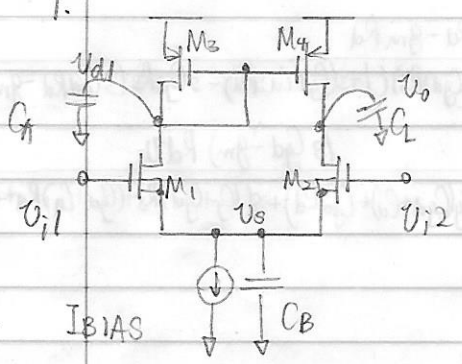
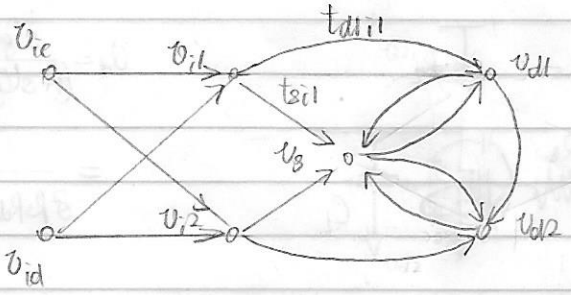
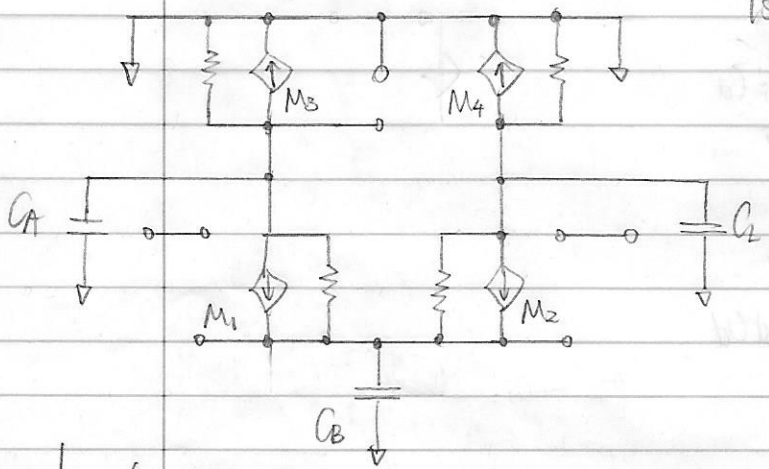
ECE264A Lect 4 Diff to SE Amp

1.







$v_{i1} \to v_{d2}$, $v_{i2} \to v_{d2}$

1st: $t_{d1,s} t_{s,d1}$, $t_{d2,s} t_{s,d2}$, $t_{d1,s} t_{s,d2} t_{d2,d1} t_{s,d2}$

$$v_{i1} = v_{ic} + \frac{1}{2} v_{id}$$
$$v_{i2} = v_{ic} - \frac{1}{2} v_{id}$$

$$\frac{v_{d2}}{v_{id}} = \frac{1}{\Delta}\left(t_{d2,d1} t_{d1,i1} t_{i1,id}\right.$$
$$+ t_{d2,d1} t_{d1,s} t_{s,i1} t_{i1,id}$$
$$+ t_{d2,s} t_{s,i1} t_{i1,id}$$
$$+ t_{d2,i2} t_{i2,id} t_{d1,s} t_{s,d1}$$
$$+ t_{d2,s} t_{s,i2} t_{i2,id}$$
$$\left. + t_{d2,d1} t_{d1,s} t_{s,i2} t_{i2,id}\right)$$

matching is good: $g_{m1,2}$, $g_{m3,4}$, $r_{o1,2}$, $r_{o3,4}$

$$\Delta = 1 - t_{d1,s} t_{s,d1} - t_{d2,s} t_{s,d2} - t_{d1,s} t_{s,d2} t_{d2,d1}$$
$$= 1 - \frac{g_{m1}}{g_{m3}+sC_A} \frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B} - \frac{g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} \frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B}$$
$$- \frac{g_{m1}}{g_{m3}+sC_A} \frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B}$$

$$v_{d1} = \frac{1}{g_{m3}+sC_A}(-g_{m1}v_{i1} + g_{m1}v_s)$$

KCL at D_1 (v_{d1})

$$(g_{m3} + sC_A + \frac{1}{r_{o1}} + \frac{1}{r_{o3}})v_{d1} + g_{m1}v_{i1} = (g_{m1} + \frac{1}{r_{o1}})v_s \quad (v_{d1}, v_{i1}, v_s)$$

$$v_{d2} = \frac{1}{sC_L + \frac{1}{r_{o2}} + \frac{1}{r_{o4}}}$$

KCL at D_2 (v_{d2})

$$(sC_L + \frac{1}{r_{o2}} + \frac{1}{r_{o4}})v_{d2} + g_{m2}v_{i2} + g_{m4}v_{d1}$$
$$- g_{m2}v_{i2} - g_{m4}v_{d1} + g_{m2}v_s) = (g_{m2} + \frac{1}{r_{o2}})v_s \quad (v_{d2}, v_{i2}, v_{d1}, v_s)$$

KCL at S (v_s)

$$v_s = \frac{1}{g_{m1}+g_{m2}+sC_B}$$

$$(g_{m1}+g_{m2}+\frac{1}{r_{o1}}+\frac{1}{r_{o2}}+sC_B)v_s = g_{m1}v_{i1} + g_{m2}v_{i2} + \frac{1}{r_{o1}}v_{d1} + \frac{1}{r_{o2}}v_{d2}$$
$$(g_{m1}v_{i1} + g_{m2}v_{i2} + \frac{1}{r_{o1}}v_{d1} + \frac{1}{r_{o2}}v_{d2})$$

$(v_s, v_{i1}, v_{i2}, v_{d1}, v_{d2})$

Cramer's rule

$$\Delta = \begin{vmatrix} 1 & \frac{-g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} \\ \frac{1}{r_{o1}} & 2g_{m1}+sC_B \end{vmatrix} + \frac{g_{m1}}{g_{m3}+sC_A} \begin{vmatrix} \frac{1}{r_{o1}} & \frac{g_{m3}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} \\ 2g_{m1}+sC_B & \frac{r_{o3}}{2g_{m1}+sC_B} \end{vmatrix}$$

$$= 1 + \frac{\frac{g_{m1}}{r_{o1}}}{(2g_{m1}+sC_B)(sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}})} + \frac{\frac{g_{m1}}{r_{o1}}}{(2g_{m1}+sC_B)(g_{m3}+sC_A)}$$

$$\left(1 - \frac{g_{m3}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}\right)$$

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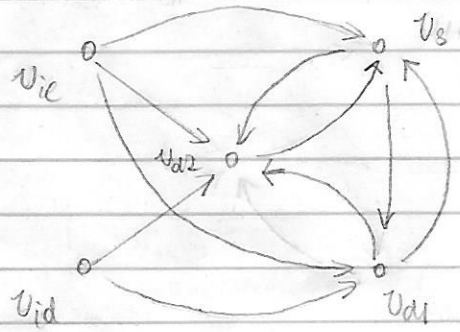
$$v_{od1} = \frac{1}{g_{m3}+sC_A}\left(g_{m1}v_{ic} - \frac{1}{2}g_{m1}v_{id} + g_{m1}v_s\right)$$

$$v_{od2} = \frac{1}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}\left(-g_{m1}v_{ic} + \frac{1}{2}g_{m1}v_{id} - g_{m3}v_{od1} + g_{m1}v_s\right)$$

$$v_s = \frac{1}{2g_{m1}+sC_B}\left(2g_{m1}v_{ic} + \frac{1}{r_{o1}}v_{od1} + \frac{1}{r_{o1}}v_{od2}\right)$$

	v_{od2}	v_{od1}	v_s	v_{ic}	v_{id}
v_{od1}	0	-1	$\frac{g_{m1}}{g_{m3}+sC_A}$	$\frac{g_{m1}}{g_{m3}+sC_A}$	$\frac{\frac{1}{2}g_{m1}}{g_{m3}+sC_A}$
v_{od2}	1	$\frac{g_{m3}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}$	$-\frac{g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}$	$-\frac{g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}$	$\frac{\frac{1}{2}g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}$
v_s	$\frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B}$	$\frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B}$	1	$\frac{2g_{m1}}{2g_{m1}+sC_B}$	0



$$L_1 = t_{d1,s}t_{s,d1}$$
$$L_2 = t_{d2,s}t_{s,d2}$$
$$L_3 = t_{d1,s}t_{s,d2}t_{d2,d1}$$

$$G_2\Delta_2 = t_{od2,d1}t_{d1,id} = \frac{-g_{m3}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}\cdot\frac{-\frac{1}{2}g_{m1}}{g_{m3}+sC_A}$$

$$\Delta = 1 - t_{d1,s}t_{s,d1} - t_{d2,s}t_{s,d2} - t_{d1,s}t_{s,d2}t_{d2,d1}$$

$$= 1 - \frac{g_{m1}}{g_{m3}+sC_A}\cdot\frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B} - \frac{g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}\cdot\frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B} - \frac{g_{m1}}{g_{m3}+sC_A}\cdot\frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B}\cdot\frac{-g_{m3}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}$$

$$G_3\Delta_3 = t_{d2,s}t_{s,d1}t_{d1,id} = \frac{g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}\cdot\frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B}\cdot\frac{-\frac{1}{2}g_{m1}}{g_{m3}+sC_A}$$

$$\frac{v_{od2}}{v_{id}} = \frac{}{(\dots) - \frac{g_{m1}}{r_{o1}}(sC_L+sC_A)}$$

$$G_1\Delta_1 = t_{d2,id}t_{d1,s}t_{s,d1} = \frac{\frac{1}{2}g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}\cdot\frac{g_{m1}}{g_{m3}+sC_A}\cdot\frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B}$$

$$\frac{v_{od2}}{v_{id}} = \frac{\sum_i G_i\Delta_i}{\Delta}$$

$$= \frac{\frac{1}{2}g_{m1}g_{m3}(2g_{m1}+sC_B)}{(g_{m3}+sC_A)(2g_{m1}+sC_B)(sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}) - \frac{g_{m1}}{r_{o1}}(sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}+g_{m3}+sC_A) + \frac{g_{m1}}{r_{o1}}g_{m3}}$$

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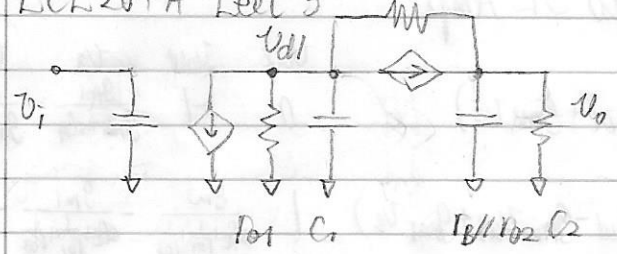
2.



KCL at d_1

$$\left(\frac{1}{r_{o1}}+\frac{1}{r_{o2}}+sC_1+g_{m2}'\right)v_{d1}=\frac{1}{r_{o2}}v_o-g_{m1}v_i$$

KCL at o/p

$$\left(\frac{1}{r_{o2}}+\frac{1}{r_B}+sC_2\right)v_o=\left(\frac{1}{r_{o2}}+g_{m2}\right)v_{d1}$$

$$\frac{v_o}{v_i}=\frac{-g_{m1}z_{d1}\left(g_{m2}+\frac{1}{r_{o2}}\right)z_{d2}}{1-\frac{1}{r_{o2}}\left(g_{m2}+\frac{1}{r_{o2}}\right)z_{d1}z_{d2}}$$

$$\frac{-g_{m1}\left(g_{m2}+\frac{1}{r_{o2}}\right)}{\left(g_{m2}+sC_1+\frac{1}{r_{o1}}+\frac{1}{r_{o2}}\right)\left(\frac{1}{r_B}+\frac{1}{r_{o2}}+sC_2\right)-\frac{1}{r_{o2}}\left(g_{m2}+\frac{1}{r_{o2}}\right)}$$

$$\Delta_{vd2}=\begin{vmatrix} \frac{\frac{1}{2}g_{m1}}{g_{m3}+sC_A} & -1 & \frac{g_{m1}}{g_{m3}+sC_A} \\ \frac{\frac{1}{2}g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} & \frac{g_{m3}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} & -\frac{g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} \\ 0 & \frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B} & 1 \end{vmatrix}$$

$$=-\frac{\frac{1}{r_{o1}}}{2g_{m1}+sC_B}\begin{vmatrix} \frac{\frac{1}{2}g_{m1}}{g_{m3}+sC_A} & \frac{g_{m1}}{g_{m3}+sC_A} \\ \frac{\frac{1}{2}g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} & -\frac{g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} \end{vmatrix}$$

$$+\begin{vmatrix} \frac{\frac{1}{2}g_{m1}}{g_{m3}+sC_A} & -1 \\ \frac{\frac{1}{2}g_{m1}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} & \frac{g_{m3}}{sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}} \end{vmatrix}$$

$$=\frac{\frac{g_{m1}^2}{r_{o1}}}{(2g_{m1}+sC_B)(g_{m3}+sC_A)(sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}})}$$

$$+\frac{\frac{1}{2}g_{m1}g_{m3}+\frac{1}{2}g_{m1}(g_{m3}+sC_A)}{(g_{m3}+sC_A)(sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}})}$$

$$\frac{v_{od2}}{v_{id}}=\frac{\Delta_{vod2}}{\Delta}=\frac{\frac{g_{m1}^2}{r_{o1}}+\frac{1}{2}g_{m1}g_{m3}(2g_{m1}+sC_B)+\frac{1}{2}g_{m1}(g_{m3}+sC_A)(2g_{m1}+sC_B)}{(2g_{m1}+sC_B)(sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}})(g_{m3}+sC_A)+\frac{g_{m1}}{r_{o1}}(g_{m3}+sC_A)+\frac{g_{m1}}{r_{o1}}(sC_L+\frac{1}{r_{o1}}+\frac{1}{r_{o3}}-g_{m3})}$$

$$\approx\frac{1}{2}\frac{g_{m1}g_{m3}+g_{m1}(g_{m3}+sC_A)}{(\frac{1}{r_{o1}}+\frac{1}{r_{o3}})(1-\frac{s}{p_1})g_{m3}(1-\frac{s}{p_2})}\qquad g_{m1}(2g_{m3}+sC_A)$$