EE 140/240A **ANALOG INTEGRATED CIRCUITS** **FALL 2013**

C. NGUYEN

PROBLEM SET #1

Issued: Tuesday, Sep. 3rd, 2013

Due: Wednesday, Sep. 11th, 2013, 8:00 a.m. in the EE 140/240A homework box

1. An *npn* transistor has an emitter area of 10μm × 10μm. The doping concentrations are as follows: in the emitter $N_D = 10^{19}\text{cm}^{-3}$, in the base $N_A = 10^{17}\text{cm}^{-3}$, and in the collector $N_D = 10^{15}\text{cm}^{-3}$. The transistor operates at T = 300K, where $n_i = 1.5 \times 10^{10}\text{cm}^{-3}$. For electrons diffusing in the base, L_n = 19μm and $D_n = 21.3\text{cm}^2/\text{s}$. For holes diffusing in the emitter, L_p = 0.6μm and $D_p = 1.7\text{cm}^2/\text{s}$. Calculate the saturation current I_s and β assuming that the base width W is (a) 1μm; (b) 2μm; (c) 5μm.

2. **(a)** Calculate the built-in potential, depletion layer depths, and maximum field in a plane-abrupt *pn* junction in silicon with doping densities $N_A = 8 \times 10^{15}\text{atoms/cm}^3$ (p-type) and $N_D = 10^{17}\text{atoms/cm}^3$ (n-type). Do this for (i) 5V reverse bias, (ii) zero external bias and (iii) 0.3V forward bias.

(b) Calculate the junction capacitance at (i) 5V reverse bias, (ii) zero bias and (iii) 0.3V forward bias, respectively. Assume a junction area of $2 \times 10^{-5}\text{cm}^2$.

3. A lateral *pnp* transistor has an effective base width of 10μm

(a) If the emitter-base depletion capacitance is 2pF in the forward-active region and is constant, calculate the device f_T at I_C = -0.5mA (Neglect C_μ). Also, calculate the minority-carrier charge stored in the base of the transistor at this current level. Assume a hole diffusion constant of $D_P = 13\text{cm}^2/\text{s}$ in silicon.

(b) If the collector-base depletion layer width changes 0.11μm per volt of V_{CE}, calculate r_o for this transistor at I_C = -0.5 mA.

4. An *NMOS* transistor has parameters W = 10μm, L = 1μm, $k' = 194\mu\text{A/V}^2$, $\lambda = 0.024\text{V}^{-1}$, t_{ox} = 80Å, Φ_f = 0.3V, V_{t0} = 0.6V, and $N_A = 5\times10^{15}$ atoms/cm^3. Ignore velocity saturation effects.

(a) Sketch the I_D-V_{DS} characteristics for V_{DS} from 0 to 3V and V_{GS} = 0.5V, 1.5V, and 3V. Assume V_{SB} = 0.

(b) Sketch the I_D-V_{GS} characteristics for V_{DS} = 2V as V_{GS} varies from 0 to 2V with V_{SB} = 0, 0.5V, and 1V.

5. For the devices in the Fig. PS1.1, $|V_t| = 1\text{V}$, $\lambda = 0$, $\gamma = 0$, $\mu_n C_{ox} = 50\mu\text{A/V}^2$, $L = 1\mu\text{m}$, and $W = 10\mu\text{m}$. Find V_2 and I_2. How do these values change if Q_3 and Q_4 are changed to have $W = 100\mu\text{m}$.

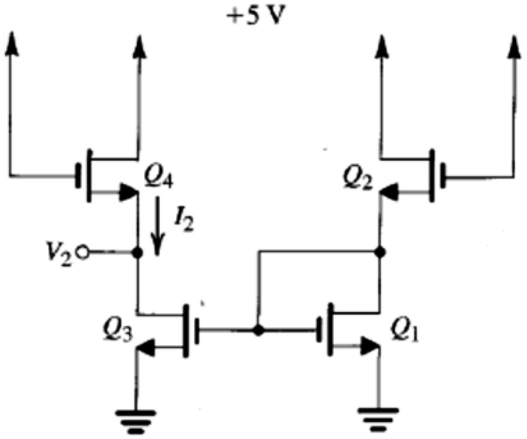


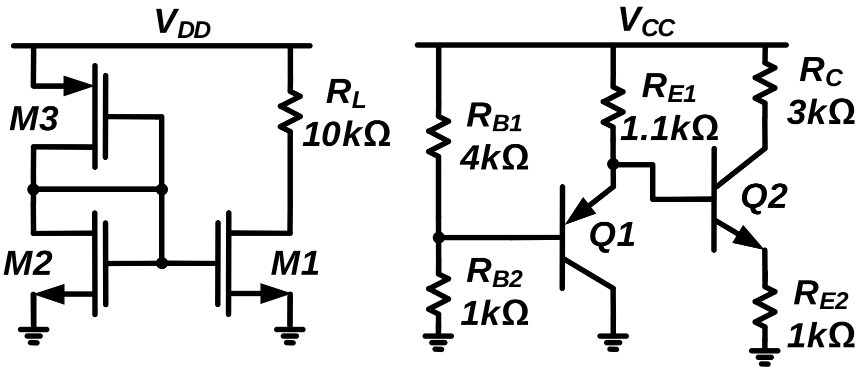
Fig. PS1.1

6. Calculate the DC operating points including the current flowing through each branch and DC voltage at each node for the circuits shown in Fig. PS1.2:

$V_{DD} = V_{CC} = 5\text{V}$, $\beta_f = 100$, $V_A \rightarrow \infty$, $r_b = 0$, $V_{BE(on)} = 0.7\text{V}$, $V_{CE(sat)} = 0.2\text{V}$,

$k'_n = 140\mu\text{A/V}^2$, $V_{tn} = 0.7\text{V}$, $k'_p = 40\mu\text{A/V}^2$, $V_{tp} = -0.8\text{V}$, $\lambda=0$,

$(W/L)_1 = 10\mu\text{m}/0.5\mu\text{m}$, $(W/L)_2 = 5\mu\text{m}/0.5\mu\text{m}$, $(W/L)_3 = 10\mu\text{m}/0.5\mu\text{m}$,



(a) **(b)**

Fig. PS1.2