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A Power Efficient Gain Enhancing Technique for Current Mirror

T. Azadmousavi*, H. Faraji Baghtash^{*(C.A.)} and E. Najafi Aghdam*

Abstract: This work introduces a new and simple method for adjusting the gain of current mirror. The major advantage of the proposed architecture is that, unlike the conventional variable gain current mirror, it does not need the change of the biasing current to adjust current gain. Therefore, the power dissipation remains constant in all of the gain settings. In addition, the proposed variable gain current mirror have linear-in-dB gain control characteristic, simple structure, and small occupied area. The gain of the current mirror can be simply varied from 1.3dB to 21dB while the 3-dB bandwidth of the circuit remains around 12.3MHz or 33.6MHz at operation frequency range of 1.9MHz-14.2MHz and 6.6MHz-40.2MHz respectively. The proposed circuit draws negligible power of $6.9\mu\text{W}$ from 1.8V supply voltage. The simulation results of designed variable gain current mirror in $0.18\mu\text{m}$ standard CMOS technology confirms the effectiveness of the proposed circuit.

Keywords: Variable Gain Current Mirror, Constant Power Consumption, Relocating Pole-Zero, Linear-in-dB.

1 Introduction

IN the recent years, using current mode signal processing has received significant attention due to the low-power operation, wide dynamic range, high frequency operation and simple structure [1-4]. One of the most important and widely used building blocks of current mode signal processing is variable gain current mirror (VGCM). For instance, it is commonly used in applications such as tunable filters and adjustable gain amplifiers. It also find its application in circuits designed for biomedical applications [5-8]. So far, various techniques introduced to control the current gain of current mirrors [9-11]. Currently, the research on tunable current mirrors are mainly focused on the reduction power consumption and increment of gain tuning range, and operating speed [12-15]. For instance, the power consumption in [12] has been decreased,

however, its tuning range and frequency bandwidth are very limited. On the other hand, [13] can deliver wide tuning range and frequency bandwidth, but it has a relatively high power consumption that is not suitable for ultra-low power applications. In all of these circuits, the operating current or voltage of circuit is varied to adjust the gain. As a result, the power consumption will be different at various gain settings. This, however, may not suitable for specific high performance applications that require ultra-low and constant power consumption.

In this work, a new low power, linear-in-dB VGCM structure is introduced which delivers constant power consumption profile all-over the gain range. The proposed technique enables the structure to deliver some ever interesting features of low power consumption, wide programmable gain range, and acceptable frequency bandwidth. The paper is organized in four subsequent sections. The structure of proposed VGCM is described in Section 2. In the next section, simulation results using $0.18\mu\text{m}$ standard CMOS technology is presented. Finally, Section 4 concludes this work.

2 Proposed Circuit

2.1 Operational Principle

The conceptual schematic of the gain adjusting

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technique, is shown in Fig. 1. The main idea is to achieve the variable gain function through relocating the pole or zero of the circuit which originally proposed by authors in [16]. To better understand the operation of proposed technique, consider a current mirror with two dominate poles (P_1, P_2) and one zero (Z_1), so that $Z_1 < P_1 < P_2$. Two distinct methods for tuning the gain of current mirror can be introduced by relocating the pole or zero locations of current transfer function (see Fig. 2 and Fig. 3). The first method which we named it constant-zero variable gain current mirror (CZ-VGCM) is depicted in Fig. 2. As is depicted in this figure, in this method, our option to change the gain is to keep the values of Z_1 and P_2 constant, while relocating the P_1 in frequency axis. This gives a constant 3-dB cutoff frequency at upper corner of frequency bandwidth that is very interesting in many automatic gain control (AGC) applications [17].

The second method to obtain variable gain function is to keep P_1 constant while shifting both the P_2 and Z_1 in the frequency axis. This method which we called it adjustable-zero variable gain current mirror (AZ-VGCM), in contrast with the first method, gives a frequency transfer function that has constant 3-dB cutoff frequency at lower corner while delivers different 3-dB cutoff frequency at higher corner of frequency bandwidth (see Fig. 3). The resulted VGCM, however finds its applications well in multi-standard transceiver structures [18]. Interestingly, in both cases of CZ-VGCM and AZ-VGCM, the current amplification is simply accomplished through varying the value of passive capacitors, which does not require extra power consumption. Thus, the resulted structure promised to be extremely low power. In other words, the proposed VGCM structure can interestingly works well with very low power consumption while, delivers high performance with acceptable gain control range. The transistor level realization of the proposed technique is described in the following section.

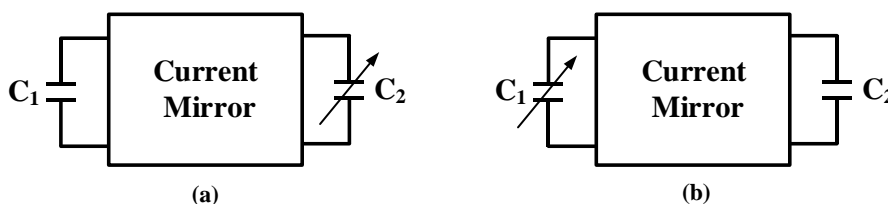


Fig. 1 Conceptual schematic of the proposed technique: a) relocating pole and b) relocating zero.

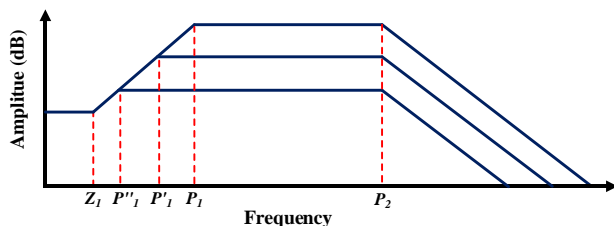


Fig. 2 The frequency response of CZ-VGCM.

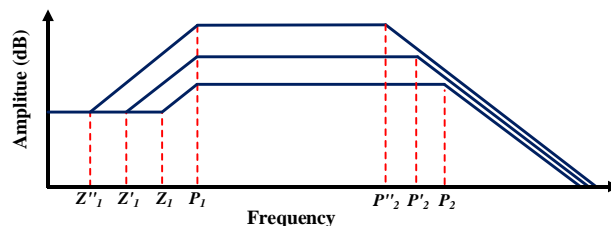


Fig. 3 The frequency response of AZ-VGCM.

2.2 Transistor level implementation of proposed VGCM

Figure 4 shows a current mirror with constant gain of I_1/I_2 . In this circuit, the M_1 and M_8 form a source follower voltage buffer as well as M_2 and M_9 do. Through these two voltage followers, the gates of M_3 and M_4 follow the voltage of input node, constructing a current mirror circuit. There is an interesting feature with this structure, that is the capability of separately setting the gate voltage of M_3 and M_4 and consequently the mirroring ratio of current mirror by simply adjusting I_1 and I_2 (see Fig. 4). Transistors M_5 - M_6 are cascade transistors which used to enhance the gain accuracy of current mirror. In order to add variable gain capability to the proposed CM, two adjustable capacitors are applied to the gate-drain nodes of M_3 and M_4 . The final schematic of proposed VGCM is shown in Fig. 5. The proposed VGCM has two main poles and one zero. The capacitors C_1 and C_2 determine Z_1, P_2 and P_1 , respectively. By selecting the appropriate amount for C_1 and C_2 , the zero can be located at lower frequencies compared to the poles. Therefore, as described in previous section, the gain of the VGCM can be changed by relocating either zero and second pole or first pole.

3 Simulation Results

The proposed structure is simulated in TSMC 0.18 μ m standard CMOS technology. As the two versions of proposed VGCM (CZ-VGCM, AZ-VGCM) find very different applications, thus we examined the performance of each structure at different operating frequencies.

Therefore, in the circuit of CZ-VGCM, C_1 is 29fF and C_2 varied from 6fF to 96fF and for AZ-VGCM, C_2 is 29fF and C_1 varied from 8fF to 128fF. Fig. 6 shows the frequency response of the CZ-VGCM and AZ-VGCM at various gain settings. Fig. 6 (a) illustrates that the

current gain can be changed from 1.3dB to 21dB by varying of C_2 , while its 3-dB bandwidth well-remains constant around 33.6MHz. Also, by changing of C_1 the current gain of the AZ-VGCM ranges from 1.8dB to 21.6dB while its 3-dB bandwidth remains around 12.3MHz.

The Monte-Carlo simulation are done on the threshold voltage of the CZ-VGCM in the case of C_1 is 6fF. The results are depicted in Fig. 7 and it shows that for the 15mv deviation of threshold voltage, the gain of the CZ-VGCM varied only 2.4dB. The current gain versus capacitor for CZ-VGCM and AZ-VGCM are plotted in Fig. 8, illustrating the linear-in-dB characteristic of the proposed structure.

The Power Consumption versus different capacitors of the proposed CZ-VGCM is shown in Fig. 9 and it validated the constant power consumption during the gain settings.

The input referred noise characteristic of the both VGCMs are shown in Fig.10, demonstrating very low

input referred noise. Fig.10 (a) represents that the input referred noise value well remains less than 1.1pA/√Hz all over the interested frequency bandwidth for CZ-VGCM. Also as shown in Fig.10 (b), the input referred noise value of the AZ-VGCM at its entire frequency bandwidth is evaluated to be less than 5.2pA/√Hz. The layout of the proposed VGCM is shown in Fig. 11 and the occupied area is 58 x 20 μm².

Table 1 compares performance of the two versions of VGCM with Pre-Layout and Post-Layout simulation results. It demonstrates that AZ-VGCM is appropriate choice for applications which their operation frequency falls at 1.9MHz-14.2MHz range. On the other hand, for applications with operation frequency range from 6.6MHz to 40.2MHz, CZ-VGCM would be a good candidate. The transistors aspect ratios are given in Table 2. The performance comparison between the proposed VGCM (CZ-VGCM) and some other published works is reported in Table 3.

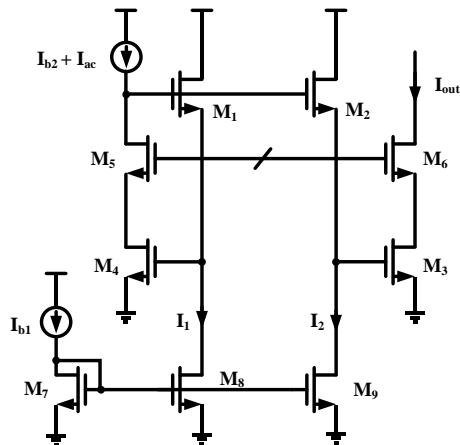


Fig. 4 Schematic of the current mirror with constant gain.

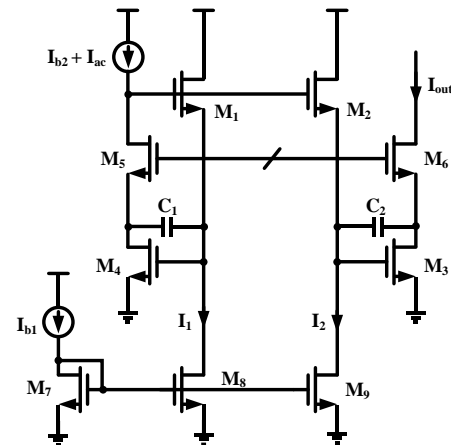
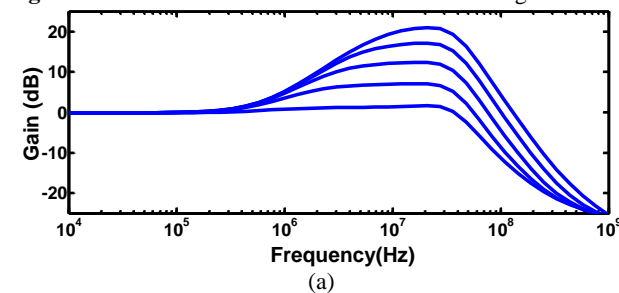


Fig. 5 Schematic of the proposed VGCM.

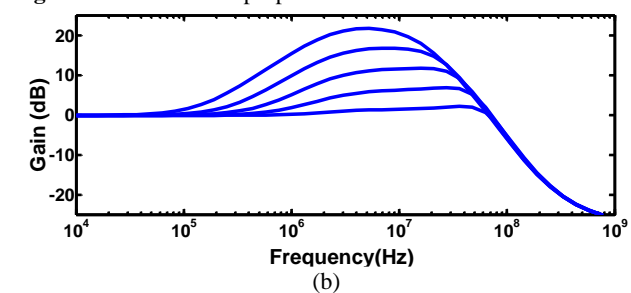


Fig. 6 The frequency response a) CZ-VGCM and b) AZ-VGCM.

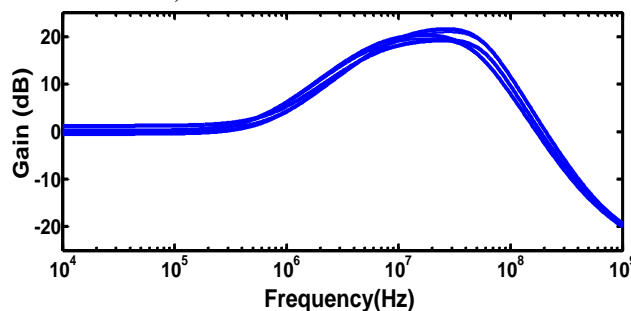


Fig. 7 The Monte-Carlo simulation results of 15mv deviation of threshold voltage.

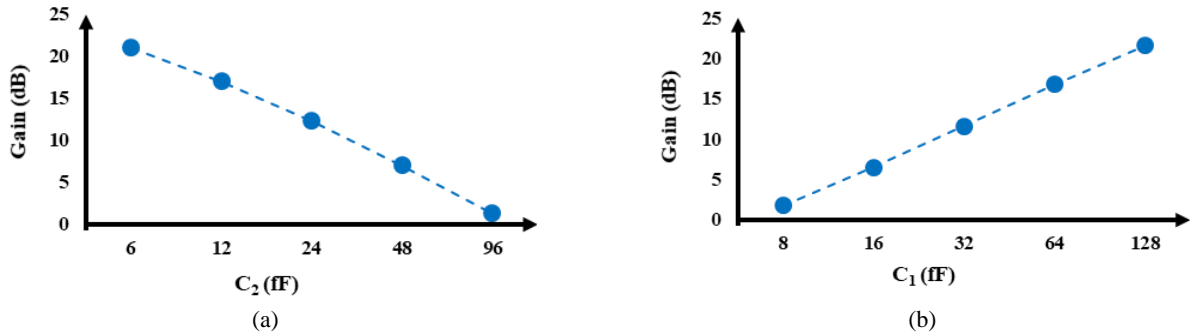


Fig. 8 The dB-linearity characteristic a) CZ-VGCM and b) AZ-VGCM.

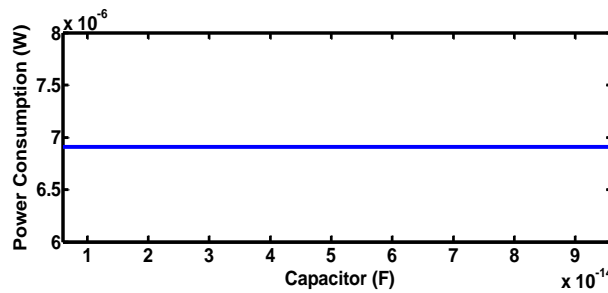


Fig. 9 The Power Consumption versus different capacitors.

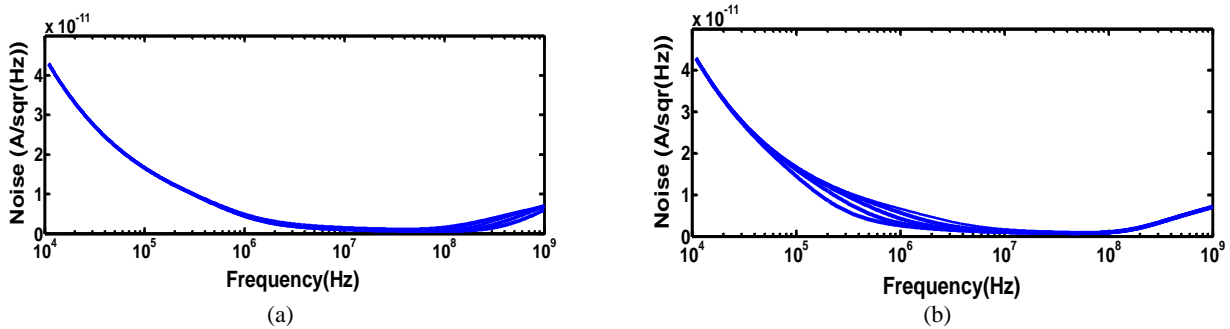


Fig. 10 The input referred noise as a function of frequency a) CZ-VGCM and b) AZ-VGCM.

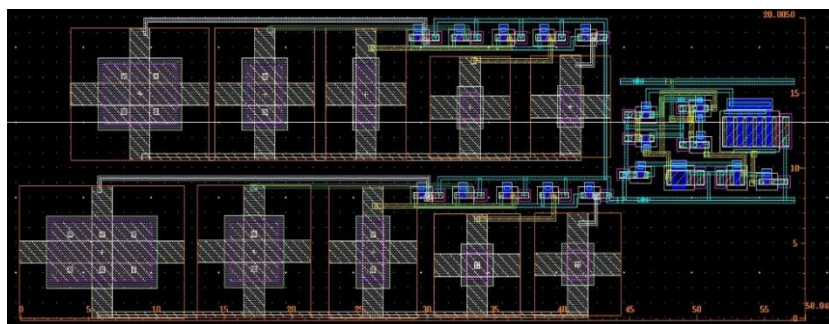


Fig. 11 The layout of the proposed CZ and AZ VGCM.

Table 1 Comparison between two methods of tuning gain.

	C_1 (fF)	C_2 (fF)	Gain range (dB)	Bandwidth 3-dB (MHz)	Frequency Operation (MHz)	Input Referred Noise (IRN) $\text{pA}/\sqrt{\text{Hz}}$
CZ-VGCM^a	29	6-96	0-20.7	45	6.46-51.5	< 1
CZ-VGCM^b	29	6-96	1.3-21	33.6	6.6-40.2	< 1.1
AZ-VGCM^a	8-128	29	0-21	12	1.77-13.8	< 5
AZ-VGCM^b	8-128	29	1.8-21.6	12.3	1.9-14.2	< 5.2

Table 2 Transistors aspect ratios.

Transistor	W/L ($\mu\text{m}/\mu\text{m}$)	Transistor	W/L ($\mu\text{m}/\mu\text{m}$)
M ₁ ,M ₂ , M ₃ ,M ₄ ,M ₅ ,M ₇	0.4/0.18	M ₈	1/0.9
M ₆	5* \times 2/0.18	M ₉	1/0.18

* Number of Fingers

Table 3 Performance Comparison.

Works	[12]*	[13]	[14]	[15]	This work
CMOS Process (μm)	0.35	0.18	0.5	0.18	0.18
Power Consumption (μW)	61	900	2.05	41.1	6.9
Supply Voltage (V)	1.5	1.5	\pm 1.2	1	1.8
3-dB Bandwidth (MHz)	1.708	100	0.189	93.7	33.6
Gain range (dB)	-1.9 to 1.58	0 to 20	0 to 16	-4.3 to 14.9	1.3 to 21
IRN ($\text{pA}/\sqrt{\text{Hz}}$)	-	-	-	4.33	< 1.1

*Measurement Results

4 Conclusion

In this paper a power efficient current gain adjustment technique is described. The operating principle of proposed structure is discussed. The proposed structure majorly enjoys from very low and constant power consumption all over the entire gain range. The proposed structure draws only $6.9\mu\text{W}$ from 1.8V power supply. Interestingly, the gain varies linear-in-dB with control signal and the structure presents constant bandwidth characteristic, both of which are very interesting parameters in variable gain structures. Simulation results in TSMC $0.18\mu\text{m}$ standard CMOS technology, confirm the proper function of the proposed design.

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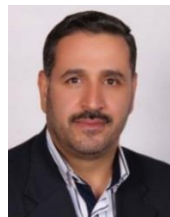


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