(1) $V_{EB2} = V_T \ln \frac{I_{C2}}{I_{S2}} = V_T \ln \frac{I_{E2}}{I_{S2}}$ because base current is ignored

$$I_{E2} = \frac{\Delta V_{EB}}{R_3}$$

Now double I_{S1} & I_{S2}. ΔV_{EB} is constant. See (4.272)
Therefore I_{E2} & I_{C2} are constant

So V_{EB2} changes by $V_T \ln \frac{1}{2} = -18\text{ mV}$

From (4.248) $\quad V_{EB2} = V_{G0} - V_T\left[(\gamma-\alpha)\ln T - \ln(EG)\right]$

$$\frac{dV_{EB2}}{dT} = \frac{-V_T(\gamma-\alpha)}{T} - (\gamma-\alpha)\ln T\,\frac{V_T}{T} + \frac{V_T}{T}\ln(EG)$$

$$= \frac{-V_T(\gamma-\alpha)\overbrace{-V_T\left[(\gamma-\alpha)\ln T - \ln(EG)\right] + V_{G0}}^{V_{EB2}} - V_{G0}}{T}$$

$$= \frac{V_{EB2} - V_{G0} - V_T(\gamma-\alpha)}{T}$$

Under nominal conditions, the slope of the V_{EB2} term and the slope of the ΔV_{EB} term at the output are set equal in magnitude and opposite in polarity at 25°C to set $TC_F = 0$. However, under the specified conditions, V_{EB2} has fallen by 18mV, and its slope has fallen by $\frac{18\text{ mV}}{25+273} = \frac{18}{298} = 60\ \frac{\mu V}{°K} = 60\ \frac{\mu V}{°C}$

Since V_{EB2} contributes directly to the output, [see (4.266)], the output slope changes by the same amount.

Therefore $\left.\frac{dV_{OUT}}{dT}\right|_{T=25°C} = -60\ \frac{\mu V}{°C}$

(2) With I_{S1} and I_{S2} doubled from the nominal value but the gain equal to the nominal value, SPICE gives $\left.\frac{dV_{OUT}}{dT}\right|_{T=25°C} = -58\ \frac{\mu V}{°C}$

With the gain readjusted so that V_{OUT} = target at 25°C, $\left.\frac{dV_{OUT}}{dT}\right|_{T=25°C} = 0$

Therefore, the case of $I_S \neq$ nominal can be corrected by trimming the gain to set the output equal to the target.

(3) Because $M_3 = M_4$, $|I_{D3}| = |I_{D4}| = I_{D1} = I_{D2} = I_{BIAS}$

KVL: $V_{GS1} - V_{GS2} = I_{BIAS} R$

Ignore body effect $\longrightarrow V_{t1} = V_{t2}$

$V_{OV1} - V_{OV2} = I_{BIAS} R$

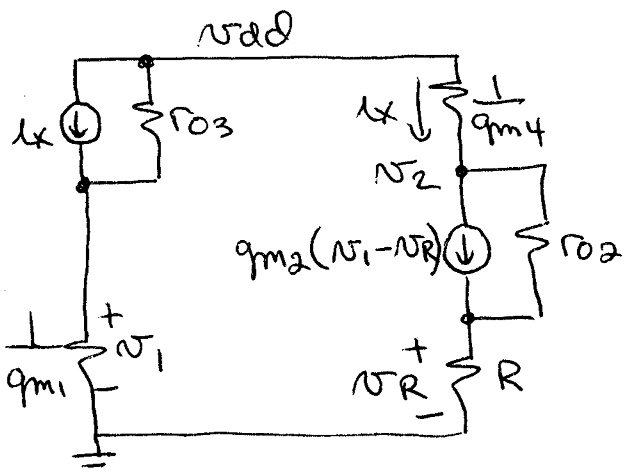
$$\sqrt{\frac{2 I_{BIAS}}{\mu_n C_{ox} (W/L)_1}} - \sqrt{\frac{2 I_{BIAS}}{\mu_n C_{ox} (W/L)_2}} = I_{BIAS} R$$

$$\sqrt{\frac{2 I_{BIAS}}{\mu_n C_{ox}}} \left\{ \sqrt{\frac{1}{(W/L)_1}} - \sqrt{\frac{1}{(W/L)_2}} \right\} = I_{BIAS} R$$

$$I_{BIAS} = \frac{2}{\mu_n C_{ox} R^2} \left\{ \sqrt{\frac{1}{(W/L)_1}} - \sqrt{\frac{1}{(W/L)_2}} \right\}^2$$

As $T\uparrow$, $R\uparrow$ and $\mu_n \downarrow$ ($\mu_n \propto T^{-n}$). These effects tend to cancel. The precise behavior depends on the exact dependence of μ_n and R versus T.

(4) small signal model



KCL $i_x = \dfrac{v_1 - v_{dd}}{r_{o3}} + v_1 g_{m1}$

$\longrightarrow v_1 \left(\dfrac{1}{r_{o3}} + g_{m1} \right) = i_x + \dfrac{v_{dd}}{r_{o3}}$

$v_2 = v_{dd} - \dfrac{i_x}{g_{m4}} = v_R + v_{ro2}$

$= i_x R + [i_x - g_{m2}(v_1 - v_R)] r_{o2}$

So $v_{dd} - \dfrac{i_x}{g_{m4}} =$

$i_x R + i_x r_{o2} - g_{m2} r_{o2} v_1 + g_{m2} r_{o2} i_x R$

$$v_{dd} = i_x \left(R + r_{o2} + g_{m2} r_{o2} R + \frac{1}{g_{m4}} \right) - \frac{g_{m2} r_{o2} \left(i_x + \frac{v_{dd}}{r_{o3}} \right)}{g_{m1} + 1/r_{o3}}$$

$$v_{dd} \left(1 + \underbrace{\frac{g_{m2} r_{o2}}{1 + g_{m1} r_{o3}}}_{\text{small}} \right) = i_x \left(\underbrace{R}_{\text{small}} + \underbrace{r_{o2}}_{\text{small}} + g_{m2} r_{o2} R + \underbrace{\frac{1}{g_{m4}}}_{\text{small}} - \underbrace{\frac{g_{m2} r_{o2}}{1 + g_{m1} r_{o3}}}_{\text{small}} r_{o3} \right)$$

Assume $r_{o2} \simeq r_{o3}$

$$\frac{i_{bias}}{v_{dd}} = \frac{i_x}{v_{dd}} \simeq \frac{1 + \frac{g_{m2}}{g_{m1}}}{g_{m2} r_{o2} R}$$

The use of cascodes on the top and bottom would reduce $\dfrac{i_{bias}}{v_{dd}}$ by another factor of $g_m r_o$