School of
Electronics and Communication Engineering

Mini Project Report

on

ACTIVE FILTER DESIGN - SECOND ORDER LOW PASS AND HIGH PASS

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Semester: V, 2023-2024

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K.L.E SOCIETY'S
KLE Technological University,
HUBBALLI-580031
2022-2023

SCHOOL OF ELECTRONICS AND COMMUNICATION ENGINEERING

CERTIFICATE

This is to certify that project entitled " **ACTIVE FILTER DESIGN - SECOND ORDER LOW PASS AND HIGH PASS** " is a bonafide work carried out by the student team of "**Yatirajgouda Patil - 01FE21BEC083, Pratham Naik - 01FE21BEC103, Prateek Shettar - 01FE21BEC081, Sarpabhushan Angadi - 01FE21BEC069** ". The project report has been approved as it satisfies the requirements with respect to the mini project work prescribed by the university curriculum for BE (V Semester) in School of Electronics and Communication Engineering of KLE Technological University for the academic year 2023-2024.

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ACKNOWLEDGMENT

We extend our heartfelt gratitude to the KLE Technological University, Hubballi, for providing us with the resources and infrastructure necessary to successfully complete our project, ”Active Filter Design: Second Order Low Pass and High Pass.” We are deeply indebted to our esteemed guide, Dr. Sujata Kotabagi, for entrusting us with this challenging and enriching project. Her invaluable guidance, expert insights, and unwavering support throughout the journey helped us achieve remarkable results. We also express our sincere appreciation to Dr. Suneeta V Budihal, Dean of the School of Electronics and Communication, for providing crucial direction and steering us towards an industrial-scale perspective. A special thanks goes to the Prakalp team for their valuable recommendations and timely assistance, which significantly enhanced our project. We are forever grateful to our guardians for their unwavering support and encouragement. Their faith in our abilities provided us with the strength and motivation to persevere through challenges and ultimately achieve success. Finally, we acknowledge and cherish the contributions of everyone who, directly or indirectly, supported us and contributed to the joy of completing this project.

- Yatirajgouda, Pratham, Prateek, Sarpabhushan

ABSTRACT

This study presents the design and simulation of a biquad active low-pass and high-pass filter employing a two-stage differential amplifier topology with a custom-designed operational amplifier. The proposed design utilizes switched capacitor circuits instead of traditional resistors, leveraging the advantages of switched capacitor technology, such as high precision and low sensitivity to process variations.The active filter architecture is implemented using Cadence Virtuoso in a 180nm technology node. Simulation results demonstrate the functionality and performance of the designed biquad active low-pass and high-pass filters. The filters exhibit desirable frequency response characteristics, including cutoff frequencies, passband gain, and stopband attenuation, meeting the specifications outlined for the project. The use of switched capacitor circuits enhances the filter's performance, providing improved linearity and noise rejection compared to conventional resistor-based designs.

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Chapter 1

Introduction

Active filters play a crucial role in modern electronic systems, providing essential signal processing capabilities for a wide range of applications including communications, audio processing, and instrumentation. Unlike passive filters, which rely on passive components such as resistors, capacitors, and inductors, active filters utilize active components such as operational amplifiers (op-amps) to achieve desired filtering characteristics.

In recent years, there has been a growing demand for active filters with improved performance, smaller footprints, and lower power consumption to meet the requirements of modern integrated circuits. One promising approach to address these demands is the integration of switched capacitor circuits into active filter designs. Switched capacitor circuits offer several advantages over traditional resistor-based circuits, including higher precision, reduced sensitivity to process variations, and the ability to implement complex filtering functions using digital control techniques.

This project focuses on the design and simulation of biquad active low-pass and high-pass filters using a two-stage differential amplifier topology integrated with custom-designed op-amp symbols. The design aims to leverage the benefits of switched capacitor technology to achieve superior filter performance while minimizing area and power consumption.

The selection of Cadence Virtuoso as the simulation platform and the use of a 180nm technology node enable accurate modeling and characterization of the proposed active filter designs. Through careful component sizing, circuit configuration, and compensation techniques, the active filters are optimized to meet specific frequency response requirements and performance metrics.

The integration of a custom-designed op-amp symbol tailored to the active filter topology ensures efficient signal processing and optimal performance. By replacing traditional resistor elements with switched capacitor circuits, the active filters exhibit enhanced linearity, noise rejection, and versatility, making them well-suited for a variety of analog signal processing applications.

1.1 Motivation

As second-order filters, universal biquadrate filters often provide five filtering functions—low-pass (LP), band-pass (BP), high-pass (HP), band-stop (BS), and all-pass (AP) transfer functions—with a single topology. Biquadrate filters find application in electronic and communication systems, including cross-over networks for three-way, high-fidelity loudspeakers, touch-tone telephone tone decoders, and phase-locked loops (PLL). Additionally, it is commonly recognized that these filters fall into one of three categories: multiple output single input (MISO), multiple input multiple output (MIMO), or single input multiple output (SIMO). Each output terminal of a SIMO filter can produce filtering functions like LP, BP, HP, BS, and AP when a single signal is applied at the filter's input. As a result, a SIMO filter can produce the output for several filtering functions without requiring extra circuitry or altering the input terminal. Regretfully, if five common filtering functions are used, a SIMO filter typically needs multiple active and passive components. Since the filtering function of MISO and MIMO filters is chosen by properly applying the input signals and/or choosing the output signals, they require less active and passive components than SIMO filters. However, more summation and subtraction amplifiers are necessary if five filtering operations are desired. This requirement is challenging, particularly for voltage-mode (VM) filters that need to use multiple passive components as addition and subtraction voltage amplifiers. Thankfully, current-mode (CM) filters do not have this issue because it is simple to implement the summing and subtraction of currents. Furthermore, multiple-output current mirrors make it simple to implement many copies of an input signal.

1.2 Objectives

The objectives of this project are outlined to guide the systematic development and evaluation of the designed biquad active low-pass and high-pass filters. The primary goals encompass both technical and practical aspects, aimed at achieving a comprehensive understanding of active filter design principles and their application in real-world scenarios.

a. Design and Implementation of Biquad Active Filters:

The foremost objective is to design and implement biquad active filters capable of performing low-pass and high-pass filtering functions. This involves selecting appropriate circuit topologies, component values, and operational amplifier configurations to achieve the desired filter characteristics, including cutoff frequencies, passband ripple, and stopband attenuation.

b. Integration of Two-Stage Differential Amplifier Topology:

The project aims to incorporate a two-stage differential amplifier topology into the active filter design to enhance filtering performance and signal fidelity. This involves analyzing the advantages of differential amplifiers in terms of common-mode rejection, gain bandwidth product, and distortion characteristics, and integrating them effectively into the filter architecture.

c. Custom Op-Amp Symbol Design:

To optimize the performance and efficiency of the active filters, custom operational amplifier symbols will be designed to match the specific requirements of the filter topology. This includes considerations such as input impedance, output impedance, slew rate, and bandwidth, ensuring compatibility with the overall filter design and simulation environment.

Utilization of Switched Capacitor Technology:

d. The project aims to leverage switched capacitor circuits as a viable alternative to traditional resistor-based implementations, offering advantages such as improved linearity, reduced sensitivity to process variations, and enhanced flexibility in filter design. The use of switched capacitor technology will be explored to optimize filter performance while minimizing area and power consumption.

e. Simulation and Verification Using Cadence Virtuoso:

The active filter designs will be simulated and verified using Cadence Virtuoso in a 180nm technology node. Simulation results will be analyzed to validate the functionality, stability, and performance of the designed filters across a range of operating conditions, ensuring compliance with project specifications and design objectives.

f. Performance Evaluation and Analysis:

Finally, the project aims to evaluate the performance of the designed active filters in terms of key metrics such as frequency response, phase response, noise performance, and dynamic range. Comparative analysis with existing filter designs and theoretical predictions will be conducted to assess the effectiveness and practical utility of the proposed approach.

1.3 Literature survey

The buffered CMOS two stage op-amp, which uses 180nm and 45nm processes for design and analysis of CMOS two stage op-amp, is presented in the publication "Design and Analysis of CMOS Two Stage OP-AMP in 180nm and 45nm Technology." maintaining a constant input common mode ratio, 1.8V power supply, 20µA bias current, aspect ratio W/L, and 20V/µs slew rate. Measured is the trade-off between a number of factors, including power consumption, phase margin, gain bandwidth product, and open loop gain. It has been shown that recent advancements in transistor size scaling result in a corresponding decrease in power dissipation within the device. Cadence design tools were used to complete this design.[1].

A two-stage CMOS Op-amp design with a miller capacitor, nulling resistor, and common-gate current buffer for frequency compensation is introduced in the 2020 publication "Design Method for Two-Stage CMOS Operational Amplifier Applying Load or Miller Capacitor Compensation." Equations related to phase margin, power dissipation, gain, slew rate, and phase margin were utilized to establish design parameters. The design was verified by HSPICE simulations, which confirmed the high unity-gain, broad input common-mode range, appropriate gain bandwidth, and workable slew rate. [2].

Operational amplifiers (Op-Amps) can assist in the construction of fully differential circuits for the purpose of creating high gain and power analog components. Two steps of input voltage amplification can be included in the design of the Op-Amp. By including ideas like cascade, CS amplifier, and other similar ones, the two stage Op-Amp features can be enhanced. As technology is scaling down, the Op-Amp design for high speed applications demands appropriate selection of biasing, logic style, and CS amplifier. By including the CS Amplifier, the performance metrics of this basic Op-Amp can be enhanced. Using Cadence's comprehensive custom design suite for 90nm technology, the OpAmps are developed for both single operational amplifier and CS amplifier applications with gain improvement. [3].

S. Saini, H. Rana and P. Bhulania presented low power novel universal biquad filter design, where the universal Biquad filter using GmC has been proposed and implemented on 180 nm CMOS technology.State variable filters treat both the signal and its derivatives as variables and offer a generic systematic approach to the active filter design process. All three major parameters (gain, Q and omega) can be adjusted independently, and low-pass, high-pass, and band-pass outputs are available simultaneously[4].

This thesis[5] presents and simulates a detailed comparison of several OTAs using the corresponding small signal models in 180nm CMOS technology. Utilizing Op Amp-RC and Gm-C integrators with ladder synthesis and biquad, respectively, a passive Butterworth filter has been built. Tanner v.14.1 software has been used to produce transistor level simulation based on Gm-C biquad, while Op amp-RC integrators are simulated in the Multisim Environment. While the Gm-C integrator based filter delivers 85 MHz and a pass band gain of 0 dB, the Opamp-RC based filter has a band width of 425 kHz. With a 1.8V DC supply, the Gm-C filter dissipates 4.3mW of power overall.

In the book, 'MOS Switched-Capacitor and Continuous-Time Integrated Circuits and Systems' by Analysis and Designwe describe two large classes of analog integrated circuits: switched capacitor (SC) networks and continuous-time CMOS (unswitched) circuits. SC networks are sampled-data systems in which electric charges are transferred from one point to another at regular discrete intervals of time and thus the signal samples are stored and processed. Other circuits are charge transfer devices (CTD) and charge coupled dev ices (CCD). In contrast to SC circuits, continuous-time CMOS circuits operate continuously in time[6].

1.4 Application

One essential and significant method in signal processing is filtering. With the use of filtering technology, one may separate out undesired interference signals and extract the desired signal from a variety of signals. When analyzing a signal's frequency domain, a filter is a crucial component.

a. Communications Industry:

The communication power distribution system's UPS usage capacity has considerably expanded to accommodate the operational requirements of large-scale data center equipment rooms. The switching power supply, inverter air conditioner, UPS, and other equipment are the primary harmonic source components of the communication low-voltage power distribution system, according to the survey. These harmonic source devices have a very high displacement power factor and a high harmonic content. Active filters can be used to increase the stability of power distribution and communication systems, prolong the life of power and communication equipment, and better align the power distribution system with harmonic environment design specifications.

b. Semiconductor Industry:

The majority of semiconductor companies have extremely dangerous triple harmonics, mostly as a result of the numerous single-phase rectifiers that are employed in business. The triple harmonics are a part of the zero-order harmonic family, which is characterized by accumulating in the neutral line, which raises the pressure in the neutral line, and even sparking, which poses serious risks to production safety. Moreover, triple harmonics have the potential to trip the circuit breaker, which would delay production. The transformer ages more quickly as a result of the triple harmonics creating a circulation inside the device. Equipment in power distribution systems will eventually experience reduced durability and efficiency due to severe harmonic pollution.

c. DC Motor Harmonic Control:

Large DC motor locations require rectification equipment to convert AC power to DC power. Due to the high load capacity of these projects, there is significant harmonic pollution on the AC side, which can lead to voltage distortion and, in extreme situations, accidents. the application of precise machinery and automated production lines. Harmonics can interfere with the regular operation of automated manufacturing lines and precision machinery, leading to malfunctions in PLC and intelligent control systems, among other systems.

d. Speech Signal Processing:

One of the initial applications of digital filters and an early driver of the advancement of digital signal processing theory was speech processing. The voice signal's waveform properties, statistical properties, model parameters, etc. are all computed and examined. utilizing speech-generating software on a general-purpose computer. identifying the speaker or recognizing the words they utter using specialized hardware or a computer. It is possible to separate the masked voice signal from interference or noise. Speech coding is used to compress voice data. A number of international standards have been established for speech coding, which is extensively utilized in audio processing and communication.

Chapter 2

System design

Any electronic and communication system that modifies the frequency-dependent amplitude and/or phase properties of a signal needs filters as fundamental components. A filter is essentially a linear circuit that helps to eliminate undesirable elements from the input signal, such as noise, interference, and distortion. The ideal filter modifies the phase properties and the relative amplitudes of the different frequency components; its "Gain" is solely dependent on the signal frequency.

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 frequencies.

The voltage transfer function $H(s)$ of a Filter Circuit is written as:

$$H(s) = \frac{V_{\text{out}}(s)}{V_{\text{in}}(s)}$$

Where:

$$\begin{aligned} V_{\text{out}} &= \text{Output voltage} \\ V_{\text{in}} &= \text{Input Voltage} \\ s &= \text{Complex Frequency} \end{aligned}$$

By replacing the variable s in the above equation with $j\omega$, where j is equal to $\sqrt{-1}$ and ω is the radian frequency $(2\pi f)$, we can find the filter's effect on the Magnitude and Phase of the Input signal.

Transitioning from Passive to Active Filters:

Passive filters, consisting primarily of resistors, capacitors, and inductors, are widely used in electronic circuits to shape or manipulate signals. They are relatively simple in design and implementation, and they perform essential filtering functions such as low-pass, high-pass, band-pass, and band-stop filtering. Passive filters are advantageous for their simplicity, low cost, and ease of integration into circuits.

However, despite their advantages, passive filters have inherent limitations that sometimes make them unsuitable for certain applications. One significant drawback is the reliance on inductors. While inductors are crucial components for many circuits, they present several challenges. Firstly, inductors tend to be bulky and heavy, making them impractical for applications where size and weight are critical factors. Secondly, inductors are susceptible to temperature variations and environmental conditions, which can affect their performance and stability. Moreover, the design and implementation of inductors require careful consideration of factors such as core material, wire gauge, and winding configurations, which can complicate the manufacturing process and increase costs.

To overcome these limitations and address the evolving needs of electronic systems, active filters emerged as a viable alternative to passive filters. Active filters leverage operational amplifiers (op-amps) to achieve filtering functions without the need for bulky inductors. Op-amps offer several advantages over traditional passive components. They are compact, lightweight, and highly versatile, allowing for the implementation of complex filtering topologies in a relatively small footprint. Op-amps also exhibit excellent performance characteristics, such as high input impedance, low output impedance, and wide bandwidth, making them well-suited for a wide range of filtering applications.

By replacing inductors with op-amps, active filters offer improved performance, reliability, and flexibility compared to their passive counterparts. They can be easily configured and adjusted to meet specific design requirements, and they exhibit superior stability and precision across varying operating conditions. Additionally, active filters can provide higher order filtering capabilities and sharper roll-off characteristics, enabling more precise signal processing and noise rejection.

2.1 Functional block diagram

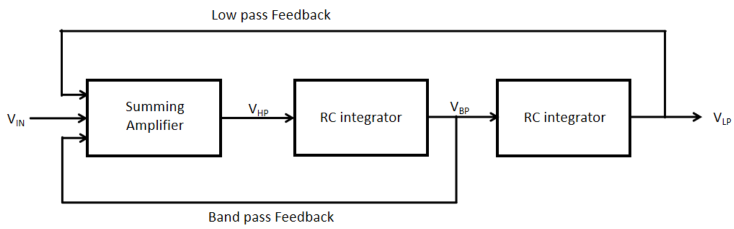

Figure 2.1: Block diagram of universal biquad filter

Summing Amplifier (Input Stage):

- The summing amplifier combines the input signal with the feedback signals from the low-pass and band-pass filter stages.
- It is represented by a node where all the signals are summed.

RC Integrators (Two Stages):

- Each RC integrator represents a stage of filtering.
- The RC integrators implement the necessary frequency-dependent behavior for the filter.
- The first RC integrator typically represents the low-pass filter behavior, while the second RC integrator represents the band-pass filter behavior.

- The transfer function of each RC integrator is given by the equation of an RC circuit, which is a first-order low-pass filter:

$$H(s) = \frac{1}{1 + RCs}$$

where s is the Laplace variable and R and C are the resistance and capacitance values, respectively.

Low-pass Feedback:

- The output of the second RC integrator is fed back to the input of the first RC integrator to provide low-pass feedback.
- This feedback reinforces the low-pass filtering behavior of the circuit.
- The transfer function of the low-pass feedback loop depends on the gain of the operational amplifier used in the integrator and the feedback resistance and capacitance. It is typically represented as:

$$H_{\text{LPF\_feedback}}(s) = \frac{R_f}{R_f + R_i}$$

where:

  - R_f is the resistance in the feedback path.
  - R_i is the input resistance of the operational amplifier.

This transfer function determines the strength of the low-pass feedback, which reinforces the low-pass filtering behavior of the circuit.

Band-pass Feedback:

- The output of the second RC integrator is also fed to a band-pass filter stage.
- This band-pass filter enhances the band-pass characteristics of the biquad filter.
- The transfer function of the band-pass feedback loop depends on the design of the band-pass filter stage. It can vary based on the specific implementation and requirements of the filter.

  For a simple band-pass feedback stage, the transfer function may be represented as:

$$H_{\text{BPF\_feedback}}(s) = \frac{R_{fb}}{R_{fb} + R_{in}}$$

where:

  - R_{fb} is the resistance in the band-pass feedback path.
  - R_{in} is the input resistance of the band-pass filter stage.

This transfer function determines the strength of the band-pass feedback, which enhances the band-pass characteristics of the biquad filter.

Output:

- The output of the filter is taken from the second RC integrator or from the band-pass filter stage, depending on the desired output characteristics.

This captures the flow of signals through the various stages of the universal biquad filter, incorporating low-pass and band-pass feedback to achieve the desired filtering characteristics. The specific transfer functions and equations for the filter depend on the component values and circuit configurations chosen for the RC integrators, summing amplifier, and feedback loops.

2.2 Design alternatives

a. Sallen-key topology

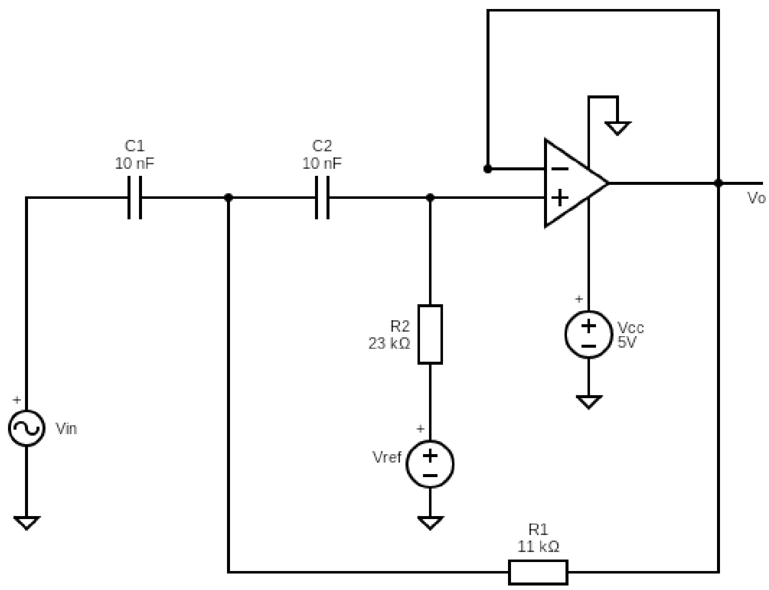

Figure 2.2: Second order high pass active filter with sallen-key topology

- The Sallen-Key topology is a popular choice for designing second-order low-pass filters.
- It offers simplicity and flexibility in component values
- It uses operational amplifiers and passive components such as resistors and capacitors.

b. Multiple feedback topology

- The MFB topology is another option for implementing second-order low-pass filters.
- It offers good performance with fewer components compared to the Sallen-Key topology.
- It also employs operational amplifiers and passive components.

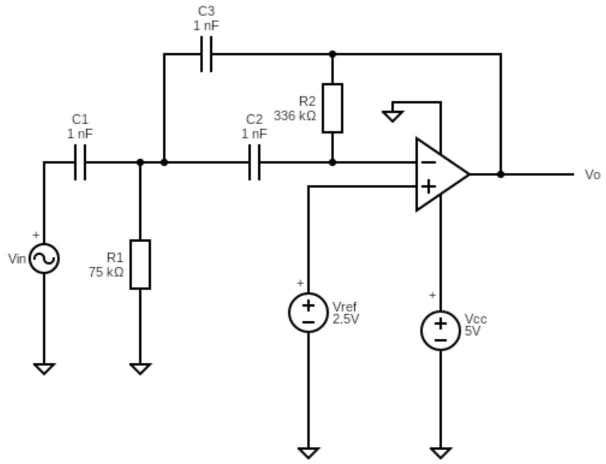

Figure 2.3: Second order high pass active filter with multiple feedback topology

2.3 Final design

State-variable filter

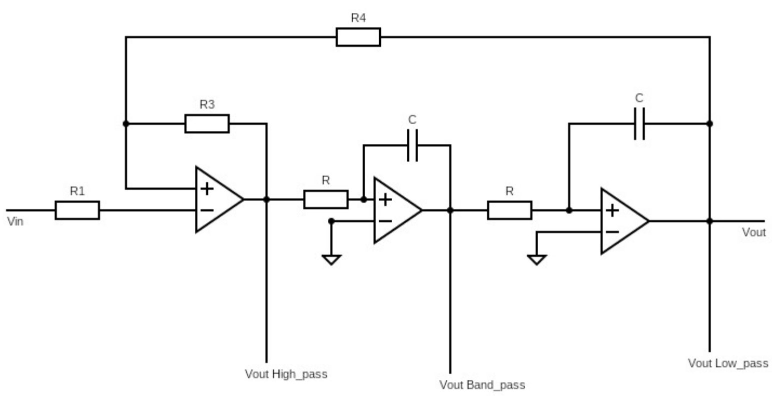

Figure 2.4: Block diagram of universal biquad filter

- The state variable filter offers several filter responses (low-pass, high-pass, band-pass, etc.) in a single configuration.
- It utilizes multiple operational amplifiers and passive components.
- It allows for easy control of filter parameters such as bandwidth and quality factor.

Chapter 3

Implementation details

3.1 Specifications

3.1.1 Two stage Op-amp Design

We employ two-stage amplifiers to achieve higher gain than what a single amplifier can provide, as well as to mitigate amplifier noise.

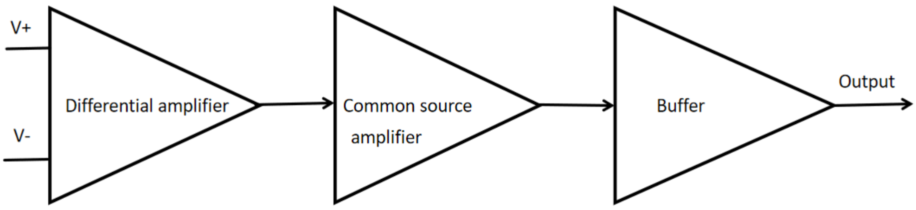

Figure 3.1: Two-stage amplifier

Process = 180nm (VDD = 1.8V)
DC gain = 1000 (60 dB)
PM $\leq$ 60°
SR = 20V/μs
ICMR+ = 1.6V
ICMR- = 0.8V
CL = 2μf
Power $\leq$ 300μw
GBW = 30 MHz

1. L = 500nm

2. $C_c \geq$ 0.22CL
   $C_c \geq$ 440fF
   Including the effect (Disturbance of parasitic)
   $C_c \geq$ 800fF let

3. Deciding Is
   SR = $\dfrac{I_s}{C_c}$

$$I_5 = \left(\frac{20V}{1\mu s}\right)(800\text{fF})$$

$I_5 = 16\mu A$

Let $I_5 = 20\mu A$ (For better Slew rate)

4. Design of M1,M2

   $g_{m1} = \frac{(GBW)C_c \times 2\pi}{(30\text{MHz}) \times (800}\text{fF}) \times 2\pi$

   $g_{m1} = 150.79\mu s$

   $g_{m1} = 160\mu s$

   Now from $g_{m1} = \sqrt{2I_{D1} \times (\mu_n C_{ox} \times \frac{W}{L})}$

   $\frac{1}{(W/L)_{1,2}} = \frac{g_{m1}^2}{2\mu_n C_{ox}^2 \times (I_2 s)}$

   as $I_{D1} = I_{25}$

   $\left(\frac{W}{L}\right)_{1,2} = 4.266$

5. Designing of M3,M4

   For M1 to be in Saturation

   $|Vin| \leq Vd1 + VT1$

   $Vd1 = VDD - Vsg3$

   where

   $Vd1 = V_{DD} - \left\{\sqrt{\frac{2I_{\beta 3}}{3}} + |V_T|\right\}$

   $Vin \leq |VD1 + VT1|$

   $ICMR+ \leq VD1 + VT1$

   $ICMR+ \leq V_{DD} - \sqrt{\frac{2ID3}{\beta 3}} - |VT3| + |VT1|$

   $\left(\frac{W}{L}\right)_{3,4} = \frac{2ID3}{\mu_n C_{ox}[V_{DD} - ICMR + -VT3 + VT1]}$

   So $\left(\frac{W}{L}\right)_{3,4} = 13.02$ or $\left(\frac{W}{L}\right)_{3,4} = 14$

6. Design for M5

   For M5 to be in saturation

   $Vin \geq Vgs1 + VDsat5$

   $ICMR- \geq Vgs1 + VDsat5$

   $ICMR- \geq [\sqrt{\frac{2ID1}{\beta 1}} + VT1] + VDast5$

   Or

   $VDast5 \leq ICMR - -[\sqrt{\frac{2I_{D1}}{\beta 1}} + VT1]$

   From simulation $VT1 = 590\text{mV}$

7. Design of M6

   For PM=60o

   For M6 and M4 (Vgs6=Vgs4)

   $\left(\frac{W}{L}\right)_6 \left(\frac{W}{L}\right)_4 = \frac{I6}{I4} = \frac{Gm6}{Gm4}$

   $\left(\frac{W}{L}\right)_6 = \left(\frac{W}{L}\right)_4 \times \frac{Gm6}{Gm4} = 1600/129 \times 61/14 = 172.82$

   $\left(\frac{W}{L}\right)_6 \approx 173$

   Now

   $\frac{I6}{I4} = \left(\frac{W}{L}\right)_6 \left(\frac{W}{L}\right)_4$

$I6 = 124.28\mu A$ or $I6 = 125\mu A$

8. Design of M7
   $Vgs7 = Vgs5$
   So
   $\frac{I7}{I5} = \left(\frac{W}{L}\right)_7 \left(\frac{W}{L}\right)_5$
   $\left(\frac{W}{L}\right)_7 = 75$
   $I5 = 20\mu A$
   $C_c = 800\text{fF}$

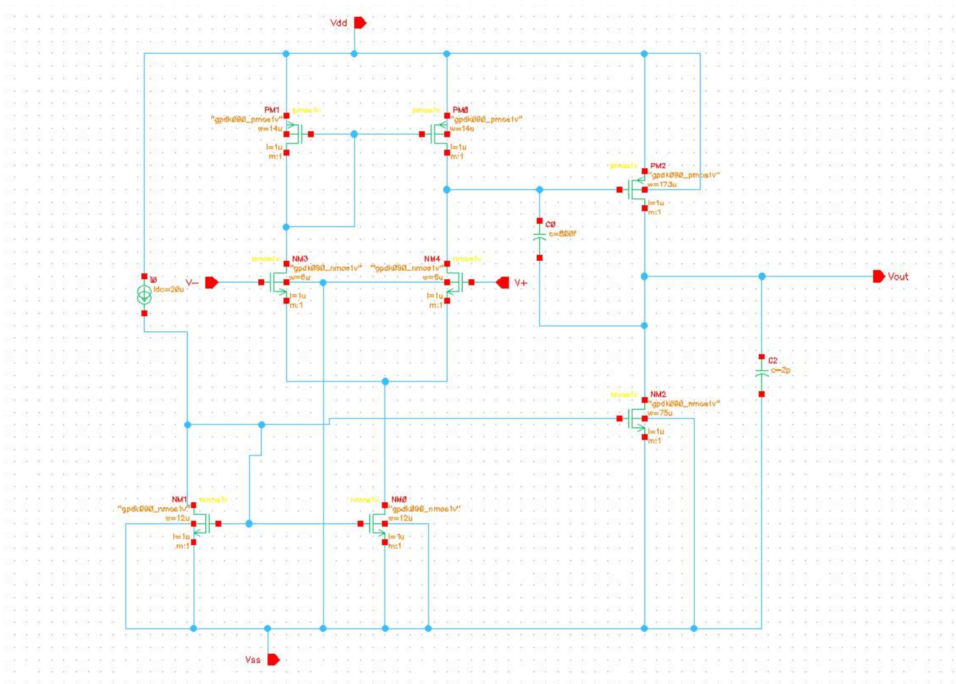

Figure 3.2: Two-stage amplifier schematic

Two-stage amplifiers represent a common architecture in integrated circuit design and are widely used due to their ability to provide higher gain and improved performance compared to single-stage amplifiers.At the heart of a two-stage amplifier lies the concept of cascading amplification stages to achieve desired performance characteristics. Each stage typically consists of a an amplifier coupled with a passive component capacitor for biasing.

In terms of operation, the first stage, often referred to as the input stage, is responsible for providing the initial amplification and impedance matching to the input signal. This stage sets the foundation for the overall amplification process and is designed to handle the incoming signal with minimal distortion. The second stage, known as the output stage, further amplifies the signal while providing necessary buffering and impedance matching to drive the load. This stage ensures that the amplified signal retains its integrity and can be efficiently transmitted to subsequent stages or output terminals.

3.2 Flowchart

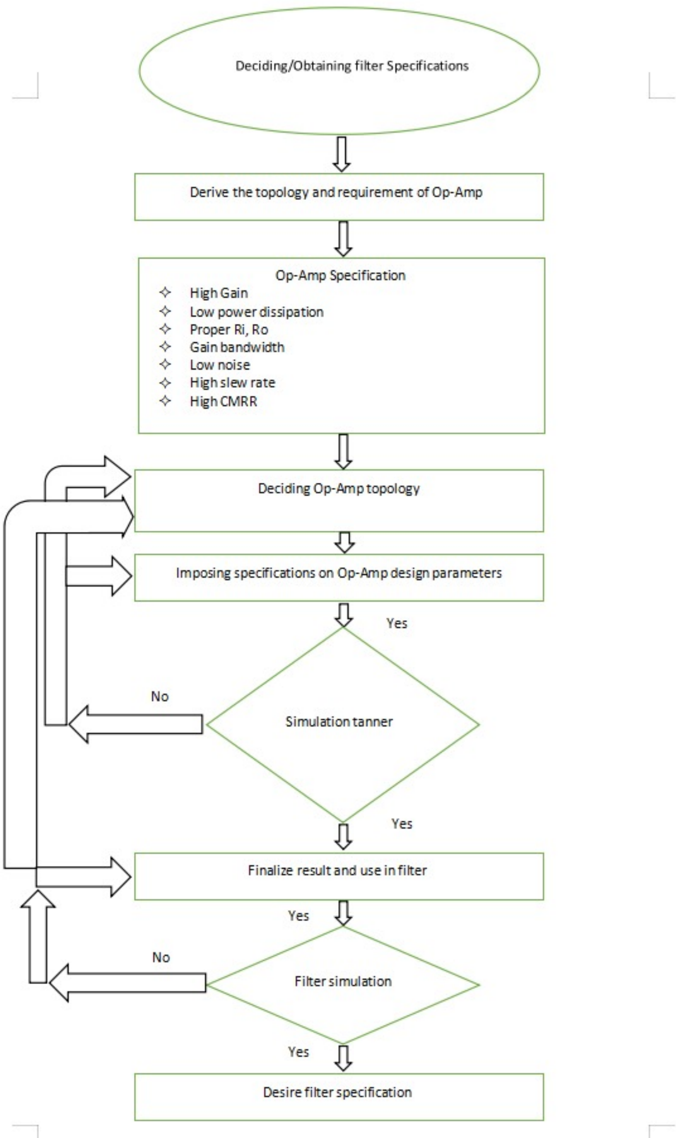

Figure 3.3: Flow chart of active filter design

The flowchart depicts the process of obtaining filter specifications. It starts with deriving the topology and requirements of an operational amplifier (op-amp). Based on these requirements, specifications are imposed on the op-amp's design parameters. If these specifications are met, then the op-amp topology is decided upon and the result is finalized for use in the filter. If not, then the process starts again from deriving the topology and requirements of the op-amp. Once the op-amp topology is finalized, a filter simulation is conducted. If the desired filter specifications are met, then the process is complete. If not, then the op-amp specifications are modified and the filter simulation is conducted again.

Chapter 4

Optimization

4.1 Introduction to optimization

In VLSI technology, integrating resistors with large values onto a chip poses challenges. To address this, alternative circuits such as switched capacitors are employed. This report presents the design of a low pass filter using switched capacitors and comparators. The switched capacitor comprises two switches and a capacitor, with an operational amplifier serving as the comparator. The switches, which can be NMOS, PMOS transistors or transmission gates, facilitate switching based on the clock driver output signal applied to their gate terminals. We examine the frequency response of low pass filters using pass transistors and transmission gates, calculating the cutoff frequency in each case using Cadence Virtuoso. Our observations reveal that the transmission gates exhibit superior roll-off compared to pass transistors. Additionally, the combination of PMOS and NMOS in the transmission gate configuration mitigates issues associated with reduced noise margin.

4.2 Types of Optimization

They are two ways in which the second order low pass and high pass filter can be designed using switched capacitor, they are:

Pass Transistor Configuration

In this approach, switched capacitors are integrated in series with two NMOS pass transistors. The pass transistors facilitate the switching action, controlling the flow of charge through the capacitors. This configuration is characterized by its simplicity and efficiency, making it suitable for various low pass and high pass filter applications.

Transmission Gate Configuration

Alternatively, switched capacitors can be paired with two CMOS transmission gates in series. Transmission gates offer bidirectional signal flow and improved linearity compared to pass transistors. This configuration is favored for its reduced charge injection, enhanced noise rejection, and superior bandwidth characteristics.

4.3 Selection and justification of optimization method

Transmission gates are often considered superior to pass transistors for certain applications, including switched capacitor-based filter designs, due to several key advantages:

1. **Improved Linearity**:
    - Transmission gates offer better linearity compared to pass transistors.
    - This is because transmission gates utilize complementary metal-oxide-semiconductor (CMOS) technology, which inherently provides symmetric switching characteristics and reduced distortion.
2. **Reduced Charge Injection**:
    - Charge injection, which refers to the unintentional transfer of charge between the switch terminals and the circuit nodes, is typically lower in transmission gates compared to pass transistors.
    - This is due to the symmetric nature of CMOS transmission gates, which helps minimize charge injection effects and improve signal integrity.
3. **Bidirectional Signal Flow**:
    - Transmission gates allow bidirectional signal flow, meaning they can pass signals in both directions with minimal distortion.
    - This feature is particularly advantageous for certain filter configurations and signal processing applications where bidirectional operation is required.
4. **Lower ON Resistance**:
    - Transmission gates typically exhibit lower ON resistance compared to pass transistors.
    - As a result, transmission gates introduce less voltage drop and attenuation when conducting signals, leading to improved signal fidelity and reduced insertion loss in filter circuits.
5. **Higher Bandwidth**:
    - Due to their improved linearity, reduced charge injection, and lower ON resistance, transmission gates are capable of operating at higher frequencies compared to pass transistors.
    - This makes them well-suited for high-speed and wideband filter applications where maintaining signal integrity and bandwidth is crucial.
6. **Isolation and Noise Rejection**:
    - Transmission gates provide better isolation between the input and output signals, resulting in improved noise rejection and signal-to-noise ratio compared to pass transistor-based circuits.
    - This helps preserve the integrity of the filtered signals and minimizes unwanted noise components.

Chapter 5

Results and discussions

5.1 Result Analysis

The two stage opamp is used as building block for the design of desired filter circuit.Opamp used as active element in the circuit.The symbol of opamp is shown below.

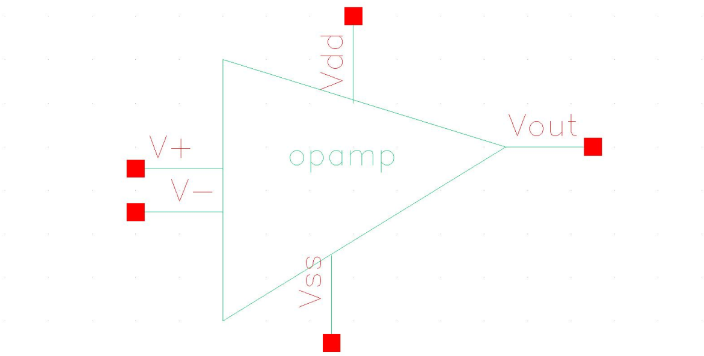

Figure 5.1: Symbol of two stage opamp.

The output of opamp is given below.

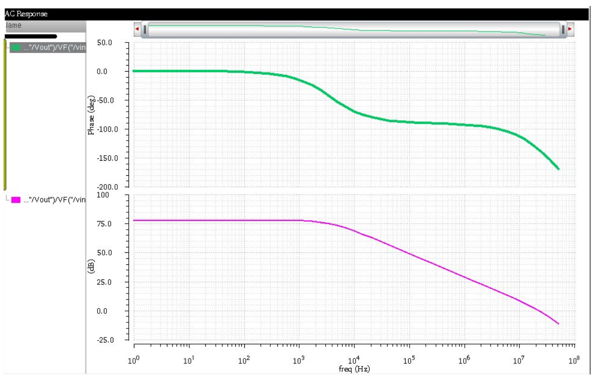

Figure 5.2: Open loop magnitude and phase vs frequency.

Taking into consideration the various operation performed by the filter circuit The result obtained is given below.

a. Low pass filter result

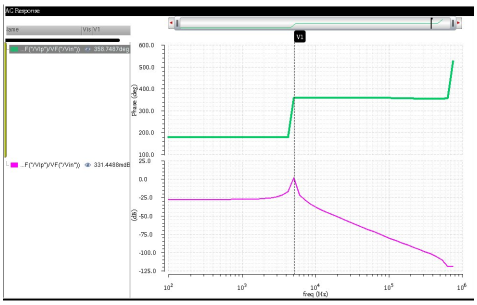

Figure 5.3: Low pass filter result.

b. High pass filter result

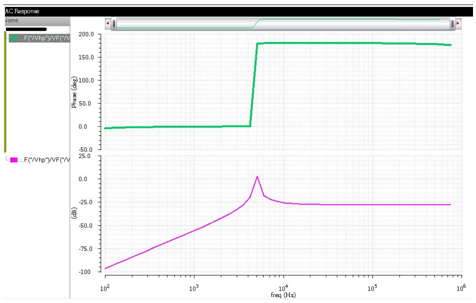

Figure 5.4: High pass filter result.

c. Bandpass filter result

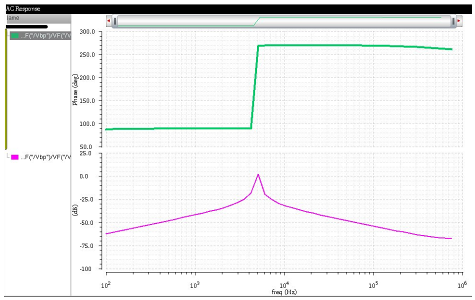

Figure 5.5: Band pass filter result.

Chapter 6

Conclusions and future scope

6.1 Conclusion

In conclusion, this project successfully designed and simulated a biquad active low-pass and high-pass filter employing a two-stage differential amplifier topology with a custom-designed operational amplifier. By adopting switched capacitor circuits instead of traditional resistors, the filters demonstrated superior performance, showcasing high precision and low sensitivity to process variations. The implementation in Cadence Virtuoso at a 180nm technology node yielded simulation results that met the specified project requirements for cutoff frequencies, passband gain, and stopband attenuation. The advantages of switched capacitor technology were evident, as the filters exhibited enhanced linearity and noise rejection compared to conventional resistor-based designs. This study highlights the efficacy of the proposed design in achieving the desired frequency response characteristics, thereby contributing valuable insights to the field of active filter design.

6.2 Future scope

The successful design and simulation of the biquad active low-pass and high-pass filter with switched capacitor circuits present promising avenues for future applications in various societal contexts. Here are some potential future scopes and applications:

Biomedical Signal Processing

The filters designed in this study can find applications in biomedical signal processing. For example, they could be incorporated into wearable devices or medical equipment to enhance the quality of physiological signal processing, aiding in tasks such as filtering out noise and unwanted frequencies from biomedical signals.

Communications Systems

The filters' precision and low sensitivity to process variations make them suitable for communications systems. Integration into communication devices, such as radios or modems, can help improve signal quality and reduce interference, ultimately enhancing the overall performance of communication networks.

Audio Processing and Music Production

In the field of audio engineering and music production, the designed filters could contribute to the development of high-quality audio processing equipment. This includes equalizers and audio filters that enhance the clarity and fidelity of sound, providing musicians and audio engineers with advanced tools for shaping and refining audio signals.

Sensor Networks

The filters can be integrated into sensor networks for applications like environmental monitoring or industrial automation. By ensuring precise signal filtering, these filters can improve the accuracy and reliability of sensor data, leading to more effective monitoring and control systems.

Wireless Sensor Networks for IoT

As the Internet of Things (IoT) continues to expand, the designed filters can be employed in wireless sensor networks to filter and process data from various sensors. This can improve the efficiency of IoT applications by enhancing the quality of information collected from the sensors.

Smart Grids and Power Electronics

In the realm of power electronics and smart grids, the filters can play a role in conditioning and filtering signals to ensure the stable and efficient operation of power systems. This can contribute to the development of more reliable and resilient energy distribution networks.

Radar and Sonar Systems

The precision and performance of the designed filters make them suitable for radar and sonar systems. Integration into these systems can improve target detection and tracking by filtering out unwanted signals and noise, enhancing the overall accuracy and reliability of these technologies.
In summary, the designed filters have the potential to make significant contributions across a wide range of societal applications, improving the efficiency, performance, and reliability of various systems and technologies. Further research and development in these areas can unlock additional possibilities for the practical implementation of these advanced filters.

Bibliography

[1] Design and Analysis of CMOS Two Stage OP-AMP in 180nm and 45nm Technology, International Journal of Engineering Research and Technology (IJERT), Vol. 4 Issue 05, May-2015

[2] Design method for two-Stage CMOS operational amplifier applying load/miller capacitor compensation, Sadeqi, Abolfazl and Rahmani, Javad and Habibifar, Saeed and Ammar Khan, Muhammad and Mudassir Munir, Hafiz, MPRA Paper No. 102931, posted 15 Sep 2020 17:34 UTC

[3] TWO STAGE OPERATIONAL AMPLIFIER USING 90nm TECHNOLOGY, 2018 IJCRT, Volume 6, Issue 2 April 2018, ISSN: 2320-2882

[4] S. Saini, H. Rana and P. Bhulania, "State Variable Universal Biquad GmC Filter Design and Comparative Study between Voltage and Current Modes in 180nm CMOS Process," 2021 8th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2021, pp. 237-241, doi: 10.1109/SPIN52536.2021.9565937

[5] UNIVERSAL BI-QUAD Gm-C BASED KHN FILTER DESIGN AND IMPLEMENTATION IN 180nm CMOS TECHNOLOGY, February 2020, DOI:10.13140/RG.2.2.21664.61442.

[6] DESIGN OF SWITCHED CAPACITOR FILTER WITH TRANSMISSION GATE SWITCHES, pp. 63–116, Dec. 2017, doi: 10.1201/9781420037869-2.

[7] Rolf Unbehauen, Andrzej Cichocki. "MOS Switched-Capacitor and Continuous-Time Integrated Circuits and Systems", Springer Science and Business Media LLC, 1989.

[8] K. Martin and A. S. Sedra, "Effects of the op amp finite gain and bandwidth on the performance of switchedcapacitor filters," IEEE Transactions on Circuits and Systems., vol. 28, pp. 822–829, 1981.

[9] R. Gregorian and G. C. Temes, Analog MOS Integrated Circuits G. C. Temes, "Finite amplifier gain and bandwidth effects in switched-capacitor filters," IEEE JOURNAL OF SOLID-STATE CIRCUITS., vol. 15, pp. 358– 361, 1980.

[10] C.-M. Chang, B. M. Al-Hashimi, and J. N. Ross, Unified Active Filter Biquad Structures," IEE Proc.-Circuits Devices Syst., vol. 151, No. 4, August 2004, pp. 273-277.

[11] B. Razavi, Fundamentals of Microelectronics, 2nd Edition, John Wiley, 2008.

[12] A. S. Sedra, K.C. Smith, Microlectronics Circuits, Oxford Publications, Ch. 11.