Spring 14

Low Pass & High Pass Filter

Vivek Porush

LPF & HPF first order

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Low Pass Filter & High Pass filter

First Order

Documentation And Reference

Analogue and Mixed Signal VLSI Design

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Aim: The primary purpose of this project is to design a comparator circuit using *Op-Amp* in SPICE. H*SPICE* is industry standard software to design and simulate electrical circuits. It is derived from original SPICE program where, SPICE is acronym for ***S****imulation* ***P****rogram with* ***I****ntegrated* ***C****ircuit* ***E****mphasis*. In this lab we will simulate and verify transfer functions of first order Low and High pass filters. Plotting output voltage of would verification of theoretically derived transfer functions. Output must be in good agreement with the theoretical values.

Sections: This project has two sections:

- Part I is implementation of LPF (First Order).
- Part II is implementation of HPF (First Order).

Part I

Design Parameters: This section deals with implementation of *inverting amplifiers* as a Low Pass filter. As specified by the circuit we have following parameters available:

Circuit parameters are as follows:

Parameter	Value	Unit	Specification
V_s	0.5	V	AC SIN Input Voltage
C	0.01	uF	Shunt Capacitor
R1	500	Ω	Input Resistance
R2	2.5	KΩ	Feedback Resistance
Op- Amp Biasing Parameters			
Parameter	**Value**	**Unit**	**Specification**
LM741	-	-	Sub circuit from National Semiconductors
V_{cc} (V+)	12	V	Positive Bias Voltage
V_{ee} (V-)	-12	V	Negative Bias Voltage

Table 1. Circuit Parameters

Required Output: This problem requests to compute the transfer function of following circuit and verify it by implementing circuit in *HSPICE*.

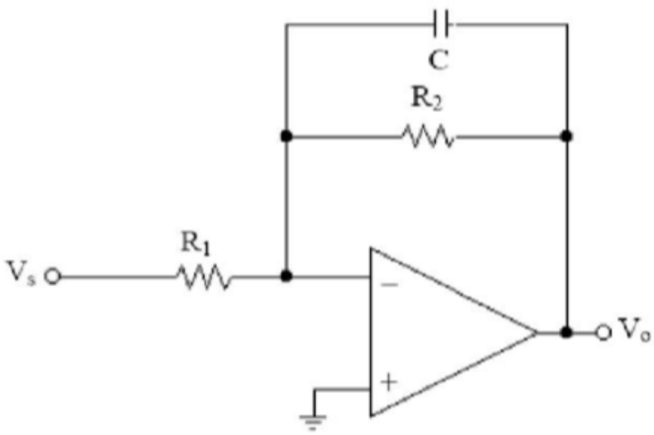


Figure 1. Circuit implementation of Inverting Amplifier as a Low Pass Filter

Theoretical Analysis: Filters are a key component of analog designing. Filters process an input signal and removes unwanted features (frequency/noise) base on its characteristics. Low pass filters can be constructed in many ways. However, for this lab the implementation is using *Op-Amp*. LPF are briefly explained below:

- *Low pass Filters:* Low pass filters are characterized such as they pass low frequencies up-to f_c and attenuate frequencies, which are above f_c, where f_c is the cutoff frequency of the filter.

Consider the circuit shown below, which shows a first order passive LPF:

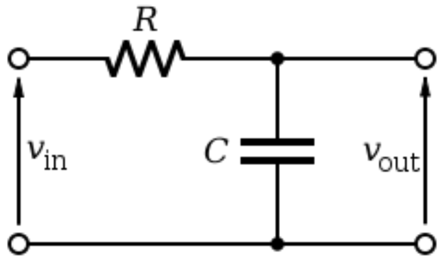


Figure 2. A passive first order LPF

In this circuit values of R & C dictate cutoff frequency. The output is obtained across capacitor. Since capacitive reactance decreases with frequency, the RC circuit exhibits attenuation towards high frequencies. Thus only low frequency component of the input signal can be obtained at output. However it should be noted that this attenuation is not sudden as desired. Signal amplitude generally falls off -6dB/oct beyond the cutoff frequency. If steeper cut of is desired higher order filters should be used.

The Cutoff frequency of a LPF is give as:

$$F_c = \frac{1}{2\pi RC};$$

Where;

$F_c =$ *Cutoff Frequency*

$R =$ *Resistance*

$C =$ *Capacitance*

Now the transfer function of figure 1 can be calculated as shown below:

$$Z_i = R_1;\ Z_f = R_2 \parallel C$$

$$H(s) = \frac{V_o}{V_i} = -\frac{Z_f}{Z_i} = -\frac{R_2 \parallel \frac{1}{sC}}{R_1} = -\frac{\frac{R_2}{sC}}{R_1\left(R_2 + \frac{1}{sC}\right)} = -\frac{\frac{R_2}{C}}{R_1\left(sR_2 + \frac{1}{C}\right)}$$

$$= -\frac{\frac{R_2}{R_1}\left(\frac{1}{R_2C}\right)}{s + \frac{1}{R_2C}} = -K\frac{\omega_c}{s + \omega_c}$$

Where

$$Gain:\quad K = \frac{R_2}{R_1} \qquad and \qquad Cutoff\ Frquency:\quad \omega_c = \frac{1}{R_2C}$$

Theoretically anticipated values: For the given value of R_2 & C the cut off frequency can be calculated as shown below:

$$F_c = \frac{1}{2\pi R_2 C}$$

$$F_c = \frac{1}{2\pi \times 2.5\times 10^3 \times 0.01\times 10^{-6}}$$

$$F_c = \frac{1}{0.00015708}$$

$$F_c = 6366.1977 \ Hz$$

$$F_c = 6.3 \ KHz$$

Gain $A_v = R_2/R_1 = 5$. Thus max output voltage must be 2.5V. Thus, voltage at cutoff frequency must be 0.707 (2.5) = 1.7675 V

Nodal Circuit Diagrams: The circuit shown below is the nodal (representing 'nets') circuit as implemented in the *HSPICE*.

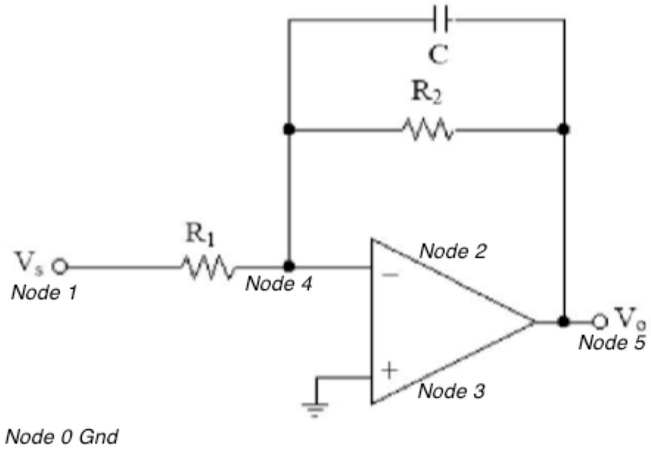


Figure 3. Low Pass Filter as implemented in HSPICE

Error: Table below shows the error in the output voltage as compared to the theoretical predictions:

Frequency F_c	Input Voltage	Predicted Output Voltage (Cutoff)	Actual Output Voltage (cutoff)	Frequency	Error (cutoff)
6.3 KHz	0.5	1.7675	1.7485	6.309KHz	0.019

Table 2. Deviations of V_0 at F_c from predicted values

It is clear from the above data that the observed error is negligible and can attribute it to sampling of data.

Conclusion: The circuit for Low pass filter was designed and simulated in *HSPICE* successfully. Following conclusions can be drawn from simulation:

- The observed error is small and can attribute sampling of data.
- Cutoff frequency is in good accordance with predicted values.
- Gain is in good accordance with the predicted values.

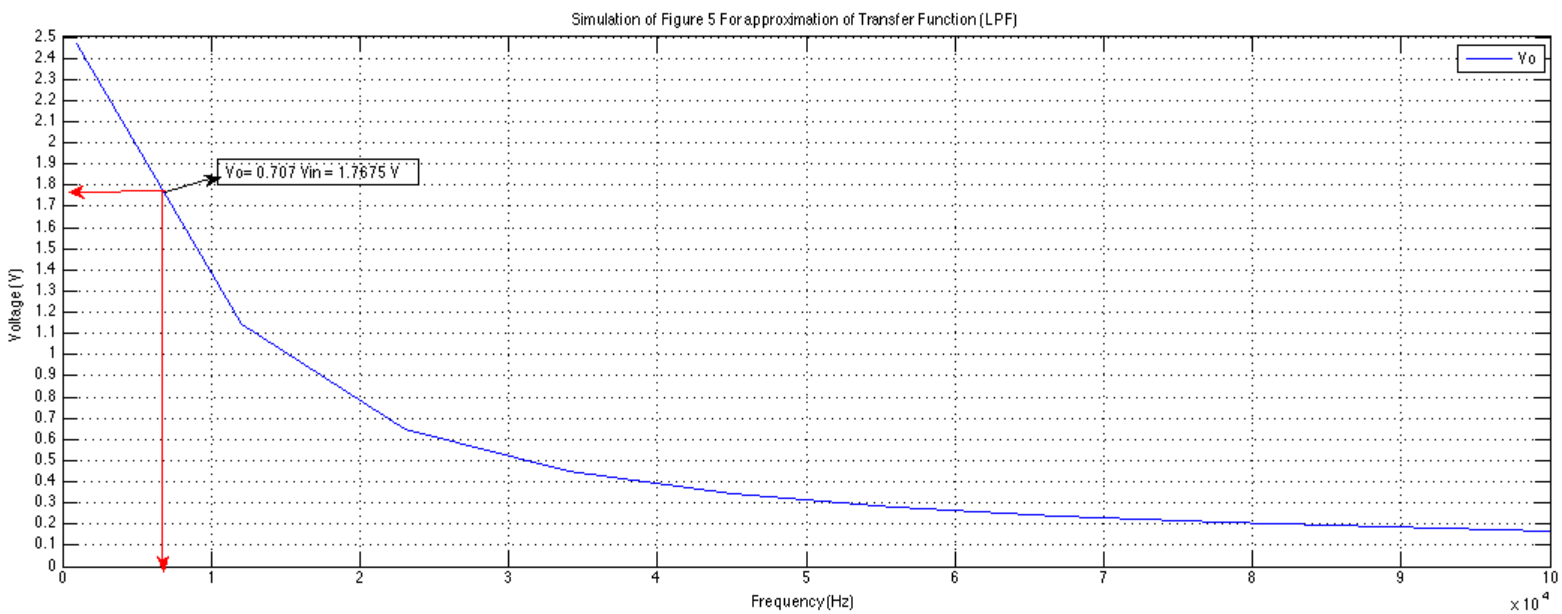
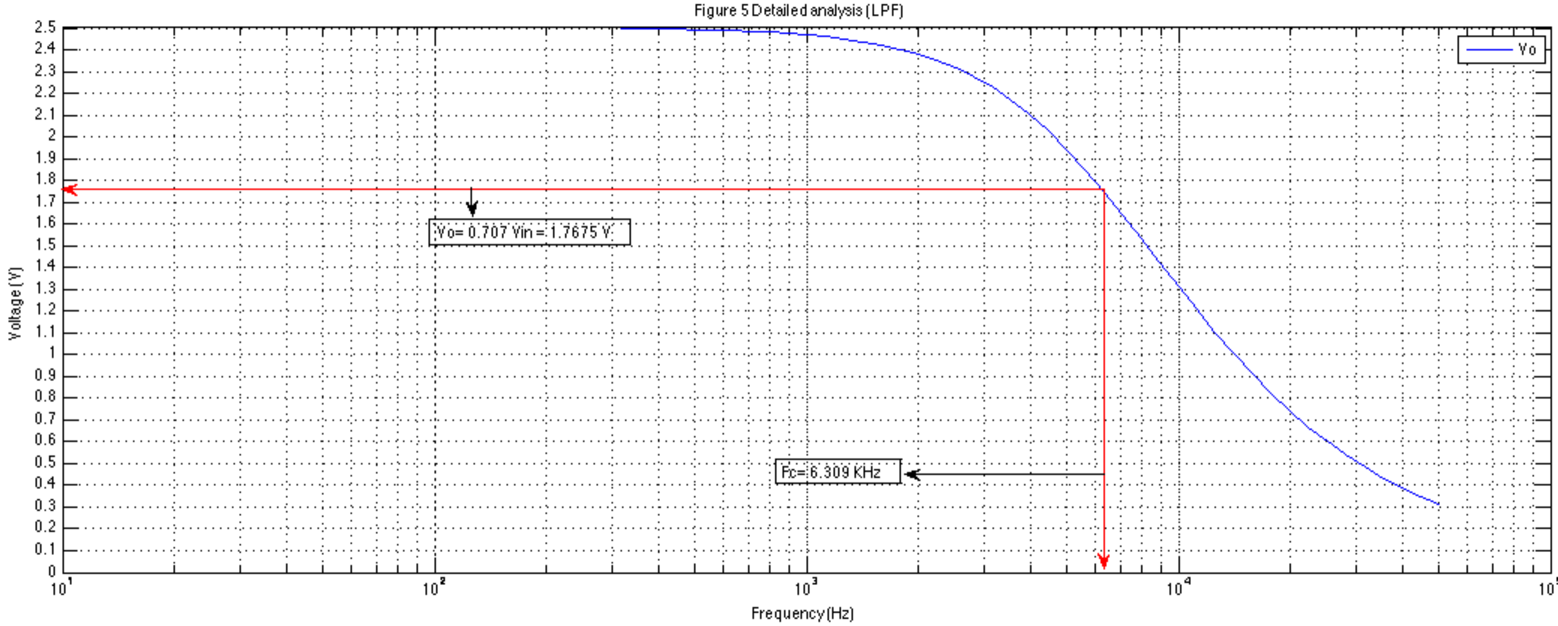

Simulation of Figure 5 For approximation of Transfer Function (LPF)
Vo
Vo= 0.707 Vin = 1.7675 V
Voltage (V)
Frequency (Hz)
x 10^4
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10

Figure 5 Detailed analysis (LPF)



Part II

Design Parameters: Final problem deals with implementation of *inverting amplifiers* as a High Pass filter. As specified by the circuit we have following parameters available:

Circuit parameters are as follows:

Parameter	Value	Unit	Specification
V_s	0.5	V	AC SIN Input Voltage
C	0.01	uF	Shunt Capacitor
R1	500	Ω	Input Resistance
R2	2.5	KΩ	Feedback Resistance
Op- Amp Biasing Parameters			
Parameter	**Value**	**Unit**	**Specification**
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Table 1. Circuit Parameters

Required Output: This problem requests to compute the transfer function of following circuit and verify it by implementing circuit in *HSPICE*.

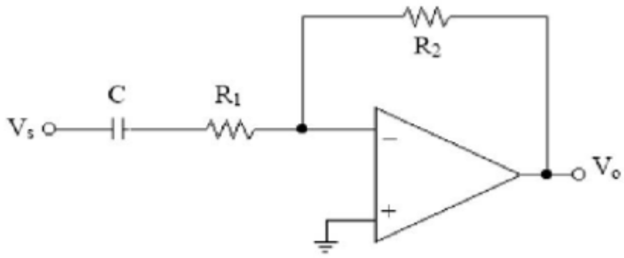

Figure 1. Circuit implementation of Inverting Amplifier as a High Pass Filter

Theoretical Analysis: Filters are a key component of analog designing. Filters process an input signal and removes unwanted features (frequency/noise) base on its characteristics. High pass filters can be constructed in many ways. However, for this lab the implementation is using *Op-Amp*. HPF are briefly explained below:

- *High pass Filters:* High pass filters are characterized such as they attenuate low frequencies up-to f_c and pass frequencies, which are above f_c, where f_c is the cutoff frequency of the filter.

Consider the circuit shown below, which shows a first order passive HPF:

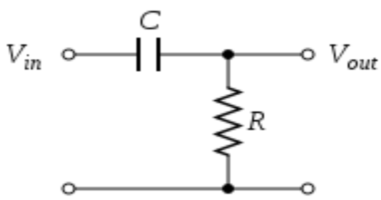

Figure 2. A passive first order HPF

In this circuit values of R & C dictate cutoff frequency. The output is obtained across resistor. Since capacitor acts as a short circuit at high frequencies, the CR circuit exhibits attenuation towards low frequencies. Thus only high frequency component of the input signal can be obtained at output. However it should be noted that this attenuation is not sudden as desired. Signal amplitude generally falls off -6dB/oct beyond the cutoff frequency. If steeper cut of is desired higher order filters should be used.

The Cutoff frequency of a HPF is give as:

$$F_c = \frac{1}{2\pi RC};$$

Where;

$F_c =$ *Cutoff Frequency*

$R =$ *Resistance*

$C =$ *Capacitance*

Now the transfer function of figure 1 can be calculated as shown below:

$$H(s) = -\frac{Z_f}{Z_i} = -\frac{R_2}{R_1 + \frac{1}{sC}} = -K\frac{s}{s+\omega_c}$$

$$Gain: \quad K = \frac{R_2}{R_1} \qquad and \qquad Cutoff\ Frquency: \quad \omega_c = \frac{1}{R_1 C}$$

Theoretically anticipated values: For the given value of R_1 & C the cut off frequency can be calculated as shown below:

$$F_c = \frac{1}{2\pi R_1 C}$$

$$F_c = \frac{1}{2\pi \times 500 \times 0.01 \times 10^{-6}}$$

$$F_c = \frac{1}{0.00015708}$$

$$F_c = 31830.988\ Hz$$

$$F_c = 31.8\ KHz$$

Gain $A_v = R_2/R_1 = 5$. Thus max output voltage must be 2.5V. Thus, voltage at cutoff frequency must be 0.707 (2.5) = 1.7675 V

Nodal Circuit Diagrams: The circuit shown below is the nodal (representing 'nets') circuit as implemented in the *HSPICE*.

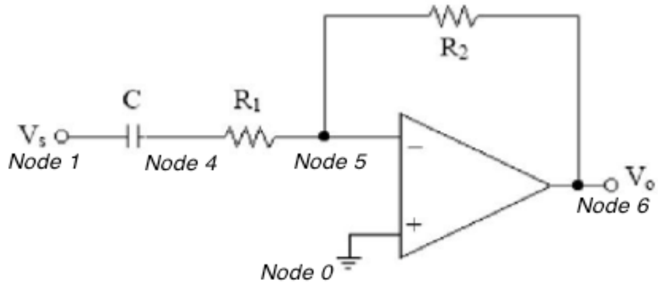

Figure 3. High Pass Filter as implemented in HSPICE

Error: Table below shows the error in the output voltage as compared to the theoretical predictions:

Frequency F_c	Input Voltage	Predicted Output Voltage (Cutoff)	Actual Output Voltage (cutoff)	Frequency	Error (Cutoff)
31.8 KHz	0.5	1.7675	1.7829	28.1KHz	0.0154

Table 2. Deviations of V_o at F_c from predicted values

It is clear from the above data that the observed error is within range. At 31KHz voltage is 1.9. This error is mainly because of internal parasitic of the LM741. Due to these parasitic LM741 behaves as a LPF whose cut off frequency is close to the cut of frequency of aforementioned HPF.

Conclusion: The circuit for High pass filter was designed and simulated in *HSPICE* successfully. Following conclusions can be drawn from simulation:

- The observed error is within range.
- Cutoff frequency is lower than the predicted values.
- Gain is in good accordance with the predicted values.

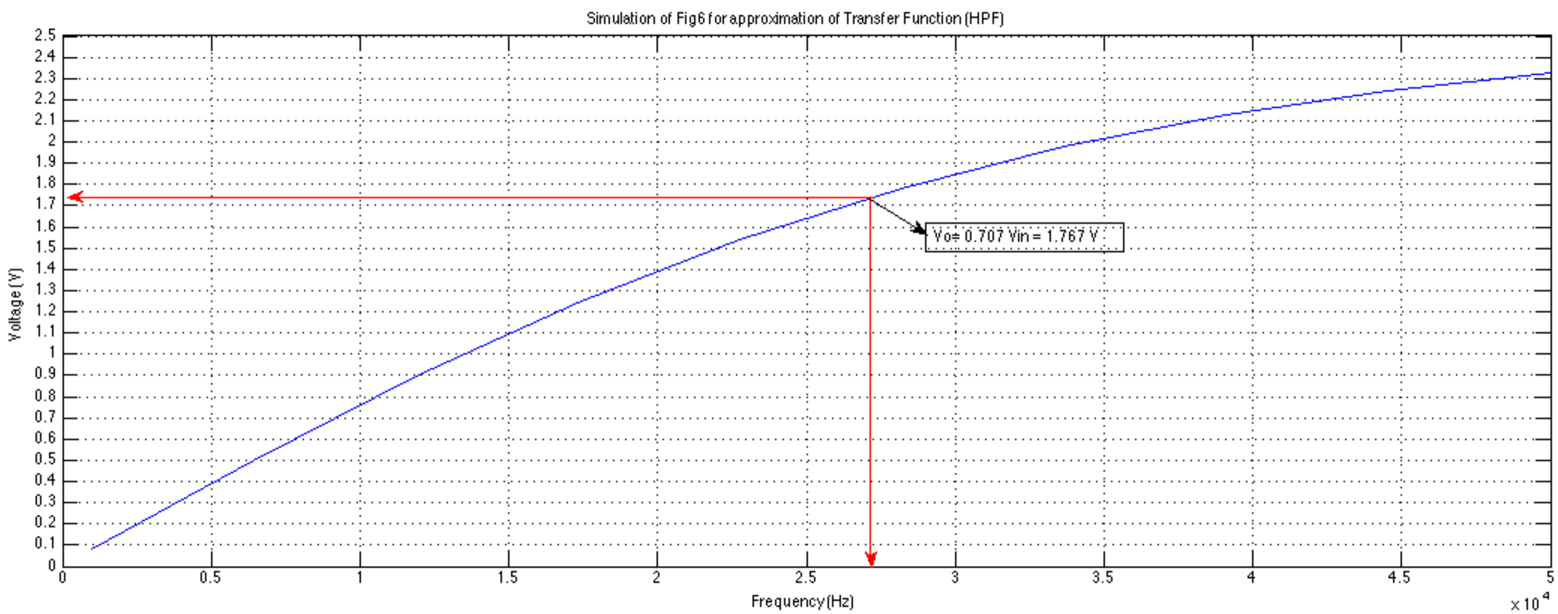
Simulation of Fig6 for approximation of Transfer Function (HPF)
Voltage (V)
Frequency (Hz)
x 10^4
Vo= 0.707 Vin = 1.767 V

Figure 6 Detailed analysis (HPF)