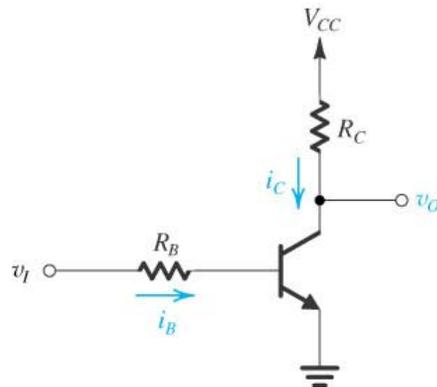


## Lecture 24: BJT as an Electronic Switch.

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. 5.74)

- 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,

$$i_B \approx 0, i_C \approx 0, \text{ and } i_E \approx 0 \quad (1)$$

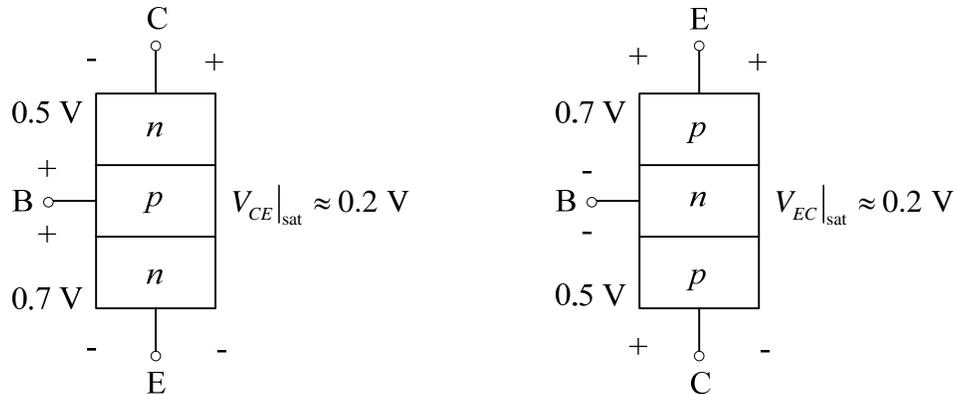
which means

$$v_O = V_{CC} \quad (2)$$

These are the cutoff conditions and the BJT is in the “**off**” state.

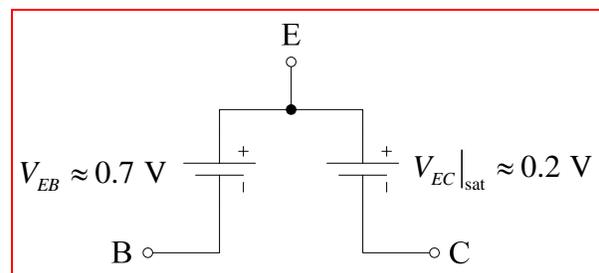
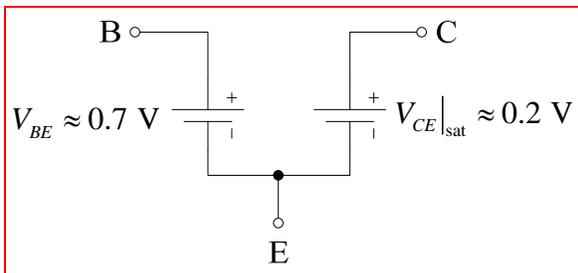
- Saturation Region. For the “**on**” state of the switch, we increase  $v_I$  until the BJT **saturates**. This occurs when the EBJ and the CBJ are both forward biased.

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

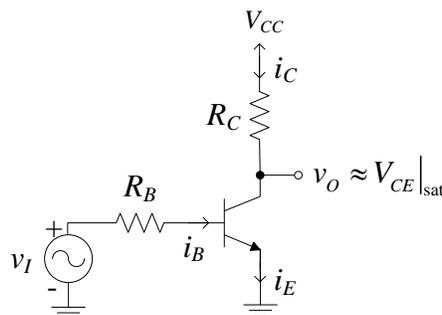


These are only **approximate values** for saturated BJTs. The actual values of  $V_{CE}|_{sat}$  and  $V_{EC}|_{sat}$  depend heavily on  $i_C$ .

Equivalent circuit models for these saturated BJTs are:



So, with  $v_I$  "large," then



With  $v_O = V_{CE}|_{\text{sat}}$  (3)

then

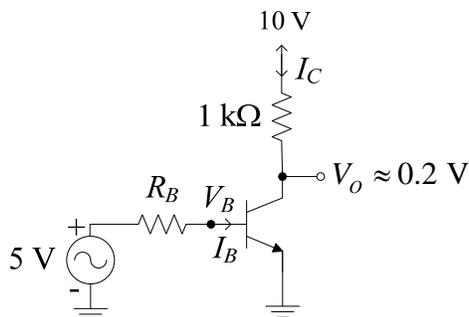
$$i_B = \frac{v_I - 0.7}{R_B}, \quad i_C|_{\text{sat}} = \frac{V_{CC} - V_{CE}|_{\text{sat}}}{R_C}, \quad i_E = i_B + i_C|_{\text{sat}} \quad (4)$$

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

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

**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 at “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). For an “**overdrive factor (ODF)**” of 10 means we want to force 10 times this current into the base of the BJT:

$$I_B = \text{ODF} \cdot I_B|_{\text{EOS}} \quad (6)$$

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

Therefore, since

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

Now, with this design and the transistor saturated, what is the “**forced**”  $\beta$ ?

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

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

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

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 smaller indicating that the transistor is becoming *more* saturated.