A high-performance operational amplifier for infrared readout circuit application

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Abstract. The infrared readout circuit is a highly integrated circuit that integrates various functions into a single semiconductor chip. As the important part of readout circuit, the operational amplifier (OPA) decides the performance of the readout circuit. This paper describes a kind of OPA, which is used in infrared focal plane array (IRFPA) readout circuit structure based on the capacitive trans-impedance amplifier (CTIA) including the analysis and design of the OPA. Spectra is employed to simulate the circuit and obtain the results which is according with the designed objectives. The open-loop gain reaches 101 dB and the phase margin is 87° with the ICMR (input common-mode range) ranging from 201.6 mV to 4.01 V.

1. Introduction

The basic function of readout circuit is to convert and amplify the signal of the infrared detector and transmit the output signal to the focal plane imaging circuit [1, 2]. The study on readout circuits is closely related to the development of focal plane arrays. Since the emerging of infrared focal plane arrays, some readout circuit technologies for CCD imaging have begun to be used in infrared focal plane arrays gradually [3, 4]. At present, the application of mature readout circuit structures, including source follower structure, direct injection structure, gate modulation input type, buffer injection type and capacitive feedback trans conductance, can be used for different infrared focal plane arrays. Different readout circuit configurations should be chosen for different detectors, different application constraints and different application requirements.

CTIA is one of the most widely used readout circuits at present [5, 6]. It is a reset integrator consisting of an op amp and a feedback integral capacitor [7, 8]. Detector current is integrated over the feedback capacitor. A reset switch is used to discharge the integral capacitor and reset its output to the input reference voltage. The bias of the detector can be well controlled due to the virtual ground characteristics of the negative input of a negative feedback op amp. This structure has a high dynamic output voltage range and injection efficiency. This paper proposed a high-performance operational amplifier which is used for infrared readout circuit. The open-loop gain reaches 101 dB and the phase margin is 87° with the ICMR (input common-mode range) ranging from 201.6 mV to 4.01 V.
2. Circuit Description
The designed readout circuit is shown in Fig. 1 [1], which makes the improvement based on the traditional CTIA structure. A high swing cascode current mirror is introduced at the input of the integration circuit to suppress the background current. Moreover, the high swing cascode current mirror also reduces the integration error due to the voltage instability of the front-end circuit. Due to the influence of Miller effect, the integral capacitor can be very small to achieve low noise and high sensitivity performance.

The performance of the operational amplifier determines the performance of the integration unit, so it is very important to design a high-performance operational amplifier. Since the output node of the folded cascode operational amplifier is a high impedance point, the integrated capacitor (Fig. 2) is connected with the output node to compensate effectively for this structure; The folded cascode operational amplifier also satisfies the characteristics of low noise, high gain and low offset. Therefore, the folded cascode operational amplifier is chosen as the integrated operational amplifier.

![Image](image1.png)

**Figure 1.** The structure of designed readout circuit

![Image](image2.png)

**Figure 2.** Schematic diagram of integral circuit operational amplifier

The designed operational amplifier in this paper can be divided into four parts: differential input unit, high output impedance unit, Miller compensation unit and current source load output unit. The differential input unit can suppress the influence of common-mode noise and increase the voltage swing; the high output impedance is composed of a Wilson current mirror and a folded cascode operational amplifier, which ensures the input common-mode range while increasing the circuit gain; Miller compensation capacitor adjusts the zero and pole of the circuit to make it possible...
to achieve high output impedance, which will lead to the stabilization of the circuit. The current source load output unit enlarges the output range of the circuit while increasing the gain.

The conversion rate $SR = V_{dsat} \times \omega_u$ ($V_{dsat}$ is overdrive voltage, $\omega_u$ is unity-gain frequency). When the aspect ratio is consistent, $V_{dsat}$ of PMOS transistor is larger than that of NMOS transistor, so PMOS transistor can effectively improve the conversion rate of the circuit, and PMOS transistor has less l/f noise than NMOS transistor. Therefore, PMOS transistor is chosen as the differential input pair of the differential input unit.

The schematic design of the bias circuit for operational amplifier is shown in Figure 3. It is divided into four parts: reference current generation circuit, startup circuit, NMOS bias circuit and PMOS bias circuit. The reference current generating circuit generates a reference current which is independent of the power supply, the startup circuit is to enable the bias circuit to power up and start working, the NMOS bias circuit generates the bias voltage for the NMOS, and the PMOS bias circuit generates the bias voltage for the PMOS in the operational amplifier.

![Figure 3. Schematic diagram of the bias circuit for integral circuit operational amplifier](image)

### 3. Simulation experiment and analysis

The bias circuit shown in Figure 3 provides four bias voltages for the integrated op amp, NBIAS, NCAS, PBIAS and PCAS. Figure 4 is the DC simulation curve of the bias circuit. As seen from Figure 4, $I_{OUT} = I_{REF}$, $I_D1 = I_D2$ is validity when the power supply voltage is in the range of 3V~5V, and the reference branch current has good local stability. Therefore, the supply voltage range is 3V~5V. When the supply voltage is 5V, the four bias voltages are 0.649V (NBIAS), 0.851V (NCAS), 3.753V (PCAS), 3.965V (PBIAS), and the overdrive voltage is approximately 80mV. Figure 5 is the AC simulation curve of the integrated operational amplifier. It can be seen from the curve that the integrated operational amplifier has a high open-loop gain of 101 dB. The frequency compensation is carried out by Miller capacitor, which makes the operational amplifier also have a good frequency effect. The unit gain bandwidth is 51.53 MHz, and the phase margin is 87 degrees, which will ensure the stability when applied. The power consumption and output swing of the amplifier are also important factors in the design. Combining with the consideration of the overall power consumption of the chip and the trade-off of other operational parameters, the power consumption of the amplifier is 18.6μA. The input common-mode range of the amplifier is 3.8 V and the output swing is 4.68 V at 5V supply voltage. Other parameters of the amplifier are shown in Table 1.
Figure 4. DC simulation curve of the bias circuit

Figure 5. AC simulation curve of the integrated operational amplifier

Table 1. The simulated parameters of the amplifier

| Spec.                              | Simulation results              |
|------------------------------------|--------------------------------|
| Open-loop gain                     | 101dB                          |
| Phase margin                       | 87°                            |
| Unity gain bandwidth               | 51.53M                         |
| Output swing                       | 160.31mV ~ 4.842V@5V VCC       |
| ICMR                               | 201.6mV ~ 4.01V @5V VCC        |
| CMRR                               | 53dB                           |
| Power supply rejection ratio       | 87 dB                          |
| Slew rate                          | 52V/μs                         |
| Power supply range                 | 3V~5V                          |
| Quiescent current                  | 18.6μA                         |
When the detectors receive infrared radiation, the resistance will change, resulting in different detection current. Figure 6 is the output simulation waveform under the condition of different detector resistance. To verify the linearity and output swing of the circuit, the detector resistance RD is set to 50.25K, 50.51K, 51.02K, 52.08K, 54.35K, 49.75K, 49.02K, 48.08K and 46.30K at 0.1V bias voltage (VB = 2.6V, VR = 2.5V), and the corresponding signal currents are 1.99 μA, 1.98 μA, 1.96 μA, 1.92 μA, 1.84 μA, 2.01 μA, 2.02 μA, 2.04 μA, 2.08 μA and 2.16 μA respectively. Noise-free constant current source is employed to replace the background current compensation circuit, the constant current source is set to 2 μA, the integrator reset time is 2 μs and the integration time is 30 μs. The simulation results show that the integrator output can achieve a small integration error (<0.1%) and good linearity (>99%). The output swing of the integrator is more than 4.65V at 5V supply voltage.

![Figure 6. Simulation of output swing and linearity of integration](image)

**4. Conclusion**
A high-performance operational amplifier for infrared readout circuit application is proposed in the paper, which can be divided into four parts: differential input unit, high output impedance unit, Miller compensation unit and current source load output unit. The simulation results show that the proposed operational amplifier enjoys features of high open-loop gain, large output voltage swing and low noise, which is suitable for high performance infrared focal plane arrays.

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