Compact CMOS constant-gm rail-to-rail input stages with gm-control by an electronic zener diode

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Abstract- A family of compact rail-to-rail input stages are presented. To obtain a constant-gm over the common-mode input range, an electronic zener diode is inserted between the tails of the complementary input pairs. The zener keeps the sum of the gate-source voltage of the input pairs, and therefore the gm of the input stage, constant. Two possible implementations of the zener have been realized. The input stages have been inserted in a two stage compact amplifier. Both amplifiers have been realized in a 1 μm BiCMOS process. The unity-gain frequency is 2-MHz, for a load of 20 pF

I. Introduction

The design of mixed/mode VLSI systems requires compact power-efficient analog library cells, such as the opamp. In a low-voltage environment, especially in non-inverting feedback applications, the input stage should be able to deal with rail-to-rail common-mode (CM) input voltages, in order to maximize the signal-to-noise ratio.This can be achieved by placing an N-channel and P-channel input pair in parallel. Drawback of such an input stage is that its g_m varies with a factor 2 over the CM-input voltage range, which impedes a power-optimal frequency compensation [1]. To obtain a power-efficient frequency compensation, the g_m of the input stage has to be regulated at a constant value. If the input stage operates in strong inversion, which for instance is required in high slew-rate applications, the g_m is proportional to the gate-source voltage. Hence, a constant-g_m can be obtained by keeping the sum of the gate-source voltages of the input pairs constant [2].

Published, rail-to-rail input stages control the g_m by adapting the tail-currents of the complementary input pairs [3], [4]. Drawback of these methods is that they result in complex, die area consuming, designs. Moreover, the control circuits introduces additional current paths between the supply rails, which rises the dissipation of the input stage.

In this paper compact constant-g_m rail-to-rail input stages will be presented. The input stage operates in strong inversion. The g_m is regulated by placing an electronic zener diode between the tails of the complementary input pairs.The zener diode keeps the sum of the gate-source voltages of the input pairs, and therefore the g_m, constant. Since the zener is placed between the tails of the input pairs, no additional current paths are introduced between the supply rails. Thus, the g_m-control circuit does not increase the dissipation of the input stage.

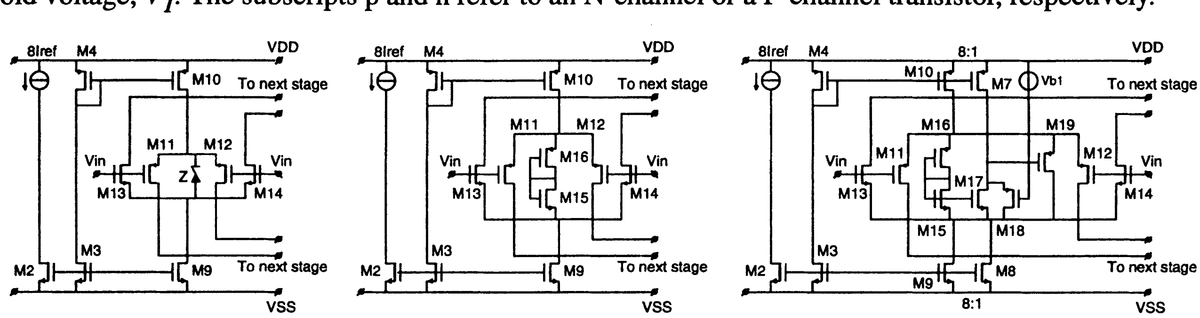
Two possible implementations of a zener diode have been designed. The input stages have been inserted in a two stage amplifier, which have been realized in a 1µm BiCMOS process. The amplifiers measure only 0.06 mm^2, which makes them suitable as VLSI library cell. Both amplifiers have a unity-gain frequency of about 2 *MHz*, while driving a load of 20 *pF*.

II. Input stages

Fig. 1a shows the basic principle of the constant-g_m rail-to-rail input stage. The circuit consists of a complementary rail-to-rail input stage, M_{11}-M_{13}. The g_m-control is implemented by means of the zener, Z. This zener diode keeps the sum of the gate-source voltages of the input transistors, M_{11}-M_{13}, and therefore the g_m of the input stage, constant. The g_m of this circuit is given by:

$$g_{m,r\text{-}r} = g_{mn} + g_{mp} = (KV_{gs,\,eff})_n + (KV_{gs,\,eff})_p \quad \text{with } V_{gs,\,eff} = \sqrt{\frac{1}{K}I_D} \tag{1}$$

where K is the transconductance factor, which depends on process parameters and on the sizes of a transistor. The factor K of a P-type and N-type transistor can be made equal by dimensioning the W over L ratios properly. $V_{gs,eff}$ is the effective gate-source voltage , i.e. gate-source voltage, V_{gs}, minus a threshold voltage, V_T. The subscripts p and n refer to an N-channel or a P-channel transistor, respectively.



(a) *(b)* *(c)*

Fig. 1 *Rail-to-rail input stage. The gm-control is implemented by an ideal zener (a), two diodes (b), or an electronic zener diode (c).*

The operating principle of the circuit is as follows: In the intermediate part of the CM input range, both input pairs are active. The zener keeps the sum of the gate-source voltages constant, by absorbing a part of the tail currents. Giving the zener diode a zener voltage of

$$V_Z = -V_{TP} + V_{TN} + 2KV_{gs,\,ref} \quad \text{with } V_{gs,\,ref} = \sqrt{\frac{1}{K}I_{ref}} \tag{2}$$

results in a total transconductance of

$$g_{m,r\text{-}r} = 2KV_{gs,ref} = 2\sqrt{KI_{ref}} \tag{3}$$

In the outer parts of the CM input range, only one input pair is active. Now, the zener diode is not zenering, so the actual active input pair is biased with a tail-current of 8 I_{ref}. It can easily be calculated that the g_m of the input stage is also given by (3). It can be concluded that the g_m is constant over the whole CM input range, as is shown in Fig. 2a.

Two possible implementations have been designed. The first one uses two complementary diodes, M_{15}-M_{16}, as is shown in Fig. 1b. In order to obtain the desired zener voltage, the diodes should have a W over L ratio which is six times larger than the input transistors. Fig. 2b displays that the g_m varies about 25 % over the CM input range. This variation occurs because the zener voltage shows a current dependency, when the input voltage travels across the CM input range.

For some applications, this variation of the g_m cannot be allowed. Fig. 1c shows a more accurate implementation of the zener diode, M_{15}-M_{19}. It uses two diodes, M_{15}-M_{16}, as a reference chain. Transistor M_{17} is biased by M_7 at a current of I_{ref}. This current is drained away by M_8. Although, M_8 introduces an additional curent path between the supplies, the increase of dissipation is much lower compared two conventional g_m-control circuits. M_{19} together with M_{17} keep the current through the diodes a constant value of I_{ref}. Hence, the zener voltage is only slightly current dependent. To obtain the desired zener voltage, the diodes should have the same W over L ratio as the input transistors. M_{18} limits the drain voltage of M_{17}, it also bypasses the current of M_7 to M_8 when the zener is inactive. Fig. 2c shows that the g_m varies only 6% over the whole CM input range.

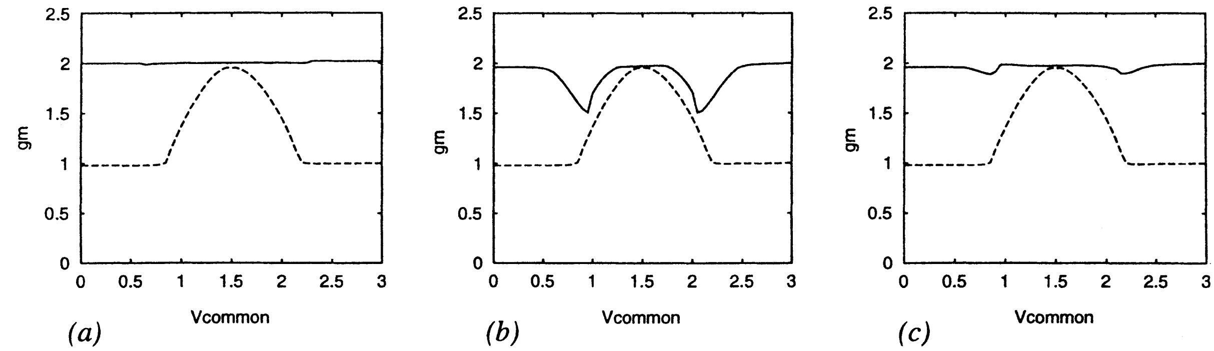


Fig. 2 *Normalized gm versus the CM-input voltage for the input stage with an ideal zener (a), two diodes (b), or a electronic zener diode (c).*
----- *Rail-to rail input stage* —— *Rail-to-rail input stage with gm-control*

III. Realizations and Measurement Results

The input stages have been inserted in the amplifiers as shown in Fig. 3. Both amplifiers consist of a class-AB rail-to-rail output stage, M_{30}-M_{39}, a summing circuit, M_{21}-M_{28} and a rail-to-rail input stage, M_{11}-M_{14}. A floating current source, M_{41}-M_{46}, biases the summing circuit [5]. The amplifiers are compensated using two Miller capacitors, C_{M1} and C_{M2}. The amplifier shown in Fig. 3 is equipped with a g_m-control circuit which consists of two diodes, M_{15}-M_{16}. The amplifier as shown in Fig. 4 uses an electronic zener diode, M_{15}-M_{19}, to control the g_m. Both opamps have been realized in a 1 μm BiCMOS process. The N-channel and P-channel transistor have a threshold voltage of 0.8V and -0.8V, respectively. The micrographs of the opamps are shown in Fig. 5. Fig. 6a shows a Bodeplot of the amplifier with gm-control by two diodes. The amplifier has a unity-gain frequency of 1.7 MHz and a unity-gain phase margin of 76 °, for a capacative load of 20 pF. The Bodeplot of the amplifier using a zener diode to control the g_m is shown in Fig. 6b. This amplifier has a unity-gain frequency of 1.9 MHz and a phase-margin of 80°, for the same load. A detailed list of specifications is shown in Table 1.

IV. References

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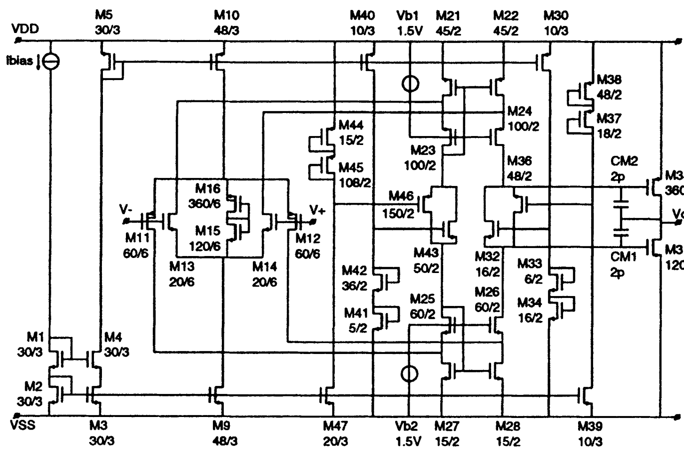


Fig. 3 *Realization of the compact opamp. The gm-control is implemented by means of two complementary diodes.*

Table 1: Specifications, Vsupply=3V, RL=10 kΩ, CL=20 pF, unless otherwise indicated

Parameter	Opamp1	Opamp2	Unit	Parameter	Opamp1	Opamp2	Unit
Die Area	.06	.06	mm^2	Offset voltage	3	3	mV
Supply voltage range	2.7-5.5	2.7-5.5	V	Open loop gain	83	85	dB
Quiescent current	210	215	μA	Unity-gain frequency	2	2	MHz
Peak output current	7.5	7.5	mA	phase margin	76	80	°
CM-input voltage range	V_{SS}-.5 to V_{DD}+.8	V_{SS}-.5 to V_{DD}+.8	V	Slew-rate	8	8	V/μs

Opamp1 refers to circuits as shown in Fig. 3; Opamp2 refers to the circuit as shown in Fig. 4

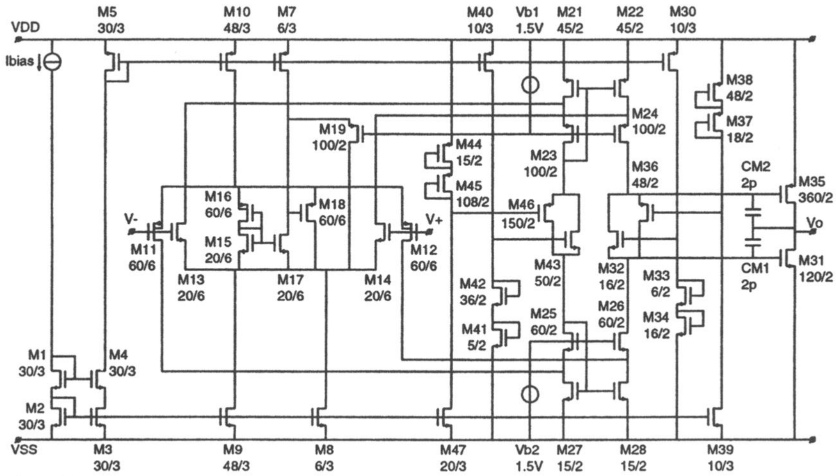
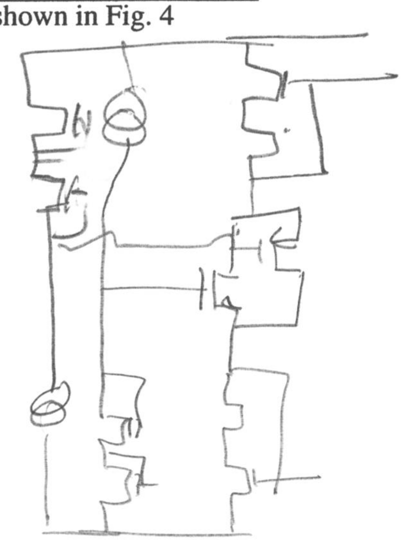
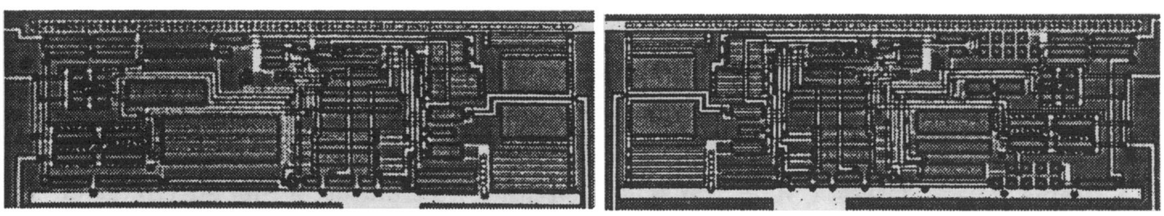


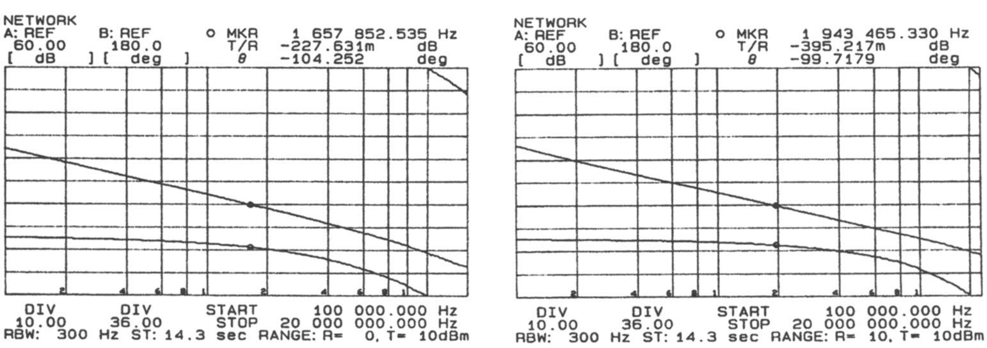
Fig. 4 *Realization of the compact opamp. The gm-control is implemented by means of an electronic zener diode*





(a) *(b)*

Fig. 5 *Micrographs of the amplifiers as shown in Fig. 3 (a) and Fig. 4 (b)*



(a) *(b)*

Fig. 6 *Bodeplot of the amplifiers as shown in Fig. 3 (a) and Fig. 4 (b)*