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THE APPLICATIONS EMPLOYED TO DESIGN A NEW KIND OF FILTER USING THE ACTIVE ELEMENT (VDBA)

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ABSTRACT

The paper presents a new configuration of biquad filters using the well known active element (VDBA) Voltage Differencing Buffered Amplifier. The proposed item contains properties such as high input impedance terminal and low output impedance terminal which allow perfect performance in voltage circuit fields. In addition, the circuit is used without exterior resistor because of the transconductance gain that exists in VDBA. The proper method to design such a filter is satisfied by using both active and passive elements. In this paper, two filter applications are designed based on Multi Inputs Single Output (MISO) filter configuration. The first proposed filter uses two VDBAs and two capacitors. Whereas, the second filter contains two VDBAs, two capacitors and one resistor. Both circuits satisfy the voltage mode (low pass, band pass, high pass, band stop, & all pass) filters. The low output impedance of biquad filters award more cascadabilities for the voltage circuit. Moreover, the matching conditions of the conclusive elements are not needed. The adjustment in the resistance employed by the second biquad filter developed the quality factor to be as independent natural frequency. The introduced biquad filters are tested and simulated in LTSPICE simulator to confirm the theoretical concepts. The simulation results agree with the main theoretical concepts.

Keywords: *Voltage differencing Buffered Amplifier, CMOS Circuits, voltage mode filter, biquad filters, Multi Inputs Single Output (MISO).*

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التطبيقات المستخدمة في تصميم نوع جديد من المُرَشِحات باستخدام العنصر الفعال (VDBA)

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الملخص

يركز البحث على تصميم نوع جديد من أنواع المُرَشِحات وذلك باستخدام العنصر الفعال المسمى بمكبرات فرق الجهد المخزون (VDBA). العنصر المقترح يحتوي على بعض الخصائص مثل طرف الإدخال ذو الممانعة العالية والواطئة والتي بدورها تقوم بأداء رائع خصوصا في مجالات دوائر الفولتية. بالإضافة إلى ذلك، فان الدائرة لا تحتوي على مقاومة خارجية وذلك بسبب توصيلية (VDBA) العالية. الطريقة الدقيقة لتصميم مثل هذه المُرَشِحات تتم عن طريق استخدام كلا العناصر الفعالة والغير الفعالة. لقد تم تصميم واستخدام نوعين من الدوائر التطبيقية لإثبات مبدأ وصحة عمل المرشح المقترح على أكمل وجه. جدير بالذكر أن هذه التطبيقات صممت حسب تصاميم المُرَشِحات من نوع متعددة الإدخالات ووحيدة الإخراج (MISO). التطبيق الأول يحتوي على اثنين من العناصر الفعالة المسماة (VDBA) مع متسعتين. بينما، المُرَشِح الأخر تم تصميمه بشكل مشابه للأول في بعض العناصر المستخدمة، حيث يحتوي على زوج من العناصر الفعالة (VDBA) وزوج من المتسعات ومقاومة واحدة. المُرَشِحات المقترحة في هذا البحث تمكنت من العمل بصورة متقنة. كلا التطبيقين المقترحين تمكنا من الحصول على الأداء الكامل للمُرَشِح حيث تم الحصول على مُرَشِح ذو (الترددات الواطئة، الحزمة الترددية، الترددات العالية، المانعة للحزمة الترددية ، ومُمَرر جميع الترددات). ممانعة الإخراج الواطئة للمُرَشِحات منحت قابلية الربط المتوالي لدوائر الفولتية المستخدمة في التصميم، كما أنها جعلت من شروط المطابقة شيئا لا حاجة له. الشيء المثير للاهتمام والذي يعتبر العامل الرئيسي لتصميم التطبيق الثاني بشكل مغاير بعض الشيء للتطبيق الأول، هو أن المقاومة لعبت دورا مهما في تحسين عامل الجودة في المرشح الثاني حيث انه كلما كانت قيمة المقاومة اكبر فان عامل الجودة يتحسن أكثر. أن الاختبارات والمحاكاة التي حدثت لهذه

المرشحات، تمت عن طريق المحاكي المسمى (LTSPICE). النتائج المعروضة في هذا البحث تتناسب تماما مع الخلفيات والنظريات والمفاهيم الأساسية لمجال المُرَشِحات.

الكلمات الدالة: مكبرات فرق الجهد المخزون(VDBA). دوائر الـ CMOS. أساليب تصفية الفولتية. المُرَشِحات العامة. المُرَشِحات المتعددة الإدخال والوحيدة الإخراج.

1. INTRODUCTION

Depending on the active elements characteristics and features, the filters are designed using several types of active elements. Different analog signal processing circuits are also designed by using these active elements. These active elements can work as Operational Transconductance Amplifier OTA [1]. In addition, a great role is performed by Current Differencing Transconductance Amplifier CDTA [2] particularly the Operational Transresistance Amplifier OTRA [3] also the Current Differencing Buffered Amplifier CDBA [4] and the first generation of Current Conveyor CCI [5], finally the Fully Balanced Voltage Differencing Buffered Amplifier FB-VDBA [6]. In addition, VDBA and OPAMP are similar to each other in their characteristics specially the high input and the low output impedances that are realized by both of them. VDBA circuit is alternative to CDBA [7] but the main difference is that the voltage is set as input to VDBA. Whereas, the current is set as input to CDBA.

The input voltage of the circuit is converted to current at side (z) using voltage drop and transconductance gain. New reflection happens at side (z) to another impedance zone identified as side (w). According to the comparison between VDBA and OP-AMP [8,9]at current mode sides, VDBA gives some properties such as good linearity, less power consumption, high slew rate, and larger bandwidth. The point that states that VDBA contains low output impedance which can be considered as the main difference between VDBA and OTA, makes it more adaptable than voltage circuit due to the effect of the loading that is typically faded out. The circuit works without using exterior resistance, therefore VDBA remains making use of the transconductance characteristics specially, controlling the value of the transconductance electronically.

This research work presents the design of VDBA biquad filter based on [10] by using different circuits and applications in order to obtain the same results. Referring to voltage mode transconductance is generated using three inputs and single output TISO filter circuits, the circuits in [11,12] have great features such that the natural frequency and quality factor are controlled by biasing the voltage and the current, also the exterior resistors and the low sensitivities are not needed. Conversely, these have the following defects:-

Large number of active elements are needed [13,14]. Two types of active elements are used [13,14]. Matching terms of the elements are required in some filters [11,15,16]. Inappropriate for voltage filter construction because of the high impedance of the output [11,17,18,12].The quality factor is not under control as the natural frequency [11,15,17,18,12].

The paper demonstrates a unique CMOS recognition of voltage differencing buffered amplifier VDBA. It also shows two kinds of voltage biquad filters. The proposed circuits connection principle is based on TISO filter systems. Besides, each circuit consists of two VDBAs and two or more passive elements.

The typical filter functions (low pass LP, band pass BP, high pass HP, band stop BS & all pass AP) are created after the first proposed biquad filter is designed by using two VDBAs and two capacitors. It has to be mentioned, that the input voltage signal of AP should be inverted type. Whereas, the typical filter functions are realized without using inverted input type by the second filter which is designed using two VDBAs, two capacitors and one resistor. Moreover, the resistor is considered an ultimate component which manages the quality factor in the second biquad filter. Furthermore, This resistor complies with NMOS transistors, consequently the voltage gate can manage the quality factor electronically [19]. Hence, the proper and vigorous filters design use a small number of active and passive elements and demonstrate low passive sensitivity. Finally, VDBA transconductance gain helped awfully to manage the natural frequency and the quality factor.

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2. OVERVIEW OF VDBA CIRCUITS

Fig. (1) demonstrates the symbol of VDBA. Where, P and N are input terminals, whereas, Z and Ware output terminals.

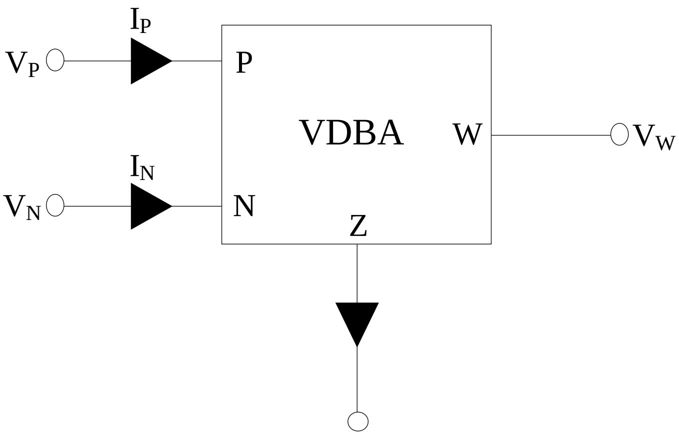

Fig. (1): VDBA Circuit Symbol

VDBA circuit model is illustrated using the following equations:

$$\begin{pmatrix} I_P \\ I_N \\ I_Z \\ V_W \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ g_m & -g_m & 0 \\ 0 & 0 & \alpha \end{pmatrix} = \begin{pmatrix} V_P \\ V_N \\ V_Z \end{pmatrix} \quad \cdots\cdots\cdots (1)$$

The voltage ratio of VDBA is denoted as α where $\alpha = 1- \varepsilon_V$. That is, ε_V is the voltage tracking error. The tracking error has magnitude much less than unity. As shown in Fig. (1), the voltage differencing buffered amplifier VDBA is implemented by two high impedance voltage inputs denoted as VP and VN, one high impedance current output denoted as IZ and low impedance voltage output denoted as VW.

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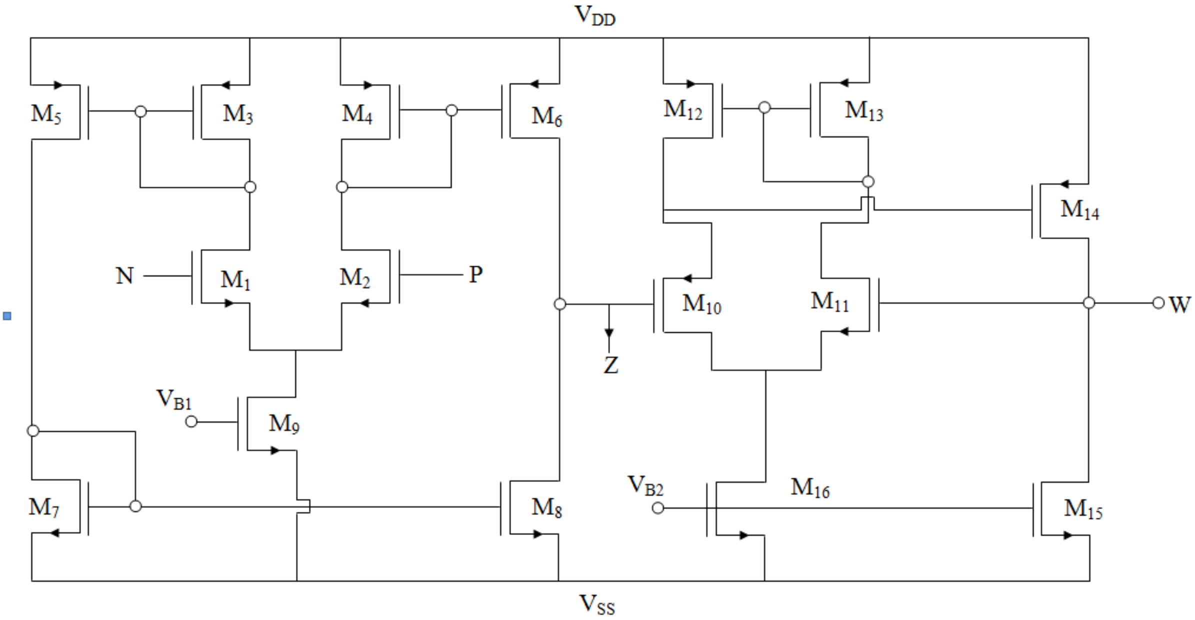

Fig. (2): VDBA Circuit Using CMOS Performance

The diagram in Fig. (2) illustrates the entire VDBA circuit. The circuit uses voltage buffer by (M10 – M16) and OTA circuit by (M1 – M9) [20,21]. VDBA input point is consisted of the differential OTA input and the voltage buffer is associated with current OTA output. Furthermore, the differential input voltage of OTA generates output current known as voltage controlled current source (VCCS).

Generally, a buffer amplifier presents electrical impedance changed over through the circuits. the transconductance of the amplifier is controlled using the multi input current that is generally exists in such VDBA filter circuits. The typical operational amplifier is considered analogous to the Operational Transconductance Amplifier OTA because both have high impedance differential input stage, and the last can be used to create the negative feedback.

3. PROPOSED VDBA FILTER MODULE

The block diagram in Fig. (3) presents MISO filter module that allows multi voltage input and single voltage output. In this paper, a new voltage mode VDBA filter applications are designed. The proposed applications consist of two VDBAs and three or two passive elements. These applications realized (low pass, band pass, high pass, and all pass) filter functions. The paper shows, two VDBA filter application circuits based on MISO diagram module.

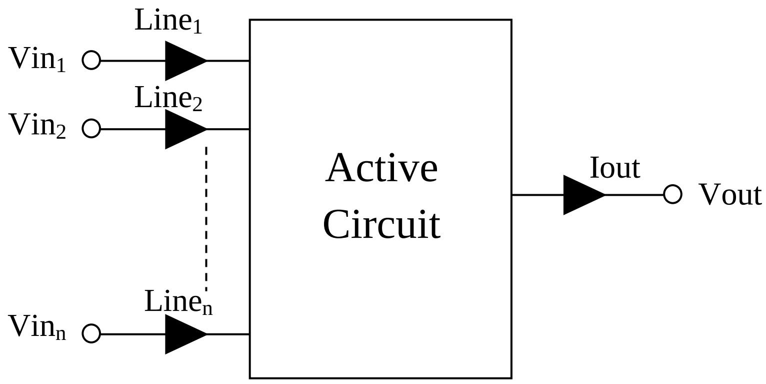

Fig. (3): General MISO Filter Block Diagram

3.1. THE FIRST PROPOSED APPLICATION CIRCUIT

The first application in Fig. (4) uses two VDBAs, two capacitors, three voltage inputs and single voltage output.

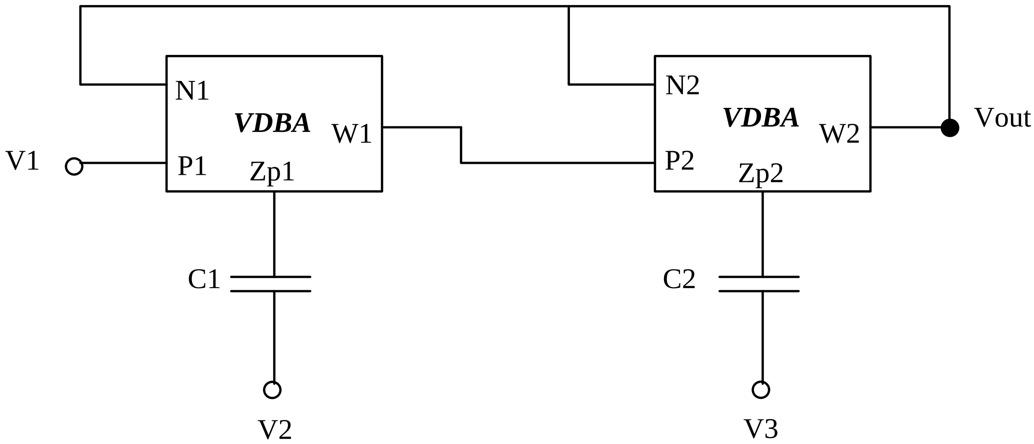

Figure (4): Proposed VDBA Multi Inputs Single Output First Filter Circuit

The proposed filter circuit in Fig. (4) gives the following output voltage transfer function formula:

$$V_O = \frac{V_1\, g_{m1}g_{m2} + V_2 g_{m2} sC_1 + V_3 s^2 C_1 C_2}{g_{m1}g_{m2} + g_{m2} sC_1 + s^2 C_1 C_2} \quad \dots\dots\dots (2)$$

The output transfer function Vo of the filter mode circuit in Fig. (4) is computed depending on the following Table (1) :

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Table (1): The computation of the proposed filters transfer functions

Filter Type	V_1	V_2	V_3	Transfer Function
LP	V_{IN}	0	0	$V_O = \dfrac{V_1\, g_{m1}g_{m2}}{g_{m1}g_{m2} + g_{m2}sC_1 + s^2C_1C_2}$
BP	0	V_{IN}	0	$V_O = \dfrac{V_2 g_{m2}sC_1}{g_{m1}g_{m2} + g_{m2}sC_1 + s^2C_1C_2}$
HP	0	0	V_{IN}	$V_O = \dfrac{V_3 s^2C_1C_2}{g_{m1}g_{m2} + g_{m2}sC_1 + s^2C_1C_2}$
BS	V_{IN}	0	V_{IN}	$V_O = \dfrac{V_1\, g_{m1}g_{m2} + V_3 s^2C_1C_2}{g_{m1}g_{m2} + g_{m2}sC_1 + s^2C_1C_2}$
AP	V_{IN}	- V_{IN}	V_{IN}	$V_O = \dfrac{V_1\, g_{m1}g_{m2} - V_2 g_{m2}sC_1 + V_3 s^2C_1C_2}{g_{m1}g_{m2} + g_{m2}sC_1 + s^2C_1C_2}$

The passive elements with a certain limits must be used to design the biquad VDBA filters in order to realize all filter functions mentioned in Table (1) with the same pole frequency and quality factor. The ideal pole frequency ($\boldsymbol{\omega_O}$) and the quality factor ($\boldsymbol{Q}$) for such proposed circuits are obtained as follows [10]:

$$\boldsymbol{Q = \sqrt{\frac{g_{m2}C_1}{g_{m1}C_2}}} \quad \cdots\cdots\cdots (3)$$

$$\boldsymbol{\omega_O = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}}} \quad \cdots\cdots\cdots (4)$$

The proposed first circuit pole frequency (ω_O) and quality factor (Q) sensitivity with respect to the passive elements is given as follows:

$$\boldsymbol{S^{\omega_o}_{g_{m2}} = S^{\omega_0}_{g_{m2}} = -S^{\omega_o}_{C_1} = -S^{\omega_o}_{C_2} = \frac{1}{2}} \quad \cdots\cdots\cdots (5)$$

$$\boldsymbol{S^{Q}_{g_{m2}} = -S^{Q}_{g_{m1}} = S^{Q}_{C_1} = -S^{Q}_{C_2} = \frac{1}{2}} \quad \cdots\cdots\cdots (6)$$

The absolute value of the sensitivity for the pole frequency and the quality factor at the ideal case is obtained by choosing the value of all passive elements equaled to 0.5 as given in the equations (5) and (6).

3.2. THE SECOND PROPOSED APPLICATION CIRCUIT

The second application circuit in Fig. (5) consists of two VDBAs, two capacitors, three voltage inputs and single voltage output. The difference between the two circuits is that the connection principle is changed and the resistance (R_1) is added to the circuit. The resistance (R_1) is employed by the second circuit for quality factor adjustment and performance improvement issues.

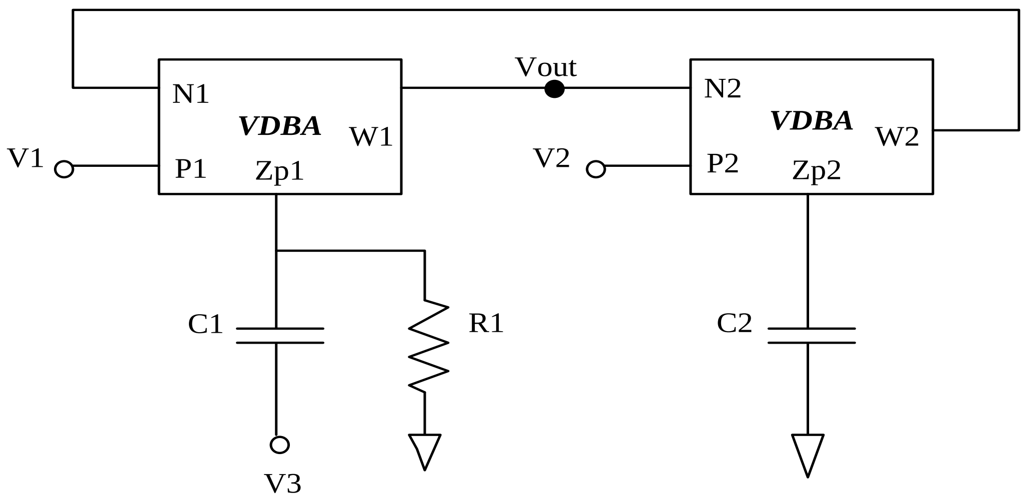

Figure (5): Proposed VDBA Multi Inputs Single Output Second Filter Circuit

The proposed filter circuit in Fig. (5) gives the following output voltage transfer function formula:

$$V_O = \frac{V_1\, g_{m1} g_{m2} + V_2 g_{m1} s C_2 + V_3 s^2 C_1 C_2}{g_{m1} g_{m2} + s C_2 G_1 + s^2 C_1 C_2} \quad \cdots\cdots\cdots (7)$$

The circuit in Fig. (5) allows three inputs and single output and the results are calculated based on equation (7) that allows (Low Pass Filter, Band Pass Filter, High Pass Filter, Band Stop Filter and All Pass Filter) to be obtained in accordance with Table (2).

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Table (2): The computation of the proposed filters transfer functions

Filter Type	V_1	V_2	V_3	Transfer Function
LP	V_{IN}	0	0	$V_O = \frac{V_1\, g_{m1}g_{m2}}{g_{m1}g_{m2} + g_{m2}sC_1G_1 + s^2C_1C_2}$
BP	0	V_{IN}	0	$V_O = \frac{V_2 g_{m2}sC_1}{g_{m1}g_{m2} + sC_1G_1 + s^2C_1C_2}$
HP	0	0	V_{IN}	$V_O = \frac{V_3 s^2C_1C_2}{g_{m1}g_{m2} + sC_1G_1 + s^2C_1C_2}$
BS	V_{IN}	0	V_{IN}	$V_O = \frac{V_1\, g_{m1}g_{m2} + V_3 s^2C_1C_2}{g_{m1}g_{m2} + sC_1G_1 + s^2C_1C_2}$
AP	V_{IN}	V_{IN}	V_{IN}	$V_O = \frac{V_1\, g_{m1}g_{m2} + V_2 g_{m2}sC_1 + V_3 s^2C_1C_2}{g_{m1}g_{m2} + sC_1G_1 + s^2C_1C_2}$

The ideal pole frequency (ω_O) and the quality factor (Q) for the application circuit in Fig. (5) are obtained using equation (7) as follows:

$$Q = \frac{1}{G_1}\sqrt{\frac{g_{m1}g_{m2}C_1}{C_2}} \quad \cdots\cdots\cdots (8)$$

$$\omega_O = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \quad \cdots\cdots\cdots (9)$$

For more clarity, Q can be replaced with different resistance value as independent natural frequency. Additionally, the resistance R1 can use NMOS transistor and can be altered electronically through the control voltages. The sensitivity analysis of the second proposed circuit with respect to active and passive elements is given as:

$$S^{\omega_o}_{g_{m1}} = S^{\omega_0}_{g_{m2}} = -S^{\omega_o}_{C_1} = -S^{\omega_o}_{C_2} = \frac{1}{2} \quad \cdots\cdots\cdots (10)$$

$$S^{Q}_{g_{m1}} = S^{Q}_{g_{m2}} = S^{Q}_{C_1} = -S^{Q}_{C_2} = \frac{1}{2}, S^{Q}_{g_1} = -1 \quad \cdots\cdots\cdots (11)$$

As a result, it is obvious form the equations (5), (6), (10) and (11), that the active and passive sensitivity of Q and ω_O do not exceed unity.

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4. SIMULATION RESULTS

The theoretical analysis of the proposed biquad filter is proved by the computer simulation. Simulation results are generated using LTSPICE program with TSMS CMOS 0.35 µm. In the simulations the VDBA supply voltages , Biasing currents and the other parameters of the first application filter circuit have been selected as follows:

supply voltage V_{DD} = 1.5 V , V_{SS} = -1.5 V , biasing current I_B = 10 µA , I_{SS} = 100 µA , transconductance value of $g_m = 730.7\ \mu A/V$, pole frequency $\omega_O = 1.16$ MHZ , quality factor $Q = 1$, passive elements $C_1 = C_2 = 0.1$ nF.

By using these parameters (Low pass, band bass, high pass, band stop, all pass) filter functions are obtained as show in Fig. (6) and Fig. (7).

Whereas, the parameters of the second biquad filter that are used in the simulations have been selected as follows:

supply voltage V_{DD} = - V_{SS} = 1.5 V , biasing current I_B = 10 µA , I_{SS} = 100 µA , passive elements $C_1 = C_2 = 0.1$ nF and $R_1 = (1, 2, 10)$ KΩ.

The filter functions realized by the second filter are the same as the functions of the first filter. For clarification, the aspect ratios of the transistors used in the circuit in Fig. (2) are declared in Table (3) :

Table (3): Transistors aspect ratios for the VDBA

Transistors	W(μm)	L(μm)
M_1-M_4-M_{10}-M_{11}-M_{15}-M_{16}	7	0.35
M_5-M_6	21	0.7
M_7-M_8	7	0.7
M_9	3.5	0.7
M_{12}-M_{14}	14	0.35

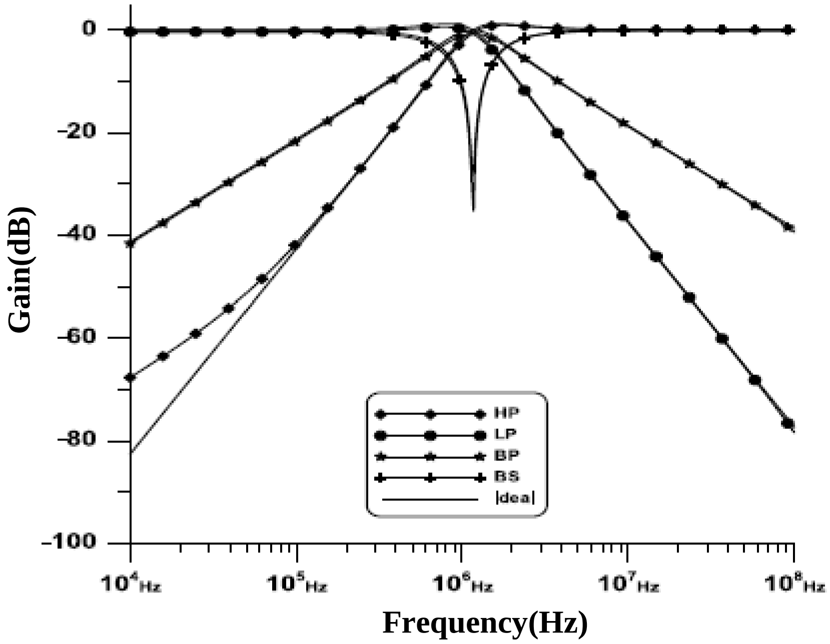

Fig. (6): The simulated result of the gain frequency response of Figure (4)

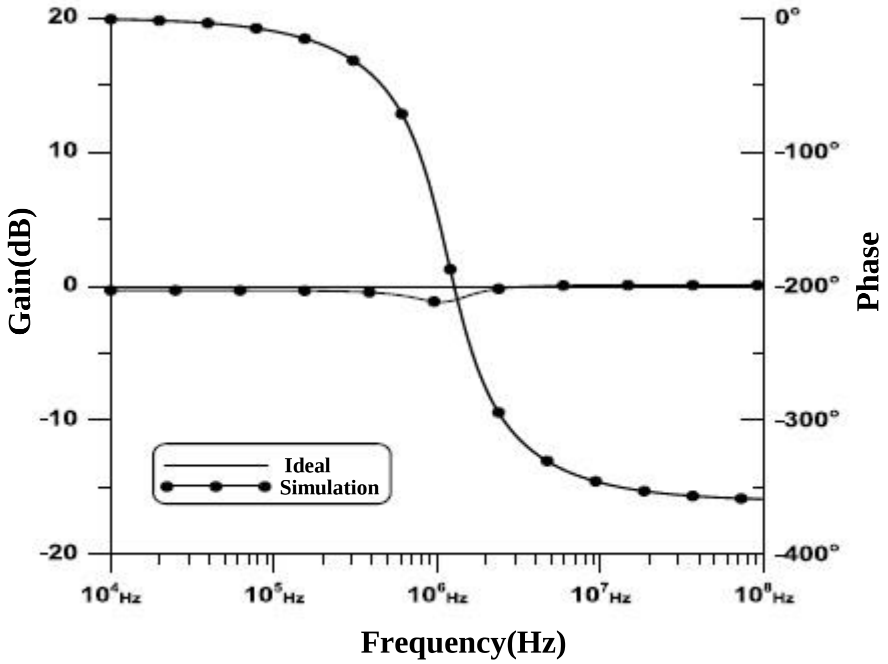

Fig. (7): Gain and phase frequency response of all pass filter of Figure (4)

The frequency response of the simulated second filter is presented in Fig. (8) and Fig. (9). The signal shown in Fig. (10) is large signal analysis of the second application circuit which is simulated using 1 MHz input sinusoidal signal with 0.4 amplitude. The curves are generated using (Golden Software Grapher v8.4.696).

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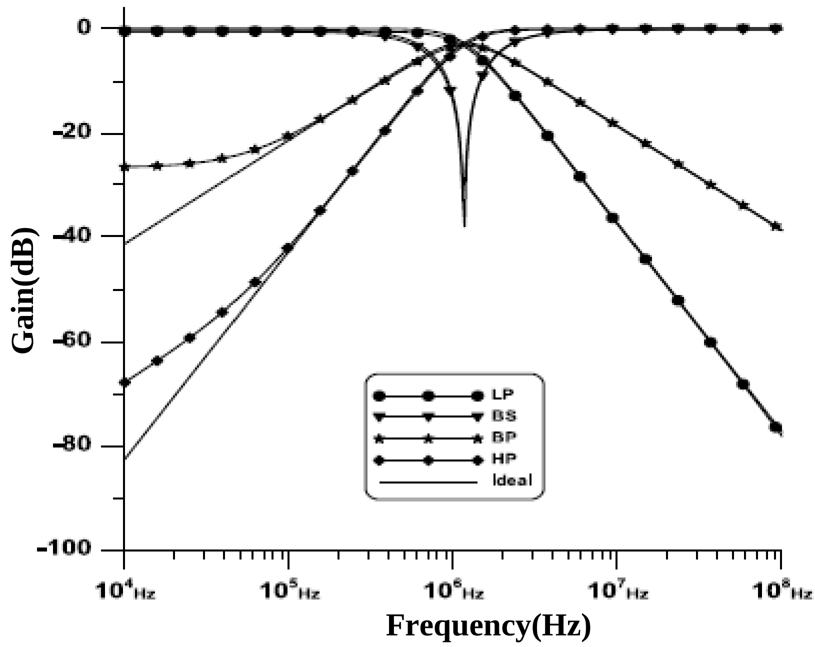

Fig. (8): The simulated result of the gain frequency response of Figure (5)

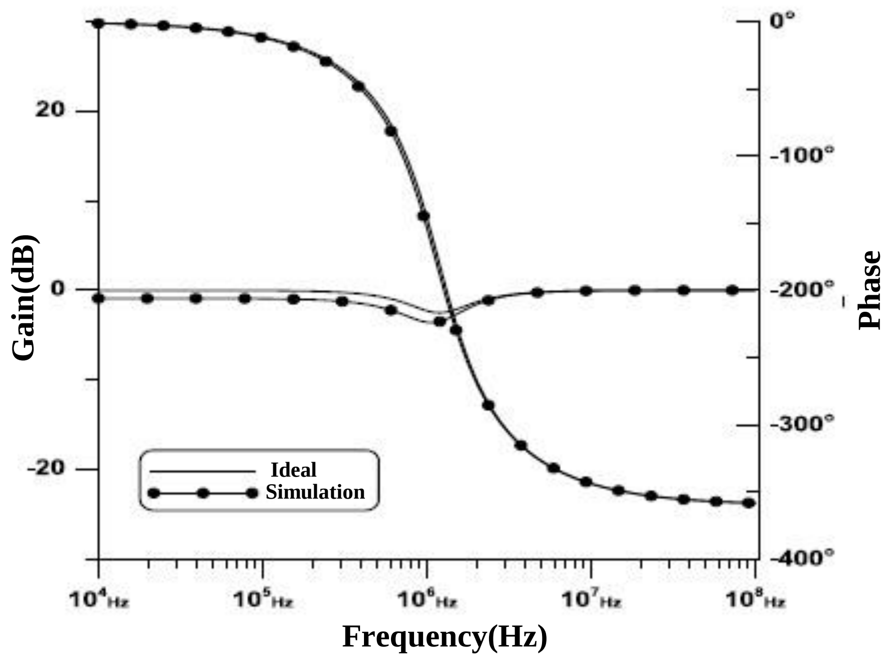

Fig. (9): The simulated result of the gain frequency response of Figure (5)

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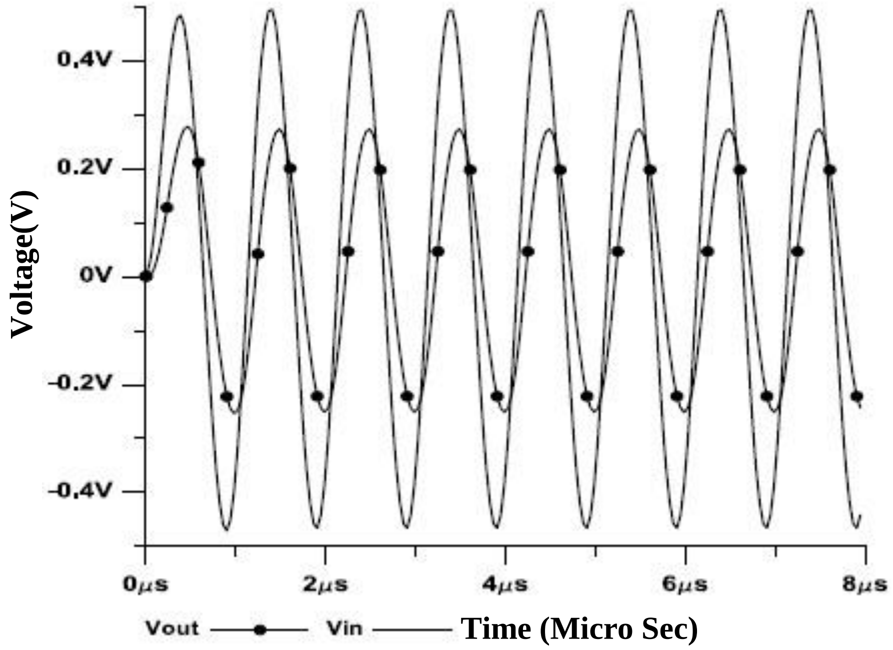

Fig. (10): Large signal analysis of Figure (5) using 0.4 $V_{peak\ to\ peak}$ sinusoidal input voltage

In addition, the distortion performance of the second proposed filter circuit is tested and simulated in order to obtain the result in Fig. (11). For an input less than 1.2 Vp-p, the harmonic distortion increases slowly depending on the input voltage. It is obvious in Fig. (11) below that (THD) still in tolerable range (1%). Therefore, the realistic usefulness of the second circuit demonstrated in Fig. (11).

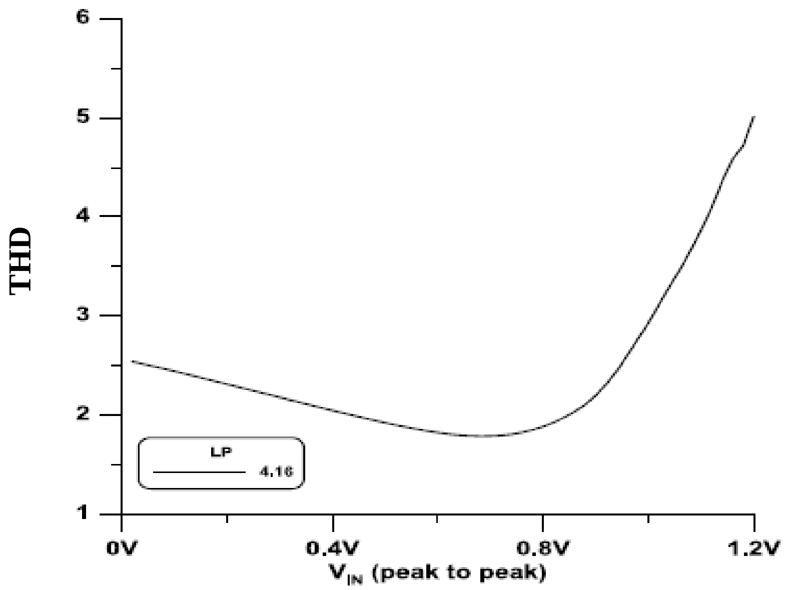

Fig. (11): Total harmonic distortion of Figure (5)

Fig. (12) shows that the quality factor can be improved by changing the value of the resistor (R_1) between (1K, 2K, 10K) ohm without modifying the pole frequency.

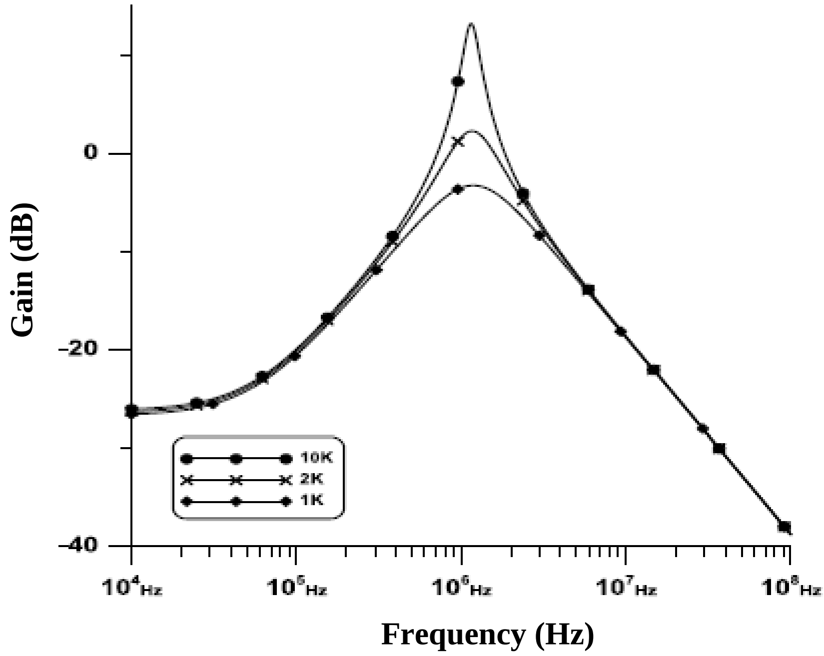

Fig. (12): The impact of the resistance R_1 to develop the Quality Factor

5. CONCLUSION

The paper focuses on designing a new kind of CMOS realization of voltage differencing buffered amplifier. The implementation is satisfied using two voltage mode (MISO) biquad filters. Each circuit constructed of two VDBAs and two or three passive elements. Both filter circuits recognize the entire filter functions such that the natural frequency is adjusted electronically with the bias voltage. Whereas, the quality factor of the second filter works as independent natural frequency after being adjusted to resistor. As a result, the quality factor and the natural frequency can be controlled independently in the second proposed filter circuit. The circuits used in this paper, do not put the matching conditions of the employed elements into consideration .Hence, this point plays a great role to make it appropriate for IC technologies in order to feed the output signal with low impedance.

The designed circuits have the following features:

- Low passive sensitivity.
- Acceptable THD value range.
- Few passive elements.

- In addition, all filter functions (LPF, HPF, BPF, BSF, APF) are realized by adjusting the input voltage.

Both filter applications realize the same filter functions but the second application is considerably better than the first one due to the additional component (resistor R_1) that is employed by the second application which optimized the quality factor without modifying the pole frequency.

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