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A Continuous-Time Common-Mode Feedback Circuit for High-Gain, Wide-Output-Range Fully-Differential OTAs

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1. Introduction

Fully-differential operational transconductance amplifiers (OTAs) are widely used for the applications of high-speed pipelined A/D converters, continuous-time filters, and biosensors. Common-mode feedback (CMFB) circuit stabilizes the common-mode (CM) output voltage in fully-differential OTAs, and its generic continuous-time implementations are explored in details in [1]. However, in scaled CMOS technologies, reduction of intrinsic gain and low-voltage operations necessitate complex topologies, such as gain-boosted folded-cascode (GBFC) OTA, as shown in Fig. 1 [2], and the resulting high-output impedance prevents the use of simple resistive CM voltage sensor; moreover, its wide-output-range operation demands topology optimization in the CMFB circuit.

In this paper, we illustrate the output range problem in the conventional CMFB circuit, and propose a wide input-range CM sensor for the high-gain OTAs. The specification for the OTA and associated CMFB circuit is summarized in Table I.

2. Conventional and Proposed CMFB Circuits

Conventional Current-Steering CMFB Circuit

Conventional current-steering CMFB circuit is presented in Fig. 3 [1]. In this circuit, the CM current components flowing in M_{a3} and M_{a6} are obtained by summing currents in M_{a4} and M_{a5}. When both V_{op} and V_{om} rise over the reference voltage $V_{oc,ref}$ the current flowing in M_{a7} increases; thereby, CMFB voltage V_{CMFB} increases, and the resulting increase of the bias current in M_{55} in Fig. 1 lowers the output CM voltage. The obtained characteristics with regard to conversion gain, speed and harmonic distortion indicate superiority over the simple differential pair and resistive degeneration CMFB circuits [1][3]. However, this circuit suffers from the OTA output range limitation. The maximum output voltage is calculated as [V_{DD}-($2V_{ov}$+V_{th})], where V_{ov} and V_{th} are gate-overdrive and threshold voltage, respectively. If V_{op} or V_{om} rises above this value, the notable CM voltage error is observed.

Proposed CMFB Circuit with Wide-Input-Range Common-Mode Sensor

The proposed CM sensor is presented in Fig 4 (a). The input circuit incorporates both nMOS and pMOS transistors to extend the OTA output range. When the input CM voltage approaches V_{DD}, nMOS transistors maintain normal operation; when the input CM voltage falls to the ground, pMOS transistors function properly.

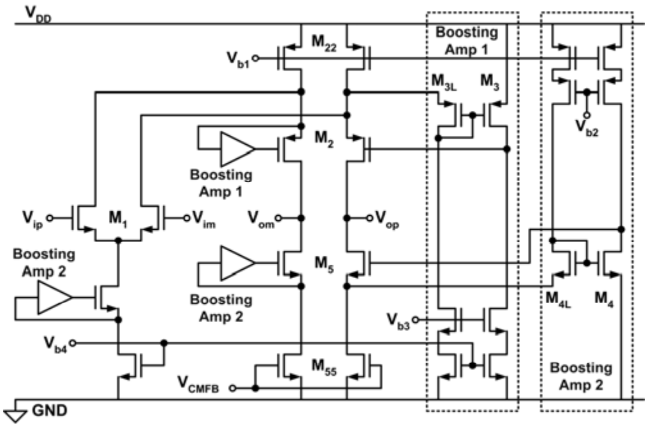

Fig. 1 Gain-boosted folded-cascode OTA.

Table I Specification for OTA and CMFB circuit.

	Min	Typ	Max
Supply Voltage V_{DD} [V]	1.6	1.8	2
Operating Temperature [°C]	-40	25	125
OTA Output Range V_{od} [V]	-0.5		0.5
Common-Mode Voltage V_{oc} [mV]		V_{DD}/2	
Common-Mode Error V_{cme} [mV]	-25		25
OTA DC Gain [dB]	75.8		
OTA Crossover Frequency [MHz]	70		
OTA Phase Margin [°]	65		
OTA Load Capacitance [pF]		1.25	
CMFB Crossover Frequency [MHz]	25		

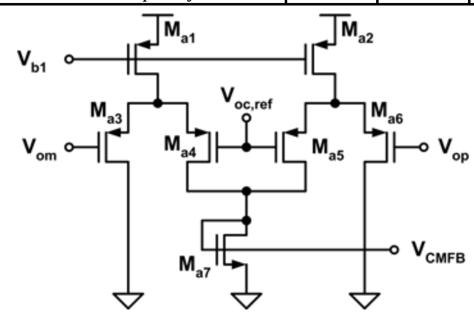

Fig. 3 Conventional current-steering CMFB circuit.

The CM sensor is organized as a folded-cascode OTA based voltage follower. The CM voltage V_{oc} is obtained through the feedback network by equalizing the modulated current (g_mV_{op}+g_mV_{om}) in M_{c7} to the modulated current $2g_mV_{oc}$ in M_{c8}, where g_m is the transconductance of input transistors, M_{c1}-M_{c4}. The primary concern in this circuit is the nonlinearity associated with the transconductance variation according to the input CM level; however, its influence can be mitigated to the permitted level through feedback networks in the entire OTA.

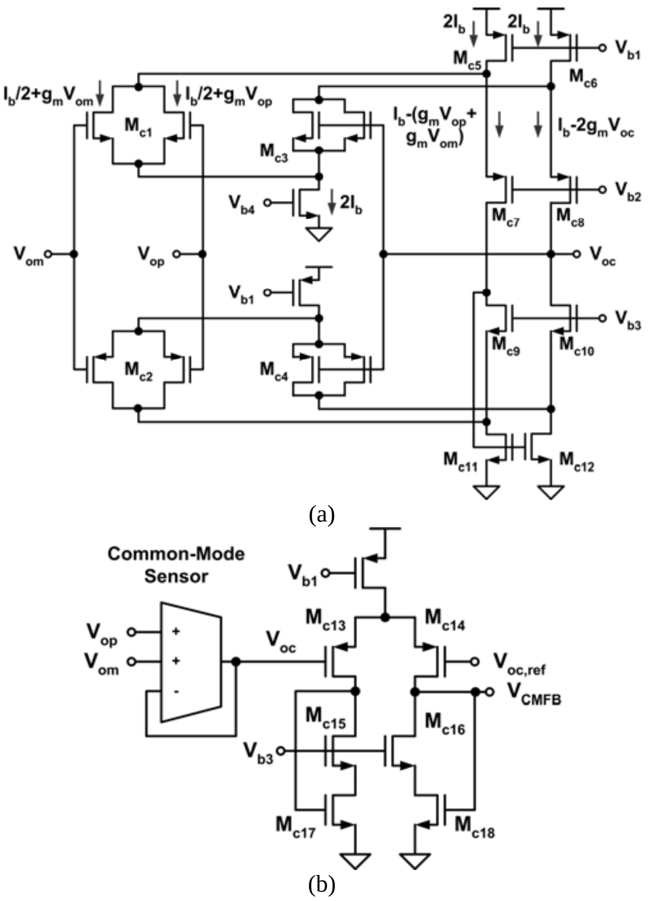

Fig. 4 Proposed CM sensor (a) and entire CMFB circuit (b).

Table II Transistor Sizes of the proposed CMFB circuit.

Transistor	W/L [μm]	Transistor	W/L [μm]
M_{c1}	2.4/0.22	M_{c9} , M_{c10}	4.8/0.22
M_{c2}	7.2/0.22	M_{c11} , M_{c12}	9.6/0.22
M_{c3}	2.4/0.22	M_{c13} , M_{c14}	134.4/0.22
M_{c4}	7.2/0.22	M_{c15} , M_{c16}	12/0.22
M_{c5} , M_{c6}	28.8/0.22	M_{c17} , M_{c18}	12/0.22
M_{c7} , M_{c8}	14.4/0.22		

The entire CMFB circuit shown in Fig. 4 (b) consists of a CM sensor and a current-steering driver to generate the CMFB voltage V_{CMFB} from the difference of V_{oc} and $V_{oc,ref}$. Transistors M_{c17} and M_{c18} can be diode-connected; however, the cascode topology in Fig. 4 (b) can reduce the maximum CM voltage error from 23mV to 8mV. This improvement is attributed to the minimization of current mismatch in the CM sensor and the CMFB circuit.

3. Experimental Results

The proposed CMFB circuit and the GBFC OTA have been designed in a 0.18μm CMOS technology. Transistor sizes and bias currents are determined through g_m/I_D lookup table methodology [4], where g_m/I_D for all transistors is picked as 12S/A to minimize the power consumption in our design. Transistor sizes are listed in Table II, and the current consumptions for the CM sensor, the current-steering driver, and the GBFC OTA are 205μA, 250μA, and 1046μA, respectively.

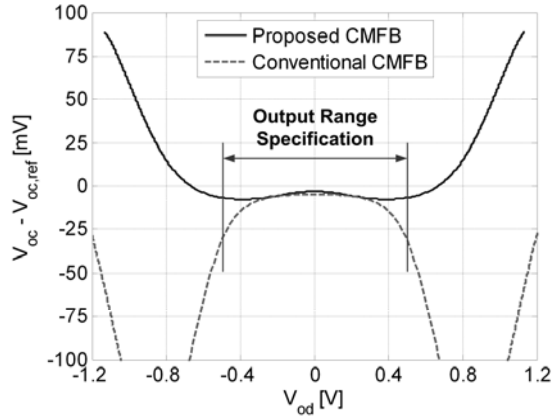

Fig. 5 Relationship between V_{cd} and CM voltage error (V_{oc}-$V_{oc,Ref}$) for the conventional and proposed CMFB circuits.

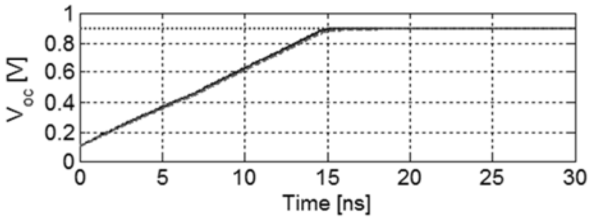

Fig. 6 Settling behavior of the proposed CMFB circuit.

The simulation result of the relationship between V_{od} and CM voltage error V_{cme} equal to (V_{oc}-$V_{oc,ref}$) is plotted in Fig. 5. In the conventional CMFB circuit, the maximum output range is 946mV, which cannot satisfy the specification; while in the proposed circuit, this value can be improved up to 1712mV, 1.8-times larger than the conventional one. The simulated settling behavior for the proposed CMFB circuit is presented in Fig. 6. The CM voltage settles within 15nsec from the initial 0.1V to the final 0.9V. The relative performance represented as A_{CM}/A_{DM}, which is equal to the ratio of the CM gain-bandwidth product to the differential-mode gain-bandwidth product, is simulated as 0.97, sufficiently large and comparable to the previous current-steering CMFB circuit. Total harmonic distortion for 1MHz sinusoidal differential input signal with the amplitude of 0.5V is less than 0.01%.

Acknowledgement

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