The Voltage Transfer Characteristic

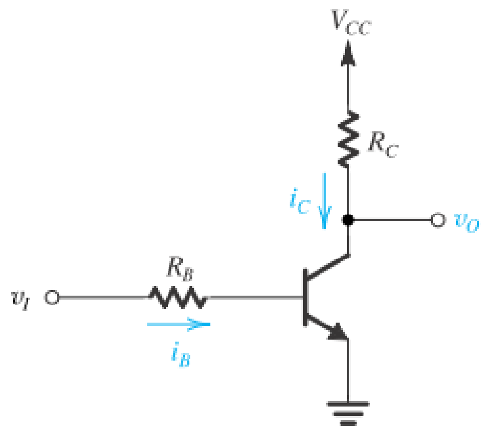


FIGURE 5.74 Basic BJT digital logic inverter.

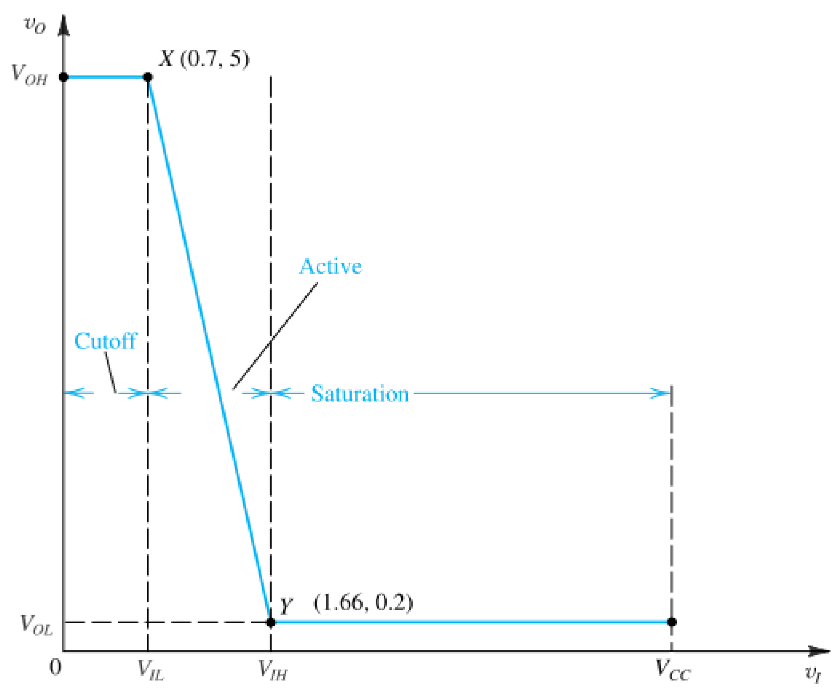
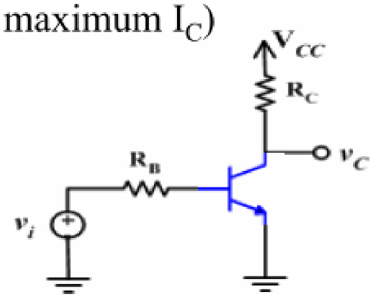


FIGURE 5.75 Sketch of the voltage transfer characteristic of the inverter circuit of Fig. 5.74 for the case $R_B = 10\ \text{k}\Omega$, $R_C = 1\ \text{k}\Omega$, $\beta = 50$, and $V_{CC} = 5$ V. For the calculation of the coordinates of X and Y, refer to the text.

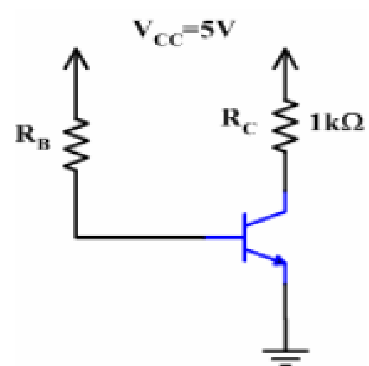
- In chapter 5, BJT operating in active mode is used to design Amplifier. Now we will concentrate on the other two modes. At one extreme BJT operates in cutoff region (BJT ➔ OFF or $I_C \approx 0$) and at other extreme BJT operates in saturation region (BJT ➔ ON, maximum I_C)



- If $v_i < 0.5$ volt, the EBJ is reverse biased (R.B). Since CBJ is also reverse biased (*as V_{cc} is '+'*)
  ➔ BJT is OFF or operating in cutoff mode
  Thus, $I_B=0$, $I_C=0$, $I_E=0$, $V_C=V_{CC}$
- If $v_i \geq 0.7$ volt, the EBJ is forward biased. If CBJ is still reverse biased (if $V_C > 0.7$) ➔ BJT is ON but in Active region (*can't be used as a switch*)
- With ↑ v_i ; I_B ↑ resulting an ↑ V_B and ↑ I_C. Thus, V_C will ↓ and when $V_C < V_B$ by 0.5v, CBJ will be F.B. As EBJ is still F.B➔ BJT is Saturated
  Thus, $V_{BE}= 0.7$, $V_{BC}= 0.5$, $V_{CEsat}= 0.2$, $I_{Csat}= (V_{CC} - V_{CESat}) / R_C$ *and* $I_B= I_C / \beta_{Sat}$

BJT Switches (cont'd.):

- If due to some reason (i.e. temperature change), the base current is reduced than the transistor will enter the active mode from the edge of saturation. So the base current is designed to be higher than the edge of saturation value, by a factor of 2 to 10. This is called overdrive factor.
- Example: For the circuit shown, select a value for R_B so that transistor saturates with an overdrive factor of 10. The BJT have a minimum β=30 and V_{CEsat}=0.2V. What is the resulted value of forced β?



- Solution:

  $I_C = (5 - 0.2) / 1\text{ k} = 4.8\text{ mA}$; $I_B = I_C / \beta = 0.16\text{ mA}$;

  So, $10\, I_B = (V_{CC} - V_{BE}) / R_B$; $R_B = 2.7\text{ k}$

  and $\beta_F = I_C / I_{BF} = 3$

We shall now compute the coordinates of the breakpoints of the transfer

characteristic of Fig. 5.75 for a representative case—$R_B = 10$ kΩ, $R_C = 1$ kΩ, $\beta = 50$, and $V_{CC} =$ 5 V—as follows:

1. At $v_I = V_{OL} = V_{CEsat} = 0.2$ V, $v_O = V_{OH} = V_{CC} = 5$ V.
2. At $v_I = V_{IL}$, the transistor begins to turn on; thus,

$$V_{IL} \cong 0.7 \text{ V}$$

3. For $V_{IL} < v_I < V_{IH}$, the transistor is in the active region. It operates as an amplifier whose small-signal gain is

$$A_v \equiv \frac{v_o}{v_i} = -\beta \frac{R_C}{R_B + r_\pi}$$

The gain depends on the value of r_π, which in turn is determined by the collector current and hence by the value of v_I. As the current through the transistor increases, r_π decreases and we can neglect r_π relative to R_B, thus simplifying the gain expression to

$$A_v \cong -\beta \frac{R_C}{R_B} = -50 \times \frac{1}{10} = -5 \text{ V/V}$$

4. At $v_I = V_{IH}$, the transistor enters the saturation region. Thus V_{IH} is the value of v_I that results in the transistor being at the edge of saturation,

$$I_B = \frac{(V_{CC} - V_{CEsat})/R_C}{\beta}$$

For the values we are using, we obtain $I_B = 0.096$ mA, which can be used to find V_{IH},

$$V_{IH} = I_B R_B + V_{BE} = 1.66 \text{ V}$$

5. For $v_I = V_{OH} = 5$ V, the transistor will be deep into saturation with $v_O = V_{CEsat} \cong 0.2$ V, and

$$\beta_{\text{forced}} = \frac{(V_{CC} - V_{CEsat})/R_C}{(V_{OH} - V_{BE})/R_B}$$

$$= \frac{4.8}{0.43} = 1.1$$

6. The noise margins can now be computed using the formulas from Section 1.7,

$$NM_H = V_{OH} - V_{IH} = 5 - 1.66 = 3.34 \text{ V}$$
$$NM_L = V_{IL} - V_{OL} = 0.7 - 0.2 = 0.5 \text{ V}$$

Obviously, the two noise margins are vastly different, making this inverter circuit less than ideal.

7. The gain in the transition region can be computed from the coordinates of the breakpoints X and Y,

$$\text{Voltage gain} = -\frac{5 - 0.2}{1.66 - 0.7} = -5 \text{ V/V}$$

which is equal to the approximate value found above (the fact that it is exactly the same value is a coincidence).