Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 28, Sayı 2, 235-239, 2024

Süleyman Demirel University
Journal of Natural and Applied Sciences
Volume 28, Issue 2, 235-239, 2024

DOI: 10.19113/sdufenbed.1512118

Current Mode KHN Low-Voltage, High-Performance CMOS Transistor Based on Multi-Output Operational Transconductivity Amplifier for Universal Filter Applications

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(Alınış / Received: 07.07.2024, Kabul / Accepted: 31.07.2024, Online Yayınlanma / Published Online: 23.08.2024)

Anahtar Kelimeler
MO-OTA, current-mode KHN universal filter, LT-Spice simulations.

Abstract: This study proposes a current-mode KHN universal filter design that can perform three standard functions simultaneously: low-pass, high-pass, and band-pass. The circuit is built around a multiple-output operation transconductance amplifier (MO-OTA), which allows for electronically adjustable pole frequency and quality factor by modifying input bias currents (IB). The circuit layout is straightforward, with two MO-OTAs and two grounded capacitors, eliminating the need for external resistors and depending entirely on grounded components. Because of its simplicity, the circuit is suited for use in a tiny, efficient design. The proposed circuit's operation was validated using LT-Spice simulations, and the results were in line with theoretical expectations. The circuit used around 298µW of power at ±0.2V power supply voltages. These results demonstrate the circuit's potential for low-power applications, which are crucial in many modern electronic devices. The suggested current-mode KHN universal filter offers a viable option for combining various filter functions in a single circuit with customizable parameters. Its simplicity, efficiency, and performance qualities make it a feasible choice for incorporation into a variety of electronic systems, allowing for more filter design freedom

Modu KHN Evrensel Filtre Uygulamaları için Çok Çıkışlı Operasyonel Transiletkenlik Amplifikatörüne Dayanan Düşük Voltajlı, Yüksek Performanslı CMOS Transistör Tasarımı ile Gerçekleştirilmesi

Keywords
çoklu çıkışlı çalışma transiletkenlik amplifikatörü (MO-OTA), akım modu KHN üniversal filtre,
LT-Spice simülasyonları

Özet: Bu çalışma, aynı anda üç geleneksel işlevi yerine getirebilen akım modlu KHN evrensel filtre tasarımını sunmaktadır. Bunlar; düşük geçişli, yüksek geçişli ve bant geçişli filtrelerdir. Devre, giriş yanlılık akımlarını (IB) ayarlayarak elektronik olarak değişken kutup frekansı ve kalite faktörüne izin veren çoklu çıkışlı işlemsel transiletkenlik amplifikatörü (MO-OTA) temel alınarak tasarlanmıştır. Devre topolojisi, iki MO-OTA ve iki topraklanmış kapasitör kullanılarak inşa edilmiştir; bu, harici direnç gereksinimini ortadan kaldırır ve yalnızca topraklanmış bileşenlere dayanır. Basitliği nedeniyle, devre küçük ve verimli bir tasarım için idealdir. Önerilen devrenin işleyişi LT-Spice simülasyonlarıyla doğrulanmış ve sonuçlar teorik beklentilerle uyumlu bulunmuştur. Devrenin en yüksek güç tüketimi, ± 0,2V güç kaynağı voltajlarında yaklaşık 290µW olarak tespit edilmiştir. Bu bulgular, devrenin düşük güç tüketiminin kritik olduğu birçok mevcut elektronik cihaz için uygun olduğunu göstermektedir. Önerilen akım modlu KHN evrensel filtresi, çeşitli filtre işlevlerini tek bir devrede özelleştirilebilir parametrelerle birleştirmek için uygun bir seçenek sunmaktadır. Sadeliği, verimliliği ve performans nitelikleri, onu farklı elektronik sistemlere dahil etmek için cazip bir seçenek haline getirerek daha fazla filtre tasarım özgürlüğü sağlamaktadır.

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1. Introduction

Over the past two decades, in the design of electronic circuits, efforts have been made to reduce the supply voltage for circuits, especially portable devices, reducing the voltage supply. It is therefore necessary with the design technique of current-mode circuits that are more characteristic of the voltage mode, so it is the purpose of synthesizing current-mode circuits, since they have a dynamic amplitude range. Assumes (Lager dynamic range) has a higher signal band width, greater linearity, easy circuit design (simple circuitry) and low power consumption [1-2].

Analog frequency filtering circuits are very important in the field of electronic engineering and have wide applications in many fields, such as communication, instrumentation, especially in medical meters and control systems [3-8].

KHN (Kerwin Huelsman Newcomb) universal frequency filter circuit is popular because it uses fewer active and passive devices, less sensitivity to devices, and good stability [9-10].

According to the survey, a research paper has been published related to universal frequency filtering circuits in current mode. There are many active devices that can operate in current mode, such as Operational Transconductance Amplifier (OTA), Current Conveyor (CCII). Current Differential Buffer Amplifier (CDBA), Current Differential Buffer Amplifier (CDBA), Current Differential Transconductance Amplifier. (CDTA), according to the report some of the disadvantages of various articles are found below.

1) Very active and passive devices are used, especially external resistors.
2) The partial frequency response, the output is low impedance [16-17] in current mode, so it is difficult to implement
3) cannot be controlled electronically. [11-14], [16]
4) 4) The circuit must be changed to achieve full response effect. [17-18]
5) 5) Floating capacitors [19] are required to do so. It is suitable for use as IC.

Operational Transconductance Amplifier (OTA) is a popular device for signal processing circuits, as it can operate in both voltage and current modes and can control the operation of the circuit electronically.
Therefore, in this article, it is proposed a universal frequency filtering circuit in KHN current mode with MO-OTA coupled with two ground-coupled capacitors, which are characterized by three basic frequency filtering, low frequency through high pass frequency and bandpass frequency. In the same structure, pole frequency and quality value can be controlled. The factor is obtained electronically, free of external resistors and simulated with the PSpice program to test the performance of the circuit presented.

2. The Principle of Operation of the Circuit

2.1. The principle of operation of OTA

Due to the circuit offered, the circuit device extends the conductivity of the current. It is an active device that operates in a voltage-controlled current supply (Voltage Controlled Current Source: VCCS) manner. The conversion of voltage value into current is called (transconductance) or gm. The characteristic is that it has a high impedance input and output value, while the conductivity value can be controlled by the bias current from external relationship of current and voltage of OTA according to Equation 1.

$$I_0 = gm(V_{(+)} - V_{(-)}) \tag{1}$$

by gm can be expressed as .

$$gm = \sqrt{KI_B} \tag{2}$$

and

$$K = \mu oCox(W/L)$$

The values k and IB are the conductivity parameters of the device used to make an MO-OTA. Here, this is a transistor. In Figure 1, the symbol and equivalent circuit of MO-OTA are shown.

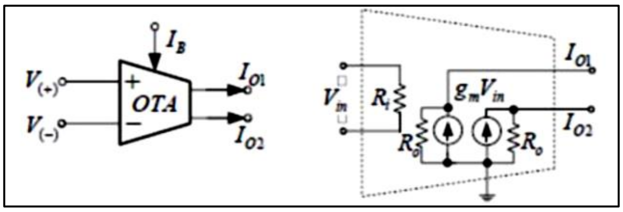


Figure 1. OTA (a) Symbol (b) Symbol (b) Equivalent circuit

2.2. Structure of KHN universal filter circuit

The circuit structure of the KHN frequency filter circuit consists of 2 lossless integrator circuits and an integrated circuit. As shown in Figure 2, from the diagram, the transfer equation of high frequency through, through frequency band and low frequency through can be written as equation (3) - (5), respectively.

$$\frac{M_{HP}}{N_{in}} = \frac{s^2}{s^2+s\frac{1}{\lambda_1}+\frac{1}{\lambda_1\lambda_2}} \tag{3}$$

$$\frac{M_{BP}}{N_{in}} = \frac{s\frac{1}{\lambda_1}}{s^2+s\frac{1}{\lambda_1}+\frac{1}{\lambda_1\lambda_2}} \tag{4}$$

and

$$\frac{M_{LP}}{N_{in}} = \frac{\frac{1}{\lambda_1\lambda_2}}{s^2+s\frac{1}{\lambda_1}+\frac{1}{\lambda_1\lambda_2}} \tag{5}$$

From equations (3) — (5), the value of the pole frequency and the value of the quality factor can be written as equations (6) and (7).

$$w_0 = \sqrt{\frac{1}{\lambda_1 \lambda_2}} \quad (6)$$

And

$$Q_0 = \sqrt{\frac{\lambda_1}{\lambda_2}} \quad (7)$$

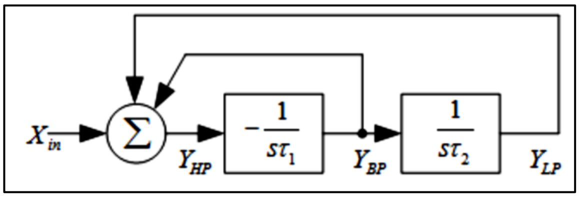


Figure 2. The structure of the KHN universal filter circuit

2.3. KHN universal filter circuit with OTA offered

This section is an important part that presents the KHN universal filter circuit with MO-OTA, which consists of 2 integrator circuits. Thus, it does not consume the equipment, so the KHN universal frequency filter circuit with OTA presented in Figure 3 can be written as follows:

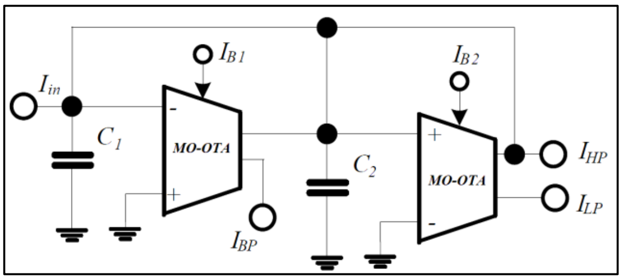


Figure 3. KHN universal filter circuit presented

$$\frac{M_{HP}}{N_{in}} = \frac{s^2}{s^2 + s\frac{gm1}{C_1} + \frac{gm1gm2}{C_1C_2}} \quad (8)$$

$$\frac{M_{BP}}{N_{in}} = \frac{s\frac{gm1}{C_1}}{s^2 + s\frac{gm1}{C_1} + \frac{gm1gm2}{C_1C_2}} \quad (9)$$

$$\frac{M_{LP}}{N_{in}} = \frac{s\frac{gm1gm2}{C_1C_2}}{s^2 + s\frac{gm1}{C_1} + \frac{gm1gm2}{C_1C_2}} \quad (10)$$

$$w_0 = \sqrt{\frac{gm1gm2}{C_1C_2}} \quad (11)$$

and

$$Q_0 = \sqrt{\frac{gm1C_1}{gm2C_2}} \quad (12)$$

When replacing gm with $\sqrt{KI_B}$ into Equations (11) and (12)

$$w_0 = \sqrt{\frac{(K_1K_2IB_1IB_2)^{\frac{1}{2}}}{C_1C_2}} \quad (13)$$

$$Q_0 = \sqrt{\frac{(K_1IB_1)C_1}{(K_2IB_2)C_2}} \quad (14)$$

From the equations ω_0 and Q_0, the pole frequency values, and the quality factor values can be adjusted electronically. Moreover, the ratio, if the current values I_{B1} and I_{B2} are given constant, the pole frequency can also be adjusted. At the same time, if a high Q value is desired, this can be done by giving C_1 more than C_2 and BW can be obtained as in equation (15).

$$BW = \frac{w_0}{Q_0} = \sqrt{\frac{K_1I_{B1}}{C_1}} \quad (15)$$

2.4. The sensitivity of the presented circuits

The sensitivity value of the presented frequency filter circuit is obtained by equations (16) and (17).

$$S_{IB1}^{wo} = S_{IB2}^{wo} = 0{,}5 \quad , S_{IB2}^{Qo} = S_{C2}^{wo} = -0.5 \quad (16)$$

and

$$S_{IB1}^{Qo} = S_{C2}^{Qo} = -0.5, \; S_{IB2}^{Qo} = S_{C2}^{wo} = -0.5 \quad (17)$$

The sensitivity of all active and passive devices must always be equal to or less than 1.

3. Simulation Results

To confirm the performance of the presented circuit, the operation of the circuit was simulated with the LT-Spice program for the PaMOS and NMOS transistors used to simulate the operation of the circuit, using the parameters of the company TSMC CMOS with 65 nm technology. [20]

Figure 4 shows the internal structure of OTA by the conditions of this simulation. The supply of the circuit is ±0.2V. The resistance at the circuit load is equal to 2 ohms. Capacitor values $C_1=C_2=2nF$ and $I_{B1}=I_{B2}=10nA$ will obtain a pole frequency of 6MHz from the simulation.

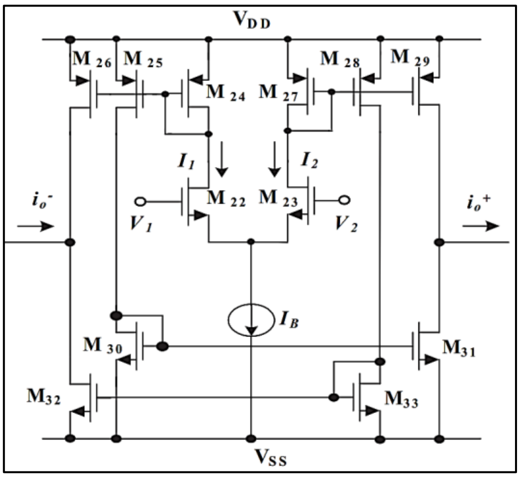


Figure 4. Internal structure of OTA

As a result of Figure 5, let's try to do the task of frequency response of a general-purpose filter circuit. KHN with MO-OTA to clearly demonstrate the simulation results of the circuit, low-pass filtering, high-pass filtering, and band-pass filtering. In the structure of the presented circuit, it has not changed, and in the operating condition there is a power consumption of 298µW, as Figure 6 shows the frequency response in dB threshold form in the frequency range. 100KHz-100MHz.

Figure 7 shows the response of the bandpass filtering. From adjusting IB1=25nA, 60nA, 125nA to IB2=25nA, it was found that the pole frequency value corresponds to the value obtained from the calculation in Equation (12), and the calculation results are consistent and can be practically applied. In Figure 8. The frequency response was demonstrated by giving IB1=IB2, which adjusted the values of 25nA, 60nA,125nA, resulting in the pole frequency values consistent with the values obtained from the simulation, namely the polarity values of 6.104MHz, 7.8071MHz and 8.991MHz, respectively. It was found that the adjustment of the current IB1=IB2 causes Bandwidth and polarity change accordingly and have no effect on the quality factor value and THD= 2.1%.

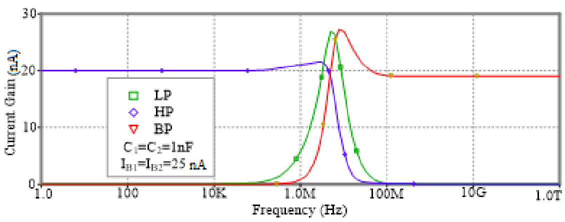
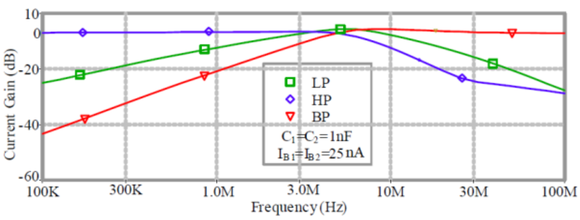


Figure 5. Frequency response effect of the filter circuit presented



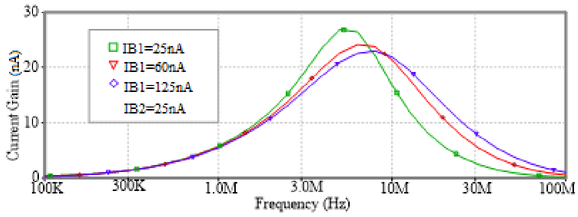


Figure 7. Response effect of bandpass filtering by adjusting IB1=25nA, 60nA, 125nA, and IB2=25nA

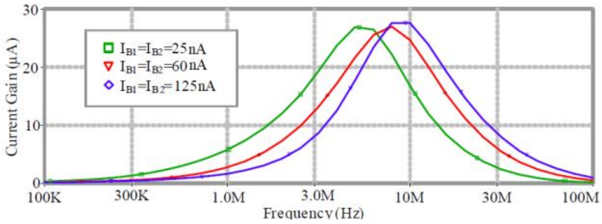


Figure 8. Response effect of bandpass filtering by setting IB1=IB2 to be equal to 25nA, 60nA, and 125nA

4. Discussion and Conclusion

A study was done on a multi-purpose universal filter circuit in KHN current mode which employed a multiple-output operational transconductance amplifier (DO-OTA). This circuit can also be used as an integrated circuit (IC) as it was designed to function with two grounded capacitors. Its ability to independently adjust the pole frequency without the need for additional resistors or components that are floating-mounted is one of this circuit's unique features. Better flexibility and control over its usage are made possible by the suggested circuit, which permits electrical modification of the pole frequency and quality factor value.

The LT-Spice program's simulation results were discovered to be closely consistent with theoretical predictions. With its low consumption of 298µW and need for a supply voltage of ±0.2V, this circuit is a cost-effective option for various electrical uses. When used with a DO-OTA, KHN current mode enhances performance and versatility in frequency filtering applications.

The research study focuses on the potential and viability of incorporating the proposed multi-purpose frequency filter circuit into integrated circuit designs. Changeable pole frequency and low power consumption are two of the circuit's unique features that make it a desirable option for a range of electronic systems that need accurate frequency filtering. The study highlights how innovative circuit designs contribute to the advancement of electrical technology and enhance performance across a range of applications.

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics

Directive" are complied with, and that none of the actions stated under the heading "Actions Against Scientific Research and Publication Ethics" are not carried out.

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