# Design of OTA-C Active Low Pass Filter Using Multiple OTA's

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***Abstract****:The studies are carried out on OTA-C active filter using single OTA-C and multiple OTA-C filter . The multiple OTA-C filters have the advantage of tuning the floating inductor resulting in enhancement of gain and increase in cut-off frequency with increase in bias current. Different cases of tuning transconductance $g_{m1}$, $g_{m1}$, $g_m$, and $g_{m2}$ by changing the bias currents of multiple OTA 's are studied and results are discussed. The only one method of setting of $g_{m1} g_{m1}$ greater than $g_m g_{m2}$ is an innovative in changing the cut off frequency as we have flexible tuning transconductances of $g_{m1}$, $g_{m1}$, $g_m$ and $g_{m2}$. Results are consistent and are encouraging in respect of tuning of transconductance with bias current under the condition of $g_{m1} g_{m1}$ greater than $g_m g_{m2}$. However an OTA-C active filter other than the studied criteria has the limitations in designing of filters.*
***Keywords:*** *OTA Operational Transconductance Amplifier OTA-C Operational Transconductance Amplifier – Capacitance*

## I. Introduction

Limitations of passive filter studies are completely eliminated in active filter studies. However voltage controlled Op-Amp and current controlled OTA are considered as basic active elements in the design of active filters. The active filter design using op amp has a serious limitation over the applications in the high frequency regions. To overcome these limitations active filters using OTA are popular due to the salient features of OTA such as , the adjustable $g_m$ over wide range of bias current , excellent matching between amplifiers, the linearity of transconductance with bias current , controlled impedance buffers and high output signal to noise ratio, which popularises OTA in active filter design. In this paper first order active low pass filter using OTAs and C is explained in order to use the linearity of transconductance of OTA with bias current [1,8,9].

Electronically tuneable circuits attracted considerable attention in the design of analog integrated circuits because different values of resistance, inductance capacitance can be obtained by the same device. Programmability is one the most attractive features of the Operational Transconductance Amplifier (OTA), since it possible to tune analog devices such as; filters, oscillators etc, electronically. OTA is a differential voltage controlled current source (VCCS) where the output current is controlled by an applied input voltage signal. This tunability is obtained by varying the transconductance ($g_m$) of the OTA which in turn is controlled by the bias current or voltage. However, tunability is restricted by the limited bandwidth of $g_m$, which depends on the bias current. OTA is a commercially available active component which has been used widely in many applications. OTA circuits have been shown to be potentially advantageous for the design of many first and second order high-frequency analog filters. To achieve any required cut-off frequency in passive filter, we require different values of resistors & inductors as calculated from mathematical expression; which may or may not be available in the market. To solve this problem, we can use OTAs. We achieve the required resistance and inductance values by varying its $g_m$. The OTA's can be connected to design active elements, simulating the property of an inductor in order to be an alternative choice of an on-chip inductor instead of a passive spiral inductor which usually has low Q-factor and also not tunable. These elements are called the OTA-based inductors, grounded and floating [3-9].

A number of different OTAs are available in market from various manufacturers. With the use of LM13600 and CA3080 OTA's it is possible to achieve extremely linear transconductance characteristic with respect to amplifier bias current.

LM13600 consists of two current controlled transconductance amplifiers each with differential inputs & push pull outputs. The two amplifiers shares common supplies but operate independently. Linearalizing diodes are provided at the inputs to reduce distortion and allow higher levels. The result is a 10dB signal to noise improvement referred to 0.5%. Controlled impedance buffers which are especially designed to compliment the dynamic range of the amplifier are provided.

OTA LM 13600 has the following features which make it suitable in the design of active filters.
1) $g_m$ adjustable over wide range and is linear
2) Excellent matching between amplifiers.
3) Linearising diodes
4) Controlled impedances buffers

5) High output signal to noise ratio.

These featured are taken into consideration in studying OTA active filters. The practical applications of OTA-C filter is given in the studies of low pass filter, high pass filter and band pass filters. Since the device is current controlled transconductance amplifier, the filter exhibits various enhanced range of pass band and cut off frequency as shown by the observations [10,11].

**1.1 OTA Fundamentals**

The OTA is a transconductance device in which the input voltage controls the output current. The transconductance gm makes the OTA as voltage controlled current source; whereas the op-amps are voltage controlled voltage source [1].

An ideal OTA is defined by $I_o = g_m (V_{in+} - V_{in-})$ where the input and output resistances are infinite. The transconductance $g_m$ is given by:

$$g_m = \frac{1}{2\,VT} I_{bias}$$

where $V_T$: thermal voltage = 26 mV at room temperature.

$I_{bias}$: bias current. The transconductance gm is directly proportional to bias current $I_{bias}$

Characteristics of Ideal OTA can be summarized as follows,

Input impedance (Zin ) = ∞

Output Impedance (Z0) = ∞

Inverting input current $I_o$- = Non-inverting input current $I_O$+

Bandwidth = ∞

The Figures 1 & 2 shows the basic schematic and equivalent circuit of OTA.

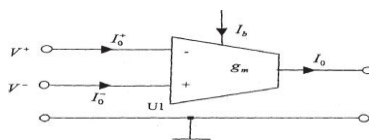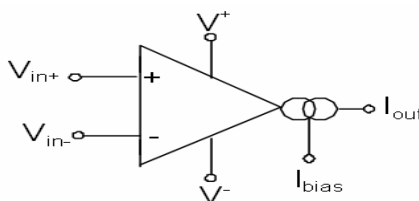

Fig.1. Circuit symbol of OTA [1]



Fig.2. Small signal equivalent circuit of OTA [1]

Circuit symbol of OTA can also be represented as shown in below figure



**1.2 Floating Inductor**

Floating inductors which are difficult to simulate with op-amps are very easy to be simulated by the use of OTA. The only task is to lift the inverting gm1 terminal of fig. 3 off the ground and device a circuit that generates $I_2 = I_1$ at the second impedance terminal.

Fig. 8 shows a simple method, which needs only one additional OTA.

we have $I_1 = \dfrac{g_{m1}g_{m2} (V1 - V2)}{SC}$ and $I_2 = \dfrac{gm1gm3 (V1 - V2)}{SC}$ for $g_{m2} = g_{m3} = g_m$

Floating inductor of value : $L = C / g_{m1}\, g_m$ has been simulated.
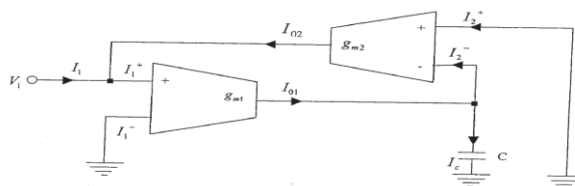


Fig 3    Simulation of floating inductor

**1.3 Derivation of OTA-C Filters from Passive Filters**

First order low pass filter. Consider a first order low pass filter as shown in fig.3 below

Vin = I [SL + R]   and   Vo = IR          Therefore

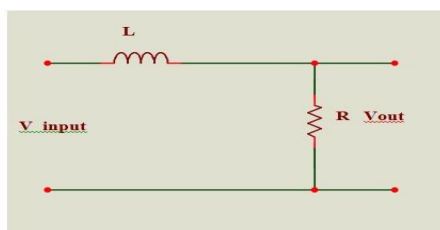$$\frac{Vo}{Vin} = T(s) = \frac{R/L}{S + R/L}$$

[12,13,14]



Fig. 4 Circuit diagram of passive Low Pass filter

**1.3 Realization using single OTA-**
From below figure we get
$I_1 = g_m (Vin - V0)$
From above equation, the transfer function for considered filter is given by
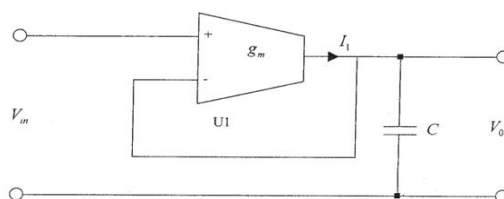
$$T(s) = \frac{g_m/C}{S + g_m/C}$$



Fig-5 First order active low pass filter using single OTA (First method)
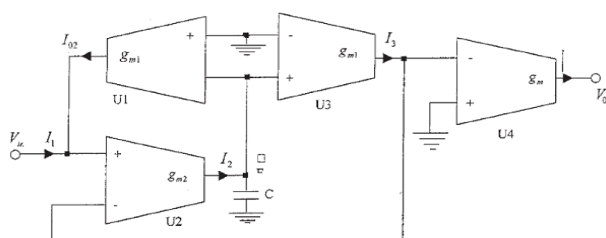
**1.4 Realization using multiple OTAs**



Fig-6 First order active low pass filter using multiple OTA (second method)

From above figure it can be inferred that
$V_3 = I_2/SC$
$I_2 = (Vin - V_0) g_{m2}$

$$V_3 = \frac{(Vin - Vo) g_{m2}}{SC}$$

Solving above equations we have

$I_4 = -g_m Vo$
$I_3 = -V_3 g_{m1}$
But we see that $I_3 + I_4 = 0$
Therefore transfer function of the designed filter is

$$\frac{V0}{Vin} = T(s) = \frac{g_{m1} g_{m2}/Cg_m}{S + (g_{m1} g_{m2}/Cg_m)}$$

The above discussion states that we can achieve a tuneable range of cut off frequencies
The advantage of using single OTA and multiple OTAs can be summarized as follows:
1. In case of first method, by using single OTA We can change cut-off frequency by changing *gm* but the degree of freedom for changing $g_m$ is only one. This will reflect change in value of floating inductance.
2. In case of second method, by using multiple OTAs cut-off frequencies can be changed by tuning $g_{m1}$ $g_{m2}$ or $g_m$ separately or in combination. So we have a larger tuneable floating inductance than the first one [2]

## II.    Experimental Setup And Results

The stated circuit in "Fig 7" is simulated using Proteus professional 7. Same circuit is arranged on bread board using usual method, the output of the filter is measured. In first order low pass filter four OTAs with transconductance $g_{m1}$ $g_{m1}$, $g_{m2}$ $g_m$ are used. The transconductance can be tuned from bias current in different cases of their magnitudes.
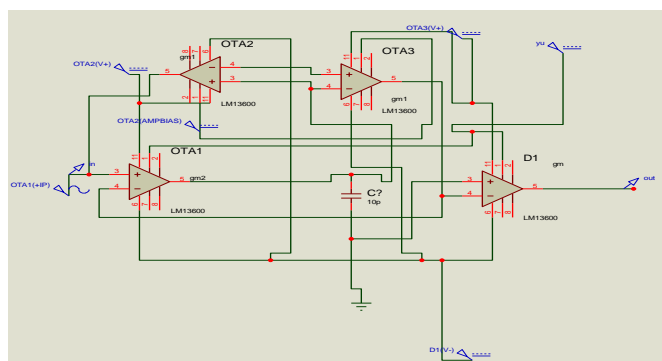


Fig. 7 Circuit diagram of OTA- C Low Pass filter

**2.1Case-1:** The bias current of $g_{m1}$ $g_{m1}$ is equal to bias current of $g_m g_{m2}$.
**2.2Case-2:** The bias current of $g_{m1}$ $g_{m1}$ is greater than bias current of $g_m g_{m2}$.
**2.3Case-3:** The bias current of $g_{m1}$ $g_{m1}$ is less than bias current of $g_m g_{m2}$.

The stated circuits in "Fig 4" are simulated using Proteus professional 7. Same circuit is arranged on bread board using usual method, the output of the filter is measured.

In OTA-C low pass filter shown in "Fig-7" the results obtained for case-1 , case-2 and case-3 are as follows.

**For case-1** The bias current of $g_{m1}$ $g_{m1}$ is equal to bias current of $g_m g_{m2}$.

Results are obtained only for bias current of $g_{m1}$ $g_{m1=}$ $g_m g_{m2 =}$ 5mA. For this bias current maximum gain or $G_{max}$ obtained is of order -2.59dB and at -10dB of gain, frequency is of order 18MHz . For bias current of $g_{m1}$ $g_{m1=}$ $g_m g_{m2 =}$ 10mA maximum gain or $G_{max}$ obtained is of order -2.96dB and at -10dB of gain, frequency is of order  27MHz. For bias  current  of  $g_{m1}$ $g_{m1=}$ $g_m g_{m2 =}$ 11mA maximum gain or $G_{max}$ obtained is of order -4.67dB and at -10dB of  gain , frequency is of order  20.8MHz.For any bias current above 11mA gain goes on decreasing. Finally as bias current increases above 10mA maximum gain or $G_{max}$ decreases with decreased cut off frequency.
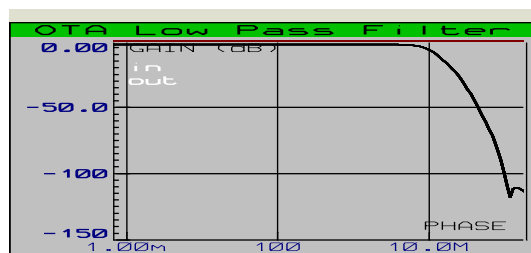


Fig. 8 Frequency response of Proteus professional 7 simulated OTA Low pass filter circuit, with pass band up to 18MHz at -10dB of gain. Maximum gain is 2.59dB, For bias current of 5mA ( i,e $g_{m1}$ $g_{m1=}$ $g_m g_{m2}$  =5mA )

**For case-2** The bias current of $g_{m1}$ $g_{m1}$ is greater than bias current of $g_m g_{m2}$

For different combinations of $g_{m1}$ $g_{m1}$ greater than $g_m g_{m2}$ we can conclude that , if the difference between the bias currents is of smaller    $G_{max}$   is also less, its around 0dB, and difference between band width or cut off frequencies  is also less.

For example, if $g_{m1}$ $g_{m1}$  =15mA and  $g_m g_{m2}$ =12mA maximum gain or $G_{max}$ is 0dB and at -10dB of gain ,frequency is of order 78MHz. If $g_{m1}$ $g_{m1}$  =10mA and  $g_m g_{m2}$ =8mA maximum gain is 2.33dB and at -10dB of gain, frequency is of order 97MHz.

If the difference between the bias currents is of larger value gain enhances and pass band width also increases. Which is more advantageous in tuning the value of floating inductance floating inductance?

For example, if $g_{m1}$ $g_{m1}$ =10mA and  $g_m g_{m2}$ =5mA, $G_{max}$   or maximum gain is 2dB and at -10dB of gain, frequency is of order 121MHz. If $g_{m1}$ $g_{m1}$ =15mA and  $g_m g_{m2}$ =10mA maximum gain or $G_{max}$ is  4.13dB and at -10dB of gain, frequency is of order  175MHz.  If $g_{m1}$ $g_{m1}$ =20mA and  $g_m g_{m2}$ =10mA, $G_{max}$  or maximum gain is 6.16dB and at -10dB of gain ,frequency is of order  270MHz.
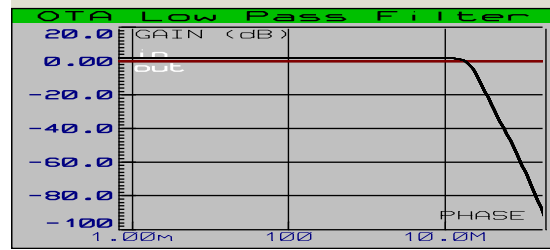
Fig. 8 Frequency response of Proteus professional 7 simulated OTA Low pass filter circuit, with pass band up to 121MHz at -10dB of gain. Maximum gain is 2dB for bias current of $g_{m1}$ $g_{m1}$ = 10mA and $g_mg_{m2}$ =5mA

**For case -3:** The bias current of $g_{m1}$ $g_{m1}$ is less than bias current of $g_mg_{m2}$ results are absurd.

# III.        Conclusion

OTA-C filter realized with minimum number of OTA's and capacitors is a innovative method of designing active filters which have flexibility in respect of the gain and pass band width. The above discussion concludes that we can achieve a tuneable range of cut off frequencies only by changing bias current which changes parameter $g_m$ transconductance of a device.

The advantage of using single OTA and multiple OTAs can be summarized as follows:

1.  In case of first method, by using single  OTA , we can change cut-off frequency by changing $g_m$ but the degree of freedom for  changing $g_m$ is only one.

2.  In case of second method, by using multiple OTAs  cut-off frequency can be changed by tuning  $g_{m1}$, $g_{m2}$ or $g_m$ separately or in combination. So we have larger tuneable parameters than the first method.

The studied low pass filter exposes the salient features of low pass filter without feedback arrangement for low bias current. The circuit has limitations with respect to  the values of   $g_{m1}$ $g_{m1}$  and  $g_mg_{m2}$ .The results are encouraging in respect of bias current having  magnitudes greater than  $g_mg_{m2}$ , (i,e $g_{m1}$ $g_{m1}$  greater than $g_mg_{m2}$ ) where the enhancement in the gain and in the cut off frequency is observed, where as in other  cases the results are not encouraging in obtaining the values of cut off  frequencies in the design of OTA-C low pass filter, due to nonlinearity of transconductance $g_mg_{m2}$.

The Low Pass filter structure using OTA has a several advantages in high frequency applications. The structure is very simple and easy to design. No external resistor is required, which can save the area in case of fabricating in a silicon chip. Moreover, the cut off frequency can be tuned electronically by adjusting the bias current of OTAs. These filters are used in high frequency mixtures and in medical applications where conventional op-amp filters can't be used in high frequency application due to their limited gain bandwidth product [1-14].

# IV.        Acknowledgements

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