.9 \, k\beta$, $RE = 100\Omega$, $\beta = 75$ for Q2; calculate $I_B$ and the upper limit of RC for the above current source to work properly as a current source.
Fig. 1

Fig. 2
Flowchart to determine BJT’s region of operation

1. Find $I_B = (V_{CC} - V_{BE})/R_B$

2. Use suggested $\beta$ to compute $I_C = \beta I_B$

3. BJT is in active or quasi-saturation region. Keep $\beta$ as suggested and use $I_C$ as in 2.

4. BJT is in saturation. Choose $V_{CE} = 0.2$ and compute new $I_C = (V_{CC} - V_{CE})/R_C$

5. Choose new $\beta = I_C / I_B$
Transistors

• Different types of transistors and their descriptions
• Classification of BJTs (NPN and PNP)
• Operational characteristics of a NPN BJT and analogy with a controlled valve
• BJT $\alpha$ and $\beta$
• Different operating regions of a BJT: active, cut-off and saturation with examples
• Large signal (DC) model of BJT and setting up bias (Q) points
• Analysis of 4 resistor bias circuit
• Small signal model of a BJT
• Analysis of CE and Emitter follower amplifiers with examples
• Voltage regulator analysis with example
• PNP BJT current source with example
Transistors

• They are unidirectional current carrying devices like diodes with capability to control the current flowing through them

• The switch current can be controlled by either current or voltage

• Bipolar Junction Transistors (BJT) control current by current

• Field Effect Transistors (FET) control current by voltage

• They can be used either as switches or as amplifiers

• Diodes and Transistors are the basic building blocks of the multibillion dollar semiconductor industries
NPN Bipolar Junction Transistor

- One N-P (Base Collector) diode one P-N (Base Emitter) diode

Figure 13.1 The $npn$ BJT.
PNP Bipolar Junction Transistor

- One P-N (Base Collector) diode one N-P (Base Emitter) diode

![Diagram of PNP Bipolar Junction Transistor]

Figure 13.13 The $pnp$ BJT.
Analogy with Transistor: Fluid-jet operated Valve
**NPN BJT Current flow**

**Figure 13.3** Only a small fraction of the emitter current flows into the base (provided that the collector–base junction is reverse biased and the base–emitter junction is forward biased).
BJT $\alpha$ and $\beta$

- From the previous figure $i_E = i_B + i_C$
- Define $\alpha = \frac{i_C}{i_E}$
- Define $\beta = \frac{i_C}{i_B}$
- Then $\beta = \frac{i_C}{(i_E - i_C)} = \frac{\alpha}{1 - \alpha}$
- Then $i_C = \alpha i_E$; $i_B = (1 - \alpha) i_E$

- Typically $\beta \approx 100$ for small signal BJTs (BJTs that handle low power) operating in active region (region where BJTs work as amplifiers)
BJT in Active Region

Common Emitter (CE) Connection

• Called CE because emitter is common to both \( V_{BB} \) and \( V_{CC} \)
Analogy with Transistor in Active Region: Fluid-jet operated Valve

In active region this stopper does not really have noticeable effect on the flow rate.
BJT in Active Region (2)

- Base Emitter junction is forward biased
- Base Collector junction is reverse biased

- For a particular $i_B$, $i_C$ is independent of $R_{CC}$
  $\Rightarrow$ transistor is acting as current controlled current source ($i_C$ is controlled by $i_B$, and $i_C = \beta i_B$)

- Since the base emitter junction is forward biased, from Shockley equation

$$i_E = I_{ES} \left[ \exp \left( \frac{V_{BE}}{V_T} \right) - 1 \right]$$
BJT in Active Region (3)

• Since \( i_B = (1 - \alpha) i_E \), the previous equation can be rewritten as

\[
i_B = (1 - \alpha) I_{ES} \left[ \exp \left( \frac{V_{BE}}{V_T} \right) - 1 \right]
\]

• Normally the above equation is never used to calculate \( i_B \) since for all small signal transistors \( V_{BE} \approx 0.7 \). It is only useful for deriving the small signal characteristics of the BJT.

• For example, for the CE connection, \( i_B \) can be simply calculated as,

\[
i_B = \frac{V_{BB} - V_{BE}}{R_{BB}}
\]

or by drawing load line on the base – emitter side.
Deriving BJT Operating points in Active Region – An Example

In the CE Transistor circuit shown earlier $V_{BB} = 5V$, $R_{BB} = 107.5$ kΩ, $R_{CC} = 1$ kΩ, $V_{CC} = 10V$. Find $I_B, I_C, V_{CE}, \beta$ and the transistor power dissipation using the characteristics as shown below.

By Applying KVL to the base emitter circuit

$$I_B = \frac{V_{BB} - V_{BE}}{R_{BB}}$$

By using this equation along with the $i_B / v_{BE}$ characteristics of the base emitter junction, $I_B = 40 \mu A$
Deriving BJT Operating points in Active Region – An Example (2)

By Applying KVL to the collector emitter circuit

\[ I_C = \frac{V_{CC} - V_{CE}}{R_{CC}} \]

By using this equation along with the \( i_C / v_{CE} \) characteristics of the base collector junction, \( i_C = 4 \text{ mA}, V_{CE} = 6\text{V} \)

\[ \beta = \frac{I_C}{I_B} = \frac{4\text{mA}}{40\mu\text{A}} = 100 \]

Transistor power dissipation = \( V_{CE}I_C = 24 \text{ mW} \)

We can also solve the problem without using the characteristics if \( \beta \) and \( V_{BE} \) values are known
Deriving BJT Operating points in Active Region – An Example (3)

Input Characteristics

Output Characteristics
BJT in Cutoff Region

• Under this condition $i_B = 0$

• As a result $i_C$ becomes negligibly small

• Both base-emitter as well base-collector junctions may be reverse biased

• Under this condition the BJT can be treated as an off switch
Analogy with Transistor Cutoff Fluid-jet operated Valve
BJT in Saturation Region

• Under this condition $i_C / i_B < \beta$ in active region

• Both base emitter as well as base collector junctions are forward biased

• $V_{CE} \approx 0.2$ V

• Under this condition the BJT can be treated as an on switch
A BJT can enter saturation in the following ways (refer to the CE circuit):

- For a particular value of \( i_B \), if we keep on increasing \( R_{CC} \)
- For a particular value of \( R_{CC} \), if we keep on increasing \( i_B \)
- For a particular value of \( i_B \), if we replace the transistor with one with higher \( \beta \)
Analogy with Transistor in Saturation Region: Fluid-jet operated Valve(1)

This stopper is almost closed; thus valve position does not have much influence on the flow rate
Analogy with Transistor Saturation Fluid-jet operated Valve (2)

The valve is wide open; thus changing valve position a little does not have much influence on the flow rate.
BJT in Saturation Region – Example 1

In the CE Transistor circuit shown earlier $V_{BB} = 5V$, $R_{BB} = 107.5k\Omega$, $R_{CC} = 100k\Omega$, $V_{CC} = 10V$. Find $I_B, I_C, V_{CE}, \beta$ and the transistor power dissipation using the characteristics as shown below.

Here even though $I_B$ is still 40 $\mu$A; from the output characteristics $I_C$ can be found to be only about 1mA and $V_{CE} \approx 0.2V(\Rightarrow V_{BC} \approx 0.5V$ or base collector junction is forward biased (how?))

$\beta = \frac{I_C}{I_B} = \frac{1mA}{40 \mu A} = 25 < 100$
BJT in Saturation Region – Example 1 (2)

Input Characteristics

BJT
BJT in Saturation Region – Example 2

In the CE Transistor circuit shown earlier $V_{BB} = 5\text{V}$, $R_{BB} = 50\ \text{k}\Omega$, $R_{CC} = 1\ \text{k}\Omega$, $V_{CC} = 10\text{V}$. Find $I_B, I_C, V_{CE}, \beta$ and the transistor power dissipation using the characteristics as shown below.

Here $I_B$ is $80\ \mu\text{A}$ from the input characteristics; $I_C$ can be found to be only about $7.9\ \text{mA}$ from the output characteristics and $V_{CE} \approx 0.5\text{V}$ ($\Rightarrow V_{BC} \approx 0.2\text{V}$ or base collector junction is forward biased (how?))

$$\beta = \frac{I_C}{I_B} = \frac{7.9\ \text{mA}}{80\ \mu\text{A}} = 98.75 < 100$$

Transistor power dissipation $= V_{CE} I_C \approx 4\ \text{mW}$

Note: In this case the BJT is not in very hard saturation
BJT in Saturation Region – Example 2 (2)

Input Characteristics

Output Characteristics
BJT in Saturation Region – Example 3

In the CE Transistor circuit shown earlier \( V_{BB} = 5V, V_{BE} = 0.7V \) \( R_{BB} = 107.5 \text{k}\Omega, R_{CC} = 1 \text{k}\Omega, V_{CC} = 10V, \beta = 400 \). Find \( I_B, I_C, V_{CE} \), and the transistor power dissipation using the characteristics as shown below

By Applying KVL to the base emitter circuit

\[
I_B = \frac{V_{BB} - V_{BE}}{R_{BB}} = 40\mu A
\]

Then \( I_C = \beta I_B = 400*40 \mu A = 16000 \mu A \)

and \( V_{CE} = V_{CC} - R_{CC} I_C = 10 - 0.016*1000 = -6V(?) \)

But \( V_{CE} \) cannot become negative (since current can flow only from collector to emitter).

Hence the transistor is in saturation
BJT in Saturation Region – Example 3(2)

Hence $V_{CE} \approx 0.2\text{V}$

$\therefore I_C = (10 - 0.2)/1 = 9.8 \text{ mA}$

Hence the operating $\beta = 9.8 \text{ mA} / 40 \mu\text{A} = 245$
**Figure 13.12** Amplification occurs in the active region. Clipping occurs when the instantaneous operating point enters saturation or cutoff. In saturation, $v_{CE} \approx 0.2$ V.
Figure 13.17 Regions of operation on the characteristics of an npn BJT.
Figure 13.16  BJT large-signal models. (Note: Values shown are appropriate for typical small-signal silicon devices at a temperature of 300 K.)
BJT ‘Q’ Point (Bias Point)

• Q point means Quiescent or Operating point

• Very important for amplifiers because wrong ‘Q’ point selection increases amplifier distortion

• Need to have a stable ‘Q’ point, meaning the operating point should not be sensitive to variation to temperature or BJT $\beta$, which can vary widely
Four Resistor bias Circuit for Stable ‘Q’ Point

By far best circuit for providing stable bias point
Analysis of 4 Resistor Bias Circuit

\[
V_B = V_{TH} = \frac{V_{cc} R_2}{R_1 + R_2} \quad R_B = R_{TH} = \frac{R_1 R_2}{R_1 + R_2}
\]

BJT
Analysis of 4 Resistor Bias Circuit (2)

Applying KVL to the base-emitter circuit of the Thevenized Equivalent form

\[ V_B - I_B R_B - V_{BE} - I_E R_E = 0 \quad \text{LP51} \]

Since \( I_E = I_B + I_C = I_B + \beta I_B = (1 + \beta)I_B \quad \text{LP52} \)

Replacing \( I_E \) by \((1 + \beta)I_B\) in LP51, we get

\[ I_B = \frac{V_B - V_{BE}}{R_B + (1 + \beta)R_E} \quad \text{LP53} \]

If we design \((1 + \beta)R_E >> R_B\) (say \((1 + \beta)R_E >> 100R_B\))

Then \( I_B \approx \frac{V_B - V_{BE}}{(1 + \beta)R_E} \quad \text{LP54} \)
Analysis of 4 Resistor Bias Circuit (3)

And \[ I_C = I_E \approx \frac{V_B - V_{BE}}{R_E} \] (for large \( \beta \)) LP55

Hence \( I_C \) and \( I_E \) become independent of \( \beta \)!

Thus we can set up a Q-point independent of \( \beta \) which tends to vary widely even within transistors of identical part number (For example, \( \beta \) of 2N2222A, a NPN BJT can vary between 75 and 325 for \( I_C = 1 \) mA and \( V_{CE} = 10 \) V)
A 2N2222A is connected as shown with $R_1 = 6.8 \, \text{k}\Omega$, $R_2 = 1 \, \text{k}\Omega$, $R_C = 3.3 \, \text{k}\Omega$, $R_E = 1 \, \text{k}\Omega$ and $V_{CC} = 30\text{V}$. Assume $V_{BE} = 0.7\text{V}$. Compute $V_{CC}$ and $I_C$ for $\beta = i)100$ and ii) 300
4 Resistor Bias Circuit – Example (1)

i) $\beta = 100$

\[
V_B = V_{TH} = \frac{V_{cc} \cdot R_2}{R_1 + R_2} = \frac{30 \times 1}{6.8 + 1} = 3.85\text{V}
\]

\[
R_B = R_{TH} = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{6.8 \times 1}{6.8 + 1} = 0.872\text{k}\Omega
\]

\[
I_B = \frac{V_B - V_{BE}}{R_B + (1 + \beta)R_E} = \frac{3.85 - 0.7}{0.872 + 101 \times 1} = 30.92\mu\text{A}
\]

\[
I_{CQ} = \beta I_B = 3.09\text{ mA}
\]

\[
I_{EQ} = (1 + \beta)I_B = 3.12\text{ mA}
\]

\[
V_{CEQ} = V_{CC} - I_C R_C - I_E R_E = 30 - 3.09 \times 3.3 - 3.12 \times 1 = 16.68\text{V}
\]
4 Resistor Bias Circuit – Example (2)

i) $\beta = 300$

$$V_B = V_{TH} = \frac{V_{cc} \cdot R_2}{R_1 + R_2} = \frac{30 \times 1}{6.8 + 1} = 3.85\,V$$

$$R_B = R_{TH} = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{6.8 \times 1}{6.8 + 1} = 0.872\,k\Omega$$

$$I_B = \frac{V_B - V_{BE}}{R_B + (1 + \beta)R_E} = \frac{3.85 - 0.7}{0.872 + 301 \times 1} = 10.43\,\mu A$$

$$I_{CQ} = 300I_B = 3.13\,mA$$

$$I_{EQ} = (1 + \beta)I_B = 3.14\,mA$$

$$V_{CEQ} = V_{CC} - I_C R_C - I_E R_E = 30 - 3.13 \times 3.3 - 3.14 \times 1 = 16.53\,V$$
The above table shows that even with wide variation of $\beta$ the bias points are very stable.

<table>
<thead>
<tr>
<th></th>
<th>$\beta = 100$</th>
<th>$\beta = 300$</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCEQ</td>
<td>16.68 V</td>
<td>16.53 V</td>
<td>0.9 %</td>
</tr>
<tr>
<td>ICQ</td>
<td>3.09 mA</td>
<td>3.13 mA</td>
<td>1.29 %</td>
</tr>
</tbody>
</table>
In both cases BJT is in Active Region. The BJT model on the left is applicable for this dc bias circuit. However this model is NOT APPLICABLE for the small signal ac equivalent circuit drawn in next slide.
Common Emitter Amplifier

Figure 13.27 Common-emitter amplifier.
How does the CE Amplifier appears to DC Source?

Why? Since all the capacitors appears as open to dc source
How does the CE Amplifier appears to AC Source?

Figure 13.27 Common-emitter amplifier.
Answer

• $C_1$, $C_2$, $C_E$ are chosen such that $1/\omega C_1$, $1/\omega C_2$, $1/\omega C_E \approx 0$, that is all capacitors appear as short to the AC source

• The DC source appears as a short to the AC source

• The base-emitter junction appears a resistance $r_\pi$ to the small signal variation around ‘Q’ point

• The BJT model appears as shown below

![BJT Model Diagram]

Figure 13.26 Small-signal equivalent circuit for the BJT.
Computing $r_\pi$

The Shockley equation for a base emitter junction working at a stable ‘Q’ point is

$$i_{EQ} = I_{ES} \left[ \exp \left( \frac{V_{BEQ}}{V_T} \right) - 1 \right]$$  \hspace{1cm} \text{LP56}

Then

$$\frac{dI_{EQ}}{dV_{BEQ}} = \frac{I_{ES}}{V_T} \exp \left( \frac{V_{BEQ}}{V_T} \right)$$  \hspace{1cm} \text{LP57}

Since in a forward biased B-E junction

$$\exp \left( \frac{V_{BEQ}}{V_T} \right) \gg 1$$
Computing $r_\pi (2)$

\[
\frac{dI_{EQ}}{dV_{BEQ}} \approx \frac{I_{ES}}{V_T} \left( \exp \left( \frac{V_{BEQ}}{V_T} \right) - 1 \right) \]

\(\text{LP58}\)

\[= I_{EQ}\]

\[\therefore \quad \frac{dI_{EQ}}{dV_{BEQ}} \approx \frac{I_{EQ}}{V_T} \quad \text{LP59}\]
Computing $r_\pi$ (3)

Define

$$r_\pi = \frac{v_{be}}{i_b} = \frac{dV_{BEQ}}{dl_{EQ}}$$

which describes the small variation in $I_{BQ}$ due to the small variation in $V_{BEQ}$. This is basically the reciprocal of the gradient of the $I_B$ versus $V_{BE}$ characteristics at the quiescent point as shown below.

Since $V_T = 26$ mV at 300°K

$$r_\pi = \frac{0.026 \beta}{I_{EQ}}$$  at 300°K
Compute $A_V$, $Z_{in}$ etc. for Common Emitter Amplifier using “Greenboard”
Common Emitter Amplifier

Find $A_v$, $A'_v$, $A_{vo}$, $A_i$, $Z_{in}$, $G$, $Z_o$, $v_o'$ of the CE Amplifier shown in the next slide. Temperature $= 300^0 K$. $V_T = 26 \text{ mV}$. $I_{EQ} \approx I_{CQ} = 3.13 \text{ mA}$, $V_T = 26 \text{ mV}$, $V_{BEQ} = 0.7 \text{ V}$. 
Common Emitter Amplifier

$+30 \text{ V}$

$R_1 = 6.8 \text{ k}\Omega$

$R_C = 3.3 \text{ k}\Omega$

$C_2 = 50 \mu\text{F}$

$R_L = 2.7 \text{ k}\Omega$

$R_s = 100 \Omega$

$R_2 = 1 \text{ k}\Omega$

$R_E = 1 \text{ k}\Omega$

$C_1 = 50 \mu\text{F}$

$V_s = 1 \text{ kHz}$; $20 \text{ mV}_{pp}$
Common Emitter Amplifier

+30 V

1 kΩ

6.8 kΩ

3.3 kΩ

+3.13 V

+30 V

1kHz; 20mV_{pp}

V_{S}

0

2.96V_{pp}

Vo

2.96V_{pp}

2.7 kΩ

+16.53 V

17.32mV_{pp}

+3.85 V

100Ω
Common Emitter Amplifier Performance

(Note the phase inversion)
Emitter Follower

(a) Actual circuit

(b) Small-signal equivalent circuit

(c) Equivalent circuit used to find output impedance $Z_o$

**Figure 13.30** Emitter follower.
Compute $A_V$, $Z_{in}$ etc. for Emitter Follower using “Greenboard”
Practical Multistage Amplifier

- **Emitter Follower** (For high input impedance so that the source does not get loaded)
- **Common Emitter Amplifier** (For voltage gain)
- **Emitter Follower** (For low output impedance so that load cannot affect amplifier gain)

$V_s$
Voltage Regulators (Derived from Emitter Followers)

The similarity between Emitter follower and voltage regulator can be readily appreciated by redrawing (a) as (b) without the capacitor (mainly used for improving transient performance)
How does the Regulator work

• Note that $V_o = V_Z - V_{BE}$

• As $V_o$ tries to change, $V_{BE}$ is disturbed since $V_Z$ is constant

• This causes $I_B$ the base current of Q1 to change

• A change of $I_B$ causes $V_{CE}$ to adjust in such a way so as to compensate for the change in $V_o$
Voltage Regulator Example

If \( V_1 = 20\text{V}, \ RL = 15 \ \Omega, \ RS = 680 \ \Omega, \ V_Z = 10\text{V}, \ \beta = 80; \) calculate \( I_Z \) and power dissipation in Q1

\[
V_o = V_Z - V_{BE} = 10 - 0.7 = 9.3\text{V}
\]

\[
\therefore I_L = \frac{V_o}{RL} = \frac{9.3}{15} = 0.62\text{A} = \text{Emitter current}
\]

\[
\therefore I_B = \frac{I_L}{(1 + \beta)} = \frac{0.62}{81} = 7.65 \text{mA}
\]

Now \( I_s = \frac{(V_1 - V_Z)}{Rs} = \frac{10}{680} = 14.71 \text{mA} \)

\[
\therefore I_z = I_s - I_B = (14.71 - 7.65) \text{mA} = 7.06 \text{mA}
\]
Voltage Regulator Example(2)

Now $I_E = I_L = 0.62$ A

$\therefore I_C = I_E - I_B \approx I_E = 0.62$ A

Now $V_{CE} = V_1 - V_o = 20 - 9.3 = 10.7$ V

$\therefore P_D = Q1$ dissipation $= V_{CE}I_C = 10.7 * 0.62 = 6.63$W

Hence Q1 will definitely need a heatsink.
Biasing PNP BJT
PNP BJT Current Source
PNP BJT Current Source

\[ V_B = V_{TH} = \frac{V_1 R_2}{R_1 + R_2} \]

\[ R_B = R_{TH} = \frac{R_1 R_2}{R_1 + R_2} \]
Analyzing PNP BJT Current Source

Applying KVL to the base-emitter circuit of the Thevenized Equivalent form

\[ V1 - I_B R_B - V_{EB} - I_E R_E - V_B = 0 \]

\[ \therefore \quad I_E = \frac{V1 - V_B - V_{EB}}{R_E + R_B/(1 + \beta)} \quad \text{By replacing } I_B = I_E/(1+\beta) \]

\[ \therefore \quad I_C = \beta I_B = \frac{\beta}{1 + \beta} I_E = \frac{\beta(V1 - V_B - V_{EB})}{R_B + R_E(1 + \beta)} \]

Thus \( I_C \) is independent of \( R_C \)
Analyzing PNP BJT Current Source (2)

The circuit works only in the active region

Thus the current source works until

\[ I_E R_E + I_C R_C \leq V_1 - V_{EC} \text{ (sat)} \]

or

\[ R_C \leq \frac{V_1 - I_E R_E - V_{EC} \text{ (sat)}}{I_C} \]

If \( R_C \) is above this value the transistor will be driven into saturation
Example of PNP BJT Current Source (2)

If \( V_1 = 15V \), \( R_1 = 9.1 \, k\Omega \), \( R_2 = 3.9 \, k\Omega \), \( R_E = 100 \, \Omega \), \( \beta = 75 \); calculate \( I_B \) and the upper limit of \( R_C \) for the above current source to work properly as a current source.

\[
R_B = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{9.1 \times 3.9}{9.1 + 3.9} = 2.73 \, k\Omega
\]

\[
V_B = \frac{V_1 \times 3.9}{9.1 + 3.9} = 4.5V
\]

\[
\therefore \quad I_E = \frac{V_1 - V_B - V_{EB}}{R_E + R_B/(1+\beta)} = 72.2mA
\]

\[
\therefore \quad I_B = \frac{I_E}{(1+\beta)} = 0.95mA
\]
Example of PNP BJT Current Source (3)

\[ I_C = \beta I_B = 71.25 \text{ mA} \]

\[ R_C \leq \frac{V_1 - I_E R_E - V_{EC} \text{(sat)}}{I_C} = \frac{15 - 72.2 \times 0.1 - 0.2}{71.25} = 101 \ \Omega \]