How to analyze a BJT circuit

Start with the large signal (DC) behavior. You need to determine which operating region the BJT is working in – there isn't a single equation useful for hand analysis which describes all of the BJT behavior. The operating regions are determined by the state of the B-E and B-C junctions.

| | | B-C JUNCTION: REVERSE | B-C JUNCTION: FORWARD |
|---|---|---|---|
| B-E JUNCTION | FORWARD | **ACTIVE**<br>$I_C = I_S e^{(V_{BE}/V_T)}\left[1+\frac{V_{CE}}{V_A}\right]$<br>$I_B = \frac{I_C}{\beta}$ | **SATURATION**<br>$V_{CE} = 0.2V$<br>$I_B$, $I_C$ DETERMINED BY EXTERNAL CIRCUIT |
| B-E JUNCTION | FORWARD | Voltage controlled current source:<br>B-E voltage $V_{BE}$ controls collector current $I_C$. Relationship is exponential: At T=300K, a 60mV increase in $V_{BE}$ causes a factor of 10X increase in $I_C$<br><br>Base current is unwanted byproduct of providing $V_{BE}$ to make $I_C$. Do not depend on $\beta$!<br><br>Not an ideal current source: Slight dependence on $V_{CE}$ due to base width modulation; described by Early voltage $V_A$ | A switch turned on, but not a very good switch:<br><br>Voltage drop $V_{CE}$ is relatively large (power dissipation) and not ohmic (nonlinear switch)<br><br>BJT is slow to come out of saturation due to large slug of minority carrier charge sitting in base.<br><br>Base current $I_B$ usually much larger than predicted by $\beta$ in active region |
| B-E JUNCTION | REVERSE | **CUTOFF**<br>$I_C = 0$<br>$I_B = 0$ | **INVERTED**<br>Rarely used. |
| B-E JUNCTION | REVERSE | A switch turned off.<br><br>Small leakage currents flow due to reverse bias voltage on B-E, B-C junctions.<br><br>Transition between cutoff and active regions can be quick. Emitter-coupled logic (ECL) family encodes logic level with differential pairs in which BJTs switch between cutoff and active regions. | |

How to determine the state of the B-E and B-C junctions? After some experience you will intuitively know (or at least make a guess with high probability of being correct). Even so, you should analyze the circuit to prove that your choice of operating region is consistent.

In cases where it's not clear from just looking at the circuit, the strategy I have found most useful is to:

- assume active region operation,
- drop in a model for the BJT,
- then analyze the circuit to show that assuming the active region produced a forward biased B-E junction and a reverse biased B-C junction.

If the assumptions are not validated, usually the analysis will tell you which region is the next most likely choice.

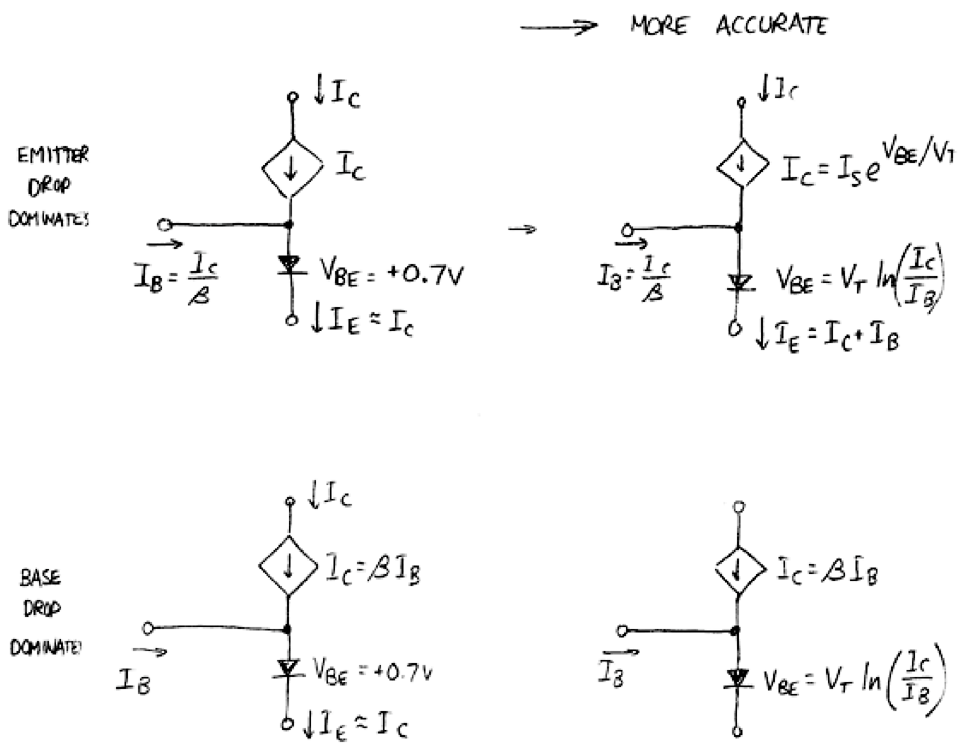
Note that for the base-collector junction, the term "reverse biased" should be interpreted as "not forward biased." What you want at the B-C junction is for carrier motion to be dominated by the electric field in the B-C depletion region, so that minority carriers in the base are collected. An example is the "diode-connected" BJT frequently seen in current mirror circuits. The base and collector terminals are shorted, so the B-C junction has zero bias and strictly speaking isn't reverse biased. But since there's no forward bias to the junction, the electric field in the B-C depletion region dominates and the BJT works according to the active region model.

MODEL CHOICE FOR DC ANALYSIS

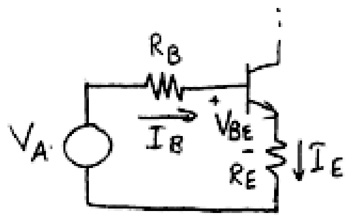
If you just drop the exponential model for the BJT into your hand analysis, you will probably wind up with an equation you can't solve explicitly. In one sense, that's not really a problem, since you always have SPICE to iteratively solve the circuit numerically. However it's good to have at least an approximate understanding of the circuit from a hand analysis, so you can

- know what magnitude of results to expect from the simulation,
- understand the design and,
- how to modify it if necessary

Four models to use are shown below. The top row will give simpler equations when the base loop is dominated by the emitter impedance; the bottom when dominated by the base impedance.



The KVL loop around the base is described below:




$$V_A = \underbrace{I_B R_B}_{\text{BASE}} + V_{BE} + \underbrace{I_E R_E}_{\text{EMITTER}}$$

If the $V_{BE}$ term is dominant, then you will have to use one of the more accurate models using the exponential and you may not get an analytic solution.