Homework Assignment No. 12

Problem 1 - (10 points)

Find the GB of a two-stage op amp using Miller compensation using a nulling resistor that has 60° phase margin where the second pole is -10x10^6 rads/sec and two higher poles both at -100x10^6 rads/sec. Assume that the RHP zero is used to cancel the second pole and that the load capacitance stays constant. If the input transconductance is 500µA/V, what is the value of C_c?

Solution

The resulting higher-order poles are two at -100x10^6 radians/sec. The resulting phase margin expression is,

$$\text{PM} = 180° - \tan^{-1}(A_v(0)) - 2\tan^{-1}\left(\frac{GB}{10^7}\right) = 90° - 2\tan^{-1}\left(\frac{GB}{10^7}\right) = 60°$$

$$\therefore\ 30° = 2\tan^{-1}\left(\frac{GB}{10^7}\right) \quad \rightarrow \quad \left(\frac{GB}{10^7}\right) = \tan(15°) = 0.2679$$

$$GB = 2.679\text{x}10^7 = \frac{g_{m1}}{C_c} \quad \rightarrow \quad C_c = \frac{500\text{x}10^{-6}}{26.79\text{x}10^7} = \underline{\underline{18.66\text{pF}}}$$

Problem 2 – P7.2-4

Use the technique of Ex. 7.2-2 to extend the GB of the cascode op amp of Ex. 6.5-2 as much as possible that will maintain 60° phase margin. What is the minimum value of C_L for the maximum GB?

Solution

Assuming all channel lengths to be 1 μm, the total capacitance at the source of M7 is

$$C_7 = C_{gs7} + C_{bd7} + C_{gd6} + C_{bd6}$$

or, $$C_7 = 75 + 51 + 9 + 51 = 186 \text{ fF}$$

$$g_{m7} = 707\ \mu S$$

Thus, the pole at the source of M7 is

$$p_{S7} = -\frac{g_{m7}}{C_7} = -605 \text{ MHz.}$$

The total capacitance at the source of M12 is

$$C_{12} = C_{gs12} + C_{bd12} + C_{gd11} + C_{bd11}$$

or, $$C_{12} = 34 + 29 + 4 + 29 = 96 \text{ fF}$$

$$g_{m12} = 707\ \mu S$$

Thus, the pole at the source of M12 is

$$p_{S12} = -\frac{g_{m12}}{C_{12}} = -1170 \text{ MHz.}$$

The total capacitance at the drain of M4 is

$$C_4 = C_{gs4} + C_{gs6} + C_{bd4} + C_{gd2} + C_{bd2}$$

or, $$C_4 = 43 + 75 + 21 + 3 + 19 = 161 \text{ fF}$$

$$g_{m4} = 283\ \mu S$$

Problem 2 - Continued

Thus, the pole at the drain of M4 is

$$p_{D4} = -\frac{g_{m4}}{C_4} = -280 \text{ MHz.}$$

The total capacitance at the drain of M8 is

$$C_8 = C_{gd8} + C_{bd8} + C_{gs10} + C_{gs12}$$

or, $$C_8 = 9 + 51 + 34 + 34 = 128 \text{ fF}$$

$$R_2 + \frac{1}{g_{m10}} = 3.4 \ K\Omega$$

Thus, the pole at the drain of M8 is

$$p_{D8} = -\frac{1}{\left(R_2 + \frac{1}{g_{m10}}\right)C_8} = -366 \text{ MHz.}$$

For a phase margin of 60°, we have

$$PM = 180^\circ - \left[90^\circ - \left\{\tan^{-1}\left(\frac{GB}{p_{S7}}\right) + \tan^{-1}\left(\frac{GB}{p_{S12}}\right) + \tan^{-1}\left(\frac{GB}{p_{D4}}\right) + \tan^{-1}\left(\frac{GB}{p_{D8}}\right)\right\}\right]$$

Solving the above equation

$$GB \cong 65 \text{ MHz.}$$

And, $A_v = 6925$ V/V

Thus, $p_1 = 9.39$ KHz, and $C_L \geq 1.54$ pF

Problem 3 - Problem 7.3-1

Compare the differential output op amps of Fig. 7.3-3, 7.3-5, 7.3-6, 7.3-7, 7.3-8 and 7.3-10 from the viewpoint of (a.) noise, (b.) *PSRR*, (c.) *ICMR* [V_{ic}(max) and V_{ic}(min)], (d.) *OCMR* [V_o)max) and V_o(min)], (e.) *SR* assuming all input differential currents are identical, and (f.) power dissipation if all current of the input differential amplifiers are identical and power supplies are equal.

Solution

	Fig. 7.3-3	Fig. 7.3-5	Fig. 7.3-6	Fig. 7.3-7	Fig. 7.3-8	Fig. 7.3-10
Noise	Good	Poor	Good	Poor	Okay	Poor
PSRR	Poor	Good	Poor	Good	Good	Good
ICMR						
V_{ic}(max)	V_{DD}-V_{ON}	V_{DD}+V_T	V_{DD}-V_{ON}	V_{DD}+V_T	V_{DD}-V_{ON}	V_{DD}-V_{ON}
V_{ic}(min)	V_{SS}+ 2V_{ON}+V_T	V_{SS}+ 2V_{ON}+V_T	V_{SS}+ 2V_{ON}+V_T	V_{SS}+ 2V_{ON}+V_T	V_{SS}+ 2V_{ON}+V_T	V_{SS}+ 3V_{ON}+2V_T
OCMR						
V_o(max)	V_{DD}-V_{ON}	V_{DD}-2V_{ON}	V_{DD}-V_{ON}	V_{DD}-V_{ON}	V_{DD}-2V_{ON}	V_{DD}-2V_{ON}
V_o(min)	V_{SS}+V_{ON}	V_{SS}+2V_{ON}	V_{SS}+V_{ON}	V_{SS}+V_{ON}	V_{SS}+2V_{ON}	V_{SS}+2V_{ON}
SR	I_{SS}/C_c	I_{SS}/C_L	I_{SS}/C_c	I_{SS}/C_L	I_{SS}/C_L	I_{SS}/C_L

Problem 4 - Problem 7.3-7

(a.) If all transistors in Fig. 7.3-12 have a dc current of 50μA and a *W/L* of 10μm/1μm, find the gain of the common mode feedback loop. (b.) If the output of this amplifier is cascoded, then repeat part (a.).

Solution

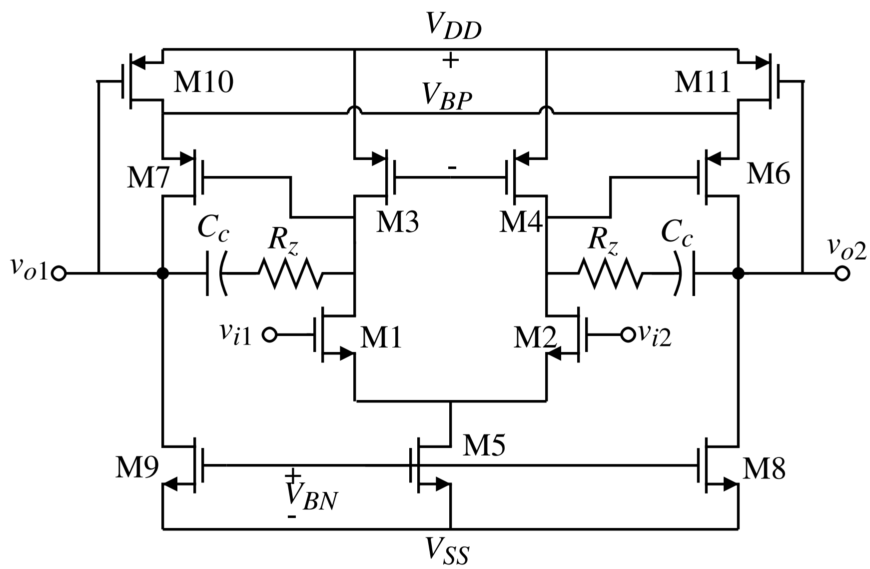

Figure 7.3-12 Two-stage, Miller, differential-in, differential-out op amp with common-mode stabilization.

The loop gain of the common-mode feedback loop is,

$$\text{CMFB Loop gain} \approx -\frac{g_{m10}}{g_{ds9}} = -g_{m10}r_{ds9} \quad \text{or} \quad -\frac{g_{m11}}{g_{ds8}} = -g_{m11}r_{ds8}$$

With I_D = 50μA and W/L = 10μm/1μm, $g_{m10} = \sqrt{\frac{2K_P'WI_D}{L}} = \sqrt{2\cdot 50\cdot 10\cdot 50)} =$ 223.6μS,

$$r_{dsN} = \frac{1}{\lambda_N I_D} = \frac{25}{50\mu\text{A}} = 0.5\text{M}\Omega \quad \text{and} \quad r_{dsP} = \frac{1}{\lambda_P I_D} = \frac{20}{50\mu\text{A}} = 0.4\text{M}\Omega$$

∴ $\boxed{\text{CMFB Loop gain} \approx -g_{m10}r_{ds9} = -223.6(0.5) = -111.8\text{V/V}}$

If the output is cascoded, the gain becomes,

$$\text{CMFB Loop gain with cascoding} \approx -\frac{g_{m10}}{g_{ds9}}\, g_m(\text{cascode})r_{ds}(\text{cascode})$$

$$= -g_{m10}\{[r_{ds9}\, g_m(\text{cascode})r_{ds}(\text{cascode})]||[g_{m7}r_{ds7}\,(r_{ds10}||r_{ds10}]\}$$

$$g_{mP} = \sqrt{\frac{2K_N'WI_D}{L}} = \sqrt{2\cdot 110\cdot 10\cdot 50)} = 331.67\mu\text{S}$$

$$= -(223.6)[(0.5\cdot 331.67\cdot 0.5)||(223.6)(0.4)(0.2)] = 223.6(14.7) = -3{,}290 \text{ V/V}$$

∴ $\boxed{\text{CMFB Loop gain with cascoding} \approx -3.290\text{V/V}}$

Problem 5 – Problem 7.4-1

Calculate the gain, GB, SR and P_{diss} for the folded cascode op amp of Fig. 6.5-7b if $V_{DD} = -V_{SS} = 1.5$V, the current in the differential amplifier pair is 50nA each and the current in the sources, M4 and M5, is 150nA. Assume the transistors are all 10µm/1µm, the load capacitor is 2pF and that n_1 is 2.5 for NMOS and 1.5 for PMOS.

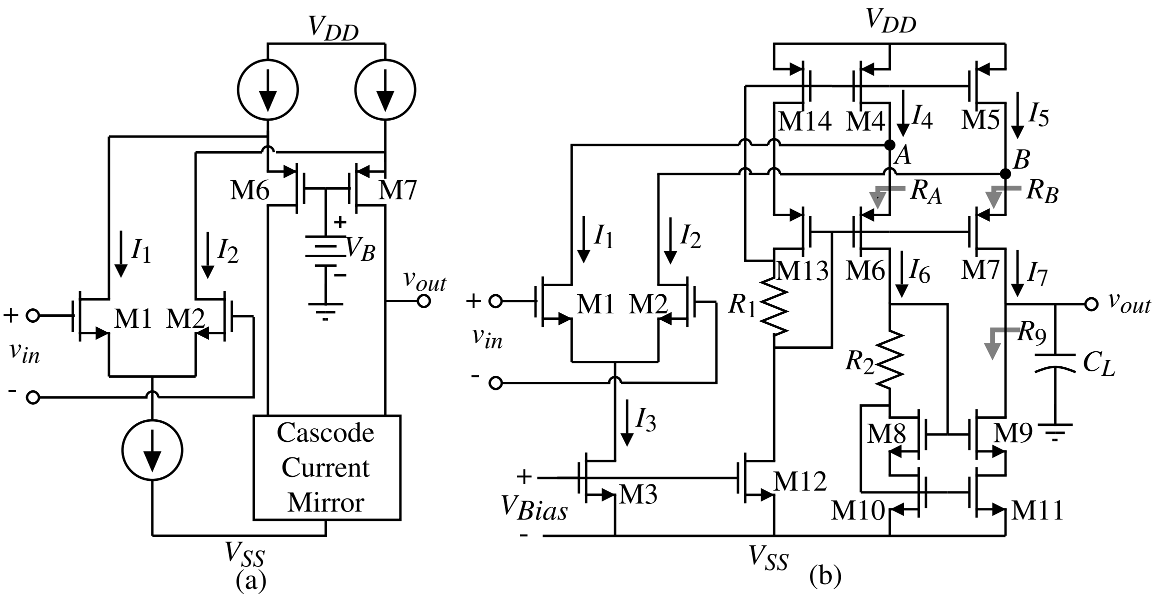

Figure 6.5-7 (a) Simplified version of an N-channel input, folded cascode op amp.
(b) Practical version (a).

Solution

$$g_{m1} = g_{m2} = \frac{I_D}{n_1(kT/q)} = \frac{50\text{nA}}{2.5\cdot 25.9\text{mV}} = 0.772\mu\text{S} \quad \text{and } r_{ds1} = r_{ds2} = \frac{1}{I_D\lambda_N} = 500\text{M}\Omega$$

$$g_{m4} = g_{m5} = \frac{I_D}{n_1(kT/q)} = \frac{150\text{nA}}{1.5\cdot 25.9\text{mV}} = 3.861\mu\text{S} \quad \text{and } r_{ds4} = r_{ds5} = \frac{1}{I_D\lambda_N} = 133\text{M}\Omega$$

$$g_{m6} = g_{m7} = \frac{I_D}{n_1(kT/q)} = \frac{100\text{nA}}{1.5\cdot 25.9\text{mV}} = 2.574\mu\text{S} \quad \text{and } r_{ds6} = r_{ds5} = \frac{1}{I_D\lambda_N} = 200\text{M}\Omega$$

$$g_{m8} = g_{m9} = g_{m10} = g_{m11} = \frac{I_D}{n_1(kT/q)} = \frac{100\text{nA}}{2.5\cdot 25.9\text{mV}} = 1.544\mu\text{S}$$

and $r_{ds8} = r_{ds9} = r_{ds10} = r_{ds11} = \dfrac{1}{I_D\lambda_N} = 250\text{M}\Omega$

Gain: $A_v(0) = g_{m1}R_{out}$,

$$R_{out} \approx r_{ds11}g_{m9}r_{ds9} || [g_{m7}r_{ds7}(r_{ds5}||r_{ds2})] = 96.5\text{G}\Omega || 34.23\text{G}\Omega = 25.269\text{G}\Omega$$

∴ $A_v(0) = 0.772\mu\text{S}\cdot 25.269\text{G}\Omega = \underline{\underline{19{,}508 \text{ V/V}}}$

$GB = g_{m1}/C_L = 386$krads/sec $= \underline{\underline{61.43\text{kHz}}}$ (this assumes all other poles are greater than

GB which is the case if C_L makes R_B approximately the same as R_A at $\omega = GB$.)

$SR = 100\text{nA}/2\text{pF} = \underline{\underline{0.05\text{V}/\mu\text{s}}}$ $\quad P_{diss} = 3\text{V}\cdot(3\cdot 150\text{nA}) = \underline{\underline{1.35\mu\text{W}}}$