Signal Processing for Pen and Touch Sensors

May 31, 2021
Masayuki Miyamoto
Wacom

for a creative world ™

wacom

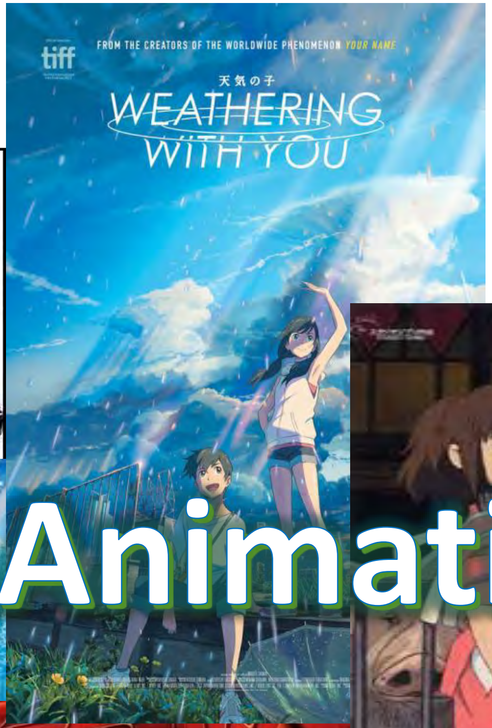
Outline

1. Pen and Touch User Interface
2. EMR (Electro-Magnetic Resonance) Sensing Technology
3. Capacitive Sensing Technology
   - Principle
   - SNR Enhancement
   - Noise Immunity
   - Sensor Requirement
   - Passive Pen
   - Active Pen
4. Latest Technical Challenges

Pen and Touch User Interface

Professional Creation Support

Industry Design



Games

Animation

Movie Production


Pen Tablet Products for Creative Users

wacom One

wacom Intuos Pro

wacom Cintiq Pro

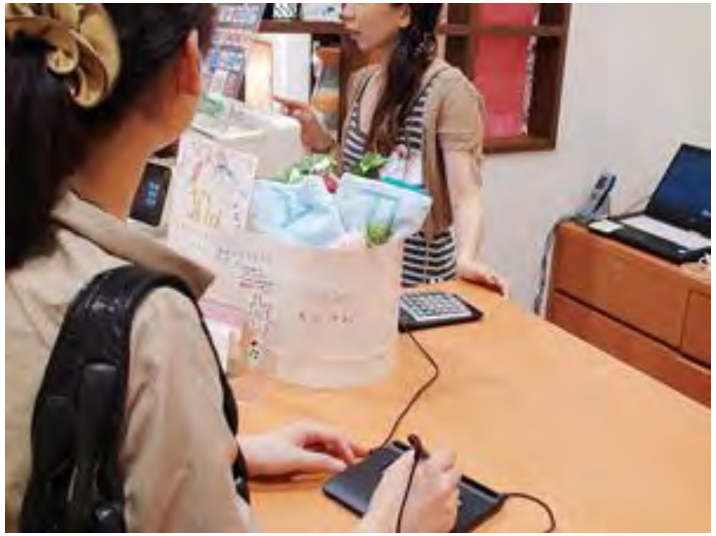
BAMBOO Ink

BAMBOO Slate

BAMBOO Folio

Digital Signature System

Citibank, Korea

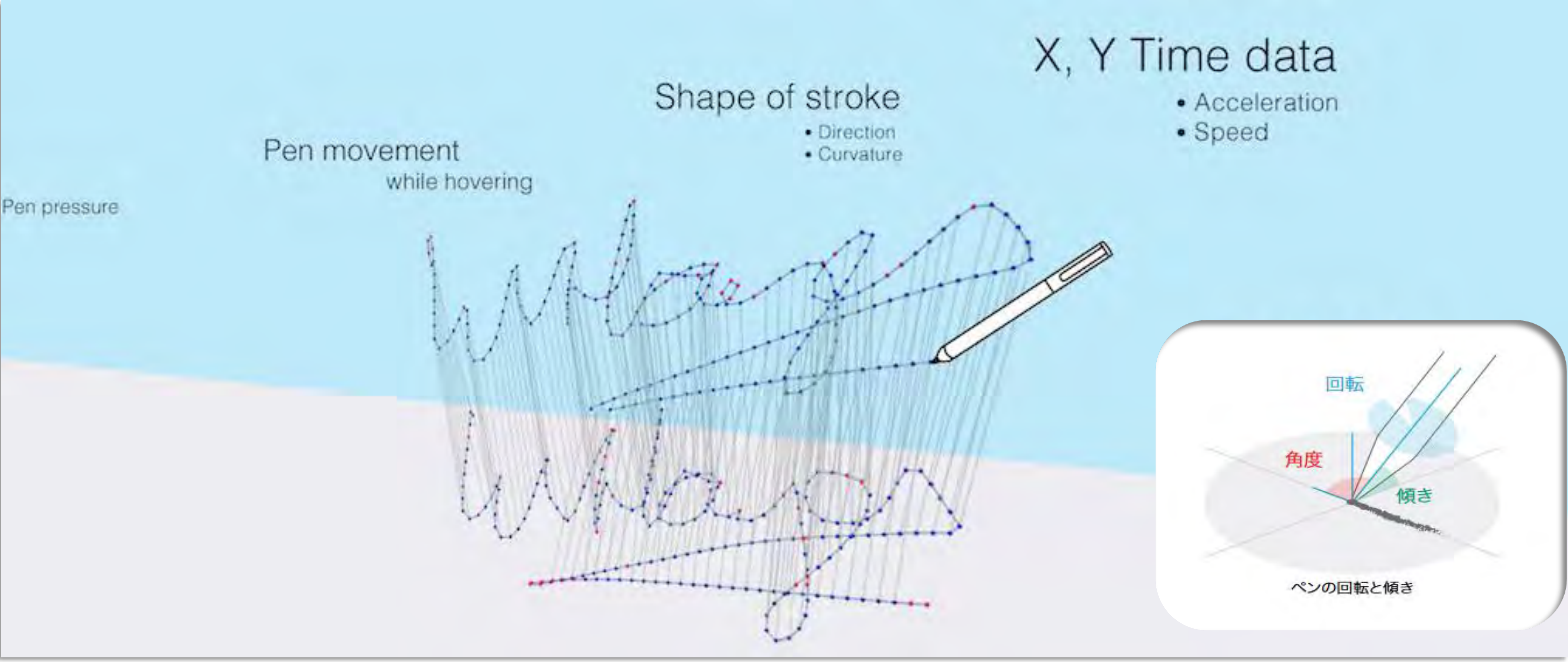


Lalaport, Mitsui Fudosan Retail Management, Japan

Wacom Clipboard

Signature Tablets

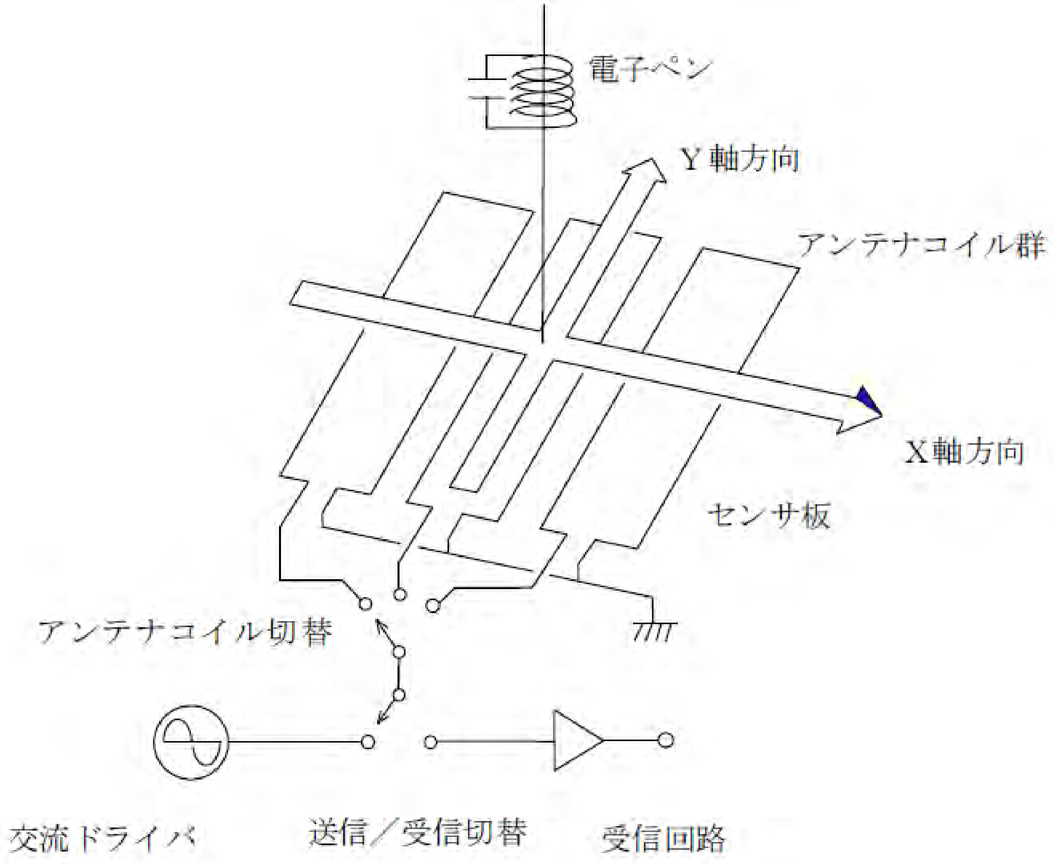
Wacom Ink Layer Language



Pen and Ink Solutions for Smartphones , Tablet, PC, Digital Stationery, etc.

Electro-Magnetic Resonance Sensing Technology

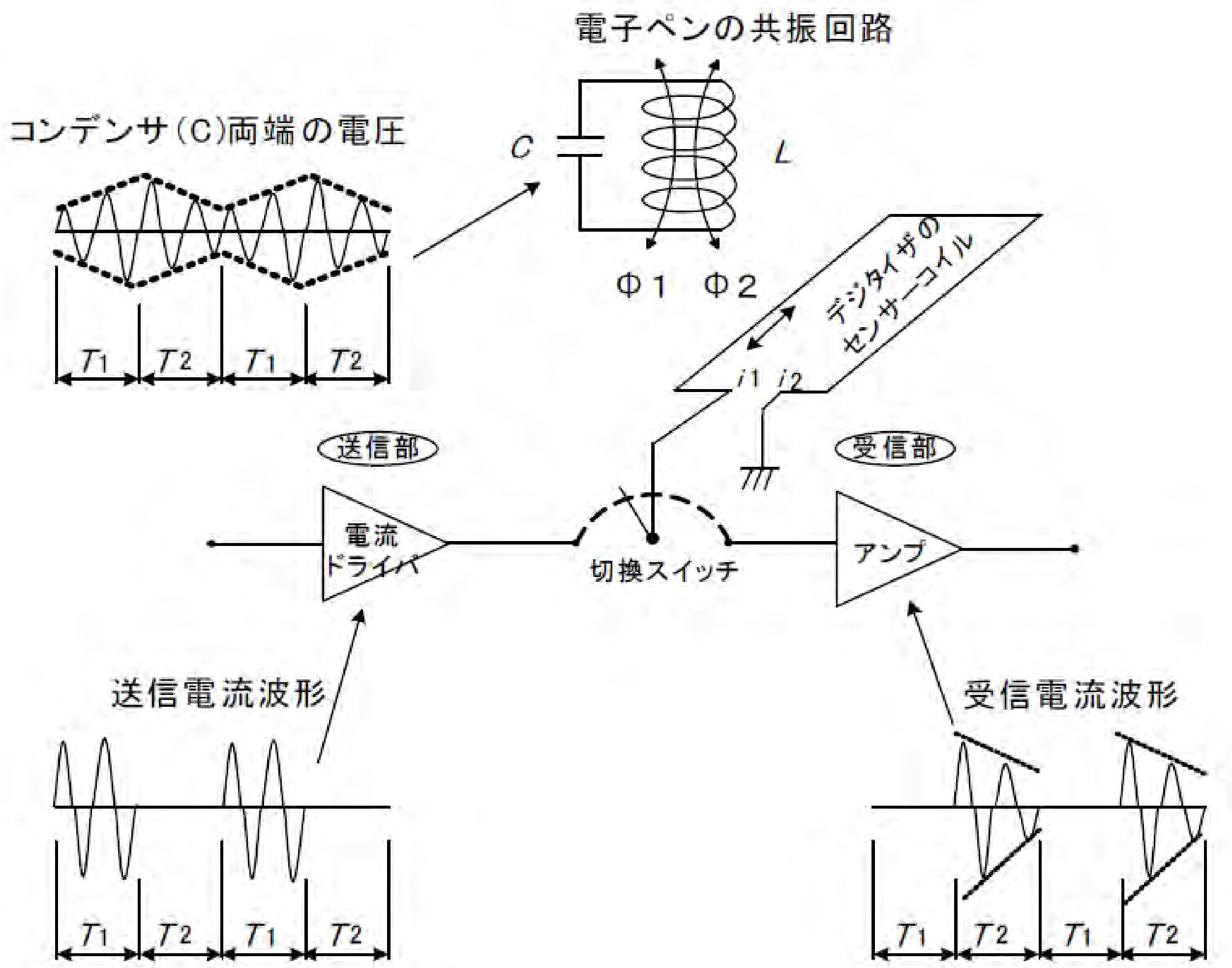
EMR: Sensing Principle



- No Battery in the pen

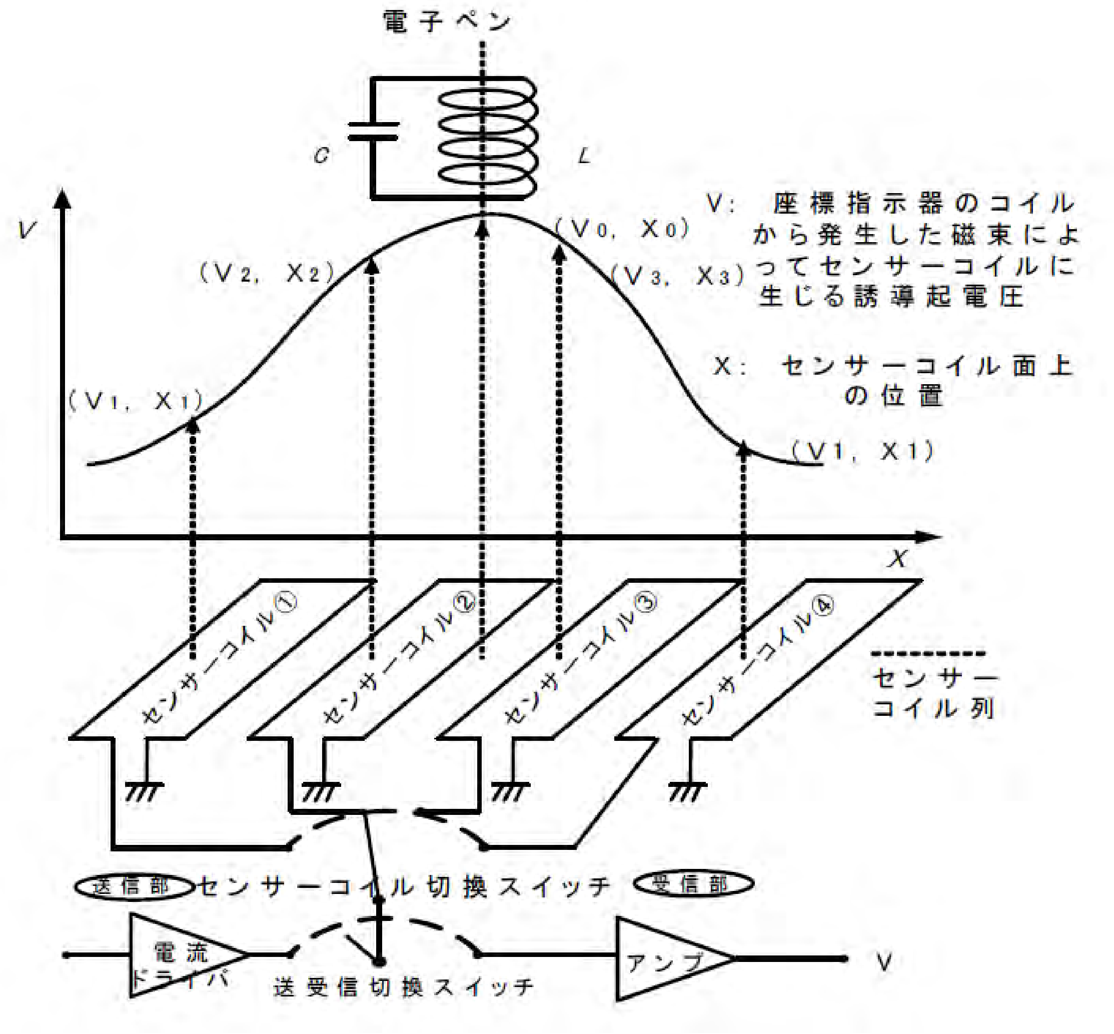
https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf

EMR: Sensing Signals



https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf

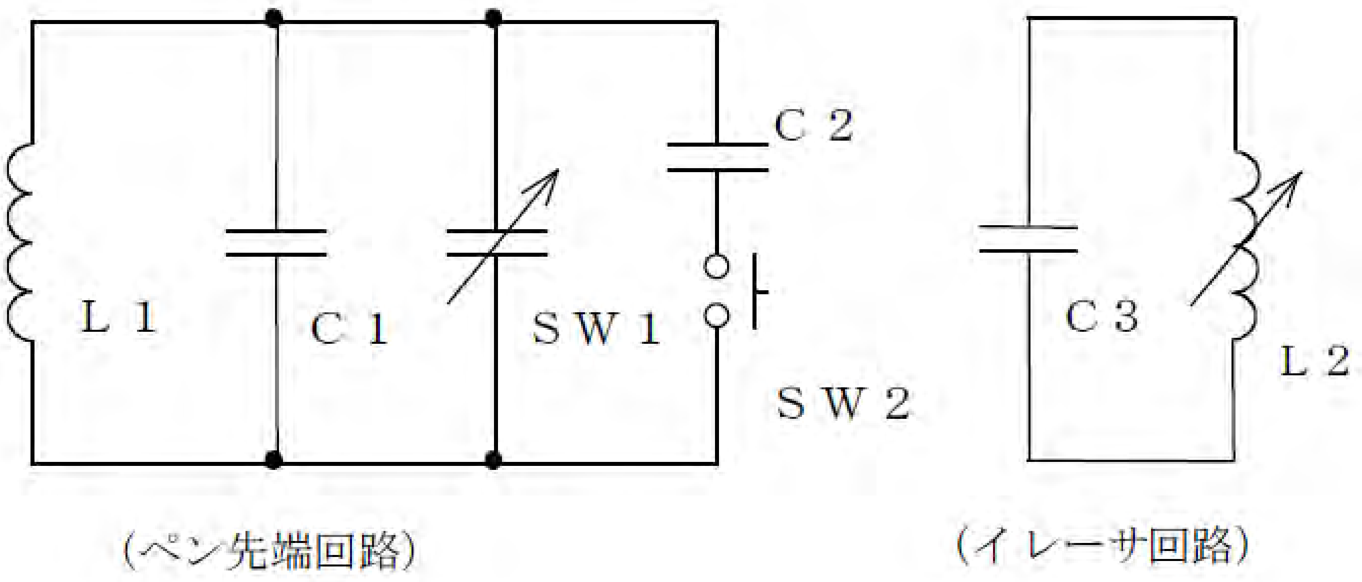
EMR: Pen Position Sensing



https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf

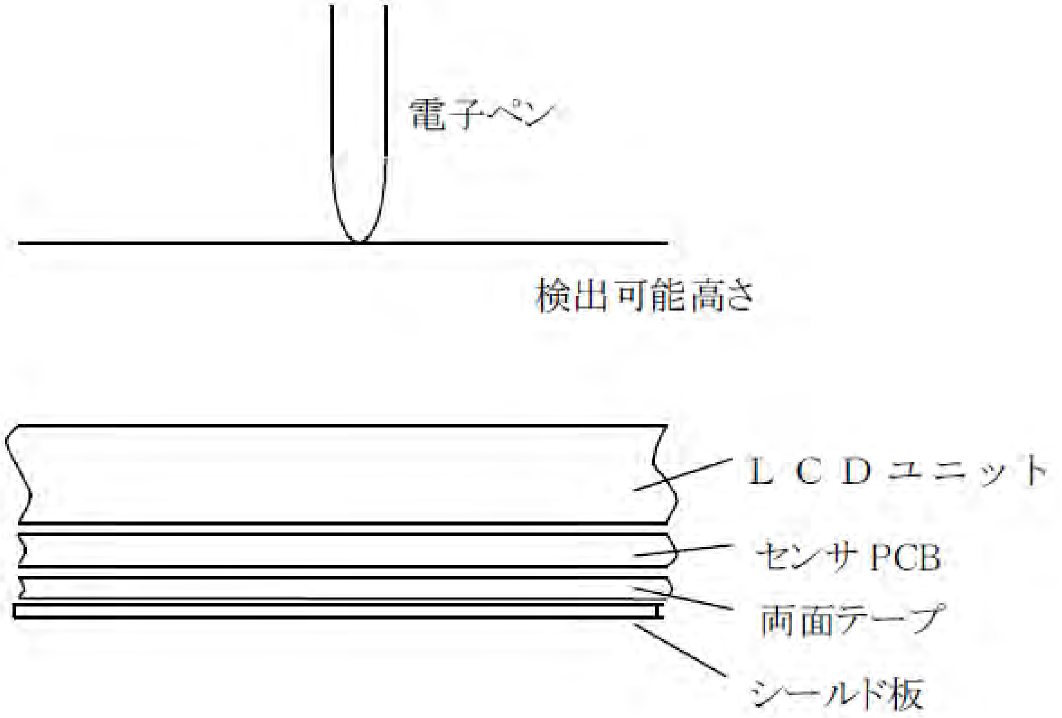
EMR: Pen Pressure, Side Switch, Eraser

[An Example]



https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf

EMR: Sensor Stack-up

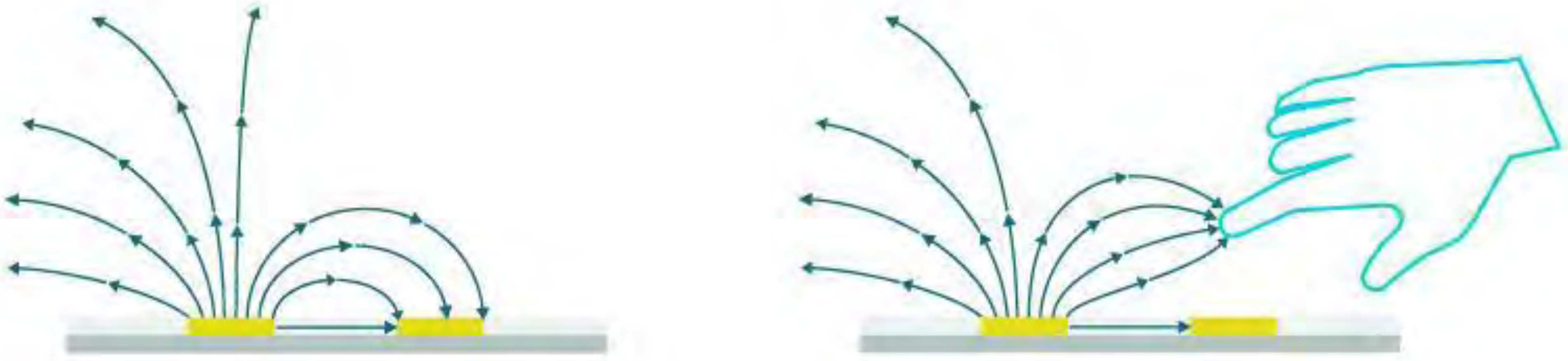


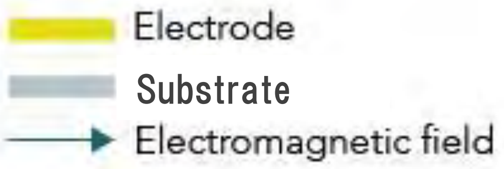
https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf

Capacitive Sensing Technology

- Principle
- SNR Enhancement
- Noise Immunity
- Sensor Requirement
- Passive Pen
- Active Pen

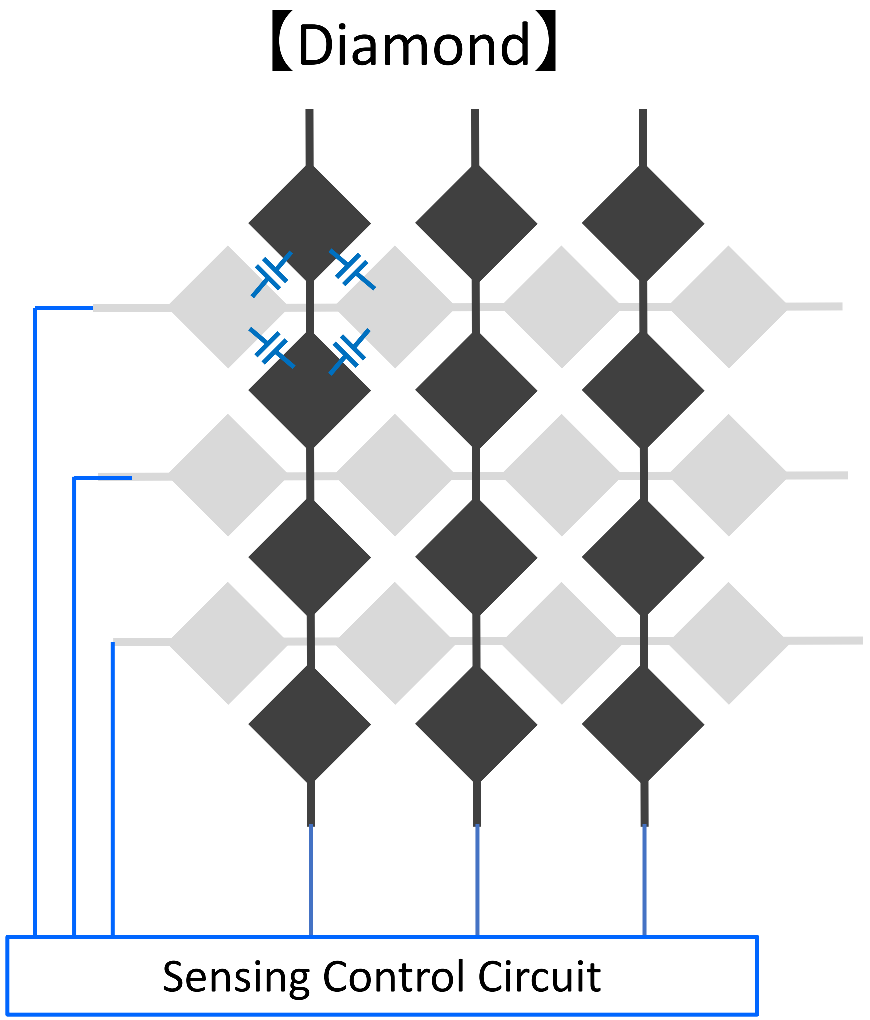
Mutual Capacitance Sensing

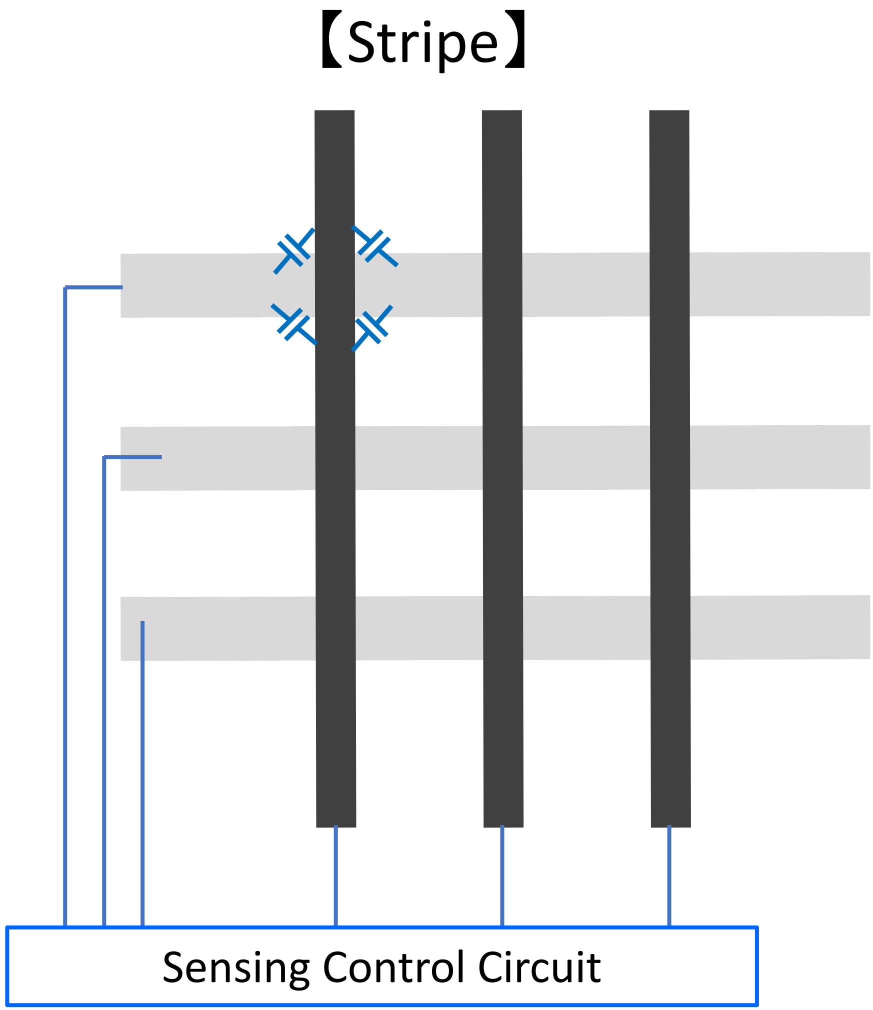




https://www.bareconductive.com/blogs/blog/how-do-the-touch-boards-capacitive-sensors-work

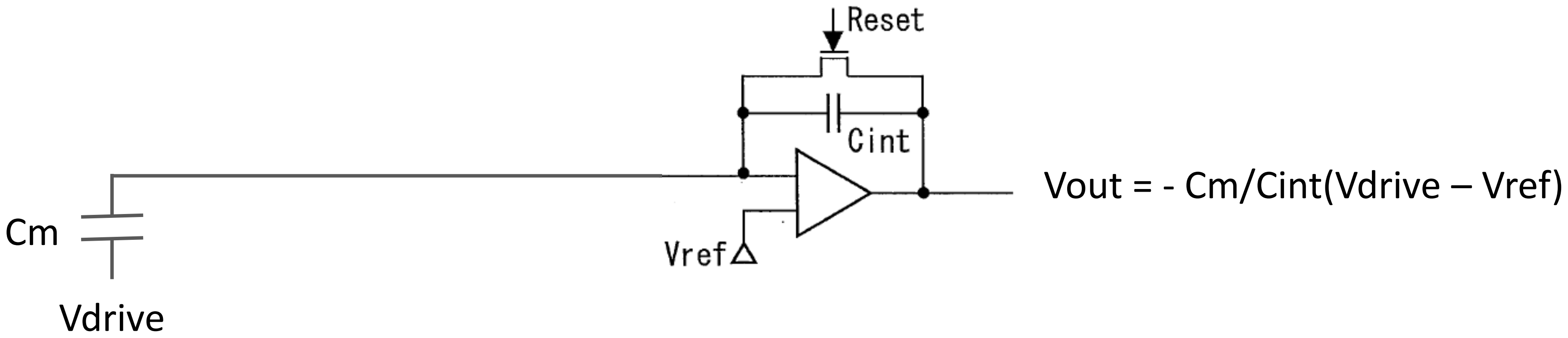
Mutual Capacitance Sensor Pattern



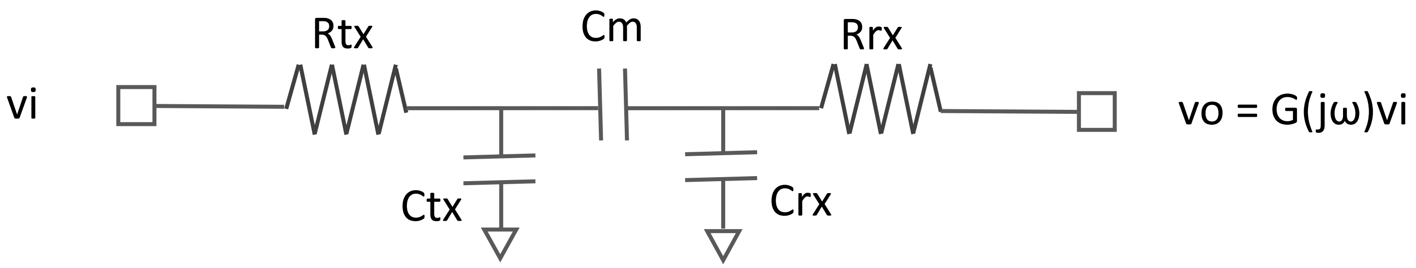


How to estimate the capacitance

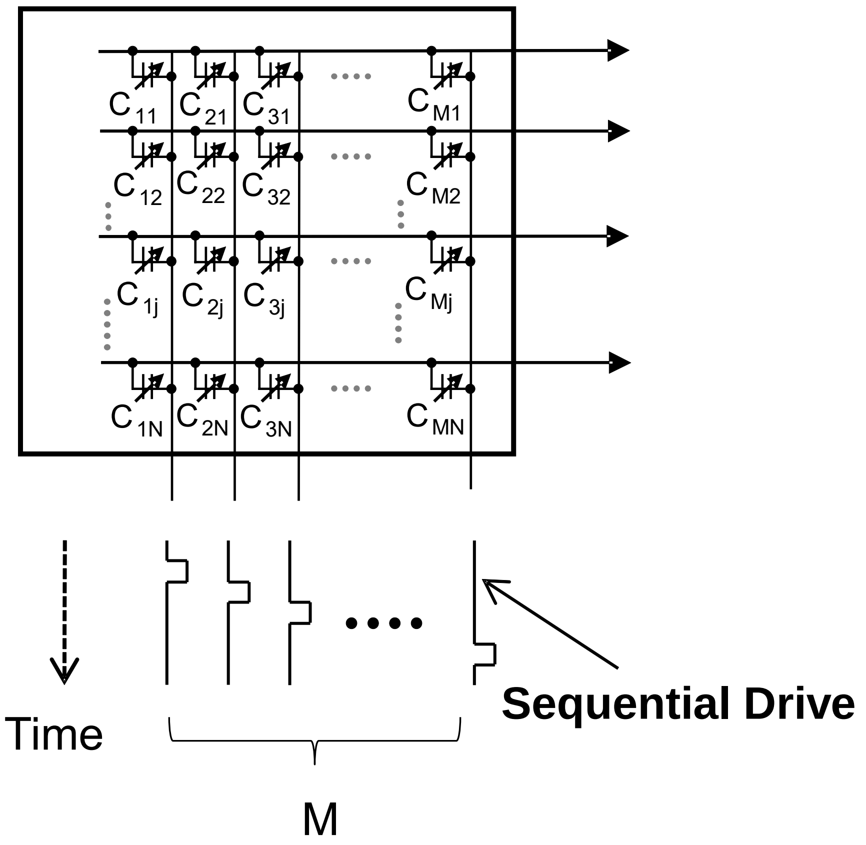
1. Charge Integration (Charge to Voltage Conversion)

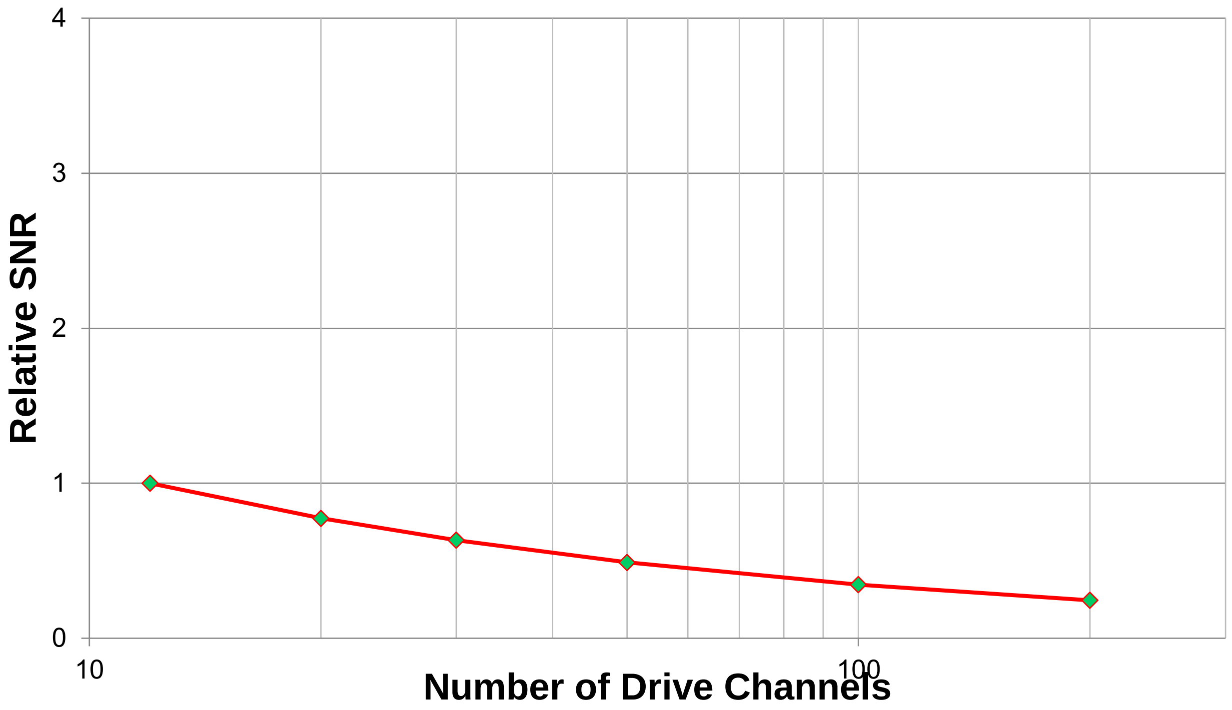


2. Frequency Response



Sequential Drive and SNR

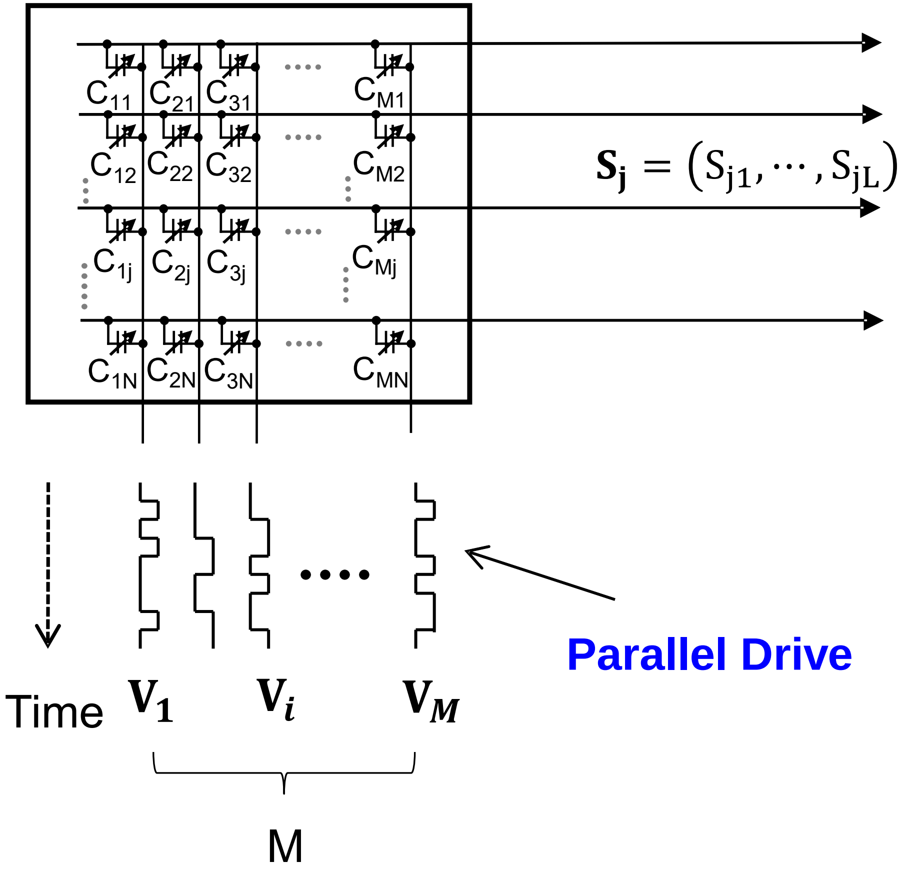




SNR decreases
as the number of channel increases

Parallel Drive

By driving all the channels in parallel, SNR increases.



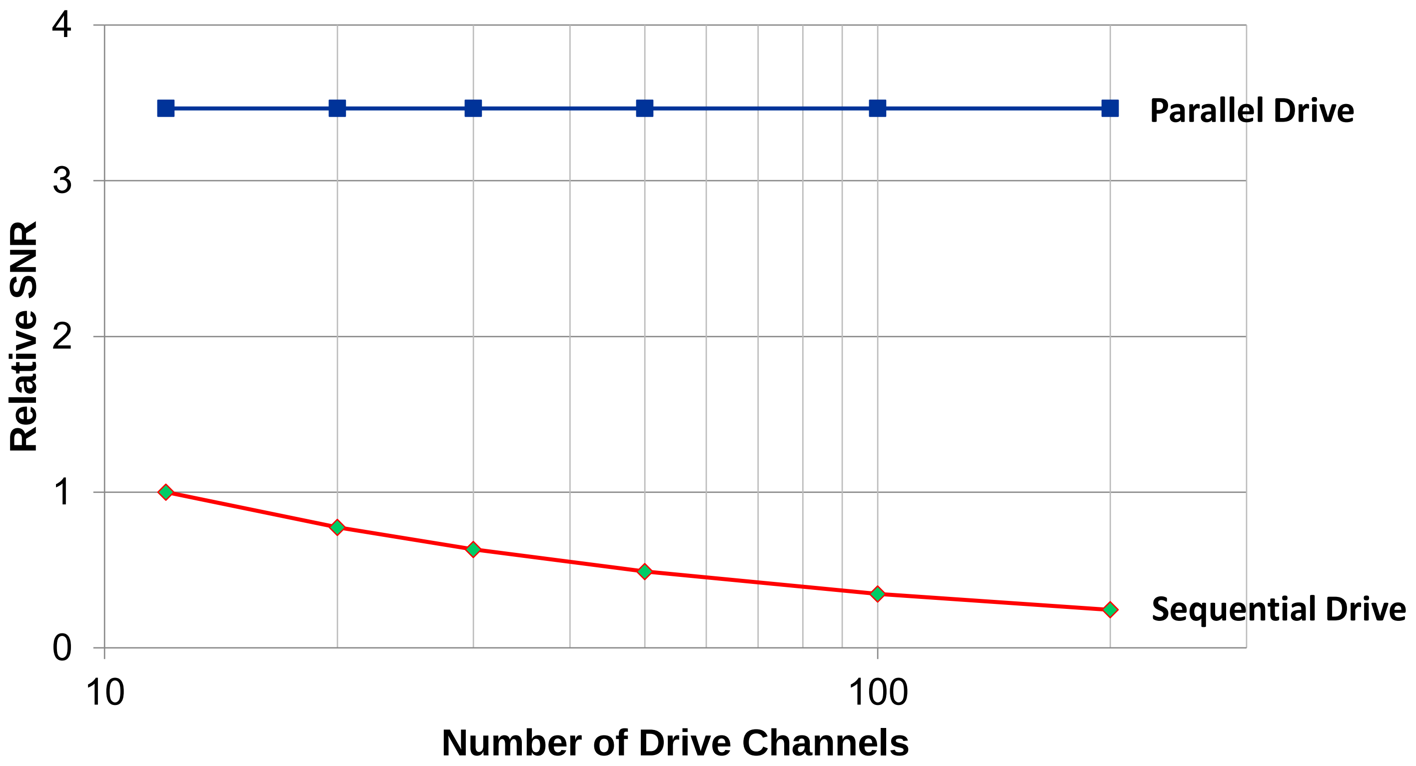
$$\mathbf{S_j} = (S_{j1}, \cdots, S_{jL}) = \sum_{i=1}^{M} C_{ij}\mathbf{V_i}$$

Signal Reconstruction

$$(\mathbf{S_j}, \mathbf{V_l}) = \left(\sum_{i=1}^{M} C_{ij}\mathbf{V_i}, \mathbf{V_l}\right)$$
$$= \sum_{i=1}^{M} C_{ij}\,(\mathbf{V_i}, \mathbf{V_l})$$
$$= \sum_{i=1}^{M} C_{ij}\, L\delta_{il}$$
$$= C_{lj}L$$

if $(\mathbf{V_i}, \mathbf{V_l}) = \sum_{k=1}^{L} V_{ik}V_{lk} = L\delta_{il}$

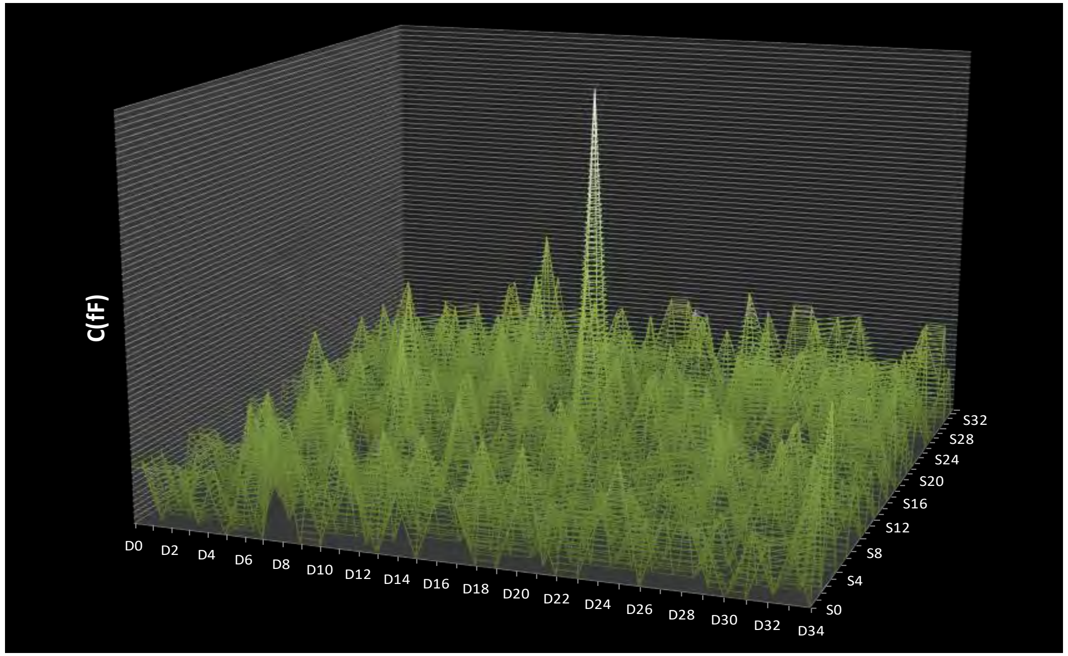
SNR Comparison: Sequential vs. Parallel



(Assumption)
Sensor’s channel resistance is 0.

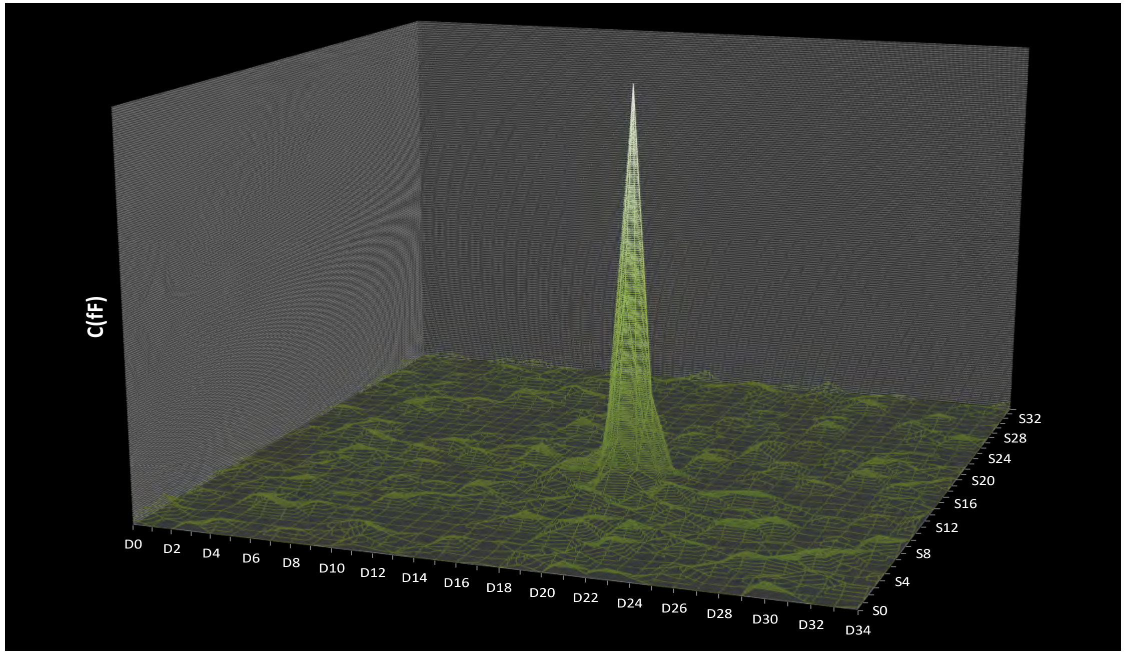
Measured Results: Sequential vs Parallel

Sequential Drive



#(Drive & Sense Cycle) = 348 = 87 x 4

Parallel Drive



#(Drive & Sense Cycle) = 254 = 127 x 2

#(Drive Channel) = 87

Parallel drive: Hadamard

Hadamard Matrix: Mutually Orthogonal

$$H_1 = [1],$$

$$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix},$$

$$H_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix},$$

and

$$H_{2^k} = \begin{bmatrix} H_{2^{k-1}} & H_{2^{k-1}} \\ H_{2^{k-1}} & -H_{2^{k-1}} \end{bmatrix} = H_2 \otimes H_{2^{k-1}},$$

for $2 \leq k \in N$, where $\otimes$ denotes the Kronecker product.

https://en.wikipedia.org/wiki/Hadamard_matrix

DC saturation of the AFE vs Gain

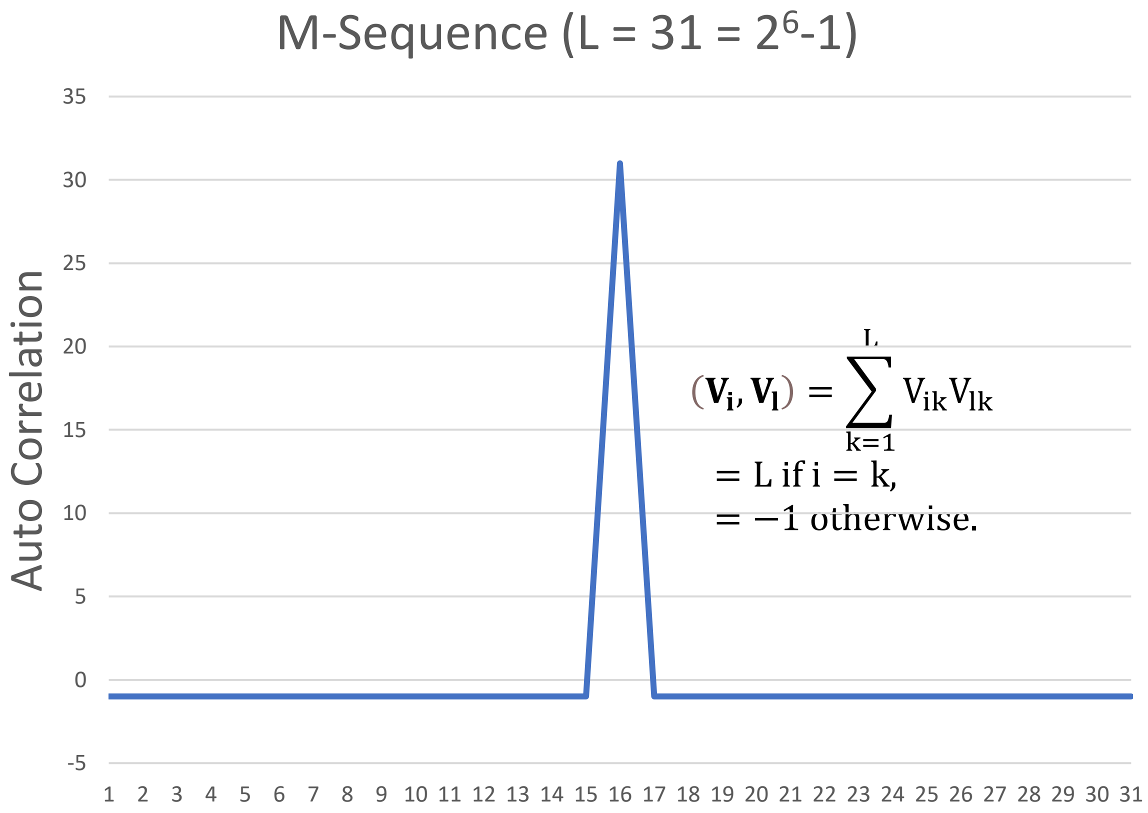
Periodicity vs Noise Immunity

Parallel drive: M-Sequence

Shifted MLS (Maximum Length Sequence)s: Pseudo Orthogonal

-1	1	-1
-1	-1	1
-1	-1	-1
-1	-1	-1
1	-1	-1
-1	1	-1
-1	-1	1
1	-1	-1
-1	1	-1
1	-1	1
1	1	-1
-1	1	1
-1	-1	1
1	-1	-1
1	1	-1
1	1	1
1	1	1
1	1	1
-1	1	1
-1	-1	1
-1	-1	-1
1	-1	-1
1	1	-1
-1	1	1
1	-1	1
1	1	-1
1	1	1
-1	1	1
1	-1	1
-1	1	-1
1	-1	1

· · ·

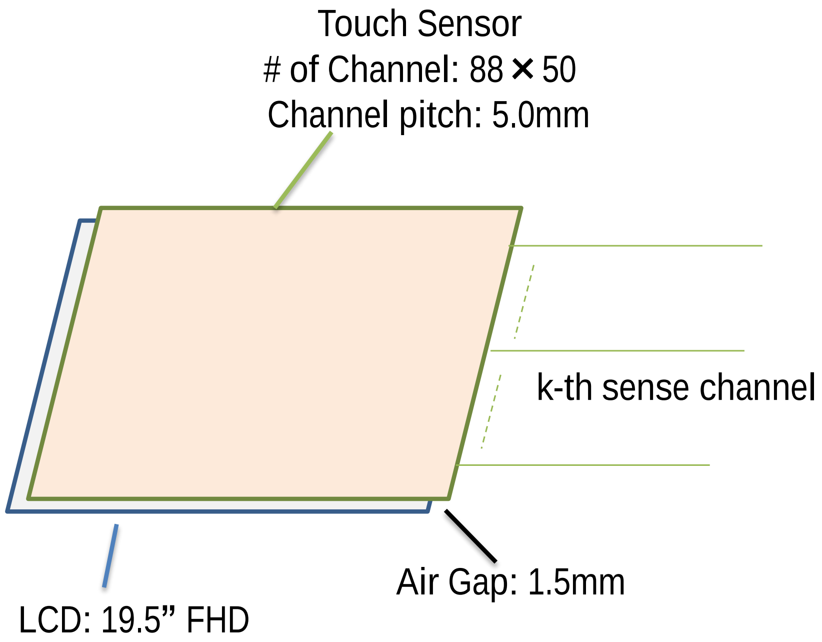


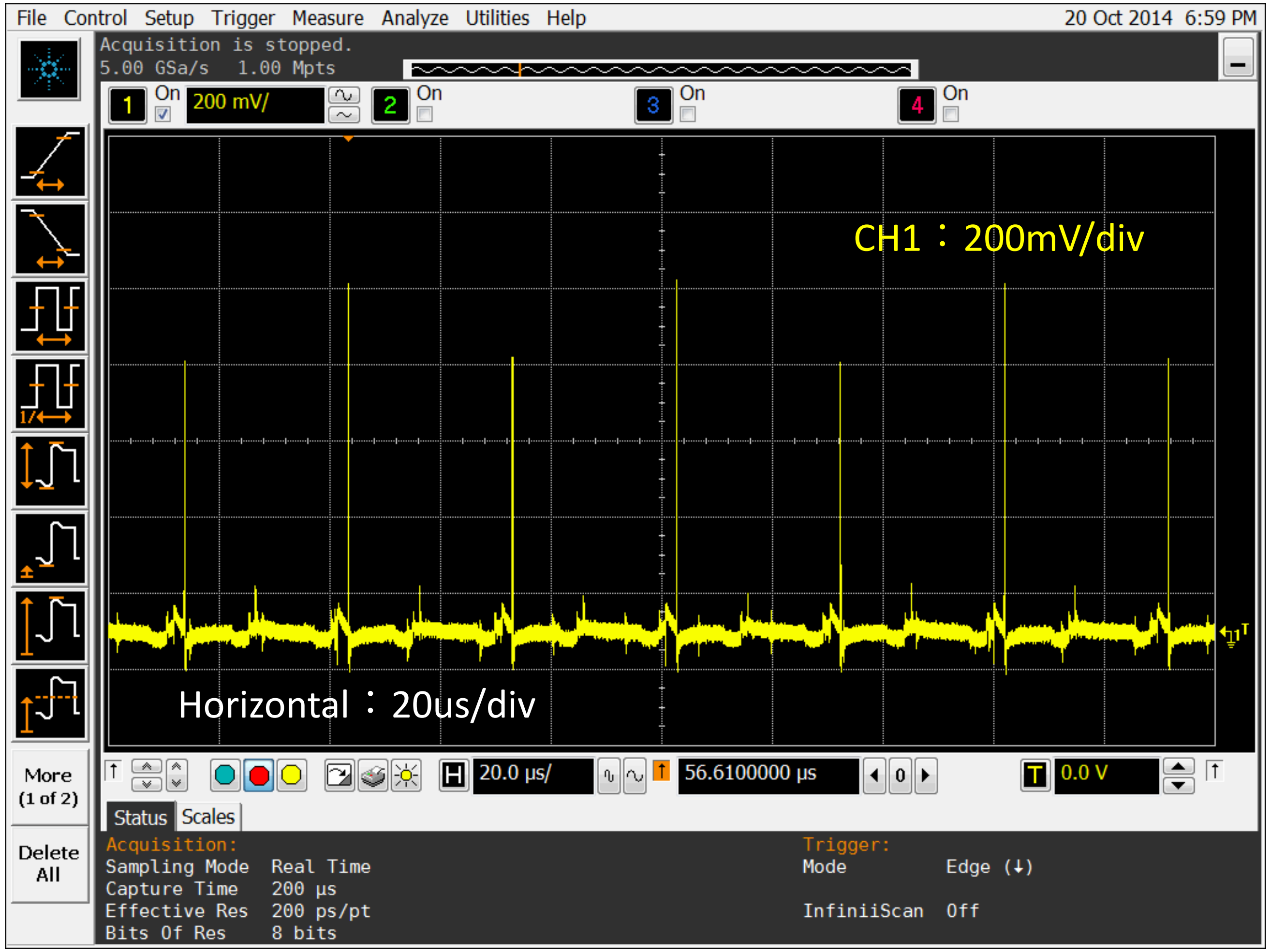
$$(\mathbf{V_i}, \mathbf{V_l}) = \sum_{k=1}^{L} V_{ik}V_{lk}$$
$$= L \text{ if } i = k,$$
$$= -1 \text{ otherwise.}$$

MLS has Pseudo Randomness
- Less DC component
  - -> No DC offset issue
  - -> Higher Gain
  - -> Higher SNR
- Pseudo Randomness
  - -> Spread spectrum
  - -> Better Noise Immunity

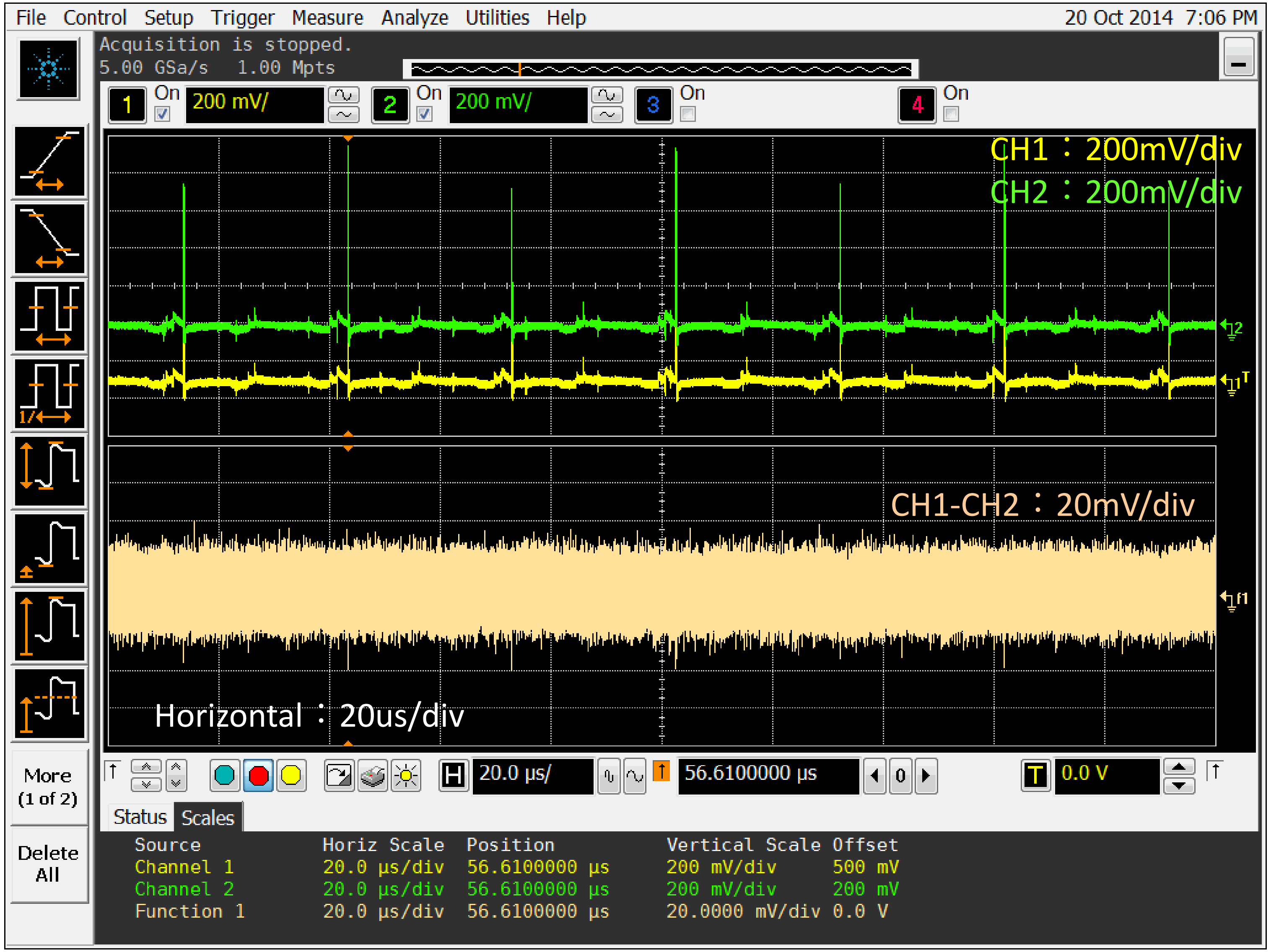
[Example Sequence] 0000100101100111110001101110101
generated from x 5 + x 2 + 1 (primitive polynomial)

Display Noise

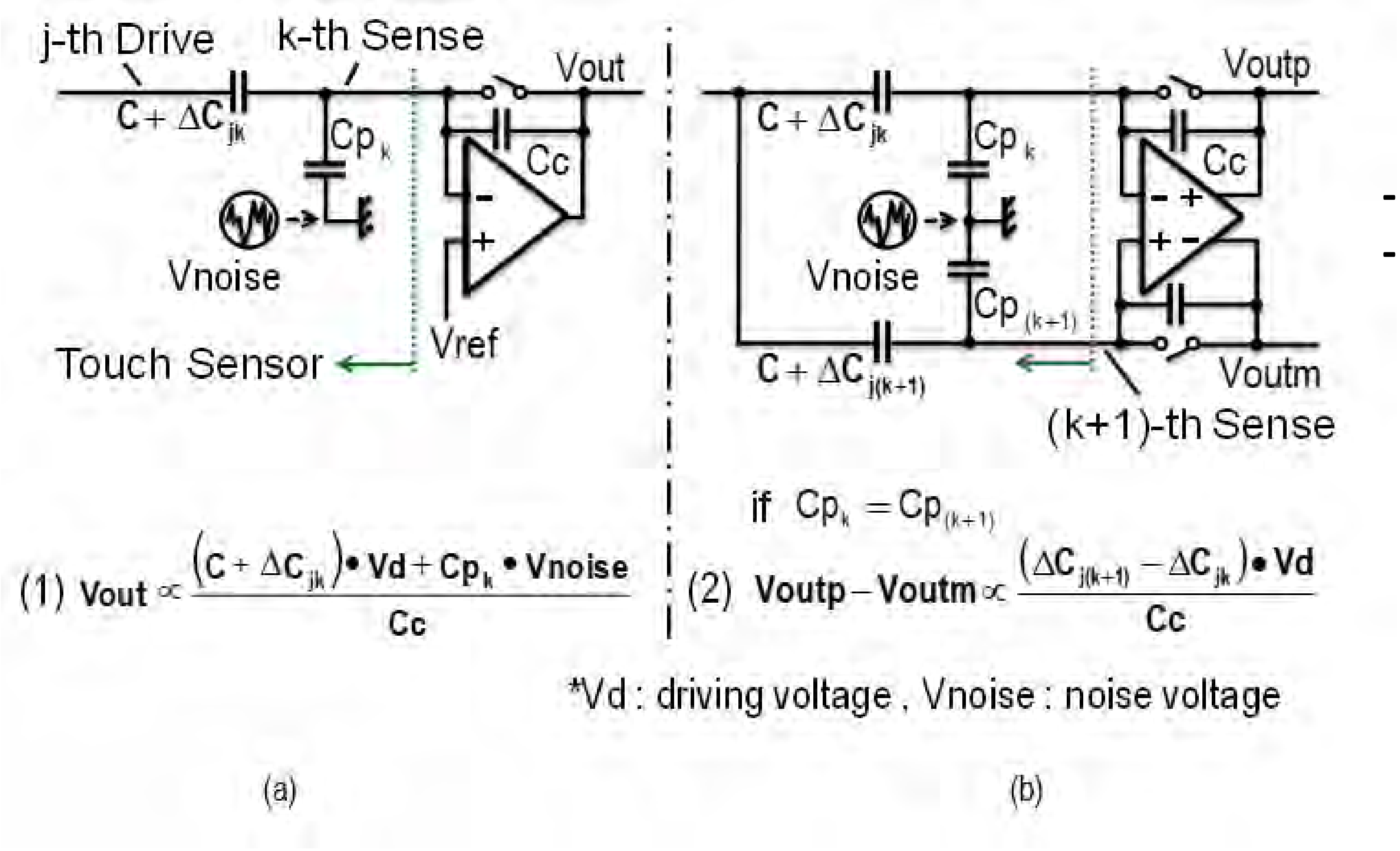




Noise Cancellation by Differential Sensing



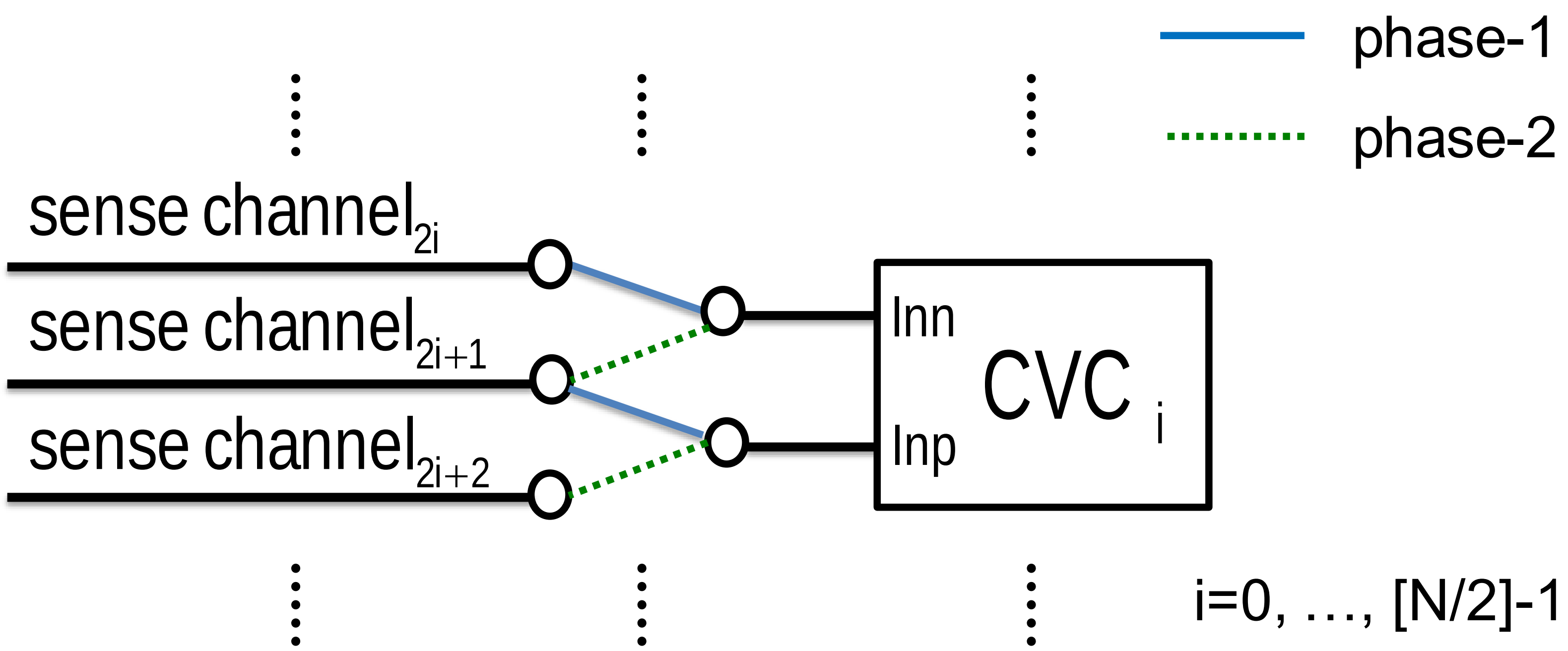
Advantage of Differential Sensing



- **Common Mode Noise Cancellation**
- **Higher SNR thanks to Higher Gain**

IEEE J. Solid-State Circuits, vol. 50, no. 1, pp. 335–343, Jan. 2015.

Two Phase Rx Circuit Operation

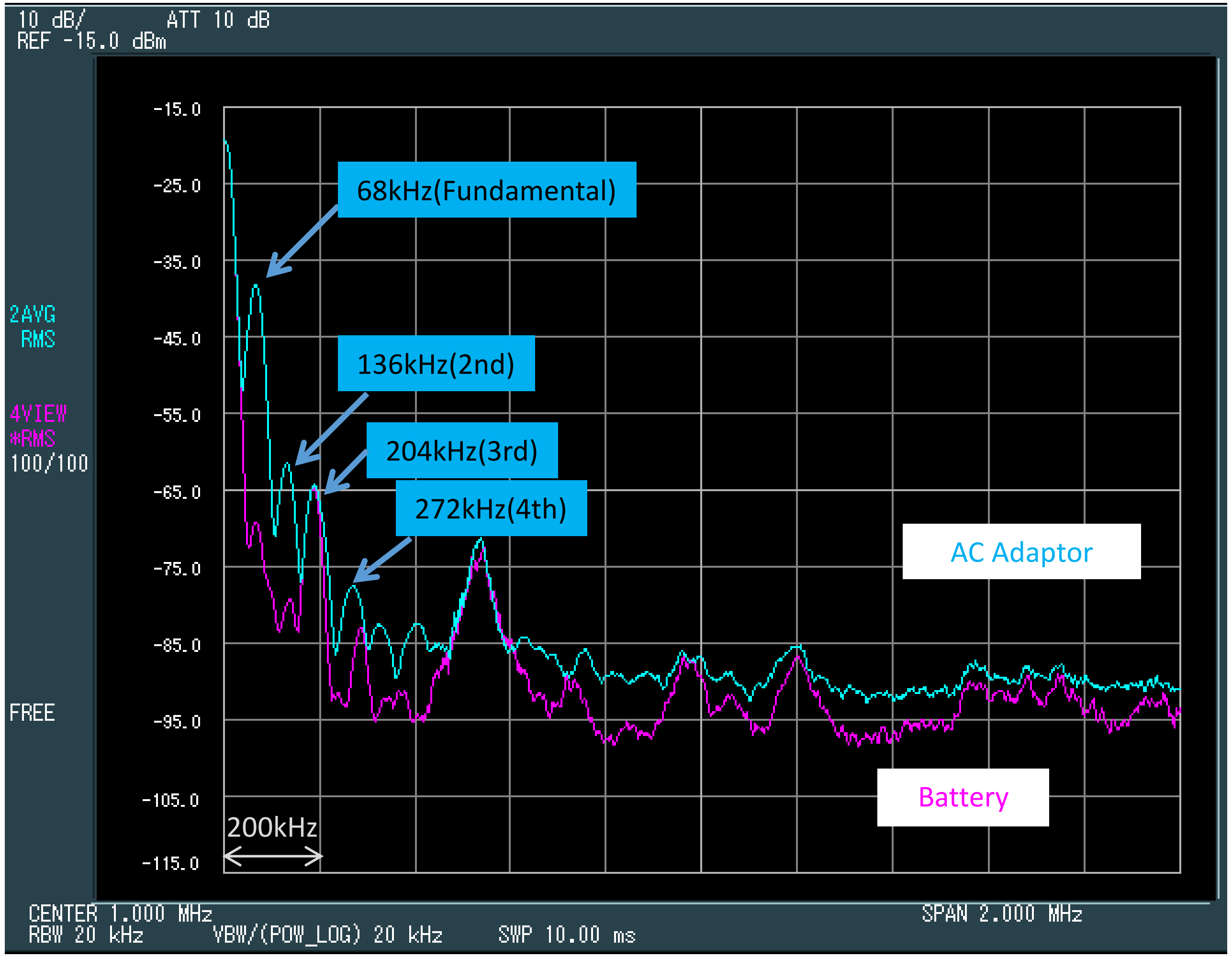


CVC: Charge to Voltage Converter

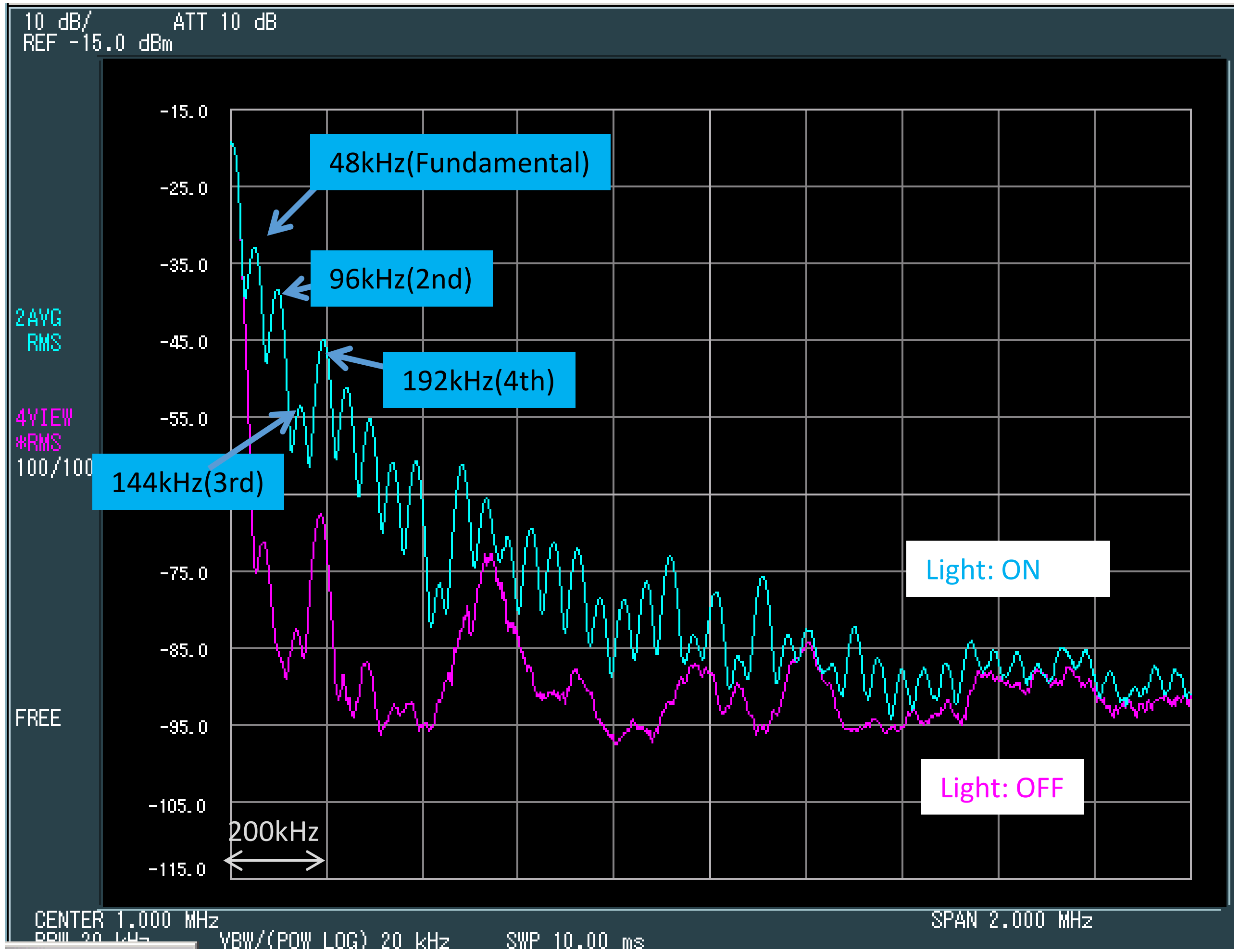
i=0, …, [N/2]-1.

IEEE J. Solid-State Circuits, vol. 50, no. 1, pp. 335–343, Jan. 2015.

Power Supply Noise



Environmental Noise: Fluorescent Light



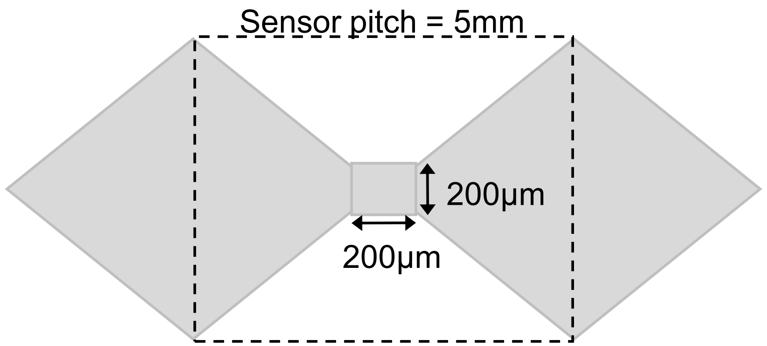
Sensor Material Requirement

- RC Time constant: ITO’s time constant is too large to realize large format sensors over 30-inch
- Light Transmittance
- Visibility: Color, Moire, etc.
- Bezel Area

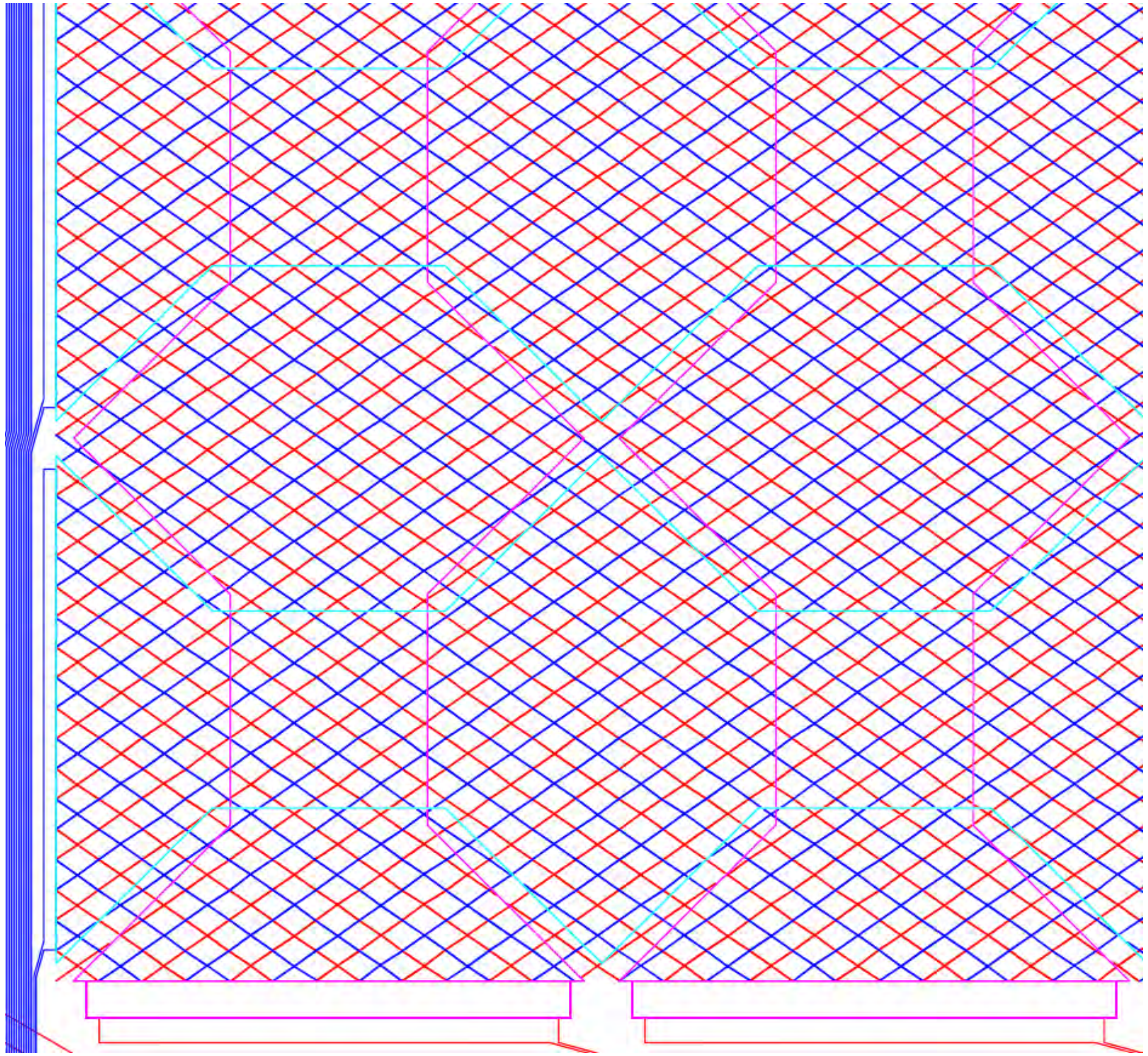
Time Constant Comparison

		Sheet Resistance	Metal Width	Time Constant (Normalized)
Metal Mesh	Copper (Thickness : 7um)	0.003Ω/sq.	7um	1
	Silver Paste (Thickness : 9um)	0.2Ω/sq.	6um	78
ITO	on Glass	20Ω/sq.	-	260
	on Film	150Ω/sq.	-	1950

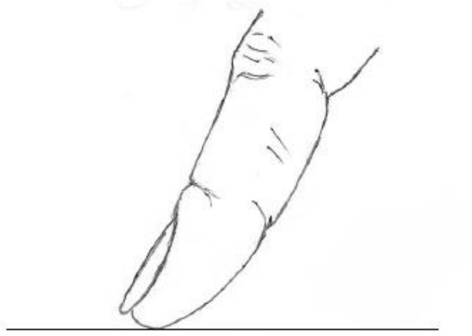
A Random Mesh Pattern

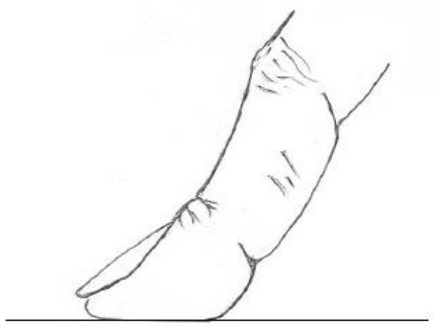


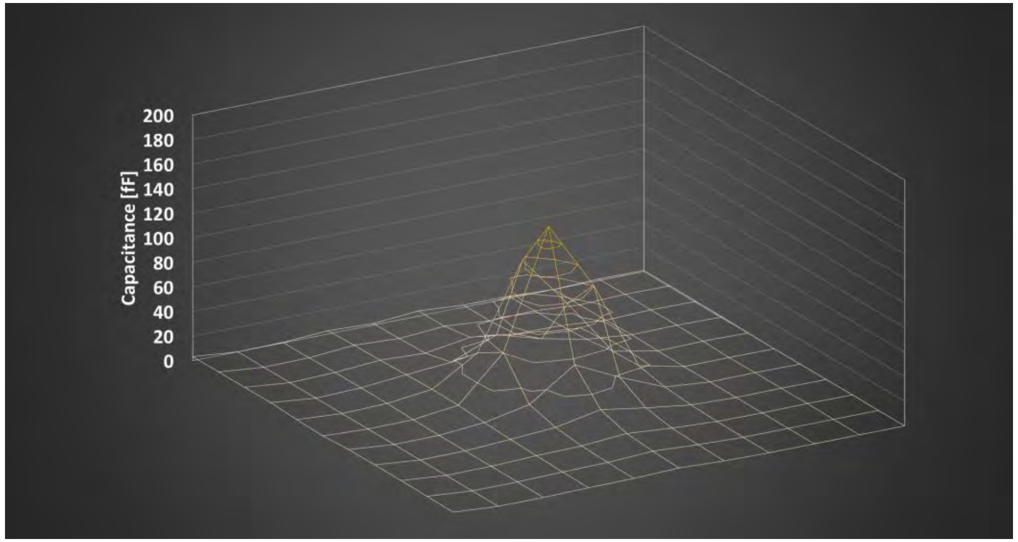
Mesh Sensor Design Example

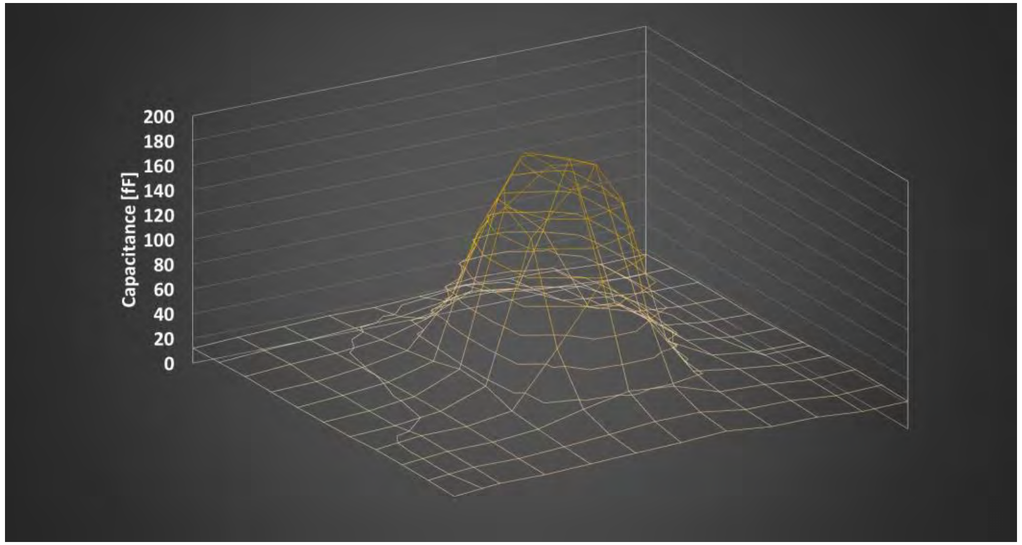


Capacitance Changes with a Finger

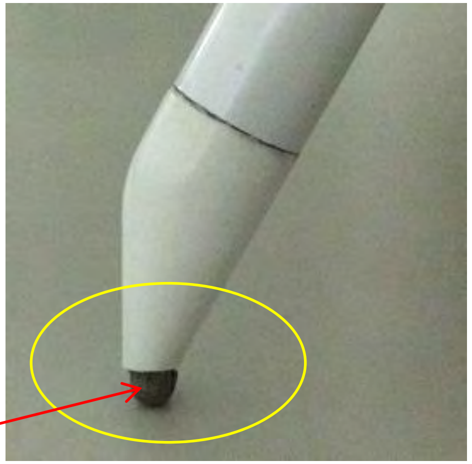






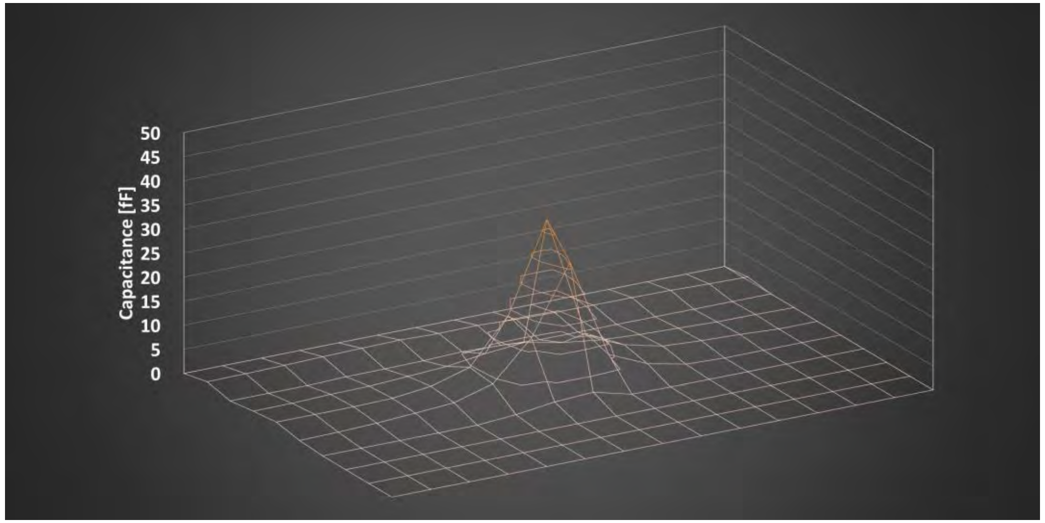


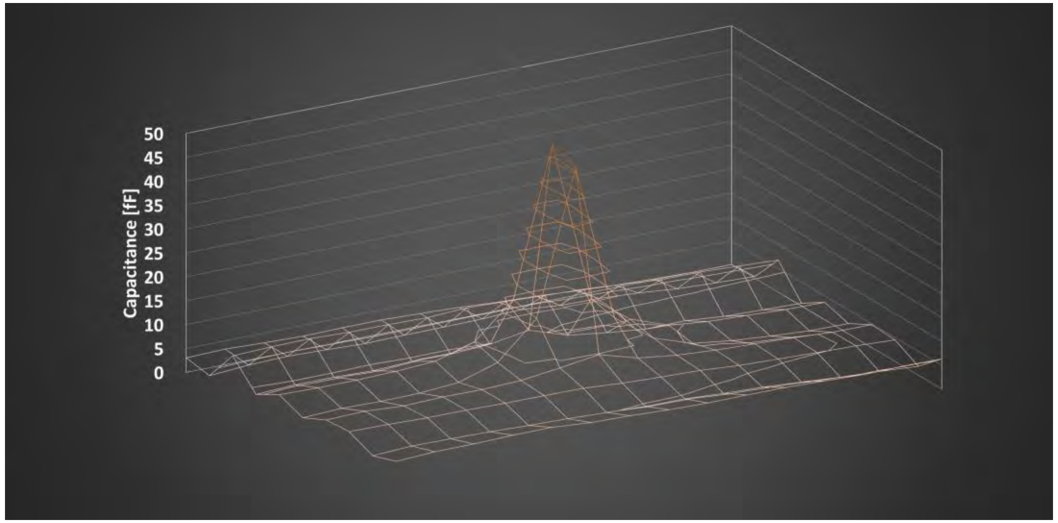
Small Capacitance Change of a Deformed Tip



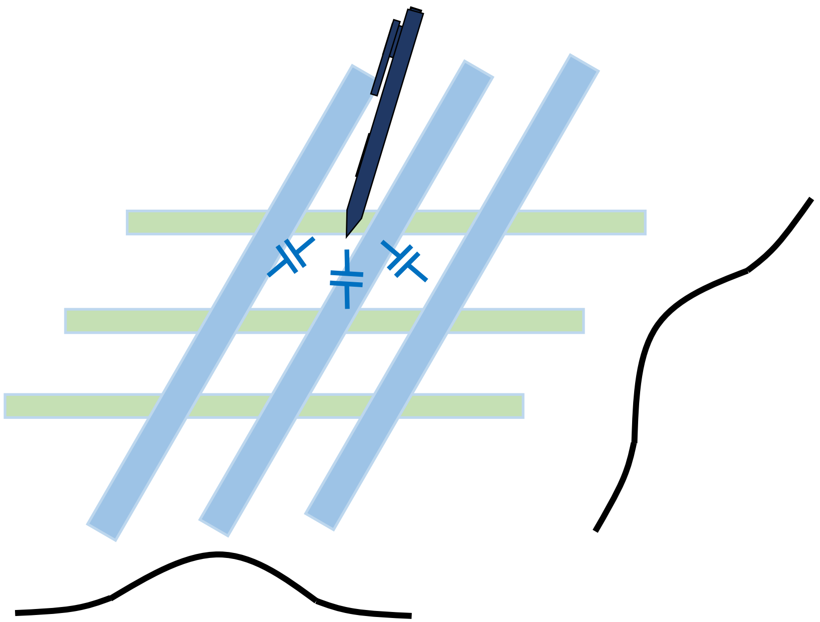
Tip Deformation

Conductive fabrics





Active Pen with Capacitive Touch Sensor

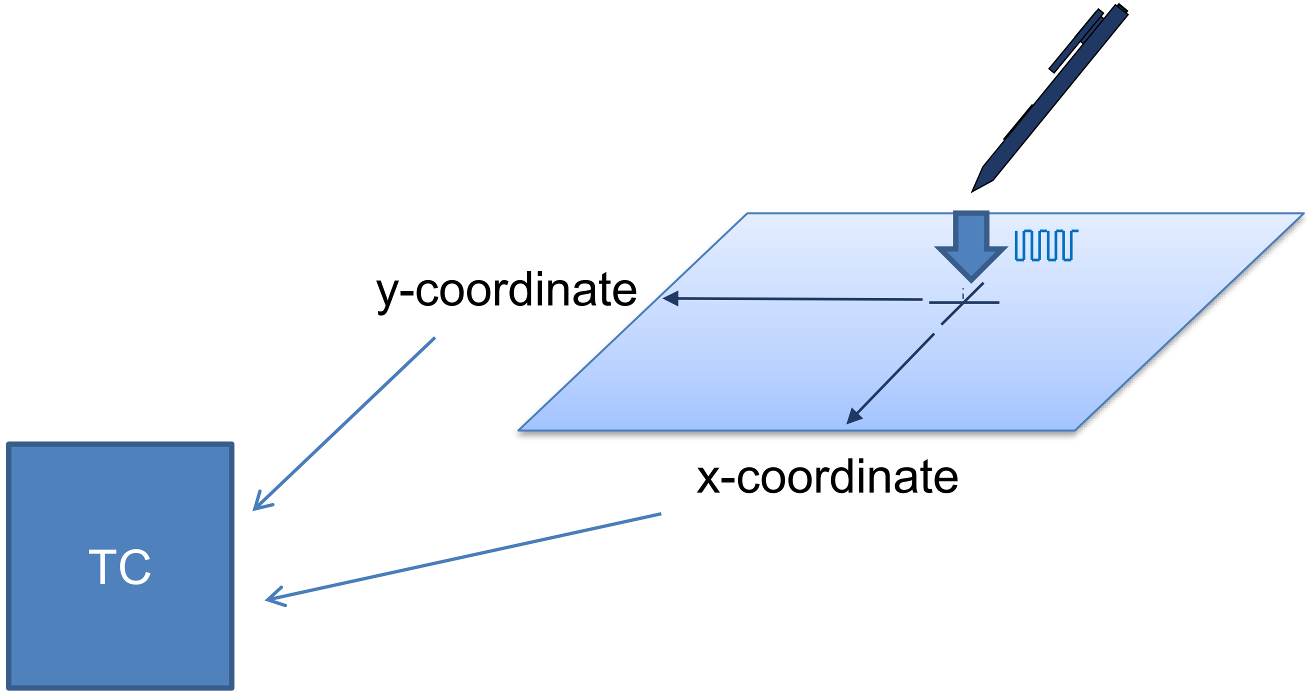


Active Pen sends out electrical signal to touch sensor.
The signal can be modulated with pen's information: the button, pressure, color, ID, etc.

Touch controller calculates stylus (x, y) coordinates from the received signal and demodulates pen's information.

One Way Active Pen System

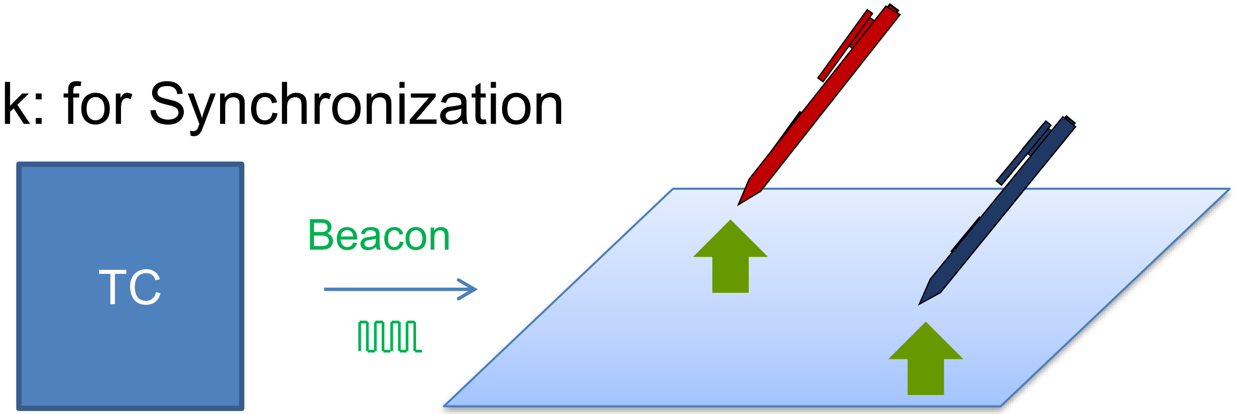
TC synchronizes to the pen
Not easy to realize Simultaneous Multiple Pens Operation.



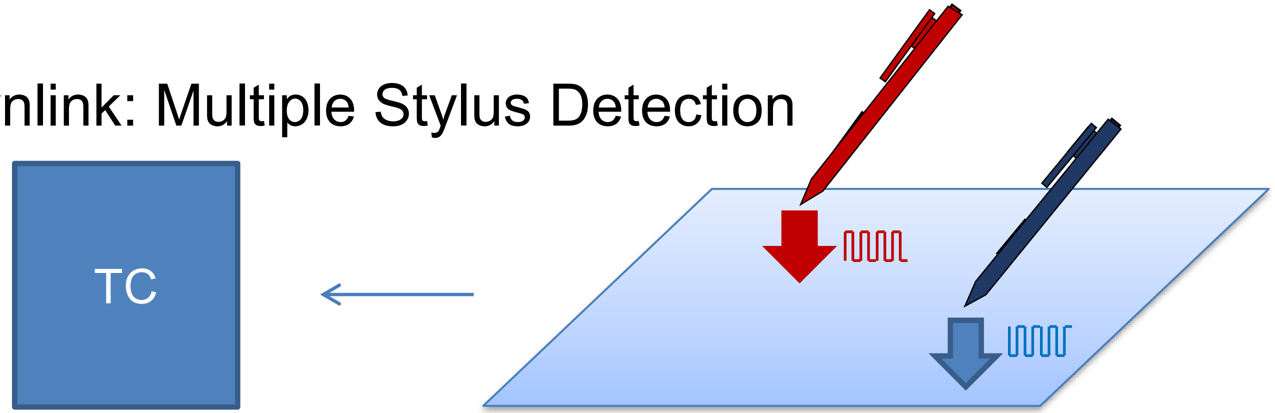
Two Way Active Pen System

Each pen synchronizes to TC through Uplink Beacon from TC.
Easy to realize Simultaneous Multiple Pens operation.

1. Uplink: for Synchronization



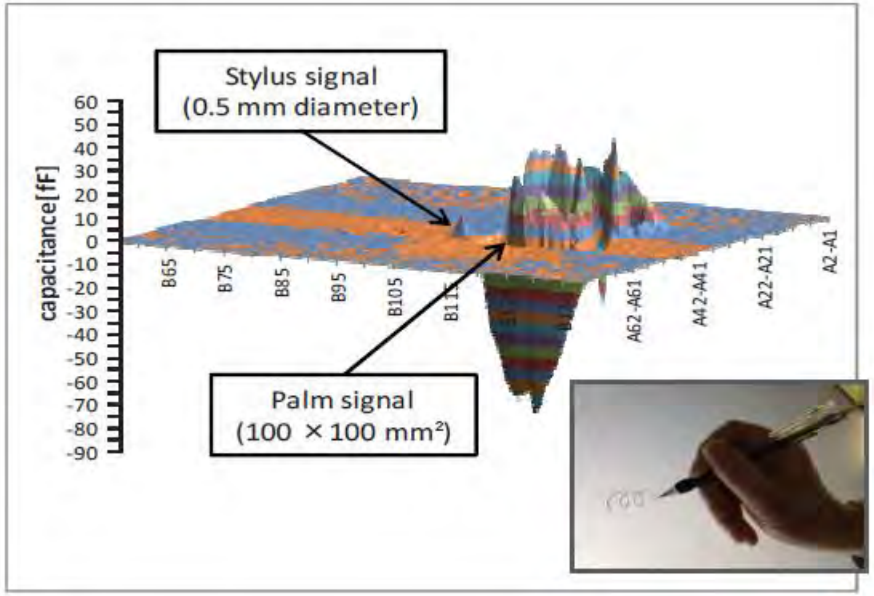
2. Downlink: Multiple Stylus Detection



Comparison of Capacitive Pen Technology

	Passive	One Way Active	Two Way Active
Button	No	Yes	Yes
Hover	NG	OK	OK
Multiple Styluses / w Different Properties	OK / No	No / No	OK / OK
Dead Region*	Yes	No	No
In-cell Panel	Yes	No	Yes

[Dead Region]
It is impossible to detect passive pen signal placed very close to a "palm",
since the passive pen signal is small and buried in the palm signal due to its fringing capacitance.



Proc. IEEE Asian Solid-State Circuits Conf. (A-SSCC), 2014, pp. 217–220

Example of Two-Way Active Pen Protocol

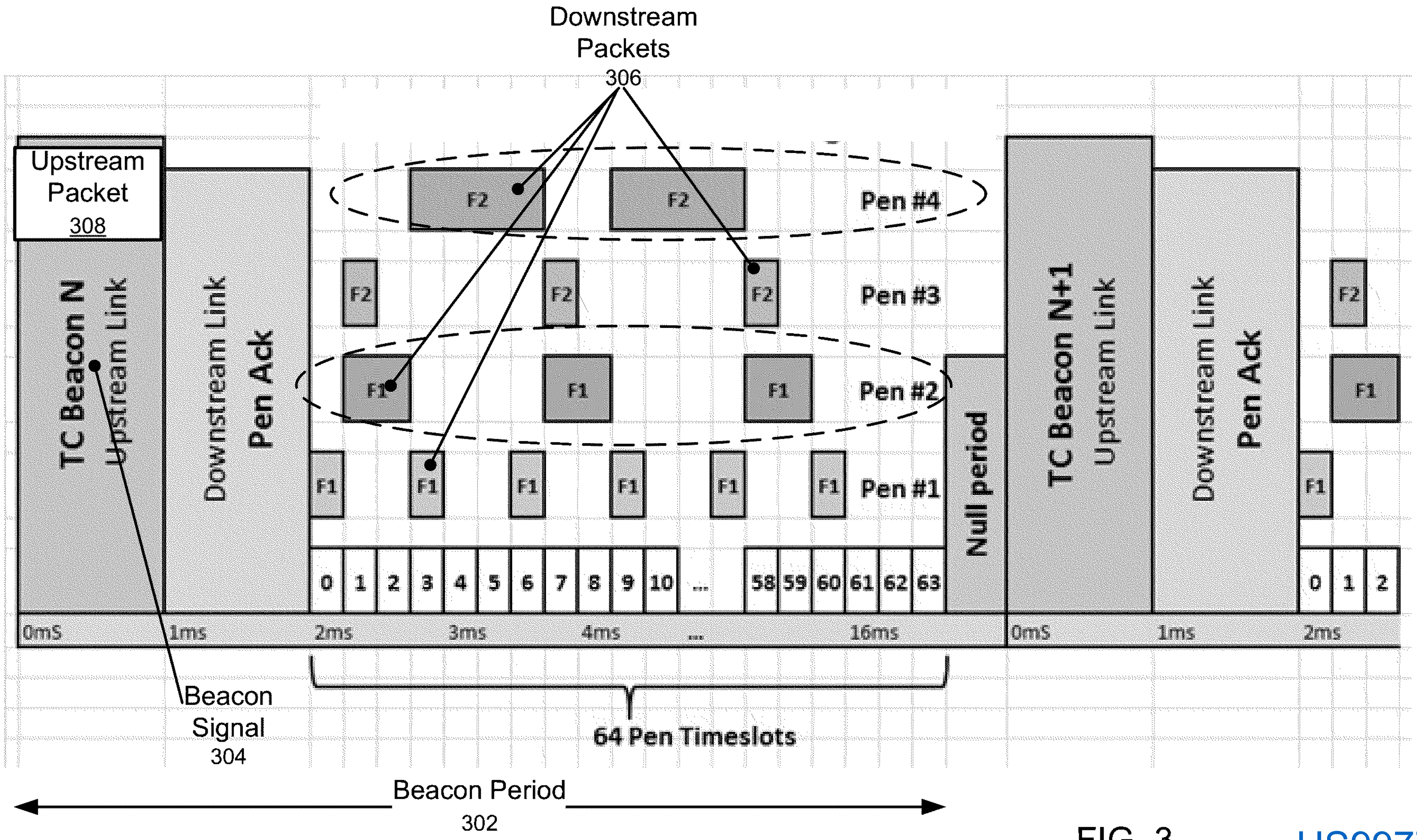
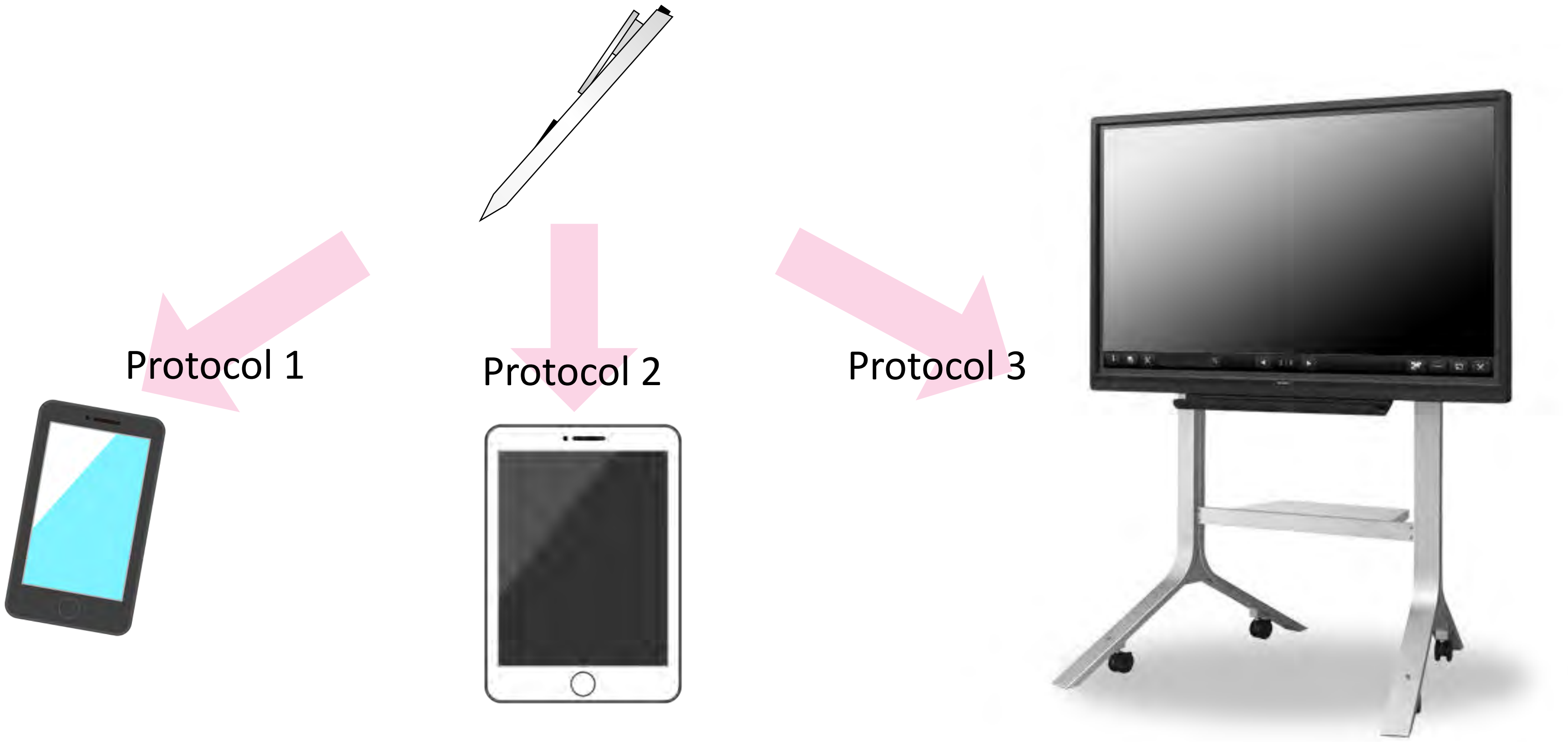


FIG. 3

US9977519B2

Universality / Interoperability of Active Pen



	Architecture	PROS	CONS
Approach 1	Pen enables all the protocol	Free competition	Complex Implementation
Approach 2	Use a unified protocol	Conceptually Simple	Restricted Competition

An Implementation

240Hz Multiple Active/Passive Pens with 41dB/32dB SNR for 0.5mm Diameter, 85nm CMOS(1P6M)
IEEE Int. Solid-State Circuits Conf. (ISSCC) Dig. Tech. Papers, pp. 120–122, Feb. 2015.

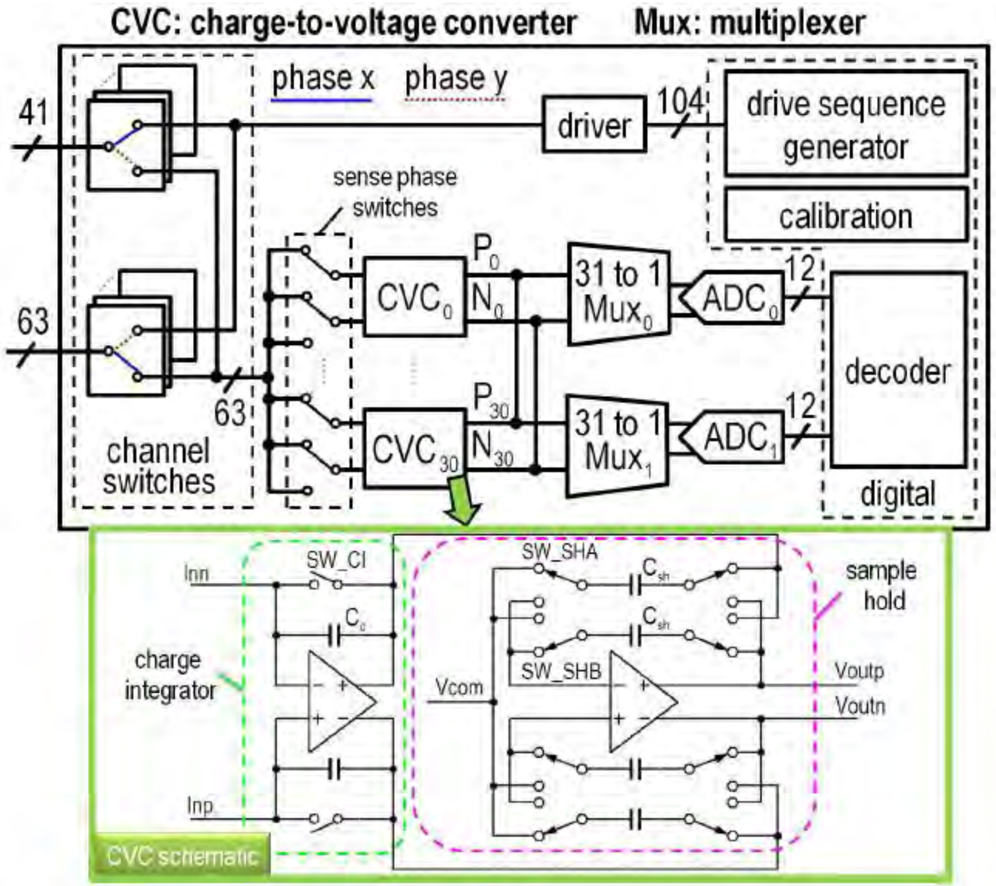


Figure 6.6.4: Block diagram of the AFE IC.

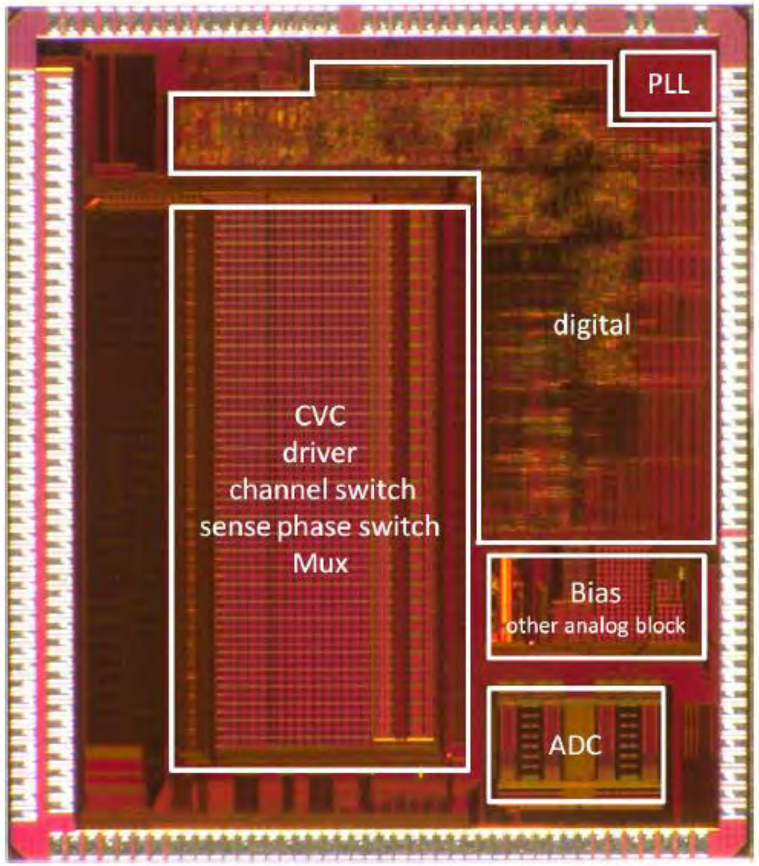


Figure 6.6.7: Die micrograph of the AFE.

Latest Technical Challenges

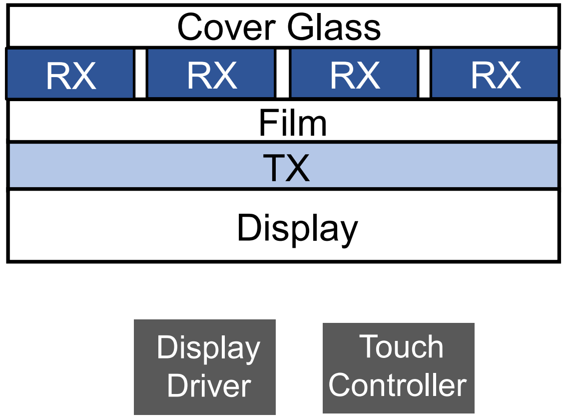
Evolution of Touch Sensor Structure and Controller IC

In-cell Sensors for LCD

Small Bezel –> Less Design Constraints

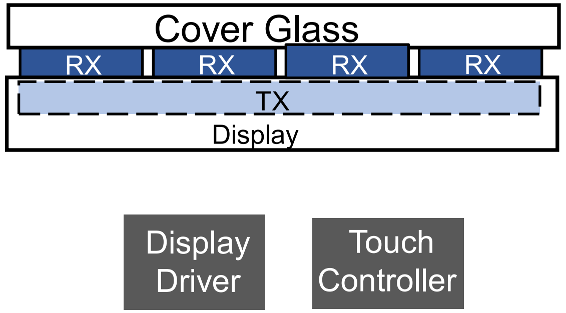
Simple Structure –> Simple Manufacturing Process / Simple Supply Chain –> Low cost / Less Lead Time

Conventional



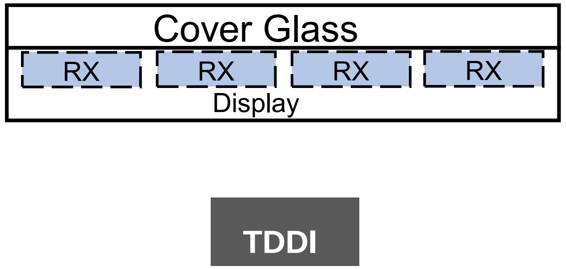
- Mutual Sensing
- Two Layer Out-cell Sensor
- Two ICs

Hybrid In-cell



- Mutual Sensing
- Hybrid In-cell Sensor
- Two ICs

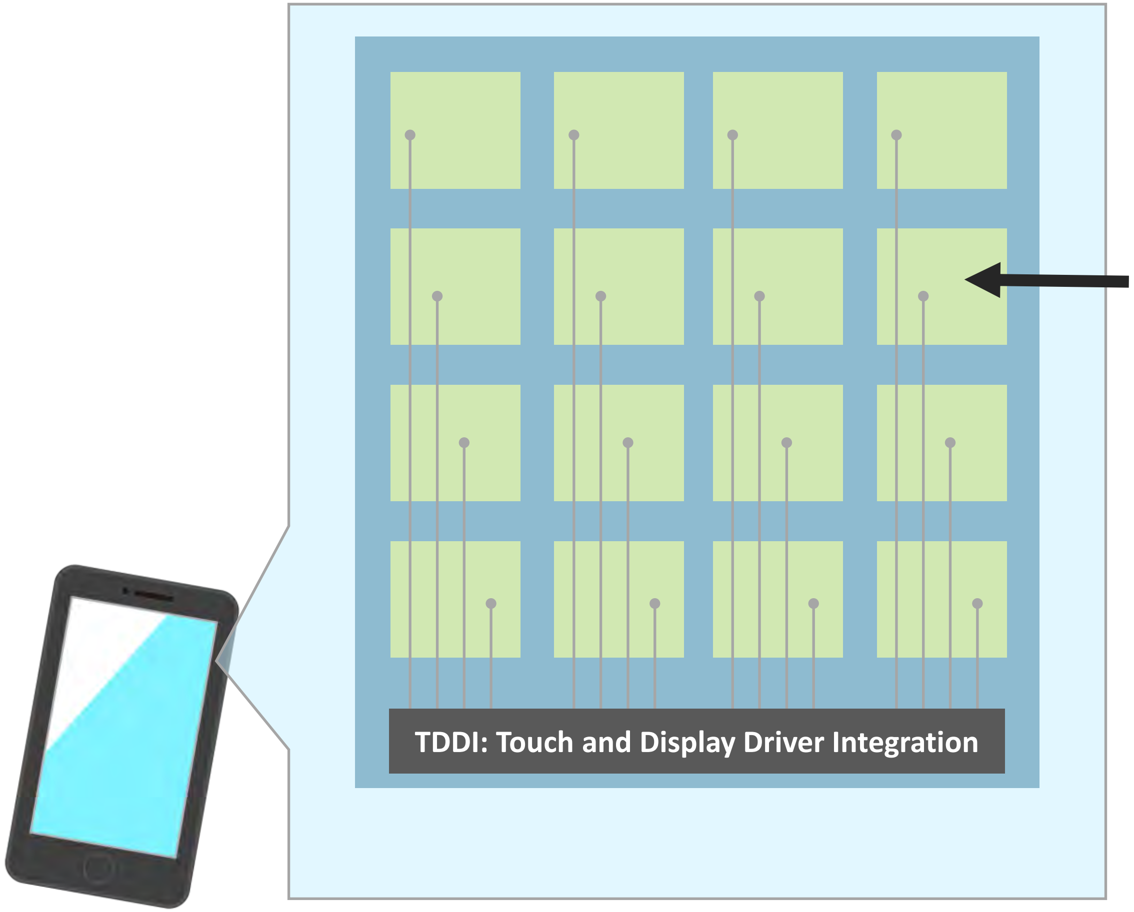
In-cell



- Self Sensing
- In-cell Sensor
- One IC: TDDI*

*Touch and Display Driver Integration

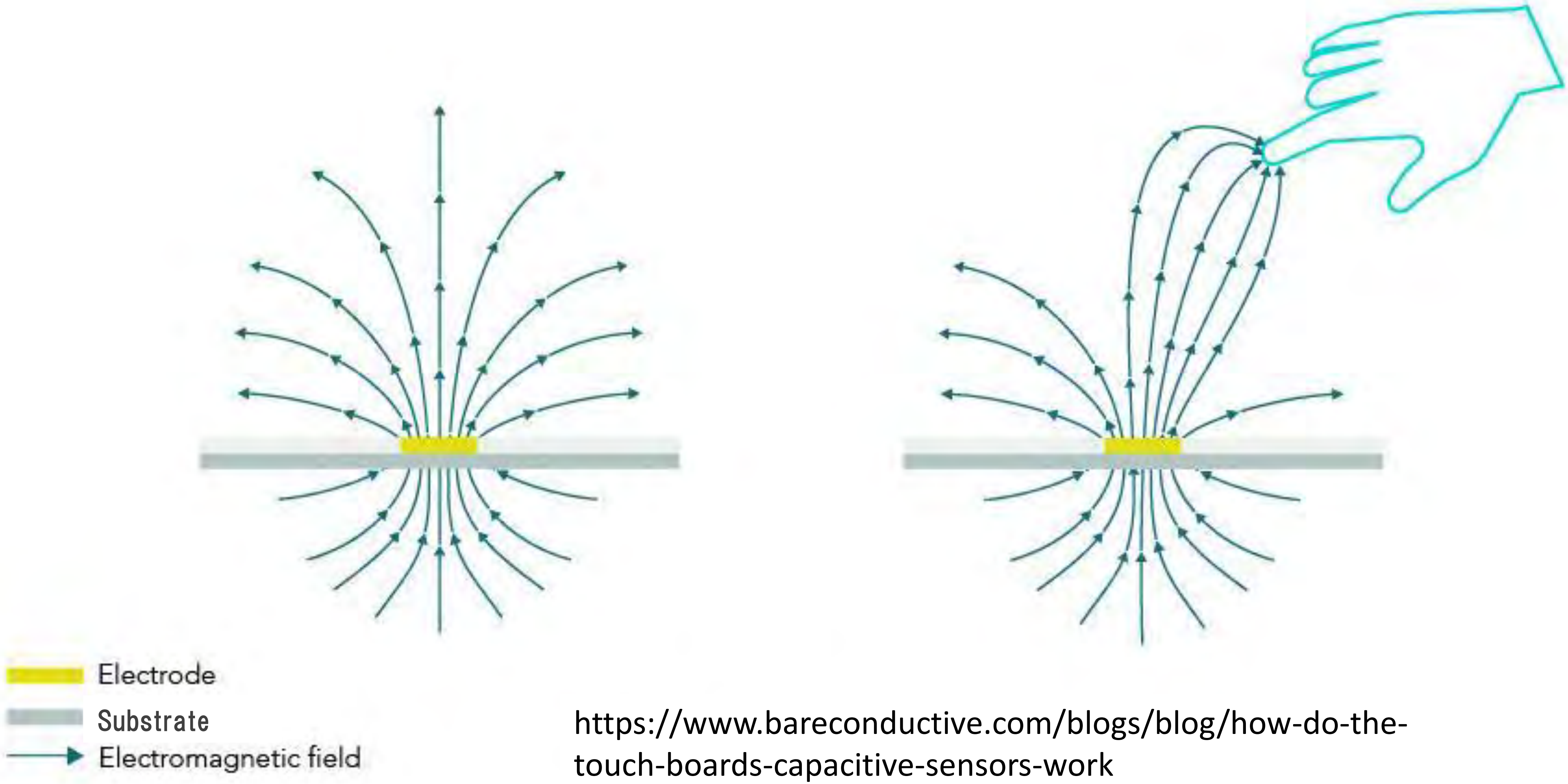
In-cell Segmented V-com Sensor



Segmented Vcom Sensor

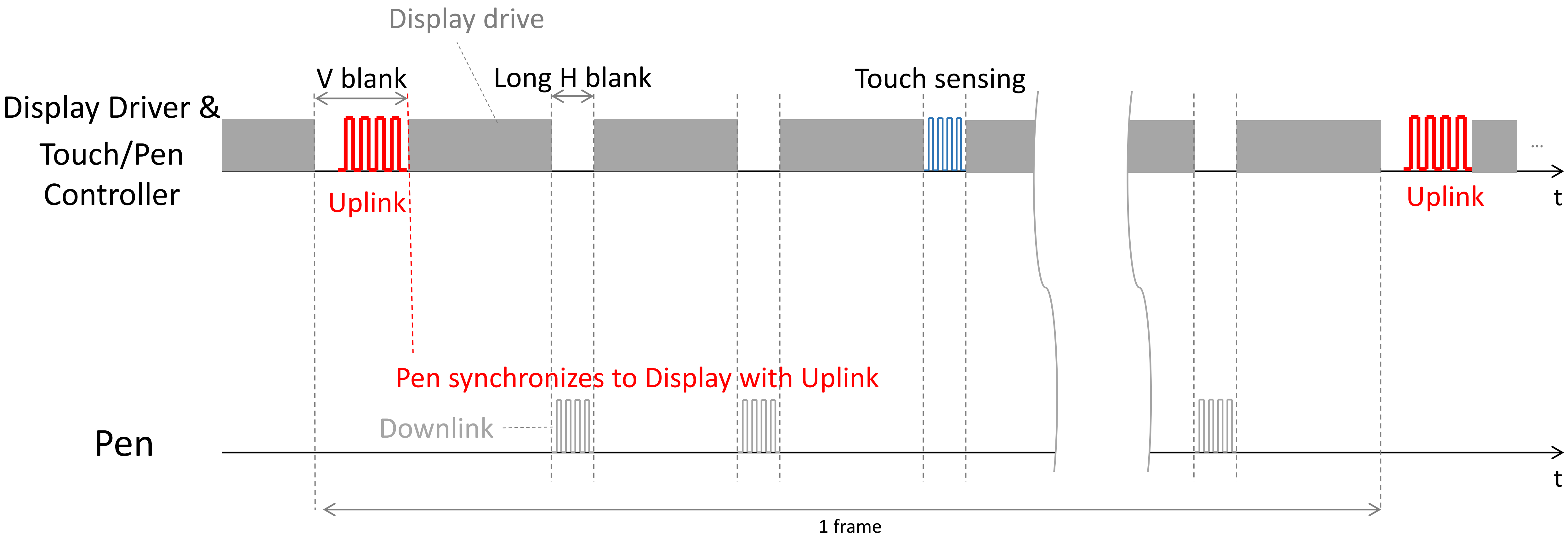
- No Additional Layer for Touch
- Sharing between Display and Touch Processing

Self Capacitance



https://www.bareconductive.com/blogs/blog/how-do-the-touch-boards-capacitive-sensors-work

Interleaved Operation for In-cell Display



CONS: Less time available for Touch/Pen processing

PROS: No Display Noise in Touch/Pen period

Technical Challenges

1. Display Technology Evolution
   - In-cell LCD
   - Foldable OLED

2. Design Constraints
   - Huge Parasitic Capacitance
   - Stronger Nosie Injection

3. Signal Processing
   - Total Architecture: Sensor structure, Panel Drive, Sensing, etc.
   - Digitally Enhanced Analog Performance: Dynamic Range, SNR, etc.

Appendix

和 + computer

Harmony “Wa” between computers & human beings

Wacom Co., Ltd.

Head Office	2-510-1, Toyonodai, Kazo-shi, Saitama, Japan
Date of Founding	July 12, 1983
Paid-in Capital	JPY 4.2 bn. (as of March 31, 2020)
President & CEO	Nobutaka Ide
Revenue	JPY 108.5 bn. (FY 03/2021)
Employees	1,012 (incl. temporary staff) (as of March 31, 2020)
Stock Market	Tokyo Stock Exchange 1st Section (6727)
Business Line	・Brand products (creative pen tablet, etc.) ・Technology solution (digital pen sensor system, etc.)

学び/教えを支えるワコム液タブとペンタブ

デジタル教室/ハイブリッド教室/リモート学習/教材準備

各種DXに寄与するワコム商品

行政窓口手続き / 書類申請 / 業務フローでのPDF書込み/電子投票


Hi-uni DIGITAL
Noris Digital
wacom
Wacom One Pen
SAMSUNG
Galaxy Book Pro 360 5G
S-penを支え続ける技術とデジタル文具エコシステム
Sシリーズにペン初搭載 / ワコムデジタル文具パートナー / 最新Note PC
All Rights Reserved. Copyright © 2021 Wacom Co., Ltd.


Lenovo
wacom
世界初折り畳みPCを支えるワコムペン&タッチ技術
今後のトレンド「折り畳みディスプレー」にペン&タッチ実装・商用化
All Rights Reserved. Copyright © 2021 Wacom Co., Ltd.

mui × wacom

Calm Technologyによる
スマートホームソリューション

for a creative world™