1975: Capacitive touch switches in use


1994:
1st laptop
capacitive
touchpad
Clyon


2003:
1st iPod
capacitive
touchwheel
iPod
Playlists
Browse
Extras
Settings
Backlight
MENU

Today:
Multi-touch
capacitive
touch screens

How
do
they
work?

CNMAT Sensor Workshop 2008
Capacitive Touch Sensors

2008-7-23

John Lazzaro
CS Division, UC Berkeley

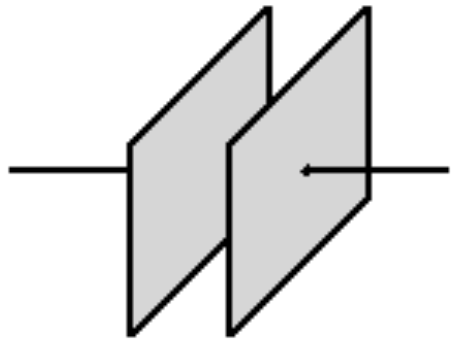
www.cs.berkeley.edu/~lazzaro

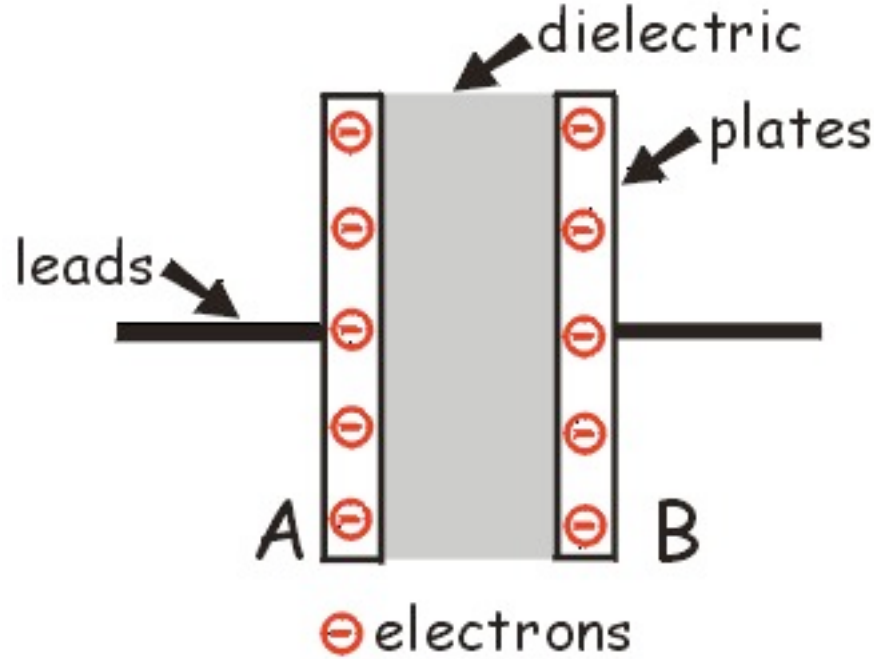
Today's lecture: Capacitive touch sensing

- Physics of capacitance
- Simple touch switches
- Touch pads and touch screens
- Novel applications

Physics of Capacitance

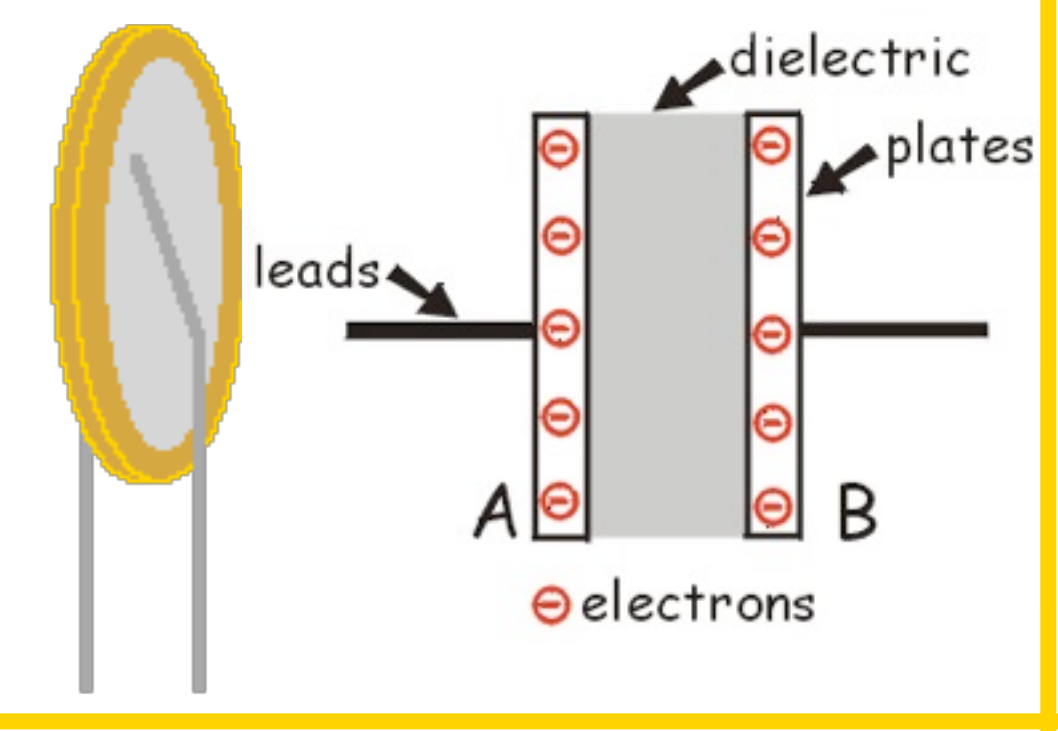
Capacitor:
A part you buy from Digikey.

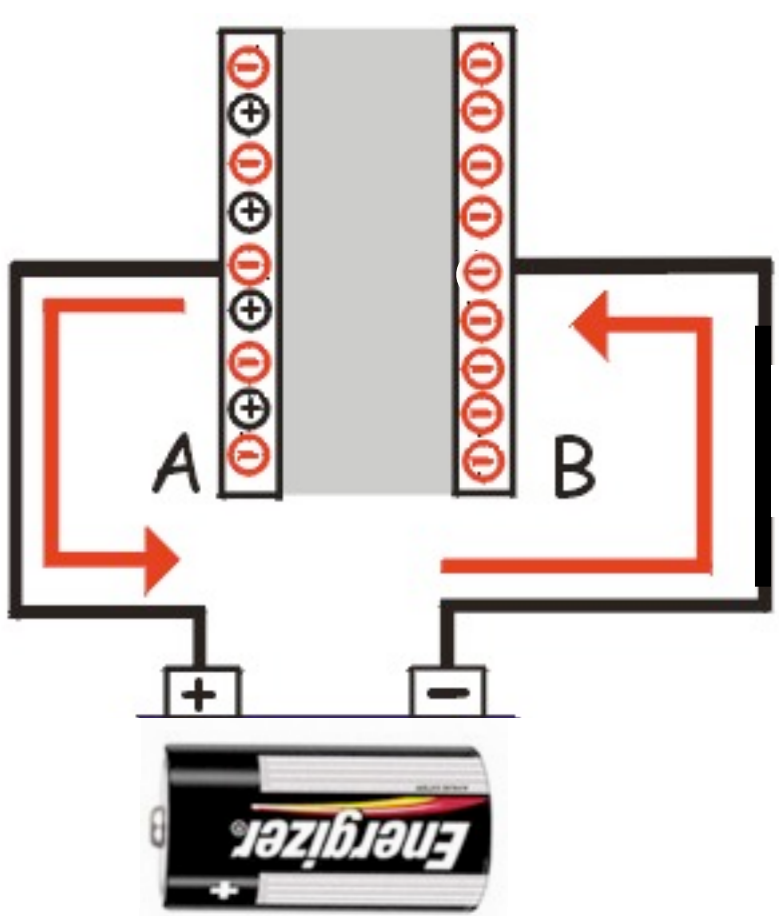




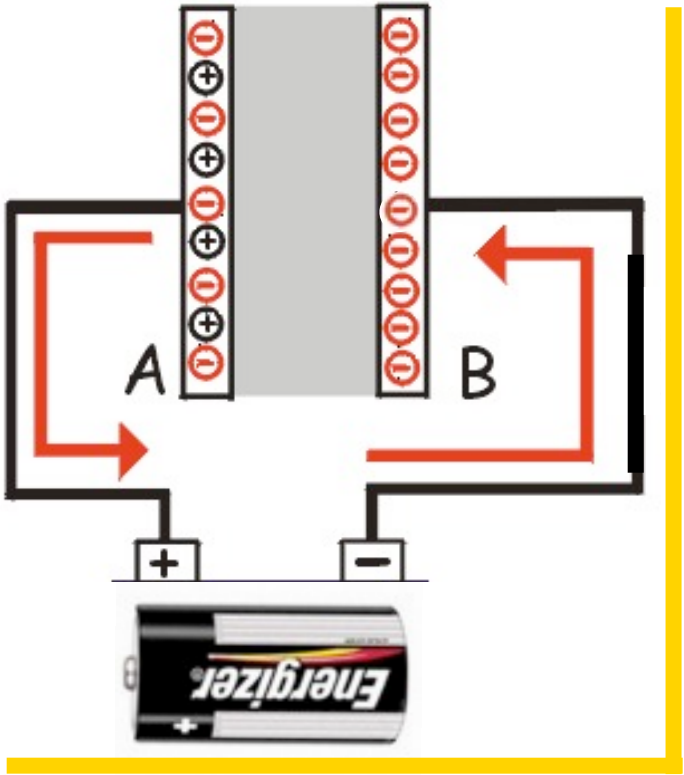
Capacitor: Two conductive plates, separated by an insulator (dielectric).

Current cannot flow through an insulator.
Thus, electrons can't pass from A to B.





Battery pumps electrons from plate A to plate B. We notate each electron pumped from A as ⊕ and refer to it as a positive charge.



How many ⊕ does a 1.5V battery place on plate A?

It depends on the 3-D shape of the capacitor, and the material properties of the dielectric.

$$\frac{Q}{V} = \frac{A\varepsilon}{d}$$

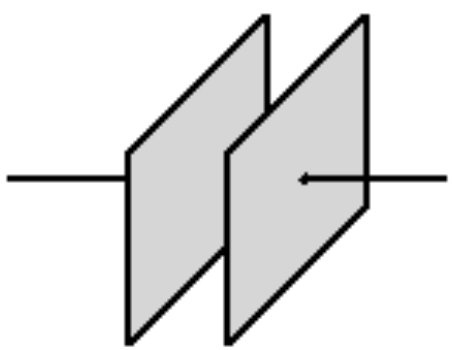
A: Area of plates

d: Plate separation

ε: Dielectric property

Q: Number of ⊕

V: Voltage on plates



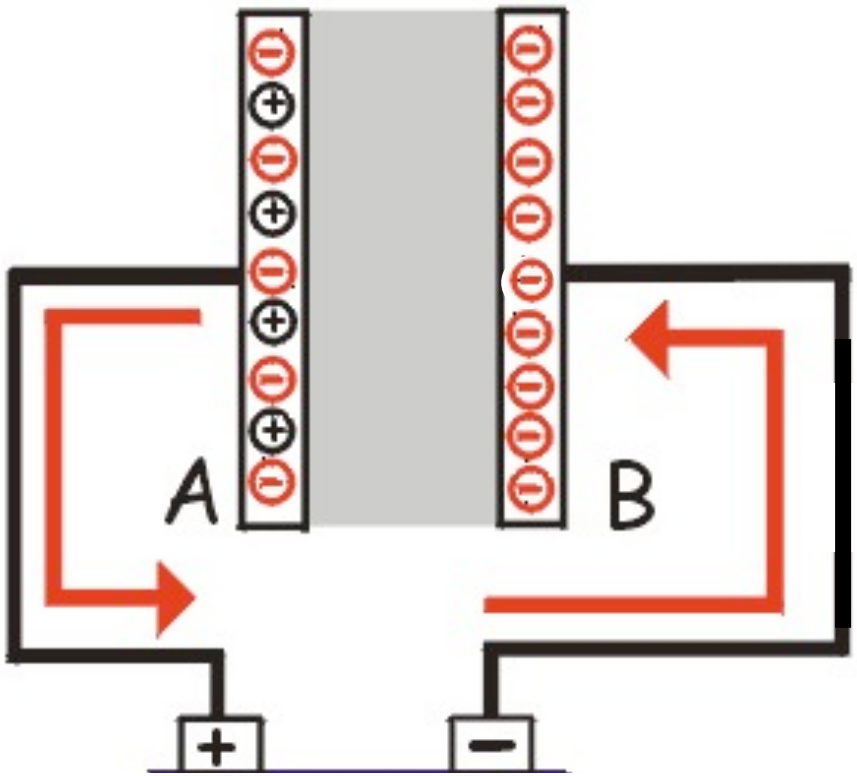
The ratio Q/V is defined as the capacitance C of the device.

$$Q = CV$$

We can use a capacitance meter to measure C.

Conceptually, the meter puts a V across the C, and then drains off the charge and counts Q.

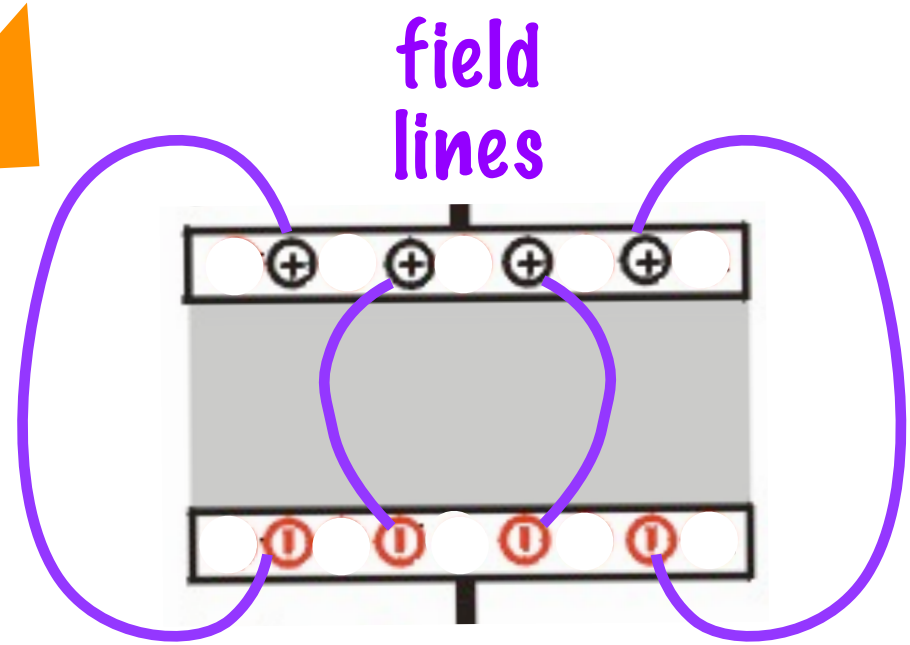
C = Q/V.



A capacitance meter counts the number of field lines (and thus, Q).

Notation alert!

From now on we draw net charge on the plates.

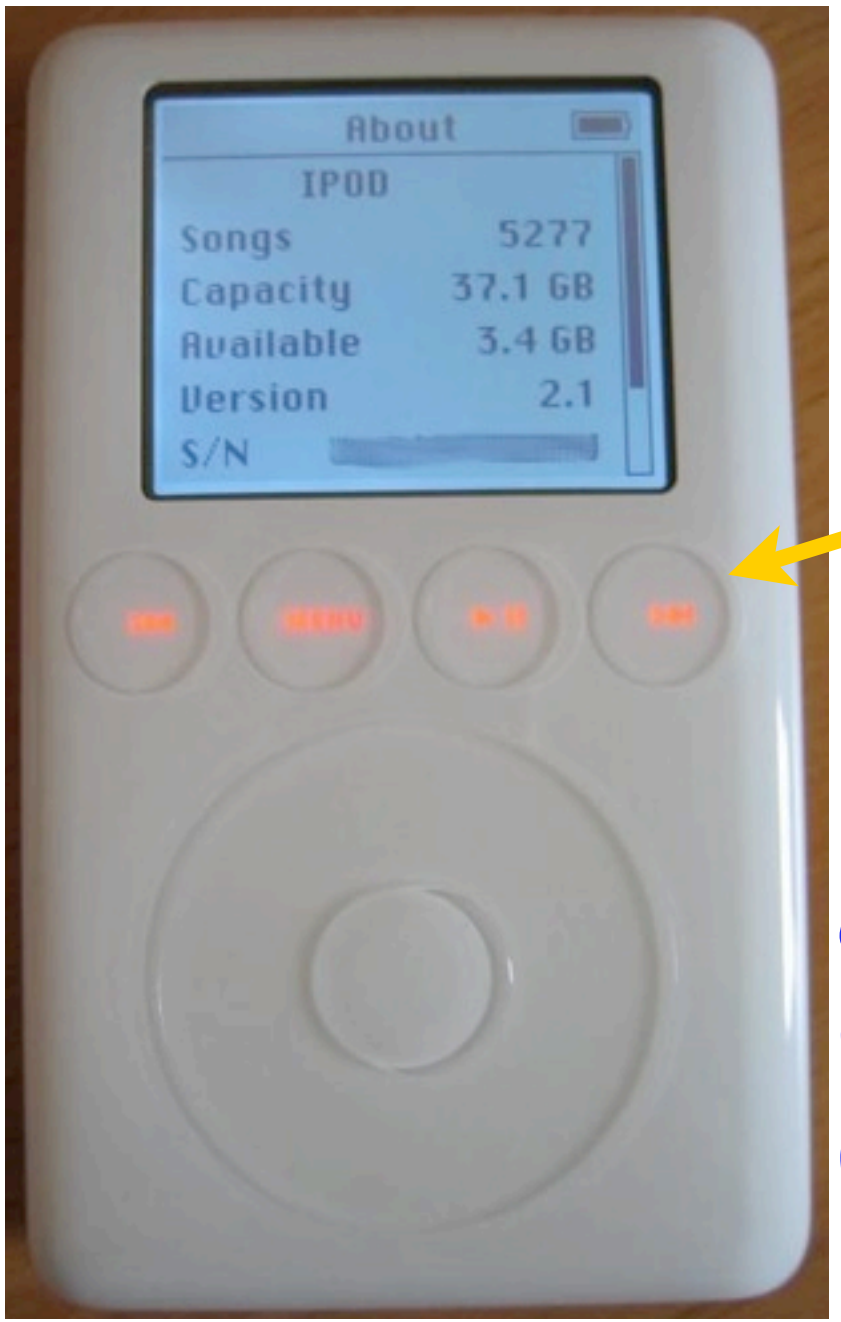


We draw field lines to illustrate the pairing of charges.

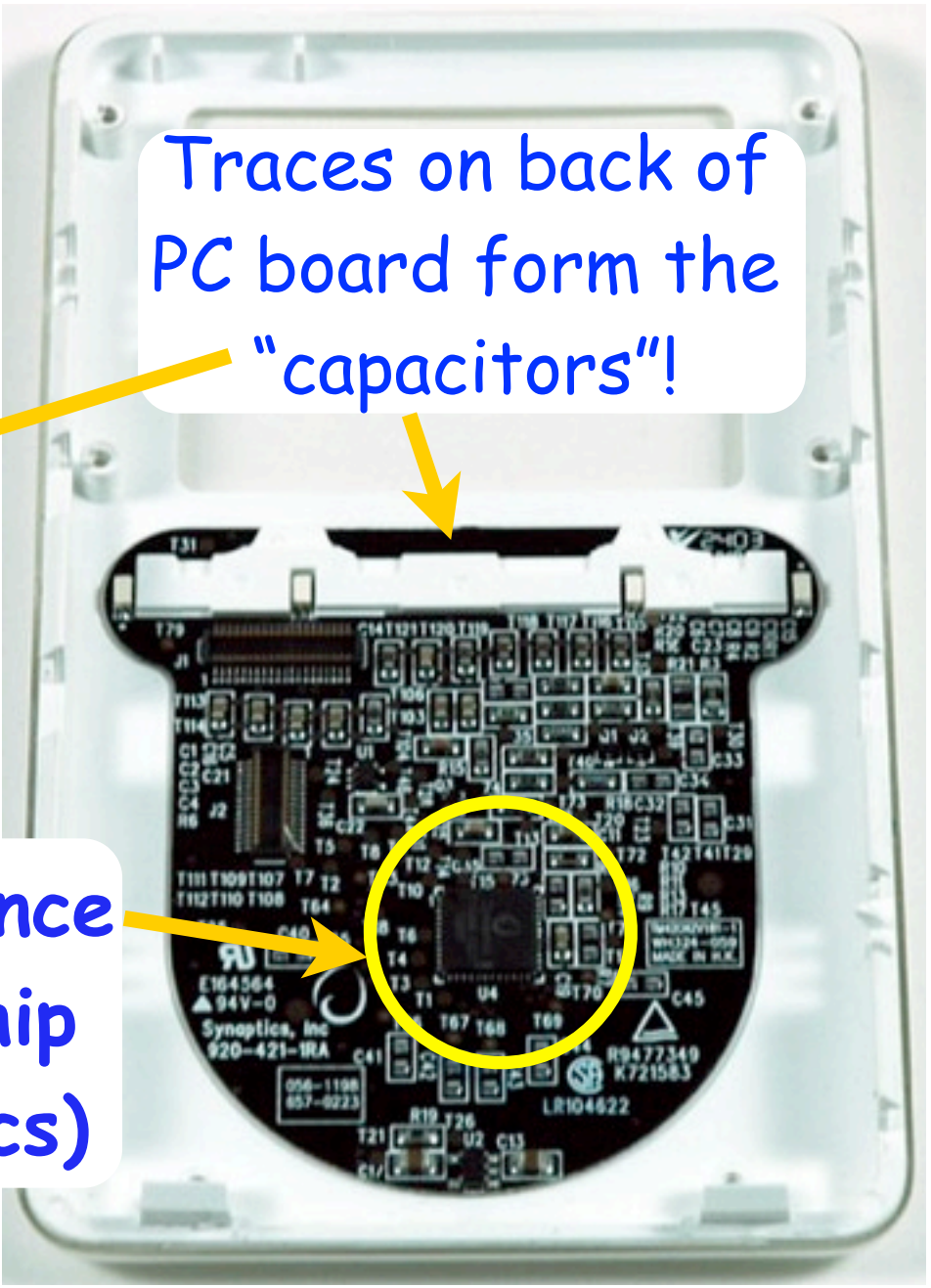
Simple Touch Switches

(Sources: Analog Devices, Cypress, and Synaptics data sheets and websites).

iPod 3G front panel



What's on the back of the PC board?

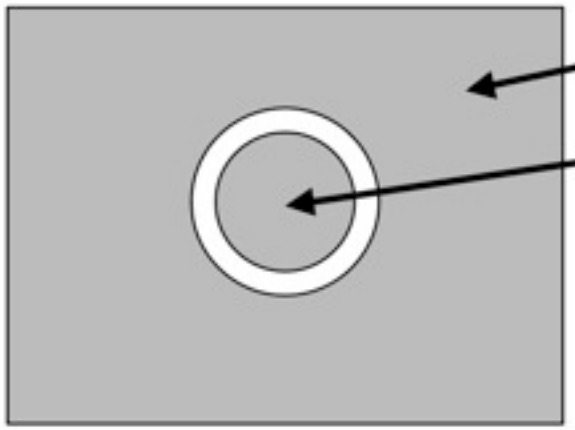


Traces on back of PC board form the "capacitors"!

Capacitance meter chip (Synaptics)

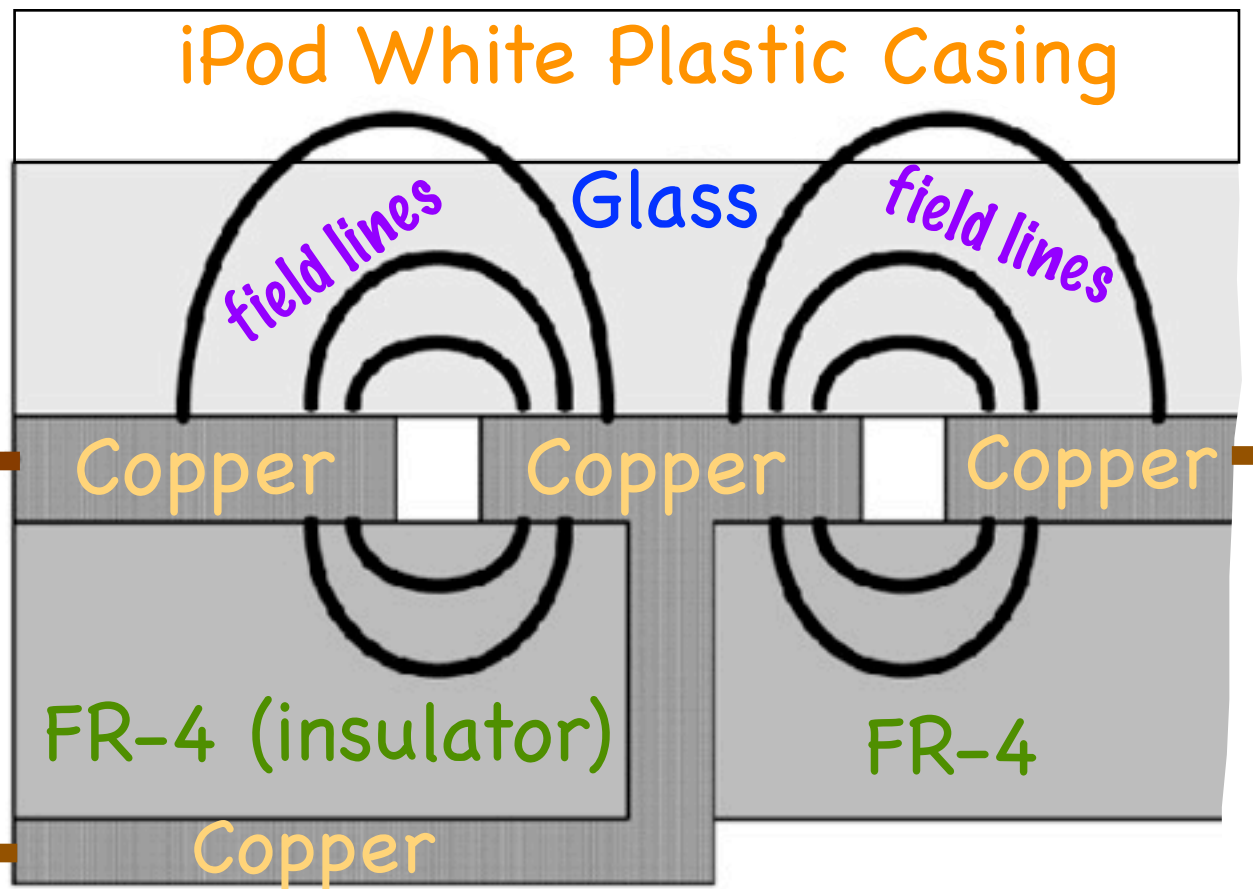
PC trace design for a capacitive button switch

PC BOARD TOP VIEW



What does the finger do?

PC BOARD CROSS-SECTION

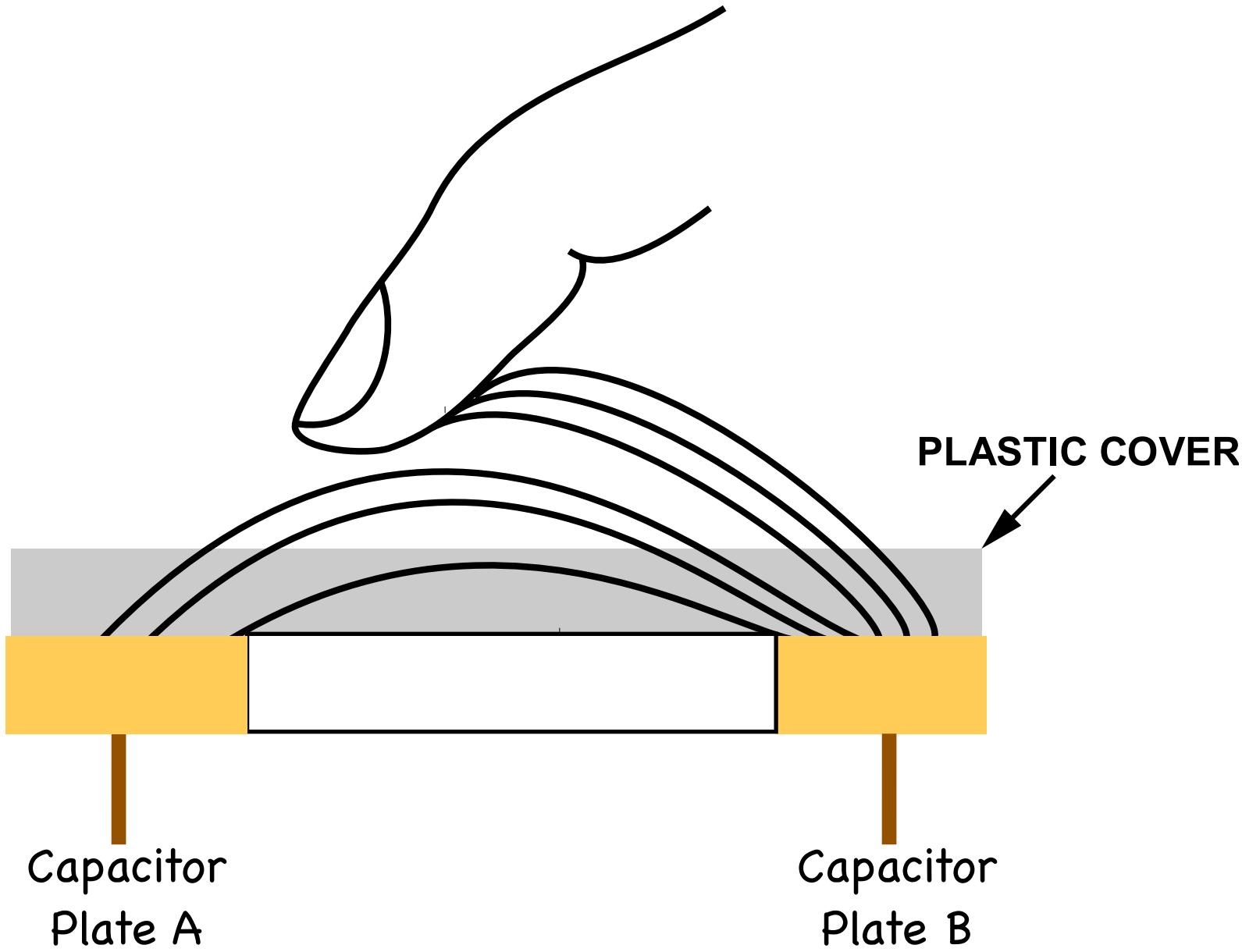


Capacitor Plate A

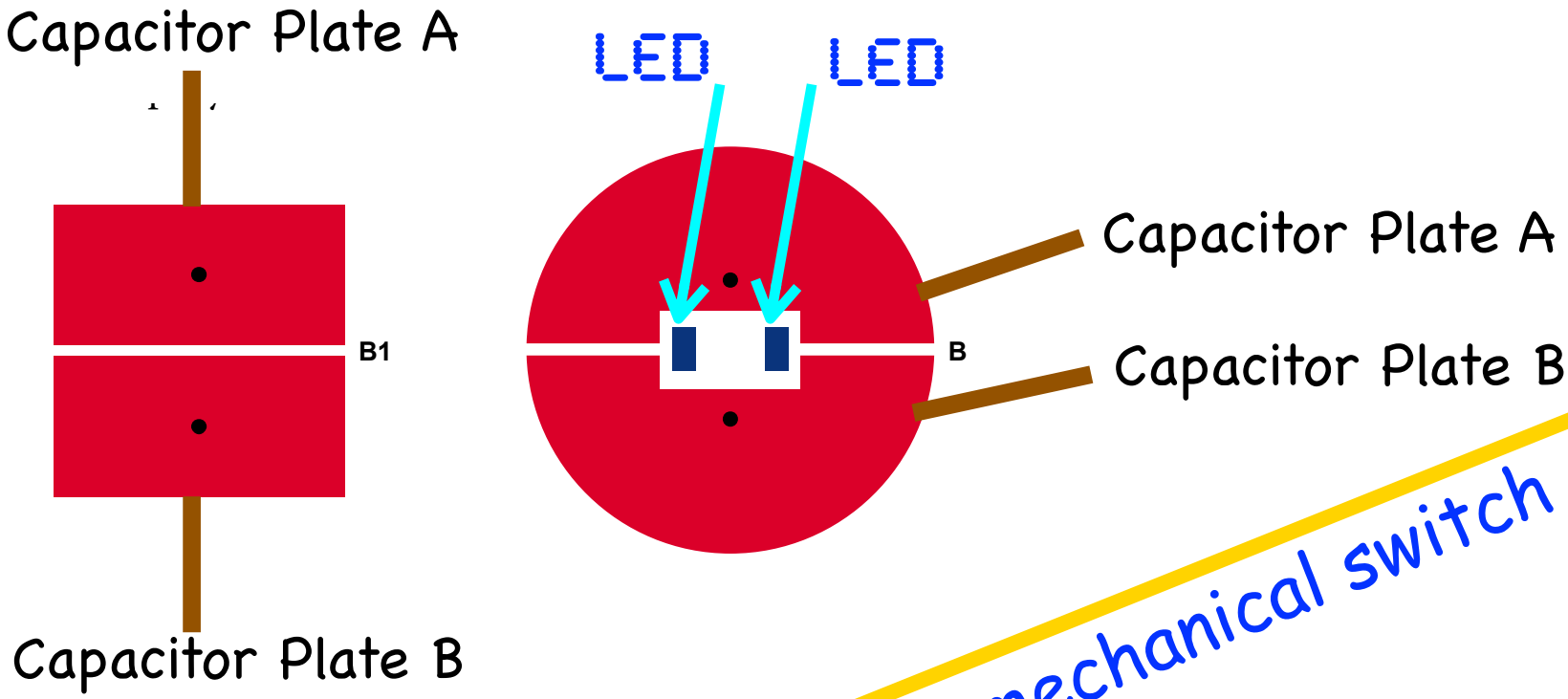
Capacitor Plate B

Some of the field lines will terminate on the iron in the red blood cells of a nearby finger.

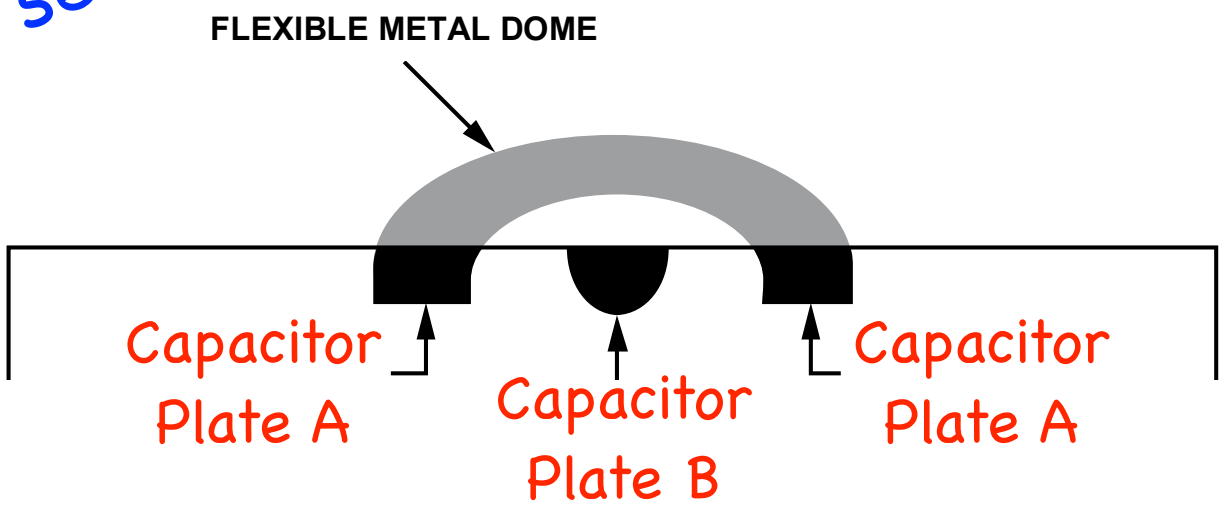
Recall
Capacitance meter counts the number of field lines to determine Q, and then computes C = Q/V



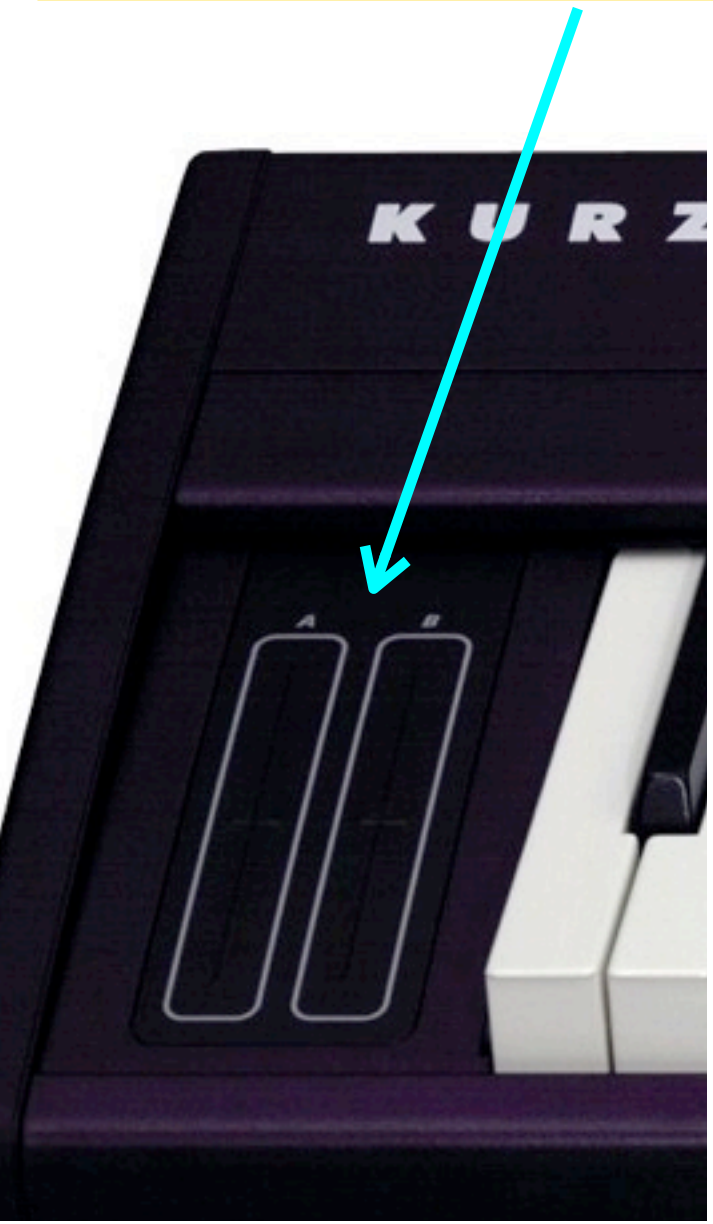
Compact button switch designs

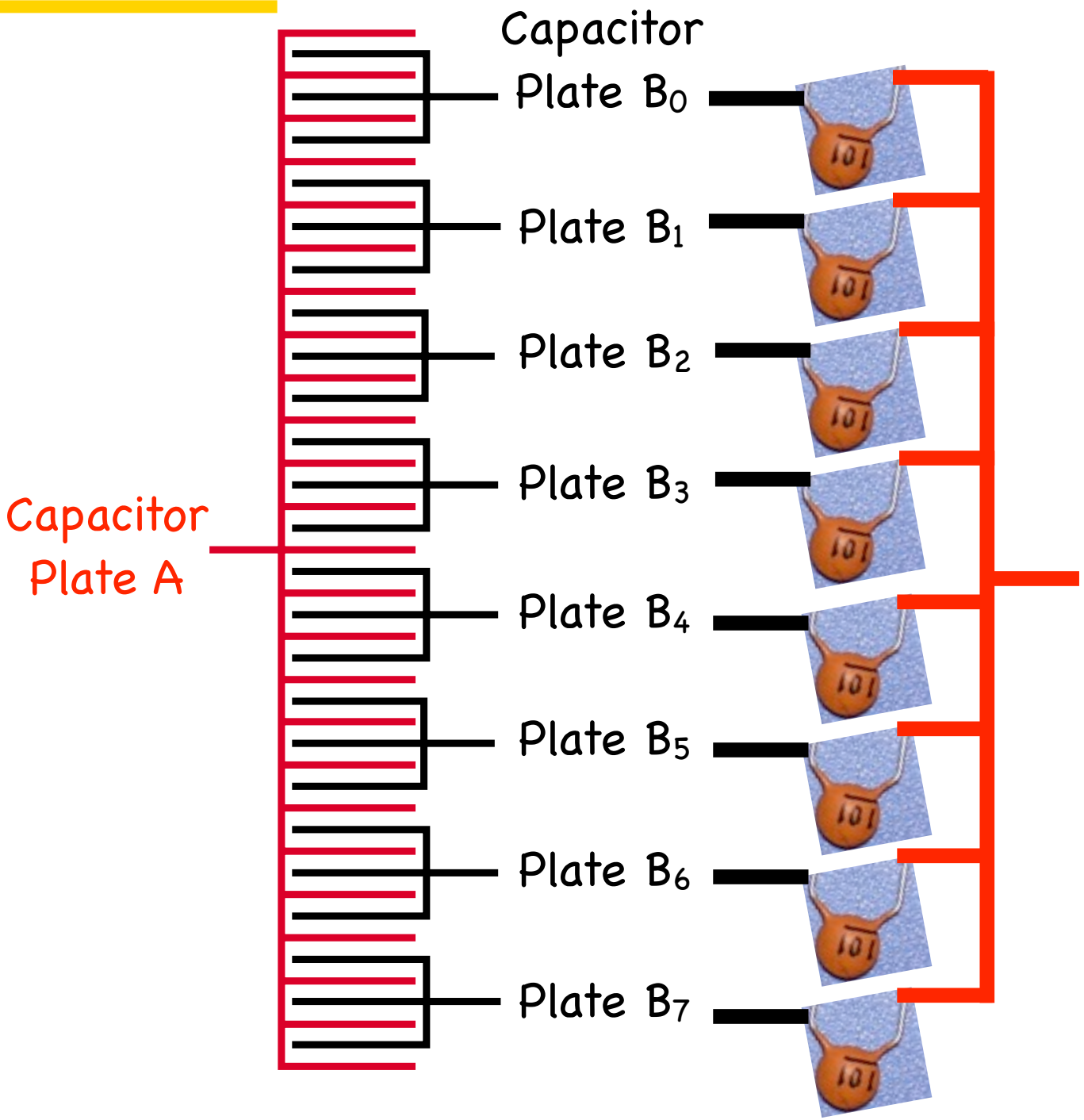


Capacitively sensed mechanical switch



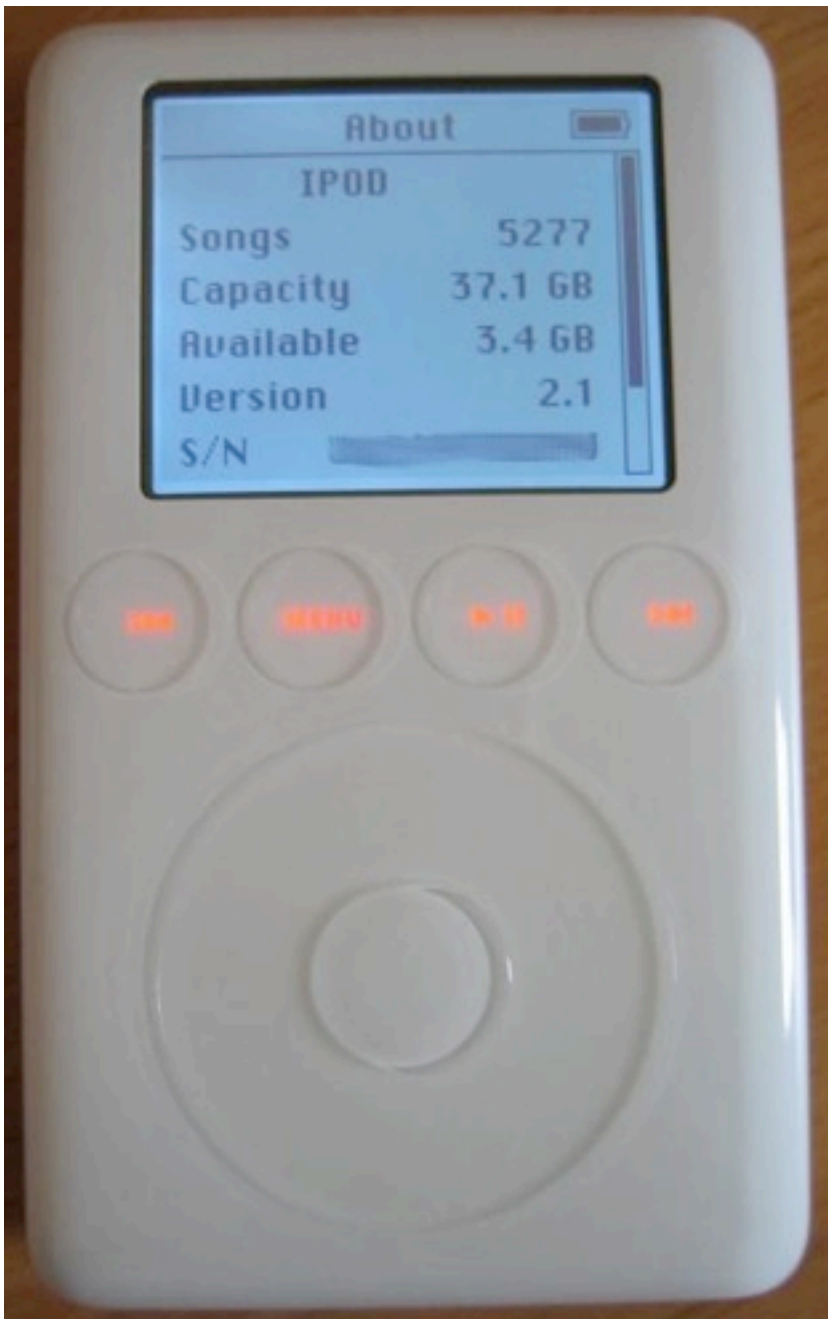
Capacitive fader design

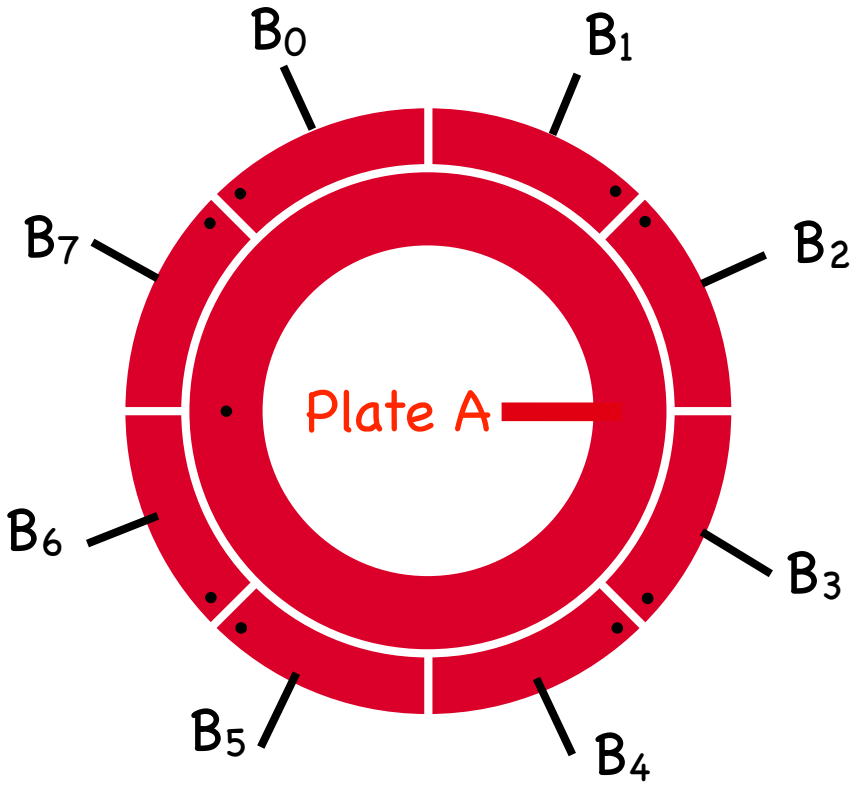


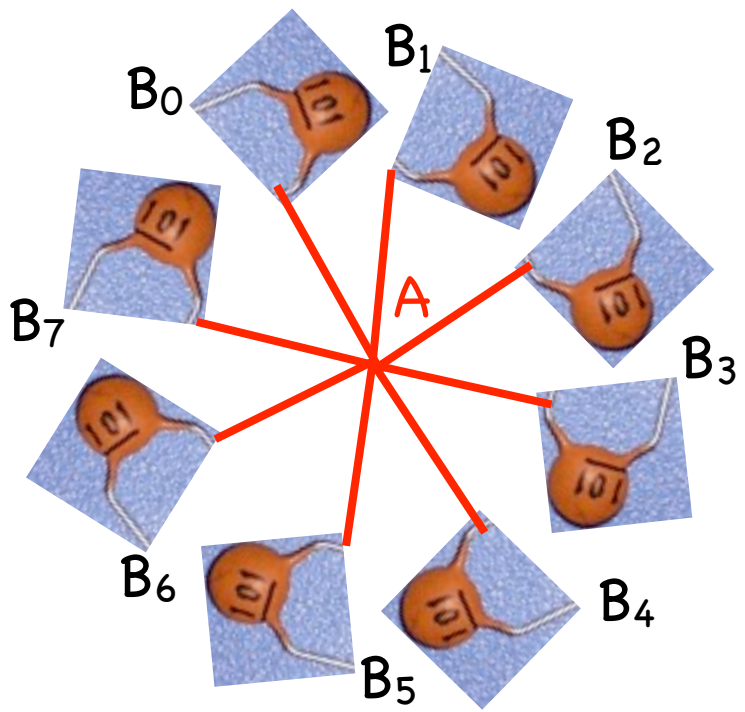


Super-resolution via interpolation ...

Touch wheel design

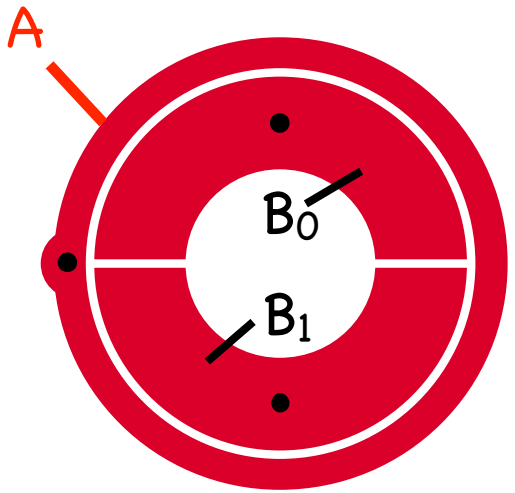


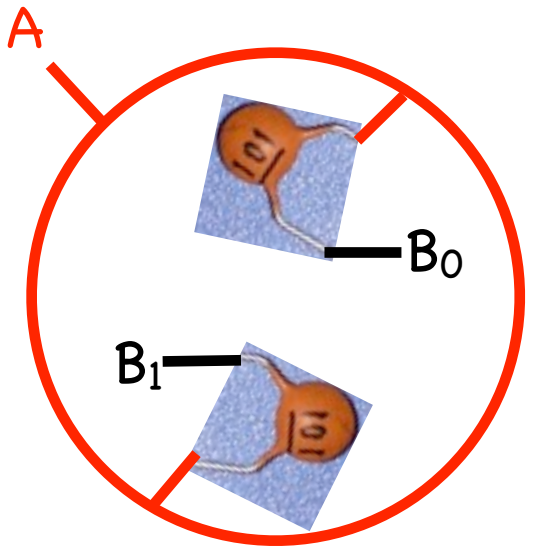




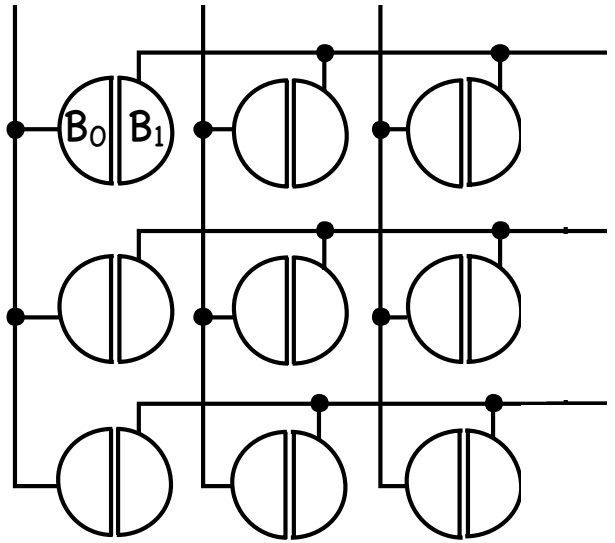
Keypad design

One switch





Switch array

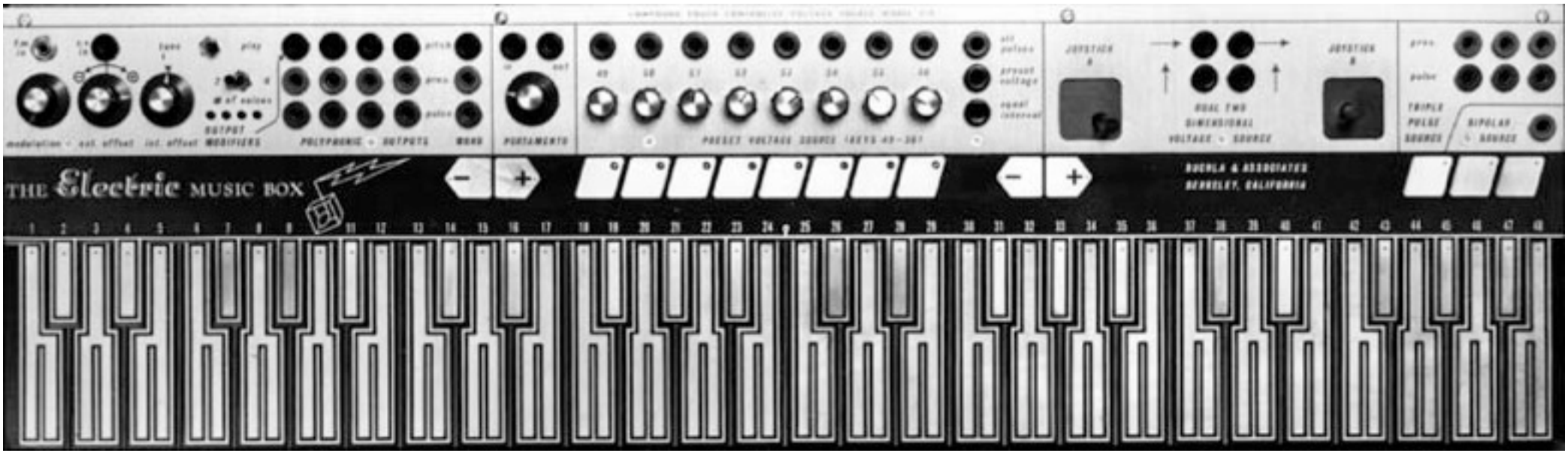


(connect all As together)

If row I and column J have big Cs, key K_{ij} is touched

Scaling up


Tab
A Z E R T Y U I O P
Entrée
Verr Maj
Q S D F G H J K L M
Maj
W X C V B N
Maj
Ctrl
Alt
Alt Gr
Ctrl


THE Electric MUSIC BOX

Typical part

ANALOG DEVICES

Programmable Controller for Capacitance Touch Sensors

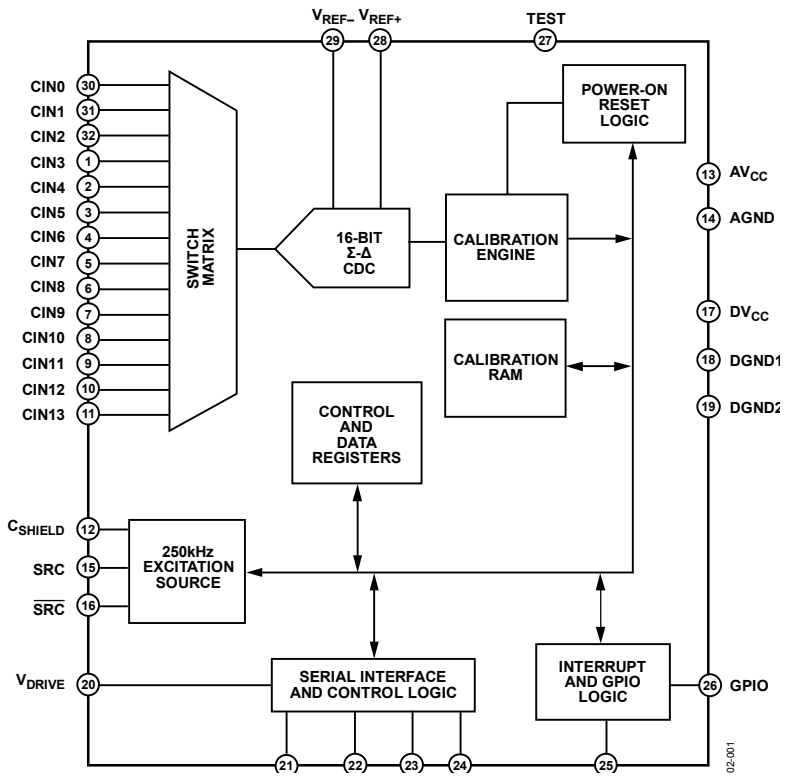
AD7142

Digi-Key Part Number	Manufacturer Part Number	Description	Manufacturer	Mounting Type	Package / Case	Type	Supply Voltage	Packaging	Quantity Available	Minimum Quantity	Unit Price USD
AD7142ACPZ-1REELTR-ND	AD7142ACPZ-1REEL	IC CAP-TO-DGTL CONV PROG 32LFCSP	Analog Devices Inc	Surface Mount	32-LFCSP	Capacitance-to-Digital Converter	2.6 V ~ 3.6 V	Tape & Reel (TR)	5,000	5,000	1.68750
AD7142ACPZ-1REELCT-ND	AD7142ACPZ-1REEL	IC CAP-TO-DGTL CONV PROG 32LFCSP	Analog Devices Inc	Surface Mount	32-LFCSP	Capacitance-to-Digital Converter	2.6 V ~ 3.6 V	Cut Tape (CT)	3,146	1	3.04000

FEATURES

- Programmable capacitance-to-digital converter
  - 36 ms update rate (@ maximum sequence length)
  - Better than 1 fF resolution
  - 14 capacitance sensor input channels
  - No external RC tuning components required
  - Automatic conversion sequencer
- On-chip automatic calibration logic
  - Automatic compensation for environmental changes
  - Automatic adaptive threshold and sensitivity levels
- On-chip RAM to store calibration data
- SPI®-compatible serial interface (AD7142)
- I²C®-compatible serial interface (AD7142-1)
- Separate V_{DRIVE} level for serial interface
- Interrupt output and GPIO
- 32-lead, 5 mm x 5 mm LFCSP_VQ
- 2.6 V to 3.6 V supply voltage
- Low operating current
  - Full power mode: less than 1 mA
  - Low power mode: 50 µA

FUNCTIONAL BLOCK DIAGRAM



$3.04
Qu 1

$1.69
Qu 5000

Senses
14 Cs

Interesting AD7142 facts ...

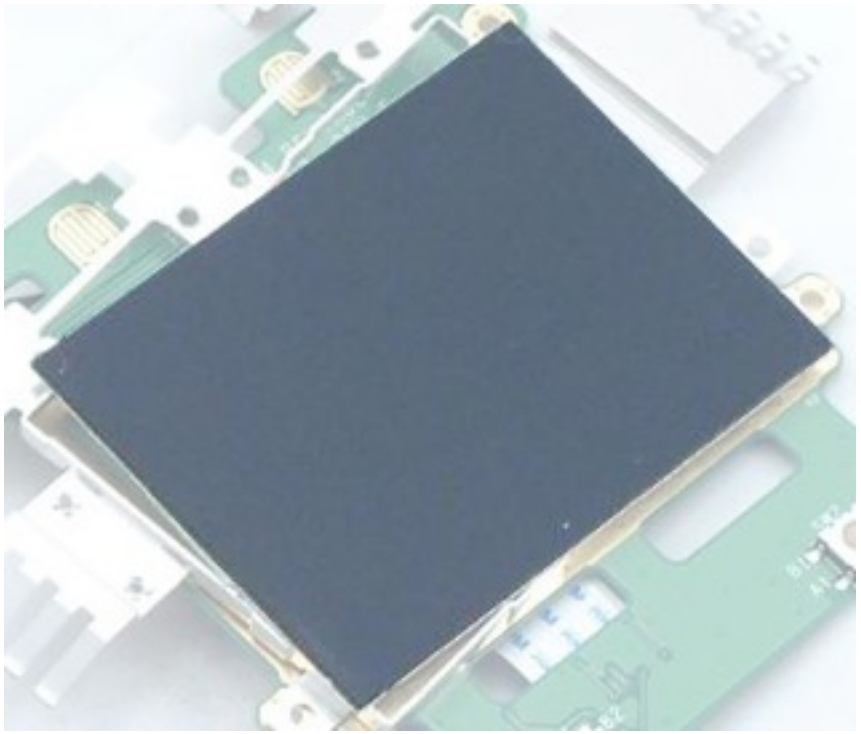
- Pad C a few pF. Finger ΔC a few fF !
- Measured pad C is always drifting. Sensor chip tracks it adaptively.
- Sense time per pad: 3ms. If all 14 channels in use: 36ms "frame rate".
- Plastic thickness over PCB: 2-4mm.

Touchpads and Touchscreens

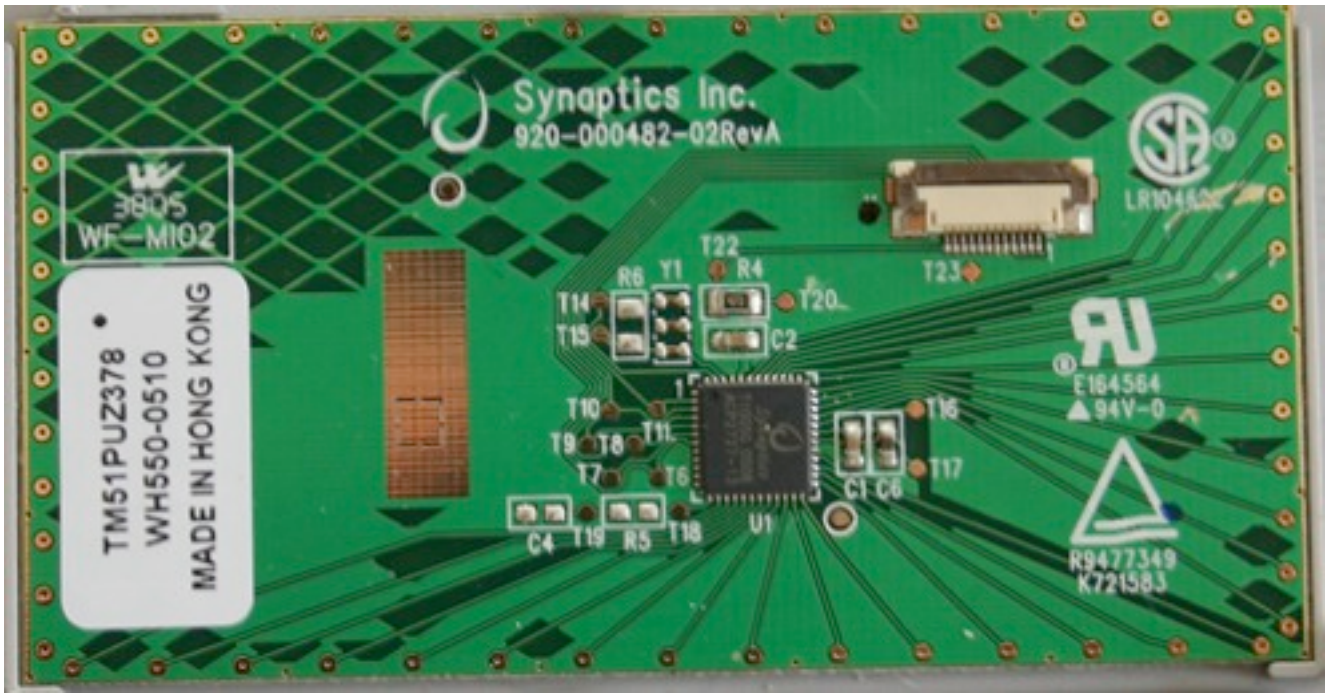
(Sources: Apple, Synaptics, and Cirque patents, various websites).

TOUCHPAD: A CIRCUIT BOARD

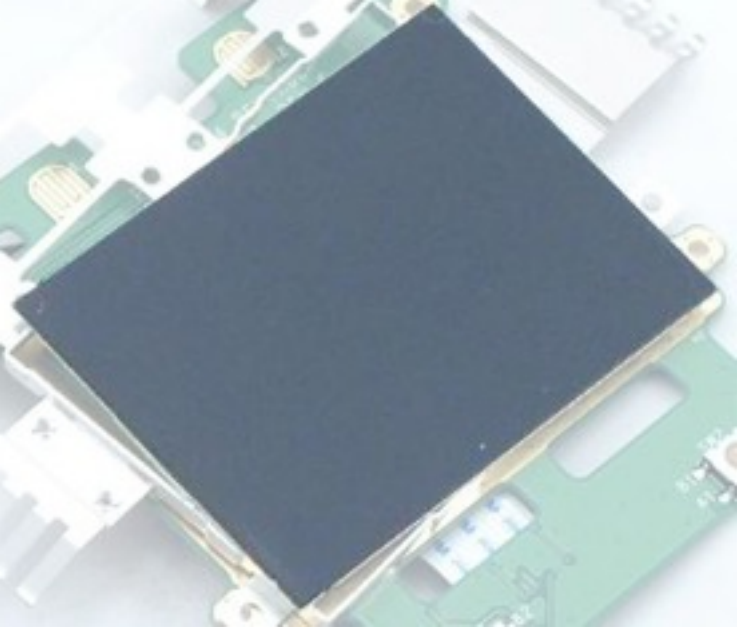
Top view - finger surface

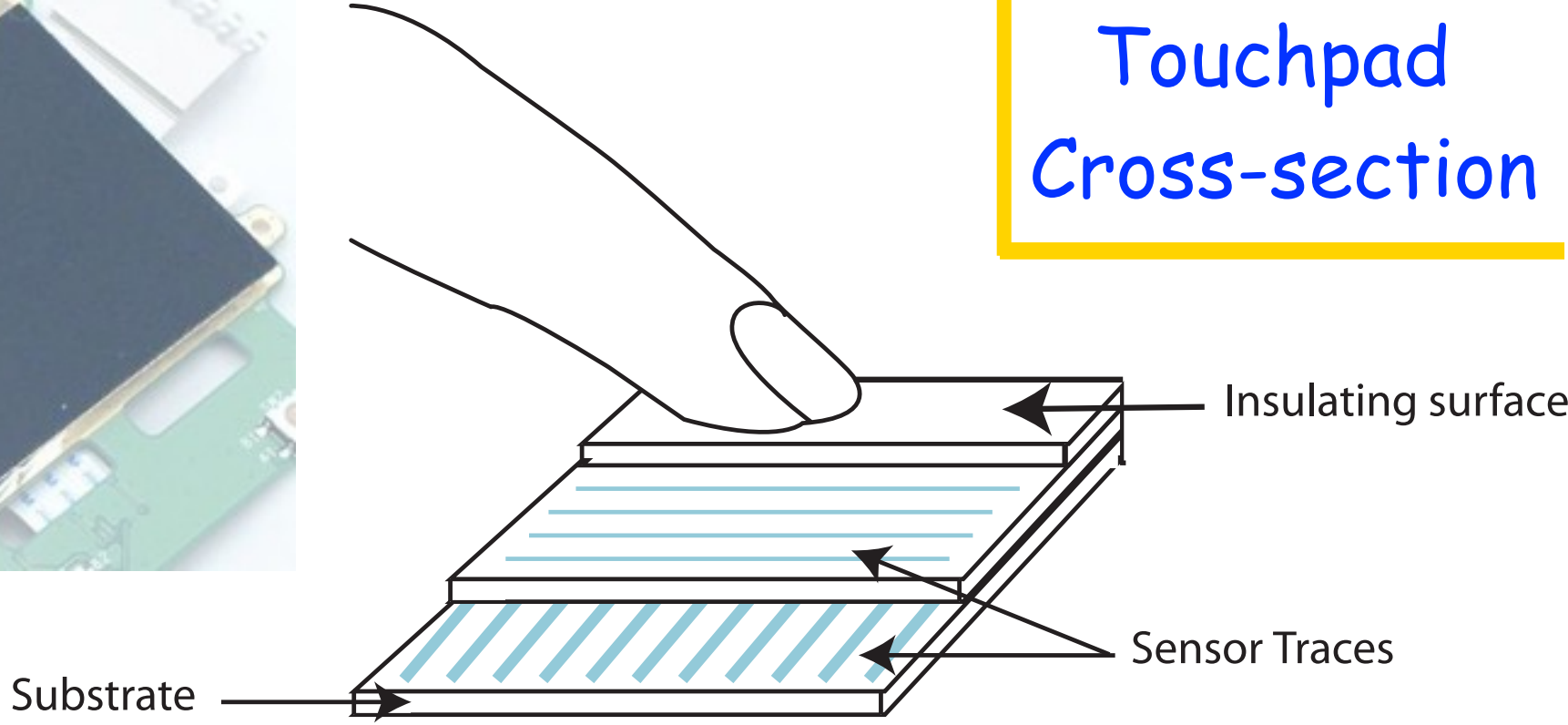


Back view: Capacitance meter chip

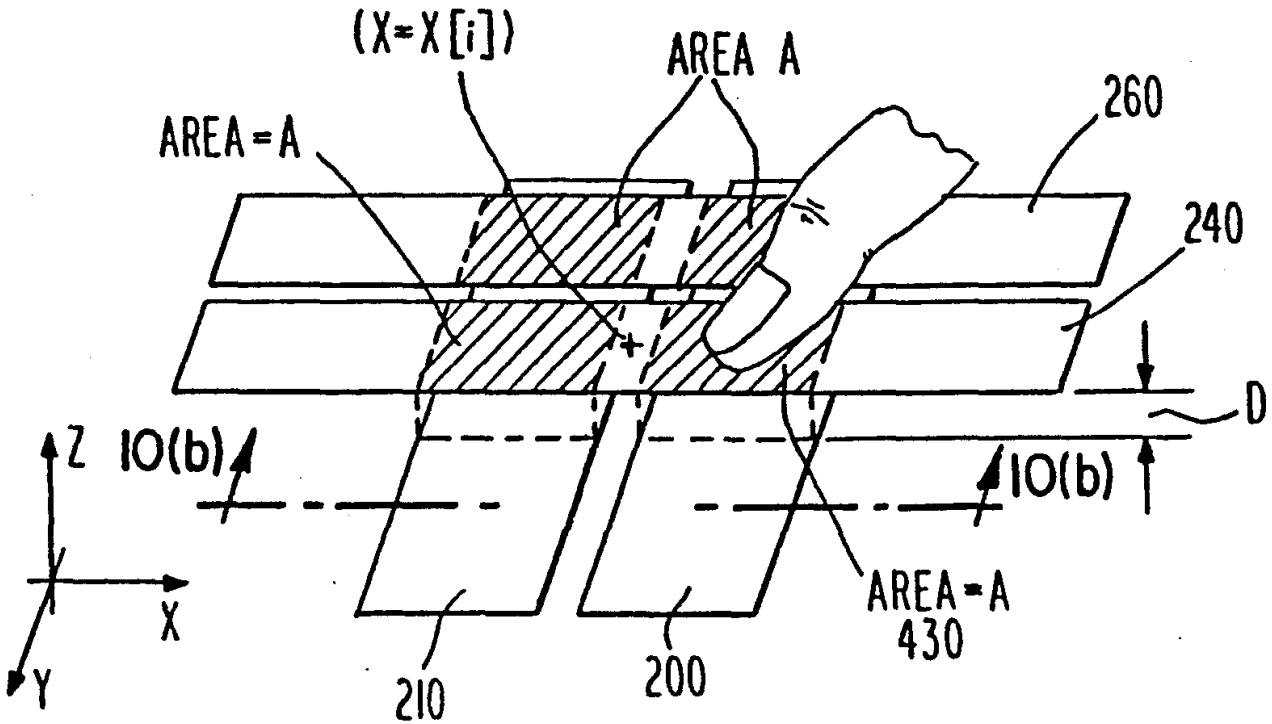


Touchpad Cross-section



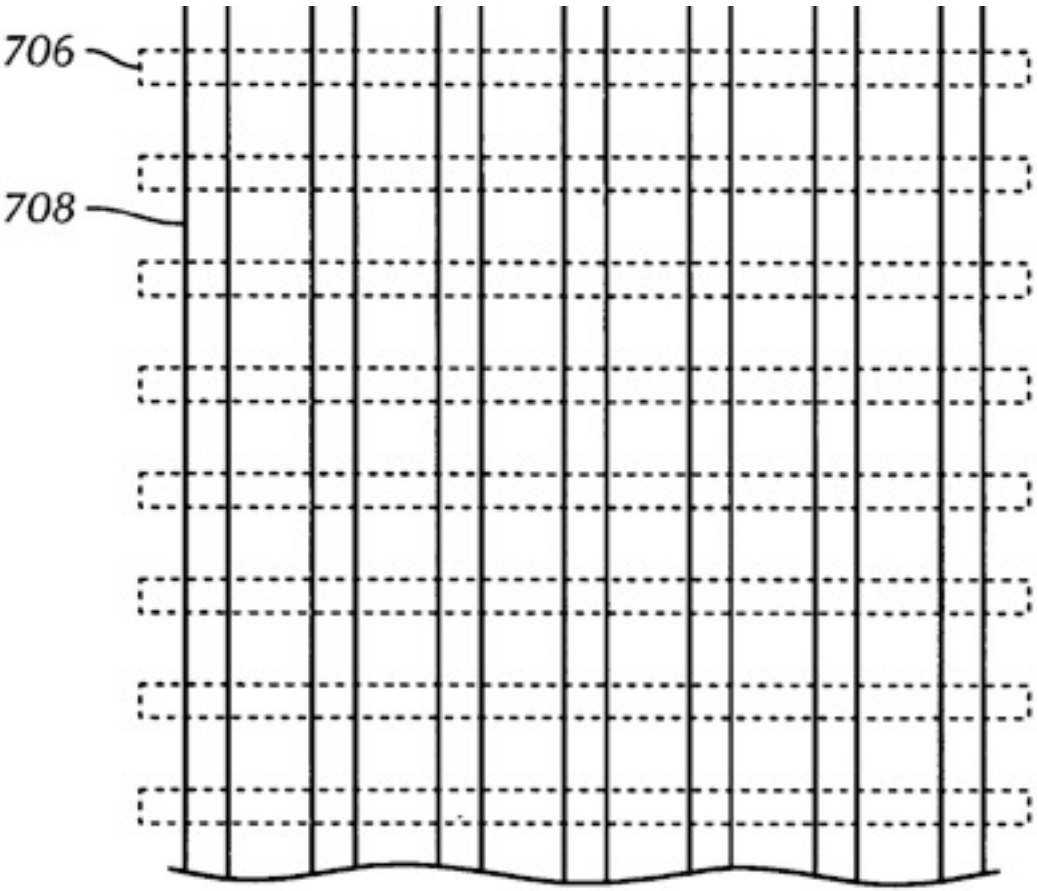


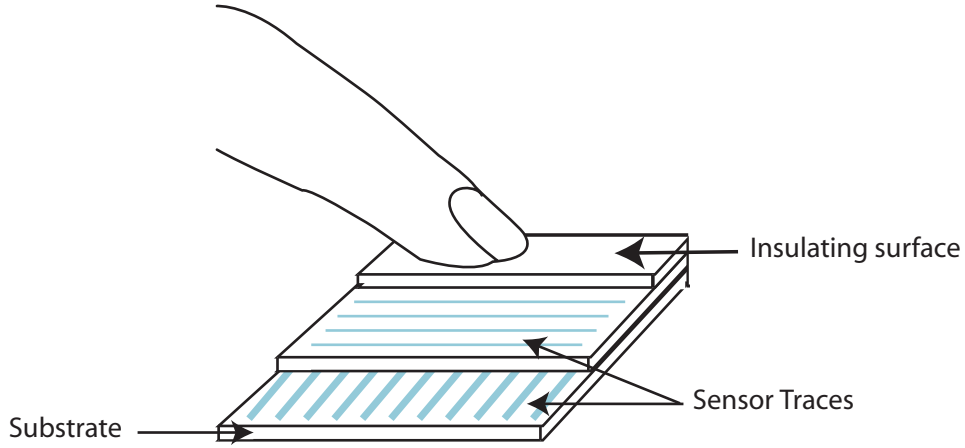
Grid cross-points are sensor capacitors.



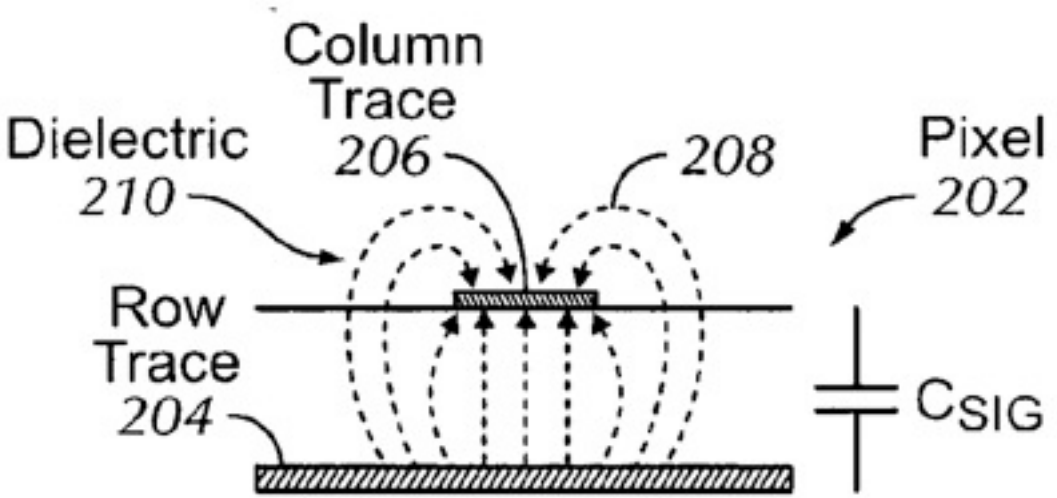
Touch screens use a transparent wire matrix (ITO, Indium-Tin Oxide) under glass or plastic.

The Sensor Array

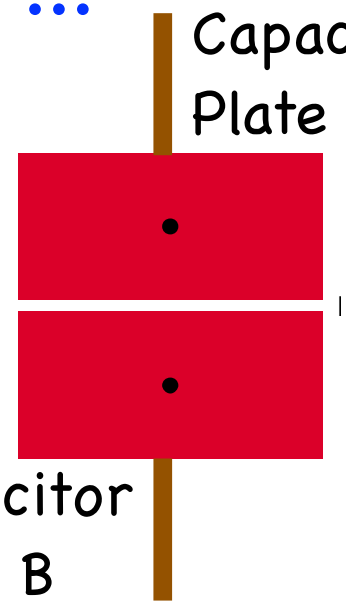




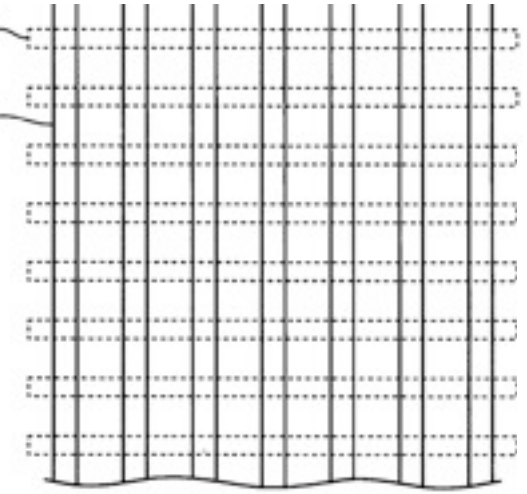
Cross-Point close-up



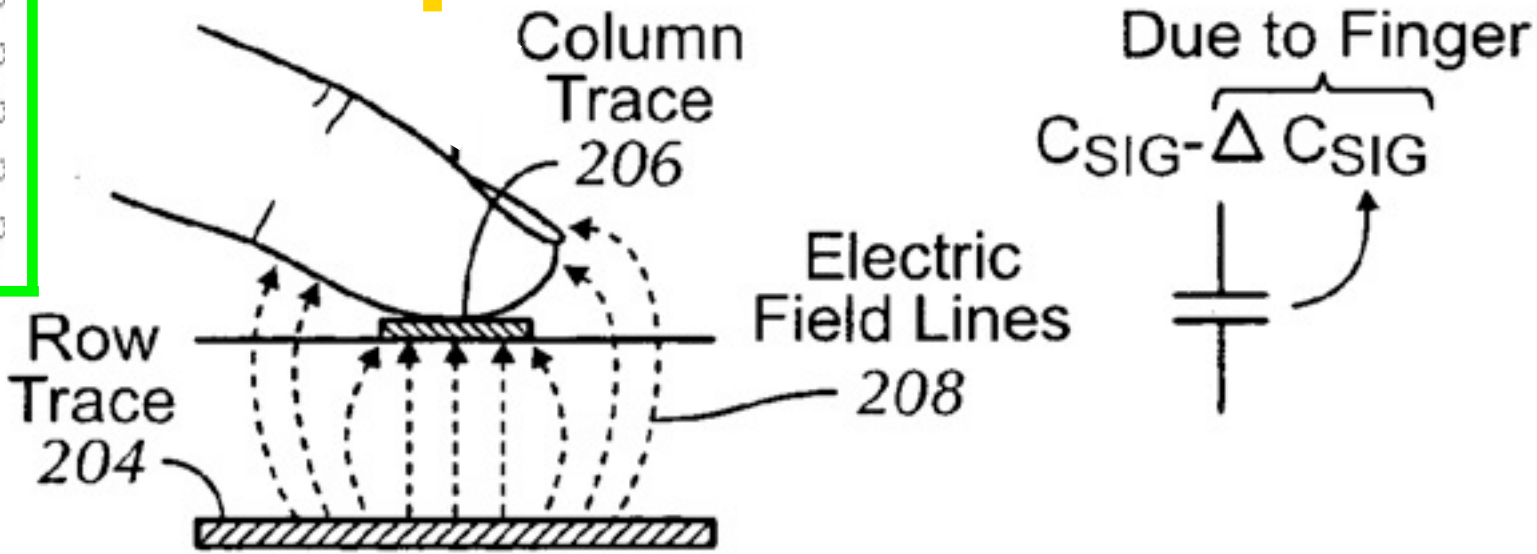
Recall ...



Sensor Array



Some of the field lines will terminate on the iron in the red blood cells of a nearby finger.



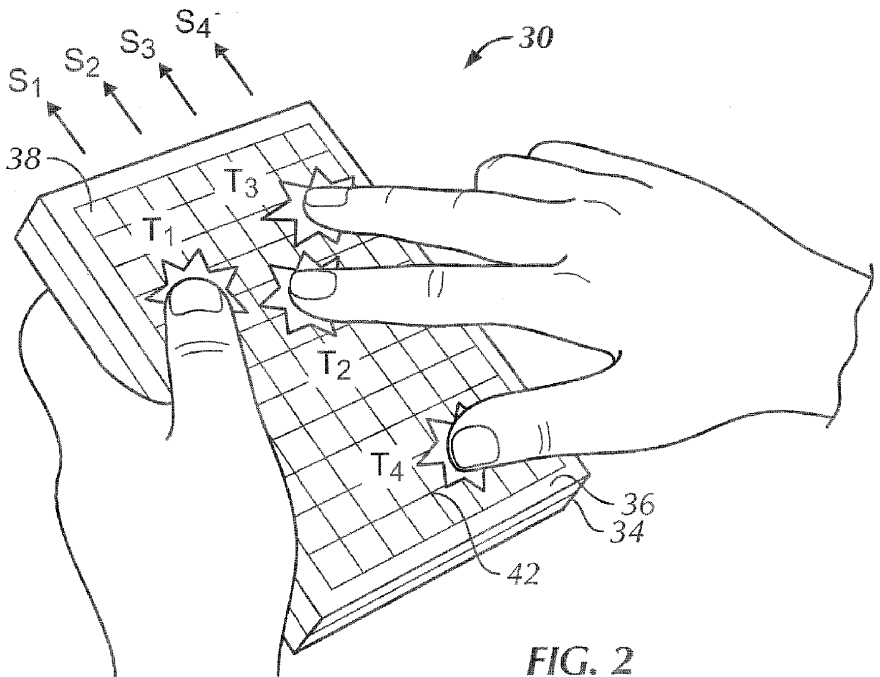


FIG. 2

If many fingers may touch at once (multi-touch), scan out C_{ij} array (frames) at a constant frame rate.

"Capacitance video camera".

Like a camera chip readout

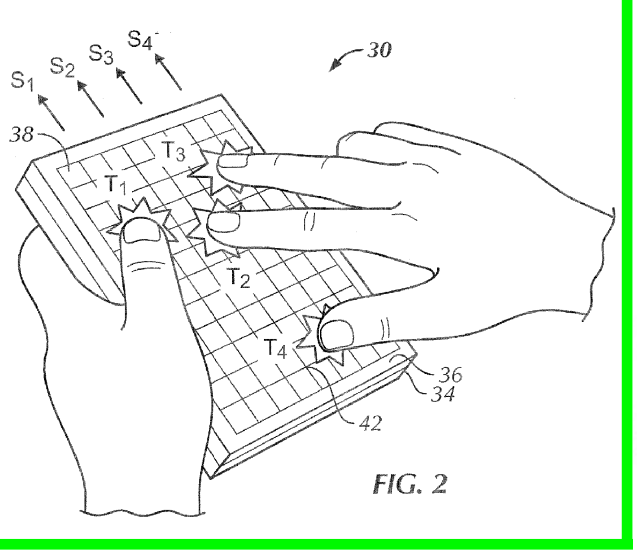
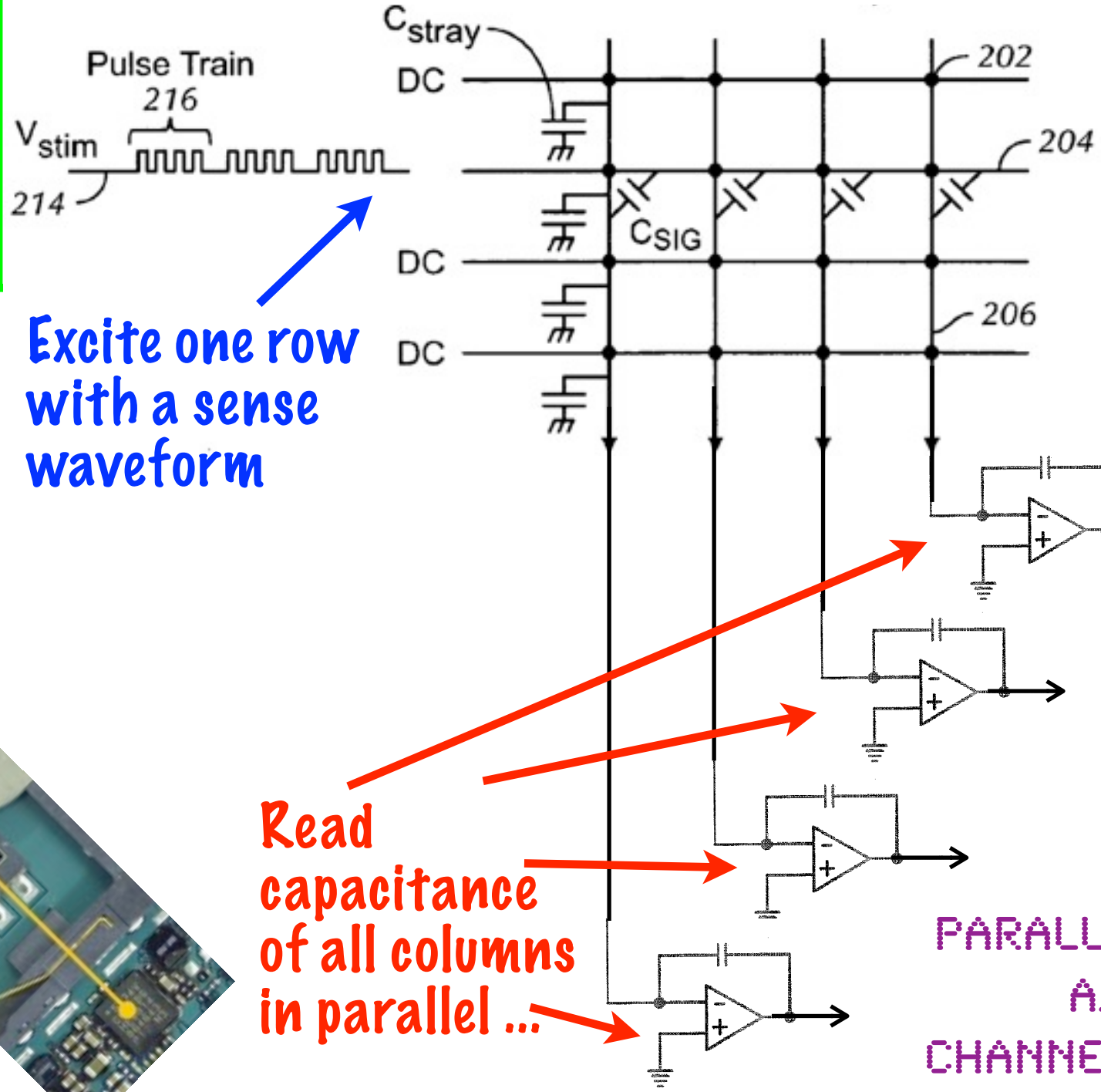
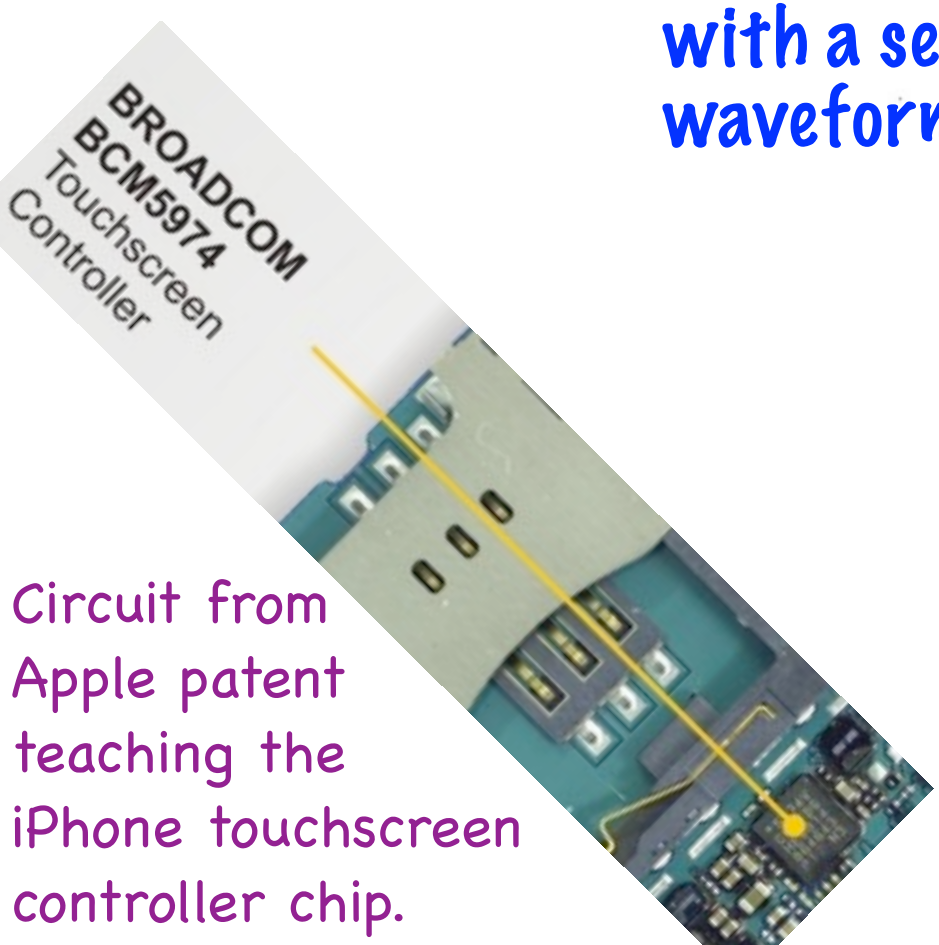


FIG. 2



Excite one row with a sense waveform

Read capacitance of all columns in parallel ...



Circuit from Apple patent teaching the iPhone touchscreen controller chip.

(19) **United States**
(12) **Patent Application Publicati**
Hotelling et al.

(54) **MULTIPOINT TOUCH SURFACE CONTROLLER**

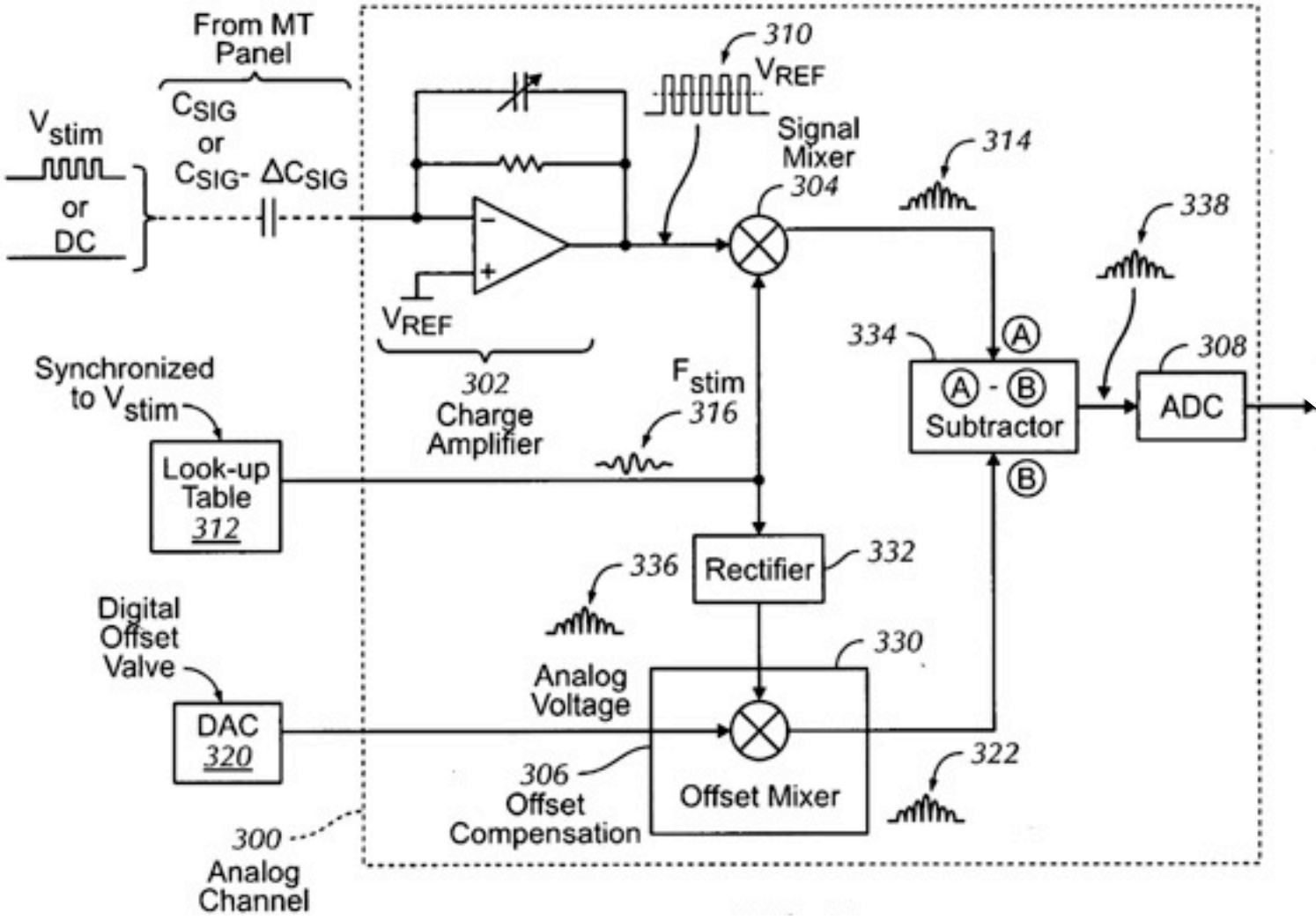
(75) Inventors: **Steven P. Hotelling**, San Jose, CA (US); **Christoph H. Krah**, Los Altos, CA (US); **Brian Quentin Huppi**, San Francisco, CA (US)

Correspondence Address:
WONG, CABELLO, LUTSCH, RUTHERFORD & BRUCCULERI, L.L.P.
20333 SH 249
SUITE 600
HOUSTON, TX 77070 (US)

(73) Assignee: **APPLE COMPUTER, INC.**, Cupertino, CA (US)

Not feasible in 1994 ...

One A/D readout channel



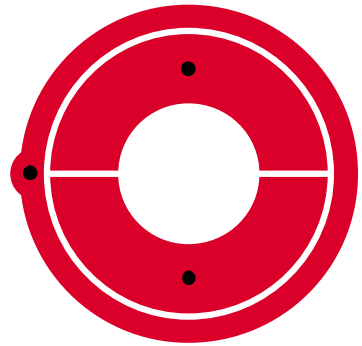
Looks a lot like a radio receiver ...
Which may be why Apple partnered with Broadcom for the design!

BEFORE MULTI-TOUCH

Single-touch: A fast accurate keypad

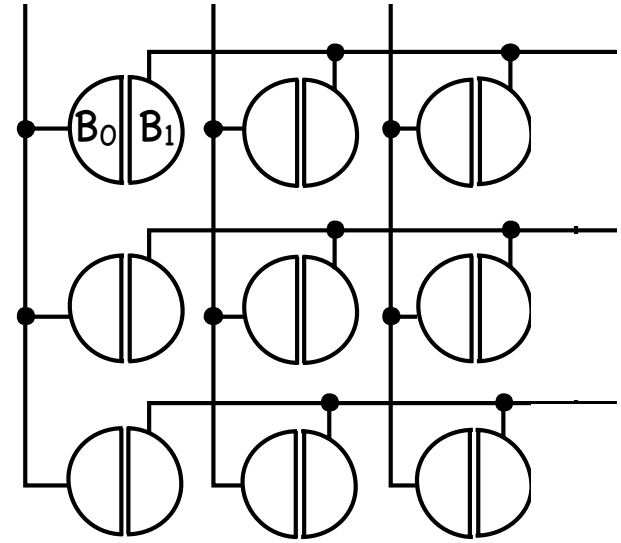
Synaptics™ adapted the keypad idea to track one finger over a track pad cross-point matrix (1991).

Keypad recap:



One switch

Switch Array



Connect all As together

If row I and column J have big Cs, key K_{ij} is touched

United States Patent [19]

Bisset et al.

[11] **Patent Number: 5,543,588**

[45] **Date of Patent: Aug. 6, 1996**

[54] **TOUCH PAD DRIVEN HANDHELD COMPUTING DEVICE**

[75] Inventors: **Stephen Bisset**, Palo Alto; **Robert J. Miller**, Fremont; **Timothy P. Allen**, Los Gatos; **Günter Steinbach**, Palo Alto, all of Calif.

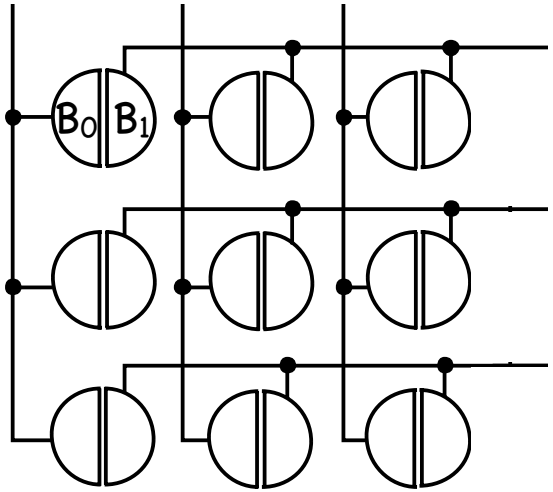
[56] **References Cited**

U.S. PATENT DOCUMENTS

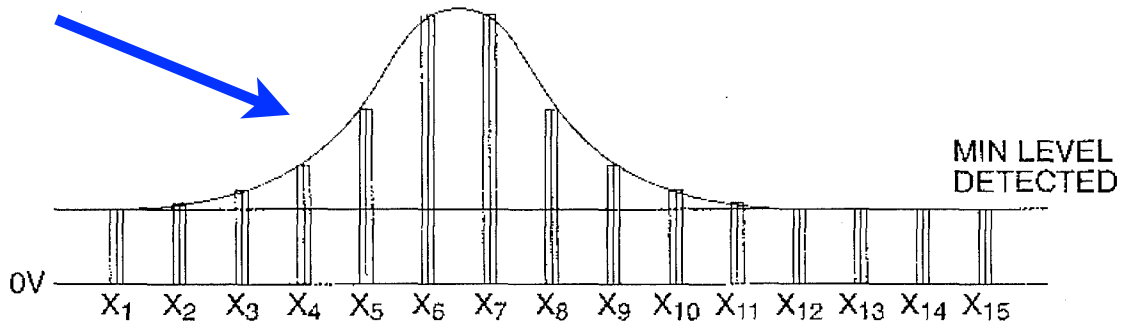
5,327,163 7/1994 Hashimoto et al. ..... 178/18 X

FOREIGN PATENT DOCUMENTS

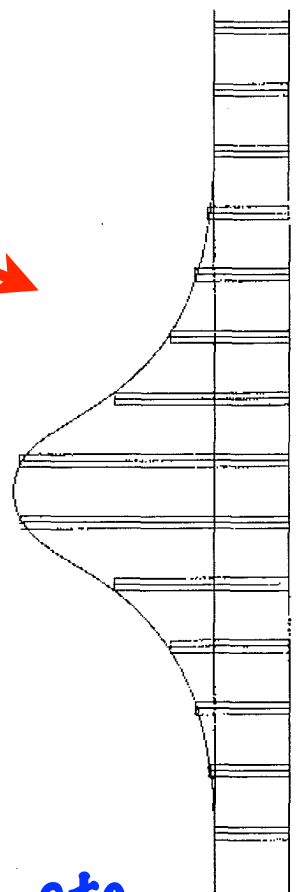
BEFORE MULTI-TOUCH

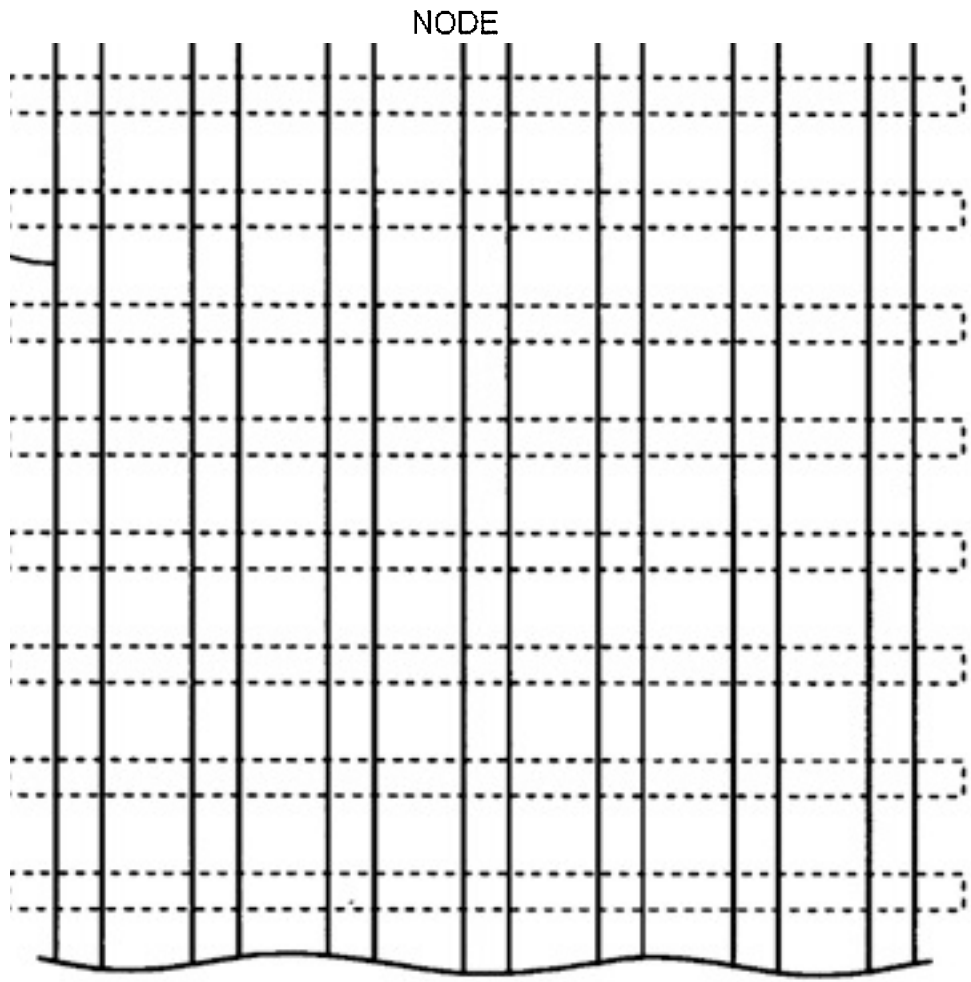


First, drive all Y lines simultaneously, and measure X capacitance vector ...



Then, drive all X lines simultaneously, and measure Y capacitance vector.





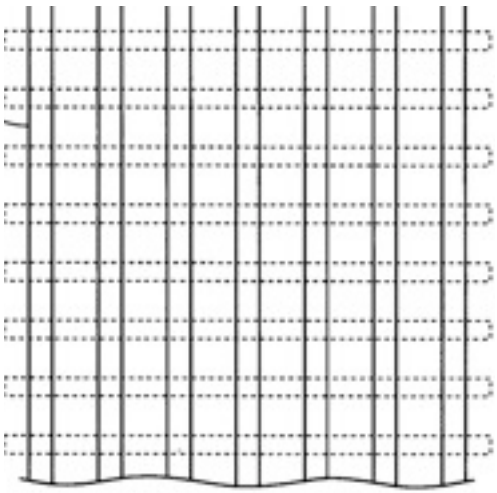
Track peaks over time, etc ...

All-analog computation !

Analog background C normalization

Analog peak interpolation

A/D at very end.



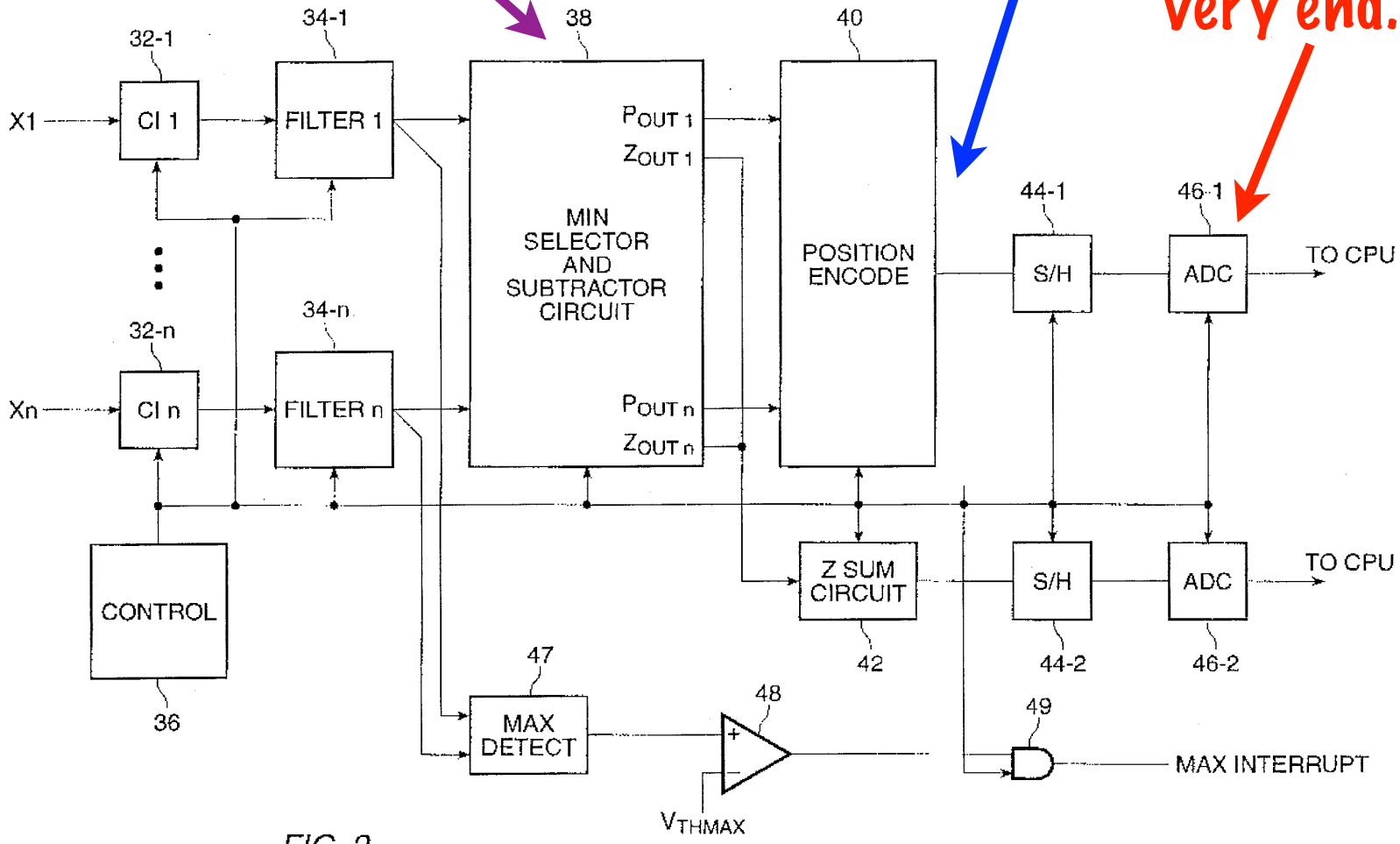


FIG. 2

To identical circuits for Y.

For your design: A typical part

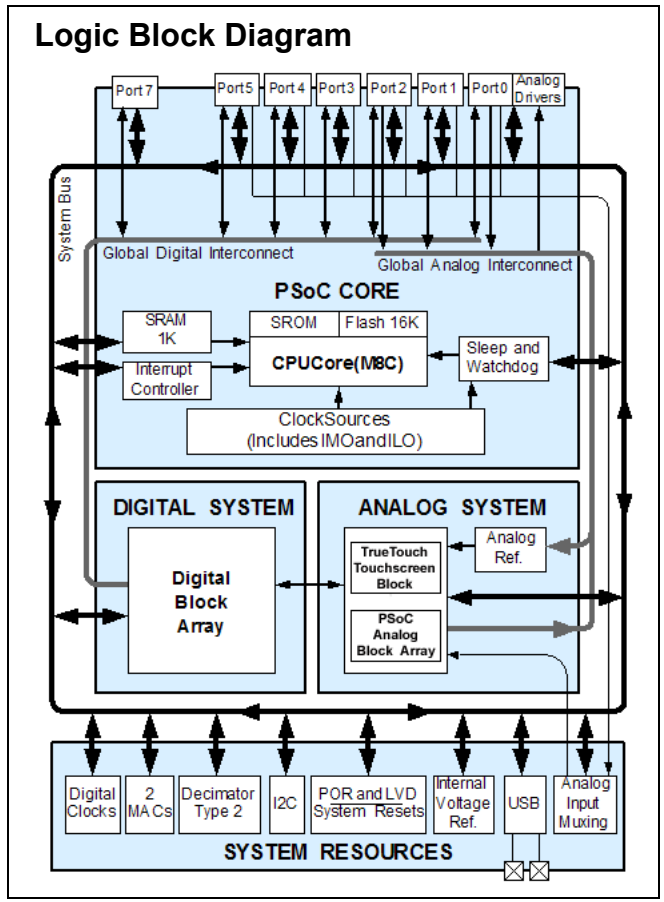
Most 2-D products are sold as per-customer custom modules (Synaptics) or done as in-house ASICs (Apple).

Recently, standard parts have started to appear …

CYPRESS PERFORM

ADVANCED **CY8CTMG120**

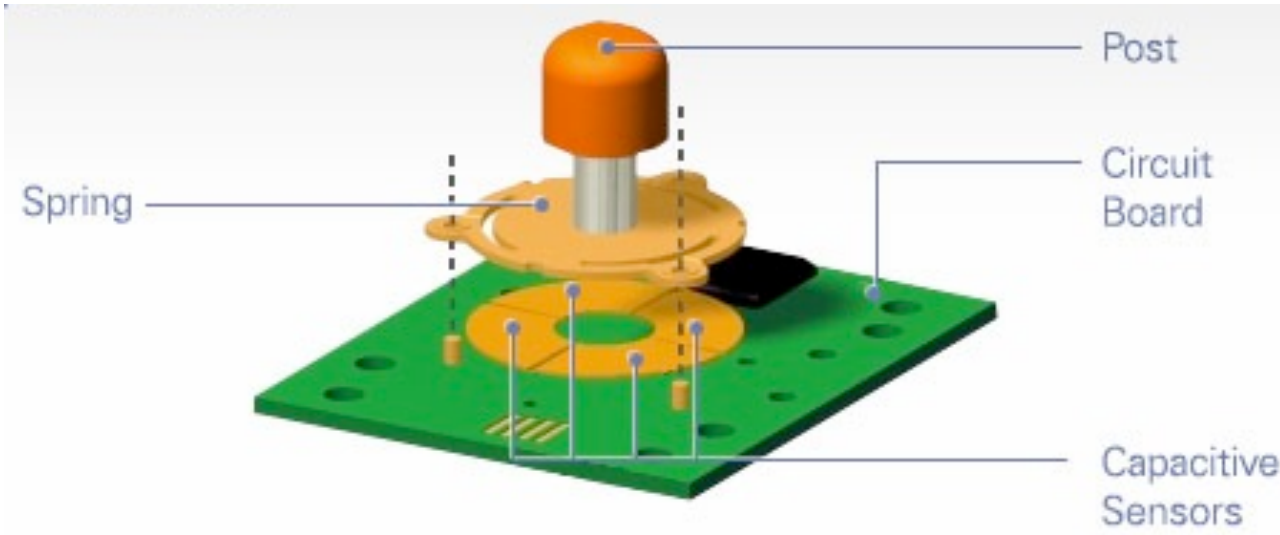
TrueTouch™ Multi-Touch Gesture Touchscreen Controller



Novel applications

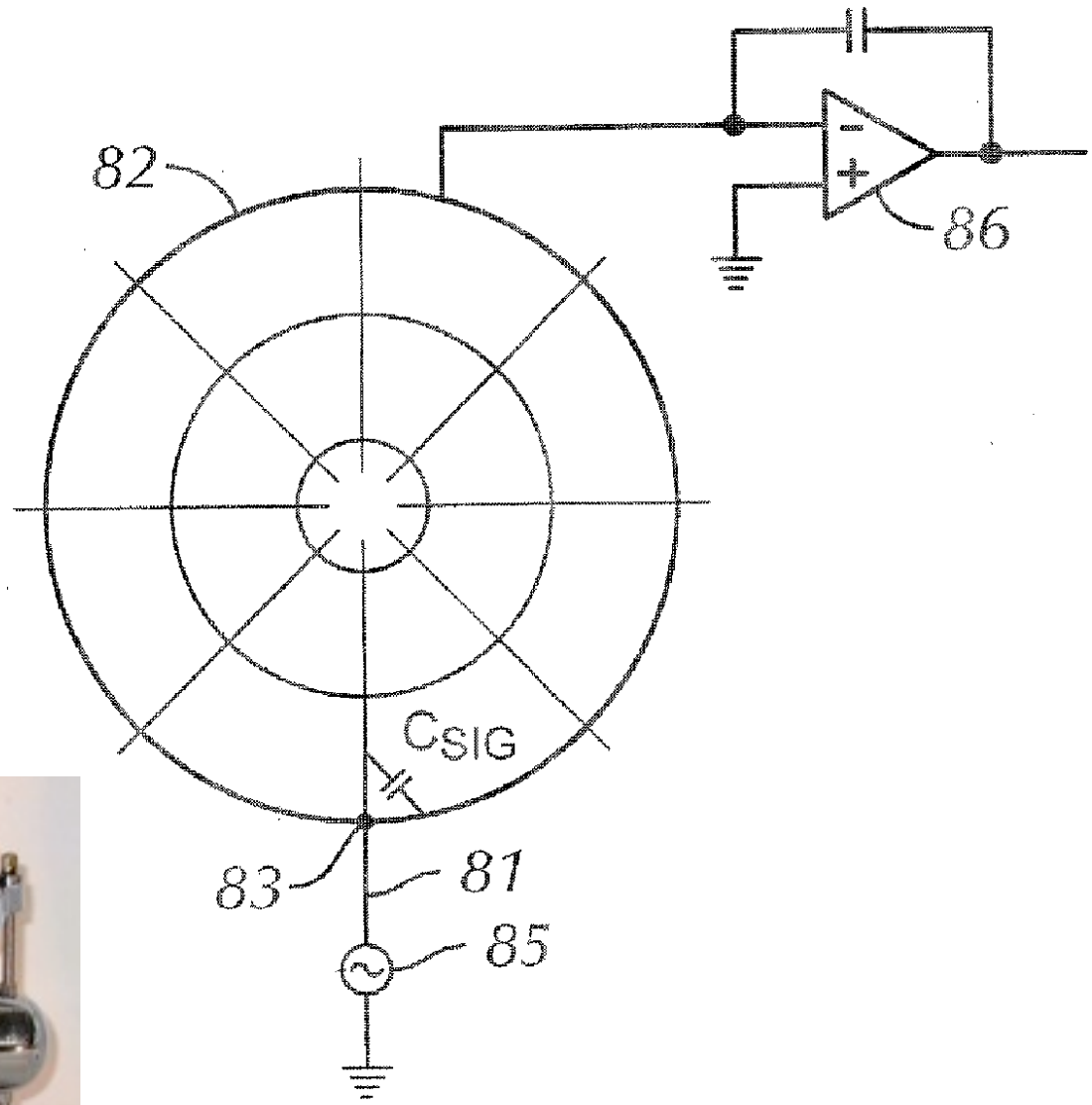
Touch sensing ideas ...

- **Techniques not limited to finger capacitance**



Touch pad and touch screen ideas ...

- **Techniques are not limited to the Cartesian coordinate space.**



Touch sensing ideas ...

- **Techniques can be adapted to flexible printed circuit technologies.**

Flexibility to meet customers needs

Design Guide

Touch user interfaces on curved surfaces (Apple patent)

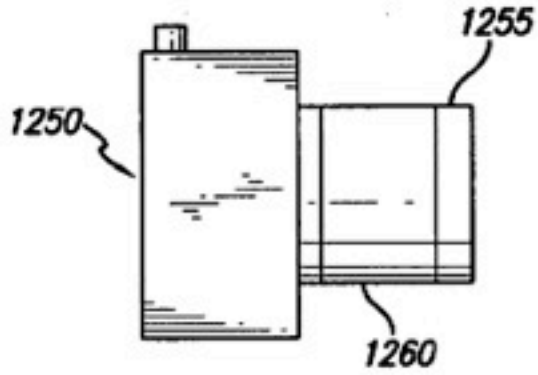


FIG. 28A

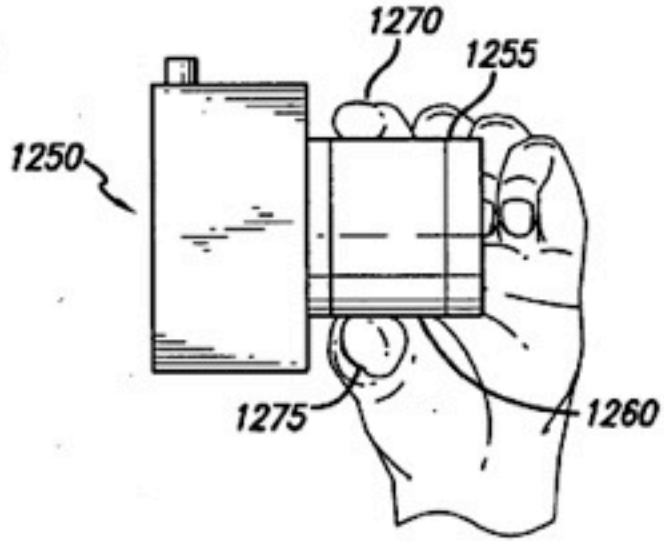
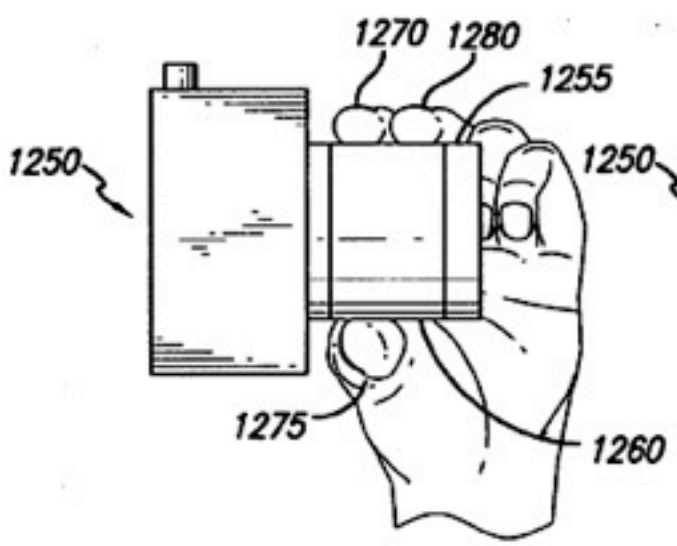
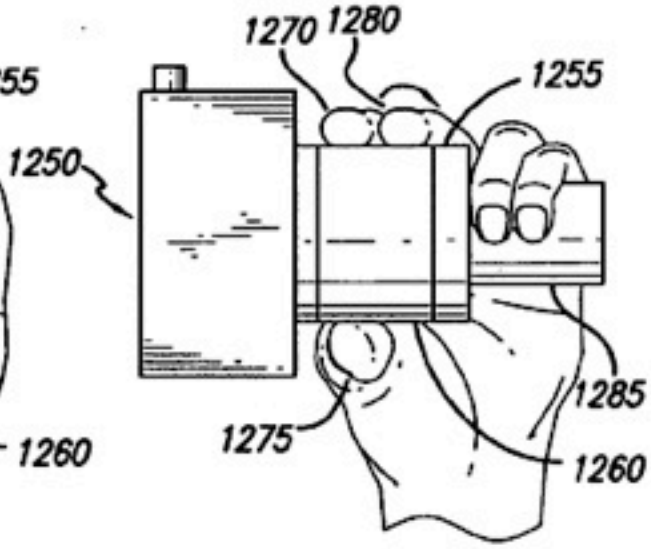
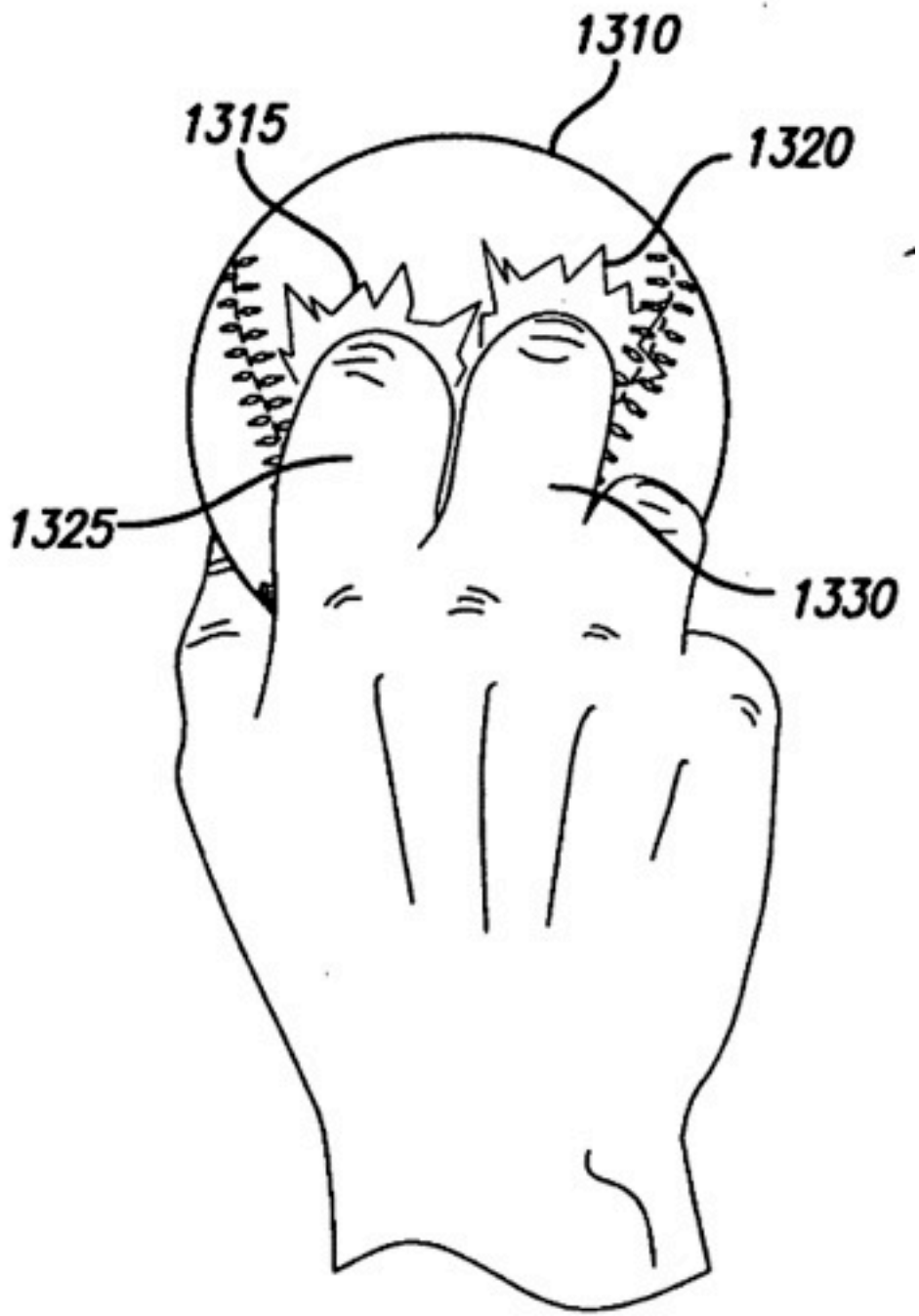


FIG. 28B





Touch user interfaces on curved surfaces (Apple patent)



Final thought

Touch Sensing = Materials + Electronics + Product Design

A decade ago, a design team needed experts in all 3 disciplines to succeed.

Today, sensor chips and Internet PC board services change the equation.

Sensing on curved surfaces await their iPod moment -- a product design concept that brings them mainstream.