# Active Filter Design using Bulk Driven Operational Transconductance Amplifier Topology

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A R T I C L E   I N F O

A B S T R A C T

In this paper, an Active filter design using OTA has been done. Operational transconductance amplifier is taking input as a voltage and produces output as a current at the output terminal. Active filter design using operational transconductance amplifier such as Low pass filter (LPF), High pass filter (HPF), Band pass filter (BPF), Band rejection filter (BRF),(or) notch filter are implemented. The total number of components used in these circuits is small, and design equation and voltage- control characteristics are attractive. Active filter designs using the transconductance amplifier are discussed. It is shown that these structures offer improvements in design simplicity and compared to op amp based structures as well as reduced component count. Simulation results of the design have been obtained and cutoff frequencies for low pass filter at 1.5 kHz, where as high pass filter 20 kHz and Bandwidth 700 kHz. At Transconductance of 10nA/v. This work has been carried out using Pspice Simulation software and the results obtained are in accordance with theoretical facts.

## Introduction

OTA is an amplifier whose differential input voltage produces an output current at the output terminal. it also called as voltage controlled current source . There is usually an additional input for a current to control the amplifier's trans conductance. The OTA is similar to a standard operational amplifier in that it has a high impedance differential input stage and that it may be used with negative feedback.

Many of the basic OTA based structures use capacitors are attractive for integration Component count of these structures is often very low when compared to VCVS designs. Convenient internal or external voltage or current control of filter characteristics is attainable with these designs. They are attractive for frequency referenced applications. Several groups have recently utilized OTAs in continuous-time monolithic filter structures. [1]**.**

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From a practical viewpoint, the high-frequency performance of discrete bipolar OTAs, such as the CA3080, is quite good. The first commercially available integrated circuits units were produced by RCA (Radio Corporation of America) in 1969 in the form of the CA3080 and they have been improved since that time. Although most units are constructed with bipolar transistors, field effect transistor units are also produced. 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 current.OTA application such as variable frequency oscillator and filter and variable gain amplifier stages which are more difficult to implement with standard op-amps.its output of a current contrasts to that of standard operational amplifier whose output is voltage. It is usually used open-loop without negative feedback in linear application. 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 voltage. The transconductance gain (gm) can be varied over several decades by adjusting an external dc bias current, IABC. The major limitation of existing OTAs is restricted differential input voltage swing required to maintain linearity [3]. For the CA 3080, it is limited to about 30 mV p-p to maintain a reasonable degree of linearity. Although feedback structures in which the sensitivity of the filter parameters is reduced be discussed, major emphasis will be placed upon those structures in which the standard filter parameters of interest are directly proportional to gm of the OTA.

Thus the gm will be a design parameter much as are resistors and capacitors. Since the transconductance gain of the OTA is assumed proportional to an external dc bias current .

Most existing work on OTA based filter design has been carried out by either concentrating upon applying feedback to make the filter characteristics independent of the transconductance gain or modifying existing op amp structures by the inclusion of some additional passive components and OTAS. In either case the circuits were typically component intense and cumbersome to tune. [1]
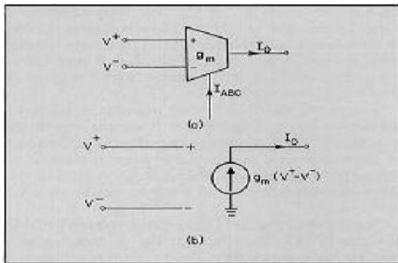


Fig.1 OTA. (a) Symbol. (b) Equivalent circuit of ideal OTA.[1]

## OTA Model

The symbol used for the OTA is shown in Fig. 1, along with the ideal small signal equivalent circuit. The transconductance gain, $gm$, is assumed proportional to $I$ABC. The proportionality constant $h$ is dependent upon temperature, device geometry, and the process [2].

$gm$  $= hI$ABC
A linear dependence on bias current is typically obtained for bipolar OTAs and MOS configurations operating in weak inversion. MOS structures operating in the saturation region typically exhibit a quadratic dependence on $I$ABC.

The output current is given by

$Io = gm \ (V+ - V-)$          (2)

As shown in the model, the input and output impedances in the model assume ideal values of infinity. Current control of the transconductance gain can be directly obtained with control of IABC- Since techniques about for creating a current proportional to a given voltage, voltage control of the OTA gain can also be attained through the IABC input. Throughout this paper, when reference is made to either the

Current or voltage controllability of OTA based circuits' it is assumed to be attained via control of $gm$ by $I$ABC.

## Basic of Filters

Filters of some sort are essential to the operation of most electronic circuits. It is therefore in the interest of anyone involved in electronic circuit design to have the ability to develop filter circuits capable of meeting a given set of specifications. Unfortunately, many in the electronics field are uncomfortable with the subject, whether due to lack of familiarity with it, or a reluctance to grapple with the mathematics involved in a complex filter design.

In circuit theory, a Filter is an electrical network that alters the amplitude characteristics of a signal with respect to frequency. Ideally filter will not add new frequencies to the input signal, nor will it change the component frequencies of the signal, but it will change the relative amplitudes of the various frequency components their phase relationships. Filters are often used in electronic systems to emphasize signals in certain frequency ranges and reject signals in other frequency ranges. Such filter has a gain which is dependent on signal frequency.

As an example, consider a situation, where a useful signal at frequency f1 has been contaminated with an unwanted signal at f2. If the contaminate signal is passed through a circuit that has very low gain at f2 compared to f1, the undesired signal can be removed. And the useful signal will remain. the gain of the filter at any frequency other than f1 and f2. As long as f2 is sufficiently attenuated relative to f1, the performance of this filter is satisfactory; In general however, a filter's gain may be specified at several different frequencies, or over a band of frequencies. Since filters are defined by their frequency-domain effects on signals. It makes sense that the most useful analytical and graphical description of filters also fall into the frequency domain.

## All region mosfet model

The circuit design has been done using the one equation all region MOSFET model presented.

$$\frac{I}{\varphi_t g_m n} = \frac{1 + \sqrt{1 + i_f}}{2} \qquad (1)$$

$$\frac{W}{L} = \frac{g_m}{2\mu C_{ox}\varphi_t \left[ \dfrac{I}{\varphi_t g_m n} - 1 \right]} \qquad (2)$$

$$i_f = \frac{I}{I_S} \qquad (3)$$

$$I_S = n\mu C_{ox} \frac{\varphi_t^2}{2} \frac{W}{L} \qquad (4)$$

$$V_{DSAT} = \varphi_t \left( \sqrt{1 + i_f} + 3 \right) \qquad (5)$$

Where

| | |
|---|---|
| I | Drain current |
| $I_S$ | Normalization current |
| $i_f$ | Inversion level |
| | $i_f \ll 1$      (weak inversion) |
| | $0.4 < i_f < 80$      (moderate inversion) |
| | $i_f > 100$      (strong inversion) |
| n | Sub-threshold slope factor (~1.3) |
| μ | Low field mobility |
| $C_{ox}$ | Gate oxide capacitance / channel area |
| $\varphi_t$ | Thermal voltage (25.8mV @ 300 K) |
| $g_m$ | Gate transconductance |
| $V_{DSAT}$ | Saturation voltage |

Essentially, it is physics based model that describes the static and dynamic characteristics of the MOS transistor using single piece equation with infinite order of continuity for all region of operation from very weak inversion through moderate inversion up to very strong inversion. The basic equations can be described as:

A closer look at the above equation (1) –(4) reveals that the aspect ratio of the transistor can be calculated by specifying a pair parameters from the set {gm,I,if).

## OTA Topologies

Two different OTA topologies were designed in moderate inversion for the same transconductance of 10nA/v and the tradeoffs concerning design parameters such as power consumption, silicon Area, THD and signal to noise Ratio were studied. Their schematics are described here in brief in this paper proposed to implemented an Active filter design using following two OTA topologies such as Low Pass Filter (LPF), High Pass Filter,(HPF),Band Pass Filter(BPF),Band Rejection (or) notch filter.
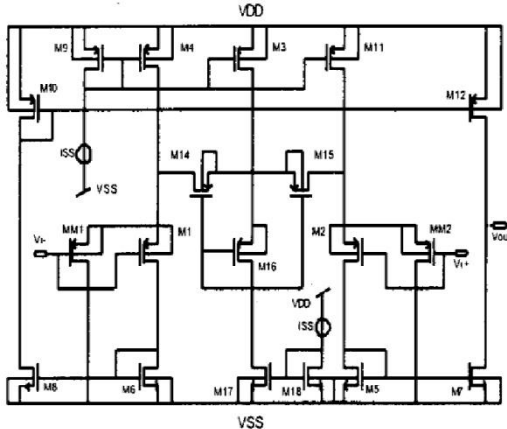
## OTA with current division



Fig 3.1 OTA with current division [2]

This structure has source degeneration linearization technique and additional transconductance reduced by implementing sink current sources (MM1 and MM2) which perform current division. The transistor M14 and M15 are biased in triode and thus act as source degeneration resistors. The purpose of M3,M16,M17 and M18 is to control the VGS of M14,M15 and thus, their resistance,MM1 and MM2 just divert a significant portion of the bias current to the rail, thus reducing the transconductance by the factor, M, of current division. Small signal analysis gives the overall transconductance Gm as,Where, gm and g0 are the transconductance and output conductance of the MOS transistor respectively. The overall transconductance can be varied by changing the bias current.

$$G_m = \frac{g_{0\_M14}}{M+1} \tag{6}$$

$$M = \frac{g_{m\_MM}}{g_{m\_M4}} \tag{7}$$

## Bulk driven ota

$$g_{0\_M14} = n\mu C_{0x} \frac{W_{M14}}{L_{M14}} \left( V_{SG\_M14} - |V_{TP}| \right) \tag{8}$$

In this topology, the inputs of the OTA are driven through the bulks of the input transistor rather than the gates. The schematic is shown below in fig 2.2.
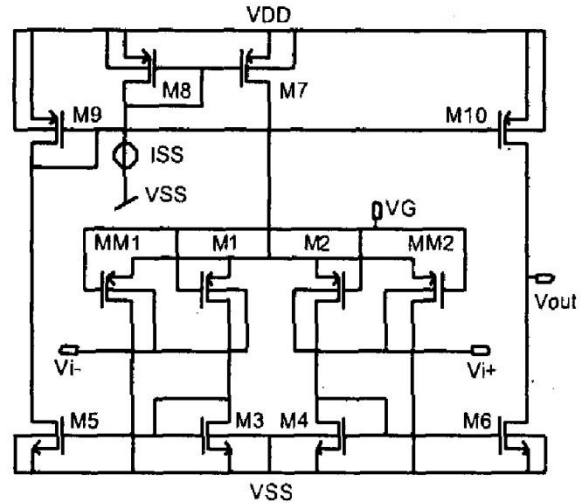


Fig 3.2 bulk driven OTA [2]

Since bulk- driven transconductance gmb is typically around 0.2-0.4 times gm, this is topology also provides naturally smaller transconductance. Current division has also been included to further reduce Gm levels. Analysis yields the overall transconductance in terms of the model parameters as

$$G_m = \left( \frac{\gamma_0}{2\sqrt{2\varphi_{FB} + |V_{BS}|}} \right) g_{m\_M} = \left( \frac{\gamma_0}{2\sqrt{2\varphi_{FB} + |V_{BS}|}} \right) \left( \frac{I_{SS}}{(M+1)\varphi n \left(1 + \sqrt{1 + i_{f\_M}}\right)} \right) \tag{10}$$

Where

$\gamma_0$     Body effect parameter (typically 0.7)

$\varphi_{FB}$     Bulk Fermi Potential (typically 0.35V)

$g_{m\_MI}$     Gate transconductance (see Fig. 4.)

### Active filter design using ota with current division topology

Fig. 4 shows that Active filter Design by using current division topology. Fig (4.1) shows that design of Low pass filter (LPF) in Which Applying input at non-inverting terminal. Connecting a feedback resistance R from output terminal to inverting terminal of OTA. Capacitance of one terminal is connected with inverting terminal of OTA. Another terminal is grounded. Whereas High pass filter (HPF) which is shown in fig (4.2) In Which Applying input at non-inverting terminal of OTA. Inverting terminal is directly grounded here. But In this design changing the position (or) place of capacitance. Components such as resistor and capacitor of design connection also different from Low pass filter. Response (or) behavior of HPF design is opposite to the LPF design. At Transconductance of 10nA/v.
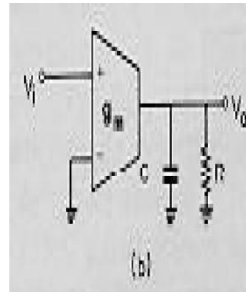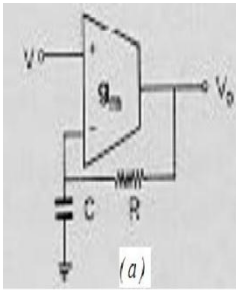
Fig (4.1). Low pass filter [1]Fig (4.2) High pass filter[1]

Fig (4.3) shows that design of Band pass filter (BPF) in which input is applying at inverting terminal of OTA through a capacitance of C1 and feedback resistance of R1 and one more capacitance C2 is connected from R1.and also same transconductance of 10nA/v, Whereas Band Rejection filter (or) notch filter, which is shown in fig (4.4) just opposite of Band pass filter. Design of Band pass filter is implemented by using three OTA's instead of one OTA connection's are made which is shown in below.
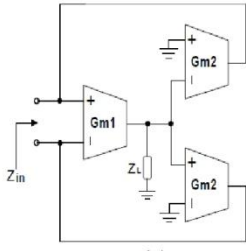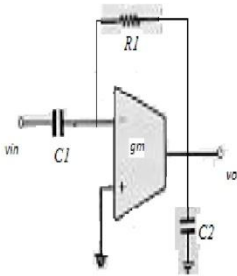


Fig (4.3) Band pass filter [1]    Fig(4.4) Band rejection filter[1]

## Active filter design using bulk driven ota topology

Fig (4.5) shows that design of Low pass filter (LPF) in Which Applying input at non-inverting terminal. Whereas High pass filter (HPF) which is shown in fig (4.6) In Which Applying input at inverting terminal of OTA through a capacitor C and non-inverting terminal is directly grounded here. But In this design changing the position (or) place of capacitance. Components such as capacitor of design connection also different from Low pass filter. Response (or) behavior of HPF design is opposite to the LPF design. At Transconductance of 10nA/v.
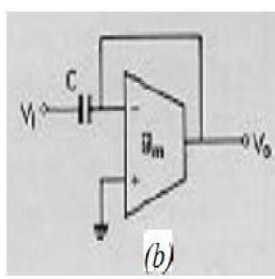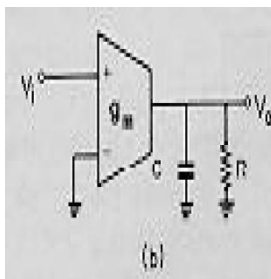


Fig (4.5) low pass filter [1]    Fig (4.6) High pass filter [1]

Fig (4.7) shows that Design of Band pass filter (BPF) In Which input is applying at inverting terminal of OTA through a capacitance of C1 and feedback resistance of R1 and one more

capacitance C2 is connected from R1.and also same transconductance of 10nA/v.Where as Band Rejection filter (or) notch filter Which is shown in fig (4.8) just opposite of Band pass filter. Design of band rejection filter is series connection of Low pass and High pass filter
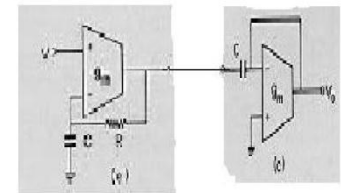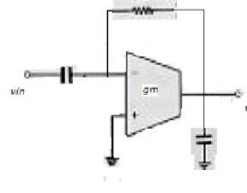


Fig (4.7) Band pass filter [1]         Fig (4.8) Band rejection filter [1]

## Frequency response of the ota based filter designs

Fig 5. Shows that responses of Active Filter Design such as Low pass Filter (LPF), High pass Filter (HPF),     Band pass Filter (BPF), Band rejection Filter (BRF).

## OTA with current division

Fig (5a) the output response of the low pass filter shows that passes low-frequency signals and attenuates signals with frequencies higher than the cut off frequency. Whereas fig (5b) behavior is opposite to the low pass filter it shows that passes high frequency signals but attenuates signals with frequencies lower than the cut off frequency.
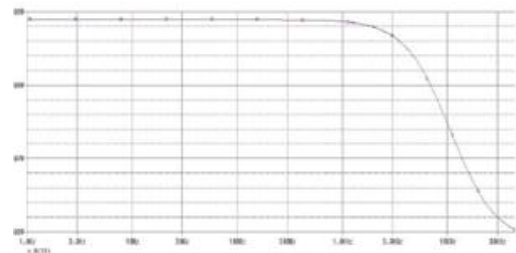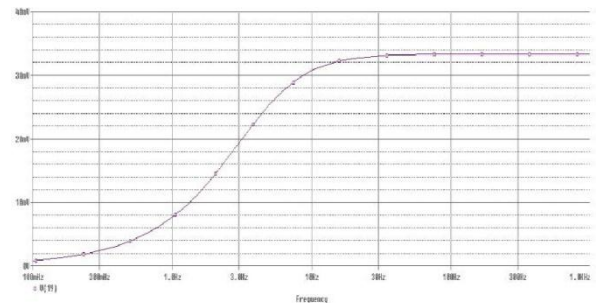


Fig (5a)



fig (5b)

Fig (5c) shows that behavior of the Band pass filter passes signals within a certain frequencies range and rejects signals outside that range. Whereas fig (5d) shows that reject (attenuates) signals within a certain frequencies range and allow passing outside of the range. It is just opposite of the Band pass filter.
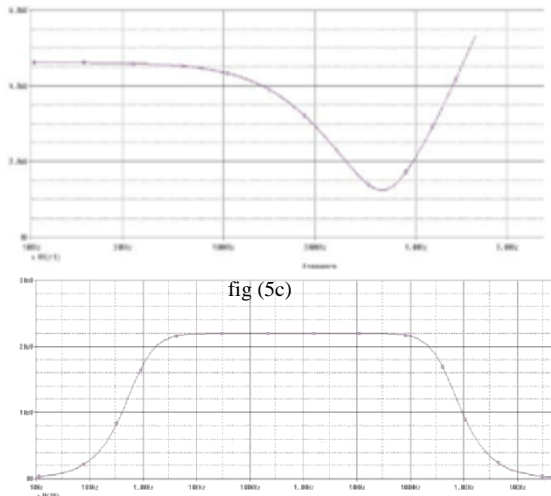
fig (5c)



fig (5d)

Fig 5.response of the Active filter design left hand side from top. fig (5a) response of Low pass filter(LPF),fig (5b) response of High pass filter(HPF), fig (5c) response of Band pass filter(BPF), fig (5d) response of Band rejection (or) notch Filter(BRF).

## Conclusion

This paper has been implemented Active filter design using OTA(operational transconductance amplifier) such as Low pass filter(LPF) at cutoff frequency of 1.5khz, High pass filter(HPF) at cutoff frequency of 20khz, and Band pass filter(BPF) at bandwidth of 700khz, Band Rejection Filter(BRF), and transconductance of these filter design is 10nA/v. This work has been carried out using Pspice Simulation software and the results obtained are in accordance with theoretical facts.

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