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19CS10039

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Experiment 4

Aim: To obtain the frequency response (magnitude and phase response) of an Active Low Pass Filter, and also obtain its cut-off frequency.

Equipment Required:
- 1 Voltage Source
- 2 Resistors (For the Filters) (R_1 and R_2)
- 2 Capacitors (for the filters) (C_1 and C_2)
- 1 Op-Amp (2 Supply Voltage also requireds for activating the Op-Amps)
- 2 Resistors (For Setting the gain of the Op-Amp) (R_f and R)
- Ground.

Formulae:
- $Q = \frac{1}{3-k}$ (where Q is Q-Factor and k is Gain of the Op-Amp)
- $k = 1 + \frac{R_f}{R}$ (where k is the Gain of the Op-Amp)
- $f_{\substack{\text{undamped}\\\text{natural}}} = \frac{1}{2\pi(R.C)}$ (where $f_{\substack{\text{undamped}\\\text{natural}}}$ frequency of the active low pass filter, $R = R_1 = R_2$ and $C = C_1 = C_2$)

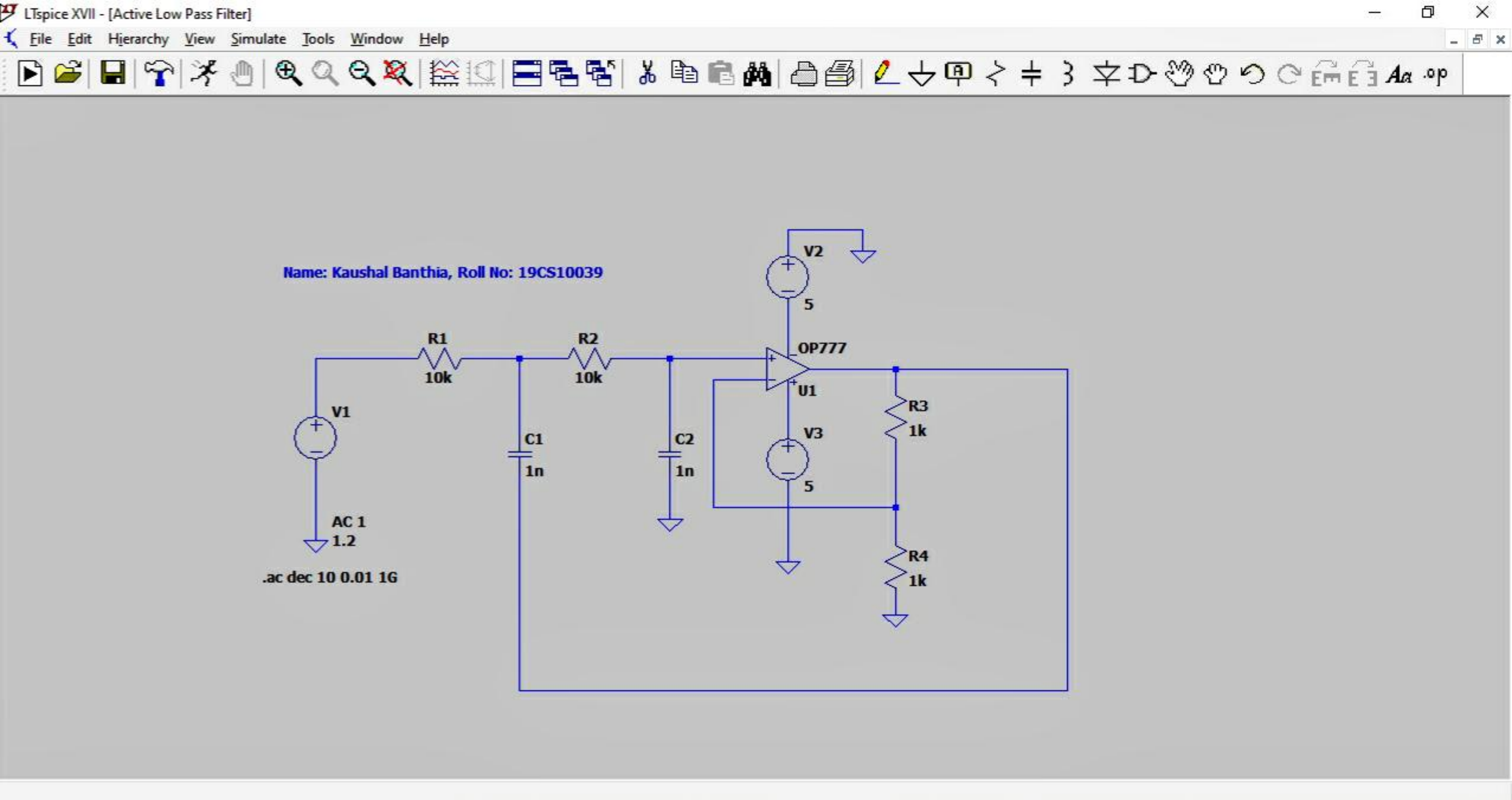
Procedure:
- Case 1 ($R_1 = R_2 = 10k\Omega$ and $C_1 = C_2 = 1nF$ and Q-factor = 1):

  Since Q-factor = 1, we get $k = 2$

  $\therefore R_f = R \Rightarrow$ we choose $R_f = R = 1k\Omega$.

  Now, theoretical $f_{\substack{\text{undamped}\\\text{natural}}} = \frac{1}{2\pi \times 10^4 \times 10^{-9}} = 15.915\ kHz$.

Comments: We get a peak around the undamped natural frequency (a characteristic of the Sallen-Key Filter). It decreases for quite a while, but for very high frequencies, the gain becomes constant. This is due to the presence of parisitic elements modelled in LTSpice. Also, the phase montonously decreases for frequency increase, although it ~~saturates~~ becomes almost constant ($\approx 360°$) at very high frequencies.


LTspice XVII - [Active Low Pass Filter]
File Edit Hierarchy View Simulate Tools Window Help
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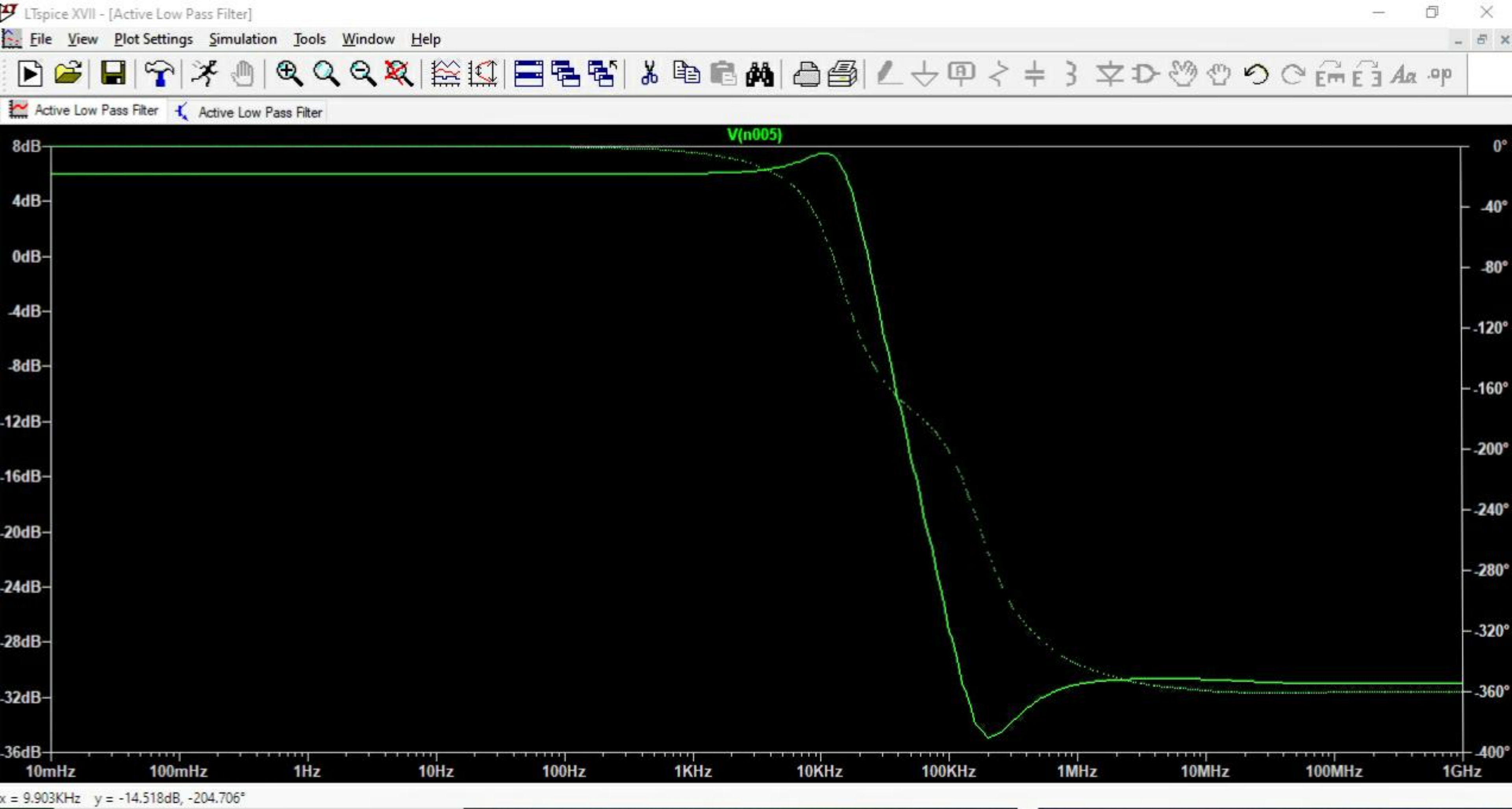
V2
5
R1
10k
R2
10k
OP777
U1
R3
1k
V1
C1
1n
C2
1n
V3
5
AC 1
1.2
R4
1k
.ac dec 10 0.01 1G


LTspice XVII - [Active Low Pass Filter]
File View Plot Settings Simulation Tools Window Help
Active Low Pass Filter
Active Low Pass Filter
V(n005)
8dB
4dB
0dB
-4dB
-8dB
-12dB
-16dB
-20dB
-24dB
-28dB
-32dB
-36dB
0°
-40°
-80°
-120°
-160°
-200°
-240°
-280°
-320°
-360°
-400°
10mHz
100mHz
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz
x = 9.903KHz y = -14.518dB, -204.706°

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- Case 2 ($R_1 = R_2 = 10\,k\Omega$ and $C_1 = C_2 = 1nF$ and Q-Factor = 1.5):

Since Q-Factor = 1.5, we get $k = 7/3 = 2.333$

$\therefore R_f = 1.333R \Rightarrow$ we choose $R = 1k\Omega$ and $R_f = 1.333\,k\Omega$.

Now, theoretical frequency $f_{\text{undamped natural}}$ remains the same, since, R_1, R_2, C_1 and C_2 remain the same.

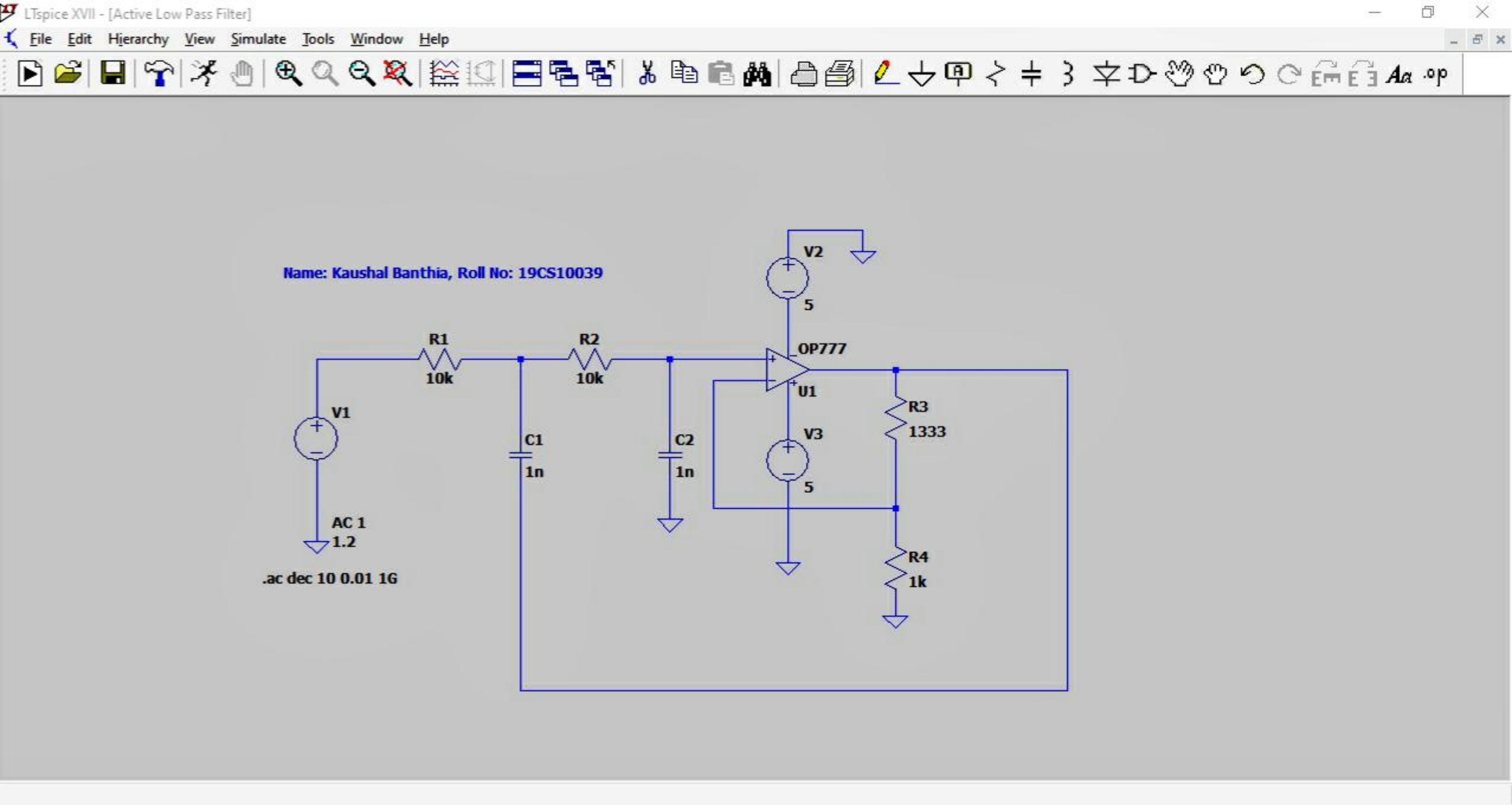
$$\therefore f_{\text{undamped natural}} = \frac{1}{2\pi \times 10^4 \times 10^{-9}} = 15.915\,kHz.$$

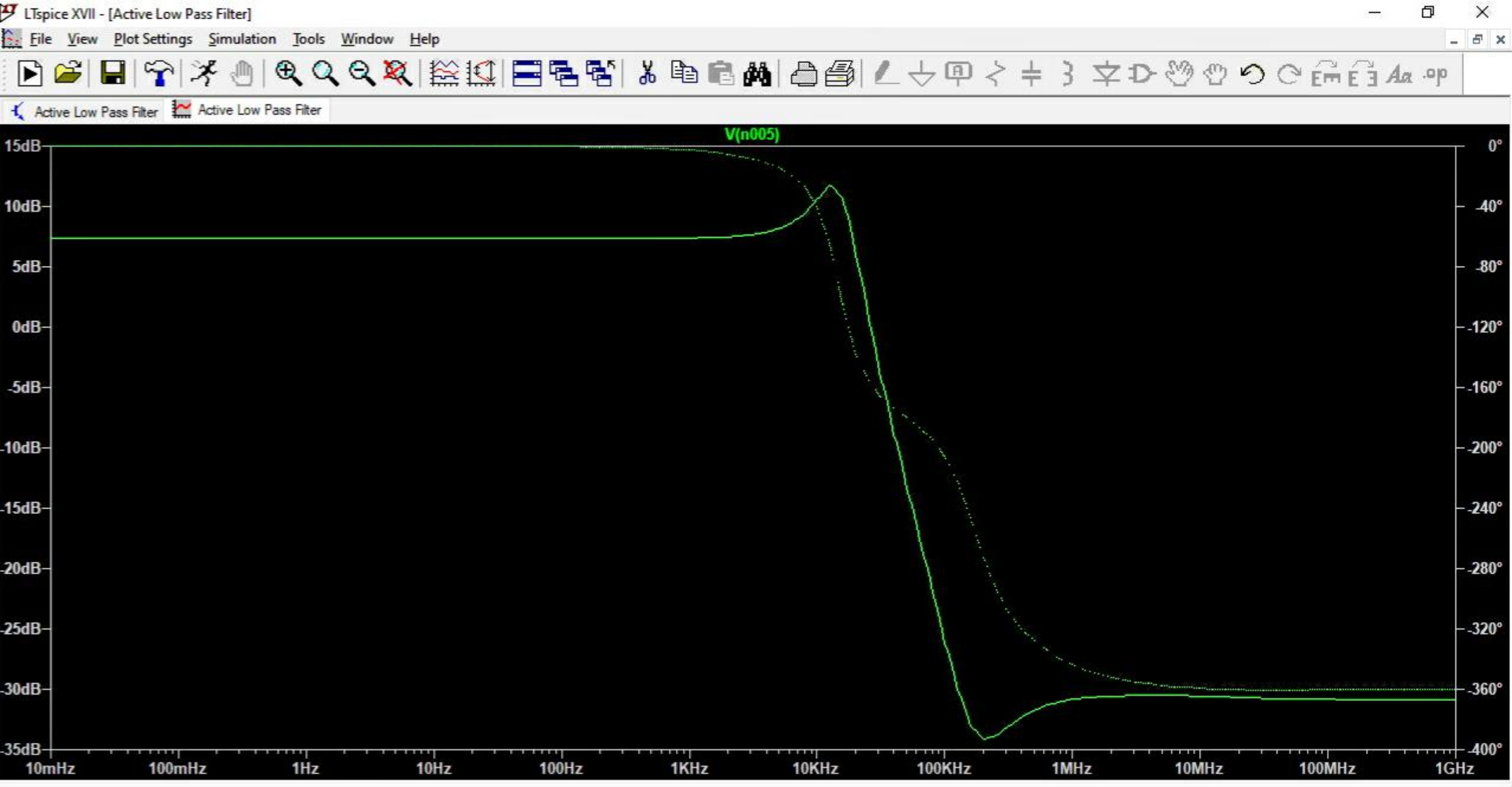
Comments : In this case too, we get the peak around the undamped natural frequency, but this time, the peak is shifted a bit towards the higher frequency side. (closer to the undamped natural frequency).

In this case too, the magnitude decreases for a while, but then becomes constant due to the parasitic elements.

Similarly, the phase response is monotonically decreasing and then becomes nearly constant ($\approx 360°$) for very high frequencies.

- Since this filter has a higher Q factor than the previous one, its peak is sharper and more prominent.


LTspice XVII - [Active Low Pass Filter]
File Edit Hierarchy View Simulate Tools Window Help
Name: Kaushal Banthia, Roll No: 19CS10039
V2
5
R1
10k
R2
10k
OP777
U1
R3
1333
V1
C1
1n
C2
1n
V3
5
AC 1
1.2
R4
1k
.ac dec 10 0.01 1G


LTspice XVII - [Active Low Pass Filter]
File View Plot Settings Simulation Tools Window Help
Active Low Pass Filter
Active Low Pass Filter
V(n005)
15dB
10dB
5dB
0dB
-5dB
-10dB
-15dB
-20dB
-25dB
-30dB
-35dB
0°
-40°
-80°
-120°
-160°
-200°
-240°
-280°
-320°
-360°
-400°
10mHz
100mHz
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz

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- Case 3 : ($R_1 = R_2 = 10\,k\Omega$ and $C_1 = C_2 = 1\,nF$ and Q-factor = 2.5)

  Since Q-factor = 2.5, we get $K = 2.6$.

  $\therefore R_f = 1.6\,R$. $\Rightarrow$ we choose $R = 1\,k\Omega$ and $R_f = 1.6\,k\Omega$.

Now theoretical cutoff frequency f_{cutoff} again remains same, since none among R_1, R_2, C_1 and C_2 were changed and $f_{natural}$ depends only on these parameters.

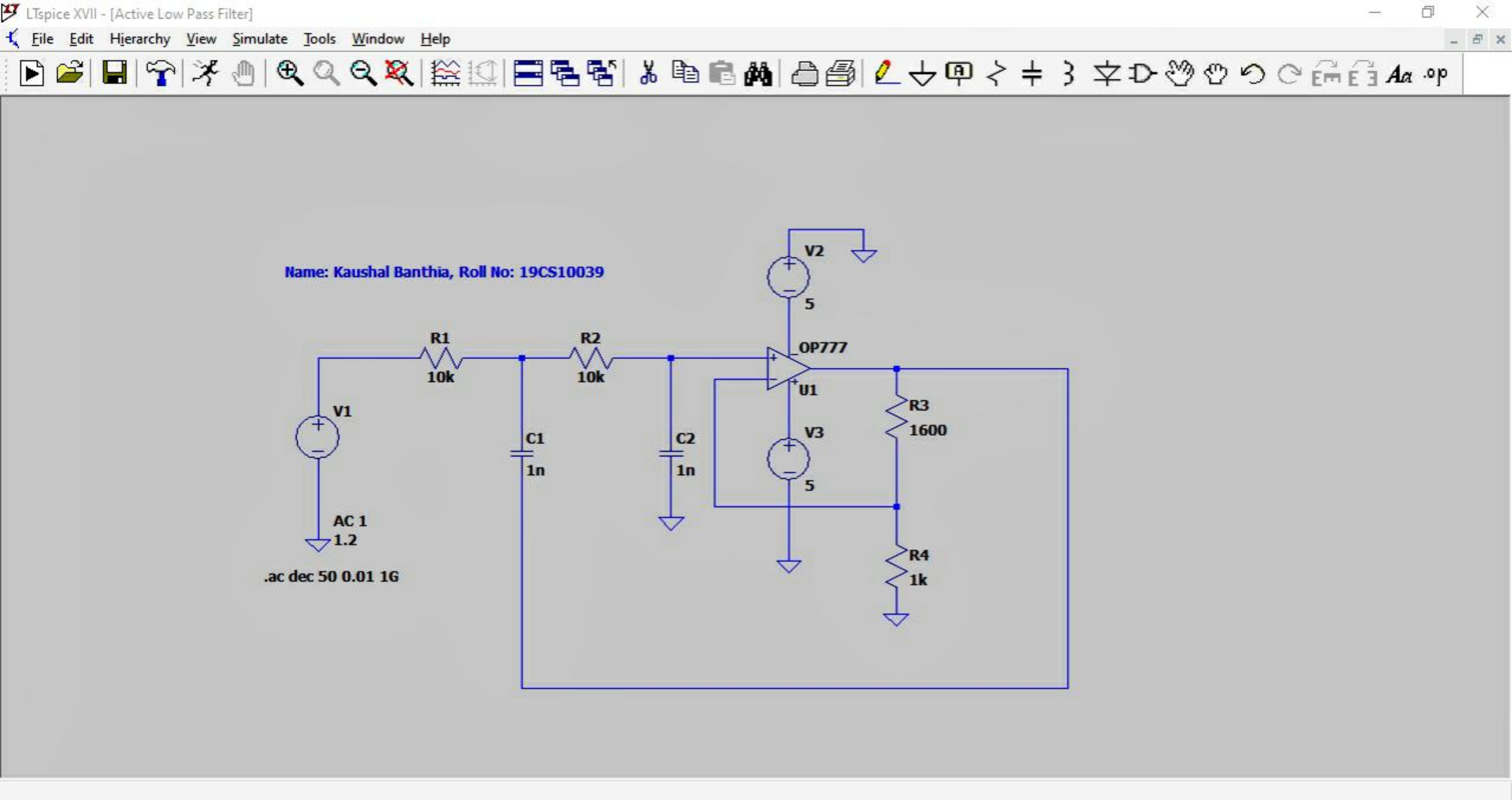
$$\therefore f_{natural} = \frac{1}{2\pi \times 10^4 \times 10^{-9}} = 15.915\ kHz.$$

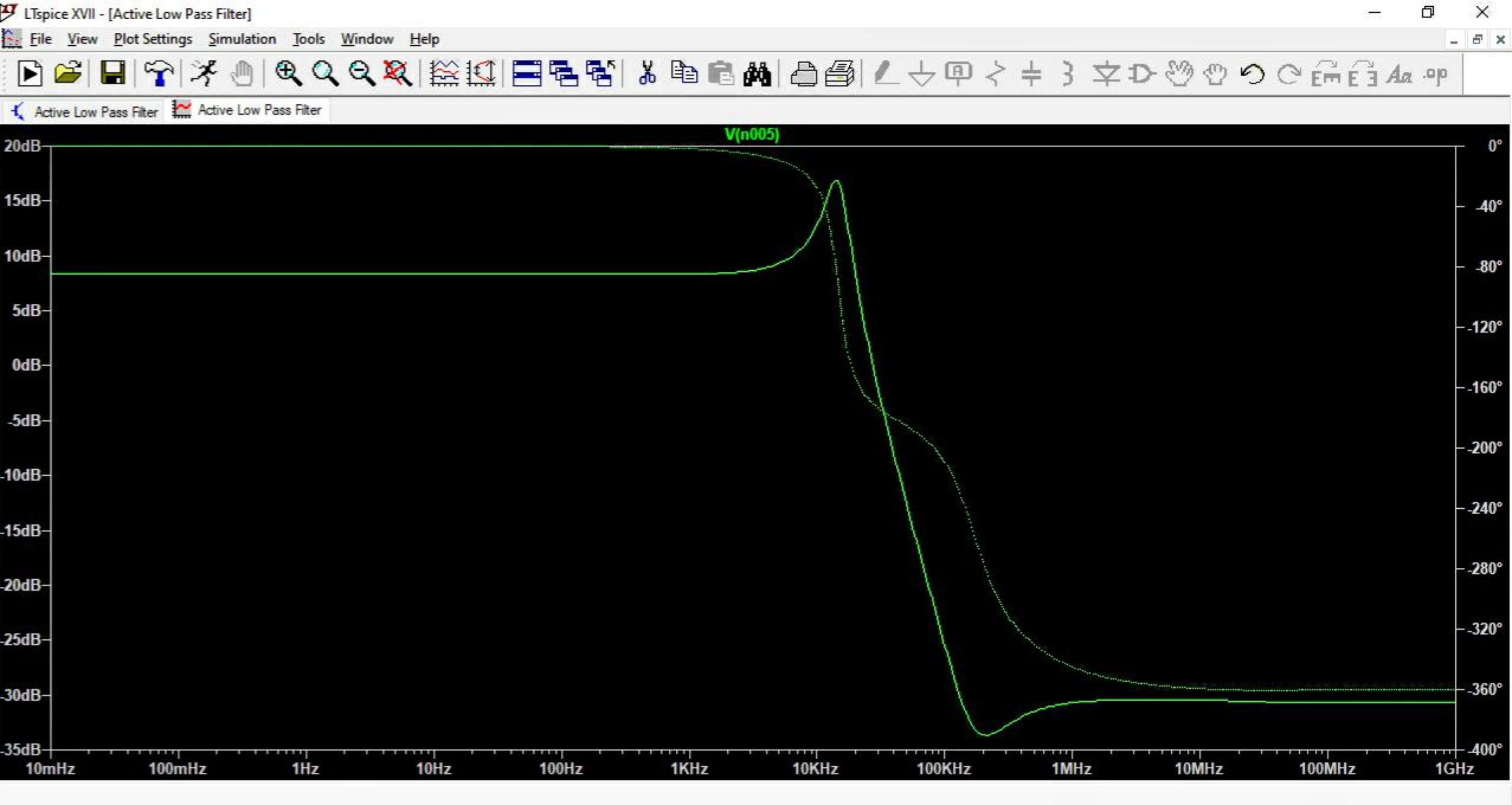
Comments : Again in this case, the peak is found close to the undamped natural frequency. Here the peak is closer to the $f_{natural}$ than before (ie, it is shifted to the right)

As before, the magnitude decreases with an increase in frequency, but at very ~~fr~~ high frequencies, its ~~se~~ becomes constant (due to the parasitic elements). (especially parasitic capacitors).

The phase response remains the shape as of before, with the only difference being that the concavity and the convexity of the graph increases by a good amount and that change is visible. This is because, now the ~~dr~~ phase decreases faster around the cutoff frequency.

Since this filter has a Q-factor than the previous one, its peak is more sharper than before.


LTspice XVII - [Active Low Pass Filter]
File Edit Hierarchy View Simulate Tools Window Help
Name: Kaushal Banthia, Roll No: 19CS10039
V2
5
R1
10k
R2
10k
OP777
U1
V1
C1
1n
C2
1n
V3
5
R3
1600
R4
1k
AC 1
1.2
.ac dec 50 0.01 1G


LTspice XVII - [Active Low Pass Filter]
File View Plot Settings Simulation Tools Window Help
Active Low Pass Filter
Active Low Pass Filter
V(n005)
20dB
15dB
10dB
5dB
0dB
-5dB
-10dB
-15dB
-20dB
-25dB
-30dB
-35dB
0°
-40°
-80°
-120°
-160°
-200°
-240°
-280°
-320°
-360°
-400°
10mHz
100mHz
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz

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Case 4: ($R_1 = R_2 = 10k\Omega$ and $C_1 = C_2 = 1pF$ and Q-factor = 2.5)

Since Q-factor is the same as before, we get the same value of $k = 2.6$.

$\therefore R_f = 1.6R \Rightarrow$ ~~R_f~~ $= R = 1k\Omega$ and $R_f = 1.6k\Omega$.

This time, since the value of $C_1 = C_2$ has changed, the theoretical undamped natural frequency will also changes accordingly

$$\Rightarrow f_{\text{undamped natural}} = \frac{1}{2\pi(10^4 \times 10^{-12})} = 15.915 \text{ MHz}.$$

Since $C_1 = C_2$ decreased by 10^{-3}, the $f_{\text{undamped natural}}$ increased by 10^3, since $f_{\text{undamped natural}} \propto \frac{1}{C}$.

Comments: As with the previous graphs, the magnitude decreases with increasing frequency but then gets constant at very high frequencies (due to the parasitic capacitances). The phase also decreases montonically untill it becomes nearly constant ($\approx 360°$) at very high frequencies.

NOTE: The parasitic capacitances modelled in LTSpice are usually attached in parallel to the circuit elements. They have very low capacitance values. Hence at ~~normal~~ low and medium frequencies, their reactance ($X_L = \frac{1}{j\omega C}$) is very large. Since they are attached in parallel, they are ignored.
But when the frequency becomes very high, then X_L becomes a small value and thus current to flow through it, leading to a voltage drop. Thus, the gain decreases, since some of the voltage gets dropped across the parasitic capacitors.

The graph is different from the previous graphs wrt to its peak. A reason ~~Another reason~~ could be that, ~~the~~ due to the shifting of the undamped natural frequency to a higher value (by an order of 10^3 Hz) the Op-Amp may be unable to function, since this frequency might be out of its Bandwidth. Thus, the Op-Amp is as good as removed. Then, the circuit remains just like a normal second order filter, which has no characteristic peak at the undamped natural frequency.

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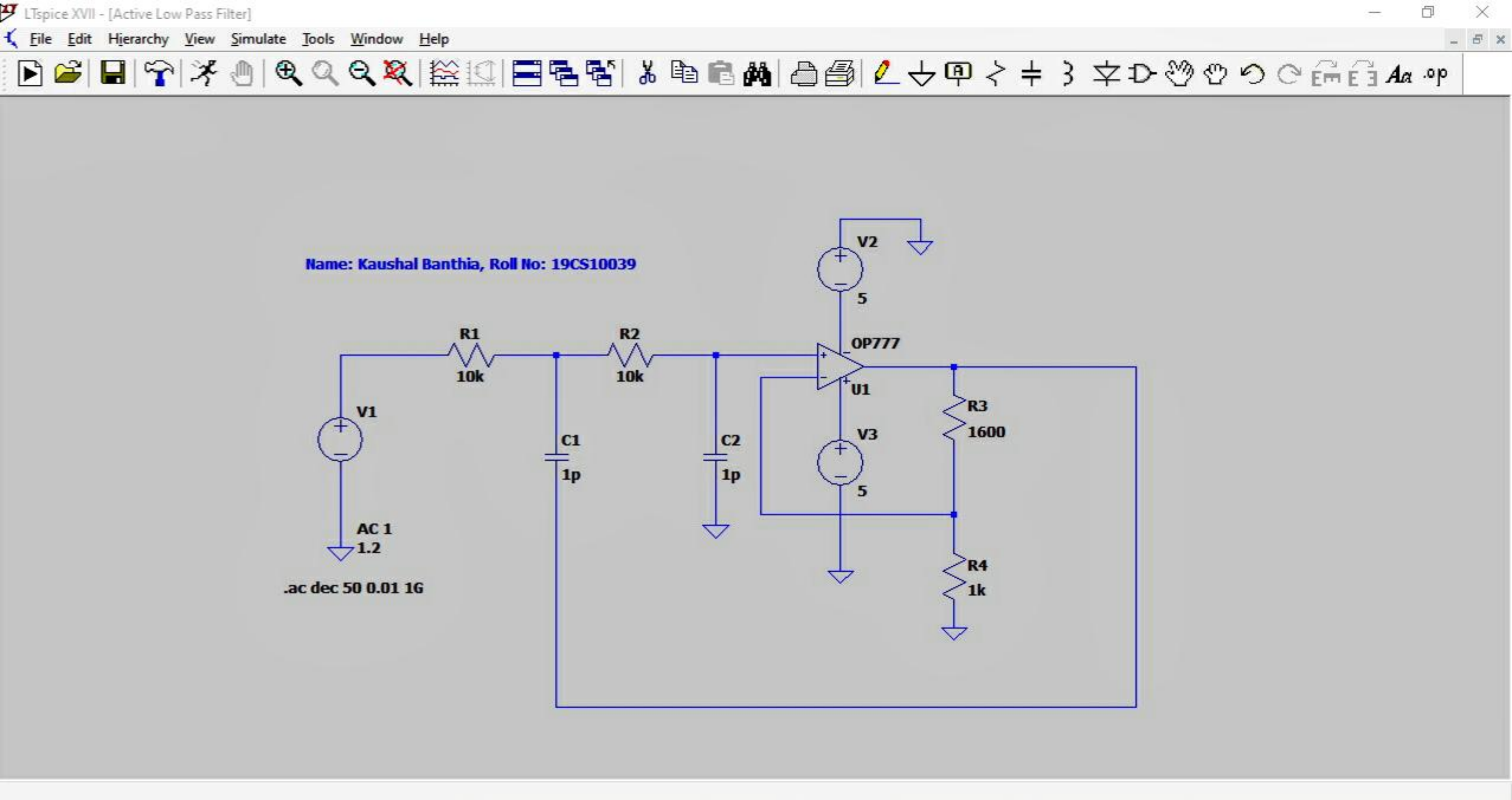

LTspice XVII - [Active Low Pass Filter]
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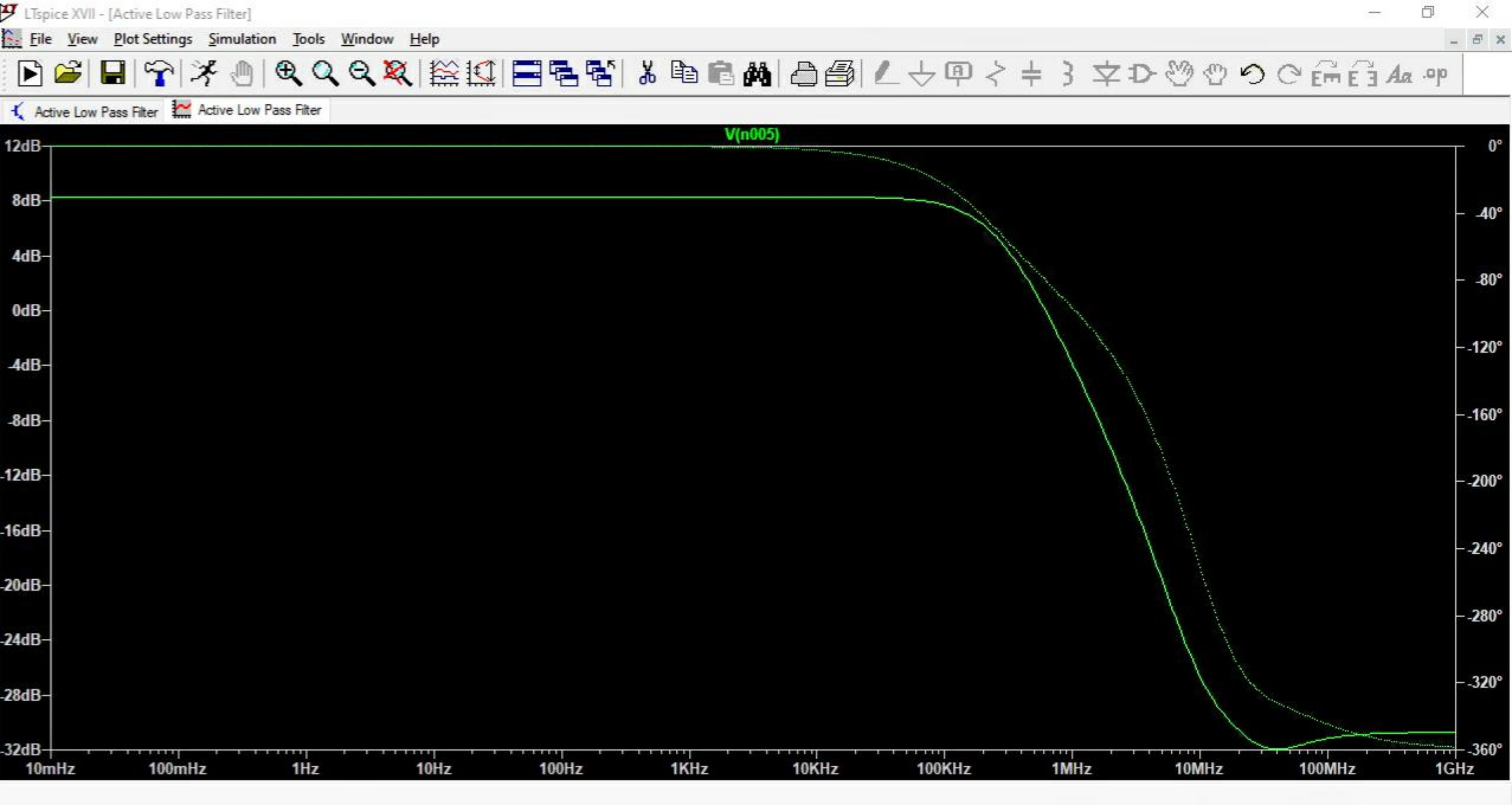
Name: Kaushal Banthia, Roll No: 19CS10039
R1
10k
R2
10k
C1
1p
C2
1p
V1
AC 1
1.2
.ac dec 50 0.01 1G
V2
5
OP777
U1
V3
5
R3
1600
R4
1k


LTspice XVII - [Active Low Pass Filter]
File
View
Plot Settings
Simulation
Tools
Window
Help
Active Low Pass Filter
Active Low Pass Filter
V(n005)
12dB
8dB
4dB
0dB
-4dB
-8dB
-12dB
-16dB
-20dB
-24dB
-28dB
-32dB
0°
-40°
-80°
-120°
-160°
-200°
-240°
-280°
-320°
-360°
10mHz
100mHz
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
1GHz