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Wide Tuning Range Gm-C Low-Pass Filter Optimization with 10 MHz Cut-off Frequency for Wireless Applications

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Abstract

Time continuous filters are suitable for use at medium speeds and low power consumption. One of these filters which is designed by MOSFET transistors based on CMOS technology, is the Gm-C filters that have been used in the industry for a long time. Such transistors are biased in the inverted area and creating a wide bandwidth to several hundred MHz. In this paper, we simulate the Gm-C low pass filter with a 10 MHz cut-off frequency for Bluetooth and CMOS applications with a power consumption of 110 VW for a single-volt source in wide tuning range. The use of the MOSFET and its bias in the downstream area is considered in this study in order to reduce the power consumption significantly. This operation will lead to the application of this method in wireless technology.

1. INTRODUCTION

Low frequency filters are considered as one of the most important blocks in medical applications. The reason is that it can be used in wireless systems. Also, such filters have a wide dynamic range and lower power consumption and so they use less power in wireless applications [1]. Two important parameters to design the integrated circuits are the power consumption and voltage source. . Nowadays, in the engineering sciences and especially in medicine, it is attempting to use portable equipment with battery and low power consumption, as well as trying to reduce the size of the circuits as an appropriate structure and configuration. Improving current density is also considered as another parameter, due to high current density leads to numerous problems and can increase power consumption. This research uses the Gm-C low pass filter to address these

issues and challenges as well as its storage and placement in wireless structures. In general, for Gm-C filter designing, some features [2] which listed in following are to be considered:

- Receive low-pass, high-pass, middle-pass, no-pass, and all-pass filter responses with a single unit without external connections.
- Electronic setting, quality factor and central frequency.
- Low sensitivity of the quality factor, the central frequency to the transduction and the filter capacitors.
- Reducing parasitic effects using grounded capacitors.
- Non-use of resistance in different sectors.
- Ability to operate in different situations including voltage, current, and transients.

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- Biasing the transistors in the downstream area to significantly reduce the consumption of the filter circuit.

The features of the Gm-C filter mentioned above, can be used in wireless applications in order to optimize the low power consumption and the low voltage in wireless circuits. The filter provided in this study is suitable for use in marine telecommunications and medical engineering systems.

2. LITERATURE REVIEW

A variety of research has been conducted in the field of Gm-C filters that pursues a variety of goals. For example, we can refer to [3] which focuses on designing the Gm-C filter switch-based capacitor-based switching frequency. The use of 0.18 μm technology was considered in the CMOS process which determines its frequency range at runtime between 147 kHz and 1.95 MHz. In another study presented in [4], a modified OTA with enhanced linear mode transduction for a low frequency of Gm-C filter was developed. Using 0.35 μm technology was considered in the CMOS process up to 30 kHz to improve the signal. In [5], a bulk-tuned Gm-C filter with a current flow was developed. In fact, this study aimed to reduce the energy consumption of integrated circuits by trying to provide a Gm-C low-pass filter that uses 0.35 μm technology in the CMOS process. Power consumption was also 24.1 μW at the end. In [6], the Gm-C low pass filter was proposed with a 160 MHz cut-off frequency for wireless applications. The purpose of this research was reduce the energy consumption in different filter modes. The results show that there were some weaknesses in this research, including the failure to determine the amplitude and phase based on the input voltage. The energy was 17.3 μW at the end of process.

A controllable adaptive bias linearization technique for a CMOS OTA with the design of the Gm-C low pass filter was presented in [7]. The main goal of this study was improvement of the 13% OTA output energy as a third-order nonlinear. This technique would be applicable in wireless and Bluetooth systems where it used 0.18 μm technology in the CMOS process. The energy consumption of this method, although optimized for about 13%, is still high and is about 420 μW.

S complete differential Gm-C filter adaptively with a CMOS-based fuzzy controller approach to automate the balancing of a channel after digital transmission presented in [8]. This method seeks to improve the extra phase, spatial optimization and energy consumption. The fuzzy logic improves the Gm-C filter and changes the filter parameters based on existing mappings. The use of standard and technology of 0.35 μm in the CMOS process has been considered in this research. Power consumption was 29.3 μW.

In [9], the use of the Gm-C low pass filter was considered as the method of transmitting data through the band with minimum energy consumption. The intervals for sending and receiving data dynamically considered as well as the comparative bias in the Gm-C low pass filter. In this study, the main standard was 130 nm in the CMOS process and had a bandwidth of 2 MHz and 600 KHz. The power consumption was 26.1 μW.

In [10], the use of the Gm-C low pass filter designed for positioning with Particle Swarm Optimization algorithm in a circuit. The low pass filter type along with the six-order butter-worth filter for Gm-C designed which can be used in wireless intelligent medical systems. The use of ZigBee and 0.18 μm technology was considered in the CMOS process. The power consumption was 12.02 μW.

3. PROPOSED APPROACH

There are 5 OTA blocks and 2 ground-coupled capacitors that have capability for realizing the use of voltage, current, transients and transients in the proposed Gm-C low-pass filter. There is no external connection to the circuit and in different modes and also there is no change in the main circuit. The general structure of the circuit in block form is shown in Fig. 1.
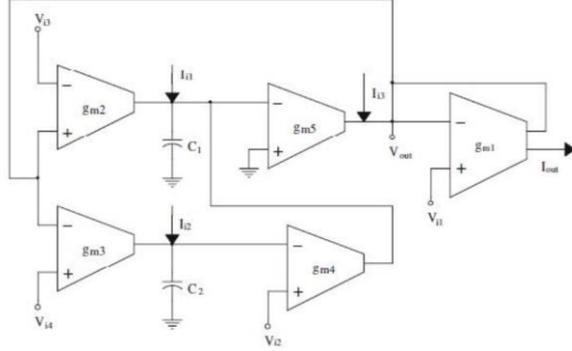
Fig. 1. Proposed filter circuit'

As shown in Fig. 1 for the proposed filter circuit, $V_{in1}, V_{in2}, V_{in3}$ and V_{in4} are input voltages and I_{in1}, I_{in2} and I_{in3} are input currents, I_{out} is output current and V_{out} is output voltage. Circuit conversion function and Gm-C filter are calculated as Eqs. (1)- (5),

$$V_{out} = \frac{N_1(s) + N_2(s)}{D(s)} \qquad (1)$$

$$I_{out} = (-g_{m1})\frac{N_1(s) + N_2(s)}{D(s)} \qquad (2)$$

$$N_1(s) = s^2 C_1 C_2 g_{m1}(V_{i1})$$
$$- sC_2 g_{m5}(g_{m4}V_{i2} - g_{m2}V_{i3}) \qquad (3)$$
$$+ g_{m3} g_{m4} g_{m5}(V_{i4})$$

$$N_2(s) = s^2 C_1 C_2 (I_{i3}) - sC_2 g_{m5}(I_{i1})$$
$$+ g_{m4} g_{m5}(I_{i2}) \qquad (4)$$

$$D(s) = s^2 C_1 C_2 g_{m1} + sC_2 g_{m2} g_{m5}$$
$$+ g_{m3} g_{m4} g_{m5} \qquad (5)$$

It should be noted that g_{mn} is the transition. According to Eqs. (1)- (5), the filter responses will be in the form of Eqs. (6)- (10) for different scenarios including in order high pass, middle-pass, low pass, non-pass or not- middle-pass , and all-pass filters with a single-unit non-interconnected structure.

High Pass Respone : $V_{in2} = V_{in3} = V_{in4} = 0$
$$V_{in1} = V_{in} \qquad (6)$$

Middle Pass Response: $V_{in1} = V_{in3} = V_{in4} = 0$
$$V_{in2} = V_{in} \qquad (7)$$

Low Pass Respone : $V_{in1} = V_{in2} = V_{in3} = 0$
$$V_{in4} = V_{in} \qquad (8)$$

Not-Middle Pass Respone: $V_{in1} = V_{in4} = V_{in}$
$$V_{in2} = V_{in3} = 0 \qquad (9)$$

Full Pass Respone: $V_{in1} = -V_{in3} = V_{in4} = V_{in}$ (10)

The same scenarios exist for current and transient states, which are in the form of Eqs. (6)-(10), defined for I_{in1} to I_{in3}. The reason is that the flow will also be in the same relationship that there is no external connection and no change will occur. In some studies, flow and transactional relationships are changing, claiming that they are the same in all filter states, and there is no external connections, is virtually wrong. The same relationships are considered to accommodate this filter in a wireless system. In a Gm-C low pass filter, there is an electronic and separate adjustment of the parameters of the Q factor and the central frequency W_0 which are in the form of Eqs. (11) and (12) as follows,

$$Q = 1 \Big/ g_{m2} \sqrt{\frac{g_{m1} g_{m3} g_{m4} C_1}{g_{m5} C_2}} \qquad (11)$$

$$W_0 = \sqrt{\frac{g_{m3} g_{m4} g_{m5}}{C_1 C_2 g_{m3}}} \qquad (12)$$

where c_i for $i=1,2$ are capacitors. Accordingly, the Gm-C filter can be simply, but robust, with improved flow and energy, which can be used in wireless applications, especially in the field of medical engineering, which seeks to reduce the battery size and energy consumption. The simulation and the results are given in Section. 4.

4. SIMULATION AND RESULTS

In this paper, simulation is done using MATLAB software and its command line. Initially it is necessary to initialize the OTA circuit, which is $V_{DD} = -V_{ss} = 0.3$ and $V_b = 0.05$, and capacitors $C_1 = C_2 = 50 \, pf$. The total power consumption of the whole circuit is 7.9 nw and the central frequency is 1 kHz. All responses including low pass, high pass, middle-pass, not- middle-pass, and all passage in voltage, current, transient and transient modes are shown in Fig. 2 by selecting capacitor $C_1 = C_2 = 50 \, pf$.
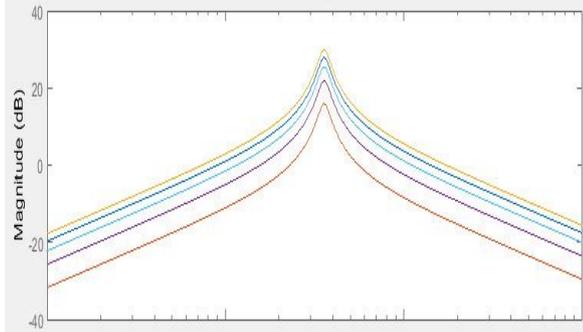
Fig. 2. *Frequency responses of filters in voltage, current, thermal and transformation.*
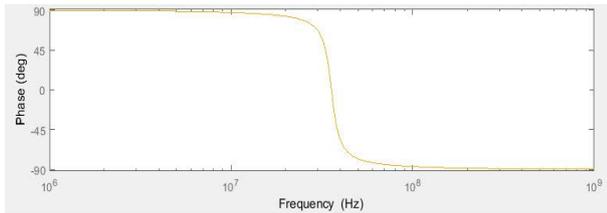
Fig. 3. *Phase in terms of the angle and frequency in Hz for the low pass Gm-C filter.*

Fig. 4. *BODE curve for the output of Fig. 2, and the upper part of Fig. 3.*
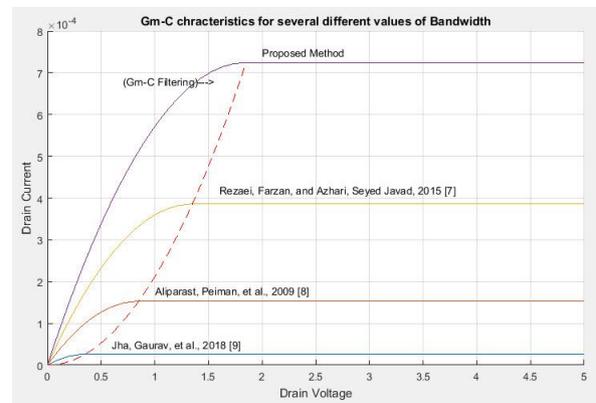
Fig. 5. *Bandwidth comparison.*

According to Fig. 1, the orange color is for the high pass filter, the blue color is for the middle-pass filter, the blue color is for the non-pass filter, the purple color is for the low pass filter and the red color is for the full pass filter, which used dB to shown on the frequency per Hz. The phase in terms of angle and frequency in Hz for the Gm-C low pass filter is shown in Fig. 3.

Similarly, the BODE curve designed as an evaluation criterion for achievements in Fig. 2, includes all responses such as low pass, high pass, middle-pass, no-pass, and all passage in voltage, current, transient and transient states in Fig. 4. The upper part and phase determination in terms of angle and frequency in Hz for the Gm-C low pass filter are shown in Fig. 3 in the lower part of Fig. 4.

It also discusses the flow discharges on the voltage drop in the Gm-C filter in wireless applications to detect bandwidth. For this purpose, a series of initial parameters is essential as shown in Table. 1.

The output is also compared with research papers [7]-[9] in terms of the bandwidth used in Gm-C low pass filter based on the current drain on the voltage discharge. The result of evaluations are shown in Fig. 5.

Based on Fig. 5, the bandwidth of the proposed approach is superior to the previous three proposed methods. As we can see, the wide rang tuned in Fig. 5. After implementing the proposed approach, the power consumption of the filter provided in wireless systems is 7.95 μW, which indicates the high ability of the proposed method to its previous state of art papers. In Table. 2, a comparison has been made based on energy consumed.

Table 1. *Flow discharges parameters on the voltage drop in the Gm-C filter in wireless applications to detect bandwidth.*

Wireless Application Distance	$650\ m$
Oxide capacity in MOSFET transistors	$6.9\ F/cm^2$
Drain layer	$11.8\ cm$
Controller port voltage	$[1 \dots 5]$

Table 2. *Energy consumption comparison.*

Reference	Energy Consumption (μW)
Moreno, Ricardo F. L., et al., 2015 [5]	24.1
Abu Bakar, Faizah, et al., 2015 [6]	17.3
Rezaei, Farzan, and Azhari, Seyed Javad, 2015 [7]	420
Aliparast, Peiman, et al., 2009 [8]	29.3
Jha, Gaurav, et al., 2018 [9]	26.1
Laouej, D., 2017 [10]	12.02
Proposed Method	7.9

5.CONCLUSION

In this paper, we tried to provide a low-pass Gm-C filter in a number of stable and resilient conditions in other modes including high pass, middle-pass and all-pass without external connectors. The designed circuit can be used in wireless applications such as marine telecommunication and medical engineering. The results are given for four modes of voltage, current and transient, and receiving all filter responses by biasing transistors in the sub-threshold which can leads to reduced energy consumption. Wide range tuning by extending the bandwidth is the main advantage of our Gm-C filter design. In addition, the use of two earth-coupled capacitors reduced the parasitic effects of the circuit. However, reducing power at runtime indicates a guarantee of the proposed approach.

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