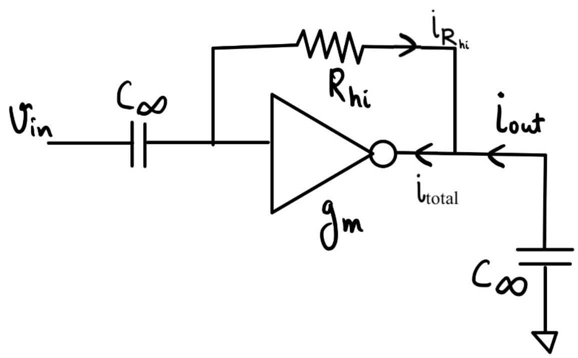
Analog Lab
Experiment 2: g_m-C Filter

Name- Pushkal Mishra
Roll- EE20BTECH11042

1. Calculating value of R_{hi}



From the circuit, by applying KCL we get-

$$i_{total} = i_{out} + i_{Rhi}$$

A capacitor with infinite capacitance will act as a short circuit since the time constant is infinite so the capacitor plates will never rise from 0V. So the voltages across the inverter are v_{in} and 0V.
Therefore-

$$i_{total} = g_m v_{in} = i_{out} + \frac{v_{in} - 0}{R_{hi}}$$

$$g_m = \frac{i_{out}}{v_{in}} + \frac{1}{R_{hi}}$$

From the question-

$$\frac{i_{out}}{v_{in}} = 0.99 g_m$$

So we get-

$$R_{hi} = \frac{100}{g_m} = \frac{100}{1.81826\, mmho}$$

$$R_{hi} = 55\, k\Omega$$

We are neglecting r_o here as it is in the order of MΩ.

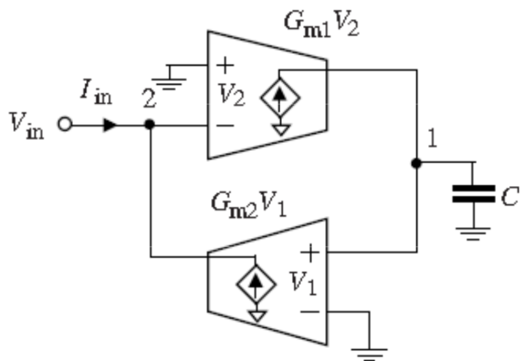
2. Designing a g_m-C filter with

Resonant Frequency: ω_0 = 10kHz

Supply Voltage: V_{DD} = 6V

Quality Factor: Q = 2

First we need to find the inductance based on g_m and C_2.



Reference link

In the circuit we can observe that the current entering the capacitor is $-g_{m1}V_2$ (due to the polarity of V_2). Also the V-I relation for capacitor in s domain is-

$$(0 - V_1) \times sC = i_{capacitor} = g_{m1}V_2$$

Therefore we get-

$$V_1 = -\frac{g_{m1}V_2}{sC}$$

Also observe that -

$$I_{in} = -g_{m2}V_1 = \frac{g_{m1}g_{m2}V_2}{sC}$$

Rearranging the terms we get-

$$V_{in} = V_2 = \frac{sC}{g_{m1}g_{m2}} I_{in}$$

The above equation suggests that the setup acts as an inductor with impedance equal to $\frac{sC}{g_{m1}g_{m2}}$ (like an inductor).

Since g_{m1} and g_{m2} are equal in the given question, the equivalent impedance becomes equal to $\frac{sC}{g_m^2}$.

Given resonant frequency as 10kHz, so

$$f_R = 10kHz = \frac{\omega_0}{2\pi}$$

$$\omega_0 = 62.832\ krad/s$$

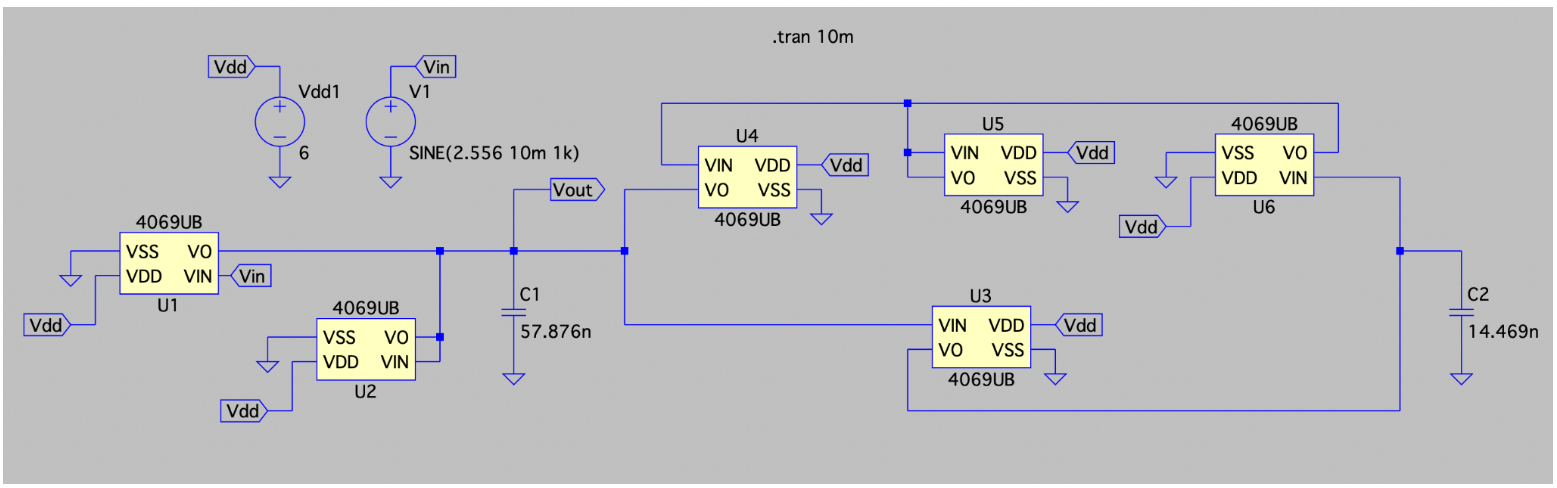
Now as we are implementing resistance R with inverter, so resistance will be $R = \frac{1}{g_m} = 549.98\Omega$

$$Q = 2 = \frac{\omega_0 C_1}{g_m} \quad => \quad C_1 = 57.876\ nF$$

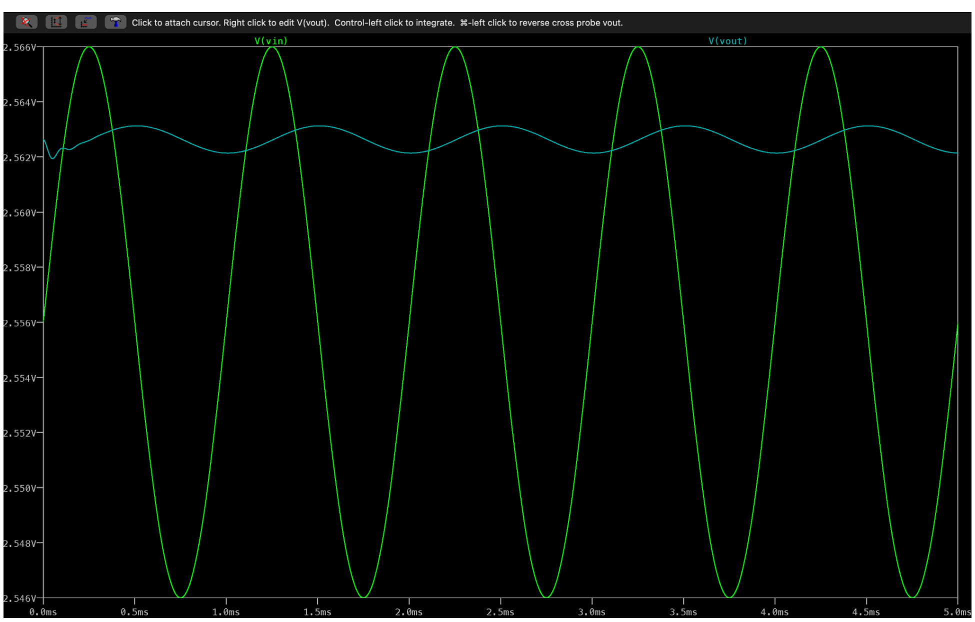
$$\omega_0 = 62.832 \times 10^3 = \frac{g_m}{\sqrt{C_1 C_2}} \quad => C_2 = 14.469\ nF$$

These formulas are from in class derivation for second order parallel RLC filters

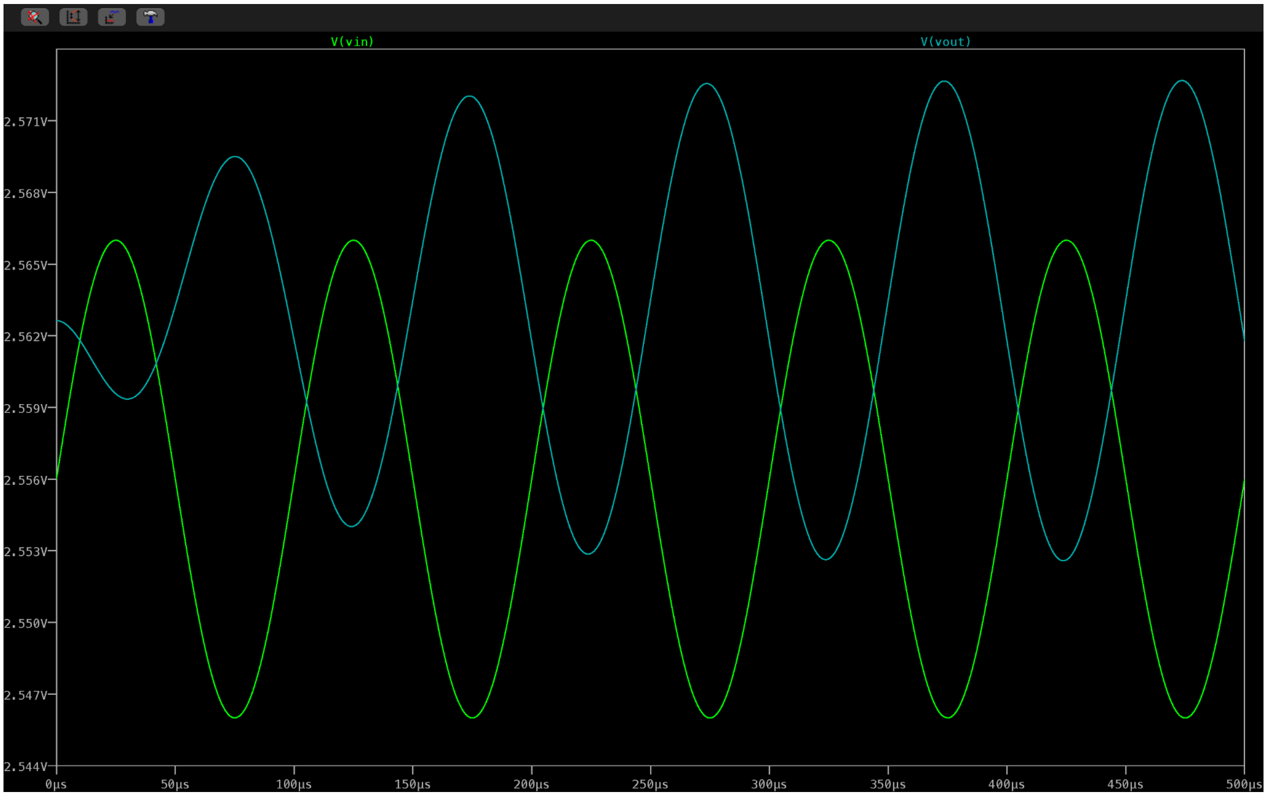
Circuit implementation in LTSpice-



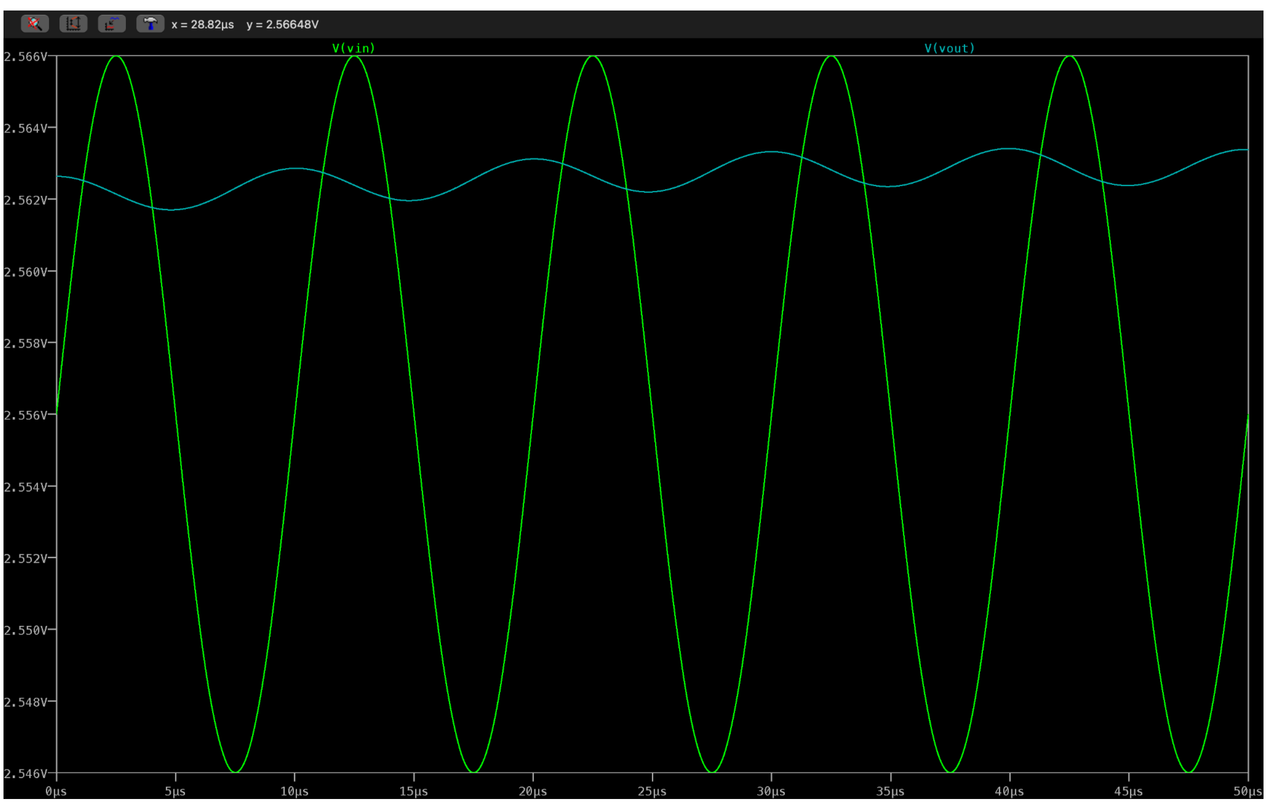
Output plot for input frequency of 1kHz-



Output plot for input frequency of 10kHz-



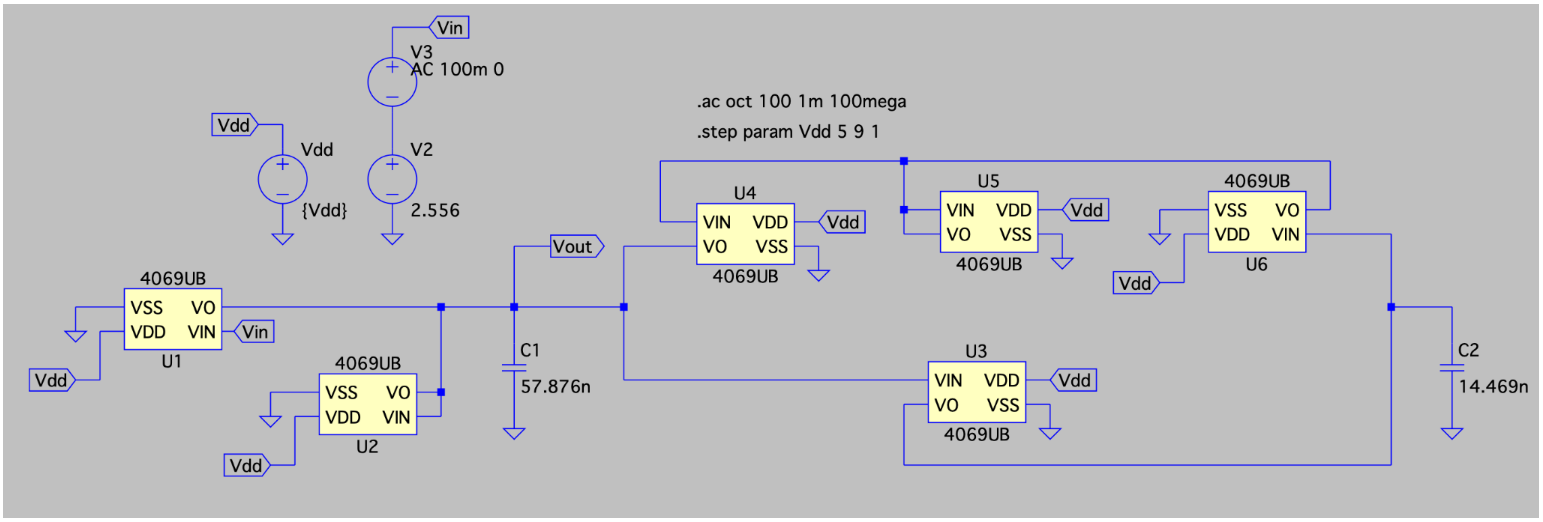
Output plot for input frequency of 100kHz-



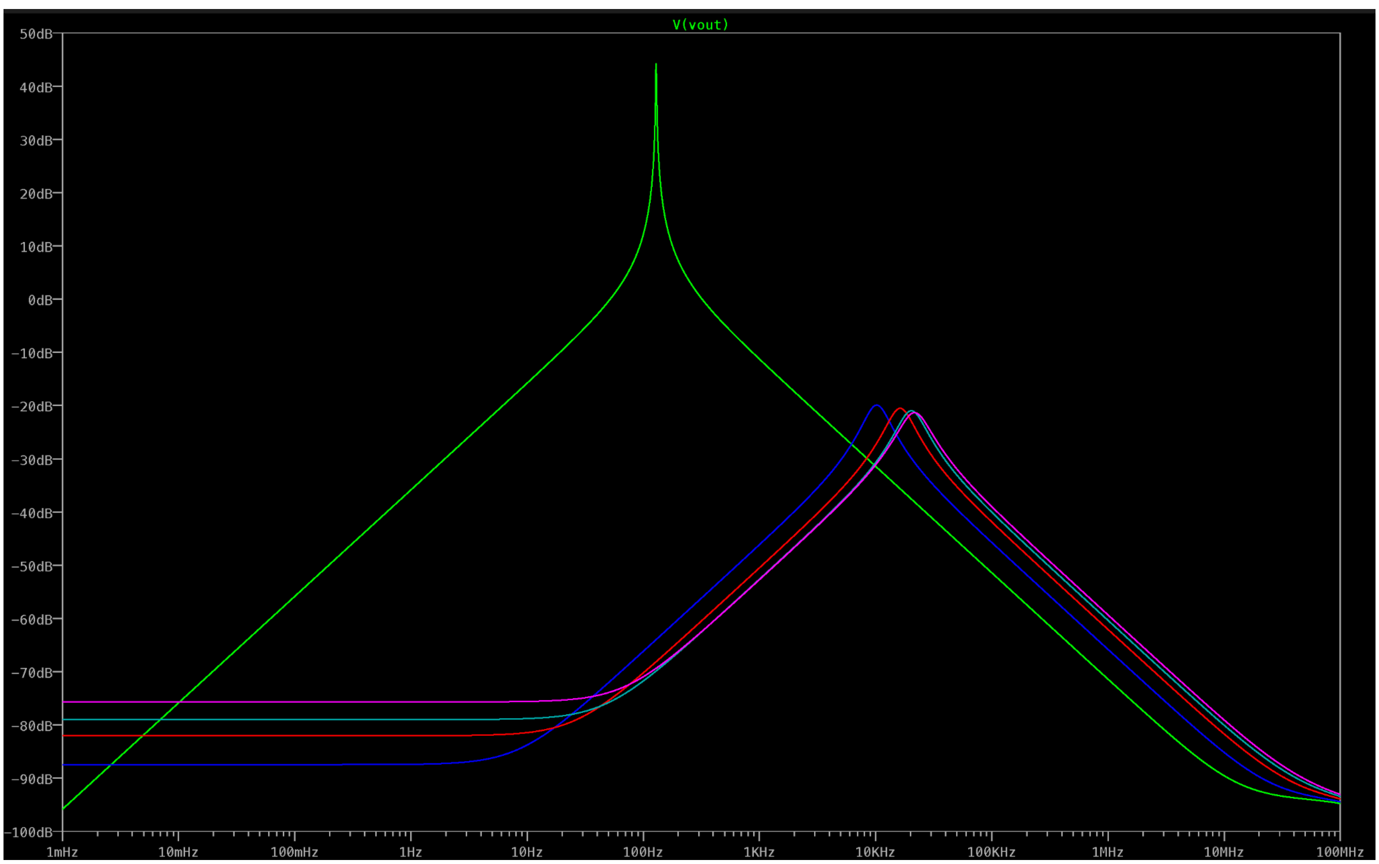
Clearly from the output plots, the filter damps the input signal at frequencies of 1kHz and 100kHz but does not damp the signal with frequency 10kHz. So we can conclude that the filter acts as a band pass filter.
Also observe that the phase difference between input and output signals are 180º at frequency 10kHz.

3. Bode plot by varying V_{DD} from 5V to 9V

Circuit used-



Bode plot obtained-



As concluded from the previous experiment, when V_{DD} equals 5V the inverter acts as a logic device and so the output voltage either stays at 0 or V_{DD}. In the bode plot, the green line indicates at V_{DD} equal to 5V.

From the previous experiment, value of g_m came out to be

$$g_m = \beta_n(V_{GS} - V_{THn})(1 + \lambda_n V_{DS}) + \beta_p(V_{SG} - |V_{THp}|)(1 + \lambda_p V_{SD})$$

Clearly g_m increases as V_{DD} increases (from the above equation) which is also observed in the right shifting of the plot as V_{DD} increases since the natural frequency ω_0 is directly proportional to g_m. Also from the graph the Q factor does not appear to change much and even from the equations in 2, Q does not depend on g_m.

One application of this phenomenon is that we can change V_{DD} to set the resonant frequency of a second order band pass filter and can be used to apply in communication devices.

(The UI is different as I am using a Mac. Also I was unable to find the legend option for the bode plot as it is not available on M1 mac.)