CDBA BASED FILTER DESIGNING AND ANALYSIS

DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE AWARD

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Candidate's Declaration

I, **Gaurav Aggarwal**, Roll No. **2K16/C&I/08**, student of **M. Tech (Control & Instrumentation)**, herewith declare that the dissertation entitled "**CDBA BASED FILTER DESIGNING AND ANALYSIS**", under the supervision of Mr. Ram Bhagat of Electrical Engineering Department, Delhi Technological University, in partial fulfilment of the need for the award of the degree of Master of Technology, has not been submitted elsewhere for the award of any degree.

I herewith solemnly and sincerely affirm that all the particulars declared above by me are true and correct to the best of my knowledge and belief.

Place: Delhi   **Gaurav Aggarwal**

Date: 20.07.2018   **2K16/C&I/08**

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Certificate

This is to certify that the dissertation entitled **"CDBA BASED FILTER DESIGNING AND ANALYSIS"** submitted by **Gaurav Aggarwal** in completion of major project dissertation for the master of Technology degree in **Control & Instrumentation** at Delhi Technological University is an authentic work carried out by her underneath my superintendence and guidance.

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Some types of filters are essential for the operation of many electronic circuits. It is Therefore it is in the interest of everyone involved in electronic circuit design to know how to develop filter circuits which are capable of meeting given specifications. Unfortunately, some in the electronics field are uncomfortable with the subject, because of lack of familiarity with it and the difficulty with the mathematics involved in a complex filter design. Also, the ladder filters which are passive in nature does not prove to be much effective. So, filters using active blocks like op amps, CFOA, OTA, CDBA and other blocks find a great importance these days. The lower order filters i.e. second and third order have high cut off frequencies and that is the reason higher order filters are designed. Higher order filters along with providing a lower cut off frequency also have response near to the ideal response. In this work this has been illustrated by designing filters starting from second order to fifth order.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Some types of filters are essential for the operation of a number of electronic circuits. Therefore, it is in the interest of everyone working in electronic circuit design to know how to develop filter circuits which are capable of meeting given specifications. Unfortunately, some people in the electronics field are sore with the subject, because of lack of knowledge with it and the effort with the mathematics involved in a composite design of filter.

1.2 FILTERS AND SIGNALS

In circuits, a filter is circuit that changes the amplitude and/or phase properties of any signal with regard to its frequency. A filter does add any new frequencies to the signal, and also will not change the component frequencies of the signal but changes the amplitude of some frequency parts and/or the phase relationships of those parts. Filters are generally used in electronics to bind signals in a particular frequency range and reject all the signals which are not in that frequency range. These types of filters have a gain depending on frequency of the signal. For example, there is a situation where a particular signal which is required having frequency f1 has been polluted with another unwanted signal having frequency f2. If the polluted signal passes through a circuit having very low gain at frequencyf2 as compared to frequency f1, the unwanted signal will be removed, and the desirous signal will remain. In this simple example, we are not worried about the gain of the filter at any frequency rather than frequencies f1 and f2. If f2 is properly removed compared to f1, the functioning of the filter can be considered acceptable. However, a filter gain can be mentioned at numerous different frequencies, or for a group of frequencies. As filters are well-defined by their frequency belongings on signals, it has sense that the greatest useful logical and graphical properties of filters also lie in the frequency domain. So, curves of

gain vs frequency and phase vs frequency are generally used to show filter features, and the most commonly-used tools are defined in the frequency domain. The frequency-domain performance of a filter is defined in terms of its transfer function or network function. This transfer function is the ratio of the Laplace transforms of its output signal and input signal. The transfer function H(s) of any filter can be written as:

$$H(s) = \frac{V_{OUT}(s)}{V_{IN}(s)} \tag{1.1}$$

where $V_{IN}(s)$ is the input signal voltage and $V_{OUT}(s)$ is the and output signal voltage and s being the complex frequncy variable.

Transfer function describes any filter's response to random input signal, but researchers are commonly concerned with its result on continuous time sinusoidal waves. The most significant is the magnitude of the transfer function expressed as a function of frequency, that indicates the result of filter on amplitudes of sine wave signals at numerous frequencies. By knowing transfer function magnitude (or gain) at every frequency helps us to decide how fine the filter can differentiate between signals at dissimilar frequencies. The transfer fuction magnitude vs freq. is known as the amplitude response or at times, specially in audio uses, the frequency response.

In the same way, phase response of a filter describes the quantity of phase shift produced in sine wave as a function of frequency. As a variation in phase of any signal represents a variation in time, the phase features of a filter become particularly significant when working with the complex signals where time relations between signal components at diverse frequencies are serious. On replacing variable s with jω (j is equal to $\sqrt{-1}$ and ω is the frequency in radians (2πf)), we can determine the filter's result on the magnitude and phase of the input signal.

The magnitude is defined as:

$$\det(H(j\omega) = \frac{V_{OUT}(j\omega)}{V_{IN}(j\omega)}) \tag{1.2}$$

and the phase is defined as:

$$\arg H(j\omega) = arg\frac{V_{OUT}(j\omega)}{V_{IN}(j\omega)} \tag{1.3}$$
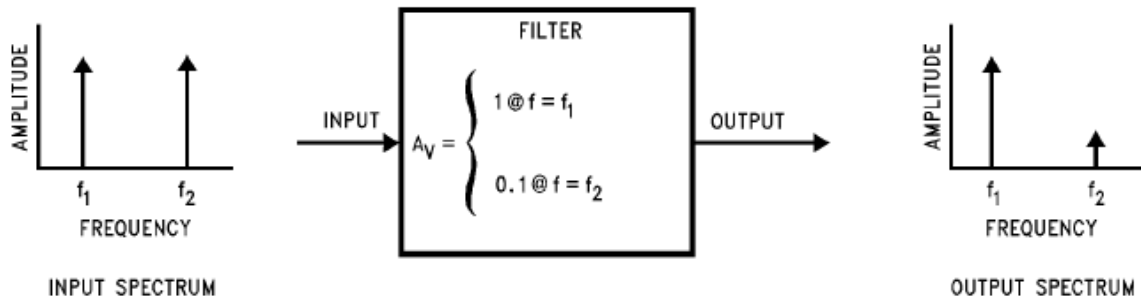
Fig. 1.1 Filter use to Decrease the Outcome of an Unwanted Signal at Frequency f2, though keeping wanted Signal at Frequency f1

1.3 THE BASIC TYPES FILTERS

1.3.1 BANDPASS FILTER

There exist five common filter types i.e. the bandpass filter, notch filter, low-pass filter, high-pass filter and all-pass filter. The amount of likely bandpass response properties are infinite but all of them have the similar basic form. Some examples of bandpass filter amplitude response curve are presented in Fig. 2. The curve in Fig.2(a) is called as an "ideal" bandpass filter response having absolutely fixed gain in the passband, zero gain outside the passband, and a sudden boundary between the two passbands. This characteristic of response is practically impossible to realize, but can be approached to variable degrees of correctness by actual filters. Curves 2(a) to 2(f) are samples of some bandpass responses which estimate the ideal curve with variable degrees of correctness. While a few bandpass responses are smooth, others are having ripple gain dissimilarities in their passbands. Some have ripple in their stopbands also. Stopband is defined as the series of frequencies in which undesired signals are stopped. Bandpass filters always have two stopbands i.e. one above the passband and one below the passband.

3
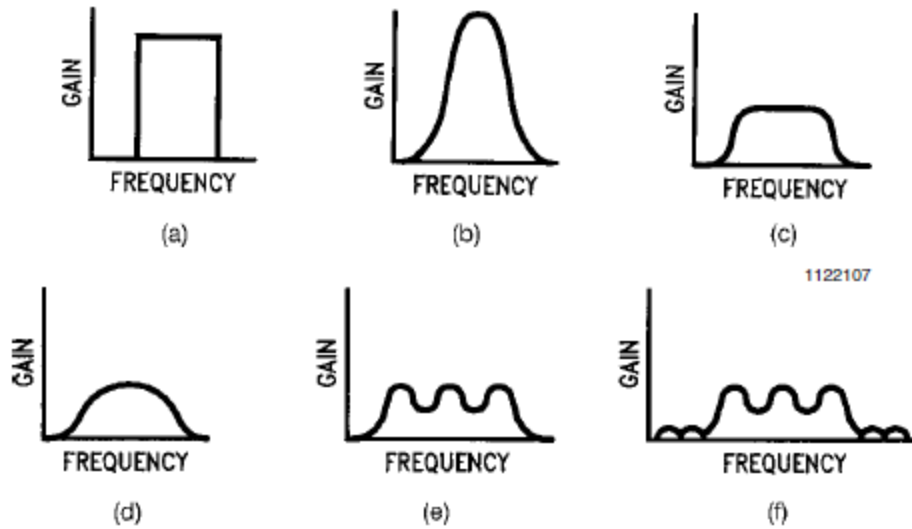
Fig. 1.2 Some examples of Bandpass Amplitude Response Curves

1.3.2 BAND-REJECT OR NOTCH FILTER

A filter having completely the opposite response of the bandpass filter is the notch or band reject filter. Band reject filters are useful in removing an undesired frequency from a signal, without touching other frequencies. Example of this band reject filter can be with an audio sequencer that is polluted by a 60 Hz power-line hum. A band reject filter having a cut off frequency of 60 Hz will remove the hum without affecting the audio signals.
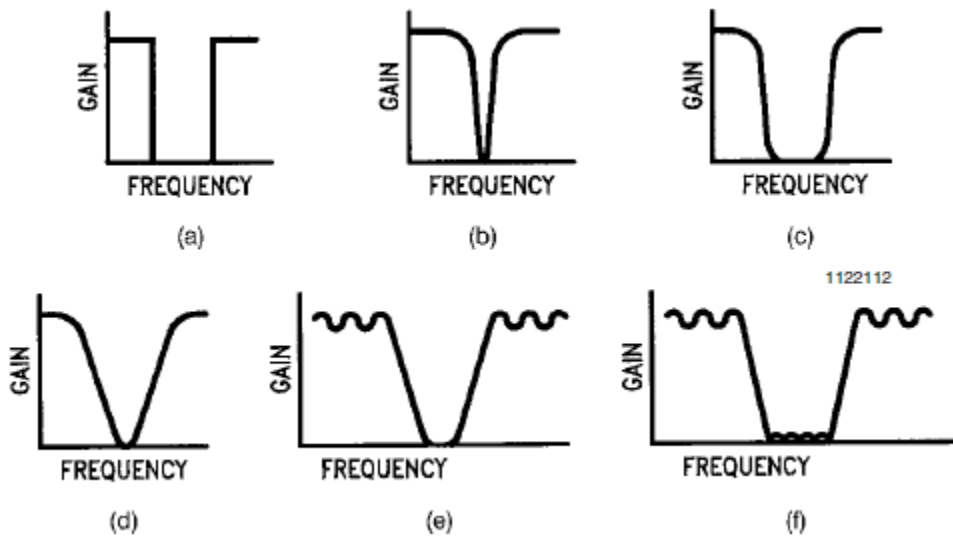
Fig.1.3 Some examples of Band Reject Filter Response Curves

1.3.3 LOW-PASS FILTER

Another filter type is a low-pass filter. A low-pass filter permits low frequency signals to pass, and discards signals of frequencies higher than the filter's crossover frequency. Low-pass filters are useful in rejecting components of high frequency from a signal. Example can be seen in a light-sensing tool having a photodiode. If levels of light are low, the photodiode output will be very slight thus letting it to be partly covered by the sensor noise and amplifier, whose spectrum can be extended to high frequencies. A low-pass filter placed at the amplifier output having cutoff frequency high adequate to let the wanted signal frequencies to pass, the complete noise can be removed.
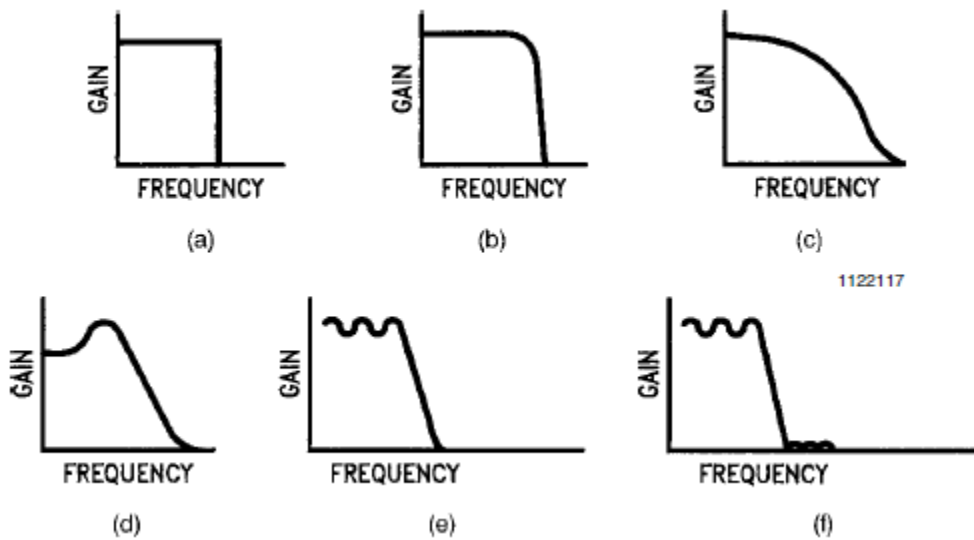
Fig.1.4 Some examples of Low-Pass Filter Response Curves

1.3.4 HIGH-PASS FILTER

The reverse of the low-pass filter is high-pass filter, which discards signals below its crossover frequency. High-pass find applications in needing the blocking of signals of low-frequency. One of the application is high reliability loudspeakers. Music comprises substantial energy in range from about 100 Hz to 2 kHz, but drivers of high-frequency gets damaged if audio signals of low frequency and insufficient energy appears at their input terminals. A high-pass among the broadband signal and tweeter input terminals can stop

program material of low frequency from arriving at the tweeter. In combination with a low-pass for the low-frequency driver, the high-pass is portion of what is identified as a "crossover network".
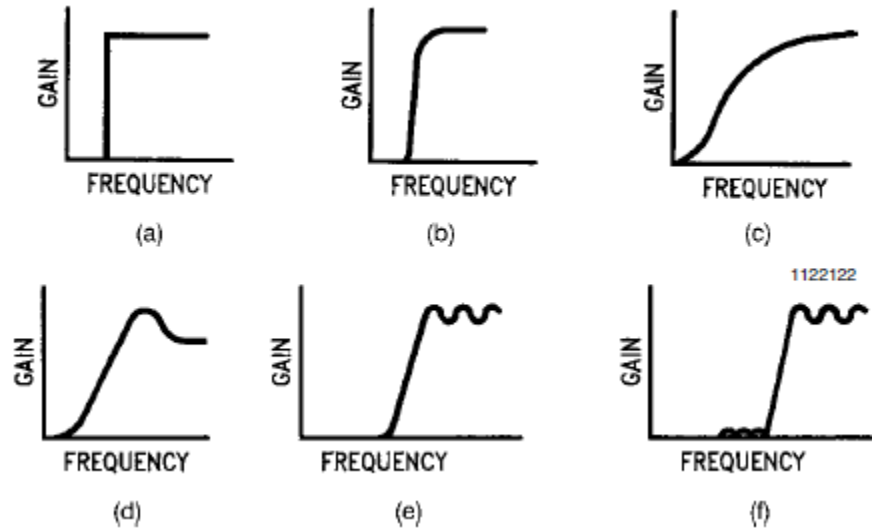
Fig.1.5 Some examples of High-Pass Filter Response Curves

1.3.5 ALL-PASS OR PHASE-SHIFT FILTER

The fifth filter response kind has zero effect on amplitude of the signal at distinct frequencies. In its place, its purpose is to alter the phase of the signal without touching its amplitude. This filter is called a phase shift or an all-pass filter. The result of a phase shift is illustrated in Fig.6. Two sine waves, one in dashed lines and the other having a solid line, are revealed. The curves are alike but the peaks as well as zero crossings of dashed curve befall at later periods than the solid curve. Thus, it can be said that the dashed curve has undertaken a delay time w.r.t the solid curve.
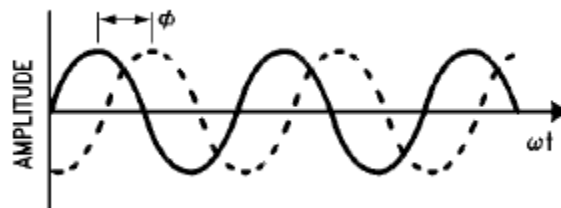
Fig.1.6 Two sine waves with phase difference θ.

1.4 ORGANIZATION OF THESIS

The thesis is organized as follows:

Chapter one presents a brief introduction on filters and its types. The uses and applications of the various types of filters is also described in this chapter. This chapter also consists of organization of the thesis.

Chapter two gives a literature review of all the references used to carry out the study.

Chapter three gives a detailed description of the components used i.e. the CFOA and CDBA. This chapter also describes the CDBA implementation from CFOA.

Chapter four presents the inductor simulation using CDBA along with its circuit diagram and graph.

Chapter five presents the designing of various order filters. The circuit diagrams, PSPICE Code and output waveforms of various order filters are presented in the chapter.

Chapter six gives a conclusion of the complete study. Also, it mentions the future scopes of the study.

CHAPTER 2
LITERATURE REVIEW

2.1 Literature review:

R. SENANI [1] presents the simulation of a lossless floating inductor (LFI) using only two op amps rather than the previous papers which used three or four op amps for the simulation of LFI. Also, the circuits described can have further equivalent realizations (given the same number, i.e. two, of op-amps and RC components).

M. Koksal, S.E. Oner and M. Sagbas [2] Presents the simulation of second order multi-function filter using a single CDBA and a total of four/five RC components. The paper also includes the non-ideality effects and sensitivity analysis as well as simulation and experimental verifications.

Kunal Gupta, Priyanka Gupta, Neeta Pandey and Rajeshwari Pandey [3] Presents the CDBA implementation using CFOA. Further it presents the implementation of an instrumentation amplifier using two CDBA and two resistors. The circuit presented is simulated using PSPICE with CFOA based implementation of CDBA.

U. Çam, O. Çiçekoğlu, and H. Kuntman [4] Presents the designing of a novel lossless floating immitance using four terminal floating nullors (FTFNs). No problem of component matching is observed in the circuit. To verify the proper functioning of the inductor it is used in a fifth order elliptic filter.

J.K. Pathak, A.K. Singh & R. Senani [5] Presented a new lossy inductor using a single CDBA and only three passive components i.e. two resistors and one grounded capacitor. The new inductor is then compared with the previously known inductors. Further the inductor is used in designing a quadrature oscillator and the results are verified using PSPICE.

K.K. Abdalla, D.R. Bhaskar and R. Senani [6] Presents the simulation of a new universal filter having a single input and multiple outputs using three dual output current conveyors (DOCCII) and five grounded passive elements which can be used to design all the five basic filters i.e. the low pass, high pass, band pass, band stop and all pass. The working of the circuit is verified using PSPICE.

W. Tangsrirat, K. Klahan, T. Dumawipata & W. Surakampontorn [7] Firstly provides a design methodology of a CDBA using low voltage NMOS. The design is explained properly with diagrams and equations. Then the CDBA is used in designing a third order low pass filter. The results of the filter designed the verified using PSPICE.

W. Tangsrirat, K. Klahan, T. Dumawipata & W. Surakampontorn [8] presents a new circuit using a single current conveyor of second generation (CCII), a single capacitor and two resistors for the simulation of a lossy frequency independent floating inductance without any cancellation of terms.

C. Acar and S. Özoğuz [9] presents a detailed step by step signal flow graph design approach of CDBA. CFOA design of the CDBA is also described with the circuit explained using the low frequency equivalent of CDBA.

Z. Czarnul [10] presents a new NOS circuit with four matched MOS transistors which allows the design of RC filter structures. Also, integrators, summers and lossy integrator circuits are designed using a single op-amp.

S. Takagi, Z. Czarnul, T. Iida, and N. Fujii [11] proposes the generalization of MOS resistive circuits (MRC's) having m inputs and n outputs. The application of this generalized MRC is then presented in variable gain amplifiers, integrators and filters.

Andrii Zazerin, Anatolii Orlov & Oleksandr Bogdan [12] presents the use of active elements like gyrator to imitate simple LC circuits employed in low pass filters, high pass

filters and band pass filters. Hence by this approach a passive filter is converted into an active filter.

A. Toker, S. Özoğuz, O. Cicekoglu, and C. Acar [13] presents the realization of two types of first order current mode all pass filters using only one active element and minimum no of passive components with the active element being a CDBA.

C., Toumazou, F.J., Lidgey and D.G., Haigh [14] explains in detail the construction and working of the current mirrors, current reflectors, current conveyors and current sources. Bipolar current mirrors are also explained in detail with their output waveforms.

U., Kumar, and S.K., Shukla [15] explains the use of current rather than voltage as the active parameter which can result in higher usable gain, accuracy and bandwidth due to reduced voltage excursion at sensitive nodes. A current-mode approach is not just restricted to current processing, but also offers certain important advantages when interfaced to voltage-mode circuits.

Jiun-Wei Horng [16] describes three current-mode universal biquadratic filters each with five input terminals and one output terminal. The first proposed circuit uses three multi-output second-generation current conveyors, two grounded capacitors and three resistors. The second proposed circuit uses three multi-output second-generation current conveyors, two grounded capacitors and two resistors. The third proposed circuit uses three multi-output second-generation current conveyors, two grounded capacitors and three grounded resistors. Each of the proposed circuits can get five kinds of filter functions by using only one current input signal.

S. O¨ zcana, A. Tokera, C. Acara, H. Kuntmana, O. C¸ ic¸ekog¸lub [17] The basic aim of this paper is to present several of a newly introduced current differencing buffered amplifier (CDBA)-based oscillator topologies achieving orthogonal control of oscillation condition b and oscillation frequency ω_0 with a reduced number of components. A single resistor is used for adjusting their frequency, and further, this resistance is grounded, which

is important from the integration point of view. Taking these considerations into account they are very suitable for voltage-controlled oscillator (VCO) implementation.

Saleha Bano, Ghous Bakhsh Narejo, S.M. Usman Ali Shah [18] presents a bilinear (first order) current mode universal filter using a single current differencing buffered amplifier (CDBA). The main feature of this proposed circuit configuration is that it can provide all the filter responses i.e. low-pass, high-pass and all-pass responses. It uses single CDBA and minimum passive components that is one resistor and one grounded capacitor only to realize all the filter responses. The proposed circuit topology is verified by simulating the circuit on PSPICE.

M. Sagbas and M. Koksal [19] presents Four new filter configurations which employ single DOCCII. The proposed filters operate in current mode (CM). The filters are canonical in the number of capacitors (2) and resistors (2). Depending on the choice of the type offour passive components, each filter structure can realize either the band-pass, low-pass or high-pass responses all at high impedance outputs. No difference terms appears in the denominators of the transfer functions. Therefore, the filters are always stable. Further, they enjoy low sensitivities. The validity of each filter is verified through PSpice simulations.

Muhammad Talha, Saleha Bano, Talat Altaf [20] presents a versatile first order current mode CDBA based universal filter. The filter is capable of realizing all the filter responses such as low-pass, high-pass and all-pass responses. It also works as a unity gain non-inverting amplifier. It uses a single current mode input to realize all the filter responses. The components required in this proposed circuit is one active and three passive components i.e. one CDBA, one grounded resistor and two grounded capacitors in which one is a virtually grounded capacitor. It is found that the passive sensitivities are very low. The theoretical results are verified by simulating the circuit in PSPICE software.

Ersin Alaybeyoglu, Arda Güney, Mustafa Altun, and Hakan Kuntman [21] In current mode analog circuit design, current differencing unit is widely used at the input stage of the current mode analog building blocks. The low input impedance current differencing unit is excellent for current mode circuit realization. In the current study, the positive feedback is used for reducing the input impedance of current differencing unit. The proposed current differencing unit is tested at the input stage of the ZC-CDBA (Z copy current differencing buffered amplifier) recently published as a

current mode analog building block. The proposed circuit for ZC-CDBA is verified with the KHN analog filter application. The circuit simulations are verified by using SPICE parameters.

Cem CAKIR, Oguzhan CICEKOGLU [22] presents a new realization of a low voltage, high-performance CMOS current-differencing buffered amplifier (CDBA). The proposed circuit can be operated with the power supplies down to ±0.75V and it also consumes less power than its counterparts that have been reported so far. Moreover this CDBA has good voltage and current accuracies. UMC 0.18 μm CMOS technology is used for the simulations. The performance of the CDBA is verified with the HSPICE. To show the performance of the circuit, a second-order current-mode notch filter is selected from the literature. The results are in good agreement with the theoretical ones.

S.E. Oner, M. Koksal and M. Sagbas [23] presents three new electronically tunable filter configurations which employ only one current controlled differencing buffered amplifier (CDBA). The proposed filters operate in voltage-mode (VM) and use three passive elements. Each proposed filter can realize one of the band-pass, low-pass or high-pass responses. The parameters wo and wo/Q enjoy independent electronic tunability. Effect of the non-idealities and the sensitivity analysis of the proposed filter are also examined.

Shahram Minaei, Erkan Yuce [24] presents a current-mode circuit for realizing high-order low-pass (LP) and high-pass (HP) filter responses is presented. The proposed circuit uses dual output second generation current controlled conveyors (DO-CCCII) and only grounded capacitor. The coefficients of the filter transfer functions (TFs) can be tuned electronically via external biasing currents of the active elements. Also, LP and HP filters are connected in cascade to obtain a band-pass (BP) filter. Simulations are performed for fourth-order and eighth-order filter responses to illustrate the frequency domain performance of the circuit.

Priyanka Gupta, Rajeshwari Pandey, Neeta Pandey [25] presents A voltage mode multifunction second order filter topology employing single current differencing buffered amplifier (CDBA). This topology can be used to synthesize low pass (LP), band pass (BP), and high pass (HP) filter functions with appropriate admittance choices. This configuration

is a suitable choice for implementing filters with high quality factor. The demonstration of the proposed configuration is done through PSPICE simulations. The CDBA block is realized using CMOS 0.18μm technology. The simulation results are found in close agreement with the theoretical results.

U. Cam [26] presents a novel current-mode second-order notch filter configuration. The presented circuit uses single current differencing buffered amplifier (CDBA) and minimum passive components. High output impedance of the proposed filter enables the circuit to be cascaded without requiring any impedance matching device. It has also low passive sensitivities. The theoretical results are verified with PSPICE.

Koushick Mathur, Palaniandavar Venkateswaran, Rabindranath Nandi [27] presents a new current feedback amplifier (CFA) based dual-input differentiator (DID) design with grounded capacitor; its time constant (τo) is independently tunable by a single resistor. The proposed circuit yields a true DID function with ideal CFA devices. Analysis with nonideal devices having parasitic capacitance (Cp) shows extremely low but finite phase error (θe); suitable design θe could be minimized significantly. The design is practically active-insensitive relative to port mismatch errors (ε) of the active element. An all pass phase shifter circuit implementation is derived with slight modification of the differentiator. Satisfactory experimental results had been verified on typical wave processing and phase-selective filter design applications.

Shen-luan Liu [28] shows a new configuration for high input impedance bandpass. Lowpass and high pass filters with low component spread using IWCI current-feedback amplifiers is presented. It has the following features: orthogonal control of the natural frequency and quality factor by grounded resistors or capacitors, simple conversion into a voltage controlled filter, minimum active components, low active and passive sensitivities, low component spread suitable for high-Q applications and low output impedance. Experimental results are given to demonstrate the feasibility of the proposed circuits.

Pavel Brandstetter, Lukas Klein [29] The main target of the paper is to theoretically and practically demonstrate the versatility of a commercially available non-inverting positive second generation current conveyor (CCII +). The paper discusses the current conveyors theory and selected functional block structures with CCII, which represent well-known modern active elements. Highpass and low-pass filter of second order were proposed and practically implemented with the circuit structure with CCII+ functionally replacing operational amplifier. Behavior of proposed circuits was verified by OrCAD PSpice simulations. Realization of frequency filters were tested on a specialized measuring workplace for the analysis of analog circuits using vector network analyzer R&S ® ZVB4.

J.A. Svoboda [30] describes a procedure for synthesizing active networks in view of recent interest in current conveyors. It is seen that Hilberman's work provides a general procedure for designing RC current conveyor networks to have a specified voltage transfer function, an example is considered in which the current conveyors are implemented using the AD844.

C. Acar [31] presents a general synthesis method for the realization of an nth-order voltage transfer function using an active RC circuit comprising a commercially available active component, AD844, which is equivalent to the combination of a second-generation current conveyor having a gain of + I (CCIIt) and a unity gain voltage buffer. The use of this active component simplifies the implementation, making the proposed circuit attractive.

Timothy A Brown [32] presents the designing and simulation of a number of higher order Butterworth and Chebyshev filters along with their simulation results.

Rolf Schaumann and Mac E. Van Valkenburg [33] the book explains a lot about deigning of ladder filters. These ladder filters are then used to design higher order filters. It helped me a lot in deriving the transfer functions of various higher order filters.

M. Jagiela* and B.M. Wilamowski [34] raises issues concerning the synthesis of

ladder reactance analog filter. In all existing algorithms of synthesis of such filters it is assumed that the reactance elements are ideal ones. Since actual reactance elements are lossy, which means the Q-factor has a finite value, the frequency response of real filters differs widely from the desired frequency response, assumed before designing the filter. In this article, a new approach to the synthesis of reactance ladder filters have been introduced. In this approach, the lossiness of reactance elements is taken into consideration during the synthesis process. This method allows to design a ladder filter with desired frequency response with the use of lossy capacitors and what is more important, lossy inductors.

Pradeep Dandamudi, Timothy A. Brown, Xing Wu, Marcin Jagiela, and Bogdan M. Wilamowski [35] The purpose of this study is to redesign filters in such way that, despite of non-ideal elements, the filter characteristics is very close to ideal ones. This can be done by changing values of Ls and Cs in such way that the filter regains close to ideal characteristics. As a result of this approach, a lossy filter obtained in this way can have exactly the same frequency response as the ideal filter, designed using the classical algorithm.

Robert D. Koller and Bogdan Wilamowski, [36] A software package for advanced analog filter design and simulation has been developed. This new package has many features, including polynomial manipulation, transfer function design, and post design simulation. This paper includes a description of LADDER, along with some example filter designs, which help demonstrate LADDER'S usefulness in education.

R. D. Koller, B. M. Wilamowski [37] Ladder filter structures are important for filter designs with modern circuit elements. This paper presents a modern algorithm for ladder filter synthesis. This method is general, and only a few differences in the continued fractio expansion are all that separates a Butterworth synthesis from a Cauer-Elliptic synthesis.
The generality of this approach also allows the synthesis of transfer functions designed by non-traditional methods. In addition, the algorithm generates many possible circuit implementations for transfer functions with zeros.

Alexander J. Casson and Esther Rodriguez-Villegas [38] This paper presents a methodology for the design of doubly terminated LC ladder structures making use of the symbolic maths engines in programs such as MATLAB and MAPLE. The methodology is explained through the detailed synthesis of an example 7th order bandpass filter transfer function for use in electroencephalogram (EEG) analysis.

Raj Senani, D. R. Bhaskar & A. K. Singh [39] This book describes a variety of current feedback operational amplifier (CFOA) architectures and their applications in analog signal processing/generation. Coverage includes a comprehensive survey of commercially available, off-the-shelf integrated circuit CFOAs, as well as recent advances made on the design of CFOAs, including design innovations for bipolar and CMOS CFOAs.

2.2 Conclusion

This chapter describes an extensive literature review on filter designing using active building clocks. It also discusses about the internal structure and construction of various building blocks.

CHAPTER 3

DESCRIPTION OF COMPONENTS

3.1 CURRENT FEEDBACK OPERATIONAL AMPLIFIER (CFOA)

The current feedback operational amplifier (CFOA or CFA) is a kind of an electronic amplifier having inverting input sensitive to current and not to voltage like a normal voltage-feedback operational amplifier (VFA). CFA are produced having the same pin configuration as that of a VFA thus letting the two kinds to be exchanged without doing the wiring again provided the design of circuit allows to do so. In normal configurations, like linear amplifiers, a CFOA can be employed in place of a VFOA without any circuit alterations while in some cases like integrators, a completely changed circuit design is essential.

 CFOA started fascinating consideration of the analog circuit researchers and designers as it was understood that anyone can develop amplifiers showing characteristics having the most important withdrawal from the characteristics showed by the renowned VFOA-based designs in a manner that circuits based on CFA could have variable-gain along with fixed bandwidth in contradiction of the inevitable gain-band-width-issue lying in the VFOA-based circuits. Also, it was realised that the presence of higher slew rates in order of hundreds to thousands V/µs in contrast to a very low value i.e. 0.5 V/µs for the universal purpose and most prevalent µA741-type VFOA, CFAs can lead to circuits proficient of working over much broader frequency values than those permissible with VFOAs.

Though in opinion of the fame of the CFAs they are manufactured as integrated circuits by many IC manufacturers and there are two variabilities which are in usage. There are CFOAs pin-compatible to VFOAs without externally accessible compensation pin. But, AD 844 CFOA by Analog Devices has the choice that its compensation pin (number 5) is externally-accessible along with having pin-capability with VFOAs. The AD844 IC of Analog Devices is a high speed monolithic operational amplifier which is invented using junction- isolated complementary bipolar (CB) method having high bandwidth and very fast large signal response with outstanding DC performance characteristics and very high slew rate about 2,000 V/µs. Though it is improved for usage in current to voltage change applications and as inverting amplifier, it is also appropriate for usage in a number of non-inverting and added uses.

Some applications suggested by the producers comprise High speed current DAC interfaces, Video buffers, Flash ADC input amplifiers, and pulse amplifiers and cable drivers.
.

The CFOA can be used for removing of normal VFOAs but because of its current feedback style it causes much better AC response along with high linearity and outstanding pulse response. The off-set vltage and input bias currents of the CFOA are laser- trimed to reduce DC errors in a way that drift in the offset voltage is naturally 1 µV/C and bias current drift is approximately 9 nA/C. AD844 IC is particularly suitable for video applications as well as an input amplifier for flash type ADC.

Due to AD844 IC being vended, camouflaged as a large bandwidtth and high slew-rate operational amplifier, initially it nearly got ignored that its interior architecture is a trans-linear second generation plus type Current Coonveyor (CCII+) shadowed by a (trans linear) voltage buffer.
Since the interior design of AD844 IC consists of a CCII + shadowed by voltage buffer, this suppleness was found to be useful in letting the AD844 IC to be used as a CCII + and CCII as pin-by-pin change of a VFOA, with pin 5 kept open and finally, as a 4-terminal building block.

Its front end i.e. a CCII + and the back end a voltage follower, the terminal equations of the current feedback operational amplifier CFOA are expressed as
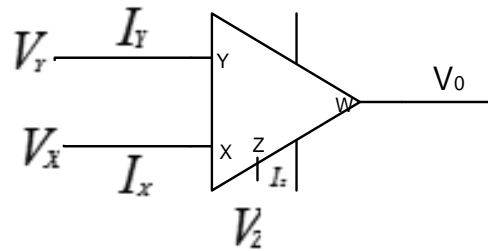

Fig.3.1 Symbolic representation of CFOA

The terminal equations of the above figure are:

$$I_Y = 0 \tag{3.1}$$

$$V_W = V_Z \tag{3.2}$$

$$V_X = V_Y \tag{3.3}$$

$$I_Z = I_X \tag{3.4}$$

18

3.2 CURRENT DIFFERENCING BUFFERED AMPLIFIER (CDBA)

A CDBA is an active component having multiple terminals i.e. two input terminals and two output terminals which was developed by Cevdet Acar and Serdar Özoğuz. The block diagram of the CDBA is shown in figure 8. It is designed from the current feedback operational amplifier (CFOA).
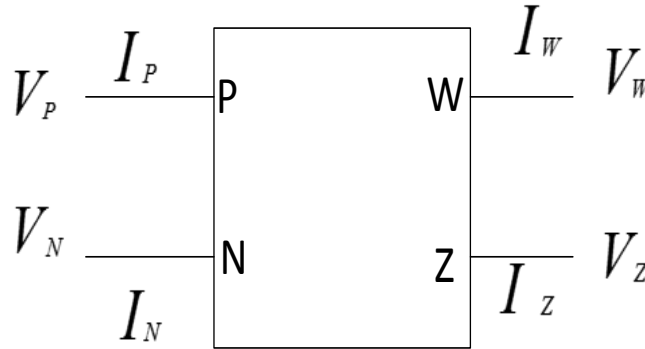
Fig.3.2 Symbolic representation of CDBA

The terminal equations as shown from the above figure are:

$$V_P = V_N = 0 \tag{3.5}$$

$$I_Z = I_P - I_N \tag{3.6}$$

$$V_W = V_Z \tag{3.7}$$

In this current flowing through z-terminal shadows the difference of the currents flowing through p and n-terminal of the CDBA. The Input terminals i.e. p-terminal and n-terminal are internally grounded. The input currents difference are transformed into the output voltage i.e. Vw and so CDBA can be said as a special type of current feedback operational amplifier with current input in differential mode and y input grounded.

The CDBA helps in simplifying the application along with free from parasitic capacitances and also able to work in the range of frequency of more than hundreds of MHz and suitable for operation in current mode along with providing a voltage signal at the output.

3.3 REALISATION OF CDBA FROM CFOA

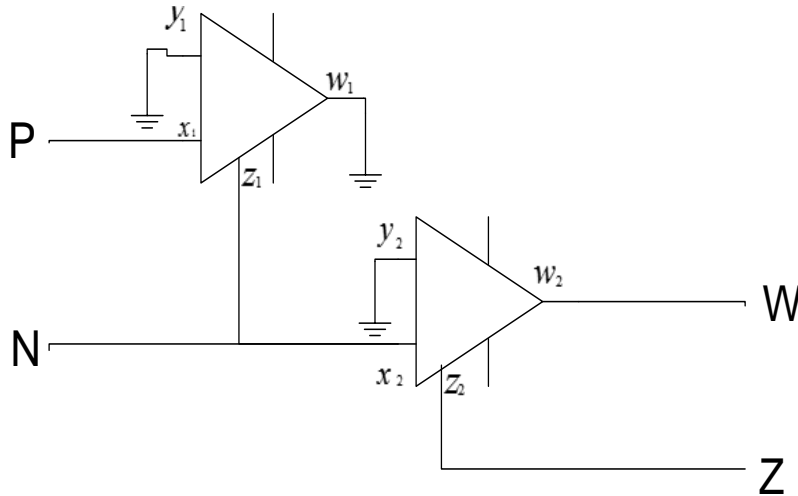The CDBA can be designed using the easily available CFOA AD844 IC which is shown in Fig.9

Fig.3.3 Realization of CDBA from CFOA proposed by Kunal Gupta, Priyanka Gupta, Neeta Pandey and Rajeshwari Pandey [3]

In ideal case the input impdance at the x is zero and z-terminal output resistance is infinite. Input terminals i.e. p and n of CDBA are virtually grounded internally. The current coming out of z-terminal equals the difference of currents flowing into p-terminal and n-terminal of the CDBA and the w-terminal voltage follows the z-terminal voltage.

CHAPTER 4

INDUCTOR SIMULATION USING CDBA

4.1 INDUCTOR DESIGN

An inductor can be simulated using a single CDBA only. The proposed simulation of a lossy inductor using CDBA is shown in the Fig.10
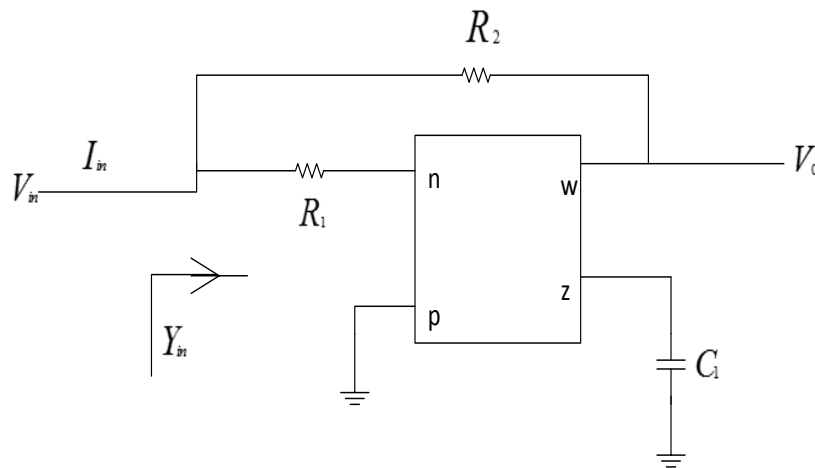
Fig.4.1 Inductor circuit using CDBA J.K. Pathak, A.K. Singh and R. Senani in [5]

On analyzing the above circuit and applying the terminal equations of a CDBA the above circuit can be simplified as shown in Fig.11
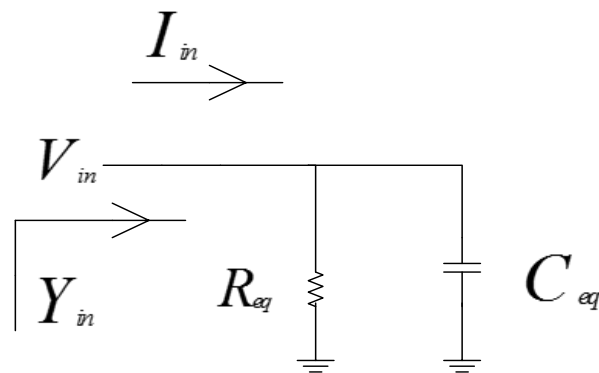
Fig.4.2 Equivalent circuit of inductor

According to the above circuit

$$Y_{in} = \frac{1}{Z_{in}} = \frac{1}{R_{eq}} + \frac{1}{sL_{eq}} \qquad (4.1)$$

where

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \qquad (4.2)$$

$$sL_{eq} = C_1 R_1 R_2 \qquad (4.3)$$

The main features of the proposed circuit are the canonical structure, absence of passive component matching conditions and the provision that the parasitic impedances are absorbed at the z- terminal of the CDBA.

The use of this proposed inductor in simulation of various filters using CDBA is thus shown in the next chapter.

4.2 VERIFICATION OF INDUCTOR DESIGNED USING CDBA

To verify the above circuit of the inductor the inductor has been supplied with an AC sinusoidal signal and its current and voltage waveforms are plotted in PSPICE. The component values chosen for the same are $R_1 = R_2 = 10K$ and $C_1 = 22\mu F$.
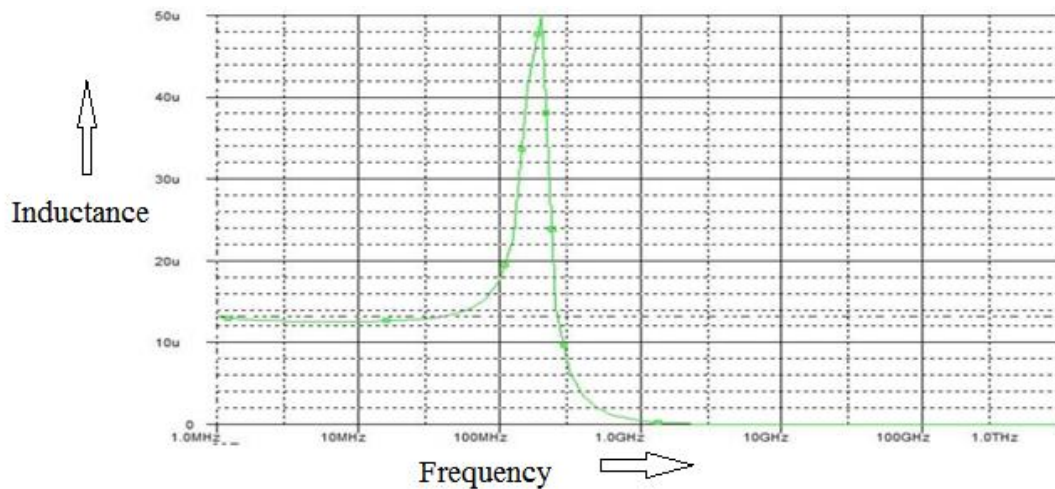

Fig.4.3 Inductance v/s frequency curve for CDBA based floating inductor

CHAPTER 5

FILTER DESIGN USING CDBA

5.1 SYNTHESIS PROCEDURE

In the doubly terminated circuits as shown in Fig 5.1 we have seen the current from the source, I_1, and its reference flowing direction, and Z_{in} seen as the input impedance of the RLC circuit what consists of the lossless ladder terminated by R_2. We assume that the circuit is under working condition in sinusoidal steady state. The input impedance is having both a real and imaginary component
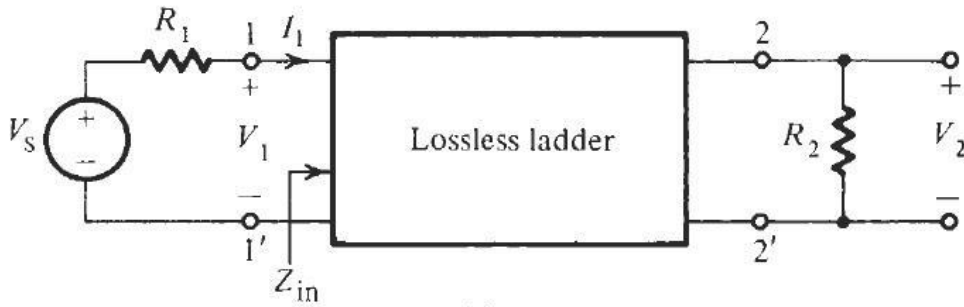

Fig. 5.1 Doubly resistively terminated LC ladder lossless filter

Here,

$$Z_{in} = R_{in} + jX_{in} \tag{5.1}$$

And the current at the input terminal is

$$I_1 = \frac{V_s}{R_1 + Z_{in}} \tag{5.2}$$

Now since the LC circuit acts as lossless, we may make the average power equating to the circuit, P1, equation, to that of the load. Thus,

$$P_1 = R_{in}|I_1(j\omega)|^2 = \frac{|V_2(j\omega)|2}{R_2} \tag{5.3}$$

Substituting Eq. (2) for I1 into this equation provides us

$$\frac{R_{in}|V_s(j\omega)|2}{|R_1 + Z_{in}|2} = \frac{|V_2(j\omega)|2}{R_2} \tag{5.4}$$

From this equation, we have a tendency to get the magnitude square of the required transfer perform

$$\left|\frac{V_2(j\omega)}{V_s(j\omega)}\right|^2 = |T(j\omega)|2 = \frac{R_2 R_{in}}{|R_1 + Z_{in}|2} \tag{5.5}$$

To make this expression relate to the transfer function H(s) that we represent to use for LC filter and if we take the ratio of power, we get,

$$|H(j\omega)|^2 = \frac{P_2}{P_{1.max}} = \frac{4R_1}{R_2}\left|\frac{V_2(j\omega)}{V_s(j\omega)}\right|^2 = \frac{4R_1}{R_2}\frac{R_2 R_{in}}{|R_1 + Z_{in}|2} \leq 1 \tag{5.6}$$

With Eq. (1) we obtain,

$$|H(j\omega)|^2 = 1 - \frac{|R_1 - Z_{in}|2}{|R_1 + Z_{in}|2} = 1 - |\rho(j\omega)|^2 \tag{5.7}$$

Where the auxiliary function ρ(s) is termed as the reflection coefficient. P(s) is a measure to know how well R₁ and Z_in are matched; we have always |ρ(jω)|2≤1 and for matching purpose, ρ(s)=0. Evidently, ρ(s) is described as

$$|\rho(j\omega)|^2 = \left|\rho(s)|\rho(-s)\right|\big|_{s=j\omega} = \frac{|R_1 - Z_{in}|2}{|R_1 + Z_{in}|2} \tag{5.8}$$

From this equation, we can see that ρ(s) may be separated from ρ(-s) to give the result as

$$\rho(s) = \pm\frac{|R_1 - Z_{in}|}{|R_1 + Z_{in}|} \tag{5.9}$$

Clearly, this equation may be deduced for Z_in in terms of ρ(s) and R₁. The result is

$$Z_{in} = R_1\frac{1 - \rho(s)}{1 + \rho(s)} \tag{5.10}$$

Observe that these expressions result into two reciprocal impedances. Now, since is described in terms of the prescribed transfer function H, we have reduced the problem to determining a lossless circuit terminated in a resistor R2 from a defined Zin. Sidney Darlington (1939) showed in his classic publication that this was always possible, and so the circuit may be designed from a given Zin. To depict the implementation of the strategy, consider the problem to determine circuits which have a Butterworth response where there are equal terminations with R₁=R₂=1, a normalized value that may later be magnitude scaled by denomalizing the element parameters to obtain the desired cutoff or centered frequency.

The Butterworth response is expressed as:

$$|H(j\omega)|^2 = \frac{1}{1 + \omega 2n} \tag{5.11}$$

Note that this magnitude-squared function is less than or equal to unity and so it satisfies the condition of Eq. (6). Since the magnitude-squared function is:

$$|H(j\omega)|^2 = \left|H(s)|H(-s)\right|\big|_{s=j\omega} \tag{5.12}$$

Then,

$$|H(j\omega)|^2 = \frac{K_H}{|D(j\omega)|2} = \left|\frac{K_H}{D(s)|D(-s)|}\right|_{s=j\omega} \tag{5.13}$$

The constant KH relates to the constant K by $K_H = 2\sqrt{\frac{R_1}{R_2}}K$, and D(s) is known from our study of the Butterworth response function.

We may determine from Eq. (5.7) the auxiliary function of Eq. (5.9), We have

$$|H(j\omega)|^2 = 1 - \frac{1}{1+\omega 2n} = \frac{\omega 2n}{1+\omega 2n} \tag{5.14}$$

We see that

$$\rho(s) = \frac{s^n}{D(s)} \tag{5.15}$$

Substituting this value of ρ(s) into Eqs. (10) and (11), we get,

$$Z_{in} = R_1\left[\frac{1-\rho(s)}{1+\rho(s)}\right]^{\pm} = R_1\left[\frac{D(s)-s^n}{D(s)+s^n}\right]^{\pm} \tag{5.16}$$

It is convenient way to normalize the impedance level of the circuit by setting. The realization of the n-th order transfer function uses exactly n reactances, one for each degree of freedom; such a realization is referred to be canonic. The realization of all pole low-pass filters is always considered as canonic but this is not a generalized case for LC ladders. When we use, Table 5.1, the two resistors are having equal and normalized with respect to the impedance level in that R1=R2=1Ω and with respect to the frequency that is considered to be 3-dB frequency, ωp=1. If αmax≠3dB, we have to denormalize the elements to have the Butterworth frequency written as

$$\omega_B = \in^{\frac{1}{n\omega_p}}$$

5.2 LOW PASS FILTERS:

5.2.1 SECOND ORDER LOW PASS FILTER USING CDBA:

A second order low pass filter [2] circuit is given in Fig.5.2
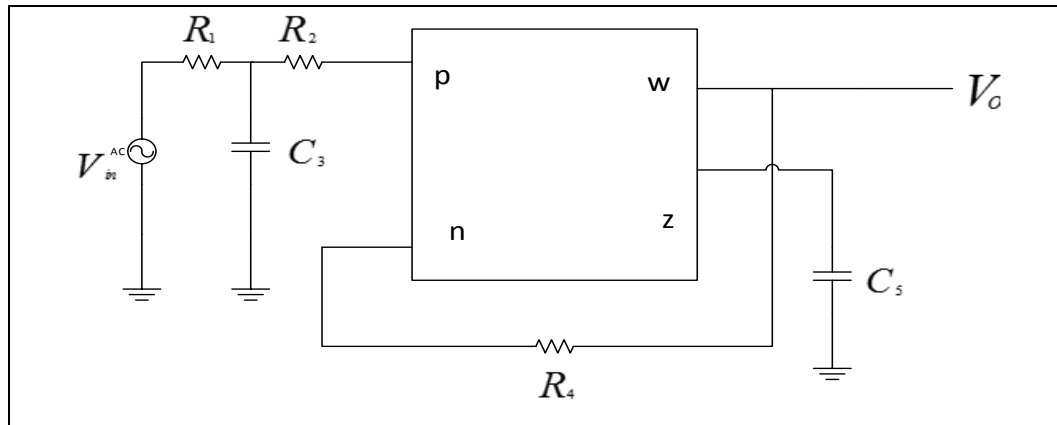

Fig.5.2 2nd order low pass filter proposed by M. Koksal, S.E. Oner and M. Sagbas [2]

. The transfer function of the circuit is given as follows:

$$\frac{V_O}{V_{in}} = \frac{\dfrac{G_1 G_2}{C_3 C_5}}{s^2 + s\dfrac{C_3 G_4 + C_5 G_1 + C_5 G_2}{C_3 G_5} + \dfrac{G_4(G_1 + G_2)}{C_3 G_5}}$$

The PSPICE code to simulate the above circuit is as follows:

.LIB AD844.LIB

X1 1 2 3 4 5 6 AD844

X2 7 6 3 4 8 9 AD844

V+ 3 0 DC 12V

V- 0 4 DC 12V

R1 11 10 10K

VIN 11 0 AC 10V

R2 10 2 10K

C3 10 0 1N

R4 6 8 10K

C5 9 0 1N

.AC DEC 10 10 1G

.PROBE

.OP

.END

The values of components taken from M. Koksal, S.E. Oner and M. Sagbas [2] and further tuned to realize a second order low pass filter using CDBA are $R_1 = R_2 = R_4 = 10K$ and $C_3 = C_5 = 1nF$. The simulated output result is shown in Fig.5.3. The cut off frequency of the circuit is found as 15.73 K Hz.
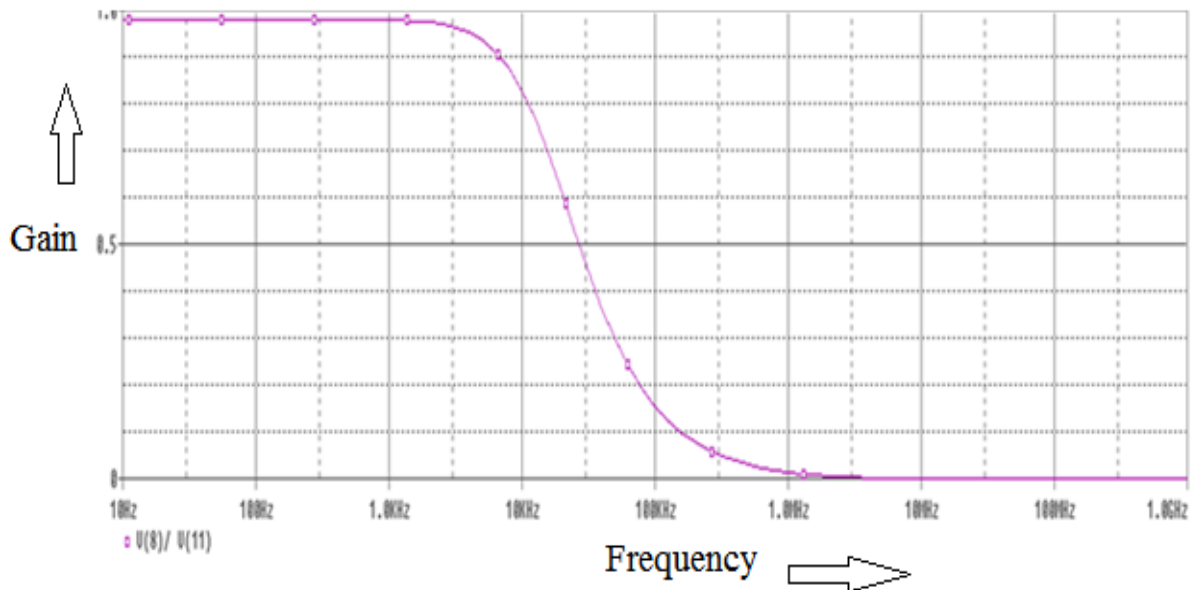

Fig.5.3 Frequency response of 2nd order low pass filter

5.1.2 THIRD ORDER LOW PASS FILTER USING CDBA:

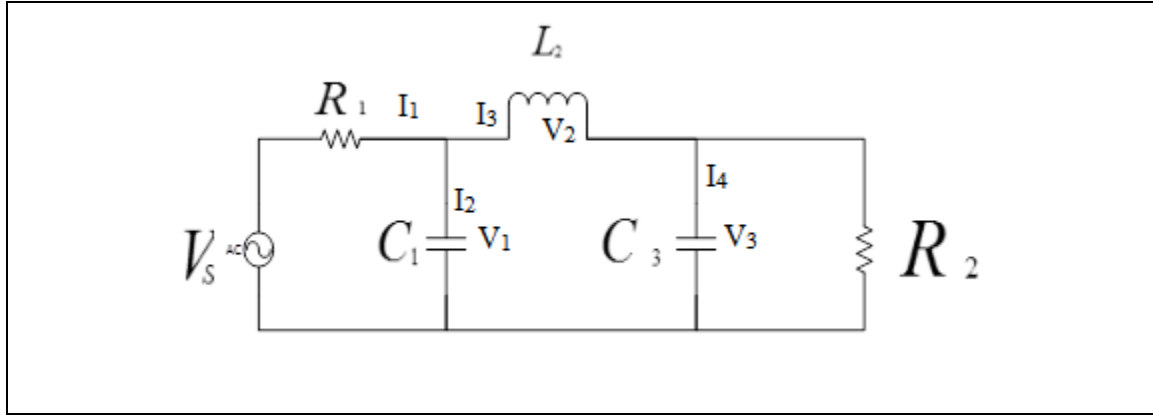A third order passive ladder filter configuration is shown in Fig.5.4

Fig.5.4 3rd order low pass filter passive ladder prototype [33]

The transfer function of the filter can be calculated as follows:

$$Y_1 = sC_1 + G_1 \tag{5.17}$$

$$Z_2 = sL_2 \tag{5.18}$$

$$Y_3 = sC_3 + G_2 \tag{5.19}$$

Now,

$$I_3 = I_4 = Y_3V_3 \tag{5.20}$$

$$V_2 = Z_2I_3 = Z_3Y_3V_3 \tag{5.21}$$

$$V_1 = V_2 + V_3 = Z_2Y_3V_3 + V_3 \tag{5.22}$$

$$I_1 = I_2 + I_3 \tag{5.23}$$

$$V_S = I_1Y_1 \tag{5.24}$$

On solving the above equations, the transfer function becomes:

$$\frac{V_3}{V_s} = \frac{1}{s^3(L_2C_1G_2C_3) + s^2(C_1L_2 + R_1L_2G_2C_3) + s(G_2C_3 + R_1L_2 + G_2C_1) + (1 + G_2R_1)}$$

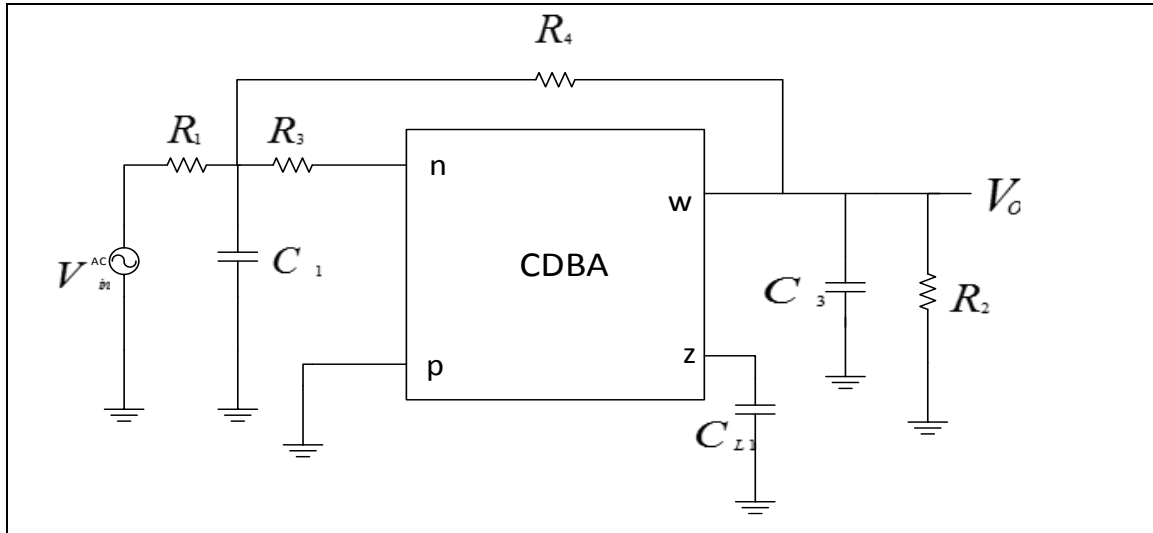The active filter using CDBA corresponding to this ladder circuit is shown in Fig.5.5

Fig. 5.5 3rd order low pass active filter using CDBA

The PSPICE code to simulate the above circuit is as follows:
.LIB AD844.LIB

X1 0 0 3 4 0 6 AD844

X2 0 6 3 4 8 9 AD844

V+ 3 0 DC 12V

V- 0 4 DC 12V

IS 10 0 AC 20UA

RS 10 0 1K

C1 10 0 0.01P

R1 10 6 1K

R2 10 8 1K

CL1 9 0 0.02P

C3 8 0 0.01P

RL 8 0 1K

.AC DEC 10 10 1G

.PROBE

.OP

.END

The LC ladder (doubly terminated) that represents a third order low-pass filter (Butterworth) at 1rad/sec is depicted in Fig.5.4. where $R_1=1\Omega$, $C_1=C_2=1F$ and $L=2H$. Let us select a minimum inductance ladder so that the very first and last elements are capacitors. To have frequency scaling we must denormalize the elements which depends on source, load resistance and cut-off frequency. Let us consider $\alpha_{max} = 0.7$.

Therefore, $\in = \sqrt{10^{0.07} - 1} = 0.4182$ so that

$\omega_B = \in^{\frac{1}{n\omega p}} = 0.4182^{-1/(3*10K)} = 84$ Krad/s

With these numbers, we denormalize the resistors by multiplying by 1 KΩ and the inductors and capacitors value can be calculated as:

$$L_2 = \frac{1K\Omega}{84Krad/s} * 2 = 1.9 \, mH$$

$$C_1 = C_3 = \frac{1}{1K\Omega * \frac{84Krad}{s}} = 0.01pF$$

Now with $R_3 = R_4 = 1K\Omega$, the value of C_{L2} is calculated as:

$$C_{L2} = \frac{L_2}{R_3 R_4} = \frac{1.9mH}{1K * 1K} = 0.02pF$$

Thus, the values of components used to realize the third order low pass filter using CDBA are $R_1 = R_2 = R_3 = R_4 = 1K\Omega$, $C_{L2} = 0.02pF$ and $C_3 = C_1 = 0.01pF$. The simulated output result is shown in Fig.5.6. The cut off frequency of the circuit as seen from the PSPICE simulation is found as 13.077 KHz.

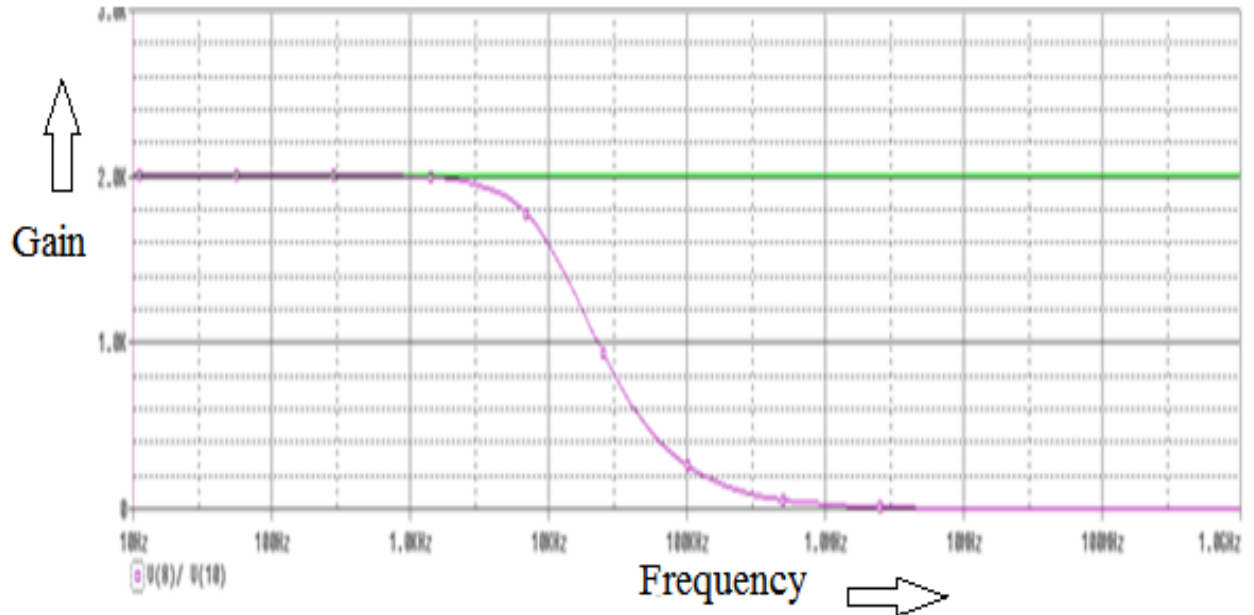Fig.5.6 Frequency response of 3rd order low pass filter

5.2.3 FOURTH ORDER LOW PASS FILTER USING CDBA:

A fourth order passive ladder filter configuration is shown in Fig.5.7

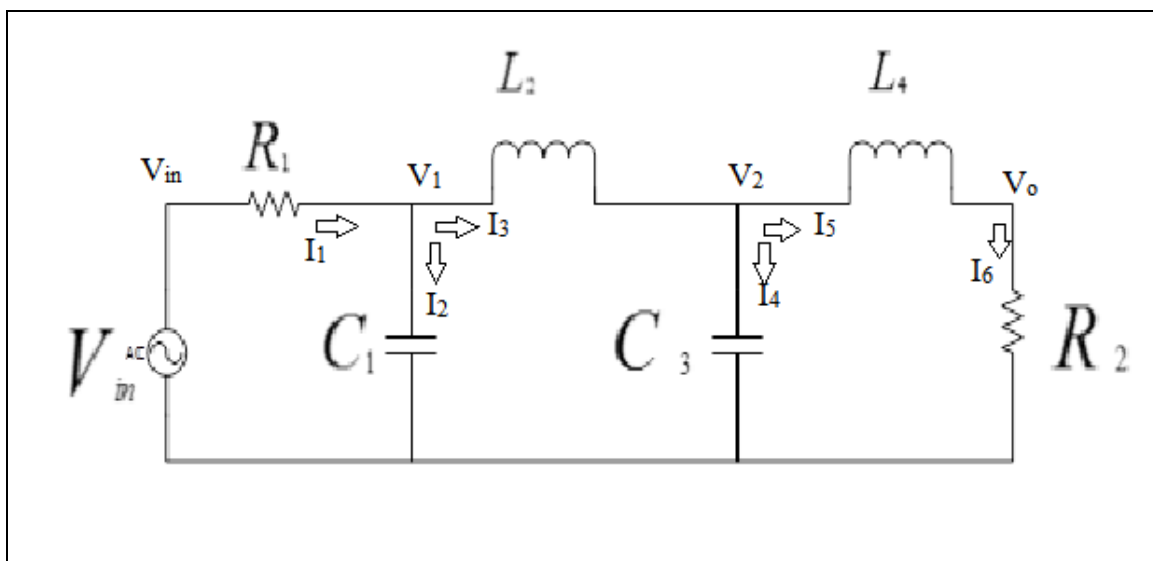Fig.5.7 4th order low pass filter passive ladder prototype [33]

The transfer function of the filter can be calculated as follows:

$$Y_1 = sC_1 \tag{5.25}$$

$$Z_2 = sL_2 \tag{5.26}$$

$$Y_3 = sC_3 \tag{5.27}$$

$$Z_4 = sL_4 \tag{5.28}$$

Now,

$$I_6 = I_5 = V_O * G_2 \tag{5.29}$$

$$V_2 = I_5 * Z_4 + V_O \tag{5.30}$$

$$V_2 = V_O(1 + G_2 Z_4) \tag{5.31}$$

$$I_3 = I_4 + I_5 = Y_3 V_O(1 + G_2 Z_4) + V_O G_2 = V_O[Y_3(1 + G_2 Z_4) + G_2] \tag{5.32}$$

$$V_1 = I_3 Z_2 + V_2 = V_O[\{Y_3(1 + G_2 Z_4) + G_2\}Z_2 + (1 + G_2 Z_4)] \tag{5.33}$$

$$I_1 = I_2 + I_3 = V_1 Y_1 + I_3 \tag{5.34}$$

$$V_{in} = I_1 R_1 + V_2 \tag{5.35}$$

On solving the above equations and putting the values of Y_1, Z_2, Y_3 and Z_4 the transfer function of the filter can be written as:

$$\frac{V_o}{V_{in}} = \frac{1}{\begin{array}{c} s^4(C_1 L_2 C_3 L_4) + s^3(L_2 L_4 R_1 C_3 + G_2 L_2 C_1 C_3) + s^2(L_2 R_1 G_2 C_3 + C_1 L_2 \\ + L_4 C_3 + L_4 C_1) + s(L_4 R_1 + C_3 G_2 + R_1 L_2 + C_1 G_2) + (1 + G_2 R_1) \end{array}}$$

The active filter using CDBA corresponding to this ladder circuit is shown in Fig.5.8
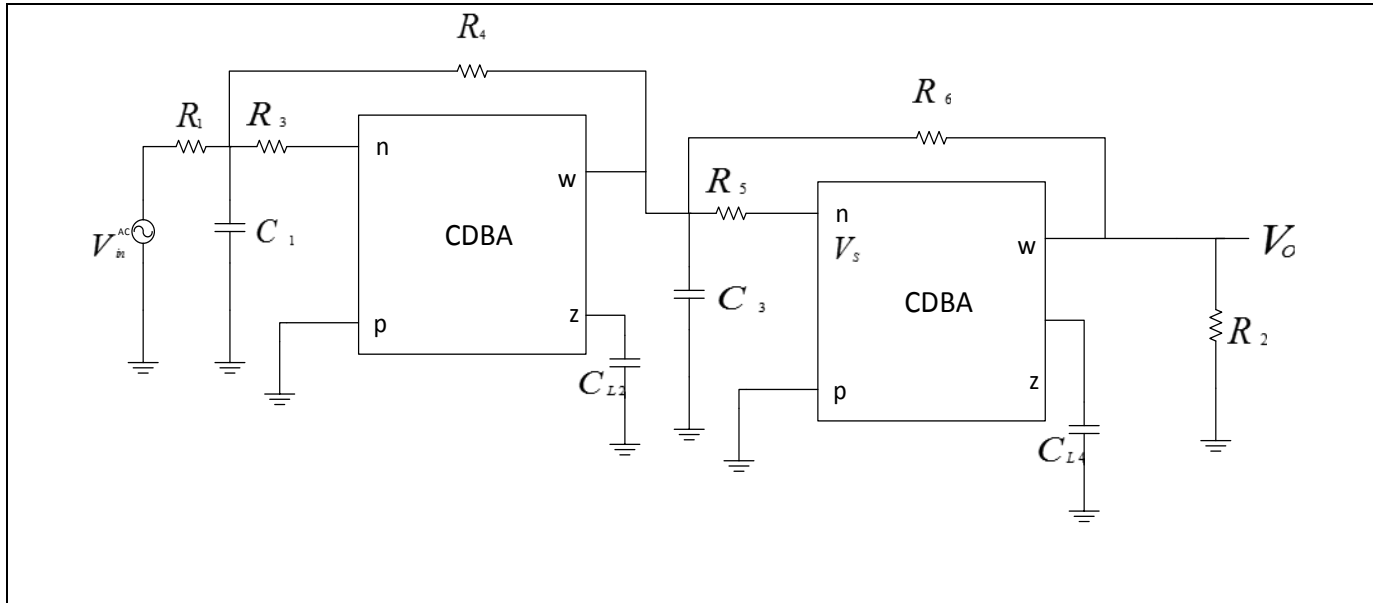

Fig.5.8 4th order low pass active filter using CDBA

The PSPICE code to simulate the above circuit is as follows:

```
.LIB AD844.LIB
X1 1 2 3 4 5 6 AD844
X2 7 6 3 4 8 9 AD844
X3 10 11 3 4 12 13 AD844
X4 14 13 3 4 15 16 AD844
VS 18 0 AC 10V
R1 18 17 1M
R3 17 6 100K
R4 17 8 100K
C1 17 0 100P
CL2 9 0 200P
R5 8 13 100K
R6 8 15 100K
R2 15 0 100K
```

CL4 16 0 200P

C3 8 0 100P

.AC DEC 10 10 1G

.PROBE

.OP

.END

The LC ladder (doubly terminated) that represents a third order low-pass filter (Butterworth) at 1rad/sec is depicted in Fig.5.7, where R_1=1Ω, C_1=C_2=1F and L=2H. Let us select a minimum inductance ladder so that the very first and last elements are capacitors. To have frequency scaling we must denormalize the elements which depends on source, load resistance and cut-off frequency. Let us consider $\alpha_{max} = 0.7$.

Therefore, $\in = \sqrt{10^{0.07} - 1} = 0.4182$ so that

$$\omega_B = \in^{\frac{1}{n\omega p}} = 0.4182^{-1/(4*10K)} = 78 \text{ K rad/s}$$

With these numbers, we denormalize the resistors by multiplying by 100 KΩ and the inductors and capacitors value can be calculated as:

$$L_2 = \frac{100K\Omega}{78Krad/s} * 2 = 1.98H$$

$$C_1 = C_3 = \frac{1}{100K\Omega * \frac{78Krad}{s}} = 100pF$$

Now with $R_3 = R_4 = 1K\Omega$, the value of C_{L2} is calculated as:

$$C_{L2} = \frac{L_2}{R_3 R_4} = \frac{1.98H}{100K * 100K} = 200pF$$

Thus the values of components taken to realize this fourth order low pass filter using CDBA are $R_1 = R_2 = R_4 = R_3 = R_5 = R_6 = 100K$, $C_{L2} = C_{L4} = 200pF$ and $C_1 = C_3 = 100pF$. The simulated output result is shown in Fig.5.9. The cut off frequency of the circuit is found as 9.521 KHz.

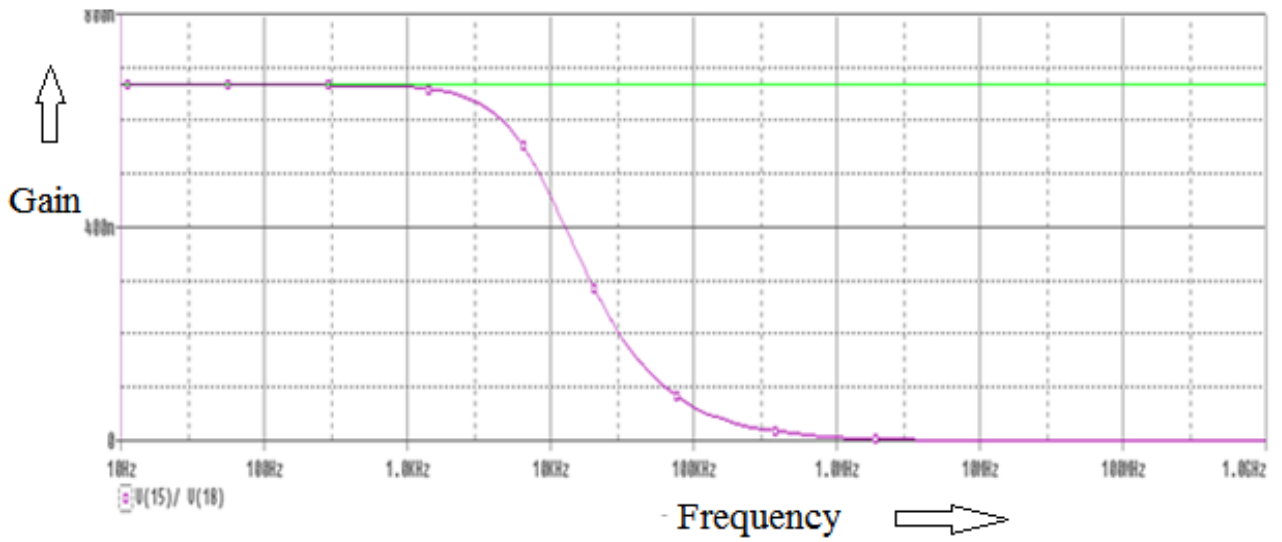Fig.5.9 Frequency response of 4th order low pass filter

5.2.4 FIFTH ORDER LOW PASS FILTER USING CDBA:

A fifth order ladder passive filter configuration is shown in Fig.5.10

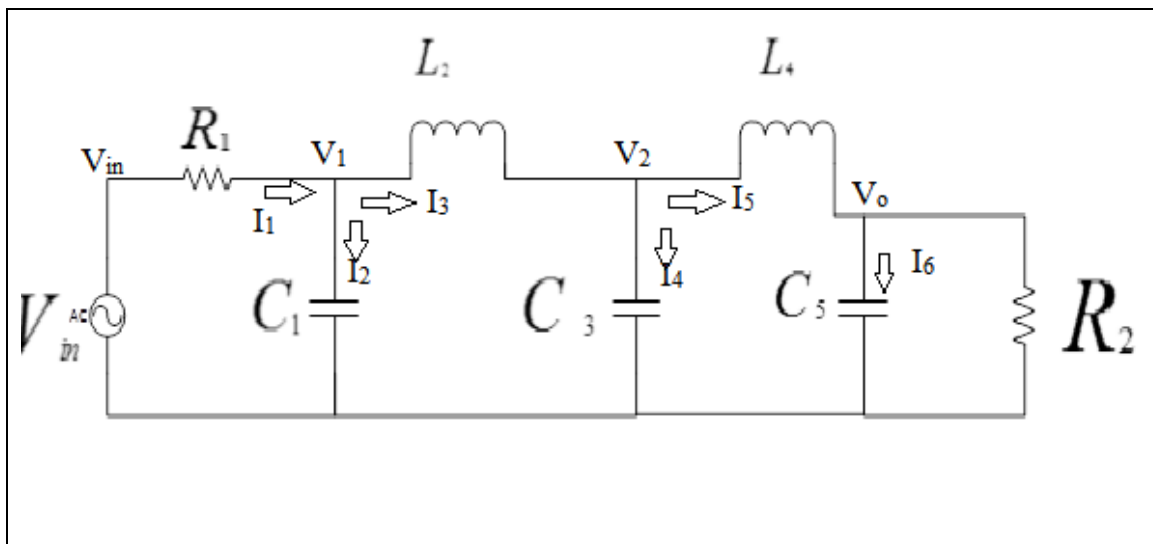
Fig.5.10 5th order low pass filter passive ladder prototype [33]

The transfer function of the filter is as follows:

$$Y_1 = sC_1 \tag{5.36}$$

$$Z_2 = sL_2 \tag{5.37}$$

$$Y_3 = sC_3 \tag{5.38}$$

$$Z_4 = sL_4 \tag{5.39}$$

$$Y_5 = sC_5 + G_2 \tag{5.40}$$

Now,

$$I_6 = I_5 = V_O * Y_5 \tag{5.41}$$

$$V_2 = I_5 * Z_4 + V_O \tag{5.42}$$

$$V_2 = V_O(1 + Y_5 Z_4) \tag{5.43}$$

$$I_3 = I_4 + I_5 = Y_3 V_O(1 + Y_5 Z_4) + V_O Y_5 = V_O[Y_3(1 + Y_5 Z_4) + Y_5] \tag{5.44}$$

$$V_1 = I_3 Z_2 + V_2 = V_O[\{Y_3(1 + Y_5 Z_4) + G_2\}Z_2 + (1 + Y_5 Z_4)] \tag{5.45}$$

$$I_1 = I_2 + I_3 = V_1 Y_1 + I_3 \tag{5.46}$$

$$V_{in} = I_1 R_1 + V_2 \tag{5.47}$$

On solving the above equations and putting the values of Y_1, Z_2, Y_3, Z_4 and Y_5 the transfer function of the filter can be written as:

$$\frac{V_o}{V_{in}} = \frac{1}{\begin{aligned} &s^5(C_1 L_2 C_3 L_4 C_5 G_2) + s^4(R_1 L_2 C_3 L_4 C_5 G_2 + C_3 L_4 L_2 C_1) + s^3 \\ &(C_3 L_4 C_5 G_2 + + C_1 L_4 C_5 G_2 + C_1 L_2 C_5 G_2 + L_2 C_3 C_1 G_2 + L_2 C_3 R_1 L_4) \\ &+ s^2(R_1 L_4 C_5 G_2 + R_1 L_2 G_2 C_5 + L_2 R_1 C_3 G_2 + C_3 L_4 + C_1 L_4 + C_1 L_2) \\ &+ s(C_5 G_2 + C_3 G_2 + C_1 G_2 + L_4 R_1 + L_2 R_1) + (1 + R_1 G_2) \end{aligned}}$$

The active filter using CDBA corresponding to this ladder circuit is shown in Fig.5.11
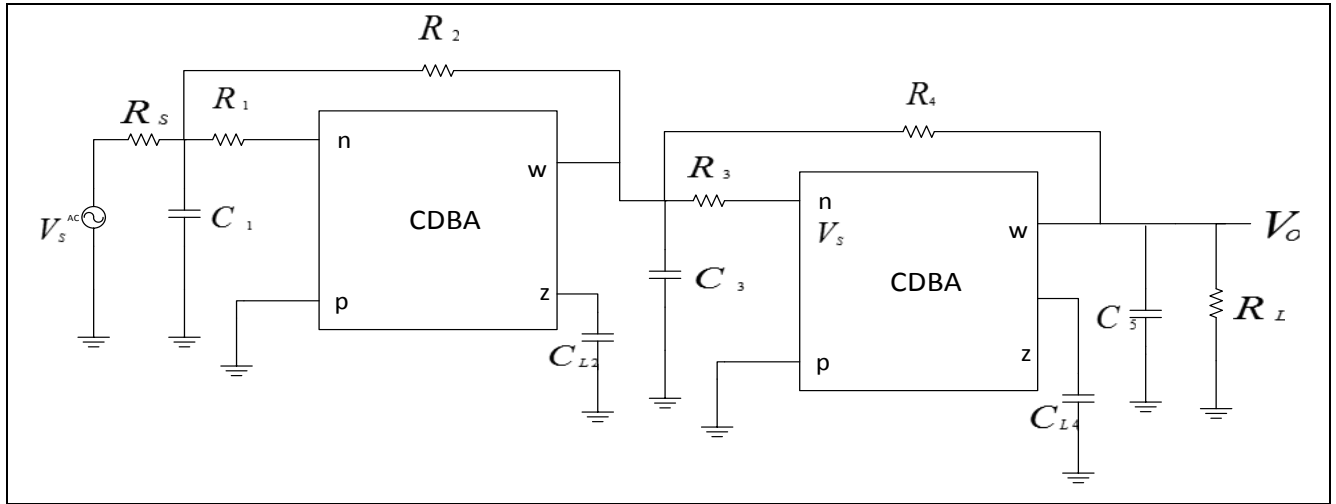

Fig.5.11 5th order low pass active filter using CDBA

The PSPICE code to simulate the above circuit is as follows:

.LIB AD844.LIB

X1 1 2 3 4 5 6 AD844

X2 7 6 3 4 8 9 AD844

X3 10 11 3 4 12 13 AD844

X4 14 13 3 4 15 16 AD844

IS 17 0 AC 20U

C1 17 0 100P

RS 17 0 100K

R1 17 6 100K

CL2 9 0 200P

C3 8 0 100P

R2 17 15 100K

R3 8 13 100K

CL4 16 0 200P

C5 15 0 100P

RL 15 0 100K

.AC DEC 10 10 1G

.PROBE

.OP

.END

The LC ladder (doubly terminated) that represents a third order low-pass filter (Butterworth) at 1rad/sec is depicted in Fig.5.10, where $R_1=1\Omega$, $C_1=C_2=1F$ and $L=2H$. Let us select a minimum inductance ladder so that the very first and last elements are capacitors. To have frequency scaling we must denormalize the elements which depends on source, load resistance and cut-off frequency. Let us consider $\alpha_{max} = 0.7$.

Therefore, $\in = \sqrt{10^{0.07} - 1} = 0.4182$ so that

$\omega_B = \in^{\frac{1}{n\omega p}} = 0.4182^{-1/(5*10K)} = 74.83$ K rad/s

With these numbers, we denormalize the resistors by multiplying by 100 KΩ and the inductors and capacitors value can be calculated as:

$$L_2 = \frac{100K\Omega}{74.83Krad/s} * 2 = 1.98H$$

$$C_1 = C_3 = \frac{1}{100K\Omega * \frac{74.83Krad}{s}} = 100pF$$

Now with $R_3 = R_4 = 1K\Omega$, the value of C_{L2} is calculated as:

$$C_{L2} = \frac{L_2}{R_3R_4} = \frac{1.98H}{100K * 100K} = 200pF$$

Thus the values of components taken to realize this fifth order low pass filter using CDBA are $R_1 = R_2 = R_3 = R_4 = R_S = R_L = 100K$, $C_{L2} = C_{L4} = 200pF$ and $C_1 = C_3 = C_5 = 100pF$. The simulated output result is shown in Fig.5.12. The cut off frequency of the circuit is found as 7.934 KHz.
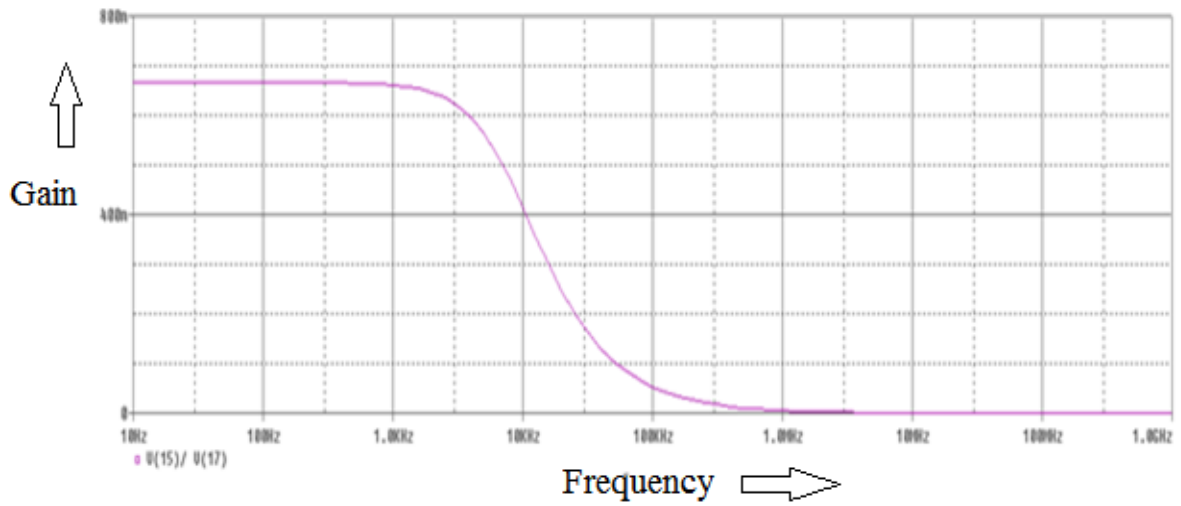
Fig.5.12 Frequency response of 5th order low pass filter

5.2.4.1 Hardware Implementation Of Fifth Order Low Pass Filter:

The breadboard circuit of fifth order low pass filter of Fig.5.11 with $R_1 = R_2 = R_4 = R_3 = 1K$, $C_{L2} = 0.2nF$ and $C_3 = C_1 = 0.1nF$ is shown in Fig.5.13
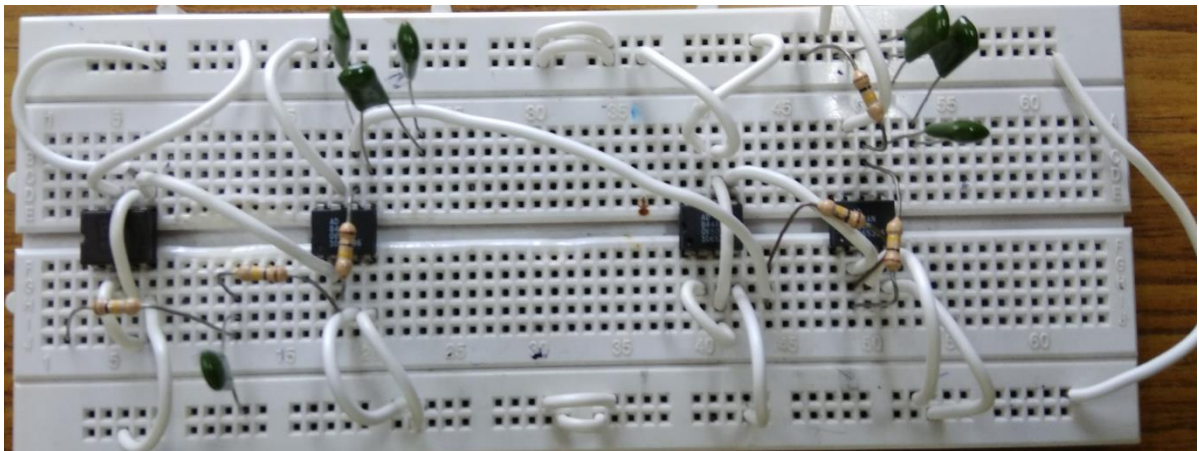

Fig.5.13 5th order low pass active filter bread board circuit using CDBA

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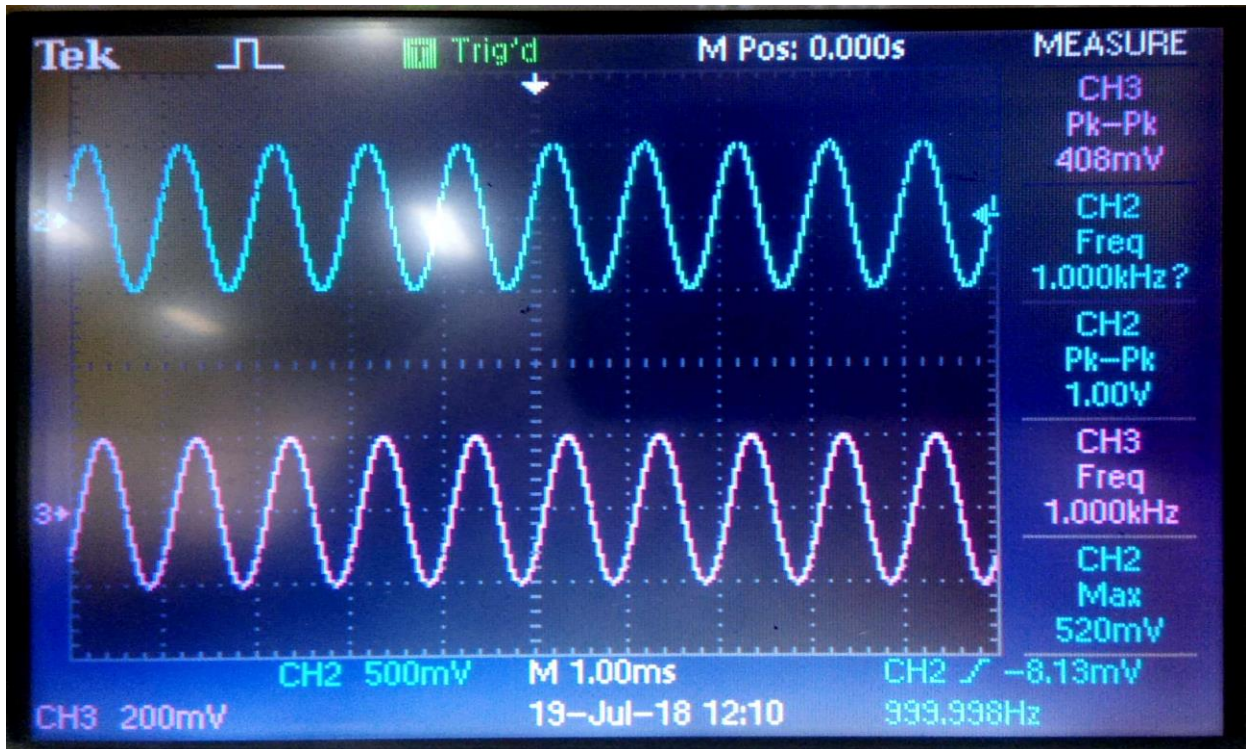The CRO waveforms for the above circuit is shown in Fig.5.14

Fig.5.14 Transient response of 5th order low pass filter

The observations for the above circuit are as follows:

Sr. No.	Frequency(f)	Output Voltage (V_o)	Input Voltage (V_i)	Gain $=\frac{V_o}{V_i}$
1	100Hz	550 mV	1.07 V	0.514
2	150Hz	550 mV	1.07 V	0.514
3	200Hz	550 mV	1.07 V	0.514
4	300 Hz	550 mV	1.07 V	0.514
5	400 Hz	540 mV	1.07 V	0.504
6	500 Hz	540 mV	1.07 V	0.504
7	600 Hz	540 mV	1.07 V	0.504

8	700Hz	530 mV	1.07 V	0.495
9	800 Hz	510 mV	1.07 V	0.476
10	900 Hz	500 mV	1.07 V	0.467
11	950 Hz	495 mV	1.07 V	0.462
12	1 K Hz	490 mV	1.07 V	0.457
13	1.2 K Hz	450 mV	1.07 V	0.420
14	1.3 K Hz	450 mV	1.07 V	0.420
15	1.5 K Hz	430 mV	1.07 V	0.401
16	1.6 K Hz	410 mV	1.07 V	0.383
17	1.7 K Hz	400 mV	1.07 V	0.373
18	1.8 K Hz	380 mV	1.07 V	0.355
19	1.9 K Hz	370 mV	1.07 V	0.345
20	2 K Hz	360 mV	1.07 V	0.336
21	3 K Hz	270 mV	1.07 V	0.252
22	4 K Hz	190 mV	1.07 V	0.177
23	5 K Hz	147 mV	1.07 V	0.137
24	10 K Hz	100 mV	1.07 V	0.093

Table 1 Observations for 5th order low pass filter hardware readings

The row in red shows the cut off frequency point in the observation table. When observed from the PSPICE simulation of the same circuit with the same component values the cut off frequency is observed as 1.87 KHz which is approximately equal to that observed from the hardware simulation of the circuit.

5.2.5 COMPARATIVE ANALYSIS OF LOW PASS FILTERS

2nd Order $> 3^{rd}$ Order $> 4^{th}$ Order $> 5^{th}$ Order
15.73KHz $>$ 13.077KHz $>$ 9.521KHz $>$ 7.934KHz

5.3 LOW PASS TO HIGH PASS TRANSFORMATION

A low pass filter circuit can be transformed into a high pass filter circuit using the transformation shown in Fig.5.15.
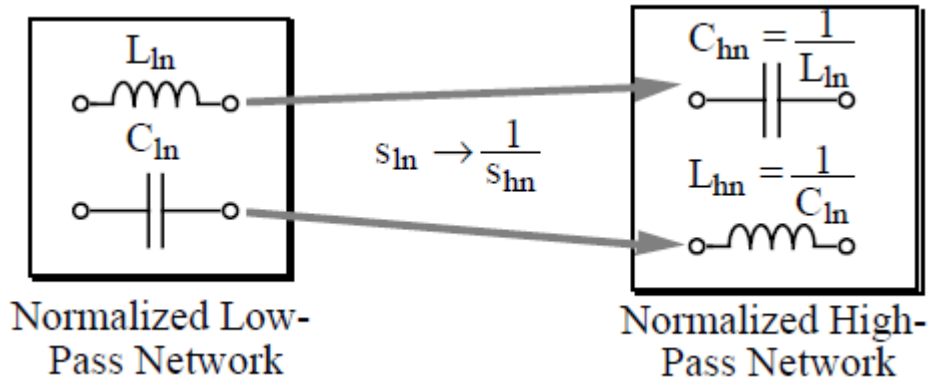

Fig.5.15 Low pass to High pass transformation

5.4 HIGH PASS FILTER

5.4.1 SECOND ORDER HIGH PASS FILTER USING CDBA:

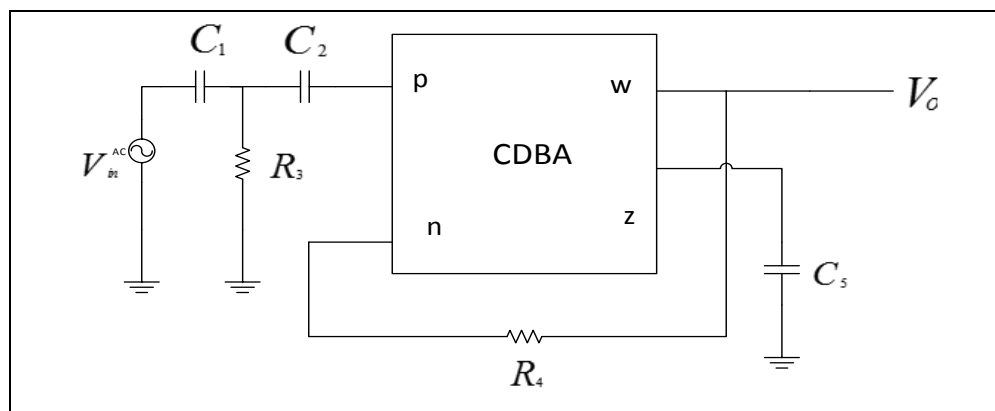A second order high pass filter [3] circuit is given in Fig.5.16

Fig.5.16 2nd order high pass filter

The transfer function of the circuit is given as follows:

$$\frac{V_O}{V_{in}} = \frac{s^2 \dfrac{C_1 C_2}{C_5(C_1 + C_2)}}{s^2 + s\dfrac{C_1 G_4 + C_5 G_3 + C_2 G_4}{C_5(C_1 + C_2)} + \dfrac{G_3 G_4}{C_5(C_1 + C_2)}}$$

The PSPICE code to simulate the above circuit is as follows:

.LIB AD844.LIB

X1 1 2 3 4 5 6 AD844

X2 7 6 3 4 8 9 AD844

V+ 3 0 DC 12V

V- 0 4 DC 12V

C1 11 10 0.1N

VIN 11 0 AC 10V

C2 10 2 0.1N

R3 10 0 100K

R4 6 8 100K

C5 9 0 0.1N

.AC DEC 10 10 .01G

.PROBE

.OP

.END

The values of components which were chosen to realize a second order high pass filter using CDBA are $R_1 = R_2 = R_4 = 100K$ and $C_3 = C_5 = 0.1nF$. The simulated output result is shown in Fig.5.17. The cut off frequency of the circuit is found as 19.08 K Hz.
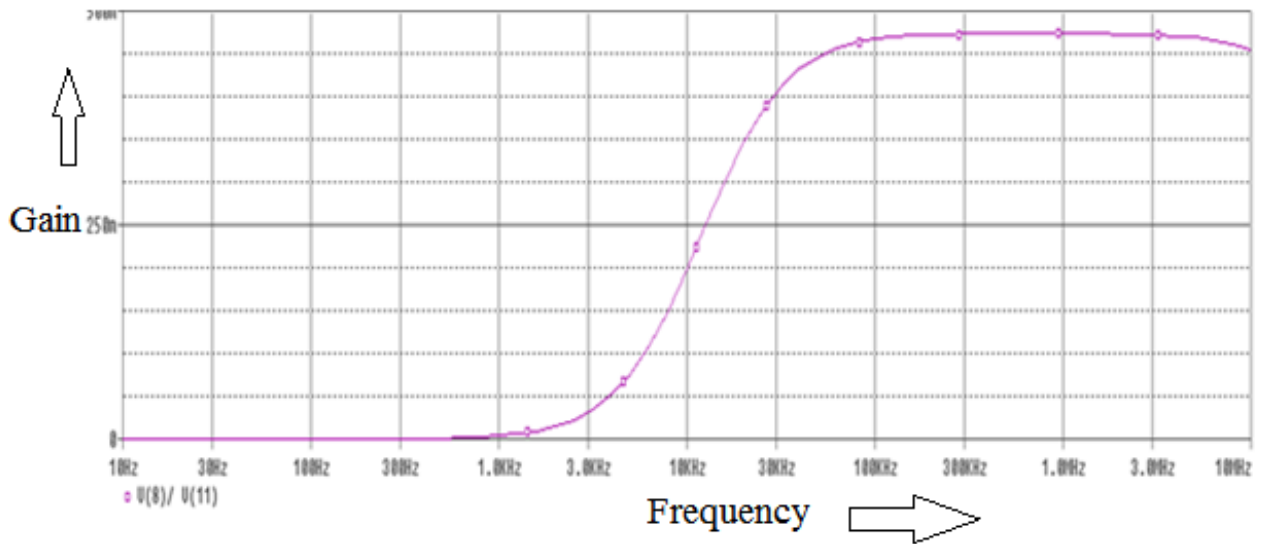
Fig.5.17 Frequency response of 2nd order high pass filter

5.3.2 THIRD ORDER HIGH PASS FILTER USING CDBA:

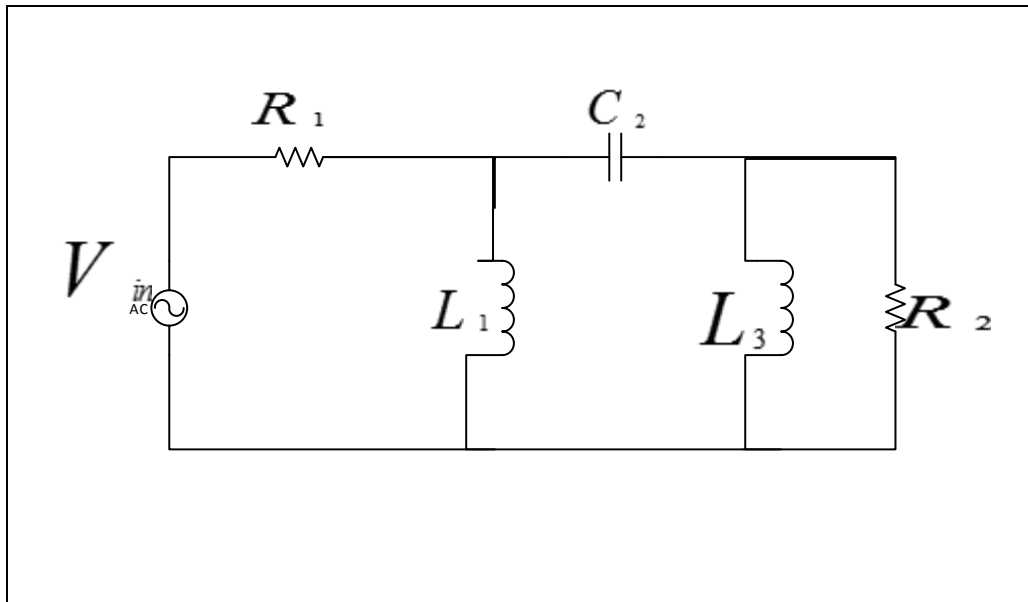A third order passive ladder filter configuration is shown in Fig.5.18

Fig. 5.18 3rd order high pass filter passive ladder prototype [33]

The transfer function of the filter is as follows:

$$\frac{V_o}{V_{in}} = \frac{s^3 L_1 C_2 L_3}{s^3(L_1 C_2 L_3 + G_2 R_1 C_1 C_2 L_3) + s^2\left[G_2\left(\begin{matrix}C_2 L_3 +\\ C_2 L_1\end{matrix}\right)\right] + s(L_3 + R_1 G_2 L_1)}{+G_2}$$

The active filter using CDBA corresponding to this ladder circuit is shown in Fig.5.19
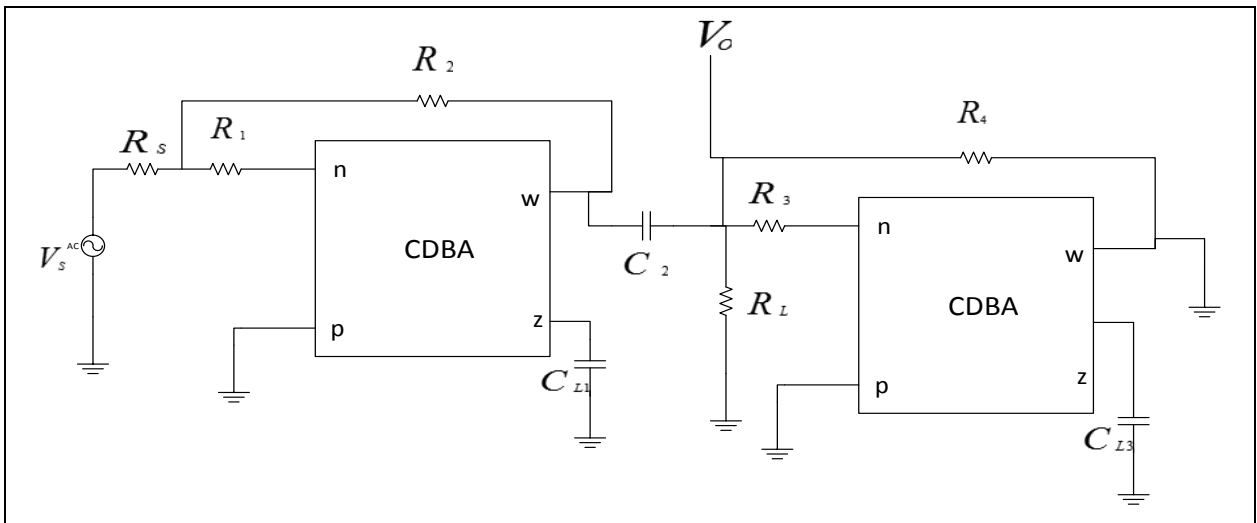

Fig.5.19 3rd order high pass active filter using CDBA

The PSPICE code to simulate the above circuit is as follows:

.LIB AD844.LIB

X1 1 2 3 4 5 6 AD844

X2 7 6 3 4 8 9 AD844

X3 10 11 3 4 12 13 AD844

X4 14 13 3 4 15 16 AD844

V+ 3 0 DC 12V

V- 0 4 DC 12V

IS 17 0 AC 10U

RS 17 0 100K

R1 17 6 100K

R2 17 18 100K

CL1 9 0 200P

C2 18 19 100P

R3 19 13 100K

R4 19 15 100K

RL 19 0 100K

CL3 16 0 200P

VW 15 0 0V

.AC DEC 10 10 1G

.PROBE

.OP

.END

The values of components which were selected to realize the third order high pass filter using CDBA are $R_1 = R_2 = R_4 = R_3 = R_S = R_L = 100K$, $C_{L1} = C_{L3} = 200pF$ and $C_2 = 100pF$. The simulated output result is shown in Fig.5.20. The cut off frequency of the circuit is found as 12.064 KHz.

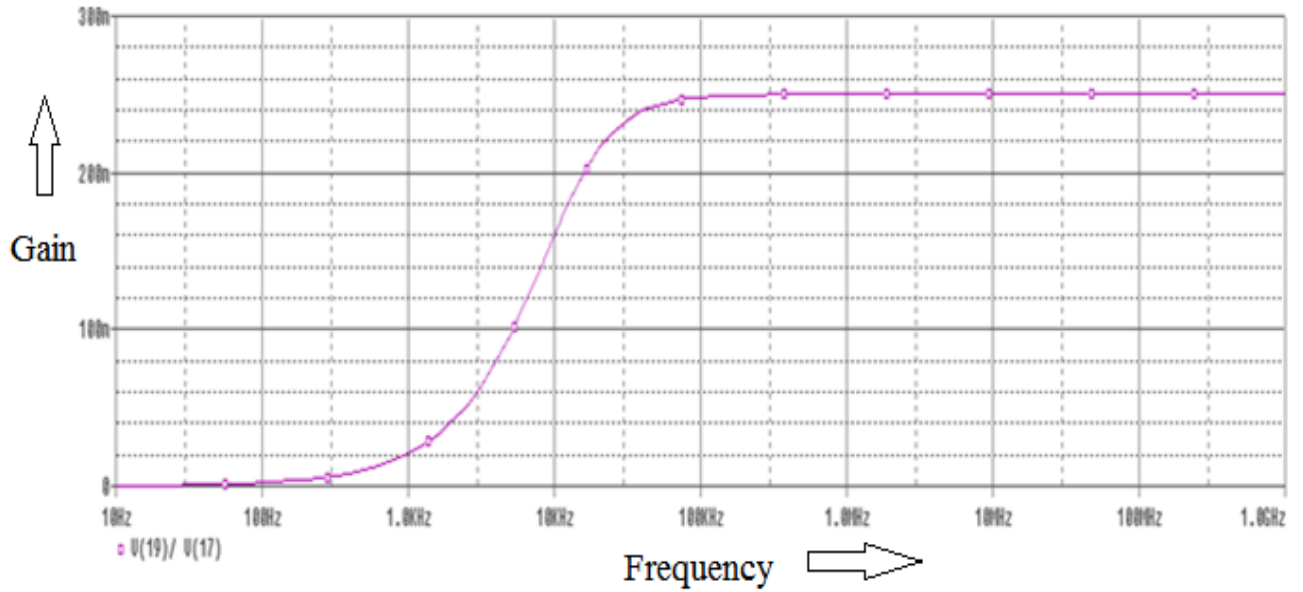Fig.5.20 Frequency response of 3rd order high pass filter

5.3.3 FOURTH ORDER HIGH PASS FILTER USING CDBA:

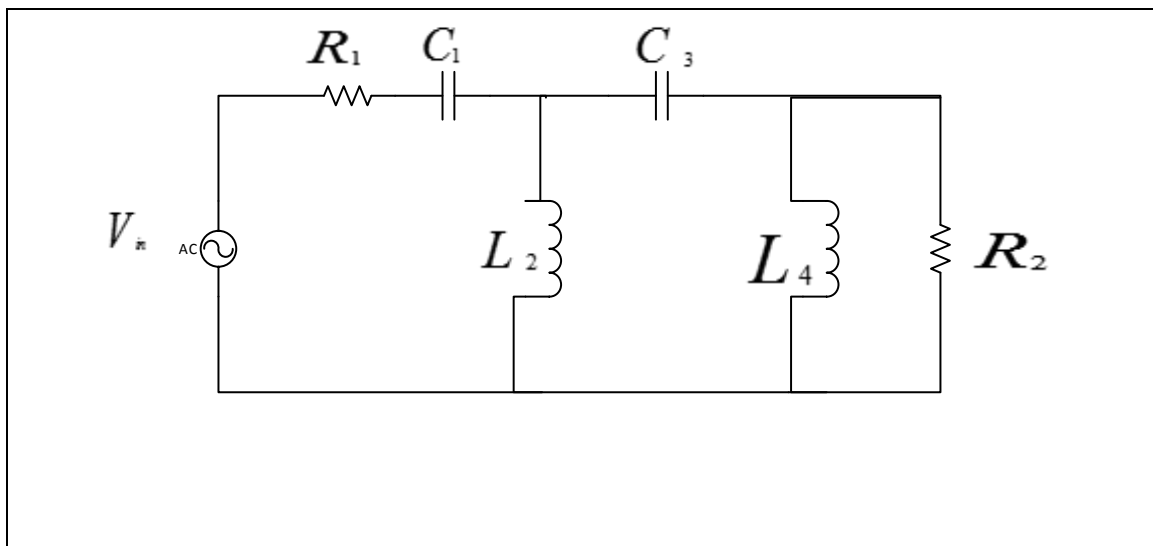A fourth order passive ladder filter configuration is shown in Fig.5.21

Fig.5.21 4th order high pass filter passive ladder prototype [33]

The transfer function of the filter is as follows:

$$\frac{V_o}{V_{in}} = \cfrac{s^4 C_1 L_2 C_3 L_4}{\begin{aligned}&s^4(C_1 L_2 C_3 L_4 + G_2 R_1 C_1 L_2 C_3 L_4) + s^3 \begin{pmatrix} R_1 C_1 L_2 C_3 + G_2 L_2 C_3 L_4 + \\ G_2 C_1 L_2 L_4 + R_1 C_1 C_3 L_4 \end{pmatrix} + \\ &s^2(L_2 C_3 + C_1 L_2 + C_3 L_4 + G_2 R_1 C_1 L_4) + s(R_1 C_1 + G_2 L_2) + 1\end{aligned}}$$

The active filter using CDBA corresponding to this ladder circuit is shown in Fig.5.22
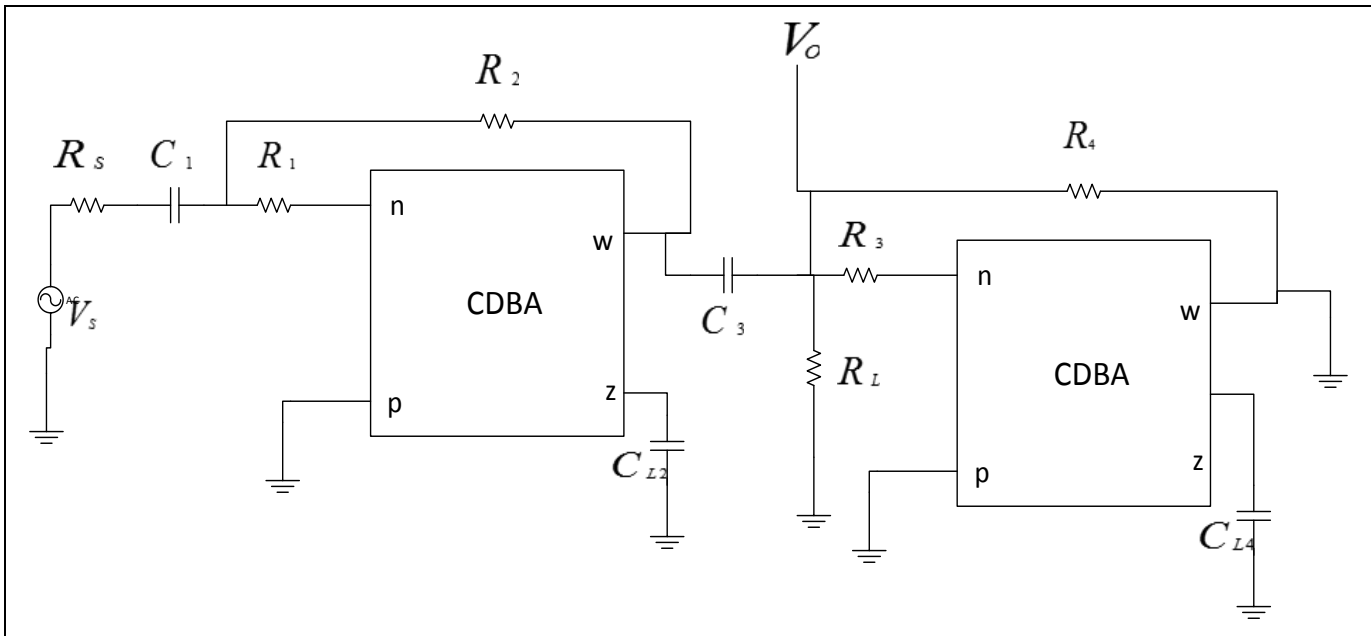

Fig.5.22 4th order high pass active filter using CDBA

The PSPICE code to simulate the above circuit is as follows:

.LIB AD844.LIB

X1 1 2 3 4 5 6 AD844

X2 7 6 3 4 8 9 AD844

X3 10 11 3 4 12 13 AD844

X4 14 13 3 4 15 16 AD844

48

V+ 3 0 DC 12V

V- 0 4 DC 12V

IS 17 0 AC 10U

RS 17 0 1K

R1 17 6 1K

R2 17 8 1K

CL1 9 0 2P

C2 8 18 1P

R3 18 13 1K

R4 18 15 1K

CL3 16 0 2P

RL 19 0 1K

C4 18 19 1P

VW 15 0 0V

.AC DEC 10 10 100K

.PROBE

.OP

.END

The values of components which were selected to realize this fourth order high pass filter using CDBA are $R_1 = R_2 = R_3 = R_4 = R_s = R_L = 1K$, $C_{L2} = C_{L4} = 2pF$ and $C_1 = C_3 = 1pF$. The simulated output result is shown in Fig.5.23. The cut off frequency of the circuit is found as 9.64 KHz.

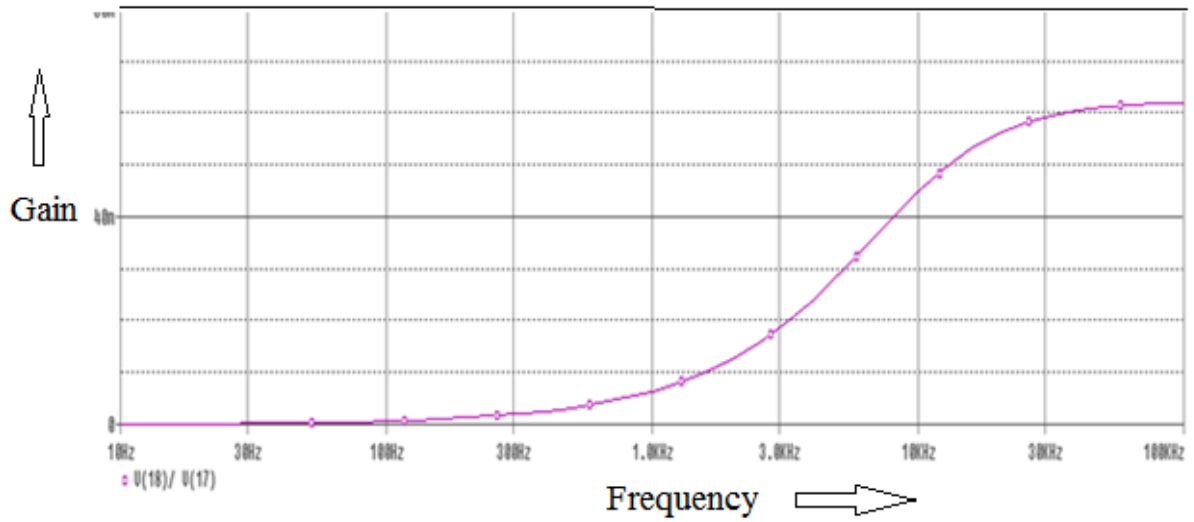Fig.5.23 Frequency response of 4th order high pass filter

5.3.4 FIFTH ORDER HIGH PASS FILTER USING CDBA:

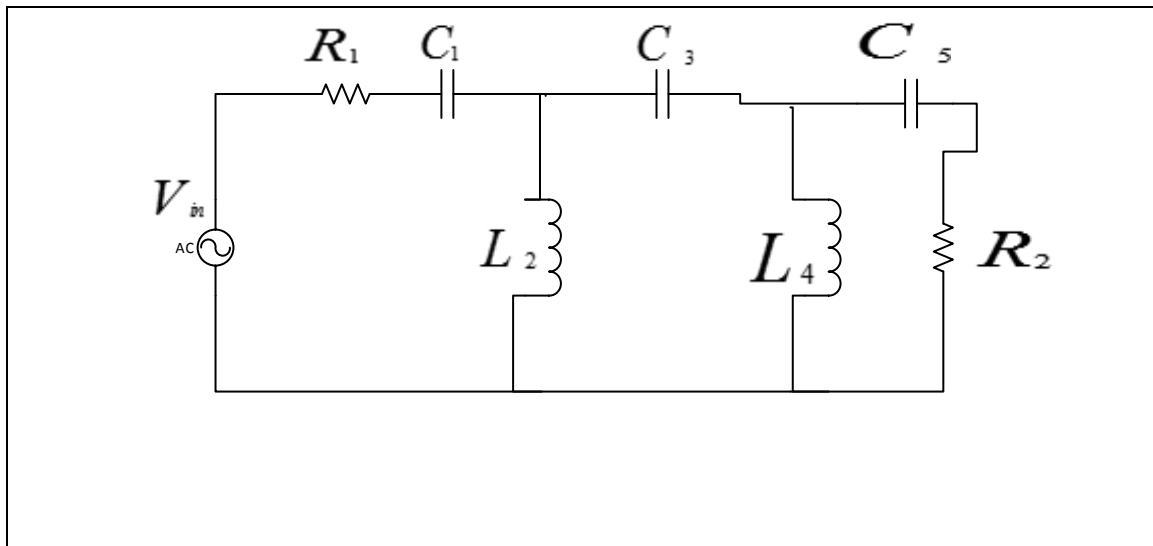A fifth order ladder passive filter configuration is shown in Fig.5.24

Fig.5.24 5th order high pass filter passive ladder prototype [33]

The transfer function of the filter is as follows:

$$\frac{V_o}{V_{in}} = \frac{s^2 C_1 L_2 C_3 L_4 C_5}{\begin{array}{c} s^5(C_1 L_2 C_3 L_4 C_5 + R_1 G_2 C_1 L_2 C_3 L_4 C_5) + s^4(R_1 C_1 C_3 L_4 C_5 + \\ R_1 C_1 L_2 C_3 C_5 + G_2 L_2 C_3 L_4 C_5 + G_2 C_1 L_2 L_4 C_5 + G_2 C_1 L_2 C_3 L_4) \\ + s^3(C_3 L_4 C_5 + L_2 C_3 C_5 + R_1 G_2 C_1 L_4 C_5 + R_1 G_2 C_1 C_3 L_4 + \\ R_1 G_2 C_1 L_2 C_3 + C_1 L_2 C_5) + s^2(R_1 C_1 C_5 + G_2 L_4 C_5 + G_2 C_3 L_4 + \\ G_2 L_2 C_3 + G_2 C_1 L_2) + s(C_5 + R_1 G_2 C_1) + 1 \end{array}}$$

The active filter using CDBA corresponding to this ladder circuit is shown in Fig.5.25
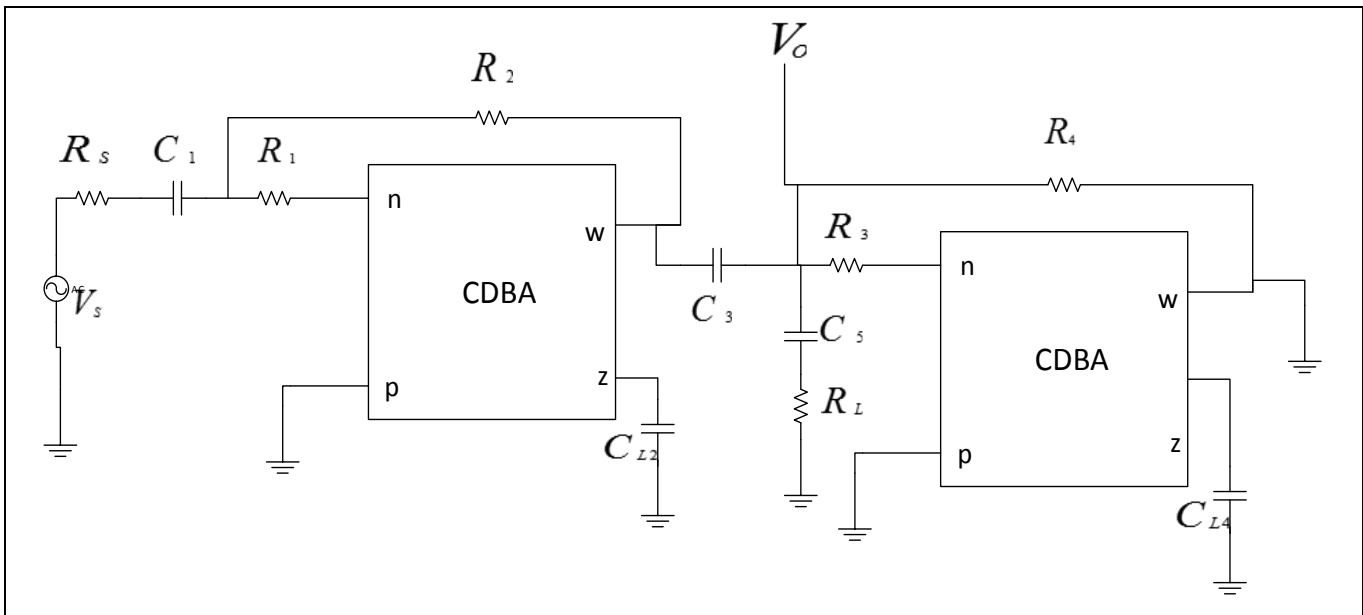
Fig.5.25 5th order high pass active filter using CDBA

The PSPICE code to simulate the above circuit is as follows:

.LIB AD844.LIB

X1 0 0 3 4 0 0 AD844

X2 0 0 3 4 1 2 AD844

X3 0 0 3 4 0 0 AD844

51

X4 0 0 3 4 0 9 AD844

V+ 3 0 DC 12V

V- 0 4 DC 12V

IS 6 0 AC 10U

RS 6 0 10

C1 6 5 1U

R1 5 0 10

R2 5 1 10

C3 1 7 1U

CL2 2 0 2U

R3 7 0 10

R4 7 0 10

CL4 9 0 2U

C5 7 8 1U

RL 8 0 10

.AC DEC 10 10 100G

.PROBE

.OP

.END

The values of components which were selected to realize this fifth order high pass filter using CDBA are $R_1 = R_2 = R_3 = R_4 = R_s = R_L = 10\Omega$, $C_{L2} = C_{L4} = 2\mu F$ and $C_1 = C_3 = C_5 = 1\mu F$. The simulated output result is shown in Fig.5.26 The cut off frequency of the circuit is found as 8.102 KHz.

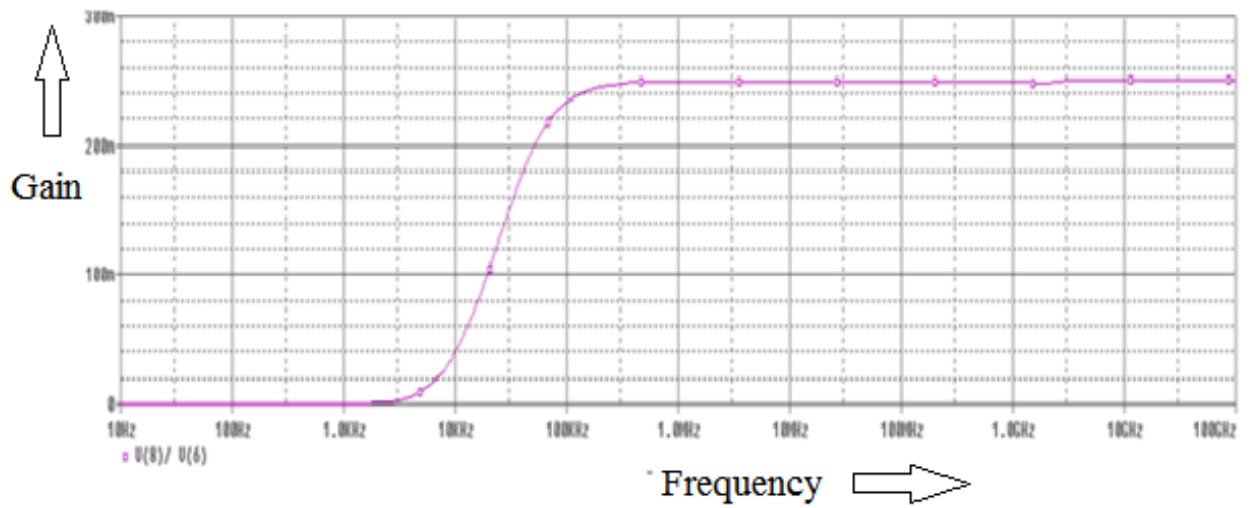Fig.5.26 Frequency response of 5th order high pass filter

5.3.5 COMPARATIVE ANALYSIS OF HIGH PASS FILTERS

2nd Order $>$ 3rd Order $> 4^{th}$ Order $> 5^{th}$ Order

19.08KHz $>$ 12.064KHz $>$ 9.64KHz $>$ 8.102KHz

CHAPTER 6
CONCLUSION AND FUTURE SCOPES

6.1 CONCLUSION:

A new active building block i.e. CDBA is thus used to simulate a number of higher order filters. Previously the higher order filters using CDBA used more no of CDBA blocks like the third order filter implementation using three CDBA and the fifth order filter implementation using five CDBA but the circuits proposed here thus uses minimum no of CDBA like the third order implementation using single CDBA and the fourth and fifth order using only two CDBA. The proposed circuits are thus simulated using PSPICE and the simulation results are thus found satisfactory.

6.2 FUTURE SCOPES OF THE STUDY:

As the study shows the use of minimum number of CDBA the study can be used in future in the following ways:

1. For further designing of higher order filters like sixth, seventh or more using CDBA.
2. For the design of other circuits like oscillators, amplifiers etc. using minimum number of CDBA.
3. In the design of more complex structures in which filters are required because least no of active as well as passive components are used.

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