Equations in Electronics : Semicon, BJT, MOSFET

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Semiconductor

1. **Boltzmann's Constant** $K = 8.6 \times 10^{-5} \dfrac{\mathbf{eV}}{\mathbf{K}}$
2. **Electron Charge** $e = -1.6 \times 10^{-19} C$
3. **Electron Volt** $1eV = 1.6 \times 10^{-19} J$
4. **Thermal Voltage** $V_T = \dfrac{kT}{q} \approx 26mV_{300K}$
5. **Intrinsic Electron Concentration** $n_i = BT^{\frac{3}{2}} \exp \dfrac{-E_g}{2kT}$
6. **Hole-Electron Relationship** $np = n_i^2$
7. **Charge Carrier concentration with doping** $n_p = \dfrac{n_i^2}{N_A}$ $p_n = \dfrac{n_i^2}{N_d}$
8. **Simplified Constant** $B_{Si} = 5.23 \times 10^{15} cm^{-3} K^{-3/2}$ $B_{Ge} = 1.66 \times 10^{15}$ $B_{GaAs} = 2.1 \times 10^{14}$
9. **Gap Energy** $E_{g,Ge} = 0.66eV$ $E_{g,GaAs} = 1.4eV$
10. **Drift Velocity of Charge Carrier under external E-field** $v_{d,n} = -\mu E$ $v_{d,p} = \mu E$
11. **Dirft Current Density and Electrical Conductivity** $J_{drift} = (en\mu_n + ep\mu_p)\, E = \sigma E$ $\sigma(S/cm)$
12. **Mobility of Charge Carrier** μ_n **: 1350**$cm^2/V-s$ μ_p**: 480**$cm^2/V-s$
13. **Diffusion Current Density** $J_{diff,n} = eD_n \dfrac{dn}{dx}$ $J_{diff,p} = -eD_p \dfrac{dp}{dx}$ $D(cm^2/s)$
14. **Einstein Relationship** $\dfrac{D_p}{\mu_p} = \dfrac{D_n}{\mu_n} = \dfrac{kT}{q} = V_T$
15. **Build-in Voltage** $V_{Bi} = V_T \ln\left(\dfrac{N_D N_A}{n_i^2}\right)$
16. **Junction Capacitance** $C_j = \dfrac{C_{jo}}{\sqrt{1 + \dfrac{V_{emf}}{V_{bi}}}}$
17. **Turn on voltage** $V_\gamma(pn) = 0.7$ $V_\gamma(SB) = 0.3$

18. **DC Diode Current** $I_D = I_S\left(e^{\frac{V_D}{V_T}} - 1\right) \quad I_S = 10^{-15} \sim 10^{-13} A$

19. **AC Diode Current** $i_d = \dfrac{I_{DQ}}{V_T} v_d$

20. **AC Diode Transconductance** $g_d = \dfrac{I_{DQ}}{V_T}$

21. **AC Diode Resistance** $r_d = g_d^{-1}$

BJT

1. **Common-Emitter Current Gain , Common-Base Current Gain** $\beta = \dfrac{\alpha}{1-\alpha}$, $\alpha = \dfrac{\beta}{\beta+1}$, $i_c = \beta i_B - \alpha i_E$, $\mathrm{i}_E = (\beta+1)\, i_B$

2. **Voltage : Turn on / Saturation** $V_{BE}(on, Si) = 0.7$, $V_{BE}(on, Ge) = 0.3V$, $V_{BE}(sat) = 0.8$, $V_{BB} > V_{BE}(on)$, $V_{CE} > V_{BE}(on)$, $V_{CE}(sat, Si) = 0.3V$, $\quad V_{CE}(sat, Ge) = 0.1V$

3. **AC Collector Current and Emitter Current** $i_C = I_S \exp \dfrac{v_{BE}}{v_T}, \quad i_c = \beta i_B, \quad i_E = (\beta+1)\, i_B$

4. **AC Transconductance and Resistance** $g_m = \dfrac{I_{CQ}}{V_T}, \quad r_\pi = \dfrac{\beta}{g_m} = \dfrac{V_T}{I_{BQ}} = \dfrac{\beta V_T}{I_{CQ}}$, $r_e = \dfrac{\alpha}{g_m}$, $r_o = \dfrac{V_A}{I_{CQ}}$, $P_T = I_C V_{CE}$

MOSFET

1. **Thershold Voltage of different opeartion mode** $V_{TN,DeMod} < 0$, $V_{TN,EnMode} > 0$, $V_{TP,DeMode} > 0$, $V_{TP,EnMode} < 0$

2. **MOSFET Parameters** $K_n = \dfrac{k_n'}{2}\dfrac{W}{L}, \quad k_n' = \mu_{ox} C_{ox}$, $C_{ox} = \dfrac{\epsilon_{ox}}{t_{ox}}$

3. **Drain-Gate Voltage** $V_{DS}(sat) = V_{GS} - V_{TN} = V_{SG} + V_{TP}$

4. **Saturation Mode Current**
$I_{DS}(sat) = K_N\left(V_{GS} - V_{TN}\right)^2 = \dfrac{k_n'}{2}\dfrac{W}{L}\left(V_{GS} - V_{TN}\right)^2 = K_P\left(V_{SG} + V_{TP}\right)^2 = \dfrac{k_p'}{2}\dfrac{W}{L}\left(V_{SG} + V_{TP}\right)^2$

5. **Tri-state Mode Current**
$I_{DS}(tri) = K_n\left(2(V_{GS} - V_{TH})V_{DS} - V_{DS}^2\right) = K_P\left(2(V_{SG} + V_{TH})V_{SD} - V_{SD}^2\right)$, $V_{DS} > V_{DS}(sat)$

6. **MOSFET AC Transconductance** $g_m = 2K_N(V_{GSQ} - V_{TN}) = 2\sqrt{K_N I_{DQ}} = \dfrac{i_d}{v_{gs}}$

7. **MOSFET AC Drain Current** $i_d = 2K_n v_{gs}(V_{GSQ} - V_{TN})$

8. **Early Effect Resistance** $r_o = \dfrac{1}{\lambda I_{DQ}} = \dfrac{V_A}{I_{DQ}}$

9. **Power** $P_T = I_D V_{DS}$

10. **Amplifier Gains**

$$A_v(\text{with ench. load}) = -g_{mD}\left(r_{oD}||\frac{1}{g_{mL}}||r_{oL}\right) \approx \frac{-g_{mD}}{g_{mL}} = -\frac{2\sqrt{K_{nD}I_{DQD}}}{2\sqrt{K_{nL}I_{DQL}}} = \sqrt{\frac{K_{nD}}{K_{nL}}} = \sqrt{\frac{(W/L)_D}{(W/L)_L}}$$

$$A_v(\text{with dept. load}) = -g_{mD}\left(r_{oD}||r_{oL}\right) \approx \frac{-g_{mD}}{g_{mL}} = -\frac{2\sqrt{K_{nD}I_{DQD}}}{2\sqrt{K_{nL}I_{DQL}}} = \sqrt{\frac{K_{nD}}{K_{nL}}} = \sqrt{\frac{(W/L)_D}{(W/L)_L}}$$