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:

$$V_{BE} = 0.7 \text{ V} \quad \text{(npn)}$$

$$V_{EB} = 0.7 \text{ V} \quad \text{(pnp)}$$

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

$$V_{CB} = -0.5 \text{ V} \quad \text{(npn)}$$

$$V_{BC} \simeq -0.5 \text{ V} \quad \text{(pnp)}$$

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

$$V_{CE} = 0.2 \text{ V} \quad \text{(npn)}$$

$$V_{EC} = 0.2 \text{ V} \quad \text{(pnp)}$$

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:

$$i_B = 0$$
$$i_C = 0$$
$$i_E = 0$$

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 **regardless** of the BJT mode.

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

Q: *Which current do we need to find?*

A: Doesn't matter! For a BJT operating in the active region, if we know **one** current, we know them **all**!

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

$$V_{CE} = V_{CB} + V_{BE} \quad \text{(npn)}$$

$$V_{EC} = V_{EB} + V_{BC} \quad \text{(pnp)}$$

This of course is a consequence of KVL, and is true **regardless** of the BJT mode.

Combining these results, we find:

$$V_{CE} = V_{CB} + 0.7 \quad \text{(npn)}$$

$$V_{EC} = 0.7 + V_{BC} \quad \text{(pnp)}$$

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

$$i_B, i_C, or\ i_E$$

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:

$$V_{BE}, \; V_{CB}, \; V_{CE} \qquad (npn)$$

$$V_{EB}, \; V_{BC}, \; V_{EC} \qquad (pnp)$$

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:

$$V_{CB} > 0 \quad \text{(npn)}$$

$$V_{BC} > 0 \quad \text{(pnp)}$$

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

$$V_{CE} > 0.7 \quad \text{(npn)}$$

$$V_{EC} > 0.7 \quad \text{(pnp)}$$

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 α and β are **always** positive values, **equivalent** expressions to the one above are:

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

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**:

$$\begin{aligned} i_B &> 0 \\ i_C &> 0 \\ i_E &> 0 \end{aligned}$$

Cutoff

For **cutoff** we must CHECK two BJT **voltages**.

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

$$V_{BE} < 0 \qquad (npn)$$

$$V_{EB} < 0 \qquad (pnp)$$

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

$$V_{CB} > 0 \qquad (npn)$$

$$V_{BC} > 0 \qquad (pnp)$$

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!