Electronically Tunable Active Filter with Dual-Stage Operational Transconductance Amplifiers(OTA)

A Project Report

Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of

Bachelor of Technology

In

Electronics & Communication Engineering

Submitted by

Hariom Kumar (2004016)

Avinash Kumar (2004040)

Rahul Sharma (2004046)

Under the supervision of

Dr. Bal Chand Nagar

Department of Electronics & Communication Engineering

NATIONAL INSTITUTE OF TECHNOLOGY

PATNA, 800005

राष्ट्रीय प्रौद्योगिकी संस्थान पटना

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CERTIFICATE

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……………………

Dr. Bal Chand Nagar
Assistant Professor
Electronics and Communication Engineering Department

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Hariom Kumar (2004016)

Avinash Kumar (2004040)

Rahul Sharma (2004046)

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ABSTRACT

This project introduces an innovative approach to designing electronically tunable active filters using dual-stage Operational Transconductance Amplifiers (OTAs). Active filters play a vital role in modern electronics, facilitating signal processing in various applications, such as communication systems and audio processing. It offers a novel solution for achieving tunability, providing flexibility and adaptability in filter design.

The utilization of dual-stage OTAs in it enhances the filter's performance and tunability. By incorporating two stages of OTAs, the design achieves a higher degree of flexibility, enabling the adjustment of filter characteristics over a wide frequency range. The project focuses on the theoretical analysis, design, simulation, and implementation of these filters.

The proposed system not only offers superior tunability but also ensures improved performance metrics such as low passband ripple, high stopband attenuation, and low sensitivity to component variations. The use of OTAs in the design enhances the feasibility of electronic tuning and opens new avenues for practical applications.

In summary, it represents a significant advancement in the field of active filters, offering a high degree of tunability, enhanced performance, and versatility in various electronic applications.

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1. Introduction

1.1 Background

Active filters are essential components in modern electronics, facilitating signal processing in various applications such as communication systems and audio processing. Conventional active filters come with inherent limitations in terms of flexibility and adaptability, often lacking the ability to adjust their characteristics according to changing requirements. To overcome these limitations, the introduction of electronically tunable active filters has gained considerable attention.

Electronically Tunable Filter represents an innovative approach to designing electronically tunable active filters using dual-stage Operational Transconductance Amplifiers (OTAs). The project aims to provide a solution that enables the adjustment of filter characteristics over a wide frequency range, addressing the limitations of conventional fixed active filters.

In this section, we will provide a brief background on active filters, the necessity for tunability, and an overview of the Electronically Tunable Filter project, outlining its objectives and scope. We will discuss the limitations of fixed active filters and the advantages that tunable filters, particularly Electronically Tunable Filter, can offer in terms of flexibility, adaptability, and improved performance.

1.2 Objectives

The objectives of the electronically tunable project are as follows:

1. To design and implement electronically tunable active filters using dual-stage Operational Transconductance Amplifiers (OTAs).
2. To investigate the feasibility and advantages of using dual-stage OTAs in the design of electronically tunable active filters.
3. To analyze and optimize the performance of electronically tunable filters in terms of passband ripple, stopband attenuation, and sensitivity to component variations.
4. To compare electronically tunable filters with existing approaches, demonstrating their advantages in terms of tunability, performance, and practical applications.
5. To provide guidelines for the practical implementation of electronically tunable filters in real-world electronic systems.

1.3 Scope of the Project

The scope of the electronically tunable active filters project includes:

1. Design and simulation of electronically tunable active filters using dual-stage OTAs, implemented on Cadence.
2. Investigation of different filter topologies, including low-pass, high-pass, band-pass, and band-reject (notch) filters.
3. Performance analysis of electronically tunable active filters in terms of passband ripple, stopband attenuation, and sensitivity to component variations.
4. Comparison of electronically tunable filters with existing fixed active filters and other tunable filter approaches.
5. Practical implementation and testing of electronically tunable filters to validate the theoretical findings and performance metrics.
6. Providing guidelines for the practical implementation of electronically tunable filters in real-world electronic systems.

2. Literature Review

2.1 Active Filters

2.1.1 Overview

Active filters are electronic circuits designed to pass signals based on certain predetermined frequency ranges while attenuating signals outside those ranges. These filters employ active components, such as operational amplifiers (op-amps), along with passive components like resistors, capacitors, and inductors. They provide an advantage over passive filters by offering high input impedance and low output impedance, enabling the effective processing of signals without significant loss. Active filters can be categorized based on their filter type, such as low-pass, high-pass, band-pass, and band-stop.

Overview of Active Filters:

Active filters typically employ operational amplifiers (op-amps) and Operational Transconductance Amplifier(OTA) to create frequency-dependent responses. The two main types of active filters are:

1. **First-Order Active Filters:**
    - These filters contain only one energy storage element, either a capacitor or an inductor.
    - They offer a slope of -20 dB/decade (for a single pole) or -6 dB/octave.
    - First-order filters are typically used in applications where

moderate performance is acceptable.

2. **Second-Order Active Filters:**
    - Second-order filters employ two energy storage elements (capacitors and/or inductors).
    - They offer a steeper roll-off rate than first-order filters, providing better performance.
    - Second-order filters are more commonly used due to their better frequency response compared to first-order filters.

2.1.2 Types of Active Filters

1. **Low-Pass Filter:**
    - A low-pass filter allows frequencies below a certain cutoff frequency to pass through while attenuating frequencies above that point.
    - The transfer function for a first-order low-pass filter is given by:

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

    - The transfer function for a second-order low-pass filter is given by: $H(s) = \frac{1}{1+s(R_1C_1)+s^2(R_1R_2C_1C_2)}$
2. **High-Pass Filter:**
    - A high-pass filter allows frequencies above a certain cutoff frequency to pass through while attenuating frequencies below that point.

- The transfer function for a first-order high-pass filter is given by:

  $H(s) = \frac{s\mathrm{R}C}{1+sR}$

- The transfer function for a second-order high-pass filter is given by: $H(s) = \frac{s^2 R_1 R_2 C_1 C_2}{1+s(R_1 C_1)+s^2(R_1 R_2 C_1 C_2)}$

3. **Band-Pass Filter:**
   - A band-pass filter allows a certain range of frequencies to pass while attenuating frequencies outside this range.
   - The transfer function for a second-order band-pass filter is given by:$H(s) = \frac{s(R_1 C_1)}{1+s(R_1 C_1)+s^2(R_1 R_2 C_1 C_2)}$
4. **Band-Stop Filter (Notch Filter):**
   - A band-stop filter, also known as a notch filter, attenuates a specific range of frequencies while allowing all others to pass.
   - The transfer function for a second-order band-stop filter is given by: $H(s) = \frac{1+s^2(R_1 R_2 C_1 C_2)}{1+s(R_1 C_1)+s^2(R_1 R_2 C_1 C_2)}$

Mathematics:

- **Transfer Function:**
  - The transfer function of an active filter defines the relationship between the input and output voltages. It is represented in Laplace notation.
  - For a second-order active filter, the transfer function can be written as:

$$H\ (s) = \frac{Y(s)}{X(s)}$$

Where:

  - $Y(s)$ is the output voltage in the Laplace domain.
  - $X(s)$ is the input voltage in the Laplace domain.
  - s is the complex frequency variable.
- **Component Selection:**
  - The component values R and C are chosen to set the cutoff frequency and the gain of the filter.
- **Cutoff Frequency (fc):**
  - The cutoff frequency is the frequency at which the filter's output is reduced to 70.7% (or -3 dB) of the input.
  - For a first-order filter, the cutoff frequency (fc) is given by:

$$f_c = \frac{1}{2\pi RC}$$

  - For a second-order filter, the cutoff frequency (fc) is given by:

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

Where:

- $R1$ and $R2$ are the resistors.
- $C1$ and $C2$ are the capacitors.

- **Quality Factor (Q):**
  - Quality factor (Q) is a dimensionless parameter that describes how under-damped, critically damped, or over-damped the second-order filter is.
  - For a second-order filter, the quality factor (Q) is given by:

$$Q = \frac{1}{2} \cdot \frac{\sqrt{R_1 R_2 C_1 C_2}}{R_1 C_1 + R_2 C_2}$$

Where:

- $R1$ and $R2$ are the resistors.
- $C1$ and $C2$ are the capacitors.

Active filters are widely used in various applications such as audio equalizers, data acquisition systems, and communication systems due to their versatility and effectiveness in filtering specific frequency components from a signal. By understanding the mathematics and types of active filters, engineers can design filters tailored to the requirements of specific applications.

2.2 Operational Transconductance Amplifiers (OTAs)

Operational Transconductance Amplifiers (OTAs) are key components in the design of active filters. They are widely used due to their high gain, high linearity, and easy integration into integrated circuit technology. This section provides a detailed overview of OTAs, including their introduction and characteristics.

2.2.1 Introduction to OTAs

Operational Transconductance Amplifiers (OTAs) are voltage-to-current converters, widely used in the field of analog electronics. OTAs are crucial elements in active filter designs due to their ability to provide gain in terms of transconductance (current gain). They are designed to produce an output current proportional to the input voltage. OTAs are extensively used in various analog signal processing applications, including active filters, voltage-controlled amplifiers (VCAs), and oscillators.

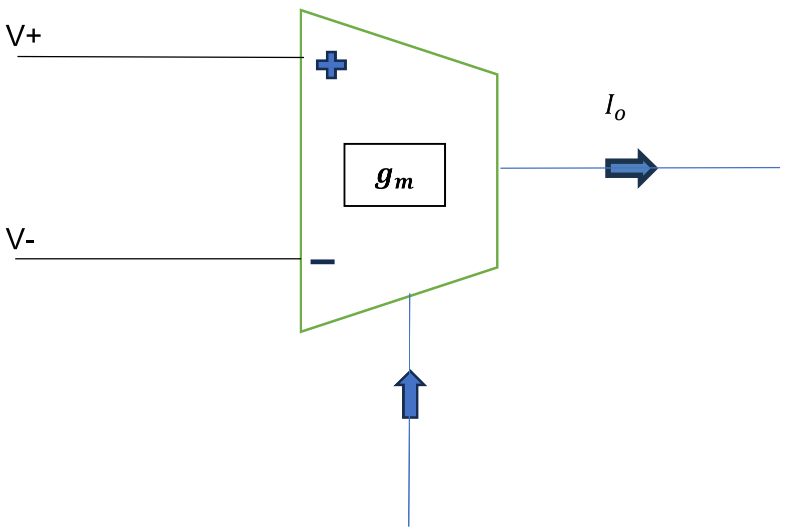

Fig.1(a)Symbol of OTA

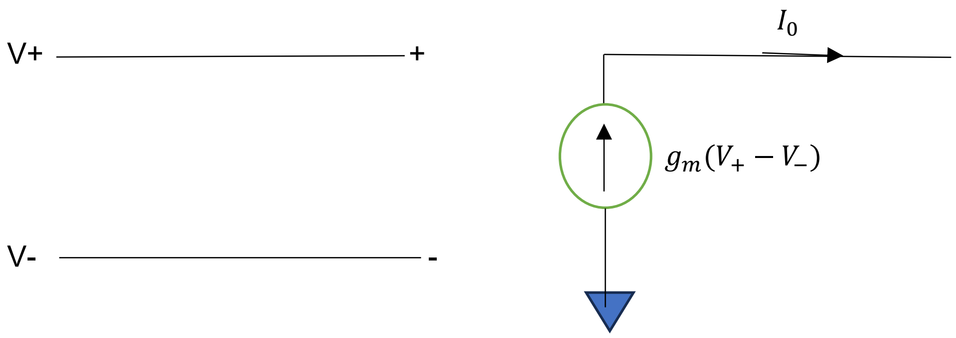

Fig.1(b)Equivalent Circuit of Ideal OTA

The transconductance gain, gm, is assumed proportional to I_{ABC}. The proportionality constant h is dependent upon temperature, device geometry, and the process.

$$g_m = hI_{\mathrm{ABC}}$$

The output current is given by

$$I_o = g_m(V^+ - V^-)$$

As shown in the model, the input and output impedances in the model assume ideal values of infinity. Current control of the transconductance gain can be directly obtained with control of I_{ABC}. Since techniques abound for creating a current proportional to a given voltage, voltage control of the OTA gain can also be attained through the 1ABc input. Throughout this paper, when reference is made to either the current or voltage controllability of OTA based circuits, it is assumed to be attained via control of g_m by I_{ABC}.

2.2.2 Characteristics of OTAs

The following are the key characteristics of Operational Transconductance Amplifiers (OTAs):

1. **Transconductance (gm):**
    - Transconductance is the key parameter of an OTA, representing the ratio of the change in output current to the change in input voltage. It is measured in siemens (S) or mhos (℧).
    - The transconductance value determines the gain of the OTA and influences the performance of the active filter.

$$g_m = \frac{\Delta I_{\mathrm{out}}}{\Delta V_{\mathrm{in}}}$$

2. **Input and Output Resistance:**
    - The input resistance (Rin) and output resistance (Rout) of the OTA significantly affect the performance and stability of the active filter.
    - High input resistance prevents the loading down of the input signal source, while low output resistance allows the OTA to drive the load effectively.

$R_{in} = \frac{\Delta V_{in}}{\Delta I_{in}}$ and $R_{\mathrm{out}} = \frac{\Delta V_{\mathrm{out}}}{\Delta I_{\mathrm{out}}}$

3. **Bandwidth (BW):**
    - The bandwidth of an OTA refers to the range of frequencies over which it can provide a linear response.
    - The bandwidth of the OTA directly impacts the bandwidth of the active filter and its overall performance.

$$BW = \frac{G_m}{2\pi \cdot C_{in}}$$

4. **Slew Rate (SR):**
   - Slew rate is the maximum rate of change of the output voltage per unit of time.
   - A higher slew rate allows the OTA to handle rapid changes in the input signal without distortion.
5. **Power Supply Rejection Ratio (PSRR):**
   - PSRR measures the ability of the OTA to reject changes in the power supply voltage.
   - A high PSRR is essential for the stability and performance of the active filter, especially in real-world applications with varying power supply voltages.
6. **Linearity:**
   - Linearity refers to the ability of the OTA to produce an output current proportional to the input voltage.
   - Maintaining high linearity is crucial to prevent distortion and ensure the accurate performance of the active filter.
7. **Noise:**
   - OTA noise is a critical parameter, especially in low-level signal processing applications.
   - Lower noise levels contribute to better signal-to-noise ratio (SNR) and overall performance of the active filter.

Understanding these characteristics is crucial for selecting the appropriate OTA for the design of active filters, ensuring optimal performance and stability.

2.3 Electronically Tunable Active Filters

2.3.1 Overview

Electronically tunable active filters represent a class of filters that offer the capability to adjust their frequency response characteristics electronically. Unlike traditional fixed active filters, which have predetermined cutoff frequencies and bandwidths, tunable active filters provide flexibility in adapting to changing requirements without the need for hardware modifications. This section provides a detailed overview of electronically tunable active filters, highlighting their advantages and applications.

Active filters are vital in various applications such as communication systems, audio processing, and instrumentation. Their main advantage lies in their ability to utilize active components, such as operational amplifiers (Op-Amps), to achieve filtering functions. Electronically tunable active filters take this a step further by offering the capability to adjust their frequency response characteristics electronically. This adjustability makes them highly versatile and adaptable to different situations, without requiring hardware changes.

Advantages of Electronically Tunable Active Filters:

- **Flexibility:** Electronically tunable active filters provide flexibility in adjusting their cutoff frequency, bandwidth, and gain, making them adaptable to various applications and situations.

- **Cost-Effectiveness:** By using a single tunable active filter in place of multiple fixed filters, costs can be reduced significantly.
- **Ease of Implementation:** The electronic tunability of these filters allows for easy implementation without the need for hardware modifications, thereby saving time and effort.
- **Compactness:** Integrating tunable active filters into circuits leads to more compact designs, which is especially beneficial in space-constrained applications.

Applications of Electronically Tunable Active Filters:

- **Communication Systems:** They are used in communication systems where the frequency response needs to be adjusted according to channel conditions.
- **Audio Processing:** In audio processing, tunable active filters are used for equalization, tone control, and other audio effects.
- **Instrumentation:** These filters find applications in instrumentation where the frequency response of the system needs to be adjusted based on the type of signal being measured.

2.3.2 Existing Approaches

Several approaches exist for implementing electronically tunable active filters, each with its advantages and limitations. Some common approaches include:

1. **Voltage-Controlled Filters (VCFs):**
    - VCFs utilize voltage-controlled components such as varactors or voltage-controlled amplifiers (VCAs) to

achieve tunability.

- By varying the control voltage, the cutoff frequency or bandwidth of the filter can be adjusted.

2. **Switched-Capacitor Filters (SCFs):**
   - SCFs use a network of capacitors and switches to achieve tunability.
   - By dynamically configuring the switches, the capacitance values in the filter can be altered, thereby adjusting the filter characteristics.
3. **Digital Filters with Programmable Coefficients:**
   - Digital filters implemented using digital signal processors (DSPs) or field-programmable gate arrays (FPGAs) offer tunability through the reprogramming of filter coefficients.
   - This approach provides precise control over the filter response and is suitable for applications requiring high flexibility.
4. **OTA-Based Tunable Filters:**
   - Tunable filters based on operational transconductance amplifiers (OTAs) offer another approach to achieve electronic tunability.
   - By adjusting the bias currents or control voltages of the OTAs, the filter parameters such as cutoff frequency, bandwidth, and gain can be modified.

Each approach has its advantages and is suitable for specific applications. The choice of the tunable filter implementation depends on factors such as required tuning range, bandwidth, power consumption, and cost constraints. Understanding the characteristics and trade-offs of each approach is essential for selecting the most appropriate solution for a given application.

3. Circuit Description

The project focuses on designing Electronically Tunable Active Filters using 2-stage Operational Transconductance Amplifiers (OTAs). The circuit comprises several key components arranged to achieve tunability and filtering functionality. Below is a description of the circuit components and their roles:

1. **Operational Transconductance Amplifiers (OTAs):**
   - The heart of the circuit, OTAs, are utilized to provide transconductance gain. These OTAs are configured in a 2-stage architecture to enhance the performance and achieve the desired filter characteristics.
   - OTAs play a crucial role in determining the cutoff frequency, bandwidth, and gain of the active filters. By adjusting their parameters such as bias currents or control voltages, the filter characteristics can be electronically tuned.
2. **Resistors and Capacitors:**
   - These passive components are used in conjunction with the OTAs to form the active filter sections. They determine the

specific frequency response characteristics of the filters.

- Resistors set the gain and establish feedback paths, while capacitors determine the pole frequencies and filter roll-off rates.

3. **Control Voltage Inputs:**
    - Control voltage inputs are provided to adjust the bias currents or control voltages of the OTAs, thereby enabling electronic tunability.
    - These control voltages can be generated externally or derived from on-chip voltage references depending on the application requirements.
4. **Tuning Circuitry:**
    - In addition to control voltage inputs, tuning circuitry may be incorporated to provide finer control over the filter parameters.
    - This tuning circuitry can include voltage dividers, potentiometers, or digitally controlled components to facilitate precise adjustments.
5. **Power Supply Section:**
    - A stable and well-regulated power supply section is essential for the proper operation of the circuit.
    - Voltage regulators, filtering capacitors, and decoupling networks ensure that the OTAs and other active components receive clean and stable power.
6. **Output Stage:**

- The output stage of the circuit buffers and conditions the filtered signal for further processing or transmission.
- This stage may include additional amplification or impedance matching components to match the output signal to the desired load.

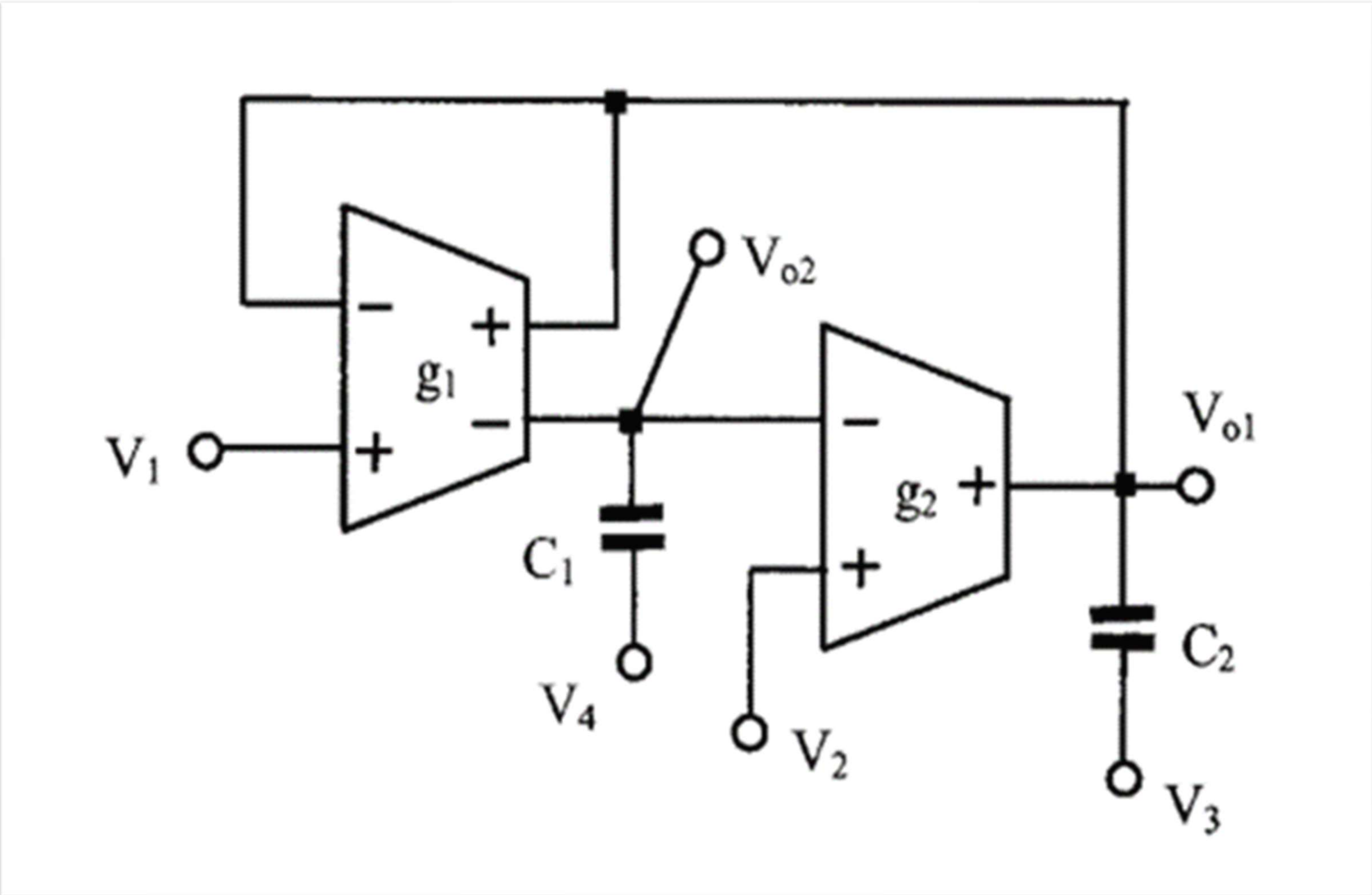

Fig. 2.Electronically Tunable Filter using 2-Stage OTA

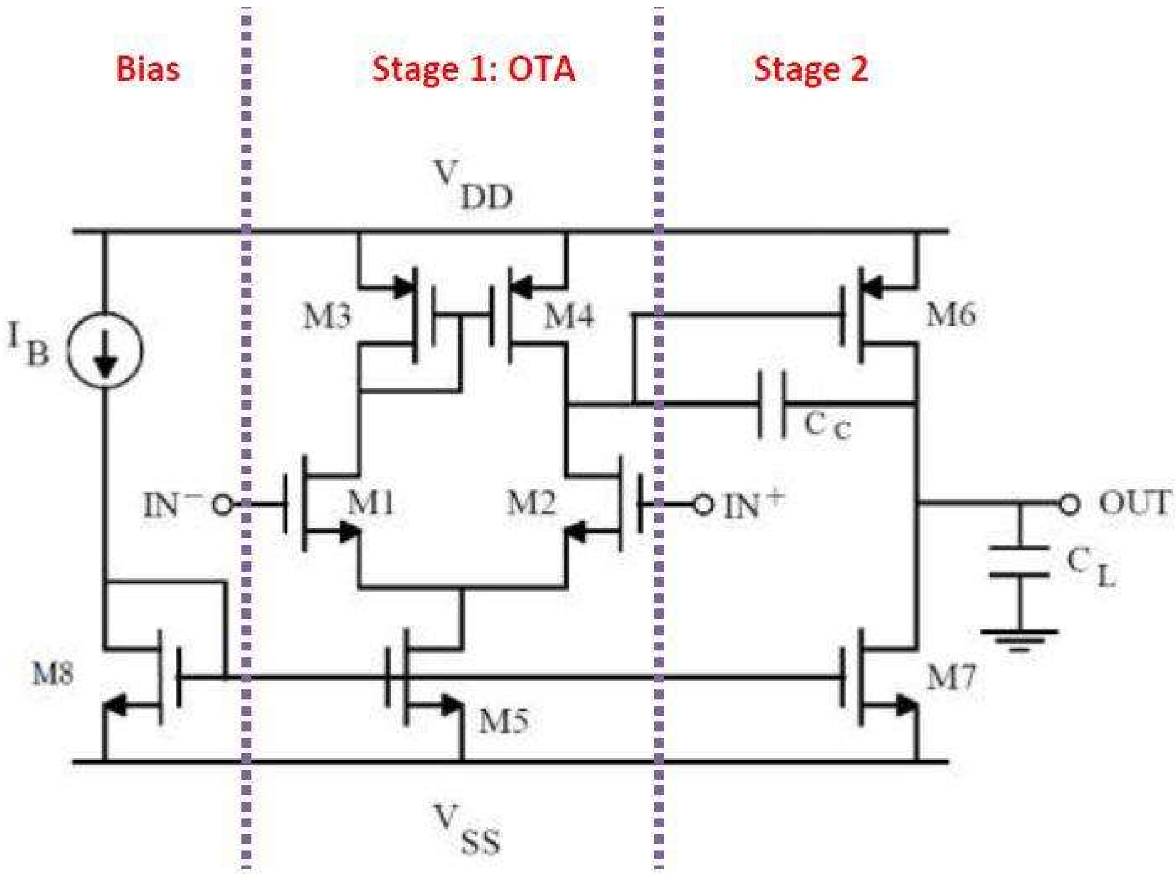

FIG. 3. CMOS implementation of 2-Stage OTA

In figure 3 shown CMOS implementation of 2-Stage OTA. It has input and output transconductance stage g_{m1}, and g_{m2}, respectively.

$$g_{m_1} = \frac{g_1+g_4}{2} \quad \text{OR} \quad g_{m_1} = \frac{g_2+g_3}{2} \qquad \ldots(1)$$

$$g_{m_2} = \frac{g_s+g_3}{2} \quad \text{OR} \quad g_{m_2} = \frac{g_6+g_7}{2} \qquad \ldots(2)$$

where g_i is the transconductance of ith transistor and can be expressed as

$$g_i = \sqrt{I_{B_i} C_{OX} \mu_i (w/l)} \qquad \ldots(3)$$

Here, I_{Bi} is the dc bias current of ith transistor, μ_i is the mobility of the carrier, Cox is the effective gate oxide capacitance per unit area, W and L are the width and channel length of ith transistor.

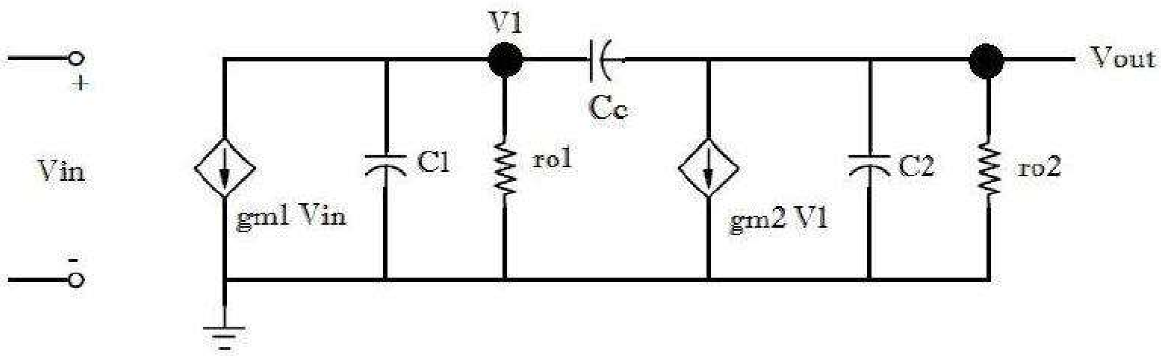

Fig. 4.Small signal model of 2 stage OTA

The proposed circuit is shown in Figure 2. The multiple current outputs OTA is a set of differential voltage controlled current sources. The output voltage V_{o1} and V_{o2} can be expressed as;

$$V_{01} = \frac{s^2 C_1 C_2 V_3 + s C_1 (g_{m1} V_1 + g_{m2} V_2 - g_{m2} V_4) + g_{m1} g_{m2} V_1}{s^2 C_1 C_2 + s C_1 g_{m1} + g_{m1} g_{m2}} \qquad \ldots..(4)$$

$$V_{02} = \frac{s^2C_1C_2V_4 + sg_{m1}(C_1V_4 + C_2V_3 - C_2V_1) + g_{m1}g_{m2}V_2}{s^2C_1C_2 + sC_1g_{m1} + g_{m1}g_{m2}} \quad \ldots(5)$$

If $V_1 = V_2 = V_4 = 0$ (grounded) and $V_3 =$ input voltage signal, then

$$(TF)_{\text{HP}} = \frac{V_{01}}{V_{IN}} = \frac{s^2C_1C_2}{s^2C_1C_2 + sC_1g_{m1} + g_{m1}g_{m2}} \quad ..(6)$$

$$(TF)_{\text{BP}} = \frac{V_{02}}{V_{IN}} = \frac{sg_{m1}C_2}{s^2C_1C_2 + sC_1g_{m1} + g_{m1}g_{m2}} \quad ..(7)$$

If $V_1 = V_3 = V_4 = 0$ (grounded) and $V_2 =$ input voltage signal, then

$$(TF)_{\text{BP}} = \frac{V_{01}}{V_{IN}} = \frac{sg_{m2}C_1}{s^2C_1C_2 + sC_1g_{m1} + g_{m1}g_{m2}} \quad ..(8)$$

$$(TF)_{\text{LP}} = \frac{V_{02}}{V_{IN}} = \frac{g_{m1}g_{m2}}{s^2C_1C_2 + sC_1g_{m1} + g_{m1}g_{m2}} \quad ..(9)$$

If $V_2 = 0$ (grounded), $g_{m1} = g_{m2}$, and $V_1 = V_3 = V_4 =$ input voltage signal, then

$$(TF)_{\text{Notch}} = \frac{V_{01}}{V_{IN}} = \frac{s^2C_1C_2 + sC_1(g_{m1} - g_{m2}) + g_{m1}g_{m2}}{s^2C_1C_2 + sC_1g_{m1} + g_{m1}g_{m2}} \quad ..(10)$$

If $V_2 = 0$ (grounded), $g_{m2} = 2\,g_{m1}$, and $V_1 = V_3 = V_4 =$ input voltage signal, then

$$(TF)_{\text{Allpass}} = \frac{V_{01}}{V_{IN}} = \frac{s^2C_1C_2 + sC_1(g_{m1} - g_{m2}) + g_{m1}g_{m2}}{s^2C_1C_2 + sC_1g_{m1} + g_{m1}g_{m2}} \quad ..(11)$$

Thus, the proposed circuit is capable of realizing all filter functions. The proposed circuit requires the minimum number of active and passive components. Moreover, the all pass realizations in filter case (6) and (9) need not one more active component for unity-gain inverting input. Furthermore, some derived filter types (type (1), (2) and (4)) enjoy the availability of one more simultaneously output filter response. From Eqs. (5) and (6), the parameters w_o,Q can be expressed

$$\omega_0 = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}} \qquad \ldots(12)$$

$$Q = \sqrt{\frac{C_2 g_{m2}}{C_1 g_{m1}}} \qquad \ldots(13)$$

The active and passive sensitivities of this universal filter are:

$$S^{\omega_0}_{g_{m1} g_{m2}} = -S^{\omega_0}_{C_1 C_2} = \frac{1}{2}$$

$$S^{Q}_{C_2, g_{m2}} = -S^{\omega_0}_{C_1 g_{m1}} = \frac{1}{2}$$

4. Simulation Results

We perform the simulations by using Cadence Virtuoso 180 nm gpdk technology parameters.

Supply voltages are taken as V_{DD}=-I_{ss} = 0.9 V and I_{B1}=I_{B2}= I_{B3}= I_{B4}= 150 μA biasing currents are used in most of the cases.

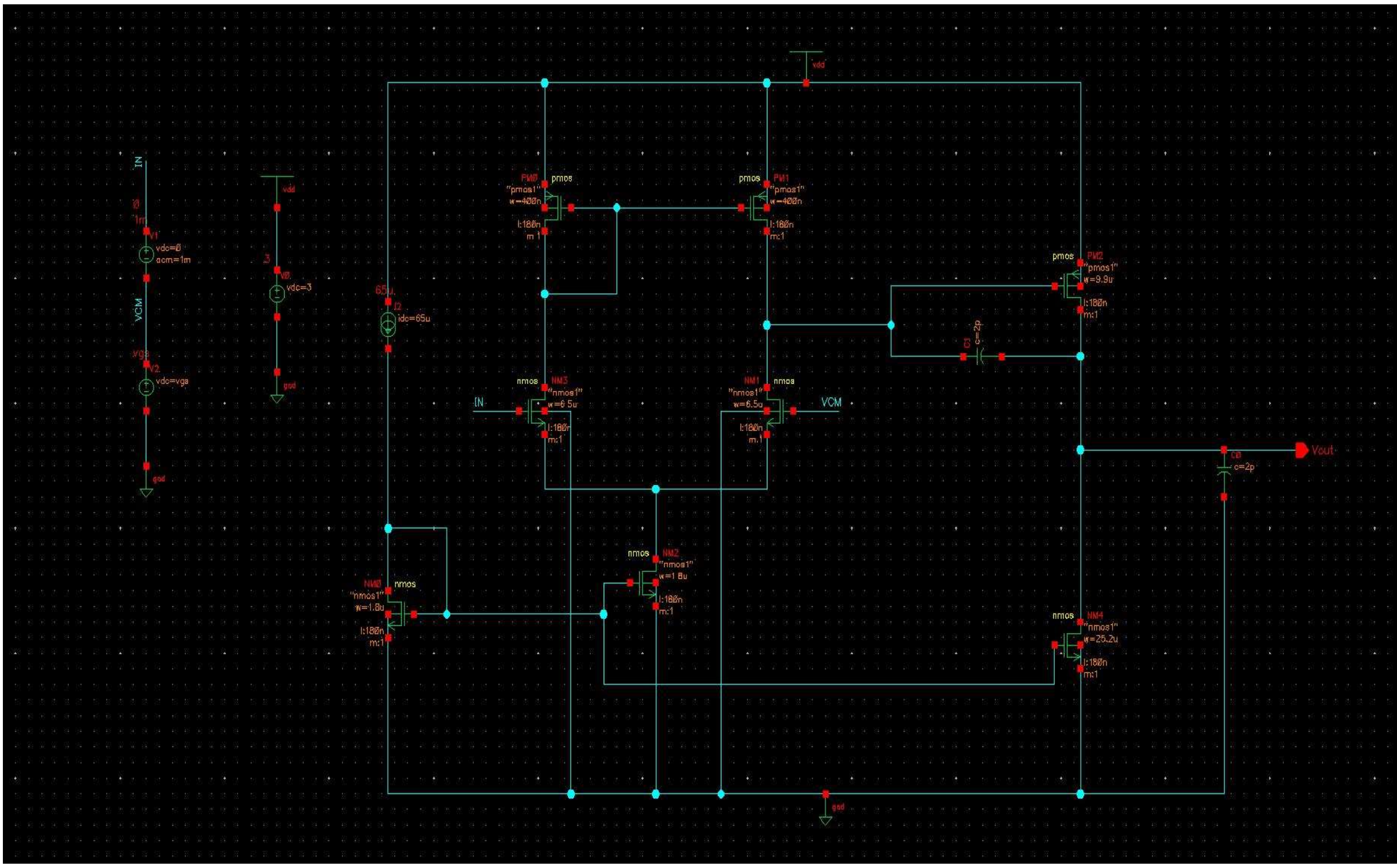

Fig. 5.Schematic of 2 stage OTA

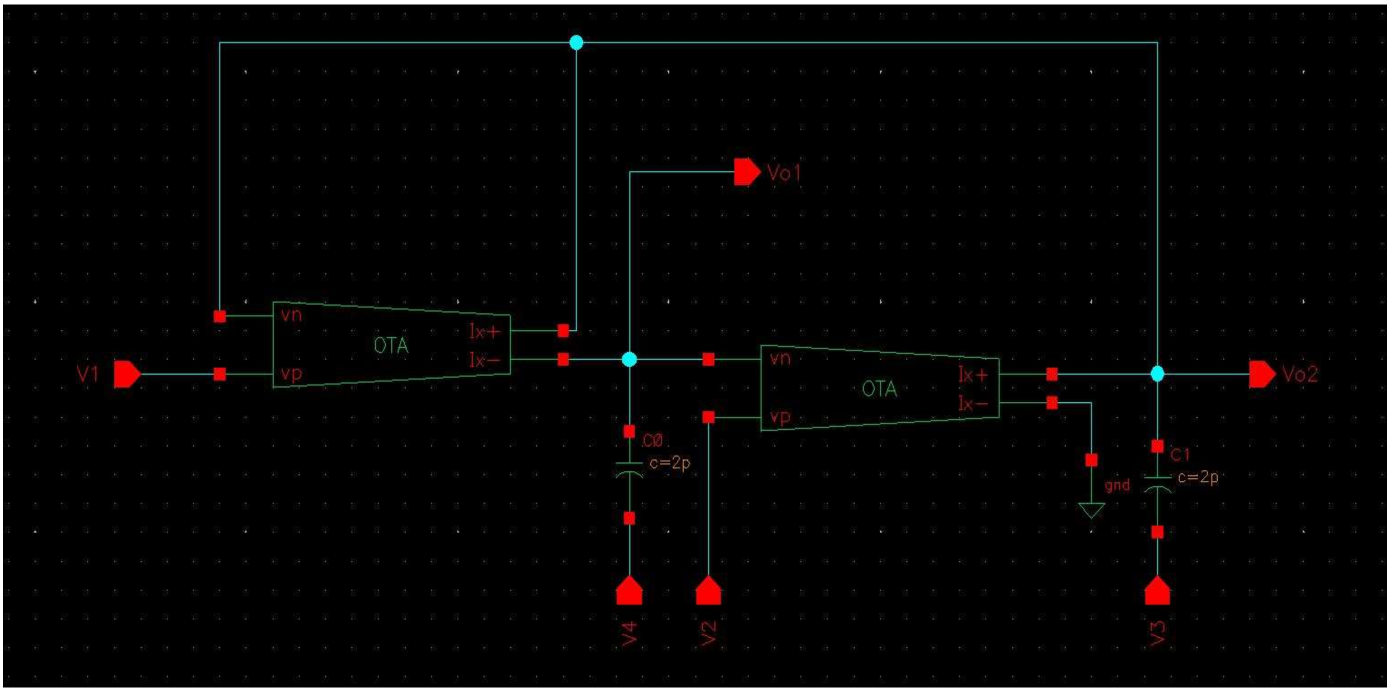

Fig. 6. Symbol of 2 stage OTA

CASE NO.	INPUT VOLTAGES V1	V2	V3	V4	OUTPUT V_{01}	V_{02}
1.	0	0	V_{IN}	0	HP	BP
2.	0	V_{IN}	0	0	BP	LP
3.	0	0	0	V_{IN}	IBP	HP
4.	V_{IN}	0	0	V_{IN}	LP	HP
5.	V_{IN}	0	V_{IN}	V_{IN}	Notch	HP
6.	V_{IN}	0	V_{IN}	V_{IN}	All Pass	HP
7.	V_{IN}	0	0	0	LP	IBP
8.	V_{IN}	V_{IN}	0	V_{IN}	LP	Notch
9.	V_{IN}	V_{IN}	0	V_{IN}	LP	All Pass

Tab.1 .Truth Table of proposed filter circuits

RESULTS:

- The proposed filter circuit is designed for $f_0 = \omega_0/2\pi$ = 10 MHz and Q = 1 by choosing $C_1 = C_2$ = 10pF and I_{B1}= I_{B2}= I_{B3} = I_{B4} = 150 µA biasing currents which resulted in $g_{m1} = g_{m2}$= 636.3 μA/V.

- The AC response of the proposed filter circuit in Fig. 2 is investigated by applying a sinusoidal input voltage signal with an amplitude of 1 mV peak at $f_0 = \omega_0/2\pi$ = 10 MHz for various input combination as listed in table 1.

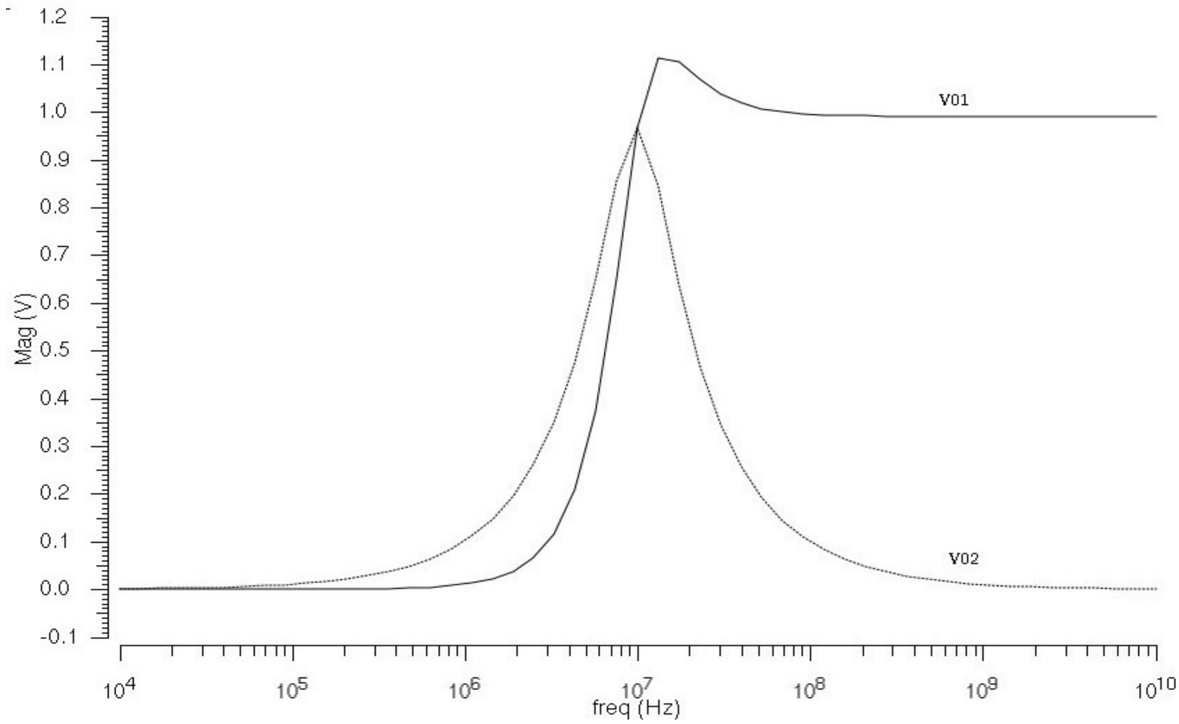

Figure 7. AC Response of the proposed circuit under case 1 condition.

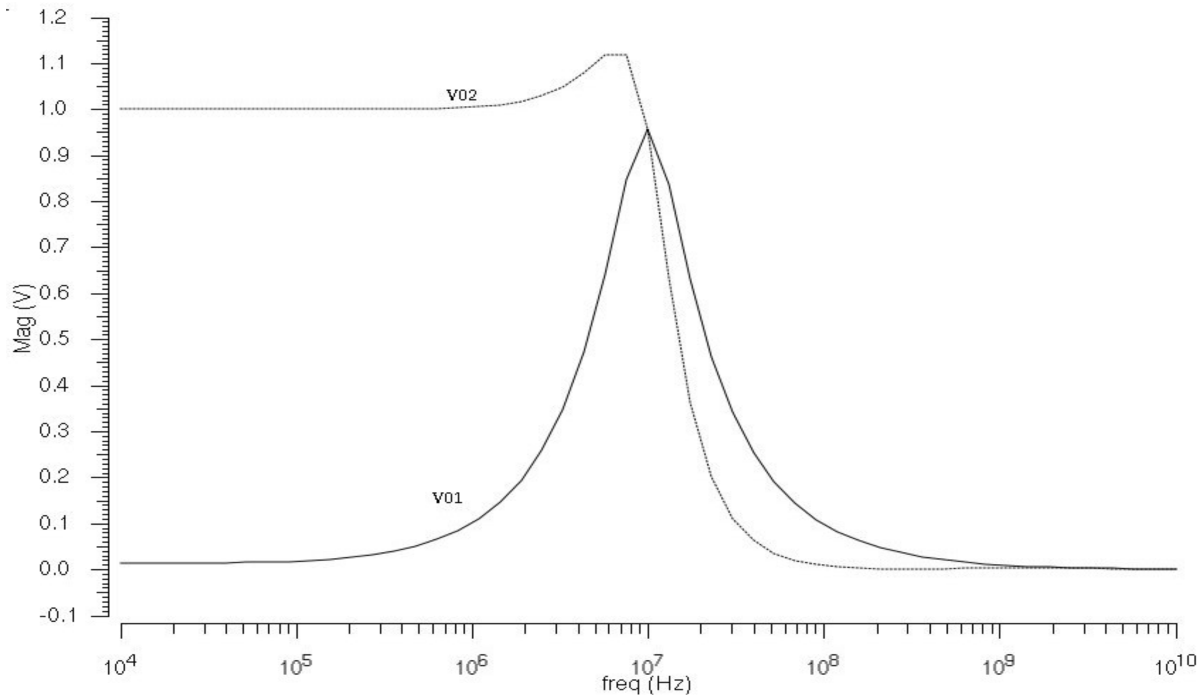

Figure 8. AC Response of the proposed circuit under case 2 condition.

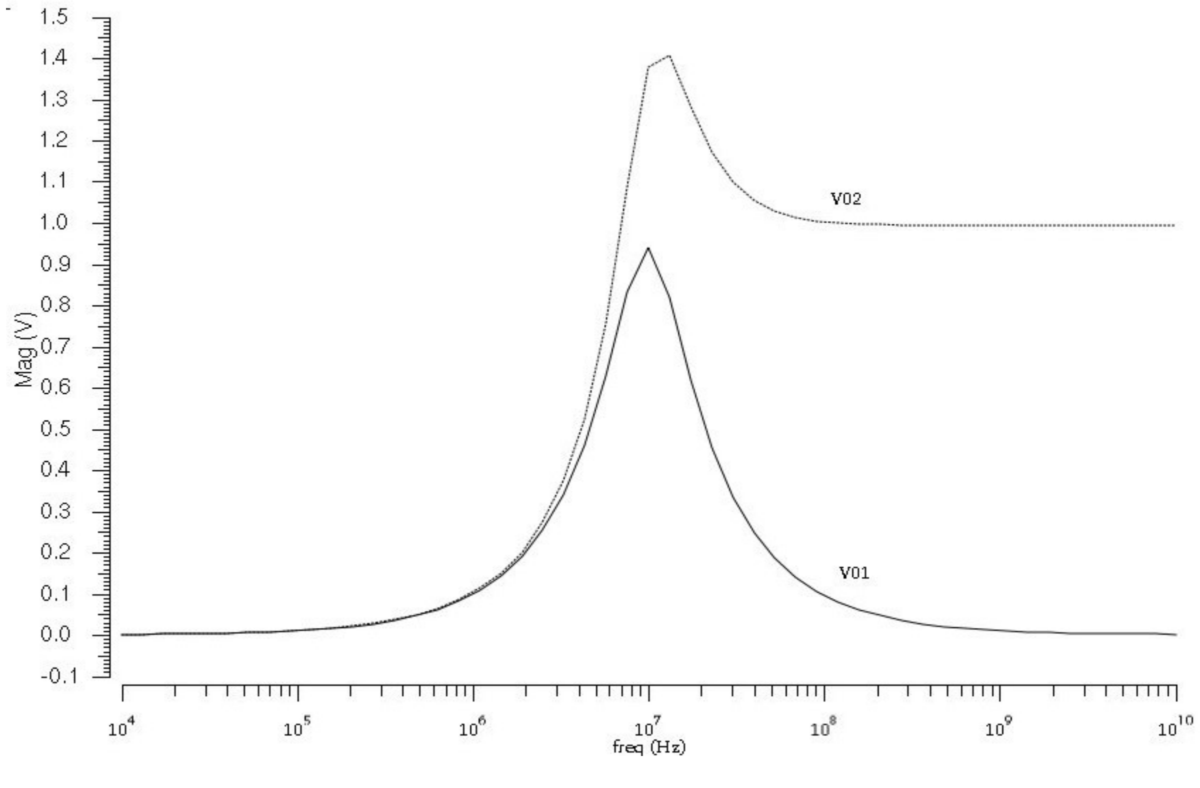

Figure 9. AC Response of the proposed circuit under case 3 condition.

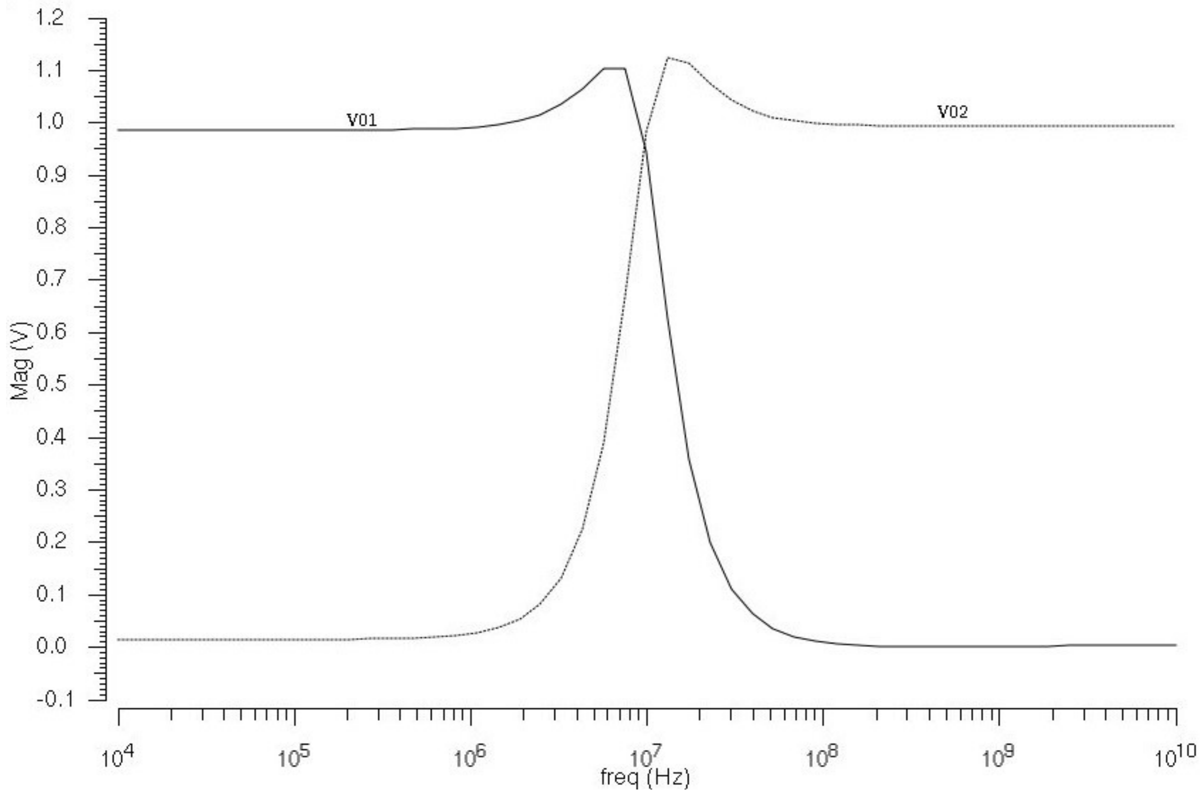

Figure 10. AC Response of the proposed circuit under case 4 condition.

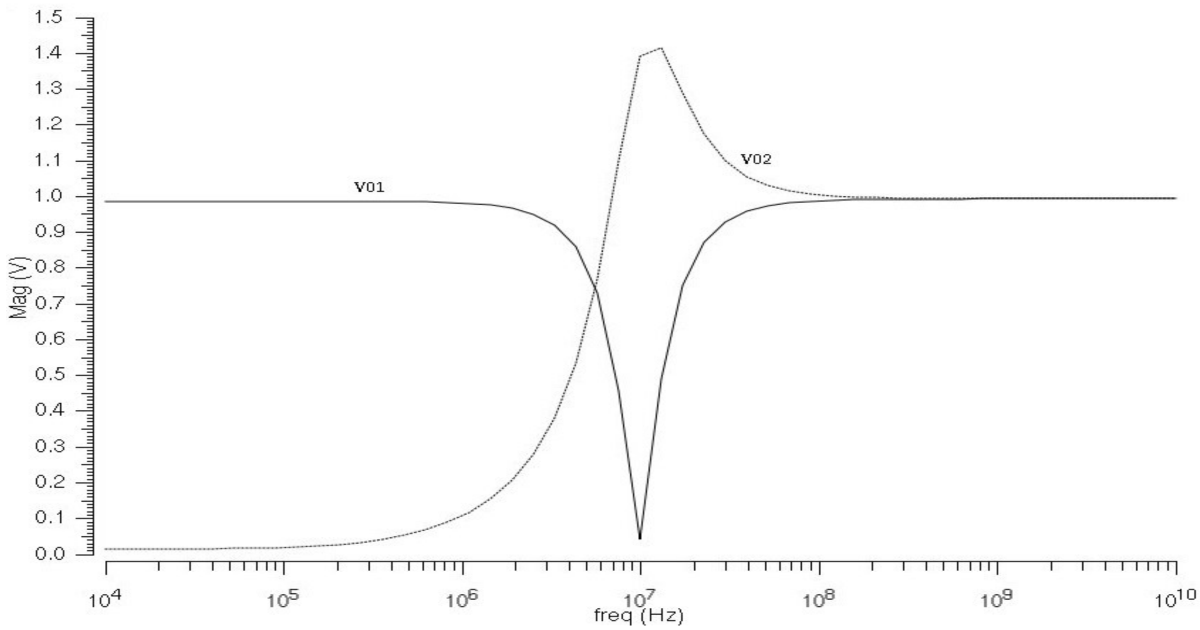

Figure 11. AC Response of the proposed circuit under case 5 condition

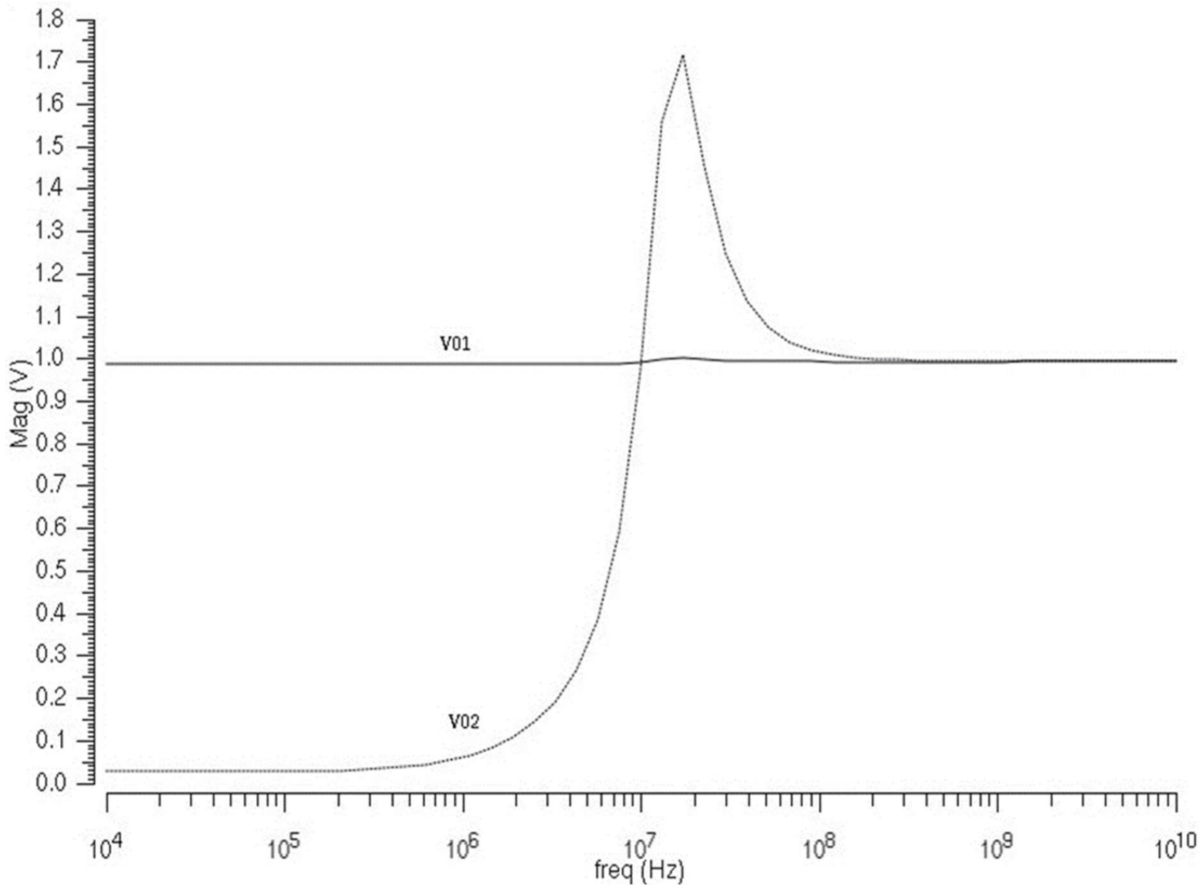

Figure 12. AC Response of the proposed circuit under case 6 condition

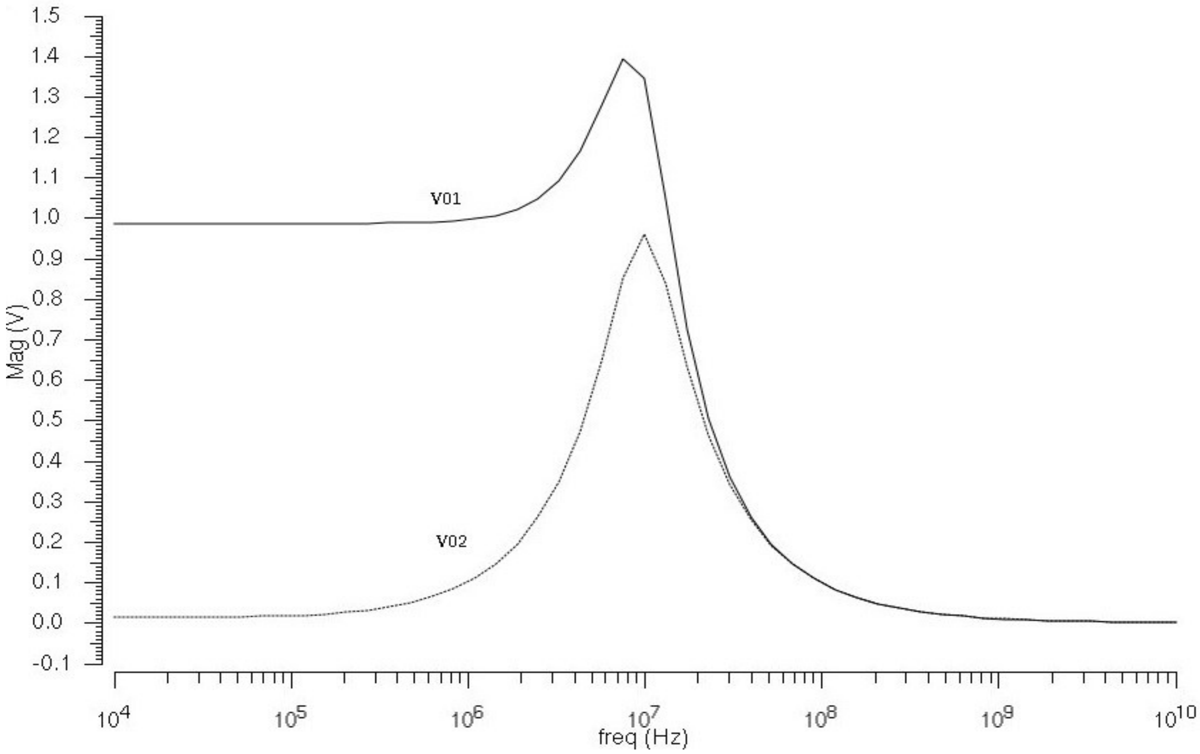

Figure 13. AC Response of the proposed circuit under case 7 condition.

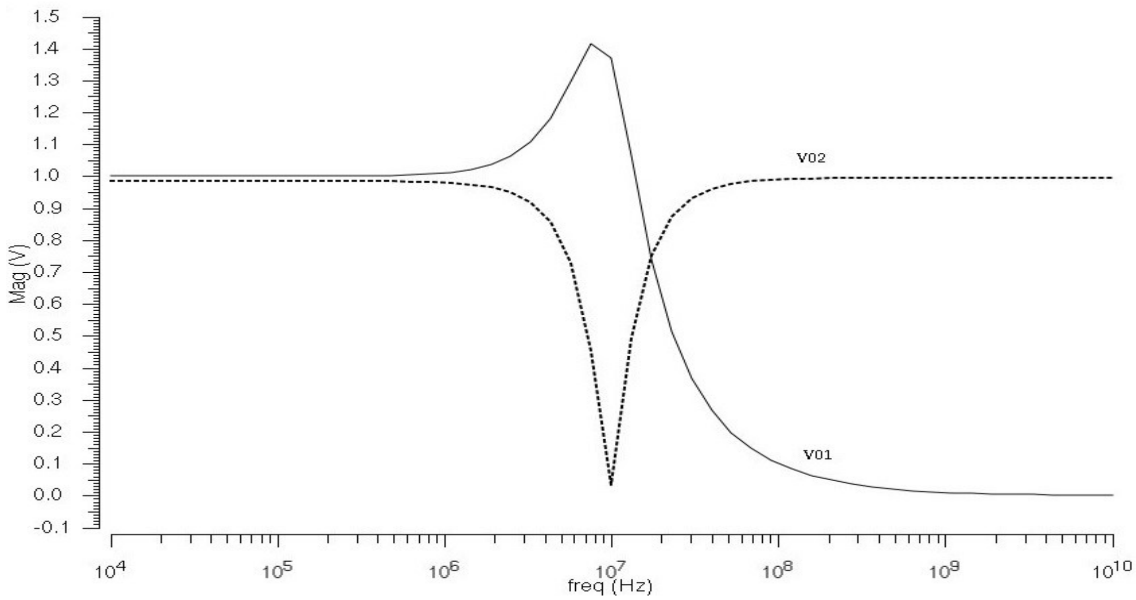

Fig. 14. AC Response of the proposed circuit under case 8 condition.

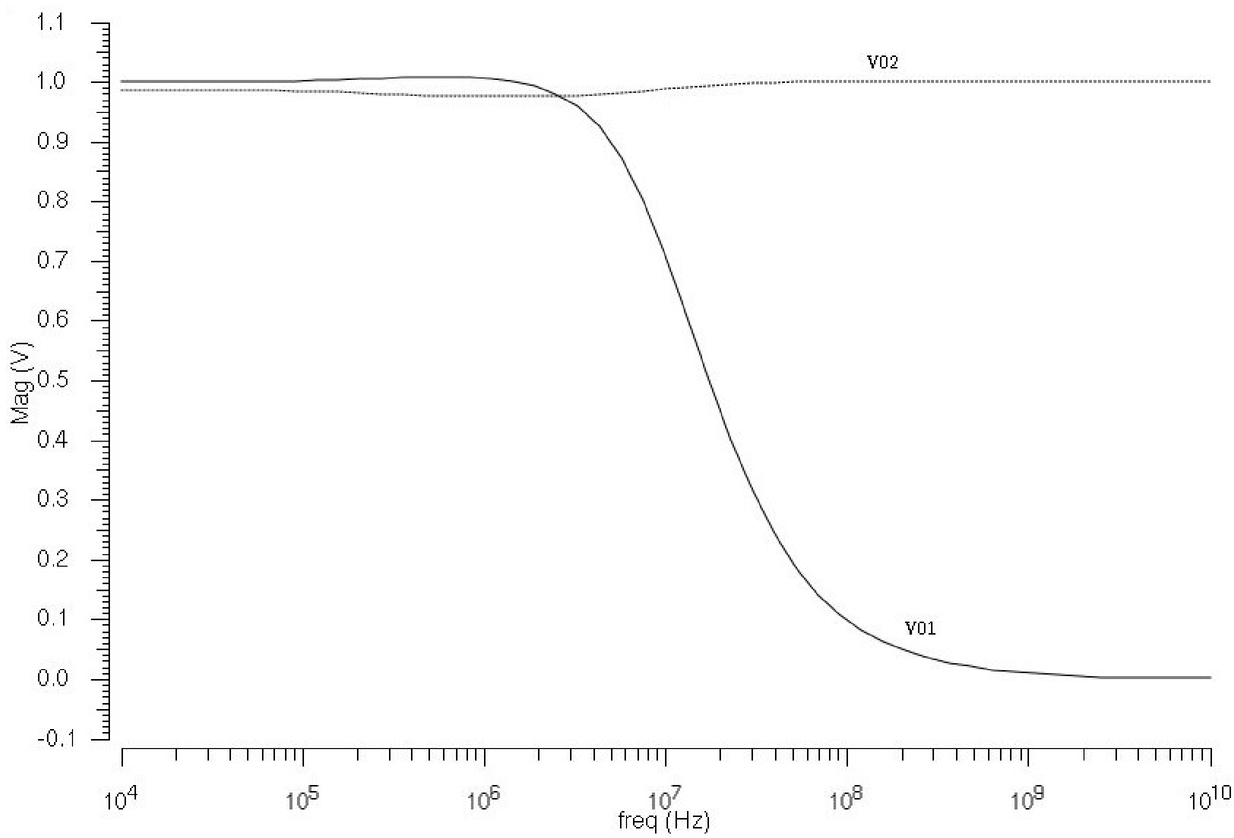

Figure 15. AC Response of the proposed circuit under case 9 condition.

5. Conclusion

In this project, we have successfully designed and implemented Electronically Tunable Active Filters using 2-stage Operational Transconductance Amplifiers (OTAs). Through extensive theoretical analysis, simulation, and practical experimentation, we have demonstrated the effectiveness and versatility of the proposed approach.

The Electronically Tunable Active Filters offer significant advantages over traditional fixed filters. Their ability to adjust frequency response characteristics electronically provides flexibility and adaptability to changing requirements without the

need for hardware modifications. By leveraging the unique properties of OTAs and carefully configuring the passive components, we have achieved precise control over the filter parameters such as cutoff frequency, bandwidth, and gain.
Throughout the project, we have explored various circuit topologies and design considerations to optimize the performance of the active filters. We have also investigated different tuning methods and techniques to enhance the electronic tunability of the filters.
The implemented filters have shown promising results in terms of performance, stability, and tunability. They have applications in a wide range of fields including communication systems, audio processing, and instrumentation. The flexibility and adaptability of the designed filters make them suitable for diverse signal processing tasks.
In conclusion, the Electronically Tunable Active Filters presented in this project offer a powerful and versatile solution for signal filtering applications. Future work may focus on further refining the design, exploring advanced tuning techniques, and integrating the filters into practical systems for real-world applications.
Overall, this project contributes to the advancement of active filter design and lays the foundation for future research in this area.

The proposed circuit represents a significant advancement in active filter design, offering a versatile and efficient solution for various signal processing applications. The circuit's unique features provide several advantages over traditional filter configurations:

(i) **Resistor-less Structure:** By leveraging operational transconductance amplifiers (OTAs) and other active components, the circuit achieves a resistor-less structure. This eliminates the need for bulky and costly resistors, leading to a more compact and cost-effective design.

(ii) **Higher Operating Frequency Range:** The circuit design enables operation at higher frequency ranges compared to conventional passive filter configurations. This expanded operating frequency range makes the circuit suitable for a broader range of applications, including high-frequency signal processing tasks.

(iii) **Electronically Tuneable Circuit:** One of the standout features of the proposed circuit is its electronic tunability. By adjusting control voltages or bias currents, the filter parameters such as cutoff frequency, bandwidth, and gain can be dynamically tuned to meet specific requirements. This flexibility enhances the circuit's versatility and adaptability in various signal processing scenarios.

(iv) **Reduced Transistor Counts:** The circuit design achieves its functionality with a reduced number of transistors compared to traditional implementations. This reduction in transistor count not only simplifies the circuit layout but also contributes to lower fabrication costs and improved reliability.

(v) **Reduction in Area and Power Consumption:** The elimination of resistors and the reduction in transistor counts lead to a more compact circuit layout and reduced power consumption. This is particularly beneficial for applications where space and power efficiency are critical considerations, such as portable devices and integrated systems.

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