Kathmandu University
Department of Electrical and Electronics Engineering
ANALOG ELECTRONICS LABORATORY WORK

EXPERIMENT 2: LC type LP and HP Filters

Objectives: To understand the operation theory, circuit structures and design of low-pass, high-pass and band-pass filters.

Software:
Multisim 8

Theory:
The frequency response of a BP filter is shown in fig. 1, to explain the related characteristic parameters of a filter.

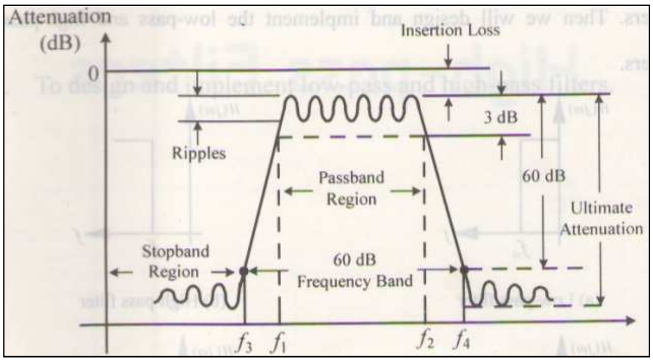

Fig: 1

The main cause of insertion loss is due to the parasitic resistance contained in the reactive components. Normally, bandwidth is taken as 3dB bandwidth ($f_2 - f_1$). Ultimate attenuation defines the maximum attenuation of filter within stopband region. Quality factor (Q) defines the ratio of centre frequency to the 3dB bandwidth.

Low Pass Filter

Low-pass (LP) filter can be either LC type or CL type as shown in fig. 2.

Fig: 2 LP filter

When the frequency is extremely low, the inductor is a zero impedance component and the capacitor is an open circuit. When the frequency is extremely high, inductor is an open circuit component and the capacitor is a zero impedance component. The transfer function of LC type second order LP filter is given in (1).

$$\frac{V_O}{V_i} = \frac{\frac{1}{SC}}{SL + \frac{1}{SC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The cut-off frequency is given by $\omega_C = \frac{1}{\sqrt{LC}}$.

(1) *Butterworth Filter*: This type of filter is known as maximally flat filter since no ripples are permitted in the pass band. The attenuation of transition band is not sharper than Chebyshev filter. Typical response of Butterworth LP filter is given in fig. 3.

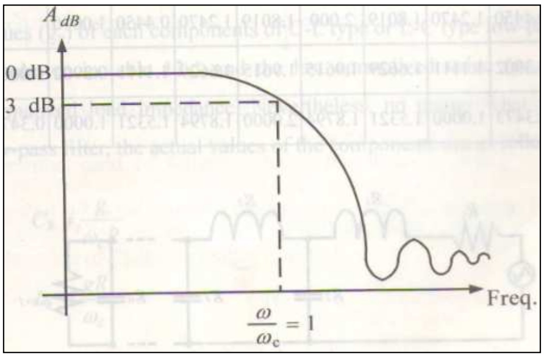

Fig: 3

The element values for the Butterworth LP filter prototypes when $R_S = R_L$ is given in table 1.

n	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}
1	2.0000	1.0000								
2	1.4140	1.4140	1.0000							
3	1.0000	2.0000	1.0000	1.0000						
4	0.7654	1.8478	1.8478	0.7654	1.0000					
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000				
6	0.5176	1.4142	1.9319	1.9319	1.4142	0.5176	1.0000			
7	0.4450	1.2470	1.8019	2.000	1.8019	1.2470	0.4450	1.0000		
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000	
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000

Table: 1

Where n represents the number of elements and g is shown in fig. 4.

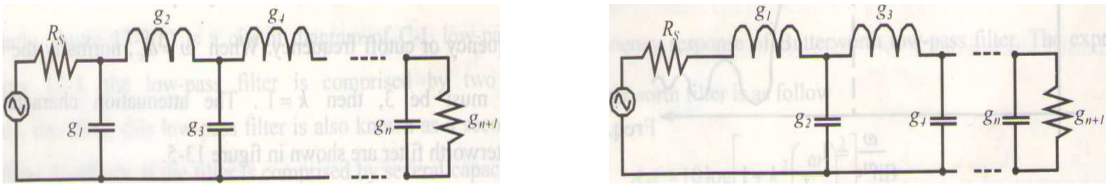

Fig: 4

The attenuation characteristics for Butterworth filter is shown in fig. 5.

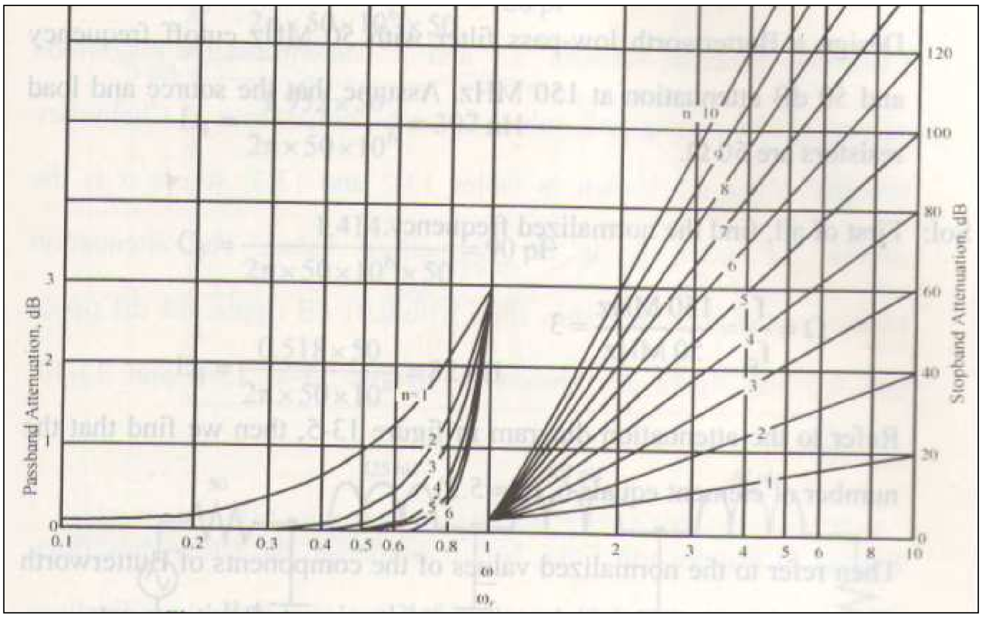

Fig: 5

After we obtain the number element, we can find the normalized values of each component through table 1. The last value g_{n+1} is the normalized load impedance. Irrespective the type of LP filter (LC or CL), the actual values of components are given in (2).

$$C_K = \frac{g}{\omega_C R} \qquad L_K = \frac{gR}{\omega_C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where R represents the load impedance or source impedance, g represents the value from table 1.

Example

1. Design a LP filter with 50 MHz cutoff frequency and 50 dB attenuation at 150 MHz. Assume the source and load resistors are 50 Ω.

Sol: First of all, find the normalized frequency,

$$\Omega = \frac{f}{f_C} = \frac{150MHz}{50MHz} = 3$$

Refer to the attenuation diagram of fig. 5 and find the number of elements required. We found $n = 6 \approx 5.2$. Then refer to the normalized values of components of Butterworth filter in table 1. If we select capacitor input circuit, we get

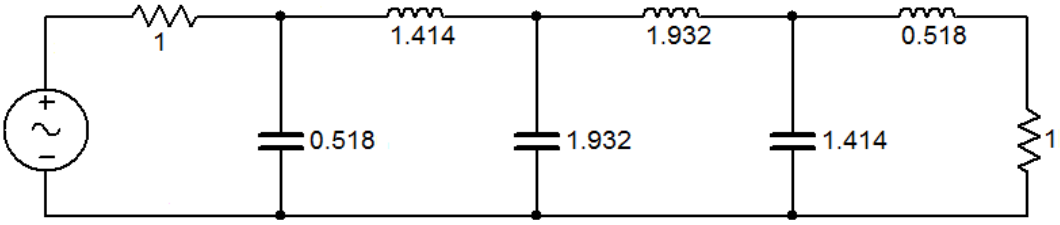

Fig: 6

Finally we calculate the actual values of components using (2) and get the fig. 7.

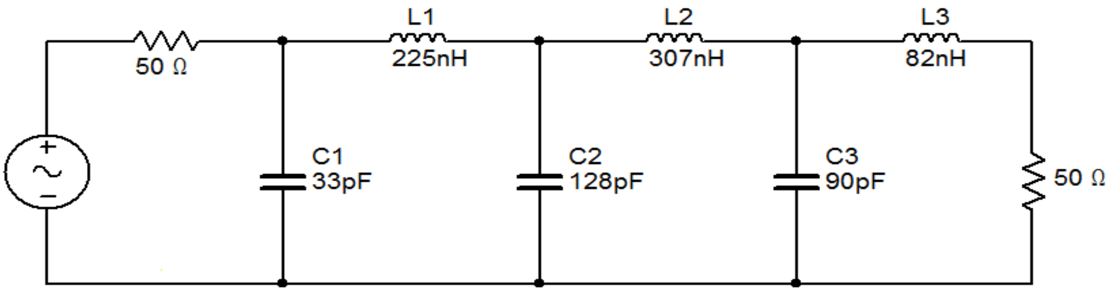

Fig: 7

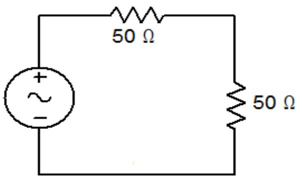

Fig: 8

Procedure

1. Connect the circuit as shown in fig. 8.
2. Use AC analysis to find the magnitude response. [Why -6dB?]
3. Find the BW of the circuit in fig. 8.
4. Connect the circuit as shown in fig. 7.
5. Use AC analysis to find the magnitude response.
6. Find the BW of the circuit in fig. 7.
7. Find the attenuation at 150 MHz and see whether it is higher than 50 dB or lower and why?
8. Check whether there is ripple in the pass band or not.
9. Do the time domain analysis of fig. 7 using the oscilloscope.
10. Sketch the output waveform for 50 MHz by giving 10 V Sine.
11. Change the CL type LP filter into LC type LP filter and find the 3dB BW and the attenuation at 150 MHz. [*Getting Confused? ☹]*
12. Use exact values of components and again analyze the result.

(2) *Chebyshev Filter:* This type of filter is also known as equal ripple filter since the ripples are equally distributed within the pass band. The attenuation of transition band is sharper than the Butterworth filter. Fig. 9 shows the comparison between Butterworth and Chebyshev filters.

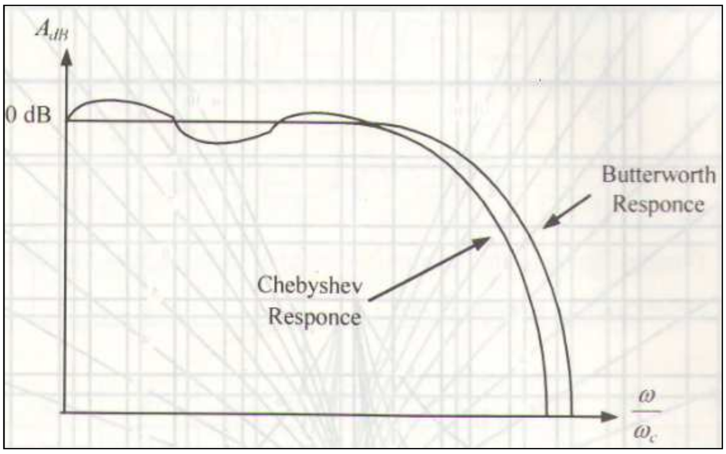

Fig: 9

Attenuation characteristics for Chebyshev filter with 0.1 dB ripple is shown in fig. 10. Attenuation characteristics for Chebyshev filter with 0.5 dB ripple is shown in fig. 11. The normalized values of element for Chebyshev LP filter with 0.1 dB ripple is shown in table 2. The normalized values of element for Chebyshev LP filter with 0.5 dB ripple is shown in table 3.

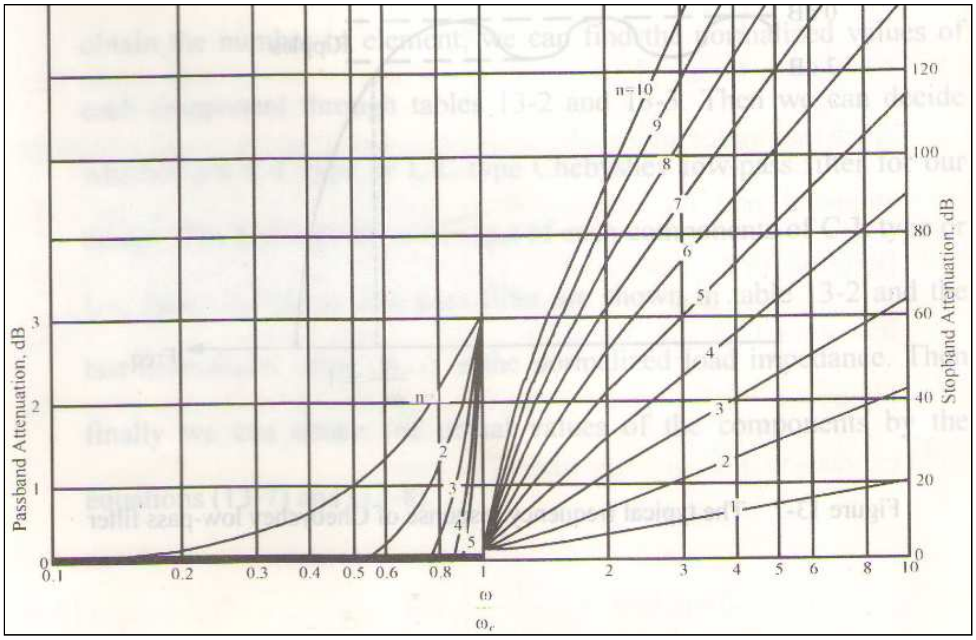

Fig: 10 Attenuation characteristics for Chebyshev filter with 0.1 dB ripple

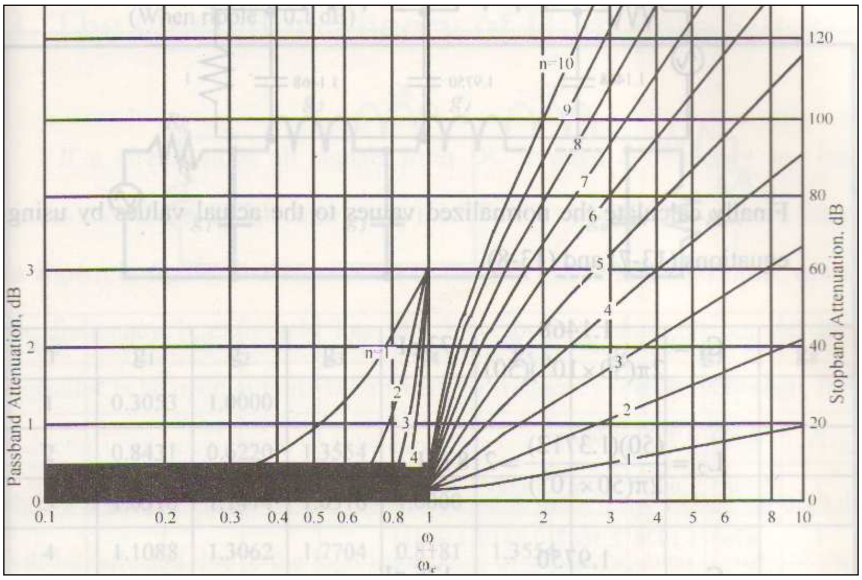

Fig: 11 Attenuation characteristics for Chebyshev filter with 0.5 dB ripple

n	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8
1	0.3053	1.0000						
2	0.8431	0.6220	1.3554					
3	1.0316	1.1474	1.0316	1.0000				
4	1.1088	1.3062	1.7704	0.8181	1.3554			
5	1.1468	1.3712	1.9750	1.3712	1.1468	1.0000		
6	1.1681	1.4040	2.0562	1.5171	1.9029	0.8618	1.3554	
7	1.1812	1.4228	2.0967	1.5734	2.0967	1.4228	1.1812	1.0000

Table: 2 Normalized values of element for Chebyshev LP filter with 0.1 dB ripple

n	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}
1	0.6987	1.0000								
2	1.4029	0.7071	1.9841							
3	1.5963	1.0967	1.5963	1.0000						
4	1.6703	1.1926	2.3662	0.8419	1.9841					
5	1.7058	1.2296	2.5409	1.2296	1.7058	1.0000				
6	1.7254	1.2479	2.6064	1.3136	2.4759	0.8696	1.9841			
7	1.7373	1.2582	2.6383	1.3443	2.6383	1.2582	1.7373	1.0000		
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841	
9	1.7504	1.2690	2.6678	1.3673	2.7939	1.3673	2.6678	1.2690	1.7504	1.0000

Table: 3 Normalized values of element for Chebyshev LP filter with 0.5 dB ripple

Example

1. Design a LP filter with number of element n = 5 and 0.1 dB ripple. The source resistance and load resistance are both 50Ω. Assume that the cutoff frequency is 50 MHz.

Sol: Given n = 5 and 0.1 dB ripple, refer to the normalized values of the components of Chebyshev filter in table 2. If we select capacitor input circuit we get

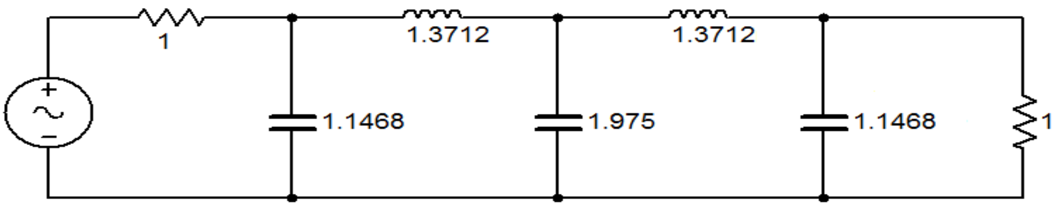

Fig: 12

Finally we calculate the actual values of components using (2) and get the fig. 13.

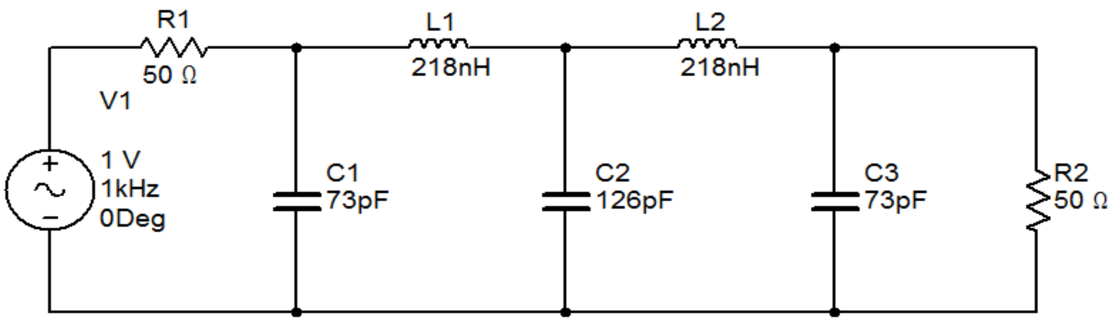

Fig: 13

Procedure

1. Connect the circuit as shown in fig. 13.
2. Use AC analysis to find the magnitude response.
3. Find the BW of the circuit in fig. 13.
4. Check whether there is ripple in the pass band or not.
5. Find the magnitude of the ripple in the pass band.
6. Compare the transition width of Butterworth filter and Chebyshev filter.
7. Change the CL type LP filter into LC type LP filter and find the 3dB BW and ripples at the pass band.
8. Use exact values of components and again analyze the result.

High Pass Filter

Fig: 14 HP filter

When the frequency is extremely low capacitor is open circuit and inductor is short circuit. When the frequency is extremely high capacitor is short circuit and inductor is open circuit. . The transfer function of CL type second order HP filter is given in (3).

$$\frac{V_O}{V_i} = \frac{SL}{SL + \frac{1}{SC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The cut-off frequency is given by $\omega_C = \frac{1}{\sqrt{LC}}$.

Comparing fig. 14 and fig. 2, we notice that the only difference between the LP and HP filter is the exchange between the capacitor and the inductor. *Therefore when designing a HP filters we must begin with the calculation of* ω_C *of LP filter. Then the normalized values of each components of HP filter can be obtained from reciprocal data of the tables.* The design procedure is shown with an example below.

Example

1. Design a HP filter with 60 MHz cutoff frequency and attenuation of 40 dB at 30 MHz. The source resistance and load resistance are both $50\,\Omega$. Assume the passband ripple is 0.5 dB.

Sol: First of all find the normalized frequency of *LP* filter.

$$\Omega = \frac{f}{f_C} = \frac{30MHz}{60MHz} = 0.5$$

Therefore the normalized frequency of HP filter is

$$\Omega = \frac{f_C}{f} = \frac{60MHz}{30MHz} = 2$$

Refer to the attenuation diagram of fig. 11. We find the number of elements $n \approx 4.5 = 5$. Now refer to the normalized values of components of Chebyshev LP filter in table 3. If we select inductor input circuit we get

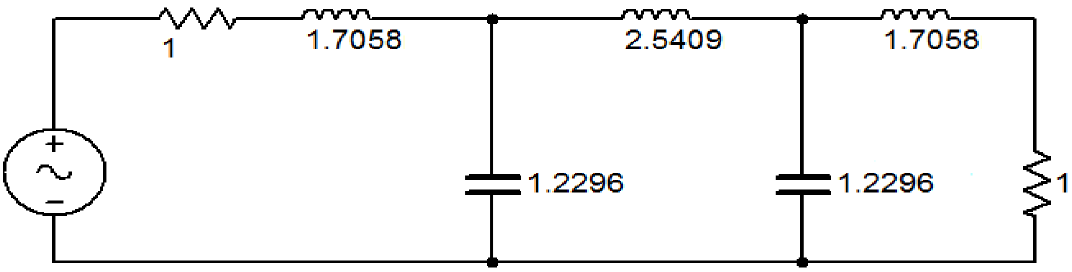

Fig: 15

After that convert the LP filter prototype to HP filter prototype then we get

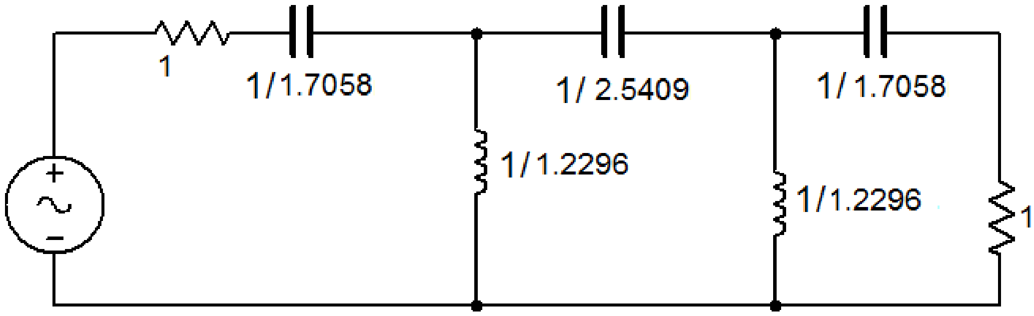

Fig: 16

Finally we calculate the actual values of components using (2) and get the fig. 17.

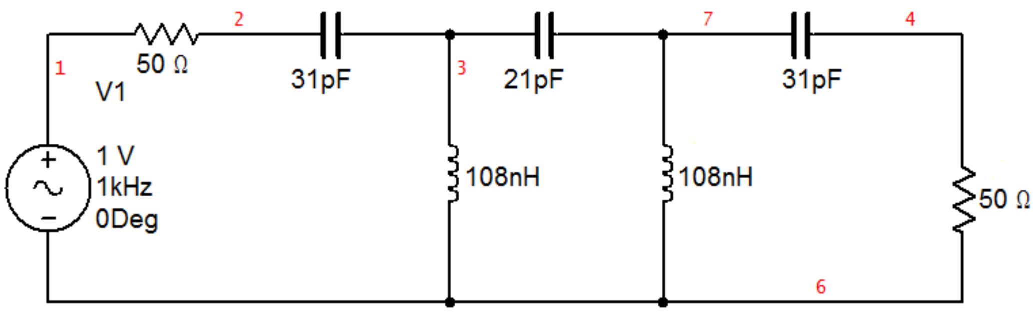

Fig: 17

Procedure

1. Connect the circuit as shown in fig. 17.
2. Use AC analysis to find the magnitude response.
3. Find the BW of the circuit in fig. 17.
4. Check whether there is ripple in the pass band or not.
5. Find the magnitude of the ripple in the pass band.

Transient Response of LP Filter

The following definitions are given with reference to fig. 18.

1. *Rise time:* The rise time of the step response is defined as the time required for the step response to rise from 10% to 90% of its final value.

2. *Settling time:* This is the time beyond which the step response does not differ from its final value by more than 2%.
3. *Ringing:* This is an oscillatory transient occurring in the response of a filter due to the sudden change in the input.
4. *Delay time:* This is the time required for the step response to reach 50% of its final value.
5. *Overshoot:* The overshoot of the step response is defined as the difference between the peak value and the final value of the step response.

Procedure

1. Connect the circuit as shown in fig. 7.
2. Set the function generator to 100 kHz square @ 10 V amplitude.
3. Now click on *Simulate, Analysis, And Transient Analysis.*
4. Set the transient period for 0 to 1e-005 sec and click on *Simulate*.
5. Zoom the area around 5 µS.
6. The transient response is shown in fig. 18.
7. Calculate the rise time, settling time, delay time and overshoot for the step response of fig. 7.

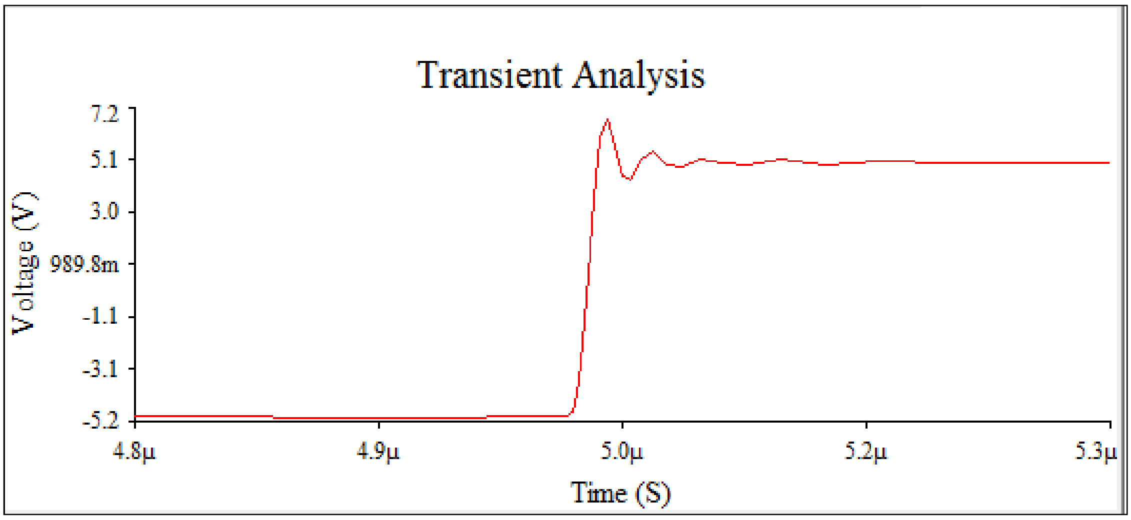

Fig: 18 Step response of Butterworth LP filter (n = 6)

RISE TIME X *BW = CONSTANT*

I want channel with high bandwidth so that the high speed digital pulses will not get smear over each other due to longer rise time☺.