Analog Lab (EE2401)
Experiment 2 : gm-C filter

EE19BTECH11041,
Srijith Reddy Pakala
Department of Electrical Engineering
IIT Hyderabad

February 6, 2021

1 Aim

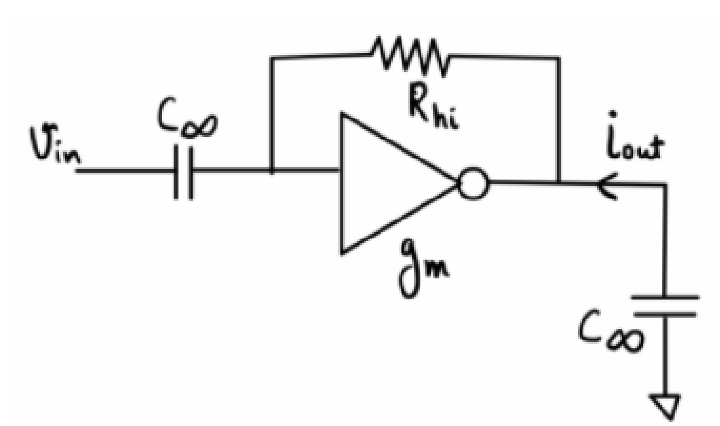
our aim here is to understand how to control and implement a gm-C filter.

Gm-C filter

A Gm-C filter is a kind of the continuous-time filter which needs the operational transconductance amplifier (OTA) to be a basic building block.

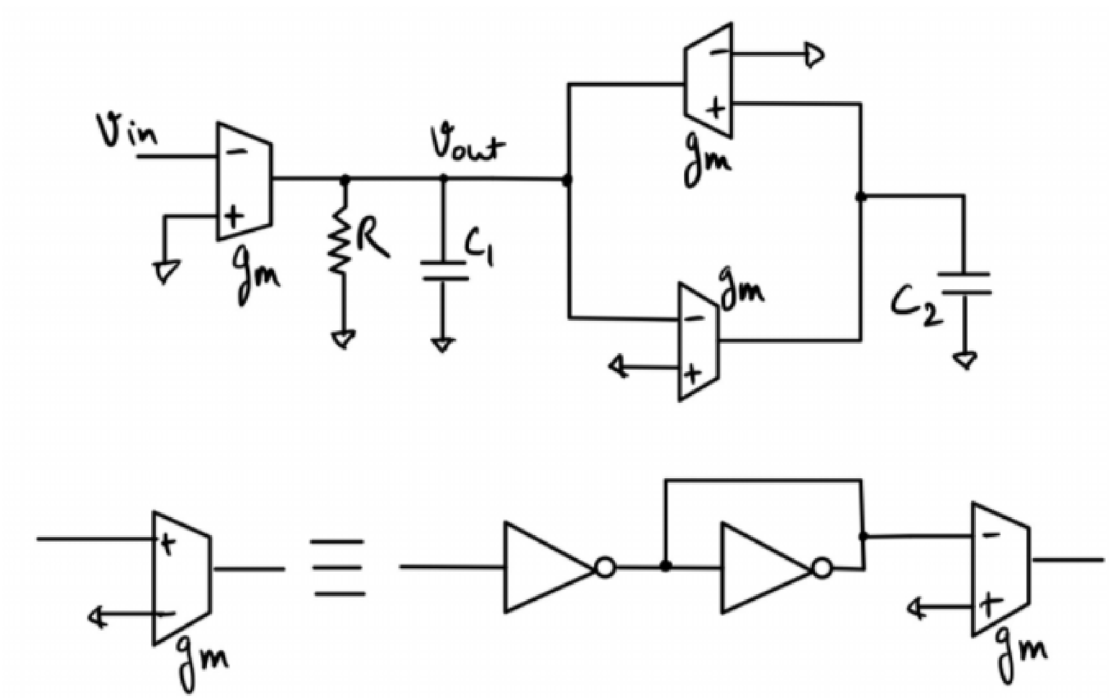
2 Problem statement

1. Calculate the value of R_{hi} required to make $\frac{i_{out}}{v_{in}} = 0.99\ g_m$, where gm is the transconductance of inverter.



2. Design a Gm-C filter using only inverters and capacitors with the following specifications:

- Resonant frequency = 10 kHz.
- Supply voltage = 6 V.
- Quality factor = 2.

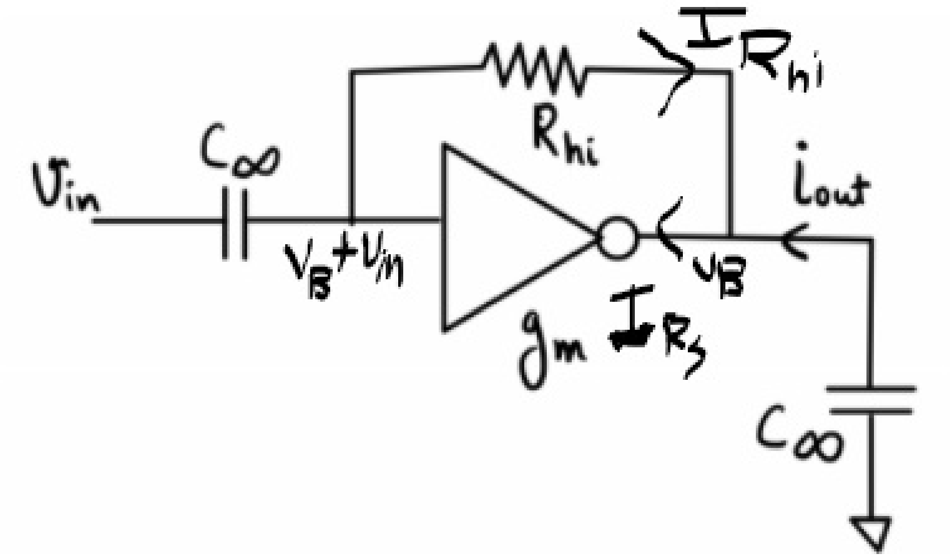


Use only transient and DC simulations to characterize the filter.

3. Now tune the above designed filter by varying the supply voltage from 5 V to 9 V.What do you observe in the filter response as the supply voltage changes?

3 Results and observations

Question 1



- Now let's calculate R_{hi} using the above circuit.

Applying KCL at output of inverter node:

$$I_{R_S} = I_{R_{hi}} + i_{out} \tag{1}$$

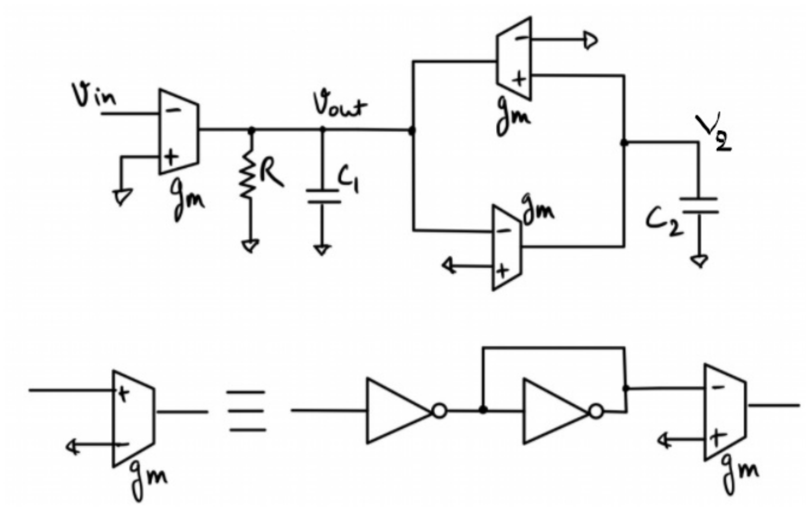
- If we recall the g_m definition we can use $I_{Rs} = V_{in}\ g_m$.

$$v_{in} = \frac{v_{in}}{R_{hi}} + 0.99 g_m v_{in} \tag{2}$$

$$R_{hi} = \frac{1}{0.01 g_m} \tag{3}$$

- By substituting the values $g_m = 0.00187$ A/V, we get $R_{hi} = 53475.93\Omega \approx 53.5K\Omega$.

Question 2



Filter circuit

- From the above circuit we can think capacitor as an integrator and write equations.

$$V_{out} \;=\; \frac{1}{SC_1}\left(-V_{in}g_m - \frac{V_{out}}{R} + V_2 g_m\right),\; V_2 = \frac{-V_{out}g_m}{SC_2} \tag{4}$$

$$V_{out}\left[1 + \frac{1}{SRC_1} + \frac{g_m^2}{S^2C_1C_2}\right] = \frac{-V_{in}g_m}{SC_1} \tag{5}$$

$$\frac{V_{out}}{V_{in}} = \frac{\dfrac{-SC_2}{g_m}}{\dfrac{S^2C_1C_2}{g_m^2} + \dfrac{SC_2}{Rg_m^2} + 1} \tag{6}$$

- Here we are using transconductor instead of R therefore $g_m = \frac{1}{R}$

Resonant frequency(f=$\frac{w}{2\pi}$) and Quality factor(Q)

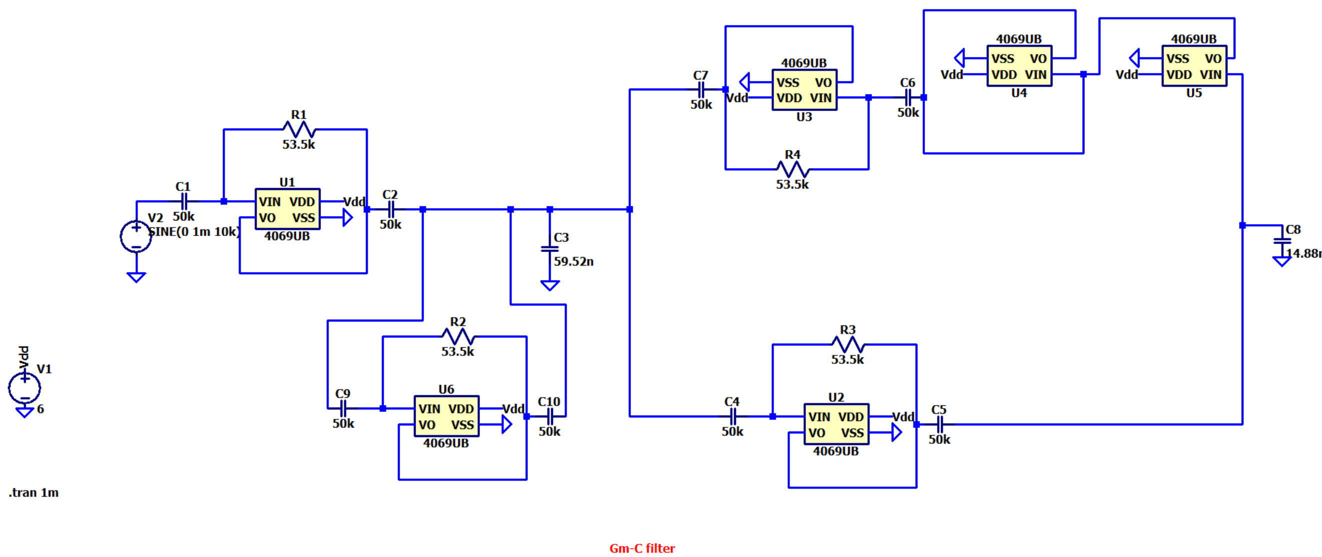
$$w = \frac{g_m}{\sqrt{C_1C_2}},\; Q = g_m R\sqrt{\frac{C_1}{C_2}} = \sqrt{\frac{C_1}{C_2}} \tag{7}$$

- After substituting the given values i.e. f = 10 kHz ,Q = 2 and $g_m = 0.00187$ A/V. we get $C_1 = 59.523$ nF, $C_2 = 14.8809$ nF.

- From the above equations , output at resonant frequency

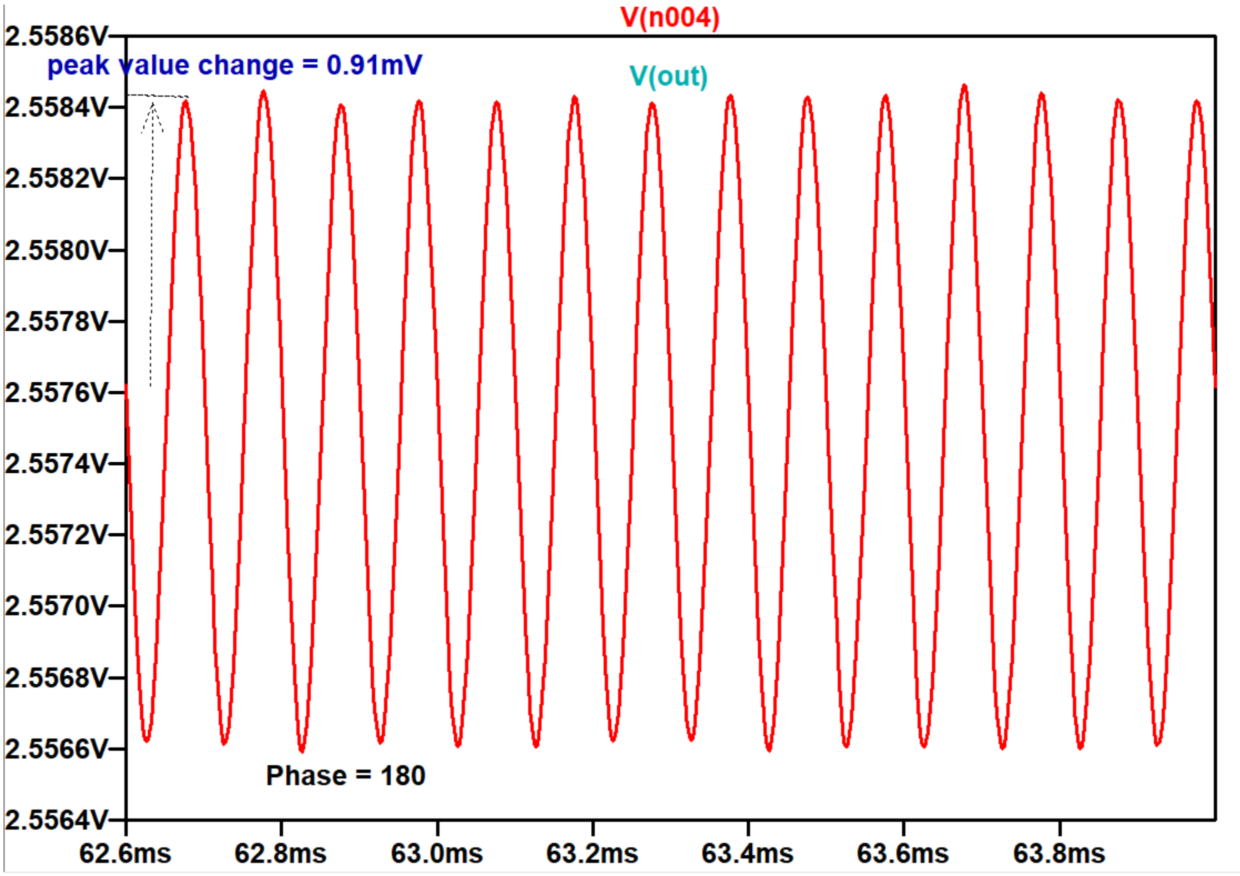
$$\frac{V_{out}}{V_{in}} = \frac{\frac{-SC_2}{g_m}}{\frac{SC_2}{Rg_m^2}} = -1 \tag{8}$$

Gm-C filter circuit diagram



Circuit diagram

Output plot



Plot : V(out) of Gm-C filter

- From the plot we can see that the V_{out} = -0.91V_{in} which is close to what we expected.

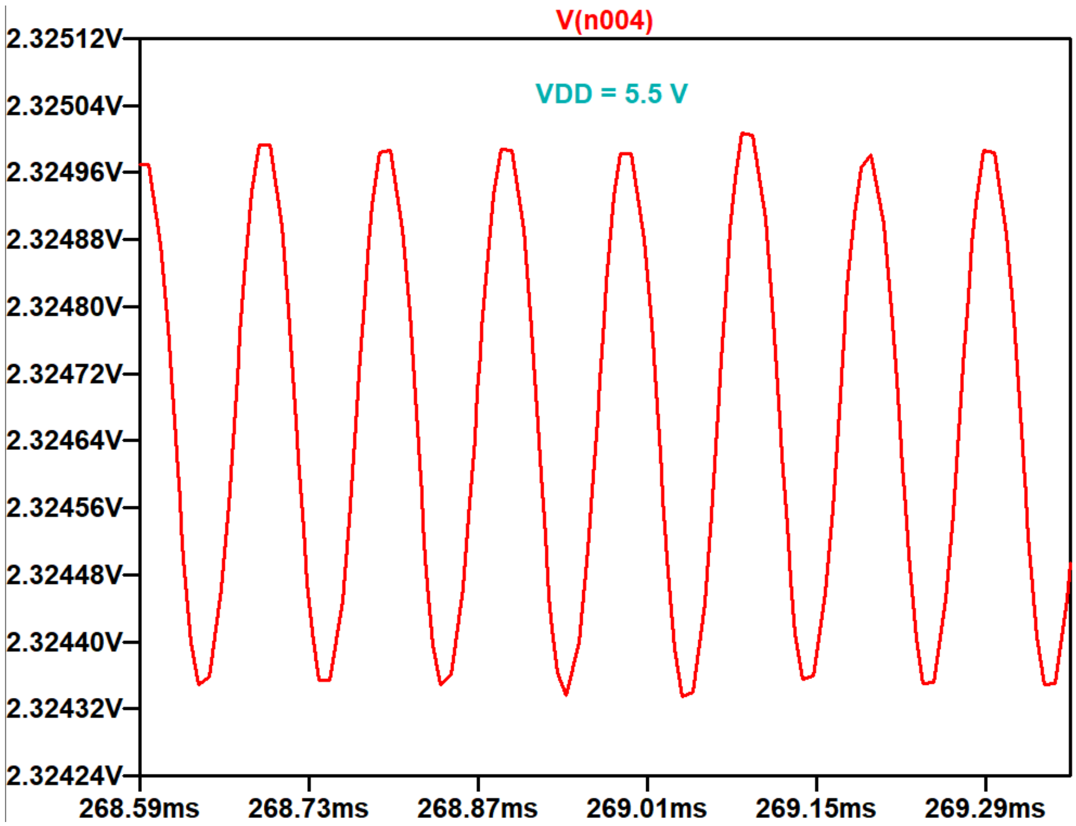
- We can see that the phase differenece is 180 ° as expected.

- The reason for the small difference in expected value can be attributed to small input current in transconductor or change in its nature at some frequencies,or that we have used 0.99 g_m here.

- The output oscillates around bias because there are no resistances in the filter circuit outside of transconductors.

Question 3

Output plot VDD = 5.5 V

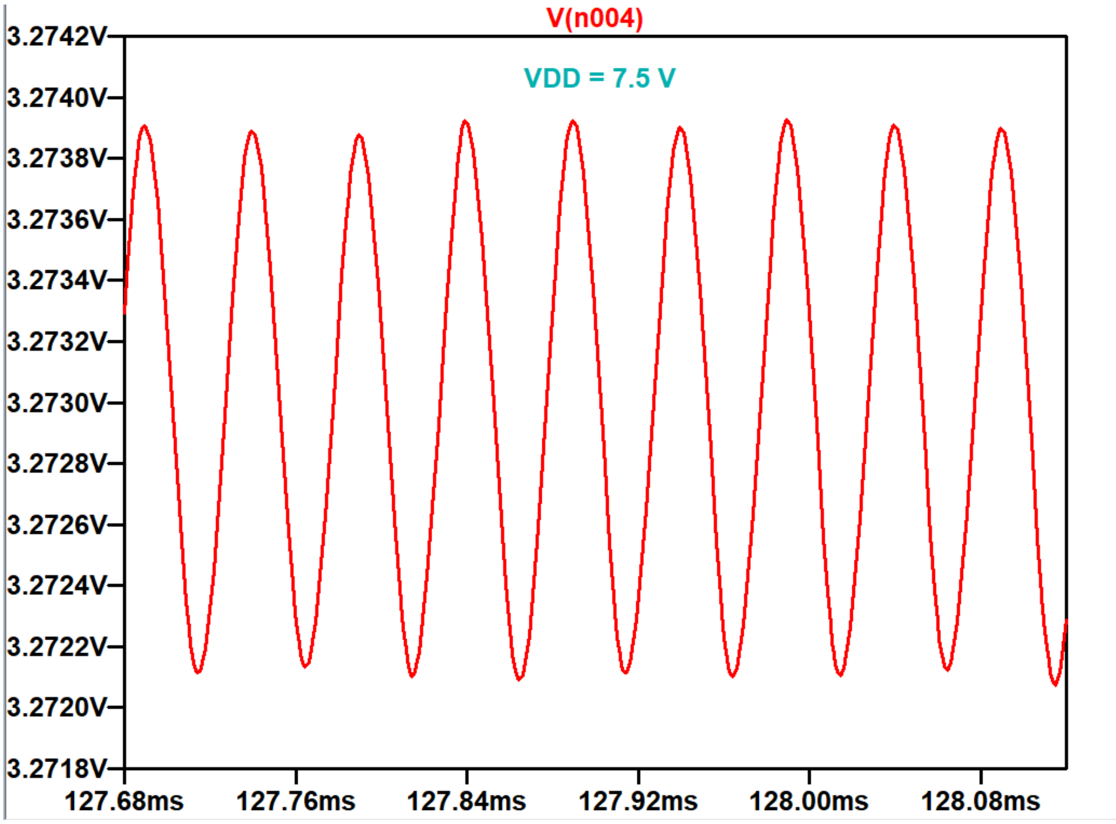


Plot: V(out) Vs time(ms)

- Here we observe Resonant frequency is 10kHz for VDD = 5.5V and output oscillates around 2.324 V.

- But the quality factor doesn't change according to equations written in previous pages but $V_{out} = 0.5V_{in}$ which means it is some unusual behaviour.

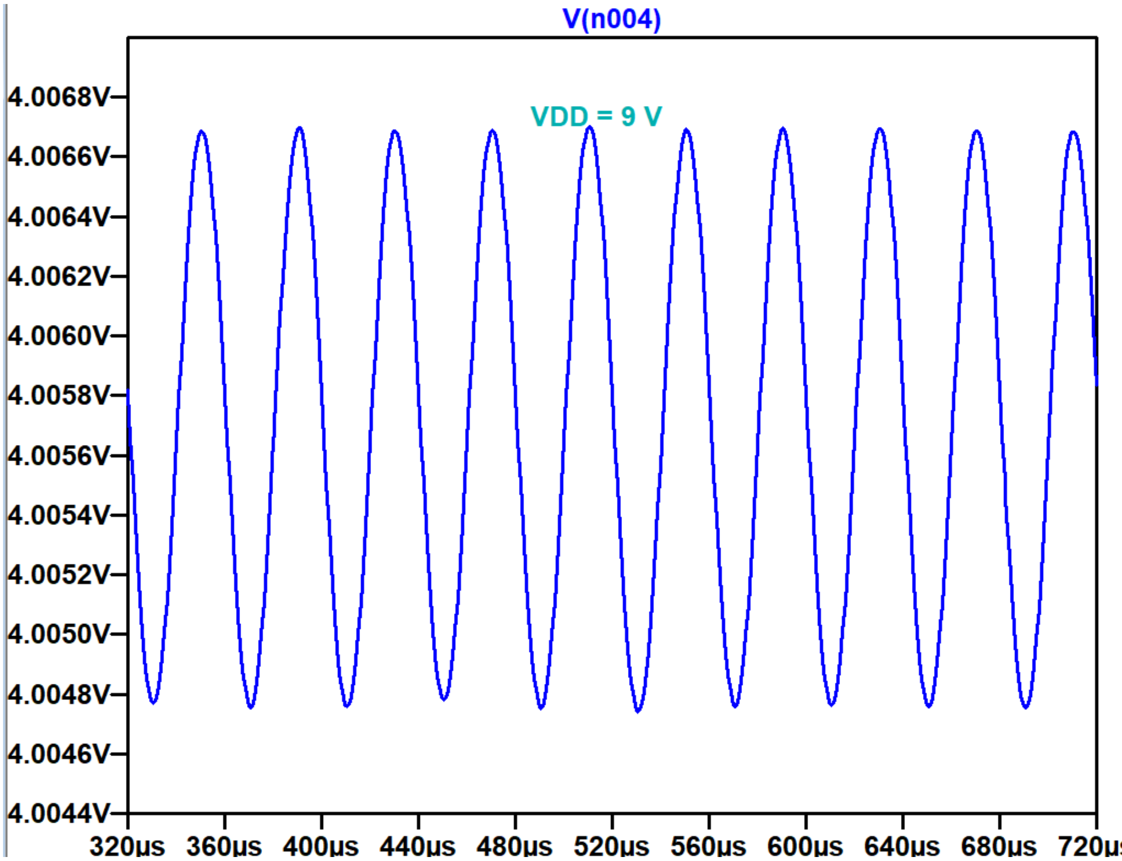
Output plot at VDD = 7.5V



Plot: V(out) Vs time(ms)

- Here we observe Resonant frequency is 20 kHz for VDD = 7.5V and output oscillates around 3.273 V.
- But the quality factor doesn't change according to equations written in previous pages and so V_{out} = 0.9 V_{in}.

Output plot at VDD = 9V



Plot: V(out) Vs time(ms)

• Here we observe Resonant frequency is 25 kHz for VDD = 9 V and output oscillates around 4.005 V.

• But the quality factor doesn't change according to equations written in previous pages and so $V_{out} = 0.96\ V_{in}$.

• From the tuning we can say that as VDD increase g_m increases so does the resonant frequency and bias point.

4 Unusual behaviour comments

• We can that output is close but not exact in question 2.

• Also when we took VDD = 5.5 V the output is different from the expected value.


thank you