ANALOG FILTER DESIGN USING VDTA AS ACTIVE BUILDING BLOCK

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Submitted by:

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2K22/C&I/06

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It is certified that **Shivani Singh**, **2k22/C&I/06** has carried out their research work presented in this thesis entitled "**ANALOF FILTER DESIGN USING VDTA AS ACTIVE BUILDING BLOCK**" for the award of Master of Technology in Control & Instrumentation, Department of Electrical Engineering, Delhi Technological University, New Delhi under our supervision. The thesis embodies results of original work, and studies carried out by the students herself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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CANDIDATE'S DECLARATION

I, **Shivani Singh**, **2K22/C&I/06** student of M.Tech (Control & Instrumentation), hereby declare that the thesis entitled " **ANALOG FILTER DESIGN USING VDTA AS ACTIVE BUILDING BLOCK** " in partial fulfillment of the requirements for the degree of Master of Technology, submitted in Department of Electrical Engineering, Delhi Technological University, New Delhi is an authentic record of my own work and not copied from any source without proper citation which is carried out under the supervision of Dr. Garima and Dr. Bhavnesh Jaint.

Candidate's Signature

Place: Delhi

Date: May 2022

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ABSTRACT

This thesis investigates the design and implementation of analog filters employing the Voltage Differencing Transconductance Amplifier (VDTA) as the core active building block. VDTAs signify a notable advancement in analog signal processing, offering superior linearity, enhanced bandwidth, and improved power efficiency compared to conventional active elements such as operational amplifiers (op-amps). The research encompasses a comprehensive study of various analog filter topologies, including low-pass, high-pass, band-pass, and band-stop filters, emphasizing the VDTA's versatility and superior performance metrics.

The study is structured to include a detailed theoretical analysis and extensive simulation of VDTA-based filters. The theoretical analysis entails deriving the design equations and comprehending the operational principles of VDTAs in filter circuits. These models are subjected to rigorous validation through extensive simulations using advanced electronic design automation (EDA) tool like PSPICE. Simulation data are scrutinized to ensure the models' accuracy and to optimize the filter designs for practical deployment. Performance evaluation includes measuring key parameters such as frequency response, stability, noise characteristics, and power consumption. A significant finding of this research is the VDTA's capability to function efficiently at lower supply voltages, leading to reduced power consumption. The thesis further explores the integration of VDTA-based filters into broader analog signal processing systems, illustrating their potential to enhance overall system performance.

In conclusion, this research makes a significant contribution to the domain of analog filter design by presenting VDTA as a robust and efficient alternative to conventional methodologies. The findings substantiate the practical advantages of VDTA, paving the way for future innovations in analog signal processing. This work establishes a solid foundation for further exploration and application of VDTA in various analog circuit designs, promising enhanced performance, reduced power consumption, and increased versatility in modern electronic systems.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 FUNDAMENTALS OF FILTER DESIGN:

Filter design is a fundamental aspect of electronic circuitry, playing a vital part in a multitude of applications like communication systems, signal processing, and instrumentation. The ability to manipulate signals through filtering operations is essential for achieving desired performance and functionality in electronic devices. Traditional filter design techniques often rely on conventional active and passive components, which may pose limitations in terms of complexity, power consumption, and performance. A filter is a circuit that processes signals on a frequency-dependent basis. Filters are categorized based on their magnitude response as low pass(LP), high pass(HP), band pass(BP), and band reject or notch (BR) filters[1]. Another category includes AP filters, which manipulate phase while keeping the magnitude constant.

Filter design stands as a cornerstone in electronic circuitry, wielding significant influence across a spectrum of applications like communication systems, signal processing, and instrumentation. The ability to manage signals via filtering maneuvers is indispensable for achieving the desired efficacy and utility in electronic devices. Traditional methods of filter design often hinge on conventional utilization of both active and passive components. However, these approaches may encounter constraints concerning intricacy, power usage, and overall performance. In essence, a filter serves as a circuitry mechanism geared towards processing signals in accordance with their frequency attributes. Based on their response to magnitude, filters are categorized into distinct types, namely LP, HP, BP, and BR filters[1].

In the realm of electronic circuit design, filters serve as indispensable tools for signal processing, allowing engineers to manipulate signals according to specific frequency characteristics. While passive components like resistors, capacitors, and inductors traditionally have been used to construct filters, the emergence of active building blocks has revolutionized filter design by offering enhanced performance, flexibility, and efficiency. This chapter explores the principles, advantages, and methodologies involved in designing filters using active building blocks, shedding light on their significance in modern electronic systems. Filters constitute indispensable elements within electronic circuits used to selectively pass or attenuate signals based on their frequency content. They are utilized across a range of fields, spanning communication systems, audio manipulation, instrumentation, and control systems.

1.2 TYPES OF FILTERS:

Filters are grouped according to their frequency response characteristics into various types:

- Low-pass filters (LPF): These filters enable signals below a given cutoff frequency to pass, and attenuating higher frequencies.
- High-pass filters (HPF): They permit signals above a certain cutoff frequency to pass through, and suppressing lower frequencies.
- Band-pass filters (BPF): These filters pass signals within a certain frequency range, while suppressing frequencies outside this range.
- Band-stop filters or notch filters (BSF): They obstruct signals within a certain frequency band, and permitting frequencies outside this band to pass.
- All-pass filters (APF): An APF is a signal processing tool that permits all frequencies to travel through it. However, its distinctive feature lies in its ability to modify the phase relationship between the input and output signals, while leaving the amplitude (or magnitude) of those frequencies unchanged.

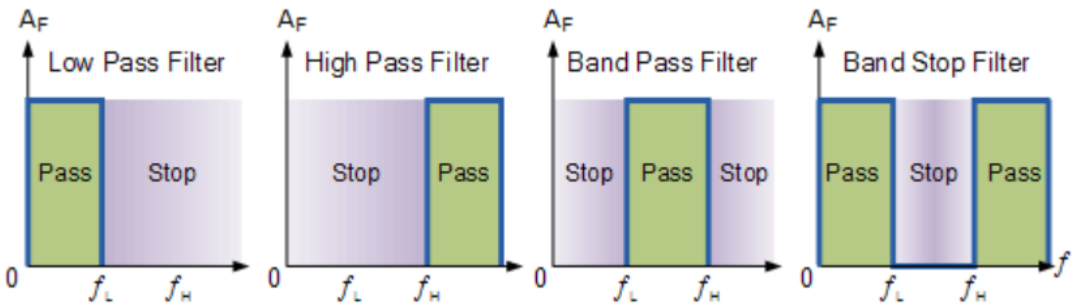


Fig.1.1. Characteristic curves of ideal filters

1.2.1 Low-Pass Filter (LPF):

Definition: A LPF is engineered to allow signals having frequencies lower than a designated cutoff frequency to pass through, while diminishing frequencies beyond

this threshold. A LP filter can be constructed using a mix of capacitance, inductance, or resistance with the aim to generate substantial reduction above a designated frequency and minimal to no reduction below it. The frequency at which this transition happens is termed as "cut-off".
Application: LPFs are generally used in audio systems to remove high-frequency noise, in anti-aliasing filters for analog-to-digital converters, and in power supply circuits to eliminate high-frequency switching noise.
Implementation: LPFs can be constructed using passive components like resistors and capacitors in simple RC or RL configurations.

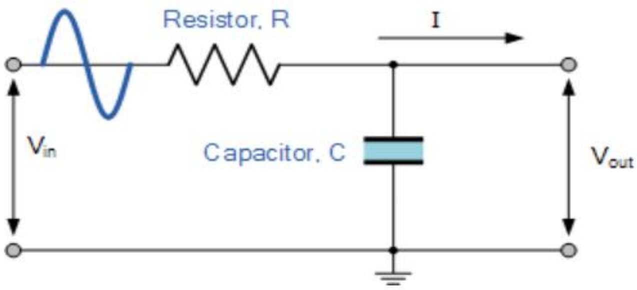


Fig.1.2. RC LPF Circuit

By graphing the output voltage of the network versus various input frequencies, one can determine the Frequency Response or magnitude Bode Plot function[2] of the LPF circuit, depicted below. A Bode plot for a LPF provides valuable insights into how the filter behaves across different frequencies. It visually represents the filter's frequency response[2], including its attenuation characteristics and phase shift behavior, making it a useful tool for analyzing and designing filter systems.

In a magnitude Bode plot, the vertical axis represents the magnitude of the system's response, typically measured in decibels (dB), and the horizontal axis represents frequency, usually on a logarithmic scale. For a LPF, the magnitude plot starts at 0 dB at low frequencies (close to DC) and decreases with increasing frequency. This represents the attenuation or suppression of higher frequencies by the filter. The slope of the magnitude plot in the low-frequency region is typically -20 dB/decade for a first-order LPF. This means that for every tenfold increase in frequency, the magnitude decreases by 20 dB. For higher-order filters, the slope becomes steeper with each additional pole.

A Bode plot is a graphical representation of the frequency response of a system [2], which includes magnitude (in dB) and phase (in degrees) information as a function of frequency. Passive Low Pass Filters[1] are commonly employed in various applications, particularly in audio amplifiers and speaker systems. Their primary function is to selectively allow lower frequency signals, such as bass, to pass through while attenuating higher frequency noise or distortions. In audio applications, these filters are often referred to as "high-cut" filters. They work by employing a simple

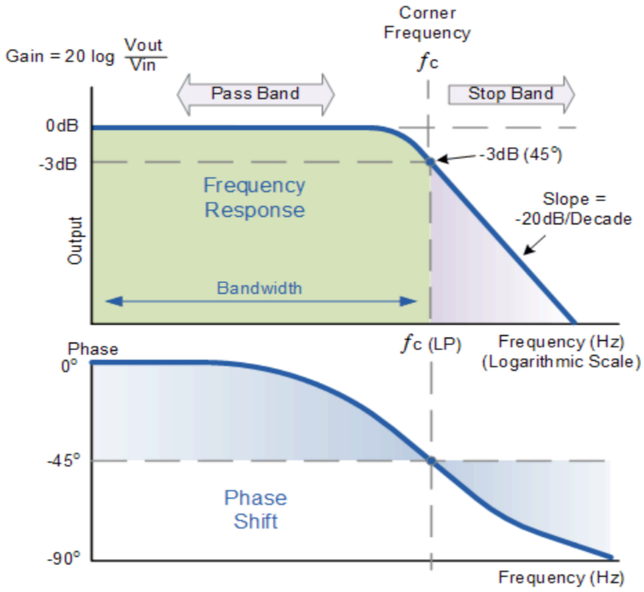


Fig.1.3. Frequency Response of a first order LPF

circuit configuration, typically consisting of a resistor and a capacitor arranged in series. The input signal is applied across this arrangement, with the output signal taken from across the capacitor.

The cut-off frequency, denoted as f_C, marks the point at which the filter begins to diminish the input signal. This frequency is expressed by the values of the resistor and capacitor based on the equation $f_C = 1/(2\pi RC)$. At the cut-off frequency, the output signal experiences a phase shift of -45 degrees, characteristic of a LPF.

1.2.2 High-Pass Filter (HPF):

Definition: A HPF allows signals with frequencies above a specified frequency to pass through while diminishing lower frequencies.
Application: HPFs are utilized in audio equalizers to boost high-frequency signals, in sensor applications to remove DC offset, and in crossover networks for speakers to separate low-frequency and high-frequency signals.
Implementation: HPFs can be made using passive components like capacitors and resistors in RC or RL configurations, or using active components such as op-amps in active filter designs.

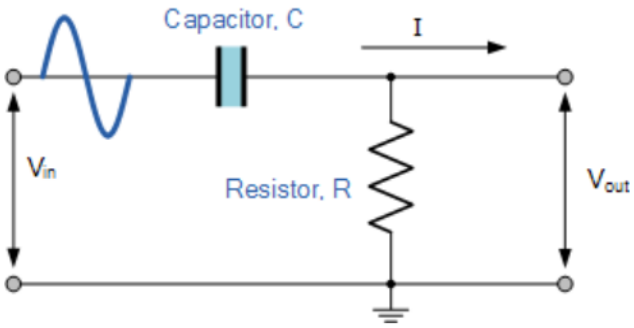


Fig.1.4. RC HPF Circuit

A Bode magnitude plot for a HPF provides a visual representation of its frequency response characteristics, including its attenuation behavior for low frequencies and phase shift properties. It's a valuable tool for analyzing and designing high-pass filters in various applications, such as signal processing, communications, and audio engineering. This plot provides a graphical representation of its frequency response[2] in terms of magnitude (in dB) and phase (in degrees) as a function of frequency. For a HPF, the magnitude plot starts at 0 dB at low frequencies (close to DC) and increases with increasing frequency. This indicates that low-frequency components of the input signal are attenuated or suppressed by the filter. The slope of the magnitude plot in the low-frequency region is typically 0 dB/decade for a first-order HPF[1]. This means that at low frequencies, the magnitude remains relatively constant.

The Bode magnitude Plot or Frequency Response Curve illustrated above for a passive HPF exhibits an inverse relationship compared to that of a LPF. Passive HPF find frequent application in audio amplifiers, often serving as coupling capacitors between amplifier stages. Within speaker systems, they redirect higher frequency signals to smaller "tweeter" speakers while suppressing lower bass signals. Additionally, they are utilized to reduce low-frequency noise or "rumble" distortion.

In the realm of audio, the HPF is occasionally referred to as a "low-cut" filter.When an AC sine wave is applied, it will act like a simple first-order high pass filter[1]. However, if the input signal is changed to a pulse shape with an almost vertical step input, the circuit's response undergoes a significant change, resulting in a configuration commonly referred to as a differentiator.

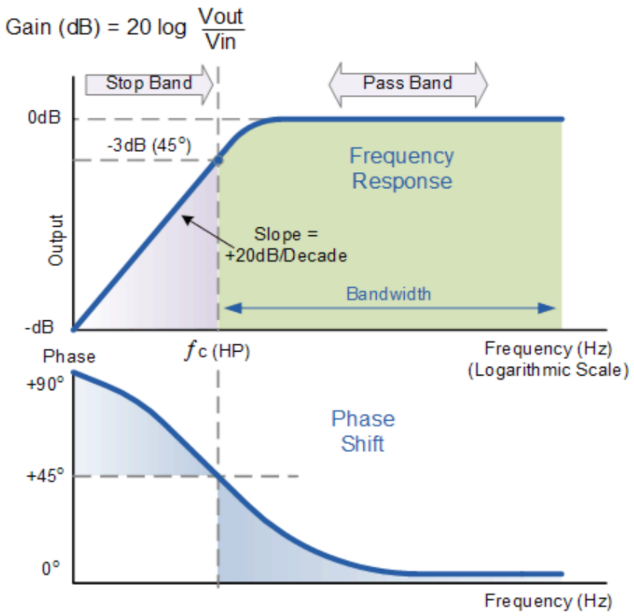


Fig.1.5. Frequency Response of a first order HPF

1.2.3 Band-Pass Filter (BPF):

Definition: A BPF permits signals within a certain frequency range (bandwidth) to pass through while attenuating frequencies outside this range.
Application: BPFs are essential in radio receivers for tuning to specific frequency bands, in medical devices for extracting physiological signals within a certain range, and in audio processing for isolating specific frequency components.
Implementation: BPFs can be realized using passive components like capacitors, inductors, and resistors in configurations such as LC filters, or using active components like op-amps in active filter designs.

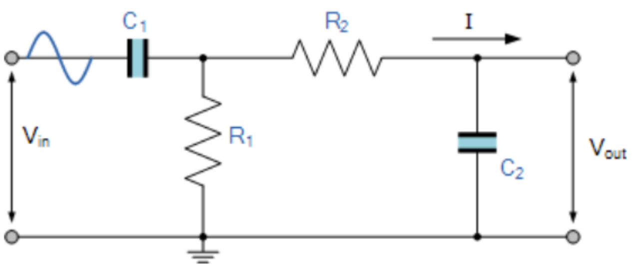


Fig.1.6. RC BPF Circuit

The Bode magnitude Plot, which illustrates the frequency response curve, reveals the behavior of the BPF. At lower frequencies, there's signal attenuation, while the output increases with a slope of +6dB/Octave until it reaches the "lower cut-off" frequency, marked as f_L. At this frequency, the output voltage reduces to 70.7% of the input signal value, corresponding to a -3dB reduction. Subsequently, the output maintains maximum gain until it reaches the "upper cut-off" frequency, f_H, beyond which it begins to decrease at a rate of -6dB/Octave, attenuating high-frequency signals.

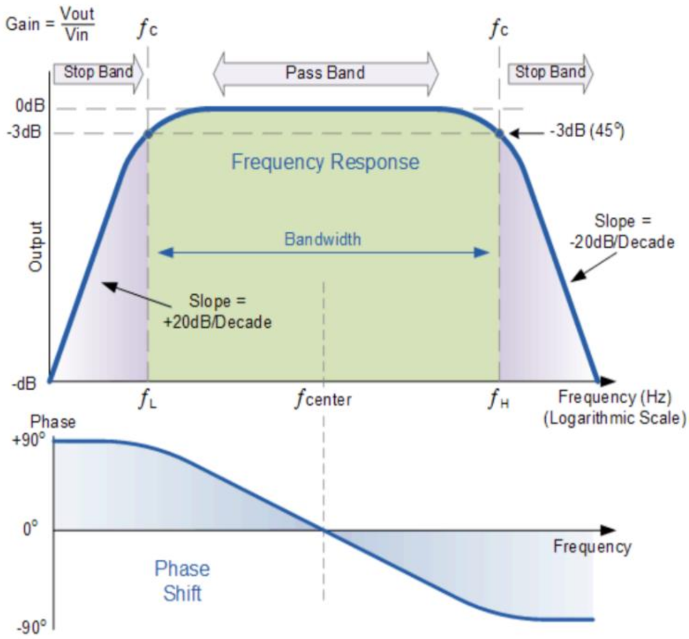


Fig.1.7. Frequency Response of a 1st-order BPF

1.2.4 Band-Stop Filter (BSF) or Notch Filter:

Definition: A BSF, also known as a notch filter, diminishes signals within a certain frequency band while allowing frequencies outside this band to pass through.
Application: BSFs are used in audio systems to eliminate specific unwanted frequencies, in instrumentation to remove interference from power lines, and in biomedical devices for filtering out noise from physiological signals.
Implementation: BSFs can be implemented using passive components like capacitors, inductors, and resistors in configurations such as LC filters, or using active components like op-amps in active filter designs.

When combining a HP and LP filter, their frequency responses don't overlap as in a BP filter. This disparity arises because their starting and ending frequencies occur at different points. For instance, imagine a scenario where a first order LPF with a frequency f_L, of 200Hz, is linked in parallel with a 1st-order HPF having a frequency,

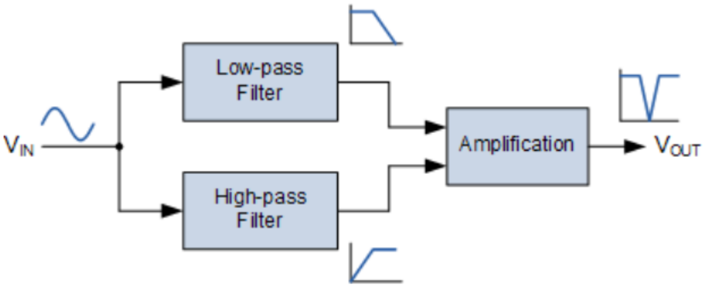


Fig. 1.8. Typical BSF Configuration

f_H, of 800Hz. As these filters are effectively connected in parallel, the input signal undergoes, simultaneous processing by both filters. Frequencies below 200Hz traverse the LPF without attenuation, while frequencies above 800Hz pass through the HPF without alteration. However, frequencies within the range of 200Hz to 800Hz are rejected by either filter, resulting in a notch in the filter's output response. Essentially, signals with frequencies of 200Hz or lower and 800Hz or higher pass through unaffected, whereas signals with frequencies between these ranges, such as 500Hz, are rejected as they are too high for the LPF and too low for the HPF to transmit. Upon examining the amplitude and phase curves for the BS circuit, it becomes evident that the parameters f_L, f_H, and f_C closely resemble those utilized in describing the behavior of the BSF[1].

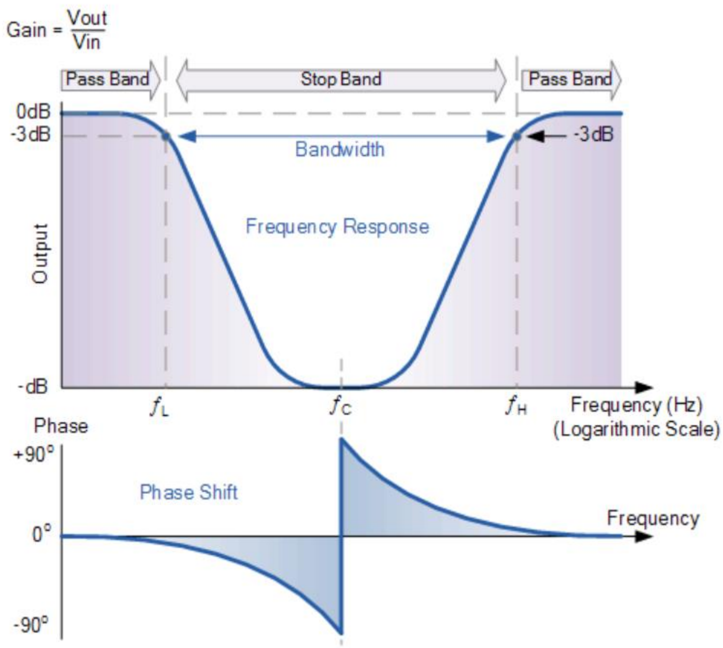


Fig.1.9. Frequency Response of a first order BSF

1.2.5 All-Pass Filter:

Definition: An APF is designed to pass all frequencies with equal gain but introduces a phase shift that varies with frequency.
Application: They are used in audio processing for phase correction, in equalization circuits for time delay correction, and in communication systems for signal synchronization.
Implementation: These filters can be constructed using passive components like capacitors, inductors, and resistors, or using active components such as op-amps. All-pass filters are characterized by a consistent frequency response, meaning they neither accentuate nor diminish any specific part of the spectrum. Instead, they alter the timing of signals based on their frequency content. This temporal adjustment, dictated by the phase response, is the hallmark of APF.

In circuit design, all-pass filters serve diverse functions that rely on frequency-dependent time alignment. They find applications in various audio contexts such as filter banks, speaker crossovers, and reverberators. Additionally, these filters are utilized in both continuous-time and discrete-time scenarios.

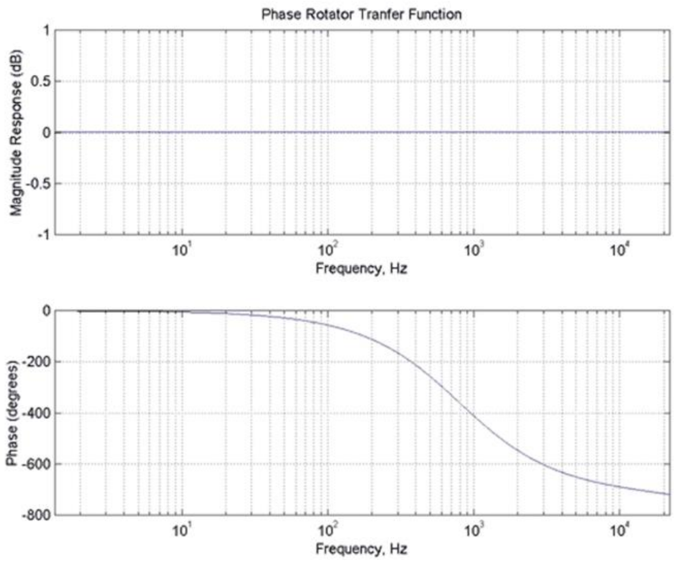


Fig.1.10. Frequency Response of APF

1.3 IMPORTANCE OF FILTERS:

Filters are integral components in various electronic systems and find applications in:

- Communication Systems: Filtering out unwanted noise and interference, channel selection, and equalization in wireless, wired, and optical communication systems.

- Audio Systems: Equalization, tone control, crossover networks, and noise reduction in audio amplifiers, mixers, and speakers.
- Instrumentation and Measurement: Signal conditioning, anti-aliasing filtering, and noise rejection in data acquisition systems, sensors, and test instruments.
- Biomedical Devices: Signal filtering and processing in medical imaging, patient monitoring, and diagnostic equipment.
- Control Systems: Filtering noise and disturbances, signal shaping, and feedback control in industrial automation, robotics, and automotive systems.

Filter design involves selecting appropriate components and configurations to achieve the desired frequency response. The basic principles of filter design include:

- Frequency Response: Describes how a filter affects the amplitude and phase of signals at different frequencies.
- Cutoff Frequency: The frequency at which the filter's response starts to change significantly.
- Order: Indicates the complexity of the filter and determines its roll-off rate and selectivity.
- Transfer Function: Mathematical representation of the filter's input-output relationship.

Filters can be implemented using passive components (resistors, capacitors, inductors) or active components (op-amps, transistors, etc.). Common filter configurations include:

- Passive RC Filters: Simple filters using resistors and capacitors to achieve basic filtering functions.
- Active Filters: Employ active components like operational amplifiers to achieve more complex filtering operations with gain and bandwidth control.
- Digital Filters: Implemented using DSP techniques in software or hardware, offering precise control and flexibility.

Filters perform a important role in building the behavior of electronic circuits, enabling precise control over signal characteristics and facilitating a wide range of applications across different industries. As technology advances, filters continue to evolve, offering improved performance, efficiency, and versatility in electronic systems. The history of filter designing reflects a continuous quest for improved performance, efficiency, and versatility in signal processing. From the early concepts of passive filtering to the sophisticated algorithms of modern digital filters, filter design has been instrumental in shaping the evolution of telecommunications, electronics, and information technology.

1.4 ANALOG SIGNAL PROCESSING:

Analog signal processing [3] involves manipulating continuous signals that vary in amplitude over time. This contrasts with digital signal processing, which deals with discrete signals shown by binary numbers. In analog processing, signals are manipulated using analog circuits, which can include components like resistors, capacitors, and operational amplifiers. Applications of analog signal processing can be found in various fields like audio processing, telecommunications, control systems, and instrumentation. Common tasks include filtering, amplification, modulation, demodulation, and signal conditioning. Analog signal processing is often used when the input or output signals are naturally analog, or when the cost or complexity of implementing digital processing is prohibitive. However, digital signal processing has become increasingly dominant due to its flexibility, accuracy, and the advancement of digital technology.

Key operations in analog signal processing (ASP) include:

1. Filtering: Filtering involves modifying the frequency content of a signal. This can be achieved through passive components like resistors and capacitors in configurations such as RC filters, or through active components like operational amplifiers in active filter designs.
2. Amplification: Amplification increases the magnitude of a signal. Opamps are commonly used for this purpose, configured in various amplifier configurations such as voltage amplifiers, current amplifiers, and transconductance amplifiers.
3. Modulation and Demodulation: Modulation encompasses impressing information onto a carrier signal, and demodulation is the process of extracting this information from the modulated signal. Techniques like AM, FM, PM are employed for communication purposes.
4. Signal Conditioning: Signal conditioning involves preparing a signal for further processing or transmission. This may include tasks such as impedance matching, noise reduction, level shifting, and signal isolation.

Analog signal processing finds applications in numerous domains including audio processing, telecommunications, instrumentation, control systems, and sensor interfacing. While digital signal processing has gained prominence due to its versatility and computational efficiency, analog signal processing remains indispensable in scenarios where real-world signals are inherently analog or where strict requirements on signal fidelity, speed, or power consumption dictate the use of analog techniques.

Utilizing active building blocks for filter design presents a dynamic approach in electronic circuitry, providing a rich array of options for signal manipulation and frequency control. LPF, employed to diminish high-frequency signals while permitting low-frequency ones, can be effectively crafted using active components like operational amplifiers (op-amps) in tandem with resistors and capacitors. Conversely, HPF, functioning to pass high-frequency signals while suppressing lower frequencies, can capitalize on active building blocks to achieve precise cutoff frequencies and enhance roll-off characteristics. Band-pass filters, crucial for isolating signals within specific frequency bands, can take shape through active components in configurations such as multiple feedback (MFB) or state-variable filters, offering adjustable center frequencies and bandwidths. Similarly, band-stop filters, known for attenuating signals within designated frequency bands while transmitting frequencies beyond, can be efficiently realized with active components to improve selectivity and eliminate unwanted frequencies. Furthermore, active building blocks facilitate the design of intricate filter structures like multiple-order filters, elliptic filters, and switched-capacitor filters, boasting advanced functionalities such as rapid roll-off, precise transition bands, and customizable cutoff frequencies. Ultimately, the adaptability and versatility of active building blocks empower engineers to tailor filter designs precisely to meet the unique requirements of diverse applications with efficiency and accuracy.

Active building blocks play a very important role in electronic circuit design, offering a versatile and efficient platform for signal processing, amplification, and control. With advancements in technology and design methodologies, active building blocks continue to drive innovation across various industries, enabling the development of advanced electronic systems with enhanced performance and functionality.

1.5 ACTIVE BUILDING BLOCKS:

Active building blocks refer to electronic components or modules that incorporate active devices such as op-amps, transistors, or voltage/current sources to provide amplification, signal conditioning, or processing capabilities. These building blocks offer distinct advantages over passive components, including:

1. Gain: Active components can provide signal amplification, enabling the design of filters with higher gain levels compared to passive filters.
2. Flexibility: Active building blocks allow for the implementation of complex filter configurations and frequency responses that may be challenging to achieve using passive components alone.
3. Tunability: Active filters provide the flexibility to modify parameters such as cutoff frequency, BW, and gain by adjusting component values or control inputs. This enables easy adaptation to different system demands.

4. Low Sensitivity: Active filters are less sensitive to component variations and parasitic effects, resulting in improved stability and robustness.
5. Integration: Active building blocks can be readily integrated into integrated circuit (IC) technologies, enabling compact and cost-effective solutions for filter design.

The design of various filters using active building blocks typically involves the following steps:

1. Specification: Define the desired filter specifications including frequency response, cutoff frequency, bandwidth, and gain requirements.
2. Topology Selection: Choose a suitable filter topology based on the specified requirements and application constraints. Common filter types include LP, HP, BP and BS.
3. Component Sizing: Determine the component values (resistors, capacitors, etc.) and operating parameters of active devices (op-amps, transistors) based on the selected topology and specifications.
4. Simulation and Optimization: Utilize circuit simulation tools to verify the performance of the designed filter and optimize component values for desired characteristics such as frequency response, passband ripple, and stopband attenuation.
5. Sensitivity Analysis: Conduct sensitivity analysis to examin the impact of component tolerances, temperature variations, and manufacturing variations on filter performance and stability.
6. Prototype Implementation: Build a physical prototype of the designed filter circuit using discrete components or integrated circuits, following best practices for layout and grounding to minimize noise and interference.
7. Performance Evaluation: Test the prototype filter under various operating conditions to evaluate its performance in terms of frequency response, gain, noise, distortion, and stability.
8. Fine-Tuning and Adjustment: Fine-tune the filter circuit parameters if necessary to meet any deviations from the desired specifications, taking into account practical constraints and limitations.

Filters designed using active building blocks find wide-ranging applications across different domains, including:

1. Communication Systems: Active filters are used for frequency shaping, channel selection, and signal conditioning in communication systems such as wireless transceivers, satellite receivers, and base stations.
2. Audio Processing: Active filters are employed in audio equalizers, crossover networks, and tone control circuits for audio processing applications in amplifiers, mixing consoles, and audio recording equipment.

3. Biomedical Instruments: Active filters are utilized in biomedical instrumentation for signal filtering and noise rejection in electrocardiography (ECG), electroencephalography (EEG), and other medical diagnostic systems.
4. Instrumentation and Control: Active filters play a very important role in instrumentation and control systems for signal conditioning, anti-aliasing filtering, and noise reduction in sensors, data acquisition systems, and industrial automation equipment.
5. Automotive Electronics: Active filters are integrated into automotive electronic systems for audio entertainment, engine control, and safety features such as active noise cancellation and adaptive cruise control.
6. Consumer Electronics: Active filters are incorporated into consumer electronic devices such as televisions, smartphones, and portable audio players for audio processing, speaker protection, and noise filtering.

Recent advancements in active building blocks have focused on enhancing performa-nce, efficiency, and integration. These advancements include:

1. High-Speed Op-amps: Op-amps with increased bandwidth and slew rate enable high-speed signal processing in communication and data acquisition systems.
2. Low-Power ICs: Low-power integrated circuits conserve energy and extend battery life in portable electronic devices and IoT applications.
3. Integrated Sensor Interfaces: ICs incorporating sensor interfaces simplify the integration of sensors into electronic systems, enabling IoT, healthcare, and environmental monitoring applications.
4. Programmable Filters: Programmable filter ICs offer configurable filter characteristics, allowing for flexible signal processing in audio, communication, and instrumentation applications.

During the past few years, several current mode active elements such as Current Conveyor (CCII)[4], Differential Difference Amplifier based Current Conveyor (DDCCII)[5], Current Differencing Buffered Amplifier (CDBA)[6], Operational Transconductance Amplifier (OTA)[7], Current Controlled Current Conveyor (CCCII) [8], Current Differencing Transconductance Amplifier(CDTA) [9], Current Controlled Current Differencing Transconductance Amplifier (CCCDTA)[10], Operational Transresistance Amplifier (OTRA)[11], Voltage Differencing Transconductance Amplifier (VDTA)[12] etc. and their applications in filter design are introduced in literature. Among these, the VDTA is a recently introduced active element. This device offers versatility by supporting operation in both CM and VM, granting circuit designers flexibility in their designs. An essential characteristic of the VDTA is its capability to display two distinct transconductance values, allowing for electronic tuning through its variable transconductance gains[12]. Hence, the VDTA device is particularly well-suited for the synthesis of electronically tunable active circuits. A widely researched and published configuration is the Single-Input Multiple-Output (SIMO) universal filter, where a single input signal is utilized. SIMO filters, requiring only one input signal, are capable of simultaneously implementing multiple filtering functions. The SIMO filter topology has proven beneficial in various applications such as PLL FM stereo demodulators and crossover networks. A variety of VDTA based SIMO biquadratic filters are available in literature. These filters can further be classified as voltage mode [12],[13], [14, 15], current mode[16, 17], and dual mode[18] structures.

The VDTA is a versatile active building block [12] which offers unique signal processing capabilities and operational flexibility. Its ability to perform VM, CM, and TAM operations makes it an indispensable component in modern electronic circuit design. With its high linearity, low power consumption, wide bandwidth, and versatile applications, the VDTA continues to play an important role in advancing electronic systems across various industries. This device is widely used in modern electronic circuit design for signal processing, filtering, and amplification. It offers unique operational characteristics that distinguish it from conventional operational amplifiers (op-amps) and make it suited for a lot of applications. At its core, the VDTA operates on the principle of transconductance amplification, where it converts voltage differences between its input terminals into output currents. Unlike traditional op-amps, which amplify voltage differences, the VDTA provides a differential output current proportional to the difference in voltage between its two input terminals. This unique functionality allows for versatile signal processing capabilities, including v operations.

The VDTA can be configured in various circuit topologies to achieve different signal processing functions. Common configurations include:

1. Voltage-Mode (VM) Operation: In this mode, the VDTA behaves as a voltage-controlled current source, where the output current is proportional to the voltage difference between its input terminals.
2. Current-Mode (CM) Operation: Here, the VDTA acts as a current-controlled voltage source, generating an output voltage proportional to the input current applied to its terminals.
3. Transadmittance-Mode (TAM) Operation: In this mode, the VDTA functions as a transconductance amplifier, where the output current is linearly proportional to the input voltage applied across its terminals.

1.6 SCOPE OF WORK:

The aim of the thesis includes the design, analysis, simulation, and implementation of a dual-mode SIMO biquad filter utilizing VDTA. The proposed filter configuration offers flexibility and adaptability by providing multiple voltage mode, transadmittance mode, and current mode functions, including low-pass, high-pass, and band-pass responses.

Key aspects of the scope include:

1. Design: The thesis involves the design of the dual-mode SIMO biquad filter architecture based on VDTAs. This includes the selection of appropriate circuit topologies, component values, and operational modes to achieve the desired filter functions and characteristics.
2. Analysis: A comprehensive analysis of the proposed filter configuration is conducted to understand its operational principles, performance characteristics, and feasibility for integration into a single integrated circuit (IC). This involves mathematical analysis, transfer function derivation, and stability analysis of the filter.
3. Simulation: PSPICE simulations are employed to validate the feasibility and performance of the proposed biquad filter configuration. Simulations are performed using the 0.18µm TSMC CMOS process specifications to ensure compatibility with standard semiconductor manufacturing processes.
4. Implementation: Practical implementation of the dual-mode SIMO biquad filter is carried out to validate its functionality and performance in real-world scenarios. This involves circuit prototyping, PCB layout design, and laboratory measurements using electronic instrumentation.

The proposed filter architecture is designed without the need for external resistors, enhancing its suitability for potential integration into a single IC. The ability to independently tune the angular frequency without affecting the bandwidth offers additional flexibility and adaptability in filter design. Overall, the thesis aims to demonstrate the feasibility and effectiveness of the proposed dual-mode SIMO biquad filter based on VDTAs through comprehensive design, analysis, simulation, and implementation efforts. A comparative analysis is done of proposed SIMO biquad filter with the previously published SIMO biquad filters previously published structures. The implementation and analysis of the proposed work is discussed in the following chapters.

CHAPTER 2

FUNDAMENTALS OF VDTA

2.1 VDTA INTRODUCTION:

The voltage differencing transconductance amplifier (VDTA) is an active versatile building block used in the realization of analog signal processing circuits and analog wave generation[19]. The VDTA represents a specialized type of active device that offers unique advantages over traditional operational amplifiers (op-amps) and other active components. At its core, the VDTA operates based on the concept of voltage differencing, utilizing transconductance amplification to achieve its functionality. Unlike op-amps which primarily amplify voltage differentials, VDTAs are designed to directly manipulate voltage differences, making them particularly well-suited for applications requiring precise control and manipulation of voltage differentials.

The advantageous feature of the use of the VDTA as an active element is that compact structures in some applications can be achieved easily[20]. Compared to other active blocks, the advantageous feature of VDTA is that this new element exhibits two different values of transconductances so that several applications such as biquad filters, oscillator, inductance and FDNR (frequency dependent negative resistor) simulator can be realized with a single active block employing one or two capacitors[12]. Another important feature, this block can be used easily at transconductance mode applications owing to input terminals is voltage and output terminals is current[12]. With the increasing demand for low-power and portable electronic devices, VDTAs offer a compelling solution for designers seeking to minimize power consumption while maintaining high-performance analog signal processing capabilities.

Furthermore, the unique characteristics of VDTAs make them suitable for application in areas such as biomedical instrumentation, sensor interfaces, communication systems, and audio processing. Their ability to accurately process small signals and maintain linearity over a wide dynamic range makes them invaluable in these domains.

In summary, VDTAs represent a significant advancement in active device technology, offering unparalleled versatility, precision, and efficiency in analog signal processing applications. As the demand for high-performance analog circuits continues to grow, VDTAs are poised to play a central role in meeting the evolving needs of the electronics industry. At its heart, the VDTA operates by managing voltage differences, utilizing transconductance amplification. This sets it apart from op-amps, which primarily focus on amplifying voltage differentials. This unique design makes VDTAs ideal for applications requiring precise manipulation and control of voltage variations.

Their distinctive traits make VDTAs well-suited for diverse applications such as biomedical instrumentation, sensor interfaces, communication systems, and audio processing. Their ability to accurately handle small signals while maintaining linearity across a broad dynamic range positions them as invaluable assets in these fields. In essence, VDTAs signify a substantial leap forward in active device technology, delivering unmatched versatility, precision, and efficiency in analog signal processing. With the continuous growth in demand for high-performance analog circuits, VDTAs are poised to play a pivotal role in addressing the evolving requirements of the electronics industry.

2.1.1 VDTA HISTORY:

The history of Voltage Differencing Transconductance Amplifiers (VDTAs) can be traced back to the mid to late 20th century, coinciding with the rapid advancements in integrated circuit technology and the growing demand for high-performance analog signal processing solutions. The concept of voltage differencing amplifiers, which form the basis of VDTAs, emerged as researchers and engineers sought to develop novel approaches to analog signal processing. Early iterations of voltage differencing amplifiers were introduced in academic literature and research papers, laying the groundwork for further exploration and development in this area. In the late 20th century, as semiconductor technologies continued to evolve, researchers began to investigate new active device architectures that could offer improved performance and versatility in ASP applications. This led to the conceptualization and development of the VDTA.

The first documented mention of VDTAs appeared in academic publications and conference proceedings in the early 2000s[3]. Researchers highlighted the unique characteristics of VDTAs, such as their ability to directly manipulate voltage differences and their suitability for a definite wide range of signal processing tasks. As interest in VDTAs grew within the academic and research communities, efforts were made to refine their design, improve their performance characteristics, and explore potential applications in various fields such as communications, instrumentation, and audio processing. In the early 21st century, with the continued advancements in semiconductor fabrication technologies, VDTAs began to find their way into commercial products and integrated circuit designs. Semiconductor companies started to incorporate VDTAs into their product portfolios, offering them as key building blocks for ASP circuits.

Today, VDTAs are recognized as essential components in analog signal processing applications, offering unparalleled versatility, precision, and efficiency. They have become standard elements in the toolkit of analog circuit designers, playing a central role in addressing the diverse and evolving needs of the electronics industry. Looking ahead, ongoing research and development efforts in the field of VDTAs are focused on further refining their performance characteristics, exploring new applications. As the demand for high-performance analog circuits continues to grow, VDTAs are poised to remain at the forefront of innovation in the field of ASP.

2.2 VDTA SYMBOLIC REPRESENTATION:

A VDTA has the voltage input at p and n ports and the current output at x_+, x- and z ports and all the ports of VDTA provide high impedance. The VDTA is composed of the current source controlled by the difference of two input voltages and a multiple-output transconductance amplifier, providing electronic tuning ability through its transconductance gains[20].

The output current at the Z terminal is obtained based on the input terminals. The voltage at the Z terminal is converted into output currents. Within the VDTA block, there are two interconnected electronic tunable transconductance sections having values g_{m1} and g_{m2}, making it appropriate for electronic tunable[21]. The block diagram as shown in Fig.2.1 illustrates the symbol of VDTA. The relationship between V and I across different input and output terminals of the VDTA can be expressed using the following equation:

$$\begin{pmatrix} I_Z \\ I_{X-} \\ I_{X+} \end{pmatrix} = \begin{pmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & -g_{m2} \\ 0 & 0 & g_{m2} \end{pmatrix} \begin{pmatrix} V_P \\ V_N \\ V_Z \end{pmatrix} \quad (2.1)$$

The mathematical expressions for g_{m1} and g_{m2} can be derived as follows.

$$g_{m1} = \frac{g_1 g_2}{g_1 + g_2} + \frac{g_3 g_4}{g_3 + g_4} \quad (2.2)$$

$$g_{m2} = \frac{g_5 g_6}{g_5 + g_6} + \frac{g_7 g_8}{g_7 + g_8} \quad (2.3)$$

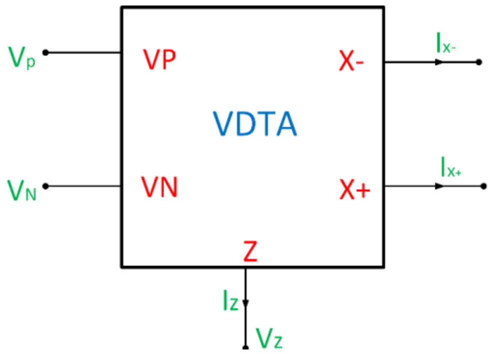


Fig.2.1 VDTA Symbolic Representation

where g_i is the transconductance value of the *i*th transistor and is expressed as:

$$g_i = \sqrt{\mu C_{ox} \left(\frac{W}{L}\right)_i I_{Bi}} \quad (2.4)$$

2.2.1 CMOS IMPLIMENTATIONS OF VDTA:

The CMOS realizations of the VDTA is illustrated in following figures given below. In the CMOS VDTA, non-ideal effects arise from input parasitic capacitances and output parasitic conductances. These parasitic capacitances manifest in parallel at the V_P, V_N, and Z terminals, while parasitic conductances are present in parallel at the Z, X+, and X- terminals. The VDTA proves highly versatile across various filter implementations and presents several advantages. By adjusting bias currents, transconductance values can be tailored, obviating the need for external resistors in circuit design. The VDTA's structure capitalizes on two distinct transconductance values, easily achieved without resistor utilization, earning it the designation of a transconductance-based element. This design aspect renders it superior to other active elements in terms of performance. Comprising a difference in voltage unit followed by a dual-output transconductance amplifier, the VDTA operates by computing the difference between input voltages under current source control. It incorporates a multi-output Transconductance Amplifier, showcasing adaptability and compatibility with both voltage and current modes.

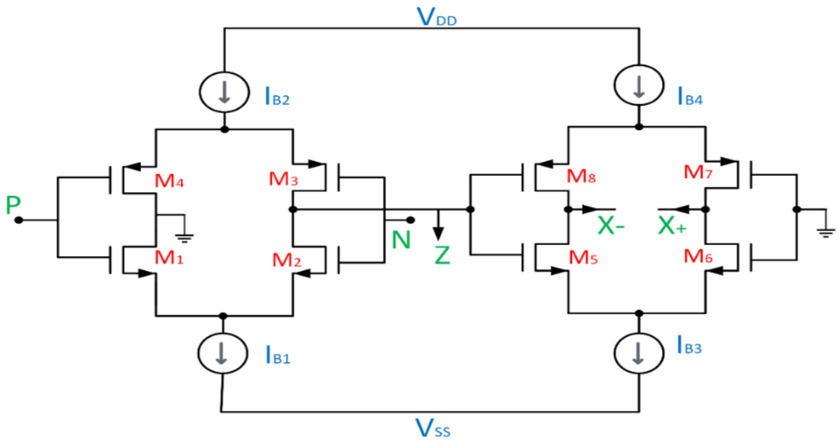


Fig2.2. CMOS Implementation of VDTA[12].

The VDTA structure employs two distinct transconductance values, which can be easily achieved without the need for resistors. This characteristic, along with its adaptability, makes it a transconductance-based element that offers advantageous features compared to other active devices. A significant advantage of this device lies in its ability to adjust transconductance gains by varying bias currents. With two transconductance gains that can be modified via bias currents, the VDTA facilitates various applications, including independent tuning of central frequency and bandwidth in filters, which is particularly relevant for the proposed work. Other CMOS structures[22-25] of VDTA are given below:

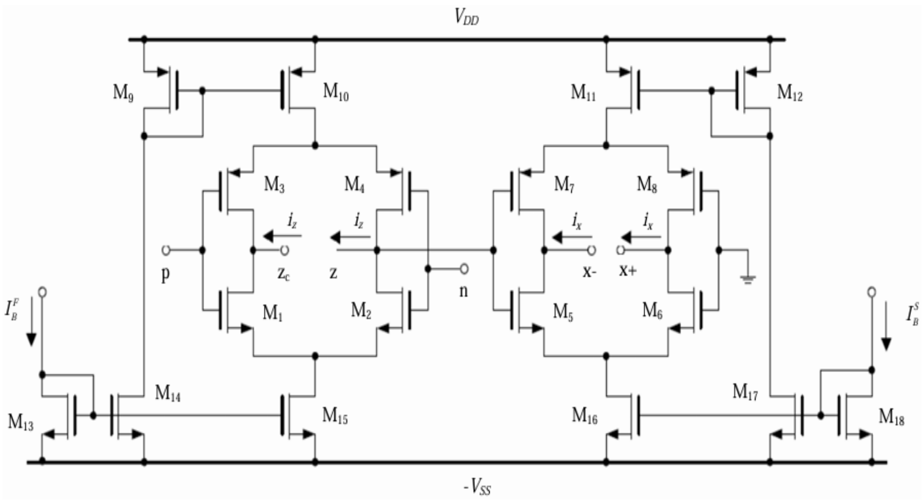


Fig2.3. CMOS Implementation of VDTA[22].

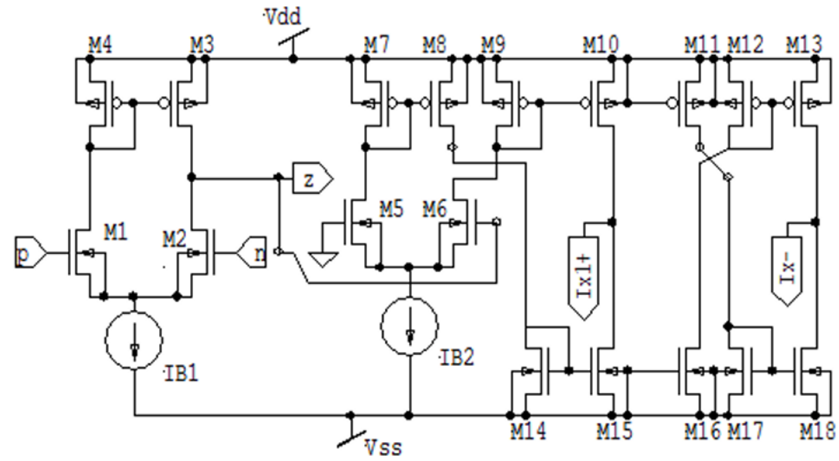


Fig2.4. CMOS Implementation of VDTA[23]

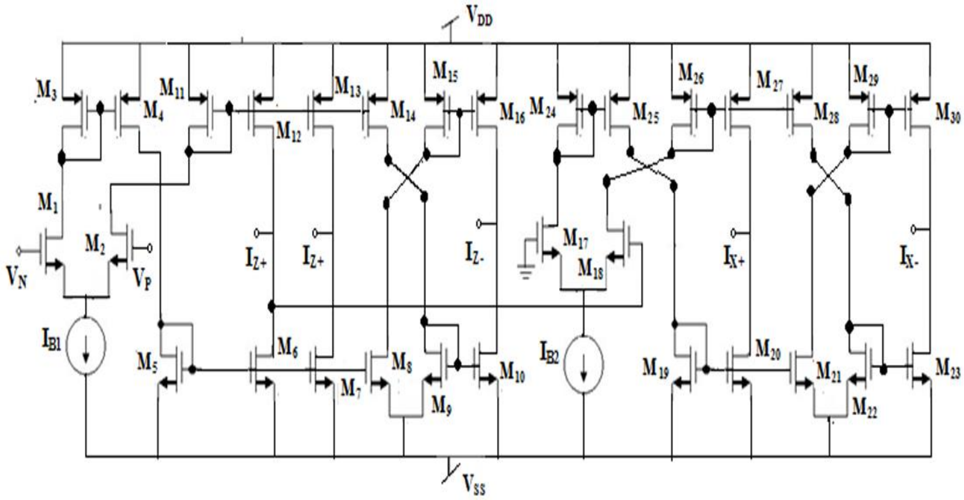


Fig2.5. CMOS Implementation of VDTA[24]

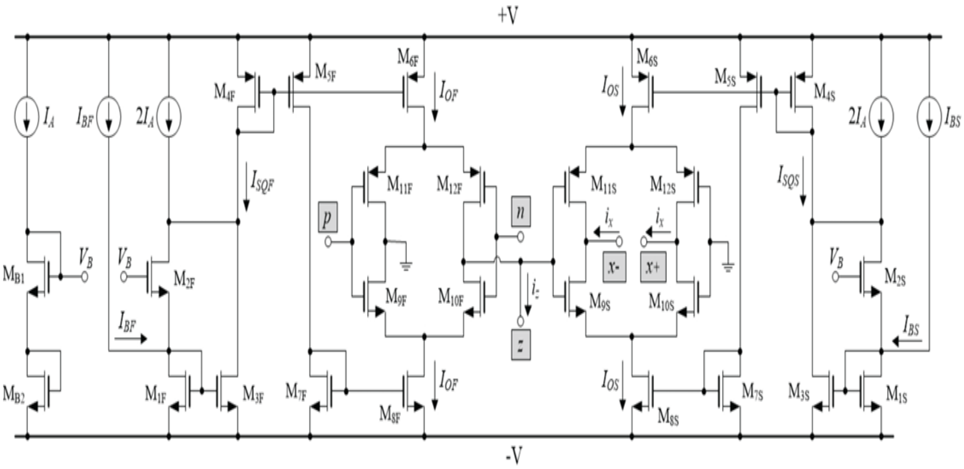


Fig2.6. CMOS Implementation of VDTA[25]

The internal block diagram of VDTA[26] is shown below:

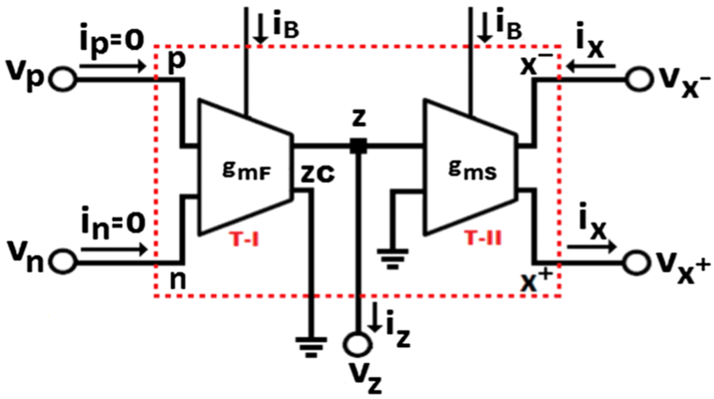


Fig.2.7. Internal Block Diagram of VDTA[26]

2.3 VDTA ANALYSIS:

The analysis of VDTA is done by using PSPICE program with TSMC CMOS 0.18 µm process parameters.

2.3.1 DC CHARACTERISTICS OF VDTA:

The DC transfer characteristic of VDTA using CMOS implementation given in [12] is depicted in Fig. 2.8. The transfer characteristic of input stage is similar to that of output stage. The transfer characteristics of a system refer to the quasi-static relationship between the input and output variables. In a voltage-in, voltage-out system, this quasi-static relationship is referred to as the dc transfer characteristics. In the realm of electronic circuits and systems, whether an entity is termed as an amplifier, circuit, filter, network, architecture, or system, the fundamental concepts remain universal. These entities are often characterized by their transfer functions and transfer characteristics, irrespective of whether they have electrical relationships. The terminology used, such as circuit, network, amplifier, filter, system, architecture, and structure, may be interchangeable. However, the distinction between these terms lies mainly in their intended usage rather than in how they are characterized or operate.

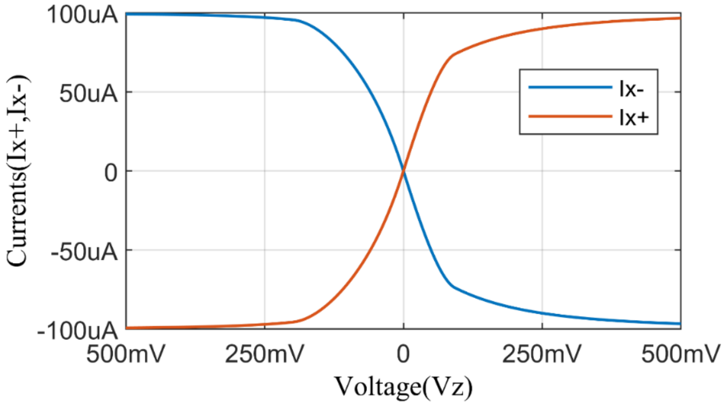


Fig.2.8. DC transfer characteristic of VDTA

2.3.2 FREQUENCY RESPONSE OF VDTA:

The frequency response of the VDTA using it's CMOS implementation given in[12] is depicted in Fig.2.9 In signal processing and electronics, the frequency response of a system quantitatively measures the output's magnitude and phase in relation to input frequency. Just as the impulse response differentiates systems in the time domain, the frequency response characterizes them in the frequency domain. In linear systems, either response fully describes the system, with a one-to-one correspondence: the frequency response being the Fourier transform of the impulse response. Furthermore, analyzing the frequency response enables calculation of the transconductance gain, which is essential for the device's application. The AC characteristics illustrate how the transconductance gain (g_{mF}) varies with frequency. Simulation results indicate that the transconductance gain decreases by 3dB at 3.09 MGHz.

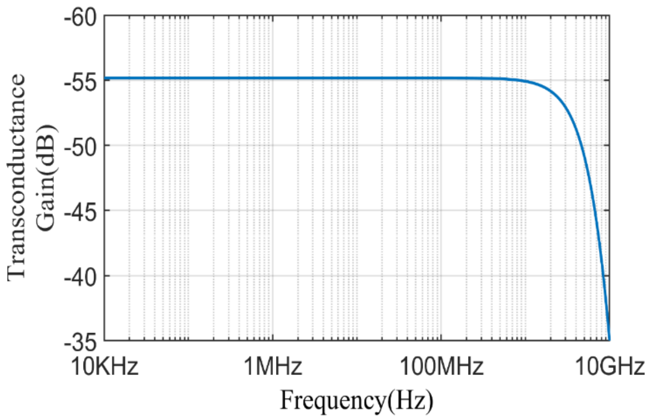


Fig.2.9. Frequency response of VDTA

2.3.3 TRANSIENT RESPONSE ANALYSIS OF VDTA:

Transient analysis of the VDTA using it's CMOS implementation given in [12] is depicted in Fig. 2.10 involves applying a sinusoidal voltage with an amplitude of 10mV at a frequency of 100kHz. The resulting transient responses are depicted by plotting the currents I_{X+} and I_{X-} over time.A transient response reflects how a system reacts to a change from its equilibrium or steady state. This response isn't necessarily triggered by sudden events but by any change affecting the system's equilibrium. Transient analysis involves calculating a circuit's response over a user-defined period, with accuracy contingent on the size of internal time steps making up the simulation time, known as the Run or Stop time. During each time step, node voltages and currents are computed and compared to the previous DC solution. Analysis progresses to the next time step only when the difference between two DC solutions falls within a specified tolerance (accuracy). The time step is automatically adjusted as long as a solution within tolerance is reached.

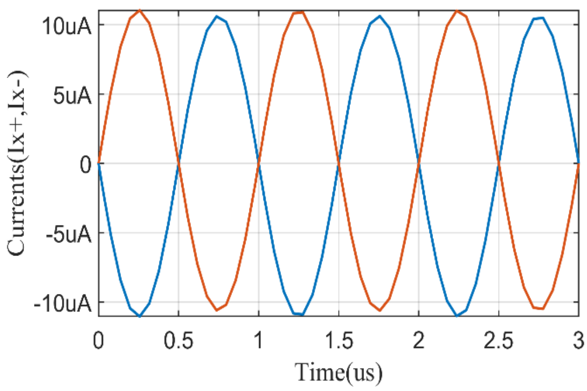


Fig.2.10. Transient Response Analysis of VDTA

CHAPTER 3

LITERATURE REVIEW

3.1 CIRCUIT TOPOLOGIES UTILIZING VDTAs:

This section delves into the application of Voltage Differencing Transconductance Amplifiers (VDTAs) in various analog signal processing circuits, as documented in existing literature [12-36]. These circuits encompass a wide range of functionalities crucial for signal processing, including oscillators, simulators for inductance, capacitance, and resistance, as well as filters operating in different modes such as VM, CM and TAM.

Oscillators are pivotal in the realm of communication systems, and VDTAs have proven effective in their realization. For instance, one oscillator design incorporates two VDTAs along with a grounded resistor and two grounded capacitors. Another oscillator is a quadrature oscillator utilizing two VDTAs and two grounded capacitors, featuring current outputs with a 90-degree phase difference. Simulators for capacitors, inductors, and resistors, whether floating or grounded, serve as essential building blocks for filter implementation. VDTAs have been leveraged to realize these simulators, such as a floating capacitor simulator employing two VDTAs and a grounded capacitor. An inductor simulator, on the other hand, employs one VDTA and a grounded capacitor. Additionally, a floating resistor simulator utilizes three VDTAs. Furthermore, designs for floating inductor and capacitor simulators are detailed in, with the inductor simulator using one VDTA and a grounded capacitor, and the capacitor simulator employing two VDTAs and a grounded capacitor. Integrators, another crucial component, are realized using VDTAs and grounded capacitors.

Filters, both 1st-order and 2nd-order, operating in various modes, are presented.
For instance, a 1st-order APF combines voltage and transadmittance modes by employing one VDTA and a capacitor. Second-order filters utilize one VDTA and two grounded capacitors, yielding multiple current outputs. Other filter designs feature a

single VDTA and two grounded capacitors, eligible of realizing various filtering functions based on the choice of inputs. Mixed-mode filters, accommodating both voltage and current inputs and outputs, are also discussed. TAM filters, where voltage serves as input and current as output, are detailed as well. Designs include those with two VDTAs or a single VDTA along with grounded components. Inverse filter topologies employing VDTAs are also presented, offering configurations for HP, BP, BR, and LP filters. Unified structures combining VDTAs and grounded capacitors are proposed to realize these functions effectively.

3.2 ANALYSIS OF CIRCUITS USING VDTA:

In this section the analysis of various circuits using VDTA is presented and analyse. The oscillator [19] is constructed by connecting together an inverting 2nd order LP F and lossless integrators, as depicted in the accompanying Fig. 3.1. By analyzing the block diagram illustrated in the figure, we derive the characteristic equation governing the behavior of the sinusoidal oscillator:

$$s^3 + bs^2 + as + ck = 0 \quad (3.1)$$

Therefore, based on Equation 3.1, one can express the conditions for oscillation (OC) and the oscillation frequency (FO) as follows.

$$OC: ab = ck \quad (3.2)$$

and,

$$w_o = \sqrt{a} \quad (3.3)$$

According to Equation 3.1, when a = c, it allows for independent adjustment of the oscillation condition and frequency. This concept is exemplified in the voltage-mode sinusoidal oscillator design presented in Figure 3.1, where the FO and CO are determined as:

$$w_o = \sqrt{\frac{g_{m1}(g_{m2} + g_{m4})}{C_1 C_2}} \quad (3.4)$$

$$\text{If } C_1 = C_2 = C \quad (3.5)$$

$$\text{FO: } w_o = \frac{1}{C}\sqrt{g_{m1}(g_{m2} + g_{m4})} \quad (3.6)$$

$$\text{CO: } \frac{1}{R_1} - (g_{m2} + g_{m4}) \le 0 \quad (3.7)$$

The equations above indicate that the criteria for oscillation can be determined by R_1, g_{m2}, g_{m4}.

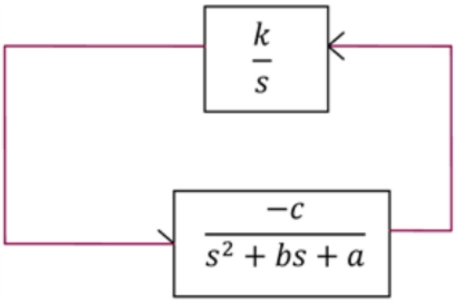


Fig. 3.1. Block diagram of oscillator

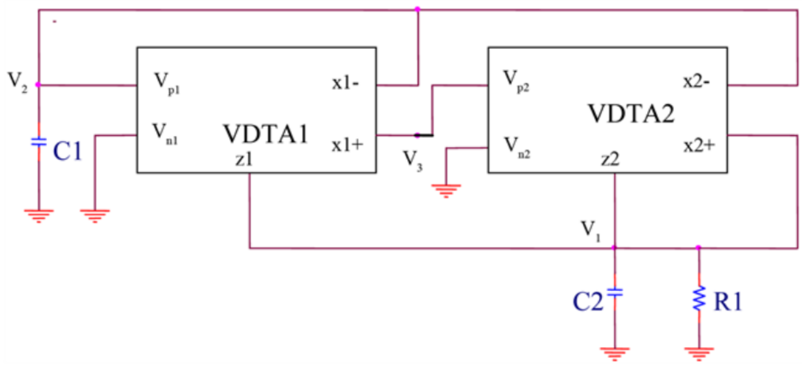


Fig. 3.2. VM-SO Circuit[19]

The frequency of oscillation can be independently tuned by the parameter a, which operates independently of the oscillation condition (CO). The VM transfer function derived from Figure 3.2 is as follows:

$$\frac{V_2(s)}{V_1(s)} = -\frac{(g_{m2} + g_{m4})}{sC_1} \tag{3.8}$$

So, this circuit generates two sinusoidal oscillations in VM at its output simultaneously. This structure is notable for its low sensitivities, both active and passive, operates on a low voltage supply, and provides a wide BW.

This CM quadrature oscillator integrates two VDTAs and two grounded capacitors [27] utilizing VDTAs. One notable feature is that the CO and FO of this quadrature oscillator are fully and independently controllable electronically.

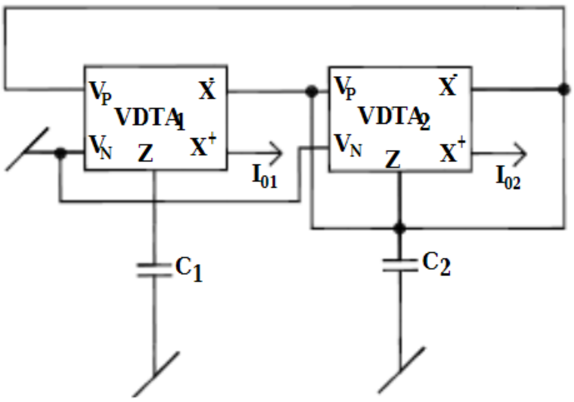


Fig.3.3. CM quadrature oscillator[27]

Figure 3.3 depicts the proposed configuration. Examination of the structure given in Figure 3.3 leads to the characteristic equation (CE) as follows:

$$s^2 + s\frac{1}{C_2}\left(g_{m4} - g_{m3}\right) + \frac{g_{m1}g_{m2}}{C_1C_2} = 0 \qquad (3.9)$$

From Equation 3.9, the CO and FO can be expressed as:

$$(g_{m4} - g_{m3}) \leq 0 \qquad (3.10)$$

and

$$\text{FO: } w_o = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \qquad (3.11)$$

Thus, from Equations 3.10 and 3.11, it is evident that the oscillation condition (CO) and frequency (FO) are entirely decoupled and can be electronically adjusted.

The transfer functions derived from Figure 3.3 are given by:

$$\frac{I_{o2}(s)}{I_{o1}(s)} = \frac{g_{m4}}{g_{m1}g_{m2}sC_1} \qquad (3.12)$$

Floating simulator [28] circuits serve as highly valuable active building blocks across various applications including filter and oscillator design, also the elimination of parasitic elements. This arises mainly due to the limitations or undesirability of using physical capacitors, especially those with larger values, in integrated circuit technology. This circuit is constructed using two VDTAs and one grounded capacitor.

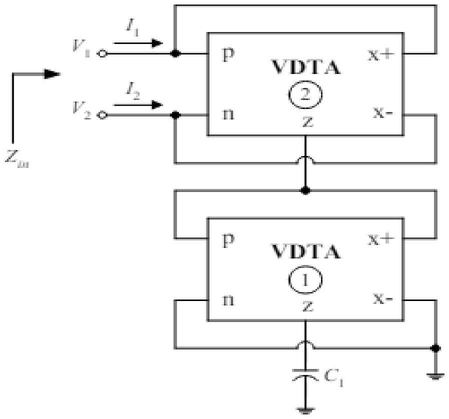


Fig. 3.4. Floating capacitance simulator topology[28]

Fig.3.4 illustrates the floating capacitance simulator circuit, which comprises solely two VDTAs and one grounded capacitor, without using any external passive resistors. Consequently, the circuit exhibits a straightforward and canonical structure, making it highly appropriate for integration into circuit designs. Analysis of the depicted floating inductor in Fig. 3.4 leads to the derivation of the following short-circuit admittance matrix:

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \frac{sC_1 g_{mF2} g_{mS2}}{g_{mF1} g_{mS1}} \begin{bmatrix} +1 & -1 \\ -1 & +1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \quad (3.13)$$

or we can achieve the following input impedance:

$$Z_{in} = \frac{g_{mF1} g_{mS1}}{sC_1 g_{mF2} g_{mS2}} = \frac{1}{sC_{eq}} \quad (3.14)$$

In this context, gmFi and gmSi denote the transconductances gmF and gmS of the i-th VDTA (where i = 1, 2) respectively. It's evident from the aforementioned equation that the circuit illustrated in Figure 3.4 has the capability to emulate a floating capacitor, with an equivalent capacitance value given by:

$$C_{eq} = \frac{C_1 g_{mF2} g_{mS2}}{g_{mF1} g_{mS1}} \quad (3.15)$$

The inductor holds significant importance in various analog circuits, including filters, oscillators, and phase shifters. Nevertheless, traditional spiral inductors face several setbacks like their large size and weight, the generation of unwanted signal harmonics from core saturation, vulnerability to electromagnetic interference, and challenges in attaining high-quality factors without enlarging their linear dimensions.

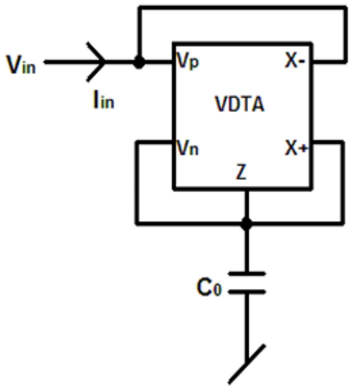


Fig. 3.5. Grounded inductance simulator configuration[29]

The grounded inductance [29] circuit is given in Fig. 3.5. By analyzing the circuit results in the following expression for the input impedance:

$$Z_{in} = \frac{sC_o}{g_m^2} \tag{3.16}$$

with $g_{m1} = g_{m2} = g_m$

By analyzing the circuit, gives a lossless grounded inductor with inductance value.

$$L_{eq} = \frac{C_o}{g_m^2} \tag{3.17}$$

which is electronically tunable by gm.
Here a grounded inductor simulator circuit, based on a single VDTA is shown. It provides electronic adjustability while minimizing the impact of parasitic effects. The suggested setup hinges on a realization criterion achievable through the equilibrium of VDTA bias currents. Numerous methods for simulating floating passive components have been suggested in previous studies and their associated references. While floating resistors are crucial in analog circuits, employing them in a floating state is often impractical for monolithic integration. Floating resistors typically demand more chip area than grounded ones, and achieving precise resistance values can be challenging. Moreover, floating resistors have fixed resistance values, limiting their adaptability to circuit requirements.

This structure is an electronically adjustable synthetic floating resistor configuration [30] utilizing three VDTAs, without the need for any external grounded resistors. The circuit exhibits low sensitivity values and demonstrates outstanding non-ideal characteristics.

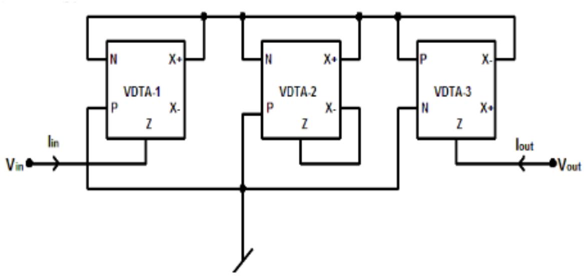


Fig. 3.6. A purely active floating resistor simulator[30]

The circuit is depicted in Fig. 3.6. Analyzing the structure shown in Fig. 3.6 using routine analysis results in the short circuit admittance matrix as follows:

$$\begin{bmatrix} I_{in} \\ I_{out} \end{bmatrix} = \frac{g_{mA} g_{mB}}{g_{m3}} \begin{bmatrix} +1 & -1 \\ -1 & +1 \end{bmatrix} \begin{bmatrix} V_{in} \\ V_{out} \end{bmatrix} \tag{3.17}$$

which simulate a floating resistor with resistance value:

$$R_{eq} = \frac{g_{m3}}{g_{m4} g_{mB}} \tag{3.18}$$

For $g_{m2} = g_{m6} = g_{mA}$ and $g_{m2} = g_{m6} = g_{mB}$

Here an electronically controllable lossless grounded inductor (GI) and floating inductor (FI) [31] circuits based on VDTAs, utilizing a grounded capacitor is discussed. The GI circuit employs only one VDTA and a grounded capacitor. Conversely, the FI circuit utilizes two VDTAs and a grounded capacitor.

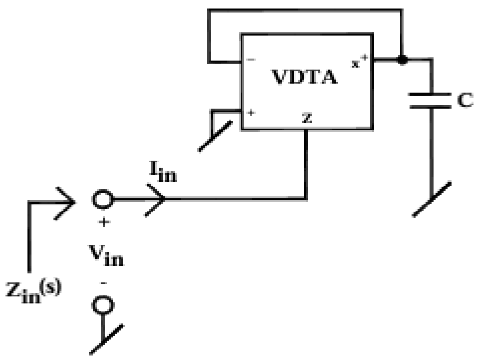


Fig. 3.7. Grounded inductance cicuit[31]

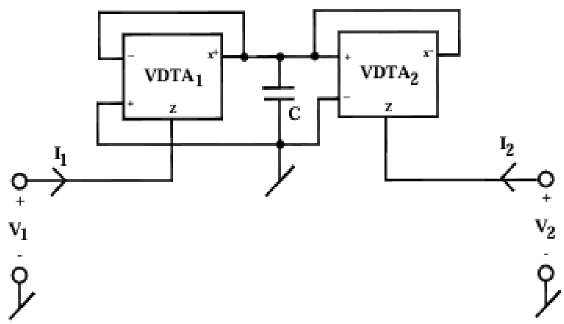


Fig. 3.8. Floating inductance circuit[31]

Performing a standard circuit analysis of the circuit depicted in Fig.3.7 yields the following expression for the input impedance.

$$Z_{in}(s) = \frac{V_{in}(s)}{I_{in}(s)} = s\left(\frac{C}{g_{m1}g_{m2}}\right) \tag{3.19}$$

The analysis of the circuit results in a grounded inductance with the inductance value given by

$$L_{eq} = \frac{C}{g_{m1}g_{m2}} \tag{3.20}$$

which is electronically controllable by either g_{m1} or g_{m2}.

Integrators are fundamental elements in continuous-time filter structures, serving as key components. They function by producing an output signal representing the time integral of the input signal. These circuits are extensively applied in ADCs, analog computers, wave-shaping circuits, and are vital in analog signal processing systems. While many RC integrator circuits designed using on op-amps, their primary setback lies in their restricted bandwidth and dynamic range. The depicted Integrator circuit [32], utilizes one VDTA, is shown in Fig. 3.9.

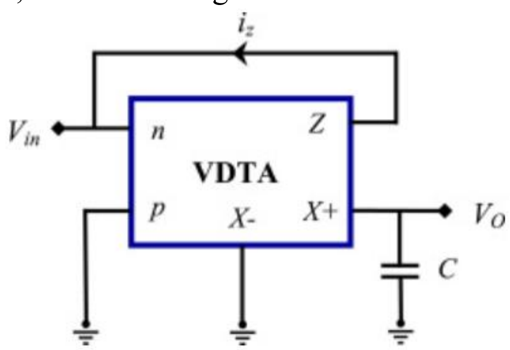


Fig. 3.9. Integrator Circuit[32]

Now, an input pulse is given at port n. The transfer function of the configuration can be expressed using Eq. 3.21 and is given as,

$$\frac{V_o}{V_{in}} = \frac{g_m}{sC} \tag{3.21}$$

From Eq.3.21, the time constant (τ) and unity gain frequency (ω_c) can be written as,

$$w_c = \frac{g_m}{C} = \frac{1}{\tau} \tag{3.22}$$

A VM Integrator circuit employing a single VDTA is discussed here. This Integrator circuit utilizes only one capacitor, eliminating the need for resistors. The suggested circuit presents numerous benefits:

1. Phase shift adjustment is achievable by tuning the current bias.
2. The circuit is described simply, requiring only one VDTA and a capacitor, thus enabling fabrication on a single chip.
3. Independent fine-tuning of the phase shift is possible.
4. The circuit exhibits low power consumption, making it energy-efficient and suitable for portable applications.
5. Its simple design ensures high reliability and ease of integration into larger systems

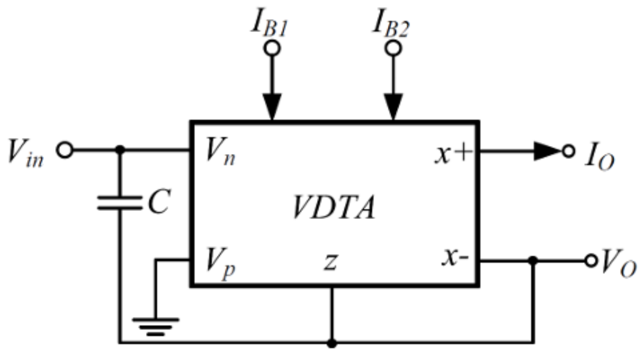


Fig.3.10. VM first-order APF[33]

The depicted VM 1st-order APF [33] is presented in Fig. 3.10. This circuit comprises

solely one VDTA and a capacitor. It not only produces the output voltage but also achieves an output current with high output impedance, commonly referred to as transconductance-mode.
The VM and TAM transfer functions can be expressed as:

$$\frac{V_o}{V_{in}} = \frac{sC - g_{m1}}{sC + g_{m2}} \tag{3.23}$$

$$\frac{I_o}{V_{in}} = g_{m2}\left(\frac{sC - g_{m1}}{sC + g_{m2}}\right) \tag{3.24}$$

This circuit presents a VM 1st-order APF that can be electronically tuned. It utilizes just one VDTA and one capacitor, simplifying fabrication for integration into ICs. Additionally, it achieves high output impedance for the output current.

Active filters serve as fundamental components extensively utilized in various electrical engineering applications. This structure is a SIMO CM universal biquad filter [17] utilizing one VDTA, two grounded capacitors, and a single grounded resistor. This filter configuration achieves all known filter functions, including LP, HP, BP, BR, and AP. Both the natural frequency $\omega 0$ and bandwidth (BW) can be independently adjusted. Additionally, the proposed circuit exhibits low sensitivities, both in terms of active and passive components.

The filter configuration is shown in Fig. 3.11.

The circuit analysis of Fig. 3.11 yields the following transfer functions:

$$T_1(\mathrm{s})\big|_{LP} = \frac{I_{o1}}{I_{in}} = \frac{g_{m1}g_{m2}}{D(\mathrm{s})} \tag{3.25}$$

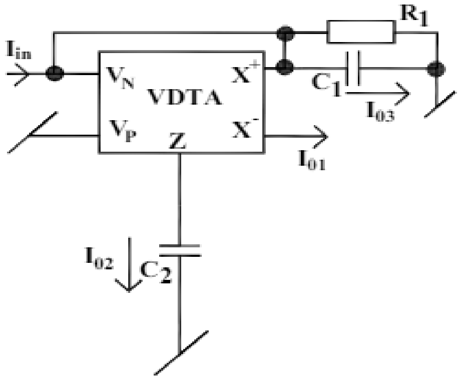


Fig.3.11. Filter configuration[17]

$$T_2(s)\big|_{BP} = \frac{I_{o2}}{I_{in}} = -\frac{s\left(\frac{g_{m1}}{C_1}\right)g_{m1}}{D(s)} \tag{3.26}$$

$$T_3(s)\big|_{HP} = \frac{I_{o3}}{I_{in}} = \frac{s^2}{D(s)} \tag{3.27}$$

$$T_4(s)\big|_{NOTCH} = \frac{(I_{o3} + I_{o1})}{I_{in}} = \frac{\left(s^2 + \frac{g_{m1}g_{m2}}{C_1C_2}\right)}{D(s)} \tag{3.28}$$

$$T_5(s)\big|_{AP} = \frac{(I_{o3} + I_{o2} + I_{o1})}{I_{in}} = \frac{\left(s^2 - s\left(\frac{g_{m1}}{C_1}\right) + \frac{g_{m1}g_{m2}}{C_1C_2}\right)}{D(s)} \tag{3.29}$$

Current-mode active building blocks are becoming increasingly popular compared to voltage-mode counterparts in analog and digital signal processing circuits. This trend is driven by their ability to potentially offer better performance characteristics such as wider bandwidth, simpler circuitry, greater dynamic range, faster operation, lower power consumption, and reduced operating voltages. The suggested active building block functions smoothly in CM, VM, and mixed mode setups.

The reported wave active filter [34] offers several advantageous features:

1. The VDTA is implemented straightforwardly in CMOS.
2. The circuit is simplified by using only one active element and a grounded capacitor.
3. Electronic tunability is provided by adjusting the bias current of the VDTA.
4. This active building block eliminates the necessity for resistors.
5. VDTAs, acting as Transconductance Amplifiers, facilitate the realization of the wave active filter.
6. Control over the transconductance of the VDTA is attained by varying the bias current.
7. The CMOS implementation of the VDTA offers compatibility with modern semiconductor fabrication processes, enhancing ease of integration into existing circuit designs.

8. By utilizing only one active element and a grounded capacitor, the circuit minimizes component count and layout complexity, reducing manufacturing costs and improving overall reliability.

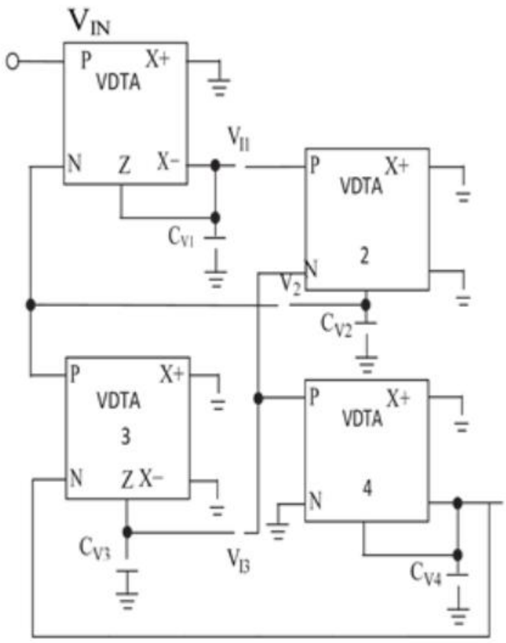


Fig.3.12. Structure of VDTA based wave active filter[34]

Fig. 3.13 illustrates the dual-mode SIMO filter [35], which includes a single VDTA, three capacitors, and a resistor. Depending on the input signal's characteristics, it can be configured as either a VM or a CM structure.

Analysis of the circuit yields VM transfer functions given by:

$$\left.\frac{V_{o1}}{V_{in}}\right|_{LP} = \frac{g_{m1}g_{m2}/C_2C_3}{\Delta} \tag{3.30}$$

$$\left.\frac{V_{o2}}{V_{in}}\right|_{BP} = -\frac{\left(g_{m1}/C_3\right)s}{\Delta} \tag{3.31}$$

$$\left.\frac{V_{o2}}{V_{in}}\right|_{BP} = \frac{s^2}{\Delta} \tag{3.32}$$

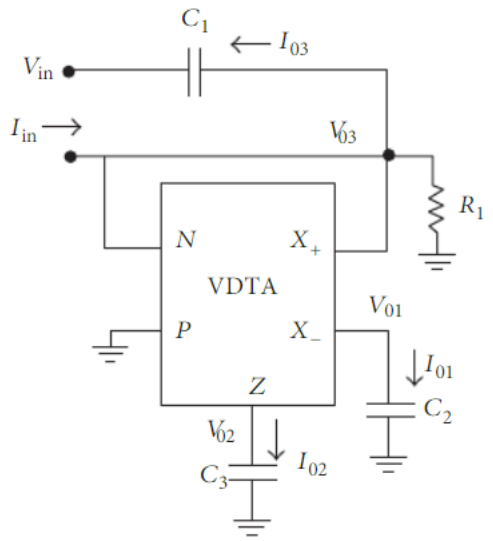


Fig.3.13. VM and CM mode SIMO filter[35]

where,

$$\Delta = s^2 + \frac{s}{R_1C_1} + \frac{g_{m1}g_{m2}}{C_1C_3} \tag{3.33}$$

Analysis of the configuration results in CM transfer function expressed as:

$$\left.\frac{I_{o1}}{I_{in}}\right|_{LP} = -\frac{g_{m1}g_{m2}/C_1C_3}{\Delta} \tag{3.34}$$

$$\left.\frac{I_{o2}}{I_{in}}\right|_{BP} = \frac{\left(g_{m1}/C_1\right)s}{\Delta} \tag{3.35}$$

$$\left.\frac{I_{o2}}{I_{in}}\right|_{BP} = -\frac{s^2}{\Delta} \tag{3.36}$$

This structure introduces a dual-mode SIMO biquad based on a single VDTA, capable of achieving LP, HP, and BP responses. Structured in a SIMO configuration, this biquad can function in either VM or CM, depending on the chosen input excitation. Both the wo and the Q of this circuit can be adjusted independently without affecting each other. Moreover, the cutoff frequency f_0 of the filter can be electronically tuned.

The depicted filter configuration [22] is shown in Fig. 3.15, utilizing two VDTAs and two capacitors, with one grounded capacitor. Analyzing the structure shown in Fig. 3.15 for three voltage inputs V_1, V_2, and V_3 yields the equation:

$$V_o = \frac{V_3 s^2 C_1 C_2 - V_2 s C_1 g_{m2}^F + V_1 g_{m1}^F g_{m2}^F}{D(\mathrm{s})} \quad (3.37)$$

$$D(\mathrm{s}) = \mathrm{s}^2 C_1 C_2 + s C_1 g_{m2}^S + g_{m1}^F g_{m2}^F$$

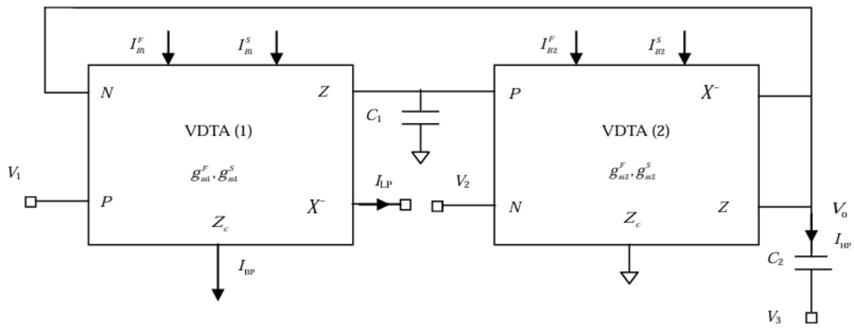


Fig.3.14. Biquad filter configuration[22]

Here, $gm1$ and $gm2$ are the transconductance gains of the 1st and 2nd stages of VDTA(1), while $gm3$ and $gm4$ are the transconductance gains of the 1st and 2nd of VDTA(2) respectively. Equation 3.39 indicates that in VM with the appropriate selection of inputs we can achieve LP, BP, HP, BS, AP filters.
In addition to the VM filtering responses mentioned above, the same circuit can be used in TAM with selecting V_2 as input. In this scenario, the TAM transfer function can be expressed as.

$$\frac{I_{BP}}{V_{in}} = \frac{s C_1 g_{m1}^F g_{m2}^F}{D(\mathrm{s})} \quad (3.38)$$

$$\frac{I_{LP}}{V_{in}} = \frac{g_{m1}^F g_{m1}^S g_{m2}^F}{D(\mathrm{s})} \quad (3.39)$$

$$\frac{I_{HP}}{V_{in}} = \frac{s^2 C_1 C_2 g_{m2}^F}{D(\mathrm{s})} \quad (3.40)$$

In this discussion, we introduce a configuration for realizing a Transadmittance universal biquad filter [36] with one input and three outputs. This circuit offers several features, including the use of only two VDTAs and two grounded capacitors. This circuit realizes LP, HP, and BP filters without changing the circuit structure. Additionally, BR and AP filter responses can be achieved through appropriate current connections.

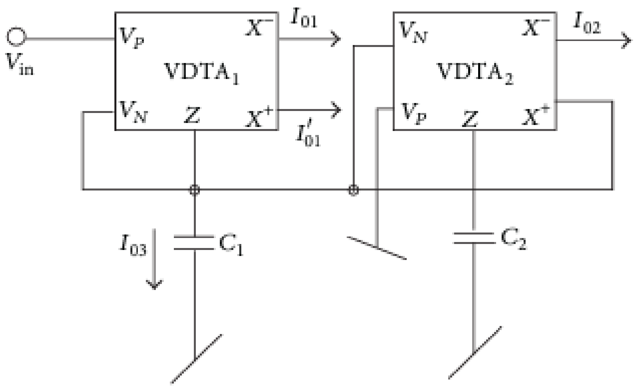


Fig.3.15. The TA biquad filter[36]

The depicted TA filter circuit is presented in Fig. 3.16. Standard analysis of the circuit displayed in Fig. 3.16 provides the following current transfer functions:

$$T_1(\mathrm{s})\big|_{BP} = \frac{I_{o1}}{V_{in}} = -\frac{s\left((g_{m1}g_{m2})/C_1\right)}{D(\mathrm{s})} \tag{3.41}$$

$$T_2(\mathrm{s})\big|_{LP} = \frac{I_{o2}}{V_{in}} = \frac{(g_{m1}g_{m3}g_{m4})/C_1C_2}{D(\mathrm{s})} \tag{3.42}$$

$$T_3(\mathrm{s})\big|_{HP} = \frac{I_{o3}}{V_{in}} = \frac{s^3 g_{m1}}{D(\mathrm{s})} \tag{3.43}$$

$$T_4(\mathrm{s})\big|_{NOTCH} = \frac{I_{o3}+I_{o2}}{V_{in}} = \frac{g_{m1}(\mathrm{s}^2 + g_{m3}g_{m4}/\mathrm{C_1C_2})}{D(\mathrm{s})} \tag{3.44}$$

$$T_5(\mathrm{s})\big|_{AP} = \frac{(I_{o3}+I_{o2}+I_{o1})}{I_{in}} = \frac{g_{m1}(\mathrm{s}^2 - s(\mathrm{g}_{m2}/\mathrm{C_1}) + g_{m3}g_{m4}/\mathrm{C_1C_2})}{D(\mathrm{s})} \tag{3.45}$$

where, $\mathrm{D(s)} = \mathrm{s}^2 + s(\mathrm{g}_{m1}/\mathrm{C_1}) + g_{m3}g_{m4}/\mathrm{C_1C_2}$

This structure introduces a novel CM filter employing only a single active element.

Fig. 3.17 depicts the CM biquadratic [24] with three current input signals (I1, I2, and I3) and a single current output signal (Iout). The circuit comprises a single VDTA, one grounded resistor (R), and two grounded capacitors (C1, C2). By analyzing the circuit in Fig. 3.17, Iout can be expressed as provided in the following equation.

$$I_{out} = \frac{s^2 g_{m1} R I_1 - \dfrac{s g_{m1} I_2}{C_2} + \dfrac{g_{m1} g_{m2} I_3}{C_1 C_2}}{s^2 + \dfrac{s g_{m1}}{C_2} + \dfrac{g_{m1} g_{m2}}{C_1 C_2}} \tag{3.46}$$

By analyzing the above equation we can achieve various CM filters. Depending on input selected we can achieve LP, HP, BP, BR, AP filters. This structure introduces a novel three-input single-output CM biquad universal filter based on VDTA. The circuit comprises only three grounded passive elements and is capable of realizing all five filtering functions: LP, BP, HP, BR, and AP.

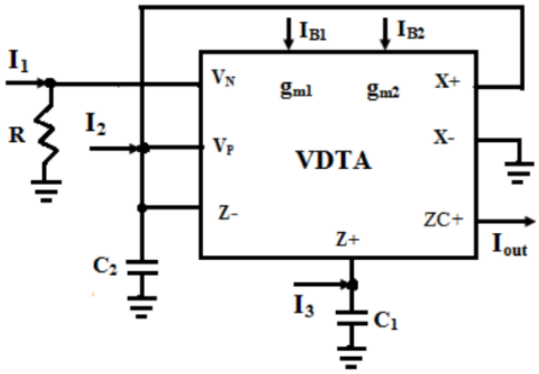


Fig.3.16. The CM biquad filter[24]

This circuit focuses on designing a VM biquadratic universal filter[20]featuring one input and five output terminals, leveraging VDTAs as active elements. This filter utilizes two VDTAs, two grounded capacitors, and two grounded resistors and can realizes LP, HP, BP, BS, AP filters from the same structure. The analysis of the configuration in Fig. 3.18 results in the following transfer functions:

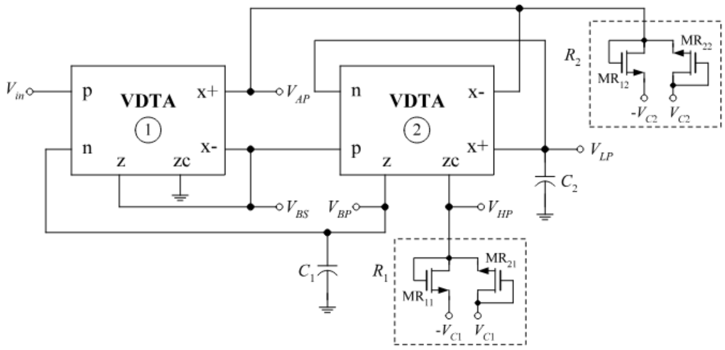


Fig. 3.17. VDTA-based VM biquad filter[20]

$$LP(s) = \frac{V_{LP}(s)}{V_{in}(s)} = \frac{\left(\frac{g_{mF1}}{g_{mS1}}\right)\left(\frac{g_{mF2}g_{mS2}}{C_1C_2}\right)}{D(s)} \tag{3.47}$$

$$BP(s) = \frac{V_{BP}(s)}{V_{in}(s)} = \frac{\left(\frac{g_{mF2}g_{mS2}}{g_{mS1}C_1}\right)}{D(s)}s \tag{3.48}$$

$$HP(\mathrm{s}) = \frac{V_{HP}(\mathrm{s})}{V_{in}(\mathrm{s})} = -\frac{\left(\dfrac{g_{mF1}g_{mF2}R_1}{g_{mS1}}\right)}{D(\mathrm{s})}s^2 \tag{3.49}$$

$$\mathrm{BS(s)} = \frac{V_{BS}(\mathrm{s})}{V_{in}(\mathrm{s})} = \frac{\left(\dfrac{g_{mF1}}{g_{mS1}}\right)\left(s^2 + \dfrac{g_{mF2}g_{mS2}}{C_1C_2}\right)}{D(\mathrm{s})} \tag{3.50}$$

$$\mathrm{AP(s)} = \frac{V_{AP}(\mathrm{s})}{V_{in}(\mathrm{s})} = \frac{g_{mF1}R_2\left(s^2 - \dfrac{g_{mF2}}{C_1}s + \dfrac{g_{mF2}g_{mS2}}{C_1C_2}\right)}{D(\mathrm{s})} \tag{3.51}$$

$$\text{where, } D(\mathrm{s}) = s^2 + \left(\frac{g_{mF1}g_{mF2}}{g_{mS1}C_1}\right)s + \frac{g_{mF2}g_{mS2}}{C_1C_2}$$

In this section, we talked about various circuit configurations which utilizes VDTA as an active building block. We discussed about oscillators, floating and grounded capacitors, inductors and floating resistor. We also discussed about different biquadratic filter configurations that utilizes VDTA as active building block.

CHAPTER 4

PROPOSED VDTA BASED FILTER CONFIGURATION

4.1 PROPOSED VDTA BASED CONFIGURATION:

In this thesis, we propose a novel approach to filter design utilizing Voltage Differencing Transconductance Amplifiers. The VDTA, a versatile building block in modern analog circuit design, offers unique advantages over traditional operational amplifiers, including high gain-bandwidth product, low voltage and power requirements, and versatile signal processing capabilities. Leveraging these advantages, we present a comprehensive study on the design, analysis, and optimization of VDTA-based filters for various signal processing applications. The proposed filter circuit employs VDTAs as active elements to realize both basic and advanced filter configurations, including LP, HP, BP, and BS filters. By utilizing VDTAs in innovative circuit topologies, we aim to achieve superior performance metrics, such as improved frequency selectivity, enhanced bandwidth, and increased dynamic range, compared to conventional filter designs. Overall, the proposed VDTA-based filter circuit represents a significant advancement in filter design methodologies, offering enhanced performance, versatility, and robustness compared to conventional approaches. Through this thesis, we aim to contribute to the advancement of analog circuit design and facilitate the adoption of VDTA-based filters in various signal processing applications, including communication systems, audio processing, biomedical instrumentation, and beyond.

Fig.4.1 depicts the proposed dual-mode SIMO biquad filter, comprising two VDTAs and two grounded capacitors. By selecting the suitable input signal, the configuration can be adjusted to function as either a voltage mode (VM), current mode (CM), or transadmittance mode (TAM) structure.

4.1.1 Current Mode Configuration:

The proposed filter structure operates in current mode if input voltage is set to zero i.e. (V_{in}= 0). It results in following transfer functions:

$$\left.\frac{I_{03}}{I_{in}}\right|_{LP} = \frac{-g_{m2}g_{m3}}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (4.1)$$

$$\left.\frac{I_{01}}{I_{in}}\right|_{HP} = \frac{s^2C_1C_2}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (4.2)$$

$$\left.\frac{I_{02}}{I_{in}}\right|_{BP} = \frac{sC_2g_{m2}}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (4.3)$$

4.1.2 Voltage Mode Configuration:

The current input is removed (I_{in}=0) in Fig.4.1 to achieve VM filter topology. The examination of the resulting topology yields the following transfer functions:

$$\left.\frac{V_{01}}{V_{in}}\right|_{BP} = \frac{sC_2g_{m1}}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (4.4)$$

$$\left.\frac{V_{02}}{V_{in}}\right|_{LP} = \frac{g_{m1}g_{m2}}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (4.5)$$

4.1.3 Transadmittance Mode Configuration:

This topology is also achieved by removing current input i.e. (I_{in}=0). It results in following transfer functions:

$$\left.\frac{I_{01}}{V_{in}}\right|_{HP} = \frac{s^2C_1C_2g_{m3}}{s^2C_2C_1 + sC_2g_{m2} + g_{m2}g_{m3}} \quad (4.6)$$

$$\left.\frac{I_{02}}{V_{in}}\right|_{BP} = \frac{sC_2g_{m2}g_{m3}}{s^2C_2C_1 + sC_2g_{m2} + g_{m2}g_{m3}} \quad (4.7)$$

$$\left.\frac{I_{03}}{V_{in}}\right|_{LP} = \frac{-g_{m2}g_{m3}^2}{s^2C_2C_1 + sC_2g_{m2} + g_{m2}g_{m3}} \quad (4.8)$$

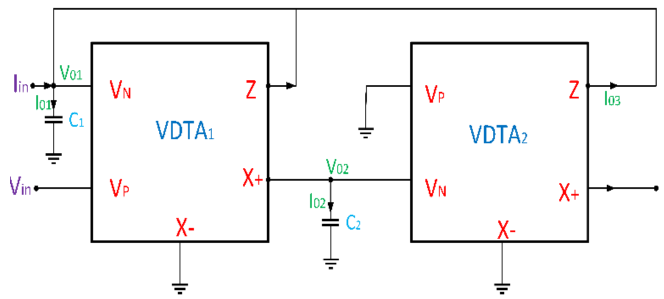


Fig. 4.1. Proposed dual mode SIMO biquad filter

The angular frequency wo for all the three filter structures is given by,

$$w_0 = \sqrt{\frac{g_{m2} g_{m3}}{C_1 C_2}} \tag{4.9}$$

Band Width for CM and VM is,

$$BW = \frac{g_{m1}}{C_1} \tag{4.10}$$

for TAM it is given as follows,

$$BW = \frac{g_{m2}}{C_1} \tag{4.11}$$

From equation 4.9-4.11, it is evident that the filter parameters w_0 and Band width (BW) can be tuned electronically and independently. We can tune w_0 by varying g_{m3} without effecting band width. The BW for CM and VM filter functions can be modified by varying g_{m1} without affecting natural pole frequency (w_0).

4.2 SIMULATION AND EXPERIMENTAL VALIDATION:

The designed filter's functionality is confirmed through PSPICE simulations utilizing TSMC CMOS 0.18µm process parameters. The aspect ratio of the transistors employed in CMOS implementation of VDTA shown in Fig.4.1 are given in Table 4.2. The DC transfer characteristics of the active device is illustrated in Fig. 4.2. The biasing currents are taken as $I_{B1}=I_{B2}=I_{B3}=I_{B4}=100\mu A$ and supply voltages are taken as $V_{DD}=V_{SS}=0.9V$. The proposed circuit is tailored to achieve a specific pole frequency (f_0) of 3.08MHz. Consequently, the component values are determined as C_1=50pf and C_2=100pf. In Fig. 4.5,6&7 the gain responses for CM, VM and TAM filter structures of the proposed biquad filter is depicted.

The simulation results indicate a pole frequency of 3.09 MHz, which closely matches the designed pole frequency of 3.08 MHz. The proposed circuit exhibits electronic tuning capability in terms of pole frequency (f_0) adjustment, which remains independent of bandwidth (BW), achieved by varying parameter g_{m3} i.e. by taking I_{B1}=I_{B2}=50µA, 150µA, 350µA (biasing currents of $VDTA_2$) is given in Fig. 4.8 which is obtained by simulating various CM and VM band pass filtering functions at constant bandwidth (4.34MHz). The values of pole frequency is obtained as 2.34MHz, 3.09MHz, 3.8MHz.

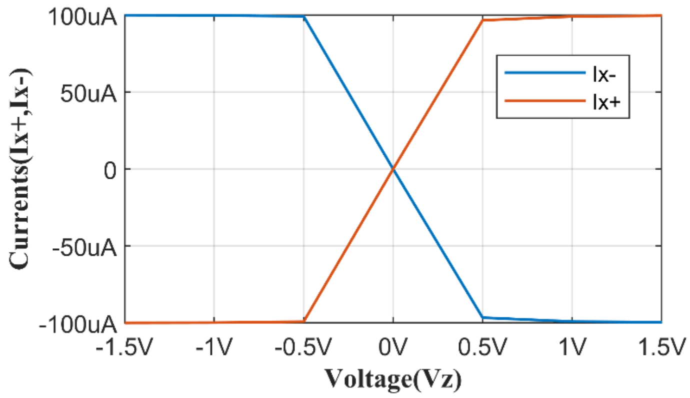


Fig. 4.2. DC Transfer Characteristics of VDTA

Also in Fig.4.9 the electronic tunability of Band Width independent of natural frequency (f_0) for CM and VM is shown by taking I_{B1}=I_{B2}= 50µA, 150µA, 350µA (biasing currents of $VDTA_1$) i.e. varying g_{m1} which results in BW= 2.5MHz, 4.4MHz, 6.6MHz at constant f_0=3.09MHz.

Table 4.1. Aspect Ratio of the Transistors

Transistors	W(µm)	L(µm)
M1, M2, M5, M6	3.6	0.36
M3, M4, M7, M8	16.64	0.36

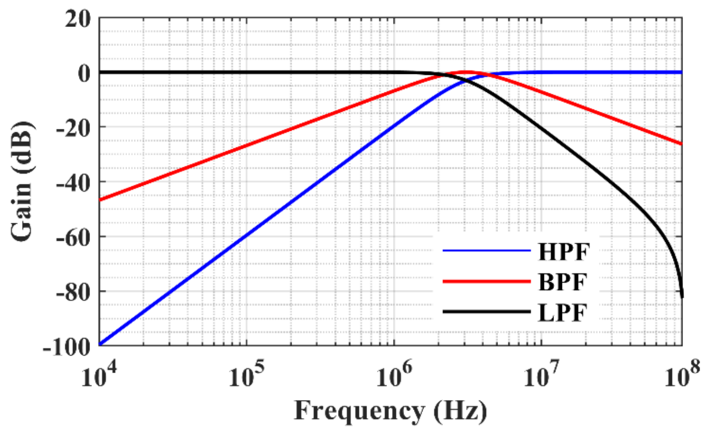


Fig. 4.3. Frequency response of CM topology

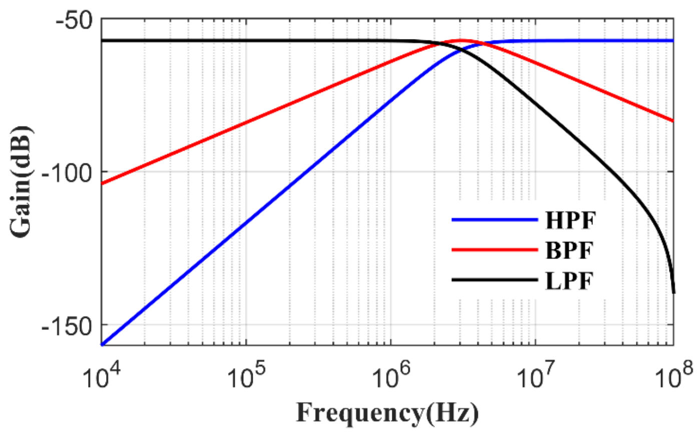


Fig. 4.4. Frequency response of VM topology

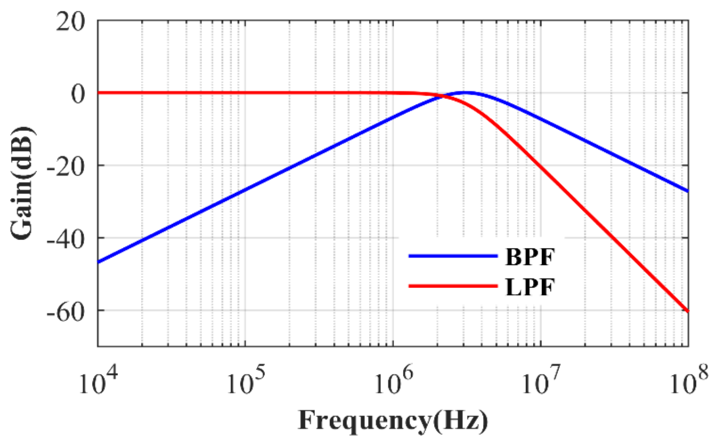


Fig. 4.5. Frequency response of TAM topology

In Fig.4.10 the electronic tuning of low pass cut-off frequency independent of low pass gain is depicted for TAM topology of the proposed filter structure. It is achieved by varying g_{m2} i.e. by taking $I_{B3}=I_{B4}$=50µA, 150µA, 350µA (biasing currents of $VDTA_1$ The values of cut-off frequency is obtained as 2.6MHz, 3.09MHz, 4.02MHz.

Fig.4.11 and Fig.4.12 illustrates the time domain response of the low-pass output for all three modes of the proposed biquad filter. The circuit is simulated by applying sinusoidal input signal i.e. current signal (for CM) of 10mA and voltage signal (for VM and TAM) of 10mV at frequency 1.2MHz. The time domain response of low pass CM function is given in Fig.4.11, low pass VM function and low pass TAM function is given in Fig. 4.12

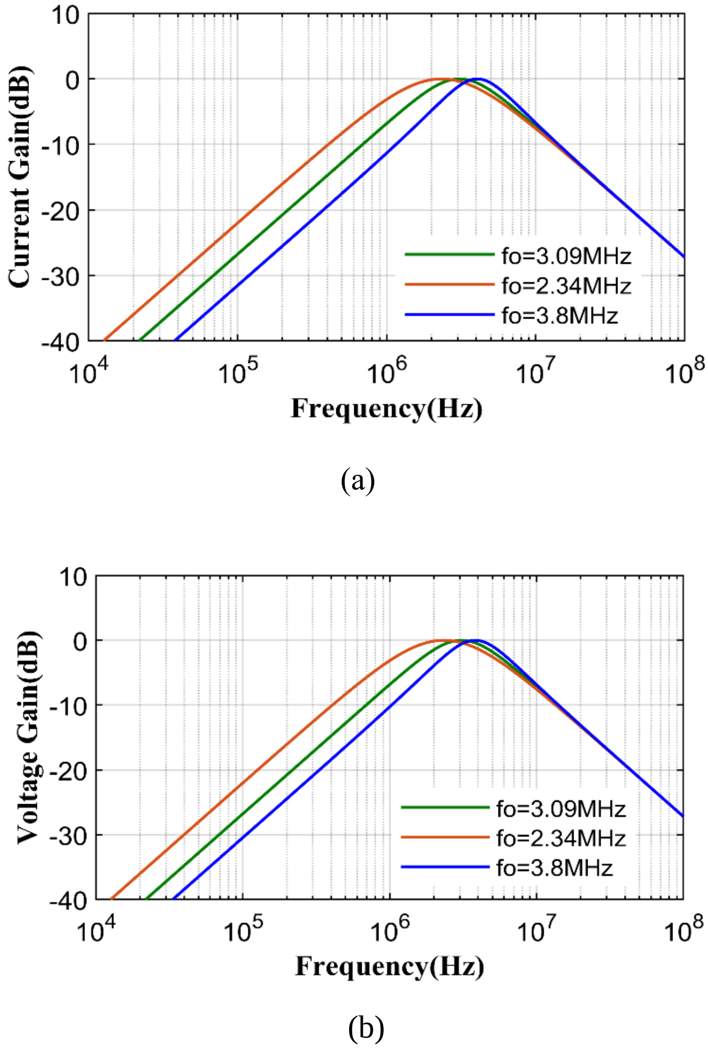
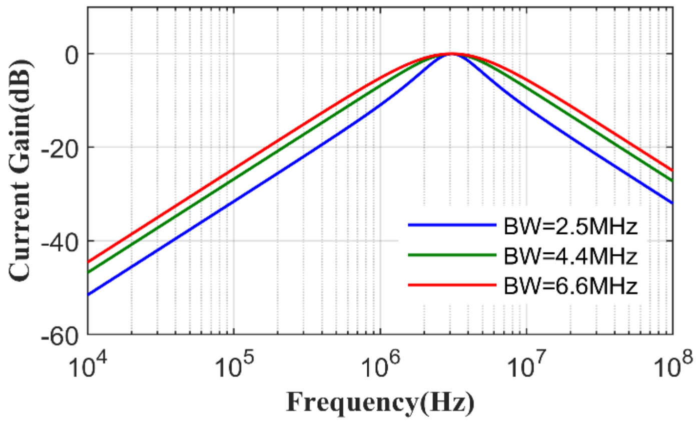
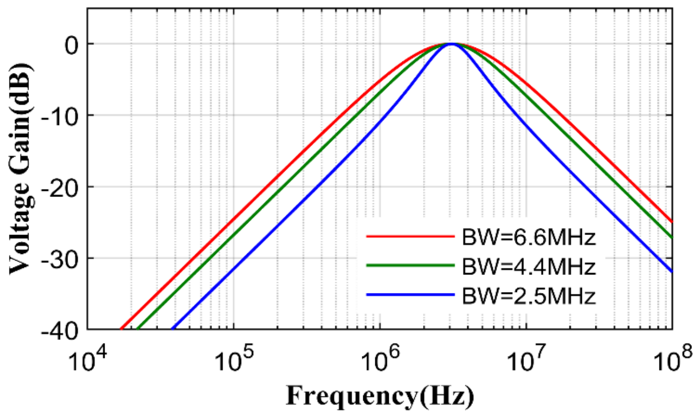


Fig. 4.6. BP responses depicting pole frequency tuning for (a) CM topology (b)VM topology



(a)



(b)

Fig. 4.7. BP responses depicting BW tuning for (a) CM topology (b)VM topology

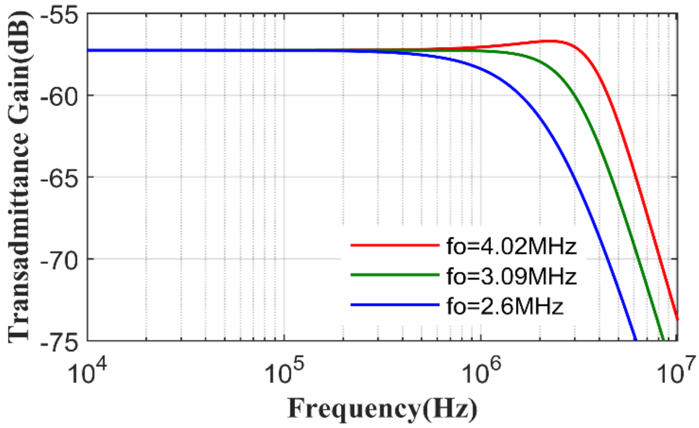
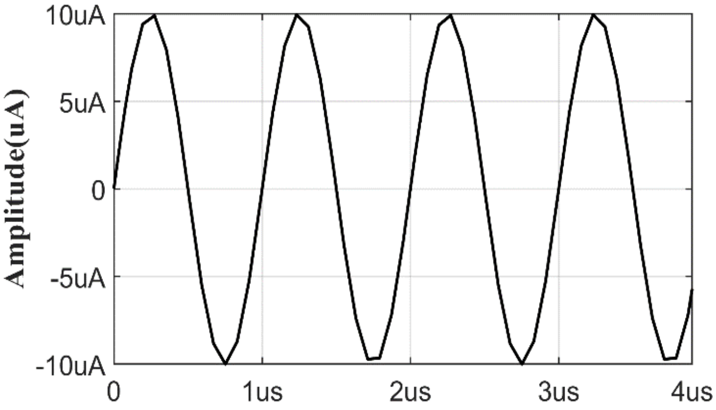
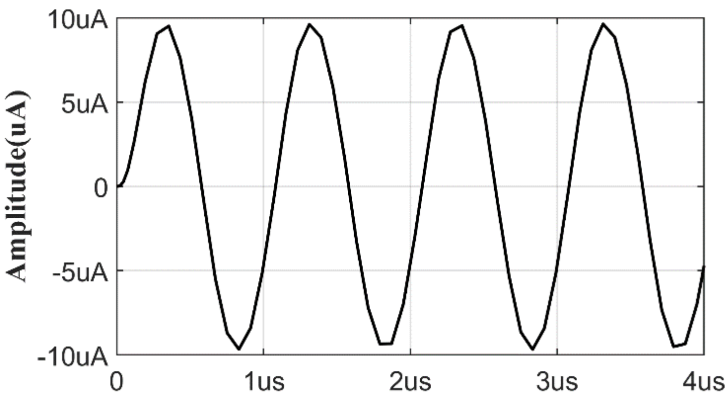


Fig 4.8. LP frequency response depicting cut-off frequency tuning for TAM topology



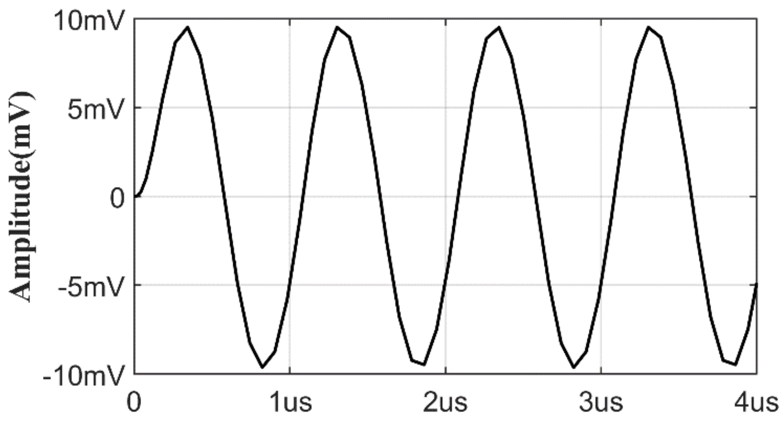
(a)



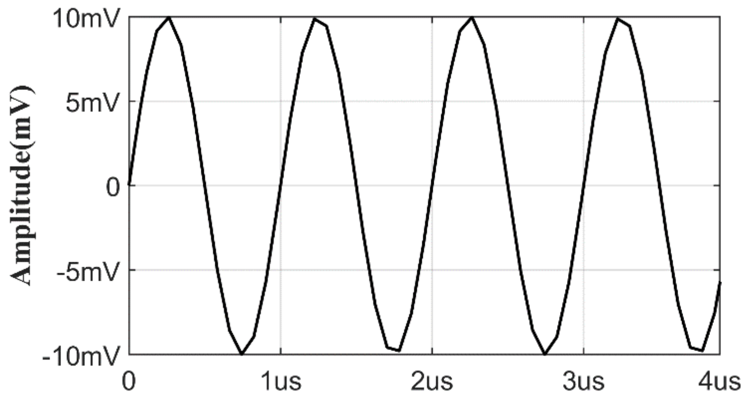
(b)

Fig. 4.9. (a) Input current signal,

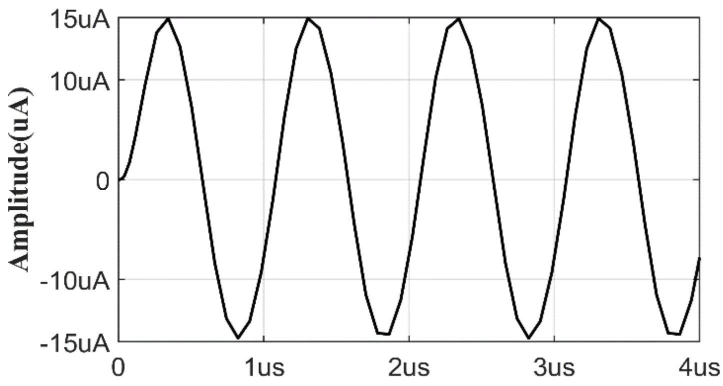
(b) Transient response of LP current output signal



(a)



(b)



(c)

Fig. 4.10. (a) Input voltage signal, Transient response of (b) LP VM output signal (c) LP TAM output signal

4.4 COMPARATIVE ANALYSIS:

VDTA-based filters offer significant advantages in terms of wide frequency range, high linearity, versatility, and reduced component count compared to traditional approaches. However, they also have limitations and trade-offs, including limited availability, sensitivity to parasitic effects, design complexity, and voltage swing limitations. Understanding these factors is essential for effectively designing and deploying VDTA-based filters in various signal processing applications. A thorough comparison of previously published structures with the presented configuration is provided in Table 4.2.

Table 4.2. Comparison between previously published SIMO biquad filter with the proposed filter structure

References	Active Elements Used	Passive Components Used	Mode	Standard filter functions
[12]	One	Two C	VM	LP, HP, BP
[13]	Two	Two C, Two R	VM	LP, HP, BP, BR,AP
[14]	One	Two C, One R	TAM	LP, HP, BP, BR, AP
[15]	Three	Two C	TAM, VM	LP, HP, BP, BR,AP
[16]	One	Two C	CM	LP, HP, BP
[17]	One	Two C, One R	CM	LP, HP, BP, BR, AP
[18]	One	Two C, One R	VM, CM	LP, HP, BP
[36]	Two	Two C	TAM	LP, HP, BP, BR, AP
[22]	Two	Two C	TAM, VM	LP, HP, BP
[23]	One	Two C, One R	TAM	HP, BP
Proposed Work	Two	Two C	VM, CM and TAM	LP, HP, BP

4.5 CONCLUSION:

This thesis introduces a dual-mode SIMO biquad filter employing Voltage VDTA as active elements. The filter offers versatile operation modes including VM, CM, and TAM, selectable based on the input excitation. With appropriate configurations, the proposed biquad realizes two voltage mode functions (low-pass and band-pass), three transadmittance mode functions (low-pass, high-pass, and band-pass), and three current mode functions (low-pass, high-pass, and band-pass). Notably, both the angular frequency and band width of the filter can be independently controlled without affecting each other, ensuring non-interactive tuning. The filter's pole frequency f_o is electronically tunable. The effectiveness of the designed biquadratic configuration is validated through PSPICE simulations, thoroughly analyzing both frequency and transient responses.

CHAPTER 5

FUTURE SCOPE, SOCIAL IMPACT AND CONCLUSION

5.1 FUTURE SCOPE OF THE PRESENTED WORK:

In the realm of biquad filter design utilizing Voltage Differencing Transconductance Amplifiers (VDTAs), there are numerous promising avenues for further exploration and advancement. One such direction involves delving into advanced circuit topologies and architectures. By exploring novel configurations, researchers can seek innovative approaches to bolster filter performance. This may involve integrating VDTAs with other active or passive elements in hybrid topologies to achieve superior frequency response, selectivity, and dynamic range, thus pushing the boundaries of filter design. Expanding the functionality of VDTA-based biquad filters to support multi-mode operation represents another fruitful area of research. Enabling filters to seamlessly switch between various modes such as LP, HP, BP, and BS or notch filtering can significantly enhance their versatility and applicability. Investigating techniques to facilitate this multi-mode operation while ensuring stable and reliable filter performance is paramount to unlocking the full potential of these filters.

Exploring the feasibility of integrating VDTA-based biquad filters into single-chip integrated circuits (ICs) presents another exciting research avenue. This endeavor involves investigating circuit design methodologies, layout techniques, and optimization strategies to optimize circuit performance, minimize power consumption, and enhance manufacturability. Successfully integrating these filters into ICs can pave the way for their widespread adoption in various electronic systems and devices. Additionally, researchers can explore methods to extend the frequency range and bandwidth of VDTA-based biquad filters to cover broader frequency bands, including ultra-high frequency (UHF) and microwave ranges. By investigating circuit techniques, component selection, and topology optimizations, researchers can strive to achieve extended frequency response and improved performance, thus expanding the applicability of these filters in wideband and high-frequency applications.

Developing adaptive and reconfigurable biquad filter architectures using VDTAs represents another promising research direction. By dynamically adjusting filter parameters based on input signals, operating conditions, or system requirements, these filters can adapt in real-time to changing environmental conditions. Exploring adaptive control mechanisms, signal processing techniques, and optimization algorithms can facilitate the development of highly adaptable filters suitable for a wide range of applications. Furthermore, integrating sensing elements and signal processing functionality within VDTA-based biquad filters opens up new possibilities for integrated sensing and processing systems. Applications such as biomedical sensors, environmental monitoring devices, and IoT sensor nodes stand to benefit from the compactness, power efficiency, and system integration offered by integrated sensing and processing capabilities. Exploring the potential of VDTA-based biquad filters for nonlinear signal processing applications represents another intriguing research direction. Investigating novel circuit architectures and signal processing algorithms to exploit the inherent nonlinear characteristics of VDTAs can enable advanced signal processing tasks such as chaos-based communication systems, nonlinear control systems, and neural network implementations.

Finally, conducting extensive experimental validation of VDTA-based biquad filters in real-world scenarios and practical applications is essential to demonstrate their effectiveness and suitability for deployment. Validating filter performance, stability, and reliability through laboratory measurements, field trials, and system-level testing can provide valuable insights into their practical utility and help guide further research and development efforts. Overall, by exploring these future research directions, the thesis on biquad filter design using VDTAs can contribute to advancing the state-of-the-art in analog filter design, signal processing, and integrated circuit technology, with potential applications across a wide range of fields including communications, instrumentation, sensing, and control systems.

The future scope of the thesis on biquad filter design using VDTA encompasses several promising avenues for further research and development:

1. Advanced Circuit Topologies: Explore novel circuit topologies and architectures for biquad filters utilizing VDTAs. Investigate innovative approaches to enhance filter performance, such as hybrid topologies combining VDTAs with other active or passive elements, to achieve improved frequency response, selectivity, and dynamic range.
2. Multi-Mode Operation: Extend the functionality of VDTA-based biquad filters to support multi-mode operation, enabling the realization of filters with multiple selectable modes such as LP, HP, BP, and BS or notch filtering. Investigate techniques to seamlessly switch between different operating modes while maintaining stable and reliable filter performance.

3. Integrated Circuit Implementation: Explore the feasibility of integrating VDTA-based biquad filters into single-chip integrated circuits (ICs) using advanced semiconductor fabrication technologies. Investigate circuit design methodologies, layout techniques, and optimization strategies to optimize circuit performance, minimize power consumption, and enhance manufacturability.
4. Wideband and High-Frequency Applications: Investigate methods to extend the frequency range and bandwidth of VDTA-based biquad filters to cover broader frequency bands, including ultra-high frequency (UHF) and microwave ranges. Explore circuit techniques, component selection, and topology optimizations to achieve extended frequency response and improved performance in wideband and high-frequency applications.
5. Adaptive and Reconfigurable Filters: Develop adaptive and reconfigurable biquad filter architectures using VDTAs to dynamically adjust filter parameters based on input signals, operating conditions, or system requirements. Explore adaptive control mechanisms, signal processing techniques, and optimization algorithms to optimize filter performance in real-time and adapt to changing environmental conditions.
6. Integrated Sensing and Signal Processing: Investigate the integration of sensing elements and signal processing functionality within VDTA-based biquad filters to enable integrated sensing and processing systems. Explore applications such as biomedical sensors, environmental monitoring devices, and IoT (Internet of Things) sensor nodes, where integrated sensing and processing capabilities offer advantages in compactness, power efficiency, and system integration.
7. Nonlinear Signal Processing: Explore the potential of VDTA-based biquad filters for nonlinear signal processing applications, such as chaos-based communication systems, nonlinear control systems, and neural network implementations. Investigate novel circuit architectures and signal processing algorithms to exploit the inherent nonlinear characteristics of VDTAs for advanced signal processing tasks.
8. Experimental Validation and Practical Applications: Conduct extensive experimental validation of VDTA-based biquad filters in real-world scenarios and practical applications. Validate filter performance, stability, and reliability through laboratory measurements, field trials, and system-level testing to demonstrate their effectiveness and suitability for practical deployment in various application domains.

By exploring these future research directions, the thesis on biquad filter design using VDTAs can contribute to advancing the state-of-the-art in analog filter design, signal processing, and integrated circuit technology, with potential applications in a wide range of fields including communications, instrumentation, sensing, and control systems.

5.2 SOCIAL IMPACT OF THE PROPOSED WORK:

The thesis on filter design using Voltage Differencing Transconductance Amplifiers has the potential to generate significant social impact across various domains:

1. Advancement of Technology: By introducing innovative filter designs based on VDTAs, the thesis contributes to advancing analog signal processing technology. These advancements have the potential to catalyze progress in diverse fields such as telecommunications, healthcare, environmental monitoring, and consumer electronics, leading to the development of more efficient and sophisticated systems.
2. Improved Signal Processing: The improved performance metrics of VDTA-based filters, such as enhanced frequency response, better passband/stopband characteristics, and increased dynamic range, can lead to higher-quality signal processing in various applications. This could translate to clearer audio signals, faster data transmission rates, more accurate biomedical measurements, and improved sensor performance, ultimately benefiting end-users and society as a whole.
3. Cost-Efficiency and Accessibility: VDTA-based filters, with their potential for integration into single-chip ICs and reduced component count, have the potential to lower production costs. This cost-efficiency could make advanced signal processing capabilities more accessible to a wider range of users and applications, including those in resource-constrained environments or developing regions.
4. Healthcare and Biomedical Applications: In the realm of healthcare, VDTA-based filters could find applications in medical devices such as electrocardiogram (ECG) monitors, pulse oximeters, and medical imaging systems. The improved performance and versatility of these filters could contribute to more accurate diagnoses, better patient monitoring, and enhanced treatment outcomes, thus positively impacting public health.
5. Environmental Monitoring: VDTA-based filters could play a very important role in environmental monitoring systems, aiding in the detection and analysis of pollutants, contaminants, and other environmental parameters. By providing more accurate and reliable data, these filters could support efforts to mitigate environmental risks, protect ecosystems, and ensure the sustainability of natural resources.
6. Communication and Connectivity: In the realm of telecommunications and information technology, VDTA-based filters could enhance communication systems, networking equipment, and wireless devices. The improved signal processing capabilities offered by these filters could lead to faster data transmission, more robust connectivity, and better overall performance in communication networks, thereby improving access to information and connectivity for individuals and communities worldwide.

In summary, the thesis on filter design using VDTAs has the potential to generate significant social impact by advancing technology, improving signal processing capabilities, enhancing healthcare and biomedical applications, supporting environmental monitoring efforts, and strengthening communication and connectivity systems. Through these contributions, VDTA-based filters have the potential to positively influence various aspects of society, ultimately leading to improved quality of life and societal well-being.

The thesis on filter design utilizing Voltage Differencing Transconductance Amplifiers (VDTAs) holds promise for substantial social impact across a spectrum of domains. Through pioneering innovative filter architectures rooted in VDTA technology, the thesis stands to propel the advancement of analog signal processing. This advancement could serve as a catalyst for progress in diverse sectors such as telecommunications, healthcare, environmental monitoring, and consumer electronics, fostering the evolution of more efficient and sophisticated systems tailored to meet modern demands.

Furthermore, the improved performance metrics demonstrated by VDTA-based filters, including enhanced frequency response, superior passband/stopband characteristics, and expanded dynamic range, signify a paradigm shift towards higher-quality signal processing across various applications. This improvement has the potential to translate into clearer audio signals, expedited data transmission rates, more precise biomedical measurements, and heightened sensor performance, ultimately enriching the experiences of end-users and benefitting society at large. Moreover, the cost-efficiency and accessibility offered by VDTA-based filters could democratize access to advanced signal processing capabilities. With the potential for integration into single-chip integrated circuits (ICs) and reduced component count, these filters could substantially lower production costs. This cost-effectiveness may democratize access to cutting-edge signal processing capabilities, making them attainable for a broader spectrum of users and applications, including those in resource-constrained environments and developing regions.

In the realm of healthcare, VDTA-based filters hold significant potential for applications in medical devices such as electrocardiogram (ECG) monitors, pulse oximeters, and medical imaging systems. The heightened performance and versatility of these filters could revolutionize diagnostic accuracy, patient monitoring, and treatment outcomes, thereby positively impacting public health outcomes. Similarly, in environmental monitoring, VDTA-based filters could play a pivotal role by facilitating the detection and analysis of pollutants, contaminants, and other environmental parameters. By furnishing more precise and reliable data, these filters could underpin efforts to mitigate environmental risks, preserve ecosystems, and ensure the sustainability of natural resources.

Lastly, within the realms of telecommunications and information technology, VDTA-based filters stand to bolster communication systems, networking equipment, and wireless devices. By harnessing their improved signal processing capabilities, these filters could drive faster data transmission rates, fortified connectivity, and enhanced overall performance in communication networks, thereby augmenting access to information and connectivity for individuals and communities worldwide.In summation, the thesis on filter design using VDTAs harbors the potential to engender substantial social impact through its contributions to technological advancement, enhanced signal processing capabilities, improved healthcare and environmental monitoring, and fortified communication and connectivity systems. By leveraging these contributions, VDTA-based filters hold the promise of positively shaping various facets of society, ultimately fostering improved quality of life and societal well-being.

5.3 CONCLUSION:

In this thesis, we embarked on a comprehensive exploration of the design, analysis, simulation, and potential applications of filters utilizing Voltage Differencing Transconductance Amplifiers (VDTAs). Through our research endeavors, we have meticulously examined the versatility, effectiveness, and promising capabilities of VDTA-based filters across various signal processing domains. By harnessing the unique attributes of VDTAs, including their high gain-bandwidth product, low voltage and power requirements, and flexible signal processing abilities, we have presented novel filter architectures that surpass conventional designs in terms of performance and functionality.

Our proposed filter design have showcased superior performance metrics compared to traditional counterparts. These advancements include enhanced frequency response, improved passband/stopband characteristics, expanded dynamic range, and enhanced linearity. Such improvements are paramount in meeting the evolving demands of modern signal processing applications, where precision, efficiency, and adaptability are crucial. A key highlight of our research lies in the inherent flexibility and adaptability afforded by VDTAs. These characteristics have enabled the realization of filters with multiple modes and functions, thereby facilitating versatile operation and seamless integration into diverse systems. The ability to configure filters to suit specific application requirements underscores the transformative potential of VDTA-based designs in addressing a wide array of signal processing challenges.Furthermore, our discussions encompassed optimization techniques, future research directions, and potential applications of VDTA-based filters. By shedding light on these aspects, we have underscored the pivotal role of VDTAs in advancing analog filter design and signal processing technology. The identified future scope encompasses a rich landscape of opportunities, including the exploration of advanced circuit topologies, multi-mode operation, integration into ICs, expansion into wideband/high-frequency applications, development of adaptive/reconfigurable filters, exploration of integrated sensing capabilities, and investigation of nonlinear signal processing paradigms.

By contributing to the expanding body of knowledge in filter design using VDTAs, this thesis underscores the transformative potential of these devices in diverse fields such as communications, instrumentation, biomedical devices, and beyond. Through continued exploration and innovation in these areas, VDTA-based filters hold the promise of revolutionizing analog signal processing and spearheading the development of groundbreaking solutions in the future. In conclusion, this thesis has explored the design, analysis, simulation, and potential applications of filters using Voltage Differencing Transconductance Amplifiers (VDTAs). Throughout this research, we have demonstrated the versatility, effectiveness, and promise of VDTA-based filters in various signal processing applications.

The proposed filter design have shown improved performance metrics, including enhanced frequency response, better passband/stopband characteristics, increased dynamic range, and improved linearity compared to conventional filter designs. The flexibility and adaptability of VDTAs have enabled the realization of filters with multiple modes and functions, allowing for versatile operation and seamless integration into different systems. Furthermore, we have discussed optimization techniques, future research directions, and potential applications of VDTA-based filters, highlighting their significance in advancing analog filter design and signal processing technology. The future scope includes exploring advanced circuit topologies, multi-mode operation, IC integration, wideband/high-frequency applications, adaptive/reconfigurable filters, integrated sensing, nonlinear signal processing, and experimental validation in real-world scenarios.

Overall, this thesis contributes to the growing body of knowledge in filter design using VDTAs and underscores their potential for various applications in communications, instrumentation, biomedical devices, and beyond. By continuing to explore these avenues of research and development, VDTA-based filters have the potential to revolutionize analog signal processing and pave the way for innovative solutions in the future.

REFERENCES

[1] A. Sedra, K. Smith, T. C. Carusone, and V. Gaudet, "Microelectronic circuits 8th edition," *Chapter,* vol. 14, pp. 1235-1236, 2020.

[2] R. Schaumann, X. Mac Elwyn Van Valkenburg, and H. Xiao, *Design of analog filters*. Oxford University Press New York, 2001.

[3] D. Biolek, R. Senani, V. Biolkova, and Z. Kolka, "Active elements for analog signal processing: classification, review, and new proposals," *Radioengineering,* vol. 17, no. 4, pp. 15-32, 2008.

[4] A. Sedra and K. Smith, "A second-generation current conveyor and its applications," *IEEE Transactions on circuit theory,* vol. 17, no. 1, pp. 132-134, 1970.

[5] H. Elwan and A. Soliman, "Novel CMOS differential voltage current conveyor and its applications," *IEE Proceedings-Circuits, Devices and Systems,* vol. 144, no. 3, pp. 195-200, 1997.

[6] A. Ü. Keskin, "A four quadrant analog multiplier employing single CDBA," *Analog Integrated Circuits and Signal Processing,* vol. 40, pp. 99-101, 2004.

[7] T. Deliyannis, Y. Sun, and J. K. Fidler, *Continuous-time active filter design*. CRC press, 2019.

[8] A. Fabre, O. Saaid, F. Wiest, and C. Boucheron, "Current controlled bandpass filter based on translinear conveyors," *Electronics Letters,* vol. 31, no. 20, pp. 1727-1728, 1995.

[9] D. Biolek, "CDTA-building block for current-mode analog signal processing," in *Proceedings of the ECCTD*, 2003, vol. 3, pp. 397-400.

[10] M. Siripruchyanun and W. Jaikla, "CMOS current-controlled current differencing transconductance amplifier and applications to analog signal processing," *AEU-International Journal of Electronics and Communications,* vol. 62, no. 4, pp. 277-287, 2008.

[11] J.-J. Chen, H.-W. Tsao, and C.-C. Chen, "Operational transresistance amplifier using CMOS technology," *Electronics letters,* vol. 28, no. 22, pp. 2087-2088, 1992.

[12] A. Yesil, F. Kacar, and H. Kuntman, "New simple CMOS realization of voltage differencing transconductance amplifier and its RF filter application," *Radioengineering,* vol. 20, no. 3, pp. 632-637, 2011.

[13] J. Satansup and W. Tangsrirat, "Single VDTA-based voltage-mode electronically tunable universal filter," in *The 27th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC 2012)*, 2012, pp. 1-4.

[14] C. Shankar and S. V. Singh, "Single VDTA based multifunction transadmittance mode biquad filter," *Int. J. Eng. Technol.(IJET),* vol. 7, no. 6, pp. 2180-2188, 2016.

[15] V. Chamnanphrai and W. Sa-ngiamvibool, "Electronically tunable SIMO mixed-mode universal filter using VDTAs," *Przegląd Elektrotechniczny,* vol. 93, no. 3, pp. 207-211, 2017.

[16] J. Satansup and W. Tangsrirat, "Single VDTA-based current-mode electronically tunable multifunction filter," in *Proceedings of the 4th International Science, Social Science, Engineering and Energy Conference (ISEEC'12)*, 2012, pp. 1-8.

[17] D. Prasad, D. R. Bhaskar, and M. Srivastava, "Universal current-mode biquad filter using a VDTA," *Circuits and Systems,* vol. 4, no. 1, pp. 32-36, 2013.

[18] N. Singhal, R. Pandey, and N. Pandey, "Dual mode biquadratic filter using single VDTA," *Int. J. Electri. Electron. Eng,* vol. 6, pp. 134-139, 2014.

[19] N. Walde and S. N. Ahmad, "New voltage mode sinusoidal oscillator using voltage differencing transconductance amplifiers (VDTAs)," *Circuits and Systems,* vol. 6, no. 8, pp. 173-178, 2015.

[20] J. Satansup, T. Pukkalanun, and W. Tangsrirat, "Electronically tunable single-input five-output voltage-mode universal filter using VDTAs and grounded passive elements," *Circuits, Systems, and Signal Processing,* vol. 32, pp. 945-957, 2013.

[21] N. Raj, S. Dutta, R. K. Ranjan, D. K. Singh, and H. Kuntman, "VDTA Based Transadmittance Mode Instrumentation Amplifier with Experimental results," 2023.

[22] G. Gupta, S. V. Singh, and S. V. Bhooshan, "VDTA based electronically tunable voltage-mode and trans-admittance biquad filter," *Circuits and Systems,* vol. 6, no. 3, pp. 93-102, 2015.

[23] C. Shankar and S. V. Singh, "A low voltage operable VDTA based biquad filter realizing band pass and high pass filtering functions in trans-admittance-mode," in *International Conference on Computing, Communication & Automation*, 2015: IEEE, pp. 1288-1293.

[24] C. Shankar and S. V. Singh, "Electronically tunable current mode biquad filter based on single VDTA and grounded passive elements," *MH,* vol. 3, p. 3, 2017.

[25] W. Tangsrirat, "Linearly tunable CMOS voltage differencing transconductance amplifier (VDTA)," *Informacije MIDEM,* vol. 49, no. 2, pp. 61-68, 2019.

[26] J. Satansup and W. Tangsrirat, "Compact VDTA-based current-mode electronically tunable universal filters using grounded capacitors," *Microelectronics Journal,* vol. 45, no. 6, pp. 613-618, 2014.

[27] D. Prasad, M. Srivastava, and D. R. Bhaskar, "Electronically controllable fully-uncoupled explicit current-mode quadrature oscillator using VDTAs and grounded capacitors," 2013.

[28] P. Mongkolwai, T. Pukkalanun, and W. Tangsrirat, "Electronically tunable floating capacitance simulator with only VDTAs and a grounded capacitor," in *4th International Science, Social Science, Engineering and Energy Conference*, 2012.

[29] M. Srivastava, D. Prasad, and D. Bhaskar, "New electronically tunable grounded inductor simulator employing single vdta and one grounded capacitor," *Journal of Engineering Science and Technology,* vol. 12, no. 1, pp. 113-126, 2017.

[30] M. Srivastava and D. Prasad, "A Novel Purely Active Electronically Controllable Configuration for Simulating Resistance in Floating Form," *ELECTRONICS,* vol. 20, no. 2, pp. 90-94, 2016.

[31] D. Prasad and D. Bhaskar, "Grounded and floating inductance simulation circuits using VDTAs," 2012.

[32] K. M. Santhoshini, S. Musala, and S. Avireni, "An integrator circuit using voltage difference transconductance amplifier," *Solid State Electronics Letters,* vol. 1, no. 1, pp. 10-14, 2019.

[33] M. Zaffer and U. Kamboj, "Application of Voltage Difference transconductance Amplifier (VDTA) for realization of analog active filter," in *Journal of Physics: Conference Series*, 2022, vol. 2267, no. 1: IOP Publishing, p. 012045.

[34] G. Singh, "CMOS realization of VDTA based electronically tunable wave active filter with minimum power consumption at low supply voltage±0.82 V," *Circuits and Systems,* vol. 11, no. 02, p. 11, 2020.

[35] R. Pandey, N. Pandey, and N. Singhal, "Single VDTA based dual mode single input multioutput biquad filter," *Journal of Engineering,* vol. 2016, 2016.

[36] D. Prasad, M. Srivastava, and D. Bhaskar, "Transadmittance type universal current-mode biquad filter using VDTAs," *International scholarly research notices,* vol. 2014, 2014.

LIST OF PUBLICATIONS

Publisher	Name of Paper	Scopus Indexed
IEEE (ICECCC) 2024	Dual Mode SIMO Biquad Filter Using VDTA	Yes

CMR INSTITUTE OF TECHNOLOGY

#132, AECS Layout, ITPL Main Road, Kundalahalli, Bengaluru-560 037

Certificate of Participation

This is to certify that

Shivani Singh

has presented a paper entitled "DUAL MODE SIMO BIQUAD FILTER USING VDTA" in International Conference on Electronics, Communication, Computing and Control Technology (ICECCC 2024) hosted by the Department of Electronics and Communications Engineering, CMR Institute of Technology, Bengaluru during 2nd and 3rd May 2024.

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***Abstract*— This paper introduces a biquadratic filter configuration that operates in dual mode with a single input and multiple outputs (SIMO) providing two voltage mode functions (low-pass and band-pass), three trans-admittance mode functions (low-pass, high-pass and band-pass) and three current mode functions (low-pass, high-pass and band-pass) based on VDTA. The proposed configuration, utilizing two Voltage Differencing Transconductance Amplifiers (VDTAs) and two grounded capacitors, is designed without the need for external resistors. This makes it well-suited for potential integration into a single integrated circuit (IC). It provides adaptability through the option to configure into voltage mode, current mode, or transadmittance mode structures, based on the selected input excitation. The proposed structure allows independent tuning of the angular frequency (w_o) without affecting the bandwidth. The feasibility of the suggested biquadratic configuration is illustrated through PSPICE simulations employing the 0.18µm TSMC CMOS process specifications.**

***Keywords*— VDTA, SIMO, VM, CM, TAM**

I. INTRODUCTION

In analog signal processing [1], versatile filters are beneficial as the same configuration can be used for various filter responses. During the past few years, several current mode active elements such as CCII, DDCCII, CDBA, OTA, CCCII, CDTA, CCCDTA, CFOA, OTRA, VDTA etc. and their applications in filter design are introduced in literature [2-28]. Among these, the voltage differencing transconducta-nce amplifier (VDTA) is a recently introduced active element [19]. This device offers versatility by supporting operation in both current and voltage modes, granting circuit designers flexibility in their designs. An essential characteristic of the VDTA is its capability to display two distinct transconductance values, allowing for electronic tuning through its variable transconductance gains. Hence, the VDTA device is particularly well-suited for the synthesis of electronically tunable active circuits. A widely researched and published configuration is the Single-Input Multiple-Output (SIMO) universal filter, where a single input signal is utilized. SIMO filters, requiring only one input signal, are capable of simultaneously implementing multiple filtering functions. The SIMO filter topology has proven beneficial in various applications such as PLL FM stereo demodulators and crossover networks. A variety of VDTA based SIMO biquadratic filters are available in literature [19-28]. These filters can further be classified as voltage mode [19],[21],[23-25],[27, 28], current mode[20, 22], and dual mode[26] structures. A thorough comparison of previously published structures with the presented configuration is provided in Table 1.

This communication introduces a novel dual-mode SIMO-type universal biquad filter that utilizes VDTA. The proposed configuration consists of two VDTAs and two grounded capacitors. By selecting the appropriate input excitation, the proposed structure can yield output signals in the form of current, voltage, or transconductance. The proposed structure can provide three current-mode functions (low-pass, high-pass and band-pass), two voltage-mode functions (low-pass and band-pass) and three transconductance-mode functions (low-pass, high-pass and band-pass). The quality factor and pole frequency can be tuned electronically and orthogonally. Proposed circuit configuration also offers low passive sensitivities. The proposed configuration's performance has been tested using SPICE simulations, utilizing the 0.18 µm TSMC CMOS process parameters for verification.

II. VDTA FUNDAMENTALS

The symbolic notation of VDTA is shown in Fig.1. In Voltage Differencing Transconductance Amplifier, the disparity between the input voltages (V_P, V_N) is converted to current at the terminal Z by first transconductance gain and the voltage drop at the terminal Z is translated into current at the terminals X+ and X- by secondary transconductance gain. External bias currents enable electronic control of both transconductance-es(g_{m1} and g_{m2}). The CMOS realization of VDTA is shown in Fig. 2. The relationship between voltage and current can be expressed through the following equation.

$$\begin{pmatrix} I_Z \\ I_{X-} \\ I_{X+} \end{pmatrix} = \begin{pmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & -g_{m2} \\ 0 & 0 & g_{m2} \end{pmatrix} \begin{pmatrix} V_P \\ V_N \\ V_Z \end{pmatrix} \qquad (1)$$

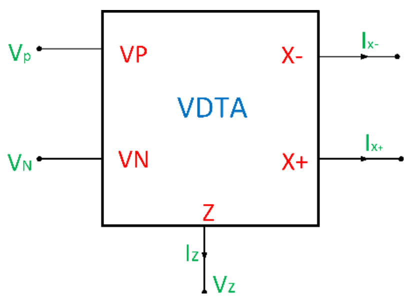


Fig. 1. Circuit symbol of VDTA

The transconductance gains, g_{m1} and g_{m2} can be mathematically represented as follows,

$$g_{m1} = \frac{g_1 g_2}{g_1 + g_2} + \frac{g_3 g_4}{g_3 + g_4} \qquad (2)$$

$$g_{m2} = \frac{g_5 g_6}{g_5 + g_6} + \frac{g_7 g_8}{g_7 + g_8} \quad (3)$$

where g_i is the transconductance value and is given by,

$$g_i = \sqrt{\mu C_{ox}\left(\frac{W}{L}\right)_i I_{Bi}} \quad (4)$$

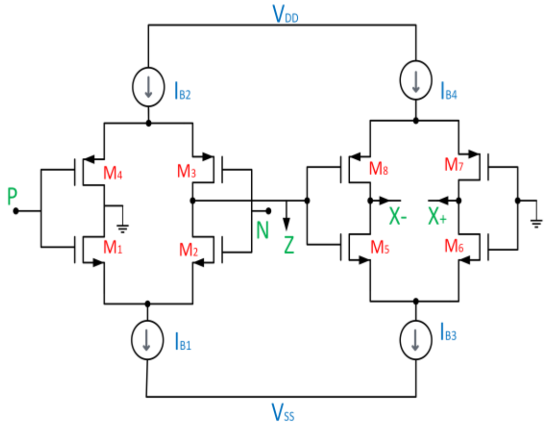


Fig. 2. CMOS Representation of VDTA

Equation (3) defines μ as the effective carrier mobility, C_{ox} as the gate oxide capacitance per unit area, I_{Bi} as the DC bias current and $(W/L)_i$ as the aspect ratio of the i_{th} MOS transistor.

III. PROPOSED BIQUAD FILTER STRUCTURE

Figure 3 depicts the proposed dual-mode SIMO biquad filter, comprising two VDTAs and two grounded capacitors. By selecting the suitable input signal, the configuration can be adjusted to function as either a voltage mode (VM), current mode (CM), or transadmittance mode (TAM) structure.

A. Current Mode Configuration.

The proposed filter structure operates in current mode if input voltage is set to zero i.e. $V_{in} = 0$. It results in following transfer functions:

$$\left.\frac{I_{03}}{I_{in}}\right|_{LP} = \frac{-g_{m2}g_{m3}}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (5)$$

$$\left.\frac{I_{01}}{I_{in}}\right|_{HP} = \frac{s^2C_1C_2}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (6)$$

$$\left.\frac{I_{02}}{I_{in}}\right|_{BP} = \frac{sC_2g_{m2}}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (7)$$

B. Voltage Mode Configuration.

The current input is removed (I_{in}=0) in fig.3 to achieve VM filter topology. The examination of the resulting topology yields the following transfer functions:

$$\left.\frac{V_{01}}{V_{in}}\right|_{BP} = \frac{sC_2g_{m1}}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (8)$$

$$\left.\frac{V_{02}}{V_{in}}\right|_{LP} = \frac{g_{m1}g_{m2}}{s^2C_2C_1 + sC_2g_{m1} + g_{m2}g_{m3}} \quad (9)$$

C. Transadmittance Mode Configuration.

This topology is also achieved by removing current input i.e. (I_{in}=0). It results in following transfer functions:

$$\left.\frac{I_{01}}{V_{in}}\right|_{HP} = \frac{s^2C_1C_2g_{m3}}{s^2C_2C_1 + sC_2g_{m2} + g_{m2}g_{m3}} \quad (10)$$

$$\left.\frac{I_{02}}{V_{in}}\right|_{BP} = \frac{sC_2g_{m2}g_{m3}}{s^2C_2C_1 + sC_2g_{m2} + g_{m2}g_{m3}} \quad (11)$$

$$\left.\frac{I_{03}}{V_{in}}\right|_{LP} = \frac{-g_{m2}g_{m3}^2}{s^2C_2C_1 + sC_2g_{m2} + g_{m2}g_{m3}} \quad (12)$$

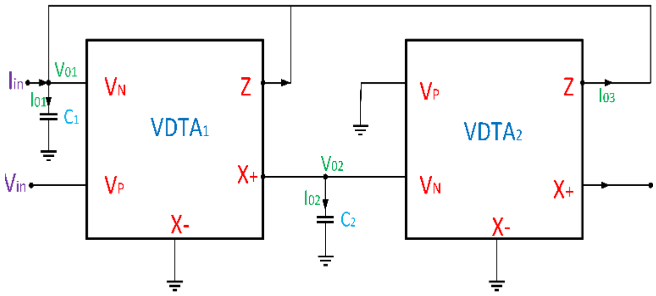


Fig. 3. Proposed dual mode SIMO biquad filter

The angular frequency wo for all the three filter structures is given by,

$$w_0 = \sqrt{\frac{g_{m2}g_{m3}}{C_1C_2}} \quad (13)$$

Band Width for CM and VM is,

$$BW = \frac{g_{m1}}{C_1} \quad (14)$$

for TAM it is given as follows,

$$BW = \frac{g_{m2}}{C_1} \quad (15)$$

From equ.13-15, it is evident that the filter parameters w_0 and Band width (BW) can be tuned electronically and independently. We can tune w_0 by varying g_{m3} without effecting band width. The BW for current mode and voltage mode filter functions can be modified by varying g_{m1} without affecting natural pole frequency (w_0).

Table 1. Comparison between previously published SIMO biquad filter with the proposed filter structure

References	Active Elements Used	Passive Components Used	Mode	Standard filter functions
[19]	One	Two C	VM	LP, HP, BP
[20]	One	Two C	CM	LP, HP, BP
[21]	Two	Two C, Two R	VM	LP, HP, BP, BR,AP
[22]	One	Two C, One R	CM	LP, HP, BP, BR, AP
[23]	Two	Two C	TAM	LP, HP, BP,

				BR, AP
[24]	Two	Two C	TAM, VM	LP, HP, BP
[25]	One	Two C, One R	TAM	HP, BP
[26]	One	Two C, One R	VM, CM	LP, HP, BP
[27]	One	Two C, One R	TAM	LP, HP, BP, BR, AP
[28]	Three	Two C	TAM, VM	LP, HP, BP, BR,AP
Proposed Work	Two	Two C	VM, CM and TAM	LP, HP, BP

IV. SIMULATION FINDINGS

The designed filter's functionality is confirmed through PSPICE simulations utilizing TSMC CMOS 0.18µm process parameters. The aspect ratio of the transistors employed in CMOS implementation of VDTA shown in Fig. 2 are given in Table 2. The DC transfer characteristics of the active device is illustrated in Fig. 4. The biasing currents are taken as $I_{B1} = I_{B2} = I_{B3} = I_{B4} = 100\mu A$ and supply voltages are taken as $V_{DD} = V_{SS} = 0.9V$. The proposed circuit is tailored to achieve a specific pole frequency (f_o) of 3.08MHz. Consequently, the component values are determined as C_1 =50pf and C_2 =100pf. In Fig. 5,6&7 the gain responses for CM, VM and TAM filter structures of the proposed biquad filter is shown. The simulation results indicate a pole frequency of 3.09 MHz, which closely matches the designed pole frequency of 3.08 MHz. The proposed circuit exhibits electronic tuning capability in terms of pole frequency (f_o) adjustment, which remains independent of bandwidth (BW), achieved by varying parameter g_{m3} i.e. by taking $I_{B1} = I_{B2} =$ 50µA, 150µA, 350µA (biasing currents of $VDTA_2$) is given in Fig. 8 which is obtained by simulating various CM and VM band pass filtering functions at constant band width (4.34MHz). The values of pole frequency is obtained as 2.34MHz, 3.09MHz, 3.8MHz.

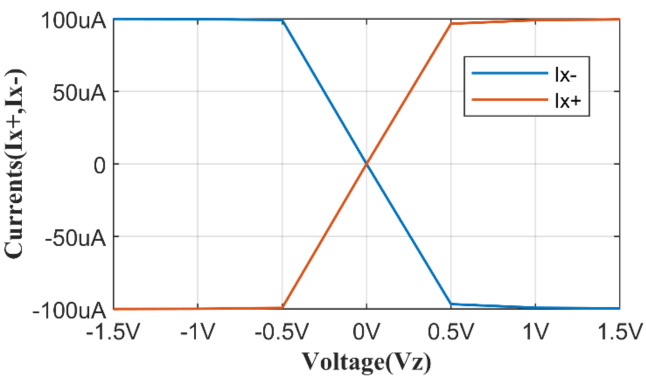


Fig. 4. DC Transfer Characteristics of VDTA

Also in Fig. 9 the electronic tunability of Band Width independent of natural frequency (f_o) for CM and VM is shown by taking $I_{B1} = I_{B2} =$ 50µA, 150µA, 350µA (biasing currents of $VDTA_1$) i.e. varying g_{m1} which results in BW= 2.5MHz, 4.4MHz, 6.6MHz at constant f_o =3.09MHz.

Table 2. Aspect Ratio of the Transistors

Transistors	W(µm)	L(µm)
M1, M2, M5, M6	3.6	0.36
M3, M4, M7, M8	16.64	0.36

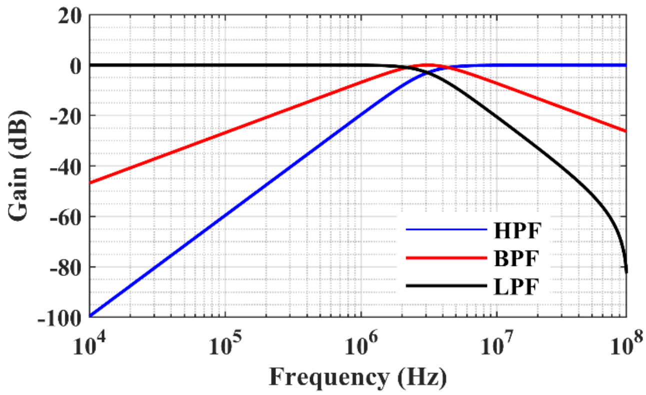


Fig. 5. Frequency response of CM topology

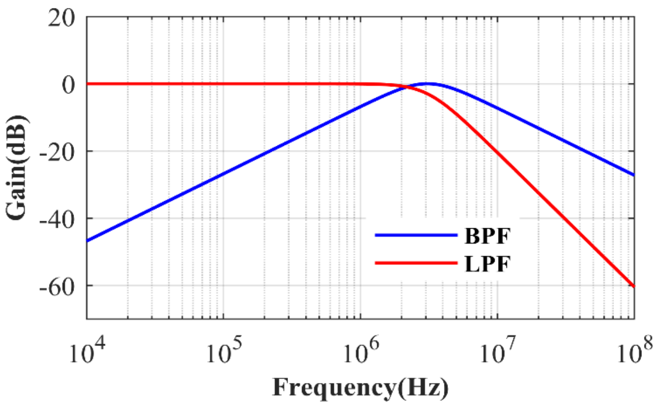


Fig. 6. Frequency response of VM topology

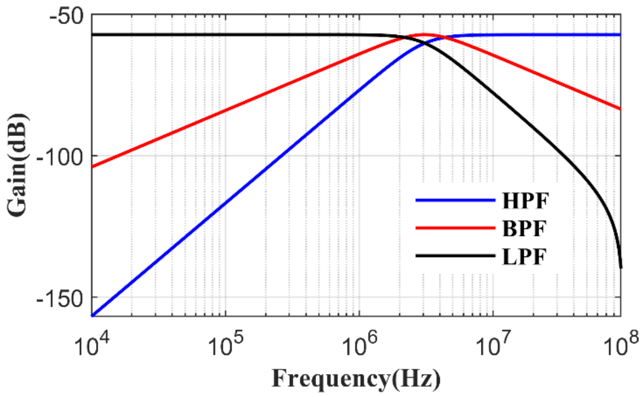
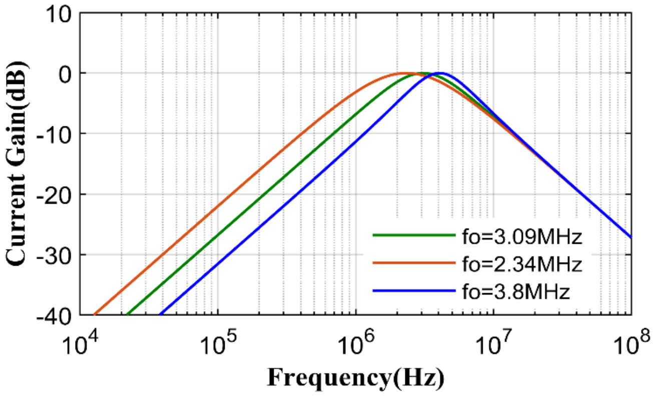


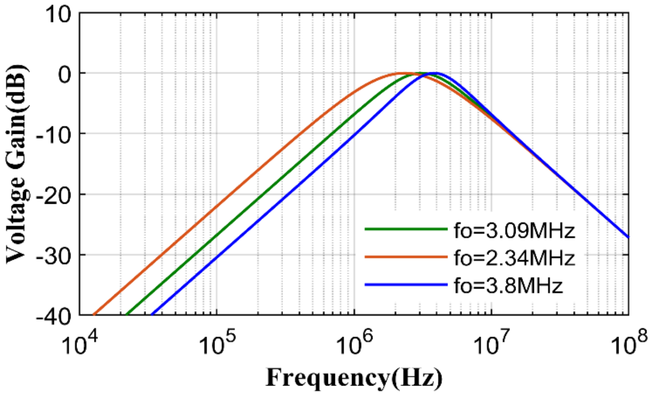
Fig. 7. Frequency response of TAM topology

In Fig. 10 the electronic tuning of low pass cut-off frequency independent of low pass gain is depicted for TAM topology of the proposed filter structure. It is achieved by varying g_{m2} i.e. by taking $I_{B3} = I_{B4} =$ 50µA, 150µA, 350µA (biasing currents of $VDTA_1$). The values of cut-off frequency is obtained as 2.6MHz, 3.09MHz, 4.02MHz.

Fig. 11 and Fig. 12 illustrates the time domain response of the low-pass output for all three modes of the proposed biquad filter. The circuit is simulated by applying sinusoidal input signal i.e. current signal (for CM) of 10mA and voltage signal (for VM and TAM) of 10mV at frequency 1.2MHz. The time domain response of low pass CM function is given in Fig.11, low pass VM function and low pass TAM function is given in Fig. 12.



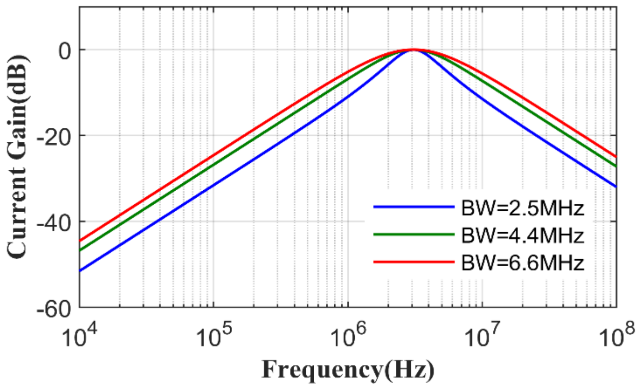
(a)



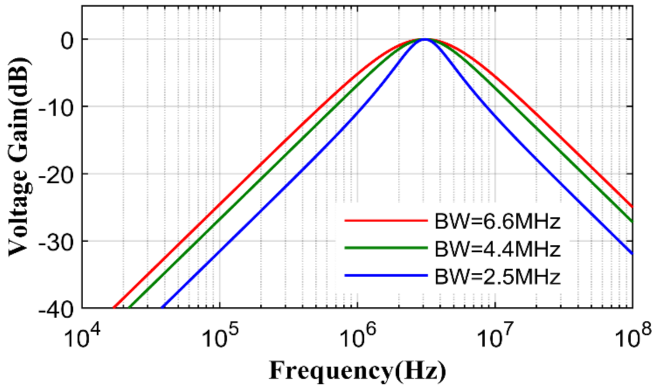
(b)

Fig. 8. BP responses depicting pole frequency tuning for

(a) CM topology (b)VM topology



(a)



(b)

Fig. 9. BP responses depicting BW tuning for

(a) CM topology (b)VM topology

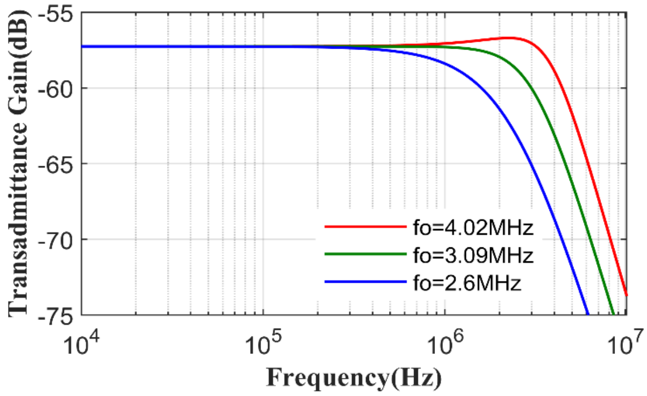
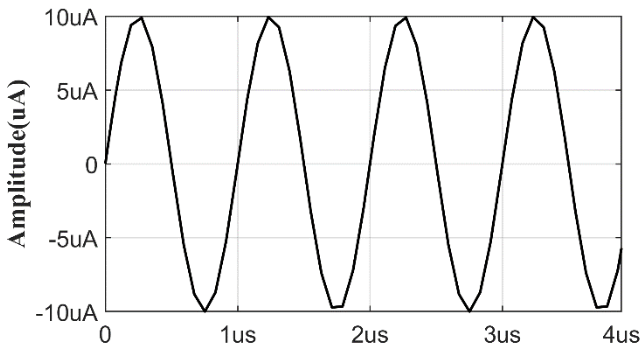
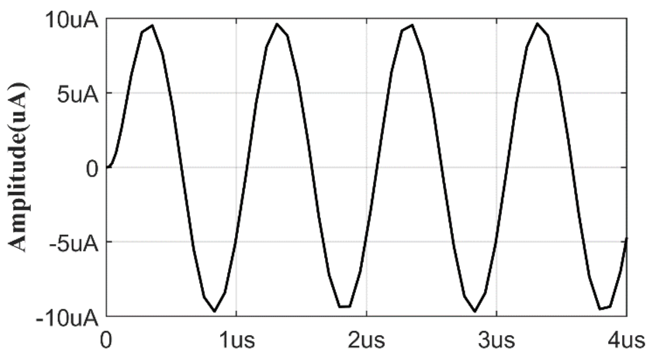


Fig 10. LP frequency response depicting cut-off frequency tuning for TAM topology



(a)



(b)

Fig. 11. (a) Input current signal,

(b) Transient response of LP current output signal

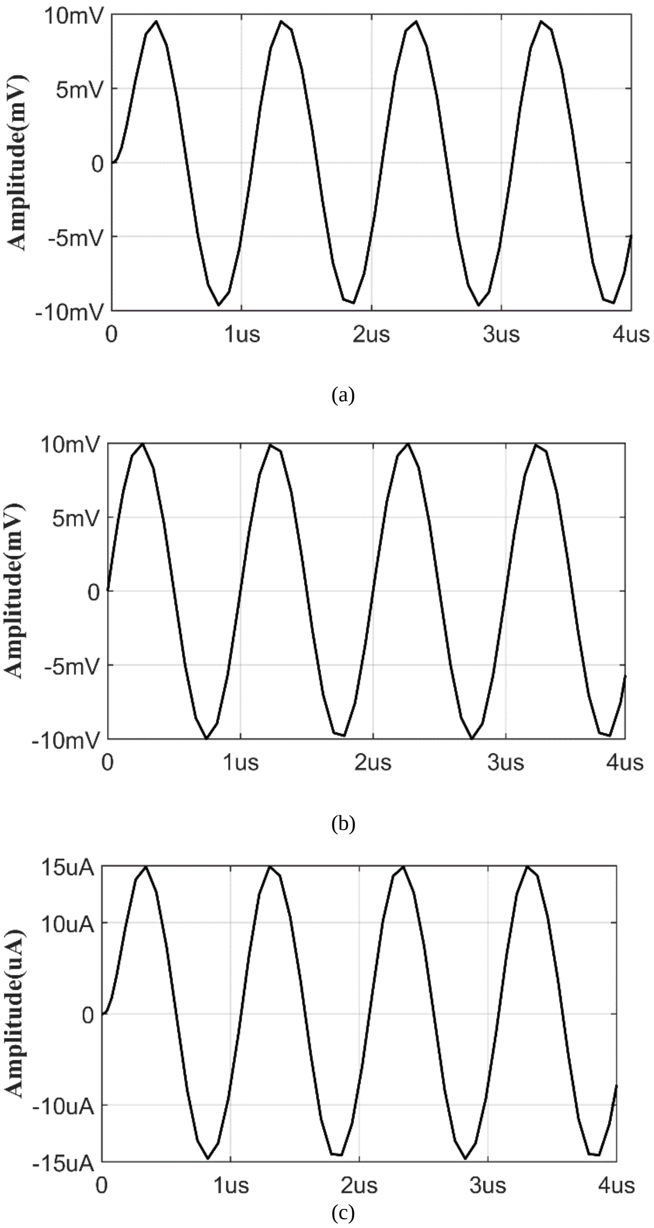


Fig. 12. (a) Input voltage signal, Transient response of (b) LP VM output signal (c) LP TAM output signal

V. CONCLUSION

This manuscript introduces a dual-mode Single-Input Multiple-Output (SIMO) biquadratic filter employing Voltage Differencing Transconductance Amplifiers (VDTAs) as active elements. The filter offers versatile operation modes including voltage mode, current mode, and transadmittance mode, selectable based on the input excitation. With appropriate configurations, the proposed biquad realizes two voltage mode functions (low-pass and band-pass), three transadmittance mode functions (low-pass, high-pass, and band-pass), and three current mode functions (low-pass, high-pass, and band-pass). Notably, both the angular frequency and band width of the filter can be independently controlled without affecting each other, ensuring non-interactive tuning. The filter's pole frequency f_o is electronically tunable. The effectiveness of the designed biquadratic configuration is validated through PSPICE simulations, thoroughly analyzing both frequency and transient responses.

VI. REFERENCES

[1] D. Biolek, R. Senani, V. Biolkova, and Z. Kolka, "Active elements for analog signal processing: classification, review, and new proposals," Radioengineering, vol. 17, no. 4, pp. 15-32, 2008.

[2] A. Sedra and K. Smith, "A second-generation current conveyor and its applications," IEEE Transactions on circuit theory, vol. 17, no. 1, pp. 132-134, 1970.

[3] A. M. Soliman, "New current-mode bandpass filters using three single-output ICCIIs," Active and Passive Electronic Components, vol. 2007, 2007.

[4] V. Singh and R. Senani, "New multifunction active filter configuration employing current conveyors," Electronics Letters, vol. 26, no. 21, pp. 1814-1816, 1990.

[5] M. T. Abuelma'Atti and S. A. M. Al-Shahrani, "New universal filter using two current-feedback amplifiers," International Journal of Electronics, vol. 80, no. 6, pp. 753-756, 1996.

[6] S. Maheshwari, "Analogue signal processing applications using a new circuit topology," IET circuits, devices & systems, vol. 3, no. 3, pp. 106-115, 2009.

[7] J.-W. Horng*, W.-Y. Chiu, and H.-Y. Wei, "Voltage-mode highpass, bandpass and lowpass filters using two DDCCs," International Journal of Electronics, vol. 91, no. 8, pp. 461-464, 2004.

[8] S. Minaei and S. Türköz, "Current‐mode electronically tunable universal filter using only plus‐type current controlled conveyors and grounded capacitors," Etri Journal, vol. 26, no. 4, pp. 292-296, 2004.

[9] W.-Y. Chiu and J.-W. Horng, "High-input and low-output impedance voltage-mode universal biquadratic filter using DDCCs," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 54, no. 8, pp. 649-652, 2007.

[10] M. T. Abuelma'atti, "A novel mixed-mode current-controlled current-conveyor-based filter," Active and passive electronic components, vol. 26, pp. 185-191, 2003.

[11] R. Senani, "New OTA-C universal current-mode/trans-admittance biquads," IEICE Electronics Express, vol. 2, no. 1, pp. 8-13, 2005.

[12] C.-N. Lee, "Multiple-mode OTA-C universal biquad filters," Circuits, Systems and Signal Processing, vol. 29, pp. 263-274, 2010.

[13] A. Ü. Keskin, D. Biolek, E. Hancioglu, and V. Biolková, "Current-mode KHN filter employing current differencing transconductance amplifiers," AEU-International Journal of Electronics and Communications, vol. 60, no. 6, pp. 443-446, 2006.

[14] D. Biolek and V. Biolková, "CDTA-C current-mode universal 2nd-order filter," in Proceedings of the 5th WSEAS International Conference on Applied Informatics and Communications, 2005, pp. 411-414.

[15] M. Siripruchyanun and W. Jaikla, "CMOS current-controlled current differencing transconductance amplifier and applications to analog signal processing," AEU-International Journal of Electronics and Communications, vol. 62, no. 4, pp. 277-287, 2008.

[16] S. Maheshwari, S. V. Singh, and D. S. Chauhan, "Electronically tunable low-voltage mixed-mode universal biquad filter," IET circuits, devices & systems, vol. 5, no. 3, pp. 149-158, 2011.

[17] W. Tangsrirat and W. Surakampontorn, "Single-resistance-controlled quadrature oscillator and universal biquad filter using CFOAs," AEU-International Journal of Electronics and Communications, vol. 63, no. 12, pp. 1080-1086, 2009.

[18] R. Pandey, N. Pandey, S. K. Paul, A. Singh, B. Sriram, and K. Trivedi, "Novel grounded inductance simulator using single OTRA," International Journal of Circuit Theory and Applications, vol. 42, no. 10, pp. 1069-1079, 2014.

[19] A. Yesil, F. Kacar, and H. Kuntman, "New simple CMOS realization of voltage differencing transconductance amplifier and its RF filter application," Radioengineering, vol. 20, no. 3, pp. 632-637, 2011.

[20] J. Satansup and W. Tangsrirat, "Single VDTA-based current-mode electronically tunable multifunction filter," in Proceedings of the 4th International Science, Social Science, Engineering and Energy Conference (ISEEC'12), 2012, pp. 1-8.

[21] J. Satansup and W. Tangsrirat, "Single VDTA-based voltage-mode electronically tunable universal filter," in The 27th

International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC 2012), 2012, pp. 1-4.
[22] D. Prasad, D. R. Bhaskar, and M. Srivastava, "Universal current-mode biquad filter using a VDTA," Circuits and Systems, vol. 4, no. 1, pp. 32-36, 2013.
[23] D. Prasad, M. Srivastava, and D. Bhaskar, "Transadmittance type universal current-mode biquad filter using VDTAs," International scholarly research notices, vol. 2014, 2014.
[24] G. Gupta, S. V. Singh, and S. V. Bhooshan, "VDTA based electronically tunable voltage-mode and trans-admittance biquad filter," Circuits and Systems, vol. 6, no. 3, pp. 93-102, 2015.
[25] C. Shankar and S. V. Singh, "A low voltage operable VDTA based biquad filter realizing band pass and high pass filtering functions in trans-admittance-mode," in International Conference on Computing, Communication & Automation, 2015: IEEE, pp. 1288-1293.
[26] N. Singhal, R. Pandey, and N. Pandey, "Dual mode biquadratic filter using single VDTA," Int. J. Electri. Electron. Eng, vol. 6, pp. 134-139, 2014.
[27] C. Shankar and S. V. Singh, "Single VDTA based multifunction transadmittance mode biquad filter," Int. J. Eng. Technol.(IJET), vol. 7, no. 6, pp. 2180-2188, 2016.
[28] V. Chamnanphrai and W. Sa-ngiamvibool, "Electronically tunable SIMO mixed-mode universal filter using VDTAs," Przegląd Elektrotechniczny, vol. 93, no. 3, pp. 207-211, 2017.

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