Problem 1 [30 points]

(a) [15 points] Consider the active LPF shown below. Assume the OP-amp is ideal [$A_v=\infty$, $Z_{in}=\infty$, and $Z_{out}=0$]. The target 3dB bandwidth and the pass band gain of the LPF are $5\cdot10^6$ [rad/sec] and 20dB, respectively. Calculate $R_1$ and $R_2$ values.

![LPF Circuit Diagram]

C$_1$ = 1 pF

(b) [15 points] Now assume the OP-amp has non-ideal gain and input impedance [$A_v\neq\infty$, $Z_{in}\neq\infty$, and $Z_{out}=0$] as shown below. Derive its transfer function, H(s), in terms of $A_v$, $C_{in}$, $R_1$, $R_2$, and $C_1$. Do not use the numerical values of $R_1$ and $R_2$ calculated in (a). [Hint: assume that the voltage on the OP-amp negative input port is $v_x$, and find the relation between $v_x$ and $v_{out}$.]
**Problem 2 [35 points]** Consider the fully differential amplifier shown below. Assume the input signal is symmetric and all transistors are in saturation. Assume $C_C = \infty$, and $R_f << r_o$.

![Fully Differential Amplifier Diagram](image)

The differential input to the differential output transfer function, $H(s)$, has three poles (one pole per each node approach). Derive the expressions for the low-frequency gain ($A_{\delta I}$) [11 points], and the three poles ($\omega_{p1}$, $\omega_{p2}$, and $\omega_{p3}$) [24 points]. Include $r_o$, $C_{gs}$, $C_{ds}$, $C_{sb}$, and $C_{gd}$. Ignore $C_{gds}$ and $C_{gqs}$. Use $r_o$, $C_{gs}$, $C_{ds}$, and $C_{sb}$ where $x$ is the number of each transistor. **The order of the three poles is not important.**

![Magnitude of Transfer Function](image)

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Problem 3 [35 points] Calculate the "low-frequency" voltage gain ($V_o/V_{in}$) of the amplifier shown below. Ignore the body effect and channel length modulation ($r_o=\infty$). Assume all transistors are in saturation, and $g_m = g_{m1} = g_{m2} = g_{m3} = g_{m4}$. Assume $R_S << r_o$.

$g_{m1}$: transconductance of M1
$g_{m2}$: transconductance of M2
$g_{m3}$: transconductance of M3
$g_{m4}$: transconductance of M4

Assume $g_m = g_{m1} = g_{m2} = g_{m3} = g_{m4}$. Assume $R_S << r_o$. 

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