A 0.9-2.6pW 0.1-0.25V 22nm 2-bit Supply-to-Digital Converter Using Always-Activated Supply-Controlled Oscillator and Supply-Dependent Activation Buffers for Bio-Fuel-Cell-Powered-and-Sensed Time-Stamped Bio-Recording

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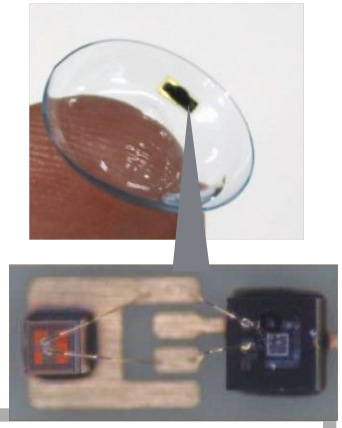
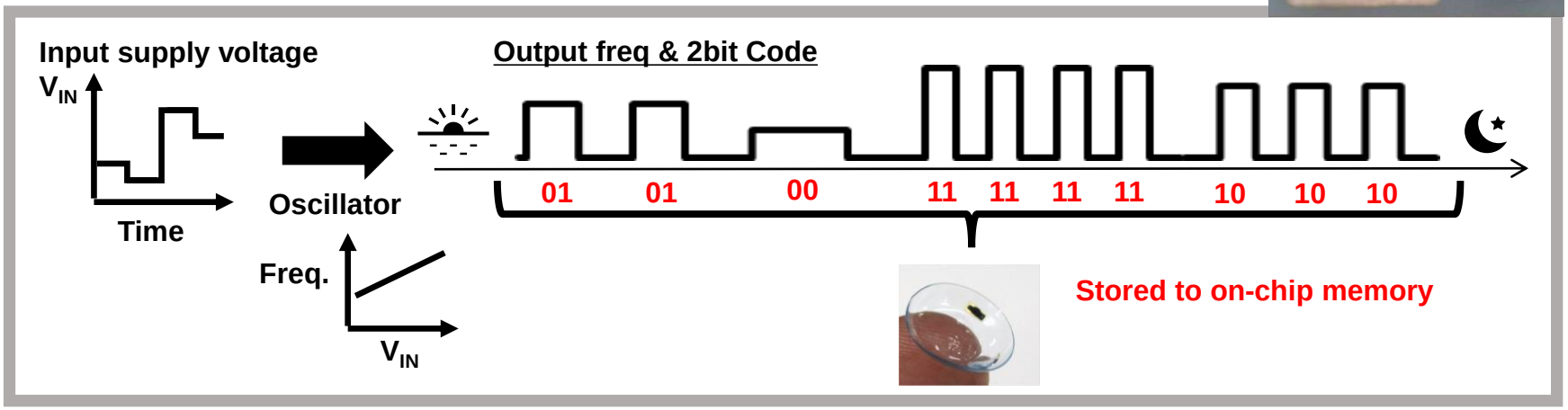
Motivations of developing new converter

- **Sensed-data-to-digital conversion is needed in IoT sensor**
- **In some IoT devices, difficult to drive existing converters due to power limitation**

Contact lens health-care device [1-5]

→The output voltage of the cell provides information on blood glucose levels



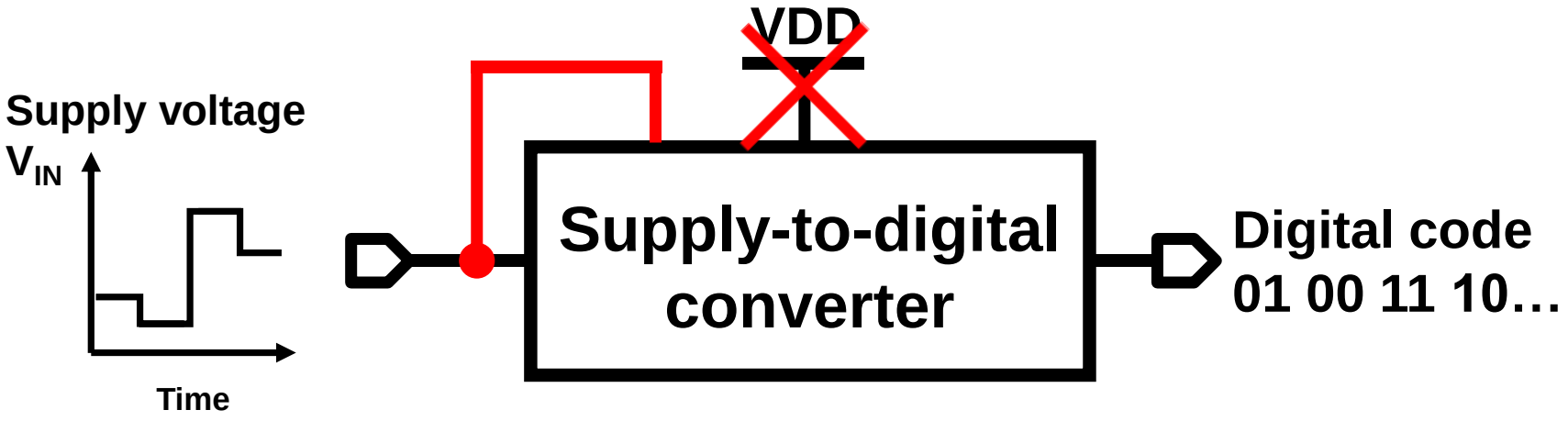


[1] A. F. Yeknami, ISSCC2018. [2] K. Hayashi, BioCAS 2018. [3] A.Tanaka,BioCAS2023. [4] A.Kobayashi,TBioCAS2019:1152. [5] A. Kobayashi, BioCAS2019.

Motivations of developing new converter

- **Convert voltage of bio-fuel-cell to digital**
- **Use the supply voltage as sensed-data as well as circuit voltage source since couldn't access to stable voltage source → 1 input / 1 output**

→Different from ordinary AD converter

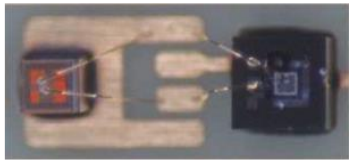


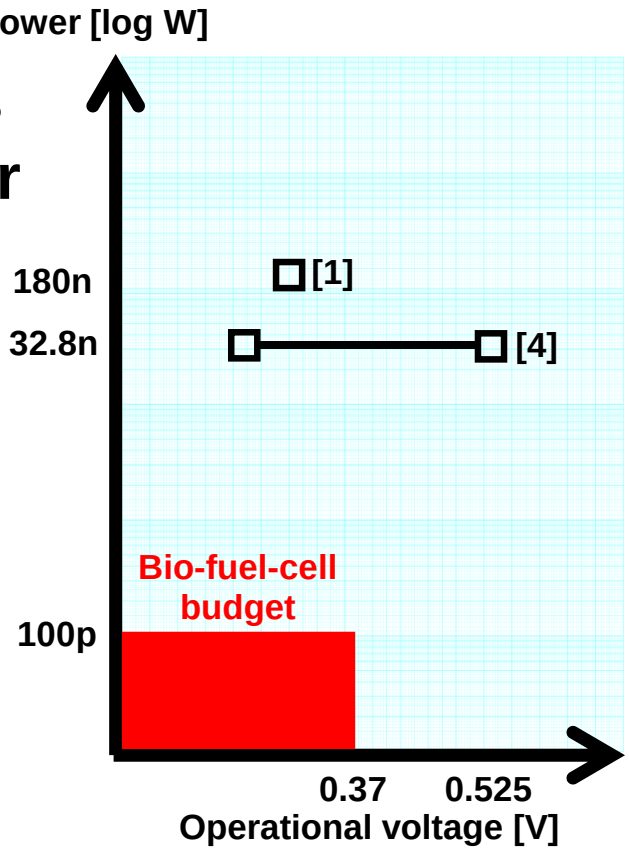
Performance Requirements

Existing SDCs are insufficient in terms of operational voltage range and power

Considering mounting on contact lens bio-fuel-cell maximum output is

- **Power budget: <100pW**
- **Operational voltage: <0.37V [8]**





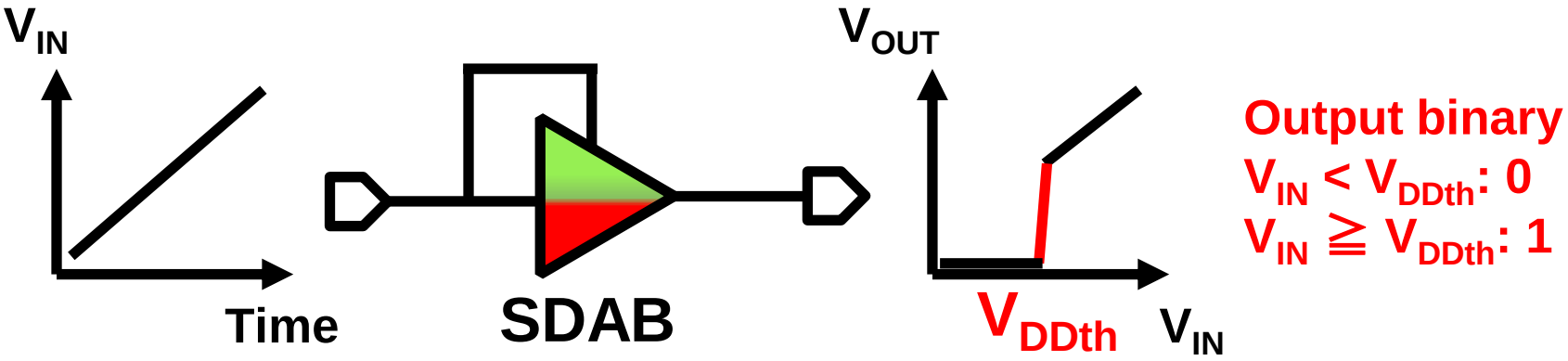
However, in condition with extremely low glucose levels, the power budget gained by bio-fuel-cell is much lower

[1] A. F. Yeknami et al., ISSCC 2018. [4] A.Kobayashi et al., TBioCAS 2019. [8]S. Arata, JJAP 2019.

Supply-Dependent-Activation-Buffer

Propose a SDC which the number of driven transistors varies dynamically according to the power generated, ensuring operation even at lower voltage

- **Introduce a supply-dependent-activation-buffer which the buffer ON/OFF varies dynamically according to the power generated…operating as a comparator of V_{IN} and V_{DDth}**



Output binary
$V_{IN} < V_{DDth}$: 0
$V_{IN} \geqq V_{DDth}$: 1

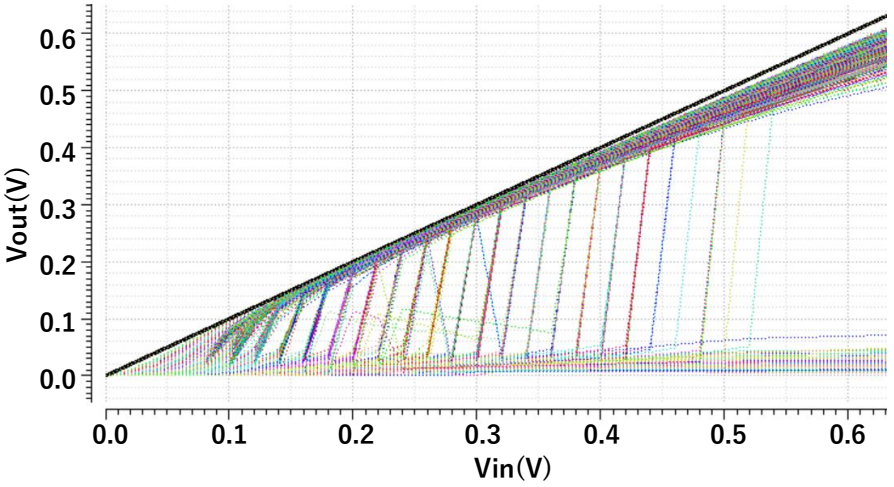
Where the buffer turns ON (reference voltage)

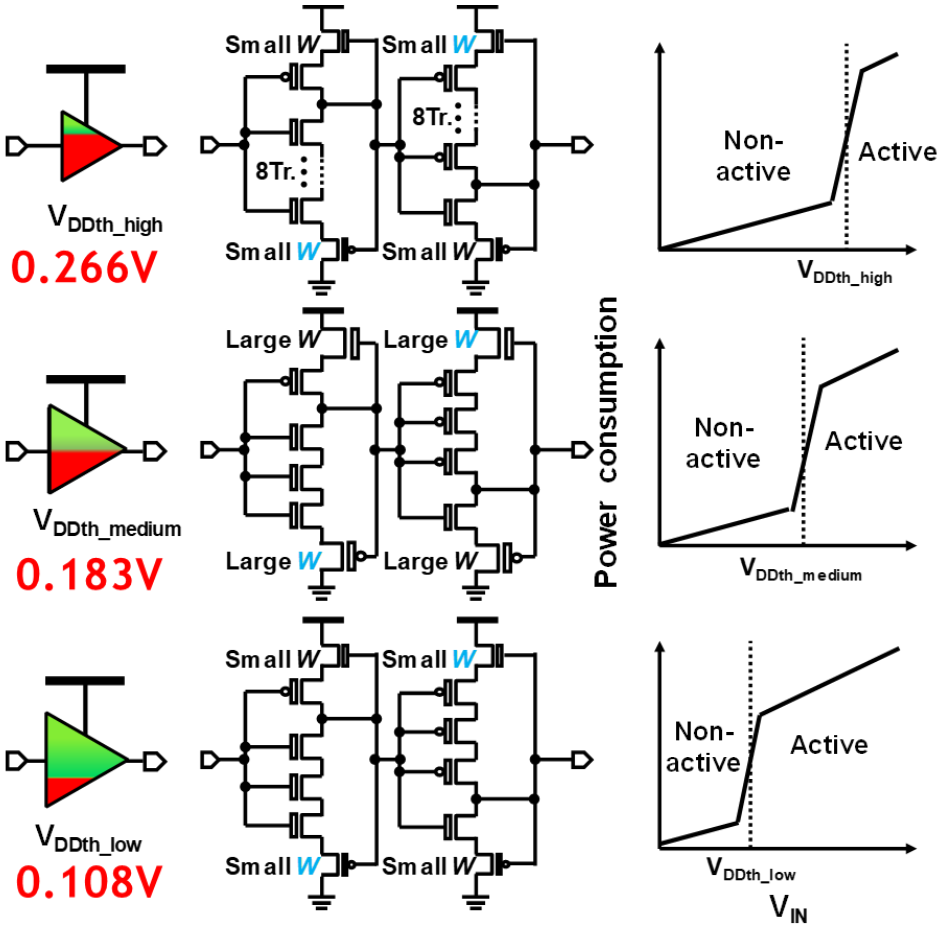
VDDth variation of SDABs

- V_{DDth} variation of DLS-buffer V_{DDth} in schematic simulation

Parameter:

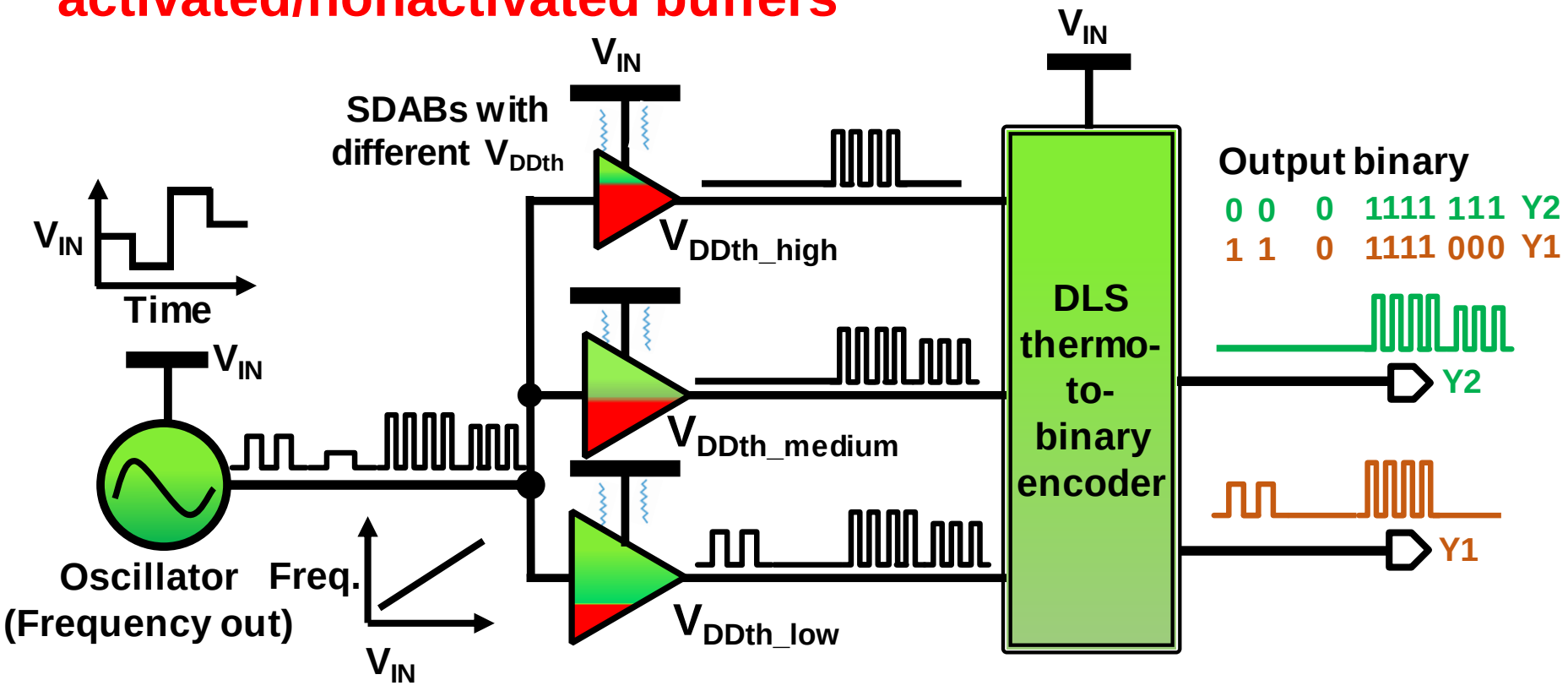
- Number of stacked transistors
- Transistor width





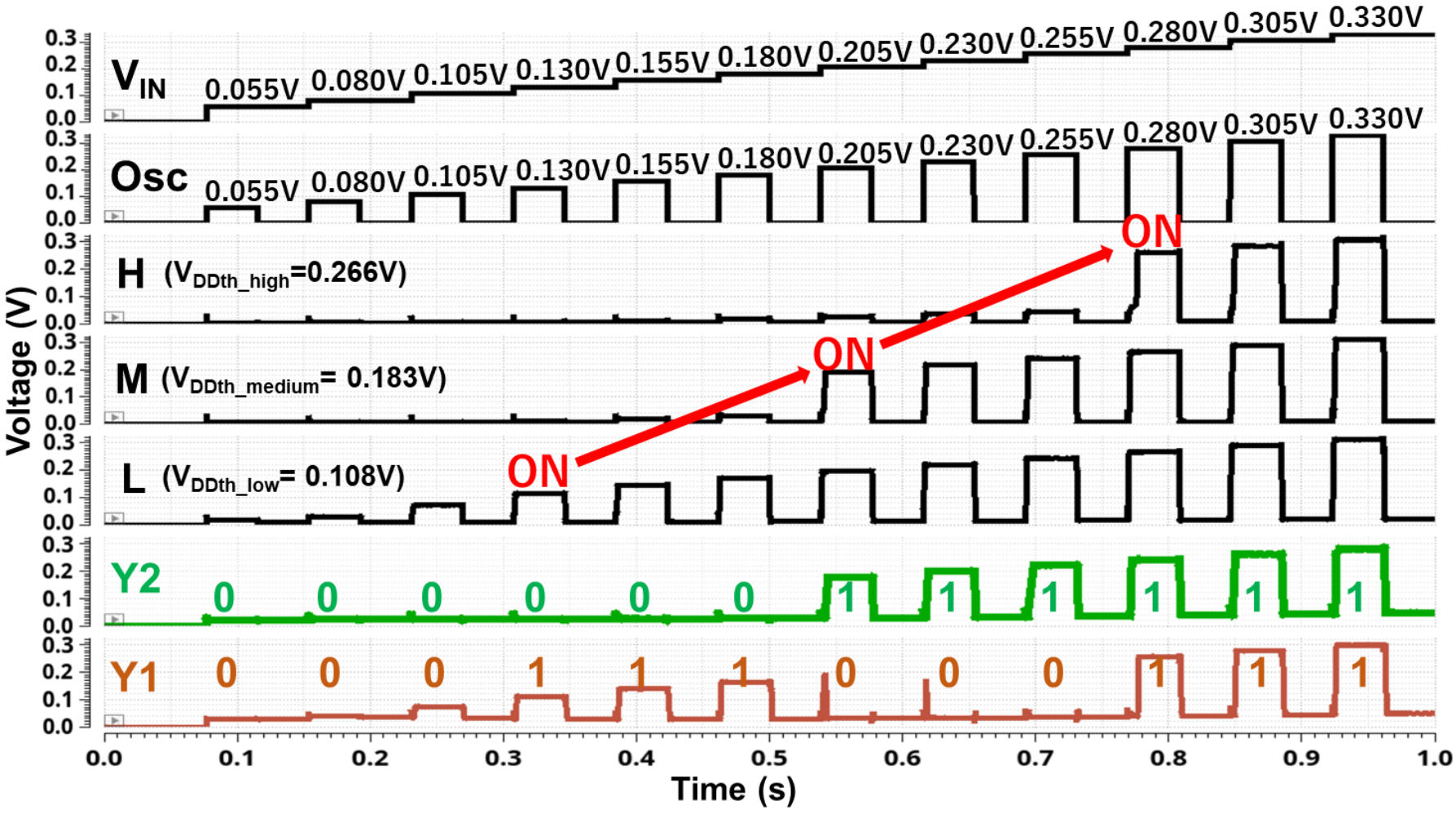
Proposed Circuit Architecture

- **Supply-to-frequency-and-digital converter by using buffers with different V-threshold**
- **Could detect V_{IN} range by encoding outputs of activated/nonactivated buffers**

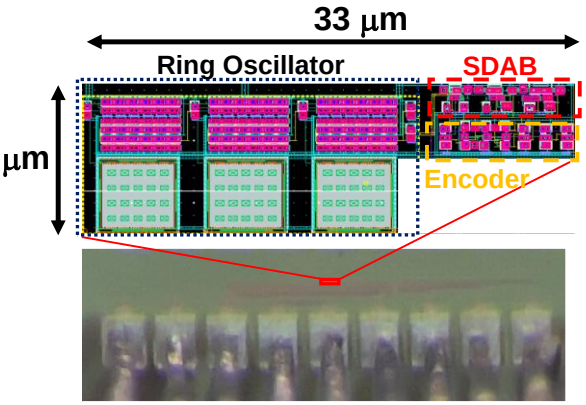


Post Layout Simulation Result

- **Buffers gradually turn on and output shifts as V_{IN} rises**

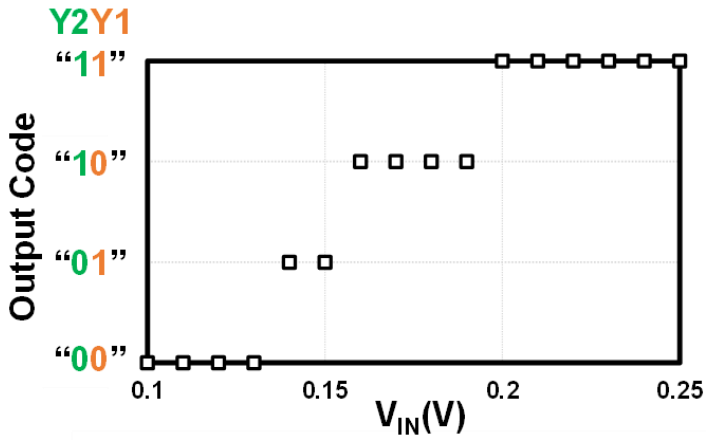


Test Chip Measurement

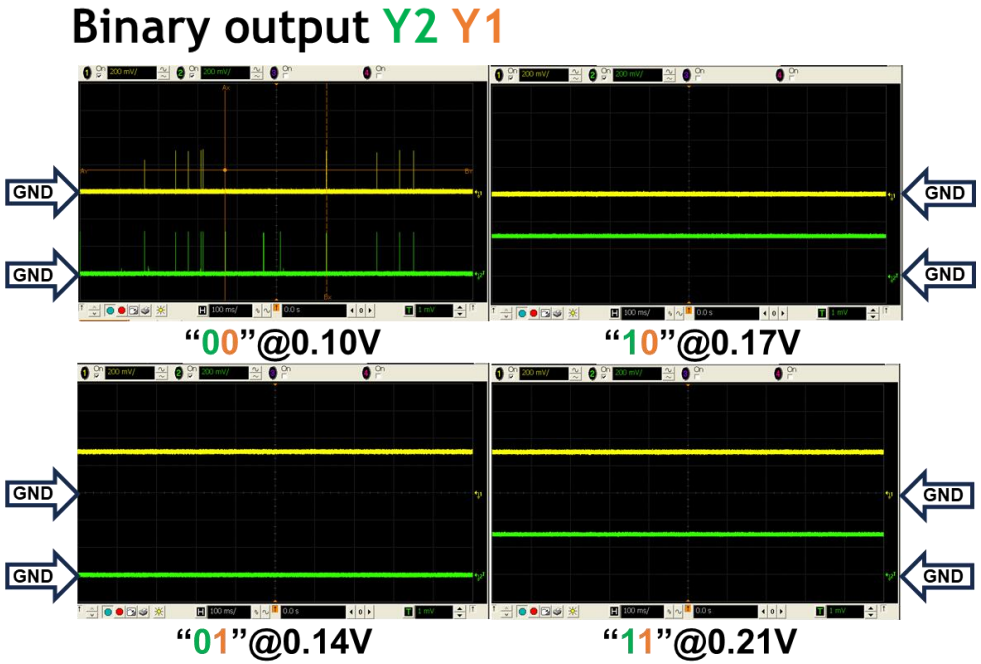


Fabricated prototype chip in 22nm-CMOS

Chip size: 0.00028mm^2



- **Successfully converted supply to binary signal**



Comparison with Previous SDC

- **Achieved lower power of 0.9-2.6 pW**
  smaller area of 0.00028 mm²
  lower operational voltage of 0.1-0.25 V

	ISSCC'18 [1]	TBioCAS'19 [4]		BioCAS'19 [5]	This work	
Technology	180-nm Bulk CMOS	55-nm DDC CMOS	65-nm Bulk CMOS	180-nm Bulk CMOS	22-nm Bulk CMOS (Ultra Low Leakage, TGO Tr.)	
Topology	Delta-Sigma	Dual-Oscillators-Based		Burst Pulse Counting	SDAB & Probabilistic counter	SDAB & Thermo-binary encoder
Output	60dB SNDR	8-bit Code	9-bit Code	9-bit Code	9-bit Code	2-bit Code
Input Voltage Range	0.3 V	0.75-1 V	0.225-0.525 V	0.18-0.35 V	0.1-0.25 V (Simulation)	0.1-0.25 V
Footprint (mm^2)	0.1 mm^2 (w/ I/O Pads)	0.0047 mm^2	0.0032 mm^2	0.018 mm^2	0.0069 mm^2	0.00028 mm^2
Footprint (F^2)	3,090,000 F^2	1,550,000 F^2	757,000 F^2	556,000 F^2	14,300,000 F^2	579,000 F^2
Conversion Time	N/A	6.2 s @ 0.75V	2.9 s @ 0.25V	117-673 ms @0.18-0.35 V	510 ms @ 0.175V (Simulation)	2.13 ms @ 0.175V (Simulation)
Power Consumption	180 nW @ 0.3 V	30.2 nW @ 0.75 V	32.8 nW @ 0.25 V	4.5 nW @ 0.3 V	122.5 – 426.1 pW @0.1-0.25 V (Simulation)	0.9 – 2.6 pW @0.1-0.25 V
Necessary Glucose-Fuel-Cell Area (Tear)	18,000 mm^2	3,020 mm^2	3,280 mm^2	450 mm^2	42.6 mm^2 (Accommodable in contact lens)	0.26 mm^2 (Accommodable in contact lens)
Application	Glucose-powered skin-patch-type	Light-powered CGM contact	Light-powered CGM contact	Light -powered CGM contact	Glucose-powered-and-sensed standalone CGM contact	Glucose-powered-and-sensed standalone CGM contact

[1] A. F. Yeknami et al., ISSCC 2018. [4] A.Kobayashi et al., TBioCAS 2019. [5] A. Kobayashi *et al*., TBioCAS 2019.

Conclusion

- **Proposed a new supply-to-digital converter by using buffers with different V_{DDth} (SDABs)**
- **Outperformed previous research in terms of power, footprint, and low operational voltage range**

  → met the needed performance (<0.37V, <100pW)

  → could realize conversion with the power only from bio-fuel-cell on a tiny contact lens

- **For a higher resolution, higher-bit resolusion SDC simulation must be conducted**
- **Since very weak to process variation, calibration method for eliminating process variation must be conducted**

Thank you for your attention!