Comparison between Different Schematic Solutions to Achieve Constant-gm in Fully Differential Operational Amplifiers

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Abstract – **The paper presents a comparative analysis between three schematic approaches to achieve constant-gm functionality in a fully differential operational amplifier. The goal is to draw conclusions concerning which of the techniques can fulfill best our preset requirements. The three techniques that are discussed in this paper are: constant-gm structure using dummies connected in parallel to the input differential pairs (the dummies technique), constant-gm structure using a common branch that connects the sources of the input differential pairs (the common-branch technique) and dynamic current scaling technique (the DCS technique) that relies on switching the currents of the input differential pairs. In order to compare the three techniques three operational amplifiers plus a fourth that does not have a constant-gm structure are designed and DC and AC simulations are performed. The results are presented graphically and in table and conclusions are made.**

Keywords – **constant-gm, fully-differential amplifier, dynamic current scaling.**

I. INTRODUCTION

In our modern world, electronics have entered every aspect of our lives. The integrated circuits become smaller, faster and more powerful. One of the main directions in which electronics is evolving is the increase of the working frequency. This poses a new, additional set of prerequisites that operational amplifiers must fulfill.

One of the main problems in designing high-frequency operational amplifiers is the noise [1]. In a substantial percentage of the newer and advanced applications, the operational amplifiers are used to amplify signals with small amplitudes. Then the noise at higher frequency can become comparable to the signal and thus can become a major problem. Maybe the best ways to suppress noise from a design point of view is to select operation amplifiers that have fully differential structures. They inherently possess a much better noise suppression compared to single-ended amplifiers.

Another very common problem in newer and more advanced applications is the requirement that the operational amplifier needs to work with variable voltage at its inputs and outputs (even rail-to-rail in some cases). This requirement can be fulfilled by using schematic with constant-gm in the entire input common mode voltage range.

The goal of the paper is to make a comparison between three different techniques to achieve constant-gm in fully differential amplifier with rail-to-rail input and output.

To this aim three amplifiers based on the compared techniques will be designed and simulated using a standard 0.18μm CMOS XFAB technology with 2.5V supply voltage (VDD)

In order to achieve a meaningful comparison the following design considerations have been implemented: 10μA (I) bias current for the amplifiers; 40μA (4*I) currents throught each transistor in the differential pairs when both pairs are active (input voltage in around VDD/2); the aspect ratios of the transistors are selected for operation in the saturation region [2]; the resulting unity gain frequency (F_U) should be higher than 50MHz.

II. PROPOSED TECHNIQUES

The three techniques that compared in this paper are:

A. The dummies technique [3]

This constant-gm technique relies on two "dummy" transistors whose gates are connected to a common mode voltage VCM. The input differential pairs with the "dummies" are shown on Fig. 1. The block schematic of the entire amplifier can be seen on Fig. 3.

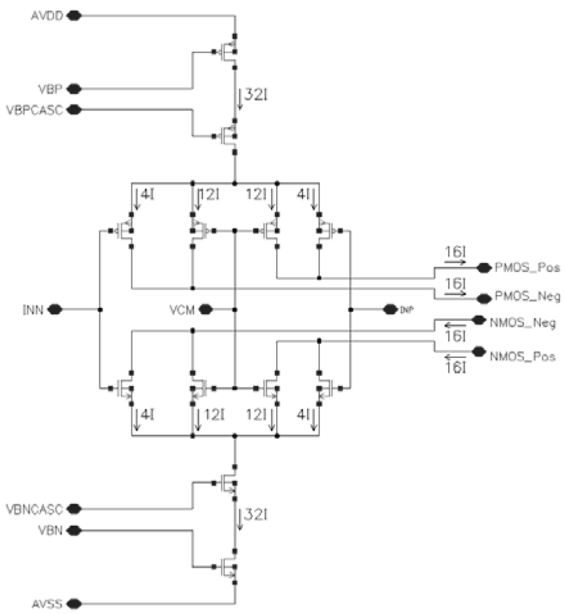

Fig. 1. Schematic with "dummies" constant-gm technique".

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B. The common branch technique [4]

This technique relies on two secondary differential pairs which are added with the goal of increasing the current and the gm of the input differential pair in saturation. The input differential pairs with the "common branch" are shown on Fig. 2. The block schematic of the entire amplifier is shown on Fig. 3.

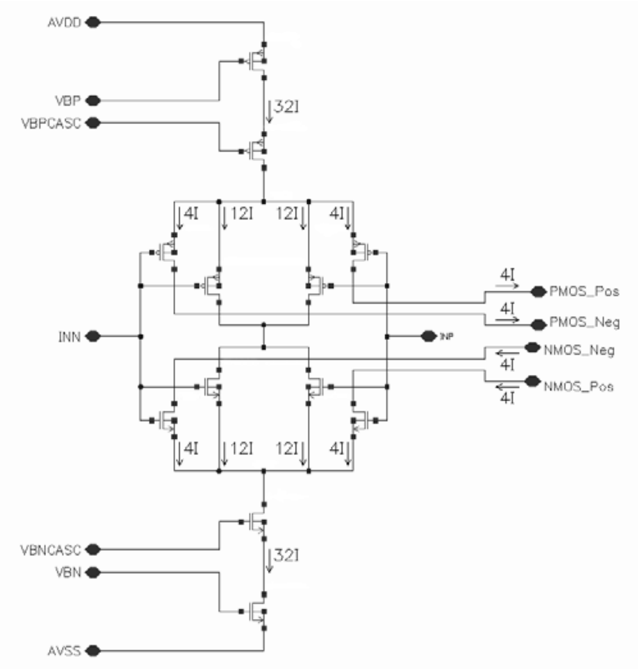

Fig. 2. Schematic of "common branch" constant-gm technique"

The common branch technique has one major drawback. The output currents from the block containing the differential pairs will not be the same - they depend on the input voltage. If only one pair is active the corresponding output currents will be four times larger compared to the case when both pairs are active. The result from this difference will be that the output impedance of the entire amplifier will vary depending on the input voltage.

C. The Dynamic current scaling technique [5]

This constant-gm technique relies on 4 pairs of switches that scale the currents coming from the input differential pairs. The switches together with their biasing circuit represent the Dynamic Current Scaling (DCS) schematic

Among the notable features of this technique is the fact that the four input currents form the differential pair block can be divided into eight at the output of the DCS block. This will reduce the gain by 6 dB but it will allow the use of two folded cascode outputs blocks with four input currents each. Potentially this can improve noise characteristics as well as offset.

By modifying the DCS a further multiplication of the output currents can be achieved (at the cost of further decrease in the gain of course) which means that in example four folded cascode outputs can be connected to one set of differential pairs.

III. SIMULATION RESULTS

Table 1 shows the achieved results after AC simulations of three amplifiers designed using the above mentioned techniques. An amplifier without any constant-gm modifications has been designed and simulated and added to the results as well to provide a better comparison.

TABLE 1. MAIN ACHIEVED CHARACTERISTICS

	AUDC [dB]	F3dB [kHz]	FU [MHz]	Variation of gm [%]	IIN [µVrms]
No const. gm	90.4	2.9	96.3	±35	250
Dummies	80.8	5.6	60	±7	194
Common Branch	90.1	2.8	90.4	±18	92
Dynamic current scaling	84.2	3.4	58	±2.2	111

Table 1 with the main achieved characteristics demonstrates the basic pros and cons of the examined techniques:

- If we look at the DC gain (AUDC) of the four simulated amplifier we can see that the common branch technique is notable for not losing on DC gain, while having a constant-gm feature.
- The DCS technique looses roughly 6 dB from the splitting of the differential pairs' currents as expected.
- The lower DC gain grants the dummies technique a slightly better 3dB frequency.
- The dynamic current scaling technique achieves an excellent result – only ±2.2 % variation of gm in the entire input voltage range.
- Despite having an impressively low variation in the gm the DCS technique also has a slightly lower unity gain frequency (F_U) similar to that of the dummies technique.
- It is of importance to note that the amplifier designed with the DCS technique has two-to-three times bigger quiescent current compared to the other amplifiers.

Furthermore on Fig.6 we can observer the gm variation of the four simulated operational amplifiers as a function of the input common mode voltage. The superiority of the DCS technique when it goes to keeping the gm of the amplifier constant in the entire input voltage range is evident.

Integrated Input Noise (IIN) is the noise at the output of the amplifier divided by its DC gain. From the simulations for integrated input noise it can be seen that the Common branch and the Dynamic current scaling (DCS) amplifiers have excellent noise characteristics compared to the other structures.

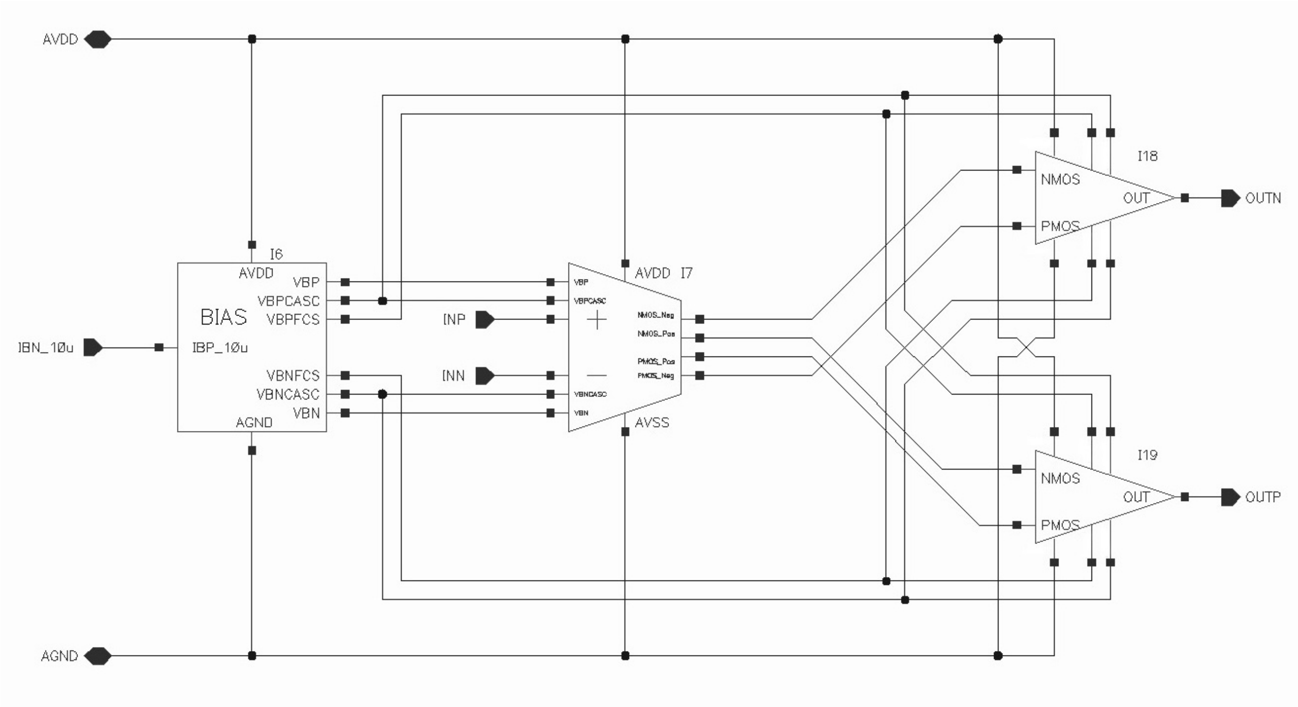

Fig. 3. Block schematic of a fully differential amplifier using either the “dummies” or the common branch techniques.

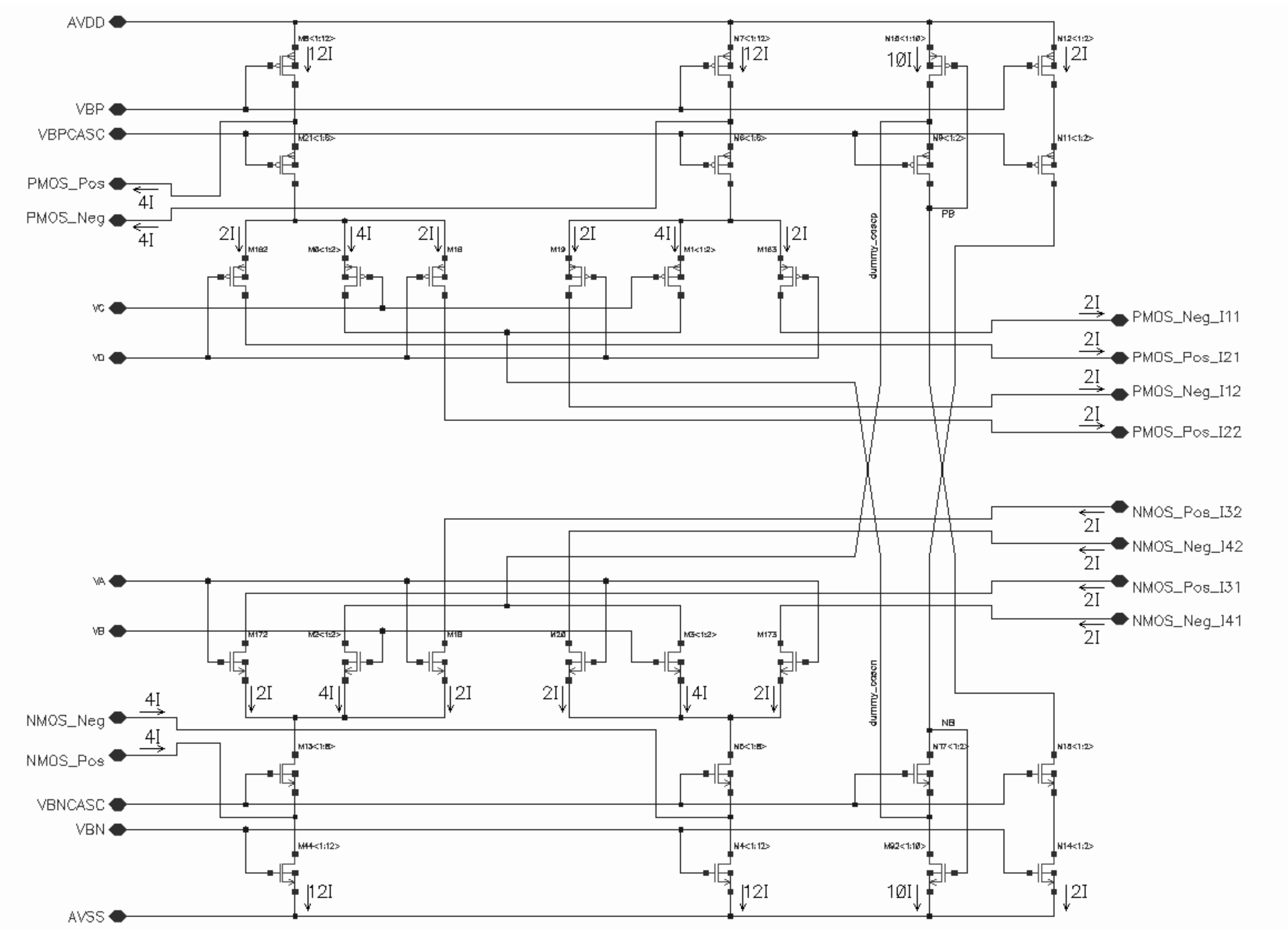

Fig. 4. Schematic of the Dynamic Current Scaling (DCS) circuit

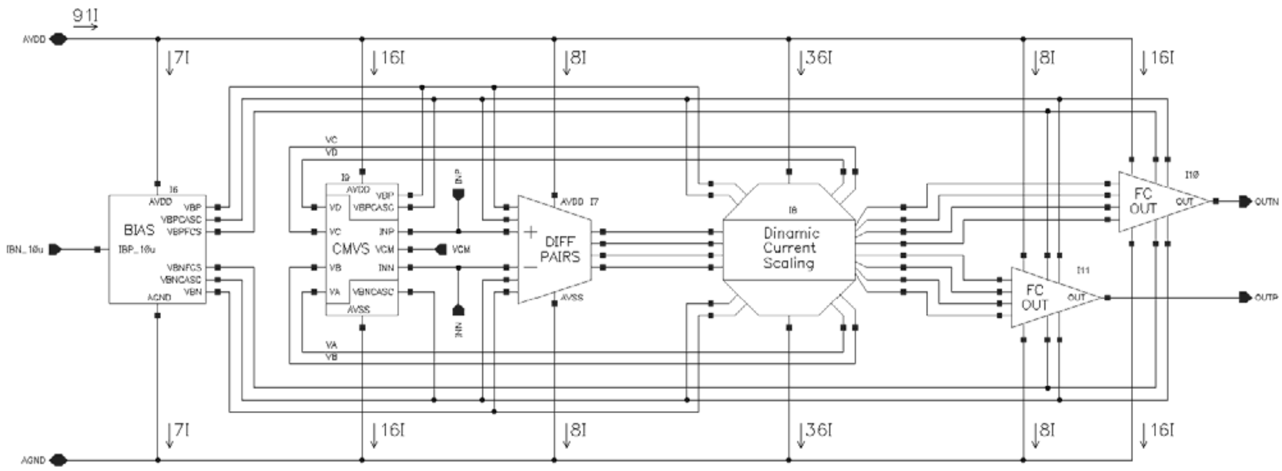

Fig. 5. Block schematic of a fully differential amplifier using Dynamic Current Scaling

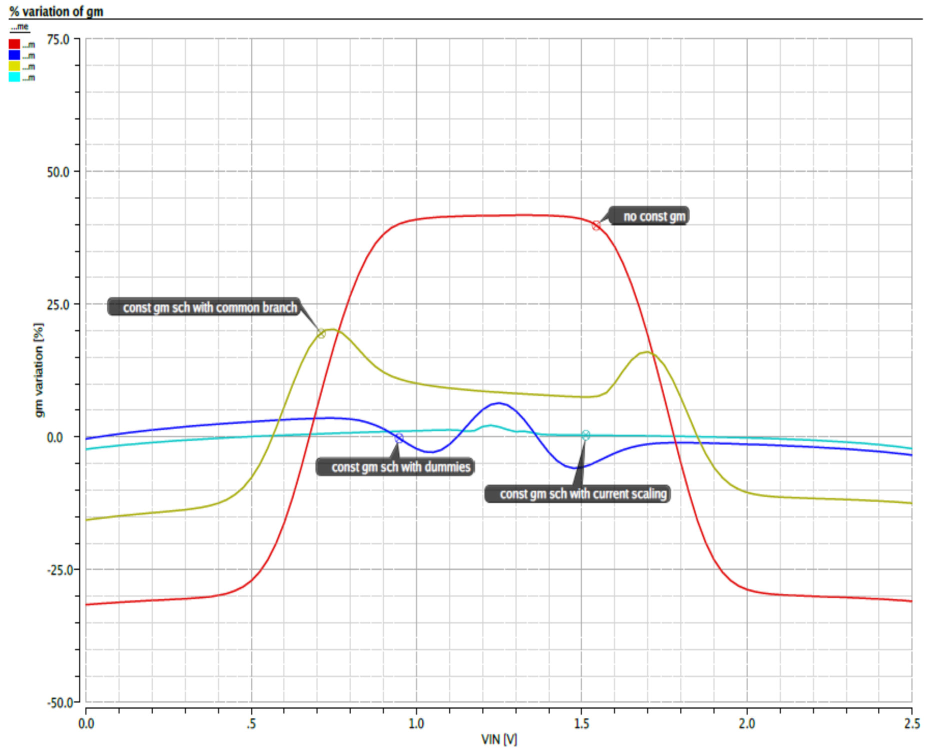

Fig. 6. Simulation result for the gm variation of the four simulated fully differential amplifiers.

IV. Conclusion

Taking into account the obtained results, we can easily see the benefits of using the dynamic current scaling technique when looking for a reliable constant-gm implementation. The more than 15 times reduction in the variation of the gm, combined with the good open loop gain and good unity gain frequency, undoubtedly makes this design one of the best possible solutions when a top priority for a designer is to keep the gm variation to a minimum. It is important to note that from [5] we can see that such design has its drawbacks – increased current consumption, complexity of the design and the need to design very carefully the circuit that control the switches, are some of the bigger issues.

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