

# 1 Question 1:

## 1.1 Low pass filter Output:

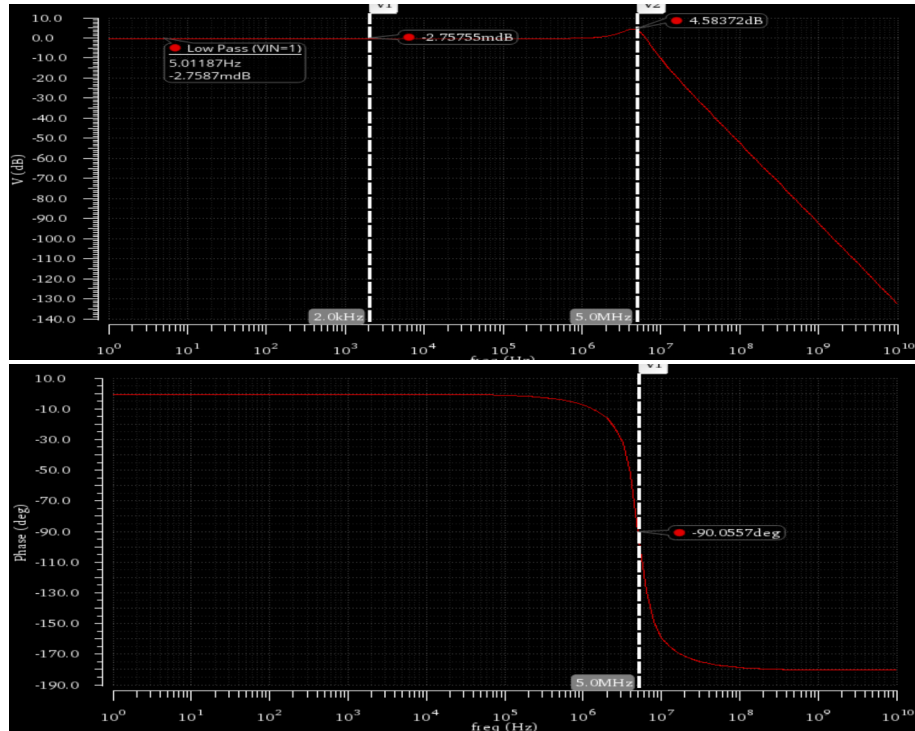


Figure 1. LPF magnitude and phase response

$H_0$  : DC gain = 1 (0dB)

$Q$ : Quality factor = 1.7 (4.6 dB) , Can be calculated from peak value =  $H_0Q$

$f_0$ : Peaking frequency = 5MHz (or frequency at  $90^\circ$  phase)

## 1.2 High Pass filter response

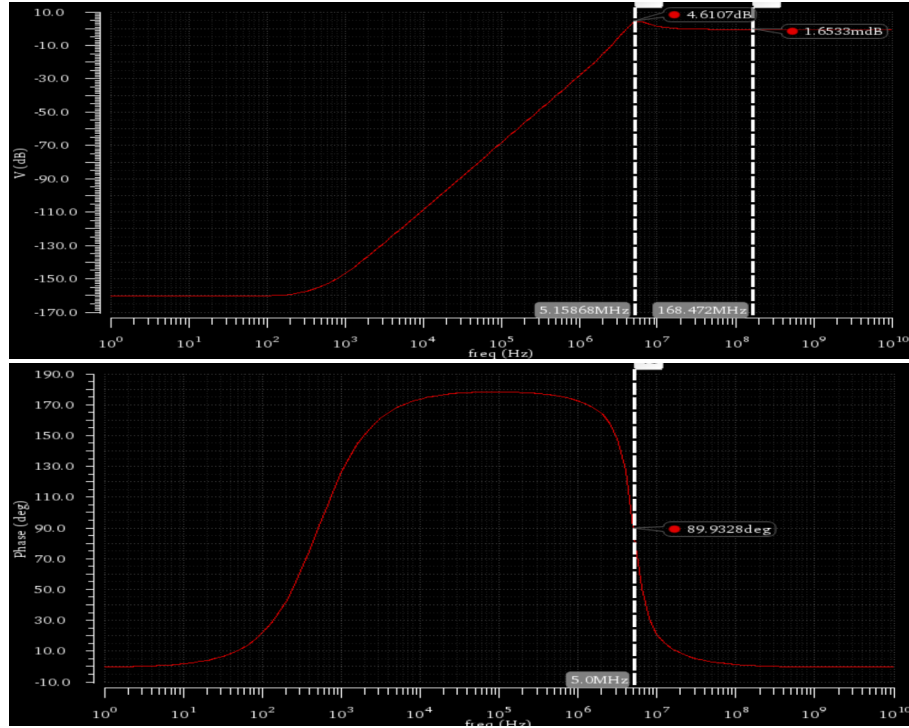


Figure 2. HPF magnitude and phase response

$H_0$ : gain at high frequency = 1 (0dB)

$Q$ : Quality factor = 1.7 (4.6dB), (peak gain =  $H_0Q$ )

$f_0 = 5\text{MHz}$  , (frequency at peak gain or frequency at  $90^\circ$  phase shift)

### 1.3 Band Pass filter response

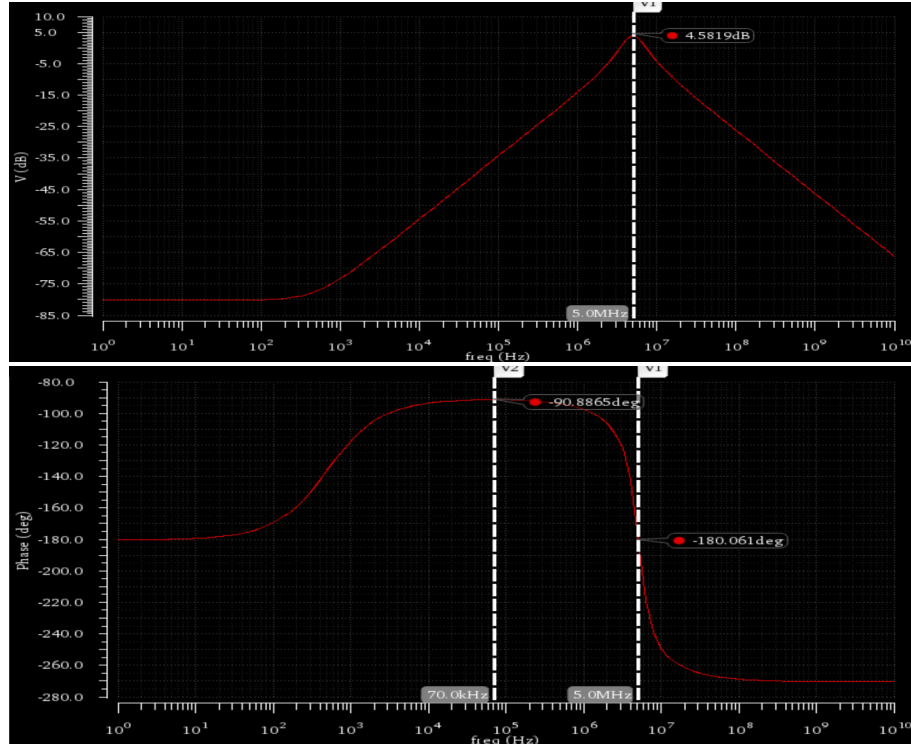


Figure 3. BPF magnitude and phase response

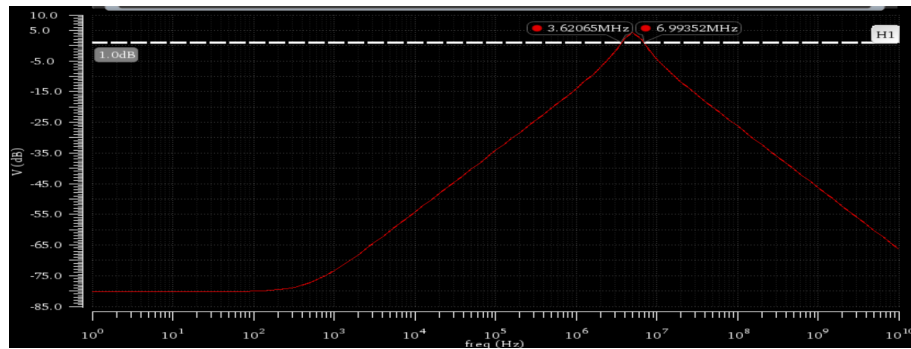


Figure 4. BPF Bandwidth Estimation

$f_0$ : Resonance frequency (frequency at peak magnitude) = 5MHz

$$Q = \frac{f_0}{BW} = \frac{5M}{3M} = 1.67 (\approx 1.7)$$

$$H_0 = \frac{H_{\max}}{Q} = 4.58\text{dB} - 4.6\text{dB} \approx 0\text{dB} = 1$$

## 1.4 Band Stop filter

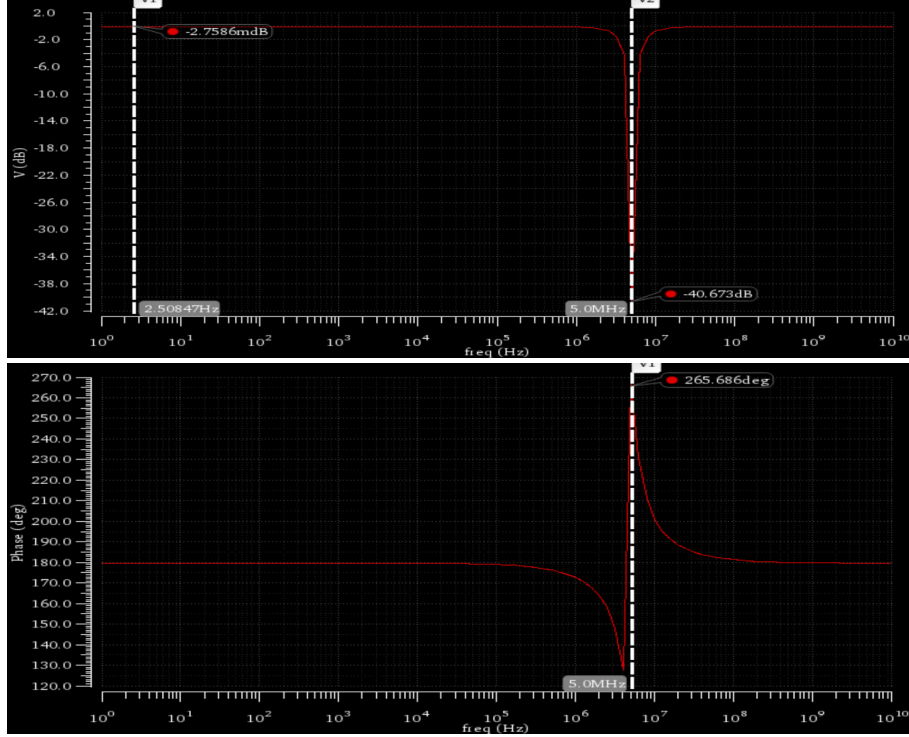


Figure 5. BSF magnitude and phase response

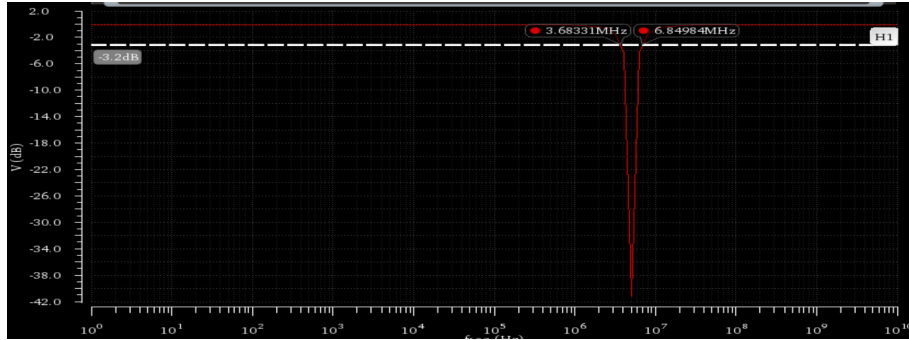


Figure 6. BSF Bandwidth

$H_0$ : gain at DC = 1 (0dB)

$f_0$ : frequency at the notch  $f_0 = 5\text{MHz}$

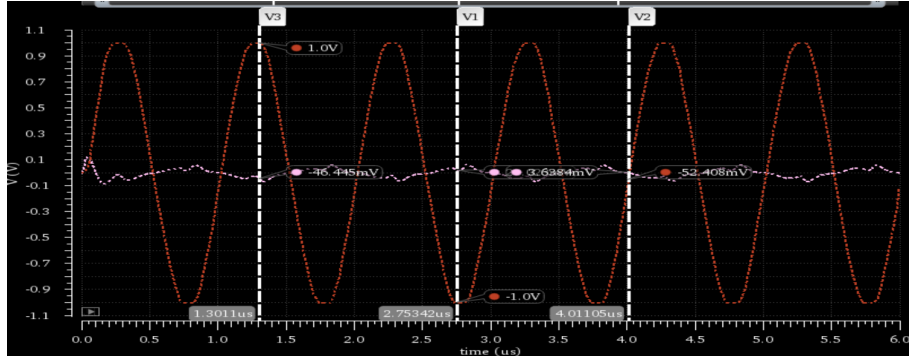
$$Q = \frac{f_0}{BW} = \frac{5}{3.1} = 1.6 (\approx 1.7)$$

## 2 Transient Analysis

### 2.1 Sinwave Input

#### 2.1.1 1MHz input

Applying a sin wave with amplitude 1



**Figure 7.** Sine wave input for LPF(Red) and HPF (white) at 1MHz

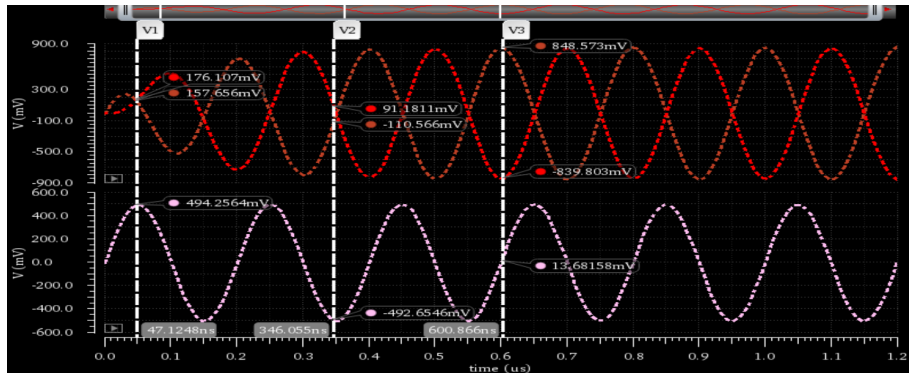
For low pass filter  $|v_{out}| = 1$ , which is expected since  $w < w_0$

Phase shift =  $1.25u - 1.3/1u * 360 = -18^\circ$

For High pass filter:  $|v_{out}| < 1$ , which is expected since  $w < w_0$

### 2.1.2 5MHz input

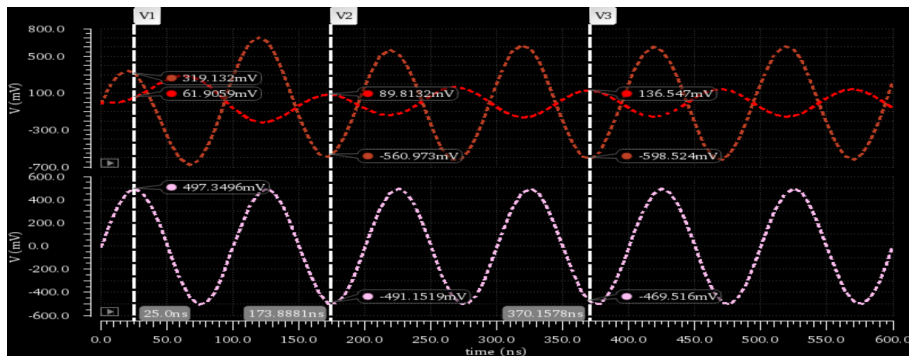
Input signal amplitude = 500mv



**Figure 8.** Sinusoidal response for LPF(red) and HPF(orange), input(white), 5MHz

Both High pass and low pass have approximately equal amplitude as expected  $1.7 * v_{in} = 0.85$ , but for Low pass filter phase shift =  $-90$  and high pass filter =  $+90$ .

### 2.1.3 10 MHz input



**Figure 9.** Sinusoidal response for LPF(red) and HPF(orange), input(white), 10MHz

For LPF output, it begins to attenuate as expected and phase shift is close to 180 degrees, for HPF output gain goes closer to unity and phase shift gets closer to 0 degree.

## 2.2 Square wave input

### 2.2.1 1MHz input

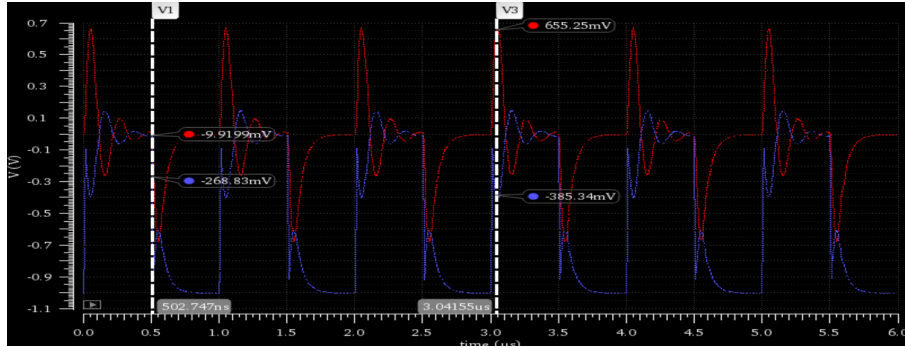


Figure 10. Bandpass (red) and Bandstop (blue) outputs

A signal with frequency 1MHz is not in the pass band of the bandpass filter, but since it's a square wave signal, the sharp transition contains high order harmonics which some of them is in the passband, those harmonics (5MHz harmonic) get amplified with gain close to 4.6dB as shown in figure.

For the bandstop the operation is opposite, high order harmonics in the sharp transition get damped making the output like an output of Low pass filter.

Overshoots and ringing occur because  $(Q=1.7) > 0.5$ .

### 2.2.2 5MHz input

square wave input amplitude = 1V

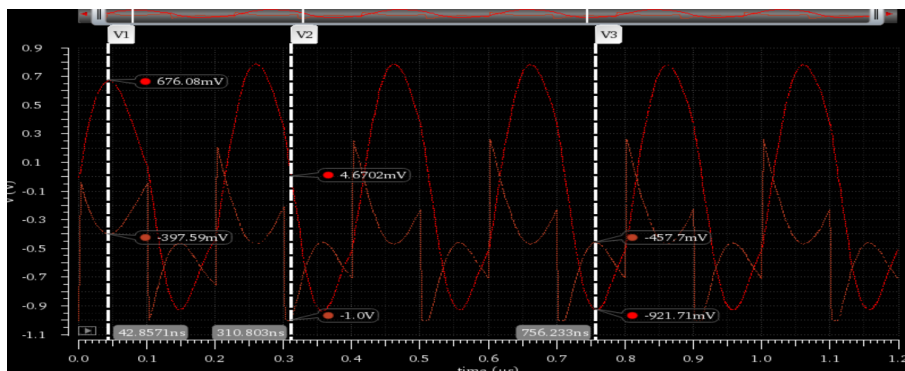
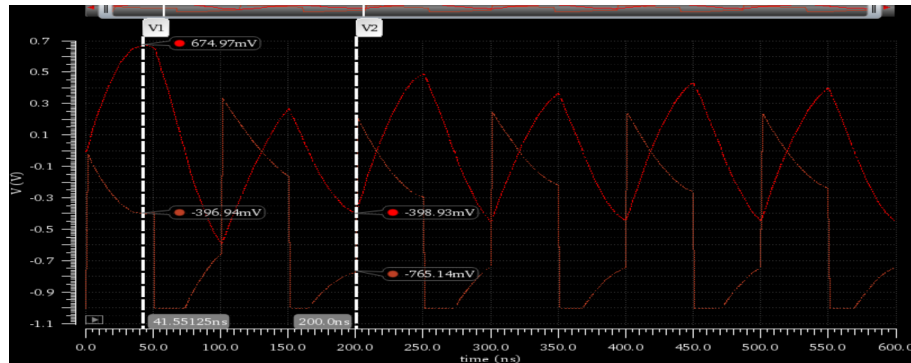


Figure 11. Bandpass output (red) and bandstop (orange) 5MHz

For bandpass : at 5MHz input square wave, bandpass filter filters higher order harmonics leaving the output signal with only the fundamental frequency of the input square wave, that's why the output is a sine wave.

For bandstop: the operation is opposite to the bandpass it attenuates the fundamental frequency at 5MHz and multiplies higher order harmonics with unity.

### 2.2.3 10 MHz input



**Figure 12.** Bandpass output (red) and bandstop (orange) 10MHz

For BandPass filter : At a fundamental frequency out of the pass band , the bandpass filter behaves like an integrator (Low pass filter) thi make the output like a triangle wave

For the Bandstop filter: the operation is opposite, the filter behave as a differentiator (High pass filter) sharp transitions has higher gain than flat part.

## 3 Non-ideal response

In case of OPamps has a limited open loop bandwidth of 5MHz.

Since DC gain of the Opamp is 10,000 , this means that  $GBW = 50\text{GHz} \gg 5\text{MHz}$  , this means that even the effect of the BW is limited and is only present at very high frequency, hence the operation of the filter will be approximately the same for both sinousoidal and step responses.