# The Design of Low Noise Chopper Operational Amplifier with Inverter

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**Abstract:** The input offset voltage is a quit important performance parameter for operational amplifiers, and the low frequency 1/f noise has a great effect on the offset voltage. In this paper, chopping technology which is an efficient approach to decrease the 1/f noise and offset voltage of CMOS amplifiers is adopted. In the low pass filter, the multiplier composed of R and C is used to filter out the modulation noise. The circuit of the presented chopper amplifier is designed and simulated with 45nm CMOS process and a 1V supply. Simulated results show that the total harmonic distortion of chopper amplifier is 54.1dB and the chopper frequency is 10 kHz. The input referred noise is 2.54 $nV/\sqrt{Hz}$ @1kHz, and the average power consumption is 65.5μW. The proposed technology has a pleasurable preference.

**Keywords:** Chopper amplifier; Low pass filter; Offset voltage; Chopping technology

## 1 Introduction

With the development of the solid state devices and integrated operational amplifiers, the performance of amplifiers has improved greatly. The offset voltage and low frequency 1/f noise [1] of the CMOS amplifier circuit have become crucial factor in restricting the circuit to single chip integrated. Modern CMOS integrated circuit technology is developing rapidly toward the deep sub-micron, which makes analog signal processing circuit face great challenges in reducing supply voltage, the 1/ f noise and offset voltage. These challenges are the key of the overall detection circuit.

The current technologies adopted to eliminate the low frequency 1/f noise and offset voltage consist of auto zeroing (AZ), correlate double sampling technique (CDS) and chopper stabilization (CHS) [2]. AZ is a technology that offsets the offset voltage drift dynamically by sampling and holding the offset voltage, and then removing it from the signal. CDS technique is a special case of AZ, which can reduce the low frequency 1/f noise substantively. However, it will increase the thermal noise of the amplifier, and improve the offset voltage because of the clock feed-through effect of switch tubes. Compared with the previous two technologies, chopping technique is a modulation and demodulation method that can be employed to reduce the effect of opamp imperfections including noise and input referred offset voltage.

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A chopper amplifier without low-pass filter is proposed in [3]. It applied double-ended input and single-ended output structure. So its power consumption and the equivalent input noise were relatively large. [4] put forward a two stage low noise chopper amplifier which consisted of amplifiers, phase-locked loop and automatic gain control. Its noise characteristic was good, but it consumed a very large current. In this paper, the chopper amplifier can decrease the input noise and drop power consumption to an ultra-low level. At the same time, its total harmonic distortion (THD) is also small.

## 2 The analysis and design of chopper

### 2.1 The principle of the chopper

Chopping technique is a continuous-time method which modulates the low frequency noise and offset voltage to high frequency band with an AC modulation signal, and then filters them out to eliminate their effect. The theory block diagram [5-6] of the chopper opamp is shown in figure1.

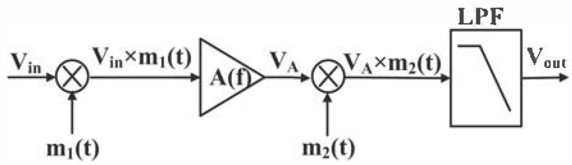



**Figure 1** The theory block diagram of the chopper opamp

$V_{in}$ means the input signal voltage and $V_{out}$ stands for the output voltage; A(f) is the linear amplifier gain; $m_1(t)$ and $m_2(t)$ are square-wave signals of modulation and demodulation respectively; the period is $T=1/f_{chop}$, where $f_{chop}$ is the frequency of the chopping signal. In order to ensure the useful signal demodulate back to baseband without aliasing, the chopper frequency must satisfy the relationship of the formula (1) [7]

$$f_{chop} \geq k \times BW_{signal} + f_{corner}, \quad (1)$$

$f_{chop}$ represents the chopping frequency; the value of k is larger than two; $BW_{signal}$ means the signal bandwidth; $f_{corner}$ stands for the noise corner frequency.

The basic process of chopper stabilization technique is demonstrated as followings. The sinusoidal input signal $V_{in}$ multiplied by $m_1(t)$ is modulated signal. Then the modulated signal is amplified by the operational amplifier. The amplified signal multiplied by $m_2(t)$ is the demodulated signal. Finally the demodulated signal passes a low pass filter to filter out the noise and voltage offset signal. The bandwidth of the low pass filter is little larger than the cutoff frequency of the input signal.

In the frequency domain analysis, the Fourier transform expression of square wave signal whose duty cycle is 50% is the formula (2).

$$M(t)=\sum_{k=1}^{\infty} C_k \cos(2\pi f_{chop} kt+\Phi_k) \quad , \qquad (2)$$

$$C_k=\begin{cases} \frac{4}{k\pi} & ; \text{k is an odd} \\ 0 & ; \text{k is an even} \end{cases} \quad ; \quad \phi_k=\begin{cases} -\frac{2}{\pi} & ; \text{k is an odd} \\ 0 & ; \text{k is an even} \end{cases}$$

The modulated signal $V_{in}\times m_1(t)$ is modulated to the odd harmonic frequencies of chopping signal, and then amplified. After demodulated by $m_2$ (t), $M_1(t)$ is shown in the formula (3)

$$M_1(t)=A(f)\times V_{in}\times\sum_{k=1}^{\infty} C_k \cos(2\pi f_{chop} kt+\phi_k) \quad , \qquad (3)$$

The coefficients $C_k$ and $\phi_k$ in formula (3) are the same as in formula (2).

Because the low-frequency noise and offset voltage are modulated only once, they are moved to high frequency band and only carried odd harmonics of chopping frequency. Therefore, the demodulated signal should go through a low-pass filter for obtaining the initial signal.

## 2.2 The chopper with inverter

Figure 2 manifests the chopper with inverter. This structure is to achieve the modulation and demodulation of the input signal with the pulse signal. The chopper is a switch circuit which consists of four switches. They are controlled by the clock signals whose phases are complementary. This circuit is simple and easy to control, but it can introduce the additional residual voltage offset due to the clock feed-through effect of the MOS switch. However, most energy of the spikes signal caused by clock feed-through is concentrated on higher frequency rather than the chopping frequency, so most residual voltage offset can be eliminated after passing the low-pass filter. Therefore, the use of CMOS switch circuit shown in figure 2 can realize the chopping function effectively.

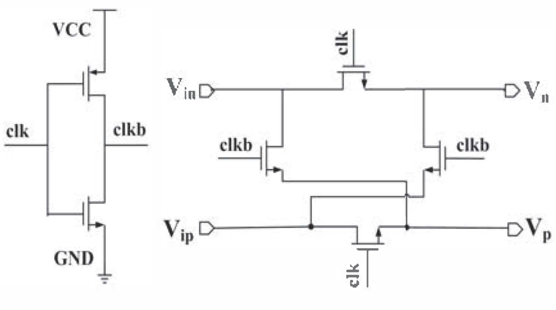



**Figure 2** The chopper with inverter

# 3 Proposed chopper amplifier

## 3.1 The folded cascode chopper operational amplifier

Analysis above shows that the offset voltage and the noise can be reduced by the selection of circuit structures. The disadvantage of the simple two-stage opamp configuration is that the frequency characteristic, the power supply rejection ratio and the common mode rejection ratio are poor. What's worse, its power consumption is large. The telescopic cascode structure has a good frequency characteristic, but it is not suitable for low-voltage operation for its common-mode input range and output swing are too small. Folded cascode opamp also has a good frequency characteristic and its non-dominant pole lies in the drain end of the input tube. Besides, the parasitic capacitance with PMOS input is smaller than that with NMOS input. What's more, the noise generated by PMOS transistor is less than that by NMOS transistor. Therefore, the paper uses folded cascode operational amplifier with PMOS transistor input which is shown in figure 3. Its bias circuit is demonstrated in figure 4.

In this configuration, two chopper modules are used to achieve the function of modulation and demodulation. The module at the input of the opamp implements the modulation functionality. The module at the output terminal gets the demodulation functionality. The offset caused by the noise and mismatch of the current source and differential input transistors has a great impact on the overall circuit. Therefore, the chopper modules are distributed at the input and output of operational amplifier.

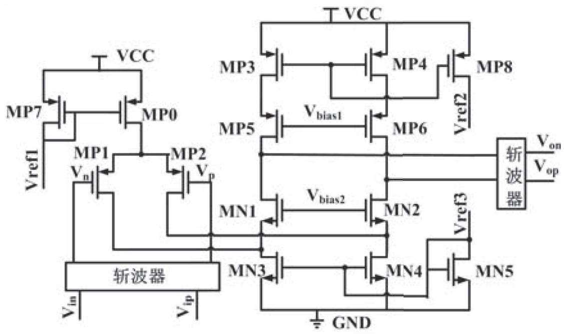



**Figure 3** The folded cascode chopper operational amplifier

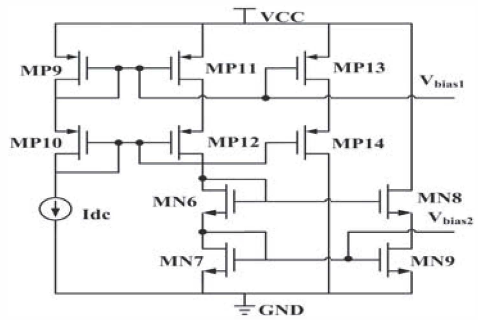



**Figure 4** The bias circuit of folded cascode chopper operational amplifier

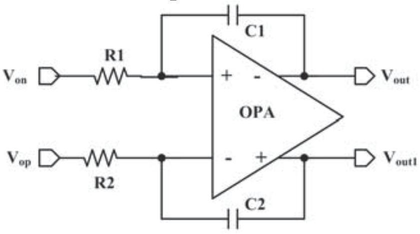
### 3.2 RC Low-pass filter

RC filter is very common in test system because the RC filter circuits have strong anti-interference and good low-frequency characteristic with simple structures. So they are adopted in this paper, and its block diagram is shown in figure 5(a). By analyzing the RC low-pass filter, the transmission function is shown in formula (4). In formula (5), bandwidth is determined by the resistance and capacitance.

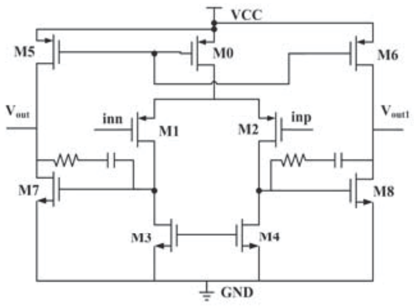
$$V_{out} = -V_{on}\frac{1}{sR_1C_1} \tag{4}$$

$$BW_{dB} = \frac{1}{R_1C_1} \tag{5}$$

The operational amplifier of RC low-pass filter is shown in figure 5(b). Miller compensation structure is adopted in the two-stage amplifier. The advantages of this construction are readily apparent. On one hand, it can use the second stage as a buffer stage to enhance the load capacity of the operational amplifier; on the other hand, its unity gain bandwidth and phase margin are basically determined by the two-stage circuits respectively, which can reduce the effect caused by the indicators mutual compromise.




**(a)**




**(b)**

**Figure 5 (a)** The RC low-pass filter block diagram
**(b)** The operational amplifier of RC filter

## 4 Simulated results

The circuit of the proposed chopper amplifier is designed and simulated with 45nm CMOS technology. The supply voltage is 1V and chopping frequency is 10 kHz. As seen from the figure 6, chopper opamp AC gain is 53dB and 3dB bandwidth is 26 kHz. Figure 7 illustrates the chopper opamp's noise waveform that the input referred noise of the chopper opamp is 2.54 $nV/\sqrt{Hz}$ @1kHz within the bandwidth. It shows that the input referred noise is very small and can realize the low noise function. Figure 8 states the total harmonic distortion (THD) of the output signal. As it can be seen, 54.15dB of THD is demonstrated.

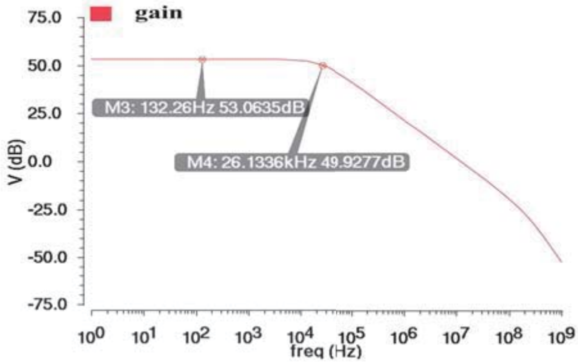



**Figure 6** AC gain Simulation

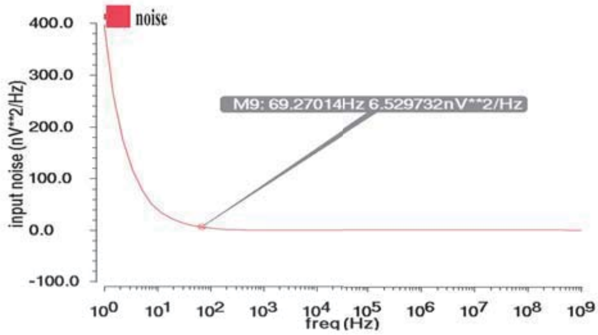



**Figure 7** The input referred noise of chopper amplifier

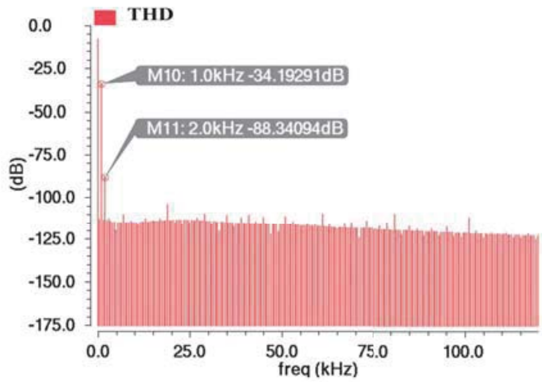



**Figure 8** The THD of chopper amplifier

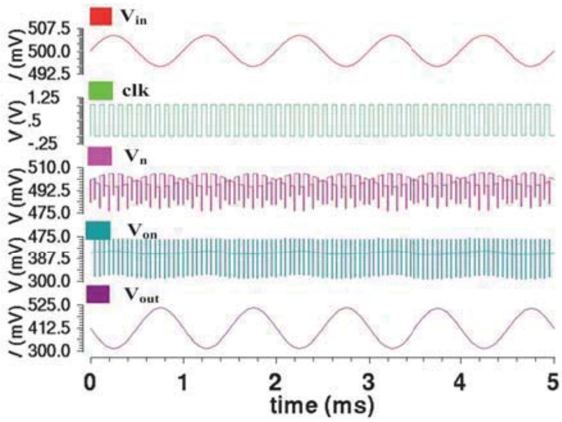



**Figure 9** The transient simulation result of the chopper amplifier.

Figure 9 shows the transient simulated results of the chopper amplifier, $V_{in}$ is a sinusoidal signal whose AC amplitude is 5mV, and frequency is 1 kHz. Clock signal is a square wave signal whose frequency is 10 kHz. That is to say, the chopper frequency is 10 kHz, meeting the requirement that the chopper frequency is lower than 1/2 of the bandwidth of the input signal. $V_n$ displays the result of the input signal multiplied by the clock signal. $V_{on}$ is the signal after demodulation. By the results of the demodulated waveform, it can be known that there is still voltage offset and low frequency noise. $V_{out}$ is the output signal after passing the low-pass filter. Table 1 gives the circuit performance comparison of this circuit with other chopper opamps.

**Table 1** Comparison of circuit performance

| literature | [8] | [3] | [4] | This paper |
|---|---|---|---|---|
| Technology | 0.5μm | 0.18μm | 0.18μm | 0.45nm |
| supply voltage (V) | 5 | 1.8 | 1.8 | 1 |
| Chopper frequency (kHz) | 5 | 15 | 10 | 10 |
| The input referred noise (nV/$\sqrt{Hz}$) | 15 | 8.2 | 39 | 2.54 |
| Power consumption (μW) | -- | 3150 | 117 | 65.5 |

## 5 Conclusions

This design of the chopper operational amplifier uses the chopper with inverter and RC low-pass filter to improve the performance of the operational amplifier while reducing the input offset and noise of the chopper opamp. Because of the large impact of the opamp's voltage offset and noise on the circuit, it has to choose the appropriate circuit structure. The chopper opamp power supply voltage is 1V, AC gain is 53dB. The circuit has a low noise and low offset features that are suitable for sensor circuits. These structures are mainly used in the continuous-time detection circuits of sensors such as the current accelerometers, the anemometers and other sensor circuits.

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