ECE 2100 Lecture Notes 3/5/03

Stuff

Exam 2: Friday 3/7/03

PSpice 9.1 is available on computers in the lab, but regular labs take priority. PSpice 9.1 is also available in the 1st floor computers lab in EMCB 130. Look under "class software".

Note for Fig. 4.8 in text: i_B should flow out of transistor.

SPICE #S1, due: W, 3/5 hw 12 handout

HW #14, due: F, 3/7 Ex3.13-15 (Note: units of D_n & D_p are wrong in Ex3.15)

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 $V_T = 25\text{mV}$

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

TA office hours, so that you can ask questions, retrieve HW etc: (Also shown on the bottom of the HW web page)

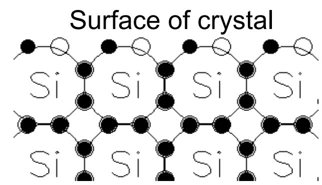
Andy Laraway	In lab: W, 2:00 - 3:00 pm & F, 11:50 - 3:50 pm
Greg Hill	In lab: W, 7:30 - 8:30 am &W, 3:05 - 6:05 pm
Chakradhar Talluri	In lab: W, 1:00 - 2:00 pm & H, 7:30 - 10:30 am & H, 2:00 - 5:00 pm
Zafeer Mohamed	In lab: T, 7:30 - 10:30 am

Note: At lab times (the 3hr blocks) TAs will attend to lab students first.

Reverse Bias Diode Leakage

The reverse leakage in a diode will actually be much larger than I_s.

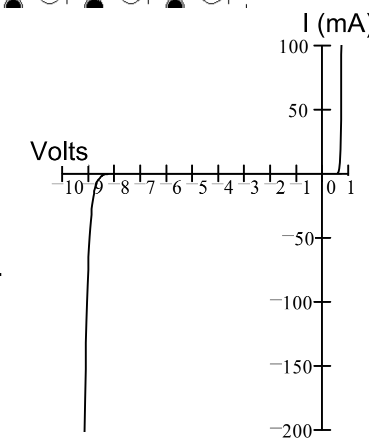
Any imperfection in the silicon crystal can lead to extra carriers and corresponding leakage current. The surface of the crystal can be seen as a large imperfection and can lead to significant "surface leakage". During manufacturing, "surface passivation" techniques can help clean up these loose bonds.



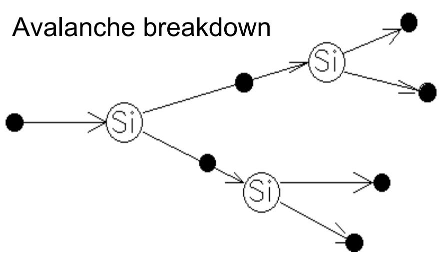
Diode Reverse Breakdown

section 3.3.4, p149 in textbook

One last diode property we ought to look at before leaving the diode.
If you place a large enough reverse voltage across the diode, the junction will "break down". This will not harm the diode as long as you don't overheat it.
Breakdown occurs in two different ways.



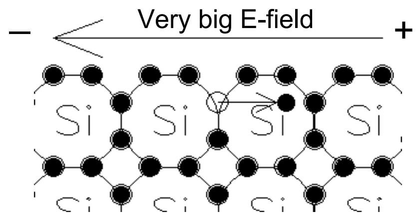
Avalanche breakdown



Naturally occurring minority carriers gain so much speed that they can ionize other atoms when they hit, causing an "avalanche".

Dominant mechanism in zener diodes that break down above ~7V. Has a positive temperature coefficient.

Zener breakdown



E-field "rips" electrons out of position, creating carriers.

Dominant mechanism in zener diodes that break down below ~5V (because they are very heavily doped and have very narrow depletion regions). Has a negative temperature coefficient.

The most temperature-stable zener diodes have v_z between 5 & 7V (5.6V is very good).

If temperature stability is important, two 6V zeners in series are better than one 12V zener.

Bipolar Junction Transistor

Notice how the base-emmitter junction is just like a diode.

Important relations (active region)

$v_{BE} = 0.7 \cdot V$ $\quad i_C = \beta \cdot i_B$ $\quad i_E = i_B + i_C \simeq i_C$ $\quad V_T \simeq 25 \cdot mV$

Small signal emitter resistance $r_e = \dfrac{V_T}{I_C}$

Relations of lesser importance

$i_C = \alpha \cdot i_E$ $\quad \alpha = \dfrac{\beta}{\beta + 1}$ $\quad \beta = \dfrac{\alpha}{1 - \alpha}$

Ebers-Moll equation: $i_C = I_S \cdot e^{\frac{v_{BE}}{V_T}}$

Temperature dependencies

$v_{BE} = 0.7 \cdot V$ (decreases about 2.1 mV / ^oC)

at constant I_C: $\Delta V_{BE} = \dfrac{-2.1 \cdot mV}{degC}$

at constant V_{BE}: I_C increases by 8% per ^oC (10x per 30^oC)

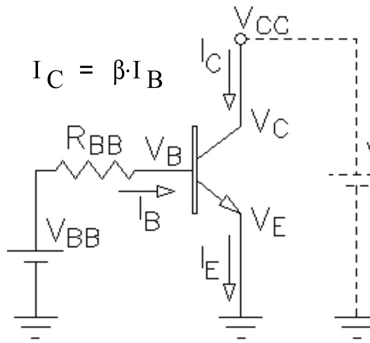
Bipolar Junction Transistor (BJT) DC and bias in the active region

Few DC circuits use the transistor in its active region. Most use the transistor only as a switch, either off (cutoff) or on (saturation). Never-the-less the DC active region is very important. That's because all linear AC (signal) circuits need to use the transistor in its active (partially on) region and for that the transistors need a DC "bias".

The simplest DC circuit:

The base current (I_B) is nice and stable, unfortunately this is more often a bad thing instead of a good thing.

$$I_B = \frac{V_{BB} - 0.7 \cdot V}{R_{BB}} \qquad I_C = \beta \cdot I_B$$

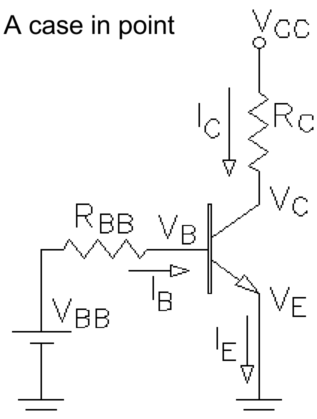


Normally this power supply is not shown

You see, β can be anything from 100 to 400 for a 2N3904 signal transistor, and that's normal for transistors. This means that I_C is not stable, and that is almost always a bad thing. In fact, to get a stable I_C, I_B will have to adjust itself to compensate for different βs.

As long as $V_{CC} < 0.2V$, this simple circuit is always in the active region.

A case in point



Say: $V_{CC} := 7 \cdot V$

R_c is very common in transistor circuits. If the collector current is fluctuating according to some signal, those fluctuations will cause voltage fluctuations across R_c which could be the output signal voltage of the circuit.

What if we want $I_C := 10 \cdot mA$ and $V_C := 3 \cdot V$ then $R_C := \frac{V_{CC} - V_C}{I_C}$ $\quad R_C = 400 \cdot \Omega$

Let's assume that $\beta := 200$ $\quad I_B := \frac{I_C}{\beta}$ $\quad I_B = 0.05 \cdot mA$

Say $V_{BB} := 2.5 \cdot V$ then $R_{BB} := \frac{V_{BB} - 0.7 \cdot V}{I_B}$ $\quad R_{BB} = 36 \cdot k\Omega$

All looks hunky-dory, right?

What if $\beta := 100$? $\quad I_B = \frac{V_{BB} - 0.7 \cdot V}{R_{BB}} = 0.05 \cdot mA$ $\quad$ no change here, looks good so far.

$I_C := \beta \cdot I_B$ $\quad I_C = 5 \cdot mA$ $\quad$ Yuk, that changed by half.

$V_C := V_{CC} - I_C \cdot R_C$ $\quad V_C = 5 \cdot V$ $\quad$ At least V_C only changed by $2V$. Still, that may be too much.

At least we're still in the active region ($V_{CE} > 0.2V$).

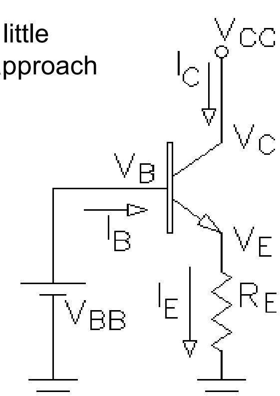
What if $\beta := 400$? $\quad I_B = \frac{V_{BB} - 0.7 \cdot V}{R_{BB}} = 0.05 \cdot mA$ $\quad$ again, no change here.

$I_C := \beta \cdot I_B$ $\quad I_C = 20 \cdot mA$ $\quad$ Oh oh, that doubled.

$V_C := V_{CC} - I_C \cdot R_C$ $\quad V_C = -1 \cdot V$ $\quad$ Oops, that can't be good. In fact, we have to assume that we're out of the active region -- way bad...

Must recalculate I_C and V_C. $\quad V_C := 0.2 \cdot V$ (Saturation) $\quad I_C := \frac{V_{CC} - 0.2 \cdot V}{R_C}$ $\quad I_C = 17 \cdot mA$

Let's try a little different approach



Again, let's design for $I_C := 10 \cdot mA$

$V_E := V_{BB} - 0.7 \cdot V$ $\quad$ It is common here to assume: $\quad I_E := I_C$

$R_E := \frac{V_E}{I_E}$ $\quad R_E = 180 \cdot \Omega$ $\quad I_E = 10 \cdot mA$

but actually, $\quad I_C = \alpha \cdot I_E = \frac{\beta}{\beta + 1} \cdot I_E$

If $\beta := 100$ $\quad \alpha := \frac{\beta}{\beta + 1}$ $\quad I_C = \alpha \cdot I_E = 9.901 \cdot mA$ $\quad I_B = \frac{I_C}{\beta} = 0.1 \cdot mA$

If $\beta := 400$ $\quad I_C = \frac{\beta}{\beta + 1} \cdot I_E = 9.975 \cdot mA$ $\quad I_B = \frac{I_C}{\beta} = 0.025 \cdot mA$

Now that's more like it, now I_B changes instead of I_C.