ACTIVE FILTER DESIGN : PROBLEM SET 4

Problem 1 : Filter with CMOS inverters, single-ended versus differential structures.

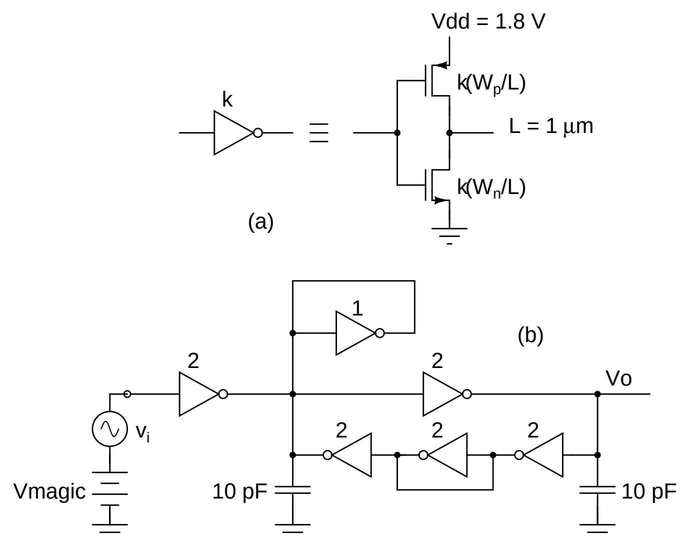

Figure 1: A Gm-C filter using CMOS inverters

One usually associates a CMOS inverter with being a "digital" circuit element. In this problem, we explore an analog filter built using CMOS inverters. The basic idea is to use the inverter as a transconductor. As shown in the upper part of the figure, an inverter of strength k is equivalent to putting k identical inverters in parallel.

- In what region of operation should the transistors be so that the inverter behaves like a transconductor ?
- Assume that the transistors are ideal in the sense that their output conductances are zero in the saturation region. If one applied just about any random voltage in the range 0-1.8 V at the input of the inverter, in all probability, *both* transistors will not be in the active region. Justify this statement. However, there is a magic DC voltage, which when applied to the inverter input, results in *both* transistors being in saturation. What is this voltage ? Can you come up with a circuit that will generate this magic voltage ?
- Derive expressions for the transconductance of a "unit" transconductor (inverter of strength 1) in terms of the usual MOS parameters. What is the DC gain of the transconductor
- Choose W_n & W_p so that both the following conditions are met at room temperature - (a) The transconductance of the unit inverter is $100\,\mu$S and (b) V_{magic} for this inverter is 0.9 V.
- Consider the filter shown in part(b) of the figure. The inverter sizes are marked, with the unit inverter being that you designed in the previous part. v_i is a small signal source riding over a bias voltage which is chosen to be $V_{magic} = 0.9$ V. Analyze the filter in the following systematic manner.
- Determine the quiescent voltages across the capacitors.
- Determine the small signal transconductances of each inverter.
- Determine the transfer function from the input to the output and express it in standard form. Neglect all parasitic effects associated with the inverter. What are the f_o and Q of the filter ?
- Simulate the frequency response in SPICE, and from this determine the f_o and Q. What do you notice and why ?
- Change the supply voltage from 1.8 V to 1.6 V. Plot the frequency response of the filter. How do f_o and Q change and why ? (When you change the supply, change V_{magic} accordingly.
- Run a transient analysis of your filter with (a) a 100 mV input signal at 1 MHz **and** a 10 mV, 5 MHz sinusoidal signal in series with the supply. The source in the supply voltage is intended to model power supply noise. What do you notice at the filter output and why ? Next, make two identical copies of your filter. The second filter has the same noisy supply voltage, but is operated with an input which is in anti-phase with the input of the first filter. What do you notice about the frequency components at the output of the second filter ? What about the frequency components in the difference between the first and second filter outputs ?

Problem 2 : Bandpass Filter Design

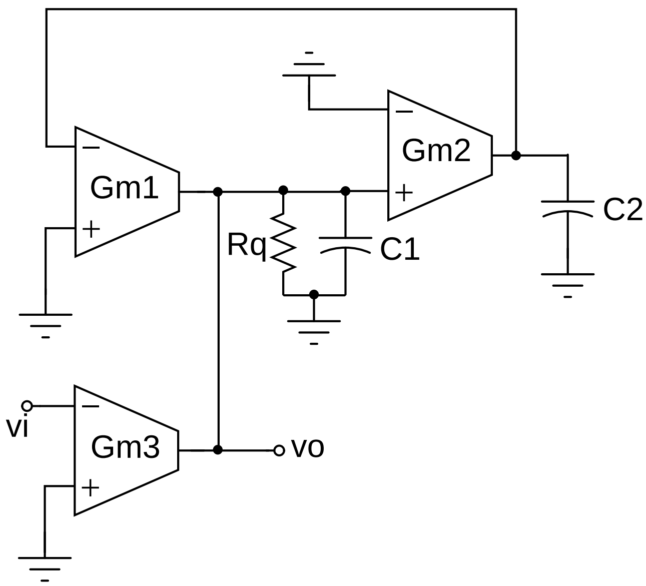

Figure 2: Second order bandpass filter.

Consider the second order bandpass filter shown in Figure 2. Find the component values of a filter that maximizes dynamic range under the following constraints

a. $\omega_p = 2\pi\, 10^6 \mathrm{rad\, s^{-1}}$, $Q_p = 20$.

b. The filter gain at ω_p should be 1.

c. The input range of the transconductors is -0.5 to 0.5 volts.

d. The absolute value of the filter input never exceeds 0.5 V.

e. $C1 + C2 \leq 20\, pF$.

Assume that all transconductors have an input voltage noise spectral density given by $\overline{v_n^2} = (4kT/G_M)$. Simulate the filter in SPICE and plot the output noise spectral density of the filter. What is the RMS output noise ?

Repeat the entire exercise for a filter with a $Q_p = 40$, and all other constraints unchanged. What is the RMS output noise now ?