ANALOG ELECTRONICS
PROJECT 2 : Filter design

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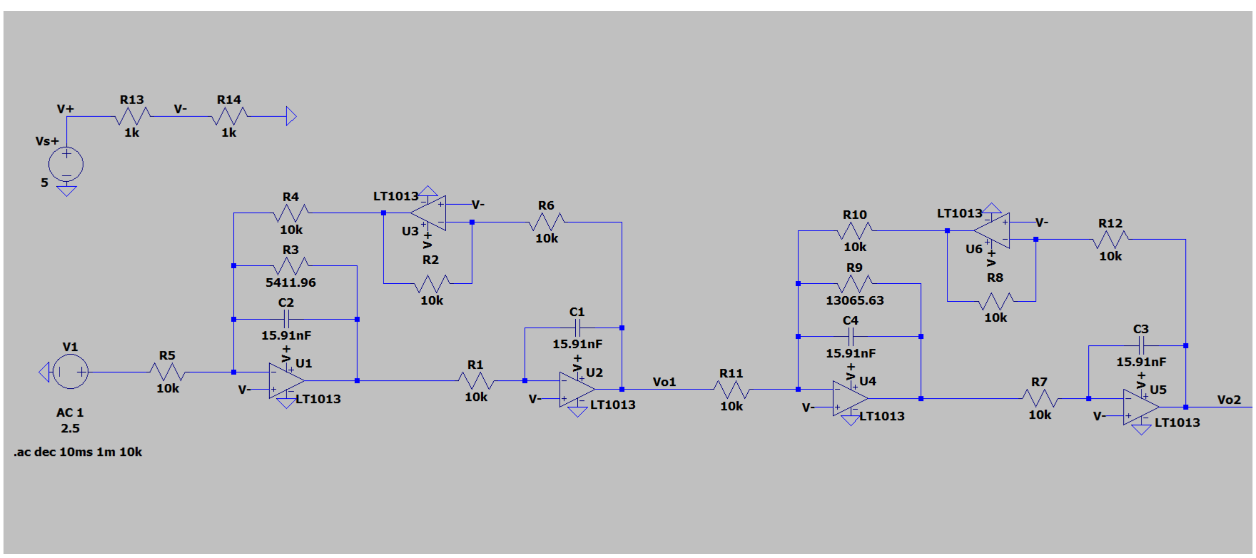
# 1 Aim

Design an active-RC maximally flat low-pass filter to meet the following specifications:

- 3 dB Bandwidth: 1 kHz
- DC gain: 0 dB
- Rejection > 20 dB for frequencies beyond 2 kHz
- Supply: Single 5 V source
- Input/Output common-mode voltage: 2.5 V

# 2 LTspice Test Bench



# 3 Hand Calculations

given 3dB bandwidth, $\omega_n = 1kHz \times 2\pi$

rejection > 20dB for f > 2kHz

w.k.t $|H(j\omega)| = \dfrac{1}{\sqrt{1+\left(\frac{\omega}{\omega_n}\right)^{2n}}}$ where n is order of the filter

$$\Rightarrow 20\log_{10}\left(\frac{\frac{1}{\sqrt{1+\left(\frac{2\pi\times 1k}{2\pi\times 1k}\right)^{2n}}}}{\frac{1}{\sqrt{1+\left(\frac{2\pi\times 2k}{2\pi\times 1k}\right)^{2n}}}}\right) > 20$$

$$\Rightarrow 20\log_{10}\left(\frac{1}{\sqrt{2}}\times\sqrt{1+4^n}\right) > 20$$

$$\Rightarrow \frac{1+4^n}{2} > 100 \quad \Rightarrow \quad 4^n > 199 \qquad \therefore n = 4$$

w.k.t roots of butterworth filter are $S = \omega_n e^{j\frac{2K+1}{2n}\pi + j\frac{\pi}{2}}$

After substuting the values, we get $\qquad K = 0, 1, \ldots n-1$

$$S = 2000\pi\left(-\sin(22.5^\circ) \pm \cos(22.5^\circ)\right) \; \& \; 2000\pi\left(-\sin(67.5^\circ) \pm \cos(67.5^\circ)\right)$$

So we coscade two second order filters with above roots for their T.F

w.k.t for state space bi-quad $T.F = \dfrac{\omega_n^2}{S^2+2\xi\omega_n S+\omega_n^2} = \dfrac{1}{(SCR)^2 + SCR.\frac{R}{R_q} + 1}$

roots are $-\omega_n\xi \pm \sqrt{1-\xi^2} \times \omega_n$

$\therefore$ After comparing with above roots

we get $\xi_1 = \sin(22.5°)$ & $\xi_2 = \sin(67.5°)$

Also wkt $\omega_n = \frac{1}{CR}$ & $\xi_q = \frac{R}{2R_Q}$

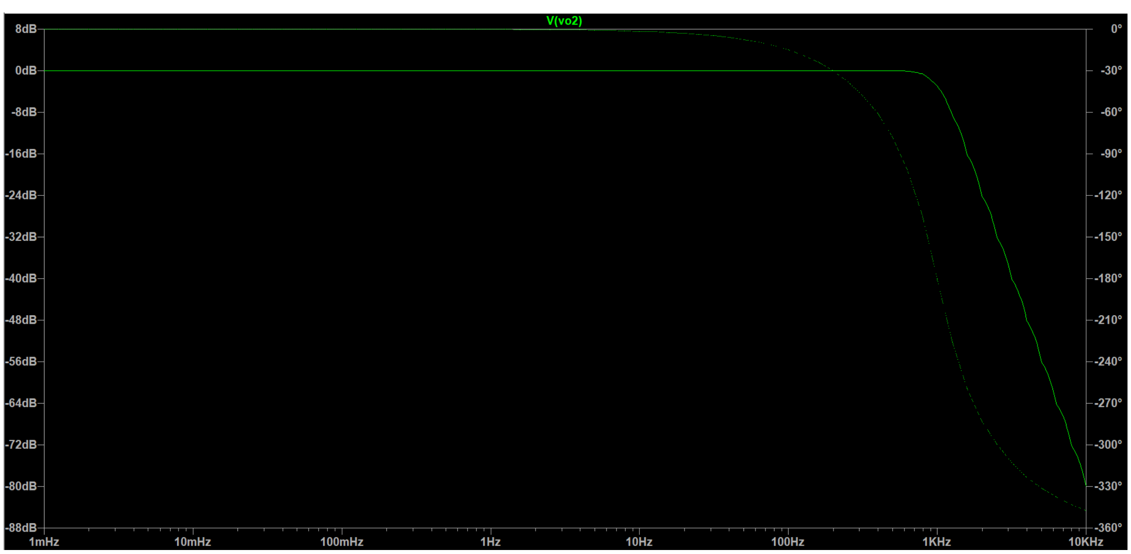
Let $R = 10k\Omega$

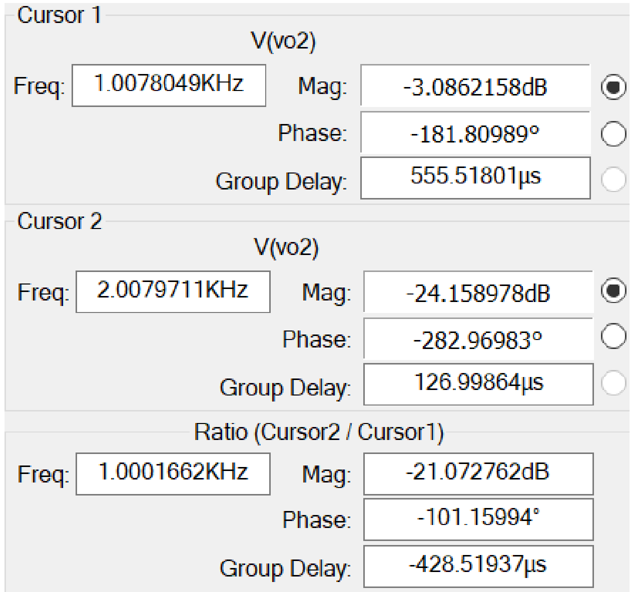
$\Rightarrow C = \frac{1}{R \times \omega_n} = \frac{1}{10k \times 2\pi \times 1k} = 15.91\,nF$

$\Rightarrow R_{Q_1} = \frac{R}{2\xi_1} = 13065.63\,\Omega$ & $R_{Q_2} = \frac{R}{2\xi_2} = 5411.96\,\Omega$

$$\therefore \text{overall T.F} = \frac{1}{\left[(sCR)^2 + \frac{sCR^2}{R_{Q_1}} + 1\right]\cdot\left[(sCR)^2 + \frac{sCR^2}{R_{Q_2}} + 1\right]}$$

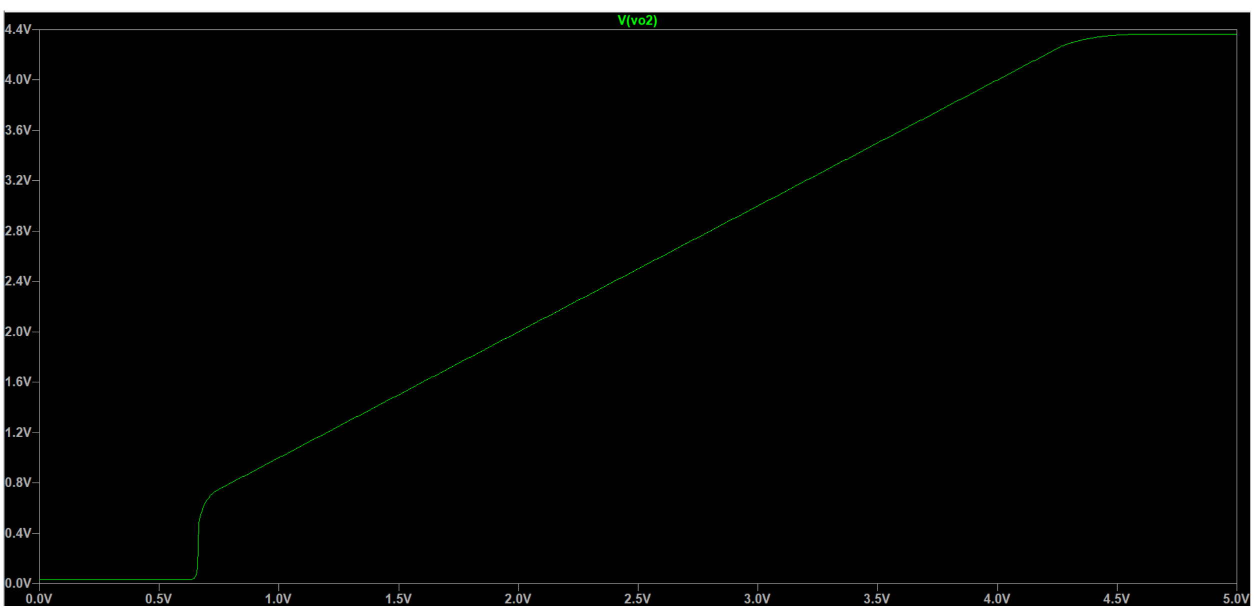
## 4 Magnitude and phase frequency response till 10 kHz indicating bandwidth and rejection.(AC simulation)





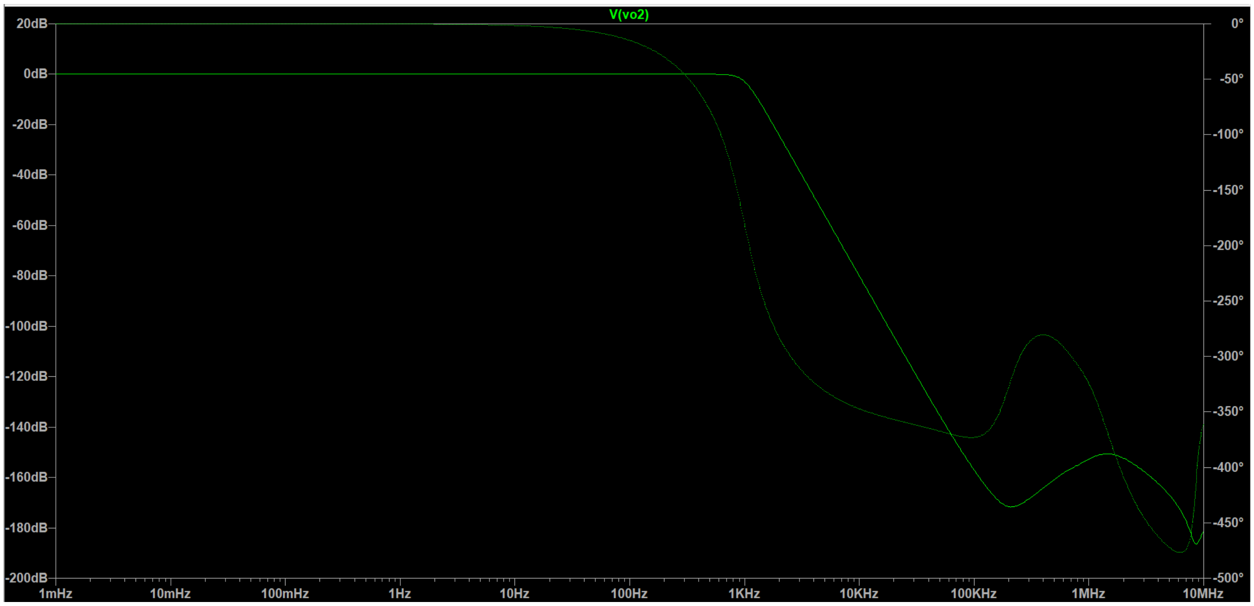

We see that at 1kHz the magnitude is around -3dB and at 2kHz the magnitude is around -24dB which are satisfying the given specifications of 3-dB Bandwidth and rejection.

# 5 Input-output DC characteristics with input varying from 0 V to 5 V. (DC sweep)



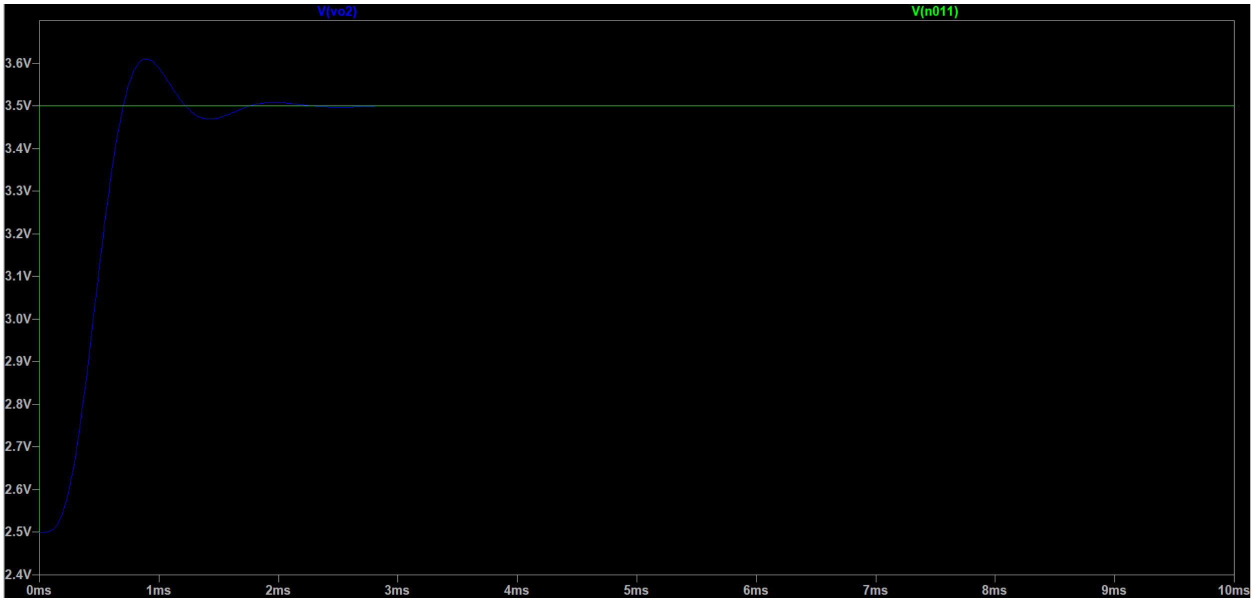

We see that the output is constant till 0.8V and it increases suddenly and then the output is equal to input, which is the expected output since DC input is being passed into a low pass filter.And finally it saturates at around 4.4 V.

## 6 Magnitude response till 10 MHz.(AC simulation)




We assumed our op-Amp to have infinite UGB in our calculations but the LT1013 has a finite UGB, so the the output is not as expected and deviates at higher frequencies.

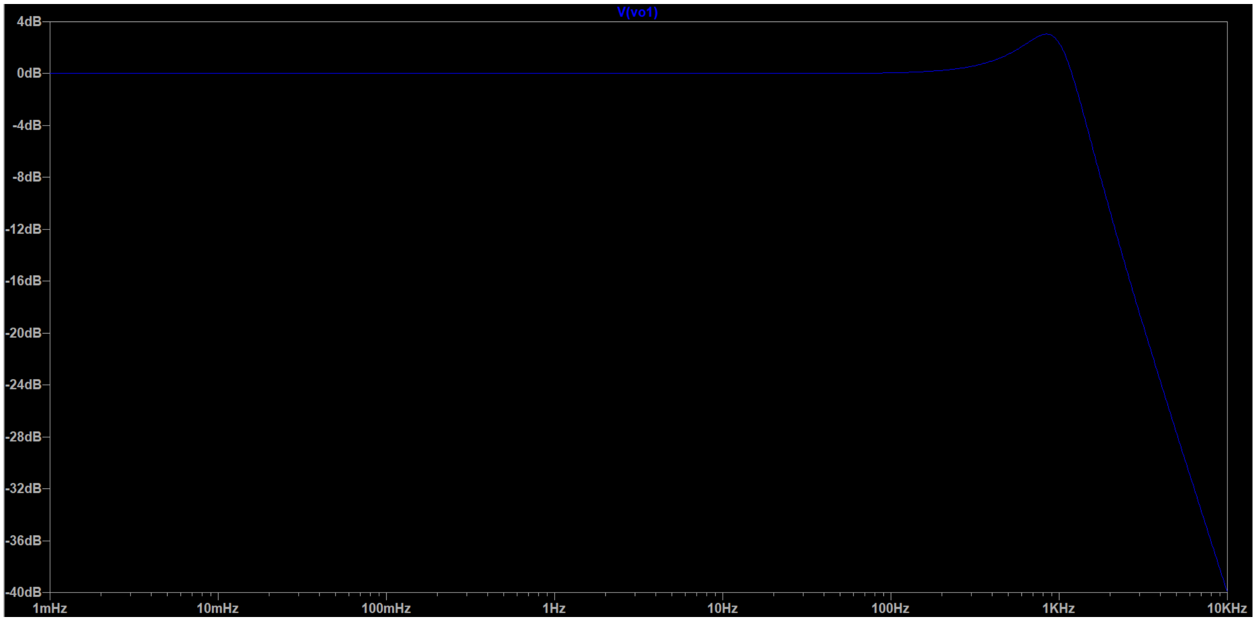
## 7 Step response for input going from 2.5 V to 3.5 V in 1 ns. (Transient simulation)



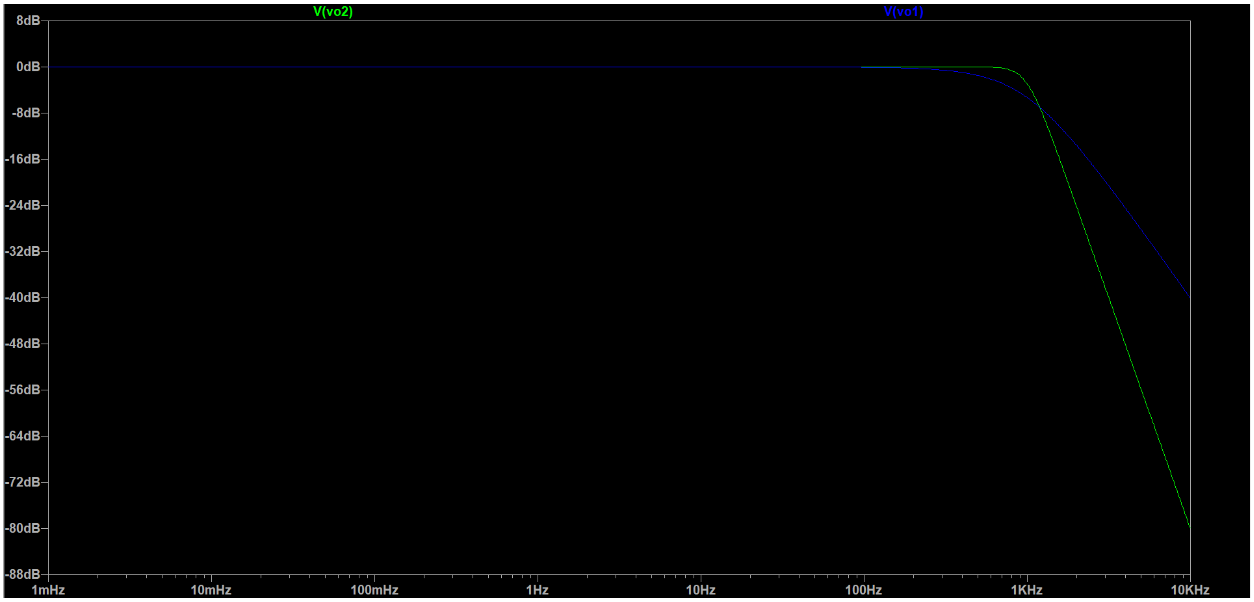

Since the poles are complex conjugates we get a underdamped response and the output settles at 3.5V at steady state.

## 8 Magnitude of all the filter output nodes in the cascade for frequency till 10 kHz.

One of the two cascaded filters has damping factor less than $\frac{1}{\sqrt{2}}$ and it shows peaking if used separately as shown below -




But if we place the other filter which has no peaking(damping factor $> \frac{1}{\sqrt{2}}$) at first position in the cascade, then at both the output nodes we get no peaking as shown below -




The blue plot shows the Magnitude at first output node and the green plot at second output node.