IDEC Chip Design Contest

Low-Noise Resistive Sensor Interface Circuit with Chopper-Stabilized Multi-Path Current-Feedback Instrumentation Amplifier

Donggeun You[1], Hyungseup Kim[1], Hyunwoo Heo[1], Yongsu Kwon[1], and Hyoungho Ko[1,*]

[1]Department of Electronics Engineering, Chungnam National University, Daejeon 34134, Republic of Korea
*Corresponding Author (E-mail: hhko@cnu.ac.kr)

ABSTRACT

This paper presents low-noise resistive sensor interface circuit with chopper-stabilized multi-path current-feedback instrumentation amplifier (CFIA). The input voltage of the readout IC changes owing to a change in input resistance and is efficiently amplified using a 3-operational amplifier instrumentation amplifier (IA) structure with high input impedance and adjustable gain. Furthermore, a chopper-stabilized multipath structure is applied to the operational amplifier in the 3-opamp IA for low noise and wide bandwidth, and a ripple reduction loop (RRL) in the low frequency path (LFP) is employed to attenuate the ripple generated by the chopper stabilization technique. A 12-bit successive approximation register (SAR) analog-to-digital converter (ADC) is employed to convert the output voltage of the 3-opamp IA into digital code. The resistive sensor interface circuit is manufactured using standard 0.18 µm complementary metal-oxide-semiconductor (CMOS) technology and draws 833 µA current from a 1.8 V supply. The input range and the input referred noise are ± 20 mV and 24.88 nV/√Hz, respectively.

INTRODUCTION

- Resistive sensors are utilized in a wide variety of applications and resistive sensor interface circuit is gradually increasing.
- The resistance-to-voltage conversion has a large dynamic range but can produce nonlinear outputs due to effects of noise and the non-zero offset of the operational amplifier.
- In order to minimize this non-linearity, a precise instrumentation amplifier (IA) with low noise and offset is required.
- The chopper stabilization technique is commonly implemented techniques for low noise and offset, but it has the disadvantage of a low bandwidth.
- In this paper, low-noise resistive sensor interface circuit with chopper-stabilized multi-path current-feedback instrumentation amplifier is presented.
- A chopper stabilized multi-path operational amplifier with high-frequency path (HFP) and low-frequency path (LFP) is used for wider bandwidth.
- A ripple rejection loop (RRL) is applied to minimize "ripple" caused by chopper.
- The sensor interface circuits consists of multi-path operational amplifiers, a fully-differential amplifier and successive approximation analog-to-digital converter (SAR ADC) is implemented to convert the analog to digital signal.

CIRCUIT IMPLEMENTATION

- Resistive sensor interface circuit
  - The proposed resistive sensor interface circuit consists of IA consisting of a 3-operational amplifier structure, a Sallen-key low pass filter (LPF), a buffer, and a SAR ADC.

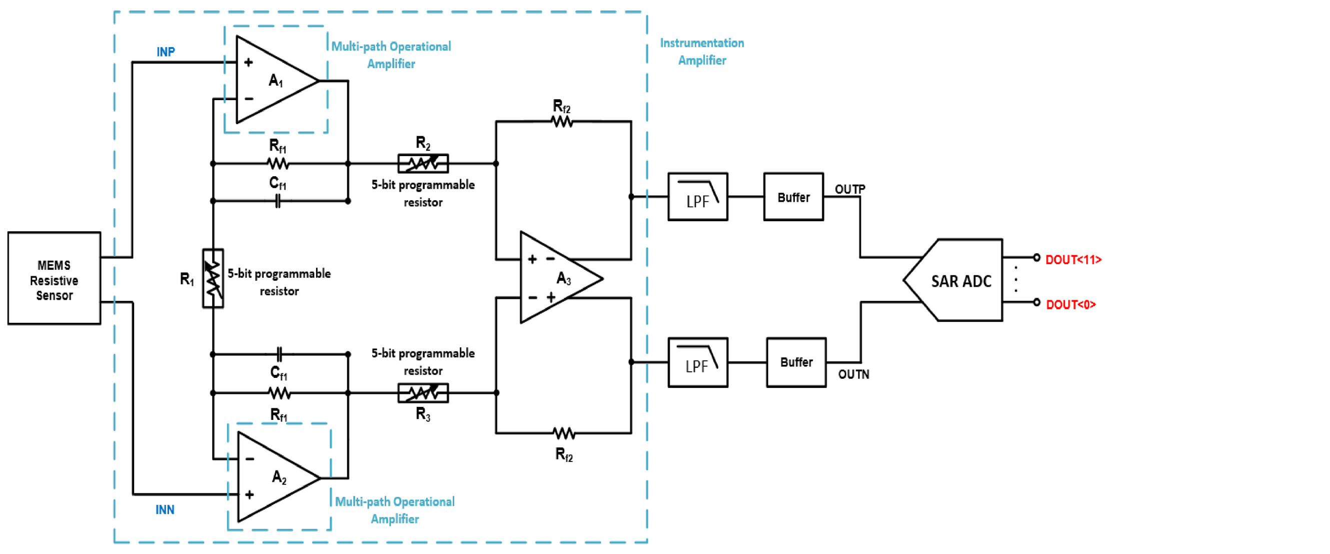

Fig. 1. Architecture of the proposed resistive sensor interface circuit

- Operation of proposed resistive sensor interface circuit
  - The micro-electromechanical systems (MEMS) resistive sensor is typically made up for a Wheatstone bridge structure and the output voltage.
  - The output voltage generated by MEMS sensor is amplified by transfer function expressed as:

$$\frac{V_{OUTP} - V_{OUTN}}{V_{INP} - V_{INN}} = \left(1 + \frac{2R_{f1}}{R_1}\right)\left(\frac{R_{f2}}{R_2}\right) \quad (1)$$

- Operating principle of multi-path operational amplifier
  - The high-frequency bypass technique is implemented for high-frequency and high-gain amplifiers, which are applied via G_{m1}, G_{m2}, and G_{m3}. Also, nested miller compensation (NMC) is applied through C_5 to compensate for the HFP.
  - The chopper stabilization technique is implemented to lower 1/f noise in LFP
  - The "ripple" caused by chopper is suppressed by an RRL consisting of G_{m7} and G_{m8}

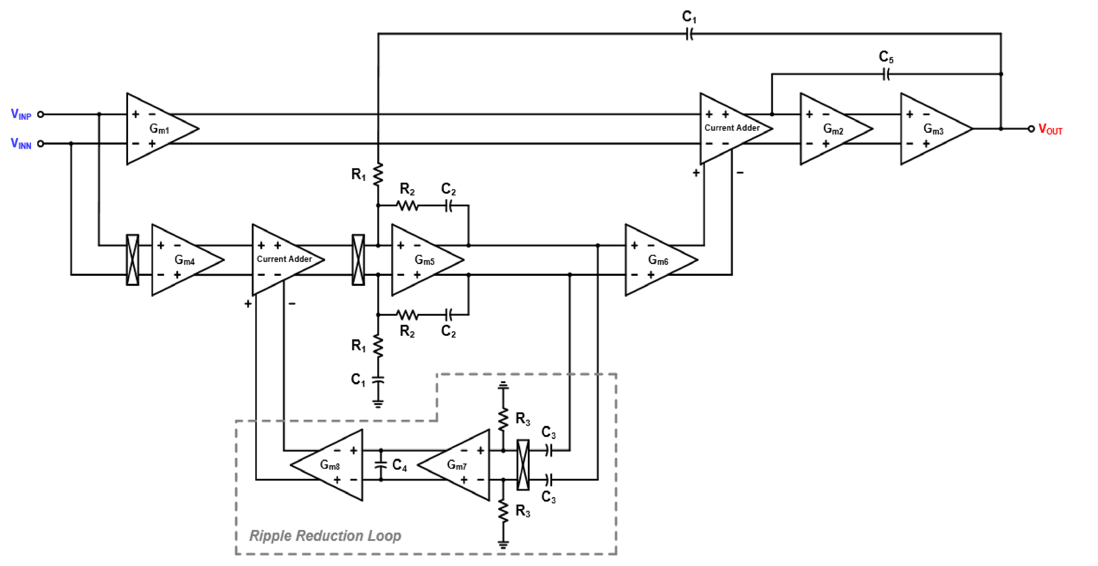

Fig. 2. Architecture of the proposed multi-path operational amplifier

EXPERIMENTAL RESULT

- Die photograph and measured transfer function

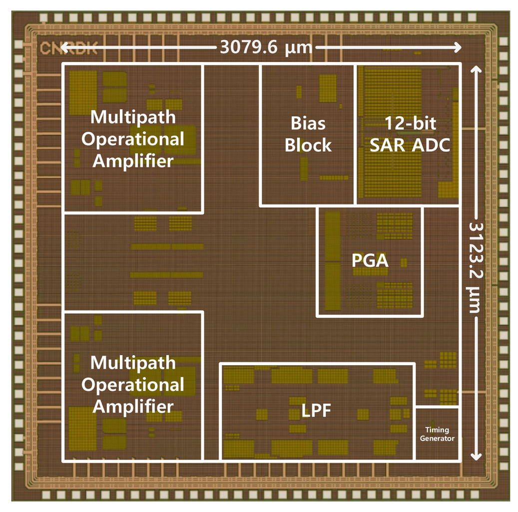

Fig. 3. Die photograph of the fabricated chip

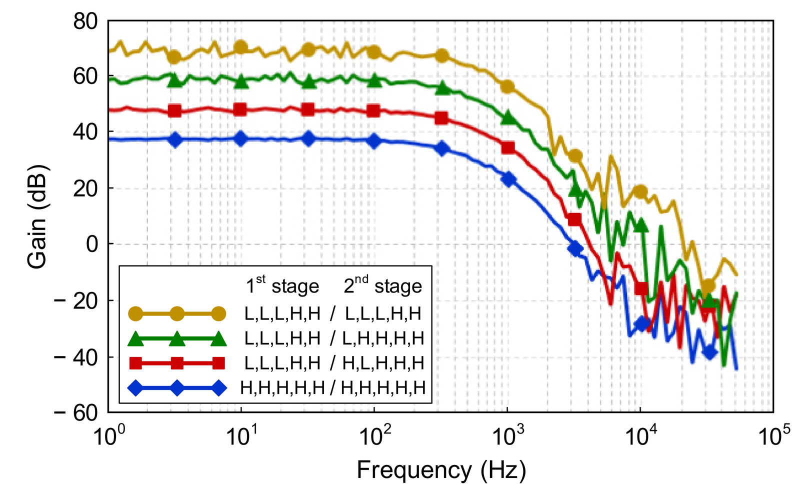

Fig. 4. Measured transfer function

- Measured data of resistive sensor interface circuit

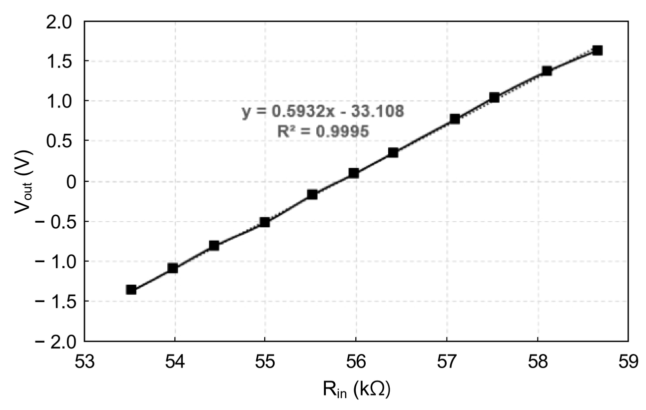

Fig. 5. Voltage output based on input resistance

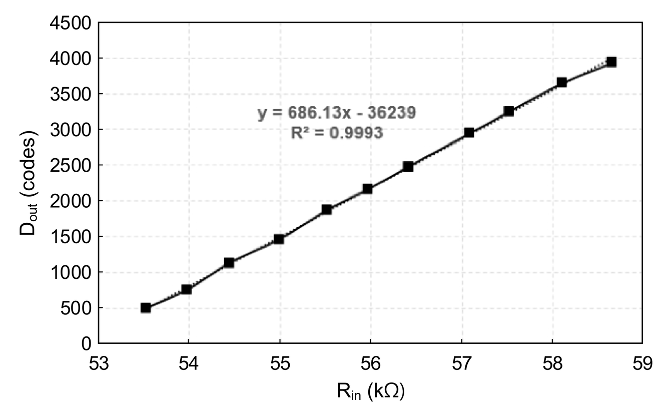

Fig. 6. Digital code output based on input resistance

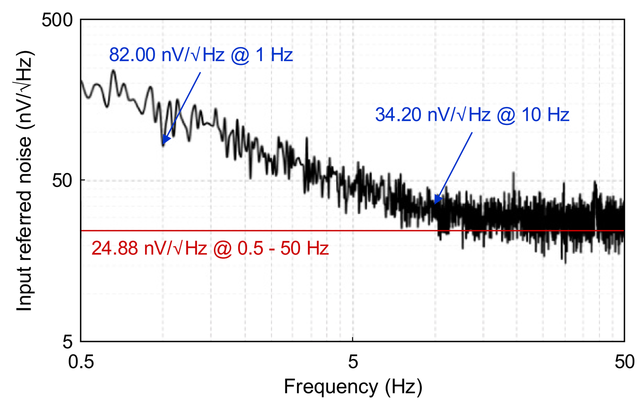

Fig. 7. Measured input referred noise

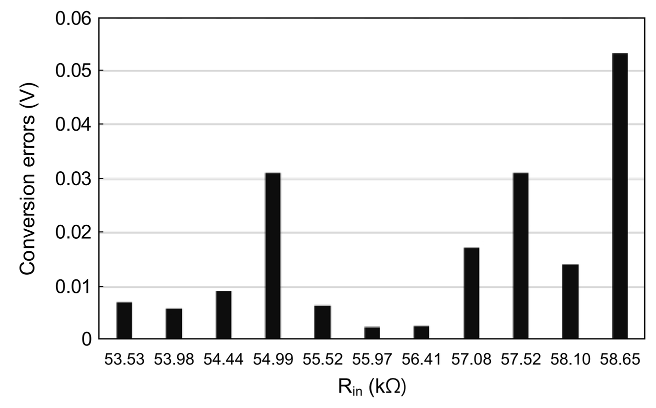

Fig. 8. Conversion errors based on input resistance.

Table. 1. Performance comparison : summary of measured parameters

	This work	K. C. Koay, et al. (2016)	G. T. Ong, et al. (2016)	Rong. W, et al. (2012)	Chih-Jen. Y, et al. (2004)
Year	2019	2016	2016	2012	2004
Technology (µm)	0.18	0.065	0.18	0.7	0.5
Techniques for IA	chopping + multipath	correlated double sampling	chopping	chopping	conventional
Supply voltage (V)	1.8	1	2.7	5	2.5
Supply current (µA)	833	12.3	27.65	270	61
Gain of IA	38-70	100	40	40	20
Input range (mV)	± 20	± 9.38	± 8.8	± 40	-
Input referred noise (nV/√Hz)	24.88	347.85	84.08	16.2	175
RRL	Y	N	N	Y	N
NEF	27.61	46.9	17	10.23	52.54

CONCLUSION

- The proposed resistive sensor interface circuit consists of a 3-operational amplifier IA, LPF, buffer and 12-bit SAR ADC.
- The chopper-stabilized multi-path operational amplifier consists of and HPF and LFP with chopping technique applied to reduce noise.
- The RRL is implemented to reduce the ripple generated by chopper.
- The input noise voltage density is measured at 24.88 nV/√Hz over the 0.5–50 Hz range.

ACKNOWLEDGEMENT

- The chip fabrication and EDA tool were supported by the IC Design Education Center (IDEC), Korea

CHUNGNAM NATIONAL UNIVERSITY
Department of Electronics Engineering
99 Daehak-ro, Yuseong-gu, Daejeon 34134, Republic of Korea

INTEGRATED CIRCUIT DESIGN LABORATORY
PHONE: +82-42-821-6285, EMAIL: hhko@cnu.ac.kr
Department of Electronics Engineering, Chungnam National University

반도체설계교육센터
IC DESIGN EDUCATION CENTER