Analysis and Simulation of Active Filters Using Operational Transconductance Amplifier (OTA)

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Abstract

As the transistors are continuously scaling down, it becomes necessary to reduce voltage supply and power requirements of the circuit to increase its performance and stability. Whereas, current- mode devices require less number of stages with high output impedance results in improved performance and large bandwidth as compared to voltage-mode techniques. OTA are current-mode device that takes voltage as input and produces current as output with high gain and large bandwidth. The frequency bands were parameters were determined such as the cutoff frequency (fc), the band width (BW), the quality factor (Q), and the angular frequency (Wo). In this paper the design and the simulation of the transfer function has been done by using (MATLAB) in order to obtain the frequency response for all types of filter (the low pass filter, high pass filter, band pass filter and band stop filter).

Keyword: Bw, Matlab, Ota

OTA model

These filters consist of operational transconductance amplifier and capacitor only. OTA is voltage control current source with transfer circuits. The symbol and small-signal equivalent circuit is shown in Figure (1) below:

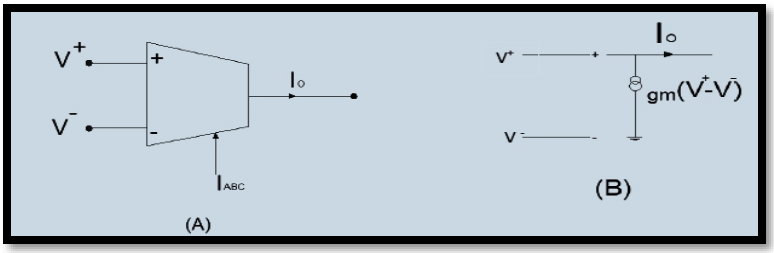


Figure (1) the symbol and small-signal equivalent circuit of OTA

The differential Transconductance equation is given by:

$$gm = \frac{Io}{V^{+} - V^{-}}$$

It is related to the external bias current (IABC) and thermal voltage by the relation:

$$gm = \frac{I_{ABC}}{2V_T}$$

The above equations were valid for several decade of bias current until leakage current limits the linearity of gm. The ideal circuits are the same as ideal voltage operational amplifier except that OTA has extremely high output impedance. However, OTA parameters are directly or inversely proportional to the external bias current, $(gm\boldsymbol{\alpha}I_{ABC})$ but the input & output impedance are inversely proportional to IABC.

Introduction

OTA is an amplifier whose differential input voltage produces an output current at the output terminal. It also called voltage controlled current source (vccs). There is usually an additional input for a current to control the amplifier's transconductance .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 which are attractive to the integration Component count of these structures which are 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 to the frequency referenced applications [Geiger and Sinencio. 2001].

From a practical viewpoint, the highest –frequency performance of the 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 [Looby 2000].

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 para meters 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 Trans conductance 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 Trans conductance 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[Geiger and Sinencio. 2001].

OTA Application:

1. This application, published by Shunn, presents the design and experimental results of advanced analog blocks manufactured in a printed complementary organic TFT technology on flexible foil. Operational Transconductance amplifiers exhibiting open-loop gain from 40 to 50 dB and gain-bandwidth product from 55 Hz to 1.5 kHz have been implemented by using different circuit topologies. An extensive amplifier characterization in both time and frequency domain (i.e., gain, gain-bandwidth product, phase margin, settling time, harmonic distortion) has been carried out, which demonstrates the performance of the adopted technology in analog circuit implementations. Finally, a 40-dB 1.5-kHz amplifier has been employed in a switched capacitor comparator that proved fully functionality up to input frequency of 50 Hz [Shunn2013].

2. This application that published by Jaims defines an approach to design the field programmable CMOS OTA. All the MOSFETs are replaced by the floating gate MOSFETs to make the OTA design programmable. The charge at the floating gate can be programmed after fabrication, based on Hot-e-injection and Fowler-Northeim tunneling techniques which results in threshold voltage variation which in turn can modify circuit's specifications. The high frequency small signal analysis of the design is prepared and specifications like output current, Trans conductance, input impedance, output impedance and offsets of the design are re-derived in terms of threshold voltages of the MOSFETs. In order to achieve circuits AC and DC characteristics, the circuit is simulated using BSIM3 level 49 MOSFET models in T-spice 0.35um CMOS process. The simulated results shows 13 bit programming precision in trans conductance, input impedance, output impedance, Temperature stability and dc offsets with respect to threshold voltage of respective MOSFETs [**Jaims 2013**].

3. In the paper which published by Ranjan and Sergio Carlothey, presents the design and optimization of a nested-Miller compensated, three-stage operational transconductance amplifier (OTA) for use in switched-capacitor (SC) circuits. Existing design methods for three-stage OTAs often

lead to sub-optimal solutions because they decouple inter-related metrics like noise and settling performance. In our approach, the problem of finding an optimal design with the best total integrated noise and settling time has been cohesively solved by formulating a nonlinear constrained optimization program. Equality, inequality, and semi-infinite constraints are formed using closed form symbolic expressions obtained by a closed loop analysis of the SC gain stage and the optimization program is solved by using the interior-point algorithm. For the optimization routine, there is no need to interface with a circuit simulator because all significant devices parasitic are included in the model. The optimization and modeling steps are general in nature and can be applied to any amplifier or filter topology. Simulation results show that a 90-nm prototype amplifier achieves a ±0.1% dynamic error settling time of 2.5 ns with a total integrated noise of 240 μVrms, while consuming 5.2 mW from a 1-V power supply [Ranjan and Sergio Carlo 2013].

Analysis of OTA circuits:

There are three all pass circuits of OTA filters which are analyzed in this paper as shown below.

1- The first circuit shown in (2), the analysis of filter is given by the following steps:

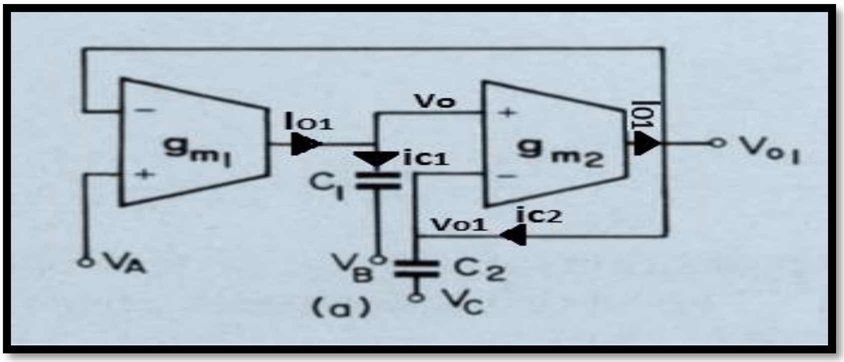


Figure (2) canonical Band pass filter

$I_{O1} = g_{m1}(V_A - V_{O1})$ ……………………… (1)

$I_{O2} = i_{C1} = S_{C1}(V_O - V_B)$ ……………………… (2)

$I_{O2} = g_{m2}(V_O - V_{O1})$ ……………………… (3)

$I_{O2} = i_{C2} = S_{C2}(V_{O1} - V_C)$ ……………………… (4)

From (1) & (2)

$$g_{m1}V_A - g_{m1}V_{O1} = S_{C1}(V_{O-}V_B)$$

$$g_{m1}V_A - g_{m1}V_{O1} = S_{C1}V_{O-}S_{C1}V_B$$

$$V_{O1}\,g_{m1=}\,g_{m1}V_A - S_{C1}V_{O+}S_{C1}V_B$$

$$V_{O1} = \frac{g_{m1}V_A - S_{C1}V_{O+}S_{C1}V_B}{g_{m1}}$$

……………………… (5)

From (3) & (4)

$$g_{m2}(Vo - V_{O1}) = S_{C1}(V_{O-}V_B)$$

$$g_{m2}V_O - g_{m2}V_{O1} = S_{C2}V_{O1} - S_{C2}V_C$$

$$g_{m2}V_O = S_{C2}V_{O1} - S_{C2}V_C + g_{m2}V_{O1}$$

$$V_O = \frac{S_{C2}V_{O1} - S_{C2}V_C + g_{m2}V_{O1}}{g_{m2}}$$

……………………… (6)

Put (6) in (5)

$$V_{O1} = \frac{g_{m1}V_A - S_{C1}\left(\frac{S_{C2}V_{O1} - S_{C2}V_C + g_{m2}V_{O1}}{g_{m2}}\right) + S_{C1}V_B}{g_{m1}}$$

$$V_{O1} = \frac{1}{g_{m1}}\left(g_{m1}V_A - \frac{S_{C1}S_{C2}V_{O1} - S_{C1}S_{C2}V_C + S_{C1}g_{m2}V_{O1}}{g_{m2}} + S_{C1}V_B\right)$$

$$V_{O1} + \frac{S_{C1}S_{C2}V_{O1}}{g_{m1}g_{m2}} + \frac{S_{C1}g_{m2}V_{O1}}{g_{m1}g_{m2}} = V_A + \frac{S_{C1}S_{C2}V_C}{g_{m1}g_{m2}} + \frac{S_{C1}V_B}{g_{m1}}$$

$$\left[\frac{V_{O1}g_{m1}g_{m2} + S_{C1}S_{C2}V_{O1} + S_{C1}g_{m2}V_{O1}}{g_{m1}g_{m2}} = \frac{V_A g_{m1}g_{m2} + S_{C1}S_{C2}V_C + S_{C1}V_B g_{m2}}{g_{m1}g_{m2}}\right]$$

$$V_{O1}g_{m1}g_{m2} + S_{C1}S_{C2}V_{O1} + S_{C1}g_{m2}V_{O1} = V_A g_{m1}g_{m2} + S_{C1}S_{C2}V_C + S_{C1}V_B g_{m2}$$

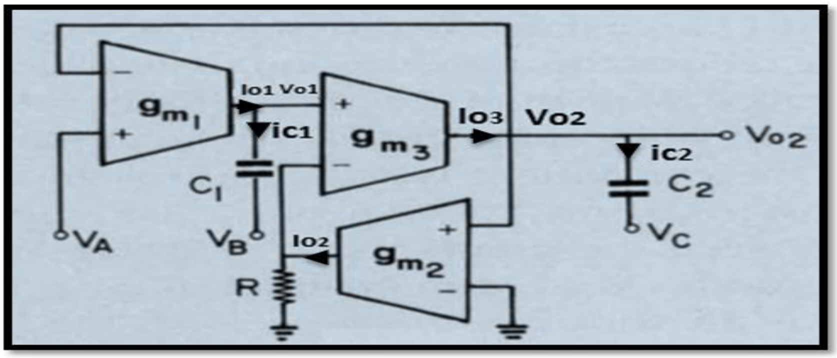
$$V_{O1}(g_{m1}g_{m2} + S_{C1}S_{C2} + S_{C1}g_{m2}) = V_A g_{m1}g_{m2} + S_{C1}S_{C2}V_C + S_{C1}V_B g_{m2}$$

$$V_{O1} = \frac{V_A g_{m1}g_{m2} + S_{C1}S_{C2}V_C + S_{C1}V_B g_{m2}}{g_{m1}g_{m2} + S_{C1}S_{C2} + S_{C1}g_{m2}}$$

$$V_{O1} = \frac{V_A g_{m1}g_{m2} + S^2 C1C2V_C + S_{C1}V_B g_{m2}}{g_{m1}g_{m2} + S^2 C1C2 + S_{C1}g_{m2}} \qquad \text{……………………… (7)}$$

The last equation represents the output of filter for all pass.

2- For the second circuit of OTA shown in figure (3). The output (Vo2) of the circuit can be derived by the following steps:



Figure(3) Non-canonical all pass filter

$I_{O1} = g_{m1}(V_A - V_{O1})$ ………………………. (8)

$I_{O2} = i_{C1} = S_{C1}(V_{O1} - V_B)$ ………………………. (9)

$g_{m1}(V_A - V_{O2}) = S_{C1}(V_{O1} - V_B)$

$g_{m1}V_A - g_{m1}V_{O2} = S_{C1}V_{O1} - S_{C1}V_B$

$g_{m1}V_{O2} = g_{m1}V_A + S_{C1}V_B - S_{C1}V_{O1}$ ………………………. (10)

$I_{O3} = g_{m3}(V_{O1} - V_O)$ ………………………. (11)

$I_{O3} = i_{C2} = S_{C2}(V_{O2} - V_C)$ ………………………. (12)

$g_{m3}(V_{O1} - V_O) = S_{C2}(V_{O2} - V_C)$

$g_{m3}V_{O1} - g_{m3}V_O = S_{C2}V_{O2} - S_{C2}V_C$

$g_{m3}V_{O1} = S_{C2}V_{O2} + S_{C2}V_C - g_{m3}V_O$

$V_{O1} = \frac{1}{g_{m1}}[S_{C2}V_{O2} + S_{C2}V_C - g_{m3}V_O]$ ………………………. (13)

From (10) & (13)

$$g_{m1}V_{O2} = g_{m1}V_A + S_{C1}V_B - \frac{S_{C1}}{g_{m1}}[S_{C2}V_{O2} + S_{C2}V_C - g_{m3}V_O]$$

$$V_{O2}\left[g_{m1} + \frac{S^2{}_{C1C2}}{g_{m3}}\right] = g_{m1}V_A + S_{C1}V_B + \frac{S^2{}_{C1C2}}{g_{m3}}V_C - S_{C1}V_O$$

$I_{O2} = g_{m2}V_{O2}$ ………………………. (14)

$V_O = R\, I_{O2} = R\, g_{m2}V_{O2}$ ………………………. (15)

Put (6) in (5)

$$V_{O2}\left[g_{m1} + \frac{S^2{}_{C1C2}}{g_{m3}}\right] = g_{m1}V_A + S_{C1}V_B + \frac{S^2{}_{C1C2}}{g_{m3}}V_C - SR_{C1}g_{m2}V_O$$

$$V_{O2}\,[g_{m1} + \frac{S^2{}_{C1C2}}{g_{m3}} + S_{C1}g_{m2}\,R] = g_{m1}V_A + S_{C1}V_B + \frac{S^2{}_{C1C2}}{g_{m3}}V_C$$
$$V_{O2}\,[\frac{g_{m1}g_{m3} + S^2{}_{C1C2} + S_{C1}g_{m2}g_{m3}R}{g_{m3}}] = g_{m1}V_A + S_{C1}V_B + \frac{S^2{}_{C1C2}}{g_{m3}}V_C$$
$$V_{O2}\,[g_{m1}g_{m3} + S^2{}_{C1C2} + S_{C1}g_{m2}g_{m3}R] = g_{m1}g_{m3}V_A + S_{C1}g_{m3}V_B + S^2{}_{C1C2}V_C$$
$$V_{O2} = \frac{g_{m1}g_{m3}V_A + S_{C1}g_{m3}V_B + S^2{}_{C1C2}V_C}{S^2{}_{C1C2} + S_{C1}g_{m2}g_{m3}R + g_{m1}g_{m3}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

3- The third circuit of OTA shown in figure (4). The analysis of this filter can be shown by the following steps:

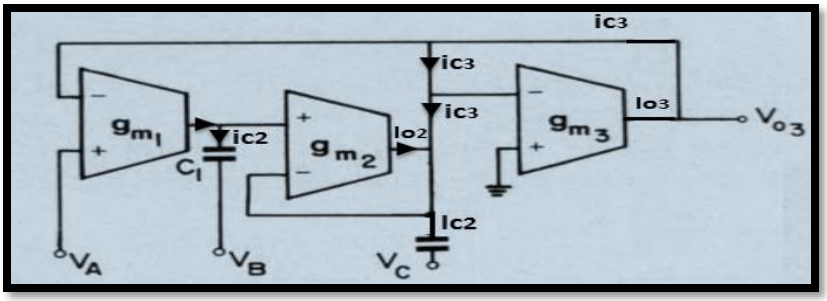


Figure (4) third type of OTA circuit

$$I_{O1} = g_{m1}\,(V_A - V_{O3}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$
$$I_{O2} = i_{C1} = S_{C1}(V_{O1} - V_B) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$
$$g_{m1}(V_A - V_{O3}) = S_{C1}(V_{O1} - V_B)$$
$$g_{m1}V_A - g_{m1}V_{O3} = S_{C1}V_{O1} - S_{C1}V_B$$
$$g_{m1}V_{O3} = g_{m1}V_A + S_{C1}V_B - S_{C1}V_{O1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$
$$i_{O2} = g_{m2}V_{O1}$$
$$i_{O3} = -g_{m3}V_{O3}$$
$$i_{C2} = S_{C2}(V_{O3} - V_C)$$
$$i_C = i_{O2} + i_{O3}$$
$$S_{C2}V_{O3} - S_{C2}V_C = g_{m2}V_{O1} - g_{m3}V_{O3}$$
$$V_{O1} = \frac{1}{g_{m2}}[V_{O3}(S_{C2} + g_{m3}) - S_{C2}V_C] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

From (19) & (20)

$$g_{m1}V_{O3} = g_{m1}V_A + S_{C1}V_B - \frac{S_{C1}}{g_{m2}}[V_{O3}(S_{C2} + g_{m3}) - S_{C2}V_C]$$
$$V_{O3}\,[g_{m1}g_{m2} + S_{C1}(S_{C2} + g_{m3})] = g_{m1}g_{m2}V_A + S_{C1}g_{m2}V_B + S^2{}_{C1C2}V_C$$

$$V_{O3} = \frac{g_{m1}g_{m2}V_A + S_{C1}g_{m2}V_B + S^2{}_{C1C2}V_C}{g_{m1}g_{m2} + S_{C1}(S_{C2} + g_{m3})}$$

$$V_{O3} = \frac{S^2{}_{C1C2}V_C + S_{C1}g_{m2}V_B + g_{m1}g_{m2}V_A}{S^2{}_{C1C2} + S_{C1}g_{m3} + g_{m1}g_{m2}} \qquad \text{………………………. (21)}$$

Simulation of OTA circuit by using mat lab tools:

The simulation of the final equations of the circuits of the OTA filters can be derived by using one of these equations (7, 16, and 21) to classify the filter to LPF, HPF, BPF and BSF.

The following equation was used to simulate the transfer function for each filter test.

$$V_{O1} = \frac{V_A\, g_{m1}\, g_{m2} + S^2\, C1C2V_C + S_{C1}V_B g_{m2}}{g_{m1}\, g_{m2} + S^2C1C2 + S_{C1}\, g_{m2}} \qquad \text{……………………….}$$
(22)

A- First test:

For this test, let $g_{m1} = 96.774\ \mu s, g_{m2} = 6.2\ ms, C_1 = 1\mu F, C_2 = 2\mu F$.

The analysis of the filter type is given by the following points:

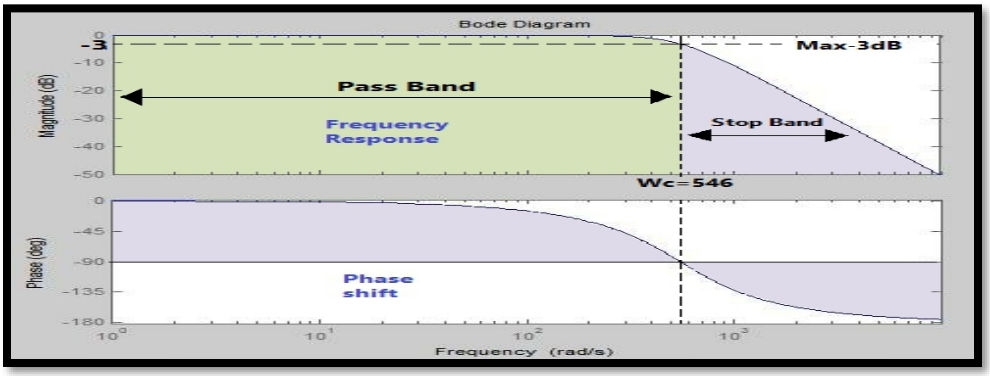
1- If VB = VC = 0, then the OTA filter is a LPF, VA is the input circuit and Vo1 is the output of circuit

$$\frac{V_{O1}}{V_A} = \frac{g_{m1}\ g_{m2}}{S^2\ C_1C_2\ + S\ C_1g_{m2} + g_{m1}\ g_{m2}} = \frac{g_{m1}\ g_{m2}}{C_1C_2\ (S^2 + S\frac{g_{m2}}{C_2} + \frac{g_{m1}\ g_{m2}}{C_1C_2})}$$

Where transfer function H(s) = $\frac{V_{O1}}{V_A}$

$$H(s)_{LP} = \frac{\frac{g_{m1}\ g_{m2}}{C_1C_2}}{S^2 + S\frac{g_{m2}}{C_2} + \frac{g_{m1}\ g_{m2}}{C_1C_2}} = \frac{300000}{S^2\ + 3100S + 300000}$$

The frequency response of the above 〖H(s)LP shown in figure (5), Where Wk =547rad/sec



Figure(5) simulation of OTA circuit for low pass filter

2- If VA = VB = 0 then the OTA filter is a HPF

$$\frac{V_{O1}}{Vc} = \frac{S^2\ C_1 C_2}{S^2\ C_1 C_2\ + S\ C_1 g_{m2} + g_{m1}\ g_{m2}} = \frac{S^2\ C_1 C_2}{C_1 C_2\ (S^2 + S\frac{g_{m2}}{C_2} + \frac{g_{m1}\ g_{m2}}{C_1 C_2})}$$

Where the transfer function H(s) = $\frac{V_{O1}}{V_C}$

$$H(s)_{HP} = \frac{\frac{S^2\ C_1 C_2}{C_1 C_2}}{S^2 + S\frac{g_{m2}}{C_2} + \frac{g_{m1}\ g_{m2}}{C_1 C_2}} = \frac{S^2}{S^2 + S\frac{g_{m2}}{C_2} + \frac{g_{m1}\ g_{m2}}{C_1 C_2}}$$

$$H(s)_{HP} = \frac{S^2}{S^2\ + 3100S + 300000}$$

The frequency response of the above transfer function is shown in figure (6) ,Where

Wc = 547 rad/sec

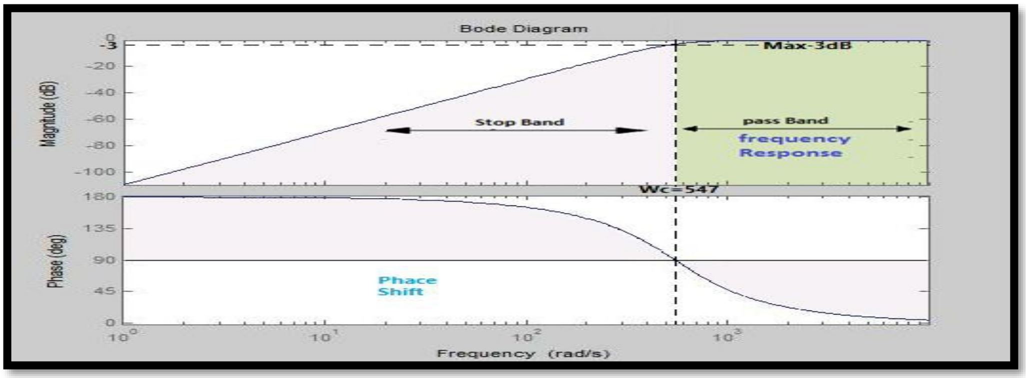


Figure (6) simulation of OTA circuit for high pass filter

3- If VA = VC = 0 then the OTA filter is a BPF.

$$\frac{V_{O1}}{VB} = \frac{SC_1 gm_1 VB}{C_1C_2(S^2 + SC_1\frac{gm_2}{C_2} + \frac{gm_1 gm_2}{C_1C_2})}$$

Where transfer function H(s) = $\frac{V_{O1}}{V_B}$

$$H(S)_{BPF} = \frac{\frac{SC_1 gm_2}{C_1C_2}}{S^2 + S\frac{gm_2}{C_2} + \frac{gm_1 gm_2}{C_1C_2}} = \frac{\frac{Sgm_2}{C_2}}{S^2 + S\frac{gm_2}{C_2} + \frac{gm_1 gm_2}{C_1C_2}}$$

$$H(S)_{BPF} = \frac{3100S}{S^2+3100S+300000}$$

The frequency response of the above transfer function was drawn and the results shown in figure (7) Where (Wo= 556rad/sec, Wc1=96rad/sec, Wc2=3150rad/sec)

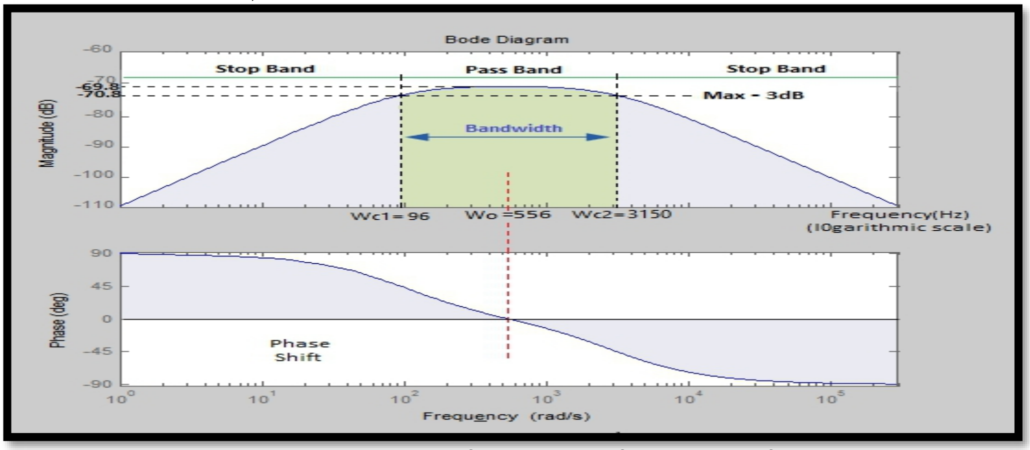


Figure (7) simulation of OTA circuit for band pass filter

4- If VB = 0 then the OTA filter is a BSF.

$$V_{O1} = \frac{S^2C_1C_2V_C + gm_1 gm_2 V_A}{S^2C_1C_2 + SC_1 gm_2 + gm_1 gm_2} = \frac{S^2C_1C_2V_C + gm_1 gm_2 V_A}{(S^2 + S\frac{gm_2}{C_2} + \frac{gm_1 gm_2}{C_1C_2})}$$

Where transfer function H(s) = $\frac{V_{O1}}{V_A}$

$$\frac{V_{O1}}{VA} = \frac{\frac{S^2C_1C_2}{C_1C_2} + \frac{gm_2 gm_2}{C_1C_2}}{S^2 + S\frac{gm_2}{C_2} + \frac{gm_1 gm_2}{C_1C_2}} = \frac{S^2 + \frac{gm_2 gm_2}{C_1C_2}}{S^2 + S\frac{gm_2}{C_2} + \frac{gm_1 gm_2}{C_1C_2}}$$

$$H(s)_{BSF} = \frac{S^2 + 300000}{S^2 + 3100S + 300000}$$

The frequency response of the above transfer function was draw and the results shown in figure (8). Where (Wo= 546rad/sec, Wc1=96rad/sec, Wc2=3180rad/sec)

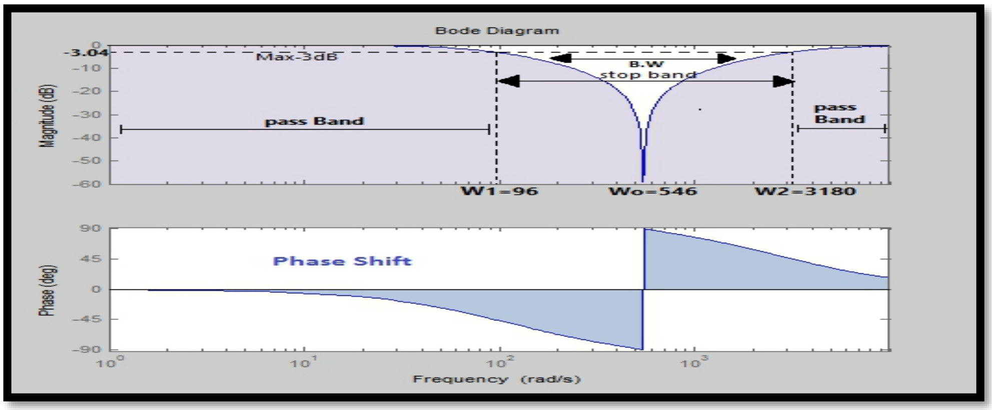


Figure (8) the simulation of the OTA circuit of a band stop filter

B- Second test:

For this test let $g_{m1} = 1\ \mu s,\ g_{m2} = 1\ ms, C_1 = 1\mu F,\ C_2 = 1\mu F.$

The analysis of the filter type can be shown below:

1- VB = VC = 0, the OTA filter is LPF

$$H(s)_{LP} = \frac{\frac{g_{m1}\ g_{m2}}{C_1 C_2}}{S^2 + S\frac{g_{m2}}{C_2} + \frac{g_{m1}\ g_{m2}}{C_1 C_2}} = \frac{W0^2}{S^2 + S\ \frac{W0}{Q} + W0^2}$$

$$H(s)_{LP} = \frac{1}{S^2 + S + 1}$$

$$Wc_{theoretically} = \sqrt{\frac{g_{m1}\ g_{m2}}{C_1 C_2}} = \sqrt{\frac{1ms \times 1ms}{1\mu s \times 1\mu s}} = 1rad/sec$$

$$\frac{Wc}{Q} = \frac{g_{m2}}{C_2} = \frac{1}{1} = 1 \rightarrow Q = 1 \text{ unitless}$$

$$Wc_{practically} = 1rad/sec$$

The frequency response of the above transfer function of the LPF is shown in figure (9).

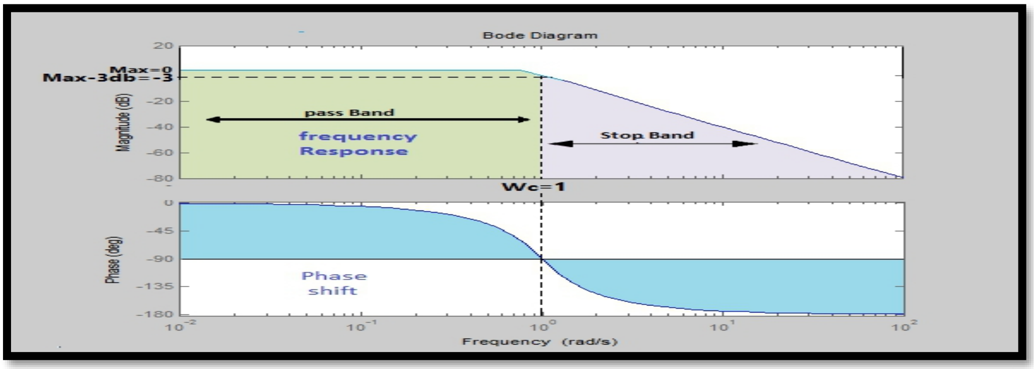


Figure (9) the simulation of OTA circuit for low pass filter

2- If VA = VB = 0 then the OTA filter is a HPF.

$$H(s)_{HP} = \frac{S^2}{S^2 + S\frac{g_{m2}}{C_2} + \frac{g_{m1}\ g_{m2}}{C_1 C_2}}$$

$$H(s)_{LP} = \frac{S^2}{S^2 + S + 1}$$

$$Wc_{theoretically} = \sqrt{\frac{g_{m1}\ g_{m2}}{C_1 C_2}} = \sqrt{\frac{1ms \times 1ms}{1\mu s \times 1\mu s}} = 1rad/sec$$

$$\frac{Wc}{Q} = \frac{g_{m2}}{C_2} = \frac{1}{1} = 1 \rightarrow Q = 1 \text{ unitless}$$

$$Wc_{practically} = 1rad/sec$$

The frequency response of the above transfer function shown in figure (10)

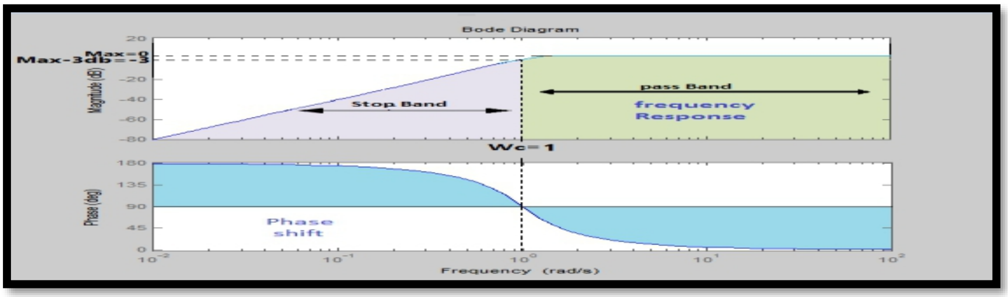


Figure (10) The simulation of OTA circuit for high pass filter

3- If VA = VC = 0 then the OTA filter is a BPF.

$$H(S)_{BPF} = \frac{\frac{Sgm_2}{C_2}}{S^2 + S\frac{gm_2}{C_2} + \frac{gm_1 gm_2}{C_1 C_2}} \rightarrow H(s)_{BPF} = \frac{S}{S^2 + S + 1}$$

$$Wo_{theoretically} = \sqrt{\frac{g_{m1}\ g_{m2}}{C_1 C_2}} = \sqrt{\frac{1ms \times 1ms}{1\mu s \times 1\mu s}} = 1rad/sec$$

$$\frac{Wo}{Q} = \frac{g_{m2}}{C_2} = \frac{1}{1} = 1 \rightarrow Q = 1 \text{ unitless}$$

$$W_{C1_{practically}} = 0.6\ rad/sec \ ; \ W_{C2_{practically}} = 1.5\ rad/sec$$

$$Wo = \sqrt{W_{C2} \times W_{C1}} = \sqrt{0.9 \times 1.5} = 0.94\ rad/sec$$

$$BW = W_{C2} - W_{C1} = 1.5 - 0.6 = 0.9\ rad/sec$$

$$\frac{Wo}{Q} = BW \rightarrow Q = \frac{Wo}{BW} = \frac{0.94}{0.9} = 1.04 \text{ unitless}$$

The frequency response of the above transfer function of the BPF shown at figure (11).

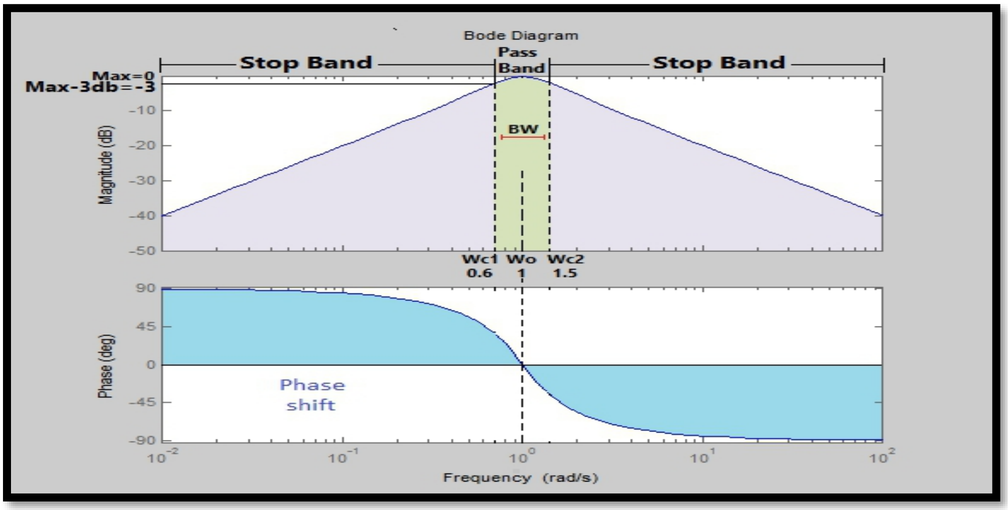


Figure (11) The simulation of OTA circuit for band pass filter.

4- If VB = 0 then the OTA filter is a BSF.

$$H(S)_{BSF} = \frac{S^2 + \frac{gm_2 gm_2}{C_1 C_2}}{S^2 + S\frac{gm_2}{C_2} + \frac{gm_1 gm_2}{C_1 C_2}} \rightarrow H(s)_{BSF} = \frac{S^2 + 1}{S^2 + S + 1}$$

$$Wo_{theoretically} = \sqrt{\frac{g_{m1}\ g_{m2}}{C_1 C_2}} = \sqrt{\frac{1ms \times 1ms}{1\mu s \times 1\mu s}} = 1rad/sec$$

$$\frac{Wo}{Q} = \frac{g_{m2}}{C_2} = \frac{1}{1} = 1 \rightarrow Q = 1 \text{ unitless}$$

$$W_{C1_{practically}} = 0.6\ rad/sec \ ; \ W_{C2_{practically}} = 1.5\ rad/sec$$

$$Wo = \sqrt{W_{C2} \times W_{C1}} = \sqrt{0.9 \times 1.5} = 0.94\ rad/sec$$

$$BW = W_{C2} - W_{C1} = 1.5 - 0.6 = 0.9\ rad/sec$$

$$\frac{Wo}{Q} = BW \rightarrow Q = \frac{Wo}{BW} = \frac{0.94}{0.9} = 1.04 \text{ unitless}$$

The frequency response of the above transfer function of the BSF was drawn and the results shown in figure (12)

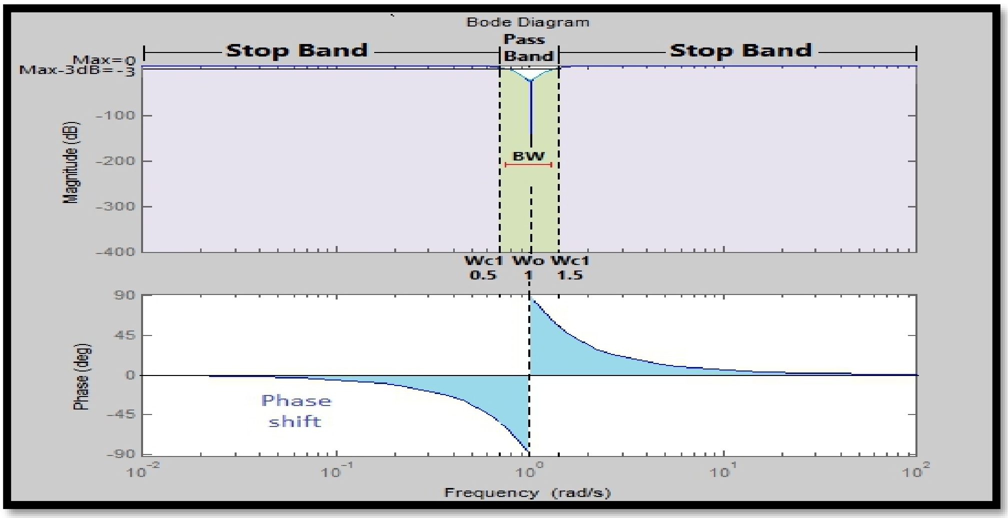


Figure (12) the simulation of the OTA circuit for the band stop filter

Conclusion

Filter is an important device in communication systems. When designing the electronic circuits that used for passing the required signals and rejecting the attenuating or the unwanted signals according to the types of filters needed in the electronic design .The circuits can be built by only using the operational trans-conductance amplifier and capacitor , the OTA circuit is a voltage control current source with its transfer circuits. OTA filters over the OP-AMP filters as shown in the following table:

Table (1) shows a simple comparison between the OTA filters and the OP-AMP filters

OTA filter	Op-amp filter
1) Voltage control current source {VCCS}.	1) Voltage control voltage source {VCVS}.
2) Filter circuit {OTAs + capacitors}.	2) Filter circuit {op-amp + resistors + capacitors}.
3) Small size circuit.	3) Large size circuit.
4) Low component count.	4) Component count greater than OTA.
5) Low passive sensitivities.	5) Large passive sensitivities.
6) Low noise {no resistance exists}.	6) Large noise {resistances exist}.
7) High stability.	7) Low stability.
8) Used for high frequencies.	8) Used for the frequencies less than OTA.
9) Electronically tunable	9) Constant frequency is changing by replacing the value of components
10) Input impedance=∞ Output impedance=∞	10) Input impedance=∞ Output impedance≅0 {very small}
11) Best dynamic range {Dr}	11) Low {Dr}.

In this project, we have analyzed some circuits for (OTA) filters and from there transfer function we can classifying them into a (low pass filter,

high pass filter, band pass filter and band stop filter).The simulation for all types of circuits has been done by using (MATLAB) program .
The frequency response has two types the (Amplitude response) and the (phase response),from the (amplitude response) some parameters of the filter can be derived, and comparing it with theoretical calculations.

For the LPF $W_{C\ theory} = 1 rad/sec$ while $W_{C\ practicaly} = 1 rad/sec$
For the HPF $W_{C\ theory} = 1 rad/sec$ while $W_{C\ practicaly} = 1 rad/sec$
For the BPF $W_{o\ theory} = 1 rad/sec$ while $W_{o\ practicaly} = 1 rad/sec$
$B.W_{theory} = 0.9\ rad/sec$ while $B.W_{practicaly} = 1.11\ rad/sec$
For the BSF $Q_{\ theory} = 1$ unitless while $Q_{\ practicaly} = 1$ unitless

Finally, by comparing between the active filter using the OP-AMP filters and those with the OTA filter is better than the OP-AMP filters because it does not use a resistor at the building of its circuit but the OTA filters are more sensitive and cannot be work for long time because it will make a phase shift in the center frequency and the selectivity after few hours of work.

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5. 345. Amit Ranjan Trivedi, Sergio Carlo" ***Exploring tunnel-FET for ultra-low power analog applications: a case study on operational trans conductance amplifier"*** **Published**(Volume: 60, Issue: 5, May 2013) ,**Page(s):** 1168 - 1174 ,**Date of Publication:** 26 March 2013