Design Choices for Folded Cascode Operational Trans-conductance Amplifiers

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1. Introduction

The operational amplifier, op-amp, is without question the most common building block in analog systems. Among many architectures, the Operational Trans-conductance Amplifiers OTAs, the structure known as "Folded Cascode OTA" (Fig.1) has found a broad use [1,2,3], because of its reduced thermal noise and a possible optimization of power consumption [4].

Although, at first glance, the calculation of elements of this structure seems to be straightforward and raises no apparent problem, choices of input transistors type (N-OTA or P-OTA configuration), currents ratios and the Overdrive Voltage *Vov* are left to the designer appreciation and did not obey well established criteria.

The purpose of our study is on the one hand, to provide directives on the tradeoffs to be made to arrive at the desired performances and on the other hand, to establish the limitations of the studied structure.

2. Main Results

It is well known that raising the input transistors trans-conductance maximizes the band-width. This can be obtained either by using larger transistors geometry (minimizing V_{OV}) or making sure that the polarization current of the input transistors is substantially higher than that of the Cascode and currents mirrors transistors. Doing so also maximizes the DC gain. However, the optimal value for R is not known and reducing V_{OV} causes an increase of the die area and a reduced differential input range [5].

Figs. 2 and 3 illustrate the evolution of Fu versus R and V_{OV} for two alternatives: N-OTA and P-OTA. In order to guarantee an equitable comparison between all configurations, we kept the polarization current of M10 and M11 transistors constant (same power consumption for all configurations), while varying the I_{M1} / I_{M5} ratio.

As expected, Fu evolves inversely with V_{OV}. However, the N-OTA case showed sharper slop in V_{OV} direction. Furthermore, Rising R pushes Fu to a maximum from which any further increase is accompanied with a bandwidth loss. However, the P-OTA curve shows a saturation region before decreasing. Furthermore, Fig. 3 reveals that a ratio between 4 and 6 lead almost always to the best results for P-OTA, whereas a value close to 3 is more adapted for N-OTA configuration.

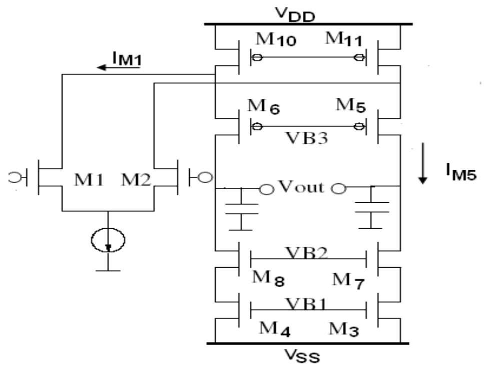


Fig.1: Simplified schematic of Folded Cascode OTA with channel input transistors (the CMFB circuit not show here).

In order to establish the limits of the studied op-amp, we carried out an AC analysis of the N-OTA and P-OTA structures under various levels of polarization currents of the transistors M_{10} and M_{11}, while varying V_{OV}, reported the correspondence of the total power consumption of each configuration with its Fu. Fig. 4 informs us about the level of power consumption needed to reach a given band-width. Moreover, the meticulous examination of the Figs 4.a and 4.b reveals that for high current levels, if one chooses V_{OV} to be less than 0.3V, then the N Channel input transistors leads to better AC performance and power efficiency.

In order to help designer choosing between an op-amp with N or P channel input transistors, we split the studied configurations in two categories: Amplifiers which occupy the same die area and the amplifiers which have the same output excursion and the same common mode range CMR (amplifiers designed with the same V_{OV}).

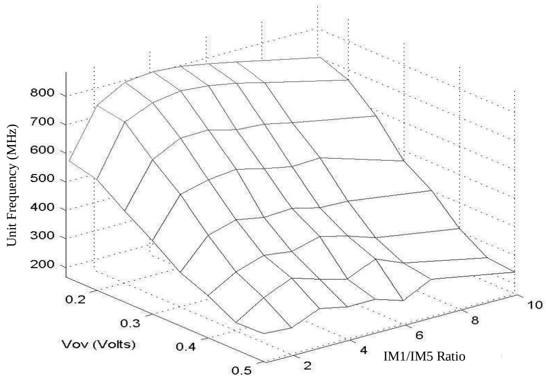


Fig.2: Simulation of N-OTA : Variation of Fu vs V_{OV} and R (N.B: Results obtained with C_L = 1pF).

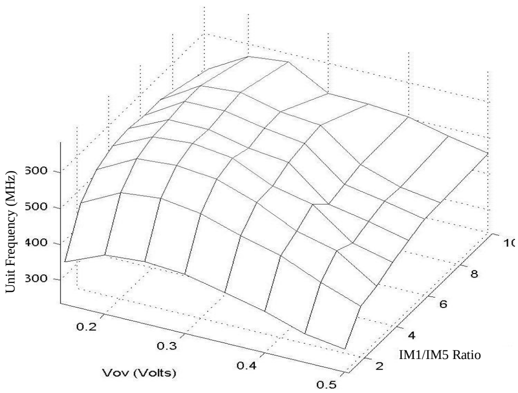


Fig.3: Simulation of P-OTA : Variation of (a) Fu vs. V_{OV} and R (N.B: Results obtained with C_L = 1pF).

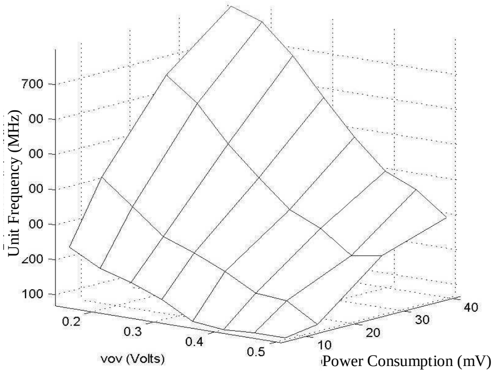
The simulation shows that with OTA consuming P=26.4mW with a load beyond C_L = 0.5pF, the band-width of P-OTA configuration is 10% larger than that of N-OTA. Nevertheless, to meet the requirement of the same surface, P-OTA is conceived with larger *Vov*, which reduces its dynamic range.

When OTAs are aimed to meet the same dynamic range the prevalence of P-OTA configuration were obvious and we observed a 30% improvement on band-width as compared to N-OTA case at 1pF load. This is due to the aptitude of P-OTA configuration to operate with a greater R without performances degradation; this allows designer to obtain, for the same level of electric power consumption, a higher input trans-conductance than that of N-OTA alternative. However, it is important to note that P-OTA configuration will occupy a larger area.

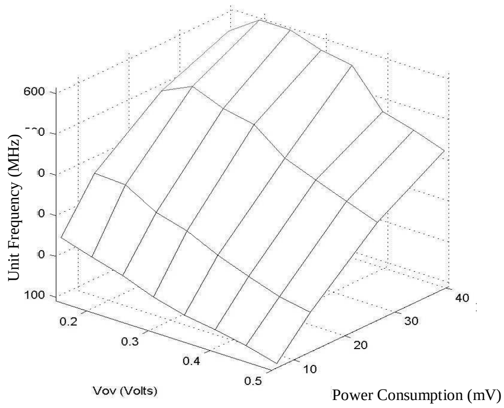
3. Conclusion

Assuming the same level of power consumption, our study allows us to make the following design guide lines:

1. If the desired dynamic range is moderate, the band-width of the N-OTA configuration will be 30% less than that of P-OTA with, however, a gain of about 45 to 70% on die area.



(a)



(b)

Fig.4 : Variation of Fu vs. V_{OV} and power consumption for (a) N-OTA case with R=3 (b) P-OTA with R=5.

2. If the designer aims at maximum dynamic range (V_{OV} very small). N-OTA will be the suitable choice.
3. If the goal is to reduce Silicon area, then P-TA configuration will present a 10% gain in band-width as compared to N-OTA, with however a dynamic range reduction.

References

[1] T. Lehmann and M. Cassia, “1V power supply CMOS cascode amplifier”, IEEE JSSC, **36**, Issue 7, July (2001).

[2] E. Sall, “A 1.8V 10-bit 80 MS/s low power track-and-hold circuit in a 0.18 µm CMOS process”, Proceedings of ISCAS '03, Volume 1, 25-28 May (2003).

[3] R. Salinas-Cruz and G. Espinosa-Flores-V, “A folded-cascode switched OTA based on current deviation”, Proceedings of the 4th IEEE ICCDCS, April (2002)

[4] D. A. Johns and K. Martin, *Analog Integrated Circuit Design* (John Wiley & Sons, 1998) ISBN 0-471-14448-70.

[5] P. R. Gray and R. G. Meyer, *Analysis and Design of Analog Integrated Circuits* (John Wiley and Sons, 1993) ISBN- 0-471-57495-3.