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Design and Analysis of Folded Cascode Operational Amplifier using 0.13 µm CMOS Technology

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Abstract. In this paper, a folded cascode operational amplifier is designed and analysed by using 0.13 µm CMOS technology. Several analyses such as DC analysis and AC analysis are carried out to analyse the performances of the proposed folded cascode op-amp. Through the simulation of Mentor Graphics, under 3.3 V power supply, the circuit' s DC gain is 32.3590 dB, the phase margin is 83.754 degree with high stability, the bandwidth is larger than 10 MHz, the unity gain bandwidth is as high as 906.8953 MHz and the power dissipation is 86.9774 mW.

INTRODUCTION

The design of high performance operational amplifier is essential in designing analog integrated circuit due to its performance which will directly affect the overall performance of circuits and system. In order to obtain high gain and better performance op-amp, various op-amp topologies have been designed using past CMOS technology with the downsizing of transistor length of CMOS over year. However, many studies on past technologies have found out that the performance parameters are still not sufficient enough in order to meet the performance goal. Besides that, it is also unclear on which circuit topologies could give the maximum performance when using CMOS 0.13µm technology. Folded cascode is one of the efforts in the field of enhancing the performance of practical op-amp in order to achieve the characteristics of an ideal op-amp.

The demand for amplifiers with high DC gain and bandwidth is increasing. In a high speed and high-resolution ADC, operational amplifiers are expected to have both high DC gain and high unity-gain frequency in order to satisfy the accuracy and fast setting requirements of the system (B. Li, "A High DC Gain Op-Amp for Sample and Hold Circuits," *Proc. 2nd Int. Conf. Comput. Sci. Electron. Eng. (ICCSEE 2013)*, vol. 9, no. Iccsee, pp. 1781–1784, 2013). For high-performance systems, high gain and high unity gain frequency amplifiers are needed to meet the requirements. It is difficult to satisfy both of these requirements, since high unity gain frequency calls for short channel devices which lead to a low intrinsic gain while high dc gain is achieved using long-channel devices and multistage design (L. Ping, "A Fully Differential CMOS Operational Amplifier Implemented with Mos Gain Boosting Technique," p. 84, 1996). It is important to ensure that the system can reach high open loop gain and wide unity-gain bandwidth with low supply voltage in designing analog circuits. In order to implement the negative feedback concept, the primary requirement is to have a sufficiently large open-loop gain (E. Rajni, "Design of High Gain Folded-Cascode Operational Amplifier Using 1.25 um CMOS Technology," *Int. J. Sci. Eng. Res.*, vol. 2, no. 11, pp. 1–9, 2011).

This paper presents the design of a folded cascode op-amp by using 0.13 µm CMOS technology with the Mentor Graphics pyxis software. This paper is presented as follows: In Folded Cascode Operational Amplifier, the concept of this topology will be discussed and the circuit design for this work will be presented in Proposed Circuit Design. Meanwhile, Results and Discussions will be analyzed from the simulated results obtained. Lastly, the conclusion will deduce the findings of this work.

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FOLDED CASCODE OPERATIONAL AMPLIFIER

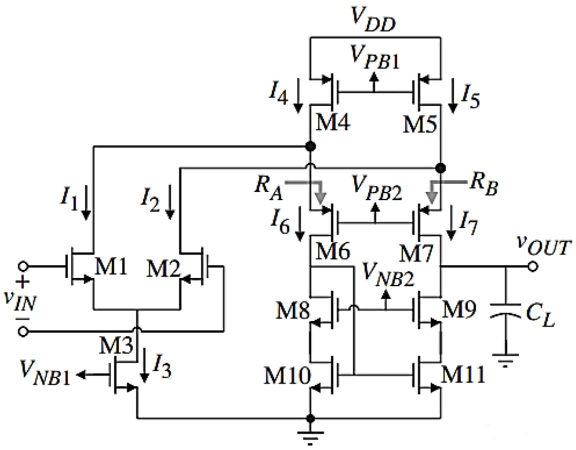

FIGURE 1. Basic folded cascode operational amplifier

Figure 1 shows typical structure of a folded cascode op-amp Folded cascade topology is called as 'folded cascode' because it comes from a folding down n-channel cascode active loads of a different-pair and changing the MOSFET to the p-channel. These topologies allow the input common-mode level of being close to the power supply voltage as well as providing a high output swing, wide input common-mode range and preferably steering in low voltage supply circuits. However, this topology has higher noise compare to the telescopic op-amp (C. Paper, I. S. Ishak, S. Anuar, Z. Murad, A. Universiti, S. Chin, and N. Universiti, "Design of Folded Cascode Operational Amplifier (Op-Amp) with Common-Mode Feedback (CMFB) for Pipeline ADC Design of Folded Cascode Operational Amplifier (Op-Amp) with," no. November 2015, pp. 1–7, 2013).

Folded cascode amplifier is a single-pole operational amplifier with large output swing and has higher gain compared to the ordinary op-amp. It is very suitable for deep negative feedback because of its small signal gain that can be very large. Comparing to the ordinary telescopic amplifiers, folded cascode operational amplifiers have a larger output swing (E. Rajni, "Design of High Gain Folded-Cascode Operational Amplifier Using 1.25 um CMOS Technology," *Int. J. Sci. Eng. Res.*, vol. 2, no. 11, pp. 1–9, 2011). Input and output can be short circuited to make it easier for the selection of input common-mode level due to its relatively large output swing. The input common-mode level can be close to the power supply voltage by using folded cascode op-amp. By using NMOS input, the common-mode level of the gate pole can reach V_{DD}. While PMOS input can lower the input common-mode level to 0V.

PROPOSED CIRCUIT DESIGN

Figure 2 illustrates the schematic design of the proposed folded cascode op-amp. The circuit design of the proposed folded cascode op-amp is represented with the different colour box to focus on the basic topologies of each block.

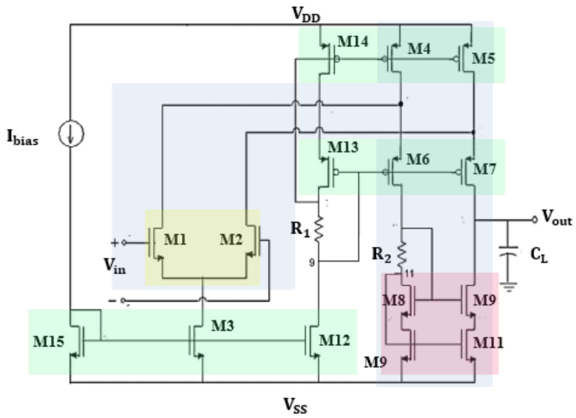

FIGURE 2. The proposed folded cascode op-amp.

The pink colour block represents the cascade current mirror. M8 and M9 pair, M10 and M11 pair are both basic current mirror. A cascode current source is used to suppress the effect of channel-length modulation. M8 is diode-connected to make sure that M9 and M10 always remain in saturation mode. The composition of this cascode current mirror transforms the double-ended output into single-ended output without the present of other extra components. In this circuit, the output voltage or current is taken from the drains of M7 and M9. While the green colour block represents the multiple current mirrors. Since the transistors are not identical pair, their currents are not identical.

The yellow colour block represents the differential input pair. M1 and M2 are NMOS differential pair with identical transistors. Thus, $I_1 = I_2$ since they are identical pair. NMOS differential pair is chosen instead of PMOS due to its high electron mobility. The input stage provides the gain for the operational amplifier. PMOS input differential pair has smaller transconductance, gm than a NMOS pair. Therefore, the NMOS differential pair has been chosen to ensure a larger gain. Besides that, NMOS has a higher transition frequency, f_T than PMOS, which able to maintain high bandwidth.

The blue colour block represents the basic folded cascode topology. It is a high gain, a single-pole operational amplifier with large output swing if compared to a two-stage or multi-stage amplifier. The advantage of a single-pole amplifier is that the phase margin is very high and stable. It has higher gain compared to the ordinary operational amplifier. The drawback to folded cascade op-amp is it consumes high power. The power dissipation is doubled for a given settling requirement since it has two extra current legs.

RESULTS AND DISCUSSIONS

The proposed folded cascode op-amp has been simulated using Mentor Graphic pyxis. The performances of the op-amp are verified based on the DC and AC analysis. The relationship of transfer characteristic of V_{in} and V_{out} is shown in this DC analysis while the performance of the gain, unity gain bandwidth (UGB), phase margin (PM) and cut-off frequency (f_c) are obtained by using AC analysis.

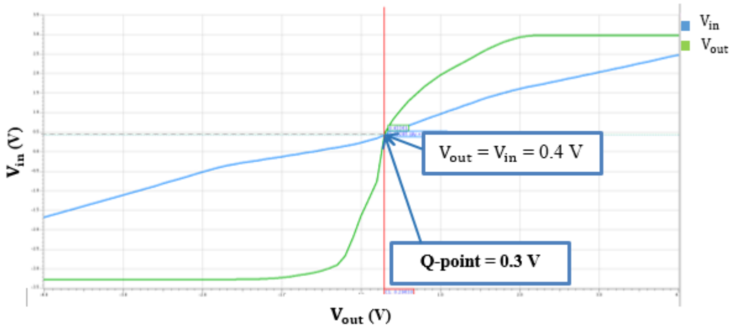

FIGURE 3. Transfer Characteristic Graph (V_{out} versus V_{in})

From the graph obtained, $V_{o(max)} = 3$ V and $V_{o(min)} = -3.3$ V. These peak-to-peak outputs represent the maximum output voltage swings. When the output voltage exceeds this range, the wave obtained will experience clipping. Q-point of approximately 0.3 V is obtained. The transistor will have sufficient biasing ($V_{out} = V_{in} = 0.4$ V) to operates in the saturation region when V_{in} reached 0.4 V.

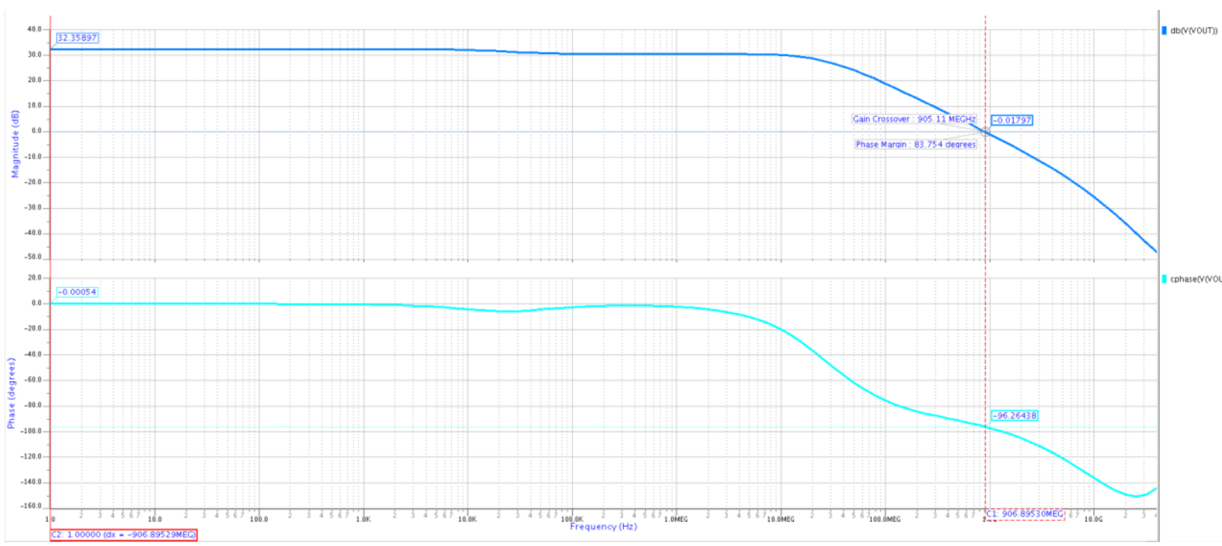

FIGURE 4. AC open-loop frequency response

The graph simulated in Fig. 4 shows a DC gain of 32.3590 dB, a gain crossover of 905.11, a phase margin of 83.754 degrees and a unity gain bandwidth of 906.8953 MHz. The -3 dB or 70.7% of Vmax down a point from the frequency response curve is given as 29.3590 dB. By taking a line across until it intersects with the main GBP curve, a cut-off frequency, f_c of 17.1092 MHz is obtained.

CONCLUSIONS

In this work, a folded cascode operational amplifier is designed and simulated. The performance of the proposed folded cascade op-amp circuit is studied. Through the simulation of Mentor Graphics, under ±3.3 V voltage supply, the circuit' s DC gain is 32.3590 dB, the phase margin is 83.754 degree with a high stability, the bandwidth is 17.1092 MHz, the unity gain bandwidth is as high as 906.8953 MHz and the slightly high power dissipation which is 86.9774 mW.

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