3D Integration of LSI, Plastic MEMS Switches and Organic Transistors for Printable Communication Sheet

Lechang Liu[1], Makoto Takamiya[1], Tsuyoshi Sekitani[2], Yoshiaki Noguchi[2], Shintaro Nakano[2], Koichiro Zaitsu[2], Tadahiro Kuroda[3], Takao Someya[2], and Takayasu Sakurai[1]

[1]Institute of Industrial Science, University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
Phone: +81-3-5452-6253 E-mail: llch@iis.u-tokyo.ac.jp
[2]Quantum-Phase Electronics Center, School of Engineering, University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[3]Department of Electronics and Electrical Engineering, Keio University
Hiyoshi 3-14-1, Kouhokuku Yokohama, 223-8522, Japan

1. Introduction

Low-power wireless communications between electronic objects scattered over tables, walls and ceiling will form an infrastructure necessary for wireless sensor networks and ambient intelligence. This paper presents a novel communication method which simultaneously achieves the mobility of wireless communication and the low-power performance of wireline communication [1]. By combining meter-scale wireline communication and μm-scale wireless capacitive coupling communication, the proposed communication system enables multiple electronic objects scattered over the sheet to communicate contactlessly with each other by establishing communication paths without cumbersome physical connections.

2. Communication Sheet

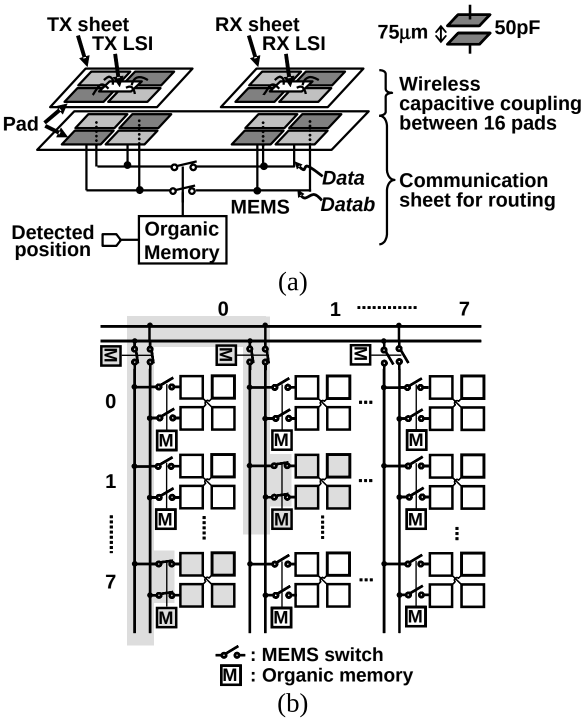


Fig. 1 (a) Overview of the communication system. (b) Communication route.

System Overview

Fig. 1(a) shows the overview of the whole system. The point-to-point communication is achieved by combining the meter-scale wireline communication on the sheet and the μm-scale proximity communication between the sheet and the transceiver. This work implements proximity communication by capacitively coupling the transmitter to the receiver. The transmitter drives a plate of metal on the transmitter (Tx) sheet that couples to a corresponding plate of routing metal on the communication sheet and the plate on the other end of the routing metal in turn drives the receiver on the receiver (Rx) sheet. The typical pad distance for the capacitive coupling is 75μm, which corresponds to 50pF capacitance. In this application differential signaling is required because there is no common ground among Tx sheet, communication sheet and Rx sheet. Another two pads are employed to compensate the sensitivity degradation due to pad misalignment.

The communication route is dynamically formed using the plastic micro-electromechanical-system (MEMS) switches and the routing information is stored in the organic nonvolatile memories. As illustrated in Fig. 1(b), the sheet is composed of 8×8 units and every unit consists of four pads. The communication between each two unit is achieved by turning on the adjacent two MEMS switches and the top two routing switches. Thus, only four switches are required for the point to-point communication. Since the information transmitted over the sheet is confined in small space close to ad hoc routed paths, the system is free from the issues related with radio frequency band allocation which has already been tight.

Device Structure

The device structure of the communication sheet is shown in Fig. 2(a). It consists of five low-cost printed sheets: a 16×16 pad array for capacitive coupling, two 9×8 MEMS-switching matrices for differential signal routing, a 9×8 organic nonvolatile memory array for routing information storage and a 8×8 position-sensing coil array [2, 3].

The 16×16 capacitive coupling pad arrays are fabricated on a polyimide film. The side length of the square pad is 9.7mm and the distance between each square is 3mm

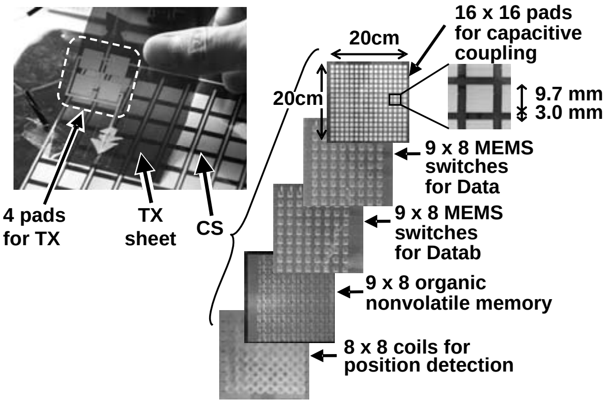


Fig. 2 Device structure of communication sheet.

Silver gate electrodes and polyimide gate dielectric layers are patterned by using inkjet printing. The MEMS-switching matrix is formed by using inkjet printing and screen printing. The electrodes for electrostatic attraction are patterned on a 25µm-thick polyimide membrane. Compared to the organic FET switch, MEMS switch provides lower ON-resistance and lower parasitic capacitance, which contributes to low energy/bit communication.

3. Transceiver Design

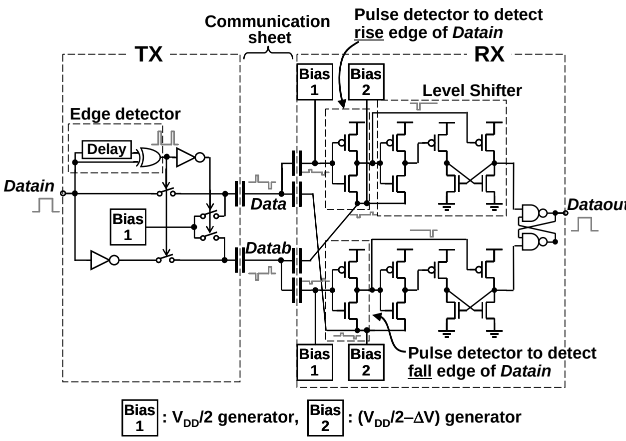


Fig. 3 Schematic of transceiver with data edge signaling and DC power-free pulse detector.

A transceiver is designed and fabricated in 0.18µm CMOS process and the schematic is shown in Fig. 3. In this study the input non-return-zero (NRZ) signal is converted into return-to-VDD/2 signal pulse to avoid the DC wander effect. The modulated data is achieved by switching the input data and the output of the half VDD generator. The edge detector is used to generate the switching signal for the selector by detecting both the rising and falling edge of the input data. To detect a small signal, an amplifier and a comparator is often used in the first stage of the receiver to amplify the received signal for the next demodulation. The major disadvantage of this topology is large DC power dissipation that occurs even for no AC input. In the transmitted signal of the communication sheet, the circuit spends a long periods of time with no AC signal. Power dissipated in these periods is wasted. The proposed pulse detector can alleviate this problem by having essentially zero power dissipation for no AC input. Two unbalanced inverters are used to detect the rising edge and falling edge respectively and the detection results are level-shifted to V_{DD}.

4. Measurement Results

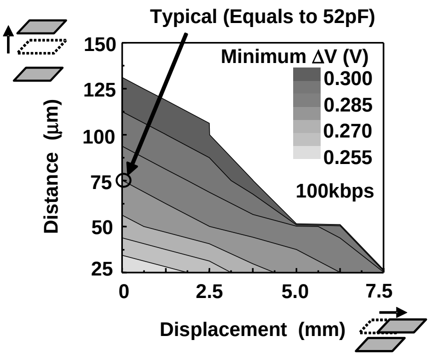


Fig. 4 Measured minimum ΔV for different displacement and distance of the pads.

For the capacitive coupling system, a critical challenge in high-performance communication is correctly aligning the chips. With misaligned pads, one transmitter will be coupled to several other receivers, simultaneously reducing the intended signal and increasing crosstalk to the other receiver. Fig. 4 shows the measured sensitivity requirement for the horizontal misalignment and the vertical pad distance. For the normal 75µm pad distance, which is equal to the sheet thickness, the sheet can operate up to 3.75mm displacement. The maximum tolerable displacement is 7.5mm, which corresponds to the 77% of the pad size.

4. Conclusions

A 20cm×20cm 3D-integaration communication sheet with data edge signaling transmitter and DC power-free receiver is developed. The proposed communication sheet achieves the lowest energy 107J/bit at 100kbps in the wireless communications at a distance of 60cm in 0.18µm CMOS and the four-pad differential signaling scheme can compensate the one-dimension misalignment up to 77%.

Acknowledgements

This work is supported in part by CREST, JST, and MEXT.

References

[1] L. Liu, et al., “A 107pJ/b 100kb/s 0.18µm capacitive coupling transceiver for printable communication sheet,” IEEE ISSCC Tech. Dig. Papers, pp. 292–293, Feb. 2008.

[2] T. Sekitani, et al., "Communication sheets using printed organic nonvolatile memories," IEEE IEDM Tech. Dig. Papers, pp. 221-224, Dec. 2007.

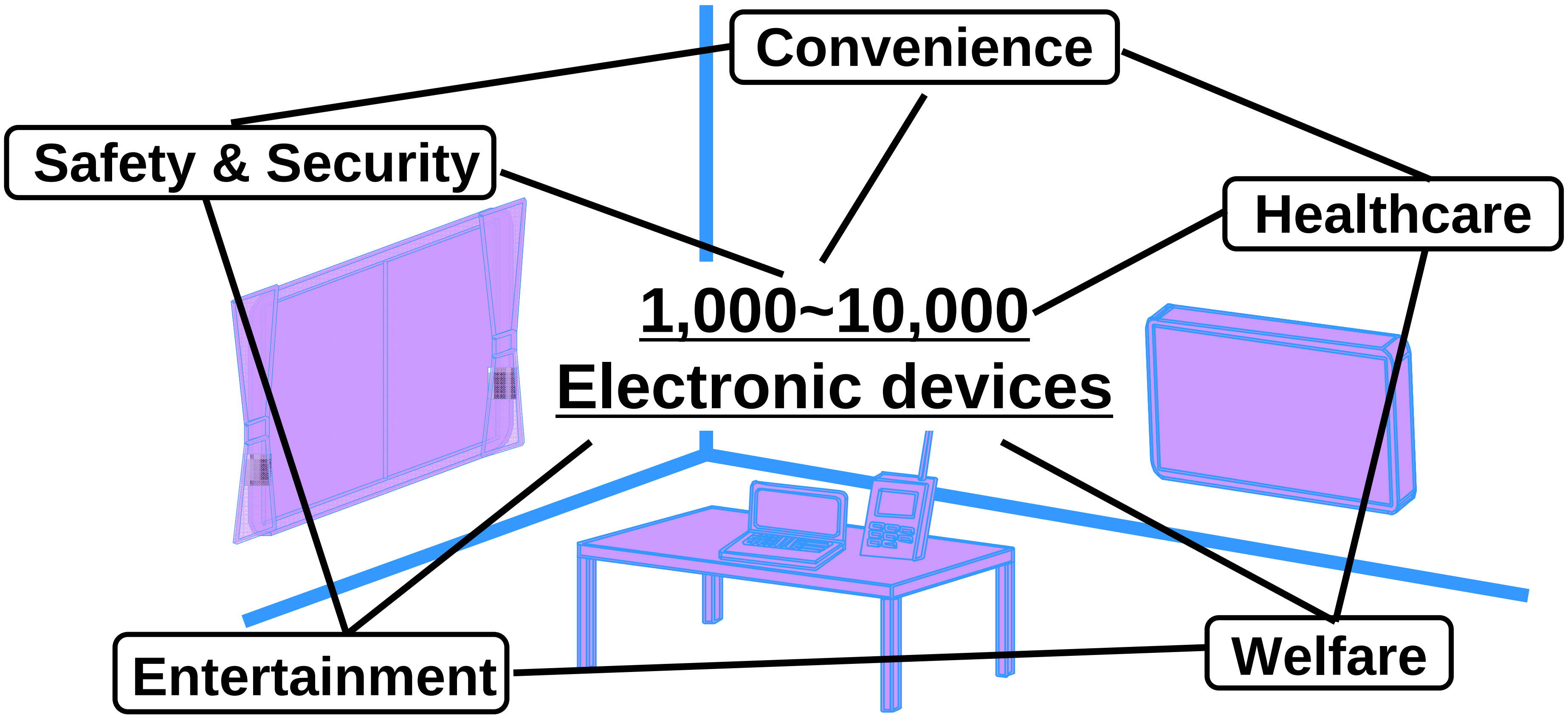
[3] M. Takamiya, et al., "Design solutions for multi-object wireless power transmission sheet based on plastic switches," IEEE ISSCC Tech. Dig. Papers, pp. 362-363, Feb. 2007.

3D Integration of LSI, Plastic MEMS Switches and Organic Transistors for Printable Communication Sheet

L. Liu, M. Takamiya, T. Sekitani, Y. Noguchi, S. Nakano, K. Zaitsu, *T. Kuroda, T. Someya and T. Sakurai

University of Tokyo
***Keio University**

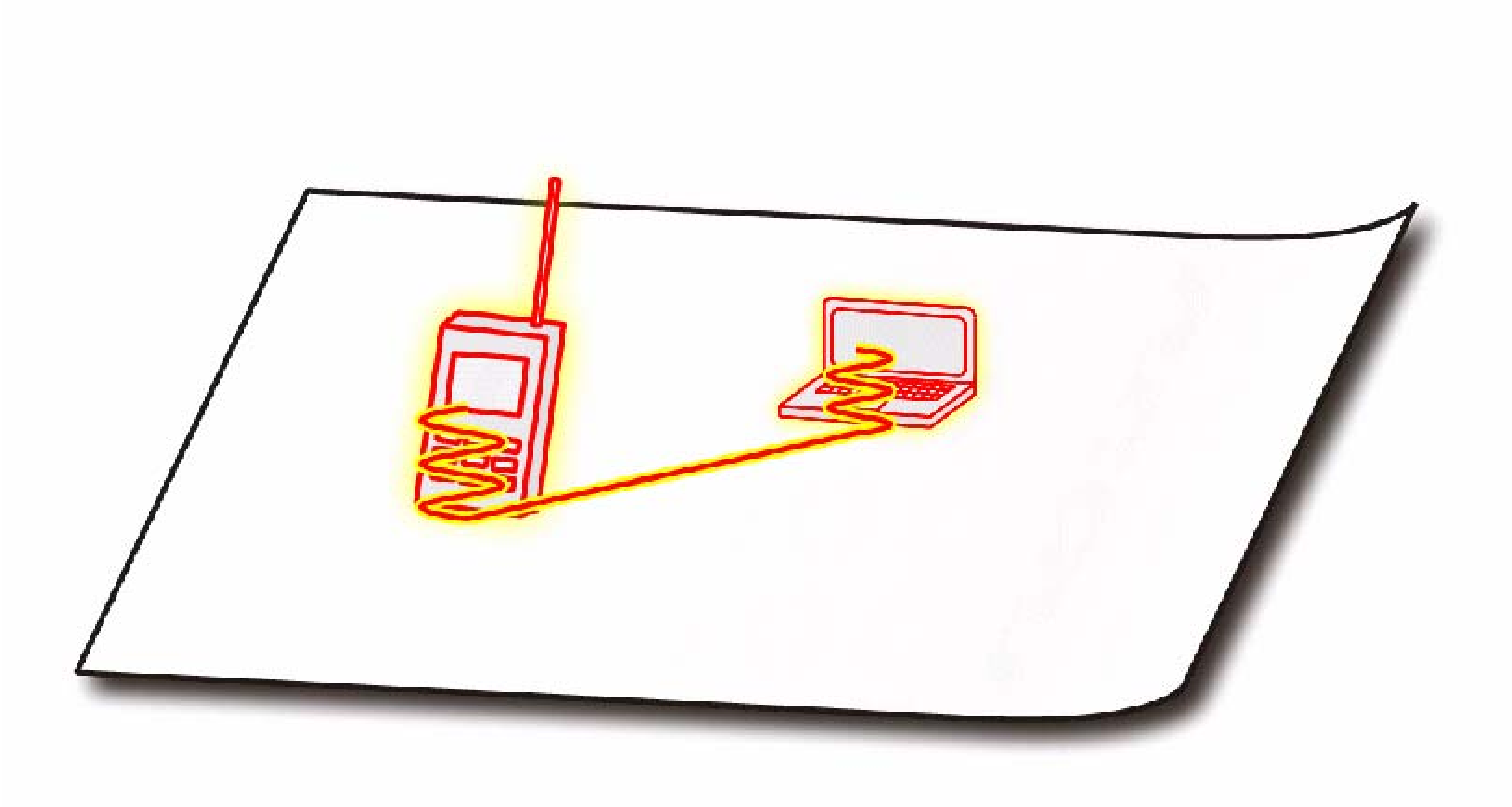
Ubiquitous Electronics



How to communicate effectively?

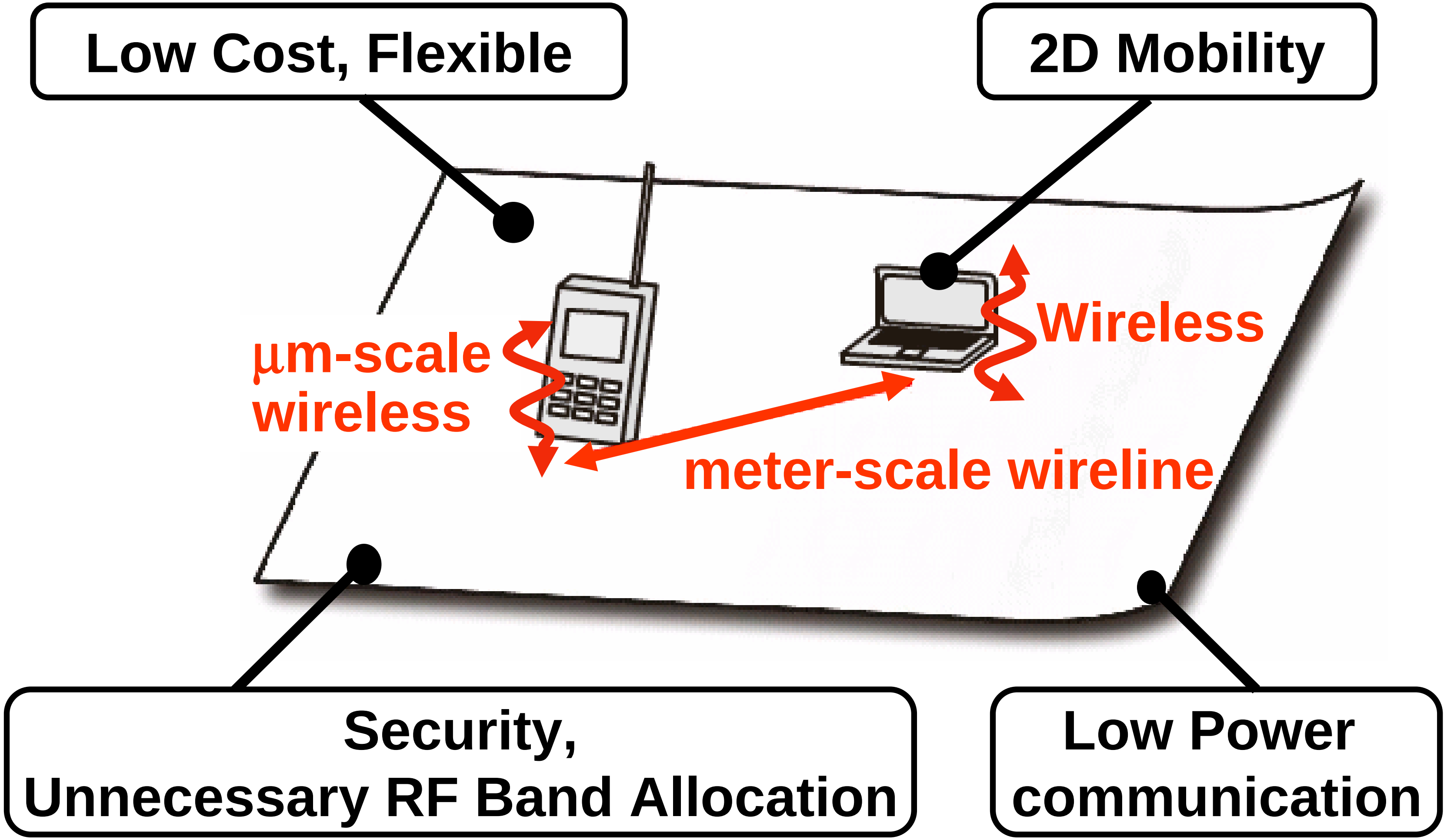
Issues
- Wireline → Immobility
- Wireless → High Power

What is Communication Sheet?



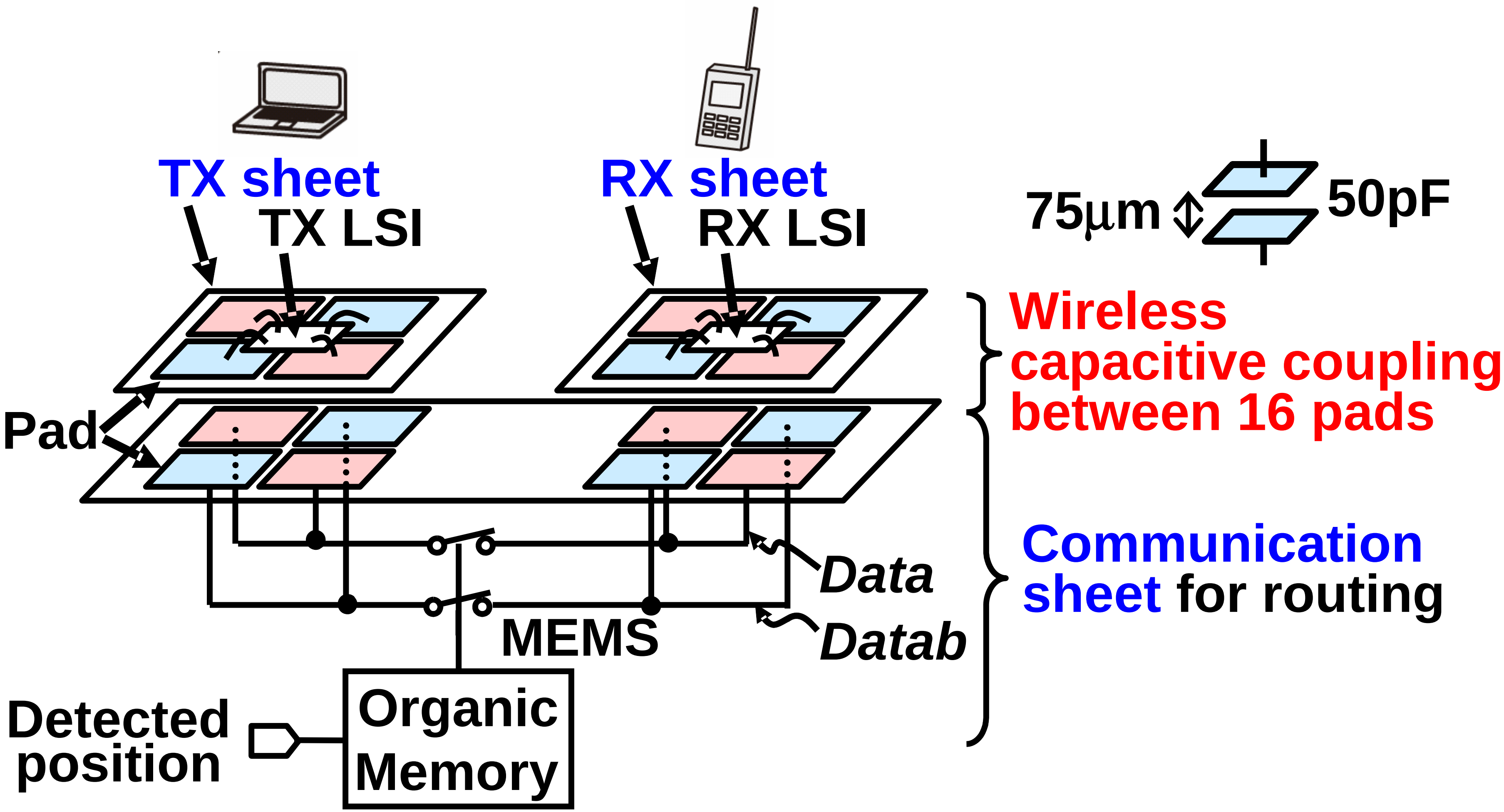
- Enabling multiple electronic objects scattered over the sheet to communicate without physical connections.
- Infrastructure for the ubiquitous electronics together with the wireless power transmission sheet.

Overview of Communication Sheet (CS)



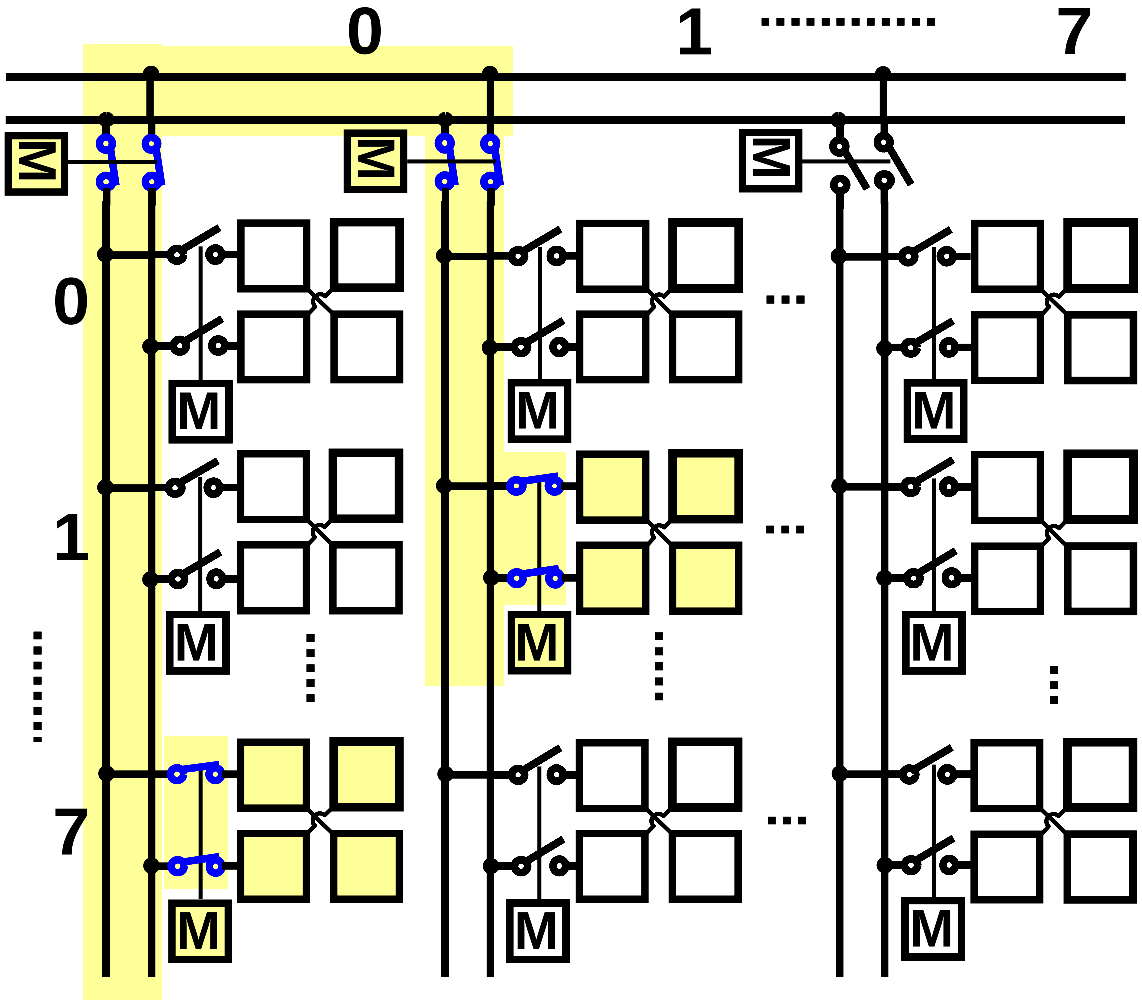
- ◆ CS enables both mobile and low power communication.

Capacitive-Coupling Transceiver in CS



- No common ground requires differential signaling.
- MEMS switches provides lower parasitic capacitance than the organic FETs.

Dynamic Routing in CS

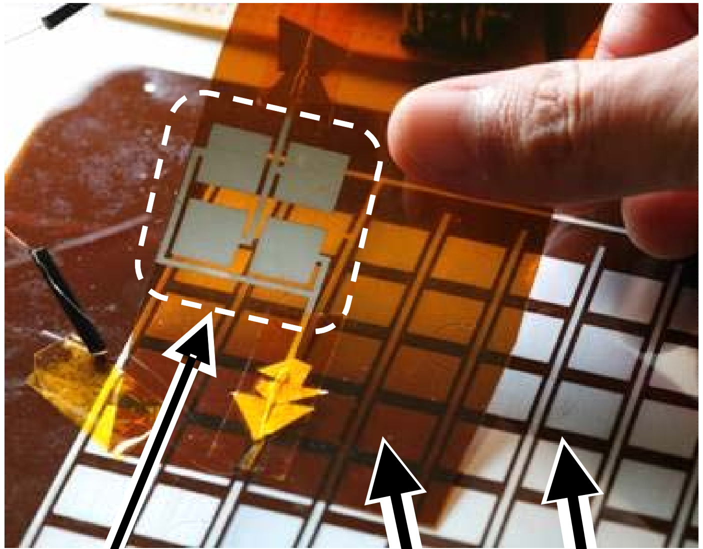


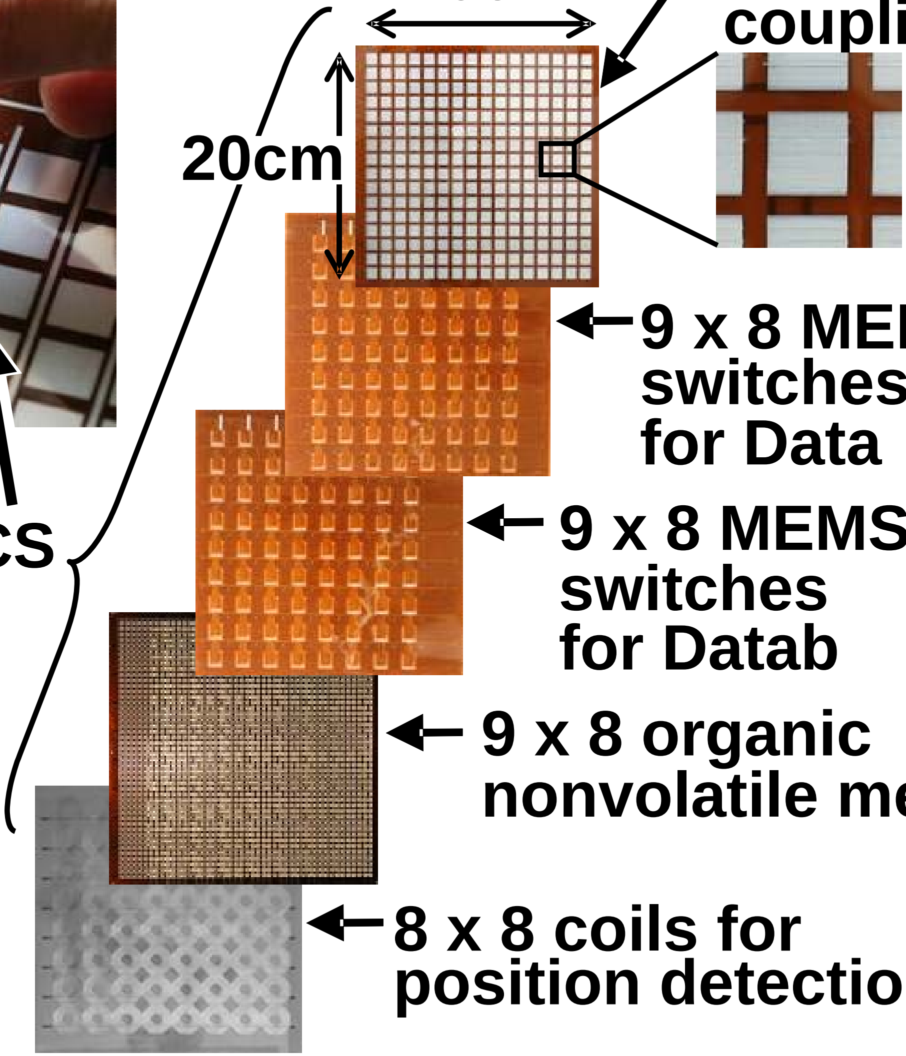
:MEMS switch

M :Organic memory

◆ **Arbitrary 2 points are connected via 4 switches.**

Device Structure of CS

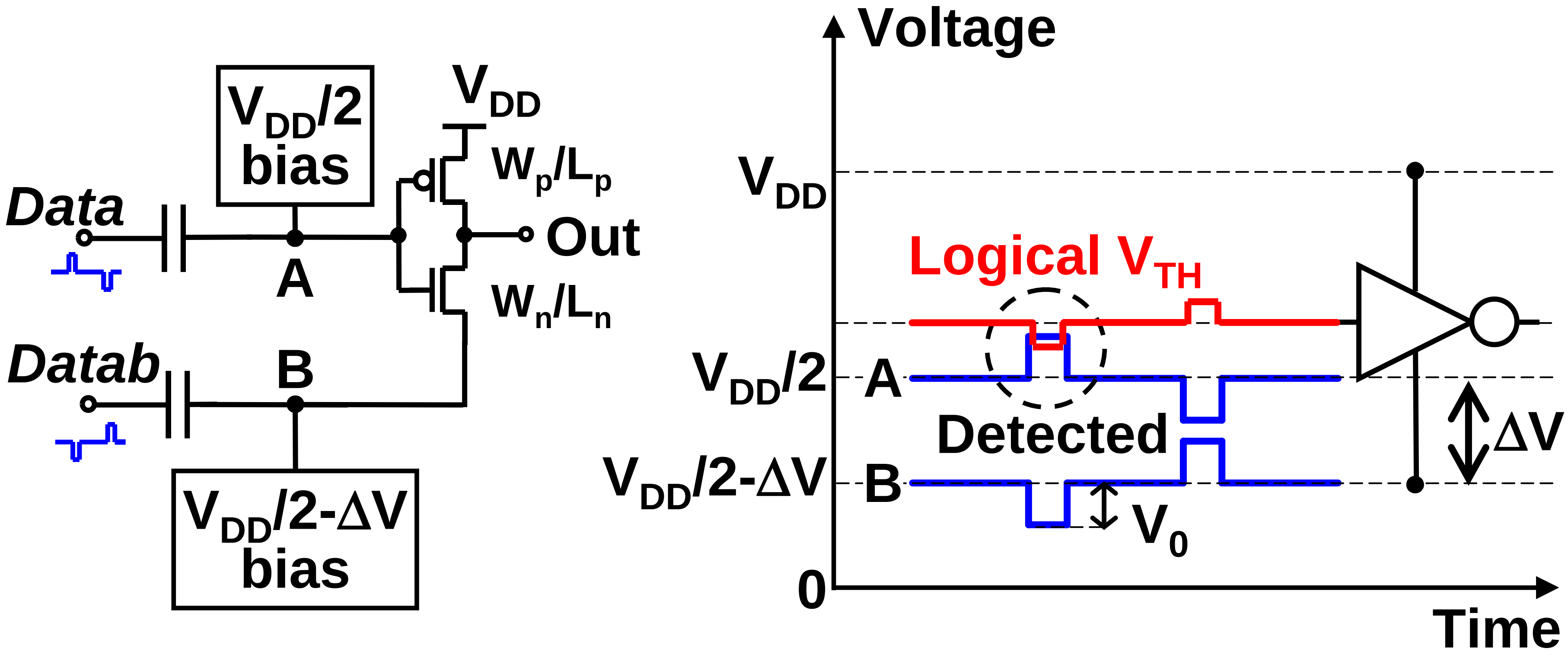




◆ CS is fabricated with printing technology.

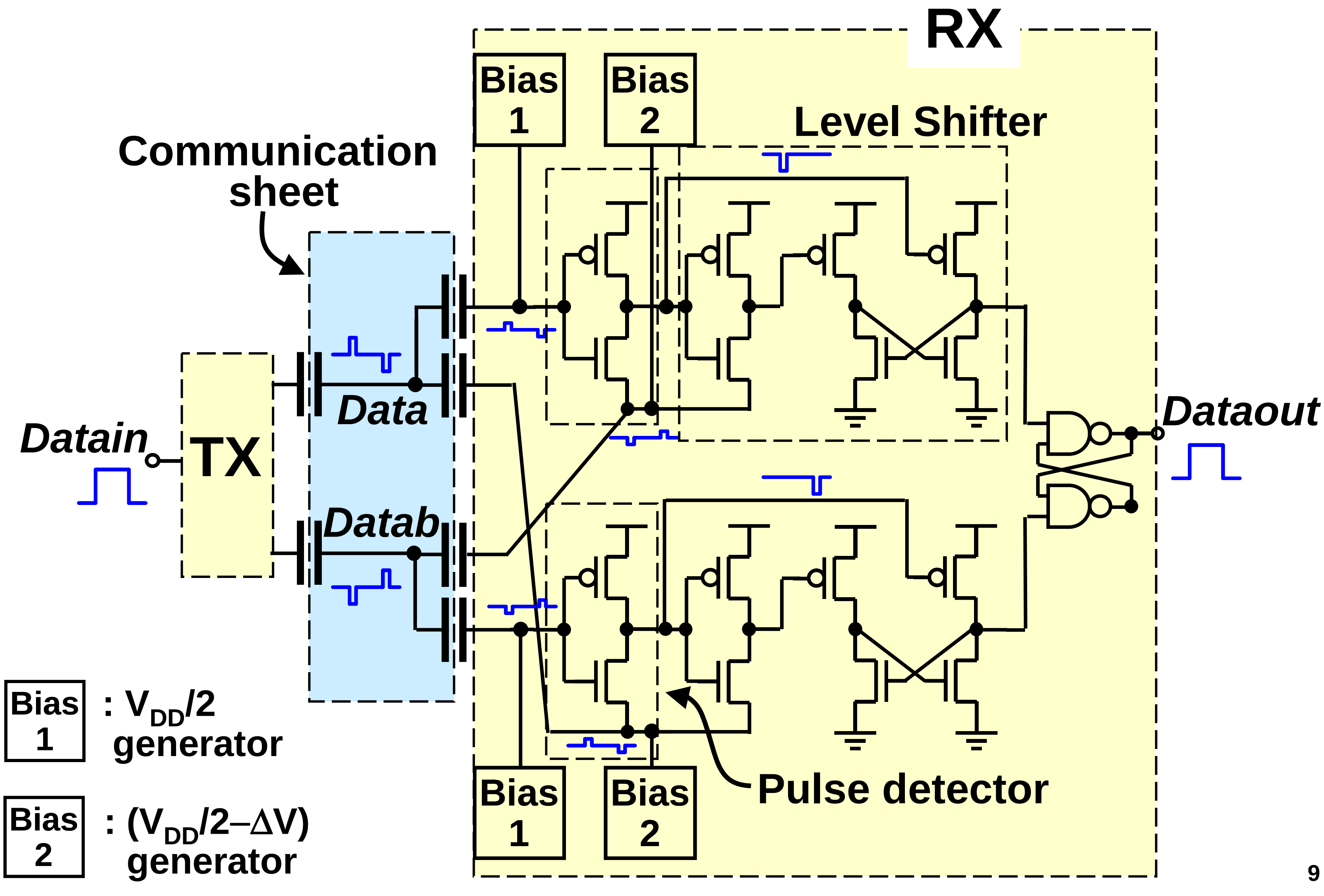
DC Power-Free Pulse Detector

- Problems of conv clock-less RX: Large DC power

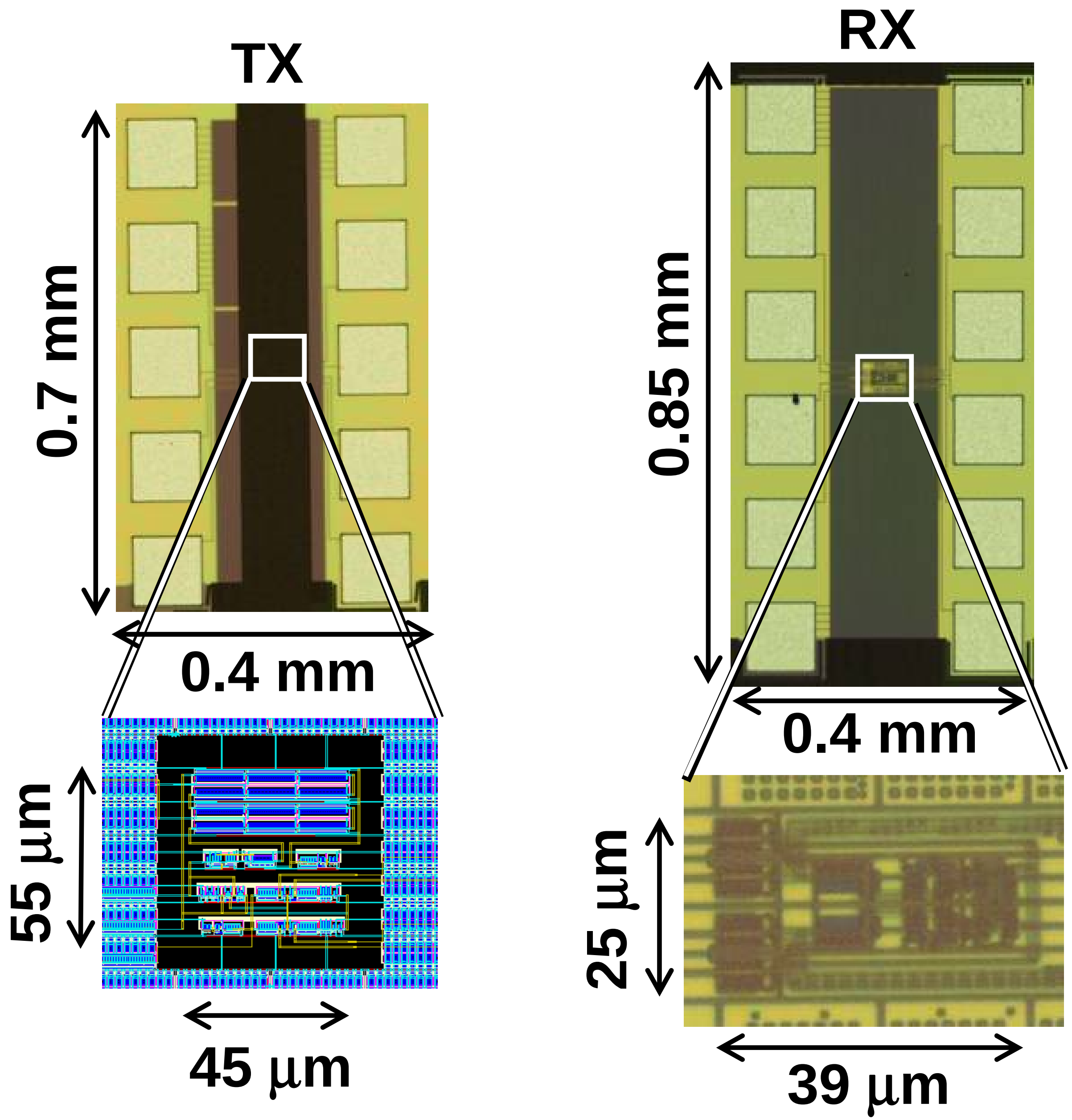


- Dynamic logical V_{TH} of the inverter achieves DC power-free pulse detection.

Receiver with DC Power-Free Pulse Detector



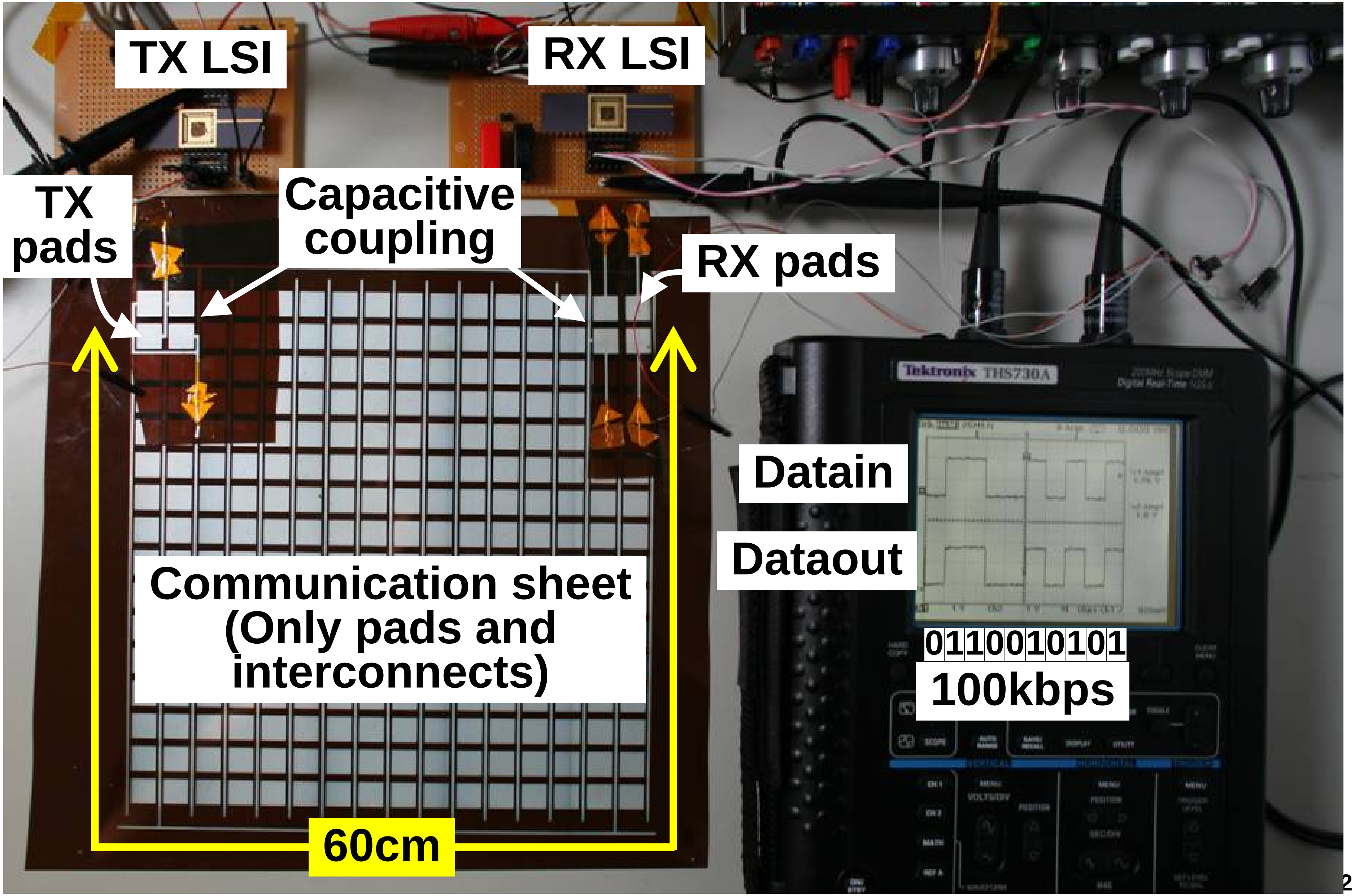
Chip Micrographs



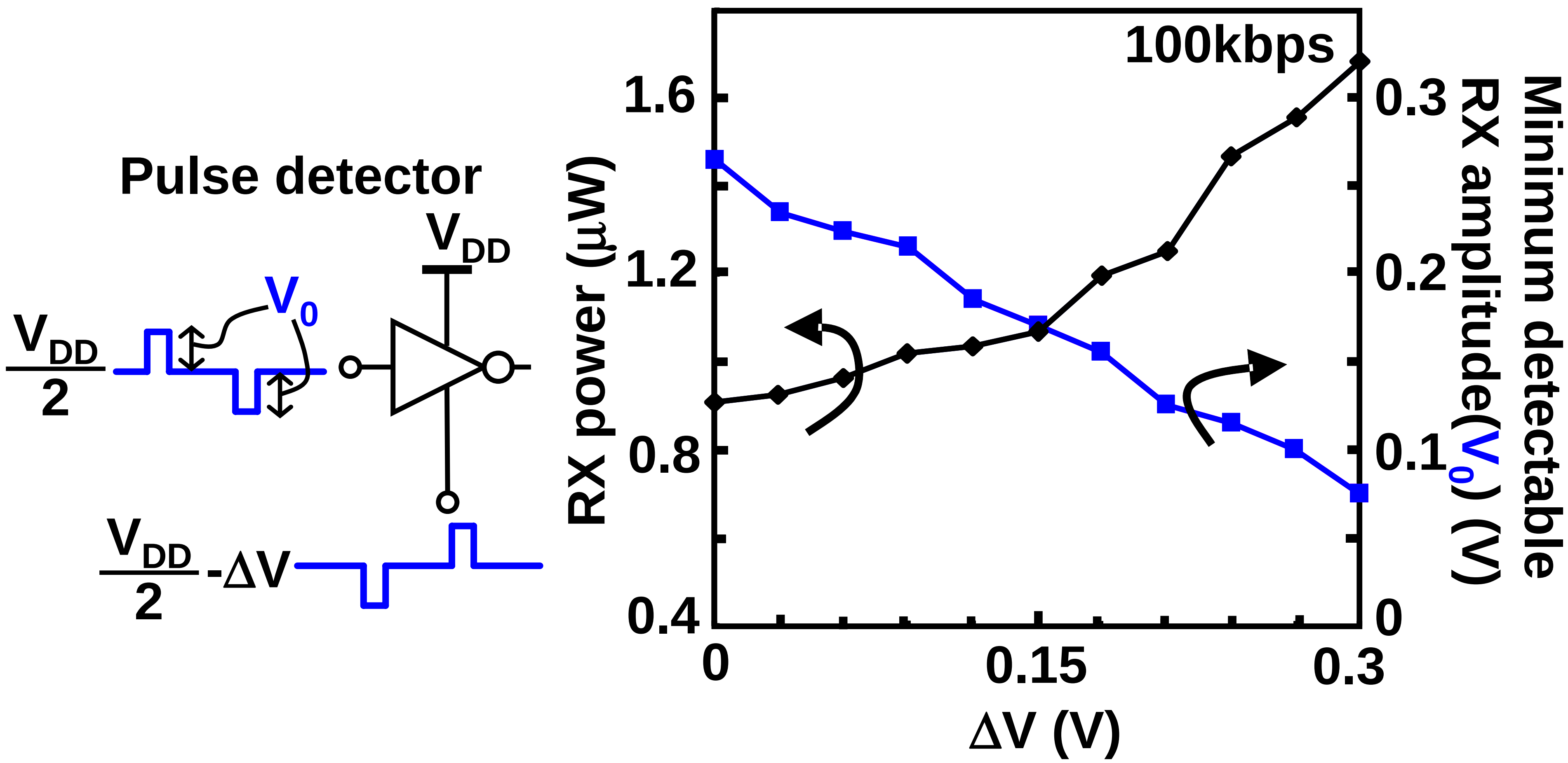
Performance Summary

Technology		0.18μm CMOS
Supply Voltage		1.8V
Data Rate	Typ	100kbps
	Max	8Mbps
Communi-cation Distance	Capacitive Coupling	150μm
	Wireline	60cm
Alignment Tolerance		7.5mm
Power @100kbps	TX	9.73μW
	RX	0.97μW
	Total	10.7μW
Energy per bit		107pJ/bit
Core Area	TX	2475μm^2
	RX	975μm^2

Capacitive-Coupling Communication on CS

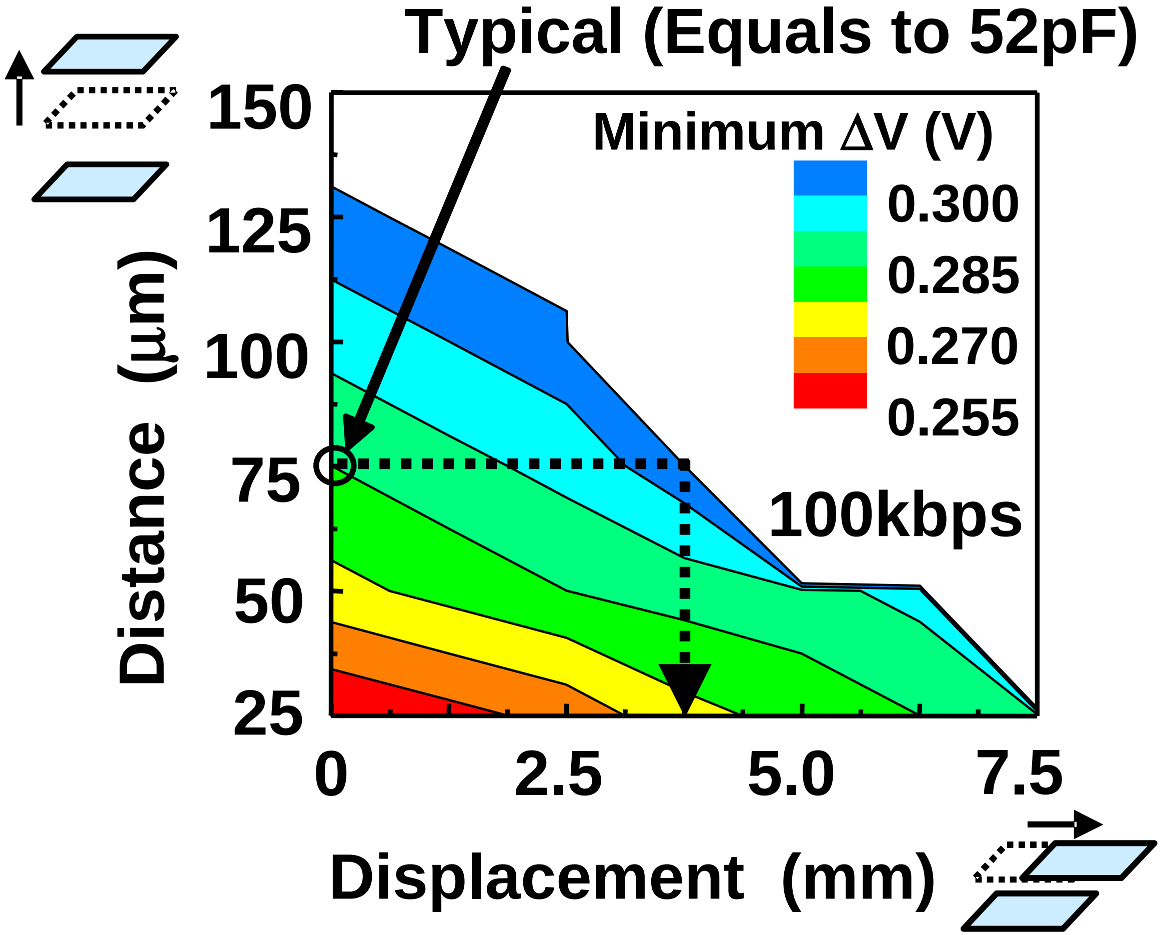


ΔV Dependence of RX



- The tradeoff between the power and the RX sensitivity can be tuned by ΔV.

ΔV dependence of Displacement



- For the 75μm distance, the sheet can operate up to 3.75mm displacement.
- The maximum tolerable displacement was 7.5mm, which corresponds to the 77% of the pad size.

Summary

◆ **The communication sheet combining the merit of wireless and wireline approaches**

➔ **Achieving both the mobility of wireless communication and the low-power performance of wireline communication.**

◆ **The 100kbps 0.18μm capacitive-coupling transceiver for the communication sheet**

- **Low power data edge signaling and DC power-free pulse detector**
- **The lowest energy of 107pJ/bit in the wireless communications**