Cairo University
Faculty of Engineering

Department of Electronics and
Communications Engineering
ELC 3060 – Spring 2023

Mini Project #1: Design and Implementation of a Biquad

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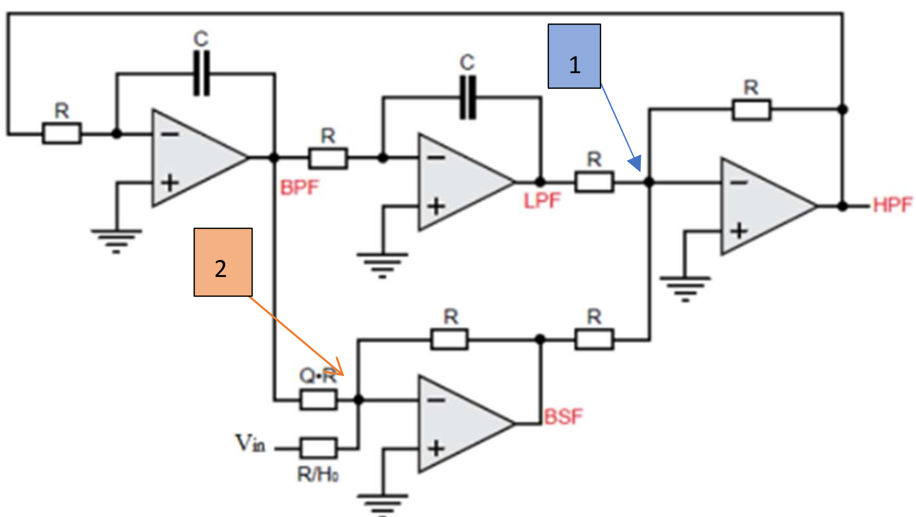
DESIGN STEP (FIRST STEP):



The BPF & LPF are integrators so:

$$BPF = \frac{-1}{sCR} HPF \quad \text{-------}\rightarrow (1)$$

$$LPF = \frac{-1}{sCR}\ BPF = \left(\frac{1}{sCR}\right)^2 HPF \quad \text{-------}\rightarrow (2)$$

By applying KCL at node 1:

$$\frac{LPF}{R} + \frac{BSF}{R} = \frac{-HPF}{R}$$

$$LPF+BSF = -\ HPS \quad \text{------------}\rightarrow (3)$$

By applying KCL at node 2:

$$\frac{BPF}{Q\,R} + \frac{Ho\ Vin}{R} = \frac{-BS}{R} \quad \text{-------------}\rightarrow (4)$$

$$\frac{-1}{Q}\ \frac{1}{SCR} HPF + Ho\ Vin = HPF + LPF$$

$$\frac{-1}{Q}\ \frac{1}{SCR} HPF + Ho\ Vin = HPF\ [1+\left(\frac{1}{sCR}\right)^2\ ]$$

$$HPF \left[\frac{1+(SCR)^2}{(SCR)^2}\right] + \frac{1}{Q}\ \frac{1}{SCR} HPF = Ho\ Vin$$

HPF $\left[\frac{SCR+Q(SCR)^2+Q}{Q(SCR)^2}\right]$ = Ho Vin

$$\boxed{\frac{HPF}{Vin} = \frac{Ho\ Q\ (SCR)^2}{SCR+Q+(SCR)^2Q} = \frac{Ho\ S^2}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}} \quad \text{------}\rightarrow(5) \quad \text{(HPF transfer function)}}$$

By substituting by Eqn (5) in Eqn (4)

$$\text{Vin}\left[-\frac{1}{Q}\ \frac{1}{SCR}\ \frac{Ho\ S^2}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}} + Ho\right] = \text{-BSF}$$

$$\text{Ho}\left[\frac{S^2+\frac{1}{(CR)^2}+\cancel{\frac{S}{CRQ}}-\cancel{\frac{S}{CRQ}}}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}\right] \text{Vin =-BSF}$$

$$\boxed{\text{-Ho}\left[\frac{S^2+\frac{1}{(CR)^2}}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}\right] = \frac{BSF}{Vin} \quad \text{-------}\rightarrow(6) \quad \text{(BSF transfer function)}}$$

By substituting by Eqn (5) in Eqn (2)

$$\text{Vin}\left[\frac{1}{(SCR)^2}\ \frac{Ho\ S^2}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}\right] = \text{LPF}$$

$$\boxed{\frac{LPF}{Vin} = \left[\frac{\frac{Ho}{(CR)^2}}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}\right] \quad \text{---------}\rightarrow(7) \quad \text{(LPF transfer function)}}$$

By substituting by Eqn (5) in Eqn (1)

$$\text{BPF}= \left[\frac{-1}{SCR}\ \frac{Ho\ S^2}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}\right] Vin$$

$$\boxed{\frac{BPF}{Vin} = \left[\frac{\frac{-Ho\ S}{RC}}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}\right] \quad \text{-------------}\rightarrow(8) \quad \text{(BPF transfer function)}}$$

From characteristic Eqn :

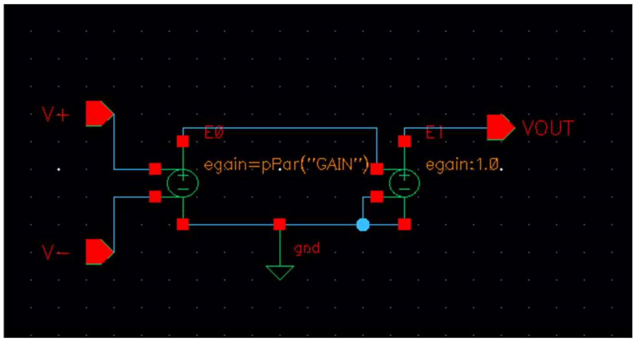
$\boldsymbol{\omega_O} = \frac{\boldsymbol{1}}{\boldsymbol{RC}}$ & $\boldsymbol{f_o}$= 1MHz

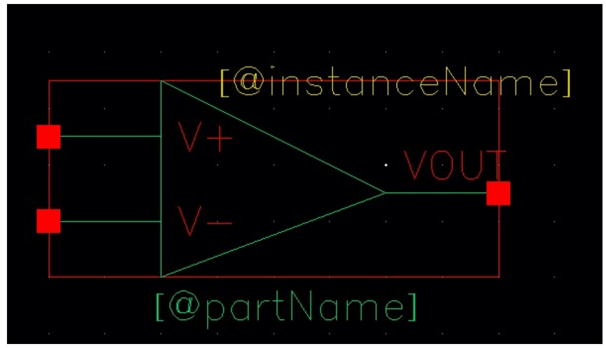
Then RC =0.159 $\boldsymbol{\mu}$

Assuming R = 1k$\boldsymbol{\Omega}$ & C= 159 PF

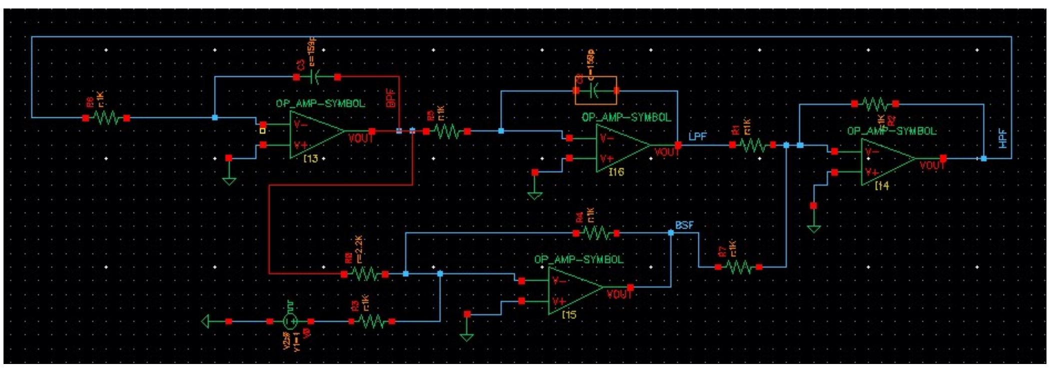
SEMULATION STEP (SECOND STEP):

IDEAL OPAMP SCHEMATIC & SYMBOL





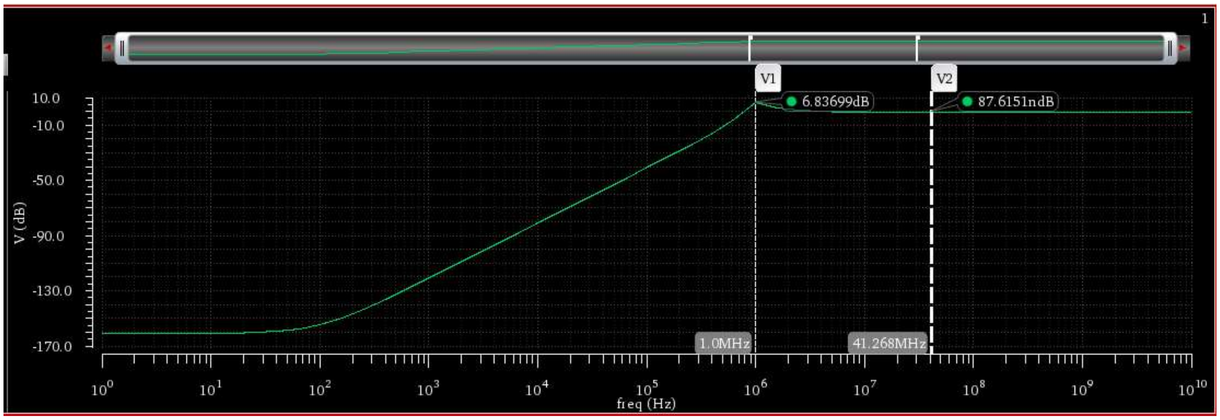
SCHEMATIC:



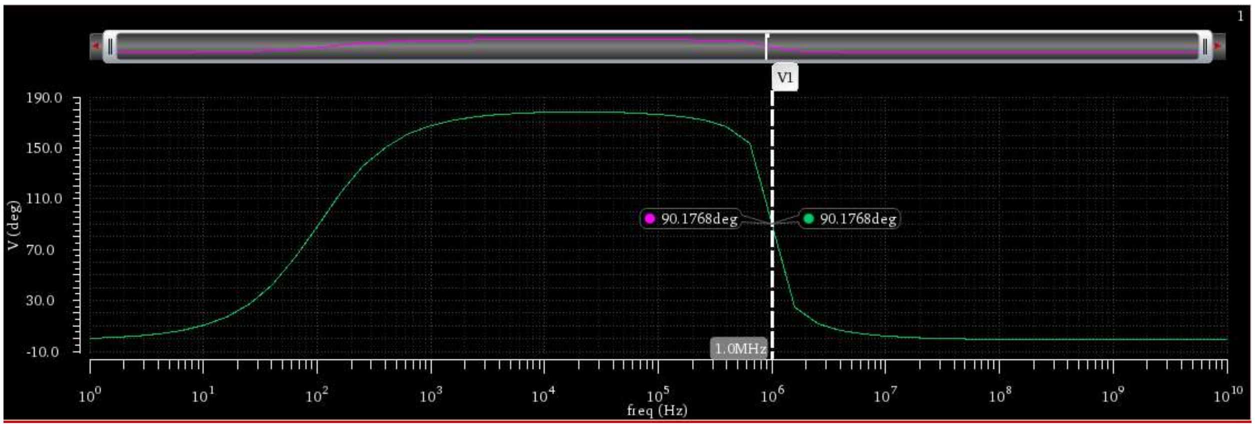
The values of R & C in the schematic are R=1kΩ & C=159 PF

FREQUENCY RESPONSE:

HPF (MAG PLOT)



HPF (PHASE PLOT):



Comments:

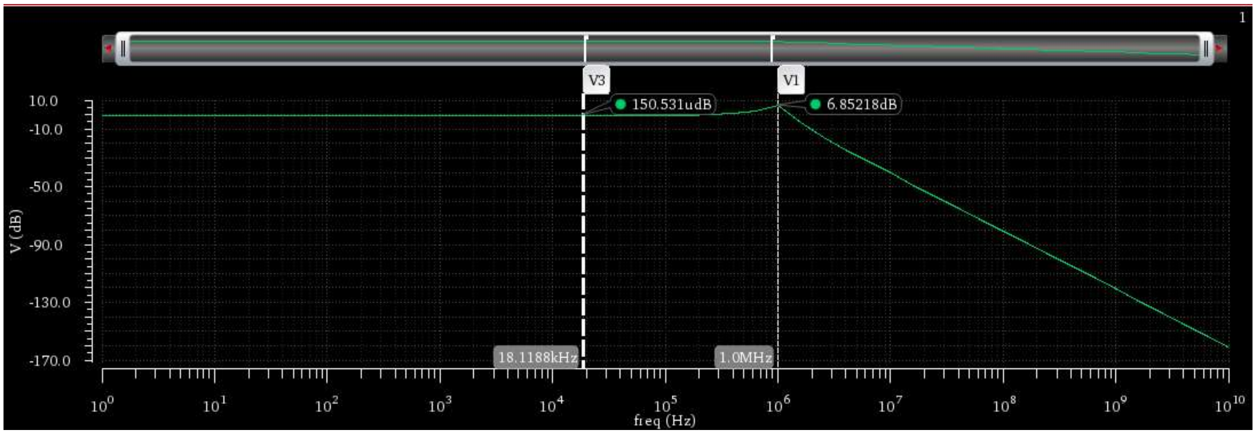
- From mag plot we can notice that f_O =1 MHZ and Q = $10^{\frac{6.836}{20}}$ =2.196 (which is the amplitude at ω_O)
  - From HPF TF = $\dfrac{Ho\ S^2}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}$ → $@\omega$ =0 → TF=0

    → $@\omega = \infty$ → TF=Ho

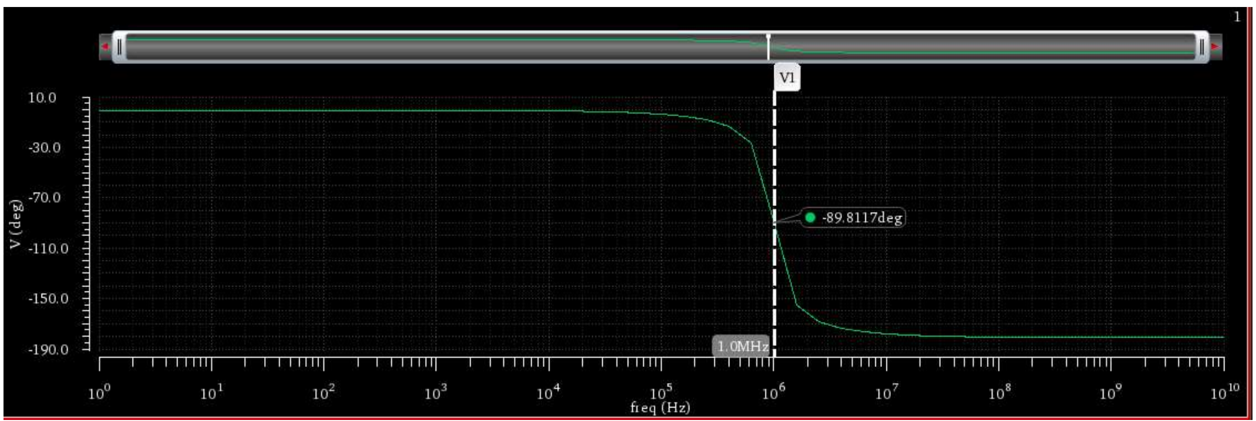
    → $@\omega = \omega_O$ → TF=QHo

- And V2 cursor show that Ho =87.615 ndB (~0dB) at very high frequencies (as it's HPF)

LPF (MAG PLOT):



LPF (PHASE PLOT):



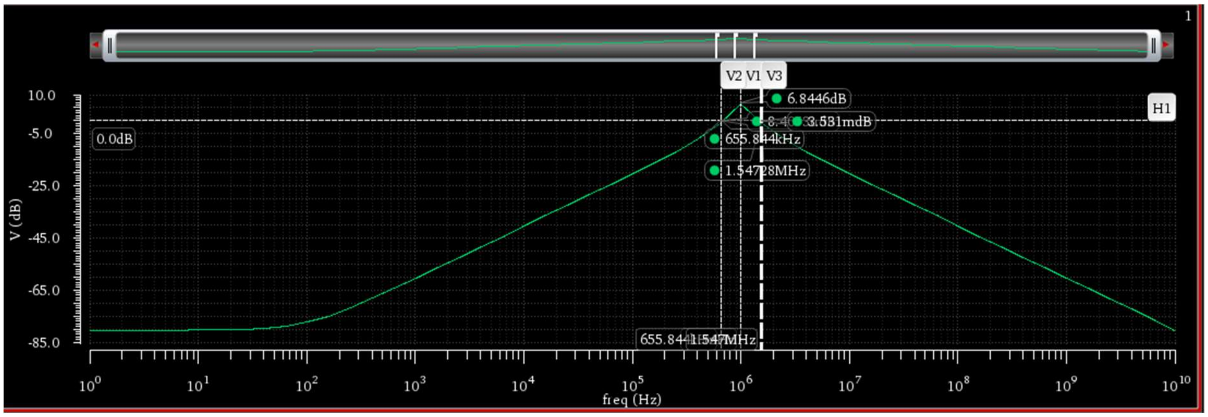
Comments:

- From mag plot we can notice that f_o =1 MHZ and Q = $10^{\frac{6.8521}{20}}$ =2.2 (which is the amplitude at ω_O)
  - From LPF TF = $\left[\frac{\frac{Ho}{(CR)^2}}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}\right]$ → $@\omega$ =0 → TF= Ho

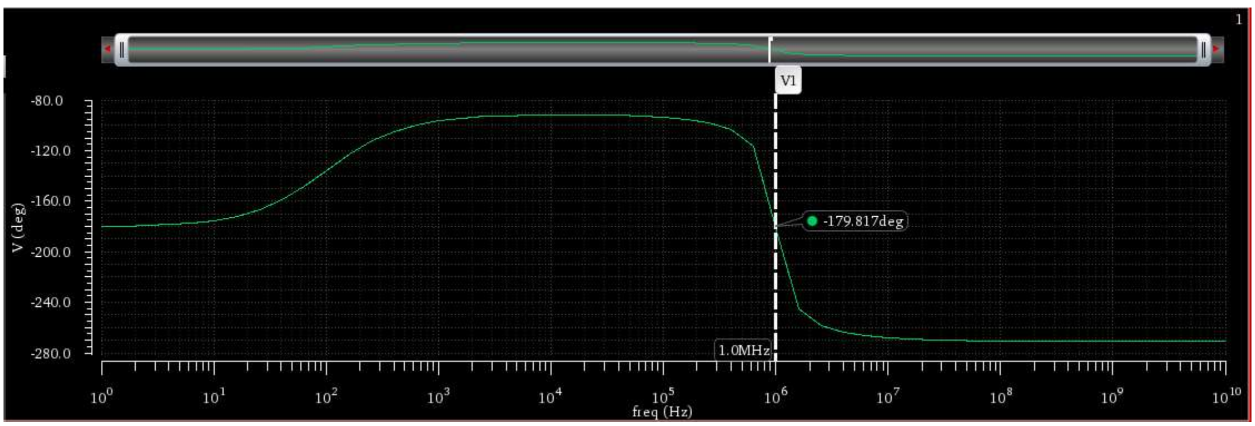
    → $@\omega = \infty$ → TF=0

    → $@\omega = \omega_O$ → TF=QHo
- And V3 cursor show that Ho =150.531 udB (~0dB) at low frequencies (as it's LPF)

BPF (MAG PLOT):



BPF (PHASE PLOT):



Comments:

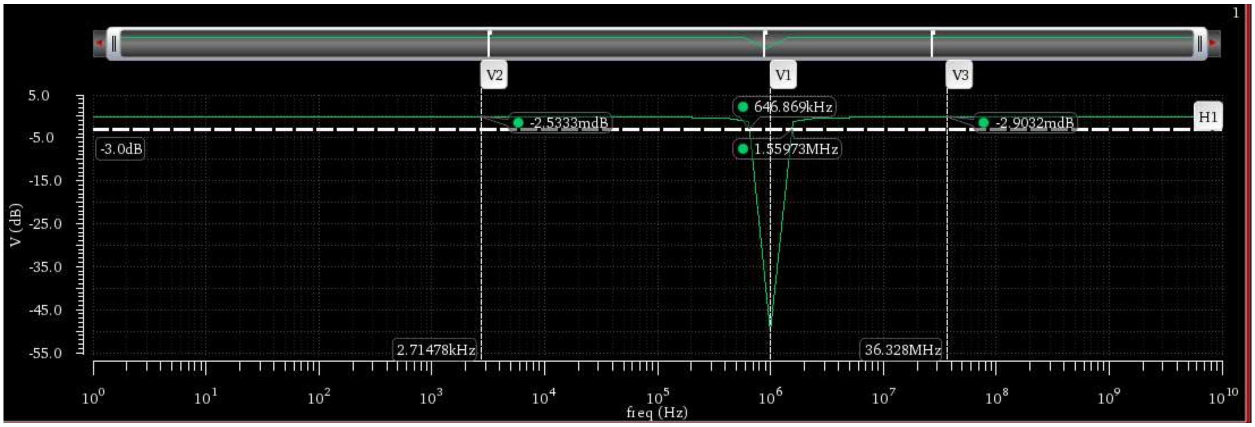
- From mag plot we can notice that f_O =1 MHZ and Q = $10^{\frac{6.8446}{20}}$ =2.199 (which is the amplitude at ω_O)
  - From BPF TF $= \left[\dfrac{\frac{-H\ \ S}{RC}}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}} \right]$ $\rightarrow @\omega = 0 \ \rightarrow \ TF = 0$

$\rightarrow @\omega = \infty \ \rightarrow \ TF = 0$

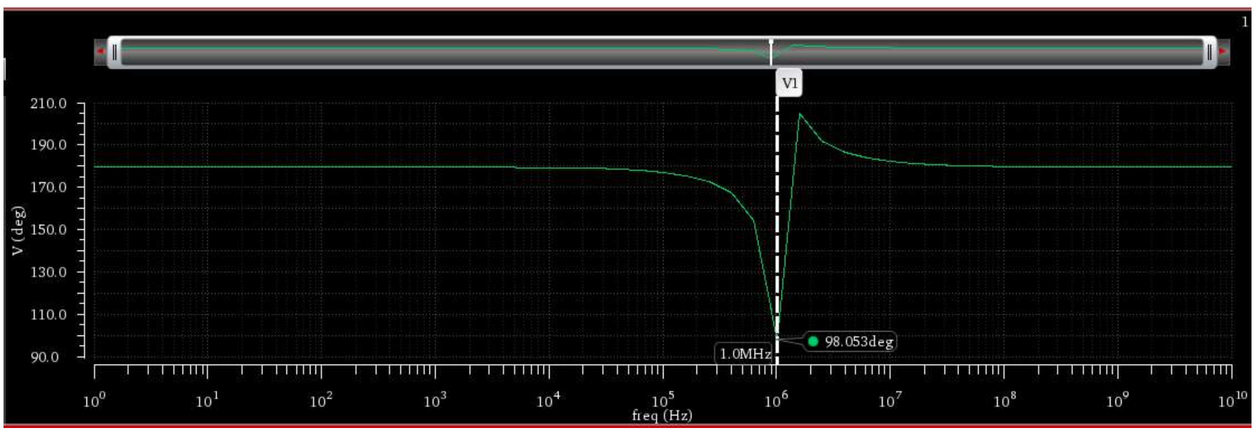
$\rightarrow @\omega = \omega_O \ \rightarrow \ TF = QHo$

- And V2 & V3 cursors show that Ho ~0dB at 655.844 kHz to 1.547 MHz (as it's BPF)

BSF (MAG PLOT):



BSF (PHASE PLOT):



Comments:

- From mag plot we can notice that f_o =1 MHZ
  - From BSF TF $= -\mathrm{Ho}\left[\dfrac{S^2+\frac{1}{(CR)^2}}{S^2+\frac{S}{CRQ}+\frac{1}{(CR)^2}}\right]$ $\rightarrow @\omega = 0 \rightarrow TF = Ho$

$\rightarrow @\omega = \infty \rightarrow TF = Ho$

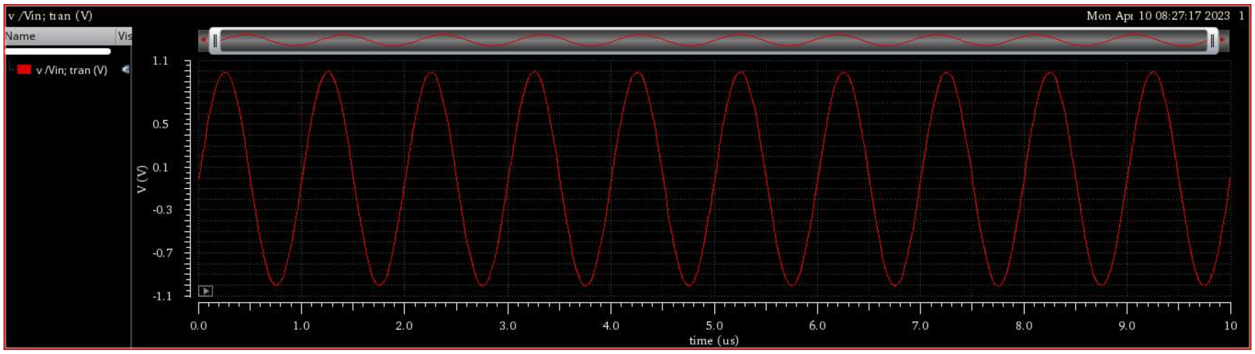
$\rightarrow @\omega = \omega_O \rightarrow TF = 0$

- And V2 & V3 cursors show that Ho ~0dB at Very low and very high frequencies (as it's BSF)

APPLYING SINE WAVE INPUT

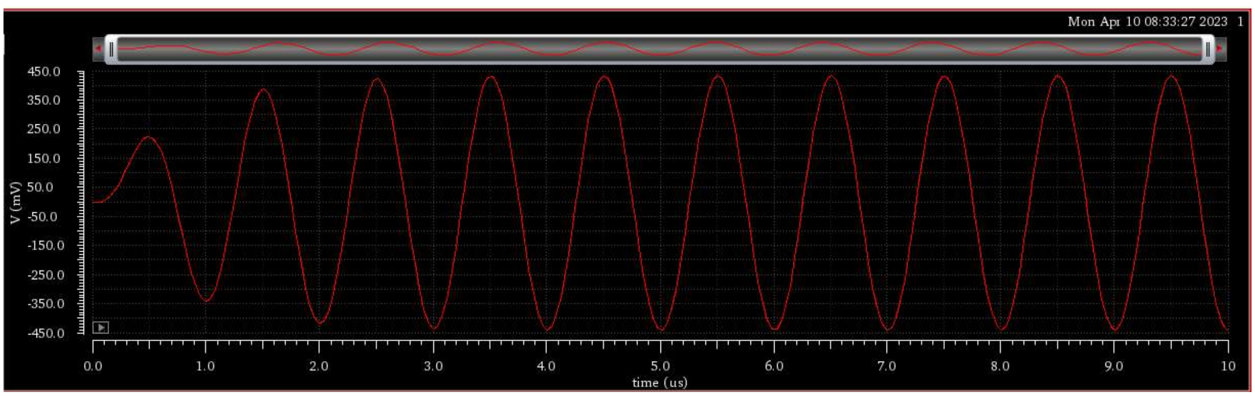
Input sine wave:

Vp-p = 200 mv and Phase =0



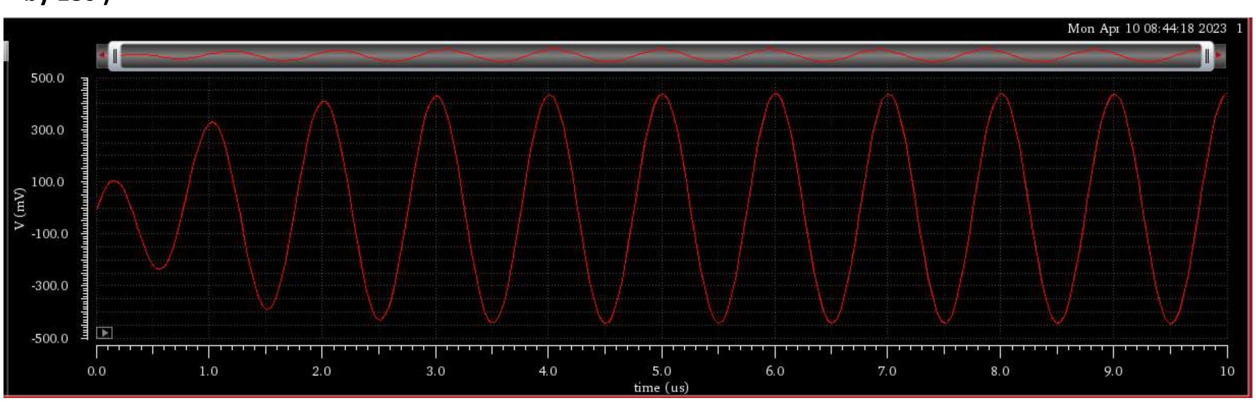
LPF:

Phase of LPF = -90 @ 1MHz and VP-P = 200m * 2.2 =440 mv and the result phase = -90 (lagging Vin by 90 and HPF by 180



HPF:

Phase of HPF = 90 @ 1MHz and VP-P = 200m * 2.2 =440 mV and the result phase = 90 (leading Vin by 90 and LPF by 180)



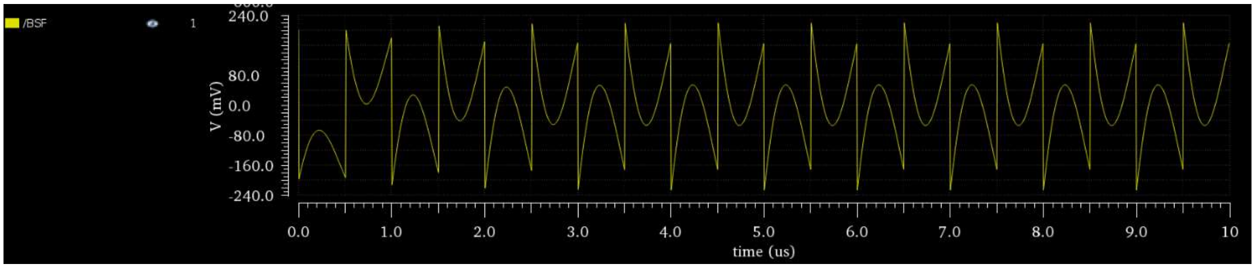
Comments:

- **As we applied an input sine wave with 200 mV and frequency 1MHz (cut off frequency of HPF & LPF) And by that they will let the signal pass because VP-P to both of them will be 440mV (which came from multiplying the amplitude of filters at cut off frequency by 200mV)**

APPLYING SQUARE WAVE INPUT

BPF:

BSF:



Comments:

From Fourier series we know that square wave is a summation of sines and cosines with many frequencies (harmonics) so at BPF it will let frequency of 1MHz pass and rejects other frequencies so it will appear as sine wave not a square wave as we expected as we see. And for BSF it will stop signal to pass at this

frequency =1MHz so the signal will appear with distortion and attenuation.