g_m-C Filter with CMOS Inverters

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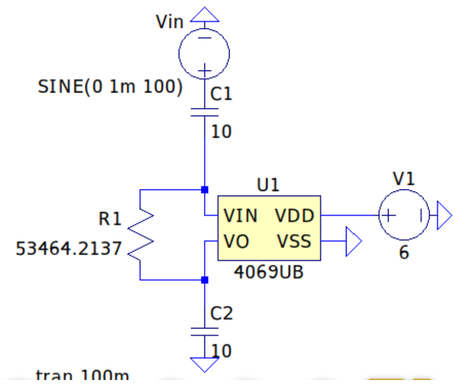
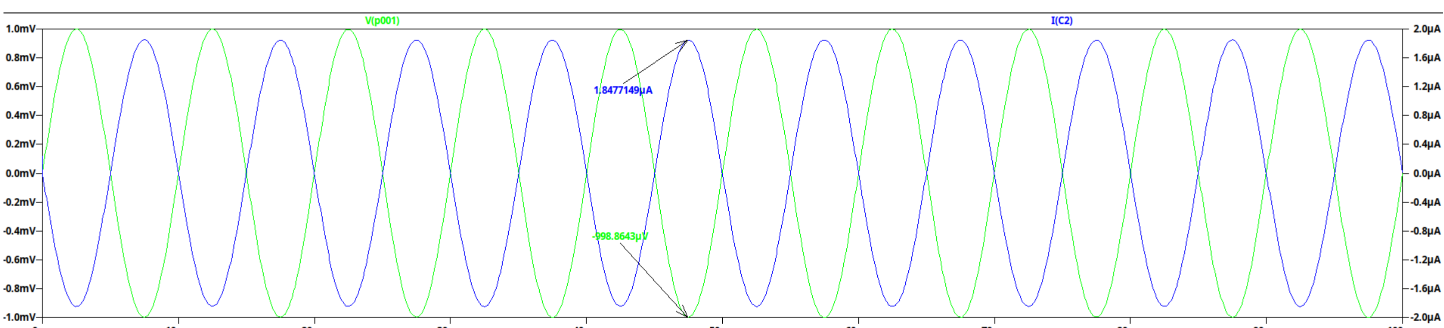
1 Problem 1

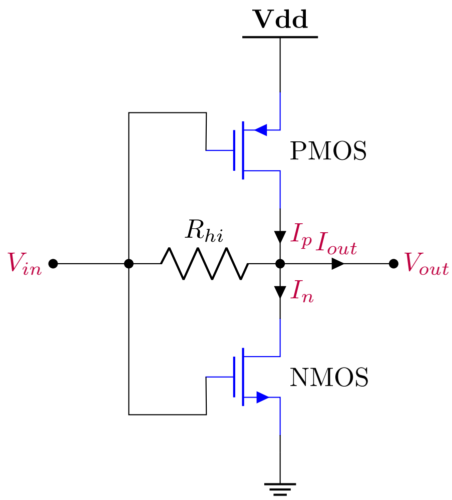
Testbench



Simulation



Observe that we obtained $\frac{i_{out}}{V_{out}}$ as **1.8498m** which is **0.98898** times g_m.



Observe that by applying KCL at node V_{out} we get,

$$I_{out} = I_p - I_n - \frac{V_{out} - V_{in}}{R_{hi}}$$

$$\implies \frac{\Delta I_{out}}{\Delta V_i n} = -g_m + \frac{1}{R_{hi}} \implies \boxed{Transconductance = g_m - \frac{1}{R_{hi}}}$$

From previous experiment we found out that g_m is 0.00187041, Thus inorder to obtain transconductance of $0.99 g_m$. We need R_{hi} of $\frac{100}{g_m}$ which is 53464.2137Ω.

Since we are applying AC signal of 1mV at 100Hz at input, and we want our perpetration to be about self bias voltage we introduce a capacitor after the source and before sink so that this self-bias voltage which is DC component doesn't flow through which makes this circuit more like a transconductor.
Thus our capacitor should have capacitance such that its time constant is far above than time period of signal.

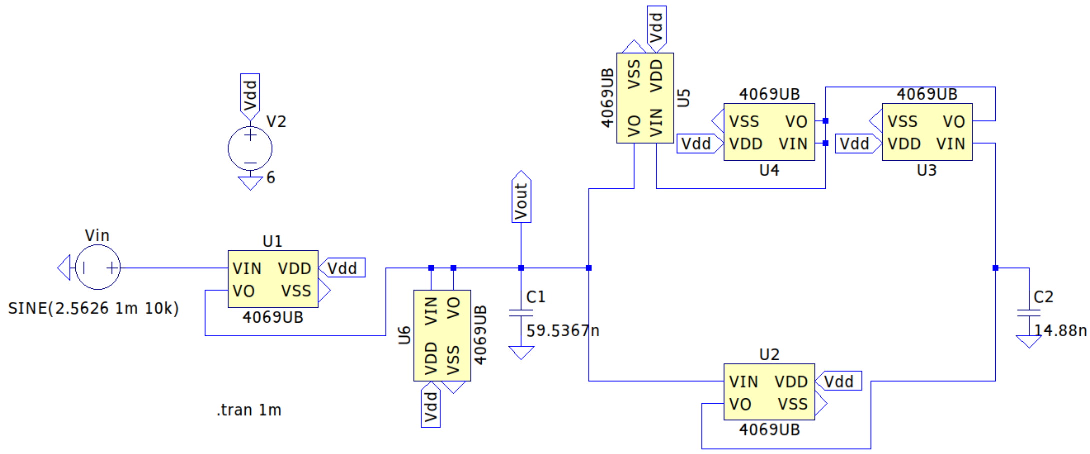
$$R_{eff}C >> \frac{1}{f}$$

$$C >> \frac{G_m}{f} \implies C >> 18.49810\mu F$$

So our capacitance is high enough than required,thus there should not be any problem with it.

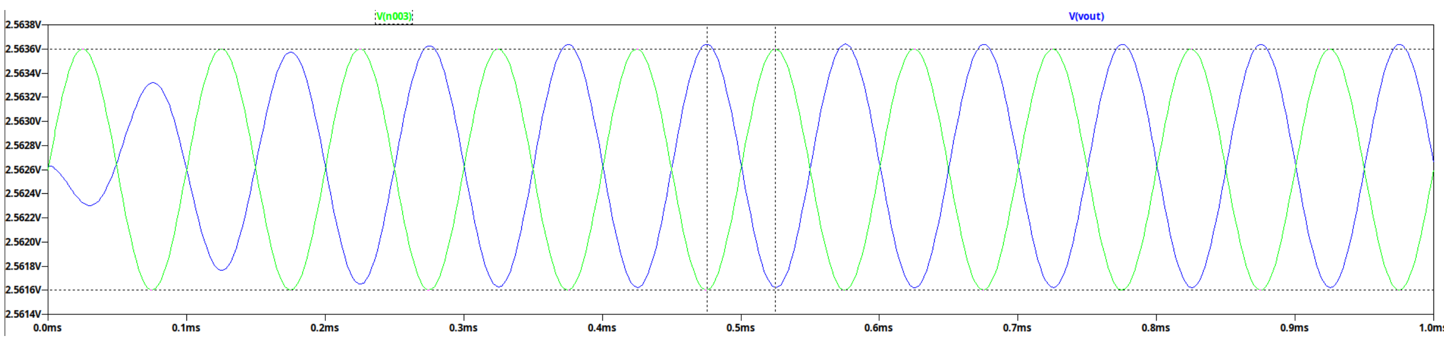
2 Problem 2

Testbench

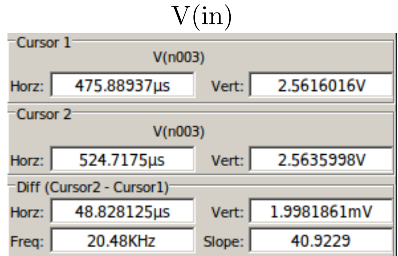


Simulations

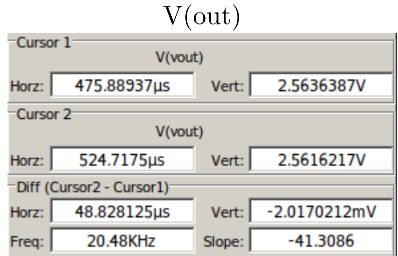
Resonant Frequency



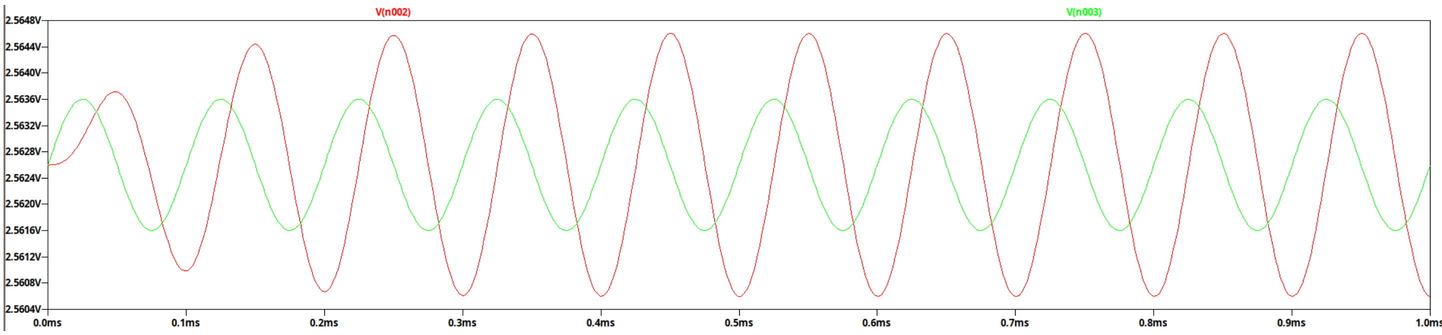
V(in)



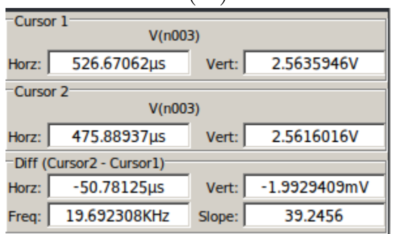
V(out)



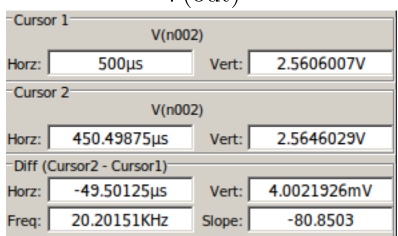
Quality factor



V(in)



V(out)



The below is the Transfer function for the given g_m-C filter in Experiment

$$\frac{V_{out}}{V_{in}} = \frac{\frac{-sC_2}{g_m}}{\frac{s^2 C_1 C_2}{g_m^2} + \frac{sC_2}{R g_m^2} + 1}$$

The following equations are the capacitances and Gain derived from the above transfer function.

$$R = \frac{1}{g_m}$$

$$\omega_n = \frac{g_m}{\sqrt{C_1 C_2}}$$

$$Q = R\sqrt{\frac{C_1}{C_2}} g_m$$

$$\implies \boxed{C_1 = \frac{Q}{R\omega_n}}$$

$$\implies \boxed{C_2 = \frac{R g_m^2}{Q\omega_n} = \frac{R g_m}{Q\omega_n}}$$

$$\boxed{\left.\frac{V_{out}}{V_{in}}\right|_{s=j\omega_n} = -g_m R = -1}$$

We can see that when we give 1mV with 10KHz AC signal we get output which is exactly -180^o of phase shift and of amplitude of 1.008 mV. And from the Transfer function we can see that at Resonant frequency gain is -$g_m R$. Thus we can say that this is the resonant frequency.

Now for verifying Quality factor, We know that at node V_{out} we get Band pass filter response and at C_2 we get 2nd order low pass filter and this has has gain of Q and phase shift of -90^o at resonant frequency. Now observe the transients of the voltage across C_2 we find that amplitude is 2.001mV and it has phase shift of -90^o w.r.t input signal. Thus we can say that ratio is approximately matching specifications.
NOTE:-

1. Even simulation is not on-par with theoretical results because the gain(g_m) is not exactly same as measured it changes with perpetration. And it is assumed that V_{out} of transconductor is constant w.r.t V_{in} but it is not in simulations. Thus these assumptions are creating mismatches with simulations.

2. Inputs/Outputs are biased at V_B=2.5626V or self-bias voltage because there is a constraint of not using resistors in circuits other in CMOS inverter. If there was any load at output or input we could have coupled it with capacitor in-order to obtain desired unbiased output.

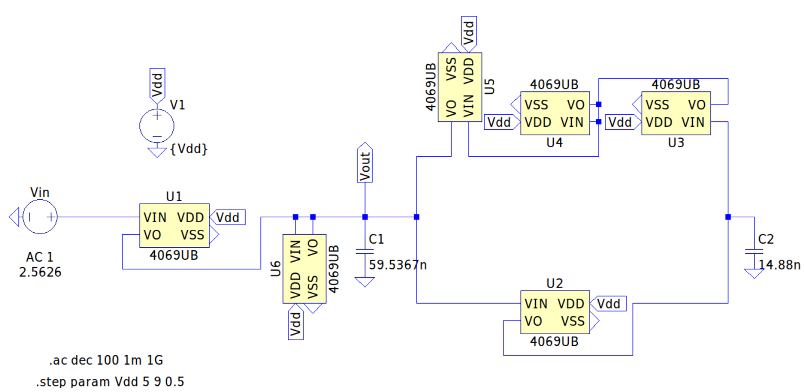
3 Problem 3

When Vdd is 5V it is evident that from previous experiment that at this conditions it cannot be used as analog device or Transconductor rather only as digital logic device. Thus any node the voltage just stays at Vdd or 0.Thus this is not appropriate supply voltage for filter.

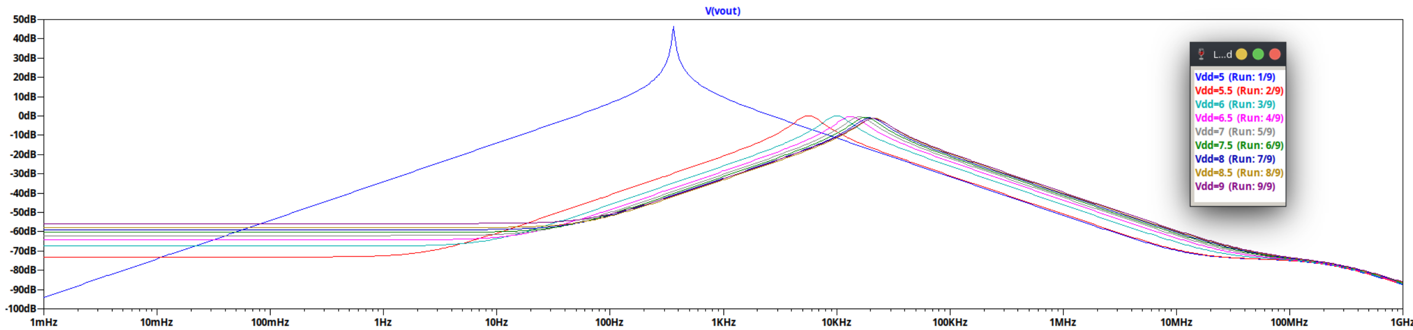
In rest of the cases only g_m transconductance varies with Vdd so as natural frequency.In previous experiment we saw input resistance reducing with increase in Vdd so this implies g_m increases with Vdd.

$$\frac{\Delta I_{out}}{\Delta V_{in}} = -g_m = -(\frac{\beta_p}{2}(Vdd - V_{in} - |V_{TH_p}|) + \frac{\beta_n}{2}(V_{in} - V_{TH_n}))$$

Thus $\boldsymbol{g_m}$ **increases with Vdd**, given the device shall work as transconductor.
Testbench



Simulations



Now this can be observed from the simulation result that Peaking frequency for increment in Vdd increases. **Now we can use this property so that by tuning Vdd we can change resonant frequency for the filter. Now this might be good tool for communication devices or any portable filters**.