(SD2018-069) A Wide Dynamic Range Current Measurement Front-End (Patent No. 11,320,468)

Tech ID: 30319 / UC Case 2018-069-0

BACKGROUND

Accurate current measurement is crucial in many biosensing applications, such as the detection of neurotransmitters and the monitoring of intercellular molecular dynamics. This need has become even more critical recently with single molecule biosensors where sub-pA signal currents are superimposed on a slowly varying nA to µA background current, as is the case with nanopores. As such, the readout circuitry requires wide dynamic range (>120dB) and high linearity (>14b) albeit often with low bandwidth (a few Hz to kHz).

TECHNOLOGY DESCRIPTION

Researchers from UC San Diego have developed and patented a very wide dynamic range current measurement for sensors, including biomedical and other sensor applications. This patented invention achieves 7ppm Integral nonlinearity (INL) and 160dB dynamic range (100fA to 10µA) resulting in state-of-the-art performance in terms of normalized conversion time for a 1nA current (0.04ms) and Schreier FoM (197dB) demonstrating an energy efficient, wide dynamic range, high linearity design for current input biosensors.

APPLICATIONS

This work provides a very wide dynamic range current measurement for sensors, including biomedical and other sensor applications.

PATENT STATUS

Country	Type	Number	Dated	Case
Patent Cooperation Treaty	Published Application	2019060461	03/28/2019	2018-069

Additional Patent Pending

INTELLECTUAL PROPERTY INFO

UC San Diego is seeking commercial partners to develop this patented technology. US patent no.11.320,468 is available for licensing.

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OTHER INFORMATION

KEYWORDS

sensor, biomedical sensor, Linearity, Current measurement, Biosensors, Dynamic range, analogue-digital conversion, delta-sigma modulation, readout electronics, electric current measurement, single-molecule biosensors, modified asynchronous modulator architecture, oscillator-based Hourglass ADC, noise shaping, digital linearity correction technique, amplifier bandwidth, current measurement front-end

CATEGORIZED AS

- **Sensors & Instrumentation**
  - Biosensors

RELATED CASES

2018-069-0

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(54) **WIDE DYNAMIC RANGE CURRENT MEASUREMENT FRONT-END**

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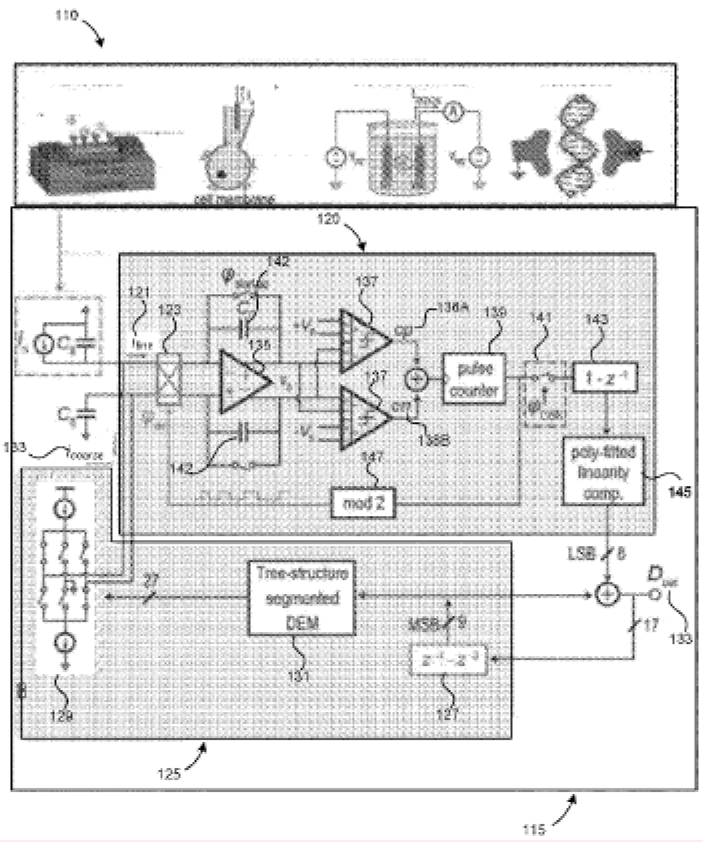
CPC *G01R 19/255* (2013.01); *H03M 3/458* (2013.01); *H03M 1/12* (2013.01); *G01N 33/483* (2013.01)

(57) **ABSTRACT**

In one aspect, an analog-to-digital converter circuit includes a transimpedance amplifier including a feedback capacitor electrically connected between an inverting or a non-inverting input of the transimpedance amplifier and an output of the transimpedance amplifier. The circuit includes an hourglass switch electrically connected on a first side to a first input and a second input, and electrically connected on a second side to the non-inverting input and the inverting input. A fine input current to the transimpedance amplifier is received at the first and second inputs. In a first mode, the hourglass switch electrically connects the first input to the non-inverting input and the second input to the inverting input, and in a second mode, the hourglass switch electrically connects the second input to the non-inverting input and the first input to the inverting input.



RELATED MATERIALS

▶ Chung-Lun Hsu and Drew Hall. A Current-Measurement Front-End with 160dB Dynamic Range and 7ppm INL. International Solid-State Circuits Conference (ISSCC - 02/14/2018

OTHER INFORMATION

Allowed Patent Claims.

1. An analog-to-digital converter circuit comprising:

a transimpedance amplifier including a feedback capacitor, wherein the transimpedance amplifier has a non-inverting input and an inverting input, and wherein the capacitor is electrically connected between the inverting or non-inverting input and an output of the transimpedance amplifier; and

an hourglass switch electrically connected on a first side to a first input and a second input, and electrically connected on a second side to the non-inverting input and the inverting input, wherein a fine input current to the transimpedance amplifier is received at the first and second inputs, wherein in a first mode the hourglass switch electrically connects the first input to the non-inverting input and the second input to the inverting input, and wherein in a second mode, the hourglass switch electrically connects the second input to the non-inverting input and the first input to the inverting input.

2. The analog-to-digital converter circuit as in claim 1, further comprising:

a linear digital-to-analog converter electrically connected to the first and second inputs, wherein the linear digital-to-analog converter generates a coarse current to remove from an input current leaving the fine input current as input current to the transimpedance amplifier at the first and second inputs.

3. The analog-to-digital converter circuit as in claim 2, further comprising:

a comparator electrically connected to the output of the transimpedance amplifier and a reference voltage, wherein when the output exceeds the reference voltage the comparator generates a pulse, and wherein the pulse causes the hourglass switch to switch from the first mode to the second mode or the second mode to the first mode.

4. The analog-to-digital converter circuit as in claim 3, further comprising:

a pulse counter electrically connected to the comparator to count pulses from the comparator including the pulse, wherein the pulse counter is representative of the fine input current.

5. The analog-to-digital converter circuit as in claim 1, wherein the hourglass switch is a cross-point switch or a cross-bar switch.

6. The analog-to-digital converter circuit of claim 2, wherein the linear digital-to-analog converter comprises a first order predictor, a dynamic element matching circuit, and a binary-weighted digital-to-analog converter.

7. The analog-to-digital converter circuit as in claim 6, wherein the first order predictor estimates the input current for a next oversampling cycle and controls the binary-weighted digital-to-analog converter to generate the coarse current to be removed from the input current leaving the fine input current.

8. The analog-to-digital converter circuit as in claim 1, further comprising:

one or more sensors including one or more of a nanotube sensor, a patch-clamp sensor, an electro-chemical sensor, or a nanopore sensor, wherein the one or more sensors provide the input current.

9. The analog-to-digital converter circuit as in any of claims 2, wherein the coarse current removed from the input current reduces a range of the fine current causing an improved linearity of the analog-to-digital converter circuit.

10. The analog-to-digital converter circuit as in claim 1, wherein the hourglass switches asynchronously between the first mode or the second mode to prevent the feedback capacitor from saturating.

11. The analog-to-digital converter circuit as in claim 1, wherein the input current lies in a range between 100 femtoamps and 10 microamps.

12. The analog-to-digital converter circuit as in claim 1, wherein the hourglass switch and the linear analog to digital converter cause the analog-to-digital converter circuit to have a dynamic range of 160 dB or more.

13. The analog-to-digital converter circuit as in claim 1, wherein the hourglass switch and the linear analog to digital converter cause the analog-to-digital converter circuit to have a Schreier figure of merit equal to or greater than 197dB.

14. A method of representing an analog voltage by a digital binary value comprising:

integrating, by a transimpedance amplifier including a feedback capacitor, a fine input current, wherein the transimpedance amplifier has a non-inverting input and an inverting input;

selecting a polarity of the fine input current by switching between a first mode, wherein a first input is connected to a non-inverting input to the transimpedance and a second input is connected to an inverting input to the transimpedance amplifier, or a second mode, wherein the first input is connected to the inverting input to the transimpedance and the second input is connected to the non-inverting input to the transimpedance amplifier, wherein an hourglass switch asynchronously selects the mode to be the first mode or the second mode to prevent the feedback capacitor from saturating; and removing a coarse current from an input current to the transimpedance amplifier, wherein the input current is equal to the fine input current added to the coarse current, wherein the coarse current removed from the input current reduces a range of the fine current and improves a linearity between the analog input voltage and the digital binary value.

15. The method of claim 14, further comprising:

comparing, by a comparator, an output of the transimpedance amplifier to a reference voltage, wherein when the output exceeds the reference voltage the comparator generates a pulse, and wherein the pulse causes the hourglass switch to switch from the first mode to the second mode or the second mode to the first mode.

16. The method of claim 15, further comprising:

counting pulses from the comparator including the pulse, wherein a count of the pulses is representative of the fine input current.

17. The method of claim 14, wherein the hourglass switch is a cross-point switch or a cross-bar switch.

18. The method of claim 14, wherein the coarse current is estimated by a linear digital-to-analog converter comprises a first order predictor, a dynamic element matching circuit, and a binary-weighted digital-to-analog converter.

19. The method of claim 18, wherein the first order predictor estimates the input current for a next oversampling cycle and controls the binary-weighted digital-to-analog converter to generate the coarse current to be removed from the input current leaving the fine current as the first and second inputs to the hourglass switch.

20. The method of claim 14, further comprising:

generating the input current by one or more sensors including one or more of a nanotube sensor, a patch-clamp sensor, an electro-chemical sensor, or a nanopore sensor, wherein the one or more sensors provide the input current.

21. The method of claim 14, wherein the input current lies in a range between 100 femtoamps and 10 microamps.

22. The method of claim 14, wherein a circuit performing the method has a dynamic range of 160 dB or more.

23. The method of claim 14, wherein a circuit performing the method has a Schreier figure of merit equal to or greater than 197dB.

24. An analog-to-digital converter circuit comprising:

a transimpedance amplifier including a feedback capacitor, wherein the transimpedance amplifier has a non-inverting input and an inverting input, and wherein the capacitor is electrically connected between the inverting or non-inverting input and an output of the transimpedance amplifier; and

an hourglass switch electrically connected on a first side to a first input and a second input, and electrically connected on a second side to the non-inverting input and the inverting input.

25. The analog-to-digital converter circuit as in claim 24, further comprising:

a linear digital-to-analog converter electrically connected to the first and second inputs, wherein an input current is received at the first and second inputs.

26. The analog-to-digital converter circuit as in claim 24, wherein in a first mode the hourglass switch electrically connects the first input to the non-inverting input and the second input to the inverting input, wherein in a second mode, the hourglass switch electrically connects the second input to the non-inverting input and the first input to the inverting input

27. The analog-to-digital converter circuit as in claim 24 further comprising:

a comparator electrically connected to the output of the transimpedance amplifier and a reference voltage, wherein when the output exceeds the reference voltage the comparator causes the hourglass switch to switch from the first mode to the second mode or the second mode to the first mode.

28. The analog-to-digital converter circuit as in claim 27, further comprising:

a pulse counter to count pulses from the comparator.

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