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A Poly-Resistor Based Temperature Sensing Chip with Digital Output

Lokesh L, Shashidhar Tantry, Karthik M

Abstract: ***This work presents a resistor-based temperature sensing chip which is designed for applications that require temperature sensing. The core of the design is a poly-resistor bridge, which generates two distinct outputs: one varies with temperature and the other provides a constant reference [2]. These outputs are then processed by a differential amplifier, ensuring reliable signal amplification and enhanced separation of the temperature-dependent signal from the reference. The amplified signal is then digitized using a compact 3-bit ADC, that is realized using an 8:3 encoder. The simplified integration of the resistor bridge, differential amplifier, and ADC demonstrates a practical approach for temperature sensing, offering a versatile solution for systems where basic thermal monitoring is essential [3].***

Keywords: ***Poly-Resistors, ADC (Analogue to Digital Converter), Resistor-Bridge, FDDA (Fully Differential Difference Amplifier).***

Abbreviations:
SAR: Successive Approximation Register
CMFB: Common-Mode Feedback
ADC: Analogue-to-Digital Converter
FDDA: Fully Differential Difference Amplifier

I. INTRODUCTION

Temperature sensing is a critical element in industrial automation, consumer electronics, and medical applications. The crucial part in determining the reliability, efficiency, and safety of electronic systems relies on proper thermal monitoring. Along with compact and power-efficient designs, temperature sensors are crucially integrated with signal processing and digital conversion. Resistor-based temperature sensors, especially those utilizing poly resistors, are relatively CMOS-compatible and straightforward. Therefore, these sensors are appropriate for integration in semiconductor-based systems. Temperature sensing based on a resistor relies on the principle that resistance varies with temperature [1]. The output signals from a poly-resistor bridge structure are two: one is proportional to temperature, and the other is a constant reference.

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*Correspondence Author(s)
Prof. Lokesh L, Department of Electronics and Communications, PES University, Bangalore (Karnataka), India. Email: lokeshl@pes.edu, ORCID ID: 0000-0003-4076-9298.
Dr. Shashidhar Tantry, Department of Electronics and Communications, PES University, Bangalore (Karnataka), India. Email: stantry@pes.edu, ORCID ID: 0000-0002-3747-1709.
Karthik M*, Department of Electronics and Communications, PES University, Bangalore (Karnataka), India. Email: pes2202101306@pesu.pes.edu, ORCID ID: 0009-0000-5078-7292.

These signals are processed by a differential amplifier, which amplifies the temperature signal in proportion to the temperature while suppressing noise and unwanted variations [4]. For easy digital integration, the amplified output is converted into a digital output through a 3-bit ADC designed with an 8:3 encoder [6].

The proposed design strikes a balance between simplicity, reliability, and digital compatibility in applications where basic temperature monitoring is required [3]. With the capabilities of poly-resistor technology and efficient analogue and digital processing, this work presents an approach toward effective temperature sensing while maintaining a compact and practical implementation.

II. DESIGN ARCHITECTURE AND FUNCTIONAL BLOCK DIAGRAM

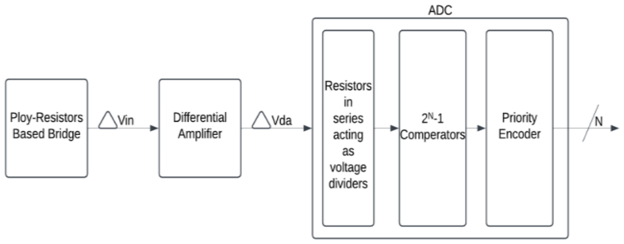
A. Block Diagram

Fig. 1 illustrates the proposed block diagram for the poly-resistor-based temperature sensing system, which incorporates a temperature sensor, a signal conditioning circuit, and an ADC circuit to produce a digital output. First, the proposed system comprises a poly-resistor bridge as its temperature-sensing element. The resistance of the poly-resistors varies with temperature, causing a temperature-sensitive differential voltage, called Vin, which is applied to the following stage.

A differential amplifier amplifies the weak sensor signal while rejecting common-mode noise, thus ensuring the signal is robust enough for further conversion without much loss of accuracy. The amplified output voltage Vda is then forwarded to the ADC for digitization.

The ADC forms a string of resistors, acting as voltage dividers. Those dividers produce reference voltages that one may compare to. The amplified signal is compared by (2^N-1) comparators against these reference voltages, making a thermometer code. The priority encoder then converts that thermometer code to an N-bit digital representation of the sensed temperature [6].

This architecture ensures reliable temperature measurement while maintaining a compact design, which is suitable for integration into low-power applications. The use of poly-resistors enhances the linearity and stability, making this approach ideal for embedded and IoT-based temperature monitoring systems.



[Fig.1: Architecture of the Proposed Temperature Sensing Chip]

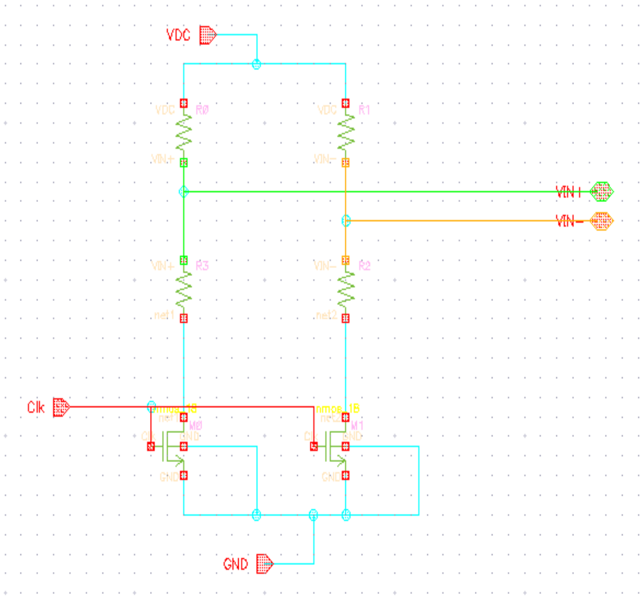
B. Poly-Resistor Based Temperature Sensing Bridge

The temperature-sensing mechanism in this design is based on the predictable temperature-dependent resistance behaviour of polyresistors. In CMOS technologies such as SCL180, poly resistors exhibit a negative temperature coefficient, meaning their resistance decreases with increasing temperature. This behaviour is commonly exploited in compact analogue sensors, as shown in [2]. This property is exploited to convert temperature variations into measurable voltage changes.

The sensing block consists of a voltage divider using two poly resistors, one with exact specifications on one side and the other with different specifications on the other side (refer to Fig. 2). One of the resistors is exposed to the ambient temperature. At the same time, the second serves as a reference or balancing component.

As the temperature changes from -25 °C to 125 °C, the poly resistor's resistance shifts accordingly, causing the output voltage of the sensor to vary. This voltage serves as the input to the amplification stage, making it crucial to preserve signal integrity at this level. This approach keeps the sensor design compact, passive, and easy to lay out during the process, while still delivering a voltage signal that effectively encodes temperature.

$$v_{in+} = \left(\frac{R_B}{(R_a + R_b)} \right) \times V_{dd}$$



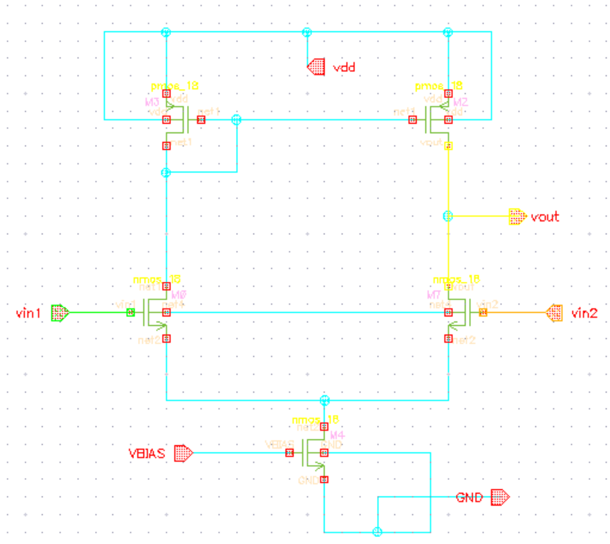
[Fig.2: Poly-Resistor Based Temperature Sensing Bridge]

C. Amplification Stage (FDDA Design)

To enhance the voltage signal generated by the temperature sensor and prepare it for analogue-to-digital conversion, a Fully Differential Difference Amplifier (FDDA)-inspired architecture is used (refer to Fig. 3). While the design preserves differential inputs, it outputs a single-ended signal for compatibility with a single-ended ADC. The differential architecture offers benefits such as improved common-mode noise rejection and better linearity.

The implemented FDDA-inspired amplifier features a differential NMOS input pair that senses the voltage difference from the poly-resistor-based temperature sensing bridge. This differential signal is converted into a single-ended output using active PMOS load devices, which also contribute to voltage gain. A tail current source, formed by an NMOS transistor biased with a constant voltage (VBIAS), ensures stable biasing and controls the overall current through the input stage. Transistor sizing and bias current were selected based on analogue design principles [5].

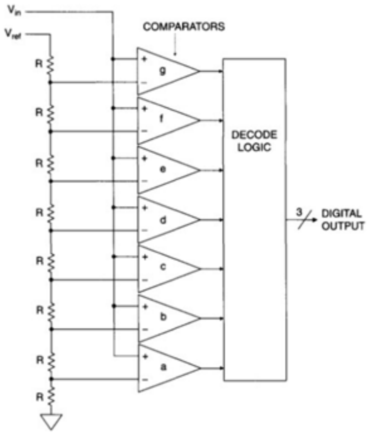
Unlike a traditional FDDA, this design does not incorporate a common-mode feedback (CMFB) circuit, as the output is single-ended and does not require active common-mode regulation. This configuration simplifies the design while still leveraging the benefits of differential sensing, such as noise rejection and improved linearity.



[Fig.3: Amplification Stage (FDDA Design)]

D. ADC Interface and Digital Readout

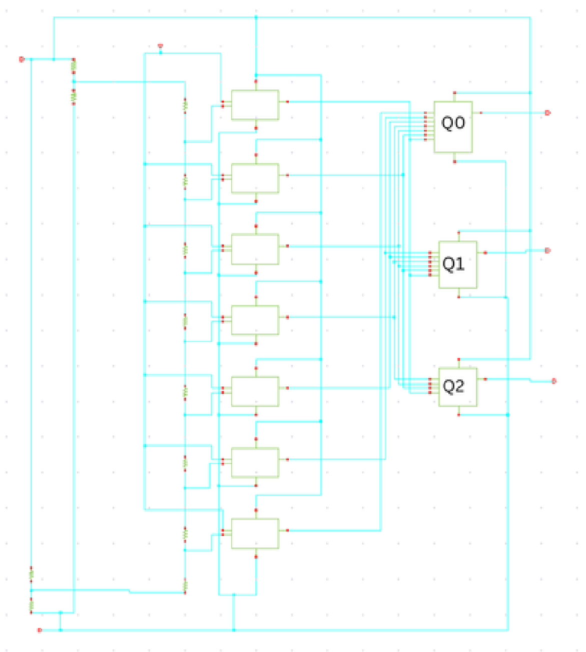
After amplification by the FDDA stage, the analog voltage corresponding to the sensed temperature is digitized using a Successive Approximation Register (SAR) Analogue-to-Digital Converter (ADC), as illustrated in Fig. 4. The SAR ADC was chosen for its accuracy and energy efficiency, making it suitable for temperature sensing where moderate speed is sufficient. The differential output from the FDDA is directly fed to the SAR ADC input, which performs a binary search to generate a digital word representing the sensed temperature. This digital output can then be easily processed, stored, or transmitted within the system.



[Fig.4: ADC Architecture]

The clock signal in this system is utilized solely to control the temperature sensing bridge, enabling a clock-gated operation that activates the sensing path only when required. This helps reduce power consumption by turning off the bridge during idle periods when the clock is low. In contrast, the ADC operates independently of this gating and is triggered as needed based on system-level control, ensuring flexibility and energy efficiency in the overall sensing and conversion process.

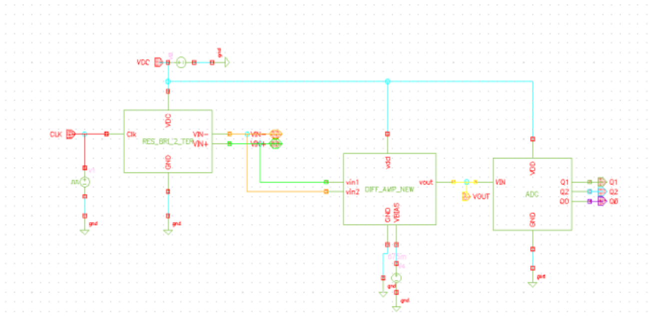
Below is the full ADC Implementation:-



[Fig.5: Full Design of ADC]

III. SIMULATION, VERIFICATION AND RESULTS

The designed temperature sensing system was simulated using Cadence tools with the SCL 180 nm technology node. Simulation analyses were conducted at various levels, starting from the resistor bridge alone, extending to its combination with a fully differential difference amplifier (FDDA), and finally integrating the entire system (refer to Fig. 6).



[Fig.6: Full Design Integration]

A. Resistor Bridge Configuration

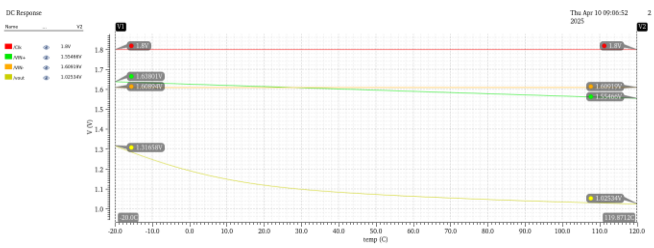
The initial simulations evaluated the behaviour of the resistor bridge independently. A transient analysis was conducted using only a clock waveform oscillating between 0 V and 1.8 V to examine the timing behaviour. The temperature was set to 40°C, resulting in VIN+ and VIN− values of approximately 1.62 V and 1.6089 V, respectively, as determined by the simulated output of the bridge (refer to Fig. 7).

To investigate temperature sensitivity, a DC analysis was performed over a temperature range of 40°C to 120°C. The differential voltage between VIN+ and VIN− demonstrated minimal variation across the temperature sweep, indicating the necessity for further signal amplification to enhance system responsiveness [2].

B. Resistor Bridge with Differential Amplifier

In the second stage, the resistor bridge output was interfaced with a fully differential difference amplifier. Transient simulations revealed amplified output voltages in the range of approximately 1.02534 V to 1.31658 V in response to the same input conditions. This clearly shows a significant improvement in voltage swing compared to the bridge-only configuration.

This validates that the Differential Amplifier not only preserves the temperature-dependent characteristics of the resistor bridge but also provides a substantial gain, thereby enabling easier interfacing with digital stages, such as ADCs or comparators.



[Fig.7: Resistor Bridge behaviour with the Differential Amplifier]

C. ADC Output Behaviour

The analogue-to-digital converter (ADC) section of the design was verified through transient simulations. The outputs q0, q1, and q2 represent a 3-bit digital encoding of the analogue input signal derived from the differential amplifier output. These outputs update

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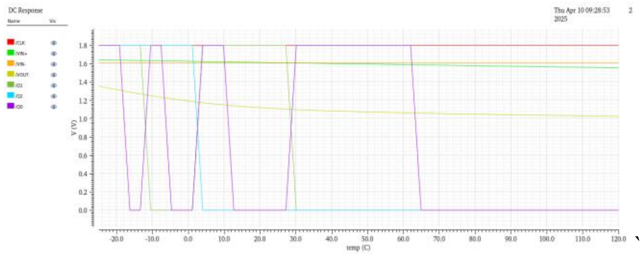
synchronously with the clock signal, effectively digitizing the analog input levels into corresponding binary values. As observed in the simulation, the transitions in q0, q1, and q2 reflect the variations in the input signal, confirming the correct functionality and resolution of the ADC (refer to Fig. 8) [6]. This validates the system's ability to translate temperature-dependent analogue signals into usable digital data.



[Fig.8: Full Design's Simulation]

D. Summary of Simulation Results

Configuration	Input Range (V)	Output Swing (V)	Observations
Resistor Bridge Only	1.55 – 1.63 (VIN+)	~80mV	Weak temperature sensitivity
With FDDA	1.02 – 1.31 (VIN+)	~300mV	Enhanced temperature-dependent gain
Full Design Integration	1.02 – 1.31 (VIN+)	Based on the temperature	System-level verification successful

IV. CONCLUSION

The simulations confirm that the inclusion of a differential amplifier is critical in translating the small differential signals from the resistor bridge into discernible voltage levels suitable for digital interpretation. The system exhibits temperature-dependent behaviour with improved linearity and an amplified response, forming a reliable analogue front end for digital temperature sensing.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors' Contributions:** Each author has individually contributed to the article. **Prof. Lokesh L:** Provided overall technical guidance and oversight throughout the development of the project. His inputs were instrumental during the architectural and simulation planning phases, ensuring the design met academic and industrial relevance. **Dr. Shashidhar Tantry**: Contributed through conceptual validation and refinement of the manuscript. He offered support in aligning the methodology with CMOS process design principles and reviewed the draft critically for intellectual content. **Karthik M:** Was responsible for the core implementation of the project. This included the design, simulation, and verification of the resistor-based temperature sensing circuit, the development of the differential amplifier stage, the integration of the ADC, the analysis of results, and the preparation of the manuscript. All schematic work, testbench creation, simulation handling, and result interpretation were carried out.

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AUTHOR'S PROFILE

Prof. Lokesh L, presently working as an Assistant Professor in the ECE department with teaching experience of 17 Years. My research area is Analogue VLSI, and I am currently pursuing a Ph.D. in the field of Analogue VLSI design at VTU, to gain teaching experience and focus on innovative ideas in Electronics and Communication.

Education: -

- B.E. (TELECOMMUNICATION ENGG), SJCIT, CHIKKABALLAPUR, 2000
- M Tech (Digital Electronics & Communication) Dayananda Sagar College of Engineering (VTU), Dayananda Sagar College of Engineering (VTU), 2014
- Ph.D. (pursuing), PES School of Engineering Research Centre (VTU), 2017

Journals: -

- Modelling of Read Channel for Biomedical Sensors, International Journal of Science & Research (IJSR-2016), Bengaluru.

Conferences: -

- Noise modelling of ECG signals for Analogue Front End, 2020 Seventh International Conference on Computing on Sustainable Global Development (IndiaCom), 12-14 March 2020, New Delhi, India
- Combined modelling of MEMS Capacitive Accelerometer and Readout Circuit. At the International Symposium on Non-Linear Theory and Its
- Applications (NOLTA-2019), Kulalumpur, Malaysia.

More Details:- Prof. Lokesh L

Dr. Shashidhar Tantry has been working as a professor since 2016. He has over 17 years of Industry experience, working with companies like Sanyo LSI, Wipro, KPIT Cummins, Sankalp Semiconductors, and Aplab. He has over 30 publications in journals and conferences. His areas of interest include Analogue VLSI, device modelling, circuit optimisation, biomedical signal

processing, and sensor interface. He is a senior member of the IEEE and an advisor to the IEEE Solid-State Circuits Student Chapter.

Publications: -

- Realisation of gyrator circuit and its application demonstration on the Cadence tool, IEEE Conference on Innovation in Technology, 2020
- A positive negative floating resistor with current as controlling parameter, IEEE CONECCT 2020
- Denoise Modelling of ECG signals for Analogue Front End□, 7th conference on computing for sustainable global development
- 6th symposium towards the future of advanced research in Shizuoka University 2020
- Detection of noise in ECG signal using Analogue Behavioural modelling for readout circuits presentation at 4th International Conference on Biomedical Imaging and Signal Processing, Nagoya, 2019, Japan

More details:- Dr. Shashidhar Tantry

Karthik M is an undergraduate student in Electronics and Communication Engineering at PES University, Bengaluru. His interests lie in VLSI design, analogue circuit development, and embedded systems. With hands-on experience in tools like Cadence Virtuoso and Innovus, Karthik has contributed to research projects in temperature sensing and digital systems. He is passionate about bridging theoretical concepts with practical applications in semiconductor technology.