

A Variable Gain Amplifier for MEMS Front End

Zuo LIU¹, Longfei WANG², Viet Nguyen-Thien³

¹ ICS Master students, Université Paris-Saclay, Paris, France

² ICS Master students, Institut Polytechnique de Paris, Paris, France

³ Laboratoire Traitement et Communication de l'Information, Telecom-Paris, Paris, France

Abstract—In this work, an analog-controlled Variable Gain Amplifier based on differential structure is proposed for the MEMS gyroscope sensor, with an input voltage of 50 to 100 mV and a target output voltage of roughly 500 mV. This design features optimization for the large voltage swing and specified gain variations, demonstrating a 360uW power consumption with simulation in XFAB xh180 technology.

I. INTRODUCTION

In MEMS analog front-ends, a Variable Gain Amplifier (VGA) is often employed to stabilize the output of a Transimpedance Amplifier (TIA). This work proposes a VGA that amplifies the TIA output voltage from a range of 50mV to 100mV up to 500mV. The proposed design is adapted from [1] and optimized for the relatively large voltage swing and the specified gain variation.

II. PROPOSED ARCHITECTURE

A. Principle of architecture

The proposed architecture is based on a differential amplifier, whose output voltage can be adjusted by the ratio of two bias currents I_{C2}/I_{C1} , which are ultimately controlled by the control voltage V_c [1], as shown in Figure 1. With $K = K_n = \frac{1}{2}(\frac{W}{L})_{M1} \cdot \mu_n C_{ox} = K_p = \frac{1}{2}(\frac{W}{L})_{M2} \cdot \mu_p C_{ox}$, and $V_{DD} = -V_{SS} = 0.9V$, the gain can be expressed as

$$A_V = \frac{g_{min}}{g_{mload}} = \sqrt{\frac{(W/L)_{input} I_{C2}}{(W/L)_{load} I_{C1}}} \\ = \sqrt{\frac{(W/L)_{input}}{(W/L)_{load}} \cdot \frac{\frac{I_0}{K(V_{DD}-|V_{TH}|)^2} + (1 + \frac{V_C}{V_{DD}-|V_{TH}|})^2}{\frac{I_0}{K(V_{DD}-|V_{TH}|)^2} + (1 - \frac{V_C}{V_{DD}-|V_{TH}|})^2}} \quad (1)$$

g_{min} and g_{mload} are the transconductances of $M_{17,20}$ and $M_{18,19}$ respectively. The equation (1) can be rewritten as

$$A_V(V_c) = \sqrt{\frac{(W/L)_{input}}{(W/L)_{load}}} \cdot \sqrt{\frac{k + (1 + a \cdot V_c)^2}{k + (1 - a \cdot V_c)^2}} \quad (2)$$

, where $k = \frac{I_0}{K(V_{DD}-|V_{TH}|)^2}$, and $a = \frac{1}{V_{DD}-|V_{TH}|}$.

Equation(2) exhibits decibel linear property for $k \leq 1$ [1]. The gain variation of proposed VGA can be controlled by $\sqrt{\frac{(W/L)_{input}}{(W/L)_{load}}}$ and by $k \propto \frac{I_0}{K}$.

With $|V_{th}| \approx 0.43$ and choosing $\frac{(W/L)_{input}}{(W/L)_{load}} = 50$, the ideal gain vs V_c at different values of k is shown in Figure 2.

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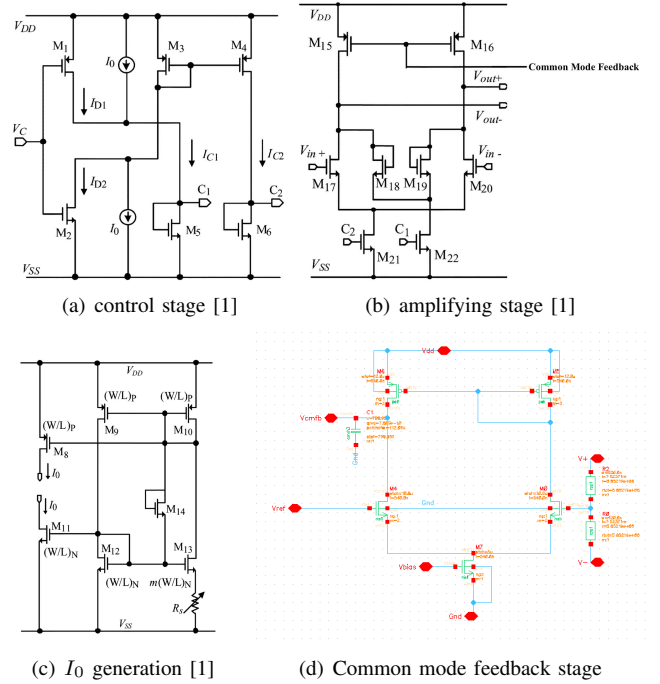


Fig. 1. Schematics of VGA

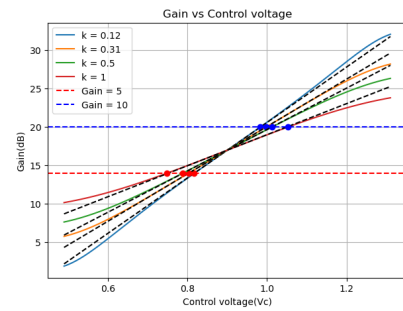


Fig. 2. Gain(dB) vs $V_c(V)$ at different k for $\frac{(W/L)_{input}}{(W/L)_{load}} = 50$

B. Valid range of operation

Each transistor needs to operate in saturation mode so that equation(1) is valid. Therefore, the dimension of control stage needs to satisfy Equation(3), and the dimension of amplifying stage needs to satisfy Equation(4).

The output voltage swing may cause one of M_{18} and M_{19} locked in cut off mode, as shown in Figure 3. Equation(5) needs to be held to avoid such undesired equilibrium.

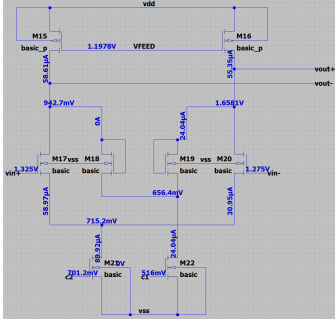


Fig. 3. Example of M18 or M19 locked in cutoff region

$$\begin{aligned}
 V_D^{M2} &= V_{DD} - (|V_{th}| + \sqrt{\frac{(W/L)_{M2} \cdot \mu_n C_{ox}}{(W/L)_{M3} \cdot \mu_p C_{ox}} \cdot (V_C - |V_{th}|)}) \\
 &> V_C - |V_{th}| \\
 &\rightarrow \frac{(W/L)_{M3}}{(W/L)_{M2}} > \frac{\mu_n C_{ox}}{\mu_p C_{ox}} \cdot \left(\frac{V_C - |V_{th}|}{V_{DD} - V_C} \right)^2 \\
 V_D^{M1} &= |V_{th}| + \sqrt{\frac{(W/L)_{M1} \cdot \mu_p C_{ox}}{(W/L)_{M5} \cdot \mu_n C_{ox}} \cdot (V_{DD} - V_C - |V_{th}|)} \\
 &< V_C + |V_{th}| \\
 &\rightarrow \frac{(W/L)_{M5}}{(W/L)_{M1}} > \frac{\mu_p C_{ox}}{\mu_n C_{ox}} \cdot \left(\frac{V_{DD} - V_C - |V_{th}|}{V_C} \right)^2 \quad (3)
 \end{aligned}$$

$$V_G^{M21} < |V_{th}| + V_{in-min} + \sqrt{\frac{2 \cdot (I_{C2}/2)}{(W/L)_{M17,M20} \cdot \mu_n C_{ox}}}$$

$$V_G^{M22} < |V_{th}| + V_{out-min} + \sqrt{\frac{2 \cdot (I_{C1}/2)}{(W/L)_{M18,M19} \cdot \mu_n C_{ox}}} \quad (4)$$

$$\begin{aligned}
 V_{out1} - V_{GS1} &< V_{out2} - |V_{th}| \\
 \rightarrow \Delta V_{out} &= 500mV < V_{GS1} - |V_{th}| = \sqrt{\frac{2 \cdot I_{C1}}{(W/L)_{load} \cdot \mu_n C_{ox}}} \quad (5)
 \end{aligned}$$

C. I_0 generation and Common Mode Feedback circuits

The I_0 generation and Common Mode Feedback (CMFB) circuits are shown in Figure 1. The I_0 generator is adopted from [1], which provides self-biased and supply-invariant currents. We chose a fixed resistance R_s instead of variable one like [1]. The theoretical currents generated are

$$I_0 = \frac{2}{\mu_n C_{ox} (W/L)_n} \cdot \frac{1}{R_s^2} \cdot \left(1 - \frac{1}{\sqrt{m}}\right)^2 \quad (6)$$

The CMFB is implemented with an Operational Transconductance Amplifier (OTA) and linear resistors. The common mode signal is obtained through voltage divider of the two resistors. The difference of common mode voltage and the reference voltage is amplified through an OTA, which is then is connected to the gates of M15 and M16. This forms an incompatible association and have a very large gain.

TABLE I
W/L FOR EACH TRANSISTORS

Control stage		I0 generator		Amplifying stage	
M1	2.27u/540n	M8	1u/540n	M15	21.6u/540n
M2	795n/540n	M9	1u/540n	M16	21.6u/540n
M3	2.72u/540n	M10	1u/540n	M17	10.8u/540n
M4	2.27u/540n	M11	335n/540n	M18	650n/1.625u
M5	32.4u/540n	M12	335n/540n	M19	650n/1.625u
M6	2.27u/540n	M13	350n/540n	M20	10.8u/540n
		M14	6u/540n	M21	32.4u/540n
				M22	32.4u/540n

TABLE II
COMPARISON BETWEEN THIS WORK AND THE PREVIOUS WORK

Ref	technology	# of stages	gain variation	allowable swing	power
[1]	180nm/1.8V	2	95dB	NA	6.5mW
This work	180nm/1.8V	1	3dB	500mV	360uW

III. SIMULATION RESULTS

$k = 0.31$ is chosen in our implementation. The final dimension of each transistor is shown in the Table I, and the layout is shown in Figure 4. The area is large since linear resistor is used. The maximum currents $IC1+IC2$ is 93uA, implying that the total current is roughly 200uA and total power of 360uW. The current may be further reduced to save power. The specification comparison can be shown in Table II.



Fig. 4. Combined layout of overall VGA

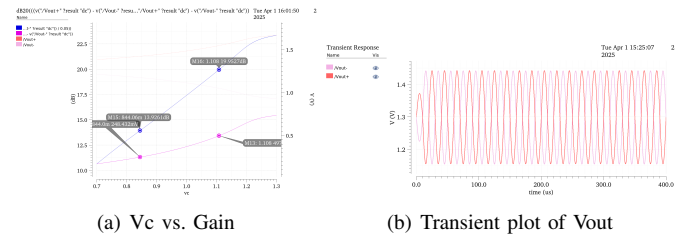


Fig. 5. Simulation results: Gain plot and transient response

IV. CONCLUSION

A single stage differential VGA is proposed for MEMS analog front end, featuring a relatively large voltage swing of 500mV peak-to-peak. The implemented results exhibit sub milliwatts level power consumption but at the expenses of large area due to the linear resistors.

REFERENCES

- [1] D.Quoc-Hoang, L.Quan, K. Chang-Wan, L. Sang-Gug, "A 95-dB Linear Low-Power Variable Gain Amplifier," *IEEE Transactions on Circuits and Systems*, vol. 53, no. 8, pp. 1648 - 1657, 2006.