Lecture 24: BJT as an Electronic Switch.

The transistor can be used as an electronic switch, in addition to an amplifier. As a switch, we use the cutoff and saturation regions of BJT operation.

![Diagram of BJT as an electronic switch]

(Fig. 1) (Sedra and Smith, 5th ed.)

- **Cutoff Region.** If \( v_I \ll 0.5 \) or so, the EBJ will conduct negligible current. Also, the CBJ will be reversed biased with a large \( V_{CC} \).

Consequently,

\[
i_B \approx 0, \quad i_C \approx 0, \quad \text{and} \quad i_E \approx 0 \tag{1}
\]

which means

\[
v_O = V_{CC} \tag{2}
\]

These are the cutoff conditions and the BJT is in the “off” state.
• **Saturation Region.** For the “on” state of the switch, we increase $v_I$ until the BJT saturates. This occurs when the EBJ and the CBJ are both forward biased.

Due to asymmetries in the device fabrication, the voltage drops are different for these two forward-biased junctions:

These are only approximate values for saturated BJTs. The actual values of $V_{CE|\text{sat}}$ and $V_{EC|\text{sat}}$ depend heavily on $i_C$.

Equivalent circuit models for these saturated $nnp$ and $pnp$ BJTs are (Table 6.3):

So, with $v_I$ “large,” then
With \( v_O = V_{CE|_{sat}} \) (3)
then
\[
i_B = \frac{v_I - 0.7}{R_B}, \quad i_C|_{sat} = \frac{V_{CC} - V_{CE|_{sat}}}{R_C}, \quad i_E = i_B + i_C|_{sat}
\] (4)

Remember that because the BJT is no longer operating in the active region, \( i_C \neq \beta i_B \).

Instead, if the BJT is operating in the saturation mode

\[
\beta_{\text{forced}} \equiv \frac{i_C|_{sat}}{i_B} < \beta
\] (5)

**Example N24.1.** The BJT in the circuit below has \( 50 \leq \beta \leq 150 \). Find the \( R_B \) that saturates the BJT with a so-called overdrive factor of at least 10.
Designing an “electronic switch” has essentially two parts: cutoff and saturation. Cutoff is easy to design. Just make $v_I \lesssim 0.5$ V or so.

Saturation is a bit more difficult to design. We need $v_I$ sufficiently large so that the collector current becomes large enough for the CBJ to become forward biased.

For this problem, assume the BJT is saturated so that $V_{CE\text{sat}} = 0.2$ V. Therefore,

$$I_C = I_{C\text{sat}} = \frac{10 - 0.2}{1,000} = 9.8 \text{ mA}.$$ 

To saturate the BJT with the smallest $\beta$ we need to provide

$$I_B = \frac{I_{C\text{sat}}}{\beta_{\text{min}}} = \frac{9.8 \text{ mA}}{50} = 0.196 \text{ mA}.$$ 

This is $I_B$ just on the edge of saturation (EOS) since we are using the active mode assumption $I_C = \beta I_B$. For an “overdrive factor (ODF)” of 10 means we want to force 10 times this current into the base of the BJT:

$$I_B = \text{ODF} \cdot I_B|_{\text{EOS}}$$ 

or

$$I_B = 10 \cdot 0.196 \text{ mA} = 1.96 \text{ mA}.$$ 

Therefore, since

$$I_B = \frac{5 - 0.7}{R_B} \implies R_B = \frac{4.3}{I_B} = 2.2 \text{ k}\Omega$$
Now, with this design and the transistor saturated, what is the “forced” $\beta$?

$$\beta_{\text{forced}} = \frac{I_C\big|_{\text{sat}}}{I_B} = \frac{9.8 \text{ mA}}{1.96 \text{ mA}} = 5$$

This value is much smaller than $\beta_{\text{min}} = 50$, as expected. Another way to compute $\beta_{\text{forced}}$ is to notice:

$$\beta_{\text{forced}} = \frac{I_C\big|_{\text{sat}}}{I_B} = \frac{I_C\big|_{\text{sat}}}{\text{ODF} \cdot I_B\big|_{\text{sat}}}$$

such that

$$\beta_{\text{forced}} = \frac{\beta}{\text{ODF}} \quad (7)$$

Using (7) for this example,

$$\beta_{\text{forced}} = \frac{50}{10} = 5$$

Lastly, what happens if $\beta$ is increased from 50 to 150 as stated in the problem? Will the transistor stay saturated? Yes, it will. Actually, nothing changes in our saturated circuit as $\beta$ varies. However, $\beta_{\text{forced}}$ becomes larger indicating that the transistor is becoming less saturated.