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Low Frequency Filter Design using Operational Transconductance Amplifier

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Abstract: - Biomedical signal processing requires low power consumption and low frequency filters. Biomedical signals are usually of 10-mHz to 100-Hz and maximum of 500Hz frequency range. The equipments used in the design of biomedical applications require portability and circuit needs to be operated with low supply voltage. These requirements can be fulfilled by using active filters designed by Operational Transconductance Amplifier.

Keywords: *Operational Transconductance Amplifier (OTA) , OTA-C, Operational Transconductance Amplifier – Capacitor.*

I. INTRODUCTION

Integrated circuit technologies for biomedical applications have been widely used in recent years. The instruments used in biomedical applications may be having some restrictions on battery charges for all portable electronic devices. To satisfy with ambulatory functions the circuit should not only with low power but also with low voltage. Therefore in this paper a low power- low voltage Operational Transconductance Amplifier (OTA) is used to design a low frequency active low pass filter, thus component count can be drastically reduced. The circuit can be operated with low supply voltage of order 1.8V, high stability and linearity in the response, with high signal to noise ratio can be obtained. The required cut off frequency can be tuned electronically. All these requirements cannot be fulfilled in the filter design using operational amplifier. In active filter design using operational amplifier, electronic tuning is not possible. To change the value of cut off frequency calculations has to be done to change values of resistance and capacitance. Portability cannot be obtained in active filters using operational amplifiers because the component count is more in comparison with OTA active filters [1]-[3].

The time constant of operational transconductance amplifier-capacitor (OTA-C) filter is determine by the ratio of load capacitor to the OTA transconductance, i.e C/g_m. For an OTA-C filter implementation in low frequency implies large capacitance and very low transconductance [4]-[5]. Thus there are two different techniques to solve this problem. One is to design an OTA with very low transconductance and another is to realize filter with large load capacitance. In this paper, current division technique is used to obtain a low transconductance, for implementation of very large time constant. Using this technique an OTA-C active filter can be designed for low frequency applications.

In this paper, a low frequency Active filter design using OTA has been explained. The total number of components used in these circuits are very small, the design equations and voltage- current characteristics are attractive. An improvement in design simplicity is observed in comparison with op amp based structures. 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 at the input, and converts it into output current.

The ideal transfer characteristic of OTA is $Io = \mathbf{g_m} (V1^+ - V2^-)$

Where $V1^+ - V2^-$ is a differential input voltage and Io is a output current and $\mathbf{g_m}$ is the transconductance gain of OTA.

By taking the pre-computed difference as the input, $Io = \mathbf{g_m}$ Vin

The transconductances $\mathbf{g_m}$ is also a function of the input differential voltage. The term “transconductance” in OTA is the ratio of output current to the input voltage, $\mathbf{g_m}$, has the unit of conductance.

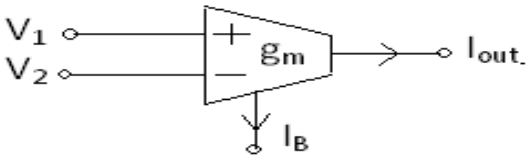


Figure 1. Circuit symbol of OTA

II. PRINCIPLE OF OPERATION AND CIRCUIT ANALYSIS

OTA-based filters are composed of the open-loop OTA-C integrators in which the devices are operated in the subthreshold region to realize a very low transconductances, typically of the order of a few nano amperes. In OTA-based circuits, the bias current will dominate the performance of the filter circuit, and the ratio of capacitance to small transconductance determines the time constant of OTA-C integrators [4].

An active RC filter can be designed using OTA as a variable resistance simulator. Variable resistors are one of the applications of OTA. There are two types of OTA variable resistance simulators , those are positive resistance simulator and negative resistance simulator, depending on their feedback polarities. "Fig 2" and "Fig 3" shows two positive resistance simulators, realized using negative feedback. The input impedance of these two versions can be derived by assuming an input voltage v_i and an input current i_i for each version.

$Z_i = v_i / i_i = 1/ \mathbf{g_m}$

OTA is assumed to have a transconductance $\mathbf{g_m}$. At frequencies much lower than the cut off frequency of the OTAs, $\mathbf{g_m}$ is real, thus Z_i becomes a resistor using single OTA and two OTAs. Resistance values are realized by varying the bias current of the OTA. OTA variable resistors with capacitors can compose OTA-C filters, where these OTA variable resistors are used to tune the filter frequencies.

The performance of the proposed circuit is illustrated by Proteus Proffessional-7.5 simulations, which are in accordance with theoretical predictions. In this paper for experimental work OTA LM13600 is used.

The transconductances $\mathbf{g_m}$ is given by, $\mathbf{g_m} = I_{bias} / 2V_T$

Where V_T: thermal voltage = 26 mV at room temperature, I_{bias} : bias current.

The proposed circuit of the floating positive resistance simulator is shown in "Fig. 2", where I_b is the bias current of the OTA.

1.1 Simulation of positive floating resistance using single OTA

Consider the circuit in "Fig. 2" it is a positive resistance simulator using single OTA. By properties of the OTA, we will get,

$R_{eq} = Vin^+ - Vin^- / I_R = 1/ \mathbf{g_m}$

Where $\mathbf{g_m} = I_{bias} / 2V_T$

Therefore , $R_{eq} = 2V_T / I_{bias}$.

From above equation it is clear that resistance value can be easily electronically varied by varying the bias current.

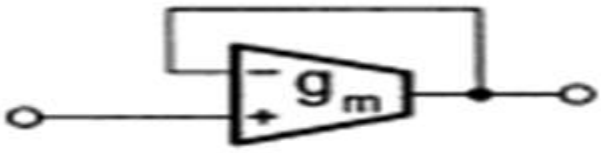


Figure 2 OTA simulation of floating resistor

1.2 Simulation of positive floating resistance using two OTAs.

Consider the circuit shown in "Fig. 3", it is a positive resistance simulator using two OTAs. The bias current applied for two OTAs is I_B (refer in "Fig. 6"). This externally applied bias current I_B divides between two OTAs. For each OTA bias current $I_b = I_B / 2$. Therefore the transconductance g_m for two OTAs is given by, $g_m = g_m$. The current division concept used in this circuit is mainly useful to obtain lower value of

transconductances, which helps in the design of active filters in low frequency range to obtain larger value of time constant. The simulated resistance which depends on bias current is reciprocal transconductances g_m .

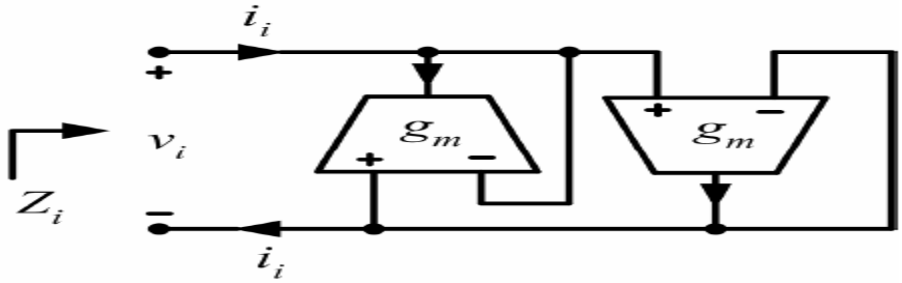


Figure 3 Simulation of floating resistor using two OTAs

1.3 Low **frequency RC low pass filter using OTA**

A low frequency RC low pass filter is designed using OTA resistance simulator. Both type of resistance simulators are used in filter design, i,e using single OTA and using two OTAs. "Fig 4" shows the conventional circuit of RC low pass filter. "Fig 5" is a RC low pass filter using single OTA and "Fig 6" is a RC low pass filter using two OTAs. Output of the filter is measured by varying the bias current to obtain required cut off frequency.[1]-[6]

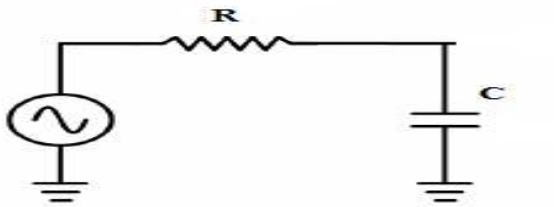


Figure 4 Conventional circuit of RC low pass filter.

III. EXPERIMENTAL SETUP

The stated circuits of "Fig 5" and "Fig 6" are simulated using Proteus professional 7.5 software. Same circuits are arranged on bread board using an OTA LM13600 to verify the software results. Output of the filter is observed by varying the bias current of OTAs.

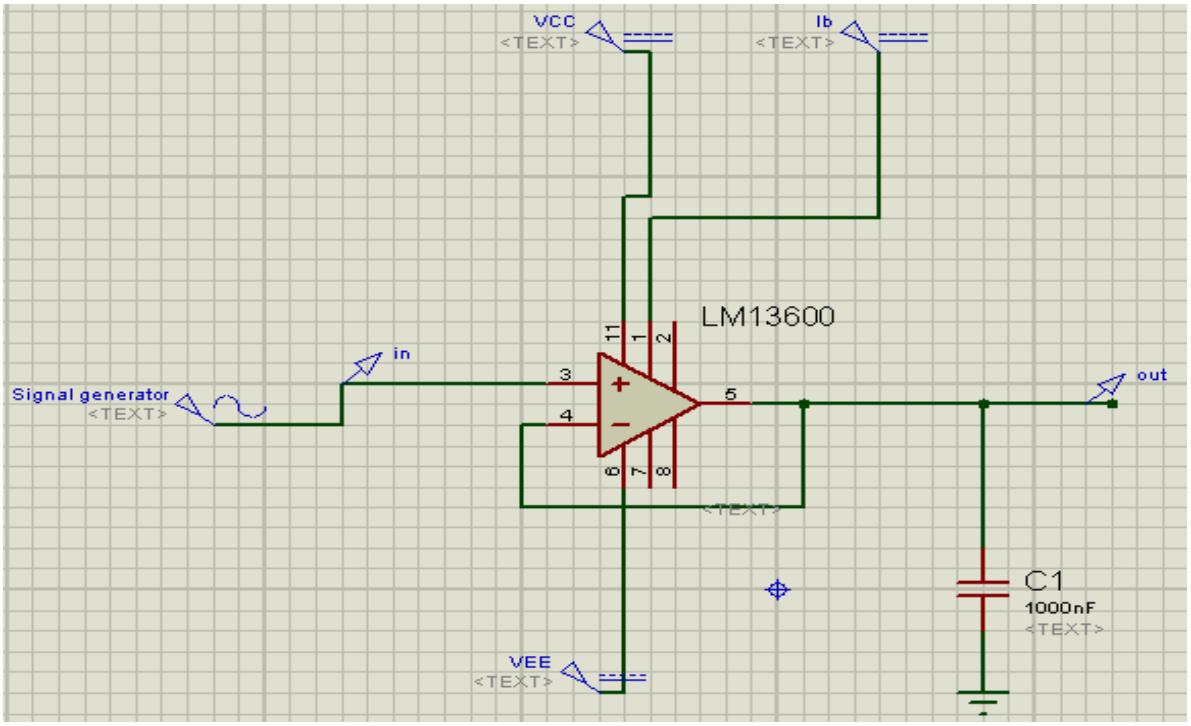


Figure. 5 Circuit diagram of OTA- C Low Pass filter using software

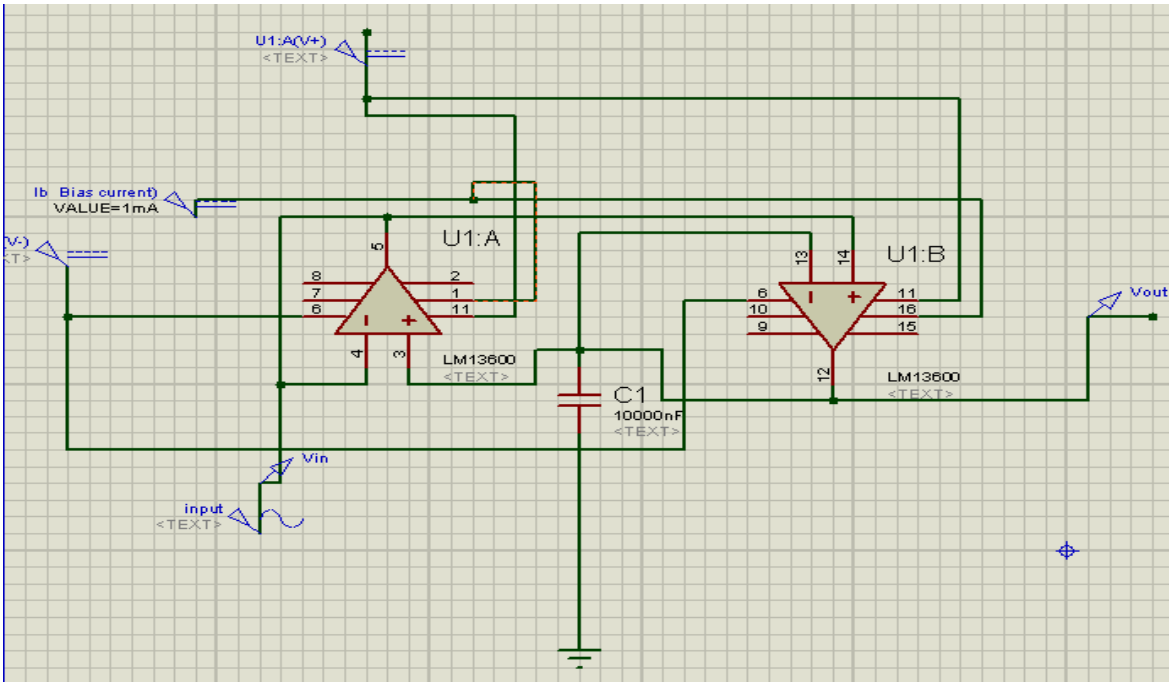


Figure. 6 Circuit diagram of Low Pass filter using two OTAs.

IV. RESULTS AND DISCUSSION

The studied circuits using single OTA and two OTAs function as low pass filter. Output of the filter is obtained by varying the bias current of OTA for two different values of output capacitive load i,e C = 10µF and 100µF. Software results are verified by theoretical calculations and also they are confirmed by connecting the circuit on breadboard and practical results validates with software results.

1.1.1 Low frequency RC low pass filter using single OTA

The circuit shown in "Fig 5" is an active RC low pass filter in which the series resistance connected in RC active filter is a OTA resistance simulator.The resistance simulator used, in this filter circuit is a positive resistance simulator,(ref Fig 2) because the output terminal is connected to negative input terminal to obtain positive resistance simulation. By mere changing I_{bias} from 100nA to 2mA, the simulated value of resistance obtained is from **520KΩ** to **26Ω** i.e Hundreds of Kilo ohms to ohms. Simulated resistance behaves like a passive resistor of positive temperature coefficient.

Proposed circuit of active RC low pass filter comprises only single OTA and a capacitor C. Resistance values are realized by varying the bias current of the OTA. The resistance values simulated by OTA for different bias currents are given in table 1.1. By using single OTA resistance simulator, an active RC low pass filter is designed which is shown in "Fig 5.". The cut off frequencies of this OTA-C RC low pass filter are obtained by varying the bias current from 100nA to 2mA, by using Proteus professional 7.5 software. These cut off frequencies are verified with calculated values of cut off frequencies of an active RC low pass filter. These results are tabulated in tables 1.1 and 1.2.

Table 1.1

C = 10µF			
Bias current I_{bias}	**Software results f_{-3dB}**	**Simulate Resistance $R = 1/g_m$**	**$f_{-3dB} = \frac{g_m}{2\pi C} = 1/2\pi RC$**
100nA	30.9mHz	520KΩ	30.06mHz
500nA	152mHz	104KΩ	153mHz
1µA	301mHz	52 KΩ	306mHz
10µA	3.13Hz	5.2KΩ	3.06Hz
100µA	31.7 Hz	520Ω	30.6Hz
500µA	154 Hz	104Ω	153Hz
1mA	303 Hz	52Ω	306Hz
2mA	600Hz	26Ω	612Hz

From table 1.1 it is clear that, by varying the bias current from 100nA to 2mA the cut off frequencies obtained are from 30.9mHz to 600Hz, for C = 10µF. Theoretical cut off frequencies validates with software results.

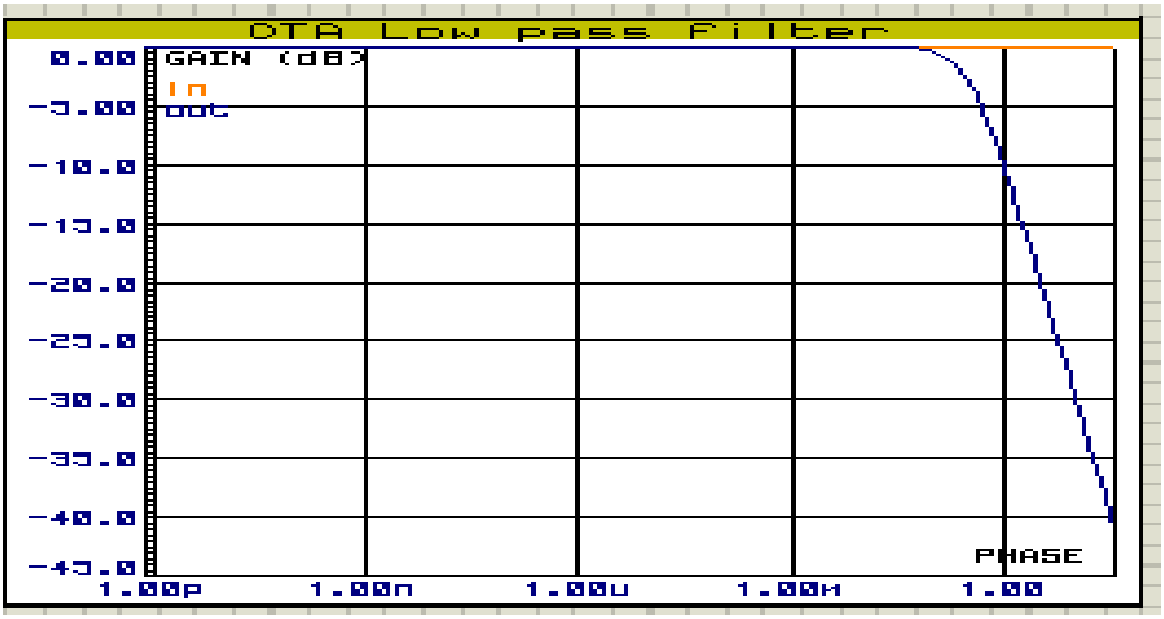


Figure.7 Frequency response of Proteus professional 7.5 simulated OTA-C low pass filter, for C = 10µF with I_{bias}= 1µA, with maximum. gain 0 dB and cut off frequency of 301mHz at - 3dB.

Table 1.2

C = 100µF			
Bias current I_{bias}	**Software results f_{-3dB}**	**Simulate Resistance $R = 1 / g_m$**	**$f_{-3dB} = \frac{g_m}{2\pi C} = 1/2\pi RC$**
100nA	3.09mHz	520KΩ	3.06mHz
500nA	15.3mHz	104KΩ	15.3mHz
1µA	30.1mHz	52 KΩ	30.6mHz
10µA	209mHz	5.2KΩ	306mHz
100µA	3.13Hz	520Ω	3.06Hz
500µA	15.2Hz	104Ω	15.30Hz
1mA	30Hz	52Ω	30.60Hz
2mA	60Hz	26Ω	61.21Hz

From table 1.2 by varying the bias current from 100nA to 2mA the cut off frequencies obtained are from 3.09mHz to 60Hz, for C = 100µF.

As capacitance value C is further increased, for given bias currents from 100nA to 2mA the cut off frequencies can be still further decreased.

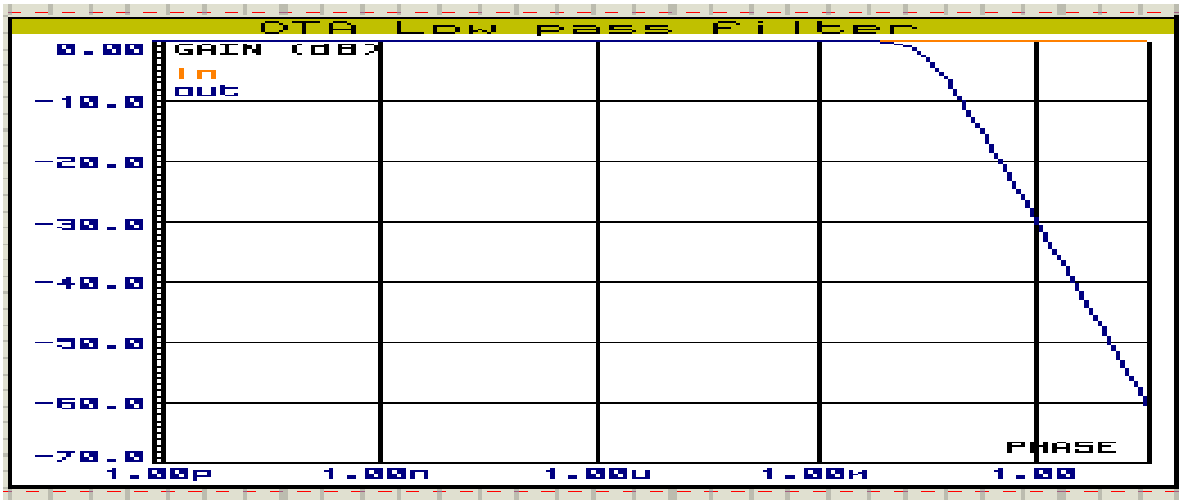


Figure.8 Frequency response of Proteus professional 7.5 simulated OTA-C low pass filter , for C= 100µF with I_{bias}= 1µA, with maximum gain 0 dB and cut off frequency of 30.1 mHz at - 3dB.

1.1.2 Low frequency RC low pass filter using two OTAs.

The circuit shown in Figure 6 is an active RC low pass filter in which the series resistance connected in RC active filter is a OTA resistance simulator using two OTAs.The resistance simulator used, in this filter circuit is a positive resistance simulator,(ref Fig 3) because the output terminal is connected to negative input terminal to obtain positive resistance simulation. In this type of resistance simulation the transconductance of two OTAs are given by $g_m = g_m$, therefore $R = 1/ g_m$. In case of bias current, current division takes place. It means I_{bias} equally divides between two OTAs. For example if I_B = 100µA then bias current of each OTA will be 50µA,and $g_m = I_{bias}/ 2V_T$ = 50µA / 2×26mV.

By mere changing I_{bias} from 100nA to 4mA, it means 50nA to 2mA for each OTA , the simulated value of resistance obtained is from **1040KΩ** to **26Ω** i.e Thousands of Kilo ohms to ohms . Therefore the advantage of this circuit is that, we can obtain 1 GΩ of resistance. Such a high resistance gives larger time constant, which is useful in filter designing. .

Proposed circuit of active RC low pass filter comprises of two OTAs and a capacitor C. Resistance values are realized by varying the bias current of the OTA. The resistance values simulated by OTAs for different bias currents are given in table 1.3. By using this, two OTAs resistance simulator an active RC low pass filter is designed which is shown in Figure 6. Cut off frequencies of OTA-C RC low pass filter are obtained by varying the bias current from 100nA to 4mA, by using Proteus professional 7.5 software. These cut off frequencies are verified with calculated value of cut off frequencies of an active RC low pass filter. These results are tabulated in tables 1.3 and 1.4.

Table 1.3

C = 10µF				
Bias current I_B	For each OTA $I_{b1} = I_{b2} = I_B/2$	Simulate Resistance $R = 1 / g_m$	**Calculated cut off frequency $f_{-3dB} = \frac{g_m}{2\pi C} = 1/ 2\pi RC$**	**Software results f_{-3dB}**
100nA	50nA	1040KΩ	15.2mHz	15.8mHz
500nA	250nA	208KΩ	7.63mHz	7.83mHz
1µA	500nA	104KΩ	15.2mHz	158mHz
10µA	5µA	10.04KΩ	1.52Hz	1.58Hz
100µA	50µA	1KΩ	15.3Hz	15.7Hz
500µA	250µA	208Ω	76.4Hz	77 Hz
1mA	500µA	104Ω	152.9Hz	152 Hz
2mA	1mA	52Ω	306 Hz	299 Hz
3mA	1.5mA	34.7Ω	458 Hz	450 Hz
4mA	2mA	26Ω	612Hz	600Hz

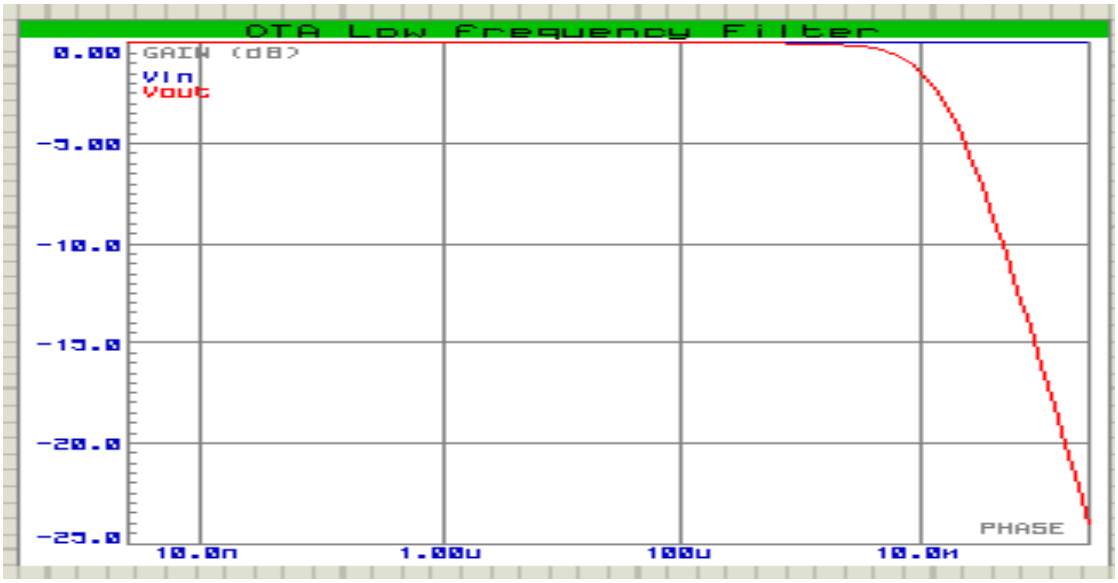


Figure.9 Frequency response of Proteus professional 7.5 simulated OTA-C low pass filter circuit, for C= 10µF with I_{bias}= 100nA, with maximum gain 0 dB and cut off frequency of 15.2 mHz at - 3dB.

From table 1.3 it is clear that, by varying the bias current from 100nA to 4mA ,(but for each OTA bias current I_B is taken as I_{b1}= I_{b2}= I_B / 2 , therefore variation of bias current is considered to be from 50nA to 2mA) the cut off frequencies obtained are from **15.2mHz** to **612Hz**, for C = 10µF.

Table 1.4

C = 100 µF				
Bias current Ib	For each OTA Ib1= Ib2 = Ib/2	Simulate Resistance R = 1 / g_m	**Calculated cut off frequency** $f_{-3dB} = \frac{g_m}{2\pi C} = 1/2\pi RC$	**Software results** f_{-3dB}
100nA	50nA	1040KΩ	1.52mHz	**1.57mHz**
500nA	250nA	208KΩ	7.63mHz	**7.86mHz**
1µA	500nA	104KΩ	15.2mHz	15.6mHz
10µA	5µA	10.04KΩ	152mHz	158mHz
100µA	50µA	1KΩ	1.53Hz	1.57Hz
500µA	250µA	208Ω	7.63Hz	7.68 Hz
1mA	500µA	104Ω	15.3Hz	15.2Hz
2mA	1mA	52Ω	30.6Hz	29.3Hz
3m	1.5mA	34.7Ω	45Hz	42.4Hz
4m	2mA	26Ω	60Hz	60 Hz



Figure.10 Frequency response of Proteus professional 7.5 simulated OTA-C low pass filter circuit, for C= 100μF with I_{bias}= 100nA, with maximum gain 0 dB and cut off frequency of 1.52 mHz at - 3dB

From table 1.4 it is clear that by varying the bias current from 100nA to 4mA that is for each OTA it is from 50nA to 2mA the cut off frequencies obtained are from 1.52mHz to 60 Hz, for C = 100μF.

As capacitance value C is further increased, for given bias currents from 50nA to 2mA , still lower value of cut off frequencies can be obtained. Current division technique used in two OTAs filter structure to obtain lower values of bias current implies very low transconductances. In this paper a low transconductance of order 2μsiemens for the external bias 100nA for single OTA filter structure and 1μsiemen of transconductance for the external bias current of 50nA for two OTAs filter structure are obtained.

V. CONCLUSION

OTA-C filter realized with minimum number of OTA's and capacitor is an innovative method of designing low frequency active filters which have flexibility in respect of pass band width. The above discussion concludes that we can achieve a tunable range of low frequencies only by changing externally accessible bias current which changes parameter $\mathbf{g_m}$ transconductance of a device. All the requirements such as low supply voltage of order 1.8V, low component count and portability are achieved.

OTA-C RC filters design using single OTA and two OTAs explain the application of OTA in active filter design of low frequency of order of 3.09mHz and 1.52mHz respectively. In these low frequency filters OTA behaves as positive resistance simulator. There is a good agreement between theoretical, and software results and also with the experimental observations. Butterworth characteristics of filter is desirable at such low frequency with out mixing of any noise signals[7]. The filter characteristics are stable at low frequency of 1.52mHz on wards, and have applications in, biomedical science , sensor circuits and neural networks[8].

VI. ACKNOWLEDGEMENTS

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