TRANSCONDUCTANCE AMPLIFIERS

Electronics and Communication Engineering

under the Supervision of

Dr.SHRUTI JAIN

by

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Certificate

This is to certify that project report entitled "**TRANSCONDUCTANCE AMPLIFIERS**", submitted by **Bhavya, Rishabh and Ubher** in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

(SHRUTI JAIN)

Date:

Supervisor's Name : Dr. Shruti Jain

Designation: Assistant Professor

Acknowledgement

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We would like to express our gratitude towards our parents & members of JUIT for their kind co-operation and encouragement which helped us in completion of this project.

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WHY THIS PROJECT?

There are four types of amplifier –voltage amplifier, current amplifier, transimpedence amplifier , transconductance amplifier.

Voltage feedback operational amplifier is a type of voltage amplifier which has properties required for amplification of the input signal. It is a direct coupled high gain amplifier and is used to amplify dc as well as ac signals. It takes the input voltage to give amplified output voltage.

We switched over to current feedback operational amplifier because of its advantages over voltage feedback operational amplifier. The current feedback is a type of transimpedence amplifier which takes current as input and gives the corresponding amplified output voltage. The current feedback amplifier has same ideal closed loop equations but has higher slew rate. The current feedback amplifier often is the best circuit available with its cost effective combination of high gain and high performance. Substituting, a current feedback amplifier for a voltage feedback amplifier in the design of production stages will result in better performance and lower cost.

In our project, we have also implemented operational amplifier which is a type of transconductance amplifier which takes the input voltage to give corresponding amplified output current. The operational transconductance amplifier comes out to be the best on the basis of parameters-CMRR and slew rate.

ABSTRACT

The operational amplifier is an extremely efficient and versatile device. Its applications span the broad electronic industry filling requirements for signal conditioning, special transfer functions, analog instrumentation, and computation, and special system design. The analog assets of simplicity and precision characterize circuits utilizing operational amplifiers.

The part of the project is to design transconductance amplifier and calculate various parameters : Voltage Gain, Input and Output Impedence, Supply Voltage Rejection Ratio, Common Mode Rejection Ratio(CMRR) and Slew Rate to obtain the performance of the circuit. To improve the CMRR, we Implemented three types of OTA i.e. Simple Differential OTA, Fully Differential OTA and Balanced OTA. The Balanced OTA was observed to be the best out of three.

In order to get the optimum value of CMRR we have proposed the design of Balanced OTA in which the Standard Current Mirror is replaced by –Bulk Driven Current Mirror and Low voltage Current Mirror.

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CHAPTER 1:OPERATIONAL AMPLIFIER

1.1 INTRODUCTION

An **Operational Amplifier** (op-amp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. In this configuration, an op-amp produces an output potential (relative to circuit ground) that is typically hundreds of thousands of times larger than the potential difference between its input terminals.

Operational amplifiers had their origins in analog computers, where they were used to do mathematical operations in many linear, non-linear and frequency-dependent circuits. Characteristics of a circuit using an op-amp are set by external components with little dependence on temperature changes or manufacturing variations in the op-amp itself, which makes op-amps popular building blocks for circuit design.

Op-amps are among the most widely used electronic devices today, being used in a vast array of consumer, industrial, and scientific devices. Many standard IC op-amps cost only a few cents in moderate production volume; however some integrated or hybrid operational amplifiers with special performance specifications may cost over $100 US in small quantities. Op-amps may be packaged as components, or used as elements of more complex integrated circuits.

The op-amp is one type of differential amplifier. Other types of differential amplifier include the fully differential amplifier (similar to the op-amp, but with two outputs), the instrumentation amplifier (usually built from three op-amps), the isolation amplifier (similar to the instrumentation amplifier, but with tolerance to common-mode voltages that would destroy an ordinary op-amp), and negative feedback amplifier (usually built from one or more op-amps and a resistive feedback network).

OPERATION:- $V_{out} = A_{OL}(V_+ - V_-)$

Where V_+ is non-inverting voltage, V_- is inverting voltage and A_{ol} is the openloop gain.

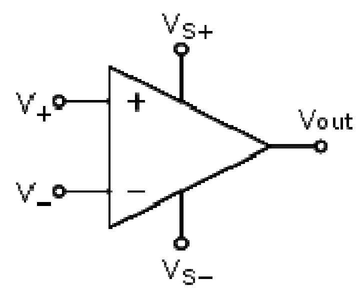


Figure 1.1 Circuit Diagram Symbol for Op-Amp

1.2 TYPES OF OPERATIONAL AMPLIFIER:

a. VOLTAGE FEEDBACK OPERATIONAL AMPLIFIER

b. CURRENT FEEDBACK OPERATIONAL AMPLIFIER

1.2.1 VOLTAGE FEEDBACK OPERATIONAL AMPLIFIER

It is an amplifier which combines a fraction of the output with the input so that a negative feedback opposes the original signal. The applied negative feedback improves performance (gain stability, linearity, frequency response, step response) and reduces sensitivity to parameter variations due to manufacturing or environment. Because of these advantages, negative feedback is used in this way in many amplifiers and control systems.A negative feedback amplifier is a system of three elements

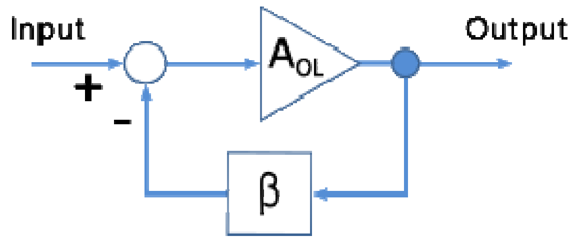


Figure 1.2 Negative Feedback Amplifier

an *amplifier* with gain A_{OL}, a *feedback network* which senses the output signal and possibly transforms it in some way (for example by attenuating or filtering it), and a summing circuit acting as a *subtractor* (the circle in the figure) which combines the input and the attenuated output.Without feedback, the input voltage V'_{in} is applied directly to the amplifier input. The according output voltage is

$$V_{out} = A_{ol}.V_{in}$$

Suppose now that an attenuating feedback loop applies a fraction $\beta.V_{out}$ of the output to one of the subtractor inputs so that it subtracts from the circuit input voltage V_{in} applied to the other subtractor input. The result of subtraction applied to the amplifier input is

$$V_{in} = V_{in} - \beta.V_{out}$$

Substituting for V'_{in} in the first expression,

$$V_{out} = A_{ol}(V'_{in} - \beta.V_{out})$$

Rearranging

$$V_{out}(1+\beta V_{ol}) = V'_{in}.A_{ol}$$

Then the gain of the amplifier with feedback, called the closed-loop gain, A_{fb} is given by,

$$A_{fb} = \frac{V_{out}}{V_{in}} = \frac{A_{ol}}{1+\beta A_{ol}}$$

1.2.2 CURRENT FEEDBACK OPERATIONAL AMPLIFIER

otherwise known as **CFOA** or **CFA** is a type of electronic amplifier whose inverting input is sensitive to current, rather than to voltage as in a conventional voltage-feedback operational amplifier(VFA). The CFA was invented by David Nelson at Comlinear Corporation, and first sold in 1982 as a hybrid amplifier, the CLC103. An early patent covering a CFA is U.S. Patent 4,502,020, David Nelson and Kenneth Saller (filed in 1983). The integrated circuit CFAs were introduced in 1987 by both Comlinear and Elantec (designer Bill Gross). They are usually produced with the same pin arrangements as VFAs, allowing the two types to be interchanged without rewiring when the circuit design allows. In simple configurations, such as linear amplifiers, a CFA can be used in place of a VFA with no circuit modifications, but in other cases, such as integrators, a different circuit design is required. The classic four-resistor differential amplifier configuration also works with a CFA, but the common-mode rejection ratio is poorer than that from a VFA.

1.2.3 COMPARISON: VOLTAGE FEEDBACK AND CURRENT FEEDBACK

Internally compensated, VFA bandwidth is dominated by an internal dominant pole compensation capacitor, resulting in a constant gain/bandwidth limitation. CFAs, in contrast, have no dominant pole capacitor and therefore can operate much more closely to their maximum frequency at higher gain. Stated another way, the gain/bandwidth dependence of VFA has been broken.

In VFAs, dynamic performance is limited by the gain-bandwidth product and the slew rate. CFA use a circuit topology that emphasizes current-mode operation, which is inherently much faster than voltage-mode operation because it is less prone to the effect of stray node-capacitances. When fabricated using high-speed complementary bipolar processes, CFAs can be orders of magnitude faster than VFAs. With CFAs, the amplifier gain may be controlled independently of bandwidth. This constitutes the major advantages of CFAs over conventional VFA topologies.

Disadvantages of CFAs include poorer input offset voltage and input bias current characteristics. Additionally, the DC loop gains are generally smaller by about three decimal orders of magnitude. Given their substantially greater bandwidths, they also tend to be noisier. CFA circuits must never include a direct capacitance between the output and inverting input pins as this often leads to oscillation. CFAs are ideally suited to very high speed applications with moderate accuracy requirements.

Development of faster VFAs is ongoing, and VFAs are available with gain-bandwidth products in the low UHF range at the time of this writing. However, CFAs are available with gain-bandwidth products more than an octave higher than their VFA cousins and are also capable of operating as amplifiers very near their gain-bandwidth products

CHAPTER 2: HIGH GAIN AMPLIFIER ARCHITECTURE

High gain amplifiers with fast settling times are needed for high-speed data converter applications. Cascading amplifiers is generally a good way to achieve the desired open loop gain however; stability and settling speed become a concern. A cascading architecture that is inherently stable and maintains good settling performance

$$\mathbf{A_f} = \frac{\mathbf{x_o}}{\mathbf{x_f}} = \frac{\mathbf{A}}{\mathbf{1 + A_F}} \sim \frac{\mathbf{1}}{\mathbf{F}}$$

Where **x** is Voltage/Current

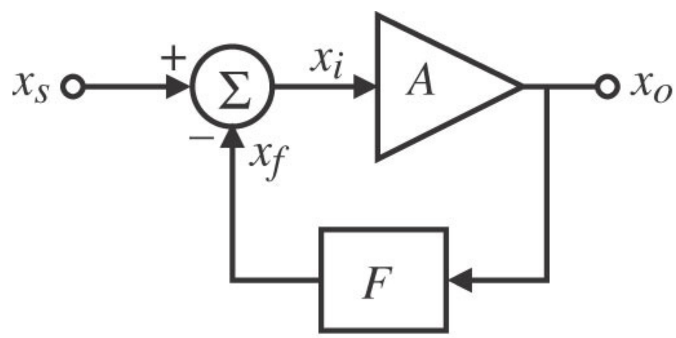


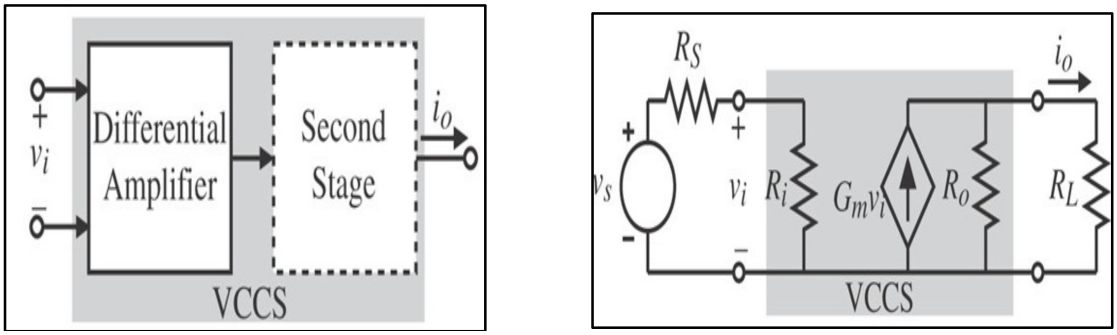
Figure 2.1 High Gain Architecture Model

2.1 Different Types of High Gain Amplifier:

1) ***Voltage Controlled Current Source Amplifier*** **(*VCCS)*-:** This amplifier has voltage as input and current as output. It has two stages i.e. differential amplifier and second stage shown in fig 2.2(a) and its small signal diagram is shown in fig.2.2(b) G is the transconductance.

$$\mathbf{G_M} = \frac{\mathbf{G_m R_o R_i}}{(\mathbf{R_i + R_s})(\mathbf{R_o + R_L})}$$

Ideally in VCCS, $R_i \& R_o \rightarrow \infty$, $\mathbf{G_M} \rightarrow \mathbf{G_m}$



(a) (b)

Figure 2.2 (*a*) Block Diagram of VCCS (*b*) Small Signal Diagram Of VCCS

Stages Of VCCS

1. **Differential Stage:** Voltage Differential Amplifier is used in this stage.

Voltage Differential Amplifier can be made using following

a. N channel

b. P channel

c. Current Mirror

Out of these three configurations Differential Amplifier using Current Mirror Load is preferred.

2. Second Stage: This stage is for obtaining high value of output resistance. Inverter or Cascode circuits are used in this stage. This stage is shown dotted because it's not compulsory to add this stage to the circuit, it's only as per requirements.VCCS must have high input resistance and high output resistance and large Transconductance gain.

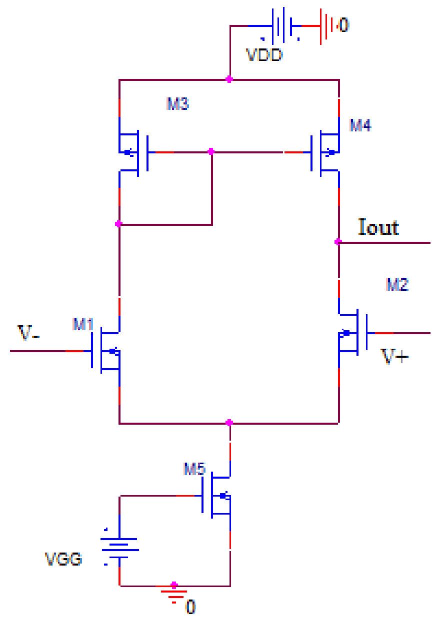
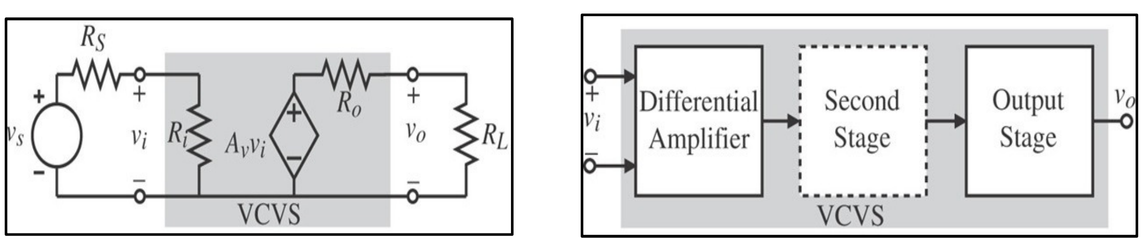


Figure 2.3 Circuit Diagram of VCCS

2) VCVS-Voltage Controlled Voltage Source Amplifier

This circuit has voltage as input and output.



(a) (b)

Figure 2.4 (a) Block Diagram of VCVS (b) Small Signal Diagram Of VCVS

$$A_V = \frac{A_v R_L R_i}{(R_i+R_s)(R_o+R_L)}$$ (A_V is the voltage gain.)

Ideally in VCVS $R_i \to \infty$ $R_o \to 0$ Then, $A_V \to A_v$

VCVS has 3 stages namely:

1. **Differential Stage:** As mentioned above in VCCS.
2. **Second Stage:** As mentioned in VCCCS.
3. **Output Stage**: This stage is basically I-V convertor providing high gain for the circuit.

   We use following circuits for output stage

   a. Class A

   b. Push Pull

   c. Source Follower(Current Sink Load)

   Usually in output stage we use combination of 2 circuits, one is Class A for high gain and Source Follower for improvement in resistance value.

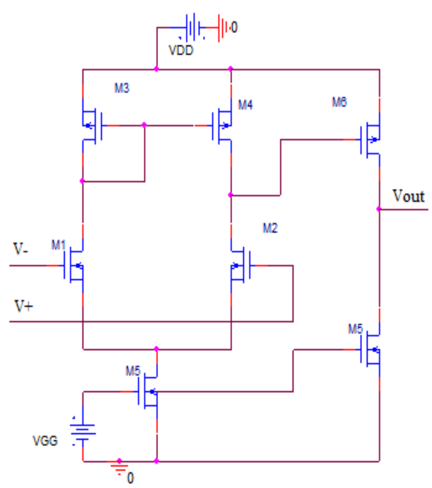
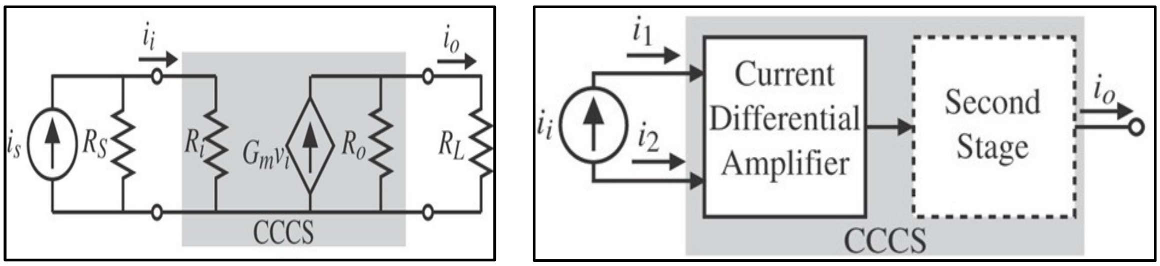


Figure 2.5 Circuit Diagram of VCVS

3) CCCS-Current Controlled Current Source Amplifier

In CCCS input and output both are Current.



(a) (b)

Figure 2.6 (a) Block Diagram of CCCS (b) Small Signal Diagram Of CCCS

$$\mathbf{A_I} = \frac{\mathbf{A_i R_s R_o}}{\mathbf{(R_i+R_s)(R_o+R_L)}} \qquad (\mathbf{A_I} \text{ is the Current Gain.})$$

Ideally in CCCS $R_i \to 0$ $R_o \to \infty$ Then, $\mathbf{A_I \to A_i}$

CCCS has 2 stages namely:

1. **Differential Stage:** In this stage Current Differential Amplifier is used. Two types of Current Differential Amplifier that can be used as per input requirements are :
   a. Single Ended- for single input.
   b. Differential Ended with Current Mirror- for two inputs.
2. **Second Stage**: This stage is for obtaining high value of output resistance. Inverter or Cascode circuits are used in this stage. This stage is shown dotted because it's not compulsory to add this stage to the circuit, it's only as per requirements.

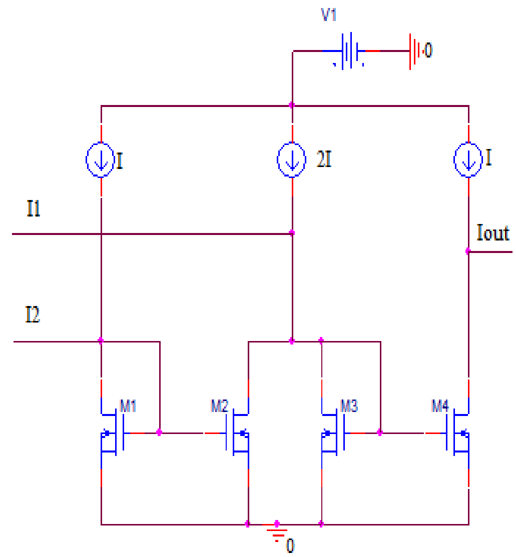
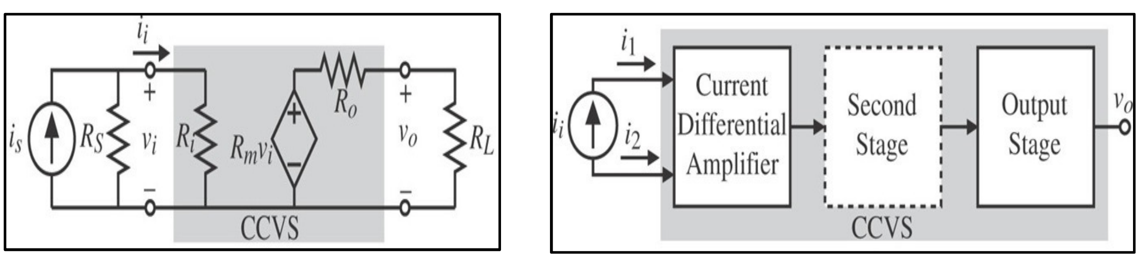


Figure 2.7 Circuit Diagram of CCCS

4) CCVS-Current Controlled Voltage Source Amplifier

In CCVS input is current and output is voltage.



(a) (b)

Figure 2.8 (a) Block Diagram of CCVS (b) Small Signal Diagram Of CCVS

$$\mathbf{R_M} = \frac{\mathbf{R_m R_s R_L}}{\mathbf{(R_i+R_s)(R_o+R_L)}}$$ ($\mathbf{R_M}$ is the Trans-resistance)

Ideally in CCVS $\mathbf{R_i \to 0}$ $\mathbf{R_o \to 0}$ Then, $\mathbf{R_M \to R_m}$

CCVS has 3 stages namely:

1. **Differential Stage**: As mentioned in CCCS.
2. **Second Stage**: As mentioned in CCCS.
3. **Output Stage**: This stage is basically I-V convertor providing high gain for the circuit.

   We use following circuits for output stage

   a. Class A
   b. Push Pull
   c. Source Follower(Current Sink Load)

Usually in output stage we use combination of 2 circuits, one is Class A for high gain and Source Follower for improvement in resistance value.

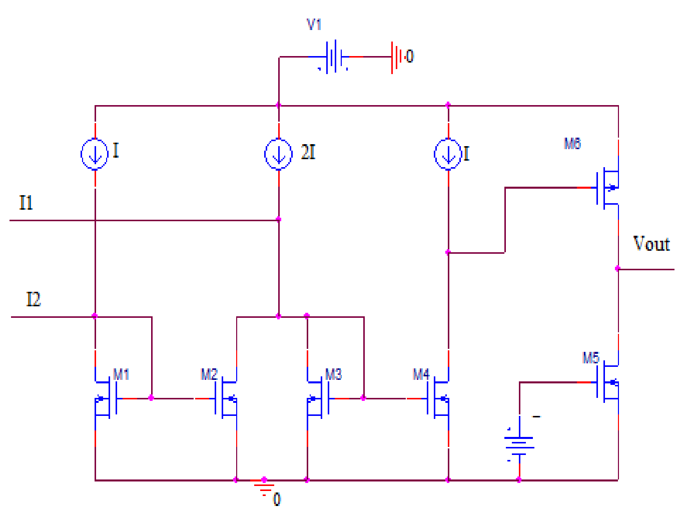


Figure 2.9 Circuit Diagram of CCVS

2.2 DIFFERENTIAL AMPLIFIER

The input is applied only to the inverting terminal as well as non inverting terminal ground. The op-amp amplifies the difference between the two signals.

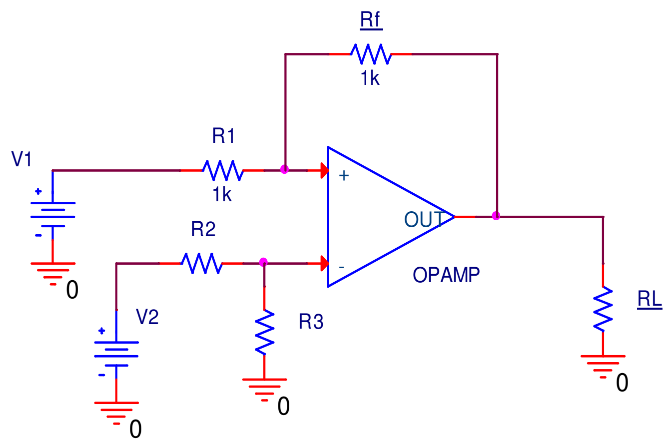


Figure 2.10 Differential Amplifier

1. DIFFERENTIAL AMPLIFIER USING NMOS TRANSISTOR:

This is a complete circuit differential amplifier and no pull of pull down is there, otherwise it will become CMOS transistor. It consists of differential inputs called source coupled pair. The V_{dd} is used to provide load.

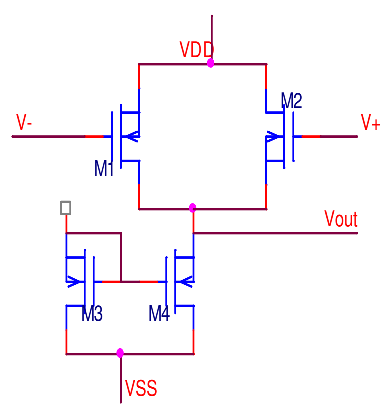


Figure 2.11 Differential Amplifier using NMOS Transistor

2. DIFFERENTIAL AMPLIFIER USING PMOS TRANSISTOR:

It consists of pull up network which act as load. It doesn't exactly provide output of differential amplifier. Thus we add current mirror load then it exactly works as differential amplifier.

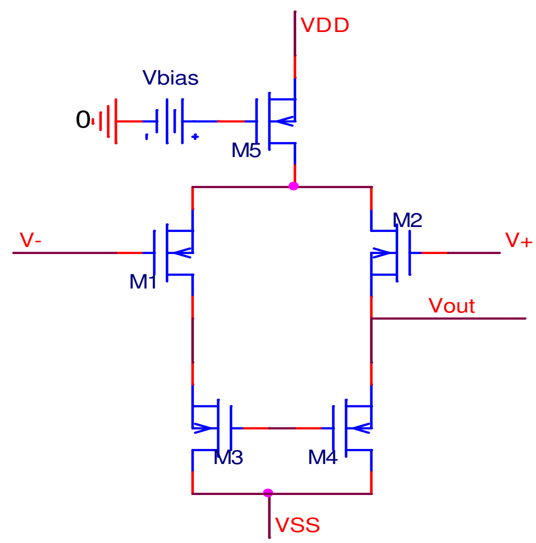


Figure 2.12 Differential Amplifier using PMOS Transistor

3.DIFFERENTIAL INPUT USING CURRENT MIRROR: It is the main CMOS differential amplifier used for operation amplifer.M4 is in saturation condition .Current mirror act as load. It also consist of differential inputs which are also called source coupled pair which as a load.

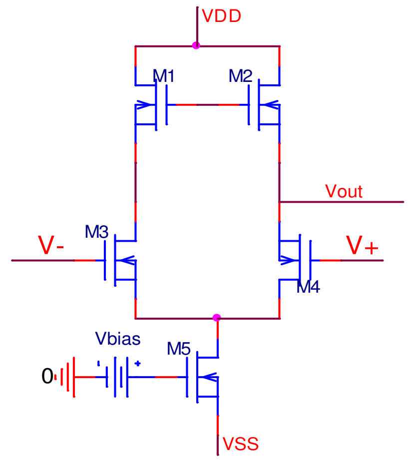


Figure 2.13 Differenial Input Using Current Mirror

Calculation of W/L ratio for current mirror load differential amplifier

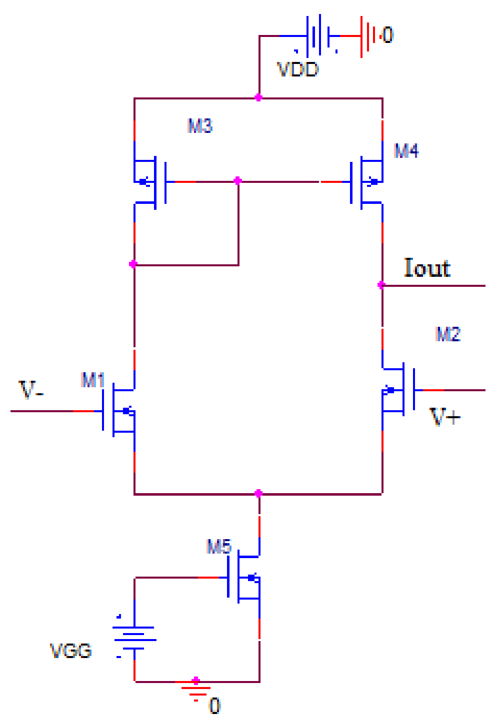


Figure 2.14 Current Mirror Load Differential Amplifier

FOR PARAMERTERS :

V_{DD}=-V_{SS}=2.5V, $k`_N$=110µA/$V^2$, $k`_P$=50µA/V^2,V_{IN}=0.7V, V_{TP}=-0.7V, λ_N=0.04V^{-1}, λ_P=0.05V^{-1} , SR >10V/µs, C_L=5PF, GAIN=100V/V, -1.5V < ICMR < 2V, P_{DIS} < 1MW

a. To evaluate the value of I_5

$$\boldsymbol{I_5 = Slew\,rate.C_i}$$

From the given parameters put the values

$$I_5 = (10).(5)$$

$$\boldsymbol{I_5 = 50\mu A}$$

Now

$$\boldsymbol{P_{dis} = (V_{DD} + |V_{th}|).I_5}$$

$$1mW = (2.5 + 2.5)I_5$$

$$1mW = 5(I_5)$$

I_5=200µA

Now, we get

I_5=50µA from **slew rate**

And

I_5=200µA from **power dissipation**

Choose Mid-Value of them

I_5=100µA (let)

Then.

Current comes from both the N-MOS is 100/2 i.e. **50µA**

b. Maximum input common mode voltage gives

$$\boldsymbol{V_{ic(max)} = V_{dd} - V_{sg3} - V_{ds1} + V_{gs1}} \qquad ....(i)$$

Now, as we know $V_{ds1} = V_{gs1} - V_{thn}$

Replace the value of $V_{gs1} - V_{ds1}$ by V_{thn}

Put in equation ....(i)

So we get,

$$V_{ic(max)} = V_{dd} - V_{sg3} + V_{thn} \qquad ....(ii)$$

From the give parameter ,put the value in equation (ii)

$$2V = 2.5V - V_{sg3} + 0.7$$

$$V_{sg3} = 1.2V$$

Now, current equation for PMOS at **saturation** is given by:

$$I_D = \frac{\beta_p(V_{sg} - |V_{thp}|)}{2}$$

$$V_{sg} - \left|V_{thp}\right| = \sqrt{\frac{2I_D}{\beta_P}}$$

$$\text{As , } \beta_P = K'_P.\frac{W}{L}$$

$$V_{SG} = \sqrt{\frac{2I_D.L}{K'_P.W}} + |V_{th}|$$

Now, put the values of given parameters in the above equation,

$$+1.2 = \sqrt{\frac{2.50.L}{50.W}} + |-0.7|$$

$$0.5 = \sqrt{\frac{2L}{W}}$$

$$0.28 = \frac{2L}{W}$$

$$\mathbf{\frac{W_3}{L_3} = \frac{W_4}{L_4} = \frac{200}{25} = \frac{8\mu m}{1\mu m}}$$

This is $\frac{W}{L}$ ratio for the **current mirror** of the above circuit.

c. Small signal gain gives

Gain=$G_{m1}.R_{out}$=100V/V

$$\boldsymbol{A_v = \frac{g_{md}}{g_{ds2} + g_{ds4}}}$$

$$g_{ds2} = \boldsymbol{\lambda}_N . I_D$$

$$g_{ds4} = \boldsymbol{\lambda}_P . I_D$$

$$g_{ds2} = 0.04\ .\ 50 = 2\mu v^{-1} amp$$

$$g_{ds4} = 0.05\ .\ 50 = 2.5\mu v^{-1} amp$$

Also $\quad g_{sd} = \sqrt{\frac{2I_D.K_N'.W}{L}}$

$$100 = \sqrt{\frac{W.2.50.110}{L}}$$

$$100^2 = \frac{W.100.110}{L}$$

$$\mathbf{\frac{W_1}{L_1} = \frac{W_2}{L_2} = \frac{18.41\mu m}{1\mu m}}$$

This W/L is for **differential input** of the above circuit

d. Using minimum input common mode voltage

$$\boldsymbol{V_{ic(min)} = V_{ss} + V_{ds5(max)} + V_{gs1}} \quad .....(iii)$$

As $I_D = \frac{\beta_n(V_{gsn}-V_{th})}{2}$

$$V_{gs1} = \sqrt{\frac{I_{D2}}{\beta_n}} + V_{thn}$$

Obtain V_{gs1} by putting the given parameters in above equation

$$V_{gs1} = \sqrt{\frac{50.2.L_1}{110.W_1}} + 0.7$$

$$V_{gs1} = \sqrt{\frac{10}{11\,.\,18.4}} + 0.7 \quad \left(As \quad \frac{W_1}{L_1} = \frac{18.4\mu m}{1\mu m}\right)$$

On solving we get

$$V_{gs1} = 0.70244V$$

Put the value of V_{gs1} in equation (iii)

$$-1.5V = -2.5 + V_{ds5} + 17.44$$

$$V_{ds5} = 0.1V$$

Now, $V_{ds5} = \sqrt{\frac{2I_5}{K_n'.\left(\frac{W_5}{L_5}\right)}}$ $(as\ M5\ in\ saturation\ state)$

Put the values of the given parameter in above,

$$0.1V = \sqrt{\frac{2.50}{110.(\frac{W_5}{L_5})}}$$

On solving we get,

$\mathbf{\frac{W_5}{L_5} = \frac{90.9\mu m}{1\mu m}}$ [This W/L is for **Current sink.**]

2.3 OUTPUT AMPLIFIERS : CMOS output amplifier is to function as a current transformer. Most of output amplifier has a high current gain and low voltage gain.

The specific requirements of an output stage might be

1. It provides sufficient output power in the form of voltage or current.

2. It avoid signal distortion,

3. It Provide protection from abnormal condition

Different types of output amplifiers :

a. Class A b. Source Follower c. Push-Pull

a. **CLASS A**: It reduces the output resistance and increase the current driving capability, a straight forward approach is to increase the bias current in the output stage. Also called CMOS inverter with current source load.

$$R_{out} = \frac{1}{g_{ds1}+g_{ds2}} \qquad R_{out} = \frac{1}{(\lambda_1+\lambda_2).I_D}$$

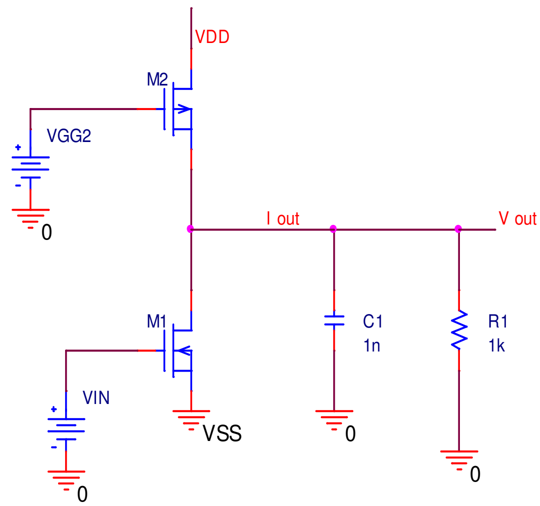


Figure 2.15 Class A Amplifier

b. **PUSH-PULL:** It consists of P-MOS and N-MOS transistor. Both the transistor are given same input V_{in}.

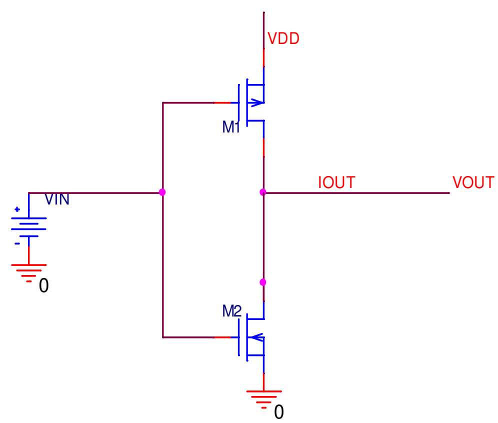


Figure 2.16 Push Pull Amplifier

c. **SOURCE FOLLOWER**:-This approach is for implementing an output amplifier by using the common drain or source follower configuration of the MOS transistor. This configuration has both large currents gain and low output resistance.

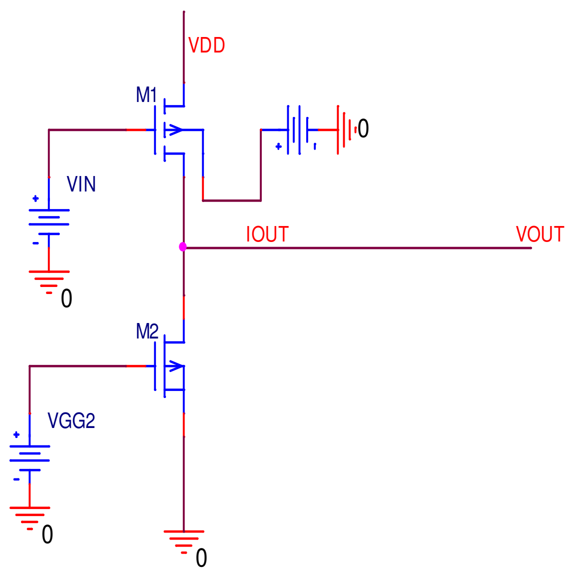


Figure 2.17 Source Follower

CHAPTER 3:CURRENT AMPLIFIER

INTRODUCTION

A current amplifier is an amplifier with low input resistance, high output resistance and defined relationship between the input and output currents. The current amplifier will typically be driven by a source with a large resistance and be loaded with a small resistance. Although the outputs of the current amplifiers are single-ended, they could easily be differential outputs.

There are several important advantages of a current amplifier compared with voltage amplifiers. The first is that currents are not restricted by the power supply voltages so the current will probably be converted into voltages, which mat limit this advantage. The second advantage is that -3 dB bandwidth of a current amplifier using negative feedback is independent of the closed-loop gain. If we assume that the small-signal input resistance looking into the + and – terminals of the current differential amplifier is smaller than R_1 or R_2 then we express i_0 as

$$i_0 = A_i(i_1 - i_2) = A_i(\frac{V_{in}}{R_i} - i_0)$$

Advantages of using Current feedback:

1. In Current feedback nodes are low impedence. Nodes where resultant voltage swings are also small
2. The bandwidth is quite high.
3. Slew Rate is high if rate of output is high.

4. Current amplifiers have simple architecture and their operations don't depend on supply voltages.

3.1 TYPES OF CURRENT AMPLIFIERS

a. Single Ended

b. Differential Input Current Mirror

a. SINGLE ENDED: It consist of the current mirror load .In this circuit we are given the input current across one of the N-MOS and obtain the output current across other N-MOS as shown in **fig. 3.1(a)**

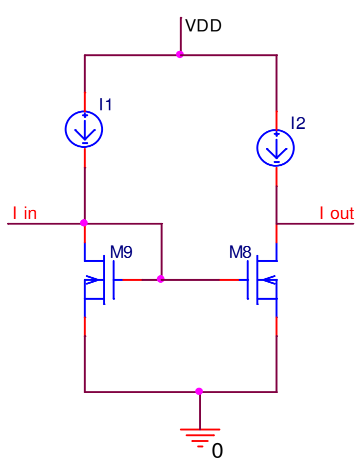


Figure 3.1 Single Ended Differential Input

$$R_{in} = \frac{1}{g_m}; \qquad R_{out} = \frac{1}{\lambda_1 . I_2}; \qquad R_i = \frac{W_2/L_2}{W_1/L_1}$$

b. DIFFERENTIAL INPUT

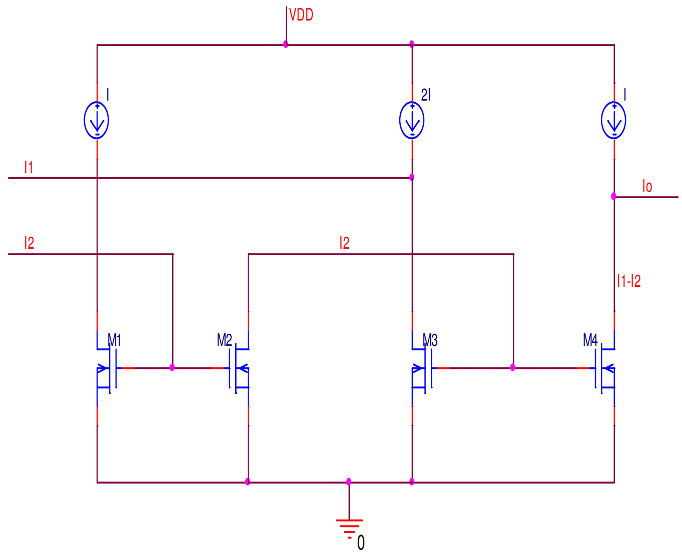


Figure 3.2 Current Amplifier using Current Mirror

$$i_o = A_{id}.i_{id} \pm A_{ic}.i_{ic}$$

$$i_o = A_{id}(i_1 - i_2) \pm A_{ic}(\frac{i_1 + i_2}{2})$$

Different types of Differential current amplifiers:

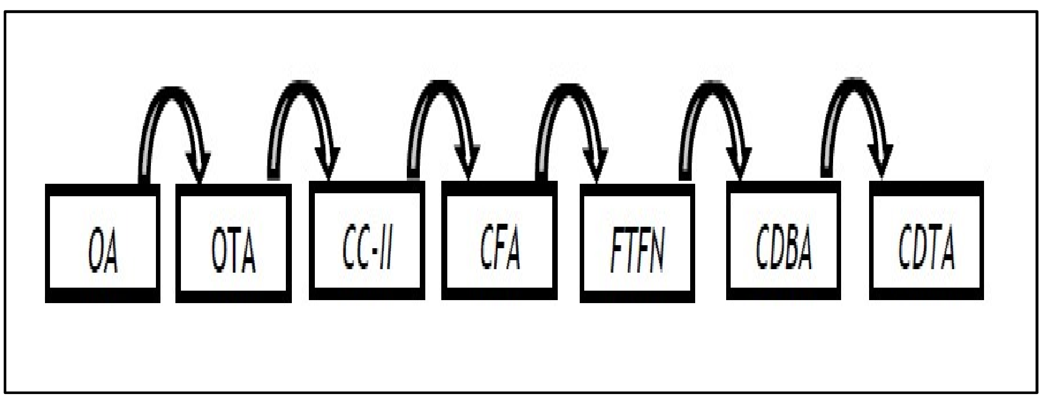


Figure 3.3

1. ***TWO STAGE CMOS OPERATIONAL AMPLIFIER :*** Main target is to design the 2 stage operational amplifier. It consists of four different stages:

a) Classic Differential amplifier (voltage to current)

b) Differential to single ended load (Current mirror) (current to voltage)

c) Transconductance Grounded gate (voltage to current)

d) Class A (source or sink load) (current to voltage)

The circuit diagram of two stage CMOS operational amplifier with its division in 4 stages is shown in Fig .

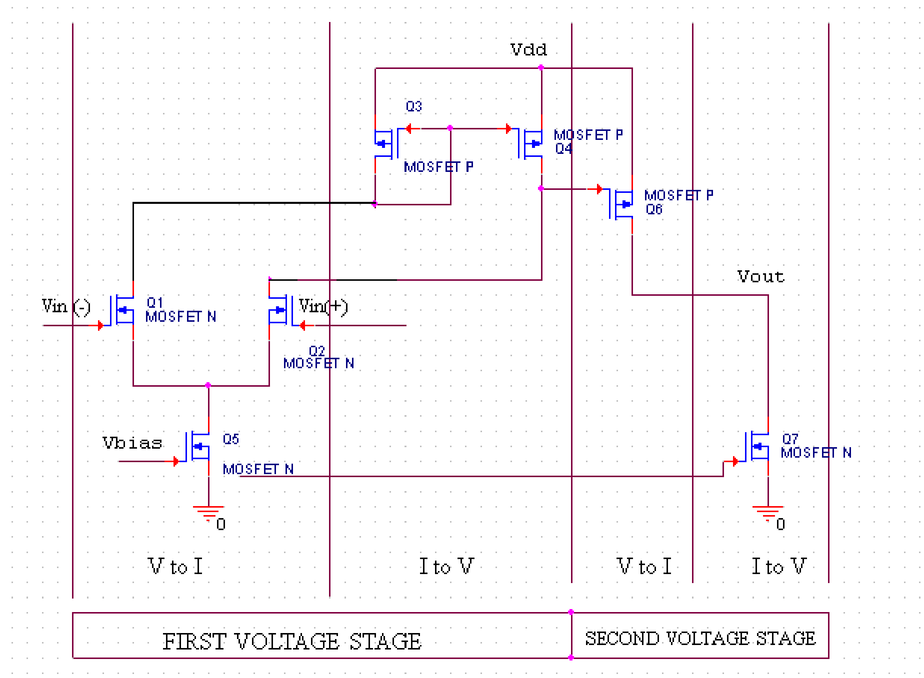
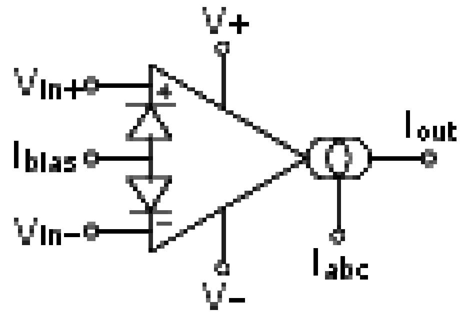
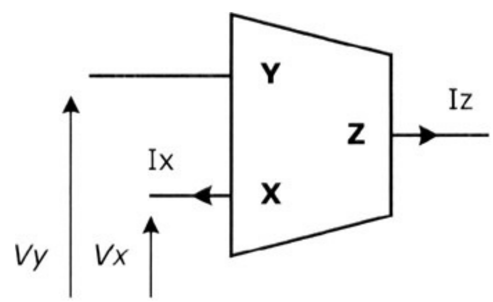


Figure 3.4 Two stage CMOS operational amplifier

2. **Operational Transconductance Amplifiers (OTAs)** are the essential active building blocks of many analog applications such as amplifiers, multiplier, active filters and sinusoidal oscillators. Moreover, they can also be applied in automatic gain control and analog multiplier circuits when the transconductance gain of the OTA can be electronically and linearly varied.

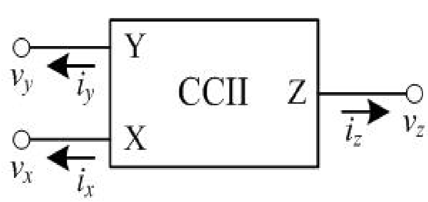


3. **CURRENT CONVEYOR :** It's a 3 terminal analogue electronic device. It is form of electronic amplifier with unity gain. It has 3 versions CCI, CCII, CCIII. These can perform analogue signal processing like Op-Amps do.



a) **First Current Conveyor (CCI) :** It was the first generation current conveyor amplifier. It contains x,y,z terminals, voltage is applied at x, y terminals. Whatever flows into y also flows into x is mirrored at z with high output impedence.

b) **Second Generation Current Conveyor (CCII) :** It was made after success of CCI amplifiers. In this no current flow through y. Ideal CCII can be seen as ideal transistor.

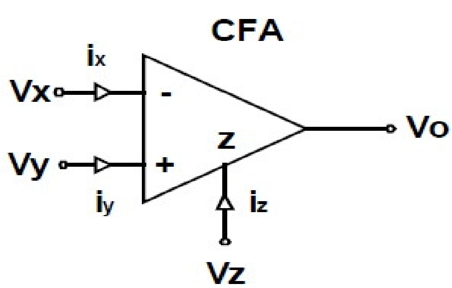


The circuit characteristics can be shown as below:

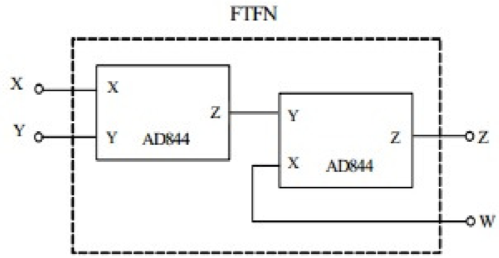
$$\begin{bmatrix} i_y \\ v_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 0 & 0 \end{bmatrix} \begin{bmatrix} v_x \\ i_x \\ v_z \end{bmatrix}$$

c) **Third Generation Current Conveyor (CCIII) :** The third generation current conveyor is similar to the CCI except the current in x is reversed.

4. **Current Feedback Amplifiers:** Current feedback refers to any closed-loop configuration in which the error signal used for feedback is in the form of a current. A current feedback op amp responds to an error current at one of its input terminals, rather than an error voltage, and produces a corresponding output voltage. The ideal voltage feedback amplifier has high-impedance inputs, resulting in zero input current, and uses voltage feedback to maintain zero input voltage. Conversely, the current feedback op amp has a low impedance input, resulting in zero input *voltage*, and uses current feedback to maintain zero input *current*.



5. **Four Terminal Floating Nullor (FTFN):** It provides floating output, which is very useful in some application such as current-amplifiers, voltage to current converters, gyrators, floating impedances etc.. Besides being flexible, FTFN is a more all-round building block than the operational amplifier and current conveyor.



The port characteristics can be defined as :

$$I_y = I_x = 0; V_x = V_y; I_z = I_w$$

The output impedance of W and Z port of an FTFN are arbitrary. In the present analysis that output impedance of W-port has been considered to be very low and that of the Z-port very high. FTFN based structure provides a number of potential advantage such as complete absence of the passive component matching requirement, minimum number of passive elements.

All four basic type amplifiers: Voltage Amplifier, Current Amplifier, Transconductance Amplifier and Transresistance Amplifier may be realized with FTFN.FTFN is therefore called a universal amplifier.

6. **Current Differencing Buffered Amplifier (CDBA):** A CDBA is a five terminal active component useful for realizing of class of analog signal processing circuits. It can be operated both in voltage as well as current mode. The current difference at input is converted to voltage V_W and is connected to z. CDBA is made of 2 parts namely DCCCS and voltage buffer. DCCCS is obtained by little modification of CCII. Voltage buffer amplifier is used to transfer a voltage from a first circuit, having high impedence to second circuit with low impedence. It basically prevents

2^{nd} circuit from loading effect the first circuit. The characteristics equation for this element is given as:

1. $V_p = V_n = 0$ 2. $I_z = I_p - I_n$ 3. $V_w = V_z$

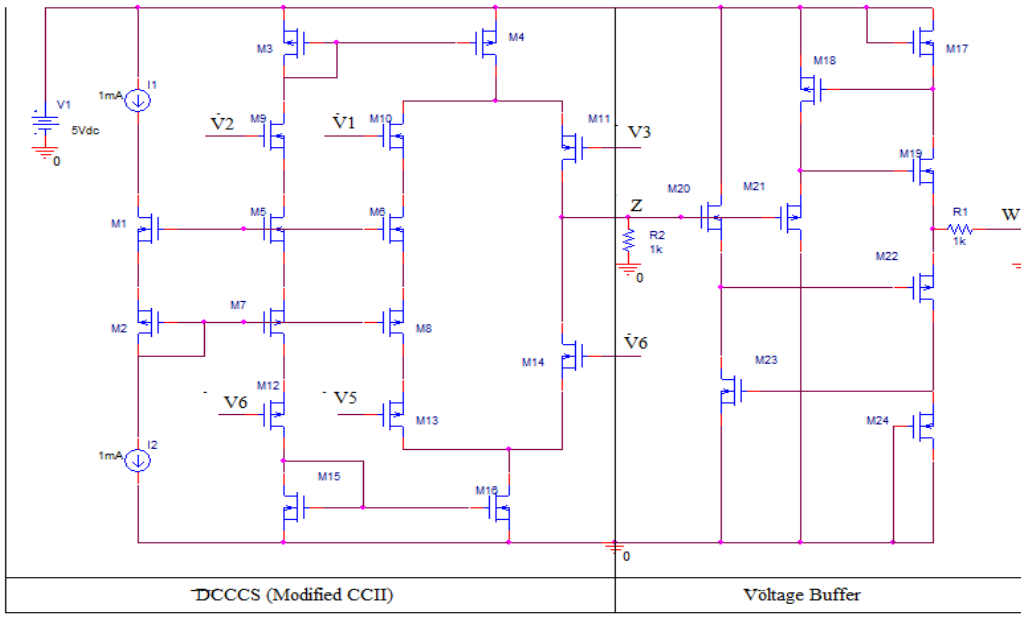
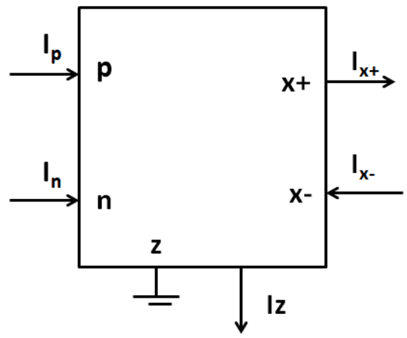


Figure 3.5 Circuit Diagram for CDBA

7. **Current Differencing Transconducting Amplifier(CDTA):** It is an active circuit element. The CDTA is free from parasitic input capacitances and it can operate in a wide frequency range due to its current-mode operation. It consists of the input current-differencing unit and of multiple-output OTA.Because of high current gain of the CDTA which is comparable to voltage gain of a classical voltage-feedback operational amplifier, the CDTA can be used as a current comparator



The equations defining CDTA are:

$$V_p = V_n = 0, \qquad I_z = I_p - I_n \qquad I_{z+} = g_m V_z \qquad I_n = -g_m V_z$$

The CDTA element takes the difference of the input signals and transfers it to z terminal The pair of output currents from the *x* terminals, shown in Figure 4 may have three combinations of directions:

1. Both currents can flow out.
2. The currents have different directions.
3. Both currents flow inside the CDTA element .

CHAPTER 4:OPERATIONAL TRANSCONDUCTANCE AMPLIFIER (OTA)

Introduction:

An operational transconductance amplifier (OTA) is a voltage controlled current source(VCCS) i:e it is an amplifier whose differential input voltage produces an output current. Earlier emphasis was on amplifiers with feedback, such as op-amps. Thus the commercial OTAs were not meant to be used in open loop mode. The maximum input voltage for typical bipolar OTA is of order of only 30mV, but with a transconductance gain tunability range of several decades. Since then, a number of researchers have investigated ways to increase the input voltage range and to linearise the OTA.

Principal differences from standard operational amplifiers:

1) Its output of a current contrasts to that of standard operational amplifier whose output is a voltage.
2) It is usually used "open-loop"; without negative feedback in linear applications. This is possible because the magnitude of the resistance attached to its output controls its output voltage. Therefore a resistance can be chosen that keeps the output from going into saturation, even with high differential input voltages.

Main Characteristics of practical OTA are:

1) Limited linear input voltage range

2) Finite Bandwidth

3) Finite signal to noise ratio(S/N)

4) Finite output impedence

4.1 Basic Operation:

In the ideal OTA, the output current is a linear function of the differential input voltage, calculated as follows:

$$\mathbf{I_{out} = (V_{in+} - V_{in-}).\, g_m}$$

Where V_{in+} is the voltage at the non-inverting input, V_{in-} is the voltage at the inverting input and g_m is the transconductance of the amplifier.The amplifier's output voltage is the product of its output current and its load resistance.

$$\mathbf{V_{out} = I_{out}.\, R_{load}}$$

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

$$\mathbf{g_{voltage} = \frac{V_{out}}{(V_{in+} - V_{in-})} = R_{load}.\, g_m}$$

The transconductance of the amplifier is usually controlled by an input current, denoted I_{abc} ("amplifier 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.

4.2 Types of operational transconductance amplifier:

1) Simple OTA 2) Fully Differential OTA 3) Balanced OTA

1. **Simple Operational Transconductance Amplifier:**It is the basic operational transconductance amplifier with only a current- mirror circuit, a differential input and a current sink inverter. Although simple OTA's are single input these are unsymmetrical an is not considered for analysis. We have used differential amplifier as current mirror load as simple OTA. The equations and analysis part remains the same as discussed above. The parameters calculated are presented in table **6.7.**

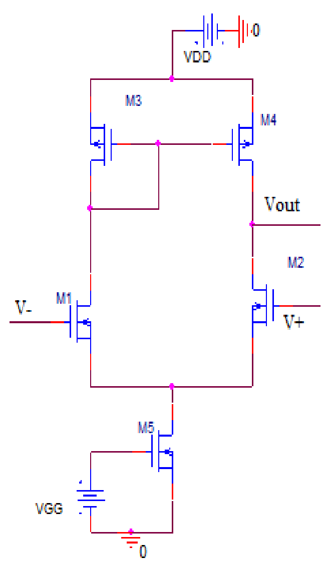


Figure 4.1 Circuit Diagram of Simple OTA

2 . Fully Differential Operational Transconductance Amplifier: Fully differential operational transconductance amplifier contains simple inversely connected current-mirror pairs. These current mirror pairs are used as active load in the circuit. Along with these current mirror pair we have a differential circuit for which we have differential inputs. We also have a current sink inverter attached to the differential circuit. This amplifier is fully symmetrical and their main advantage is due to these characteristics only.

The equations stated above in section 2.2 remains same for fully differential OTA. The (W/L) values are taken same as calculated above.

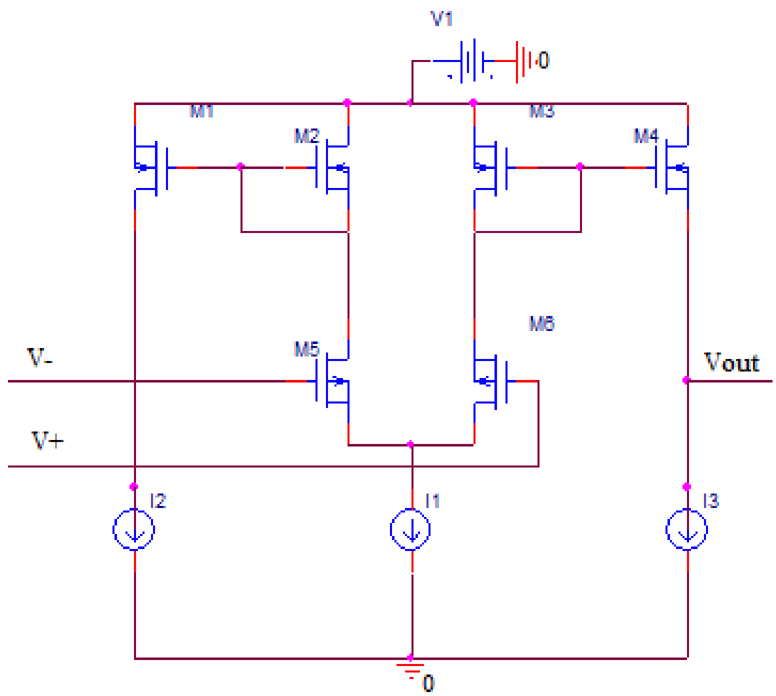


Figure 4.2Circuit Diagram of Fully Differential OTA

The circuit shown in Fig 4.2 is taken and various parameters are calculated. The circuit illustrates in fig 4.3(c) is the ***proposed circuit*** in which there are few changes compared to circuit and is simple and suitable for implementation. In this circuit instead of current source I1 we have used current sink load. The other difference is using of 2 pmos current mirror pairs and 1 pair of nmos. Different parameters are calculated for both these circuits and are presented and compared in table 4.3.

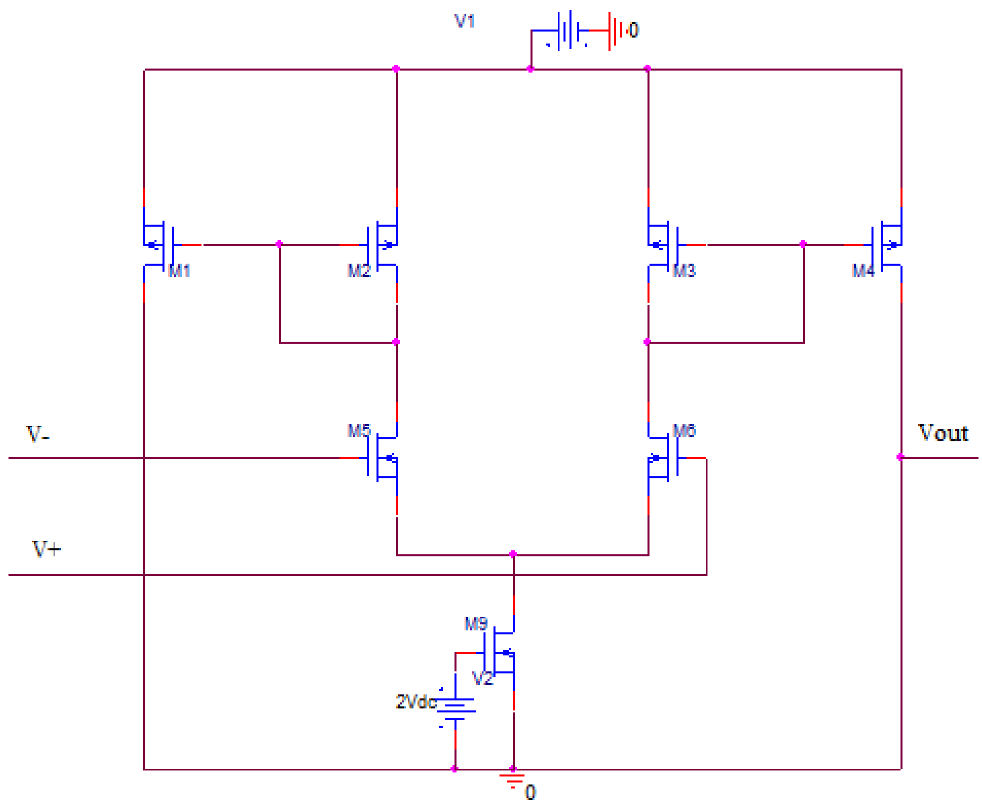


Figure 4.3 Circuit Diagram Of Fully Differential OTA Proposed

3 Balanced Operational Transconductance Amplifier (BOTA):

BOTA is the modified circuit of the two discussed above. It contains three current mirrors, a differential circuit and a current sink inverter. These are symmetrical too and have better parameters than the two discussed above. The parameters are discussed in the table **4.3.**

The main advantage of BOTA is that filters realized using BOTA provide more simplify structures and perform better performance in higher frequency range than the single output OTA'S.

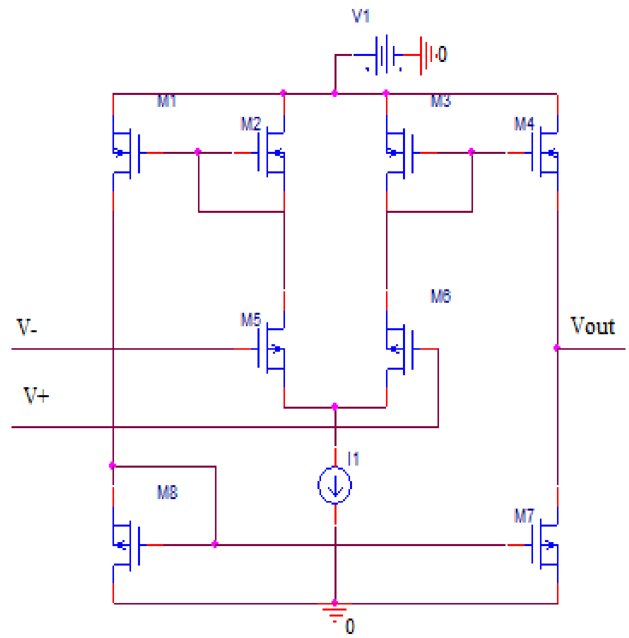


Figure 4.4 Circuit Diagram Of Balanced OTA.

The difference between the two Balanced OTA i:e the one taken from the reference no and the one that is proposed is adding the current sink load and removing current source I1. The other difference is using of 2 pmos current mirror pairs and 1 pair of nmos

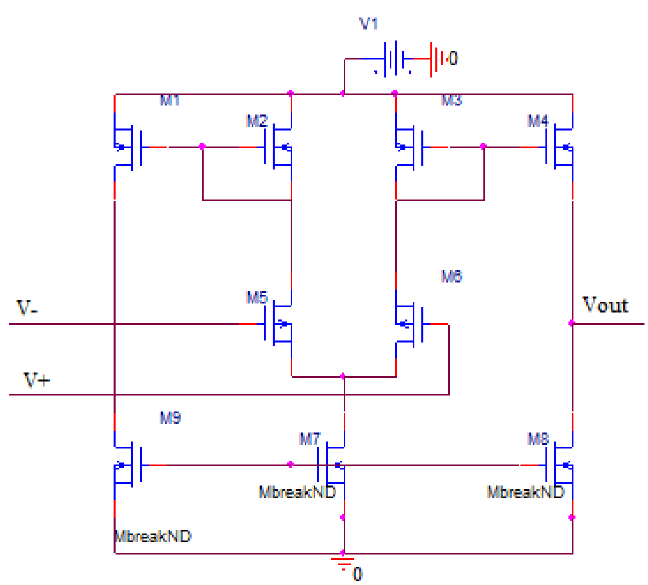
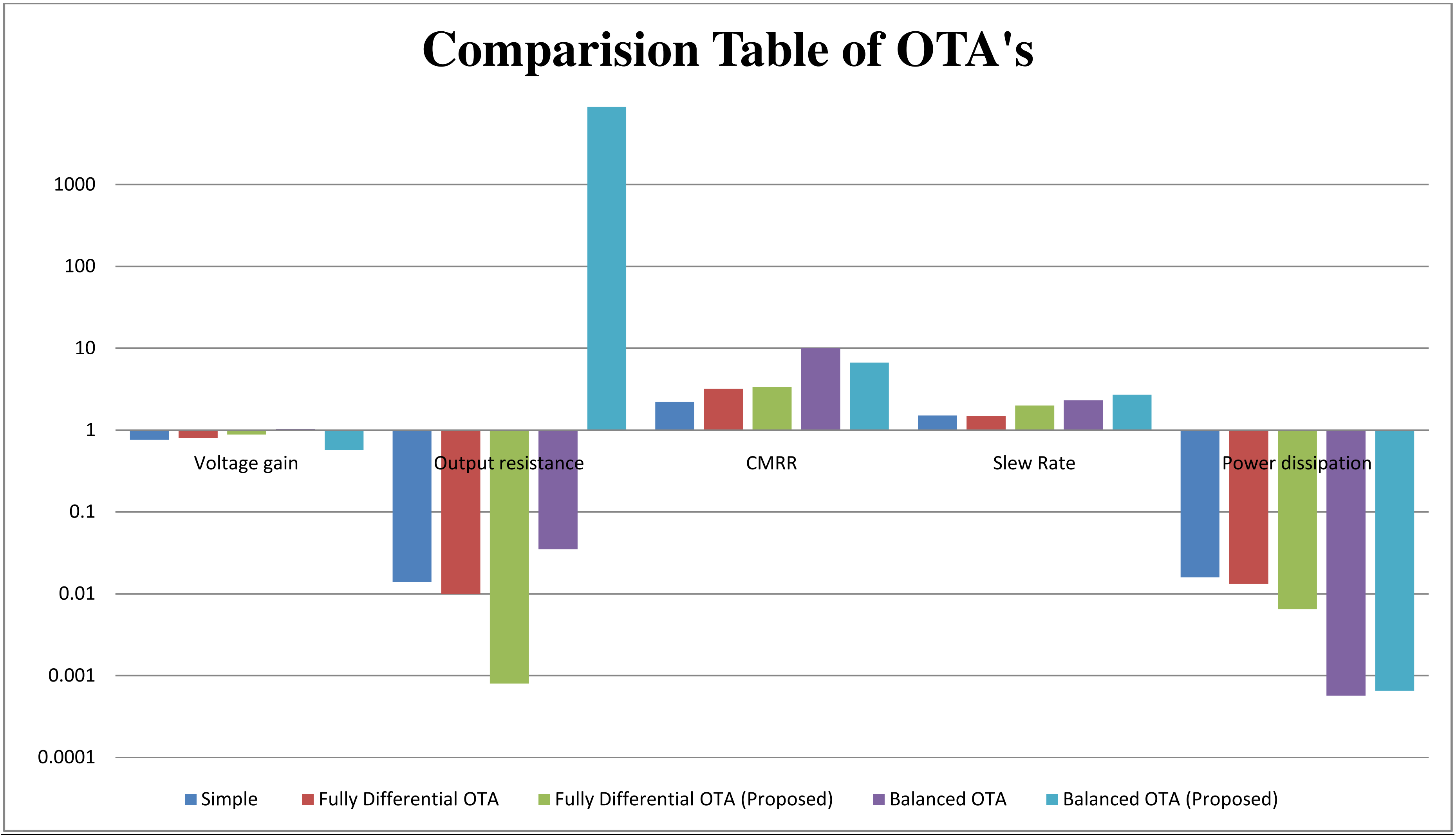


Figure 4.5 Circuit Diagram of Proposed Balanced OTA

Comparison Table:

Table 4.1 Parameters for different OTA's

Parameters	**Simple OTA**	**Fully Differential OTA**		**Balanced OTA**	
		From ref no 6	**Proposed**	**From ref no 6**	**Proposed**
Voltage Gain	0.76	0.8	0.883	1.03	0.57
Input Resistance(ohm)	1.00E+20	1.00E+20	1.00E+20	4.50E+05	4.50E+05
Output Resistance(ohm)	1.39E-02	1.00E-02	8.00E-04	3.50E-02	8.87E+03
CMMR(dB)	2.2	3.2	3.36	10.03	6.635
Slew Rate(V/us)	1.5	1.49	2	2.32	2.7
Power Dissipation(Watts)	1.59E-02	1.32E-02	6.50E-03	5.72E-04	6.52E-04



Comparision Table of OTA's
1000
100
10
1
0.1
0.01
0.001
0.0001
Voltage gain
Output resistance
CMRR
Slew Rate
Power dissipation
Simple
Fully Differential OTA
Fully Differential OTA (Proposed)
Balanced OTA
Balanced OTA (Proposed)

CHAPTER 5:FILTERS

5.1 Active Low Pass Filter:

The most common filter is the **Low Pass Filter**. It uses an op-amp for amplification and gain control. The simplest form of a low pass active filter is to connect an inverting or non-inverting amplifier to the basic RC low pass filter circuit as shown.

a) First Order Active Low Pass Filter:

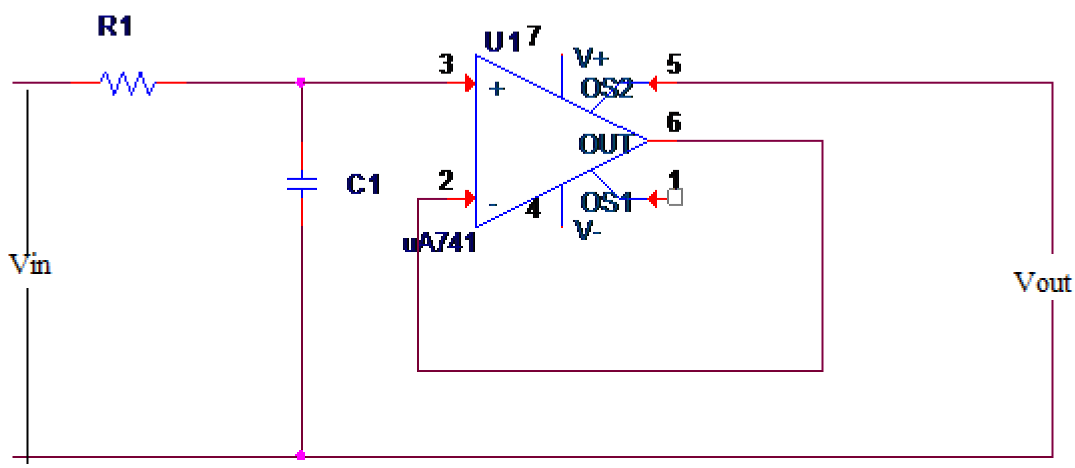


Figure 5.1 First Order Active Low Pass Filter

This first-order low pass active filter, consists of a passive RC filter stage providing a low frequency path to the input of a non-inverting operational amplifier. The amplifier is configured as a voltage-follower giving Av = +1 .

The advantage of its configuration is that the op-amps high input impedance prevents excessive loading on the output while its low output impedance prevents the filters cut-off frequency.

Gain of a first-order low pass filter:

$$Voltage\ gain, (A_V) = \frac{V_{OUT}}{V_{IN}} = \frac{A}{\sqrt{1 + \left(\frac{f^2}{f_C{}^2}\right)}}$$

Where:

A = the pass band gain of the filter, (1 + R2/R1)

f = the frequency of the input signal in Hertz, (Hz)

fc = the cut-off frequency in Hertz, (Hz)

Thus, the operation of a low pass active filter can be verified from the frequency gain equation above as:

1. At very low frequencies, $f < f$c $\quad \frac{V_{OUT}}{V_{IN}} = A$

2. At the cut-off frequency, $f = f$c $\quad \frac{V_{OUT}}{V_{IN}} = \frac{A}{\sqrt{2}} = 0.707A$

3. At very high frequencies, $f > f$c $\quad \frac{V_{OUT}}{V_{IN}} < A$

Magnitude of Voltage Gain in (dB):

$$A_V(dB) = 20\log_{10}\left(\frac{V_{OUT}}{V_{IN}}\right)$$

$$-3dB = 20\log_{10} 0.707\frac{V_{OUT}}{V_{IN}}$$

b) Second-order Active Low Pass Filter Circuit

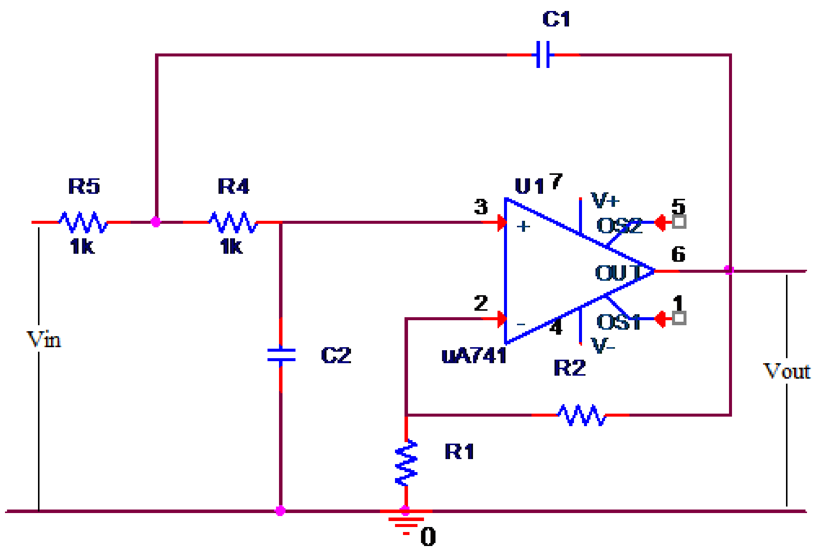


Figure 5.2 Second-order Active Low Pass Filter Circuit

5.2 Active High Pass Filter:

A first-order **Active High Pass Filter** attenuates low frequencies and passes high frequency signals. It consists simply of a passive filter section followed by a non-inverting operational amplifier. The frequency response of the circuit is the same as that of the passive filter and for a non-inverting amplifier the value of the pass band voltage gain is given as **1 + R2/R1.**

Active High Pass Filter with Amplification

a) First Order Active High Pass Filter

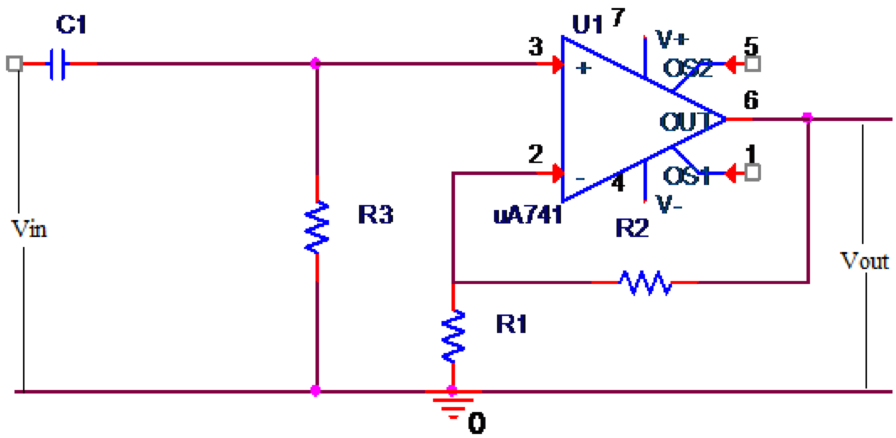


Figure 5.3 First Order Active High Pass Filter

Gain for an High Pass Filter:

$$\text{Voltage gain,}(A_V) = \frac{V_{OUT}}{V_{IN}} = \frac{A\left(\frac{F}{F_C}\right)}{\sqrt{1+\left(\frac{F}{F_C}\right)}}$$

Where:

A = the Pass band Gain of the filter, (1 + R2/R1)

f = the Frequency of the Input Signal in Hertz, (Hz)

fc = the Cut-off Frequency in Hertz, (Hz)

the operation of a high pass active filter can be verified from the frequency gain equation as:

1. At very low frequencies, $f < fc$ $\quad \frac{V_{OUT}}{V_{IN}} < A$

2. At the cut-off frequency, $f = fc$ $\frac{V_{OUT}}{V_{IN}} = \frac{A}{\sqrt{2}} = 0.707A$

3. At very high frequencies, $f > fc$ $\frac{V_{OUT}}{V_{IN}} \cong A$

Voltage Gain

$$(A_V) = \frac{V_{OUT}}{V_{IN}} = \frac{A\left(\frac{f}{f_C}\right)}{\sqrt{1+\left(\frac{f^2}{{f_C}^2}\right)}}$$

b) Second-order High Pass Active Filter:

A first-order high pass active filter can be converted into a second-order high pass filter simply by using an additional RC network in the input path. The frequency response of the second-order high pass filter is identical to that of the first-order type.

Second-order Active High Pass Filter Circuit:

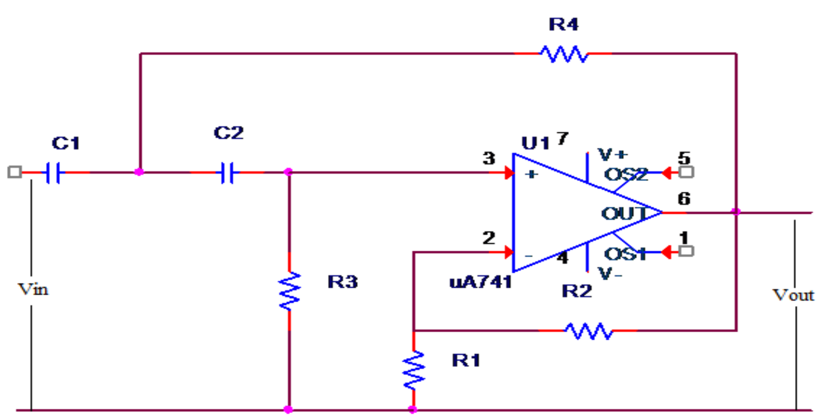


Figure 5.4 Second-order Active High Pass Filter Circuit

$A_V = 1 + \frac{R_2}{R_1}$ $f_C = \frac{1}{2\pi\sqrt{R_3 R_4 C_1 C_2}}$

Higher-order High Pass Filters are formed simply by cascading together first and second-order filters. For example, a third order high pass filter is formed by cascading in series first and second order filters, a fourth-order high pass filter by cascading two second-order filters together and so on.

Then an **Active High Pass Filter** with an even order number will consist of only second-order filters, while an odd order number will start with a first-order filter as shown.

5.3 Band Pass Filter:

The principal characteristic of a Band Pass Filter is its ability to pass frequencies relatively unattenuated over a specified band is called the PASS BAND.

For **low pass filter,** this band starts from **0Hz** and continues up to cut-off frequency point at **-3dB** down from the maximum pass band gain. But for **high pass filter,** the pass band starts from **-3dB** cut-off frequency and continues up to infinity.

The **Band Pass Filter** is used in electronic systems to separate a signal at one particular frequency, or a range of signals that lie within a certain range of frequencies from signals at all other frequencies. This range of frequencies is set between two cut-off frequency called the "lower frequency" (f_L) and the "higher frequency" (f_H) while attenuating any signals outside of these two points.

Simple **BAND PASS FILTER** can be easily made by cascading a **LOW PASS FILTER** with a **HIGH PASS FILTER** as shown below.

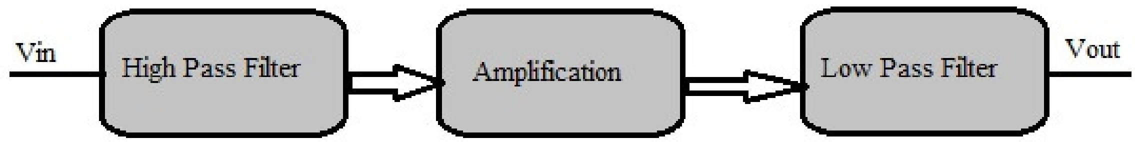


Figure 5.5

The cut-off frequency of the **low pass filter** (LPF) is higher than the cut-off frequency of the **high pass filter** (HPF) and the difference between the frequencies is called the "**bandwidth**" of the band pass filter .

Band Pass Filter Circuit

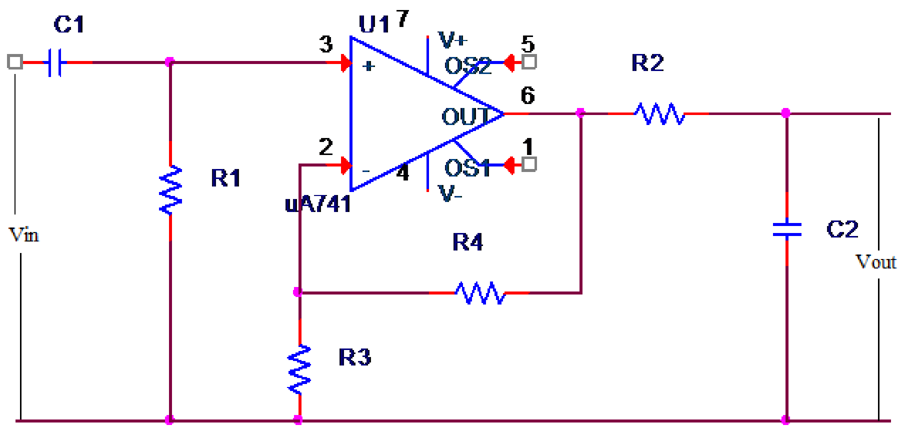


Figure 5.6 Band Pass Filter Circuit

The first stage consist of high pass stage that has capacitor to block any DC biasing from the source. This design has the advantage of producing a pass band frequency response with one half representing the low pass response and the other half representing high pass response as shown below.

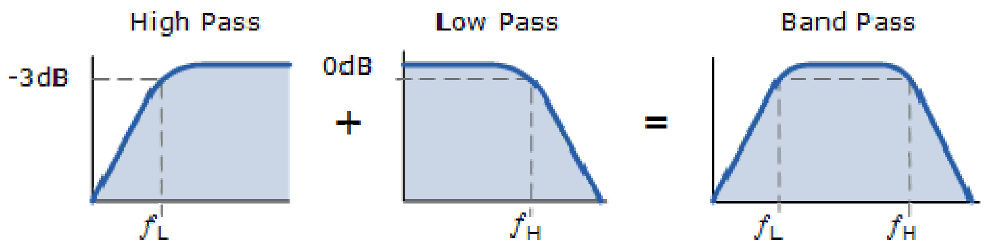


Figure 5.7

A reasonable separation is required between the two cut-off points to prevent any interaction between the low pass and high pass stages. The **amplifier** provides isolation between the two stages and defines the overall voltage gain of the circuit.

The bandwidth of the filter is the difference between these upper and lower -3dB points.

CHAPTER 6: DESIGN OF FILTERS USING 2 STAGE OPERATIONAL AMPLIFIER & OTA

6.1 CIRCUIT DIAGRAMS FOR LOW PASS FILTER

a) FIRST-ORDER LOW PASS FILTER USING 2 STAGE OP-AMP:

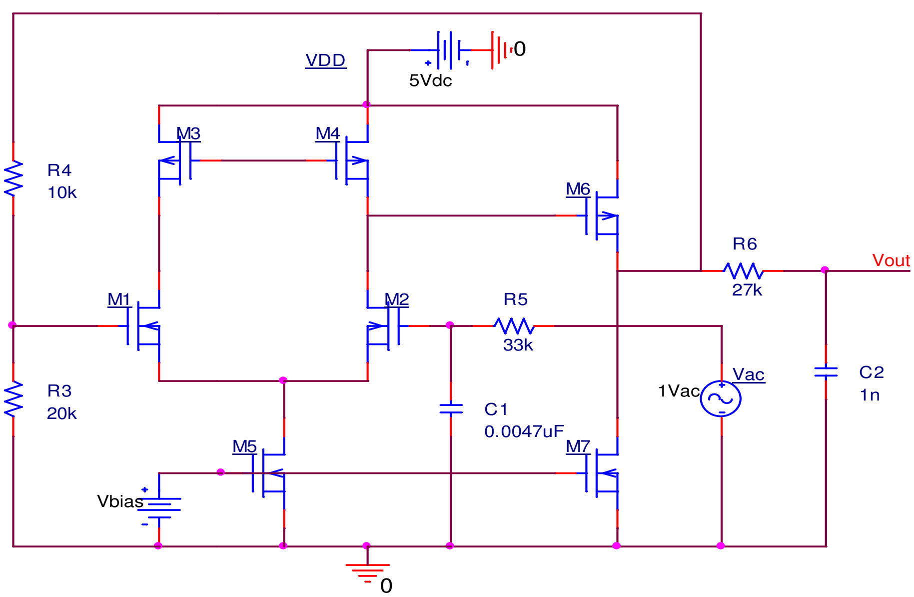


Figure 6.1 First-Order Low Pass Filter Using 2 Stage Op-Amp

OUTPUT WAVEFORM:

Figure 6.2

b) First Order Low Pass Filter using OTA

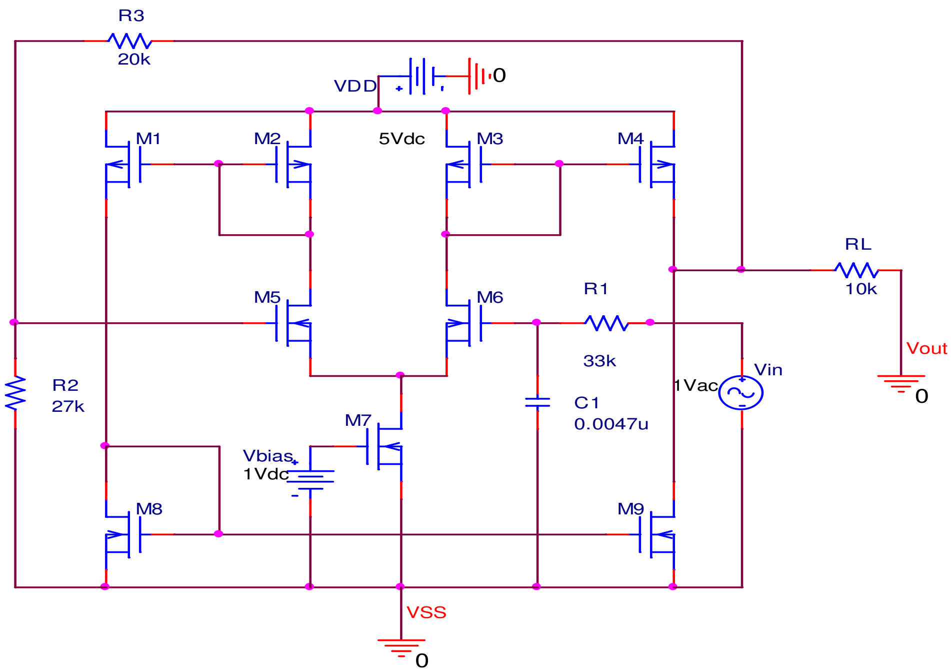


Figure 6.3 First Order Low Pass Filter using OTA

OUTPUT WAVEFORM

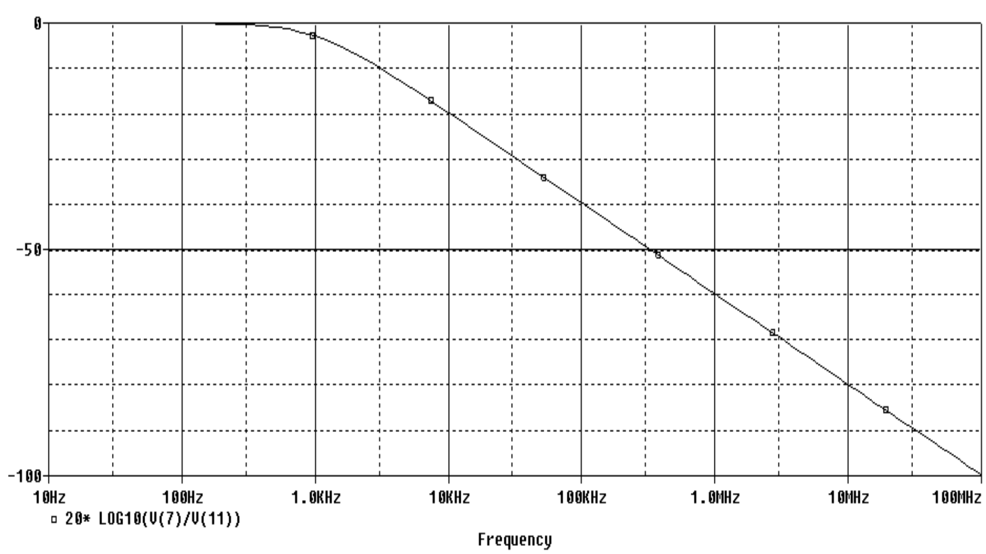


Figure 6.4

CALCULATIONS:

TABLE 6.1

First Order Low Pass Filter	Using Two-Stage Op-Amp		Using OTA	
	Theoretical	Practical	Theoretical	Practical
FREQUENCY	1.02kHz	1kHz	1.02kHz	1kHz
GAIN	1.74	1.13	1.24	1.31

c) Second-order Active Low Pass Filter Circuit Using 2 stage op-amp

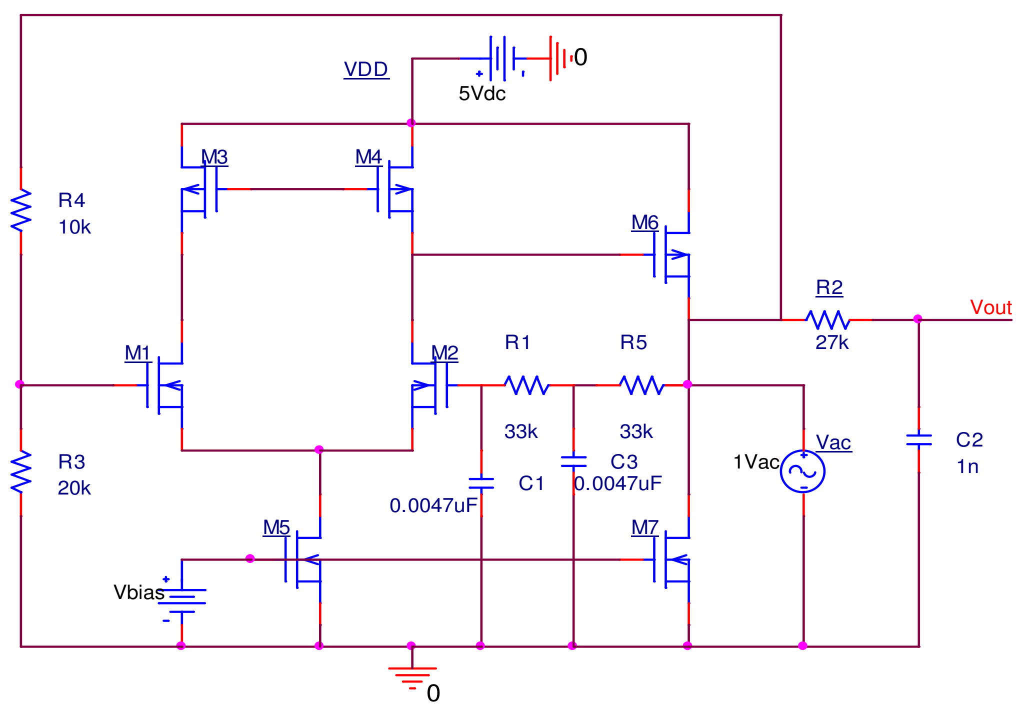


Figure 6.5 Second-order Active Low Pass Filter Circuit Using 2 stage op-amp

OUTPUT WAVEFORM:

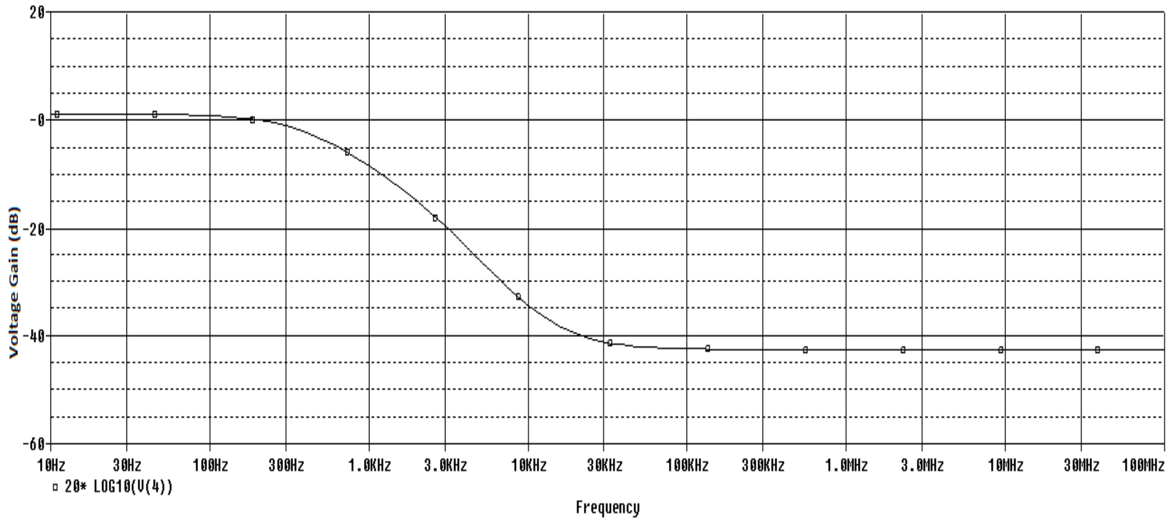


Figure 6.6

d) Second Order Low Pass Filter using OTA

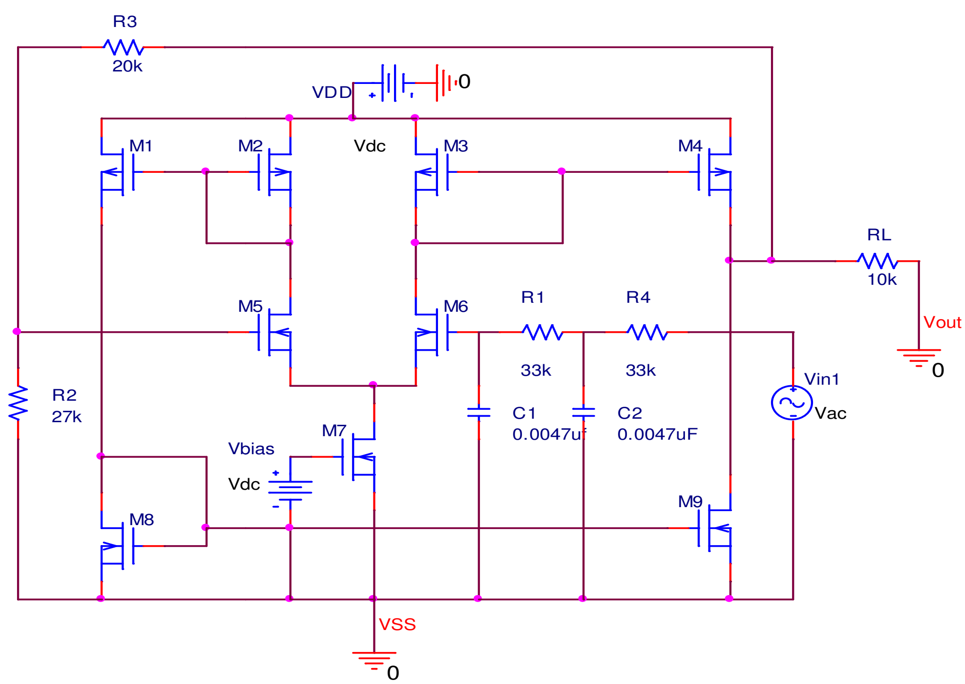


Figure 6.7 Second Order Low Pass Filter using OTA

OUTPUT WAVEFORM

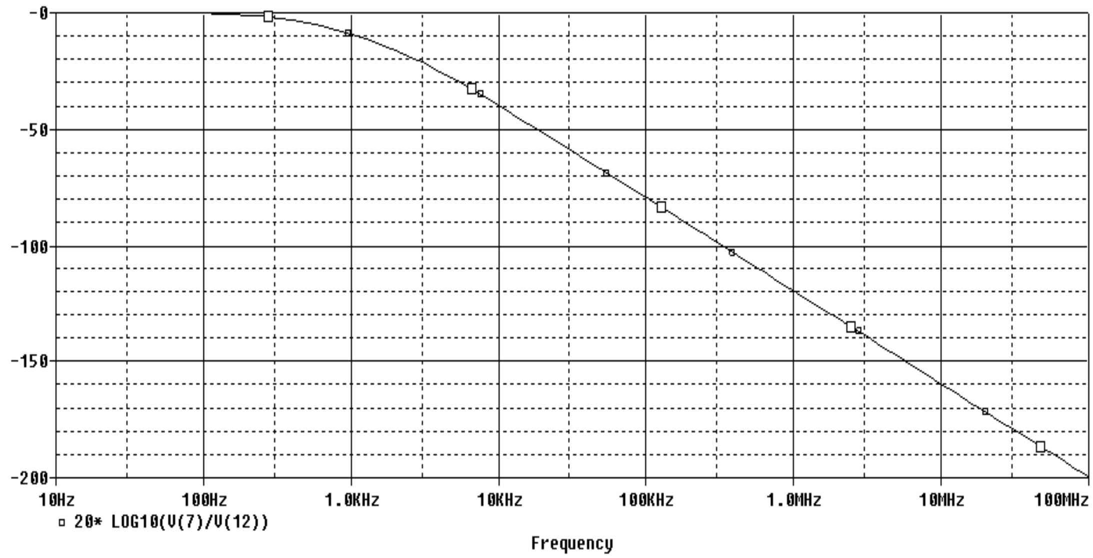


Figure 6.8

CALCULATIONS:

TABLE 6.2

Second Order Low Pass Filter	Using Two-Stage Op-Amp		Using OTA	
	Theoretical	Practical	Theoretical	Practical
FREQUENCY	1.02kHz	1kHz	1.02kHz	1kHz
GAIN	1.74	1.28	1.24	1.30

6.2 CIRCUIT DIAGRAMS FOR HIGH PASS FILTER

a) First- Order High Pass Filter Using 2 Stage Op-Amp

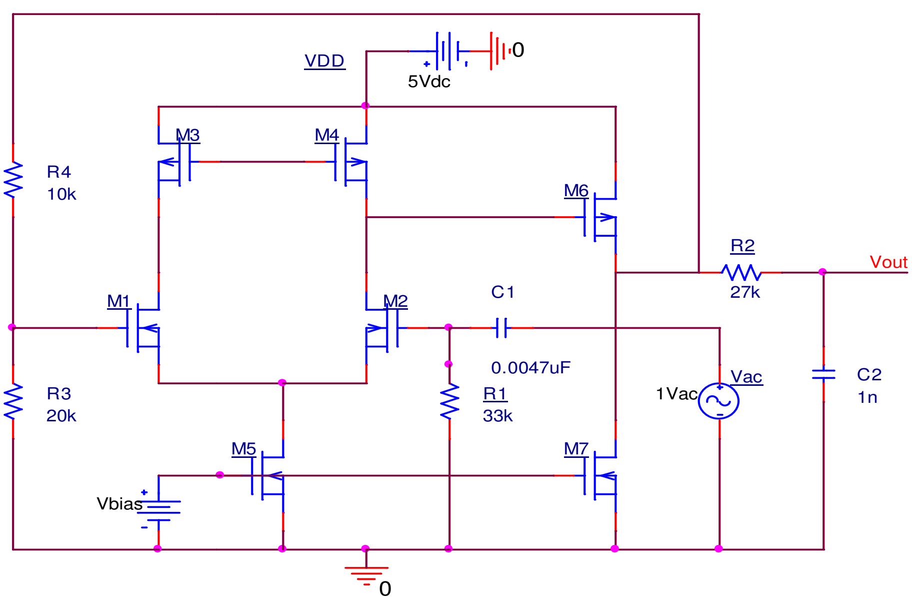
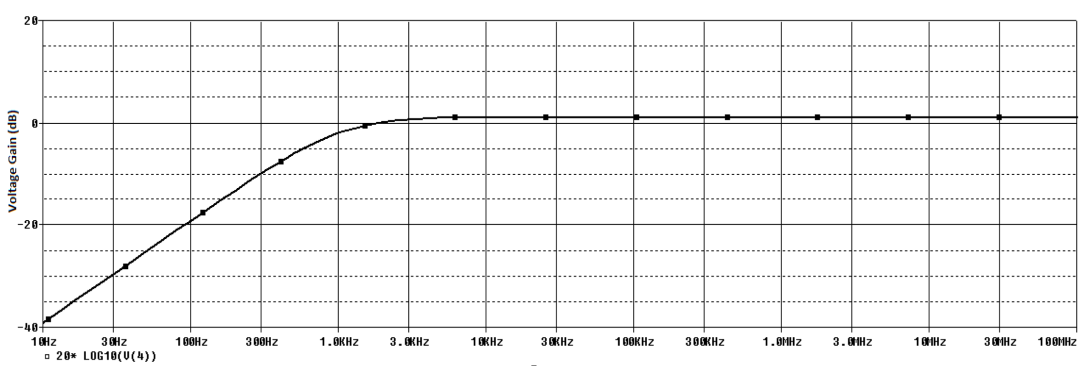


Figure 6.9 First- Order High Pass Filter Using 2 Stage Op-Amp

OUTPUT WAVEFORM:



Fgure 6.10

b) First Order High Pass Filter using OTA

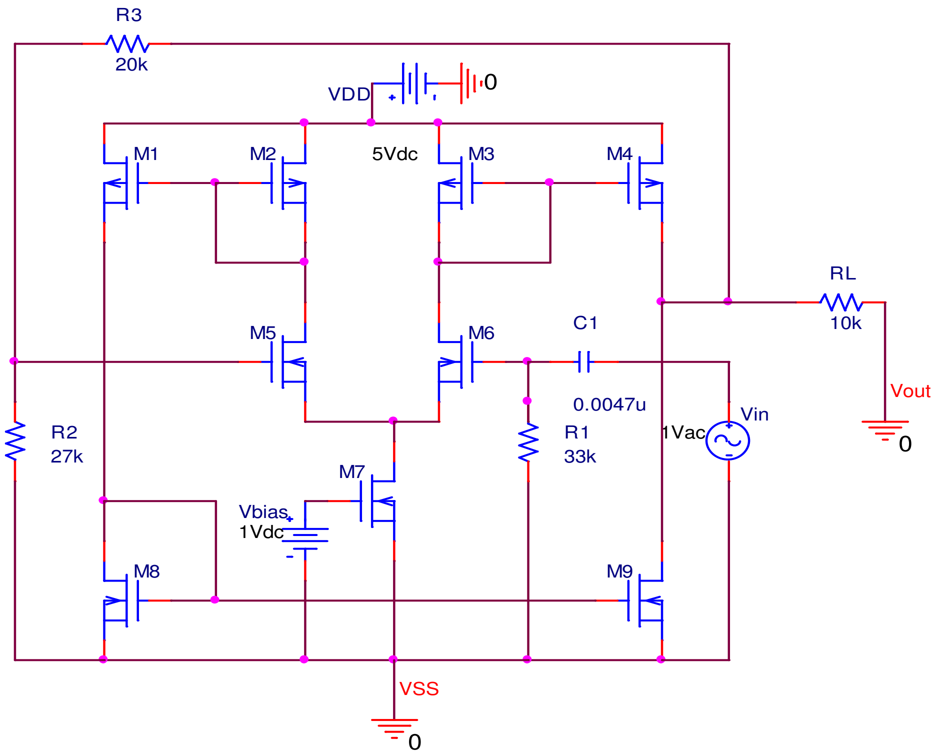


Figure 6.11 First Order High Pass Filter using OTA

OUTPUT WAVEFORM

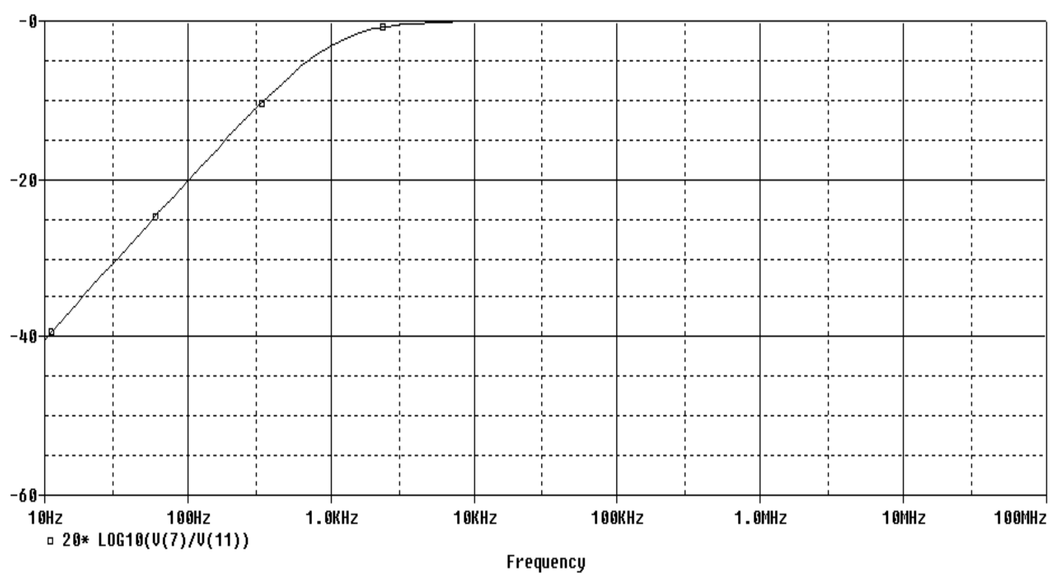


Figure 6.12

CALCULATIONS:

TABLE 6.3

First Order High Pass Filter	Using Two-Stage Op-Amp		Using OTA	
	Theoretical	Practical	Theoretical	Practical
FREQUENCY	1.02kHz	1kHz	1.02kHz	1kHz
GAIN	1.74	1.12	1.21	1.34

c) SECOND- ORDER HIGH PASS FILTER USING 2 STAGE OP-AMP:

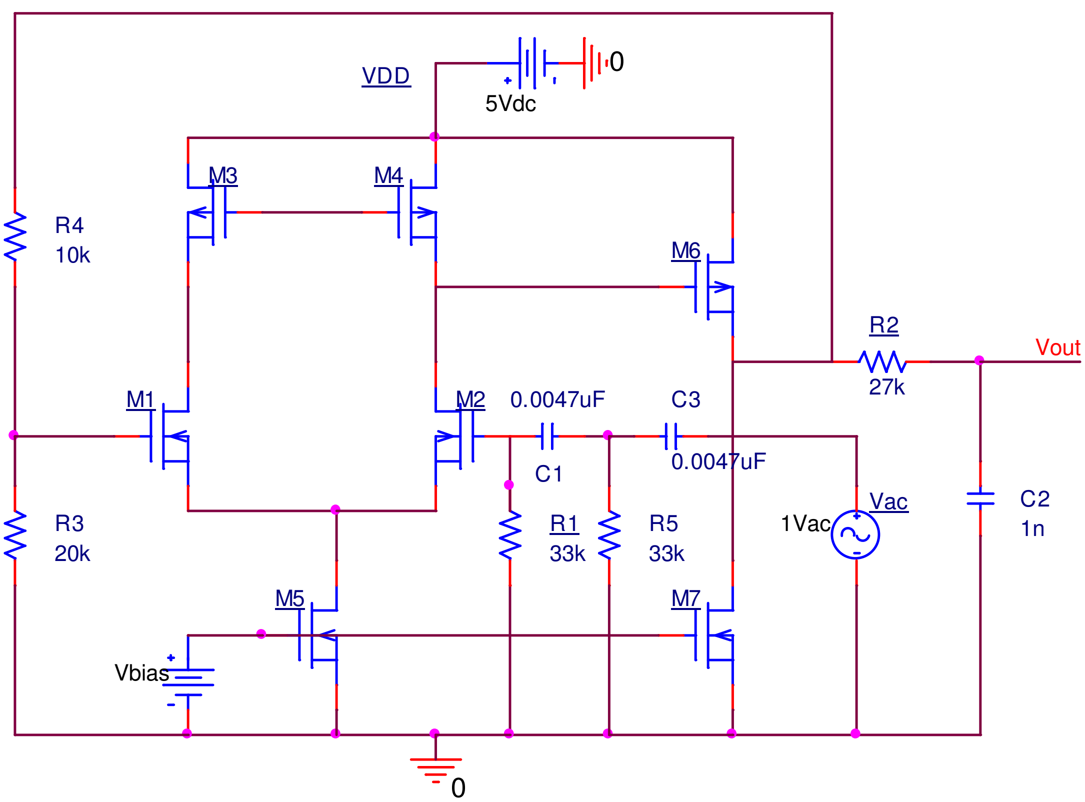


Figure 6.13 Second- Order High Pass Filter Using 2 Stage Op-Amp

OUTPUT WAVEFORM:

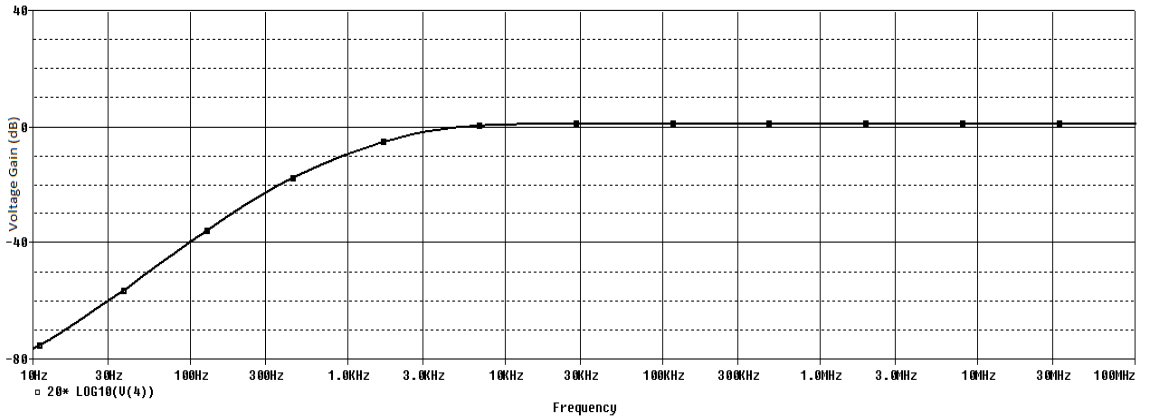


Figure 6.14

d)Second Order High Pass Filter

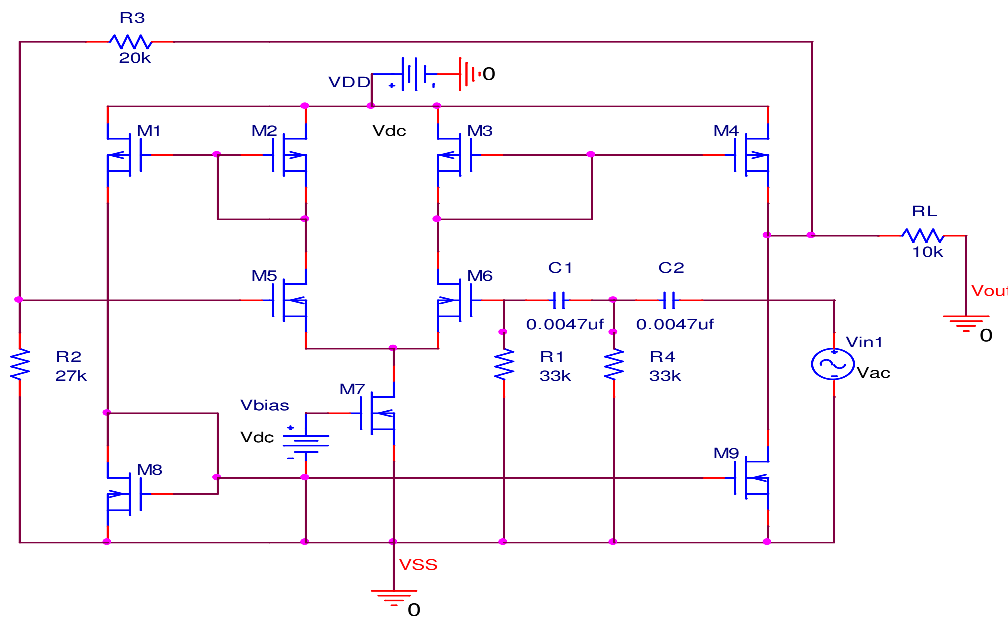


Figure 6.15 Second Order High Pass Filter

OUTPUT WAVEFORM

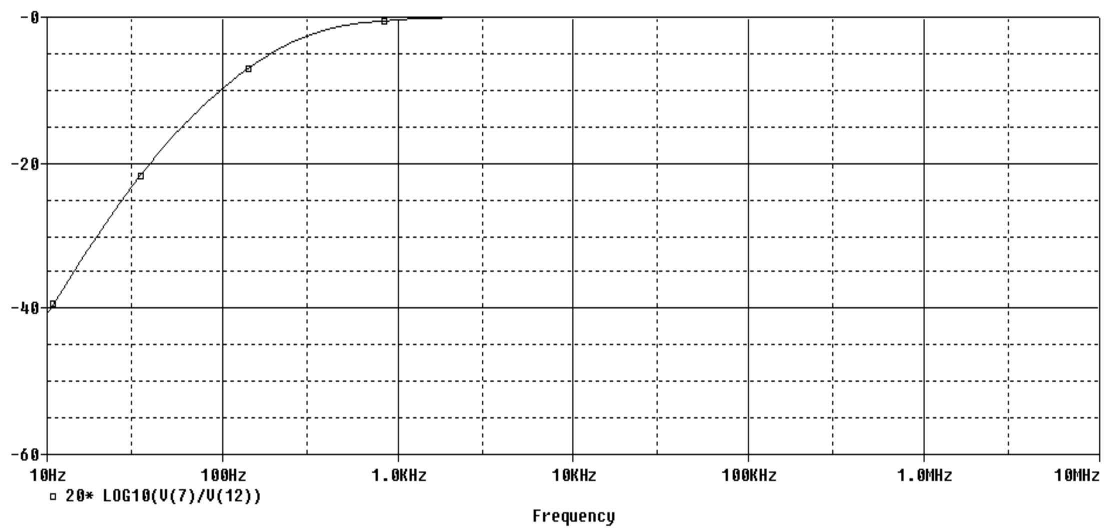


Figure 6.16

CALCULATIONS:

TABLE 6.4

Second Order High Pass Filter	Using Two-Stage Op-Amp		Using OTA	
	Theoretical	Practical	Theoretical	Practical
FREQUENCY	1.02kHz	1kHz	1.02kHz	1kHz
GAIN	1.74	1.04	1.21	1.15

6.3 CIRCUIT DIAGRAMS FOR BAND PASS FILTER

a) Band Pass Filter Using 2 Stage Op-Amp :

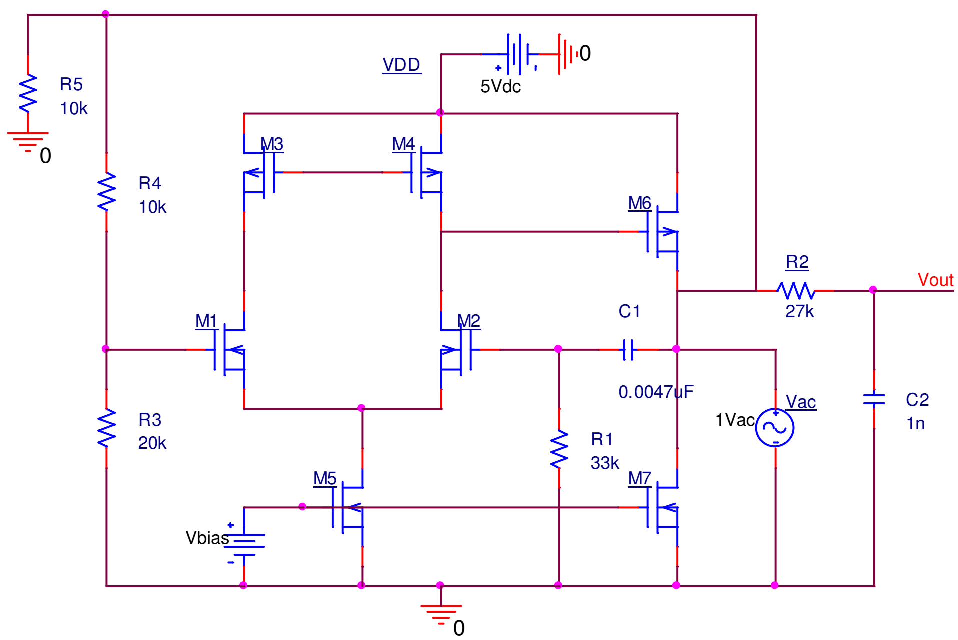


Figure 6.17

OUTPUT WAVEFORM

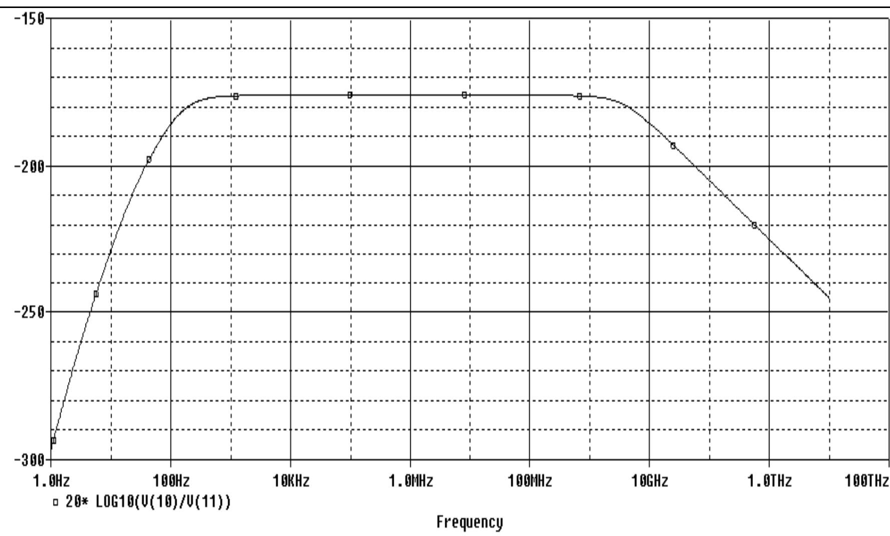
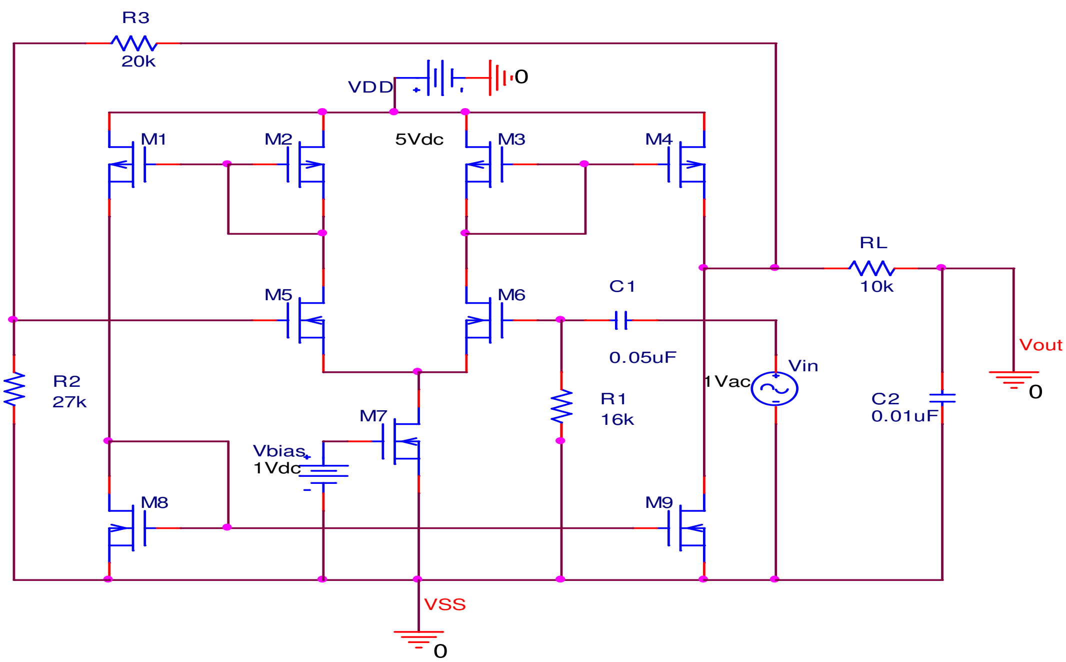


Figure 6.18

b) Band Pass Filter Using OTA



Fgure 6.19 Band Pass Filter Using OTA

OUTPUT WAVEFORM

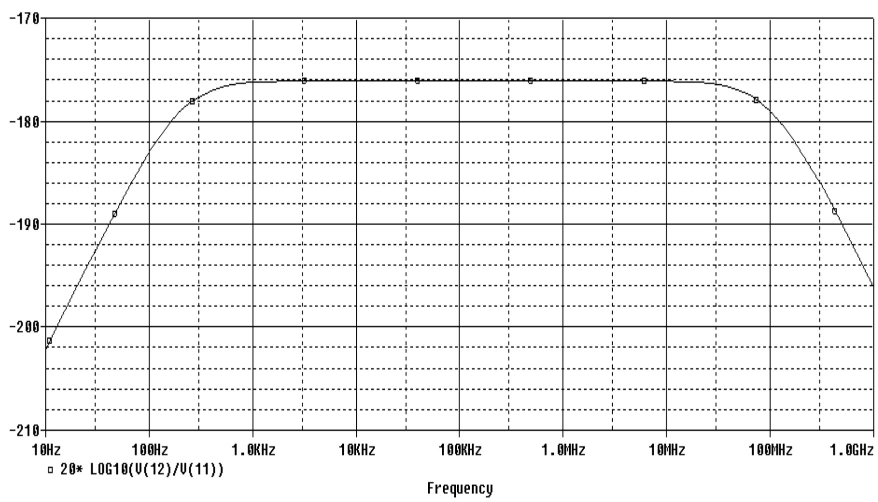


Figure 6.20

CALCULATIONS:

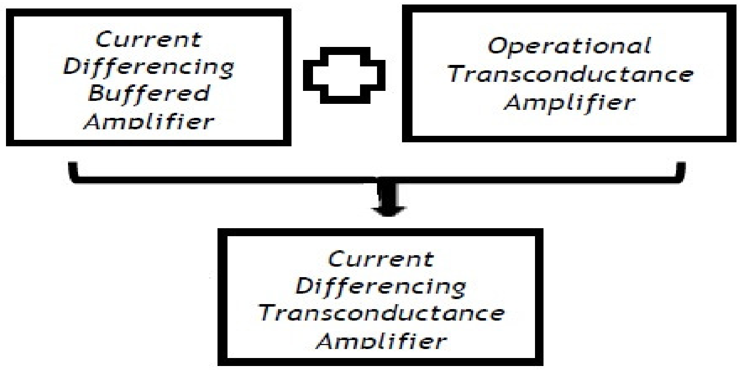
TABLE 6.5

BAND PASS FILTER	USING TWO-STAGE OPAMP		USING OTA	
FREQUENCY	Theoretical	Practical	Theoretical	Practical
	F_L=199Hz F_h=300Mhz F_c=528kHz	F_L=199Hz F_h=300Mhz F_c=547 kHz	F_L=1kHz F_h=20Mhz F_c=144.9kHz	F_L=1kHz F_h=21Mhz F_c=160 kHz
Q	2.03		7.06	

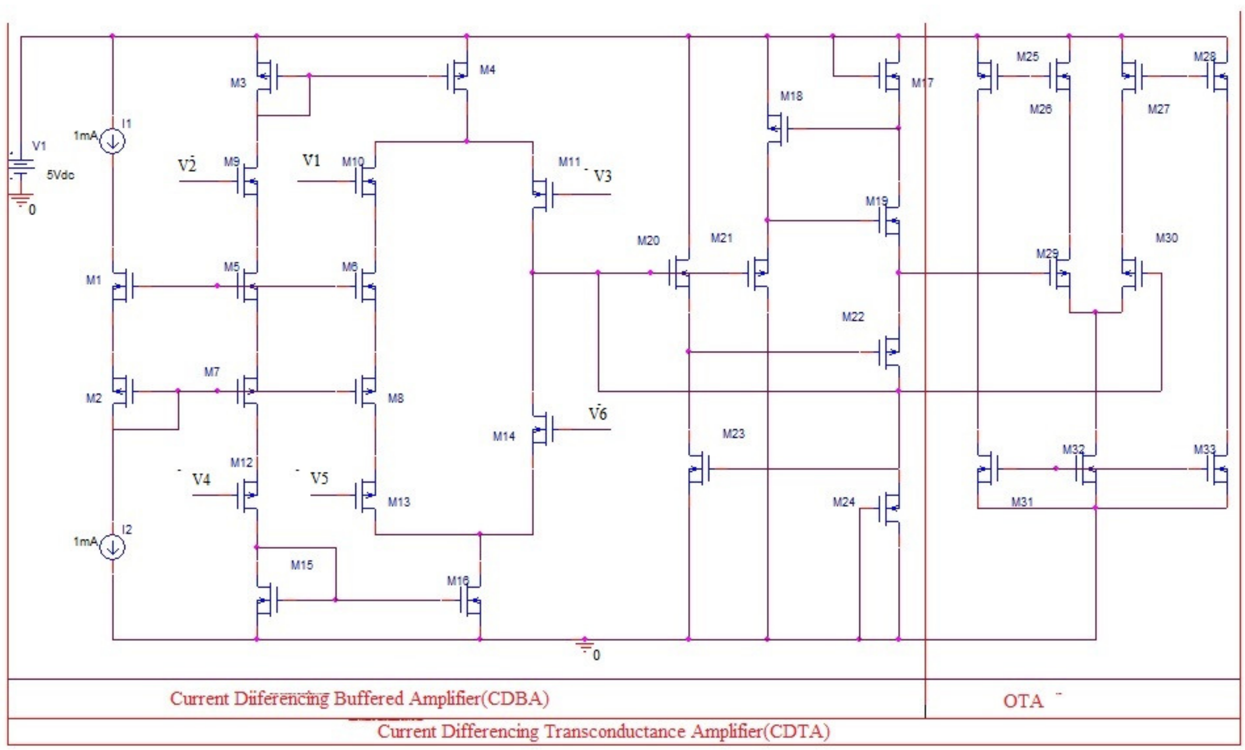
FUTURE WORK

1. Current Diffrencing Buffered Amplifier CDBA: Refer Section

2. Current Diffrencing Transconducting Amplifier (CDTA)



7.1 Proposed CDTA Circuit:



RESULTS

	CDBA(fig 3.1e)	**CDTA(fig 7.1)**
Voltage Gain	600dB	800dB
Input Resistance(ohm)	1.00E+20	1.000E+20
Output Resistance(ohm)	1.000E+06	3.274E+03
Power Dissapation	2.55E-02 WATTS	2.68E-02 WATTS

CONCLUSION

We have implemented Operational Transconductance Amplifier in three modes-simple, balanced and differential models, CDBA,CDTA. The Current Feedback Operational Amplifier in balanced mode came out to be better based upon CMRR and Power Dissipation.

In order to get the optimum value of CMRR we have proposed the design of Balanced OTA in which the standard current mirror is replaced by – Bulk Driven Current Mirror and Low Voltage Current mirror. Balanced OTA using low voltage current mirror was observed to be the best. Using 2stage Op-Amp & Balanced OTA we have implemented basic filters. Results were found to be better for OTA.

In case of further improvements in SLEW RATE and GAIN we have proposed a circuit for – Current Differencing Transconductance Amplifier (CDTA) and for further improvement CCCDTA can be implemented

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