Steps for D.C. Analysis of BJT Circuits

To analyze BJT circuit with D.C. sources, we must follow these five steps:

1. **ASSUME** an operating mode

2. **ENFORCE** the equality conditions of that mode.

3. **ANALYZE** the circuit with the enforced conditions.

4. **CHECK** the inequality conditions of the mode for consistency with original assumption. If consistent, the analysis is complete; if inconsistent, go to step 5.

5. **MODIFY** your original assumption and repeat all steps.

Let's look at each step in detail.

1. **ASSUME**

We can ASSUME Active, Saturation, or Cutoff!
2. **ENFORCE**

**Active**

For active region, we must **ENFORCE two equalities**.

a) Since the base-emitter junction is **forward** biased in the active region, we **ENFORCE** these equalities:

\[
V_{BE} = 0.7 \, \text{V} \quad \text{(npn)} \\
V_{EB} = 0.7 \, \text{V} \quad \text{(pnp)}
\]

b) We likewise know that in the **active** region, the base and collector currents are directly proportional, and thus we **ENFORCE** the equality:

\[
i_C = \beta i_B
\]

Note we can **equivalently** **ENFORCE** this condition with either of the the equalities:

\[
i_C = \alpha i_E \quad \text{or} \quad i_E = (\beta + 1) i_B
\]
Saturation

For saturation region, we must likewise ENFORCE two equalities.

a) Since the base-emitter junction is forward biased, we again ENFORCE these equalities:

\[ V_{BE} = 0.7 \text{ V (npn)} \]
\[ V_{EB} = 0.7 \text{ V (pnp)} \]

b) Likewise, since the collector base junction is reverse biased, we ENFORCE these equalities:

\[ V_{CB} = -0.5 \text{ V (npn)} \]
\[ V_{BC} \approx -0.5 \text{ V (pnp)} \]

Note that from KVL, the above two ENFORCED equalities will require that these equalities likewise be true:

\[ V_{CE} = 0.2 \text{ V (npn)} \]
\[ V_{EC} = 0.2 \text{ V (pnp)} \]
Note that for saturation, you need to explicitly ENFORCE any **two** of these **three** equalities—the third will be ENFORCED automatically (via KVL)!!

To avoid negative signs (e.g., $V_{CB}=-0.5$), I typically ENFORCE the first and third equalities (e.g., $V_{BE}=0.7$ and $V_{CE}=0.2$).

**Cutoff**

For a BJT in cutoff, both $pn$ junctions are reverse biased—no current flows! Therefore we ENFORCE these equalities:

\[
\begin{align*}
    i_B &= 0 \\
    i_C &= 0 \\
    i_E &= 0
\end{align*}
\]

**3. ANALYZE**

**Active**

The task in D.C. analysis of a BJT in active mode is to find one unknown current and one additional unknown voltage!

a) In addition the relationship $i_C = \beta i_B$, we have a second useful relationship:

\[
i_E = i_C + i_B
\]
This of course is a consequence of KCL, and is true \textit{regardless} of the BJT mode.

But think about what this means! We have \textbf{two} current equations and \textbf{three} currents (i.e., $i_E$, $i_C$, $i_B$)—we only need to determine \textbf{one} current and we can then immediately find the other two!

\textbf{Q: Which current do we need to find?}

\textbf{A:} Doesn’t matter! For a BJT operating in the active region, if we know \textbf{one} current, we know them all!

\textit{b)} In addition to $V_{BE} = 0.7 \ (V_{EB} = 0.7)$, we have a \textbf{second} useful relationship:

\begin{align*}
V_{CE} &= V_{CB} + V_{BE} \quad \text{(npn)} \\
V_{EC} &= V_{EB} + V_{BC} \quad \text{(pnp)}
\end{align*}

This of course is a consequence of KVL, and is true \textit{regardless} of the BJT mode.

Combining these results, we find:

\begin{align*}
V_{CE} &= V_{CB} + 0.7 \quad \text{(npn)} \\
V_{EC} &= 0.7 + V_{BC} \quad \text{(pnp)}
\end{align*}
But think about what this means! If we find one unknown voltage, we can immediately determine the other.

Therefore, a D.C. analysis problem for a BJT operating in the active region reduces to:

find one of these values

\[ i_B, i_C, \text{ or } i_E \]

and find one of these values

\[ V_{CE} \text{ or } V_{CB} \quad (V_{EC} \text{ or } V_{BC}) \]

**Saturation**

For the saturation mode, we know all the BJT voltages, but know nothing about BJT currents!

Thus, for an analysis of circuit with a BJT in saturation, we need to find any two of the three quantities:

\[ i_B, i_C, i_E \]

We can then use KCL to find the third.

**Cutoff**

Cutoff is a bit of the opposite of saturation—we know all the BJT currents (they’re all zero!), but we know nothing about BJT voltages!
Thus, for an analysis of circuit with a BJT in cutoff, we need to find any two of the three quantities:

\[ V_{BE}, V_{CB}, V_{CE} \quad (npn) \]
\[ V_{EB}, V_{BC}, V_{EC} \quad (pnp) \]

We can then use KVL to find the third.

4. **CHECK**

You do not know if your D.C. analysis is correct unless you CHECK to see if it is consistent with your original assumption!

**WARNING!**-Failure to CHECK the original assumption will result in a SIGNIFICANT REDUCTION in credit on exams, regardless of the accuracy of the analysis !!!

**Q:** What exactly do we CHECK?

**A:** We ENFORCED the mode equalities, we CHECK the mode inequalities.

**Active**

We must CHECK two separate inequalities after analyzing a circuit with a BJT that we ASSUMED to be operating in active mode. One inequality involves BJT voltages, the other BJT currents.
a) In the **active** region, the Collector-Base Junction is "off" (i.e., **reverse** biased). Therefore, we must **CHECK** our analysis results to see if they are **consistent** with:

\[
\begin{align*}
V_{CB} &> 0 \quad \text{(nnp)} \\
V_{BC} &> 0 \quad \text{(pnp)}
\end{align*}
\]

Since \( V_{CE} = V_{CB} + 0.7 \), we find that an **equivalent** inequality is:

\[
\begin{align*}
V_{CE} &> 0.7 \quad \text{(nnp)} \\
V_{EC} &> 0.7 \quad \text{(pnp)}
\end{align*}
\]

We need to check **only** one of these two inequalities (**not both**).

b) In the active region, the Base-Emitter Junction is "on" (i.e., **forward** biased). Therefore, we must **CHECK** the results of our analysis to see if they are **consistent** with:

\[
i_B > 0
\]
Since the active mode constants $\alpha$ and $\beta$ are always positive values, equivalent expressions to the one above are:

$$i_C > 0 \quad \text{and} \quad i_E > 0$$

In other words, we need to CHECK and see if any one of the currents is positive—if one is positive, they are all positive!

**Saturation**

Here we must CHECK inequalities involving BJT currents.

a) We know that for saturation mode, the ratio of collector current to base current will be less than beta! Thus we CHECK:

$$i_C < \beta i_B$$

b) We know that both $pn$ junctions are forward biased, hence we CHECK to see if all the currents are positive:

$$i_B > 0$$
$$i_C > 0$$
$$i_E > 0$$
For **cutoff** we must **CHECK** two BJT **voltages**.

a) Since the EBJ is **reverse biased**, we **CHECK**:  

\[
\begin{align*}
V_{BE} &< 0 \quad \text{(nnp)} \\
V_{EB} &< 0 \quad \text{(pnp)}
\end{align*}
\]

b) Likewise, since the CBJ is also **reverse biased**, we **CHECK**:  

\[
\begin{align*}
V_{CB} &> 0 \quad \text{(nnp)} \\
V_{BC} &> 0 \quad \text{(pnp)}
\end{align*}
\]

If the results of our analysis are consistent with each of these inequalities, then we have made the **correct** assumption! The numeric results of our analysis are then likewise correct. We can stop working!

However, if even one of the results of our analysis is **inconsistent** with active mode (e.g., currents are negative, or \(V_{CE} < 0.7\)), then we have made the **wrong** assumption! Time to move to step 5.
5. **MODIFY**

If one or more of the BJTs are not in the active mode, then it must be in either **cutoff** or **saturation**. We must change our assumption and start **completely** over!

In general, all of the results of our previous analysis are incorrect, and thus must be **completely** scraped!