BIQUAD FILTER DESIGN USING OTA AND PERFORMANCE ESTIMATION

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ABSTRACT:

Being broadly used and universally delve into continuous time filters detain a outstanding place in the field of analog and digital circuits. The paper introduces a Universal filter employing OTA. The proposed design works in low power and high speed using OTA biquad filter implementation. It can realize low pass band pass, high pass filters simultaneously.

Keywords

Universal filter, OTA-C biquad, multiple input-single output, active filters.

1.1 The Operational Transconductance Amplifier

The schematic symbol and equivalent circuit model for an Operational Transconductance Amplifier (OTA) are shown in Figure 1.1(a),(b) respectively.

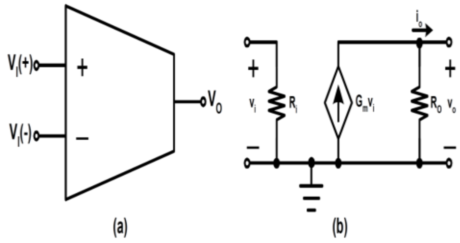

Figure 1.1 OTA Symbol and Equivalent Circuit.

The OTA changes an excitation voltage to a response current relative to a transconductance gain parameter $G_m=i_o/v_i$. Ideally, the excitation and response resistances are infinite ($R_i=R_o=\infty$) such that $i_i=i_{Ro}=0$ and a response current are absorbed solely to the load. The conventional OTA is classifying as a class A amplifier and is capable of generating maximum output currents equal to the bias current applied. The equivalent circuit model indicates the transconductance amplifier generates an output current (i_o) proportional to an input voltage (v_i) based on the transconductance gain G_m.

The open- circuit voltage gain of the conventional OTA model in Figure 1.1 (b) is given by $A=G_mR_o$.

A conventional, one stage, CMOS, Operational Transconductance Amplifier (OTA) configuration is shown in Figure 1.2.

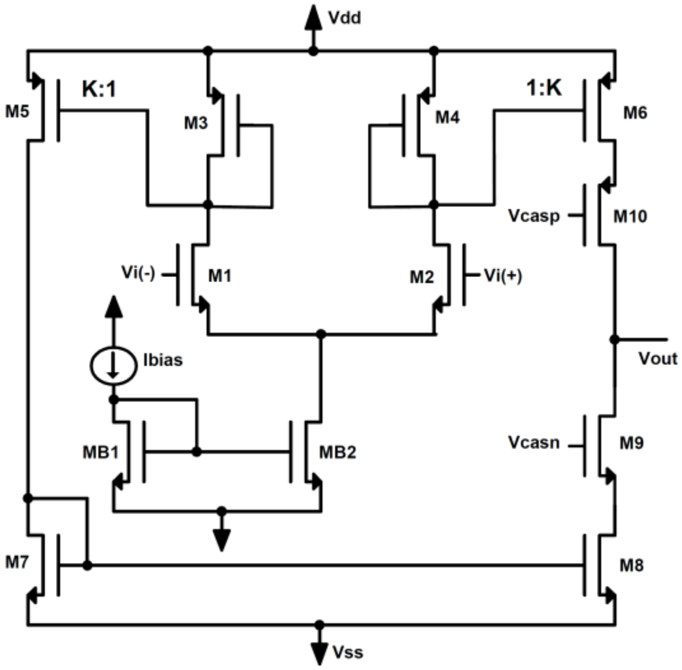

Figure 1.2 Conventional One Stage Operational Transconductance Amplifier

The OTA employs a differential input pair and three current mirrors. The differential input pair is comprised of transistors M1,2. The differential pair is biased by MB1,2. Mirrors formed by M3,5 and M4,6 reflect currents generated in the differential pair to the output shell. The current generated by the mirror of M3,5 has then reflected the output via the mirror formed by M7,8. The mirror gain factor, K, indicates the gain in mirrors formed by M3,5 and M4,6 with the following relations: $\beta5=K\beta3$, $\beta6=K\beta4$ where $\beta=(KP/2)(W/L)$. Cascading transistors M9,10 are biased by $V_{casn}/V_{casp}$and provide increased gain via increased (cascaded) output resistance.

The conventional OTA is differentiated from other amplifiers by the fact that its only high impedance node is located at the output terminal. The conventional OTA does not employ an output buffer and is, therefore only capable of driving capacitive loads. The gain of the OTA (G_mR_o) is dependent on the large output resistance of the Rif a parallel resistive load Ris applied. A detailed analysis of the conventional OTA is presented in Chapter 2. shell (M5-M10) and is decreased to $G_mR_o//R_L \approx G_{ML}$

Khanittha Kaewdang (2011), [1] worked on a new CMOS-based balanced output operational transconductance amplifier (BOTA) with a very huge linear contemporary tunable range is proposed in this paper. The design method is finished via the aggregate of a completely differential transconductor and an electronically variable modern gain stage. The transconductance advantage of the proposed BOTA may be linearly tuned via an external bias modern-day for extra than 4 many years, with less than 4% nonlinearity for the linear input-voltage range of approximately 0.2Vpeak.

Danupat Duangmalai (2011), [2] provided a third modern-mode quadrature oscillator the usage of cutting-edge managed current conveyor transconductance amplifier (CCCCTA) and operational transconductance amplifier (OTA) as lively detail as active factors. The proposed circuit is realized from a noninverting lossless integrator and an inverting second _order low-skip filter.

Data Ram Bhaskar (2011), [3] worked on a five new electronically-controllable second _order cutting-edge-mode sinusoidal oscillators using three multioutput operational transconductance amplifiers (MO-OTAs) and two grounded capacitors (GC) have been offered. Simulation outcomes are included to confirm the theoretical evaluation based totally upon CMOS OTAs implementable in 0.5 μm generation. Five new modern-mode electronically controllable OTA-C sinusoidal oscillators had been provided.

Winai JAIKLA,(2012)[4] provided a three-inputs unmarried-output biquadratic filter out acting fashionable capabilities: low-pass, high-bypass, band-pass, band-reject and all_pass capabilities, based totally on modern-day controlled modern-day conveyor transconductance amplifier .

Dattaguru V. Kamath,(2014), [5] work, a widespread -admittance modern-day-mode circuit structure using triple-output OTA is explored to derive new second-order multi-function filters using OTAs with few extra cutting-edge outputs and with/ without grounded capacitors. Biquads filters were realized with the aid of the use of diverse admittances like OTA-simulated resistor, collection and parallel OTA-C resonators within the proposed well_known structure.

Mehmet Sagbas, (2015), [6] taken a look at affords the layout of current-mode complete-wave rectifier circuits the usage of single active factor. The first proposed circuit makes use of only one operational transconductance amplifier (OTA), two diodes and two resistors. Its present _day advantage can be electronically controlled by the usage of the transconductance gain of the OTA. The 2nd proposed circuit uses the handiest one differential voltage contemporary

Yi Li, Chunhua Wang,(2017), [7] paper, a new customary present day-mode filtering circuit with unmarried enter and multi-outputs primarily based on OTAs (operational transconductance amplifiers) is proposed. The circuit simply consists of operational transconductance amplifiers, one contemporary controlled current amplifier with multi outputs (MO-CCCA), and grounded capacitors. It can recognize low-pass, band-bypass, excessive-skip, band-prevent, and all-bypass filters simultaneously.

Takao Tsukutani, (2018) [8] paper introduces a blended-mode biquad using OTAs (operational trans-conductance amplifiers) and down to earth capacitors. The circuit can carry out a combined-mode operation with the aid of deciding on the enter and output terminals. Additionally, the circuit allows low-pass, band-pass, high-bypass, band-forestall and all-skip switch features selecting the input terminals. The circuit parameters ω0 and Q can be tuned orthogonally via adjusting the trans-conductance gains of the OTAs.

Tajinder Singh Arora, (2018), [9] introduced a commonplace filter out employing 1/3-era present _day conveyor and operational transconductance amplifier with minimal passive components. The proposed design works in modern-day mode and makes use of grounded passive additives most effective, making it a higher proposition for included circuit implementation. The operating of the circuit has been tested at the excessive frequency with electronic tunability of pleasant aspect.

Ali Kircay,(2018), [10] take a look at, electronically-tunable, present day-mode, square-root-domain, 1/3-order low-skip filter is proposed. The take a look at is done with 3 circuit designs. the First circuit is third-order low-bypass Butterworth filter, the second circuit is third-order low-bypass Chebyshev filter and the final circuit is 0.33-order low-bypass elliptic filter. All the enter and output values of the filter circuit are modern. Only grounded capacitors and MOSFETs are required to recognize the filter circuit. Additionally, natural frequency f0 of the cutting-edge-mode filter may be adjusted electronically the usage of outer cutting-edge asset.

1 KHN Filters

Recently, a symbolic framework for the systematic synthesis of the linear active circuit was presented in [1]-[6]. This method, called nodal admittance matrix (NAM) expansion, is very useful in the generation of a series of novel circuits. Fortunately, the literature on the current conveyor (CCII) and inverting current convey (ICC II) based gyrators [7]-[9], oscillators [10], [11] and filters [12], [13] has explained this viewpoint well. However, most of the circuits mentioned in earlier works are based on the CC II or ICC II. Very recently, it has also been found that the NAM expansion method is generalized to the operation transconductance amplifier (OTA) [14]-[19].

It is well known that the operational transconductance amplifier (OTA) has attracted considerable attention. several OTA-based filters and oscillators have been reported [20]-[26]. Unfortunately, the design methods for the circuits using OTAs are short of the systematic characteristic. For this reason, the paper aims at using the NAM expansion method to realize KHN (W. J. Kerwin, L. P. Huelsman, and R. W. Newcomb) filters employing OTAs. First, according to the number of OTA in the filters, the filters are classified as three different types. Next, the NAM expansion method for three different types of filters is considered. The type-A filters employing five single output OTAs (SO-OTAs) have 32 different forms, the type-B filters employing four OTAs, namely four SOOTAs or one DO-OTA and three SO-OTAs, have 32 different forms, and the type-C filters employing three OTAs, namely two DO-OTAs and one SO-OTA, have eight different forms. Having used the canonic number of components, the circuits are easy to be integrated and the parameters of the filters can be tuned electronically through tuning bias currents of the OTAs. The last, the workability for one of the derived filters was verified employing the NI MULTI SIM 11.0 software. The simulation results are in agreement with the theory.

3.1.1 NAM Equation of KHN Filters:

KHN filters can provide simultaneously the three basic filtering functions, namely the high-pass, band-pass and low-pass responses, at three different outputs. Fig. 3.1 shows a non-inverting KHN circuit using three op _amps [27].

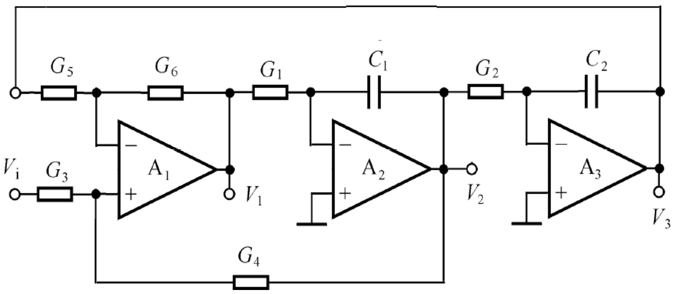

Fig. 3.1. A non-inverting KHN circuit using three op _amps.

Taking Fig. 3.1 into account, and setting *Vi* = 0, *G*3 + *G*4 = *G*5 + *G*6, the state equations are

$$\begin{cases} sC_1V_1 + G_1V_3 = 0, \\ G_2V_1 + sC_2V_2 = 0, \\ -G_4V_1 + G_5V_2 + G_6V_3 = 0. \end{cases} \quad (1)$$

From (1) and taking the capacitors *C*1 and *C*2 as external elements at nodes 1 and 2, the denominator of the transfer function is given by

$$D(s) = s^2 + sG_1G_4/C_1G_6 + G_1G_2G_5/C_1C_2G_6. \quad (2)$$

It follows that the pole frequency and the quality factor for the filter can be expressed by

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{G_1G_2G_5}{C_1C_2G_6}}, \quad (3)$$

$$Q = \frac{1}{G_4}\sqrt{\frac{C_1G_2G_5G_6}{C_2G_1}}. \quad (4)$$

From (1) the admittance matrix for the filter considered in the paper is given by

$$Y = \begin{Bmatrix} sC_1 & 0 & G_1 \\ G_2 & sC_2 & 0 \\ -G_4 & G_5 & G_6 \end{Bmatrix}. \quad (5a)$$

As shown in the literature [12], the port admittance matrices of the other three classes of Fig. 1 can be obtained as follows:

$$Y = \begin{Bmatrix} sC_1 & 0 & -G_1 \\ -G_2 & sC_2 & 0 \\ G_4 & G_5 & G_6 \end{Bmatrix}, \quad (5b)$$

$$Y = \begin{Bmatrix} sC_1 & 0 & G_1 \\ -G_2 & sC_2 & 0 \\ -G_4 & -G_5 & G_6 \end{Bmatrix}, \quad (5c)$$

$$Y = \begin{Bmatrix} sC_1 & 0 & -G_1 \\ G_2 & sC_2 & 0 \\ G_4 & -G_5 & G_6 \end{Bmatrix}. \quad (5d)$$

It can be seen that KHN filters possess four _port admittance matrices, which is the basis of the systematic synthesis of KHN filters.

3.1.2 Realization of Type A KHN Circuits

According to the number of the OTA in KHN filters, the filters considered in this paper are classified as three different types. The type A filters employ five OTAs, the type B filters employ four OTAs, and the type C filters employ three OTAs. Starting from the port admittance matrices in (5a) and taking into account the type A filters with seven nodes, the first step in the NAM expansion is to add four blank rows and columns, and then use a first nullator to link columns 3 and 7 to move *G*1 to the position 1, 7, then the first norator is connected between rows 1 and 7 to move *G*1 to the position 7, 7. A second nullator is connected columns 1 and 6 to move *G*2 to the position 2, 6, then the second norator is connected between rows 2 and 6 to move *G*2 to to the position 6, 6.

Result and Discussion

4.1 Simulation Results for OTA:

In this section, Fig 4.1 shows the circuit diagram of OTA and fig 4.2 shows the Multiple current outputs for current mode design

Fig 4.1: Circuit Diagram of OTA

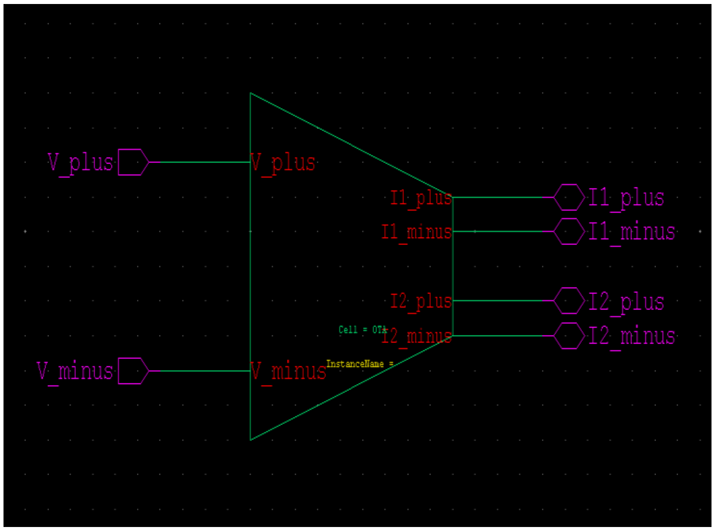

Table 4.1: Comparison Table

Design	**Minimum feature _length adopted**	**Power dissipation**	**Speed**	**Area**
1. High _speed OTA based filter (180nm CMOS)	Lo= 20 times Lmin Lo=3600um To adopt a larger device sizing approach to get higher speed	8 mW	Cutoff frequency obtained= 41 MHz (High Speed)	2*(57600*3600) + 8* (21600*3600) + 6* (14400*3600) nm^2 $=974.160um^2$
2. Low Power OTA based filter (45nm CMOS)	Lo=4 times Lmin Lo= 180nm To adopt a smaller device sizing approach to get lower power dissipation	6mW (Lower Power for similar frequency range)	Cutoff frequency obtained= 1.74 MHz	2*(2880*180) + 8* (1080*180) + 6* (720*180) nm^2 $=3.9456um^2$

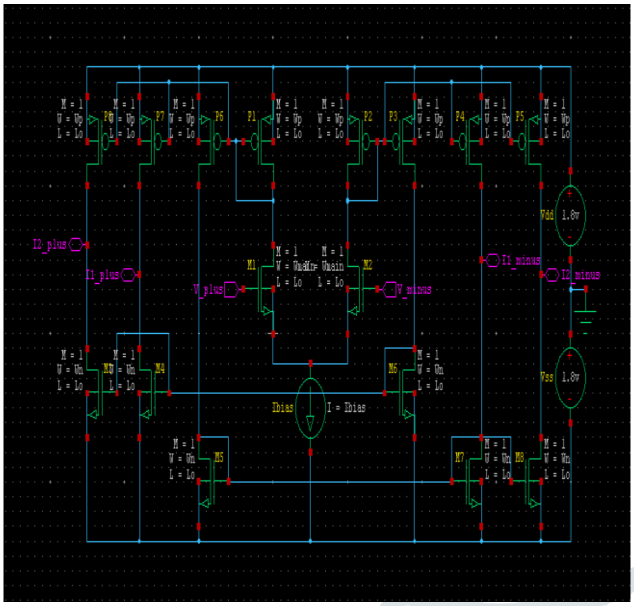

Fig 4.2: Multiple current outputs for current mode design

For the simulation of multiple current outputs for a current_mode design we are taking Ibias=400uA, Lo=1um, Wp=6um, Wn=4um, and Wmain=16um. Using these design parameters, we found transconductance gain (gm) is expected to be around 1000 uS.

4.2 DC Analysis Performance:

In this section we will discuss about DC analysis of our proposed circuit. Parameter used are
temperature=25.0

Gm=1.15879m= 1158uS

4.3 Practicing Low pass Filter using the above OTA:

Fig 4.3 shows the low pass filter using OTA. Gm was planned to be around 1000uS for the cutoff frequency around 100MHz for a load capacitor (C_L) of 10pF from $f_c=g_m/C_L$

Using these parameters we simulate this circuit fig 4.4 shows the simulation results of low pass filter using OTA. Simulation results are swept for Currents 100uA, 400uA, 700uA and 1000uA.

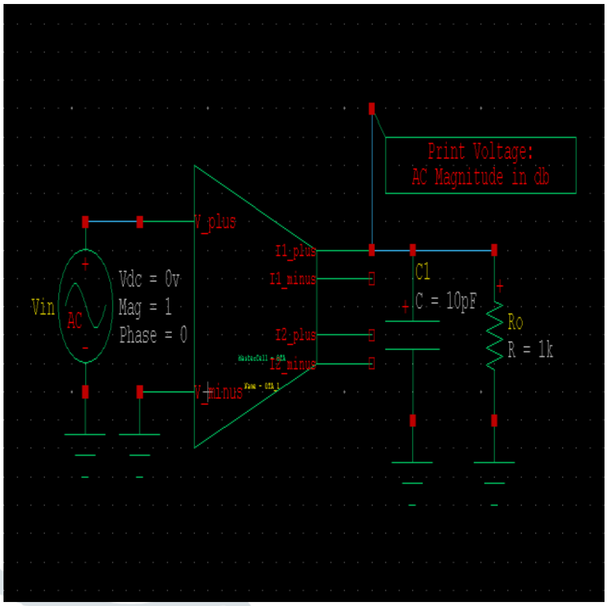

Fig 4.3: low pass filter using OTA

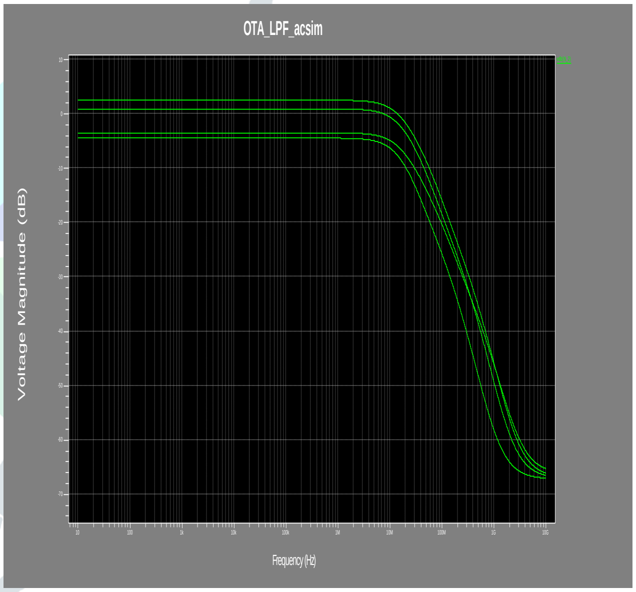

Fig 4.4: Simulation results of low pass filter using OTA

For 400uA it could be seen that cutoff freq coincides yo what was expected from theoretical analysis.

4.4 High _speed OTA based Universal Biquad filter (in the the180nm process):

We have designed a high _speed OTA design with larger devices (180nm) and a high power supply range (±2.5V). we found the results
Ibias= 400uA

Lo=3600nm (20 times of Lmin=180nm to adopt large devices approach)
Wmain=57600nm (16*Lo)
Wp=21600 nm (6*Lo)
Wn=14400nm (4*Lo)
CL= 1pF

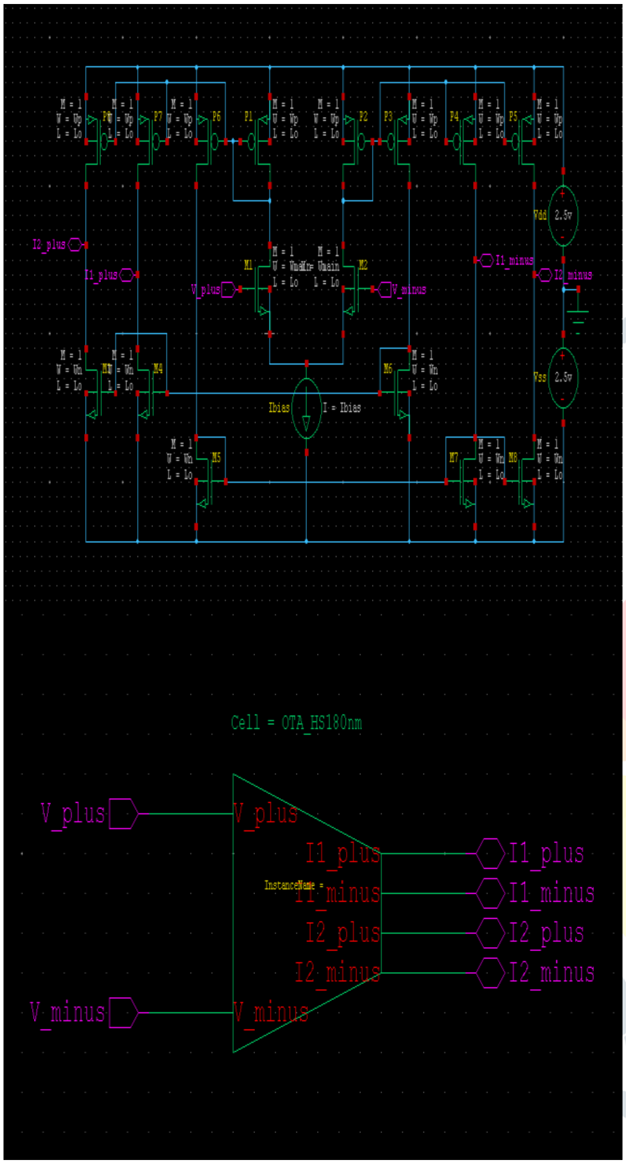

Fig 4.5: High_ speed OTA based Universal Biquad filter

Fig 4.5 shows the circuit diagram and simulation results of High_ speed OTA based Universal Biquad filter.

4.5 DC simulation:

In this section, we will discuss the DC simulation. DC simulation reveals the Gm to be around 1200uS.

	0	1	2	3
	1:MM1	1:MM2	1:MM3	1:MM4
MODEL	NMOS	NMOS	NMOS	NMOS
TYPE	NMOS	NMOS	NMOS	NMOS
REGION	Saturation	Saturation	Saturation	Saturation
GM	**1.14905m**	**1.12831m**		

4.5 High_ speed Universal-Biquad Filter using OTA at 180nm CMOS process:

We designed High_ speed, Universal-Biquad Filter using OTA at 180nm using CMOS. We found Power dissipation= 4 +4 mWatt= 8mWatt. Fig 4.6 shows the circuit of High_ speed Universal-Biquad Filter using OTA at 180nm and Fig 4.7 shows the simulation results of High_ speed Universal-Biquad Filter using OTA at 180nm.

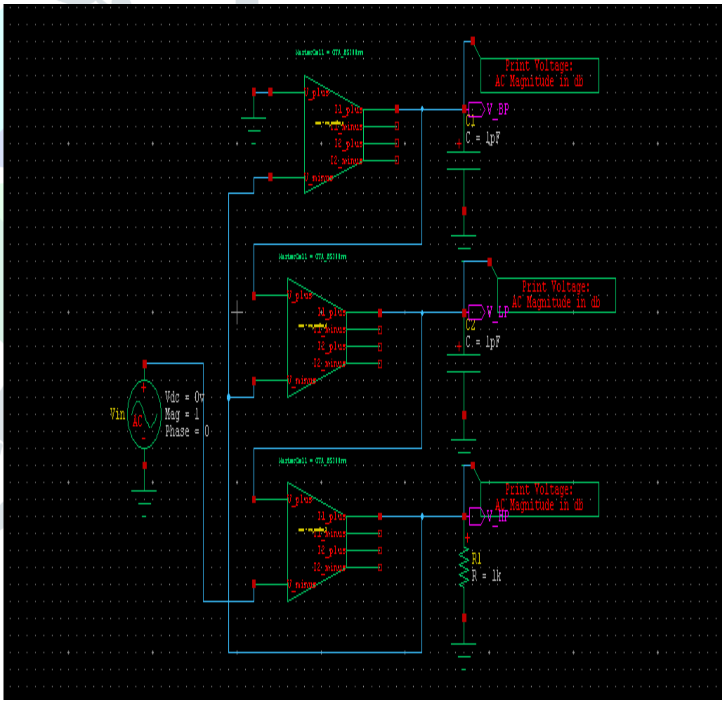

Fig 4.6: High_ speed Universal-Biquad Filter using OTA at 180nm

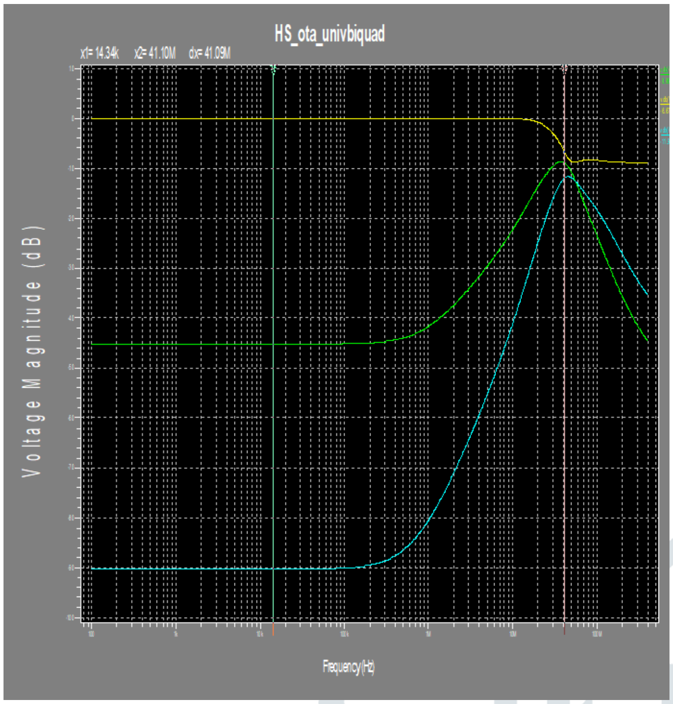

Fig 4.7: Simulation of High_ speed Universal-Biquad Filter using OTA at 180nm

After simulation, we found these results.

```
3:VVdd       3:VVss       VVin
VOLTAGE        2.50000      2.50000      0.
CURRENT       -1.61949m     -1.62673m      0.
POWER         -4.04873m     -4.06682m      0.
```

Power dissipation= 4 +4 mWatt= 8mWatt

4.6 Low power OTA based Universal Biquad Filter:

In this section, we designed Low power OTA based Universal Biquad Filter at 45 nm. In this design. we are using smaller devices (at 45nm) and lower power supply range (±1.8V). Fig 4.8 shows the Low power OTA based Universal Biquad Filter and fig 4.9 shows the simulation results of Low power OTA based Universal Biquad Filter.

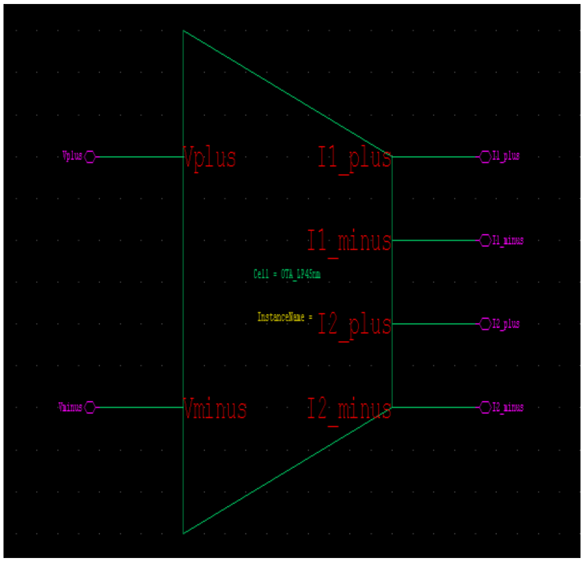

Fig 4.8: Low power OTA based Universal Biquad Filter

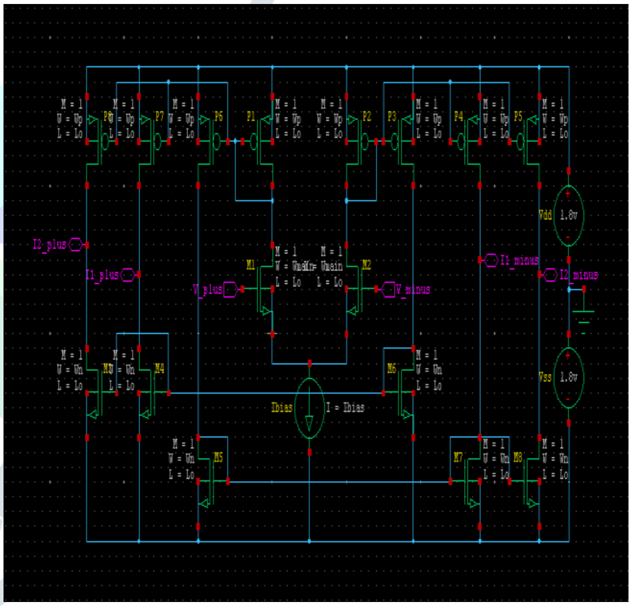

Fig 4.9: Simulation of Low power OTA based Universal Biquad Filter

After simulation, we found these results.

Ibias= 400uA

Lo=180nm (4 times of Lmin=45nm to adopt large devices approach)

Wmain=2880nm (16*Lo)

Wp=1080 nm (6*Lo)

Wn=720nm (4*Lo)

C_L= 100pF

4.7 DC Simulation:

DC simulation reveals the Gm to be around 1000uS

```
            1           2           3           4
            1:MM1       1:MM2       1:MM3
1:MM4
MODEL       nmos        nmos        nmos
nmos
TYPE        nmos        nmos        nmos
nmos
REGION      Saturation  Saturation
Saturation


gm          1.27372m    1.20808m
447.45168u  447.45160u
```

4.8 Low Power Universal-Biquad Filter using OTA:

In this section, we designed Low Power Universal-Biquad Filter using OTA at 45 nm using CMOS. We found Power dissipation= 3 +3 mWatt= 6mWatt Fig 4.10 shows the Low Power Universal-Biquad Filter using OTA and fig 4.11 shows the simulation results of Low Power Universal-Biquad Filter using OTA.

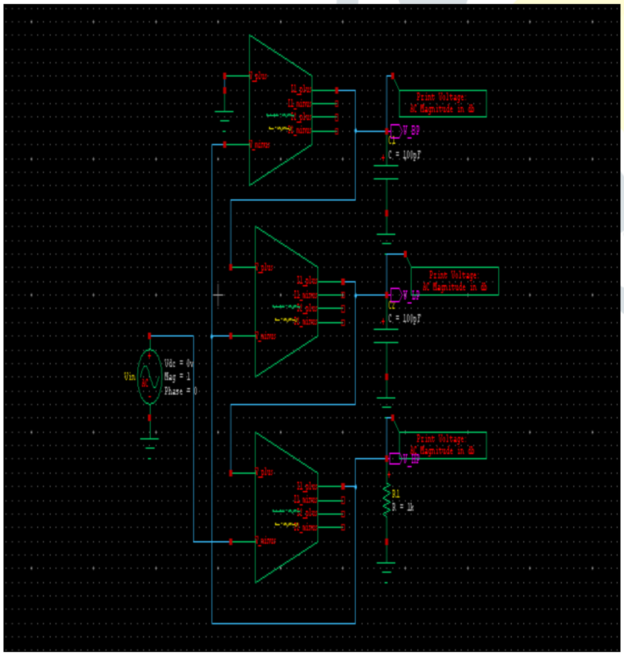

Fig 4.10: Low Power Universal-Biquad Filter using OTA

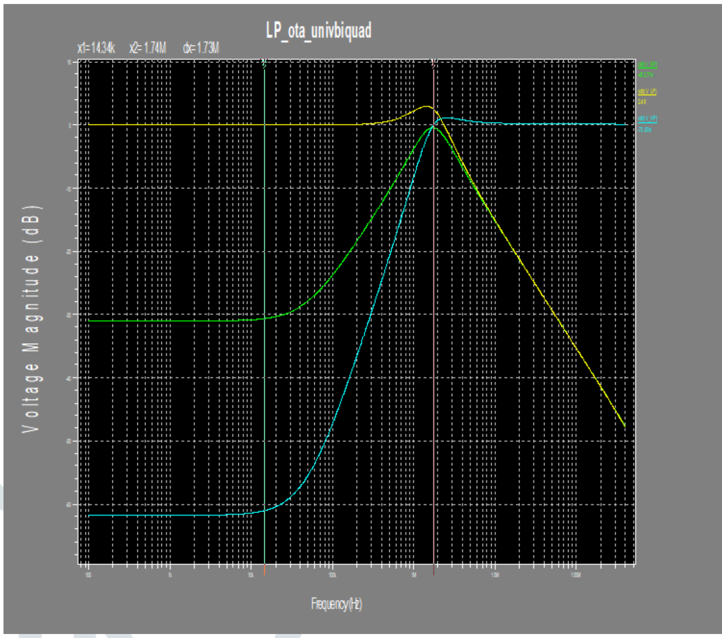

Fig 4.11: Simulation of Low Power Universal-Biquad Filter using OTA

After simulation, we found these results.

```
3:VVdd      3:VVss      VVin
VOLTAGE       1.80000      1.80000      0.
CURRENT      -1.73726m    -1.76238m   -
203.72995p
POWER        -3.12706m    -3.17228m     0.
```

Power dissipation= 3 +3 mWatt= 6mWatt

Conclusion:

The Paper Presents A New OTA-C Order Filering Circuit With MISO. In This Paper Introduces Biquad Filter Using OTA And Performance Comparsion A High Speed Of OTA-C Using 180nm And Low Power Of OTA-C Using 45nm. The Circuits Has The Following Merits

1. It Can Simultaneously Realize Second Order Low Pass, Band Pass, High Pass Filter.
2. All Passive Elements Are All Grounded.
3. It Realize Very Low Sensitivities

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