A DISSERTATION ON

ANALOG FILTER DESIGN USING OTA

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

MASTER OF ENGINEERING

(ELECTRONICS & COMMUNICATION ENGINEERING)

Submitted By:

SUNIL KUMAR

COLLEGE ROLL NO. 18/E&C/08

UNIVERSITY ROLL NO. 10054

Under the Supervision of

Mr. ALOK KUMAR SINGH

DEPARTMENT OF ELECTRONICS AND COMMUNICATION

DELHI COLLEGE OF ENGINEERING

UNIVERSITY OF DELHI

2008-2011

<u>CERTIFICATE</u>

DELHI COLLEGE OF ENGINEERING

(Govt. of National Capital Territory of Delhi)
BAWANA ROAD, DELHI – 110042

Date: ………………………

This is certified that the dissertation entitled "**Analog Filter Design using OTA"** is a work of **Sunil Kumar** (University Roll No. - 10054) is a student of Delhi College of Engineering. This work is completed under my direct supervision and guidance and forms a part of master of engineering (Electronics & Communication Engineering) course and curriculum. He has completed his work with utmost sincerity and diligence.

The work embodied in this major project has not been submitted for the award of any other Institute / University for the award of any other degree to the best of my knowledge.

Mr. ALOK KUMAR SINGH
(Project Guide)
Assistant Professor
Department of Electronics & Communication Engg.
Delhi College of Engineering,
University of Delhi, India

Prof. RAJIV KAPOOR
(Head of Department)
Department of Electronics & Communication Engg.
Delhi college of Engineering
University of Delhi, India

ACKNOWLEDGEMENT

It is distinct pleasure to express my deep sense of gratitude and indebtedness to my supervisor **Mr. Alok Kumar Singh,** Assistant Professor, Department of Electronics and communication, Delhi College of Engineering, for his invaluable guidance, encouragement and patient reviews. His continuous inspiration only has made me complete this dissertation. Without his help and guidance, this dissertation would have been impossible. He remained a pillar of help throughout the project.

I am extremely thankful to **Prof. Rajiv Kapoor**, Head of the Department, Electronics and communication, Delhi College of Engineering Delhi, and **Prof. Asok Bhattacharyya**, former HOD of the department for the motivation and inspiration. I would also like to take this opportunity to present my sincere regards to all my teachers those who came to my help in some way for marking the project successful. I am also thankful to all non-teaching staff of Electronics and communication Departments and special thank to **Mr. Rajender Kumar** for his co-operation and valuable suggestion.

I am grateful to my parents for their moral support all the time,they have been always around to cheer me up, in the odd times of this work. I am also thankful to my classmates for their unconditional support and motivation during this work. Last but not least, I special thanks to the people who are active in the field of analog filter designing issues from whom I got the knowledge and inspiration to take up this field for my project work.

(SUNIL KUMAR)
Master of Engineering
(Electronics and Communication)
University Roll No. - 10054
College Roll No. - 18/E&C/2008
Department of Electronics & communication
Delhi College of Engineering, Delhi - 110042

ABSTRACT

The presence of several analog circuits with reduced components count, low power supply, better accuracy and fast speed is an extremely challenging task. Recently a number of papers have been published on analog filter design using CMOS technology. The least power consumption and highest fidelity is possible by using CMOS- Operational Transconductance Amplifier (OTA) instead of Op-amp. As a consequence, the CMOS based circuits approach has often been claimed to provide advantages of higher frequency range of operation, lower power consumption, higher slew rates, improved linearity, and better accuracy. This report describes the implementation of electronically tunable, analog filter based on Operational Transconductance Amplifier (OTA) using CMOS technology.

The operational transconductance amplifier (OTA) is an amplifier whose differential input voltage produces an output current. Thus, it is a voltage controlled current source. There is usually an additional input for a current to control the amplifier's transcoductance. The transcoductance can be continuously controlled by an auxiliary DC current. It gives the possibility to control electronically the parameters of realized filters.

In this work electronically tunable filter circuits such low pass, high pass, band pass, band stop in first order and second order has been implemented. A floating and grounded resistance using OTA has been implemented and the same is used in realizing the filters.

In this work SPICE simulation of realization of OTA using CMOS technology, as the basic building block has been done and its DC characteristics are verified. The workability of electronically tunable, OTA based filters using CMOS technology has been confirmed by PSPICE Simulation and the results are compared with PSPICE simulation of the commercially available operational tranconductance amplifier LM13600/LM13700. Further hardware results are verified using the same commercial IC.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER-1

COMMONLY USED ANALOG BUILDING BLOCKS

1.1 INTRODUCTION

Passive component are generally the basic building block, which work normally on high frequency; but at audio frequency inductor causes problem. Inductor size increases at audio frequency and become bulky and expensive at low frequency inductor requires more number of turns which adds series resistances and degrades the inductor performance because of low quality factor (Q), which results in high power dissipation. Using the OTA the above mention problems are solved.

The filter circuits employ Operational Transconductance Amplifier (OTA) namely LM13700 as a basic building block where Transconductance of an OTA is controlled by an auxiliary current. It gives the possibility to control electronically the parameter of realized analog filters. This report contains a first order and second orders various filters with functional blocks usually operational tranconductance amplifiers. Their main advantage is greater versatility, which permits different types of the filters, or of the transfer functions, to be realized simultaneously at the available outputs of the active blocks. Usually the low-pass (LP), high-pass (HP), band-pass (BP) and band-reject (BR) functions are there realized.

Recently a progress in analogue technology has produced several functional blocks which are suitable for higher frequency ranges. One of them is the transconductor also called the operational transconductance amplifier (OTA). Commercially available transconductors are for example LM 13600/ LM 13700. These integrated circuits include two sub circuits, namely a transcoductance amplifier (OTA) and a voltage buffer (VB). There the transcoductance (gm) can be continuously controlled by an auxiliary DC current (I_{BB}) It gives the possibility to control electronically the parameters of realized filters.

1.2 CURRENT MODE PROCESSING

The growth of analog IC design has been impeded by the process technologies that are mostly optimized for digital applications only. With the evolution of submicron technologies such as 0.18 micron and 0.13 micron, the supply voltages have been reduced to 3.3 Volts and lower. This makes it difficult to design a voltage mode CMOS circuits with high linearity and wide dynamic range. Recently, current mode circuits have become a viable alternative for future applications because of their inherent advantages over voltage mode circuits [2].

The main advantage of using current mode technique is because the non-linear characteristics exhibited by most field effect transistors. A small change in the input or controlling voltage results in a much larger change in the output current. Thus for a fixed supply voltage, the dynamic range of a current mode circuit is much larger than that of a voltage mode circuit. If a supply voltage is lowered, one can still get the required signals represented by the current.

A second advantage of current mode circuits is that they are much faster as compared to voltage mode circuits. The parasitic capacitances present in the analog circuits must be charged and discharged with the changing voltage levels. In a current mode circuit, a change in current level is not necessarily accompanied by a change in the voltage level. Hence, the parasitic capacitances will not affect the operating speed of the circuit by a significant amount.

Other advantages of using current mode circuits are that they do not require specially processed capacitors or resistors; they are more compatible with digital CMOS technology making integration of mixed signal circuits more feasible. Due to all the advantages of current mode analogue signal processing there has been an emergence of new analogue building blocks ranging from the current conveyor, OTA, OTRA and current feedback op-amps through to sampled data current circuits such as dynamic current mirrors and analogue neural networks.

1.3 ANALOG BUILDING BLOCKS

1.3.1 OPAMP

The operational amplifier is one of the most useful and important components of analog electronics. They are widely used in popular electronics. Their primary limitation is that they are not especially fast: The typical performance degrades rapidly for frequencies greater than about 1 MHz. The primary use of op-amps in amplifier and related circuits is closely connected to the concept of negative feedback. Feedback represents a vast and interesting topic in itself.

An op-amp has a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. Ideally the op-amp amplifies only the difference in voltage applied between its two inputs (V_+ and V_-), which is called the differential input voltage. The output voltage of the op-amp is given by the equation,

$$V_0 = (V_+ - V_-)A_0 \quad (1.1)$$

Where V_+ is the voltage at the non-inverting terminal and V_- is the voltage at the inverting terminal and G open-loop is the open-loop gain of the amplifier.

The ideal operation is difficult to achieve and the non-ideal conditions often raise limitations like finite impedances and drift, their primary limitation being not especially fast. The typical performance degrades rapidly for frequencies greater than 1MHz, although some models are designed especially for higher frequencies. High input impedance at the input terminals (ideally infinite) and low output impedance at the output terminal(s) (ideally zero) are important typical characteristics. The other important fact about op-amps is that their open-loop gain is huge. This is the gain that would be measured from a configuration in which there is no feedback loop from output back to input. A typical open-loop voltage gain is ~ 10^4 -10^5 .

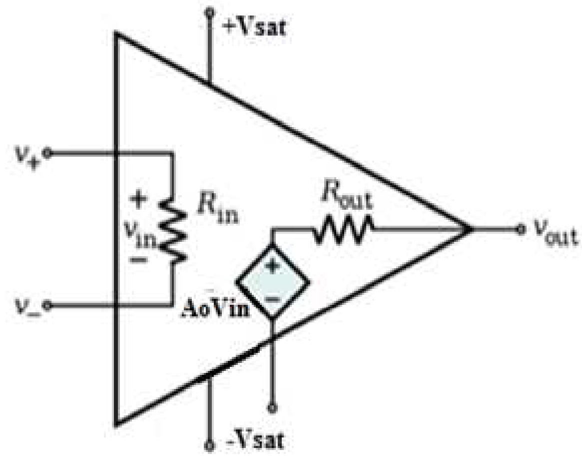


Figure 1.1 Non ideal internal circuit of Op-amp

An ideal op-amp is usually considered to have the following properties, and they are considered to hold for all input voltages:

- Infinite open-loop gain.
- Infinite voltage range available at the output (V_{out}) (in practice the voltages available from the output are limited by the supply voltages $+V_{SAT}$ and $-V_{SAT}$)
- Infinite bandwidth
- Infinite input impedance
- Zero input current
- Zero input offset voltage
- Infinite slew rate
- Zero output impedance
- Infinite Common-mode rejection ratio (CMRR)
- Infinite Power supply rejection ratio for both power supply rails.

1.3.2 OPERATIONAL TRANSCONDUCTANCE AMPLIFIER

An operational Transconductance amplifier (OTA) is a voltage controlled current source (VCCS) device [5-6]. There is usually an additional input for a current to control the amplifier's transconductance. The OTA is similar to a standard operational amplifier but output impedance is infinite in ideal OTA where it is zero in ideal Op-amp and OTA may be used with negative feedback.

The OTA is not as useful by itself in the vast majority of standard op-amp functions as the ordinary op-amp because its output is a current. One of its principal uses is in implementing electronically controlled applications such as variable frequency oscillators and filters and variable gain amplifier stages which are more difficult to implement with standard op-amps. In the ideal OTA, the output current is a linear function of the differential input voltage, and is given by:

$$I_{OUT} = g_m (V_{IN}+ - V_{IN}-) \quad (1.2)$$

The amplifier's output voltage is the product of its output current and its load resistance:

$$V_{OUT} = I_{OUT} \cdot R_{LOAD} \quad (1.3)$$

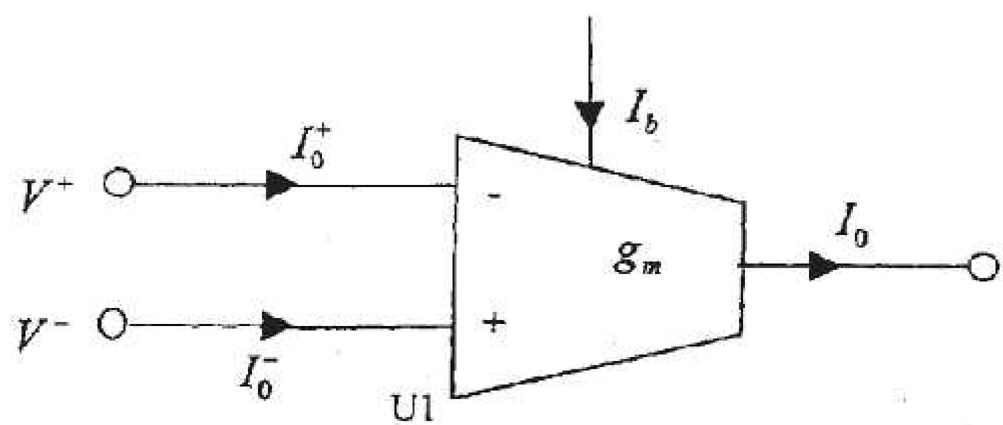


Figure 1.2 OTA Model

The voltage gain is then the output voltage divided by the differential input voltage:

$$G_{\text{voltage}} = \frac{V_{\text{out}}}{(V_{\text{in}+} - V_{\text{in}-})} = R_{\text{load}} \cdot g_{\text{m}} \quad (1.4)$$

The transconductance of the amplifier is usually controlled by an input current, denoted I_{bias} ("bias current"). The amplifier's transconductance is directly proportional to this current. This is the feature that makes it useful for electronic control of amplifier gain, etc. As an ideal OTA is usually considered to have the following properties and they are considered to hold for all input voltages:

- Infinite input impedance.
- Infinite output impedance (i.e. $R_{out} = \infty$).
- g_m is variable and $g_m = \frac{I_{BIAS}}{2V_T}$ we cannot make g_m infinite

CHAPTER 2

LITERATURE SURVEY

The demand for electronic circuits with extremely low supply voltages and power consumption is important in development of microelectronic technologies [2]. Electronically tunable analog filter are useful in many applications, such as telecommunication, multimedia and consumer electronics. Medical electronics etc. are important subsystems in such systems. Among the existing realization method of continuous-time domain integrated analog filters circuit, OTA topology is most useful one and it offer good performances with lower power consumption and high frequency operation. In many applications, additional requirements appear, particularly the extreme speed or the accuracy of signal processing. Simultaneous fulfillment of the above demands is problematic. CMOS technology, using the OTA as the active element can achieve a considerable improvement in amplifier speed, accuracy and bandwidth, overcoming the finite gain–bandwidth product associated with operational amplifiers. Literature survey reveals the emergence of OTA as an alternate analog building block. A variety of papers have been reported on OTA during last one and a half decade.

Commercially available transconductance amplifier LM13600/ LM13700 [19] using in various modern circuits in field of Electronics such Amplifier, Active filter, oscillator and non linear circuits. Some papers have been reported on Active filter Circuit with commercial available Transconductance Amplifier [19].

2.1 CMOS-OTA Realization

The commercial OTA were not meant to be used in open loop mode. The maximum input voltage for a typical bipolar OTA is of the order of only 30mV [7]. Since a number of researches have investigated to increase the input voltage range and to linearise the OTA.

So, from the realization of CMOS-OTA input voltage range increases and also linearise the OTA. Some of the attractive properties of OTA are their fast speed in comparison with conventional low-output impedance op-amps, and their bias dependence conductance tunability [6]. CMOS-OTA is used in many of application instead of commercial operational amplifies due to its features such as low power consumption, requirement of very low supply voltage and better result at high frequency. It reduces the zero cross-over distortion as compared to conventional op-amp. With the realization of CMOS-OTA which is

Transconductance amplifiers by which the following features arises that any improvement in filters, amplifier or in any other circuit characteristics, performance or flexibility can be obtained. In recent years, several high-performance CMOS OTA realizations have been presented [7]. This leads to growing interest for the design of OTA-based analog signal processing circuits.

2.2 OTA Applications

2.2.1 Amplifiers

Here, the study of the operational transconductance amplifier (OTA) as a replacement for the conventional op-amp as a inverting amplifier is done. This report wills a subset of general voltage amplifiers. [19]. for further information about the rich variety of amplifier configurations available using the OTA, the reference [Geiger-9] is extremely useful.

2.2.2 Filters

Various filters have been designed using OTA. Second order voltage mode filters are realized in [11]. Ref [12] gives two realizations, first and second order depending on the value of tranconductance and capacitance. First-order low pass and high pass filter, second- order band pass filter and notch filters are realized in [9,10].

Ref [10] presents an OTA based current controlled type biquadratic filters configration using two and three OTA, which realize all different filter functions, namely low-pass, high-pass, band-pass, notch and all-pass.

A generalized electronically tunable high-input impedance voltage-mode universal biquadratic filter based on CMOS OTAs is discussed in [13]. These are used to realize all the filtering functions like low-pass, high-pass, band-pass, notch and all-pass.

2.2.3 Grounded Resistance using OTA

The active filter realized using OTA as grounded Resistance [20-21] which makes not only the passive resistance less circuit also provided a tunable of circuits. There are two type of grounded resistance realized positive grounded resistance and negative grounded resistance. This report realized resistivity with frequency. The workability of grounded resistance circuit has conformed with CMOS Block as well as commercially available integrated circuit namely LM13700 transconductance amplifier (OTA)

2.2.4 Floating Resistance using OTA

Same as grounded resistance the active filter realized using OTA as dynamic resistance which provided electronically tunable active filter [20-21]. This report its dynamic range with frequency spectrum. The workability of dynamic resistance circuit has conformed with CMOS Block as well as commercially available integrated circuit namely LM13700 transconductance amplifier (OTA)

CHAPTER 3
CMOS REALIZATION OF OTA

This chapter presents the realization of the CMOS-Operational transconductance amplifier (OTA). CMOS implementation and simulation verifies that biased current is proportional to the transconductance of the OTA [8]. These building blocks are used in later chapters for constructing second order filters, rectifiers, etc.

3.1 INTRODUCTION

An operational transconductance amplifier (OTA) is a voltage controlled current source (VCCS) device [9-10]. They are found useful in interface circuits, instrumentation amplifiers, continuous-time-filters and oscillators. Primarily voltage amplifiers (such as: op-amp) in which the output voltage equals the gain times the input voltage. The Operational transconductance amplifier (OTA) is primarily a voltage-to-current amplifier in which the output current equals the gain times the input voltage. By definition the transconductance of electronics devices is the ratio of the output current to the input voltages. For an OTA voltage is the input variable and current is the output variable. Therefore the ratio of the output current to the input voltage is its gain which is known as transconductance (gm). Ideal characteristics of an OTA are same as that of the operational amplifier unlike infinite output impedance (which is zero in op-amp). There is also a input bias terminal besides two differential non-inverting and inverting input terminals.

The OTA is popular for implementing voltage controlled filters (VCF) and oscillators (VCO), rectifiers, multiplier and in many other circuit which plays an important role over conventional op-amp like: reduces the component count in the circuit, used at high frequency range, can be operate a very low power supply voltage which in turn reduces the power consumption of the given circuit [12].

3.2 OTA - Principle of Operation

An OTA is a voltage controlled current source, more specifically the term "operational" comes from the fact that it takes the difference of two voltages as the input for the current conversion [9].

The ideal transfer characteristic is therefore:

$$I_{OUT} = g_m (V_{IN+} - V_{IN-}) \quad (3.1)$$

Or, by taking the pre-computed difference as the input:

$$I_{OUT} = g_m V_{IN} \quad (3.2)$$

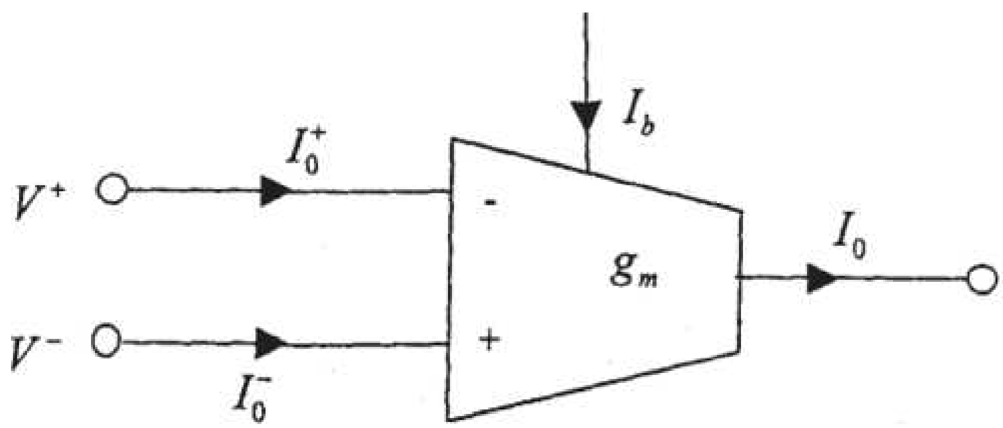


Fig: 3.1 Circuit Symbol of OTA

The above circuit is the symbol of an operational transconductance amplifier (OTA) with two differential input terminals and a bias current input with transconductance gm.

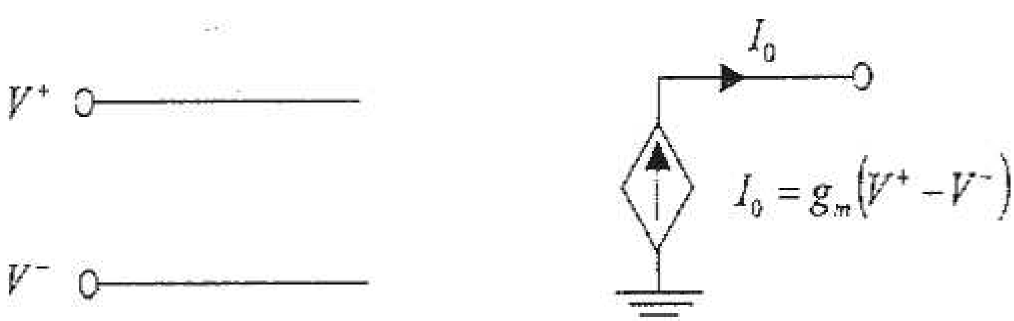


Fig 3.2: Equivalent circuit of an ideal OTA

The above figure shows that the output current depends on transconductance (gm) and on the differential input terminal voltages. This also shows that input impedance of an ideal OTA is infinite.

The proportionality factor between output current and input differential voltage is called transconductance. In reality the transconductance is also a function of the input differential voltage as shown in the below equation:

$$gm = \frac{Iout}{Vin} \tag{3.3}$$

And

$$g_m = K\, I_{BIAS} \tag{3.4}$$

Also OTA transconductance depends on a constant (K) times the bias current (where K is the temperature dependent function). Consequently, the output current of an OTA is controlled by the input voltage and the bias current as shown below:

$$I_{OUT} = g_m V_{in} = K\, I_{BIAS} V_{in} \tag{3.5}$$

To summarize, an ideal OTA has two voltage inputs and a bias current input with infinite input impedance (i.e. there is no input current) and high output impedance. The common mode input range is also infinite, while the differential signal between these two inputs is used to control an ideal current source (i.e. the output current does not depend on the output voltage) that functions as an output.

3.3 CMOS realization of OTA

The OTA has been simulated using the CMOS structure of Figure 3.1 with in put DC voltage equal to 150mV and bias voltage equal to V_{DD} = +5V and V_{SS} = -5V and Ibias = 50µA . All MOS transistors are operated in saturation region and all of the bulks are connected to power supply voltage (bulks of PMOS are connected to + 5V, and bulks of NMOS are connected -5V). The simulations are based on 0.5µm CMOS technology. Fig. 3.3 shows the CMOS implementation of simple OTA. It uses only eight MOSFET transistors and one current source. Assume four MOS transistors operating in saturation region.

3.3.1 The PSPICE schematic of CMOS realization of OTA

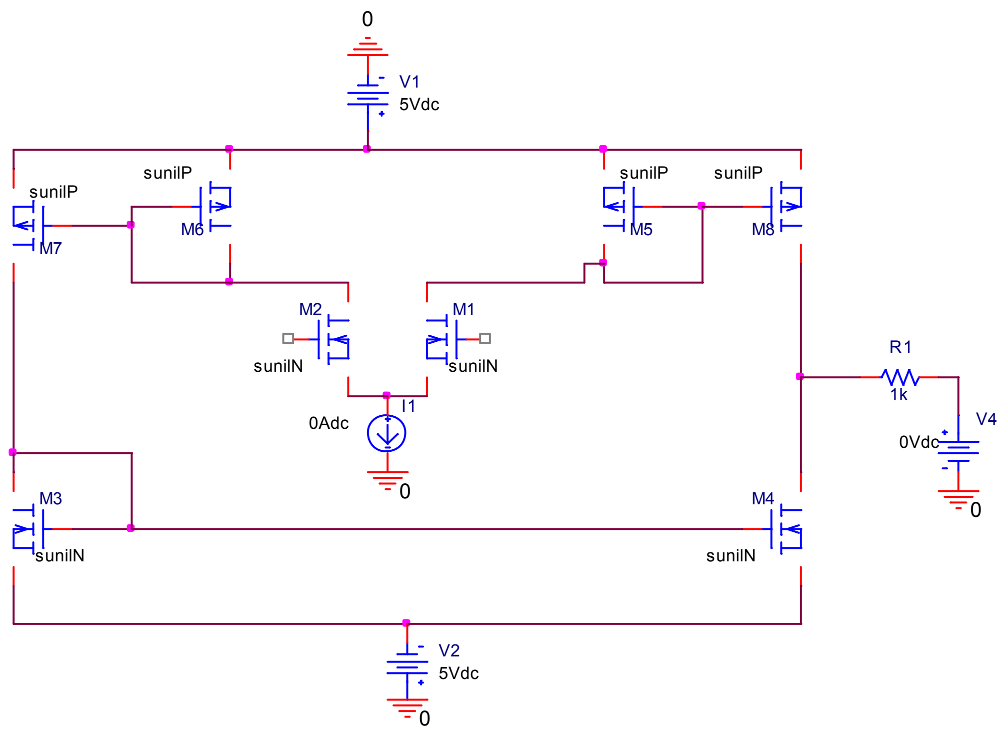


Fig. 3.3 CMOS realization of OTA

3.3.2 Result

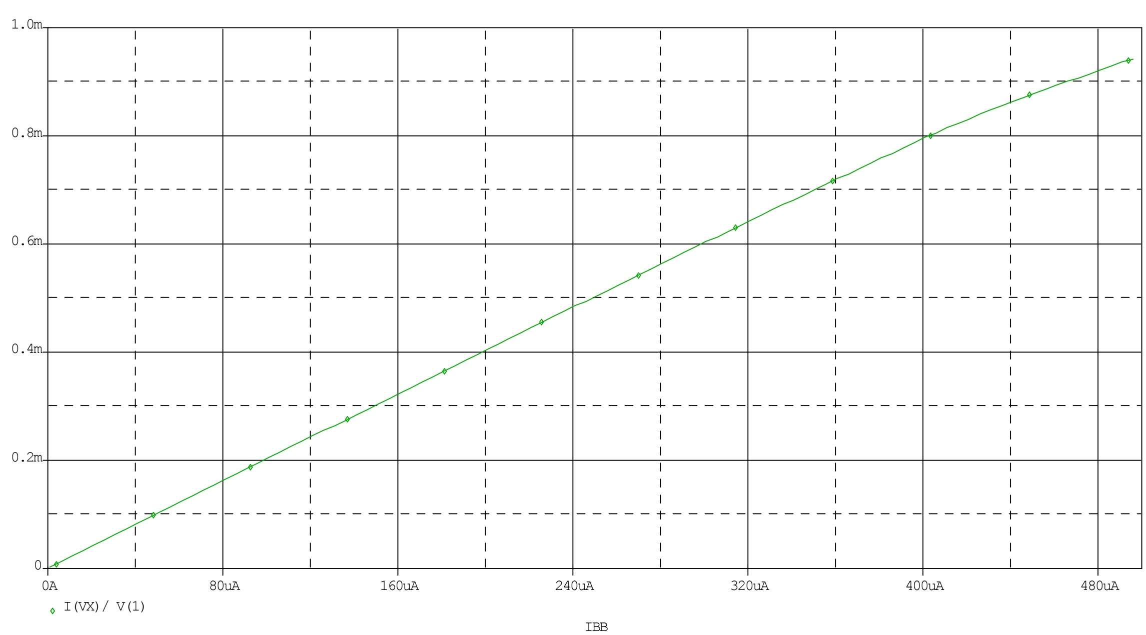


Fig 3.4 Simulated plot between transconductance (g_m) & bias current (I_{bias})

Above Fig 3.4 shows that the transconductance gain gm of the OTA can be varied by the bias current Ibb.

3.3.3 Result

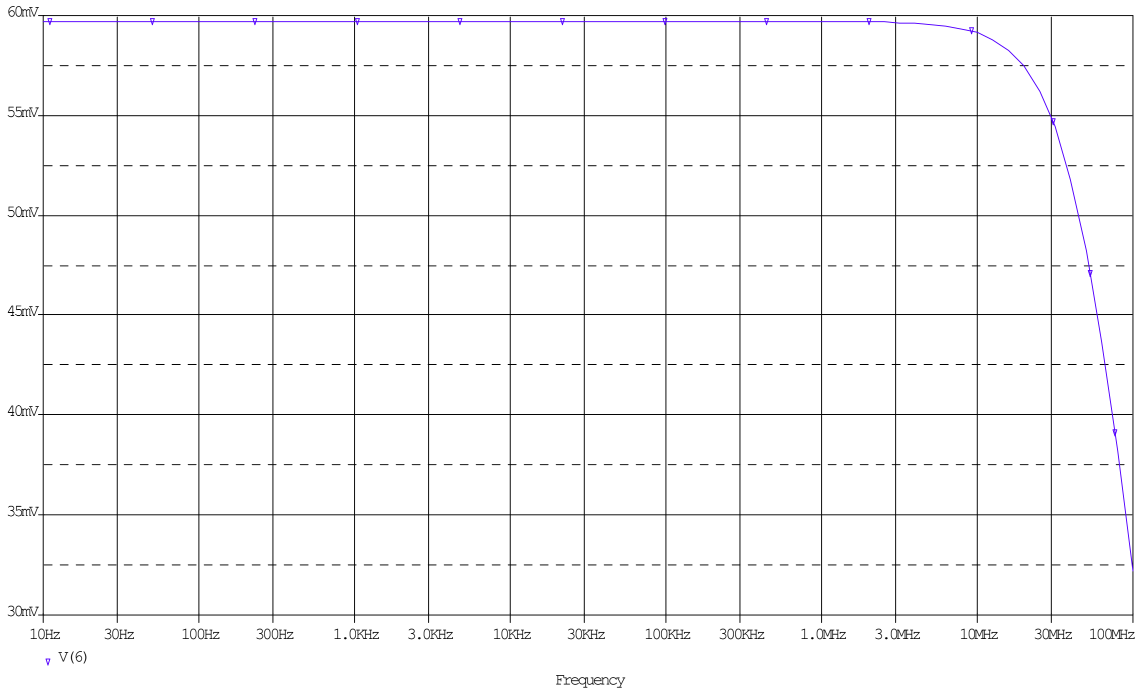


Fig. 3.5 frequency response of the CMOS-OTA

Fig3.5: shows the AC analysis which consists of open loop frequency response of the OTA for input voltage of 150mV.

CHAPTER 4

APPLICATION OF TRANSCONDUCTANCE AMPLIFIER

4.1 OTA as an Inverting Amplifier

Here, the study of the operational transconductance amplifier (OTA) as a replacement for the conventional op-amp as a inverting amplifier is done. This section will discuss a subset of general voltage amplifiers. For further information about the rich variety of amplifier configurations available using the OTA, the reference [Geiger-11] is extremely useful.

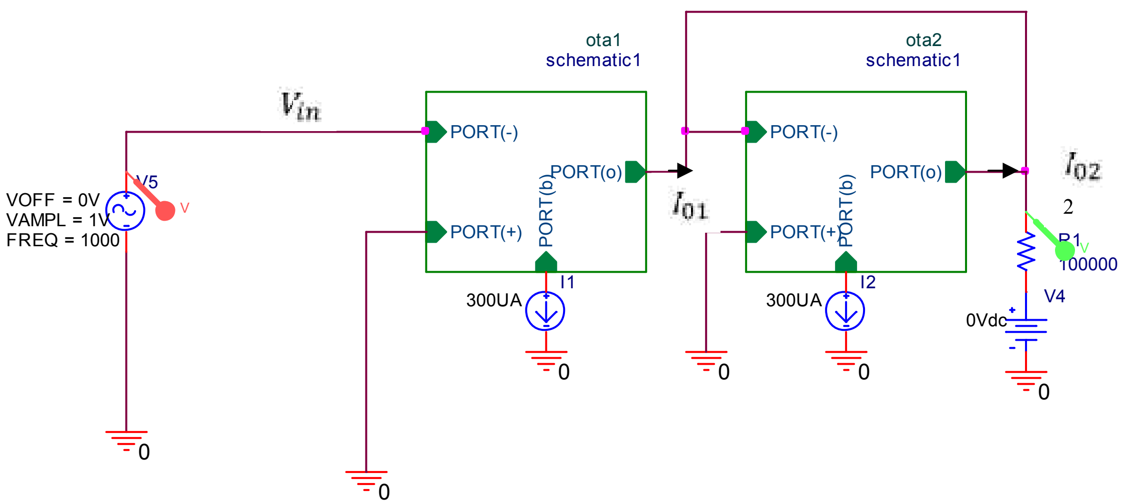


Fig 4.1 OTA as an inverting amplifier

The voltage gain and output impedance are given by:

$$I_{01} = -g_{m1}V_{in} \tag{4.1}$$

$$I_{02} = -g_{m2}V_0 \tag{4.2}$$

$$I_{01} = -I_{02} \tag{4.3}$$

On putting the value of Equations (4.1.1) and (4.1.2) in Equation (4.1.3), we get:

$$\frac{V_i}{V_0} = -\frac{g_{m1}}{g_{m2}} \tag{4.4}$$

And the input impedance is given by:

$$Z_0 = \frac{1}{g_{m2}} \tag{4.5}$$

4.1.1Result

The simulated input-output is plot of inverting amplifier shown in fig. 4.2

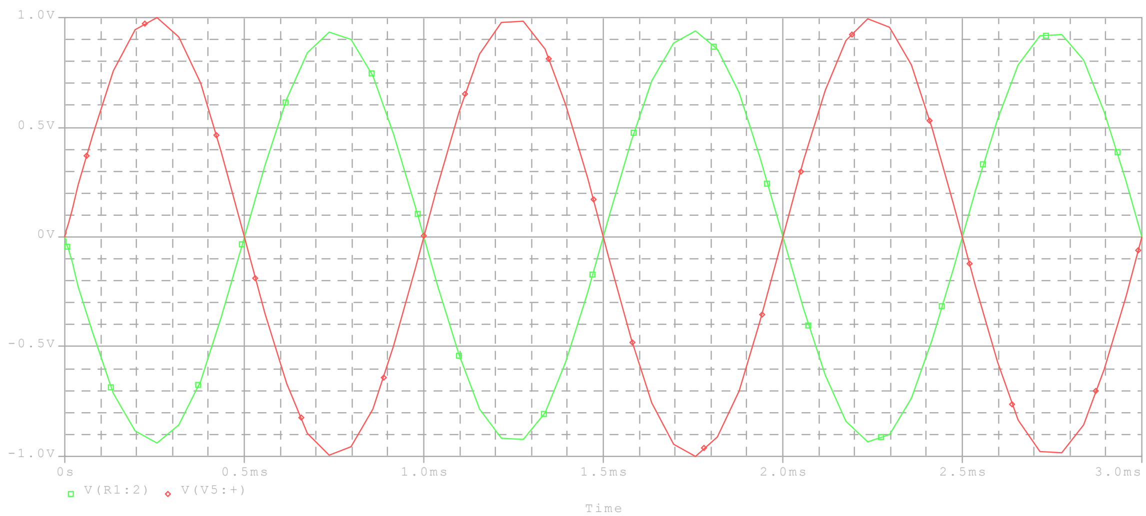


Fig 4.2 Input-output response of the inverting amplifier using OTA

The gain is completely settable by the external currents, with no external, passive components except those needed to generate the current from a standard voltage source. In the above result Ibb bias current 300ua. By changing the bias current we can change gm which increases the gain of amplifier.

4.2 OTA as Algebraic Summer

To add currents require only a node where Kirchhoff's current law sum the currents. Convert voltages into currents by means of transconductors, add the resulting current at a node, and if the result must be another voltage, use a current to voltage converter to obtain the output voltage. A current to voltage converter is a resistor.

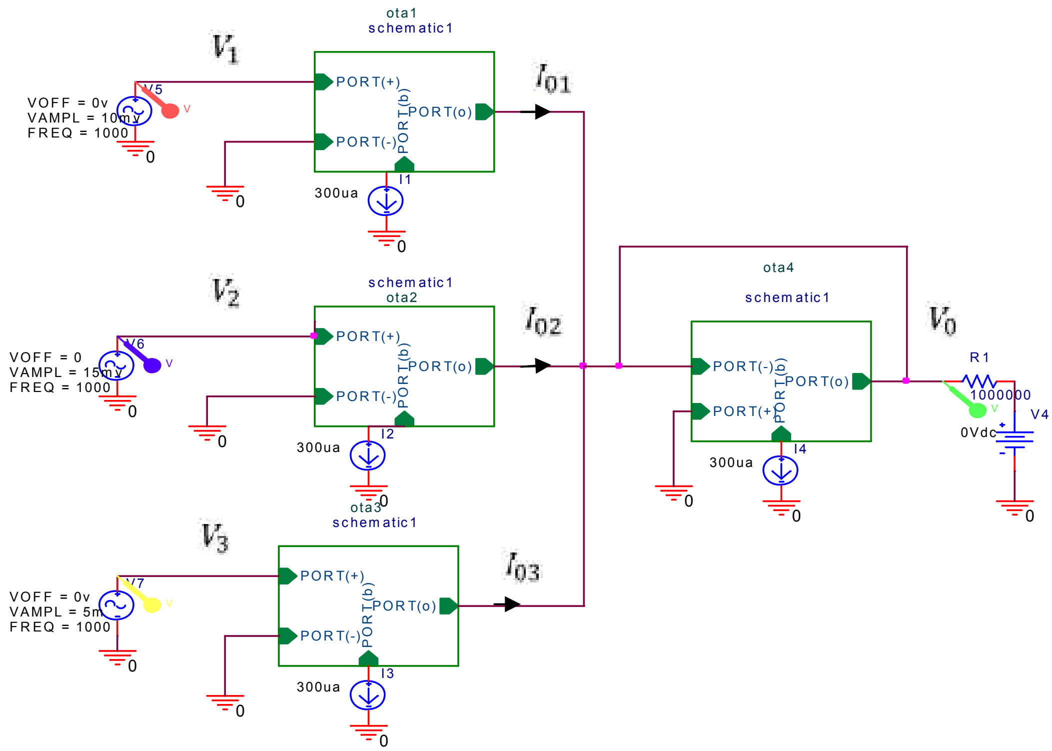


Fig 4.3 Circuit based on transconductance for summing voltages

On solving above circuit we get the output voltage in terms of ration of the transconductance of OTA1, OTA2 and OTA3 to the OTA4

$$I_{01} = g_{m1}V_1 \quad (4.6)$$

$$I_{02} = g_{m2}V_2 \quad (4.7)$$

$$I_{03} = g_{m3}V_3 \quad (4.8)$$

On applying KCL as node 2, we get:

$$I_{01} + I_{02} + I_{03} = g_{m0}V_0 \quad (4.9)$$

Putting the Equation (4.6), (4.7), and (4.8) in Equation (4.9)

$$V_0 = \left(\frac{g_{m1}}{g_{m0}}V_1 + \frac{g_{m2}}{g_{m0}}V_2 + \frac{g_{m3}}{g_{m0}}V_3\right) \quad (4.10)$$

4.2.1 Result

The simulated input-output plot of algebraic summer is shown in fig. 4.4

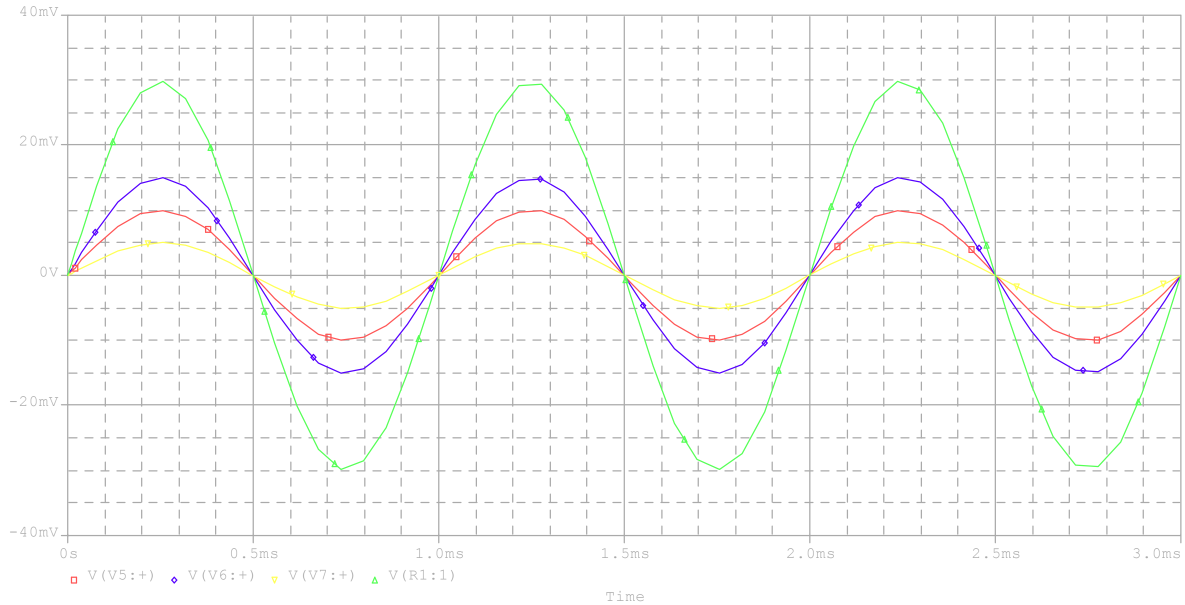


Fig: 4.4 Input-output waveform of algebraic summer circuit using OTA

4.3 First Order High Pass Filter Using Single OTA

In fig.4.5 high pass filter configuration using single CMOS-OTA which is proposed in [11] is shown. Frequency response with the input bias current of the OTA is shown in fig 4.6.

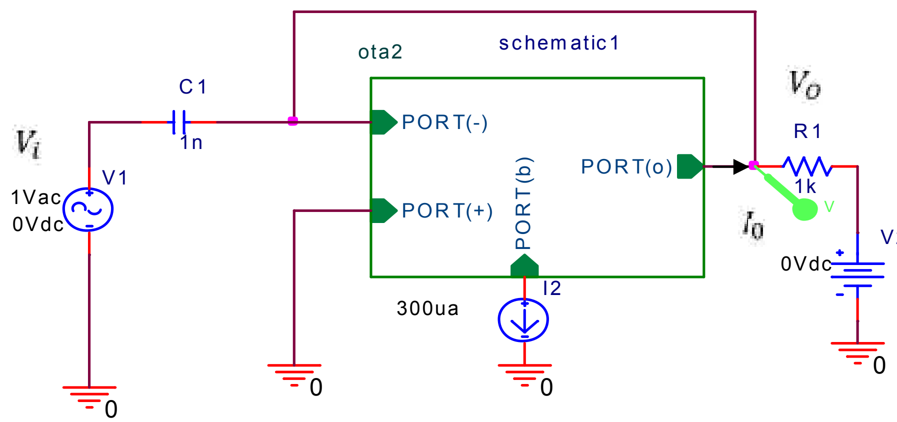


Fig. 4.5 High pass filter using OTA

4.3.2 Transfer Function

$$I_0 = g_m(0 - V_0) \tag{4.10}$$

$$I_0 = -g_m V_0 \tag{4.11}$$

$$I_0 = \frac{(V_0 - V_i)}{1/SC} \tag{4.12}$$

NOW, Equation (4.12) can be written as:

$$I_0 = SC(V_O - V_i) \tag{4.13}$$

From Equation (4.11)

$$-g_m V_0 = SC(V_O - V_i) \tag{4.14}$$

$$V_i.SC = V_O(SC + g_m) \tag{4.15}$$

$$\frac{V_0}{V_i} = \frac{SC}{SC + g_m} \tag{4.16}$$

So, the Equation (4.16) is the given transfer function of the High pass filter.

4.3.2 Results

The simulated frequency response plot of high pass filter using OTA is shown in fig. 4.6

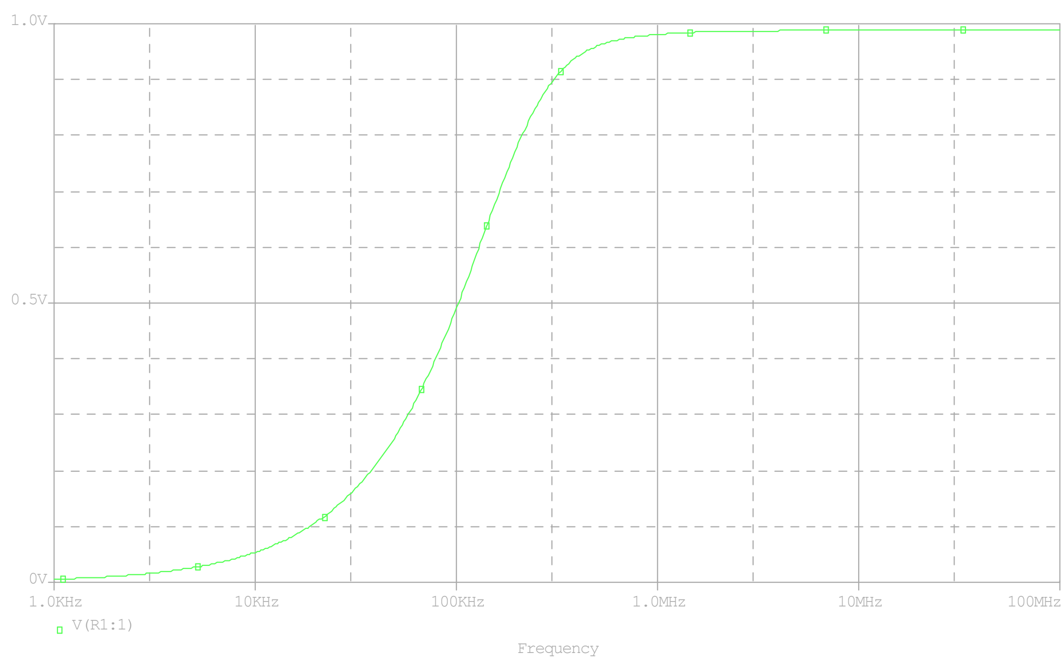


Fig. 4.6 Frequency Response of High Pass Filter using OTA

4.3.3 First Order High Pass Filter Using LM13700

The PSPICE schematic of high pass filter using LM 13600/ LM13700 is shown in figure 4.7 and the frequency response of the same is shown in fig. 4.8.

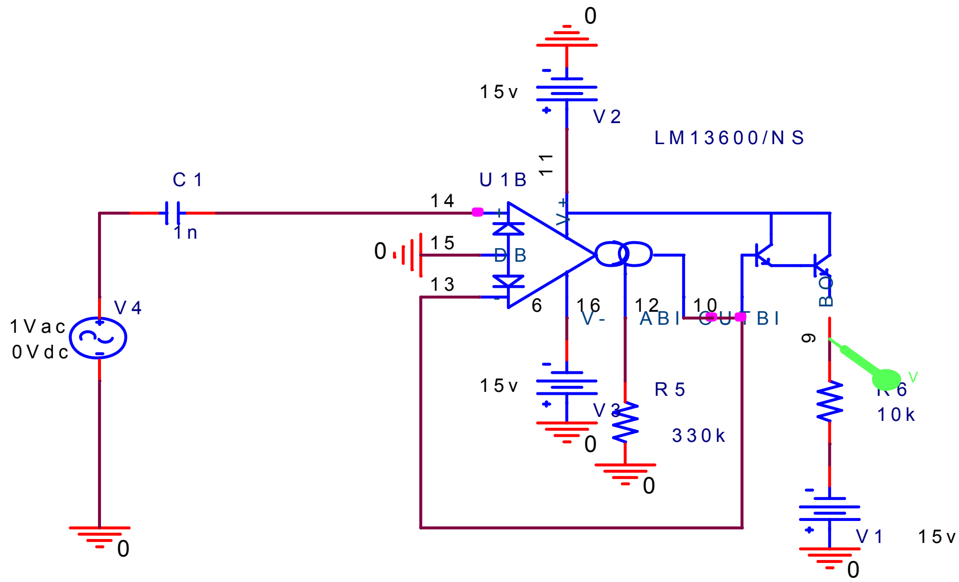


Fig. 4.7 High pass filter using LM 13700

The circuit shown in fig. 4.7 is a first order low pass filter (LPF). Here the dc voltage V_1 and V_3 is used for supplying the dc biasing. The Ibb provided by external resistance R_5 which in turn determines gm. The analysis of this circuit is simple provided with the darlington pair attached at the output of OTA is known as buffer. The input and output voltage of Darlington pair are same and that is V_O at R_6.

The purpose of using a Darlington pair at the output of OTA is to convert the OTA output i.e. current output into a voltage V_O at R6. The Darlington pair offers very large input resistance.

Transfer function of given circuit as follow.

$$\frac{V_o}{V_{in}} = \frac{1}{1 + \left(\frac{sC}{g_m}\right)}$$

$$f_c = \frac{g_m}{2\pi C}$$

4.3.4 Results

The simulated frequency response plot of high pass filter using LM 13600/LM 13700 is shown in fig. 4.8

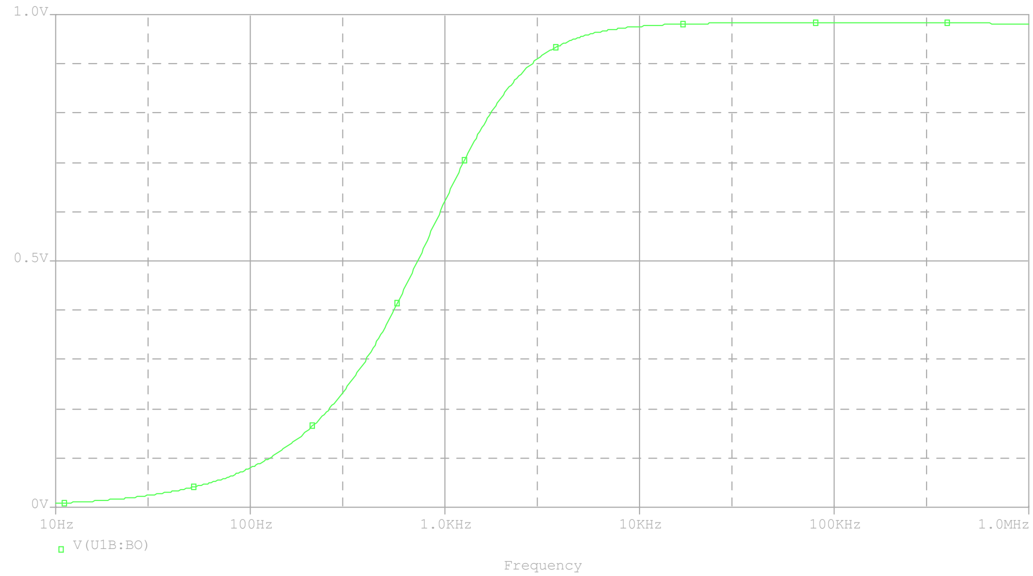


Fig. 4.8 Frequency Response of High Pass Filter using LM 13700

4.4 First Order Low Pass Filter Using Single OTA

The SPICE schematic of low pass filter using OTA is shown in fig. 4.9.

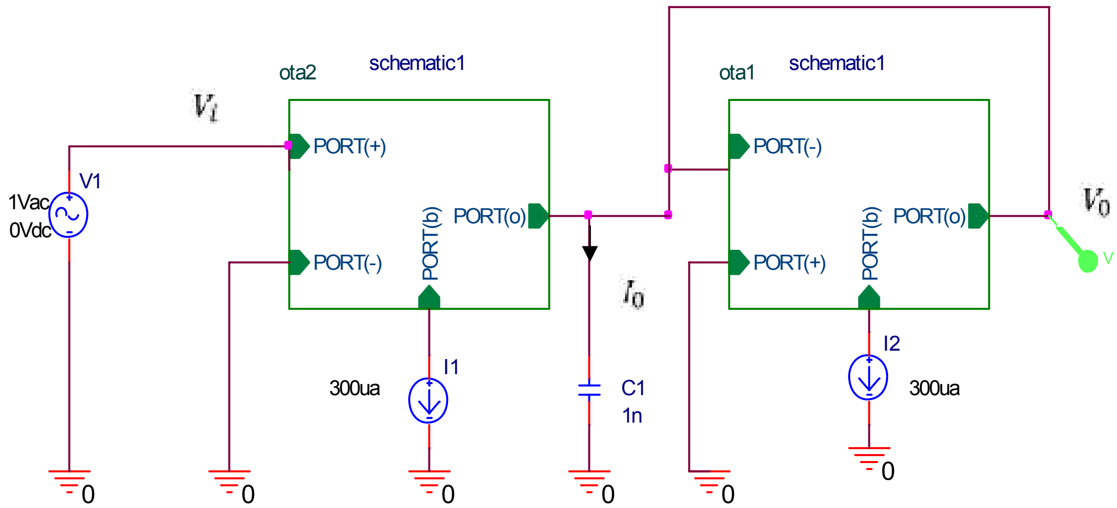


Fig. 4.9 Low pass filter using OTA

4.4.1 Transfer Function

$$I_0 = g_m(V_i - V_0) \tag{4.17}$$

$$I_0 = \frac{V_0}{1/SC} \tag{4.18}$$

On putting Equation (4.18) in Equation (4.17)

$$V_0.SC = g_m(V_i - V_0) \tag{4.19}$$

$$V_0.(g_m + SC) = g_m V_i \tag{4.20}$$

$$\frac{V_0}{V_i} = \frac{g_m}{SC + g_m} \tag{4.21}$$

Hence, Equation (4.21) is the transfer function of the first order Low pass filter.

The simulated frequency response plot of low pass filter using OTA is shown in fig. 4.10

4.4.2 Results

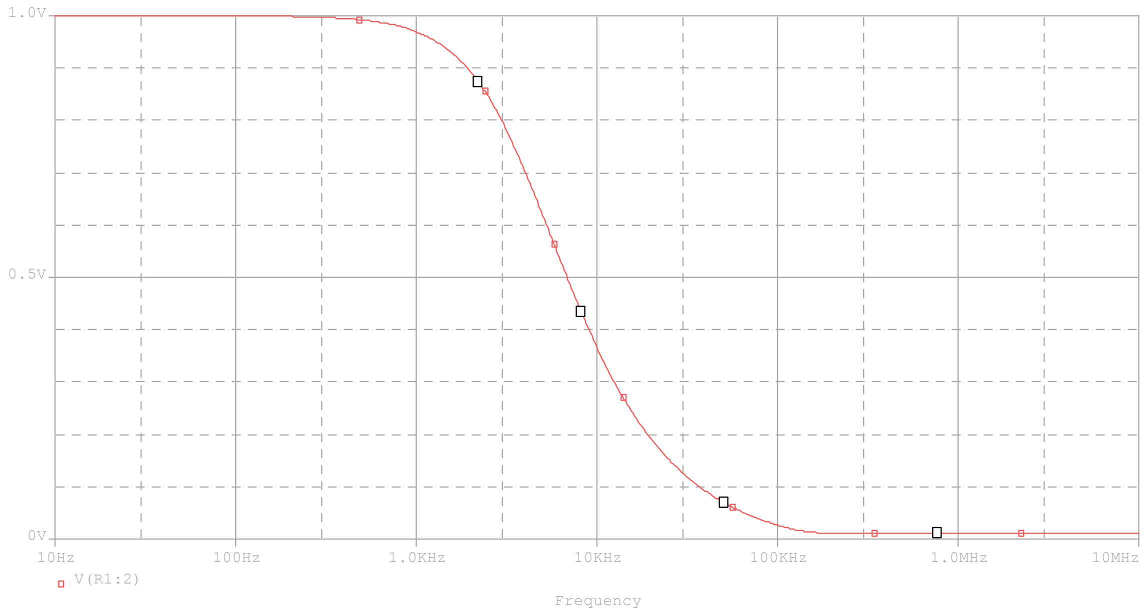


Fig. 4.10 Frequency Response of Low Pass Filter using OTA

4.4.3 First Order Low Pass Filter Using LM13700

The SPICE schematic of low pass filter using LM 13600/ LM13700 is shown in fig. 4.11.

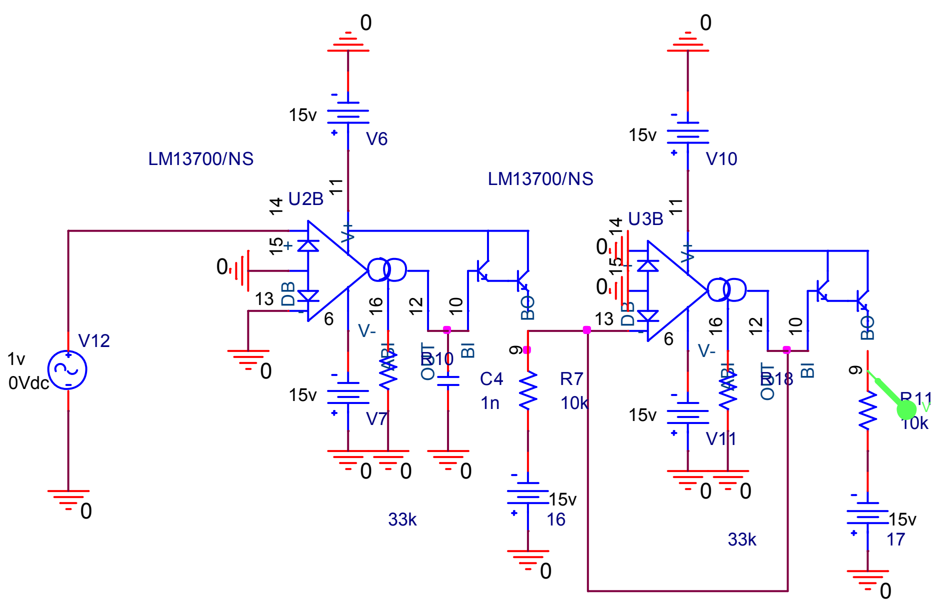


Fig. 4.11 Low Pass Filter using LM13700

The circuit shown in fig.4.11 is a first order low pass filter (LPF). Here the dc voltage V_6, V_7 used for dc biasing for single OTA IC LM13700 and $V_{10}$and V_{11} is used supply the dc biasing foe second OTA IC. The I_{BB} provided by external resistance 33k. For both trans conductance amplifier.

The gain of given circuit is

$$\frac{Vo}{Vin} = \frac{1}{1 + {sc}/{Kg_m}}$$

$$f_c = \frac{g_m}{2\pi C}$$

4.4.4 Results

The simulated frequency response plot of low pass filter using LM 13600/ LM13700 is shown in fig. 4.12

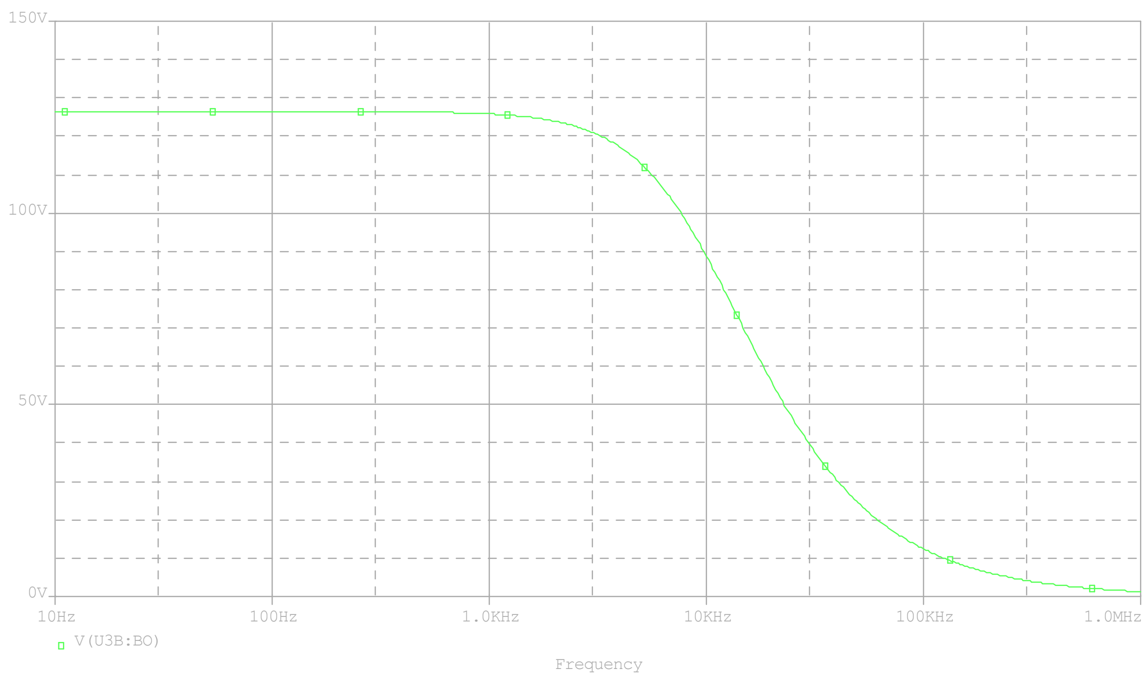


Fig. 4.12 Frequency Response of Low Pass Filter using LM13700

4.5 First Order All Pass Filter Using Single OTA

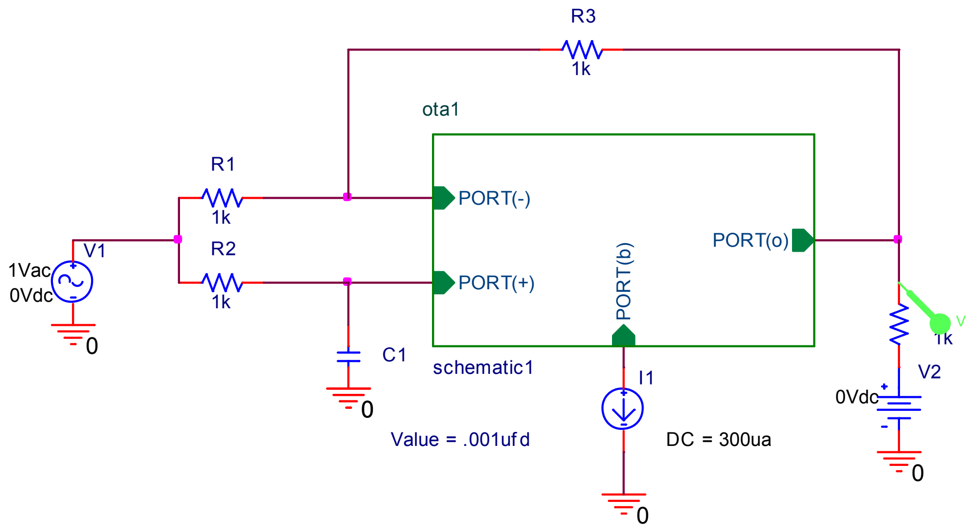


Fig. 4.13 All Pass Filter using OTA

4.5.1 Results

The simulated frequency response plot of all pass filter using OTA is shown in fig. 4.14

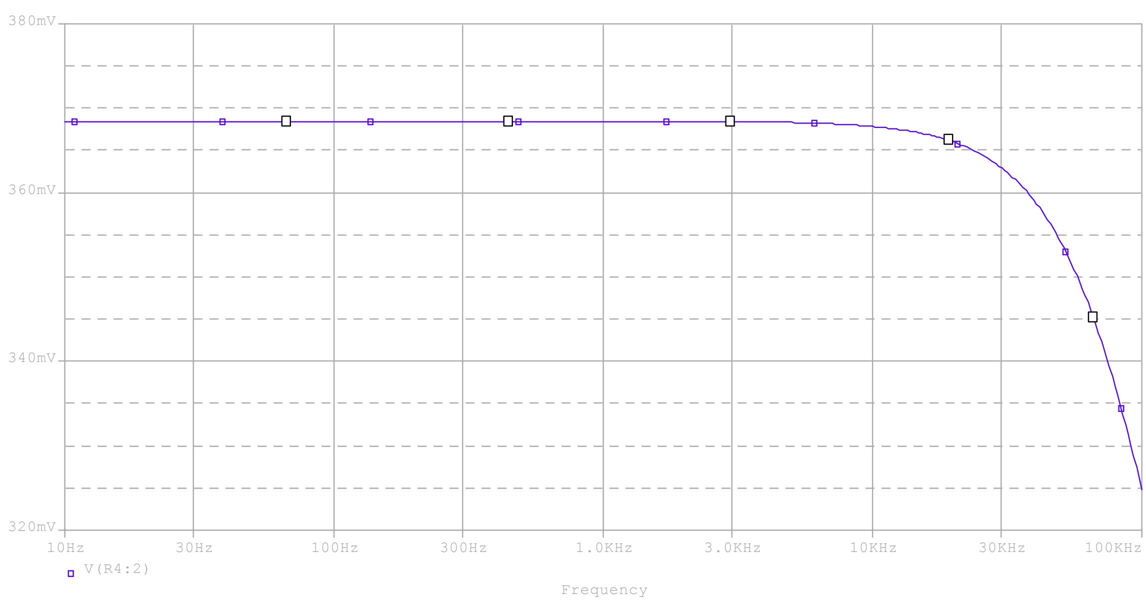


Fig. 4.14 Frequency Response of All Pass Filter using OTA

The simulated Phase response plot of All Pass filter using OTA is shown in fig. 4.15

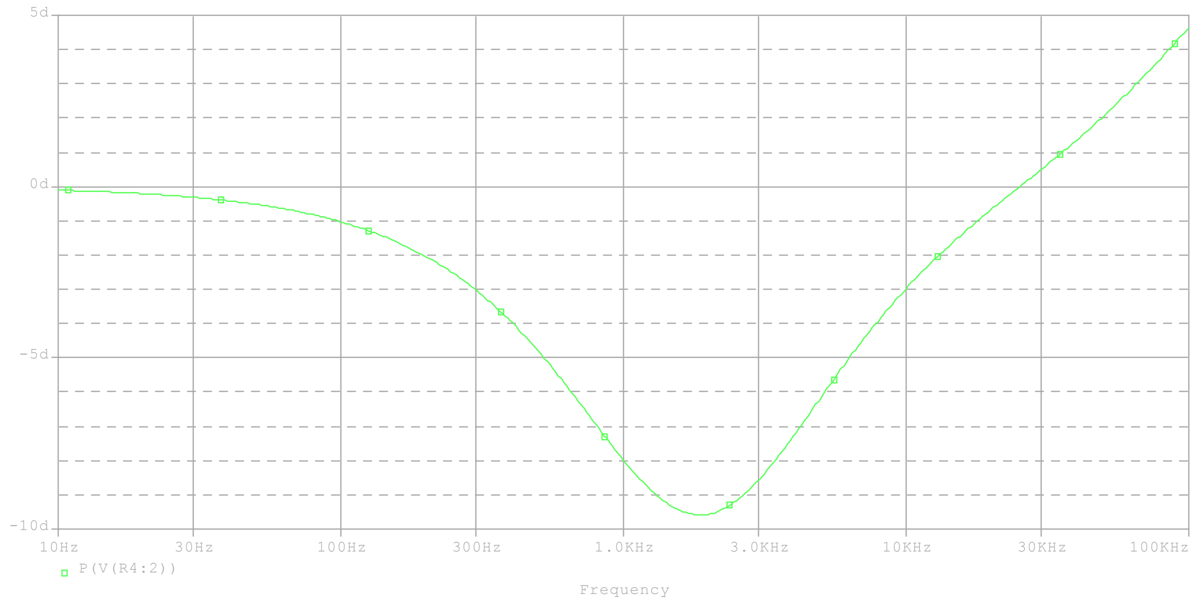


Fig. 4.15 Phase Response of All Pass Filter using OTA

4.5.2 First Order All Pass Filter Using LM13700

The SPICE schematic of low pass filter using LM 13600/ LM13700 is shown in fig. 4.16

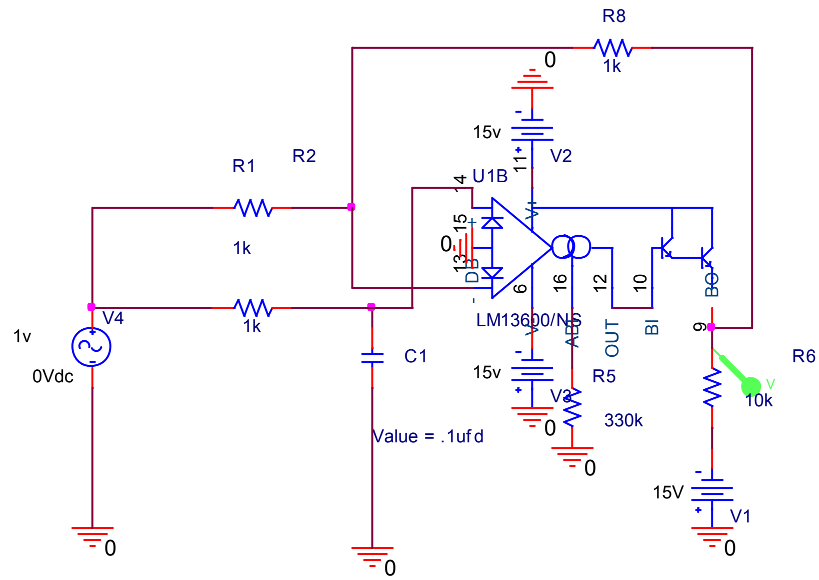


Fig. 4.16 All Pass Filter using LM13700

The circuit shown in fig. 4.16 is a first order All pass filter (APF) . Here the dc voltage V_2 and V_3 used for dc biasing for OTA IC LM13700. I_{BB} provided by external resistance R_5 33k for keep the output in linear region.

4.5.4 Results

The simulated frequency response plot of all pass filter using LM 13600/ LM13700 is shown in fig. 4.17

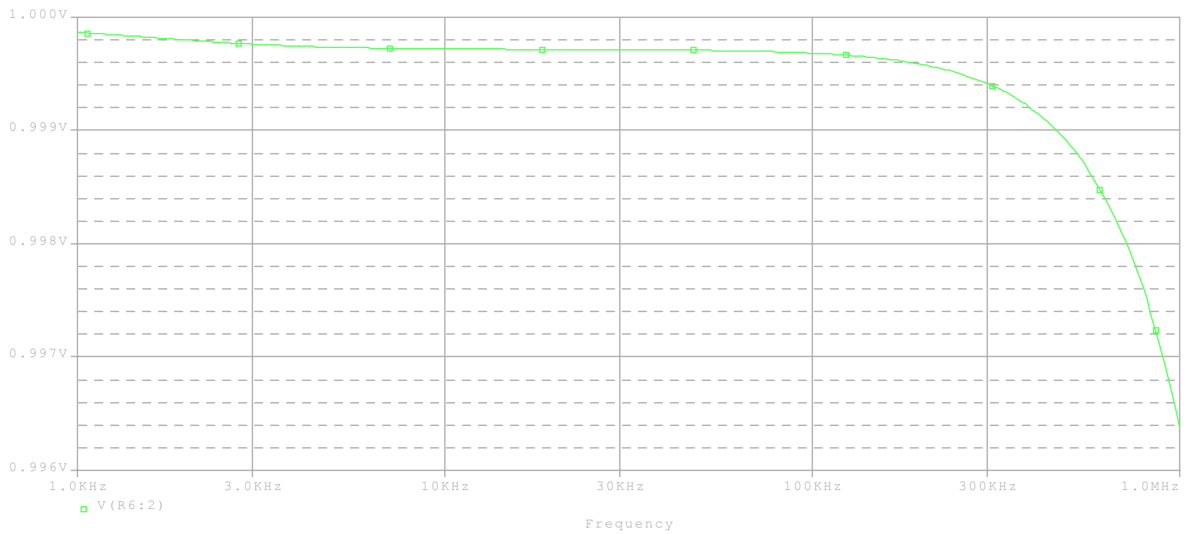


Fig. 4.17 Frequency Response of All Pass Filter using LM13700

The simulated Phase response plot of all pass filter using LM 13600/ LM13700 is shown in fig. 4.18

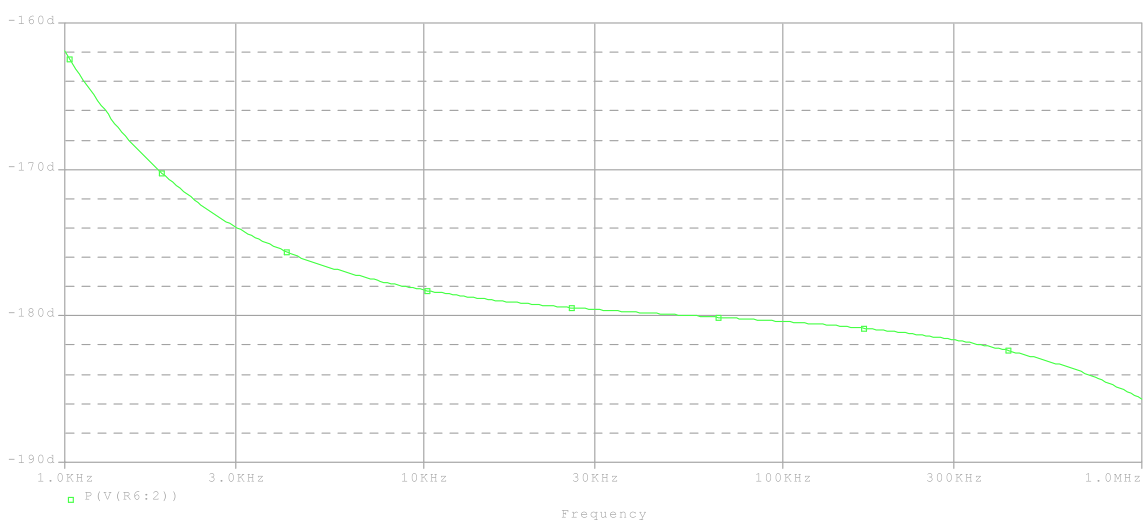


Fig. 4.18 Phase Response of All Pass Filter using LM13700

CHAPTER 5
BIQUARDRATIC FILTERS USING OTA

5.1 Second Order Biquadratic Filter

Introduction

A new electronically tunable three inputs and single output voltage-mode universal biquadratic filter based on simple CMOS operational transconductance amplifiers (OTAs) and grounded capacitors. Additionally, the circuit parameters ω_0 and Q can be set orthogonally by adjusting the transconductance and grounded capacitors. The filter also offers an independent electronic control of parameters ω_0 by adjusting the transconductance through the bias current/voltage of the OTA. The given configuration provides low pass, high pass, bandpass, and notch filter voltage responses at a high impedance input terminal, which enable easy cascadability. For realizing all the filter responses, no critical component matching condition is required, and all the incremental parameter sensitivities are low.

A **biquadratic filter** is very useful block to realize high-order filters. Several voltage-mode biquadratic filters based on OTAs have been implemented. Focusing the number of input and output ports, the voltage-mode universal filters may be divided into four categories: (i) a single-input, single-output (SISO), (ii) a single-input, multiple-output (SIMO) type, (iii) a multiple-input, single-output (MISO) type, and (iv) a multiple-input, single-output (MIMO) type. Generally, the SISO filter can simultaneously realize multi-function outputs by altering the connection way of the circuits, but altering the connection way can only realize a filtering output at a time. But the MISO and MIMO configurations provide a variety of circuit characteristics with different input and output currents, and usually does not require any parameter matching conditions and additional circuits [13].

Here, focus is on the realization of the third category where different filter functions will be realized by simply connecting appropriate input voltages. The filter performance parameters ω_0 and Q can be set orthogonally by adjusting the Transconductance and grounded capacitors and electronic tuned through adjusting the bias current/voltage of the OTA. For the realization of all the filter responses, no critical component matching conditions are required. Operational transconductance amplifiers (OTAs) have exhibit some advantages in the circuit design. An OTA provides an electronic tunability of its transconductance gain, wide tunable range and powerful ability to generate various circuits [11-14]. Moreover, OTA based circuits require no resistors and, therefore, are suitable for integrated circuit implementation. So, OTA is a very good basic block to design high-performance filters.

5.2 High Pass Biquadratic Filter Using Two OTA

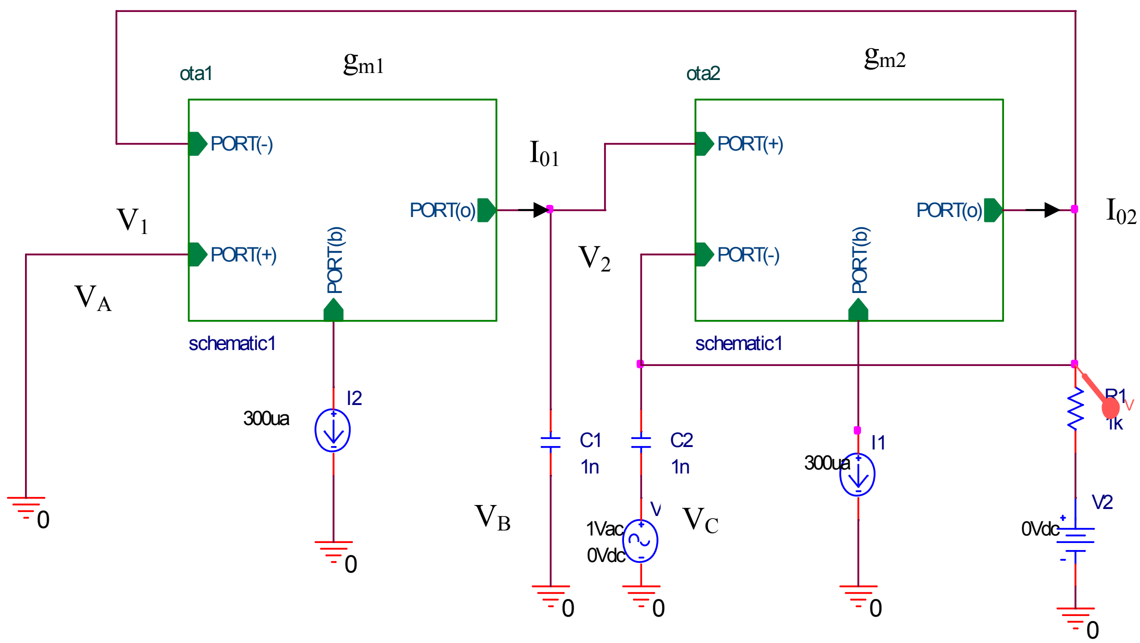


Fig 5.1 Second Order High Pass Filter using two OTA

5.2.1 Transfer function

$$I_{01} = g_{m1}\left(V_1^+ - V_1^-\right) = g_{m1}(V_A - V_{01})$$

$$V_{C1} = I_{01} X_{C1} + V_B = V_2^+ = \frac{I_{01}}{sC_1} + V_B$$

$$I_{02} = g_{m2}\left(V_2^+ - V_2^-\right) = g_{m2}\left(\left(\frac{I_{01}}{sC_1} + V_B\right) - V_{01}\right)$$

$V_{01} = \dfrac{I_{02}}{sC_2} + V_C$. Upon substituting I_{02} and I_{01} from above, one obtains

$V_{01} = \dfrac{g_{m1} g_{m2}(V_A - V_{01})}{s^2 C_1 C_2} + \dfrac{g_{m2}}{sC_2}(V_B - V_{01}) + V_C$. Bringing all terms in V_{01} together and manipulating, one finally obtains the transfer relation:

$$V_{01} = \frac{g_{m1} g_{m2} V_A + sC_1 g_{m2} V_B + s^2 C_1 C_2 V_C}{s^2 C_1 C_2 + sC_1 g_{m2} + g_{m1} g_{m2}}$$

$V_{IN} = V_C$; V_A and V_B grounded ; High pass filter.

5.2.2 Results

The simulated frequency response plot of high pass filter using OTA shown in fig. 5.2

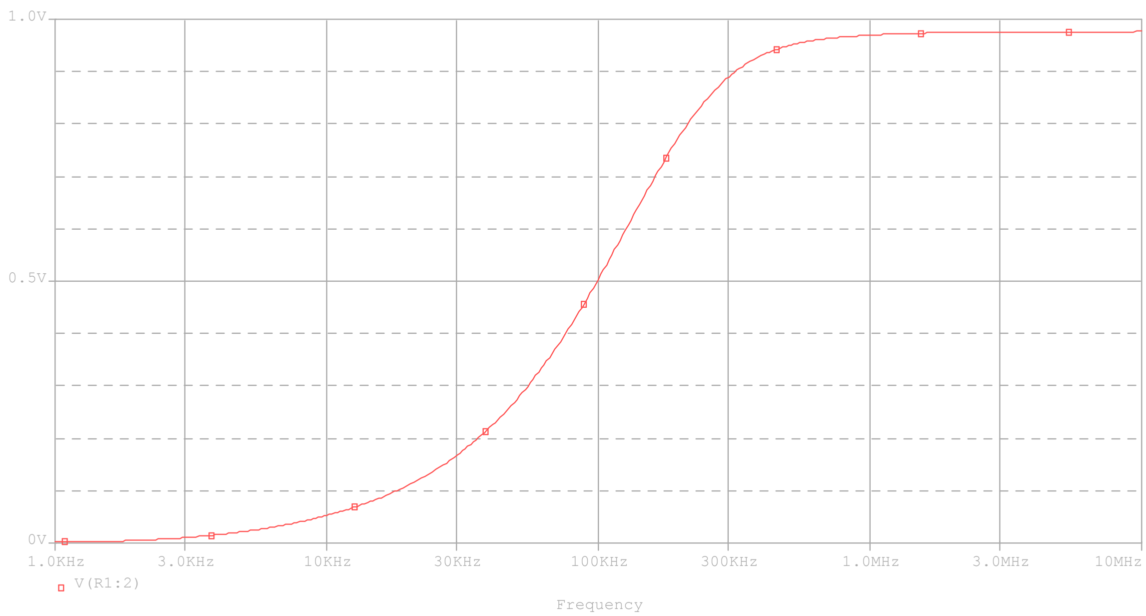


Fig 5.2 High Pass Filter response of second order filter using OTA

5.2.3 High Pass Biquadratic Filter Using LM13700

The SPICE schematic of high pass filter using LM 13600/ LM13700 is shown in fig. 5.3

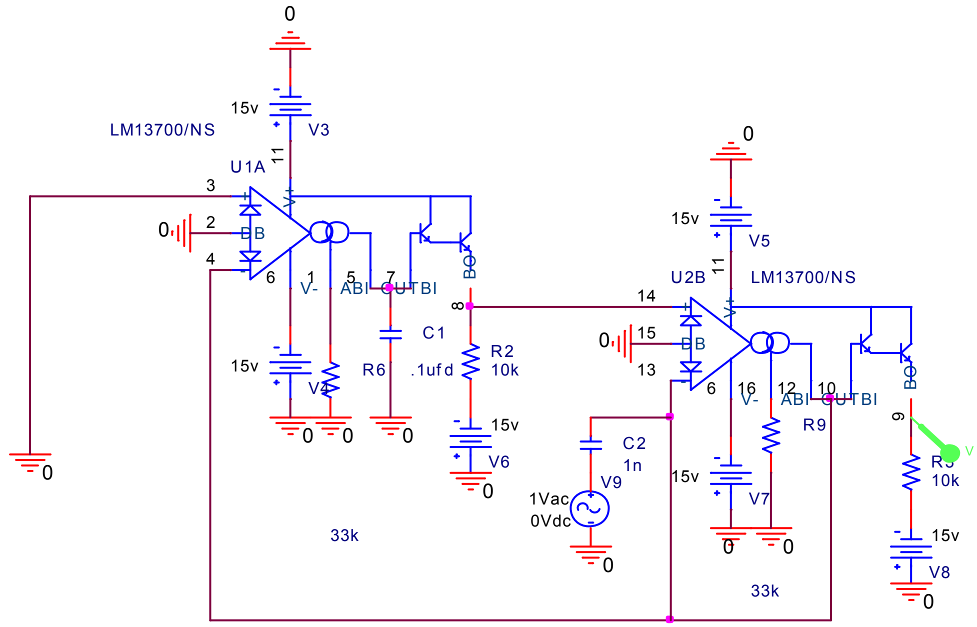


Fig. 5.3 Second Order High Pass Filter Using LM13700

The circuit shown in fig.5.3 is second order High Pass Filter using two transconductance amplifier but commercial chip LM13700 has dual transconductance amplifier. Therefore it requires a single chip to make workability in printed circuit hardware for confirm the response of second order High Pass Filter with SPICE Simulation.

5.2.4 Results

The simulated frequency response plot of high pass filter using LM 13600/ LM13700 is shown in fig. 5.4

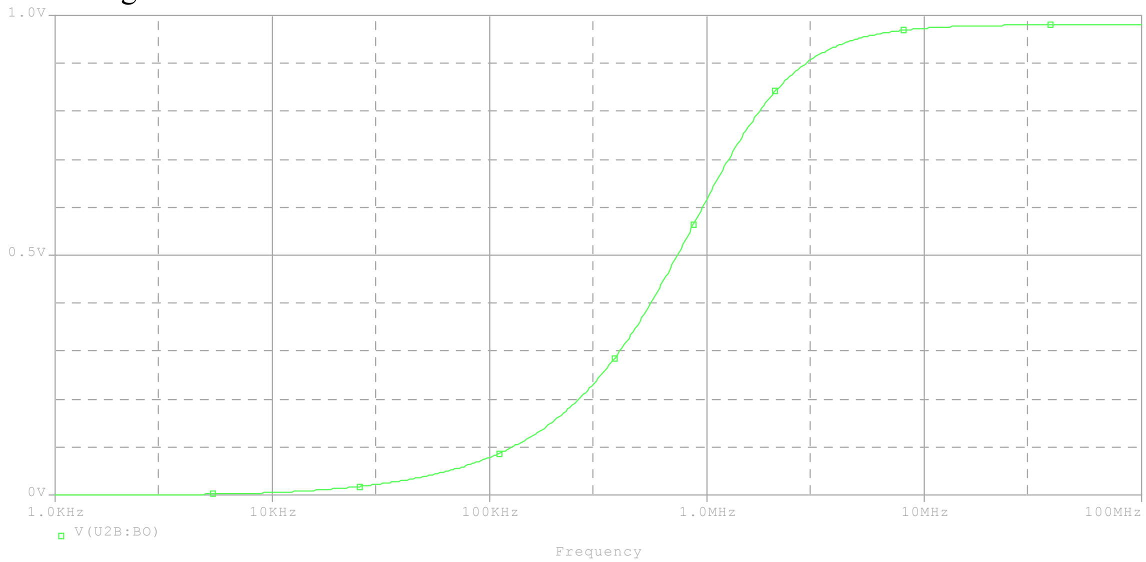


Fig. 5.4 High Pass Filter response of second order filter using LM13700

5.3 Low Pass Biquadratic Filter Using Two OTA

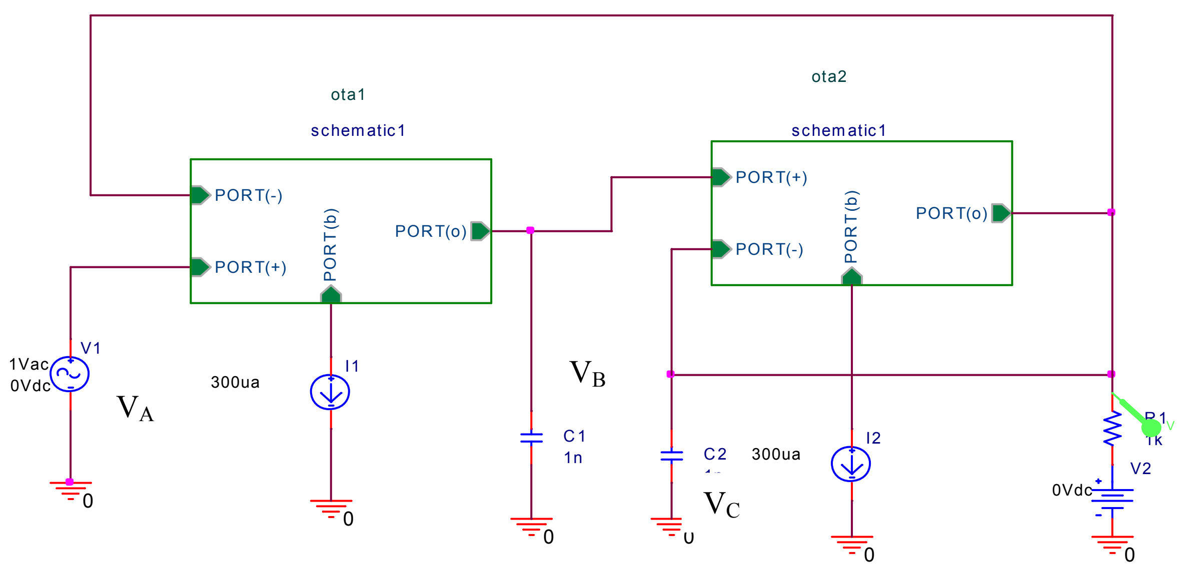


Fig 5.5 Second Order low Pass filter using two OTA

5.3.1Transfer function for second order low pass filter:

$$V_{01} = \frac{g_{m1} g_{m2} V_A + sC_1 g_{m2} V_B + s^2 C_1 C_2 V_C}{s^2 C_1 C_2 + sC_1 g_{m2} + g_{m1} g_{m2}}$$

- Set $V_{in} = V_A$; V_B and V_C are grounded.
- Set $g_{m1} = g_{m2} = g_m$.
- Divide through by C_1C_2 in both numerator and denominator to achieve a standard biquadratic form.

Result of following transfer function

$$\frac{V_{01}}{V_A} = \frac{g_m^2 / C_1 C_2}{s^2 + \frac{s g_m}{C_2} + \frac{g_m^2}{C_1 C_2}}$$

This expression has the form of the standard biquadratic circuit [Sedra-91]:

$$\frac{V_{01}(s)}{V_A(s)} = \frac{\omega_0^2}{s^2 + s\left(\frac{\omega_0}{Q}\right) + \omega_0^2}$$

Therefore, the circuit with these particular control voltage settings is a low pass filter with a critical frequency given by:

$$f_0 = \frac{g_m}{2\pi\sqrt{C_1 C_2}}$$

and a constant $Q = \sqrt{\frac{C_2}{C_1}}$. It is straightforward to show that the following transfer functions can be obtained from the indicated control voltage settings:

5.3.2 Results

The simulated frequency response plot of high pass filter using OTA shown in fig. 5.6

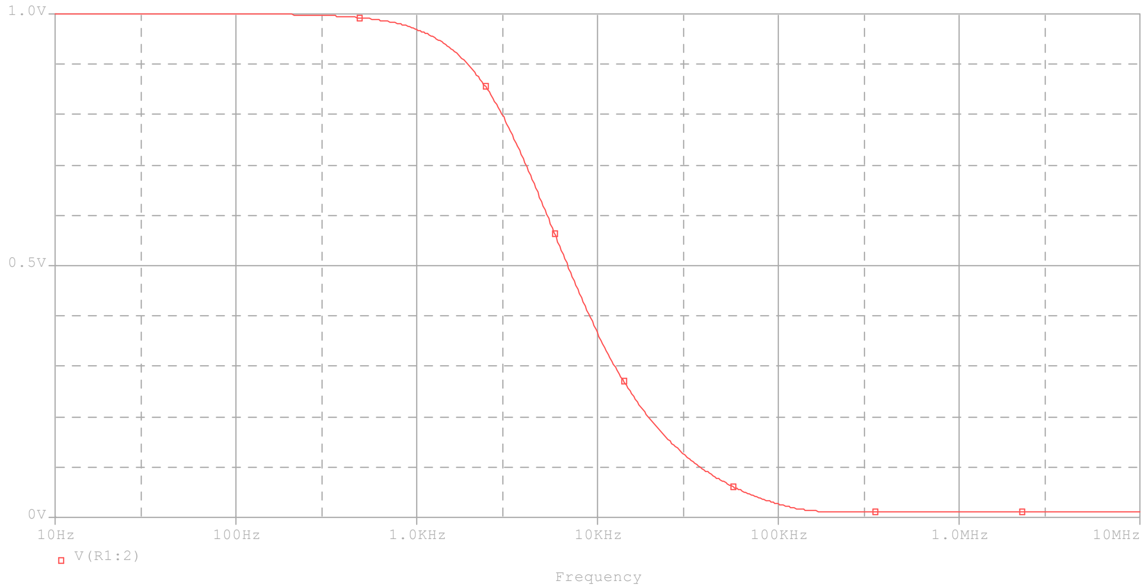


Fig. 5.6 Low Pass Filter response of second order filter using two OTA

The SPICE schematic of low pass filter using LM 13600/ LM13700 is shown in fig. 5.7

5.3.3 Low Pass Biquadratic Filter Using LM13700

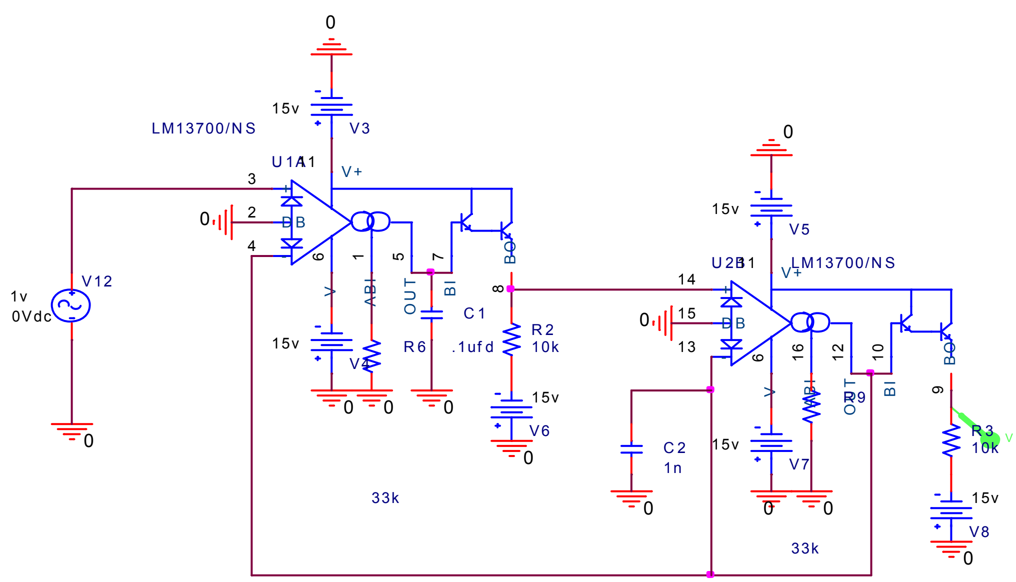


Fig. 5.7 Second Order High Pass Filter Using LM13700

5.3.4 Results

The simulated frequency response plot of low pass filter using LM 13600/ LM13700 is shown in fig. 5.8

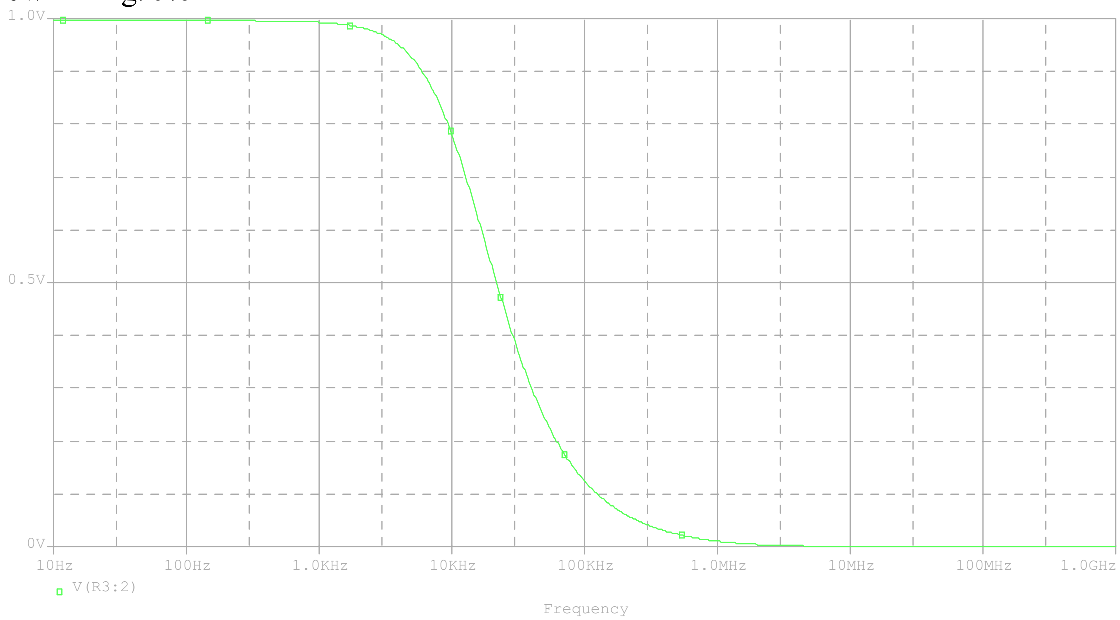


Fig. 5.8 Low Pass Filter response of second order filter using LM13600/LM13700

5.4 Band Pass Biquadratic Filter Using Two OTA

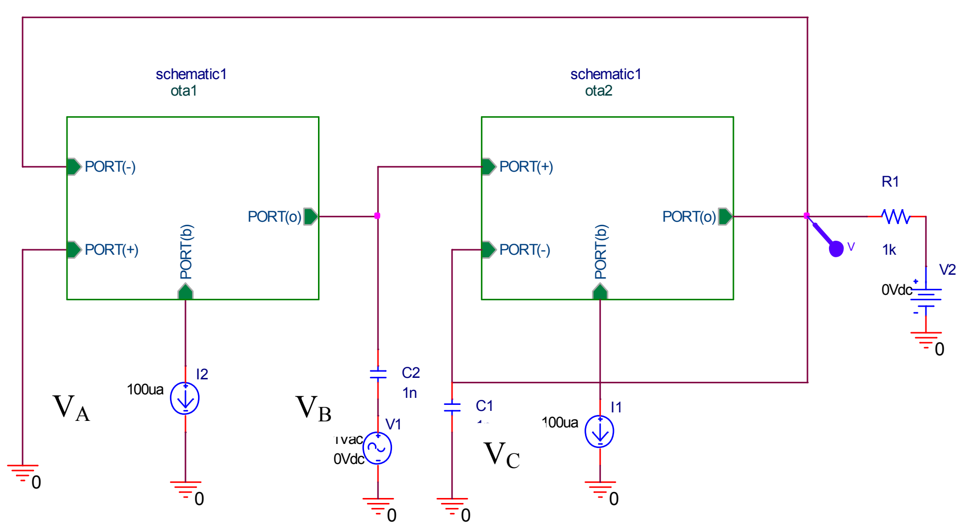


Fig. 5.9 Second Order band Pass filter using two OTA

5.4.1 Transfer function

$V_{in} = V_B$; V_A and V_C grounded ⇒ Band pass filter. Set $g_{m1} = g_{m2} = g_m$

$$V_o = \frac{s\frac{g_m}{C_2}V_{in}}{s^2 + s\frac{g_m}{C_2} + {g_m}^2}$$

5.4.2 Results

The simulated frequency response plot of band pass filter using OTA shown in fig. 5.10

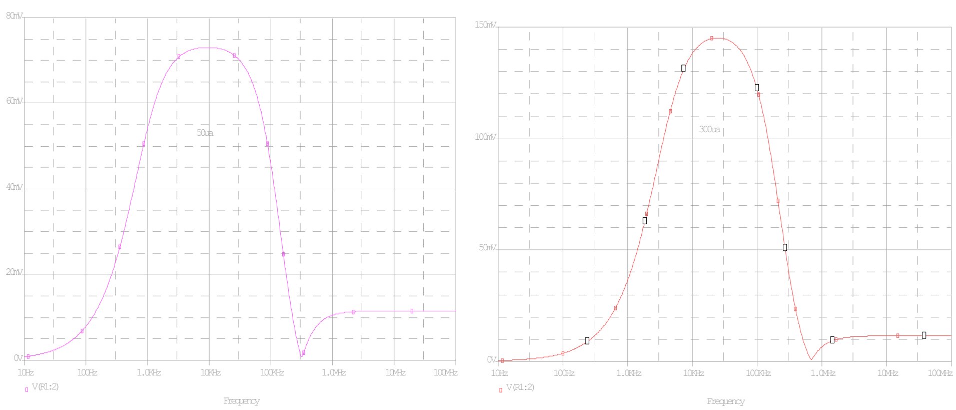


Fig. 5.10 frequency response of second order Band filter using two OTA

The performance of the proposed band pass filter in Fig. 5.10 has been simulated using CMOS block by SPICE simulation and verify the given theoretical prediction. The power supplies are selected as VDD = +5V and VSS = -5V. C1 = C2 = 1nf and IB1 = IB2 = 100uA and IB1 = IB2 = 300uA with different result which show how quality factor of band pass filter vary by changing the transcoductance (gm).

Conclusion: From the Fig. 5.10 it is clear that critical or centre frequency of the band pass filter changes from approx. 10KHz to 50KHz when at bias current changes from 50uA, and 300uA. The centre frequency changes on changing the value of the dc bias current.

Generalized Transfer function

$$V_{01} = \frac{g_{m1}g_{m2}V_A + sC_1g_{m2}V_B + s^2C_1C_2V_C}{s^2C_1C_2 + sC_1g_{m2} + g_{m1}g_{m2}}$$

$V_{in} = V_B$; V_A and V_C grounded ⇒ Band pass filter. Set $g_{m1} = g_{m2} = g_m$.

Divide through by C_1C_2 in both numerator and denominator to achieve a standard biquadratic form

5.4.3 Band Pass Biquadratic Filter Using LM13700

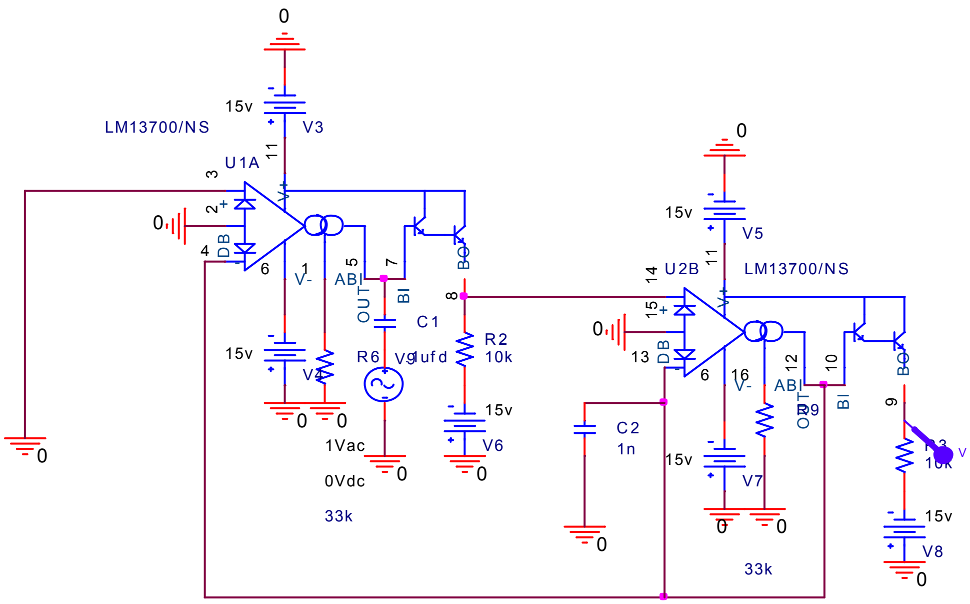


Fig. 5.11 Second Order Band Pass Filter Using LM13700

5.4.4 Results

The simulated frequency response plot of band pass filter using LM 13600/ LM13700 is shown in fig. 5.12

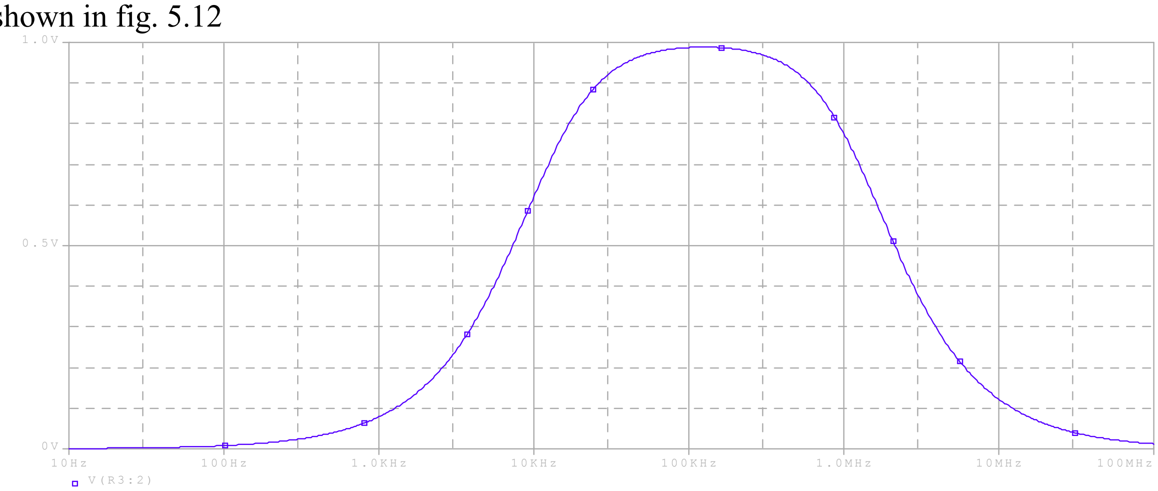


Fig. 5.12 band pass filter response of second order filter using LM13600/LM13700

5.5 Notch Biquadratic Filter Using Two OTA

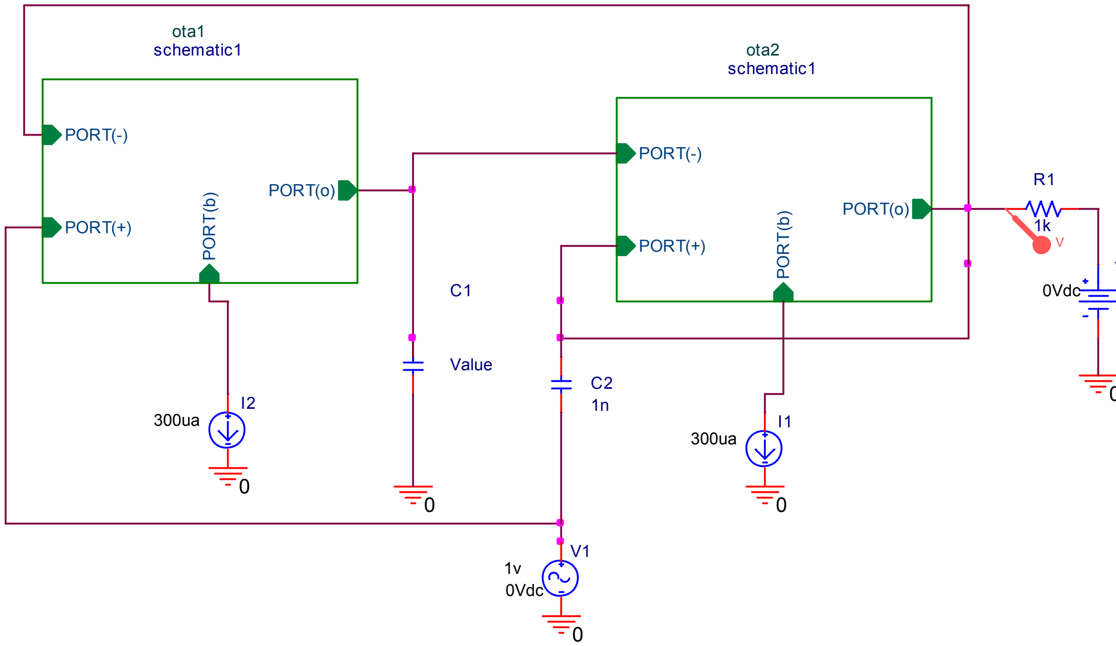


Fig. 5.13 Second Order Notch filter using two OTA

5.5.1 Results

The simulated frequency response plot of band pass filter using OTA shown in fig. 5.14

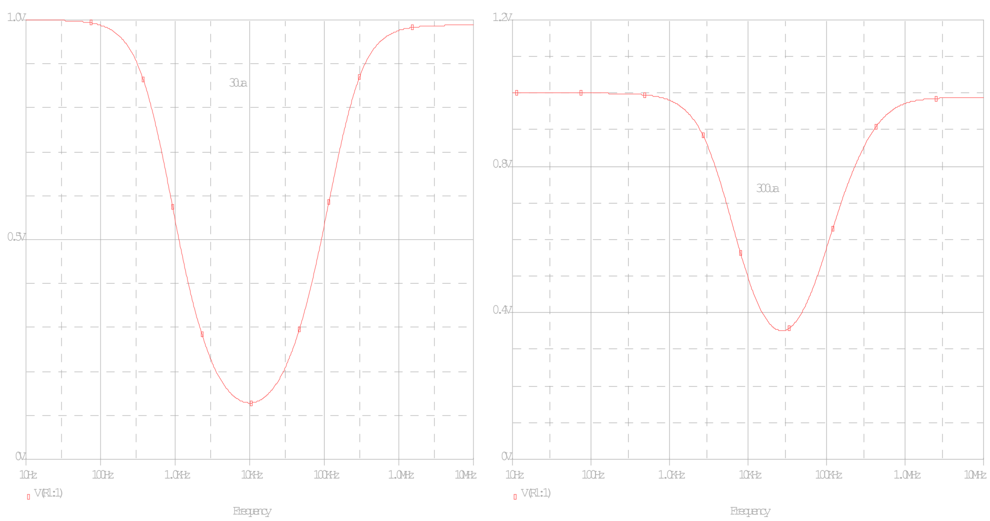


Fig. 5.14 Frequency response of Second Order Notch filter using two OTA

5.5.2 Notch Biquadratic Filter Using LM13700

The SPICE schematic of Notch filter using LM 13600/ LM13700 is shown in fig. 5.15

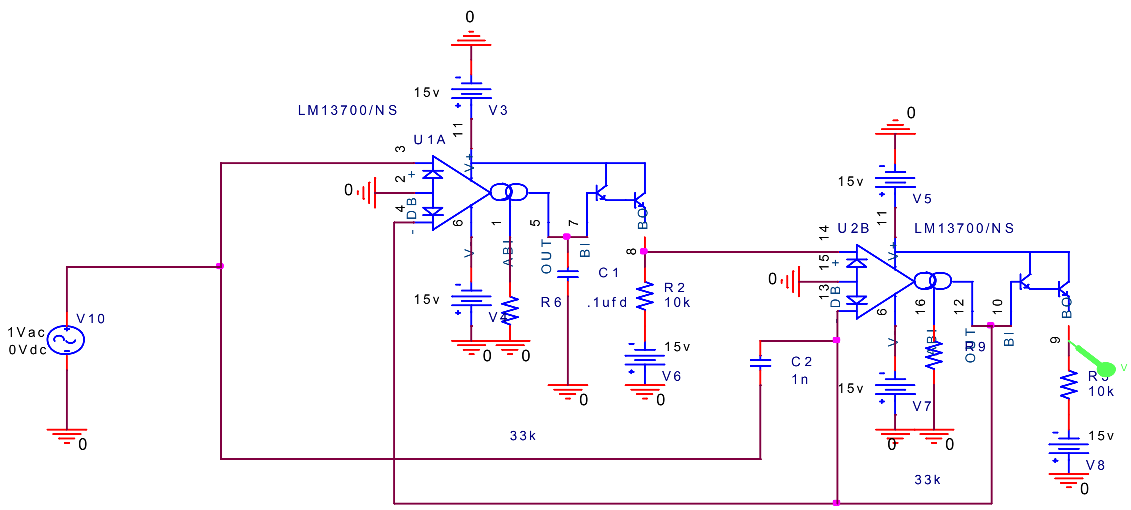


Fig. 5.15 Second Order Notch Filter Using LM13700

The simulated frequency response plot Notch filter using LM 13600/ LM13700 is shown in fig. 5.16

5.5.3 Results

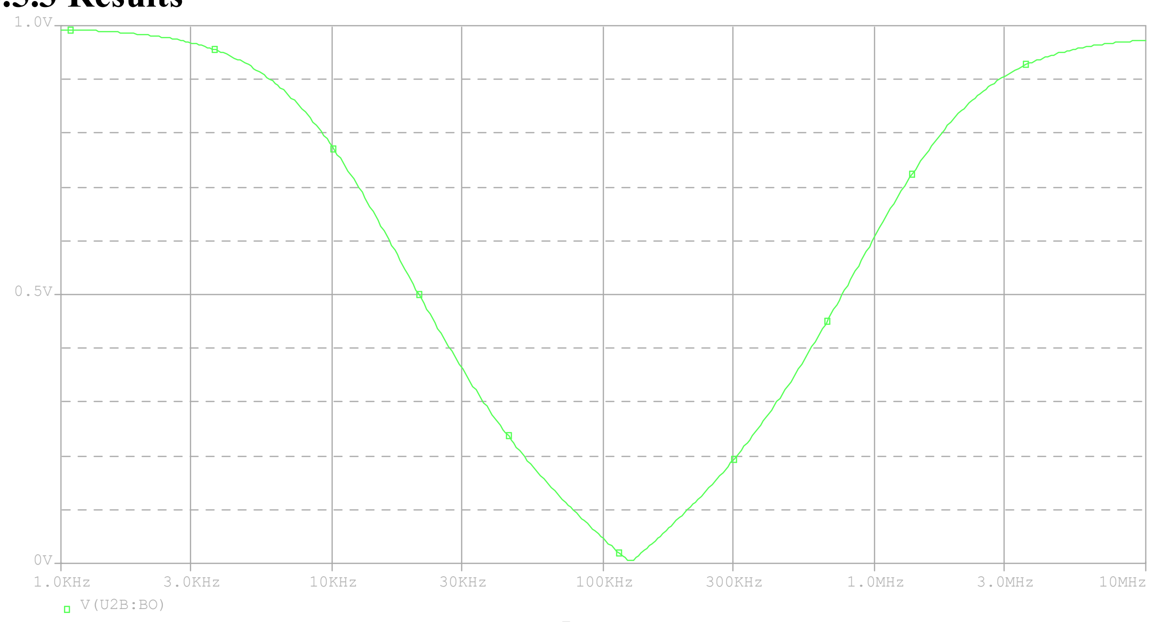


Fig. 5.16 Frequency response of second order filter using LM13600/LM13700

5.6 BIQUARDRATIC FILTERS USING THREE OTA

The Biquadratic filter using three Operational transconductance amplifiers (OTAs) which have some extra features and characteristics over the second order filter using two OTA [11] studied here. For realizing all the filter responses, no critical component matching condition is required. PSPICE simulation results are performed to confirm the theoretical analysis.

5.6.1 Introduction

An OTA provides an electronic tunability of its transconductance gain, wide tunable range and powerful ability to generate various circuits. Moreover, OTA based circuits require no resistors and, therefore, are suitable for integrated circuit implementation. So, OTA is a very good basic block to design high-performance filters. A new electronically tunable three inputs and single output voltage-mode universal biquadratic filter based on simple CMOS operational transconductance amplifiers (OTAs) and grounded capacitors.

By using the three OTA to make a second order filter the circuit parameters ω_0 and Q can be set orthogonally by adjusting the transconductance and grounded capacitors. The filter also offers an independent electronic control of parameters Q-factor by adjusting the transconductance through the bias current/voltage of the OTA which is the only difference in second order filter with two OTA that we can change only critical frequency. But in case of second order filter using three OTA we can also change the quality factor by changing the value of bias current of OTA3. We realize all the result using CMOS that on changing the value of bias current, critical or centre frequency and quality factor both will be change independently and dependently which is the attractive feature of the circuit using three OTA. So, in this circuit we can obtain both type of the result [11].

5.6.2: Generalized Circuit Using Three OTA:

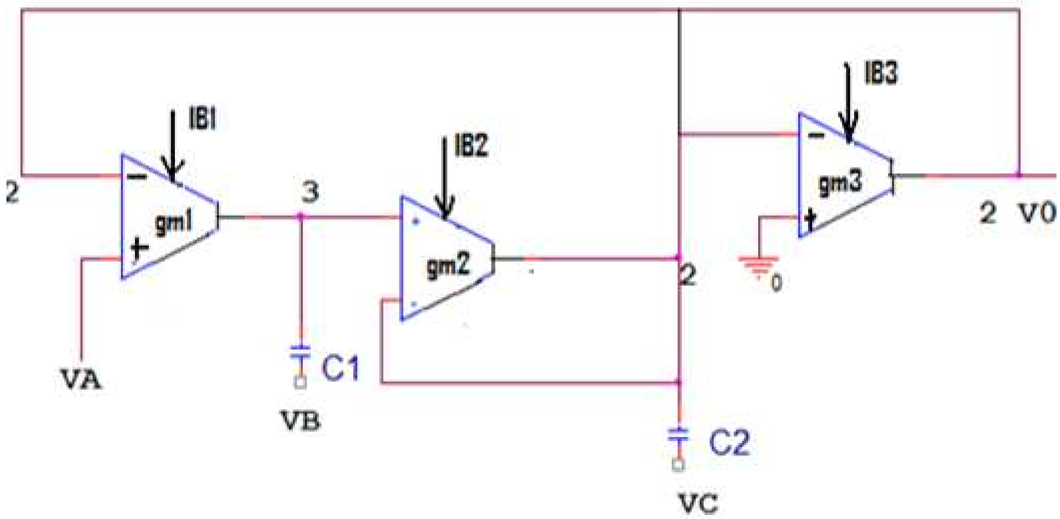


Fig: 5.17: Second Order Filter using Three CMOS-OTA

Given figure show the circuit of second order filter using three OTA, three input, two matched capacitor and a single output.

From the above transfer function we see that output voltage depends on three inputs which will decide the type of the filter [13]. The above filter is a circuit with independent pole and zero adjustment that we can adjust both the factor independently. That is, constant-Q pole adjustment filter, that is, on varying the transconductance of the OTA1 and OTA2 then ω_0 will change but the quality factor will remain same i.e. bandwidth of the filter will be change in all condition. Similarly, constant- ω_0 pole adjustment filter, that is, on only varying the transconductance of the OTA3 then Q-factor will change but the critical frequency will remain same i.e. bandwidth of the filter will be same in all condition. As we know that transconductance of the operational transconductance amplifier depend on the bias current. so the quality factor and centre frequency will change on changing the value of the bias current. This relation can be easily understood with the equation given below:

$$w_0 = \frac{\sqrt{gm1}\sqrt{gm2}}{\sqrt{C1C2}} \quad \& \quad Q = \frac{1}{g_{m3}}\frac{\sqrt{C2gm2}}{\sqrt{C1gm1}} \qquad (5.1)$$

Where **gm1, gm2, C1** and **C2** are the transconductance of the OTA1 and OTA2, similarly gm3 is transconductance of the OTA3 and capacitances respectively. Now if the transconductance of both the OTA1 and OTA2 are same i.e. **gm1=gm2** that if the bias current is same the above equations become:

$$w_0 = \frac{gm}{\sqrt{C1C2}} \quad \& \quad Q = \frac{1}{g_{m3}}\frac{\sqrt{C2}}{\sqrt{C1}} \tag{5.2}$$

From the Equation (5.2) we see that on changing the value of bias current, critical or centre frequency and quality factor both will be change independently and dependently which is the attractive feature of the circuit using three OTA. As it the second order filter using three input so it will give the standard types of the biquadratic filtering function without component matching condition requirements.

(i) The HP response can be obtained when: Vin = V_C, V_A and V_B are grounded

(ii) The BP response can be obtained when: Vin = V_B and V_A and V_C are grounded.

(iii) The LP response can be obtained when: Vin = $V_{A,}$ V_B and V_C are grounded.

(iv) The notch filter response obtained when: Vin = $V_A = V_C$ and V_B is grounded.

A general relationship between the output voltage and three control voltages namely, V_A, V_C, and V_B can be obtained from Fig…. we may write

$$Vo = V_1^- = V_3^- \quad and \quad V_A = V_1^+$$

Where V_1,V_2 and V_3 refer to the input pins of the respective OTA's. Therefore, the current out of the OTA-1 is

$$I_{o1} = g_{m1}(V_1^+ - V_1^-) = g_{m1}(V_A - V_o)$$

For OTA-2

$$V_2^+ = I_{o1}X_{C1} = g_{m1}(\frac{V_A - V_o}{sC_1})$$

and $V_2^- = 0$. Therefore, the current out of the OTA-2 is

$$I_{o2} = g_{m2}(V_2^+ - V_2^-) = \frac{g_{m1}g_{m2}(V_A - V_o)}{sC_1}$$

For OTA-3

$$V_3^+ = V_B \quad and \quad V_3^- = V_o = I_{o2}X_{c2} + V_C$$
$$I_{o3} = g_{m3}(V_3^+ - V_3^-) = g_{m3}(V_B - V_o)$$

At the output of both OTA-2 and OTA-3, Kirchhoff's current law gives us

$$I_{o2} + I_{o3} = \frac{V_o - V_C}{X_{c2}} = (V_o - V_C).\, sC_2$$

Collecting all terms in V_o together

$$V_o \left|\frac{g_{m1}g_{m2} + sC_1g_{m3} + s^2C_1C_2}{sC_1}\right| = \frac{g_{m1}g_{m2}V_A}{sC_1} + g_{m3}V_B + sC_2V_C$$

Solving for V_o gives

5.6.2.1 Transfer function

$$V_o = \frac{s^2C_1C_2V_C + sC_1g_{m3}V_B + g_{m1}g_{m2}V_A}{s^2C_1C_2 + sC_1g_{m3} + g_{m1}g_{m2}}$$

5.6.3 High Pass Filter Using Three OTA

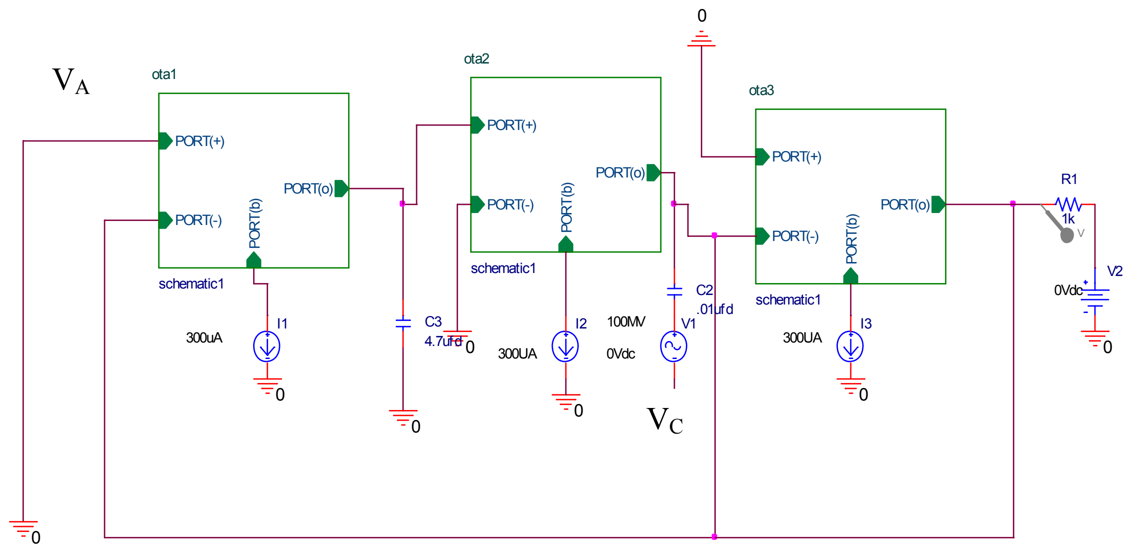


Fig. 5.18 Second Order High pass filter using three OTA

The simulated frequency response plot of high pass filter using OTA shown in fig. 5.19

5.6.3.1 Transfer function

A high pass filter can be obtained by setting V_A=V_B= ground and applying input signal to V_C. The expression for high pass filter is obtained as

$$\frac{V_{OHP}}{V_C} = \frac{s^2}{s^2 + s\left(\frac{g_m}{C_2}\right) + \left(\frac{g_m^2}{C_1 C_2}\right)} \quad [Assuming\ g_{m1} = g_{m2} = g_{m3} = g_m]$$

5.6.3.2 Results

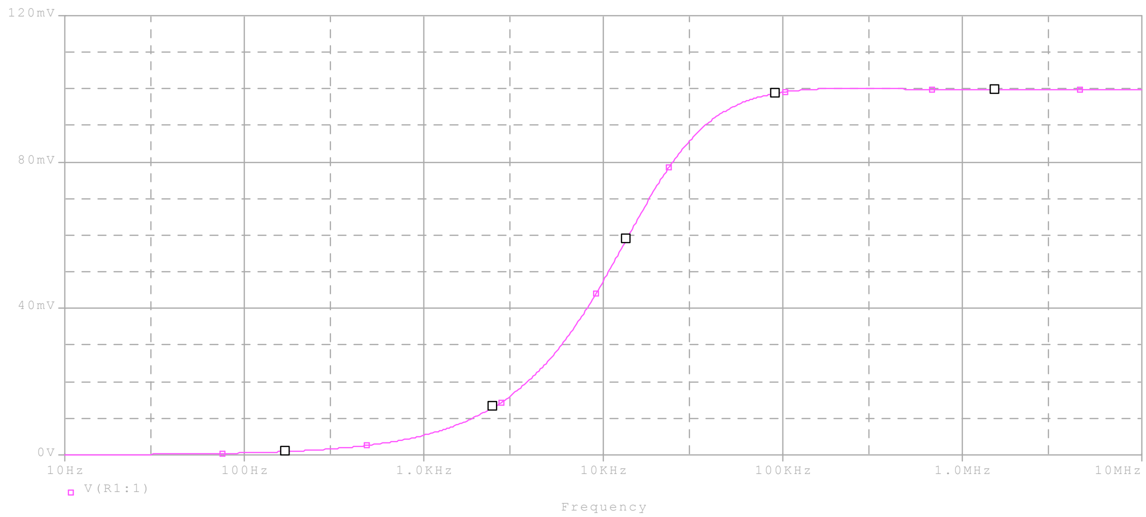


Fig. 5.19 Frequency response of Second Order high pass filter using three OTA

5.6.3.3 High Pass Filter Using LM13700

The SPICE schematic of high pass filter using LM 13600/ LM13700 is shown in fig. 5.20

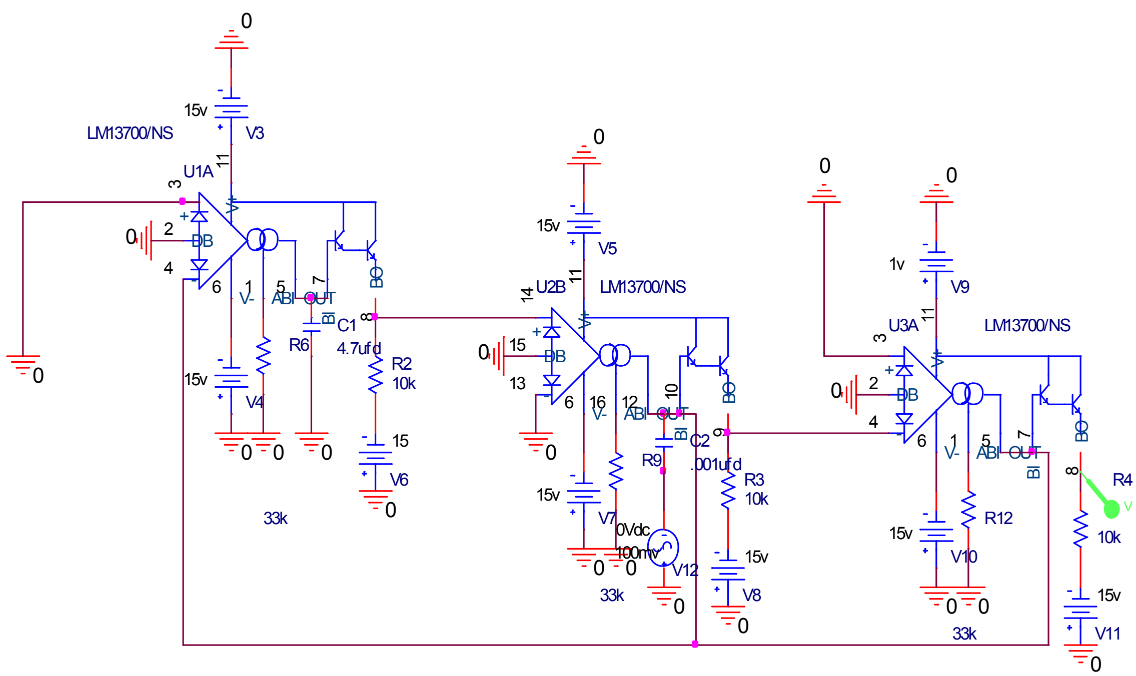


Fig. 5.20 Second Order High Pass Filter Using LM13700

5.6.3.4 Results

The simulated frequency response plot Notch filter using LM 13600/ LM13700 is shown in fig. 5.21

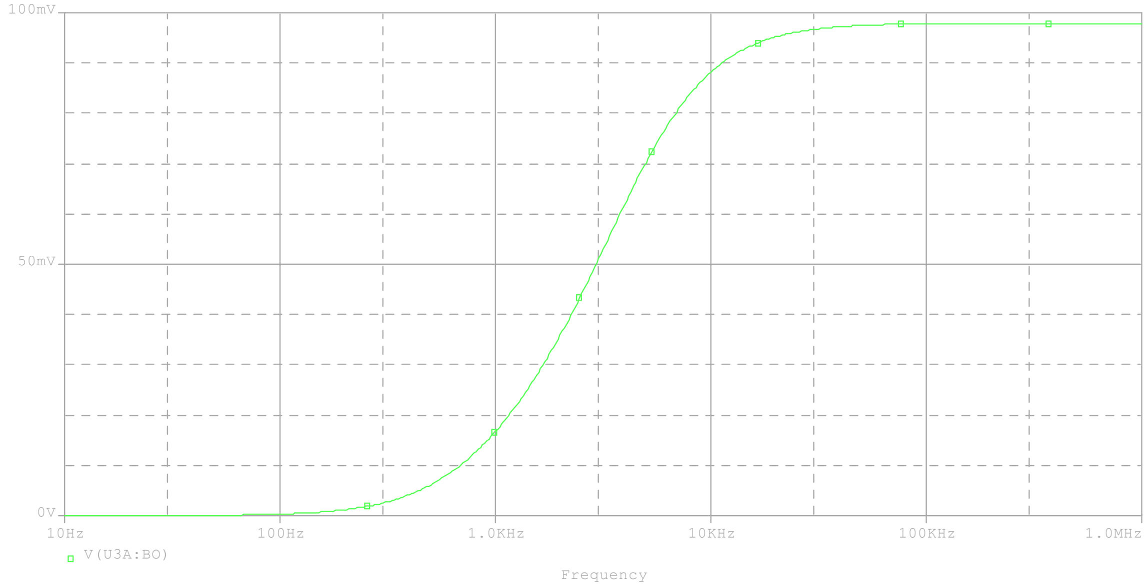


Fig. 5.21 Frequency response of Second Order high pass filter Using LM13700

5.6.4 Low Pass Filter Using Three OTA

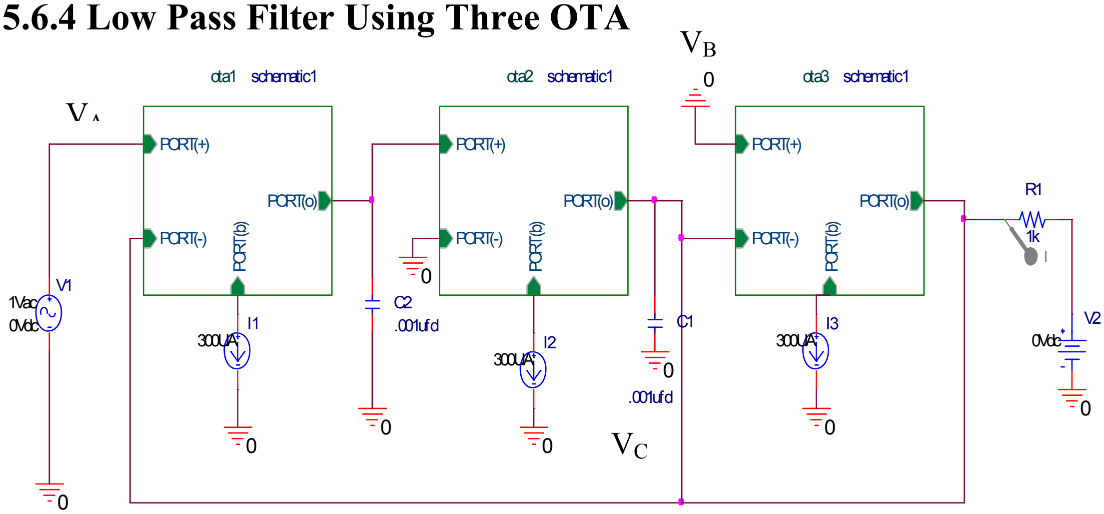


Fig. 5.22 Second Order low pass filter using three OTA

5.6.4.1 Transfer function

$$\frac{V_{oLP}}{V_A} = \frac{\frac{g_m^2}{C_1 C_2}}{s^2 + \left(\frac{s g_m}{C_2}\right) + \frac{g_m^2}{C_1 C_2}}$$

$$\frac{V_{oLP}}{V_A} = \frac{w_h^2}{s^2 + s\left(\frac{w_h}{Q}\right) + w_h^2}$$

Where $w_h = \frac{g_m}{\sqrt{C_1 C_2}}$

$$Q = \sqrt{\frac{C_2}{C_1}}$$

5.6.4.2 Results

The simulated frequency response plot of high pass filter using OTA shown in fig. 5.23

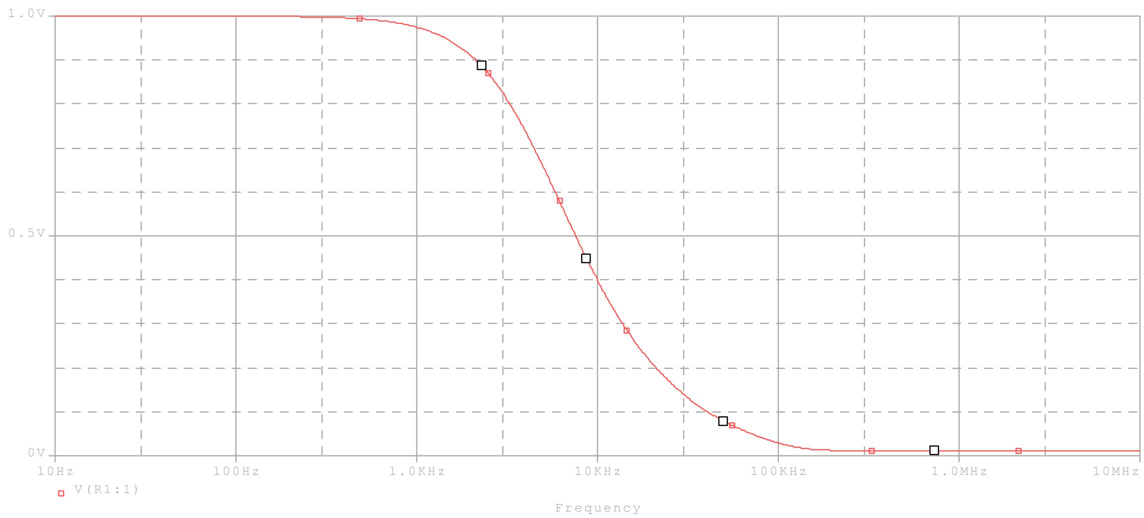


Fig. 5.23 Frequency response of Second Order low pass filter using three OTA

A second order low pass filter can be obtained by applying input signal to V_A and grounding V_C and V_B. Assuming $g_{m1} = g_{m2} = g_{m3} = g_m$ and dividing both numerator and denominator by C_1C_2, we obtain the standard biquadratic form of a low pass filter,

5.6.4.3 Low Pass Filter Using LM13700

The SPICE schematic of low pass filter using LM 13600/ LM13700 is shown in fig. 5.24

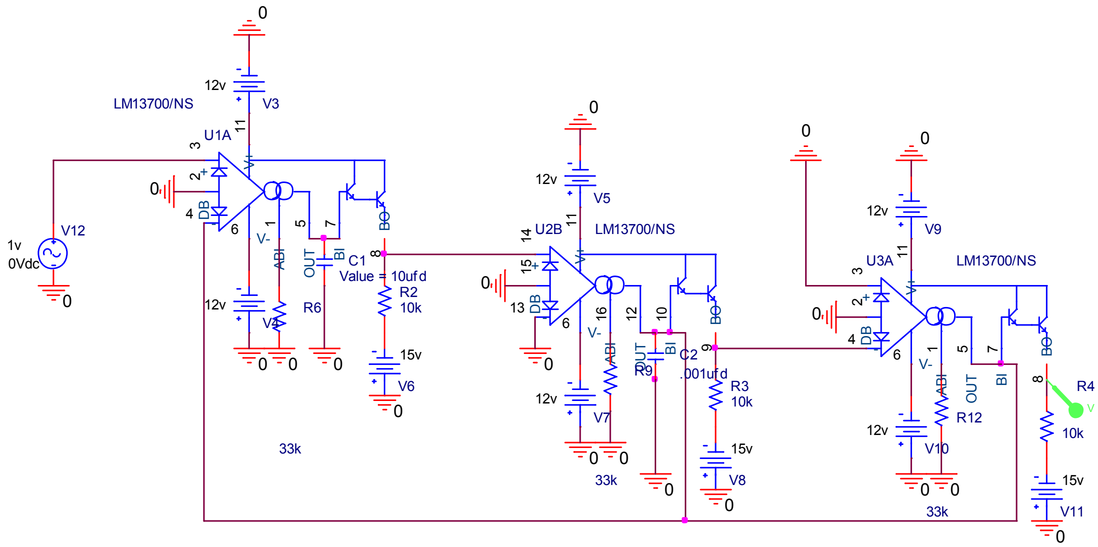


Fig. 5.24 Second Order low pass filter Using LM13700

5.6.4.4 Results

The simulated frequency response plot low pass filter using LM 13600/ LM13700 is shown in fig. 5.25

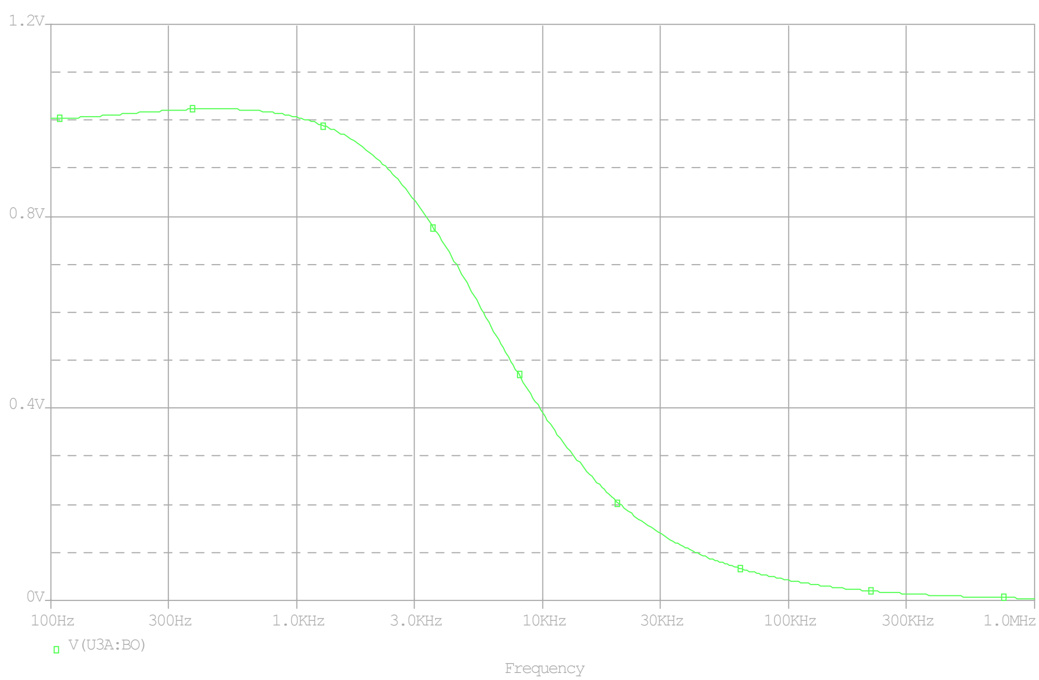


Fig. 5.25 Second Order low pass filter Using LM13700

5.6.5 Band Pass Filter Using Three OTA

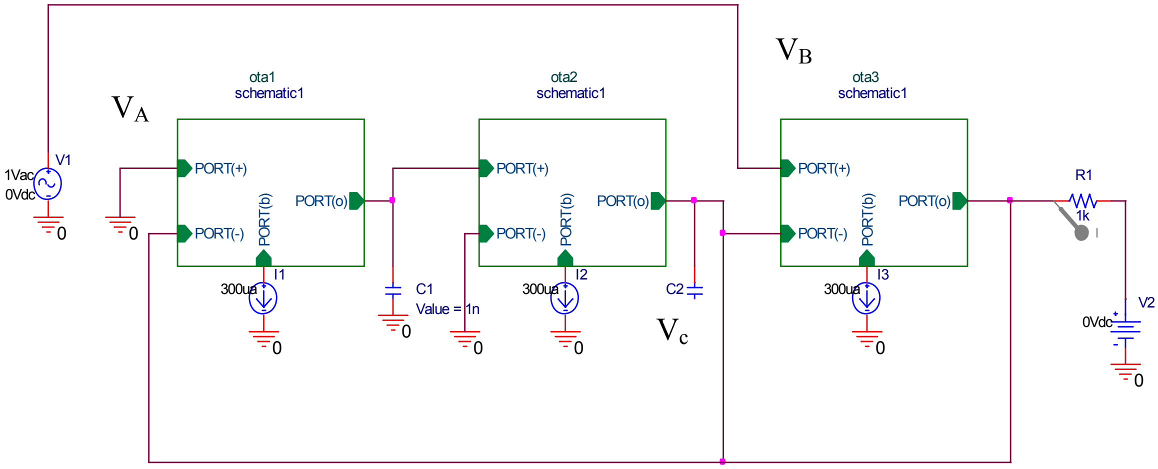


Fig. 5.26 Second Order band pass filter using three OTA

5.6.5.1 Transfer function

This transfer function is of the form

$$\frac{V_o}{V_m} = \frac{A_1 s}{s^2 + s\left(\frac{w_o}{Q}\right) + w_o^2}$$

which is the standard second order band pass filter.
Where, the center frequency of the filter is

$$w_o = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}}$$

And 3-dB bandwidth is found directly from the transfer function to be

$$BW = \left(\frac{w_o}{Q}\right) = \left(\frac{g_{m3}}{C_2}\right) \qquad (radians/\text{sec})$$

5.6.5.2 Results

The simulated frequency response plot of band pass filter using OTA shown in fig. 5.27

OTA 3 I_{BB} = 50uA **OTA 3 I_{BB} = 500uA**

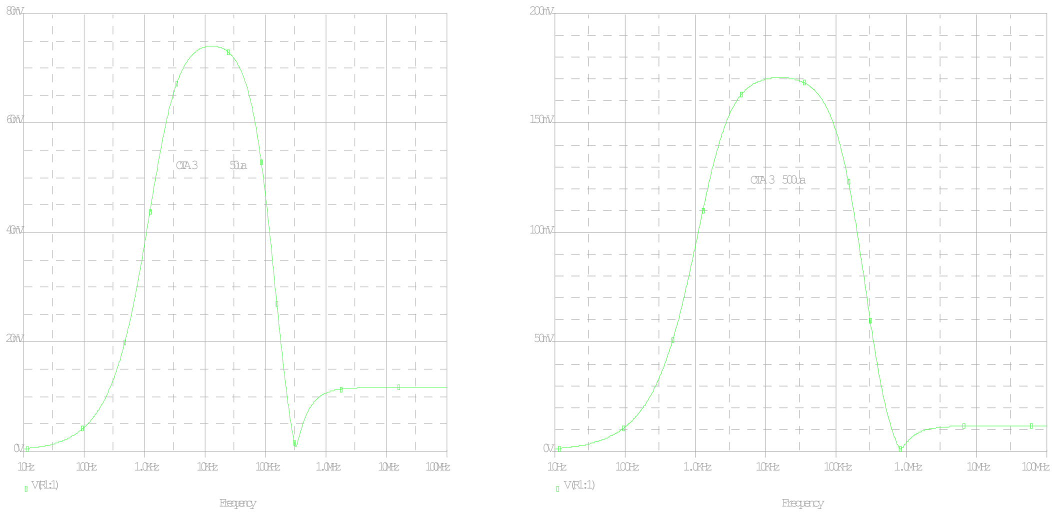


Fig. 5.27 Frequency response of Second Order band pass filter Using OTA

One can synthesize a band pass filter from the transfer function by setting V_A and V_C to ground and applying input voltage to V_B. The transfer function then becomes.

$$\frac{V_{oBP}}{V_B} = \frac{sC_1 g_{m3}}{s^2 C_1 C_2 + sC_1 g_{m3} + g_{m1} g_{m2}}$$

Dividing both numerator and denominator by C_1C_2, gives

$$\frac{V_{oBP}}{V_B} = \frac{s\left(\frac{g_{m3}}{C_2}\right)}{s^2 + \left(\frac{g_{m3}}{C_2}\right) + \frac{g_{m1} g_{m2}}{C_1 C_2}}$$

5.6.5.3 Band Pass Filter Using LM13700

The SPICE schematic of band pass filter using LM 13600/ LM13700 is shown in fig. 5.28

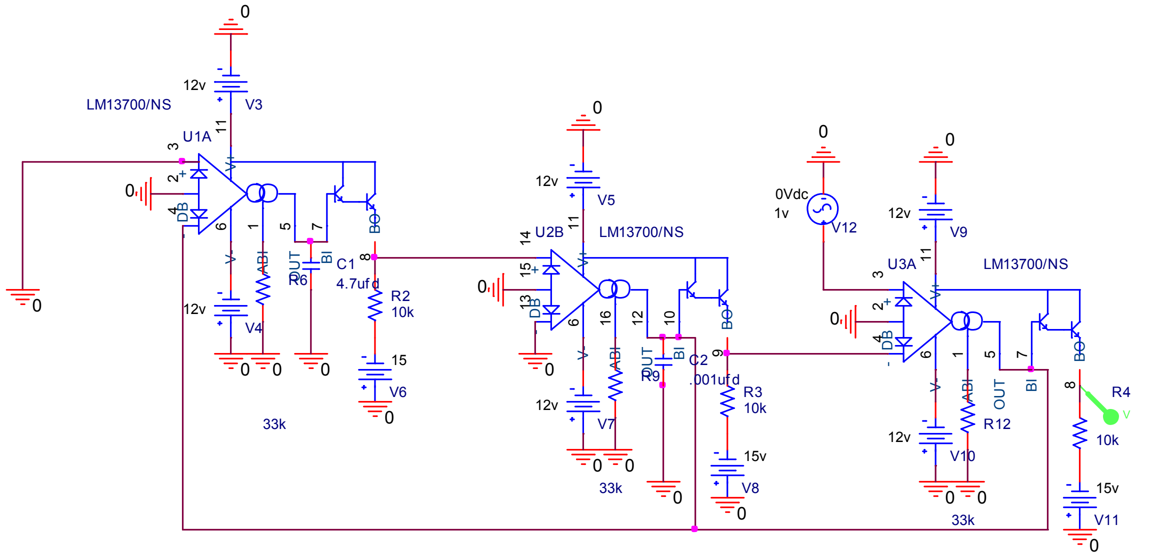


Fig. 5.28Second Order band pass filter Using LM13700

5.6.5.4 Results

The simulated frequency response plot band pass filter using LM 13600/ LM13700 is shown in fig. 5.29

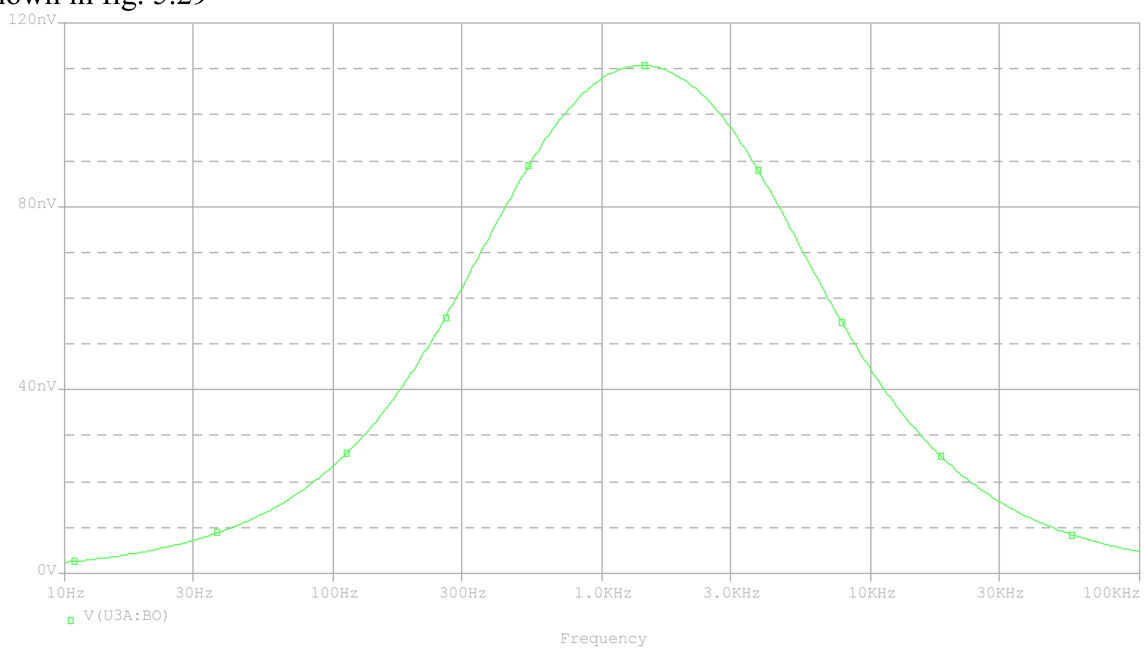


Fig. 5.29 Frequency response of Second Order band pass filter Using LM13700

5.6.6 Notch Filter Using Three OTA

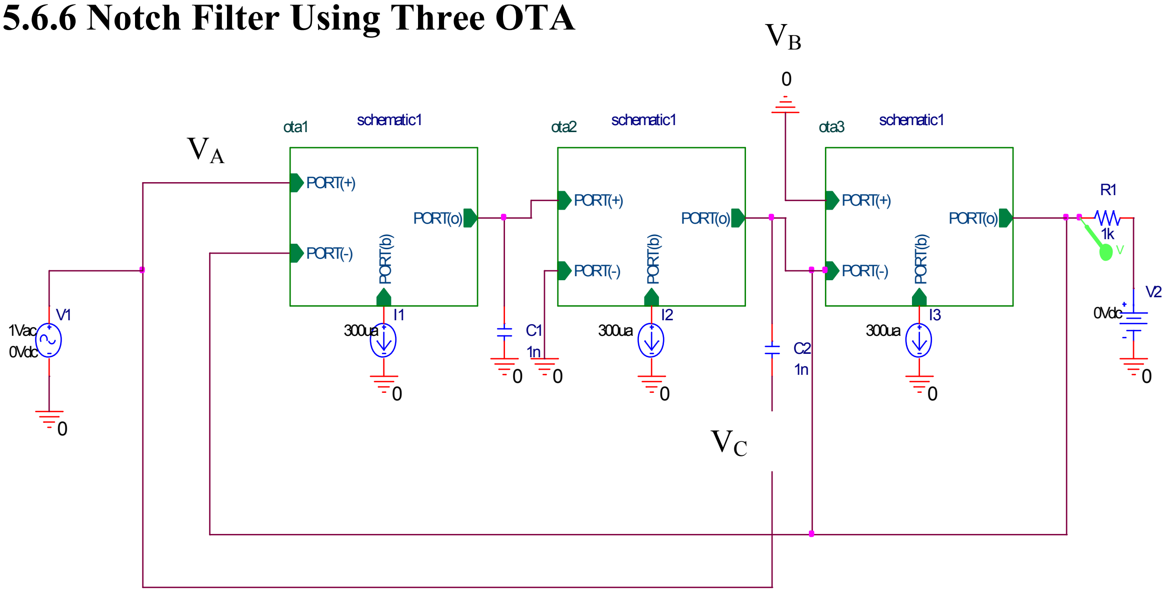


Fig. 5.30 Second Order Notch filter using three OTA

5.6.6.1 Transfer function

$$V_o = \frac{s^2 C_1 C_2 V_{in} + g_{m1} g_{m2} V_{in}}{s^2 C_1 C_2 + s C_1 g_{m3} + g_{m1} g_{m2}}$$

5.6.6.2 Results

The simulated frequency response plot of Notch filter using OTA shown in fig. 5.31

I_{BB} = 100uA **I_{BB} = 300uA**

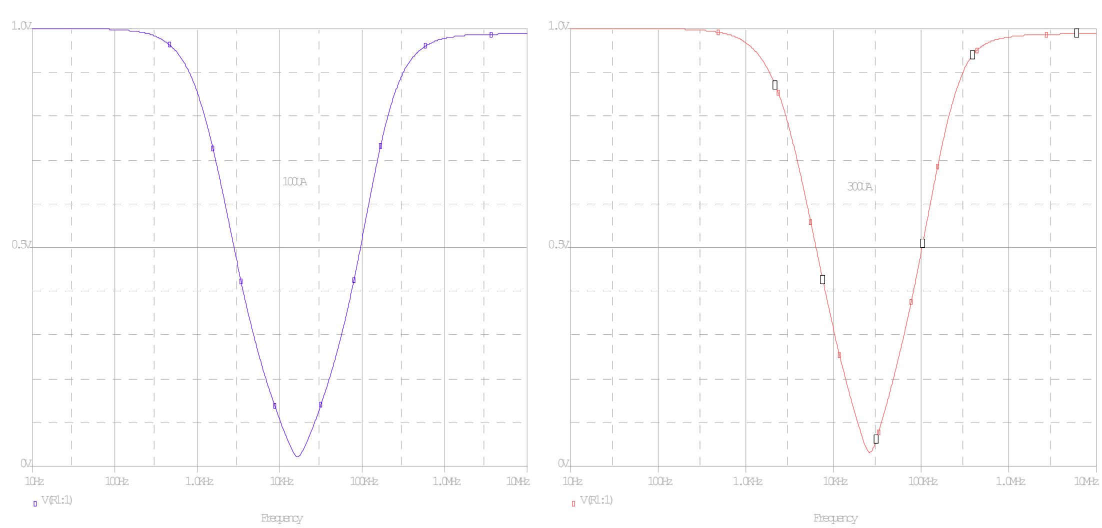
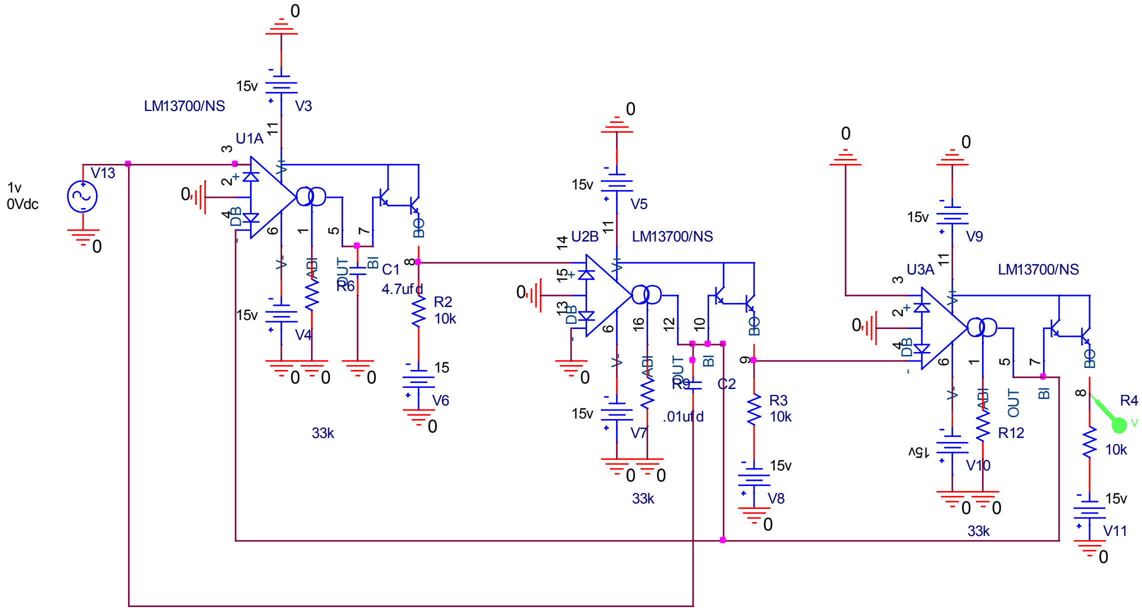


Fig. 5.31 Frequency response of Second Order Notch filter using three OTA

5.6.6.3 Notch Filter Using LM13700

The SPICE schematic of notch filter using LM 13600/ LM13700 is shown in fig. 5.32



`Fig. 5.32 Second Order notch filter Using LM13700

5.6.6.4 Results

The SPICE schematic of notch filter using LM 13600/ LM13700 is shown in fig. 5.33

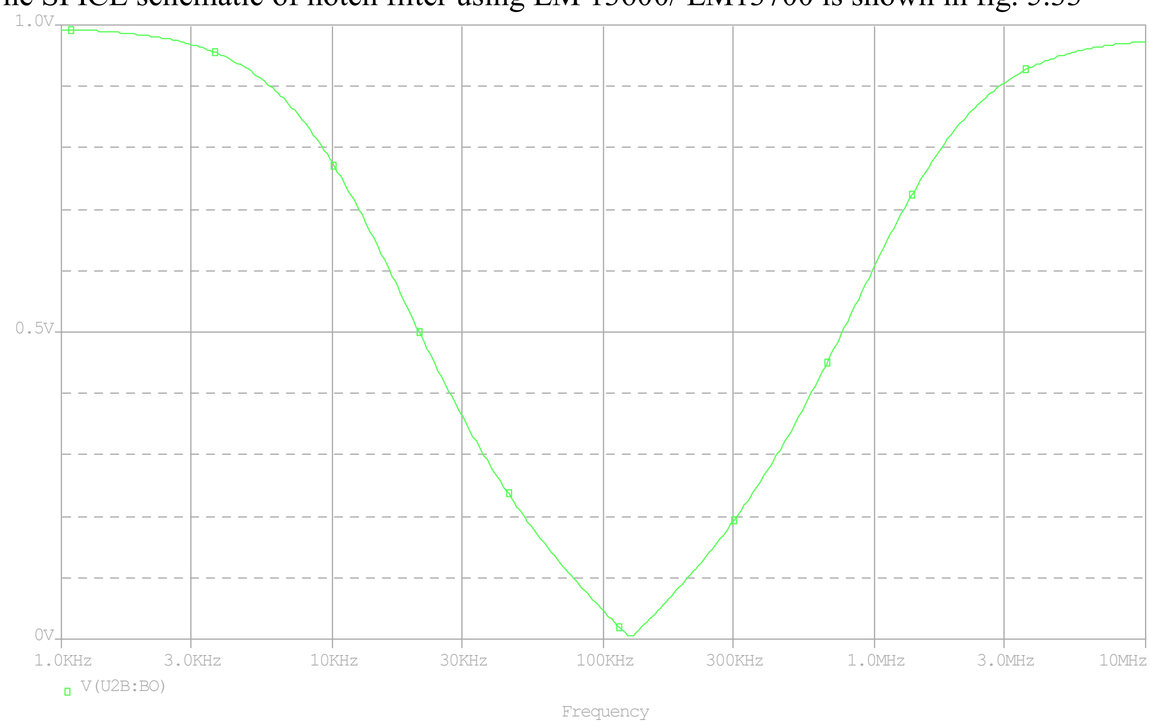


Fig. 5.33 Frequency response of Second Order notch filter Using LM13700

CHAPTER-6

OTA- COMPONENT REALIZATION AND FILTERS

6.1 Introduction

The performance of filters designed by the use of passive components degrades at audio frequencies and the required resistances and inductances values calculated from the mathematical expression are very difficult to meet from the market. To find a solution to this problem report performed a study to realize Passive component by active component using Operational Transconductance Amplifier (OTA). By controlling the Voltage Gain of OTA, one can change its transconductance, which is very useful in the designing the first order and second order active filter. at audio frequencies inductor causes problem. Inductorsize increases, at audio frequency and become bulky & expensive. At low frequencies inductor requires more number of turns which adds series resistances and degrades inductor's performance because of its low quality factor (Q), which results in high power dissipation. Using OTA the above mentioned problems are solved.

6.2 Grounded Resistance

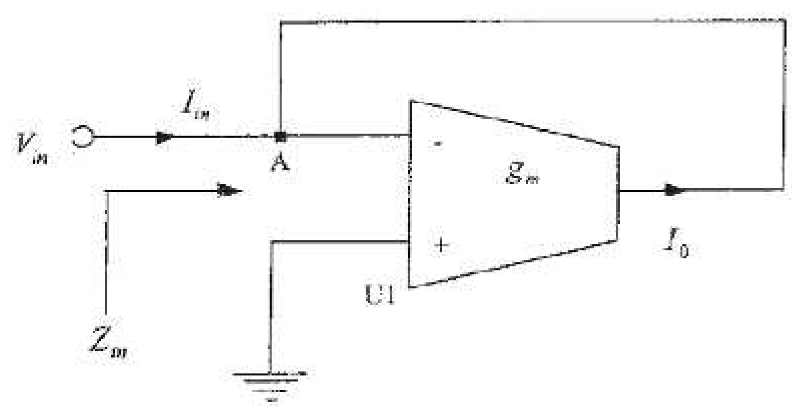


Fig. 6.1 Circuit for a grounded resistor

Considered fig. Which simulate grounded using OTA. Apply KCL at node A gives

$$I_{in} + I_O = 0 \qquad 6.1$$

Where $I = -V_m \times g_m$

Substituting the value of I from equation (6.2) in equitation (6.1) we have

$$Z_{in} = \frac{I}{g_m}$$

6.3 PSPICE schematic of Grounded resistance using OTA

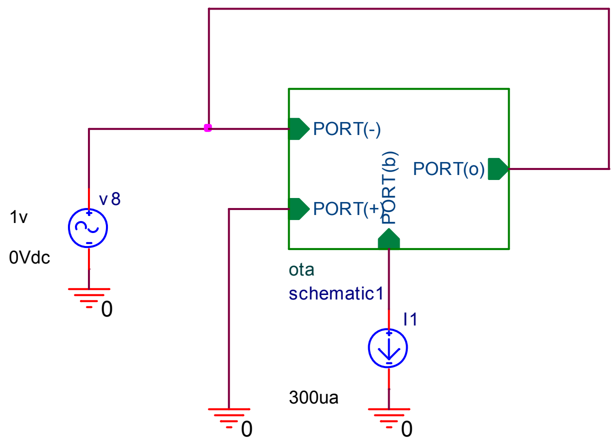


Fig. 6.2 Grounded positive Resistance using OTA

6.3.1 Results

The simulated plot of grounded positive resistance using OTA shown in fig. 6.3

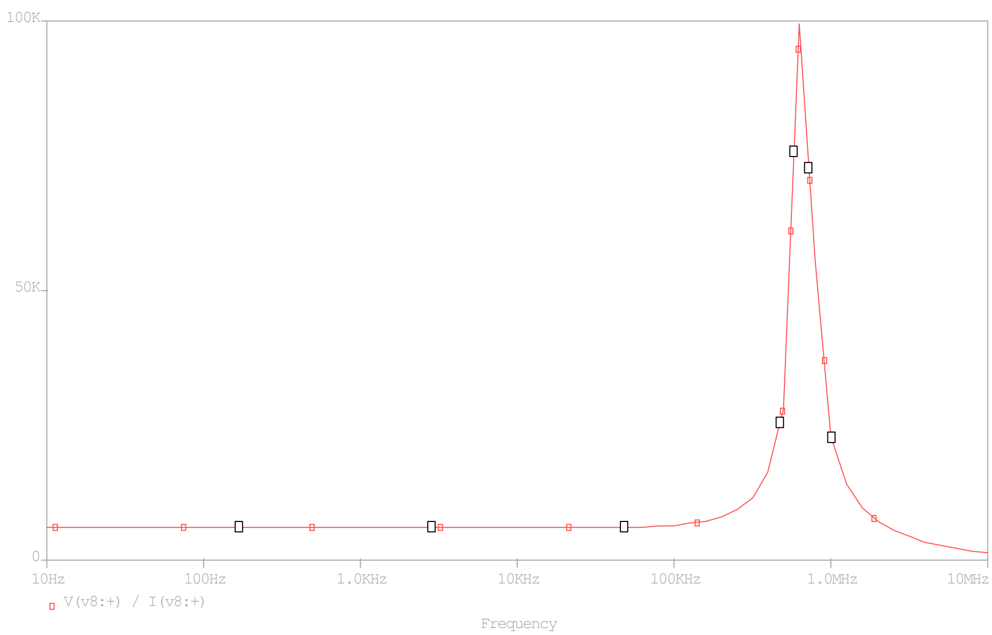


Fig. 6.3 Resistance with Frequency response using OTA

6.3.2 Grounded resistance using LM13700

The SPICE schematic of grounded positive resistance using LM 13600/ LM13700 is shown in fig. 6.4

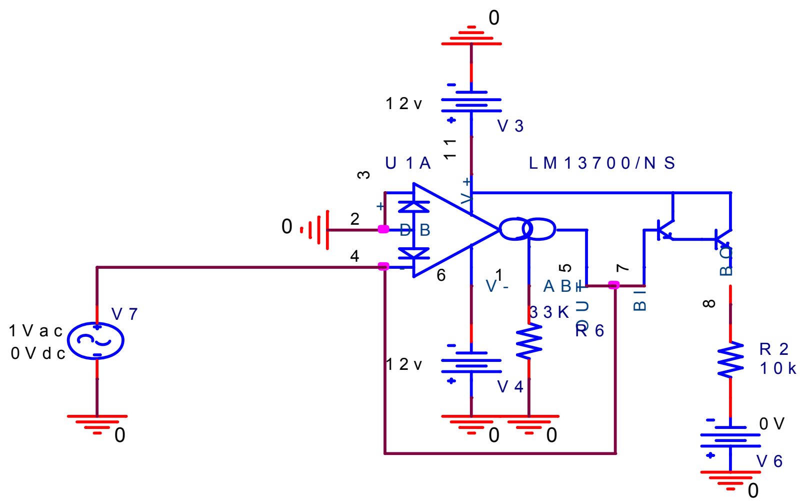


Fig. 6.4 Grounded positive resistance using LM 13700

6.3.3 Results

The simulated plot of grounded positive resistance using LM13700 shown in fig. 6.5

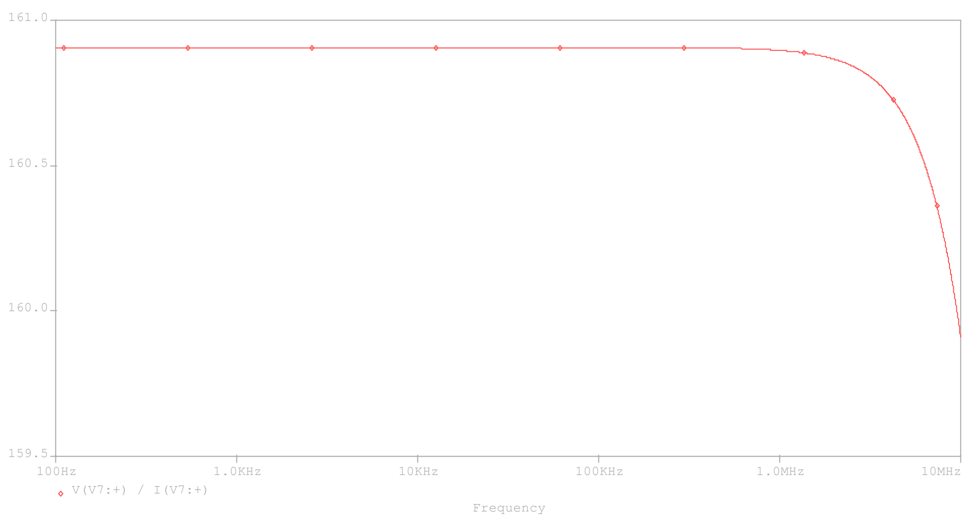


Fig. 6.5 resistance with frequency response using LM 13700

6.4 Grounded Negative Resistance

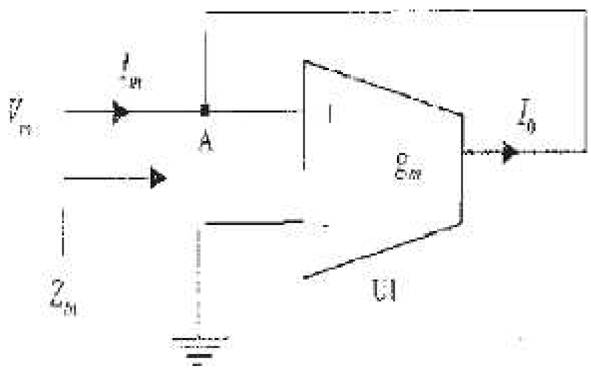


Fig. 6.6 Circuit for a grounded resistor (-R)

Considered fig. Which simulate grounded (-R) using OTA. Apply KCL at node A gives

$I_{in} + I_O = 0$ 6.3

We have Io = gm Vin 6.4

where $I = -V_m \times g_m$

Substituting the value of I from equation (6.4 in equitation (6.3) we have

$$Z_{in} = -\frac{I}{g_m}$$

6.5 PSPICE schematic of Grounded Negative Resistance using OTA

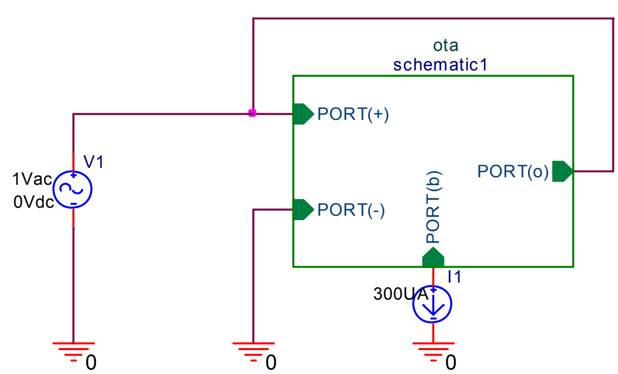


Fig. 6.7 Grounded negative resistance using OTA

6.5.1 Results

The simulated plot of grounded negative resistance using OTA shown in fig. 6.8

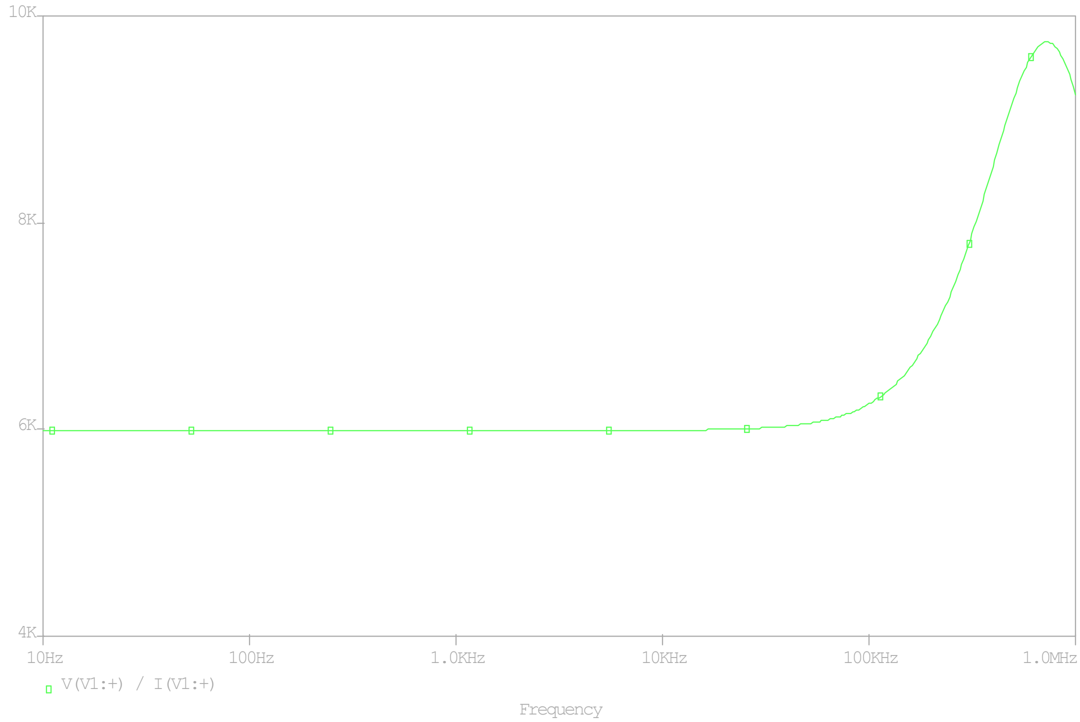


Fig. 6.8 Resistance with Frequency response using OTA

6.6 Floating Resistance

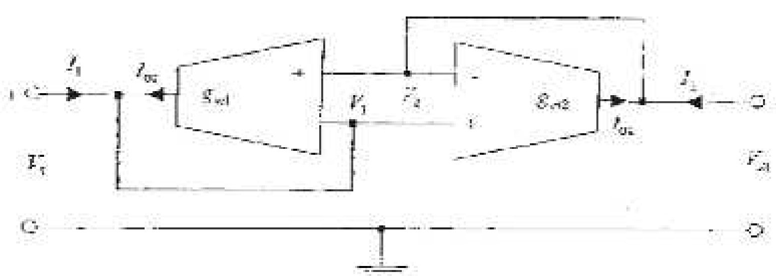


Fig. 6.9 Circuit for a floating resistor

After analyzing figure 6.9 we have

$I_{01} = g_{m1} (V_2 - V_1)$ 6.5

$I_{02} = gm2 (V_1 - V2)$ 6.6

But $I_{01} = - I_1$ and $I_{02} = -I_2$

Thus from equation 6.5 and 6.6 if $g_{m1} = g_{m2} = g_m$ we have $I_1 = -I_2$

$R = 1/g_m$ for $g_{m1} = g_{m2} = g_m$

6.7 PSPICE schematic of Floating resistance with V_2=0 using OTA

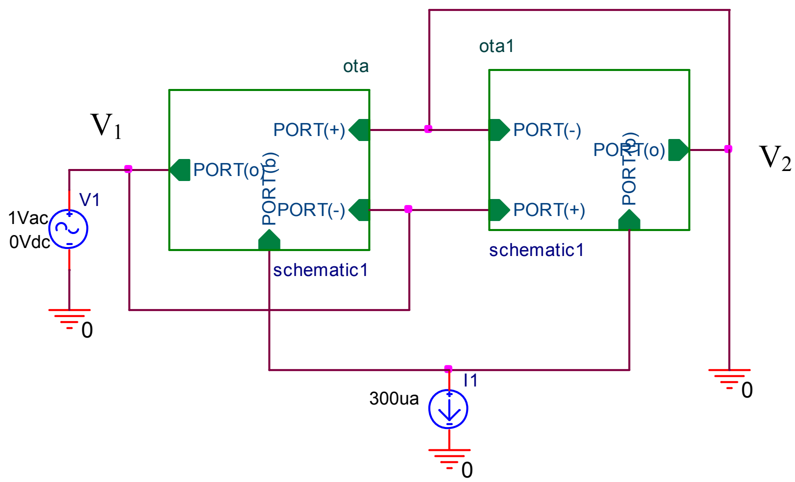


Fig. 6.10 floating resistance using OTA

6.7.1 Results

The simulated plot of floating resistance using OTA shown in fig. 6.11

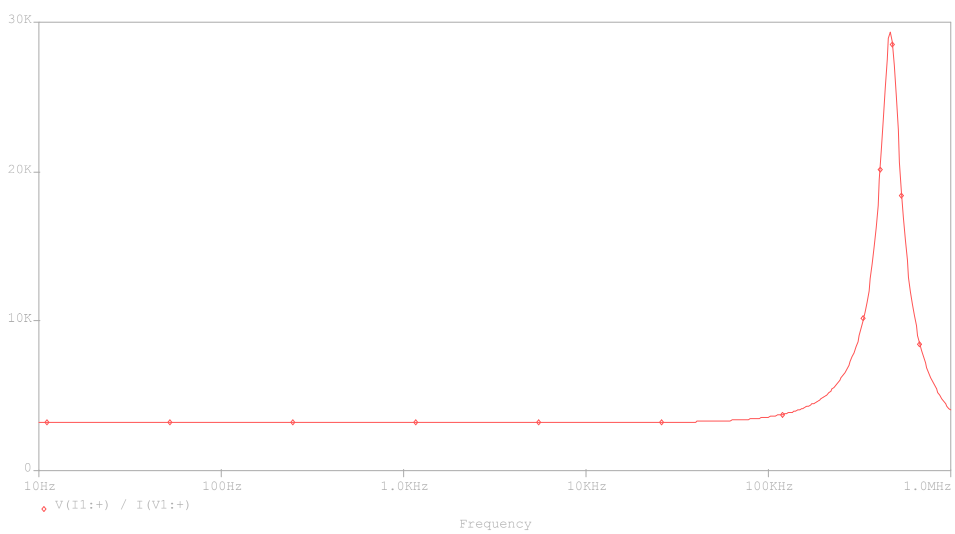


Fig. 6.11 Resistance with Frequency response using OTA

6.7.2 Floating Resistance with V_2=0 using LM13700

The SPICE schematic of floating resistance using LM 13600/ LM13700 is shown in fig. 6.12

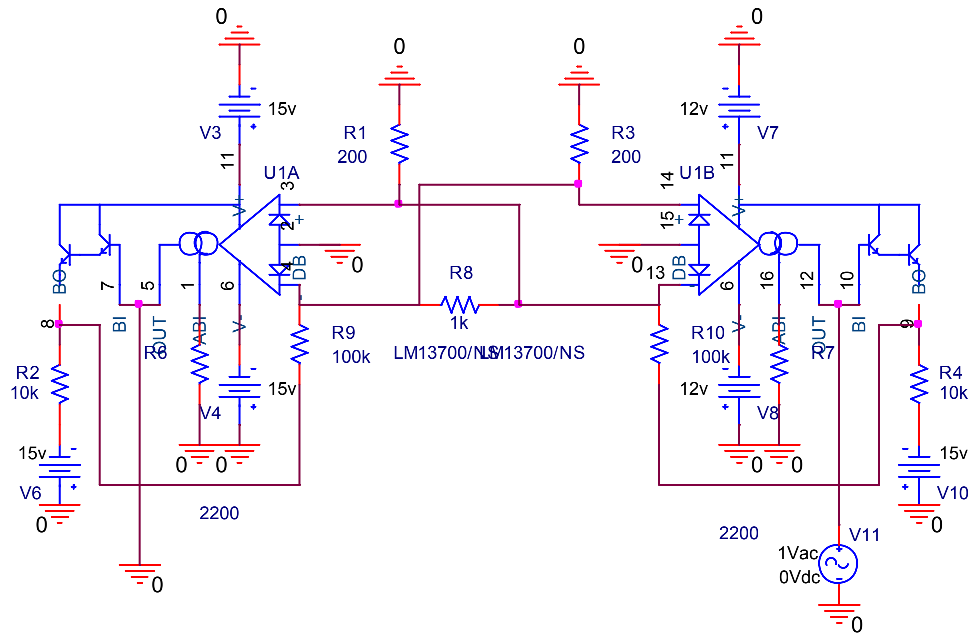


Fig. 6.12 floating resistance using LM 13700

6.7.3 Results

The simulated plot of floating resistance using LM13700 shown in fig. 6.13

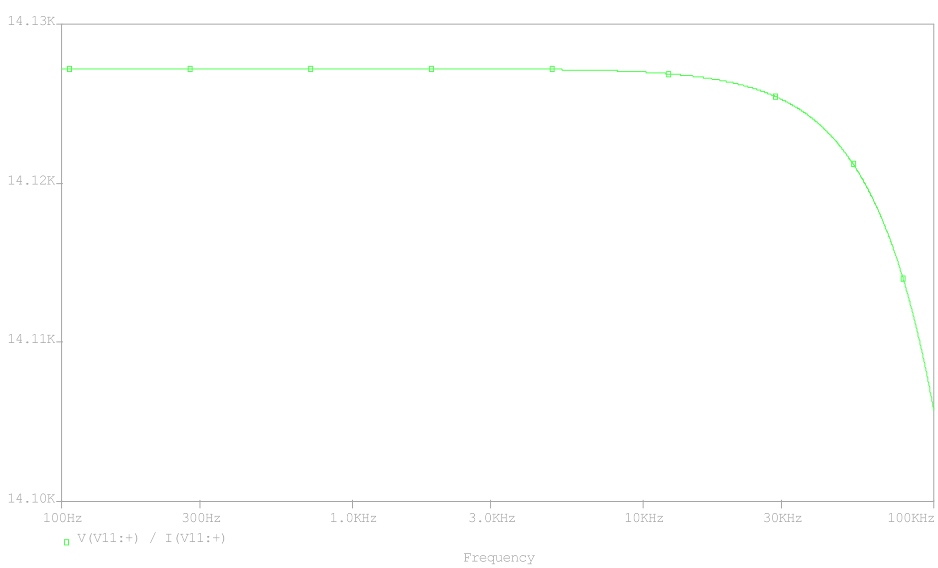


Fig. 6.13 resistance with frequency response using LM 13700/LM13700

6.8 PSPICE schematic of Floating resistance with V_1=0 using OTA

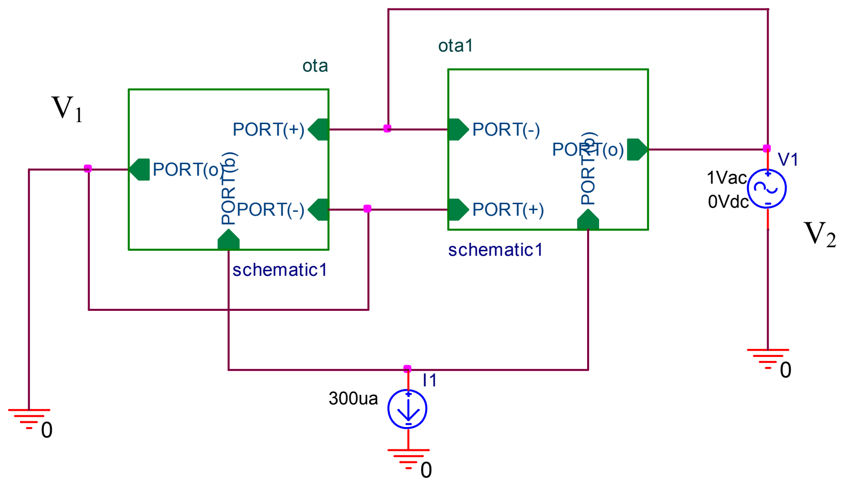


Fig.6.14 Floating Resistance using OTA

6.8.1 Results

The simulated plot of floating resistance using OTA shown in fig. 6.15

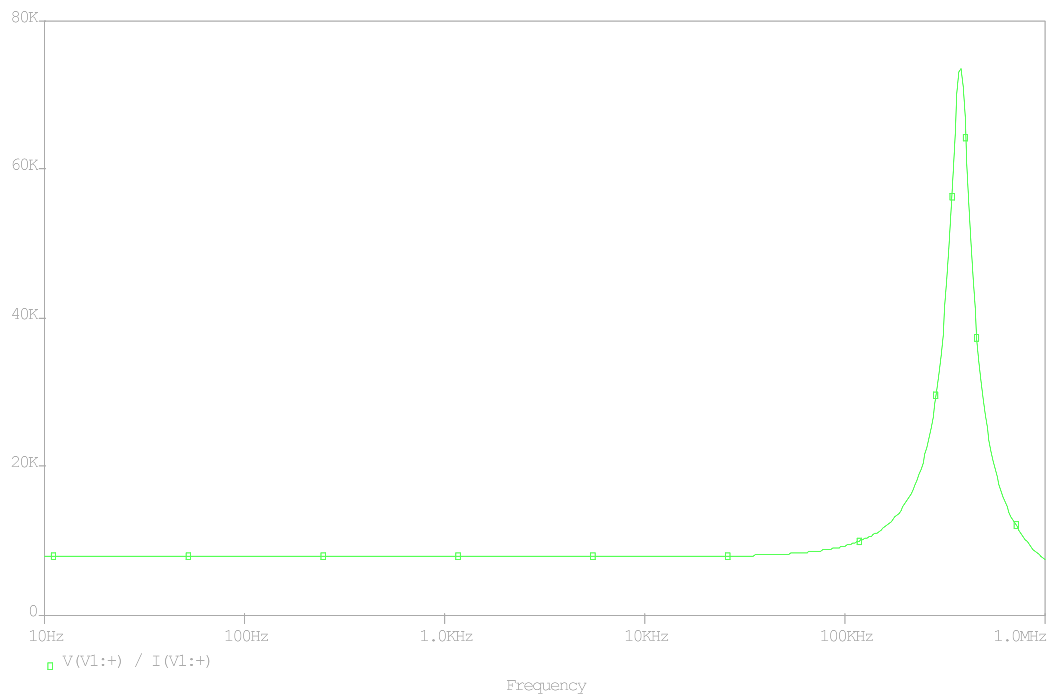


Fig.6. 15 Resistance with Frequency response using OTA

6.8.2 Floating resistance with V_1=0 using LM13700

The SPICE schematic of floating resistance using LM 13600/ LM13700 is shown in fig. 6.16

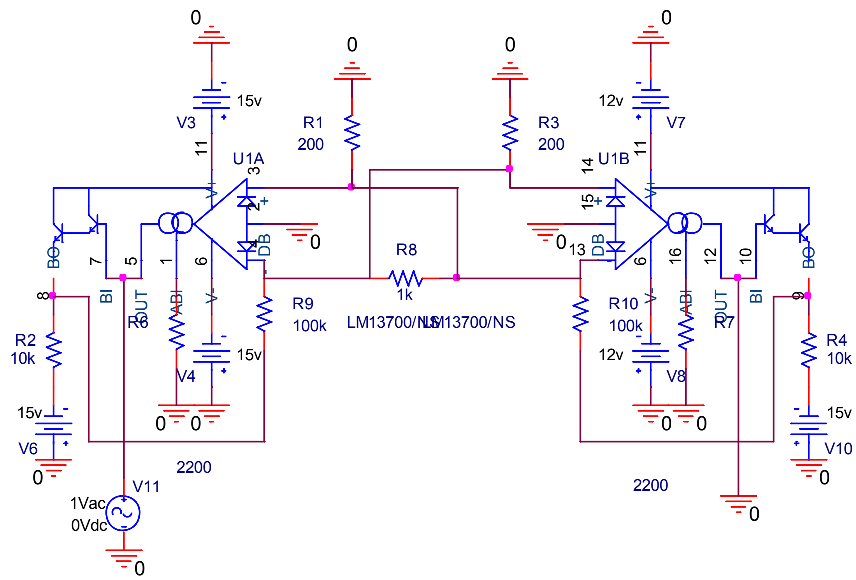


Fig 6.16 floating resistance using LM 13700

6.8.3 Results

The simulated plot of floating resistance using OTA shown in fig. 6.17

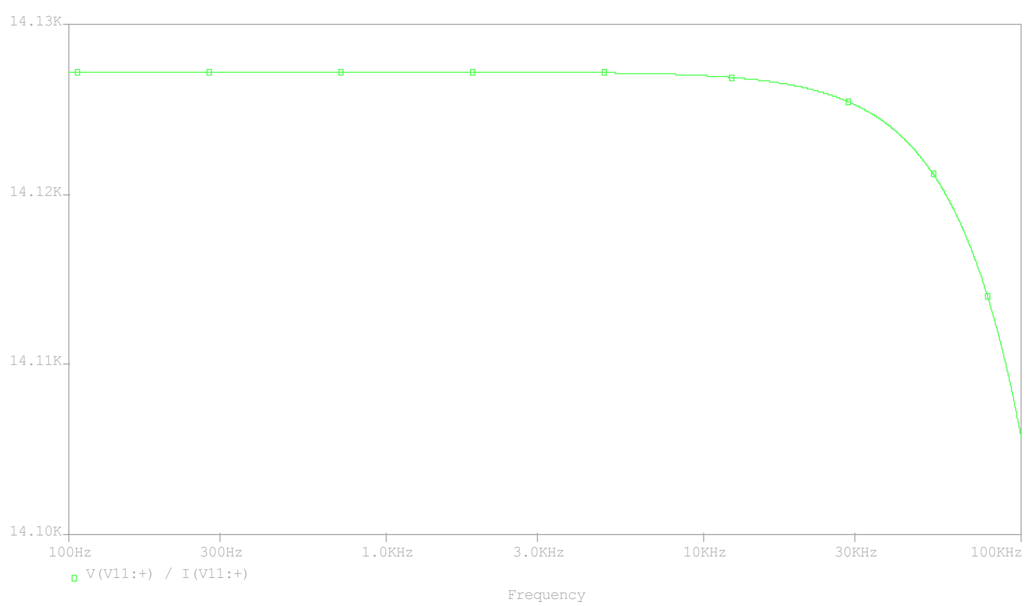


fig. 6.17 resistance with frequency response using LM 13700/LM13700

6.9 Notch Filter using Floating resistance

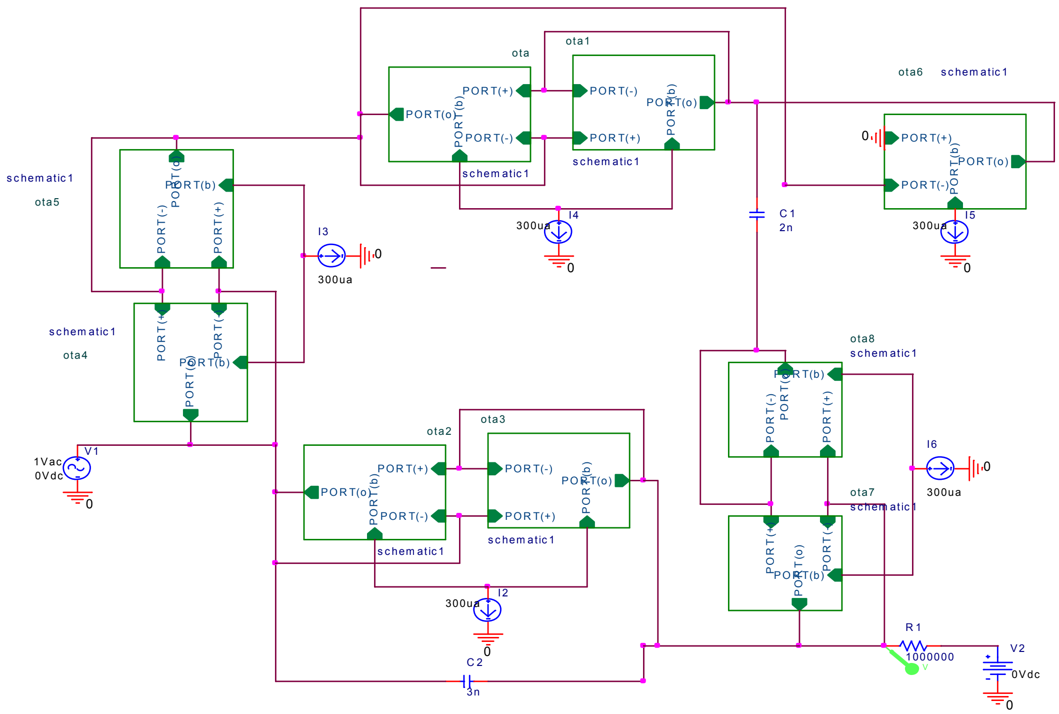


Fig. 6.18 Notch filter using floating resistance

The simulated plot of Notch filter using floating resistance shown in fig. 6.19

6.9.1 Results

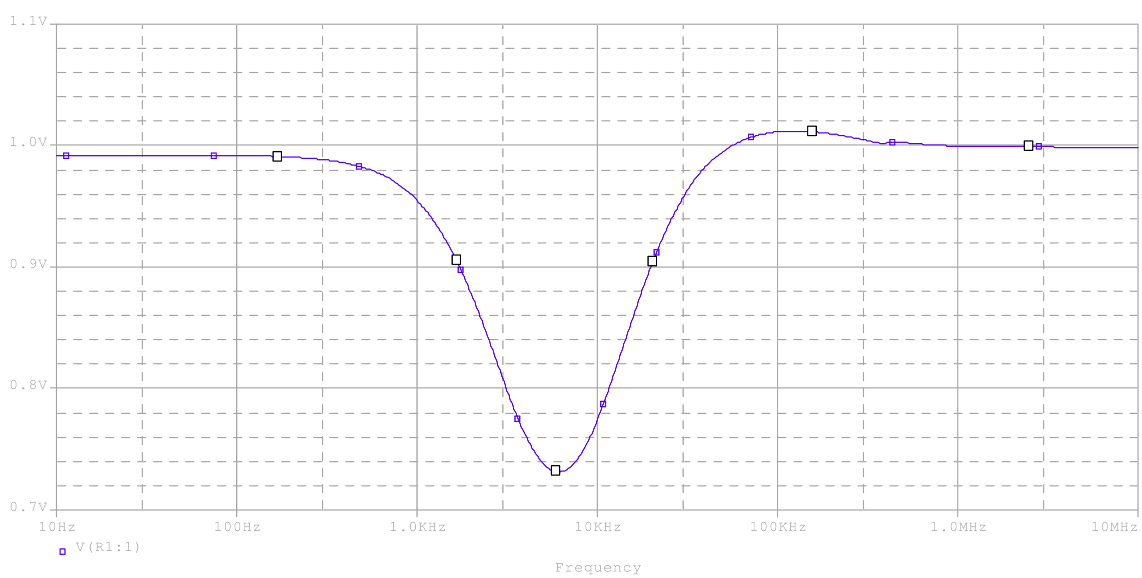


Fig. 6.19 frequency response of Notch filter using floating resistance

Simulated plot of Notch filter using floating resistance shown in fig. 6.20

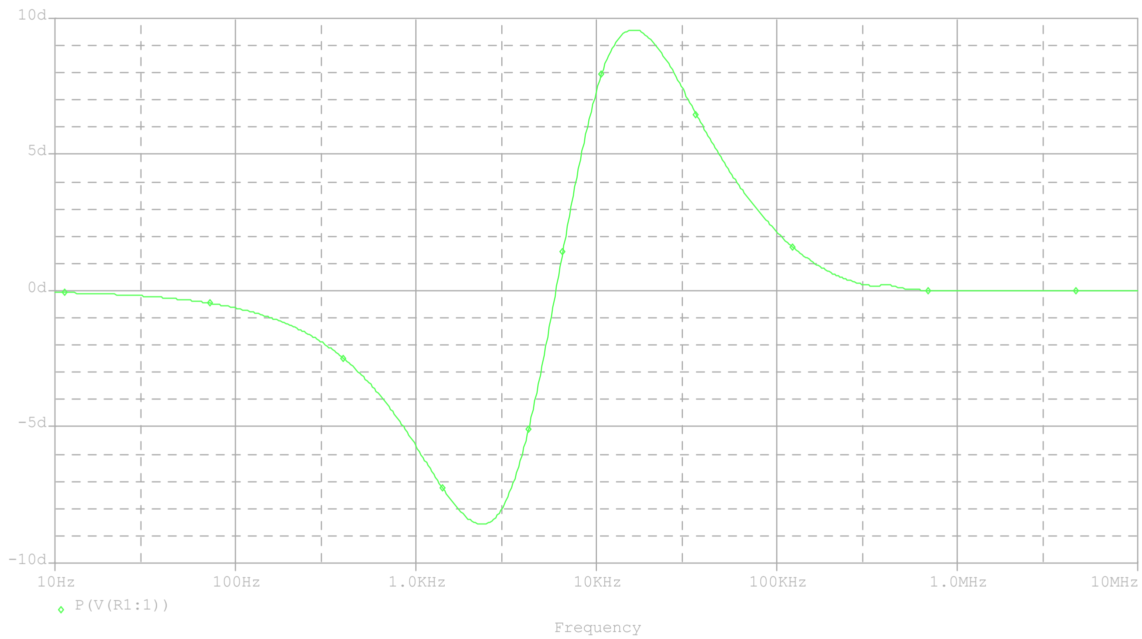


Fig. 6.20 Phase response of Notch filter using floating resistance

6.10 All pass filter using Floating resistance

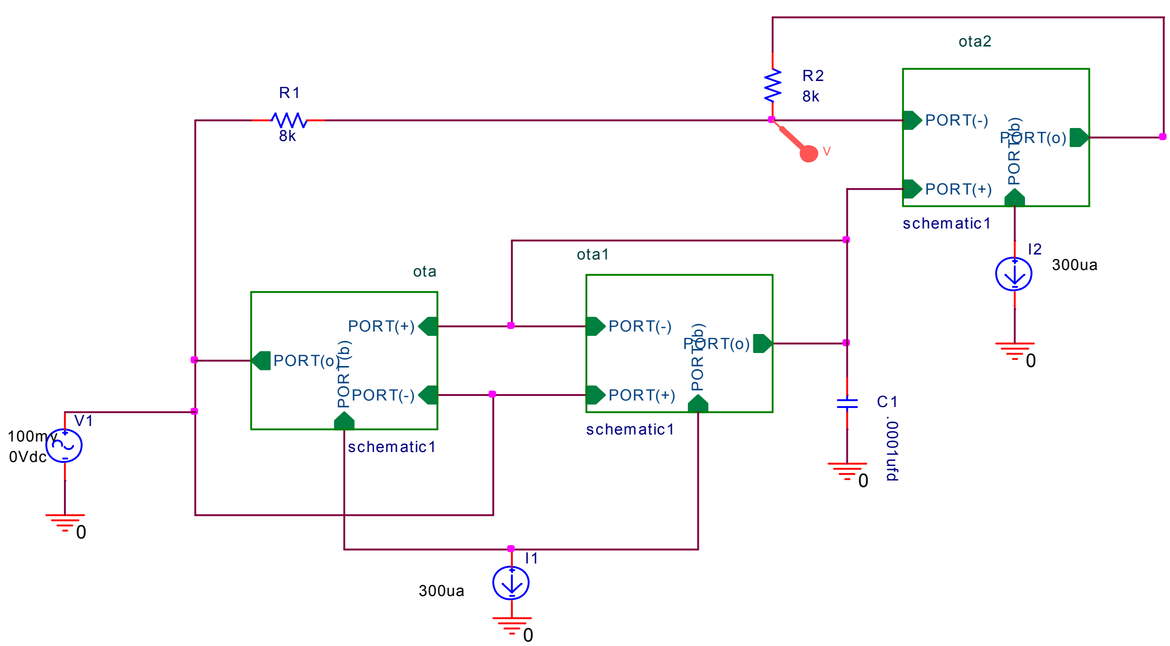


Fig.6.21 All Pass filter using floating resistance

6.10.1 Results

The simulated plot of All Pass Filter using floating resistance shown in fig. 6.22

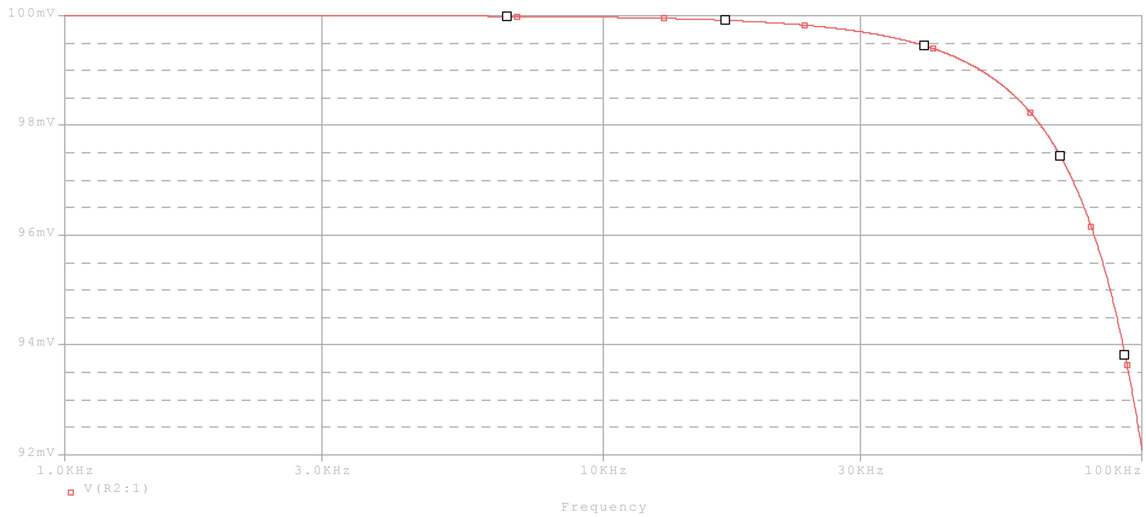


Fig. 6.22 frequency response of All Pass Filter using floating resistance

The simulated plot of All Pass Filter using floating resistance shown in fig. 6.23

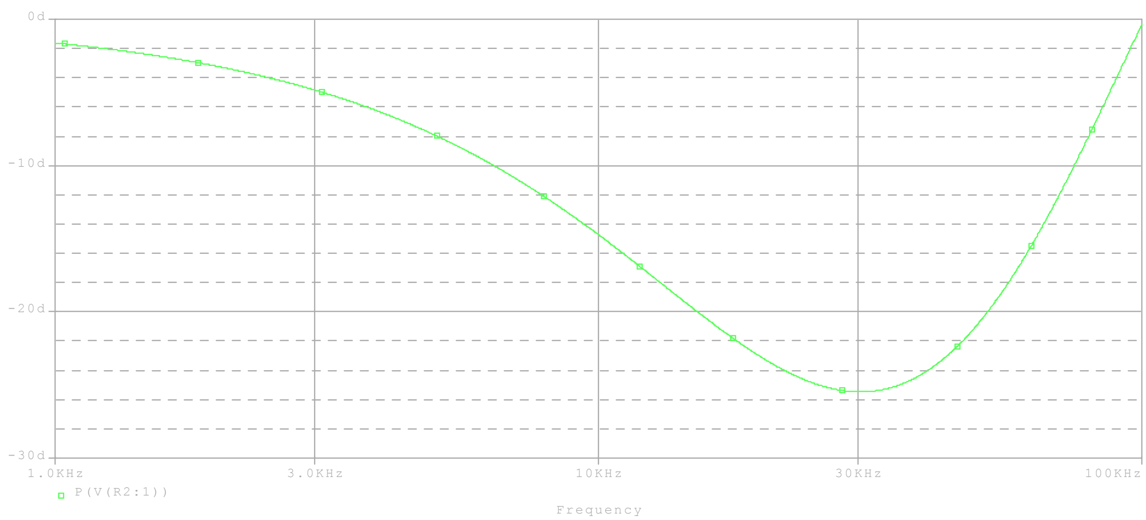


Fig. 6.23 Phase response of All Pass Filter using floating resistance

CHAPTER-7

HARDWARE IMPLEMENTATION USING IC LM13700

Filters are essential to the operation of most electronic circuits. In general, a filter is an electrical network that alters the amplitude and/or phase characteristics of a signal with respect to frequency. Hardware implementation of filter circuits using commercially available LM13700 was done. The results obtained are in good agreement with the simulated results.

7.1 Hardware for first order Low pass and high pass filter

7.1.1 LOW PASS FILTER RESPONSE

Frequency	Out put	Frequency	Out put
10	12	1900	11.6
100	12	2000	10.2
200	12	3000	10.2
300	12	4000	10.2
400	12	5000	7.6
500	12	6000	7.5
600	12	7000	6
700	12	8000	5.8
800	12	9000	4.9
900	12	10000	4.3
1000	12	11000	4.1
1100	12	12000	3.3
1200	12	13000	3.3
1300	12	14000	3.3
1400	12	15000	3.3
1500	12	16000	1.2
1600	11.6	17000	1.2
1700	11.6	18000	0.8
1800	11.6	19000	0.6
		20000	0.6

7.1.2Result

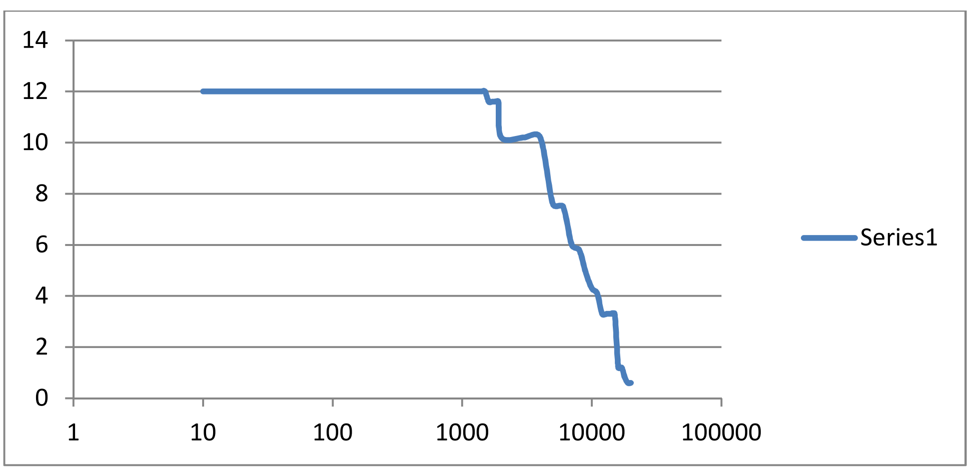


Fig. 7.1 frequency response of low pass filter using hardware

7.1.3 HIGH PASS FILTER RESPONSE

Frequency	Out put	Frequency	Out put
10	0.1	2000	0.7
100	0.1	3000	0.7
200	0.1	4000	0.9
300	0.1	5000	0.9
400	0.1	6000	1
500	0.1	7000	1
600	0.2	8000	1
700	0.2	9000	1
800	0.2	10000	1
900	0.2	11000	1
1000	0.5	12000	1
1100	0.5	13000	1
1200	0.7	14000	1
1300	0.7	15000	1
1400	0.7	16000	1
1500	0.7	17000	1
1600	0.7	18000	1
1700	0.7	19000	1
1800	0.7	20000	1
1900	0.7		

7.1.4 Result

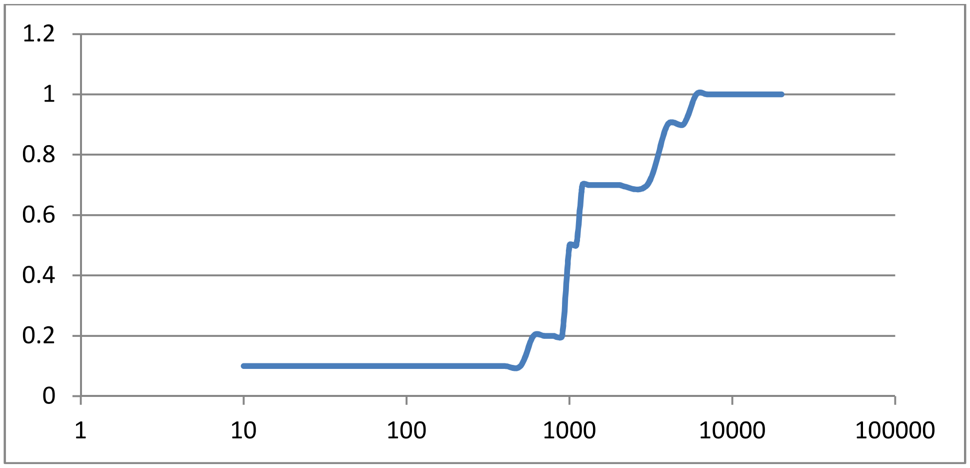
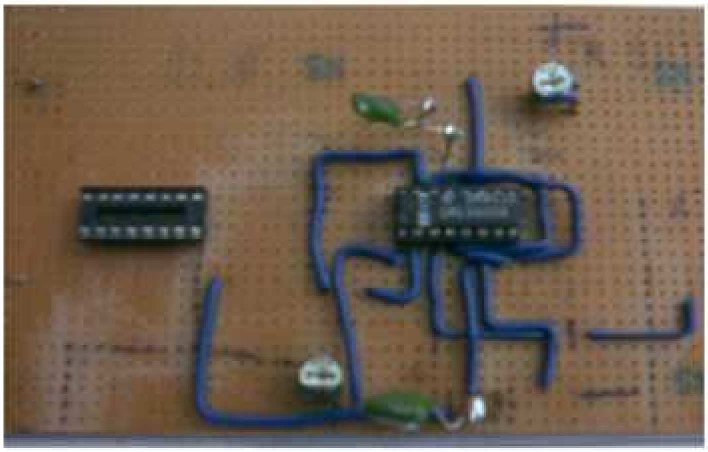
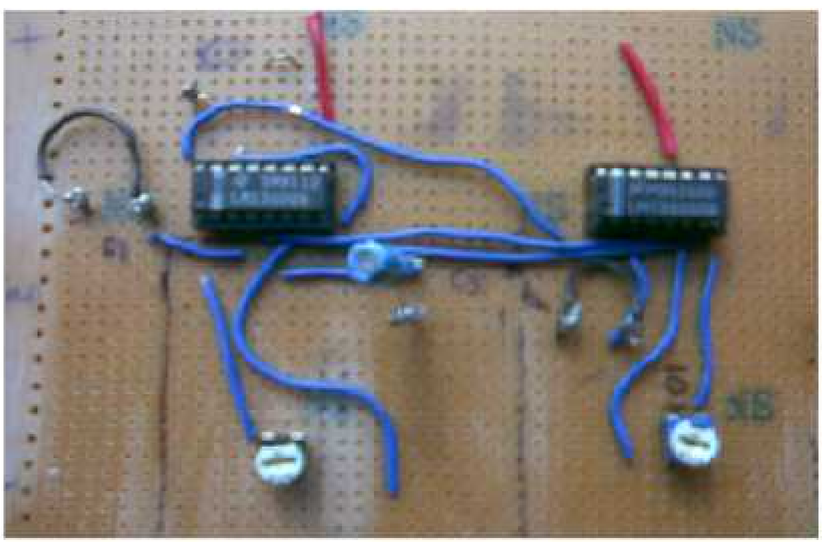


Fig. 7.2 frequency response of high pass filter using hardware

7.2 Hardware for Second order Low pass/ high pass/band pass and notch filter using two OTA



7.3 Hardware for Second order Low pass/ high pass/band pass and notch filter Using Three OTA



CONCLUSION AND FUTURE SCOPE

The OTA is receiving increasing attention as a basic building block in analog circuit design. It is relatively a new building block operating from low voltage supplies and overcomes the finite gain bandwidth product associated with traditional op-amp. The basic principle behind the design of OTA is to provide amplification of high frequency signals with the ease of using standard operational amplifier.

In this work effort is made to study the role of OTA as an active building block in various filters. CMOS realization of OTA present in the literature is studied and this building block is used to realize various filters. All the circuits were simulated using PSPICE program and 0.5um process parameters were used for it. Simulation results show that the various characteristics are in good agreement with the commercial available IC LM13600/ LM13700. In this report using CMOS technology, a systematic approach to lower the power consumption and the chip area of analog circuits is presented by using CMOS-OTA (Operational transconductance Amplifier) and also observed that OTA based circuits have good response on higher frequency.

Further, Oscillators, multivibrators and multiplier can be designed using OTA. Operational amplifiers and some commercial IC's are commonly used to construct monostable and bistable multivibrators. But these voltage mode circuits have some disadvantages like complex internal circuitries and use of more passive components.

MODEL PARAMETER FOR CMOS LEVEL 3 , 0.5 uM TECHNOLOGY

MODEL NMOD NMOS (LEVEL=3)	**MODEL PMOD PMOS (LEVEL=3)**
PHI=0.700000	PHI=0.700000
TOX=9.6000E-09	TOX=9.6000E-09
XJ=0.200000U	XJ=0.200000U
TPG=1	TPG=-1
VTO=0.6684	VTO=-0.9352
DELTA=1.0700E+00	DELTA=1.2380E-02
LD=4.2030E-08	LD=5.2440E-08
KP=1.7748E-04	KP=4.4927E-05
UO=493.4	UO=124.9
THETA=1.8120E-01	THETA=5.7490E-02
RSH=1.6680E+01	RSH=1.1660E+00
GAMMA=0.5382	GAMMA=0.4551
NSUB=1.1290E+17	NSUB=8.0710E+16
NFS=7.1500E+11	NFS=5.9080E+11
VMAX=2.7900E+05	VMAX=2.2960E+05
ETA=1.8690E-02	ETA=2.1930E-02
KAPPA=1.6100E-01	KAPPA=9.3660E+00
CGDO=4.0920E-10	CGDO=2.1260E-10
CGSO=4.0920E-10	CGSO=2.1260E-10
CGBO=3.7765E-10	CGBO=3.6890E-10
CJ=5.9000E-04	CJ=9.3400E-04
MJ=0.76700	MJ=0.48300
CJSW=2.000E-11	CJSW=2.5100E-10
MJSW=0.71000	MJSW=0.21200
PB=0.9900000	PB=0.930000
WD=1.83E-07	WD=1.83E-07
LAMBDA=0.02)	LAMBDA=0.02)

REFERENCES

[1] Toumazou C, Lidjey FJ, Haigh D. Analog IC design: the current-mode approach. Peter Peregrinus, UK: Exeter; 1990.

[2] CMOS operational transresistance amplifier for analog signal processing - Khaled n. Salama, Ahmed m. Soliman, 1999

[3] J.J. Chen, H.W. Tsao, and C. Chen, “Operational transresistance amplifier using CMOS technology.” *Electronics Letters*, vol. 28, no. 22, pp. 2087–2088, 1992.

[4] Low Voltage Analog CMOS Design By: Imre Knausz

[5] Analog Circuit Synthesis Using Linear and Nonlinear Current Amplifiers G. SOULIOTIS, N. FRAGOULIS AND I. HARITANTIS

[6] CMOS-Transconductance amplifier, architecture and active filter by: E.Sanchez and J.Silva

[7] Operational Transconductance amplifier: Achim Gratz

[8] CMOS, circuits design, layout, and simulation by: R.Jacob Baker, Harry W. Li

[9] Active Filter Design Using Operational Transconductance Amplifiers: A Tutorial," R. L. Geiger and E. Sánchez-Sinencio, *IEEE Circuits and Devices Magazine*, Vol. 1,

[10] On the realization of electronically current-tunable CMOSOTA: Khanittha Kaewdang ,Wanlop Surakampontorn

[11] Electronically tunable high-input impedance voltage-mode universal biquadratic filter Based on simple CMOS OTAs Montree Kumngern, Boonying Knobnob, Kobchai Dejhan

[12] A simple realization scheme for OTA-c universal biquadratic filter. International Journal of Electronics 1992 419–29. By: Khan IA, Ahmed MT, Minhaj N.

[13] A 2.7V Elliptical All-MOS gmC-OTA Filter Saska Lindfors, Kari Halonen, Mohammed, Ismail *Ohio State University*

[14] Design of analog filters. Rolf Schaumann, Mac E. Van Valkenburg.

[15] Microelectronics Circuits by: Sedra/Smith.

[16] **A +-**5-V CMOS Analog Multiplier**,** SHI-CAI QIN ANDRANDY L. GEIGER, SENIOMR SMREIRE,EE

[17] Linear integrated circuit; Gayakwad.

[18] Multifunctional tuned second order ARC filter with commercially Available transconductor, Tomas DOSTAL, Roman SOTER Brno University of Technology, Purkyinova 118, 612 00 Brno, Czech Republic

[19] Application of the Operational Transconductance Amplifier (OTA) to Voltage-Controlled Amplifiers and Active Filters: Department of IET Morehead State University Morehead,

[20] Realization Of Active Filters Using Operational Transconductance Amplifier Prasant K. Mahapatra, Manjeet Singh and Neelesh Kumar*Central J. Instrum. Soc. India 35(1) 1-9*

[21] Simulation of Voltage Controlled Tunable All Pass Filter using LM13700 OTA Bhaba Priyo Das, Neville Watson and Yonghe LiuInternational Journal of Electrical and Information Engineering 4:4 2010

[22] novel topology for grounded-to-floating resistor conversionin CMOS Technology S.F. Al-Sarawi Microelectronics Journal 33 (2002) 1059–1069