

## Homework 7A

Required for EE 240A students; optional for EE 140 students

Due: Friday Nov. 7, 2014 1pm

1. Determine the value of sensitivity  $S$  of output current to supply voltage for the circuit in Fig. PSA1.1, where  $S = (V_{CC}/I_{OUT})(\partial I_{OUT}/\partial V_{CC})$ .

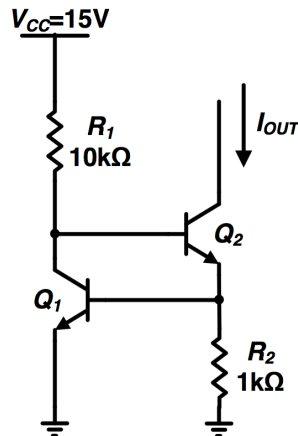


Fig. PSA1.1

2. Fig. PSA1.2 depicts a self-biasing  $V_t$  reference circuit capable of providing bias currents nearly independent of supply voltage.
- Provide expressions for the DC output current  $I_{OUT}$  and bias currents  $I_{BIAS1}$  and  $I_{BIAS2}$  in terms of circuit elements and transistor parameters and calculate numerical values. Ignore body effect and channel length modulation.
  - Calculate the ratio of small-signal variations in  $I_{OUT}$  to small-signal variations in  $V_{DD}$  at low frequencies, i.e., find the gain from  $v_{dd}$  to  $i_{out}$ . Ignore body effect but include finite transistor  $r_o$  in this calculation.

MOS parameters:

$$|V_{th}|=0.5\text{V}, k_n'=200\mu\text{A}/\text{V}^2, k_p'=100\mu\text{A}/\text{V}^2, \lambda=0.05\text{V}^{-1}, V_{DD}=3\text{V}, R=1.75\text{k}\Omega,$$

$$(W/L)_1=12.5\mu\text{m}/0.25\mu\text{m}, (W/L)_2=6.25\mu\text{m}/0.25\mu\text{m}, (W/L)_3=31.25\mu\text{m}/0.25\mu\text{m},$$

$$(W/L)_4=6.25\mu\text{m}/0.25\mu\text{m}, (W/L)_5=12.5\mu\text{m}/0.25\mu\text{m}, (W/L)_6=15.5\mu\text{m}/0.25\mu\text{m}.$$

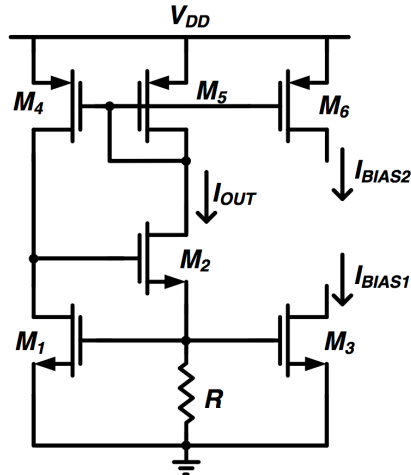


Fig. PSA1.2

3. The circuit of Fig. PSA1.3 is used to provide a bandgap reference voltage  $V_{OUT}$ . In the circuit,  $R_1 = 1\text{k}\Omega$  and  $R_2 = 2\text{k}\Omega$ . For simplicity, assume that  $M_1$ - $M_2$  and  $M_3$ - $M_4$  are identical pairs with  $(W/L)_{1-4} = 50/0.5$  and  $I_{D1} = I_{D2} = 50\mu\text{A}$ . Also assume  $\lambda = \gamma = 0$ , and  $Q_3$  is identical to  $Q_1$  whereas  $Q_2$  consists of  $n$  unit transistors identical to  $Q_1$  and  $Q_3$ , in parallel. For calculations, assume  $\partial V_{BE}/\partial T = -1.5\text{mV}/^\circ\text{K}$  and  $\partial V_T/\partial T = +0.087\text{mV}/^\circ\text{K}$  at room temperature.
- If  $(W/L)_5$  is the same as  $(W/L)_{1-4}$ , determine the value of  $n$  such that  $V_{OUT}$  has zero  $TC_f$  at room temperature.
  - If  $(W/L)_5$  is  $4\times$  that of  $(W/L)_{1-4}$ , again determine the value of  $n$  such that  $V_{OUT}$  has zero  $TC_f$  at room temperature.
  - Now, assume  $(W/L)_5$  is  $\alpha\times$  that of  $(W/L)_{1-4}$ , calculate  $\alpha$  and  $n$  values so that  $V_{OUT}$  has zero  $TC_f$  at room temperature with minimum  $\alpha+n$  value. (Numerical solution is allowed.)

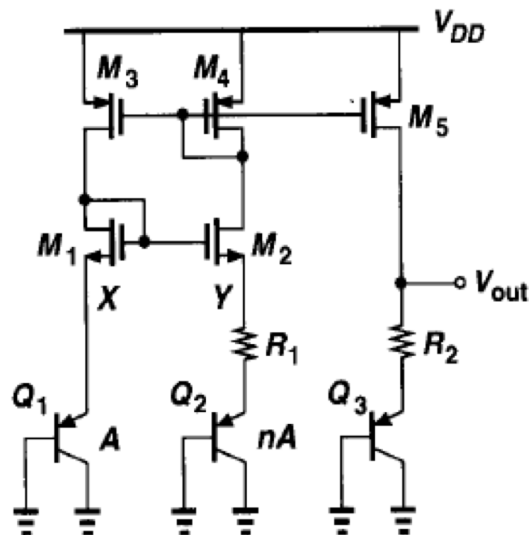
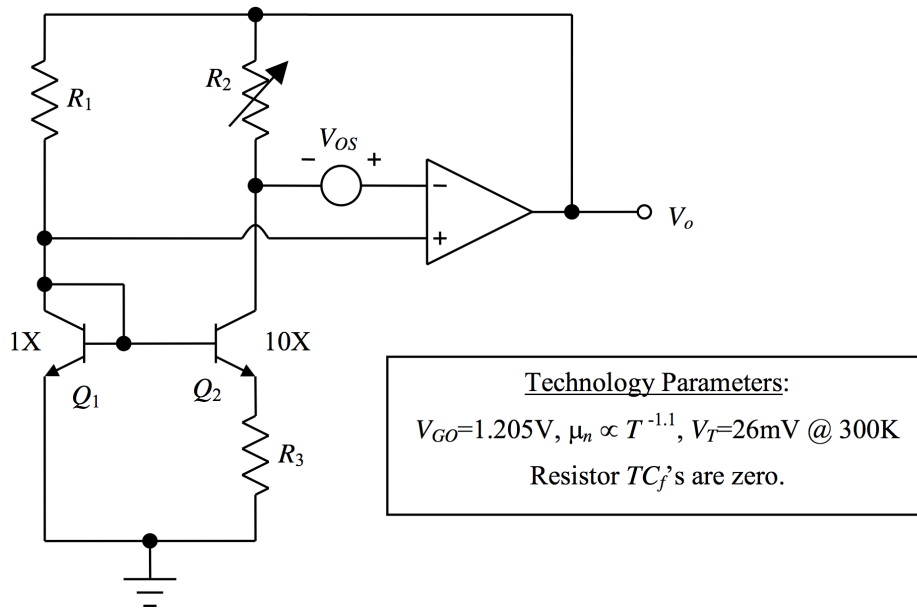


Fig. PSA1.3

4. For the voltage reference below in Fig. PSA1.4, resistor  $R_2$  is trimmed after fabrication to produce an output voltage that for the particular technology used (and assuming an ideal op amp) is known to give a zero output voltage temperature coefficient  $TC_f$  at room temperature (300K). In solving this problem, assume that  $R_1 \approx R_2$ , even after trimming, since the trim range will normally be small. (Note that you do not need to know the values of the resistors to do this problem.)



**Fig. PSA1.4**

- (a) Assuming an ideal op amp (i.e., with  $V_{OS} = 0V$ ), determine the output voltage  $V_o$  that sets the output voltage temperature coefficient to zero at room temperature.
- (b) Suppose now that the op amp actually has an offset voltage  $V_{OS}$  of 3mV. Calculate the resulting deviation from the actual zero  $TC_f$  output voltage that would result after  $R_2$  is trimmed to make  $V_o$  equal to the answer of part (a).
- (c) What is the  $TC_f$  of  $V_o$  at room temperature when  $V_{OS}$  is 3mV and  $R_2$  is trimmed as in part (b)?