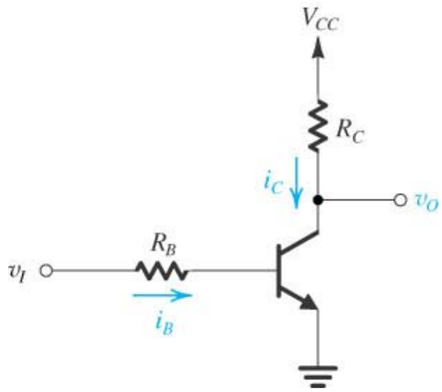
Lecture 24: BJT as an Electronic Switch.

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.



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

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

  Consequently,
$$i_B \approx 0,\ i_C \approx 0, \text{ and } i_E \approx 0 \tag{1}$$
  which means
$$v_O = V_{CC} \tag{2}$$
  These are the cutoff conditions and the BJT is in the "off" state.

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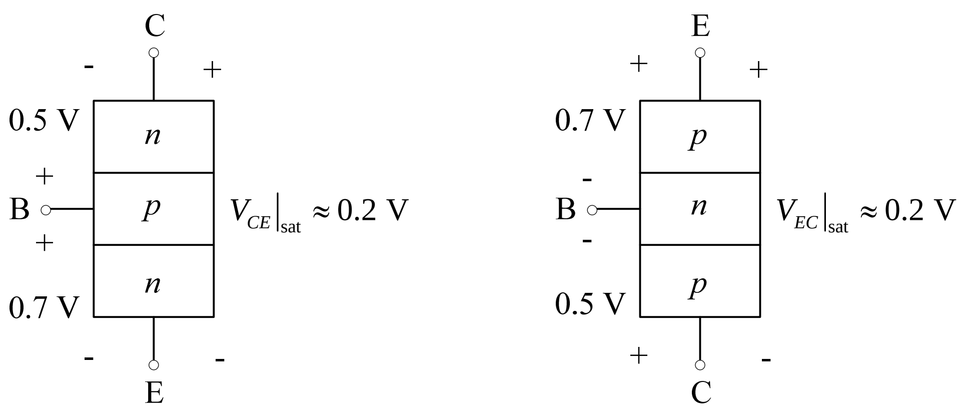
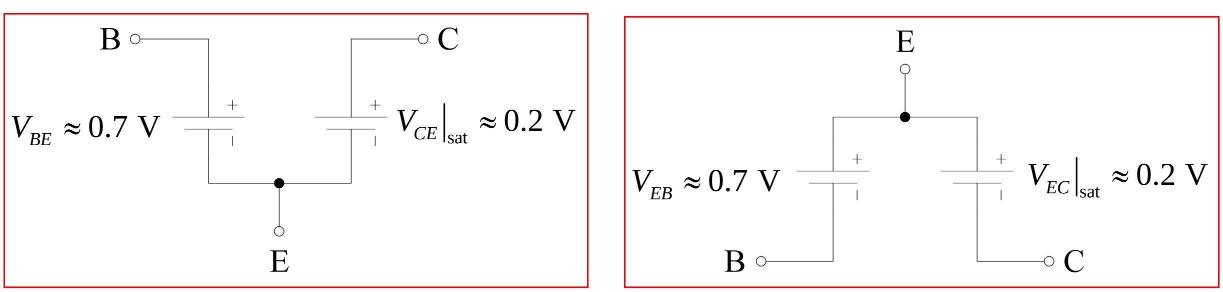
- Saturation Region. For the "on" state of the switch, we increase v_I until the BJT saturates. This occurs when the EBJ and the CBJ are both forward biased.

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

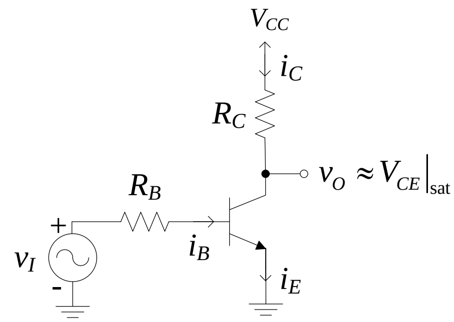


  These are only approximate values for saturated BJTs. The actual values of $V_{CE}|_{sat}$ and $V_{EC}|_{sat}$ depend heavily on i_C.

  Equivalent circuit models for these saturated *npn* and *pnp* BJTs are (Table 6.3):



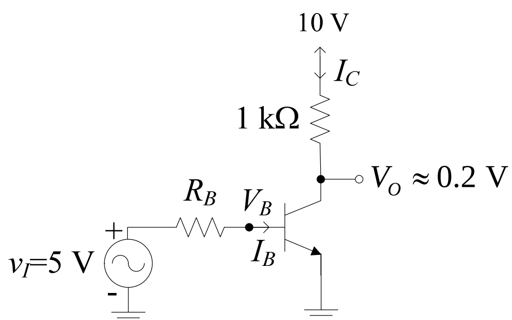
  So, with v_I "large," then



With
$$v_O = V_{CE}\big|_{\text{sat}} \tag{3}$$
then
$$i_B = \frac{v_I - 0.7}{R_B}, \quad i_C\big|_{\text{sat}} = \frac{V_{CC} - V_{CE}\big|_{\text{sat}}}{R_C}, \quad i_E = i_B + i_C\big|_{\text{sat}} \tag{4}$$
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
$$\boxed{\beta_{\text{forced}} \equiv \frac{i_C\big|_{\text{sat}}}{i_B} < \beta} \tag{5}$$

Example N24.1. The BJT in the circuit below has $50 \le \beta \le 150$. Find the R_B that saturates the BJT with a so-called overdrive factor of at least 10.



Designing at "electronic switch" has essentially two parts: cutoff and saturation. Cutoff is easy to design. Just make $v_I \lessapprox 0.5$ 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 $V_{CE}\big|_{\text{sat}} = 0.2$ V. Therefore,

$$I_C = I_C\big|_{\text{sat}} = \frac{10-0.2}{1{,}000} = 9.8 \text{ mA.}$$

To saturate the BJT with the smallest β we need to provide

$$I_B = \frac{I_C\big|_{\text{sat}}}{\beta_{\min}} = \frac{9.8 \text{ mA}}{50} = 0.196 \text{ mA}$$

This is I_B just on the edge of saturation (EOS). For an "overdrive factor (ODF)" of 10 means we want to force 10 times this current into the base of the BJT:

$$\boxed{I_B = \text{ODF} \cdot I_B\big|_{\text{EOS}}} \tag{6}$$

or

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

Therefore, since

$$I_B = \frac{5-0.7}{R_B} \quad \Rightarrow \quad R_B = \frac{4.3}{I_B} = 2.2 \text{ k}\Omega$$

Now, with this design and the transistor saturated, what is the "forced" β?

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

This value is much smaller that β_{min}=50, as expected. Another way to compute β_{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

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

Using (7) for this example,

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

Lastly, what happens if β 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 β varies. However, β_{forced} becomes smaller indicating that the transistor is becoming *more* saturated.