

# 積體電路設計研究所

## Institute of Integrated Circuit Design



### A PVT-Compensated Subthreshold Bandgap Reference for Wide-Temperature-Range Operation

#### Project Abstract

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This project proposes an integrated calibration method to improve the TC (Temperature Coefficient) performance of the bandgap reference circuit. By using the proposed subthreshold PVT Detector, the 13 digital control signals are generated to calibrate the resistance of the bandgap reference circuit, achieving the low TC performance at all PVT corners. Besides, the stacked transistors operated in subthreshold region are employed in the proposed PVT Detector, such that the power consumption is reduced. The proposed design is implemented with TSMC 0.18  $\mu\text{m}$  BCD process. The core area is  $238.81 \times 231.8 \mu\text{m}^2$ . The simulated output reference voltage is 800 mV with TC of 22.09 ppm/ $^{\circ}\text{C}$  from  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ .

#### Technical Principle

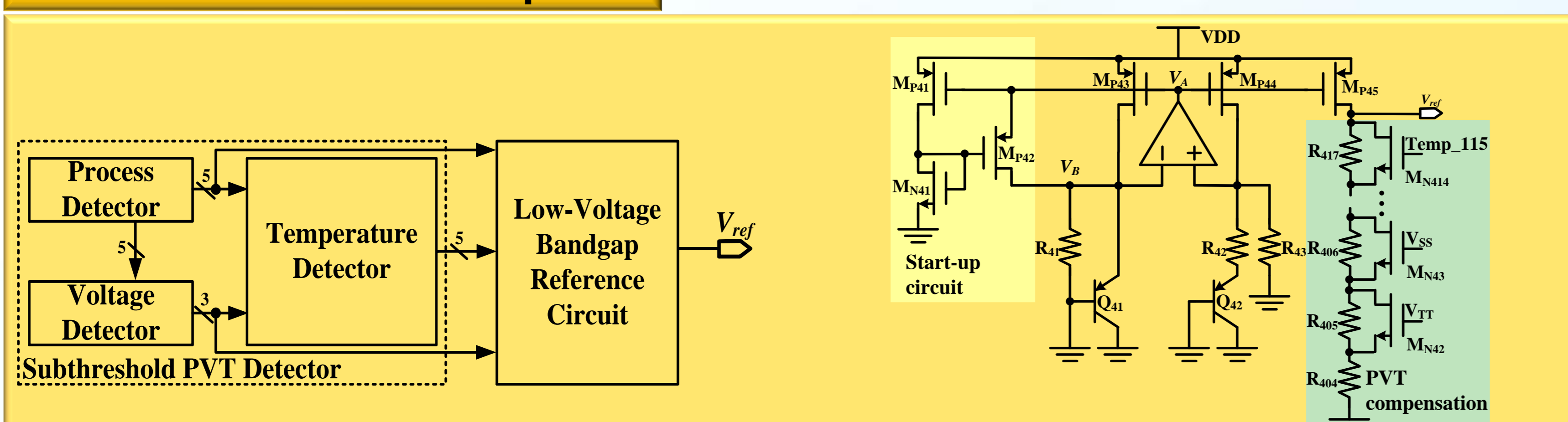


Fig. 1. The proposed design

Fig. 2. Low-Voltage Bandgap Reference Circuit

1. Fig. 1 shows the block diagram of the proposed design, which includes a Subthreshold PVT Detector and a Low-Voltage Bandgap Reference Circuit. The PVT Detector, composed of a Process Detector, a Voltage Detector, and a Temperature Detector, generates 13 digital codes to compensate for the Low-Voltage Bandgap Reference Circuit.

2. Fig. 2 shows the schematic of the proposed Low-Voltage Bandgap Reference Circuit based on the prior work. For the PVT compensation, the resistor string, R405 to R417, is controlled by parallel MOSFETs, respectively, and the proposed Subthreshold PVT Detector provides their gate voltages. The Start-up circuit prevents  $V_A$  from staying at the supply voltage, thereby avoiding the start-up issue.

#### Circuit Diagram

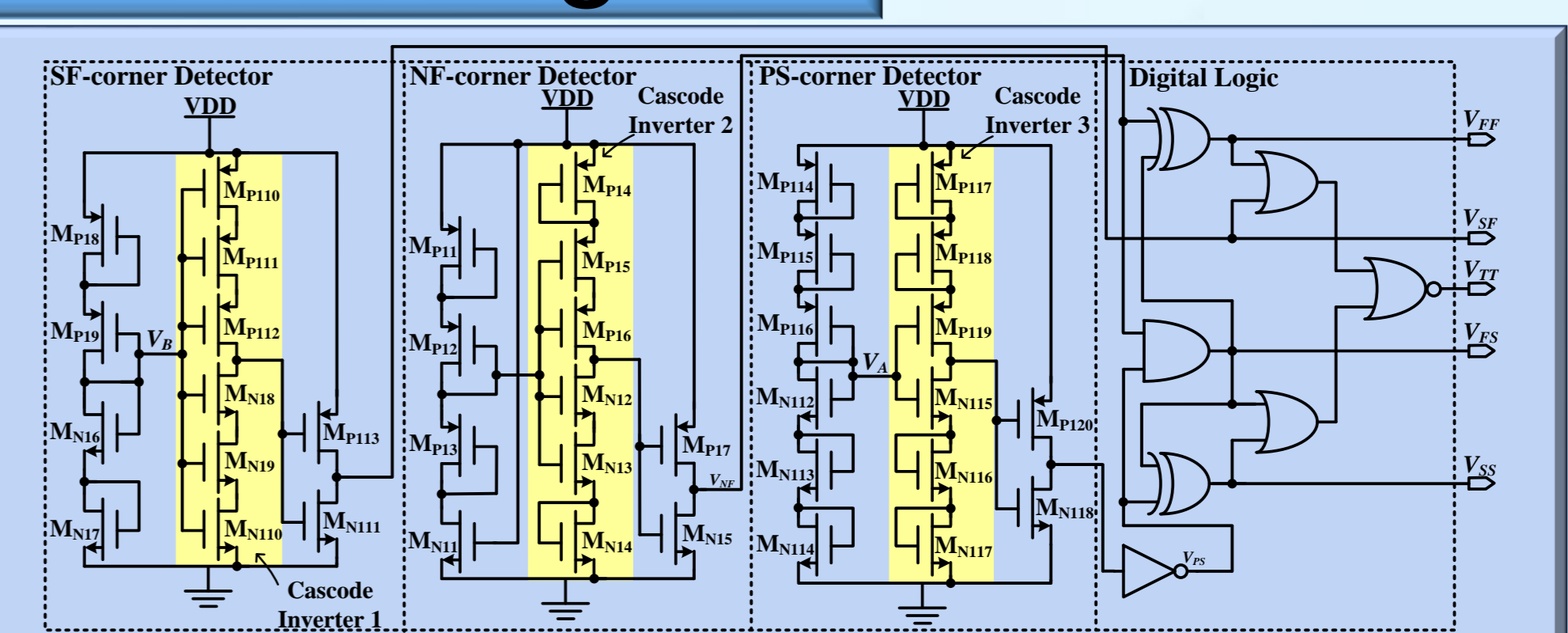


Fig. 3. Subthreshold Process Detector

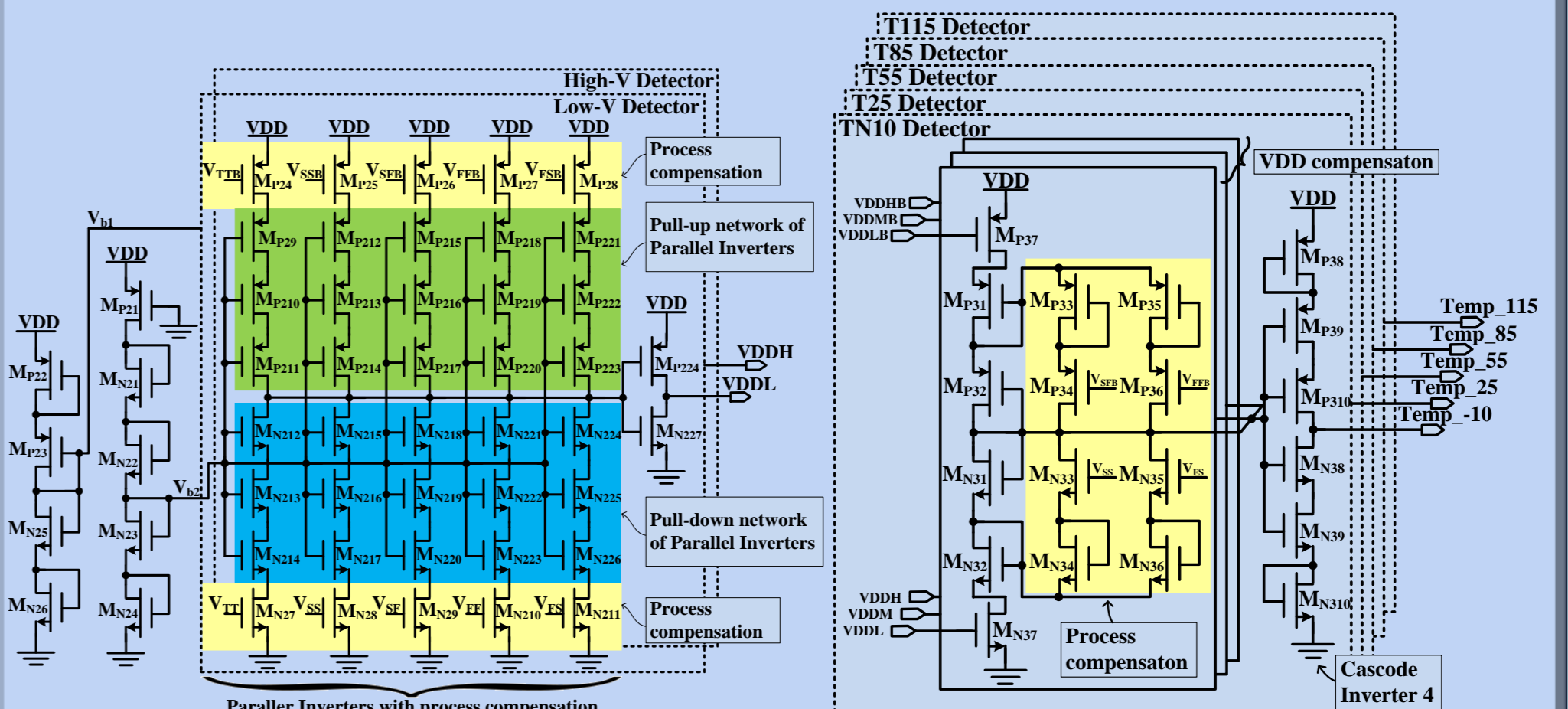


Fig. 4. Subthreshold Voltage Detector

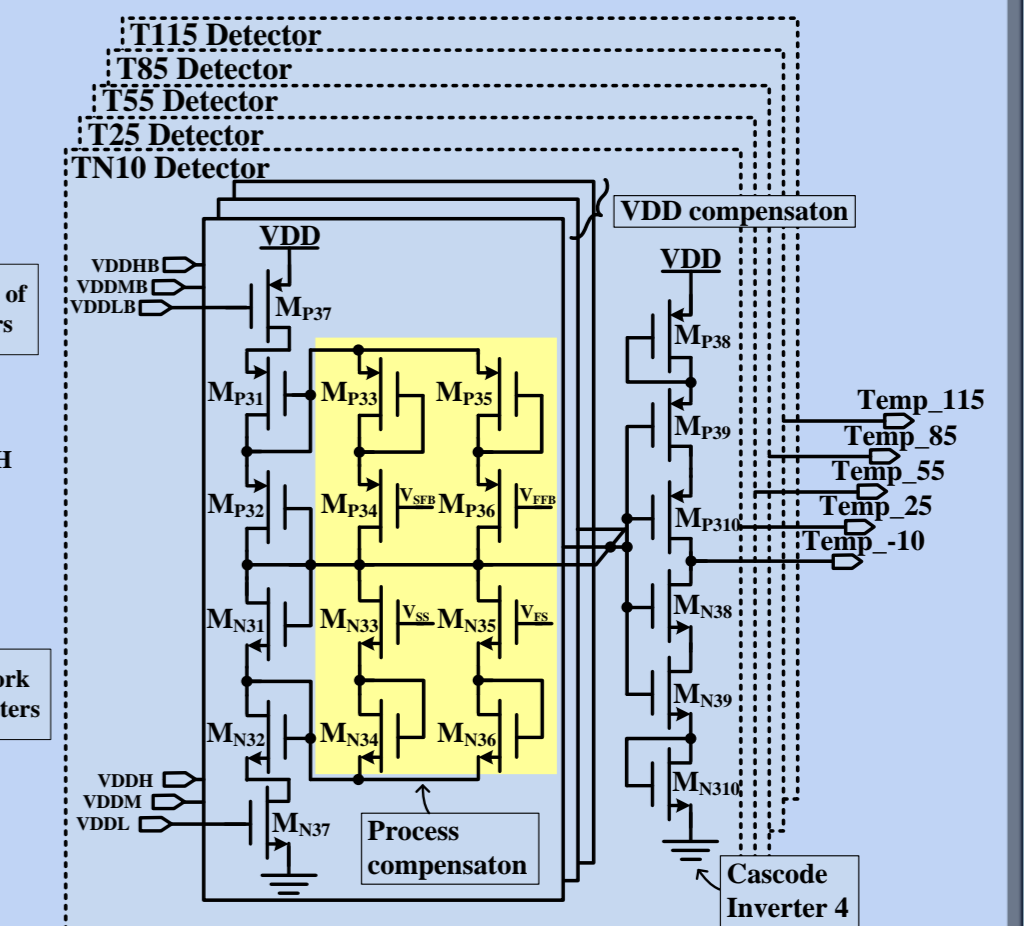


Fig. 5. Subthreshold Temperature Detector

#### Project Outcomes

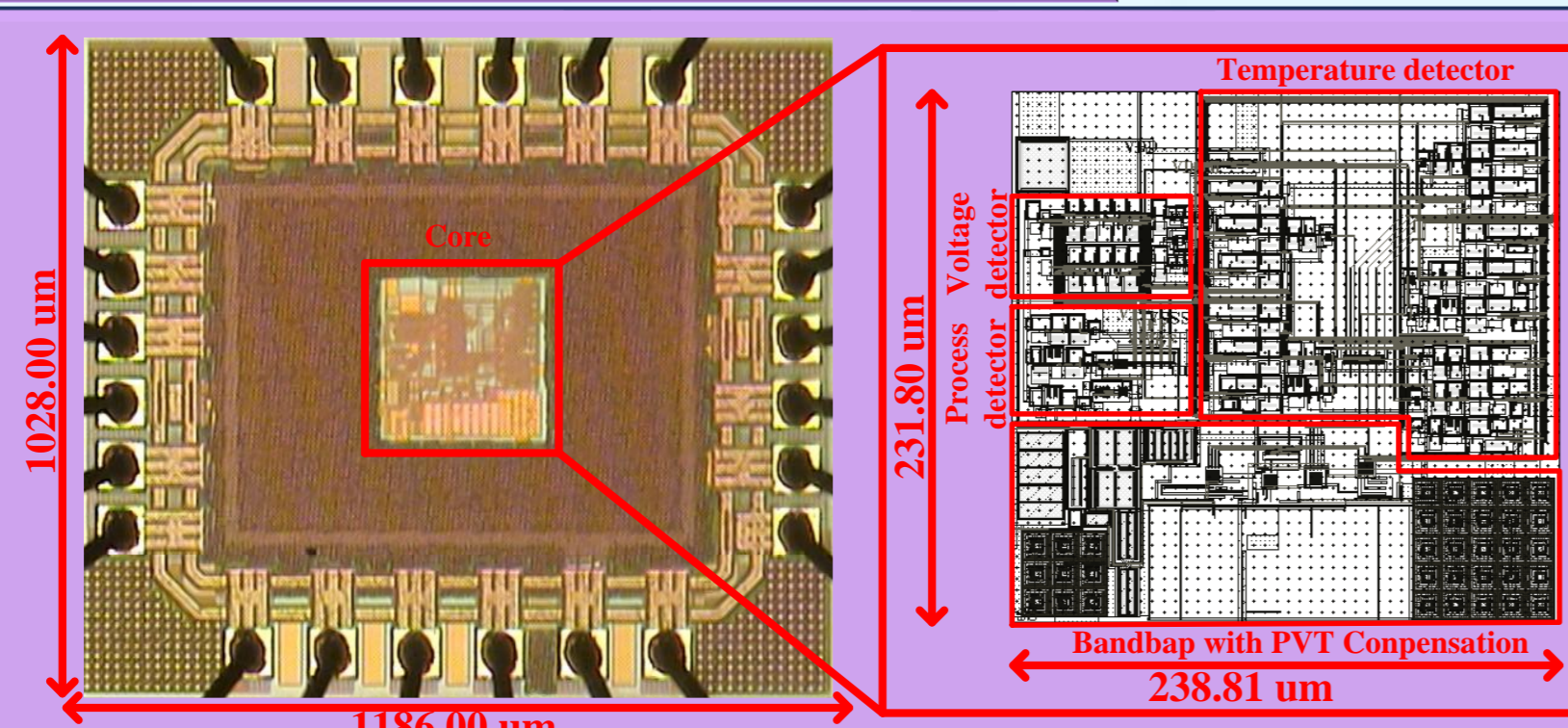


Fig. 6. Chip photograph and layout diagram

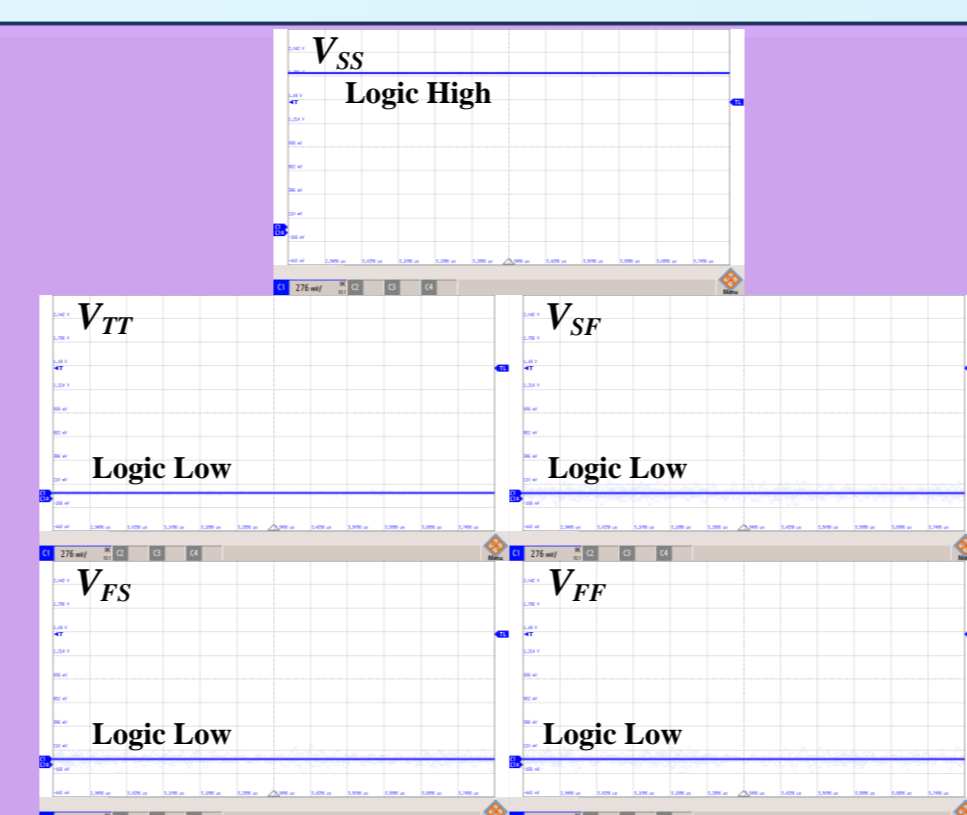


Fig. 8. Measurement Results of the Subthreshold Process Detector

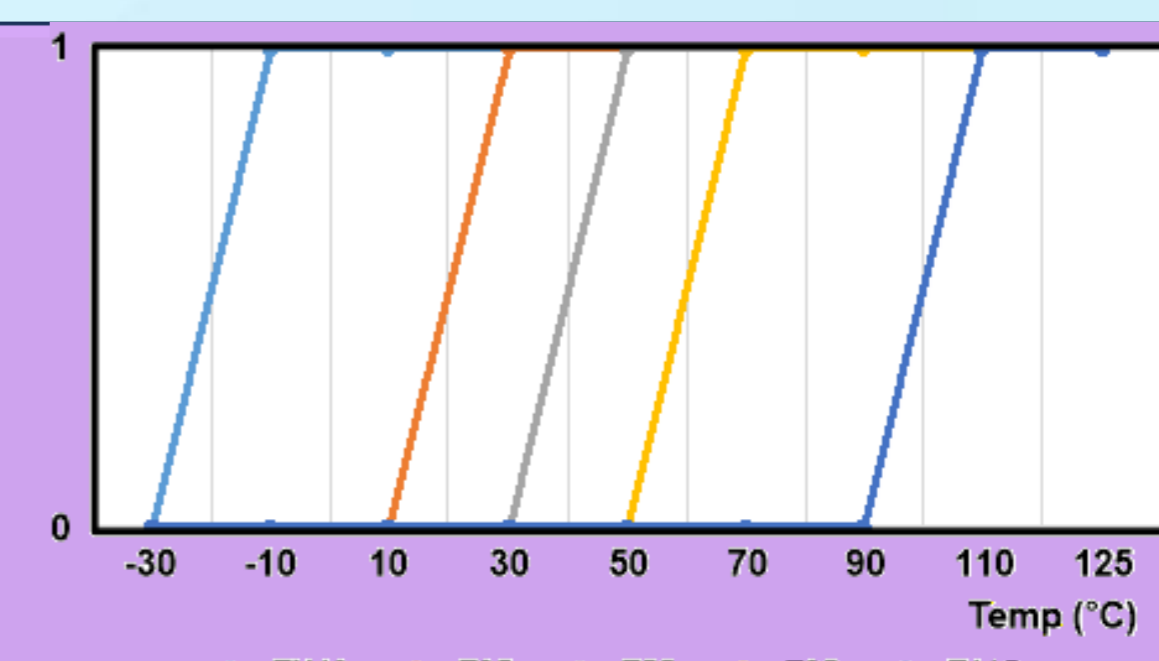


Fig. 10. Measurement Results of the Subthreshold Temperature Detector

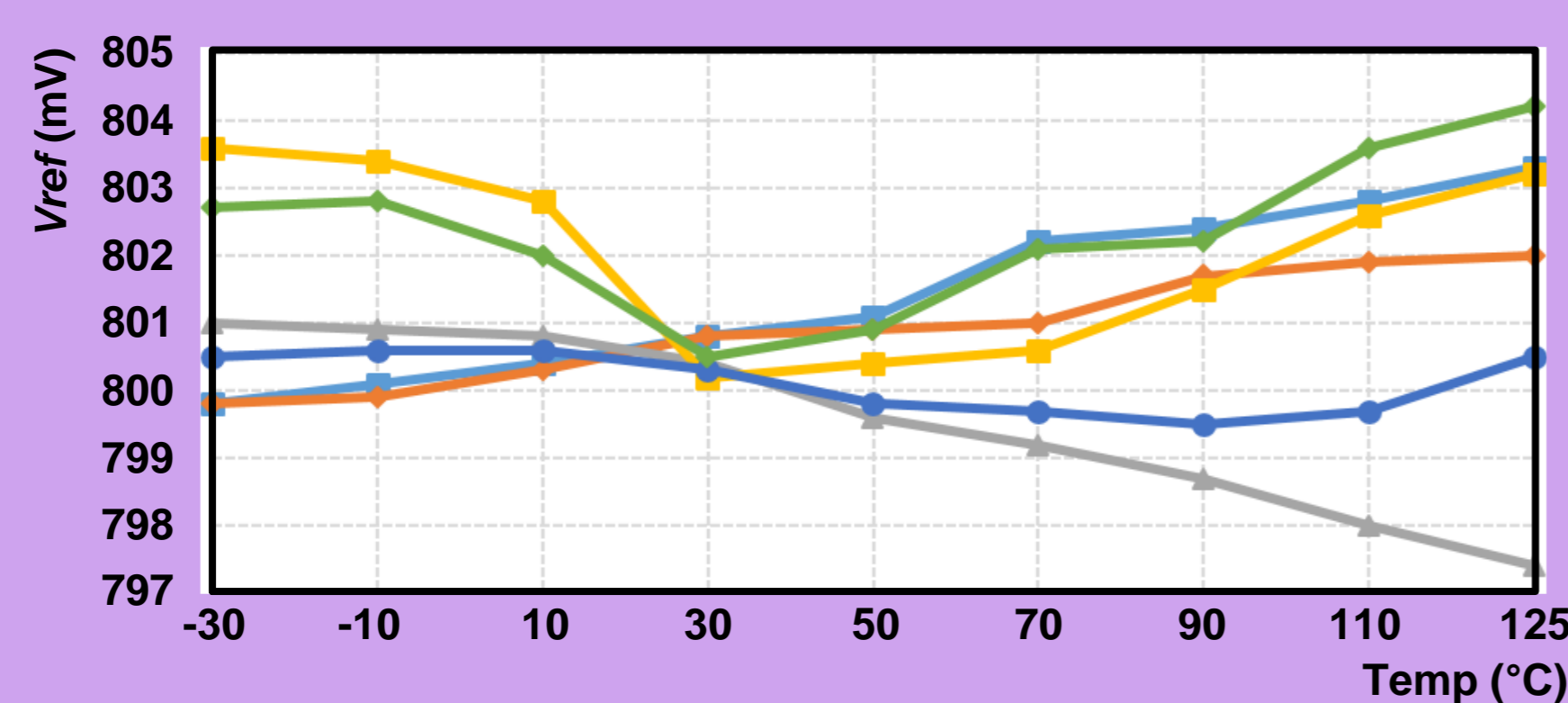


Fig. 7. The measured  $V_{ref}$  from  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$  the Subthreshold Voltage Detector

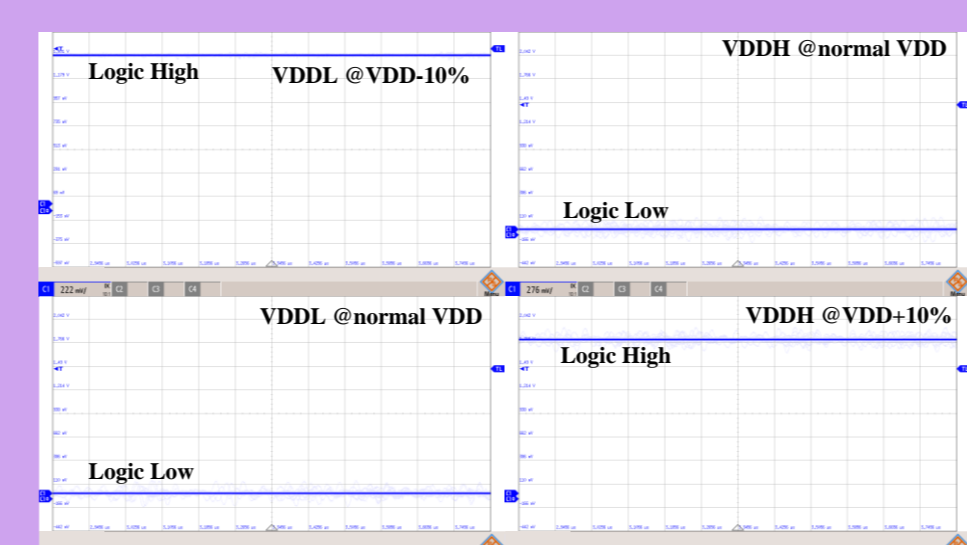


Fig. 9. Measurement Results of the Subthreshold Voltage Detector

Table I. Performance Comparison Table

| Parameters                        | [1]                | [2] <sup>a</sup> | [3]        | [4]         | [5]        | [6]                 | [7]        | This work  |
|-----------------------------------|--------------------|------------------|------------|-------------|------------|---------------------|------------|------------|
| Year                              | 2025               | 2021             | 2020       | 2024        | 2022       | 2021                | 2020       | 2025       |
| Publication                       | TVLSI              | TCAS-II          | TCAS-I     | JSSC        | TCAS-I     | JSSC                | TCAS-II    | -          |
| Process ( $\mu\text{m}$ )         | 0.065              | 0.045            | 0.065      | 0.065       | 0.065      | 0.18                | 0.04       | 0.18       |
| VDD (V)                           | 0.9                | 1.05             | 0.5        | 1.2 to 2.5  | 0.5        | 1.3 to 1.8          | 2.3 to 3.3 | 1.5 to 2.1 |
| Temp. range( $^{\circ}\text{C}$ ) | -40 to 125         | -40 to 125       | -40 to 120 | -40 to 120  | -40 to 120 | -40 to 140          | -40 to 100 | -40 to 125 |
| Vref (mV)                         | 500                | 500              | 495        | 1001.1      | 503        | 1170                | 862        | 800        |
| Power ( $\mu\text{W}$ )           | 43.52              | 7.56             | 0.038      | 0.972       | 0.024      | 0.192               | 1250       | 34.35      |
| TC (ppm/ $^{\circ}\text{C}$ )     | 27                 | 24.4             | 48/42      | *22.3       | 38.3/32    | 26.3                | 13 to 31   | 22.09      |
| Area ( $\text{mm}^2$ )            | 0.0226             | 0.0798           | 0.0532     | 0.04        | 0.0425     | 0.0082              | 0.032      | 0.055      |
| Trimming                          | No                 | No               | Yes        | Yes         | Yes        | No                  | No         | No         |
| PSRR (dB)                         | -71@DC, -35@7.5MHz | -60@DC           | -50@DC     | -58@10Hz    | -50@DC     | -52@100Hz, -44@1MHz | -          | -          |
| Line regulation (%/V)             | -                  | 0.3              | *0.64      | *0.13       | *0.66      | 0.07                | 0.00035    | -          |
| variation (3 $\sigma$ )u)         | -                  | -                | 3.08%      | 1.59%/0.36% | 1.37%      | 0.99%               | 1.10%      | 0.09%      |