Chip Design Contest

Open-loop Nanoresonator Integrated Circuit for Motional Resistance Sensing

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ABSTRACT

A nanoresonator can be applied as a bio/chemical sensor by changing the mass of the nanoresonator, and the mass change can be interpreted in the frequency domain. In this paper, we present an open-loop spectrum analyzer integrated circuit (IC) for a nanoresonator. The circuit determines the frequency characteristics of a nanoresonator, such as quality factor (Q-factor) and resonant frequency, and detects minute resistance changes of the nanoresonator that result in changes in Q-factor or resonant frequency. The proposed resonator driving circuit is implemented using an open-loop system, and to characterize the open-loop frequency response of the nanoresonator, the IC includes a voltage-controlled oscillator (VCO), a transimpedance amplifier (TIA), and a 16-bit delta-sigma analog-to-digital converter (ADC). For the compensation of the parasitic components that cause the distortions of the phase and magnitude response, a shunt-capacitance cancelling amplifier is used to cancel the effect of the shunt-parasitic capacitance of the nanoresonator. The simulated target nanoresonator is modeled by the Butterworth–Van Dyke equivalent circuit model with a resonant frequency of 10 MHz. The proposed nanoresonator driver circuit is fabricated using a standard 0.18 µm complementary metal oxide semiconductor (CMOS) process with an active area of 2.346 mm2. The simulated resistive sensitivity of the IC is 5.1 mV/kΩ.

INTRODUCTION

- The resonator driving circuit that reads out the motional resistance or inductance change can be applied to resonator-based bio/chemical sensors.
- One of the two main systems for driving a resonator, a closed-loop system using self-sustained oscillation and the resonant frequency tracking method, it is difficult to oscillate at an accurate resonant frequency if it has low Q-factor.
- The distortions of the phase and magnitude response caused by the effect of parasitic components should be adjusted.
- In the open-loop system, the resonant frequency and Q-factor can be obtained from a full frequency response curve, although in the case of low Q-factor or multiple resonant frequency.
- In this paper, an open-loop on-chip spectrum analyzer IC for a nanoresonator is presented.
- The IC determines the resonant frequency and Q-factor from the full frequency response curve of the resonator.
- The shunt capacitance cancelling amplifier is used to cancel the effect of the parasitic shunt capacitance.
- The proposed circuit is fully integrated into a single chip and implanted into the human body, which can be applied as a bio/chemical sensor for the continuous monitoring of blood glucose and blood pressure.

CIRCUIT IMPLEMENTATION

- The open loop spectrum analyzer circuit
  - The proposed open loop spectrum analyzer consists of IA consisting of a voltage-controlled oscillator(VCO), TIA, peak detector (PD), LPF, and buffer.

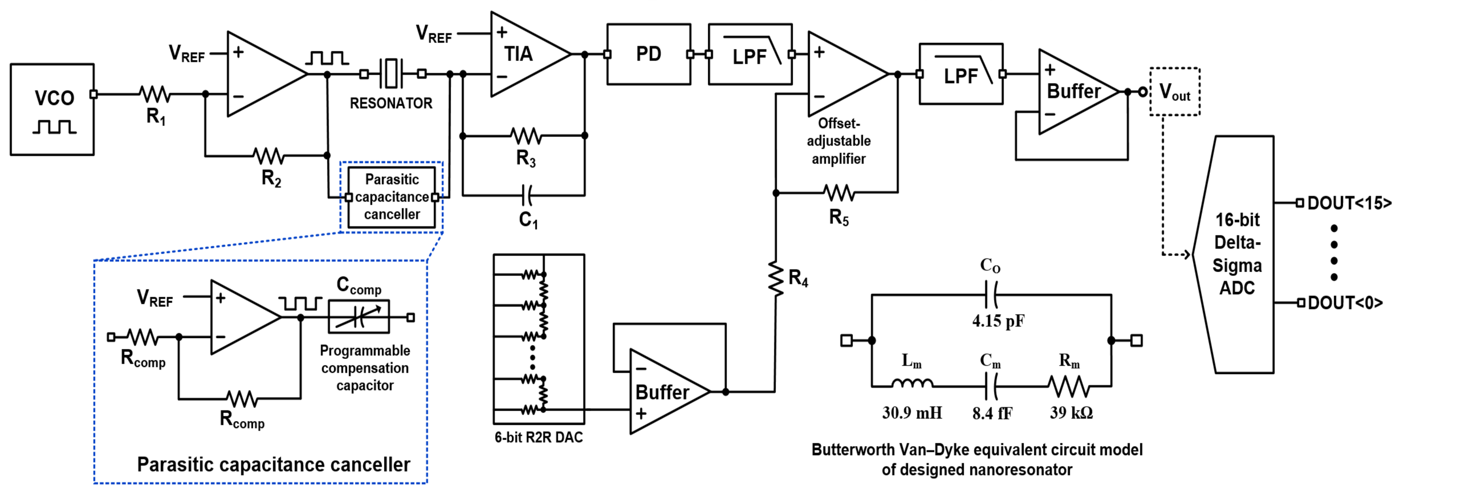


Fig. 1. Proposed architecture of the open-loop spectrum analyzer.

- Operation of proposed open loop spectrum analyzer circuit.
  - The output current of the resonator driven by the VCO is presented into the TIA and converted into an amplified voltage.
  - At the resonant frequency, the series inductance Lm and capacitance Cm cancel each other out.
  - The gain from the input of the resonator to the output of the TIA at the resonant frequency can be expressed as :

$$A_{TIA} = -\frac{R_3}{R_m} \cdot \frac{1}{1 + sC_1R_3} \quad (1)$$

  - For the implemented wide input range, M1 and M2 constitute the folded input stage and the cascode stage, M3-M10, secondly amplifies the input signal.
  - The output stage used Monticelli class AB, consisting of M11-M16, achieving power efficiency.
  - The Miller capacitor Cm is used to compensate for frequency stability.

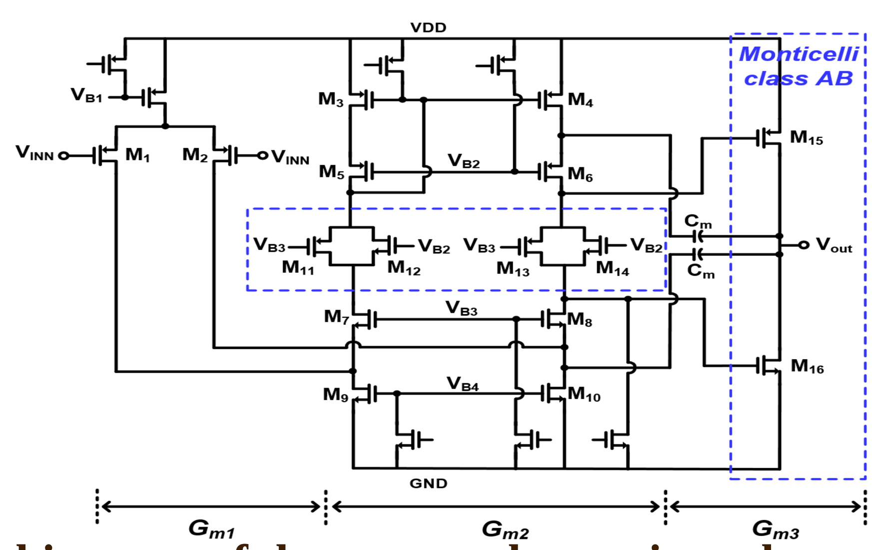


Fig. 2. Architecture of the proposed trans impedance amplifier (TIA)

EXPERIMENTAL RESULT

- Die photograph and measured 6-bit R2R DAC output

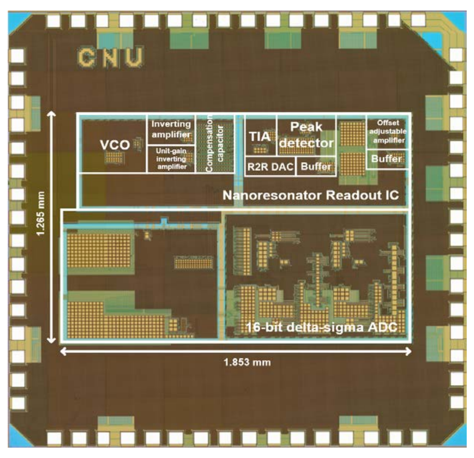


Fig. 3. Die photograph of the fabricated chip

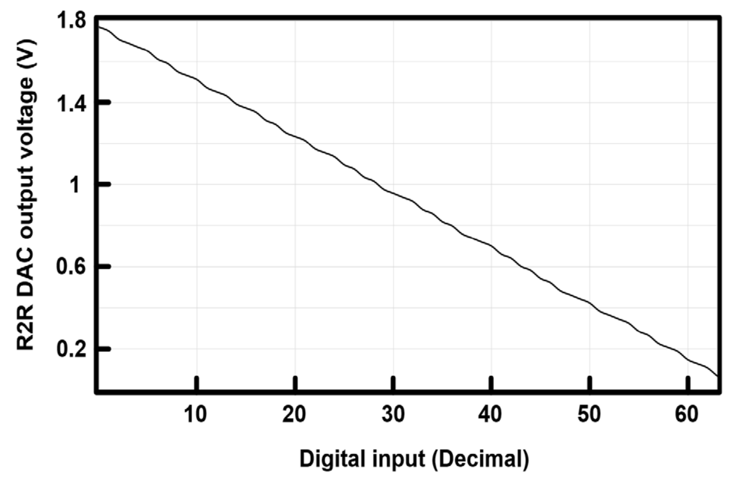
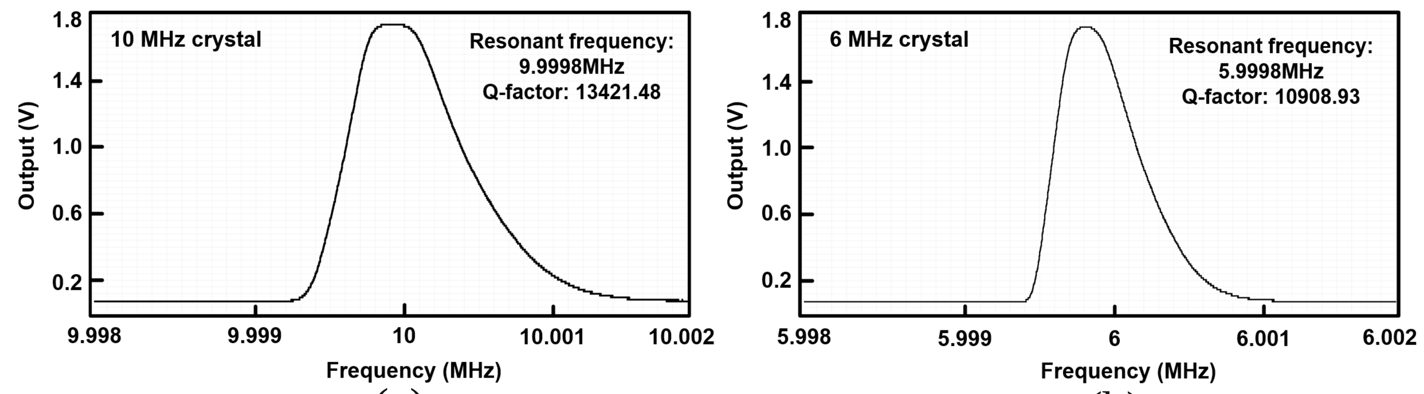


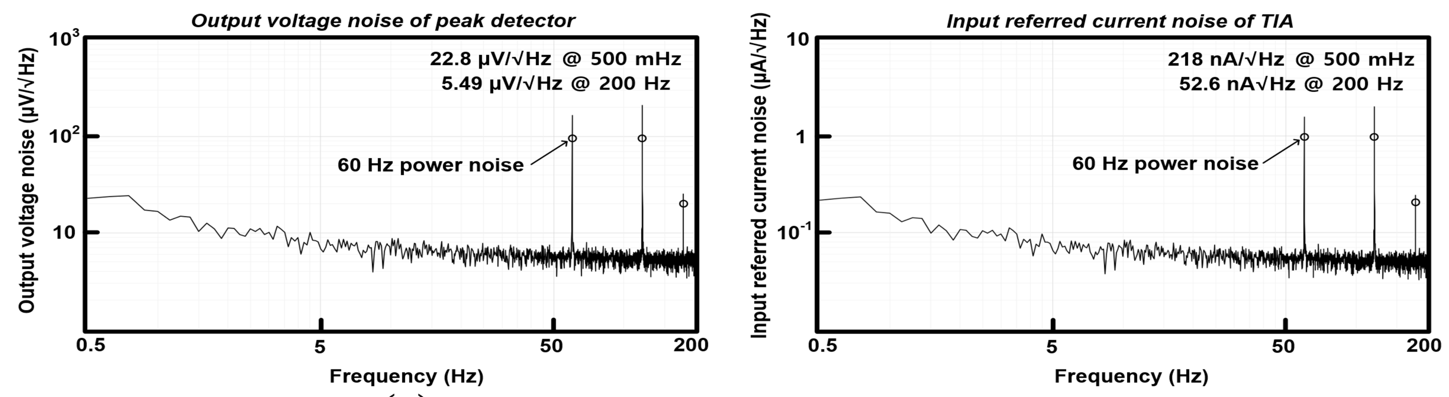
Fig. 4. Measured 6-bit R2R DAC output

- Measured data of buffer output using crystals



(a) (b)

Fig. 5. Results of buffer output measurement using crystals with resonant frequencies of (a) 10 and (b) 6 MHz.



(a) (b)

Fig. 6. Results of (a) PD output voltage noise and (b) TIA input referred current noise.

Table. 1. Performance comparison : summary of measured parameters

	This work	F. Nabki et al. (2008)	S. Seth, et al. (2012)	E. Marigo, et al. (2013)
Technology (µm)	0.18	0.18	0.35	0.35
Supply voltage (V)	1.8	2	2.5	7
Power consumption (mW)	5.92	8.7	6.9	18
Frequency (MHz)	10	8.29	20	25.6
Q-factor	13,421	1,040	160,000	334
Input referred current noise (nA/√Hz)	52.6	-	-	-
Resistive sensitivity (mV/kΩ)	5.1	-	-	-
Architecture	Open-loop	Closed-loop	Closed-loop	Closed-loop
Parasitic cancellation	Yes	No	No	No
Active area (mm²)	2.346	0.24	0.15	0.006
Technology (µm)	0.18	0.18	0.35	0.35

CONCLUSION

- The proposed open-loop on-chip spectrum analyzer IC operates as a spectrum analyzer of a nanoresonator that can obtain a full frequency curve and detect the frequency characteristics of the nanoresonator such as the resonant frequency and Q-factor.
- The total power consumption of the IC is 5.92 mW with a 1.8 V supply and has a resistive sensitivity of about 5.1 mV/kΩ.

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