Simple 4R NPN-BJT and N-MOSFET DC Circuit

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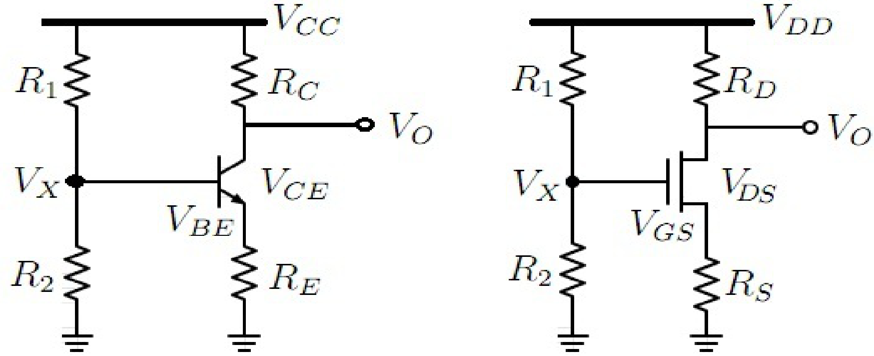
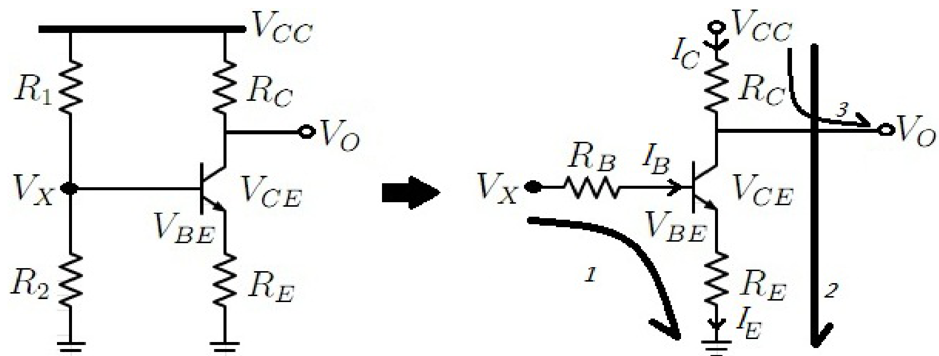
November 6, 2012



Reference Sedra, Smith *Microelectronics*
Neamen *Microelectronics*

1 4R NPN-BJT DC Circuit



By voltage division (if R_E reflected to base is very large)

$$V_X = V_{CC}\frac{R_2}{R_1 + R_2}$$

The Thevenin Equivalenct Input resistance R_B is thus

$$R_B = R_1||R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Then consider loop 1 , assume the diode of junction BE is in forward biased

$$\begin{aligned} V_X &= I_B R_B + V_{BE} + I_E R_E \\ &= I_B R_B + V_{BE} + (\beta + 1)\, I_B R_B \\ &= [(\beta + 1)\, R_E + R_B]\, I_B + V_{BE} \end{aligned}$$

$$I_B = \frac{V_X - V_{BE}}{(\beta + 1)\, R_E + R_B}$$

As it is assumed BE-Junction is forward biased

$$V_{BE} = V_{BE}(on) = 0.7$$

If $V_X < V_{BE}$, then the transistor is in cutoff mode, $I_B = 0$, so $I_C = I_E = 0$, $V_O = V_{CC}$

If it is in forward biased mode, then we can get I_C , I_E (non-zero)

$$I_C = \beta I_B \qquad I_E = (\beta + 1)\, I_B$$

Consder loop 2

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$

Then

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

$$V_{CE} > V_{CE,Saturation} = 0.3?$$

If yes, it is in saturation mode, then the I_C , I_E calculated is not valid

$$V_{CC} - I_{C,Saturation} R_C - V_{CE,Saturation} - I_E R_E = 0 \quad I_E = \frac{I_C}{\alpha}$$

$$I_C = I_{C,Saturation} = \frac{V_{CC} - V_{CE,Saturation}}{R_C + \dfrac{R_E}{\alpha}} \quad I_E = \frac{I_C}{\alpha}$$

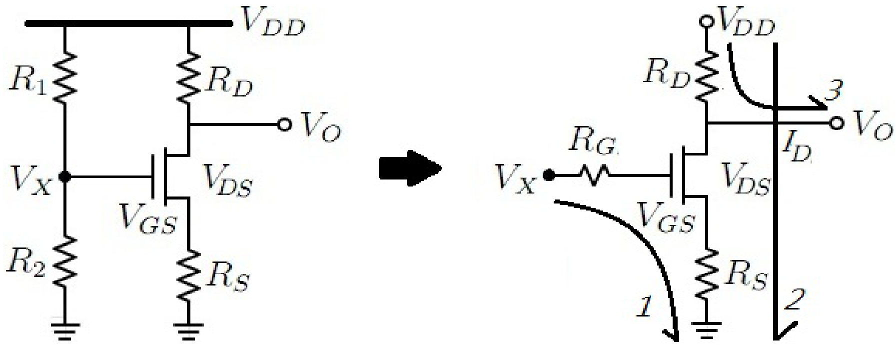
Thus ,

$$V_O = V_{CC} - I_{C,Saturation} R_C$$

If not, then it is in forward active, and then consider loop 3 to get the V_O

$$V_O = V_{CC} - I_C R_C$$

2 4R N-MOSFET DC Circuit



By voltage division (since $I_G = 0$ so no matter what R_S it is still true)

$$V_X = V_{CC} \frac{R_2}{R_1 + R_2}$$

The Thevenin Equivalenct Input resistance R_G is thus

$$R_G = R_1 || R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Then consider loop 1 , as $I_G = 0$ (always) and $I_D = I_S = I_{DS}$

$$V_{GG} = V_X = V_{GS} + I_{DS} R_S$$

Assume N-MOSFET is in saturation mode , $V_{GS} > V_{TN}$ and $V_{DS} > V_{DS,Saturation} = V_{GS} - V_{TN}$, then

$$I_{DS} = \frac{K_n}{2} \left(V_{GS} - V_{TN}\right)^2$$

So

$$V_X = V_{GS} + I_{DS}R_S = V_{GS} + R_S\left[\frac{K_n}{2}\left(V_{GS} - V_{TN}\right)^2\right]$$

$$\iff \quad V_X = V_{GS} + R_S\frac{K_n}{2}V_{GS}^2 - 2R_S\frac{K_n}{2}V_{GS}V_{TN} + R_S\frac{K_n}{2}V_{TN}^2$$

$$\iff \quad \left(R_S\frac{K_n}{2}\right)V_{GS}^2 + \left(1 - R_sK_nV_{TN}\right)V_{GS} + R_S\frac{K_n}{2}V_{TN}^2 - V_X = 0$$

Solving this quadratic equation, we can get V_{GS}

$$V_{GS} = \frac{R_sK_nV_{TN} - 1 \pm \sqrt{\left(1 - R_sK_nV_{TN}\right)^2 - 4\left(R_S\frac{K_n}{2}\right)\left(R_S\frac{K_n}{2}V_{TN}^2 - V_X\right)}}{2}$$

For the 2 roots of V_{GS} , take the one that $V_{GS} > V_{TN}$

If both roots are $V_{GS} < V_{TN}$, then the N-MOSFET is in cutoff mode

$$I_D = 0 \qquad V_O = V_{DD}$$

If there is a root that $V_{GS} > V_{TN}$

Consider loop 1 again to solve I_{DS}

$$V_X = V_{GS} + I_{DS}R_S$$

Then consider loop 2 to solve for V_{DS}

$$V_{DD} = I_{DS}R_D + V_{DS} + I_{DS}R_S$$

$$V_{DS} = V_{DD} - I_{DS}\left(R_D + R_S\right)$$

Then

If $V_{DS} \substack{\geq \\ <} V_{DS,Saturation} = V_{GS} - V_{TN}$, then it is in $\substack{\text{saturation mode} \\ \text{triode mode}}$ I_{DS} is $\substack{\text{valid} \\ \text{not valid}}$

For valid case, consider loop 3 to find V_O

$$V_O = V_{DD} - I_{DS}R_D$$

For invalid case, calculate I_{DS} again using triode mode equation

$$I_{DS} = \frac{K_n}{2}\left(V_{GS} - V_{TN} - \frac{V_{DS}}{2}\right)V_{DS}$$

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And do the process again.

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