Design and Simulation of Low-Noise Opamp

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***Abstract*—We have designed a low noise chopper stabilized operational amplifier in Cadence Virtuoso using TSM28nm technology. The topology used to design the operational amplifier is a two stage cascade of differential amplifier and common source amplifier stages. Using this topology, we have achieved a gain of $42dB$ with a bandwidth of $56MHz$ and phase margin of $30°$. Using chopper modulator and demodulator circuits, we have reduced input referred noise from $20\mu V/\sqrt{Hz}$ to $2\mu V/\sqrt{Hz}$ for a 1kHz frequency signal.**

I. INTRODUCTION

A. 2-Stage Opamp

A 2-stage operational amplifier (op-amp) is a type of op-amp that uses two separate gain stages to achieve its desired characteristics. This is in contrast to a single-stage op-amp, which only uses one gain stage.

Benefits of using multiple stages in Op-amp:

- Higher gain: By cascading two gain stages, the overall gain of the op-amp is significantly increased compared to a single stage. This is crucial for applications requiring high signal amplification.
- Larger output swing: A single-stage op-amp's output swing can be limited by its power supply voltage. Two-stage designs can overcome this limitation by allowing each stage to swing a smaller portion of the total voltage, resulting in a larger overall swing.
- Improved stability: While adding stages can introduce complexity, careful design and compensation techniques can improve the op-amp's stability and frequency response.

Drawbacks of using multiple stages in Op-amp:

Typical stages in a 2-stage Op-amp:

- Increased complexity: Adding an extra stage naturally increases circuit complexity, making design, fabrication, and troubleshooting more challenging compared to simpler single-stage designs.
- Higher power consumption: Each stage consumes power, leading to overall higher power consumption compared to single-stage designs. This can be a critical factor in battery-powered applications.
- Reduced bandwidth: Cascading stages can introduce additional poles and zeros, potentially impacting the op-amp's frequency response and reducing its bandwidth compared to a single stage.

Additional features of 2-stage Op-amp:

- Output buffer stage: Some 2-stage op-amps include a third stage called the output buffer. This stage provides a low output impedance, driving higher capacitive loads without significant distortion.
- Frequency compensation: Uncompensated 2-stage op-amps can have undesirable frequency response, leading to instability. Compensation techniques like Miller feedback or pole-splitting capacitors are used to stabilize the op-amp and ensure predictable performance.

Overall, 2-stage op-amps offer a balance between high gain, large output swing, and improved stability compared to single-stage designs. They are widely used in various applications where precise amplification and signal manipulation are required.

B. Chopper Stabilization

Modulation and demodulation process is alternation of a signal to a higher frequency and back to the original signal band using sets of switches controlled by two clocks and its inverse. Four identical switches are required for modulation and demodulation circuits each. It forms the fundamental of the chopper stabilization technique.

Chopper stabilization is a technique used in operational amplifiers (op-amps) to dramatically reduce low-frequency errors, particularly input offset voltage and 1/f noise. These errors can significantly impact the precision and accuracy of analog circuits, especially in applications like instrumentation amplifiers, sensor interfaces, and high-resolution data acquisition systems.

II. WORKING PRINCIPLE

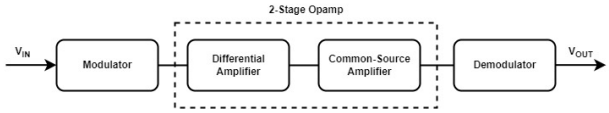

Fig. 1: Architecture for Low-Noise Opamp Design

Flicker noise, also known as 1/f noise or excess noise, is a fundamental limitation in operational amplifiers (op-amps) that plagues their low-frequency performance. It manifests as random fluctuations in the output voltage that increase inversely with frequency.

Unlike thermal noise, which is flat across the frequency spectrum, flicker noise becomes dominant at low frequencies,

significantly impacting applications taht require low noise at low frequencies.

While eliminating flicker noise entirely is impossible, several techniques can mitigate its impact:

- Choosing low-noise op-amps: Op-amps specifically designed with low-noise transistors and optimized internal layout can exhibit significantly lower flicker noise.
- Chopper stabilization: This technique modulates the input signal to high frequencies, where flicker noise is less prominent, and then demodulates it back to the original frequency band. This effectively reduces the low-frequency noise without affecting the desired signal.

In our design, we have focused solely on chopper stabilization to reduce flicker noise.

III. Results and Discussion

Fig. 2 shows the modulator circuit schematic being used in our design. It is also known as Differential nmos chopper circuit. A differential NMOS chopper circuit is a powerful tool to reduce the low-frequency noise, particularly flicker noise. The circuit operates by chopping the input signal, meaning it modulates it with a high-frequency square wave. This effectively converts the low-frequency noise into high-frequency components. These high-frequency components are then much easier to filter out using a simple demodulator, leaving behind a clean, low-noise signal.

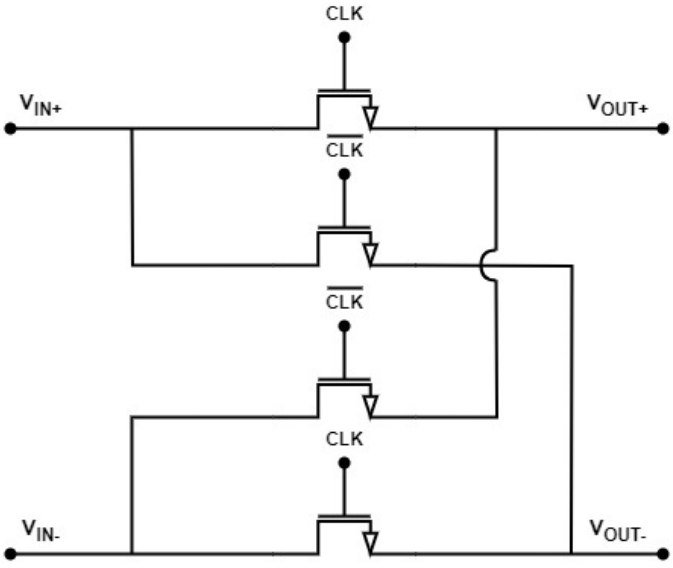

Fig. 2: Modulator Circuit Schematic

In this circuit, the clock frequency is 100kHz, which is the modulated frequency of the output. the input signal frequency is 1kHz. Fig. 3 shows the output signal from the modulator, which is a high frequency signal.

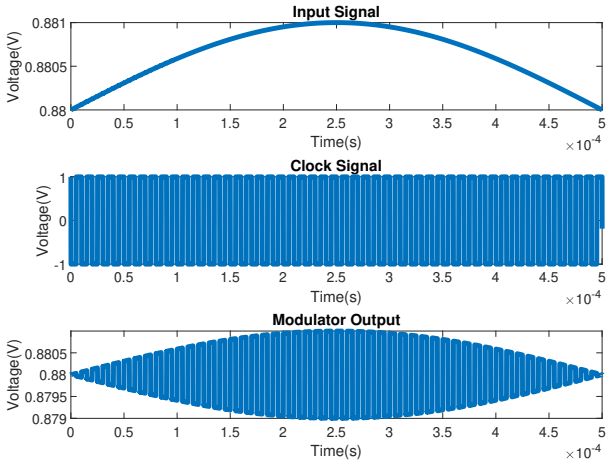

Fig. 3: Modulator Response

Fig. 4 shows the opamp circuit schematic being used to amplify the modulated circuit. Another modulator at its output converts the high frequency signal back to its original frequency.

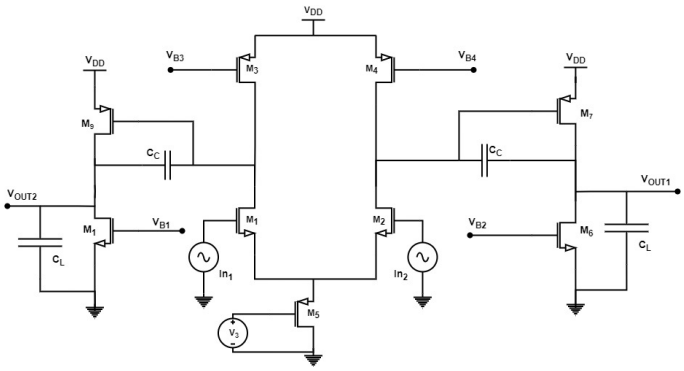

Fig. 4: 2-stage Opamp Circuit Schematic

The input signal has a DC offset of 880mV to drive M1 and M2 to saturation. Similarly, 600mV bias voltage is required for M5, M6 and M8. M3 and M4 transistors require a bias voltage of 336mV.

The gain obtained for this 2-stage opamp is 42dB. Its UGBW is 56MHz and the phase margin we obtained is 30°. For a 100kHz modulated signal, the gain obtained is 40dB. Fig. 5 gives the gain plot of the opamp circuit.

The below table gives the aspect ratio of the transistors used. The sizes are chosen such that all transistors are in saturation region.

TABLE I: Transistor sizes

SNo.	Transistor	W/L (*nm* / *nm*)
1	M_1	210 / 30
2	M_2	210 / 30
3	M_3	775 / 250
4	M_4	775 / 250
5	M_5	310 / 30
6	M_6	330 / 30
7	M_7	1490 / 250
8	M_8	330 / 250
9	M_9	1490 / 250

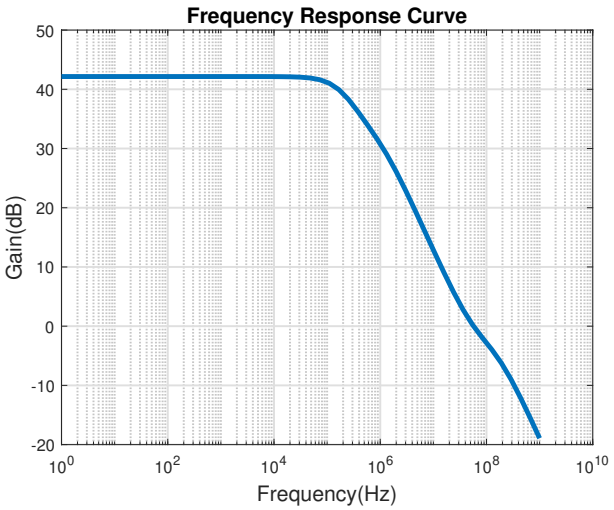

Fig. 5: Gain Plot

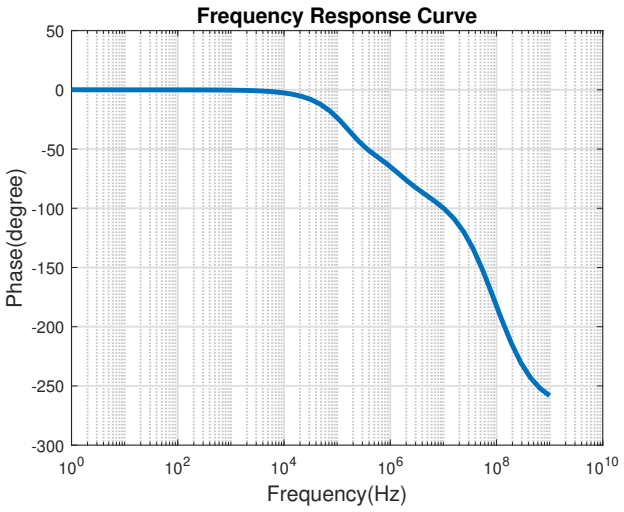

Fig. 6: Phase Plot

Fig. 6 gives the phase plot of the opamp circuit, which is used to find the phase margin. In order to get a good phase margin, we have added a Miller capacitance of 0.9pF. The load capacitance is taken as 1pF.

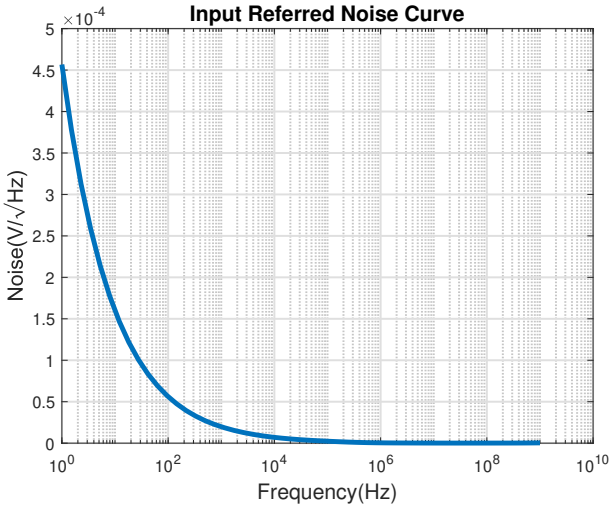

Fig. 7: Input referred noise before chopper stabilization

Fig. 7 and Fig.8 give the noise plots of the complete circuit. Without the frequency modulation, observed noise at 1kHz frequency is $20\mu V/\sqrt{Hz}$. However, withe the chopper stabilization technique applied, the noise level gets reduced to$2\mu V/\sqrt{Hz}$.

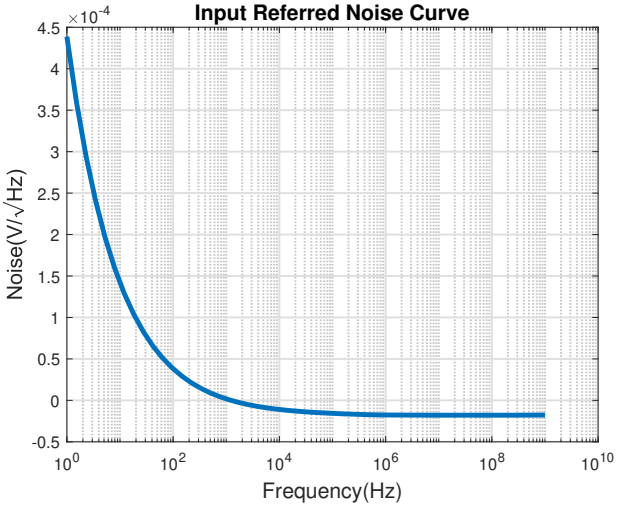

Fig. 8: Input referred noise after chopper stabilization

IV. CONCLUSION

The design of a low noise chopper stabilized operational amplifier in Cadence Virtuoso using TSM28nm technology has been successfully achieved.The input referred noise was reduced from $20\mu V/\sqrt{Hz}$ to $2\mu V/\sqrt{Hz}$ for a 1Khz frequency signal and the two stage opamp resulted in a gain of $40dB$, a bandwidth of 56MHz, and a phase margin of 30° after the implementation of chopper modulator and demodulator circuit. These findings demonstrate the effectiveness of the proposed design in achieving low noise performance for operational amplifier applications.

V. REFERENCES

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