Design and Simulation of Low Noise CMOS Operational Amplifier for Radiation Measurement

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1. Introduction

Charge-sensitive amplifiers (CSAs) are essential analog front-end circuits in radiation detection systems, where small charge signals generated by detectors must be converted into stable voltage outputs. For spectroscopy-oriented applications, high open-loop gain, sufficient phase margin, and low input-referred noise are critical design requirements.

This work presents the design and simulation of a CMOS operational amplifier intended as the core amplification stage for CSA-based radiation measurement systems. The circuit is optimized for stable closed-loop operation, adequate bandwidth, and minimized noise performance suitable for detector signal readout.

2. Circuit Design and Performance Evaluation

2.1 Amplifier Architecture

The proposed amplifier adopts a differential-input, single-ended-output topology implemented in 180 nm CMOS technology. A PMOS differential input pair is used to reduce flicker noise, while folded current mirror structures enhance voltage gain and output resistance.

To secure stability under closed-loop operation, a 500 fF Miller compensation capacitor is introduced, establishing dominant-pole behavior. Device dimensions and bias currents are optimized to achieve a balanced trade-off among gain, bandwidth, and noise performance.

Figure 1 shows the schematic of the proposed CMOS operational amplifier.

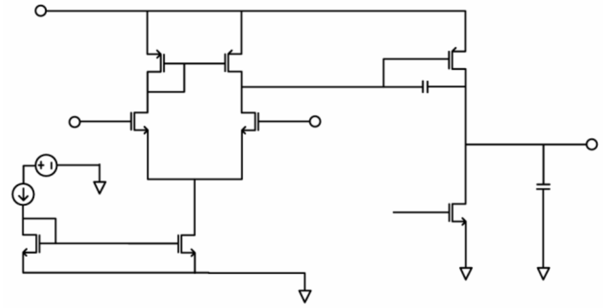

Figure 1. Proposed CMOS operational amplifier schematic for CSA implementation.

2.2 Frequency Response and Stability

AC simulations were conducted to evaluate the openloop characteristics of the amplifier. The results show a DC gain of approximately 65 dB and a unity-gain bandwidth near 10 MHz.

The phase margin is approximately 60°, indicating stable closed-loop operation. The gain response exhibits a controlled roll-off characteristic without excessive peaking near the unity-gain frequency, confirming proper compensation design.

Figure 2 presents the simulated open-loop gain and phase response.

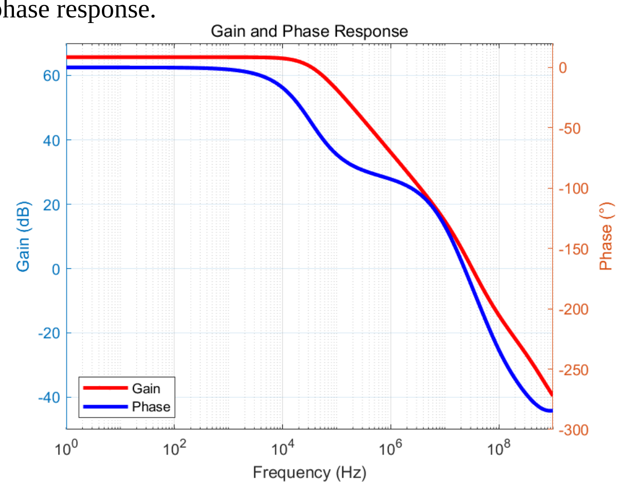

Figure 2. Simulated open-loop gain and phase response.

2.3 Dynamic and Noise Characteristics

Transient simulations were performed to verify dynamic response under small-signal excitation. The output waveform accurately follows the input sinusoidal signal without distortion in the linear operating region, confirming stable time-domain behavior.

Figure 3 illustrates the transient response of the amplifier.

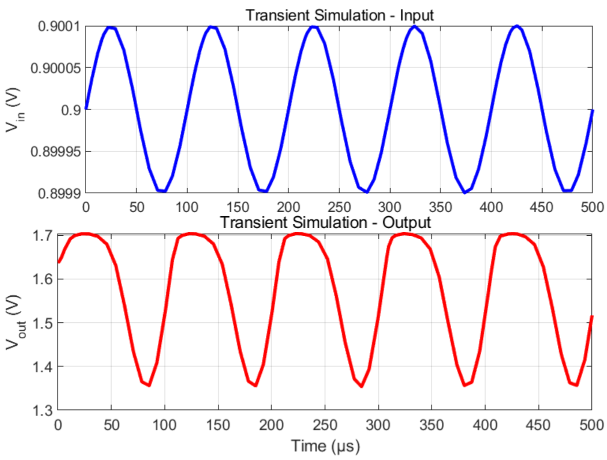

Figure 3. Small-signal transient response

Noise analysis was carried out to evaluate input-referred noise performance. The input-referred noise density floor is approximately 200 nV/√Hz. When integrated over a multi-megahertz bandwidth, the RMS noise remains within acceptable limits for radiation detector front-end systems.

Figure 4 shows the simulated input-referred noise spectrum.

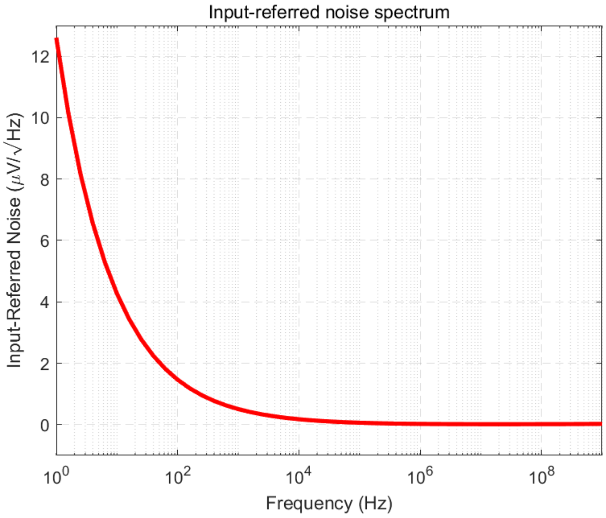

Figure 4. Input-referred noise spectrum.

The simulation results demonstrate that the proposed amplifier satisfies gain, stability, and low-noise requirements for CSA-based radiation measurement applications.

3. Conclusions

A CMOS operational amplifier suitable for low-noise radiation measurement systems has been designed and validated through circuit simulations.

The amplifier achieves approximately 65 dB open-loop gain, 10 MHz unity-gain bandwidth, and 60° phase margin with 500 fF Miller compensation. The input-referred noise floor is approximately 200 nV/√Hz.

The proposed design provides a stable and low-noise amplification stage applicable to CSA-based radiation detector front-end systems.

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