ECE 2100 Lecture Notes 3/10/03

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3/9/03

HW #15, due: W, 3/12 prob. 4.2
(ans: β = 368,122,24.2), Ex. 4.1 - 4.7
or see hw 15-16 handout Assume $V_T = 25mV$

HW #16, due: F, 3/14 Hw 15-16 handout

Stuff

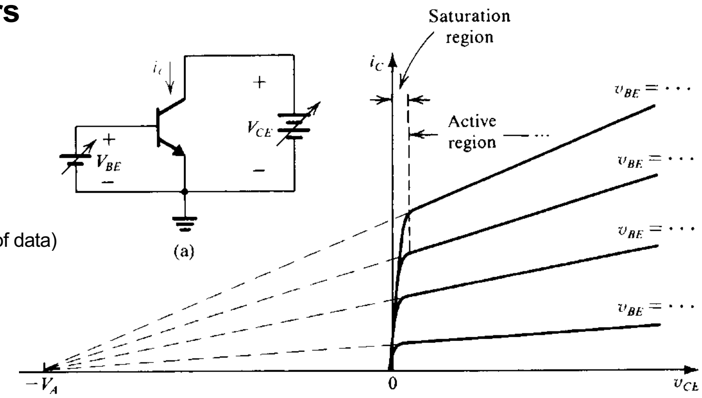
TA In lab: W, 1:00 - 2:00 pm must be Zafeer instead of Chakradhar.

Finish up Semiconductor Physics of Transistors

Early Voltage and output resistance

β depends on the effective base width, W which depends on V_{CB}. This leads to the Early effect, which is expressed as an output resistance.

output resistance = $r_o = \frac{V_A}{I_C}$ Early voltage. (guess $V_A \approx$ 100 V in absence of data)



Bipolar Junction Transistor (BJT) bias in the active region

Bias: Want a stable I_C for any transistor at any temperature

To work as an linear amplifier, a transistor must operate in the active region. To work in the active region i_B and i_C must be positive for all values of the AC signals -- they must be *biased* to some positive DC value. The AC signals will swing above and below these DC values. Furthermore, the transistor must not saturate, or it will lose control of i_C.

Bias should not depend too much on the value of β

β can vary widely from transistor to transistor of the same part number. No one wants to individually test transistors to find ones that will work in your circuit.

Bias should not depend too much on the value of V_{BE}

The relationship between V_{BE} and I_C is far too dependent on temperature and, like β, varies from transistor to transistor.

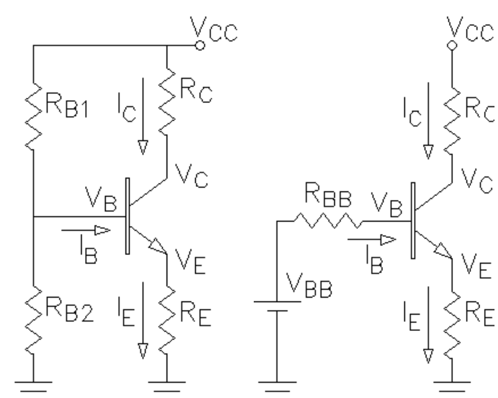
Stable bias set by a stable V_B and an R_E

As we saw last time if we set V_B with a battery (V_{BB}) then I_C is very stable. Instead of I_B controlling I_C through the unpredictable β, a stable V_B sets V_E (V_B - 0.7V) and R_E sets I_E and hence I_C. I_B then takes care of itself, and adjusts to compensate for different βs and temperatures. Unfortunately it's pretty impractical. You don't want two power supplies and besides, you can't get a signal to the base. Still, most schemes to achieve stable bias work by setting a stable voltage at the base for any reasonable I_B,

Voltage-divider bias

To make the left circuit look like the right one:

$$V_{BB} = V_{CC} \cdot \frac{R_{B2}}{R_{B1} + R_{B2}} \qquad R_{BB} = \frac{1}{\frac{1}{R_{B1}} + \frac{1}{R_{B2}}}$$

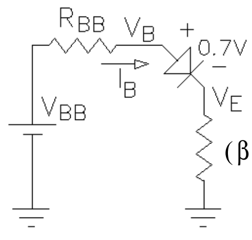


Use Thevenin's analysis

Both circuits:

$$I_B = \frac{V_{BB} - 0.7 \cdot V}{R_{BB} + (\beta + 1) \cdot R_E}$$

$$I_C = \beta \cdot I_B \approx I_E$$



$(\beta + 1) \cdot R_E \approx \beta \cdot R_E$

Note: Often in quick-and-dirty analysis you can neglect the base current, I_B. In that case:

$$V_B = V_{BB} \qquad V_E = V_B - 0.7 \cdot V \qquad I_E = \frac{V_E}{R_E} \approx I_C$$

This assumption is OK if: $R_{BB} \ll \beta \cdot R_E$

Quick check: $R_{B1} < 10 \cdot R_E$ OR $R_{B2} < 10 \cdot R_E$ Should result in <10% error if β≥100

$$V_C = V_{CC} - I_C \cdot R_C \qquad V_E = I_E \cdot R_E$$

$$V_{CE} = V_C - V_E$$

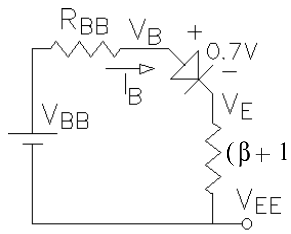
Always check that V_{CE} > 0.2 V to see if the ciruit was really in the active region.

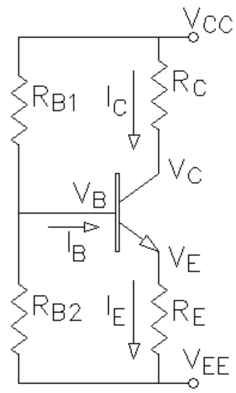
What if V_{EE} is not ground ?

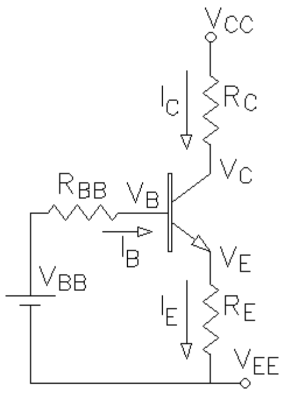
$$V_{BB} = (V_{CC} - V_{EE})\cdot\frac{R_{B2}}{R_{B1}+R_{B2}} + V_{EE} \qquad R_{BB} = \frac{1}{\frac{1}{R_{B1}}+\frac{1}{R_{B2}}}$$

$$I_B = \frac{V_{BB} - 0.7\cdot V - V_{EE}}{R_{BB}+(\beta+1)\cdot R_E}$$

$$I_C = \beta\cdot I_B \simeq I_E$$







If you can neglect the base current, I_B. In that case: $V_B = V_{BB}$ $\quad V_E = V_B - 0.7\cdot V$ $\quad I_E = \frac{V_E - V_{EE}}{R_E} \simeq I_C$

$V_C = V_{CC} - I_C\cdot R_C$ $\quad V_E = I_E\cdot R_E + V_{EE}$ $\quad V_{CE} = V_C - V_E$ Always check that $V_{CE} > 0.2$ V to see if the ciruit was really in the active region.

The equations above and on the last page are for the circuits shown, adapt them as necessary to fit your actual circuit.

BJT Bias Design

Decisions that you make for the bias will effect many other qualities of the circuit, so you should know some of your wants and expectations up front. See the tradeoffs below. Design is often an iterative process. Try something, see if it works, modify, try again. The parameters below are listed in good order for design, i.e. you usually start by selecting I_C.

select	lower value (Tradeoffs)	higher value
I_C	less power form supply less power dissipated in transistor higher input impedance	larger available output voltage swing more output power available lower output impedance

Don't want β variations to affect I_C, so make sure that I_B is the one to vary when β changes: Usually make $\beta R_E > R_{BB}$.

Temperature effects on I_C: $\frac{\Delta V_{BE}}{\Delta T} = -2.1\cdot\frac{mV}{degC}$ (constant I_C) and: For every 60 mV increase in V_{BE}, I_C will increase by factor of 10

If V_{BE} is held constant, I_C will increase by factor of 10 for every 30 °C increase in temperature.

Try to swamp the V_{BE} changes with a much bigger voltage across R_E. For a temperature range of

Ex: 0 to 40 degC, V_{BE} changes 84 mV. $\quad 24\cdot 84\cdot mV = 2\cdot V$ $\quad V_E = 2\cdot V$ swamps ΔV_{BE} pretty well (24x).

select	lower value (Tradeoffs)	higher value
V_E	(CE & CB amps) larger available output voltage swing (CC amp) Bias for output swing requirements	Better β and thermal stability (CC & CB, CE if unbypassed) higher input impedance

calculate $\quad R_E = \frac{V_E}{I_C} \quad V_B = V_E + 0.7\cdot V$ This will dictate ratio of $\frac{R_{B2}}{R_{B1}} = \frac{V_{BB} - V_{EE}}{V_{CC} - V_{BB}}$

select	lower value (Tradeoffs)	higher value
R_{B1} & R_{B2}	Better β stability	(CE & CC) higher input impedance less power form supply