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Analog Filter Design: A Succinct Investigation

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Abstract: In many systems, it is essential to extract or enhance the desired information and remove the unwanted components. This is the simplest aim of signal processing where the filter turns out to be the key element. The objective of this paper is to investigate the characteristics of analog passive and active filters. Particularly, the interest goes to the conventional Butterworth, Chebychev and Bessel filter. A comparative study of these filters is done. The different circuits are simulated using the MULTISIM software to visualize the magnitude and phase responses. The procedure of designing the different filters is presented so that it can be used in any application.

Keywords: Analog filters, Passive filters, Active filters, Butterworth, Chebychev, Bessel

1. INTRODUCTION

Filtering in its raw definition is any of the various mechanical, physical, electrical or biological operations that separate solids from fluids liquids or gases by adding a medium through which only the fluid can pass. The fluid that passes through is called the filtrate. In circuit theory, a filter is a circuit capable of passing or amplifying certain frequencies while attenuating other frequencies. Thus, a filter can extract important frequencies from signals that also contain undesirable or irrelevant frequency.

Filters can be placed in one of two classes: analog or digital. Analog filters can be *passive* where circuits contain passive elements like capacitors, inductors and resistors or *active* in which the circuits use an operational amplifier (op amp) as an active device in combination with some resistors and capacitors. Digital filters are implemented in software using a digital computer or special purpose digital hardware [2,13,14].

Ideally, filters are classified into four basic filter types: low-pass, high-pass, band-pass and all-pass. They are classified according to theirs magnitude and phase responses [1-14]. Some state of art practical approximations have been proposed [2-3]. The first filter approximation is the Butterworth or maximally-flat response. It exhibits a nearly flat pass-band with no ripple and the roll off is smooth [3,7,14]. Another approximation to the ideal filter is the Chebychev or equi-ripple response. This filter has ripple in the pass-band amplitude response [3,7,14]. A third filter is the Bessel filter characterized by a linear phase response with respect to frequency [3,7,14].

The goal of this paper is to present the properties of filters. It starts by designing passive filters and comparing the different responses of Butterworth, Chebychev and Bessel types. Then, the design of active filters with a comparison between the two conventional implementation topologies which are Sallen-Key and multiple feedback is done. Finally, active filters and passive filters are compared.

2. PASSIVE AND ACTIVE FILTERS

Filters can be classified into one of two categories: ***passive*** or ***active*.**

Passive Filter

A passive filter is a kind of electronic filter that is made only from passive elements – in contrast to an active filter, it does not require an external power source (beyond the signal). Since most filters are linear, in most cases, passive filters are composed of just the four basic linear elements – resistors, capacitors, inductors, and transformers. More complex passive filters may involve nonlinear elements, or more complex linear elements, such as transmission line [4].

Active Filter

An active filter is a type of analog electronic filter, distinguished by the use of one or more active components i.e. voltage amplifiers or buffer amplifiers. Typically this will be a vacuum tube, transistor or operational amplifier, in addition to resistors and capacitors, but not inductors. Inductance is not preferred for active filter design because it is least ideal, bulky, heavy, and expensive and does not lend itself to IC-type mass production [12].

Transfer Function

The frequency-domain behavior of a filter is described mathematically in terms of its transfer function or network function. This is the ratio of the Laplace transforms of its output and input signals. The voltage transfer function of a filter can therefore be written as:

$$H(s) = \frac{Vo(S)}{Vi(S)} \tag{1}$$

Where s is the complex frequency variable (Laplace transform variable).

The transfer function defines the filter's response to any arbitrary input signals, but we are most often concerned with its effect on continuous sine waves, especially the magnitude of the transfer function to signals at various frequencies. Knowing the transfer function magnitude (or gain) at each frequency allows us to determine how well the filter can distinguish between signals at different frequencies. The transfer function magnitude versus frequency is called the amplitude response or sometimes, especially in audio applications, the frequency response [4].

Similarly, the phase response of the filter gives the amount of phase shift introduced in sinusoidal signals as a function of frequency. Because a change in phase of a signal also represents a change in time, the phase characteristics of a filter become especially important when dealing with complex signals in which the time relationships between different frequencies are critical. By replacing the variables *s* in equation (1) with jω, where j =√-1, and ω is the radian frequency (2π*f)*, we can find the filter's effect on the magnitude and phase of the input signal [2]. The magnitude is found by making the absolute value of Equation (1) [4]:

$$A = 20\log|H(j\omega)| \text{In dB} \tag{2}$$

And the phase is:

$$\arg H(j\omega) = \arg\frac{V_o(j\omega)}{V_i(j\omega)} \tag{3}$$

Major Types Of Filters

The various types of filters can be defined according *to* the following classification that is based on the magnitude response in equation (2) or the phase response in equation (3):

A. Low Pass Filter (LPF)

A low-pass filter (LPF) is a filter that passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. The exact frequency response of the filter depends on the filter design [3].

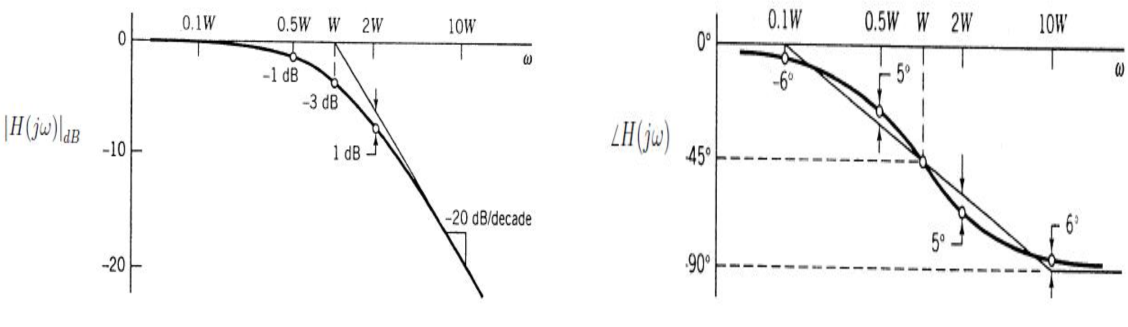


Fig. 1 Magnitude and phase response versus frequency, (a) magnitude response (b) phase response

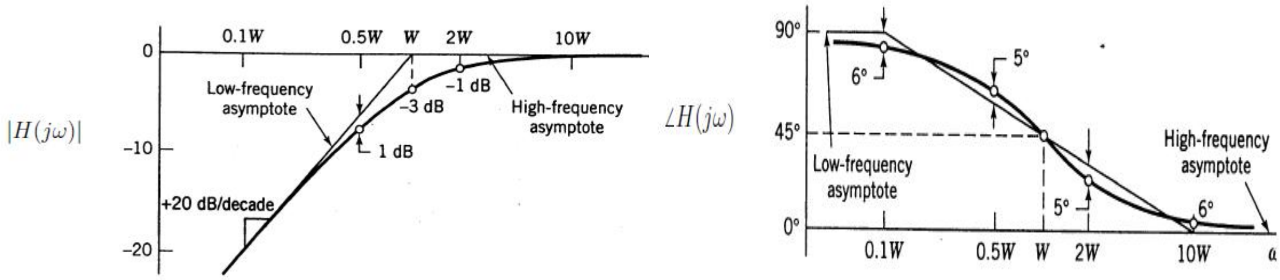
At low frequencies, $\omega/\omega_c \ll 1$, $|H(j\omega)| \approx 1$, which is a straight line in the Bode plot, and the phase is 0°.

At high frequencies, $\omega/\omega_c \gg 1$, $|H(j\omega)| \approx 1/(\omega/\omega_c)$, which is a straight line with a slope of -20 dB/decade in the Bode plot .and the phase is -90°.

At the cutoff frequency, the magnitude $|H(j\omega)|_{dB}$ =3dB and the phase is -45°.

B. High Pass Filters (HPF)

A high-pass filter (HPF) is an electronic filter that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. The amount of attenuation for each frequency depends on the filter design. [3]



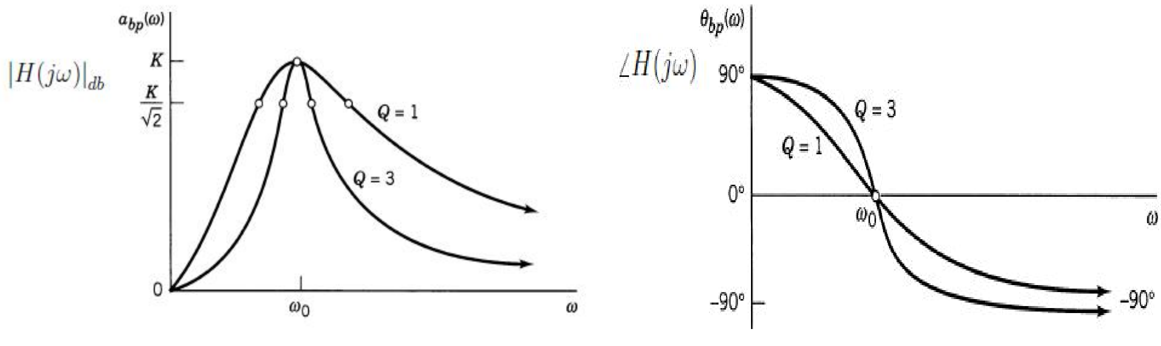
(a) **(b)**

Fig. 2 Magnitude and phase response versus frequency, (a) magnitude response (b) phase response

At low frequencies,ω/ω_c<<1, ,$|H(j\omega)| \propto \omega$, (a+20dB/decade line)and the phase is 90º.
At high frequencies,ω/ω_c>>1, $|H(j\omega)| \propto 1$, (a line with a slope of 0)and the phase is 0º.
At the cutoff frequency, the magnitude $|H(j\omega)|_{dB}$ =3dB and the phase is 45º.

C. Band Pass Filter (BPF)

A band pass filter is an electronic circuit or device which allows only signals between specific frequencies to pass through and attenuates/rejects frequencies outside the range. And it can be constructed by putting a high-pass and a low-pass filter back to back [3].



(a) (b)

Fig. 3 Magnitude and phase response versus frequency, (a) magnitude (b) phase.

ω_l: Lower cut-off frequency; ωu : Upper cut-off frequency;
$\omega_0 = \sqrt{(\omega_u \, \omega_l)}$: Center frequency; $B \equiv \omega_u - \omega_l$ Band width;
$Q \equiv \omega_0/B$: Quality factor.
At low frequencies,ω/ω_c<<1, $|H(j\omega)| \propto \omega$, (a+20dB/decade line)and the phase is 90º.
At high frequencies,ω/ω_c>>1, $|H(j\omega)| \propto \frac{1}{\omega}$, (a -20dB/decade line)and the phase is -90º.
At $\omega = \omega 0$, $H(j\omega) = K$ (purely real) $|H(j\omega)| = K$ (maximum filter gain), and the phase is 0º.

D. Band Stop Filter (BSF)

The **Band Stop Filter**, (BSF) is another type of frequency selective circuit that functions in exactly the opposite way to the Band pass filter we looked at before. The band stop filter, also known as a *band reject filter*, passes all frequencies with the exception of those within a specified stop band which are greatly attenuated.

If this stop band is very narrow and highly attenuated over a few hertz, then the band stop filter is more commonly referred to as a *notch filter* [3].

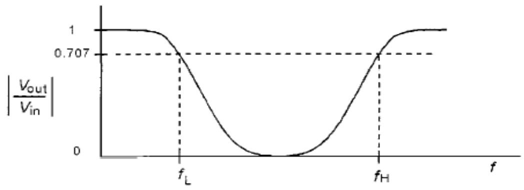


Fig. 4 band-Stop filter circuit magnitude response

E. All Pass Filter

This filter does not filter out any frequencies of a complex input signal; it allows all frequencies through it without changes in level. But just adds a linear phase shift to each frequency component, thus contributing to a constant time delay. [9]

Filter Design Parameters

The order: The order of a filter has several effects. It is directly related to the number of components in the filter and, therefore, to its price and the complexity of the design task. Therefore, higher-order filters are more expensive, take up more space, and are more difficult to design. The primary advantage of higher-order filters is that they will have steeper roll-off slopes than similar lower-order filters [13].

Attenuation Rate: The transition between the pass band and the stop band is a continuous function, and the rate at which this transition occurs is a common metric used to select a filter. Express the attenuation rate is commonly expressed in decibels per decade, where a decade is a factor of 10 in frequency.

Cut-off frequency: is the point at which the output deviate 3dB from the pass-band value, or more specially, it is the boundary between the pass-band and the stop-band region .

Center frequency: is the region equidistant between the filter's upper and lower cutoff frequencies (for the case of bandpass filter).

Bandwidth: is the frequency range between the 3dB cutoff frequency in band pass filter.

Q factor: is the ratio of the center frequency to the bandwidth when applied to band pass filter.

Impedance: is the value in ohms of the driving load impedance.

Roll-off rate: measured at [dB/decade] or [dB/octave] is defined as rate change of power at 10 times (decade) or 2 times (octave) change of frequency in the stop band.

Group Delay And Phase Delay

Phase delay: gives the *time delay* in seconds experienced by each sinusoidal component of the input signal, and is define by:

$$\tau_{PD} = -\frac{\theta(\omega)}{\omega} \tag{4}$$

Group delay

is the term used to describe the time delay versus frequency relationship of the transmitted signal. It is defined as the rate of phase change with frequency. The term "group delay" is very descriptive, in that it is the delay seen by a group of frequencies that are being transmitted through a filter. A constant group delay implies that all frequencies experience the same delay. A frequency dependent group delay implies that some frequencies are delayed more than others [13].

Group delay, denoted τ_{GR}, is mathematically defined to be:

$$\tau_{GR} = -\frac{d\theta(\omega)}{d\omega} \tag{5}$$

If $\theta(\omega = k\omega$, k a constant→ no phase distortion

For a linear phase filter τ_{PD} = τ_{GR} =k.

3. PASSIVE FILTER DESIGN

Definition of state of art approximations

A. Butterworth Filter

Butterworth(1930) introduced one of the earliest systematic analog filter design methods, and it is still one of the most widely used, The Butterworth filter design method is one of the *classical* filter design procedures [14].In the following , The Butterworth or the maximally flat response has a smoother transition through the pass band to the stop band. The phase response also is very smooth, which is important when considering distortion. The low pass Butterworth polynomial has an all-pole transfer function with no finite zeros present. It is the approximation method of choice when low phase distortion and moderate selectivity are required [14].

The magnitude response function for the Butterworth approximation is shown in equation (6)

$$\left|H_{B,n}[j(\omega/\omega_0)]\right| = \frac{1}{\sqrt{1+\varepsilon^2.(\omega/\omega_0)^{2n}}} \tag{6}$$

Where

$$\varepsilon = \sqrt{10^{2-0.1\alpha_{pass}} - 1} \tag{7}$$

Where n is the order of filter, $\varepsilon$is the pass-band gain adjustment factor.

B. Chebychev filter

Some twenty years after the development of Butterworth and elliptic filters, Chebyshev filters were developed around 1950s [14], The Chebyshev approximation function also has an all-pole transfer function like the Butterworth approximation. However, unlike the Butterworth case, it has characteristic response that roll-off greater than -20dB/decade/pole and the circuit has characteristic of overshoot and ripple response in the pass band [9].The magnitude response function for the Chebyshev approximation is shown in eq(2.3)

$$\left|H_{C,n}[j(\omega/\omega_0)]\right| = \frac{1}{\sqrt{1+\varepsilon^2.C_n^2(\omega/\omega_0)}} \tag{8}$$

And $C_n(\omega)$ is the Chebyshev polynomial of the first kind of degree *n*. The normalized Chebyshev polynomial (ω_0= 1) is defined as:

$$C_n(\omega) = \cos[n\cos^{-1}(\omega)],\ \ \omega \leq 0 \tag{9.a}$$
$$C_n(\omega) = \cosh[n\cos^{-1}(\omega)],\ \omega > 0 \tag{9.b}$$

C. Bessel filter

Although all of the classical filters presented up to this point are defined in terms of the magnitude frequency response, and are designed primarily to meet given magnitude frequency response specifications, such is not the case with Bessel filters. Bessel filters are designed to achieve a maximum frequency bandwidth while maintaining a constant time delay: as initially introduced, a Bessel filter is a constant time-delay network [14].

Passive filter design

In this section, the design of passive filters meeting some specifications and using the conventional approximations presented in the previous section.. An extensive work has been done on the different types of filters presented in section 2. The large amount of results and to avoid overloading the paper, focus is put on the presentation of the results regarding the design of lowpass filters.

A. Butterworth filter deign

The task is to design 5th, 8th and 10th Butterworth low pass filter with f_c=10KHz,R_S=R_l=1kΩ.

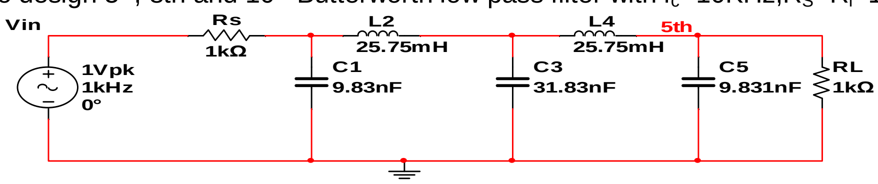


Fig. 5 5th order Butterworth passive low pass filter..

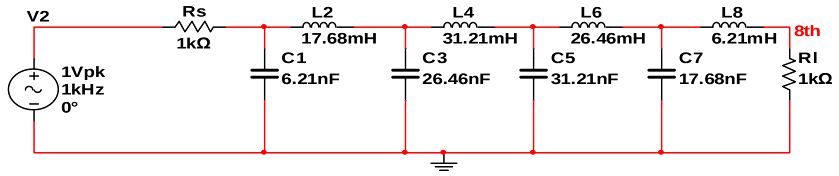


Fig. 6 8th order Butterworth passive low pass filter.

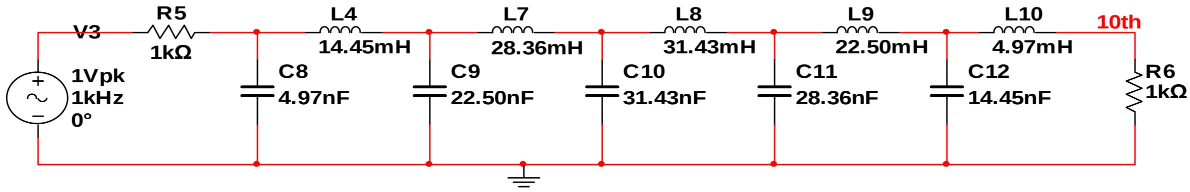
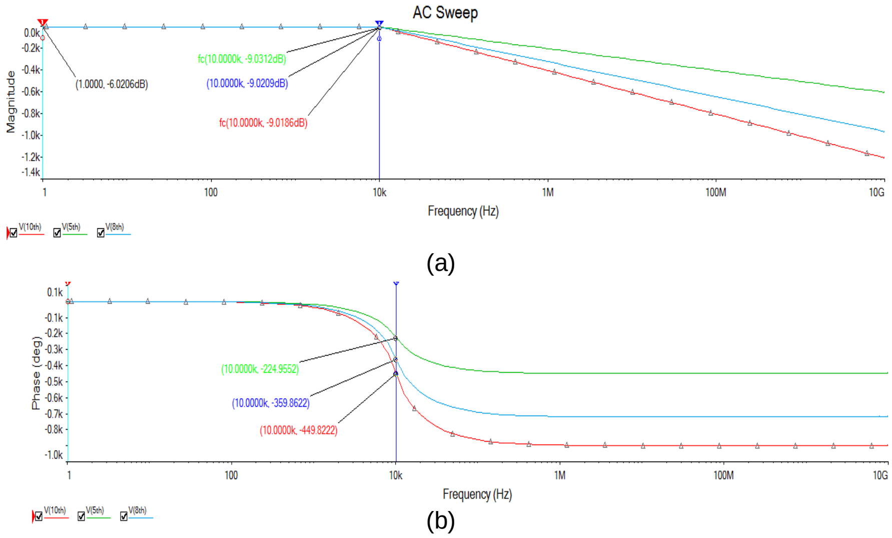


Fig. 710th order Butterworth passive low pass filter.

We use Multisim in order to get the magnitude response and phase response by using AC analysis



(a)

(b)

Fig. 8 (a) The magnitude and (b) the phase response of 5th, 8th, 10th order Butterworth low pass filter.

The results obtained are shown in Table 1:

Table 1 Comparison between Butterworth responses with different orders.

Type	Order	f_c gain (dB)		f_c phase (C°)	Roll-off Graphically dB /decade		Roll-off experimentally dB /decade		roll-off error	
Low pass	**5**	**3.01**		**-224.95°**	**-99.98**		**-100**		**0%**	
	8	**3.00**		**-359.86°**	**-159.98**		**-160**		**0%**	
	10	**2.99**		**-449.82°**	**-199.95**		**-200**		**0%**	
High Pass	**5**	**3.03**		**-134.00°**	**100**		**100**		**0%**	
	8	**3.02**		**-356.86°**	**160**		**160**		**0%**	
	10	**2.06**		**-298.81°**	**198.01**		**200**		**1%**	
Band pass	**5**	**3.04**	**4.48**	**-359.94°**	**-99.33**	**-99.25**	**100**	**100**	**0.67%**	**0.75%**
	8	**3.10**	**6.13**	**-359.98°**	**-155.34**	**-155.27**	**160**	**160**	**2.91%**	**2.95%**
	10	**3.14**	**7.34**	**0°**	**-192.65**	**-192.61**	**200**	**200**	**3.67%**	**3.69%**

From the above table, it can be deduced:
- Butterworth has very flat amplitude in the pass band and roll-off rate is increased by −n×20dB/decade/pole, where n is the order.
- The phase at cutoff frequency, is increased by $-n \times 45°$ in case of low pass, and by $+n \times 45°$ in case high pass, that's why, 8th order 's load is purely resistive at cutoff frequency ,and 10th order low pass filter's load is purely capacitive.
- The load in band pass filter is purely resistive at cutoff frequency no matter the order of filter.

B. Chebychev Low Pass Filter Design

5th, 8th, 10th Chebyshev low pass filter with: f_c=1KHz,Rs=1kΩ,are implemented :

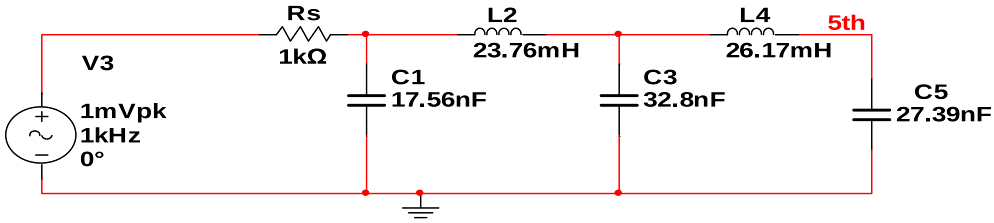


Fig. 9 Chebychev 5th order passive low pass filter.

Using the same procedures, we implement 8th and 10th order (in this case we use series inductors).

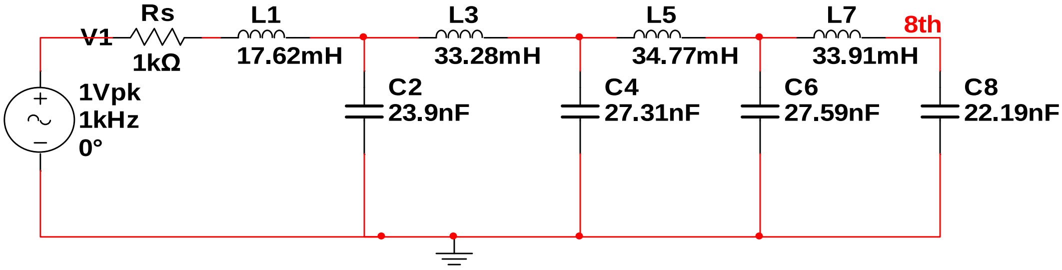


Fig. 10 Chebyshev 8th order passive low pass filter.

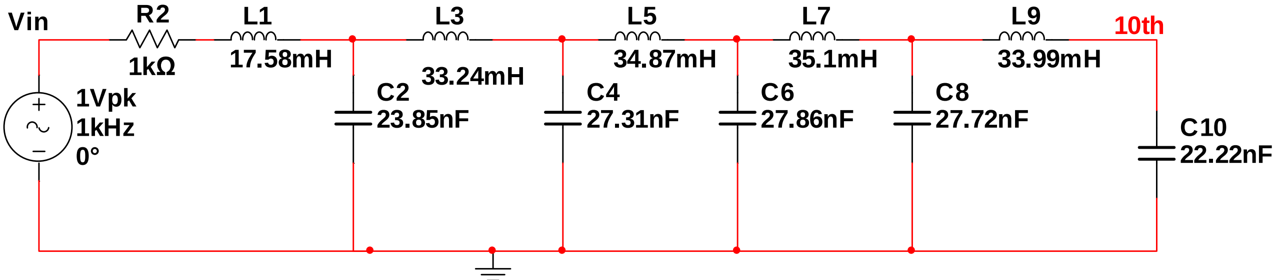
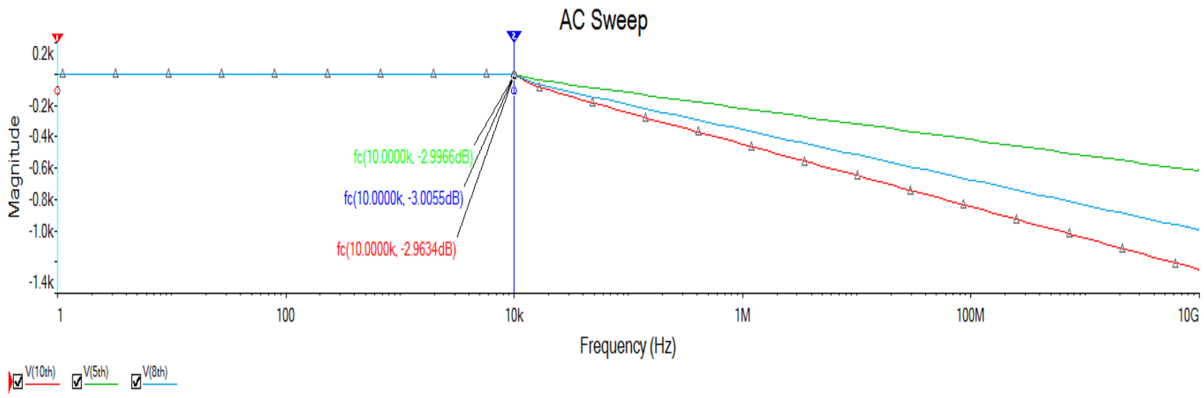
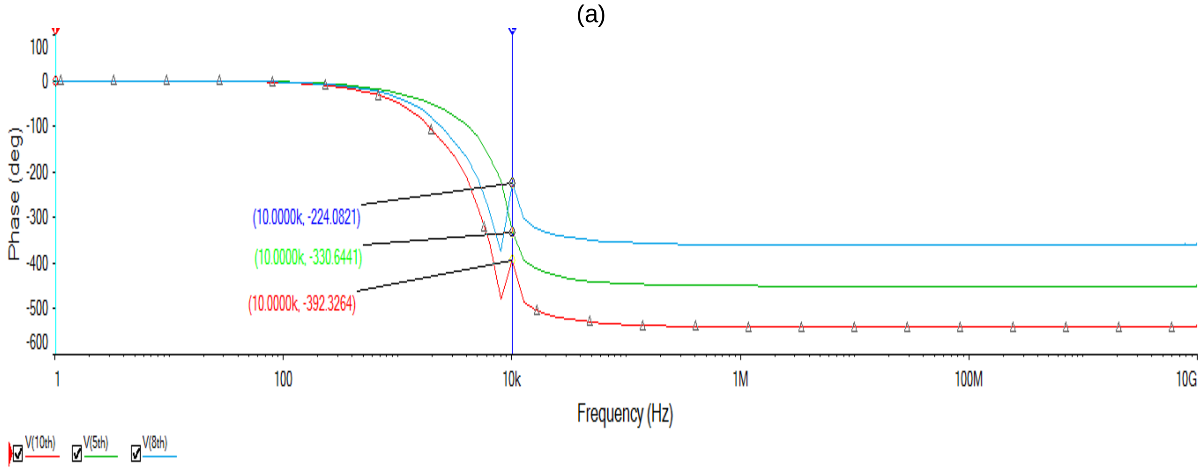


Fig. 11 Chebychev 10th order passive low pass filter.

Using Ac analysis, the bode plots obtained are:



(a)



(b)

Fig. 12 (a) The magnitude and (b) the phase response of 5th,8th,10th order chebyshev low pass filter.

The results obtained from above bode plots are shown in the following table:
-From the results obtained from previous table, it can be concluded that the roll-off of chebyshev filter approximately is -n× 24 db, where n is the filter order.
-from the phase response, as we increase the order ,the phase distortion is increased.

Table 2 Comparison between Chebychev responses with different orders

type	Order	f_c gain (dB)		f_c phase (C°)	Roll-off Graphically dB /decade	
Low pass	**5**	**3.00**		**-330.64°**	**-119.54**	
	8	**2.99**		**-224.08°**	**-196.36°**	
	10	**2.96**		**-392.32°**	**-248.10°**	
High pass	**5**	**3.04**		**-29.08°**	**-119.57°**	
	8	**3.15**		**-134.78°**	**-196.41°**	
	10	**3.16**		**33.94°**	**-248.16°**	
Band pass	**5**	**3.10**	**8.96**	**2.01°**	**-122.84**	**-112.74**
	8	**2.73**	**17.01**	**133.76°**	**-185.60**	**-185.57**
	10	**2.47**	**22.57**	**-2.54°**	**-234.62**	**-234.60**

C. Bessel's Low Pass Filter Design

The task is to design 5th, 8th, 10th order low pass filter with these specifications: f_c=10KHz ,R_L=1kΩ and R_s=0.

In this case, T topology is suggested.

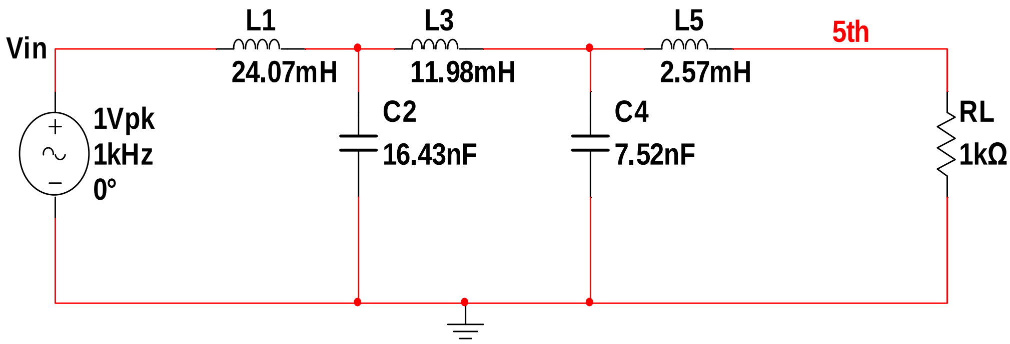


Fig. 13 5th order Bessel passive low pass filter.

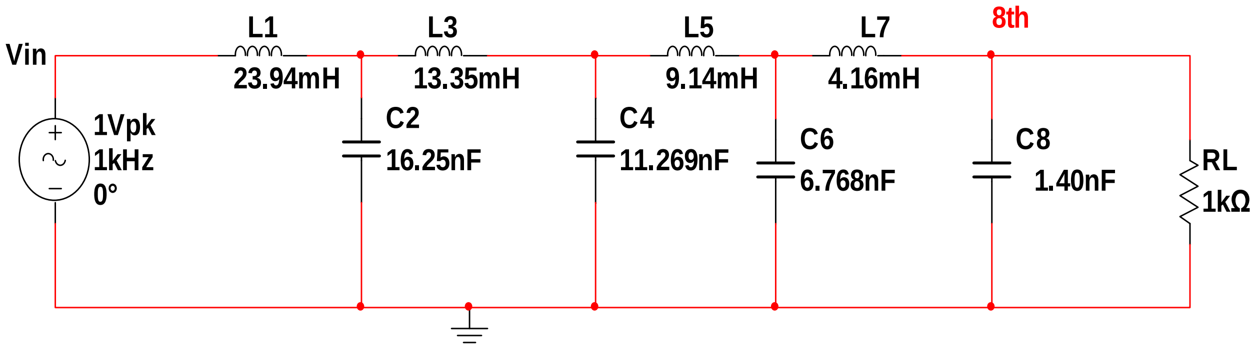


Fig. 14 8th order Bessel passive low pass filter.

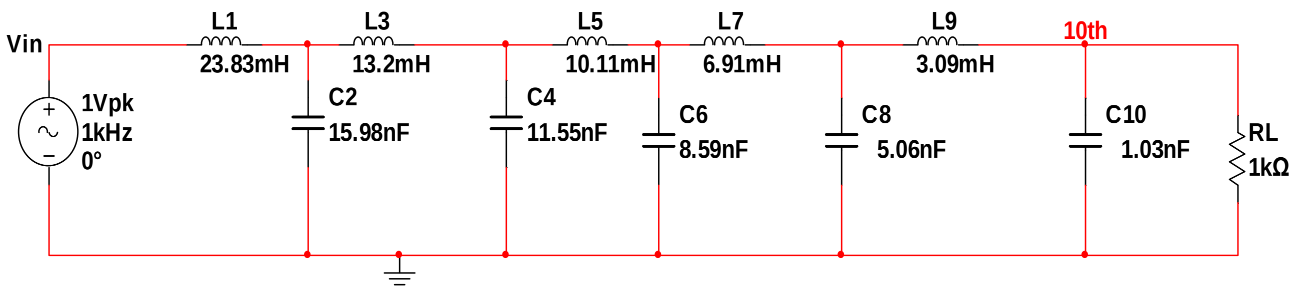
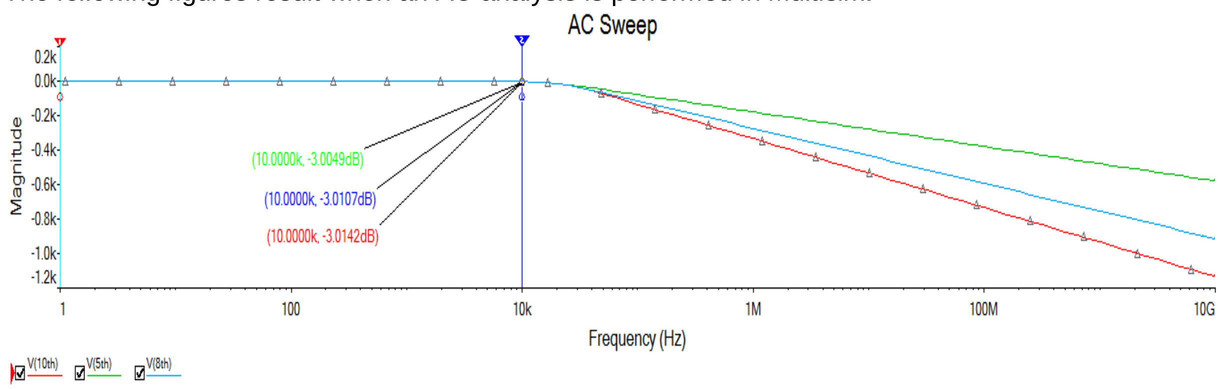
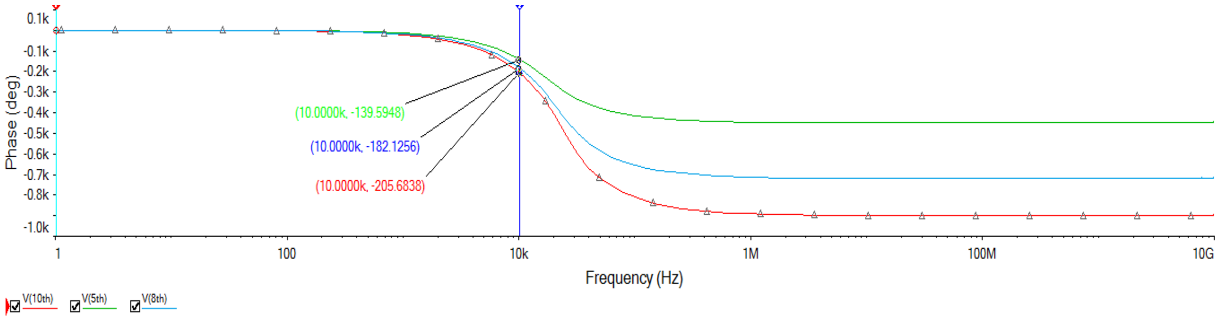


Fig. 15 10th order Bessel passive low pass filter.

The following figures result when an AC analysis is performed in Multisim.



(a)



(b)

Fig. 16 (a) The magnitude and(b) the phase response of 5th,8th,10th order Bessel low pass filter

The results obtained from above bode plots are shown in table 3. The following remarks are drawn from table 3.

-There are errors in the roll-off compared to theoretical value where it should be$-n \times 6\,\mathrm{dB/octave}$.

-The phase response around the cut-off frequency is increased linearly with frequency.

Table 3 Comparison between Bessel responses with different orders.

type	Order	f_c gain (dB)		f_c phase (C°)	Roll-off Graphically dB /octave		Roll-off experimentally dB /octave	
Low pass	**5**	**3.00**		**-139.59°**	**-14.19**		**-30**	
	8	**3.01**		**-182.12°**	**-13.68**		**-48**	
	10	**3.01**		**-205.68°**	**-13.15**		**-60**	
High pass	**5**	**3.01**		**-220.93°**	**79.19**		**30**	
	8	**3.01**		**-537.76°**	**114.41**		**48**	
	10	**3.01**		**-514.18°**	**134.93**		**60**	
Band pass	**5**	**3.03**	**3.17**	**-359.77°**	**72.49**	**-72.42**	**30**	**-30**
	8	**3.01**	**3.38**	**-718.47°**	**103.81**	**-104.43**	**48**	**-48**
	10	**3.02**	**3.15**	**-719.74°**	**121.73**	**-121.56**	**60**	**-60**

Comparaison Between Butterworth, Chebychev And Bessel Filters

Depending on what obtained earlier from section.2.2.1, section.2.2.2 and section.2.2.3, and concentrated on low pass filter type as a basis for all filters ,then circulated to other types, these points can be distinguished:

A. Magnitude Response

- Hardware required for similar order filter is same irrespective of the type. The increase in order indicates increase in hardware too. This increases the complexity of the design and the production cost too.
- The Chebyshev characteristic has a steeper roll-off near the cutoff frequency when compared to the Butterworth. Though the monotonicity in the pass band is compromised. This means that the Chebyshev filter for the same order attenuates or rejects frequencies at the stop band in a better way than the Butterworth filter because of sudden rise in attenuation immediately beyond the cutoff point. Hence, a same order Chebyshev low-pass filter will work more effectively than a Butterworth low-pass filter in disposing unwanted frequencies but, if the Butterworth filters maybe the better choice when a ripple-less and maximally flat response is desired. On the other hand, The amount of pass band ripple is one of the parameters used in specifying a Chebyshev filter.
- The Bessel response is smooth in the pass band, and attenuation rises smoothly in the stop-band. the stop-band attenuation increases very slowly until the signal frequency is serval time higher than the cutoff point, because of this the Bessel response does not have sufficient attenuation at a frequency ratio of two, no matter how high the filter order.

- Also the Chebyshev filter has a higher decrease in magnitude response with the increase in frequency than Butterworth. So, the derivative of Chebyshev's gain will be more negative than Butterworth filter and Bessel of course.

B. Phase Response And Group Delay

- ✓ The Chebychev response has a disadvantage in the time domain; its group delay has a greater peak level near the pass band edge than the Butterworth response.

Also, there are ripples in the group delay that make equalization with all-pass filters more difficult than in the Butterworth case.

- ✓ The Butterworth has a group delay that is frequency dependent; it increase with frequency and reaches a peak value close to the cutoff point.

In Bessel filter, all frequencies within the pass band, relative to the input, the phase of the output signal change in proportion to the applied frequency. So, Bessel is special in that, it introduces an almost constant delay.

4. ACTIVE FILTER DESIGN

Filters can be constructed in a multitude of ways. Combinations of capacitors, resistors, and operational amplifiers, have been used effectively for many years to produce reliable and functional filters. Just as there are a number of different elements from which a filter can be made, there are a number of different configurations those elements can be arranged to produce virtually identical results. The two architecturally similar designs will be used to design different types of filters with different responses Butterworth, Chebychev and Bessel are Sallen-Key filters and multiple feedback MFB filters which have both proven to be very reliable and stable filter designs [14].

The Sallen- Key filter and multiple feedbacks provides a second-order transfer function. High-order filters can be produced by cascading second-order sections. Odd-order filters can be produced by using a series of second-order sections and then adding a first-order section at the end.

Active filter design

A. Butterworth filter

The task is to design 6^{th} order active low pass filter with f_c=10KHz

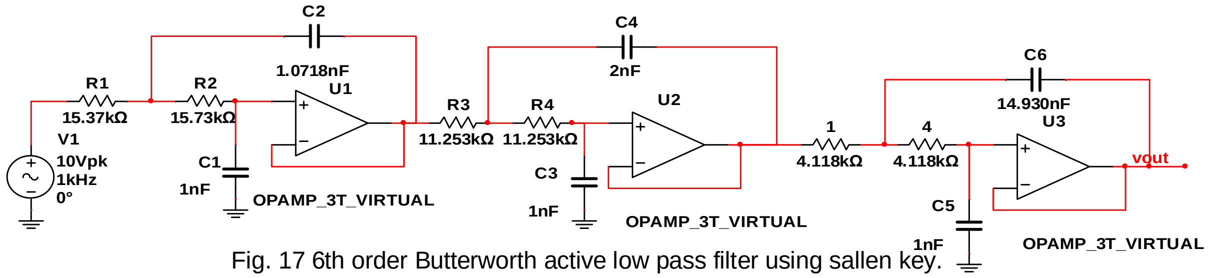


Fig. 17 6th order Butterworth active low pass filter using sallen key.

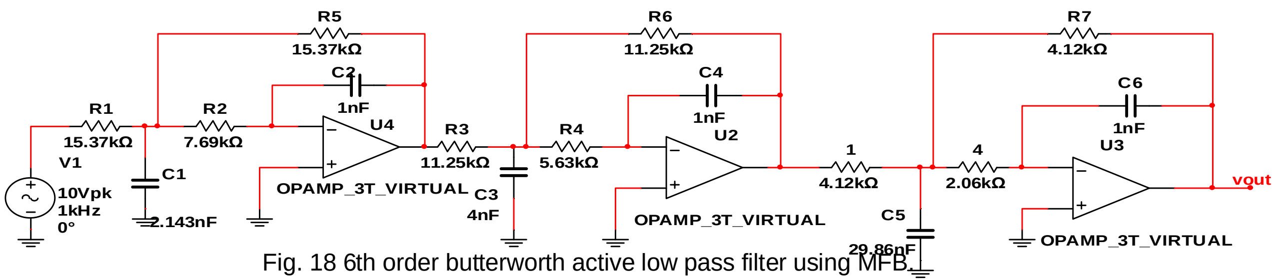
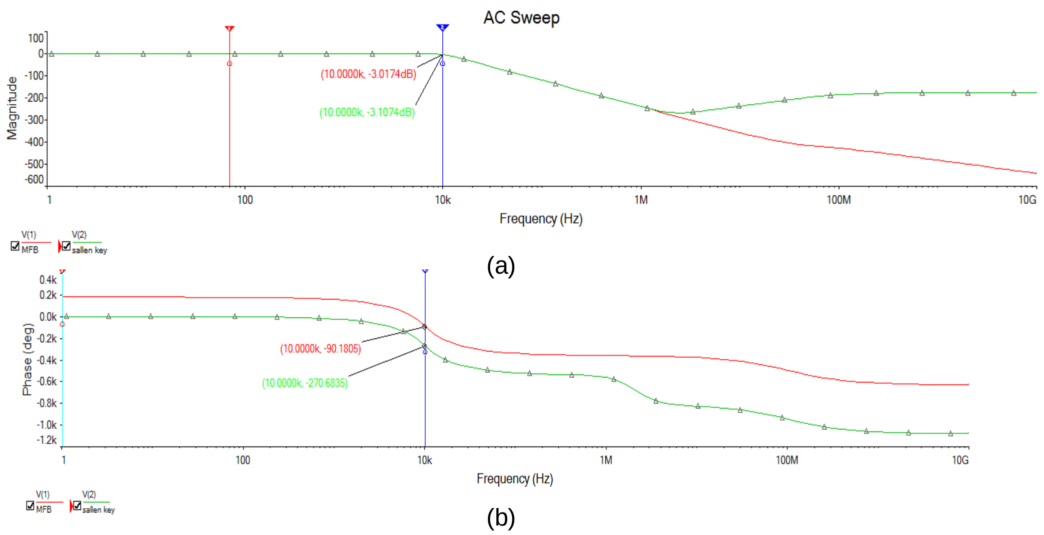


Fig. 18 6th order butterworth active low pass filter using MFB.

The previous circuits are simulated using AC analysis, the obtained bode plots are:



(b)

Fig. 19 (a) The magnitude and (b) the phase response for 6th order Butterworth active low pass filter using Sallen- key and MFB.

B. Chebyshev filter

The task is to design 6thorder active low pass filter with f_c=10KHz.

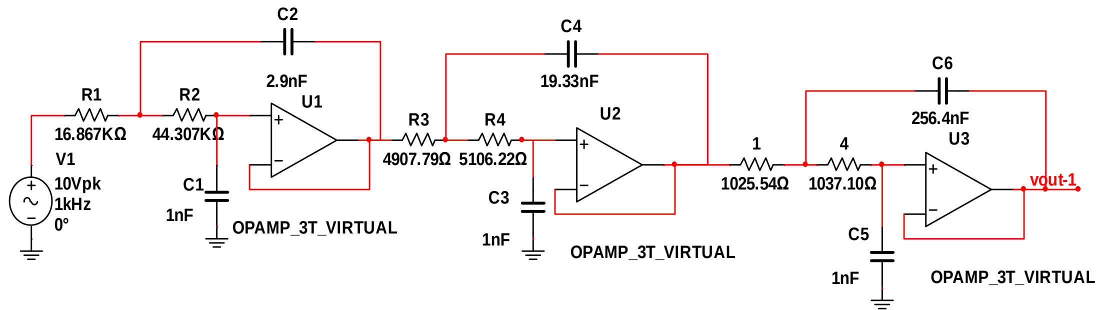


Fig. 20 6th order Chebychev active low pass filter using Sallen- Key.

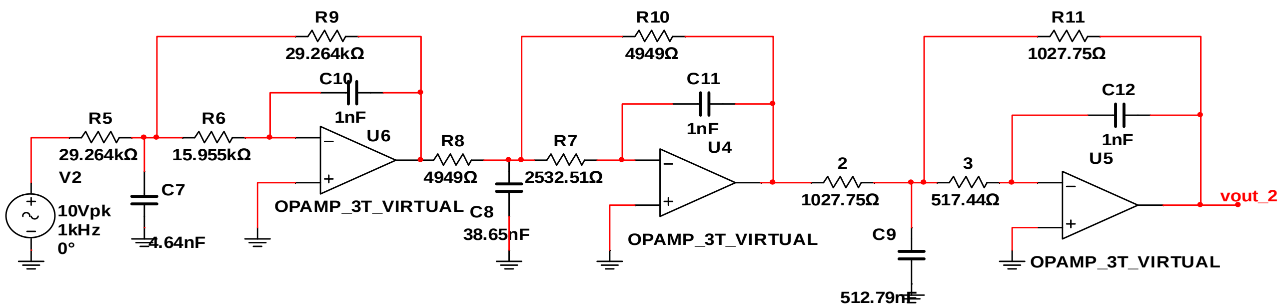
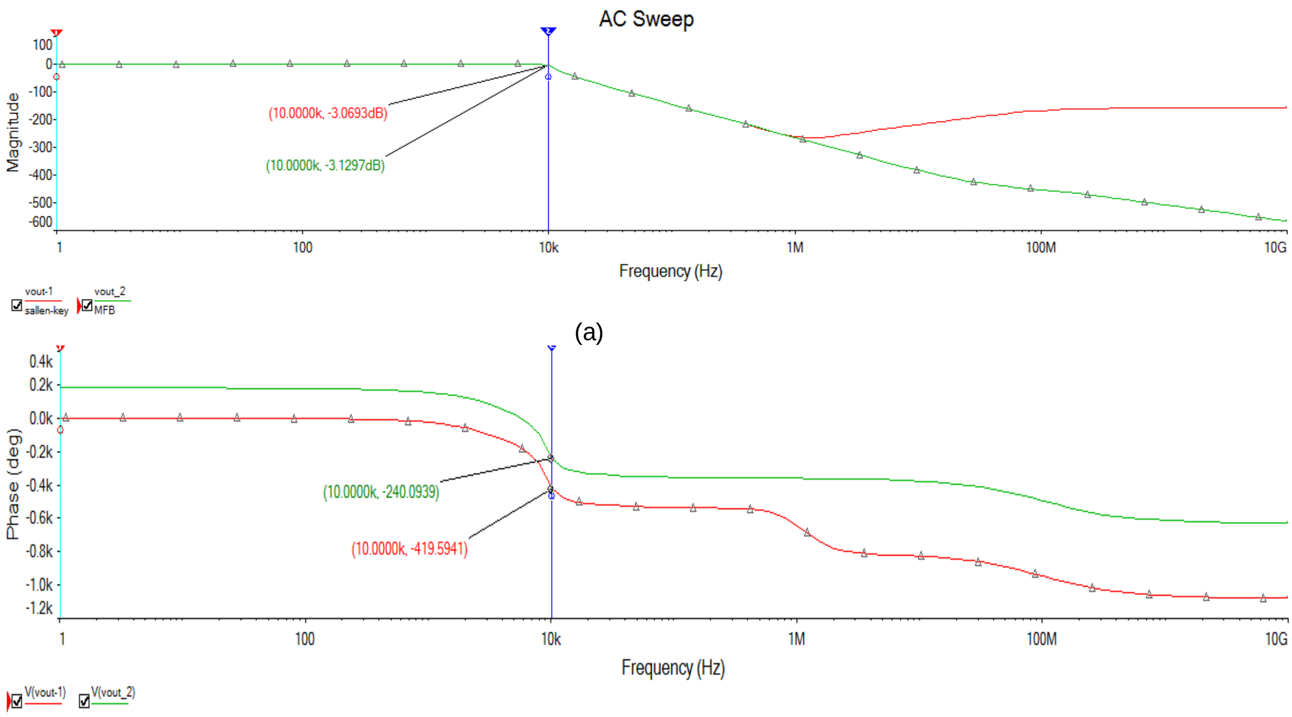


Fig. 21 6th order chebychev active low pass filter using MFB.

The above circuits are simulated using AC analysis, the obtained bode plots are:



(a)

(b)

Fig.22 (a) The magnitude and (b) the phase response for 4th order Chebyshev active band pass filter using sallen key and MFB.

C. Bessel filter

The task is to design 6[th] order active low pass filter with f_c=10KHz (see APPENDIX B)

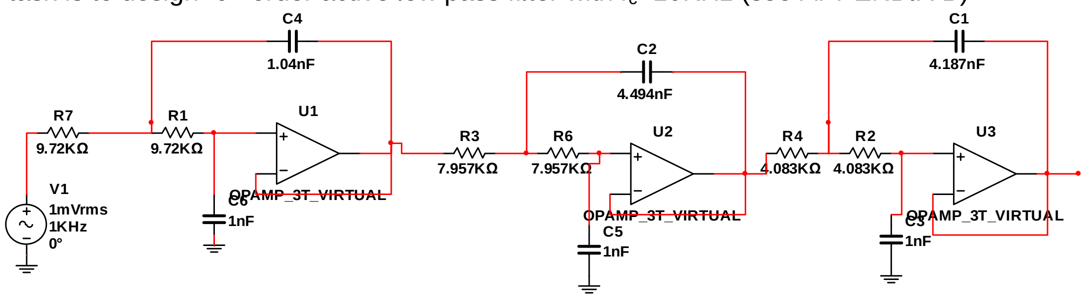


Fig. 23 6th order Bessel active low pass filter using sallen key.

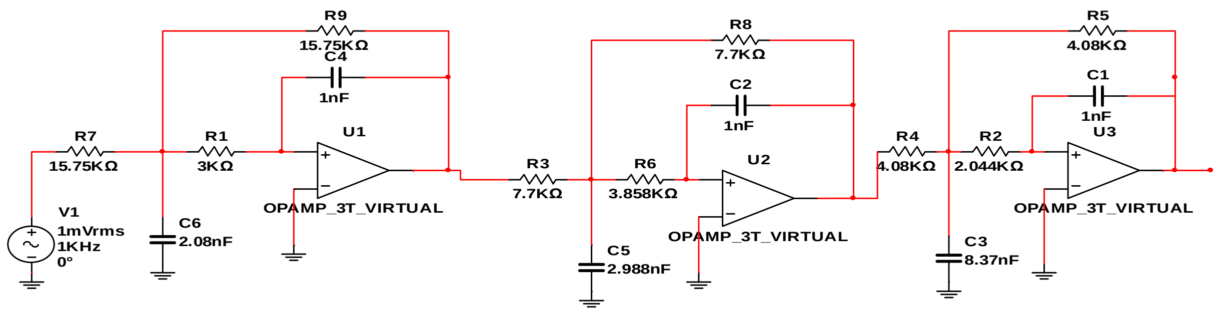


Fig. 24 6th order Bessel active low pass filter using MFB.

The above circuits are simulated using AC analysis, the obtained bode plots are:

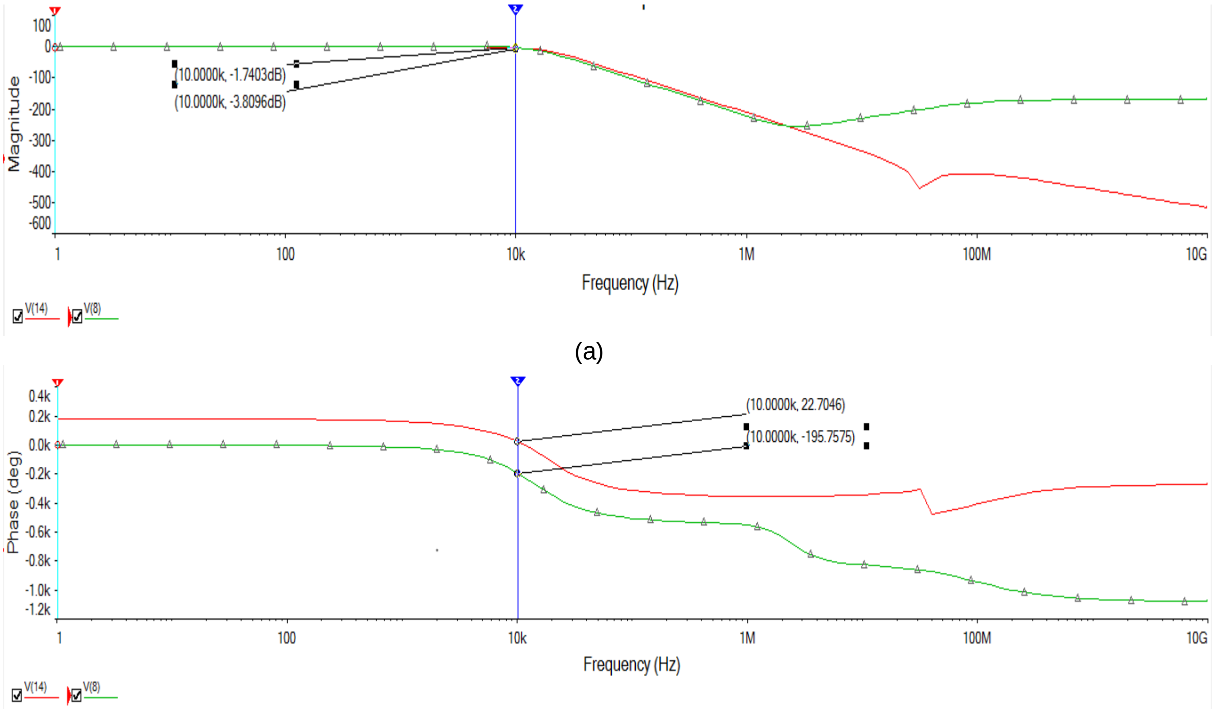


Fig. 25 (a) The magnitude and (b) the phase response for order Bessel active low pass filter using Sallen-Key and MFB.

Comparaison Between Sallen –Key And Multiple Feedback Topologies

According to the results obtained, the followings points can be determined:

- In terms of the sign orientation of these two filters, the Sallen-Key filter produces a positive voltage from input to output without changing the sign. An MFB filter changes a positive input voltage into a negative voltage at the output of the filter. This difference provides the system designer added flexibility.
- Multiple feedbacks more complicated and required more components.
- Multiple feedbacks is faster than sallen-key according to the bode plots.

For the advantages and disadvantages of each topology can be simplified in the following table:

Table 4 Advantages and disadvantages of sallen-key and multiple feedback.

	Advantages	Disadvantages
Sallen key	Not sensitive to component variation at unity gain	High-frequency response limited by the frequency response of the amplifier
MFB	MFB Less sensitive to component variations and superior high frequency response	Less simplifications available to ease design

Active Filters Versus Passive Filters

Table 5 Comparaison between active filters versus passive filters.

Frequency limitations	-passive filters have no frequency limitation while active filters have limitation due to active elements (dealing with very low frequencies). At sub-audio frequencies, LC filter designs require high values of inductance and capacitance along with their associated bulk. Active filters are more practical because they can be designed at higher impedance levels so that capacitor magnitudes are reduced.
Size considerations	-Active filters are generally smaller than their LC counterparts since inductors are not required. -Only active filters use elements like op-amps and transistors, which are active elements.

Cost	-Passive filters are relatively cheaper than active filters.
Ease of Adjustment	-In critical LC filters, tuned circuits require adjustment to specific resonances. Capacitors cannot be made variable unless they are below a few hundred micro farads.Inductors, however, can easily be adjusted.
Stages and stability	- Active filter has priority that each stage is independent from the others, so it is designed using pole and zero location which are determined from the frequency response's transfer function. In contrast, this is not possible in passive filter designs because all the components interact with each other. -passive filters have a better stability and can withstand large currents.
Gain	in active filter the signal can be amplified and filtered in same time by modify the gain of op-amp, in contract ,in passive filter it can not.

5. CONCLUSION

This work focused on providing a presentation of characteristics of analog filters with their different classes passive and the active as well as the way they can be designed according to specific rules. And the coefficients related to the selected response if it is Butterworth, Bessel or Chebychev; the work was designed and simulated with MULTISIM software.

The world of filter design is often thought of as black magic because of the myriad of configurations, unique terminology, and complex equations. But by respecting rules and applying them, the half of this magic is disappeared; in contrast, using experiment and observation, this magic will has no effect and this project proved that.

This project had a strong influence in developing our skills in the communication field, where the filter play important role to keep the signal from splashing energy into adjacent channels and conversely protect the user band from unwanted signals and noise from adjacent channels. Exploring the MULTISIM software helped us to design the different types of passive filter with different order to see the characteristics of different responses selected (Butterworth, Chebychev and Bessel) and the effects of increasing the order of magnitude and phase responses .most of the results obtained are consistent with the filter theories. The use of MULTISIM is not limited to that only, but it is used also to compare the two topologies Sallen-Key and multiple feedbacks which are utilized to create active filter in case of low pass, high pass and band pass with different responses .And finally, and according to the results obtained previously, the difference between the active filter and passive filter became apparent.

It is clear that engineers must weigh the benefits of passive and active filtering methods in each design. Cost, efficiency, ease of manipulation, and other factors come into play in these decisions. We hope that the knowledge that we have gained in this project will help us to make the right filtering decisions as we develop our engineering skills.

References

[1] Kerry lacanette, ''A Basic introduction to Filters-Active, Passive and Switched-Capacitor", National semiconductor Application Note 779 April 1996.
[2] A. Antoniou,"Digital Filters: Analysis, Design, and Applications", NY: McGraw-Hill, 1993 New York.
[3] Larry D.Paarmann" Design And Analysis Of Analog Filters,A Signal Processing Perspective".
Kluwer Academic Publishers, 2001.
[4] Huelsman, L.P. (1993). Active and Passive Analog Filter Design: An Introduction, McGraw-Hill, New York.
[5] James E. Brittain, "The Introduction of the Loading Coil: George A. Campbell and Michael I. Pupin", Technology and Culture, Vol. 11, No. 1 (Jan., 1970), pp. 36–57, The Johns
[6] *Piloty, Hans (1957),* "Cauer, Wilhelm", Neue Deutsche Biographie *(NDB) (in German),* ***3****, Berlin: Duncker & Humblot, pp. 179–180.*
[7] Haykin, S. (1989). Modern Filters, Macmillan, New York.
[8] Thomasena Brenna"Hand book of Electric current and Electronics", leo Goldberg.revised Edition 2016.
[9] S. Winder, « Analog and digital filter design », 2nd edition, Elsevier, 2002.
[10] S. A. PACTITIS" ACTIVE FILTERS Theory and Design".
[11] S.Franko, Design with Operational Amplifiers and Analog Integrated Circuits, McGraw–Hill,1988.

[12]Sergio Franco, “Design with Operational Amplifier and Analog Integrated Circuits”, third edition, McGraw Hill 2003.
[13] Les Thede “Practical Analog and Digital Filter Design”, Artech House, Inc, 2004.
[14] Jim Karki, ” Active Low-Pass Filter Design”, Texas Instruments, 2000.