Fundamentals of Projected-Capacitive Touch Technology

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Must use exact capitalization!

File Download: **www.walkermobile.com/SID_2014_Short_Course_S1.pdf**

Agenda

- Introduction
- Basic Principles
- Controllers
- Sensors
- ITO-Replacement Materials
- Modules
- Embedded
- Large-Format
- Stylus
- Software
- Conclusions
- Appendix A: Historical Embedded Touch

Introduction

- P-Cap History
- P-Cap Penetration
- P-Cap by Application
- Touch User-Experience

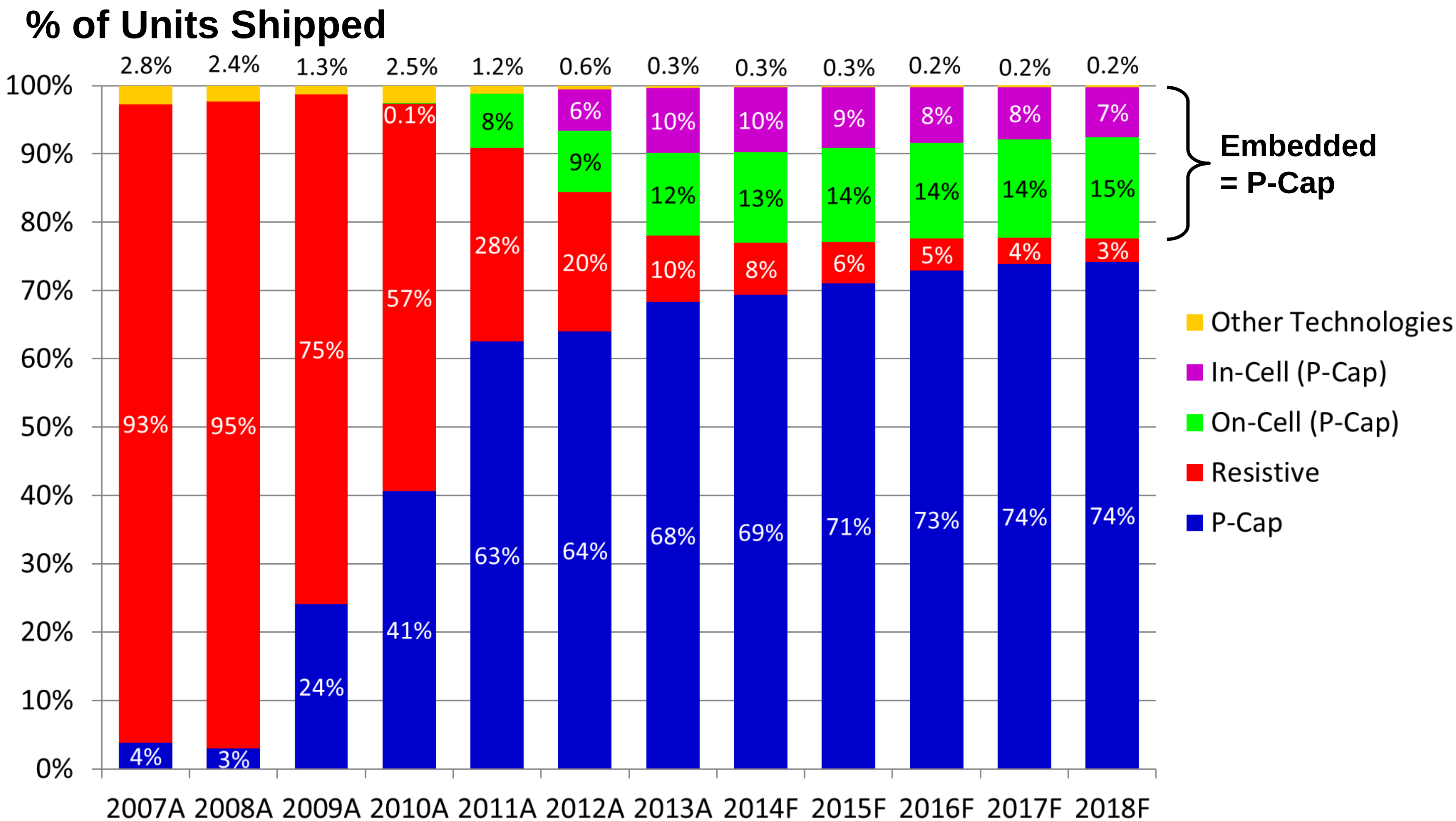
Must use exact capitalization!

File Download: **www.walkermobile.com/SID_2014_Short_Course_S1.pdf**

P-Cap History

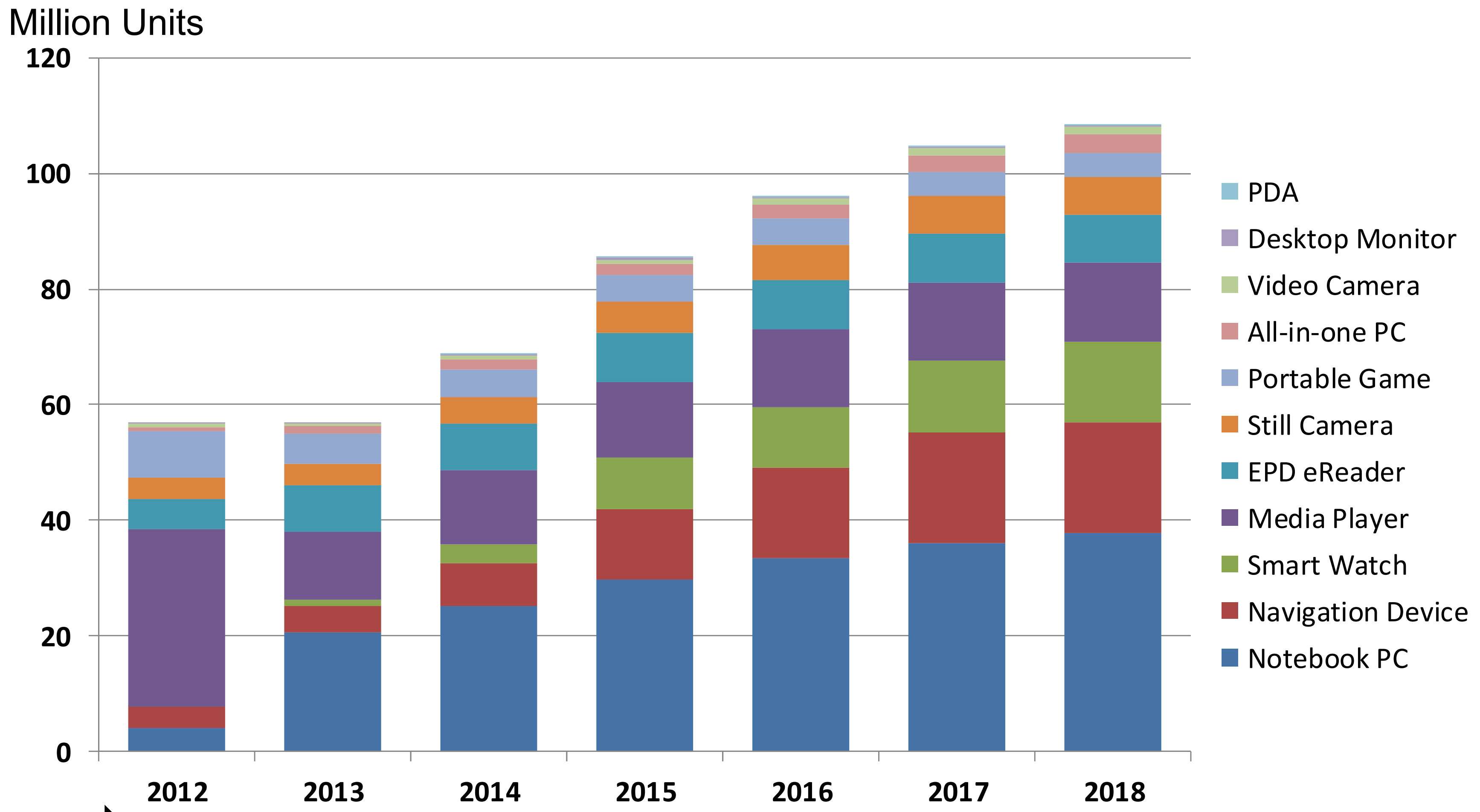
Company	Significance	Year
UK Royal Radar Establishment (E.A. Johnson)	First published application of transparent touchscreen (mutual-capacitance p-cap on CRT air-traffic control terminals)	1965
CERN (Bent Stumpe)	Second published application of mutual-capacitance p-cap (in the control room of the CERN proton synchrotron)	1977
Dynapro Thin Films (acquired by 3M Touch Systems in 2000)	First commercialization of mutual-capacitive p-cap (renamed as Near-Field Imaging by 3M)	1995
Zytronic (first license from Ronald Binstead, an inventor in the UK)	First commercialization of large-format self-capacitive p-cap; first commercialization of large-format mutual-capacitive p-cap	1998 2012
Visual Planet (second license from Ronald Binstead)	Second commercialization of large-format self-capacitive p-cap	2003
Apple	First use of mutual-capacitive p-cap in a consumer electronics product (the iPhone)	2007

P-Cap Penetration



Source: DisplaySearch Touch-Panel Market Analysis Reports 2008-2014

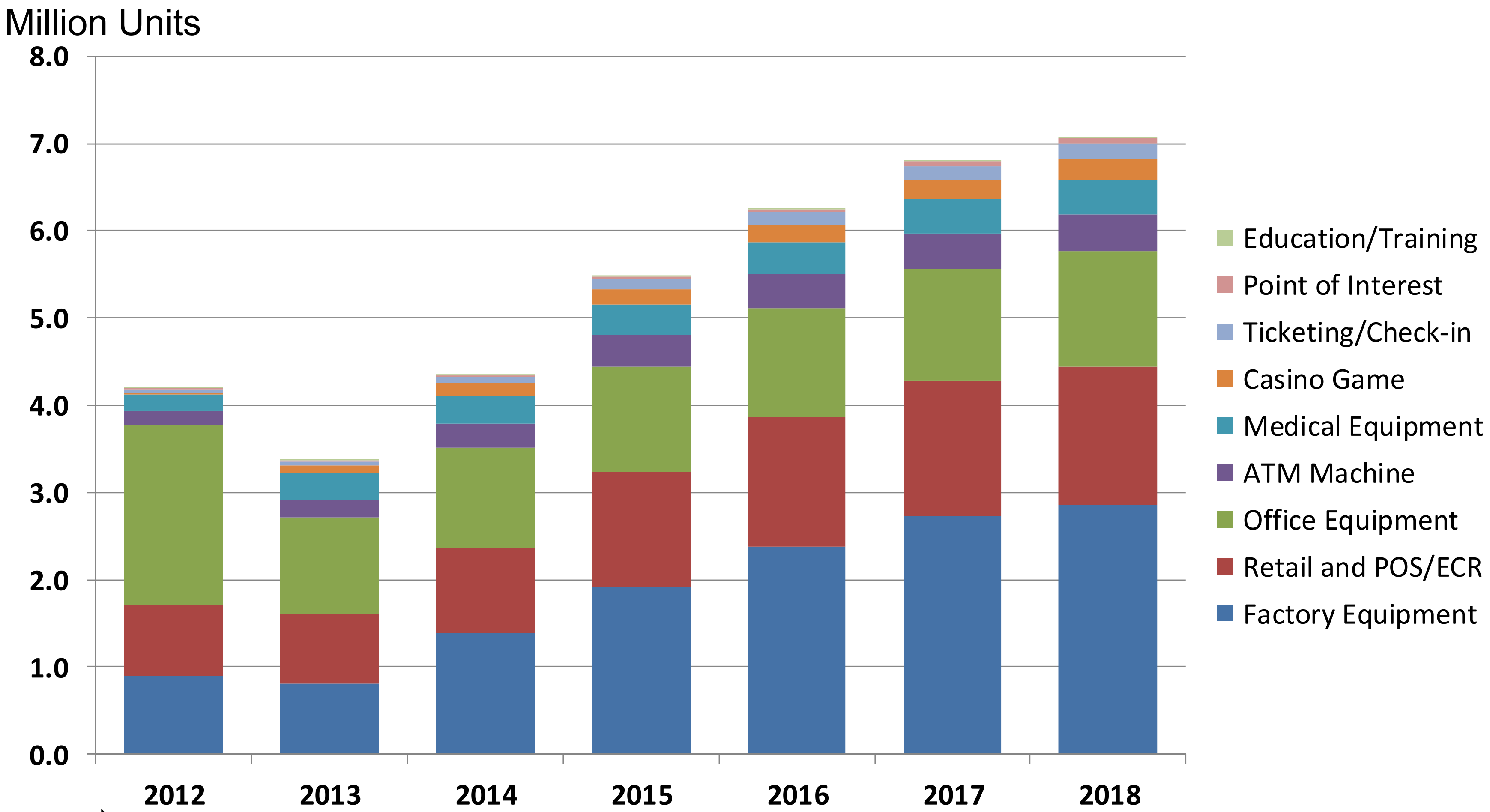
P-Cap Forecast by Application…1 (Consumer)



2018: Phones = **1.8 Billion** Units; Tablets = **447 Million** Units

Source: DisplaySearch Touch-Panel Market Analysis Report 1Q-2014

P-Cap Forecast by Application…2 (Commercial)



2018: Automobile Monitor = **42 Million** Units

Source: DisplaySearch Touch-Panel Market Analysis Report 1Q-2014

P-Cap Defines the Standard for Touch User-Experience

- **Smartphones and tablets have set the standard for touch in *SEVERAL BILLION* consumers' minds**
  - Multiple simultaneous touches (robust multi-touch)
  - Extremely light touch (zero force)
  - Flush surface ("zero-bezel" or "edge-to-edge")
  - Excellent optical performance
  - Very smooth & fast scrolling
  - Reliable and durable
  - An integral part of the device user experience

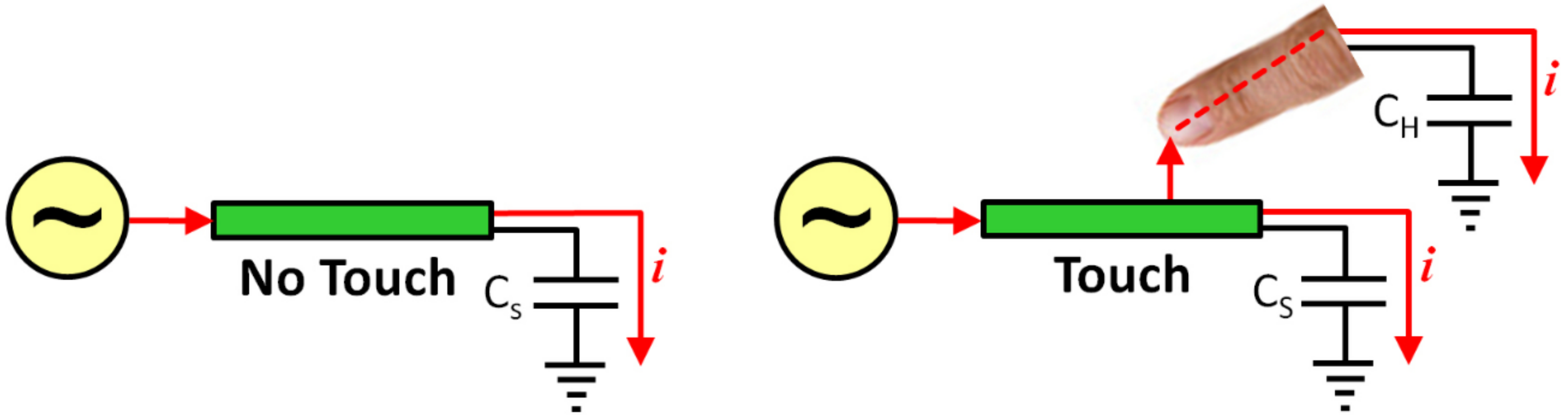
Source: AP / NBC News

Basic Principles

- Self Capacitive
- Mutual Capacitive
- Mutual Capacitive Electrode Patterns

Self-Capacitance

- **Capacitance of a <u>single</u> electrode to ground**
  - Human body capacitance <u>increases</u> the capacitance of the electrode to ground
  - In a self-capacitance sensor, each electrode is measured individually



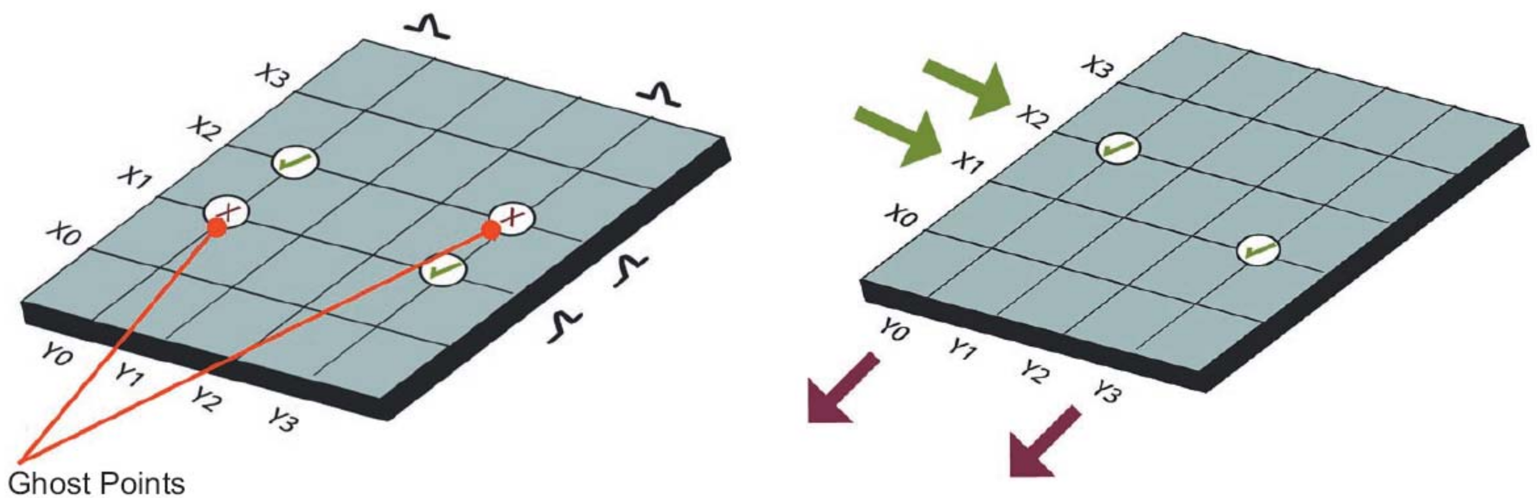
Source: The author

The Problem with Self-Capacitance

- **Touches that are diagonally separated produce <u>two maximums on each axis</u> (real points & ghost points)**
  - Ghost points = False touches positionally related to real touches

Self Capacitance

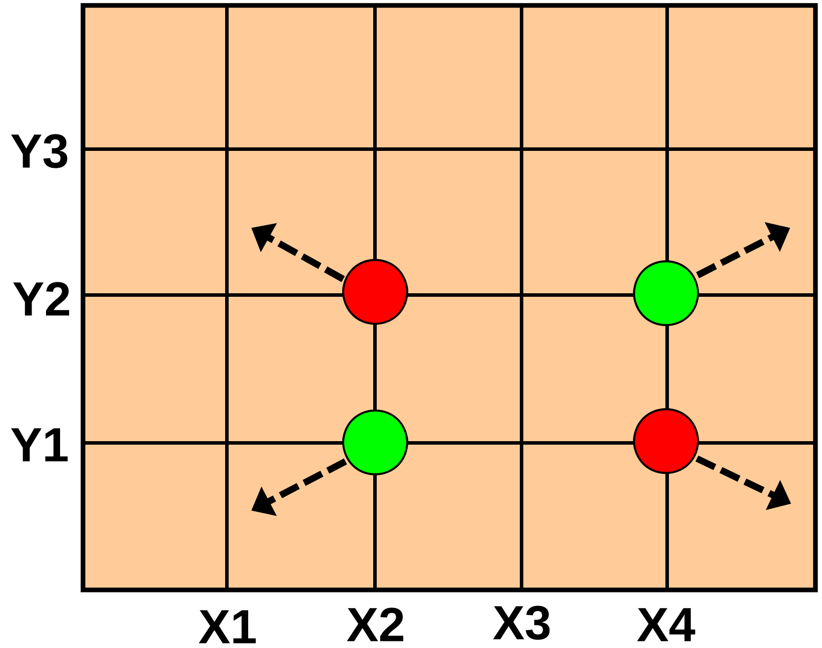
Mutual Capacitance



Source: Atmel

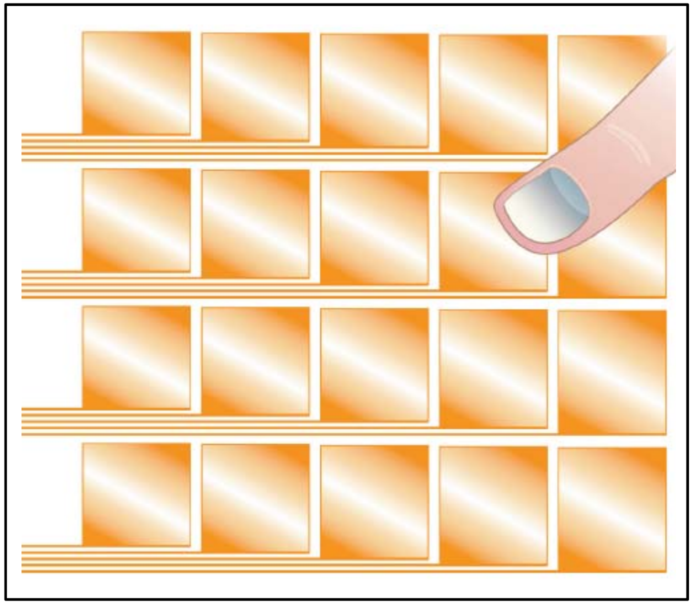
Self-Capacitance and Pinch/Zoom Gestures

- Use the direction of movement of the points rather than the ambiguous locations



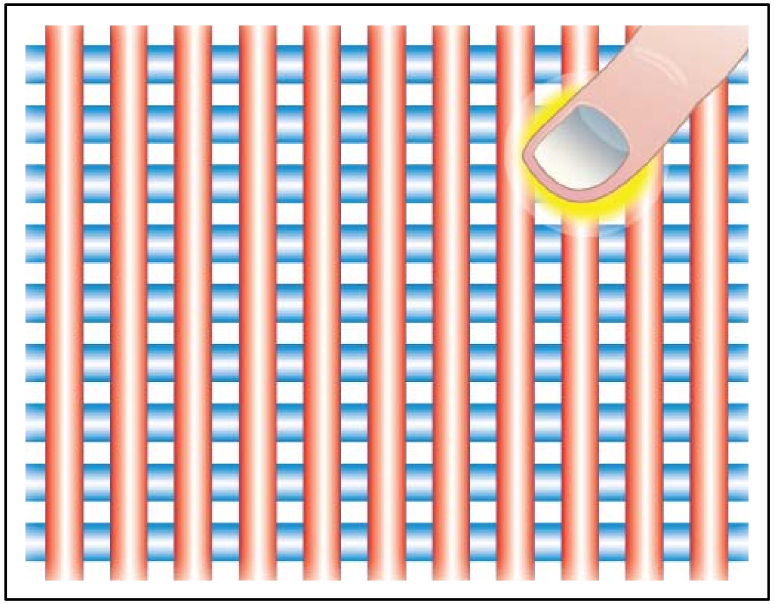
Source: The author

Self-Capacitance Electrode Variations



20 measurements

Source: 3M



20 measurements

- Multiple separate pads in a single layer
- Each pad is scanned <u>individually</u>

- Rows and columns of electrodes in two layers
- Row & column electrodes are scanned <u>in sequence</u>

Self-Capacitance Advantages & Disadvantages

Self-Capacitive Advantages	Self-Capacitive Disadvantages
Simpler, lower-cost sensor	Limited to 1 or 2 touches with ghosting
Can be a single layer	Lower immunity to LCD noise
Long-distance field projection	Lower touch accuracy
Can be used with active guard	Harder to maximize SNR
Fast measurement	

- **Where it's used**
  - Lower-end smartphones and feature-phones with touch
    - Becoming much less common due to single-layer p-cap
  - In combination with mutual capacitance to increase capability

Self-Capacitance for Hover

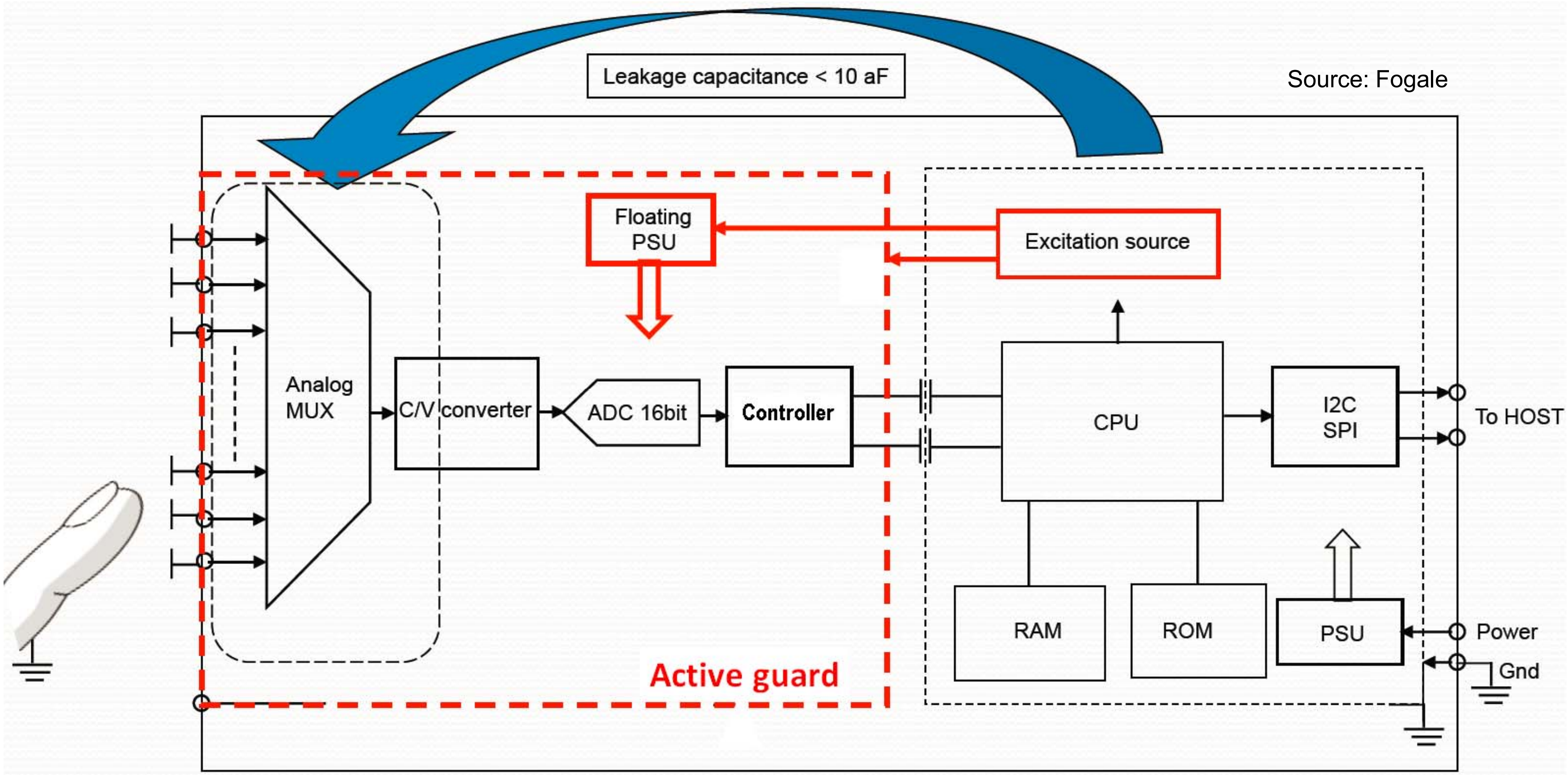
- **Self-capacitance is used to produce "hover" behavior in some smartphones (in addition to mutual-capacitance for contact-touch location)**
  - Also used for automatically detecting glove vs. fingernail vs. skin, and for dealing with water on the screen

Source: Panasonic

Source: Cypress

Multi-Touch Self-Capacitance Using Active Guard Concept…1

- Guarding is a well-known technique for reducing the effects of electrical current leakage



Multi-Touch Self-Capacitance Using Active Guard Concept…2

❖ **Another contender: zRRo**

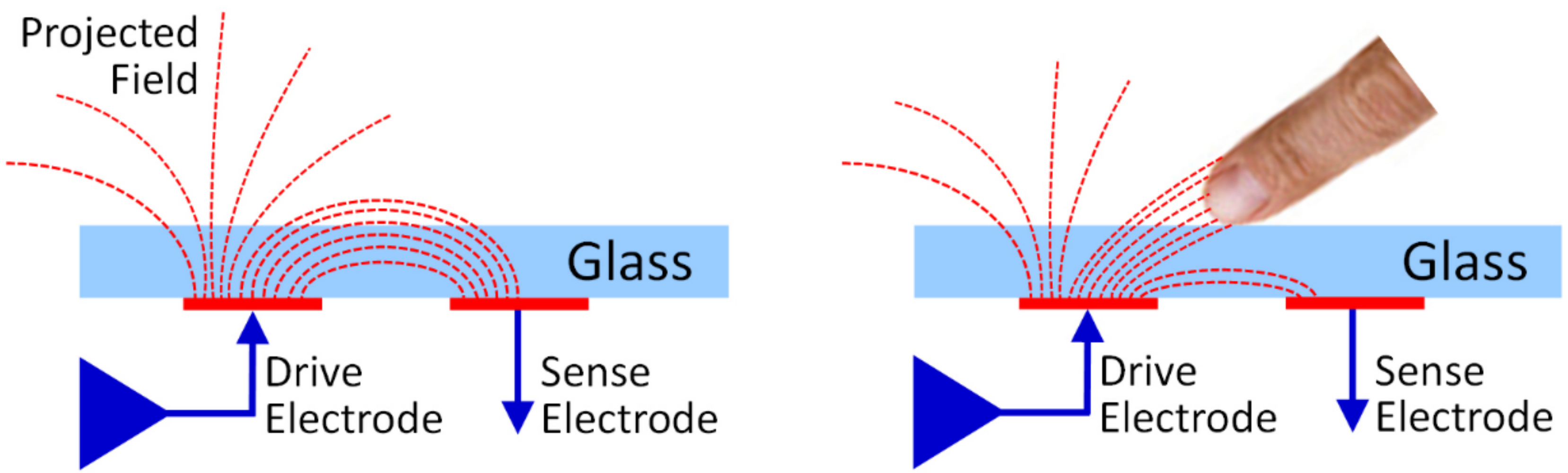
3D single-touch for smartphones

3D multi-touch for smartphones and tablets

Source: zRRo

Mutual Capacitance

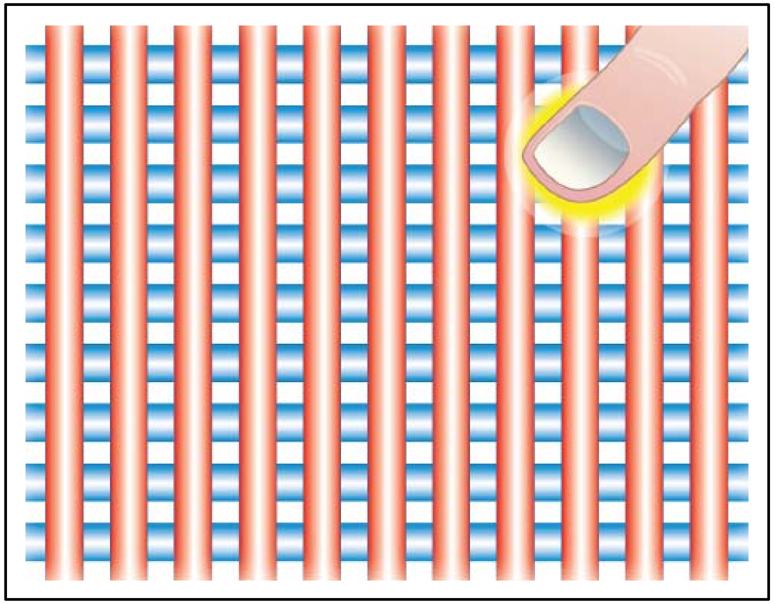
- Capacitance <u>between two electrodes</u>
  - Human body capacitance “steals charge” which <u>decreases</u> the capacitance between the electrodes
  - In a mutual-capacitance sensor, each electrode <u>intersection</u> is measured individually



Source: The author

Mutual Capacitance Electrode Patterns…1

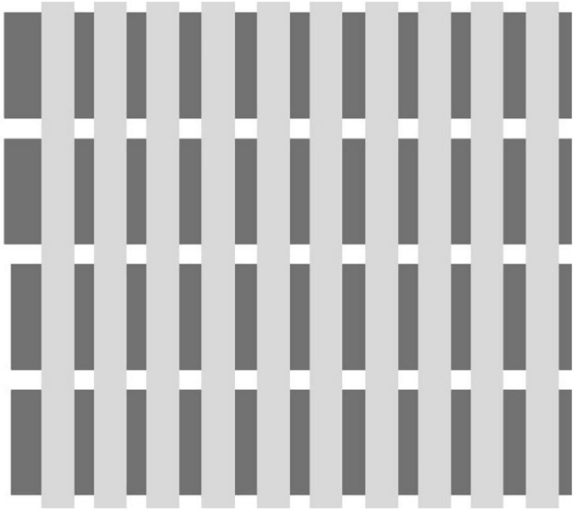
- **Rows and columns of electrodes in two layers**



Source: 3M

11 x 9 = 99 measurements

- **In the real world…**
  - “Bar and stripe”, also called “Manhattan” or “Flooded-X” (LCD noise self-shielding)

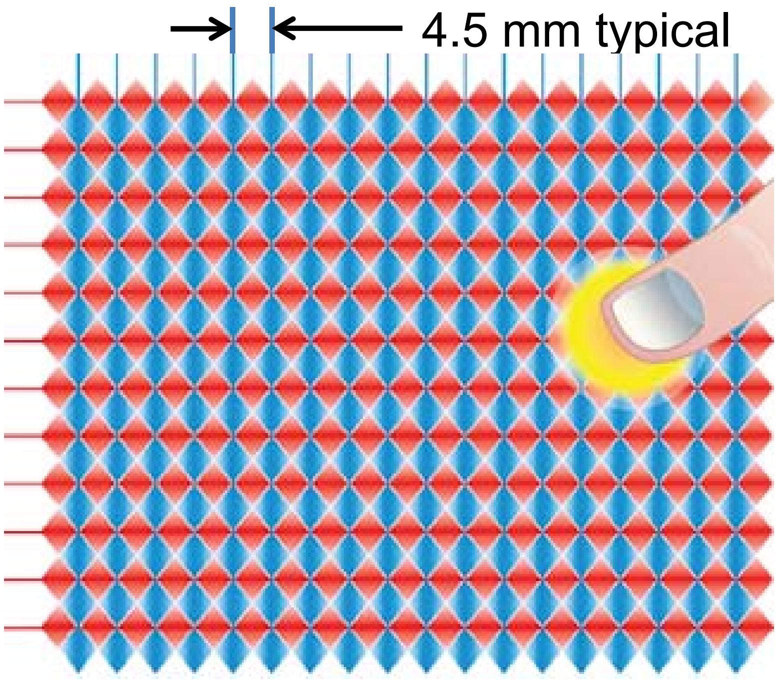


Source: Cypress

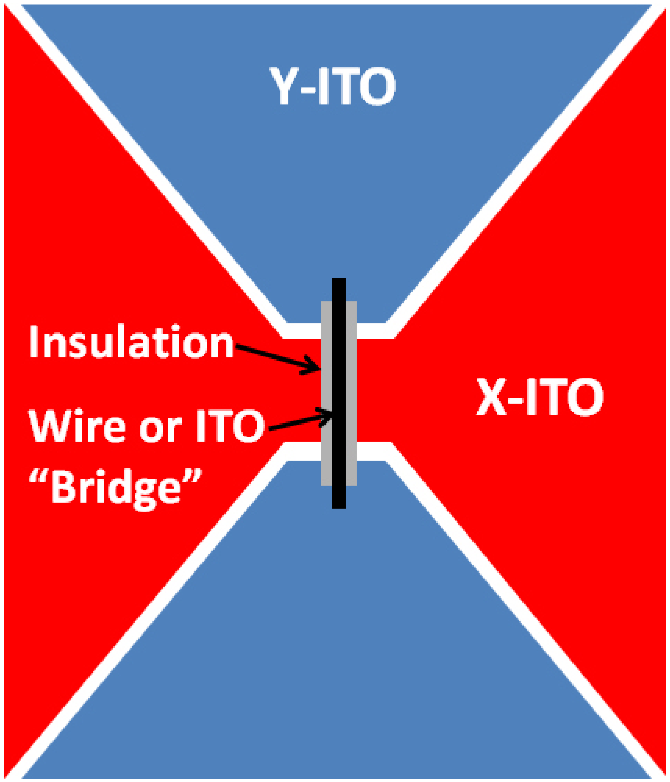
4 x 10 = 40 measurements

Mutual Capacitance Electrode Patterns…2

- **Interlocking diamond pattern with ITO in "one layer" with *bridges***



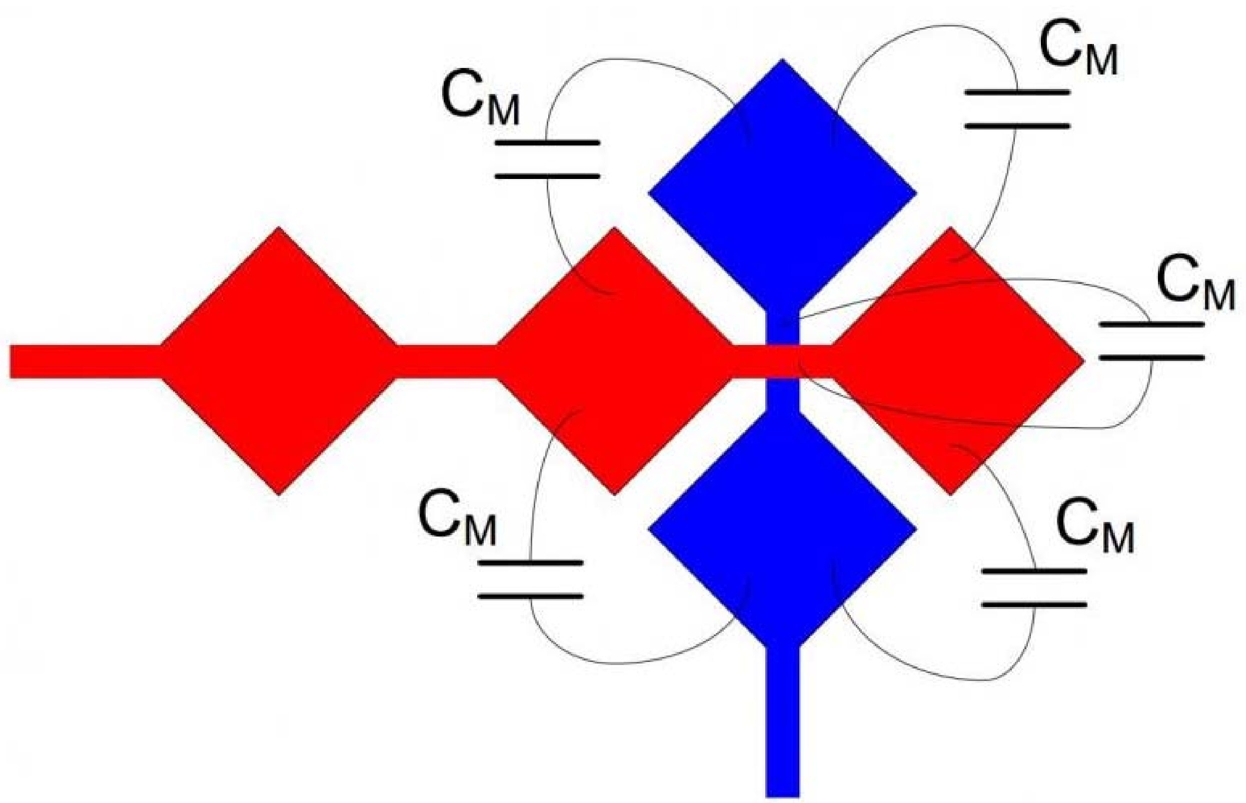
Source: 3M



Source: The author

More On Mutual Capacitance…1

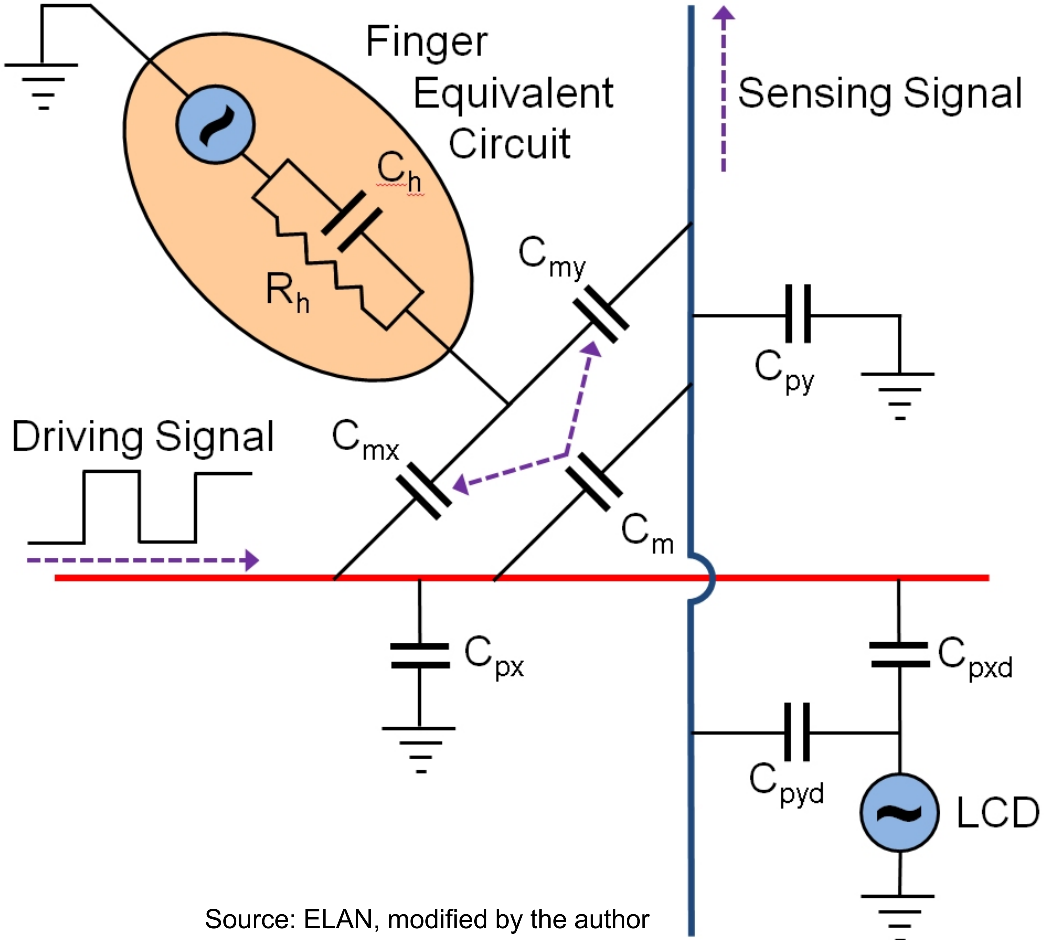
- **BTW, there isn't just <u>one</u> mutual capacitance…**



Source: Cypress

More On Mutual Capacitance…2

- And there are more capacitors than just the C_m's…



Source: ELAN, modified by the author

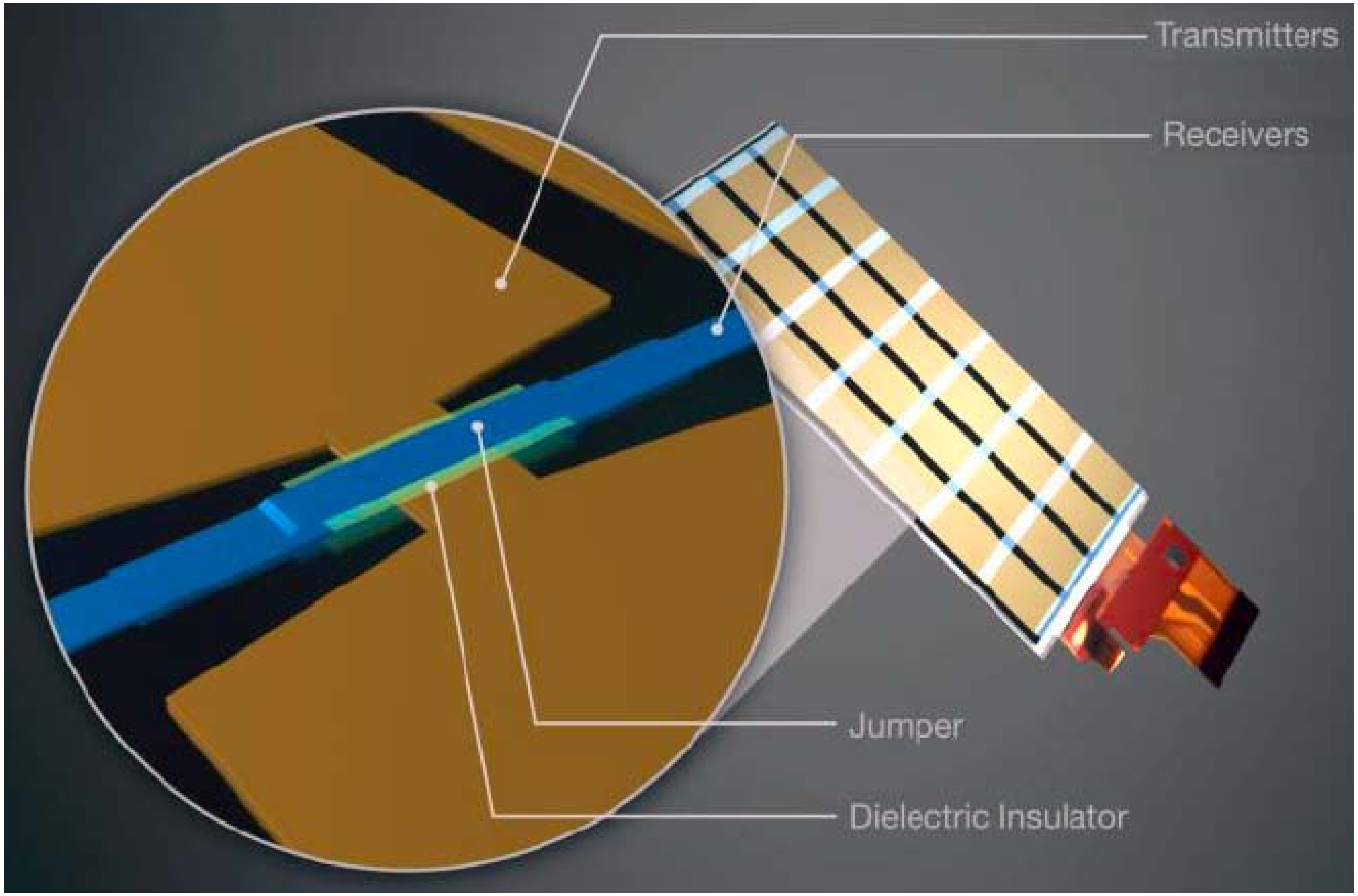
More On Mutual Capacitance…3

Mutual-Capacitive Advantages	Mutual-Capacitive Disadvantages
2 or more unambiguous touches	More complex, higher-cost controller
Higher immunity to LCD noise	2 layers (or 1 with bridges) for >3 pts
Higher touch accuracy	
More flexibility in pattern design	
Easier to maximize SNR	

- **Where it's used**
  - Mid & high-end smartphones, tablets, Ultrabooks, AiOs, commercial products
    - Standalone self-capacitive is becoming increasingly rare in consumer electronics (except for buttons)
  - With "true single-layer" sensors in low-end smartphones

Mutual Capacitance Electrode Patterns…3

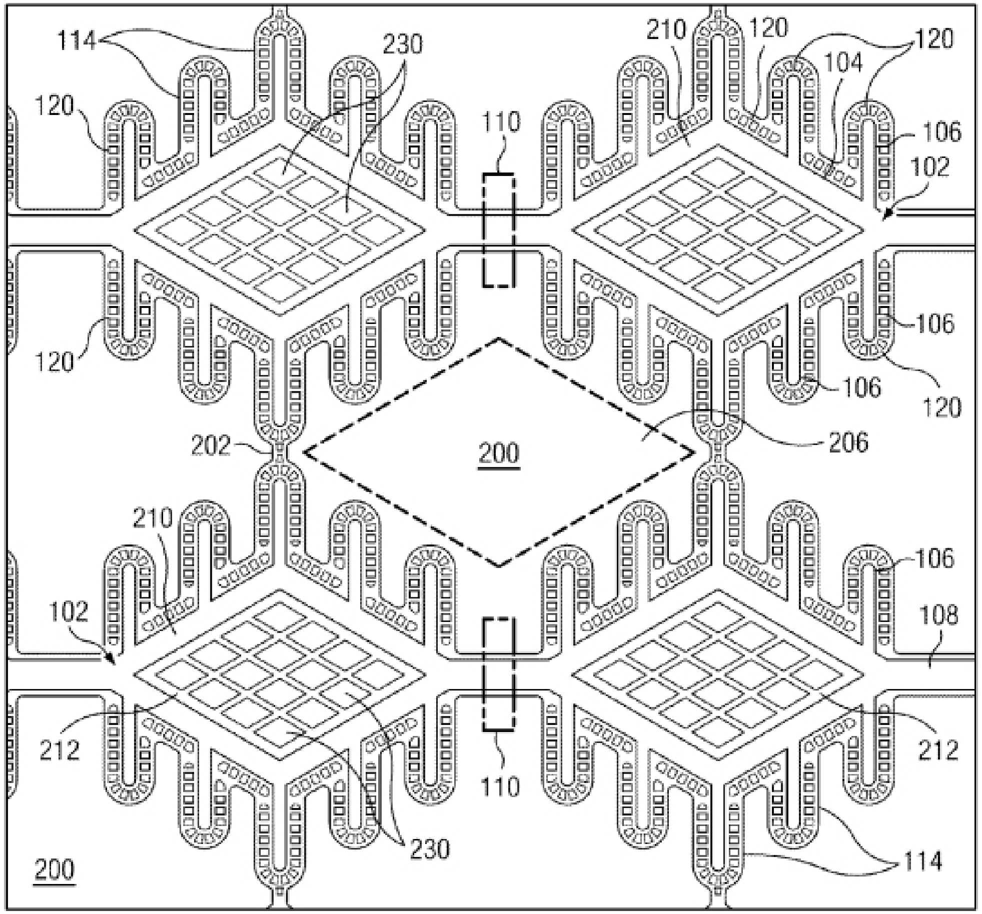
❖ **Bars & stripes require bridges too…**



Source: Synaptics

Mutual Capacitance Electrode Patterns…4

- And so does this unusual diamond pattern…



Source: STMicro

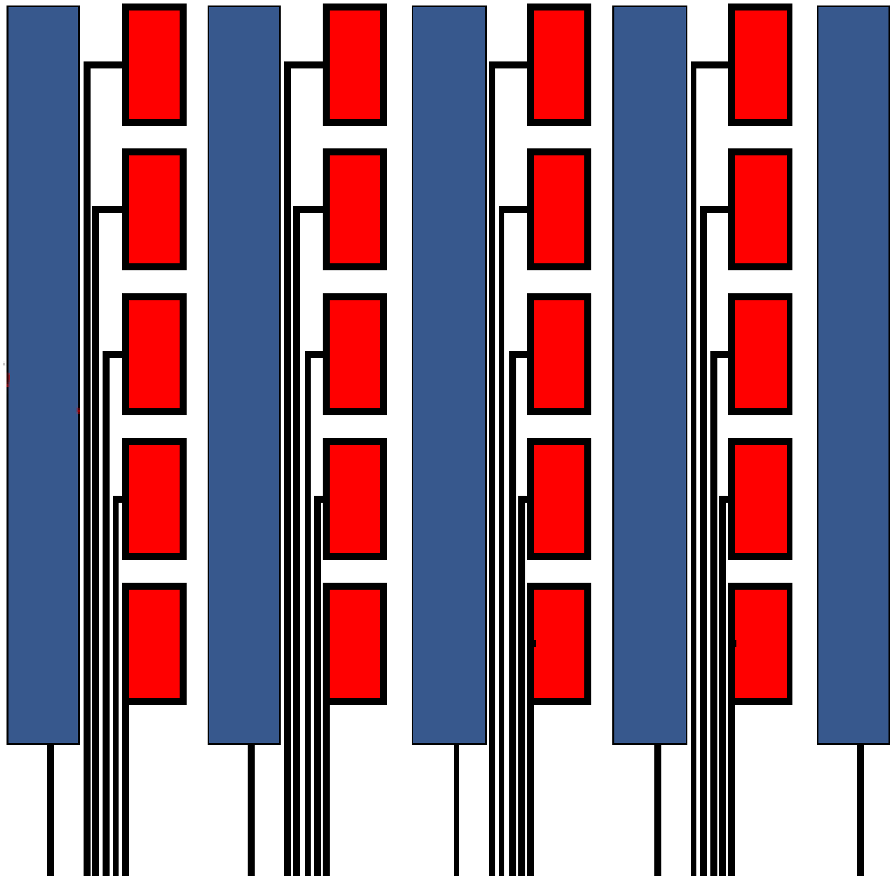
- 102, 106, 108, 210
  - Drive (X) electrodes
- 114 & 202
  - Sense (Y) electrodes
- 110
  - Bridges
- 120 & 230
  - Dummy (floating) ITO
- 200 & 206
  - Optional dummy ITO
- 212
  - Blank (no ITO)

Mutual Capacitance Electrode Patterns…5

- **Claimed advantages of this particular pattern over traditional interlocking diamond**
  - Reduction in sense electrode area reduces LCD noise pickup
  - "Finger projections" (0.1 – 0.2 mm) increase the perimeter of interaction between drive and sense electrodes, which increases sensitivity
  - Linearity is improved due to more uniform coupling across channels
  - Floating separators aid in increasing the fringing fields, which increases sensitivity

Mutual Capacitance Electrode Patterns…6

- **Holy Grail: True single-layer mutual capacitance sensor**

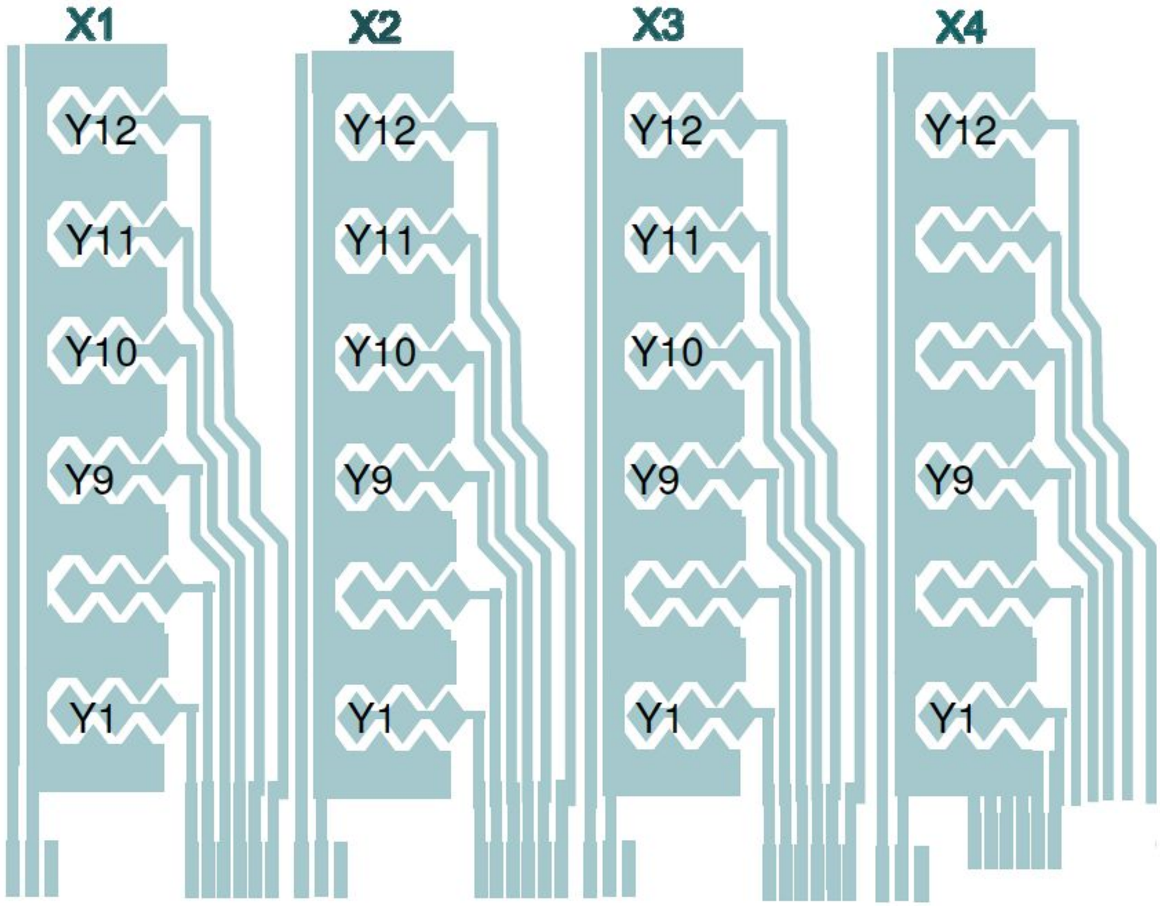


Source: Synaptics

- **"Caterpillar" pattern**
  - Everybody's single-layer patterns are proprietary
  - Requires fine patterning, low sheet resistance & low visibility
  - Benefits: Narrow borders, thin stack-ups, lower cost, can reliably handle 2-3 touches

Mutual Capacitance Electrode Patterns…7

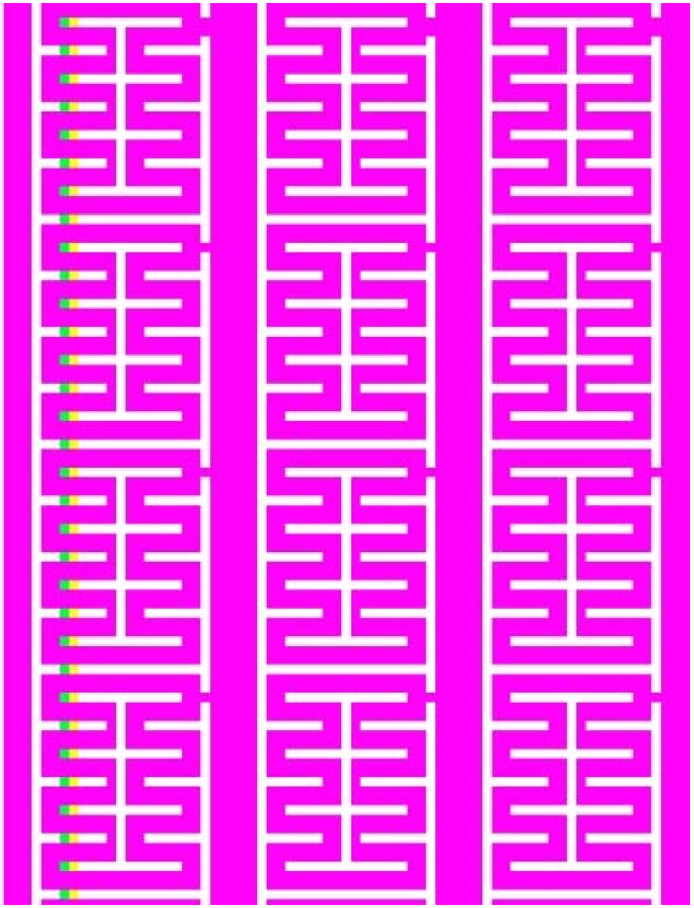
- ELAN's caterpillar pattern



Source: ELAN

Mutual Capacitance Electrode Patterns…8

- **An alternative true single-layer pattern from ELAN**
  - This is a very small portion of a much larger sensor

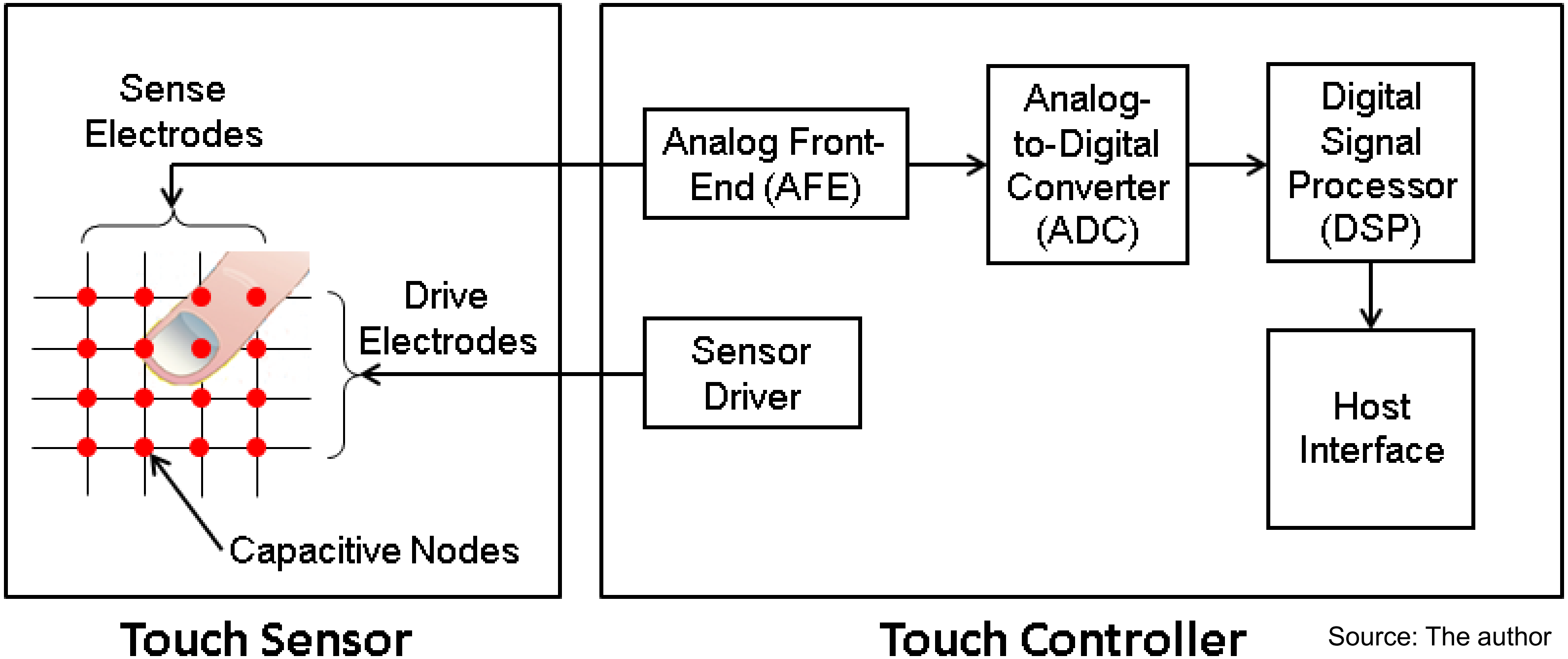


Source: ELAN

Controllers

- Architecture
- Touch Image Processing
- Key Characteristics
- Signal-to-Noise Ratio
- Noise Management
- Innovation Areas
- Suppliers

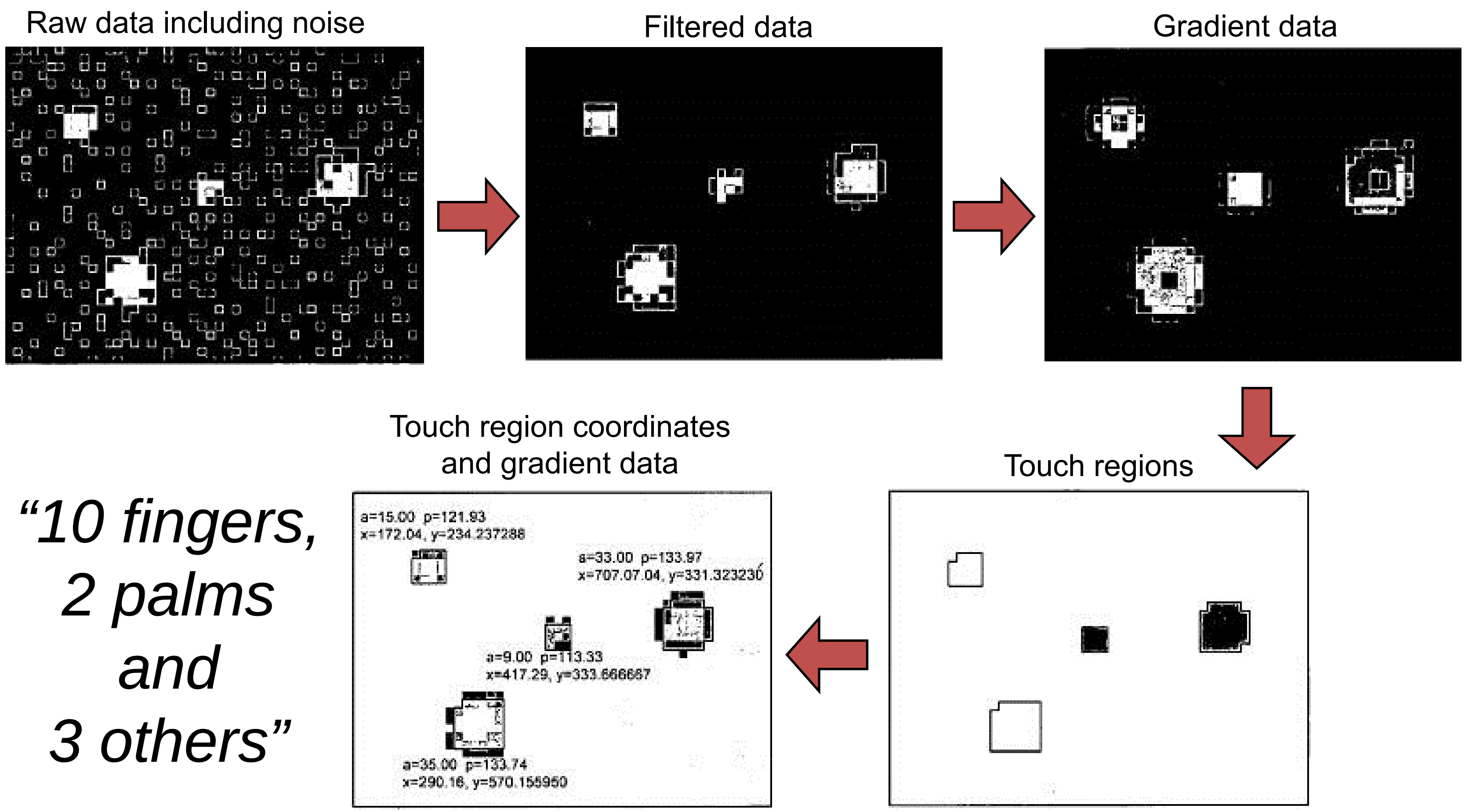
Mutual Capacitance Touch System Architecture



Source: The author

- Making X*Y measurements is OK, but it's better to measure the columns simultaneously
- Controllers can be ganged (operate in a master-slave relationship) for larger screens

Touch Image Processing



"10 fingers, 2 palms and 3 others"

Source: Apple Patent Application #2006/0097991

Key Controller Characteristics…1

- **Node count (x channels + y channels)**
  - Given typical electrode spacing of 4.5 to 5 mm, this determines how large a touchscreen the controller can support (w/o ganging)
- **Scan rate**
  - Frames per second (fps) – faster reduces latency for a better UX
  - Windows logo requires 100 fps; Android is unspecified
- **Signal-to-noise ratio (SNR)**
  - More info on upcoming slides
- **Operating voltage & current**
  - OEMs continue to request lower-power touchscreen systems
  - Win8 “Connected Standby” is a significant influence
- **Internal core (micro/DSP)**
  - Varies from small 8-bit micro to ARM-7 or higher

Key Controller Characteristics…2

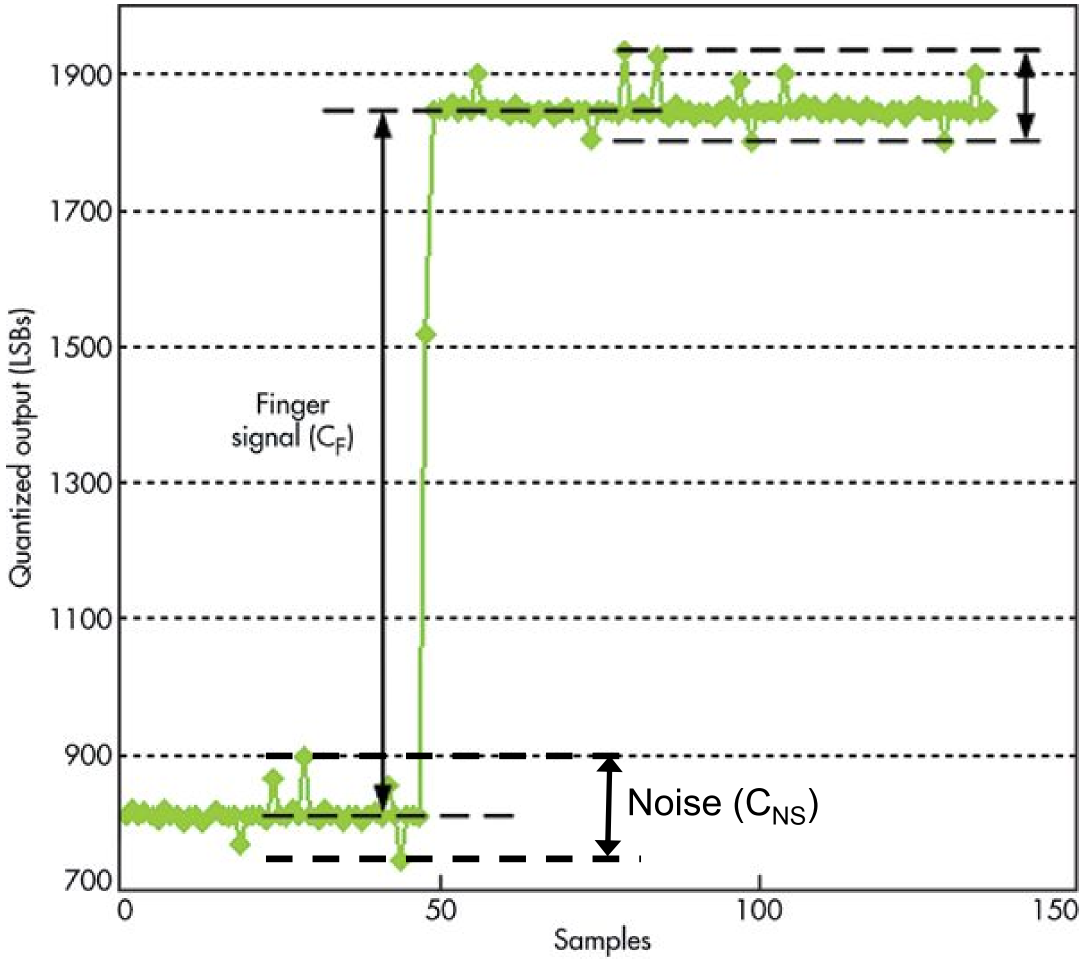
- **Number of simultaneous touches**
  - Windows Logo requires 5 (except AiO = 2); Android is unspecified
  - Market trend is 10 for tablets and notebooks
- **Support for unintended touches**
  - "Palm rejection", "grip suppression", etc.
  - Rarely specified, but critically important
  - For a 22" screen, even 50 touches isn't too many in this regard
- **Amount of "tuning" required**
  - Never specified – more info on upcoming slide

Signal-to-Noise Ratio (SNR)…1

- **SNR = Industry-standard performance metric for p-cap touchscreen systems**
  - However, no standard methodologies exist for measuring, calculating, and reporting SNR
  - The two components (signal & noise) depend heavily on the device under test
- **Noise from displays (LCDs & OLEDs) and from USB chargers is spiky – it doesn't have a normal (Gaussian) distribution – and spikes create jitter**
  - Yet marketers typically specify SNR in the absence of noise, using the RMS noise (standard deviation) of analog-to-digital convertors (ADCs)
  - With Gaussian noise, you can multiply the RMS noise by 6 to calculate the peak-to-peak noise with 99.7% confidence

Signal-to-Noise Ratio (SNR)…2

❖ **Typical system (raw ADC data, no digital filters applied)**



Source: Cypress
(modified by the author)

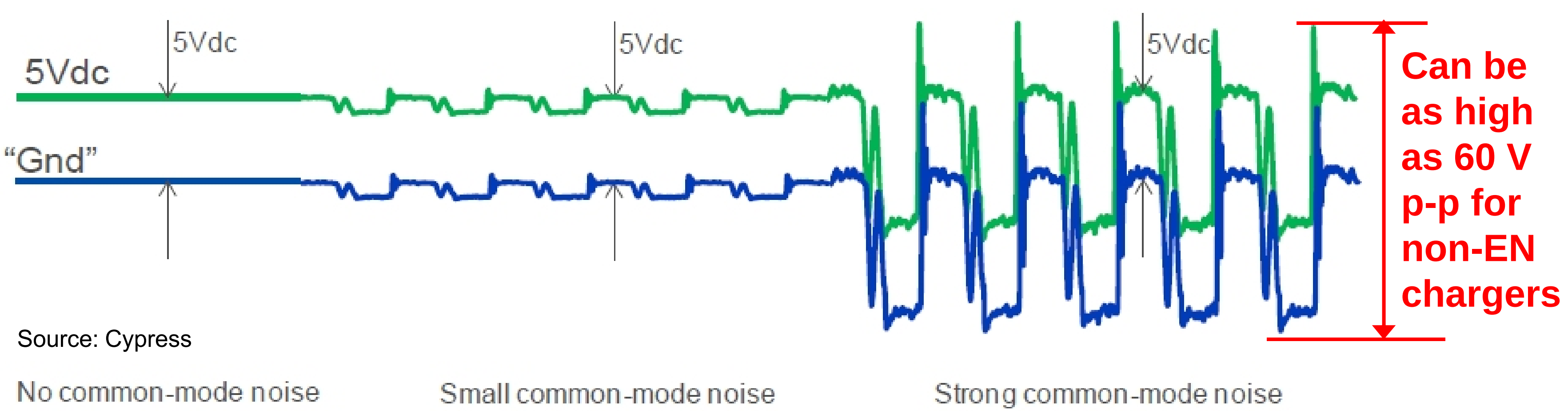
Signal-to-Noise Ratio (SNR)…3

- **SNR of system in previous slide**
  - C_{Finger} = Mean (Finger) - Mean (NoFinger)
  - C_{Finger} = 1850 - 813 = 1037
  - C_{NS} (Standard Deviation) = 20.6 counts
  - C_{NS} (Peak-to-Peak) = Max (NoFinger) - Min (NoFinger) +1
  - C_{NS} = 900 - 746 +1 = 155 counts
  - SNR (Peak-to-Peak) = 1037/155 = **6.7**
  - SNR (Standard Deviation) = 1037/20.6 = **49.9**
  - Highest SNR currently reported by marketer = 70 dB (**3,162***)

* Signal amplitude ratio in dB = $20\log_{10}(A_1 / A_0)$

Noise Management…1

- **Charger noise is common-mode**
  - A smartphone on a desk (not handheld) isn't grounded, so the entire phone moves relative to earth ground as it follows the noise
  - A touching finger provides an alternative path to ground, which is equivalent to injecting the noise at the finger location
  - The noise signal can be 10X to 100X that of the signal generated by the touching finger

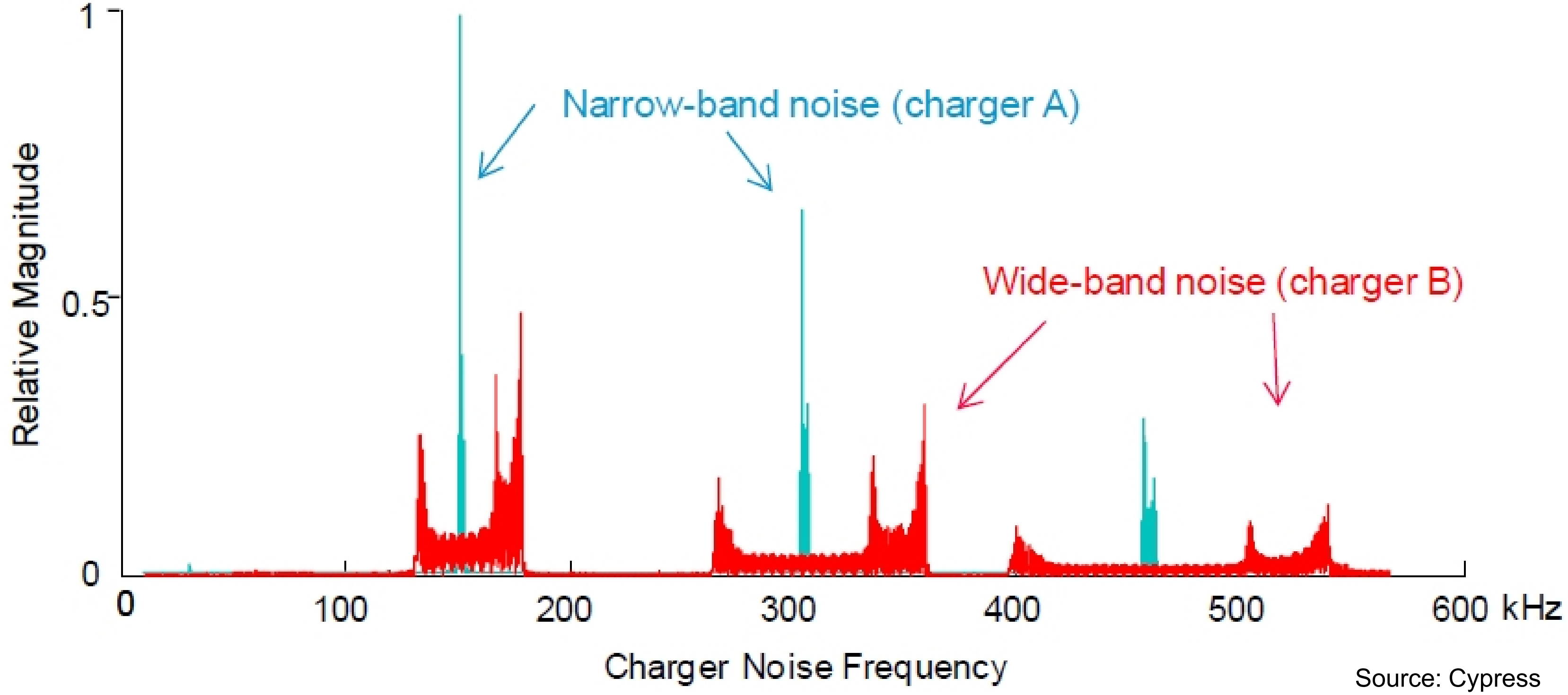


Source: Cypress

Noise Management…2

❖ Examples of charger noise spectra

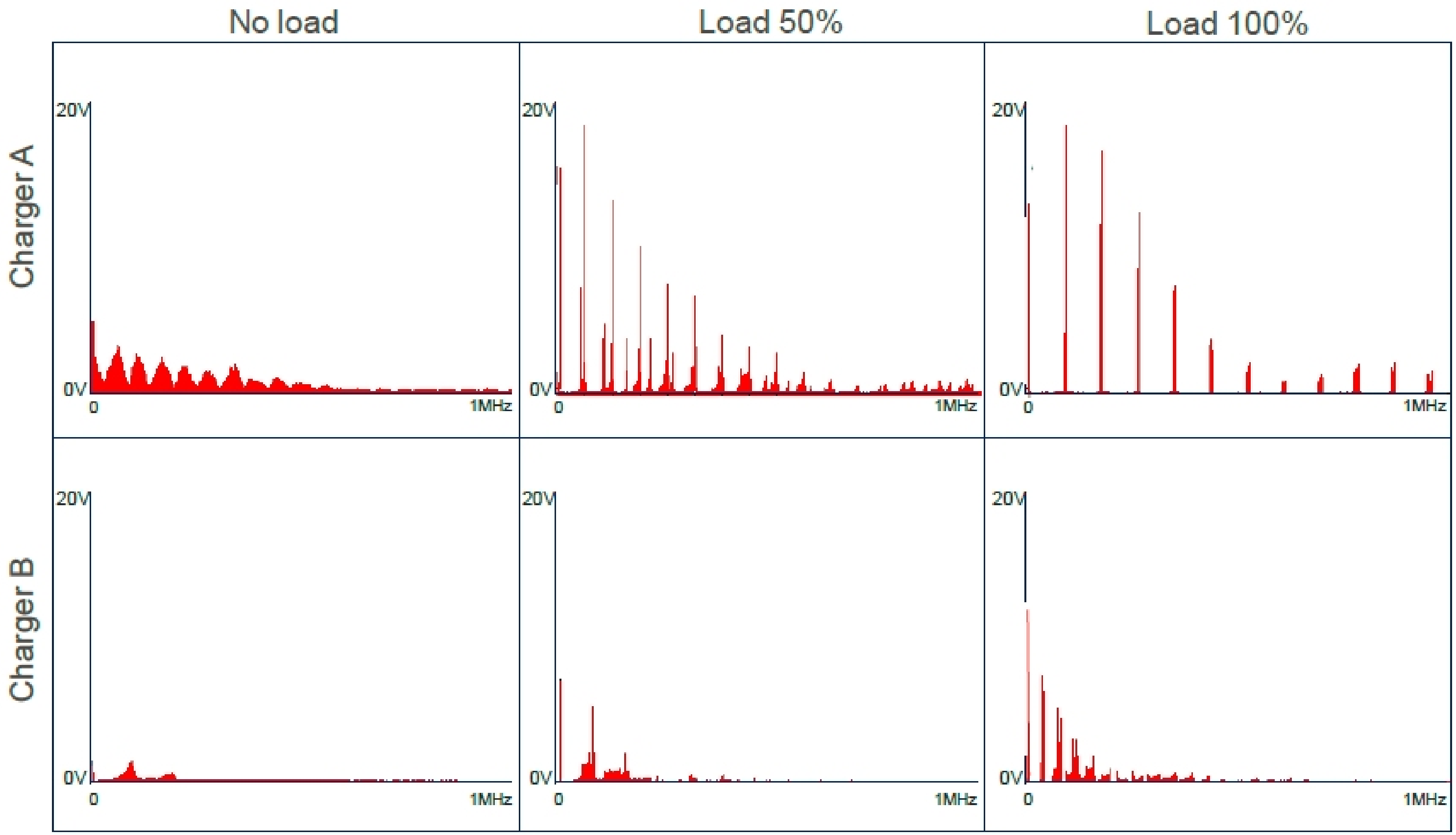
- ✦ Effect of noise is false or no touches, or excessive jitter



Source: Cypress

Noise Management…3

- Variation in common-mode noise spectra in 2 different chargers at 3 different loads



Source: Cypress

Noise Management…4

- **Techniques to combat charger noise**
  - Multiple linear and non-linear filters
  - Adaptive selection of the best operating frequency (hopping)
  - Increased drive-electrode voltage
    - Going from 2.7 V to 10 V increases SNR by 4X
  - Many proprietary methods

- **Display noise**
  - LCD noise is similar across the display; the high correlation of noise signals across all sensor signals allows relatively easy removal
  - Very high noise in embedded touch can require synchronization of the touch controller with the LCD driver (TCON)

Controller Innovation Areas

- **More information in upcoming slides**
  - Finger-hover
  - Glove-touch
  - Pressure sensing
  - Other touch-objects
  - Faster response (reduced latency)
  - Adaptive behavior
  - Water resistance
  - Software integration
  - Automated tuning

- **More information later in this course**
  - Passive and active stylus support

Finger-Hover…1

- **There are two ways of emulating “mouseover” on a p-cap touchscreen**
  - Hover over something to see it change, then touch to select
  - Press lightly on something to see it change, then press harder to select
- **The industry is moving towards hover because nobody has been able to implement pressure-sensing in a way that works well and that OEMs are willing to implement**
  - Startup: **NextInput**
    - Force-sensing using an array of organic transistors where pressure changes the gate current
  - Startup: **zRRo**
    - Multi-finger hover detection

Finger-Hover…2

- **What can you do with hover?**
  - Enlarge small links when you hover over them
  - Make a passive stylus seem to hover like an active stylus
  - Magnify an onscreen-keyboard key as you approach rather than after you've touched it, or even use a "Swipe" keyboard without touching it
  - Preview interactive objects such as an array of thumbnails
  - Use as an alternative to standard proximity detection
  - Use multi-finger gestures for more complex operations
  - And more…

Glove-Touch

- **Can be accomplished by adding self-capacitive to existing mutual-capacitive**
  - Mutual-capacitive provides touch location
  - Self-capacitive provides proximity sensing
  - Glove-touch causes the finger to remain a constant distance above the screen; proximity sensing can detect that without the user manually switching modes

Source: ELAN

Pressure Sensing

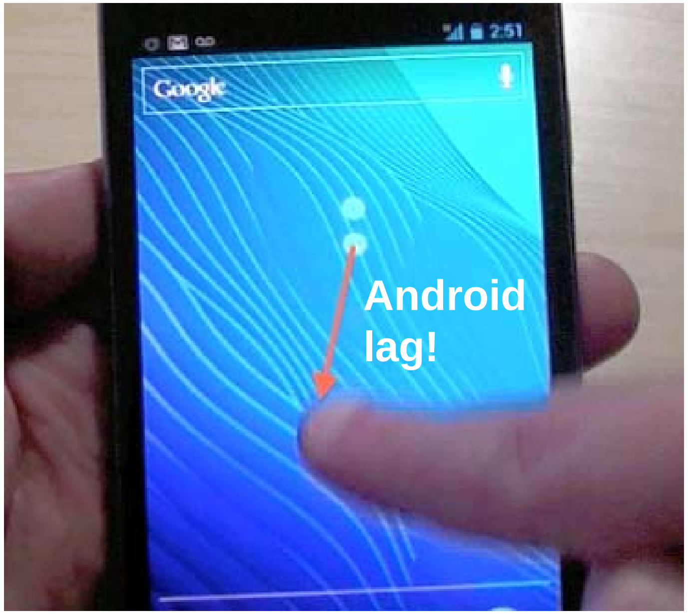
- **Pressure-sensing is an alternative selection method**
  - True absolute pressure-sensing in p-cap doesn't exist today
  - Some (including Microsoft) believe that "*touch lightly to view choices then press to select*" is more intuitive than hover
    - It has never been implemented successfully in a mobile device
      - Blackberry Storm (2 models!) failed due to terrible implementation
      - Nissha/Peratech (QTC) collaboration never made it into mass-production
  - Multiple startups are working on smartphone pressure-sensing
    - **NextInput**
      - Uses an array of pressure-sensitive organic transistors under the LCD
    - **FloatingTouch**
      - Mounts the LCD on pressure-sensing capacitors made using a 3M material

Other Touch Objects

- **You will soon be able to touch with a <u>fine-tipped</u> (2 mm) passive stylus, long fingernails, a ballpoint pen, a #2 pencil, and maybe other objects**
  - This is being accomplished through higher signal-to-noise (SNR) ratios
    - Much of this improvement may come from enhancing the controller <u>analog front-end</u> in addition to focusing on the digital algorithms
  - This enhancement to the UX will be the end of "finger-only" p-cap

Faster Response

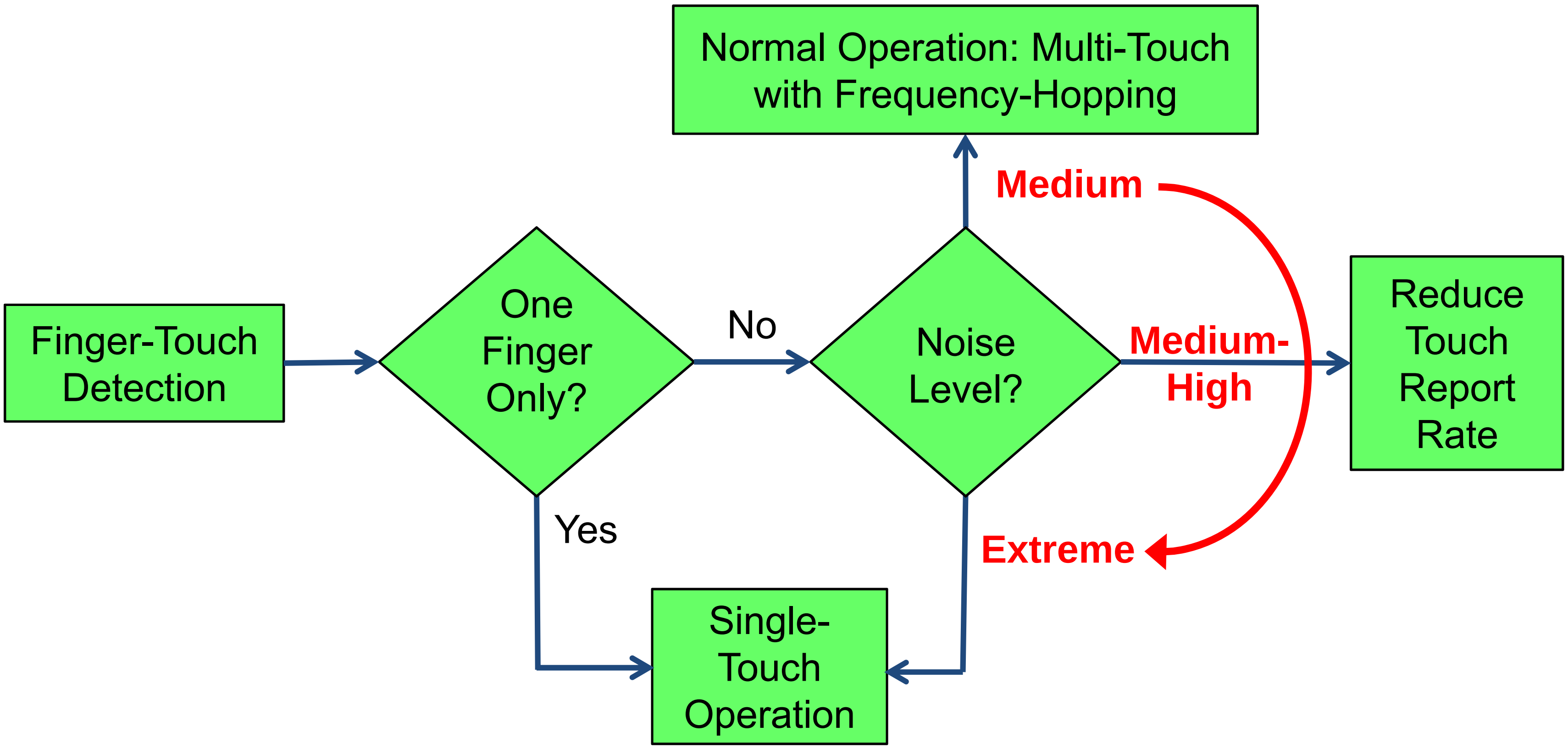
- **Make touch more natural by reducing latency**
  - The shorter the time is between a touch and the response, the better the user feels about the touch system
    - If an object lags behind your finger when you drag it, or ink lags behind a stylus when you're drawing, it doesn't feel real
  - Latency today is typically 75-100 ms; studies have shown that humans need less than 10 ms for comfort
    - Synaptics has addressed the problem by creating a direct path between the touch controller and the TCON to allow limited instant screen updates
    - **Tactual Labs** (startup) has a method of reducing latency to just a few milliseconds



Source: Gigaom.com

Adaptive Behavior: Noise Immunity

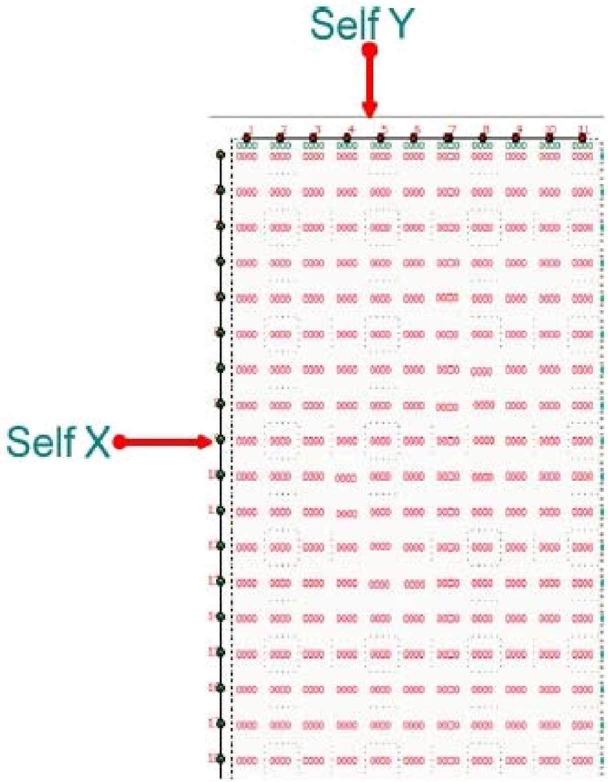
- Adaptive noise-management by N-Trig



Water Resistance…1

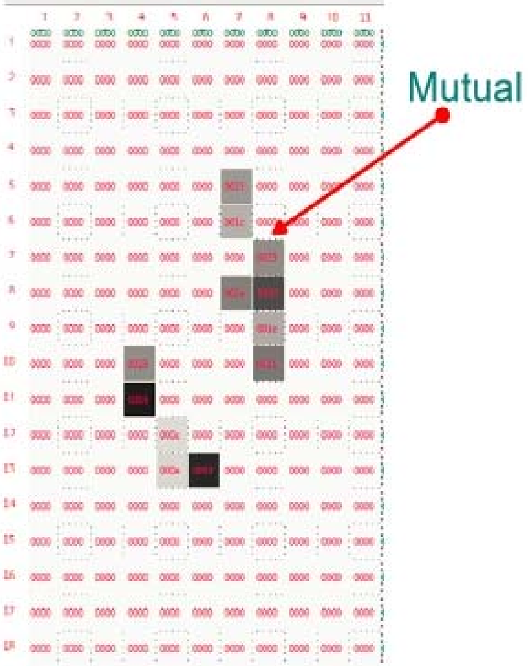
- The basic concept is combining self-capacitive and mutual-capacitive sensing (again)

Water drops on the screen



Water is not detected in self-capacitive mode

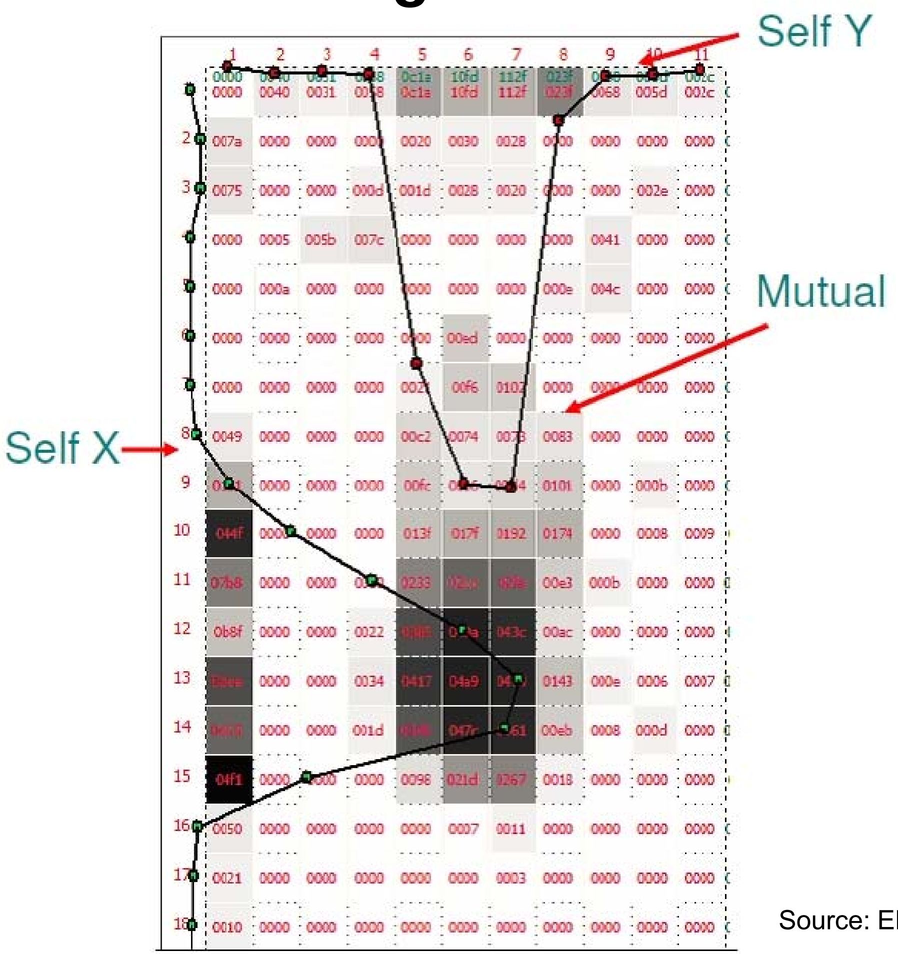
Source: ELAN



Water is detected in mutual-capacitive mode

Water Resistance…2

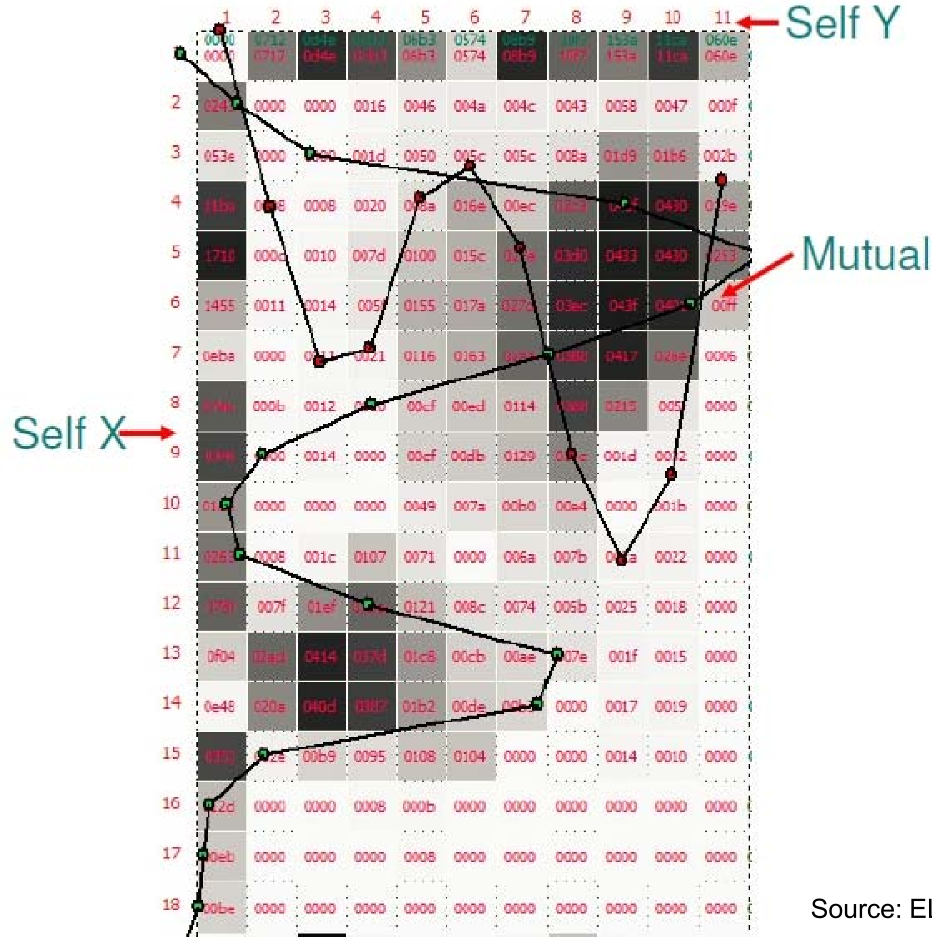
❖ **A large amount of water with single-touch**



Source: ELAN

Water Resistance…3

- **A large amount of water with two touches**



Source: ELAN

Software Integration

- **Make more resources available to the touch controller**
  - Run touch algorithms on the GPU instead of the controller micro
    - Algorithm-writers can take advantage of much larger resources on the host device (MIPS and memory)
      - This can support higher frame-rate, reduced latency, reduced power consumption, easier support of different sensor designs, etc.
    - Algorithmic code is easier and faster to change when it's in a "driver" than when it's in firmware in an ASIC
      - Most touch-controller suppliers never change the firmware in the touch controller once it ships in a device; N-Trig is the sole exception
    - Cost-reduction by elimination of one micro
      - Even more cost reduction for large screens by elimination of slave chips
  - Something similar to this has already been done in NVIDIA's "Direct Touch", but it hasn't been widely used in actual devices

Automated Tuning

- **For true "touch everywhere", p-cap has to become like resistive: Just slap it on and you're done**
  - We're far from that point today
  - Atmel says that the typical first integration of a p-cap touch-panel into a new product takes one full day of tweaking up to 200 individual parameters
  - That badly needs to be automated so that small commercial product-makers have easier access to p-cap

P-Cap Controller Suppliers

- **In order by estimated 2013 revenue**

Company	Country
Broadcom (Apple)	USA
Atmel	USA
Synaptics	USA
TI	USA
FocalTech	China & Taiwan
Melfas	Korea
Cypress	USA
Goodix	China
ELAN	Taiwan
Mstar	Taiwan
EETI	Taiwan
Zinitix	Korea
SiS	Taiwan
Ilitek	Taiwan
Imagis	Korea
Sentelic	Taiwan
Weida	Taiwan
Sitronix	Taiwan

Top 7 (30%) account for about 85% of total revenue

And a few others…

- AMT
- Avago
- Pixcir
- Silicon Labs
- STMicro
- Weltrend

Sensors

- Substrates
- Structures
- Sheet vs. Piece Method
- More on OGS
- Glass Strengthening
- Surface Treatments
- ITO Index Matching
- Suppliers

Sensor Substrates…1

- **ITO film substrates are usually PET[1] or COP[2]**
  - Thickness has dropped from 100 µm to 50 µm
  - Lowest practical ITO sheet resistivity is currently ~100 Ω/□
- **ITO glass substrates**
  - Standard thickness for GG is 0.33 mm and 0.4 mm
  - Some makers have developed a thinning process (like for LCDs) that reduces glass thickness to 0.2 mm
  - Corning and AGC have developed 0.1 mm glass but it hasn't been used in volume sensor production yet
  - Lowest practical ITO sheet resistivity on glass is ~50 Ω/□

1 = Polyethylene Terephthalate
2 = Cyclic Olefin Polymer

Sensor Substrates…2

- **PET film versus glass**

	PET	Glass
Glass Transition Temperature	70°C	570°C
Aging Effects	Yellowing, curling, surface deformation	No known effect
Transparency	85%	=>90%
Resolution Capability	10-30 μm	1 μm
Stackup	Thinner	Thicker
Weight	Lighter	Heavier
Moisture Resistance	Good	Excellent
Lamination Yield	Excellent	Good
Mechanical Strengthening	None	Chemical, heat, ion-exchange
Cost	$$ (was < glass)	$

Sensor Structures…1

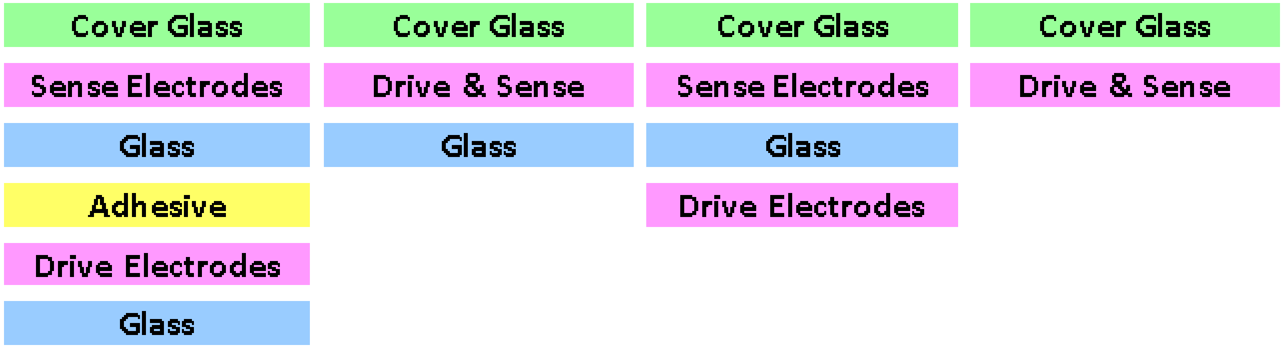
❖ Sensor structure abbreviations (for reference)

Symbol	Meaning
(G)	Cover-glass (or plastic or sapphire)
G	Cover-glass, or sensor-glass with ITO on one side, or plain glass for film lamination
GG	Cover-glass + one sensor-glass (without ITO location)
GGG	Cover-glass + two sheets of sensor-glass (rare)
G#	# = Number of ITO layers on one side of sensor-glass (G2 = "One Glass Solution" = OGS = SOC = SOL, etc.)
G1F	F = Sensor-film with ITO on one side, laminated to glass
GFF	FF = Two sensor-films, laminated to glass
GF#	1 = Two ITO layers on one side of sensor-film, laminated to glass (also called GF-Single) 2 = One ITO layer on each side of sensor-film, laminated to glass (also called GFxy with metal mesh)
SITO	ITO on one side of substrate (single-sided); usually includes metal bridges for Y to cross X
DITO	ITO on both sides of substrate (double-sided)
F1T	F1 = Single-sided sensor-film on top of CF glass; T = Transmit (drive) electrodes on TFT glass (LG Display's hybrid in-cell/on-cell)

Sensor Structures…2

Glass-only structures

Structure Names	GGG	GG or G-SITO	GG , G-DITO or G1G	OGS or SOC
Comments	Single ITO layer on each piece of glass; Obsolete	Single ITO layer with bridges	ITO layer on each side of 1 glass; or ITO on one side of 2 glass	Single ITO layer with bridges
Example Products	None	Kindle Fire, B&N Nook; Nokia Lumia 800	iPhone-1; iPad-1 (GG); Lenovo AiOs (G1G)	Google Nexus 4/7; Xiaomi 2; Nokia Lumia 920

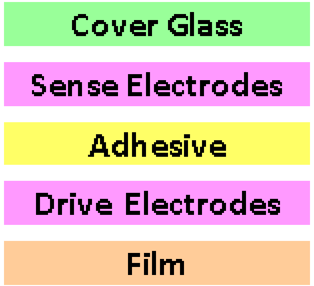


- SITO = Single-sided ITO layer; usually means there's a bridge
- DITO = Double-sided ITO layer (Apple patent)
- OGS = One Glass Solution (sensor on cover-glass)
- SSG = Simple Sensor Glass (OGS without cover-glass shaping & finishing)

Sensor Structures…3

❖ Glass-and-film structures

Structure Names	G1F
Comments	Single ITO layer on glass; single ITO layer on film
Example Products	Many Samsung products in 2013; Microsoft Surface RT



- Why would a touch-module maker use a sensor structure that requires having both glass- and film-handling equipment?
  - » One reason is that there was a shortage of ITO film in 2013

Sensor Structures…4

❖ Film-only structures

Structure Names	GFF	GF2 or DITO-Film	GF1	GF Triangle
Comments	Bare glass and two single-sided ITO films; performance is better than GF1	Bare glass and one double-sided ITO film	Bare glass with true single-layer complex pattern on film (e.g., “caterpillar”)	Bare glass with true single-layer triangle pattern on film (e.g., “backgammon”)
Example Products	Samsung Galaxy Tabs and Notes; Google Nexus 10	Apple iPads; next iPhone if Apple can’t get good yield on in-cell	Many low-end smartphones, especially in China	Low-end products with “gesture touch”, not multi-touch

GFF	GF2 or DITO-Film	GF1	GF Triangle
Cover Glass	Cover Glass	Cover Glass	Cover Glass
Sense Electrodes	Sense Electrodes	Drive & Sense	Sense Electrodes
Film	Film	Film	Film
Adhesive	Drive Electrodes		
Drive Electrodes			
Film			

- Single-layer caterpillar pattern is used to support “real” multi-touch with 2-3 touches, typically in a smartphone (that’s not enough touches for a tablet)
- Single-layer backgammon pattern is used to support “gesture touch” on low-end devices, i.e., the ability to detect pairs of moving fingers but not always resolve two stationary touches

Sensor Structures…5

- **Why do touch-module makers choose one structure over another?**
  - Transmissivity
  - Thickness & weight
  - Border width due to routing
  - Cost & availability of ITO film or deposition
  - Lamination experience & yields
  - Existing equipment and/or method experience

Sensor Structure by Application

Smartphones

Structure	Share
GFF	42%
OGS/G2	16%
GF1/Single-Layer	12%
GG SITO	11%
GF Triangle	5%
GG DITO	5%
G1F	4%
PF	3%
PFF	2%

Tablets & Notebooks

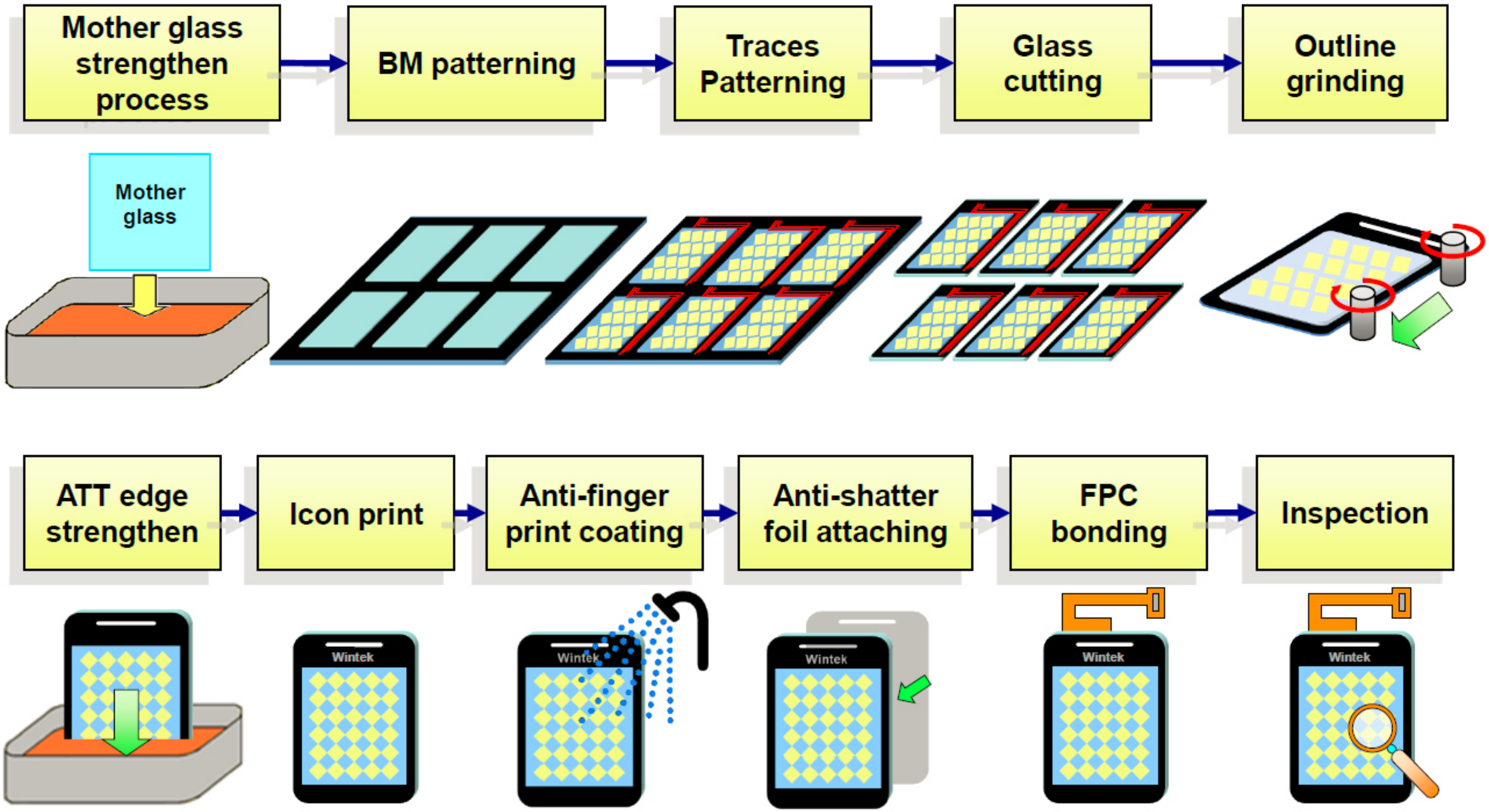
Structure	Share
GFF	44%
GF2/DITO Film	19%
OGS/G2	18%
GG DITO	11%
GG SITO	3%
G1F	2%
GF1/Single-Layer	1%
SSG	1%

All-in-Ones

Structure	Share
GG SITO	81%
GFF	13%
SSG	6%

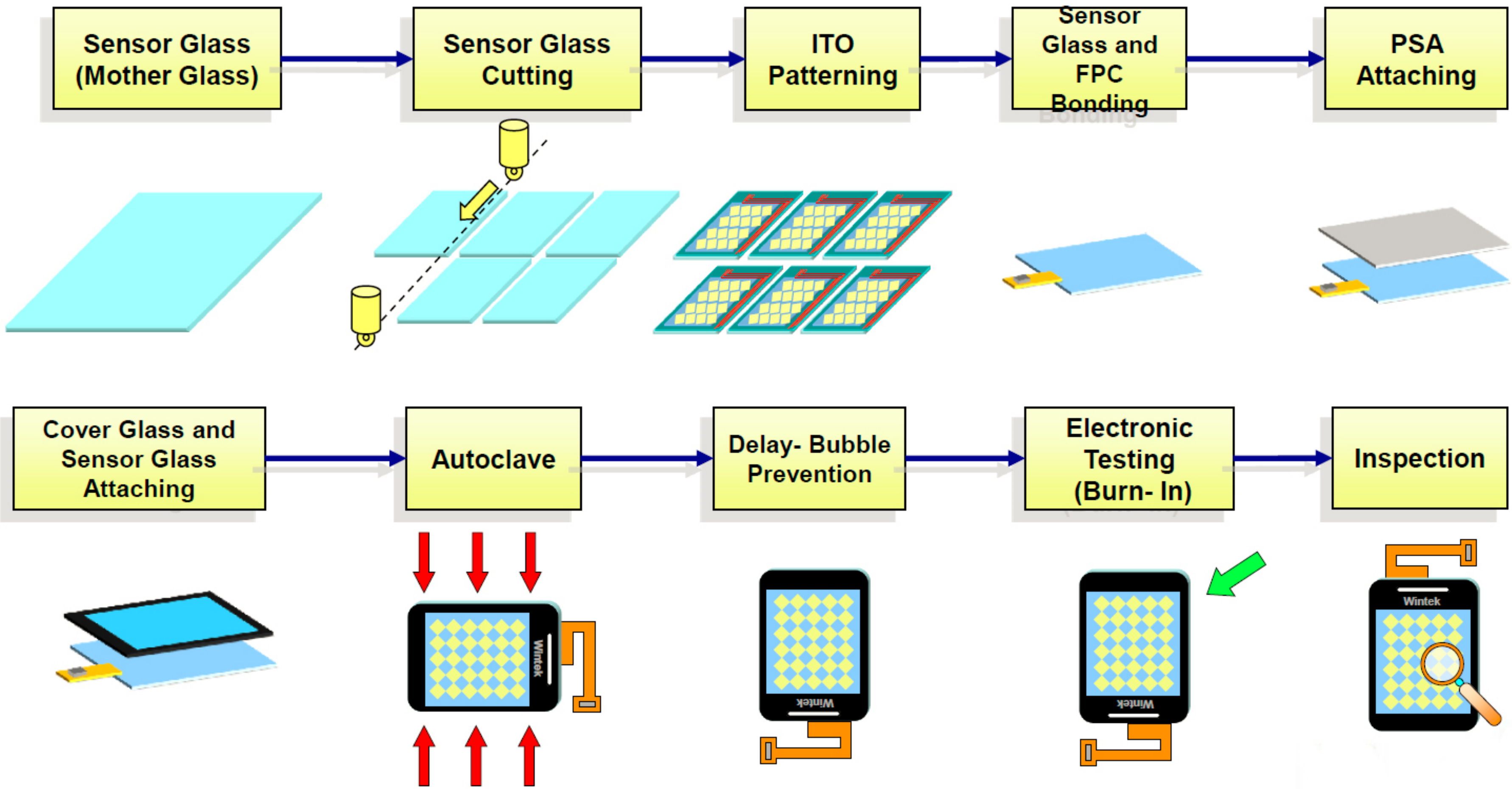
Data based on DisplaySearch's "Q1-2014 Quarterly Touch-Panel Market Analysis Report", with adjustments by the author

Sheet vs. Piece Method…1 (Wintek Sheet Example - OGS)



Source: Wintek

Sheet vs. Piece Method…2 (Wintek Piece Example - Discrete)



Source: Wintek

More On OGS

- **One-Glass Solution (OGS)**
  - Also called “touch on lens” (TOL), “sensor on cover” (SOC), “direct patterned window” (DPW) and <u>many</u> other names
  - Advantages
    - Eliminates a fourth sheet of glass (G-DITO), making the end-product thinner and lighter
    - Competitive weapon against embedded touch from LCD suppliers
  - Disadvantages
    - Requires close cooperation with cover-glass makers, or increased vertical integration (preferable)
    - Yields are lower (more complex operations)
    - Bendable cover glass can affect touch performance
    - Harder to shield touchscreen from LCD noise
  - **Note:** There is no generic name (yet) for touch sensors built on the cover-glass without direct ITO deposition (“OGS-type”)

Glass Strengthening

- **Heat strengthened**
  - Less-rigorous version of fully tempered; does not “dice” when broken; 2X as strong as standard glass
- **Fully tempered**
  - Uses heat; requires glass > 3 mm, so not used for consumer touchscreens; glass “dices” when broken (think auto windows); 4X to 6X as strong as standard glass
- **Chemical strengthened (CS)**
  - Uses ion-exchange in a salt bath; best for glass < 3mm; glass does NOT “dice” when broken; 6X to 8X as strong as standard glass
- **High ion-exchange aluminosilicate glass**
  - 6X to 8X as strong as standard glass (same as CS glass)
  - Corning Gorilla®, Asahi Dragontrail™, Schott Xensation™

Sensor Surface Treatments…1

- **Historically most common treatment is anti-glare (AG)**
  - Changes specular reflection into diffuse reflection
  - Used mostly for commercial & enterprise, not consumer (“glossy”)
  - Three methods, roughly equal cost
    - Chemical etching
    - Application of sol-gel containing silica particles
    - Mechanical abrasion
  - Level of anti-glare can be very little to a lot

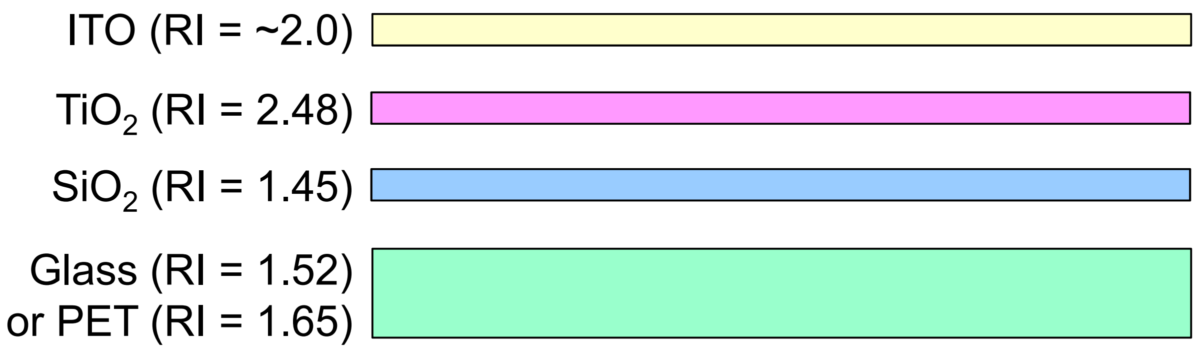
- **Anti-fingerprint (AF) treatment is rapidly growing**
  - Many different forms (spray-on, rub-on, sputter, etc.); also called “anti-smudge” (AS)
  - Demand is increasing
  - Cost is dropping (currently ~\$8.50/m^2)

Sensor Surface Treatments…2

- **Anti-reflection (AR) treatment is still a problem**
  - Reduces specular reflection to range of 2% to 0.4%
  - Durability is typically < 1 year
  - It's expensive (currently ~$34.50/m^2)
  - Yet it's really important for outdoor viewing, particularly of consumers' glossy screens (ideal is AF+AR = ~$43/m^2)
- **Other coatings are available but less common**
  - Anti-corruption (allows permanent Sharpie ink to be wiped off)
  - Anti-microbial/anti-bacterial (AM/AB, for healthcare applications)
  - Hard coating (can be made up to 9H for glass-like anti-scratch)
  - Anti-stiction (reduces finger-sticking friction)
  - Anti-crack coating (increases durability at lower cost than Gorilla glass; uses atomic layer deposition [ALD])

ITO Refractive-Index Matching

- **Reduce the reflectivity of ITO by compensating for the difference in index of refraction of ITO vs. glass/PET**
- **Limited to 2 layers on PET; more can be used on glass**
  - Alternating layers of material with low and high refractive index
  - Layer thicknesses (typically between ¼ and ½ of the wavelength of light) are chosen to produce destructive interference in reflected light, and constructive interference in transmitted light



Source: The author

Sensor Suppliers

- **Many touch-module makers manufacture their own sensors**
  - The remainder are made by the following companies, in order by estimated 2013 revenue

Company	Country
Nissha Printing	Japan
HannsTouch	Taiwan
Dongwoo Fine Chemical	Korea
Cando	Taiwan
Innolux	Taiwan
CSG	China
Token	China
CPT	Taiwan
DNP	Japan
Young Fast	Taiwan
AimCore	Taiwan

And at least one more…

- Laibao (China)

ITO-Replacement Materials

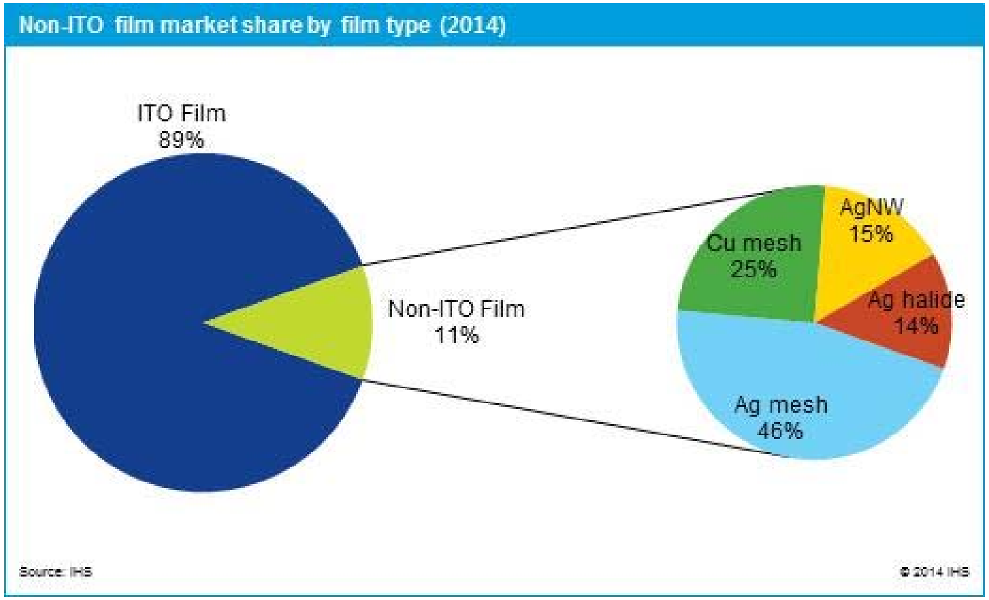
- ITO
- Metal Mesh
- Silver Nanowires
- Carbon Nanotubes
- Conductive Polymers
- Graphene
- Summary

ITO Replacements…1

- **Why replace ITO?**
  - **Costly to pattern & needs high temperature processing**
  - Highly reflective (IR = 2.6) & tinted yellow; brittle & inflexible
  - **NOT** because we're going to run out of it!
- **Replacement material objectives**
  - **Solution processing (no vacuum, no converted LCD fab)**
  - <u>Better performance</u> than ITO (transmissivity & resistivity)
  - <u>Lower material & process cost</u> than ITO
- **Five replacement candidates**
  - Metal mesh
  - Silver nanowires
  - Carbon nanotubes
  - Conductive polymers
  - Graphene

ITO Replacements…2

- **ITO-replacement materials are having a definite market impact – 11% in 2014!**
  - See the latest IHS market report on non-ITO films

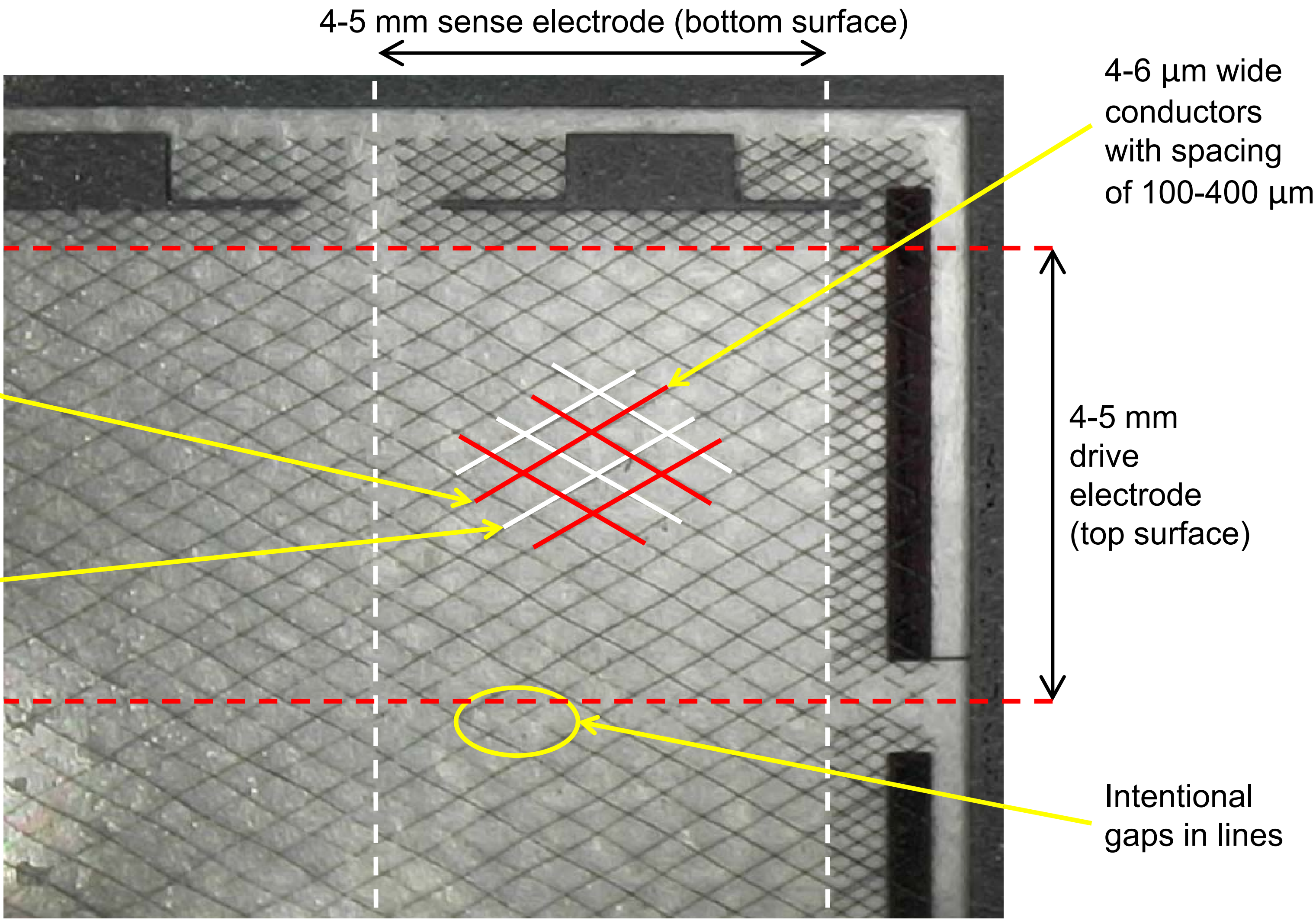


  - Ag halide is simply another method of making a silver mesh, so the mesh total is 85% vs. 15% for nanowire
  - The value is performance and cost
    - Both unit cost and CAPEX

Metal Mesh…1

- **Metal mesh is shipping in touchscreens, and it's looking very promising!**
- **Brief history of first-movers**
  - **MNTech** in Korea was the first to ship metal-mesh at the end of 2012 – but their factory burned down
  - **Atmel** (partnered with CIT in the UK) was the second to ship metal-mesh (XSense™) for a smartphone and a 7" tablet in 1H-2013
  - **FujiFilm** started production of their silver-halide-based metal-mesh product in 2Q-2013

Metal Mesh…2



Source: Photo by Unipixel, annotation by the author

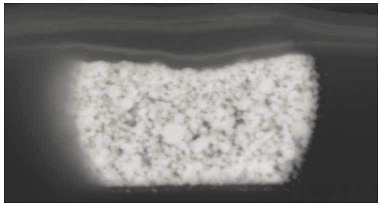
Metal Mesh…3

- **Metal mesh has significant advantages**
  - Patterning via roll-to-roll printing allows both operating and capex cost to be very low – it's going to beat both litho and laser!
    - Electrodes and border connections are printed simultaneously, which allows borders as narrow as 3 mm (typically 9 mm with ITO)
  - Sheet resistivity is much lower than ITO (**under 10 ohms/square**)
    - Reduces p-cap charge time, which allows larger touchscreens
  - Transparency is better than ITO
  - Mesh pattern creates electrical redundancy, which improves yields
  - Highly flexible – bend radius typically 4 mm

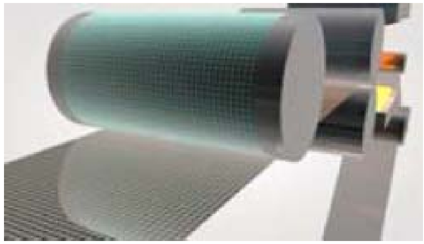
Metal Mesh…4

- **O-film is the "800-pound gorilla" of metal mesh!**
  - Largest touch-module maker in China, #3 globally
  - Like "the TPK of film"; innovative and aggressive
- **New roll-to-roll printing method**
  - "Hybrid printing" or "micro-imprinting"

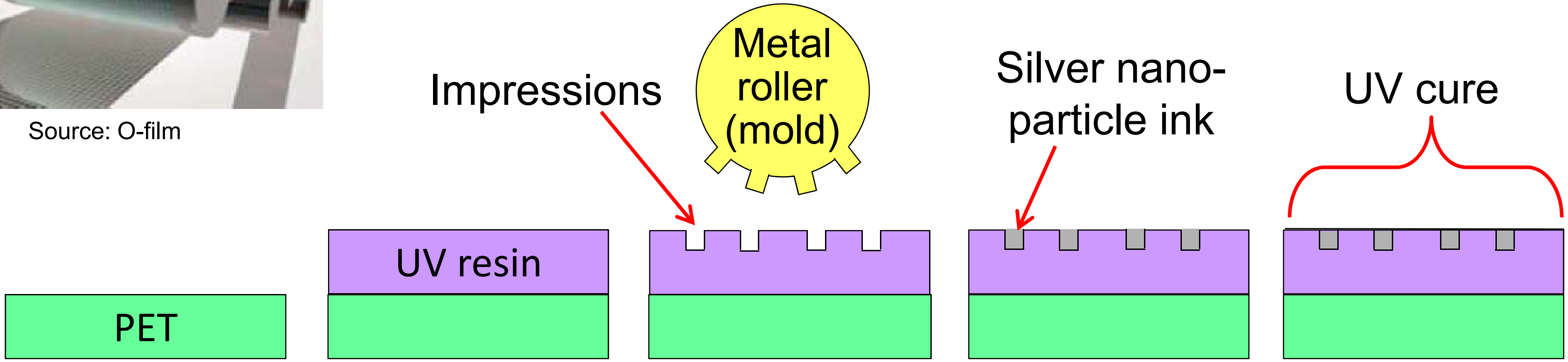
Source: O-film



Cross-section of embedded metal line



Source: O-film

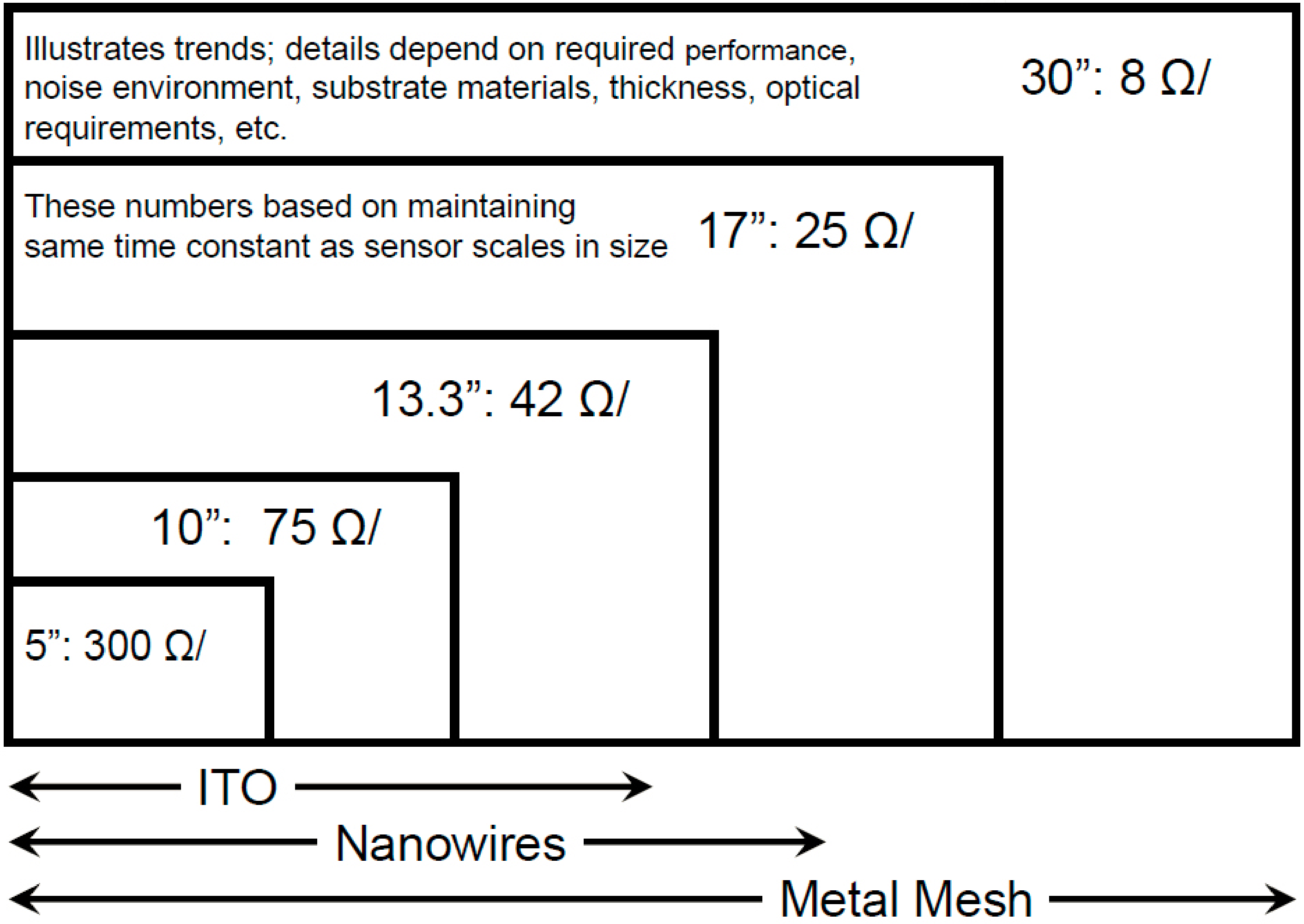


Source: The author

Metal Mesh…5

- **O-film technical details**
  - Additive process with little waste
  - **< 2 µm line width**
  - < 10 Ω/□
  - Randomized mesh design (one method of eliminating moirés)
  - Top surface of embedded metal line is blackened & sealed
  - Embedded metal reduces haze and eliminates peel-off
  - Producing > 1.5M touch sensors per month (size not stated)
- **O-film's success makes visible a developing aspect of the ITO-replacement business**
  - A vertically-integrated sensor & module-maker is in a much better position to profit from ITO-replacements than a film-only supplier, or (even worse), an ink-only supplier

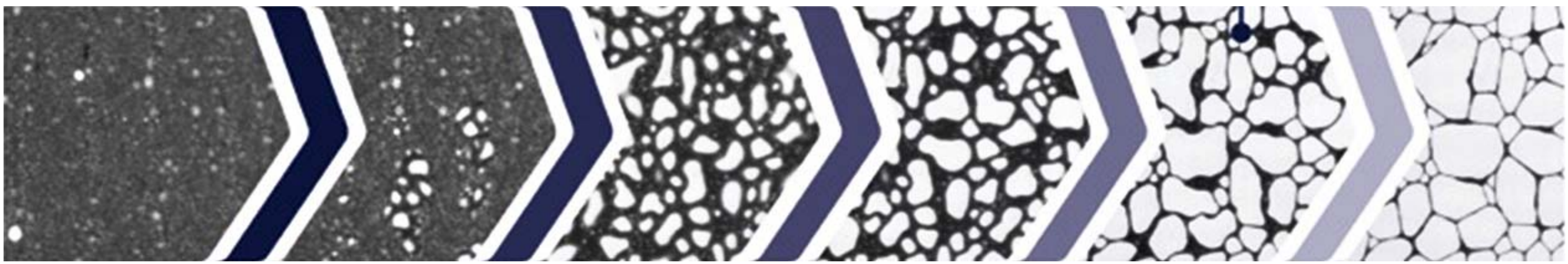
Synaptics' Opinion of Sheet Resistivity Requirements



Source: Synaptics (unmodified)

An Interesting Variation on Silver Mesh…1

- **Cima NanoTech**
  - "Self-assembling" silver mesh
  - Starts with an opaque liquid coated on film with standard equipment
  - 30 seconds later it dries into a random-pattern silver mesh



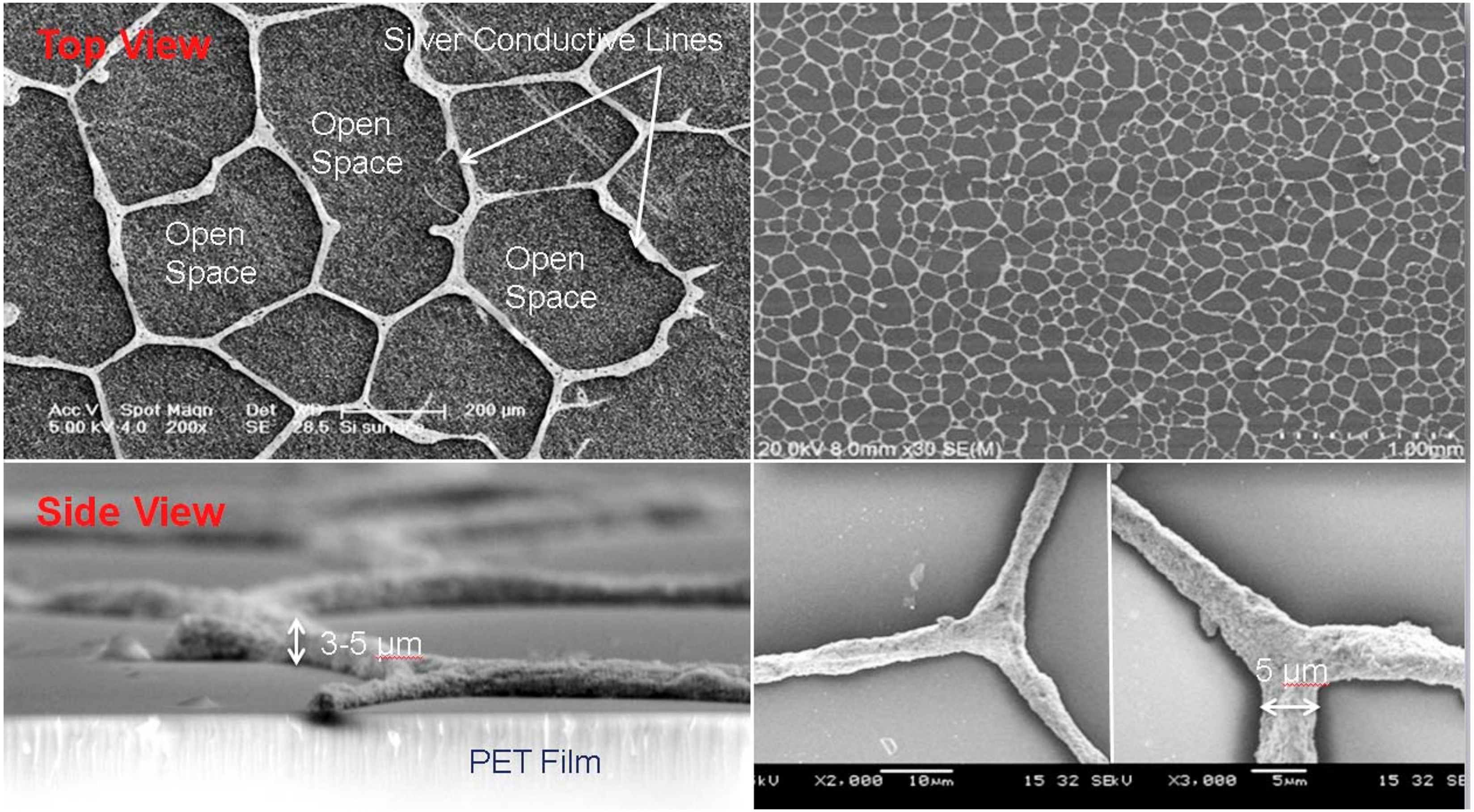
Drying sequence

Source: Cima NanoTech

  - **Pros:** Simple, standard wet-coating process; no moiré (due to randomness); very good for large-format touch
  - **Cons:** It's just a uniformly-coated film that must be patterned with a laser or other method

An Interesting Variation on Silver Mesh…2

❖ **Cima NanoTech continued…**



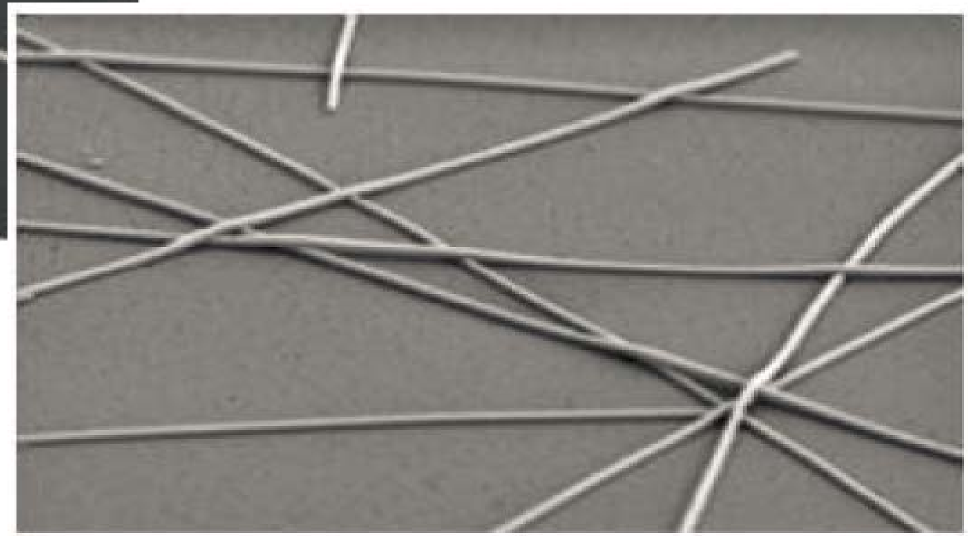
Source: Cima NanoTech

Silver Nanowires…1

- **Cambrios is the first-mover and clear leader**
  - Other suppliers include Carestream, Blue Nano, Poly IC, etc.

Plan view

70° view

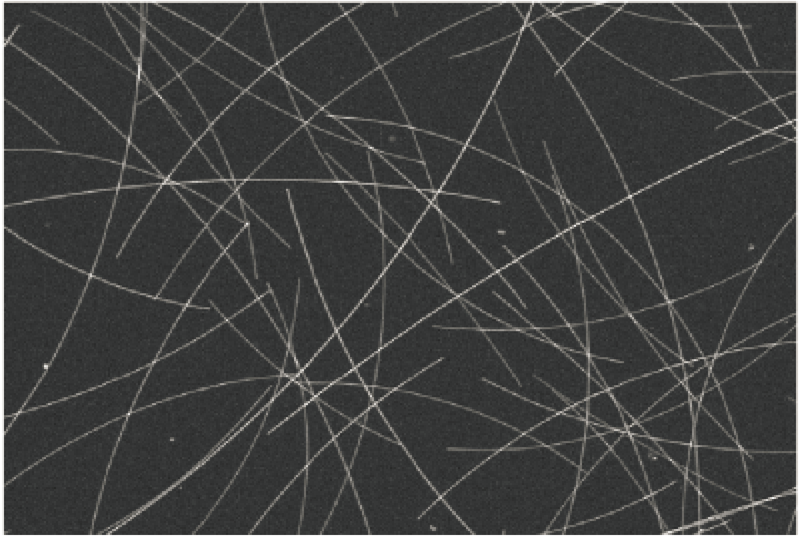


Source: Cambrios

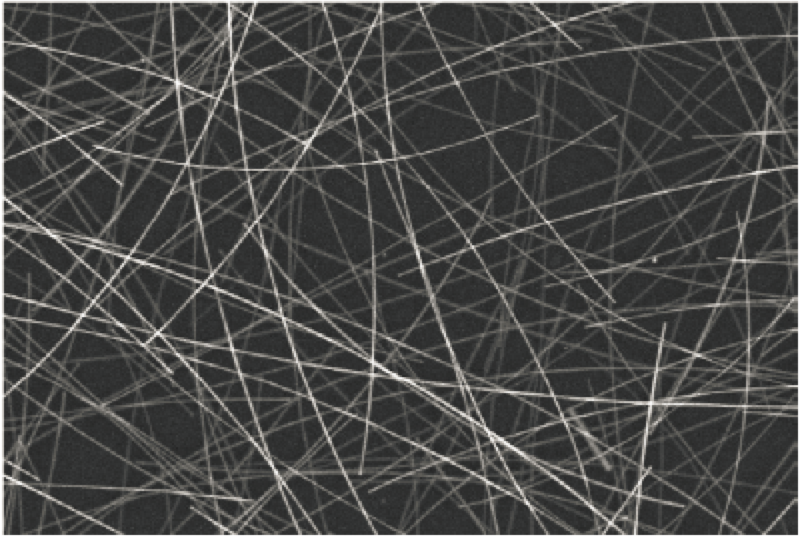
Silver Nanowires…2

- Density determines sheet resistance, independent of coating throughput

70 Ω/□



9 Ω/□



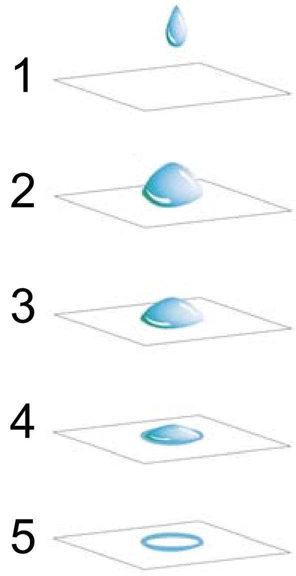
Source: Cambrios

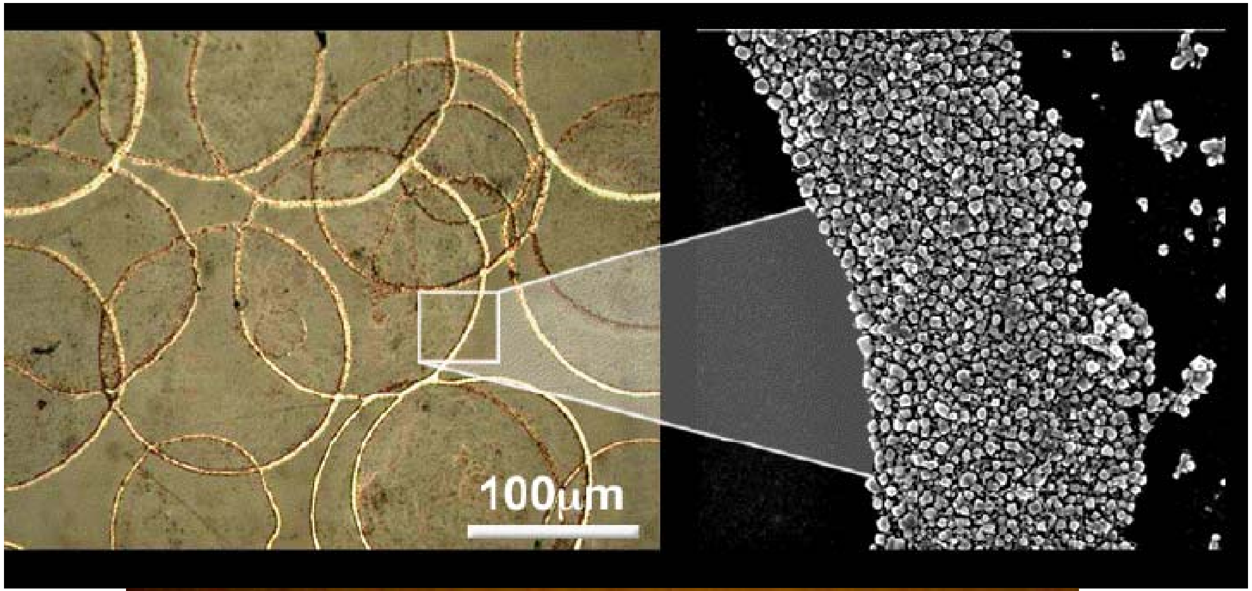
Silver Nanowires…3

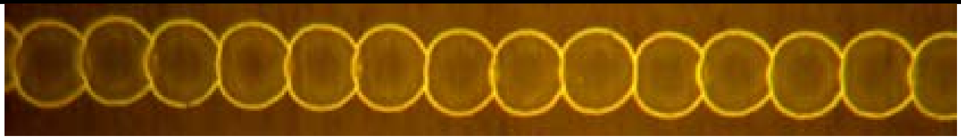
- **Advantages**
  - High conductivity (10 Ω/□ at 94% transmission)
  - High transparency
  - Can be spin-coated or slit-coated (printing is under development)
    - TPK + Cambrios + Nissha joint venture
  - Nano-scale, so no visibility or moiré issues
  - Shipping in products from phones to all-in-ones
    - Same sensor for different pixel densities (unlike metal-mesh)
  - Established supply chain
    - Film makers: Okura, Hitachi Chemical, Toray, DIC, ShinEtsu, LGE, etc.
    - Module makers: eTurboTouch, LGE, Nissha, CNi, ShinEtsu, etc.
- **Disadvantages**
  - Increased haze at < 30 Ω/□
  - Cambrios’ positioning as an ink supplier (far down the food chain)

An Interesting Variation on Silver Nano-Particles

- **ClearJet (Israel)**
  - Inkjet-printing silver nano-particle drops < 10 μm thick
  - Ink dries from center outward, leaving "coffee rings" ~100 μm
  - 95% transparency, 4 ohms/square resistivity



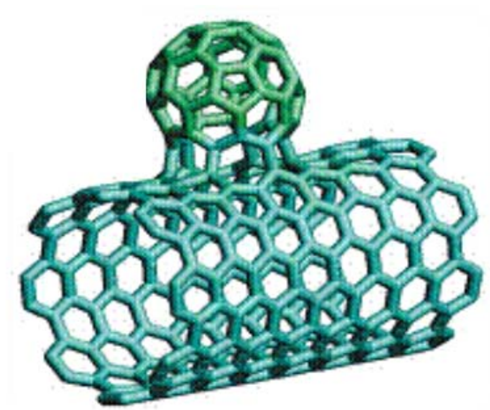


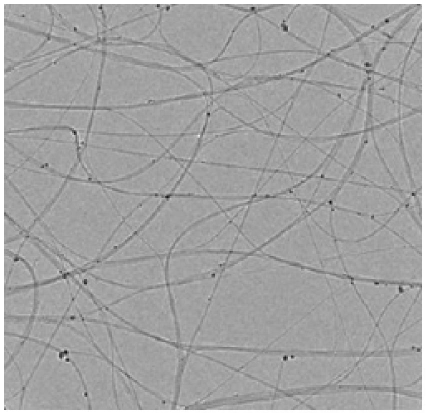


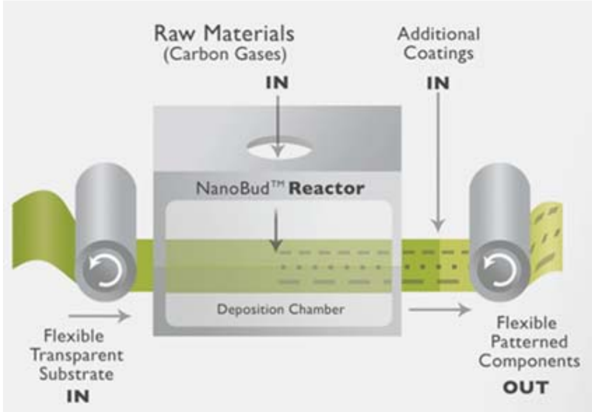
Source: ClearJet

Carbon Nanotubes

- **Carbon NanoBuds™ by Canatu (Finland)**
  - "NanoBud" = nanotubes + bucky-balls (C_{60} fullereens)
  - Probably the best current bet on CNTs, with moderate-volume production by the end of 2014
    - Better optical performance than silver nanowires
      - Very low reflectivity and lower haze
    - More flexible (bend radius 0.5 mm!)
    - Note that the "NanoBud Reactor" is a multi-step process that includes (1) deposition of CNTs, and (2) laser patterning







Source: Canatu

Conductive Polymers & Graphene

- **Conductive Polymers (PEDOT:PSS)**
  - Kodak (partnered with Heraeus) is the leader; AGFA is trailing
  - First shipments of actual sensors began in 1H-2014
  - Resistivity isn't much different from ITO, but it's easy to apply (e.g., with screen printing)
    - White-goods manufacturers can use it to make their own touch control panels in appliances (for example)
- **Graphene – it hasn't started in touchscreens yet**
  - Like unrolled carbon nanotubes, a one-atom thick sheet
    - Promising strength, transparency, and conductivity, but development is still in its infancy – and there are so many other hot applications for the material than touchscreens!
  - Resistivity, transparency, manufacturability just aren't there yet

ITO Replacements Summary…1

- **Current realities**
  - It's about the ITO in touchscreens, not in LCDs
    - ITO used in LCDs is 1-2% of cost (~$4 for a 40" display)
    - LCD makers are extremely reluctant to make changes in fabs
  - It's not really about flexible displays, at least not yet…
  - It's not really about the indium supply or cost
  - It's about the processes that ITO requires, not about ITO itself
    - The dominance of patterned-ITO touchscreens (p-cap) over uniform-ITO touchscreens (resistive) has drastically changed the picture
  - Mesh and silver nanowires are the main competitors, and mesh seems to be taking a strong lead
  - This entire market has come alive exceptionally quickly!

ITO Replacements Summary…2

- **Predictions**
  - Most current capital-intensive, glass (fab)-based, p-cap module suppliers are going to be in a world of hurt because they have to maintain a targeted return on their LARGE invested capital
  - Film-based module suppliers (formerly second-class citizens) will become the leaders of the touchscreen industry
  - Five years from now, more than 50% of p-cap sensors will be made using an ITO-replacement material
  - 10 years from now, p-cap fabs will be like many passive-LCD fabs today (fully depreciated and unused)

Modules

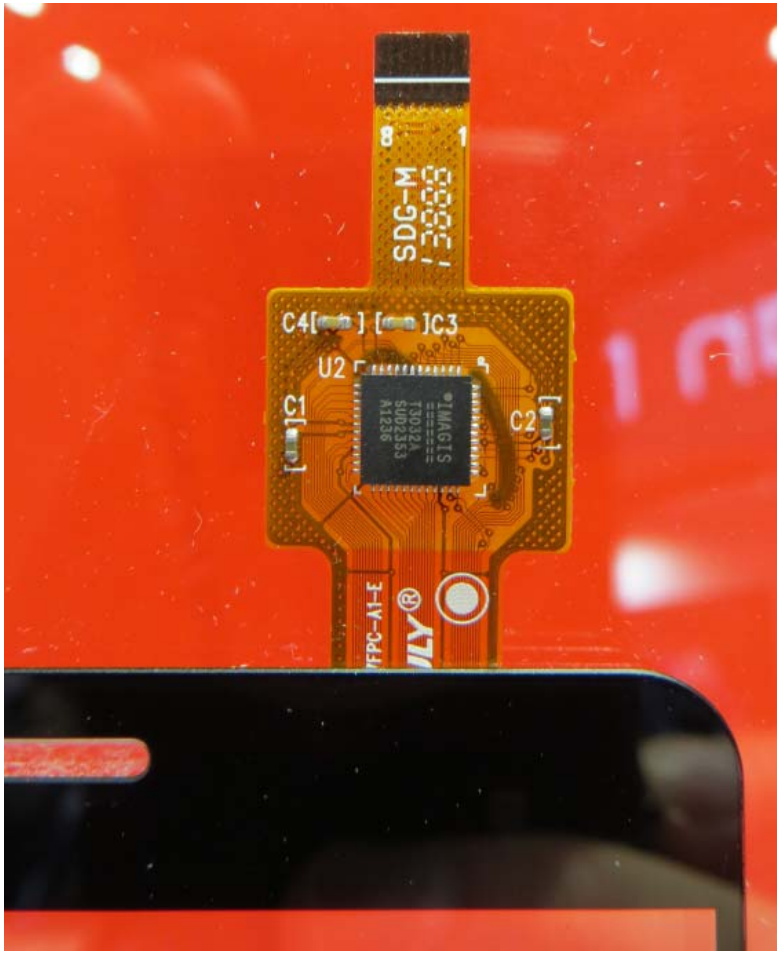
- ❖ Routing Traces
- ❖ Tail & ACF
- ❖ Cover Glass
- ❖ Lamination & Bonding
- ❖ Integration Into a Device
- ❖ Commercial Markets
- ❖ Touch System
- ❖ Advantages & Disadvantages
- ❖ Suppliers

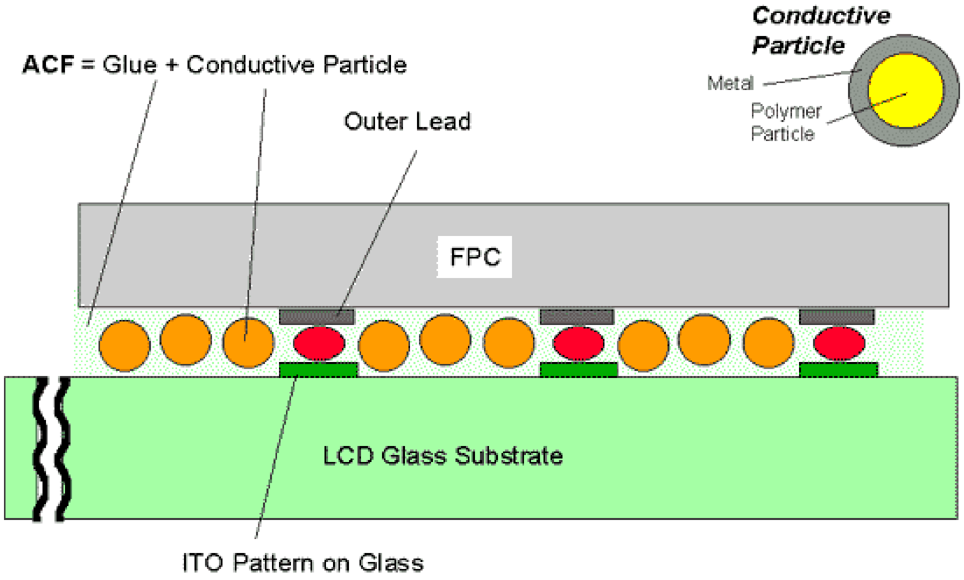
Routing Traces

- **Sensor electrode connection traces**
  - Narrow borders are the driving force
  - Glass sensors use photolithography to pattern the connection traces; “double routing” (stacking) makes even narrower borders
  - Film sensors historically used screen-printing for both the electrodes and the connection traces; many film sensor-makers are buying photolithography equipment for the traces

Tail & ACF

- FPC with controller and ACF





Cover Glass…1

- **Cover-glass types**
  - Soda-lime
  - Chemically strengthened (CS)
  - Ion-exchange strengthened (e.g., alumino-silicate)
- **Minimum cover-glass thickness (0.4 mm today) is driven by two factors**
  - Durability (resistance to damage, especially with bezel-less design)
  - Capacitive-sensing limitations when the device is ungrounded

Cover Glass…2

- **Cover-glass processing**
  - Forming
  - Decorating
  - Coating (AR, AG, AF, AC, AB…)
- **Plastic cover-glass**
  - It hasn't really happened yet
  - Deformability is a big problem (bigger than scratching)

Lamination & Bonding

- **Lamination (film to glass, or film to film)**
  - Yield is key

- **Bonding (touch module to display)**
  - Direct bonding = No air-gap, spaced filled with solid (OCA) or liquid (OCR) adhesive
  - "Air bonding" = Air-gap (gasket around periphery)

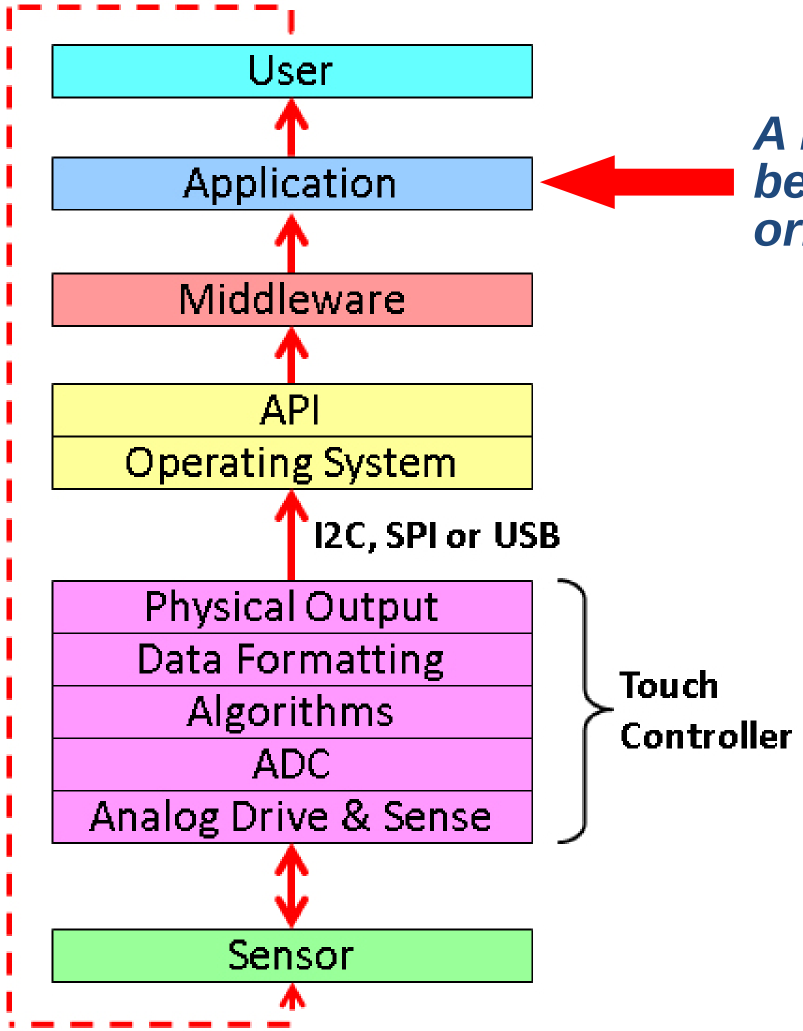
Integrating P-Cap Into a Device

- **After the mechanical & industrial design are done, it's really all about just one thing: "Tuning"**
  - Every new product must have the p-cap touch-screen controller "tuned" to account for all the variables in the configuration
    - Basic configuration (e.g., OGS vs. embedded)
    - Sensing pattern
    - Glass thickness
    - Adhesive thickness
    - LCD noise
    - LCD frame mechanics
    - Air-gap or direct-bonded… etc.
  - All controller manufacturers either supply tools (e.g., Synaptics' "Design Studio 5") or they do it themselves for their OEM customers
  - Initial tuning can take more than a full day of engineering time

Commercial Markets

- **Adoption of P-Cap Into Commercial Markets (Forecast)**
  - Healthcare – Rapid, within FDA-cycle constraints
    - Buying for the future with a very long product life
    - Zero-bezel, multi-touch, light touch are all important
  - Gaming – Rapid, within gaming regulation constraints
    - Casinos want to attract the Millennium Generation
    - Multi-touch is very important; zero-bezel is less so
  - Point of Information – Moderate
    - Software-driven; zoom gesture could be the key
  - Industrial – Slow
    - Multi-touch may be important; zero-bezel & light touch are less so
  - Point of Sales – Very slow
    - Zero-bezel is the only driver; “flat-edge resistive” is good enough

Touch System…1



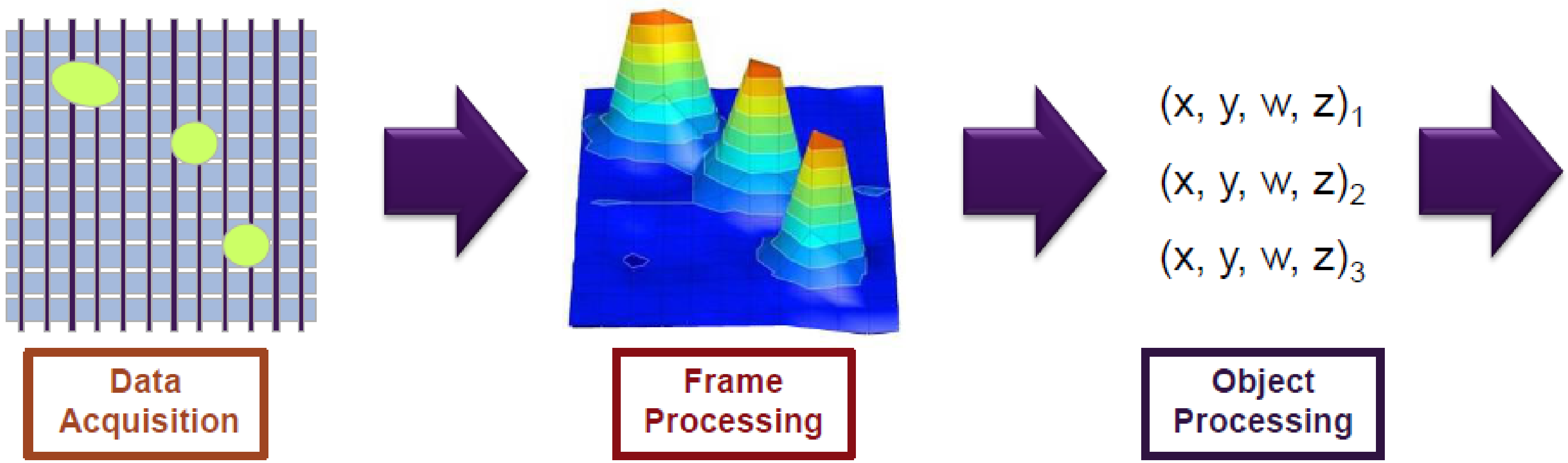
A lot of bad touch behavior actually originates here!

You don't believe it?

*Download "**Touch Explorer**" by Synaptics from Google Play and see if you can make your touchscreen fail to respond properly*

Touch Processing

- Control sensor electrodes to generate raw data
  - Noise avoidance via multiple techniques: Frequency Shifting, CDM, etc…
- Process data to convert to Image data
- Derive and report data about finger touches (position, width, gestures)



Data Acquisition
- Tx signals generated
- Rx conversion via A/D
- Noise avoidance

Frame Processing
- Collect and Scale Capacitance
- Remove Common Mode Noise
- Gain Compensate
- Apply Thresholds

Object Processing
- Segmentation
- Track Objects
- Classify Objects
- Calculate and Report Positions

Source: Synaptics

Computer Actions: Gesture Processing

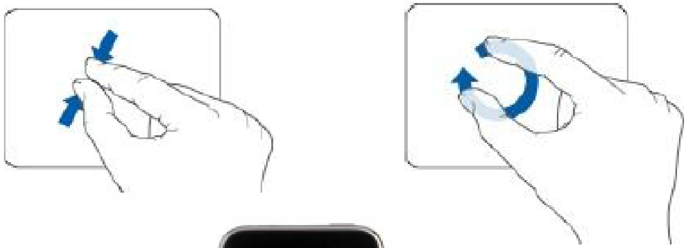
Tap and Double Tap.
- Light touch action – selects application

Flick
- Next Page of Icons, Fast directory search, Next Photo etc. ..

Scrolling
- Slider for message forward, volume, contrast, directory search control etc..

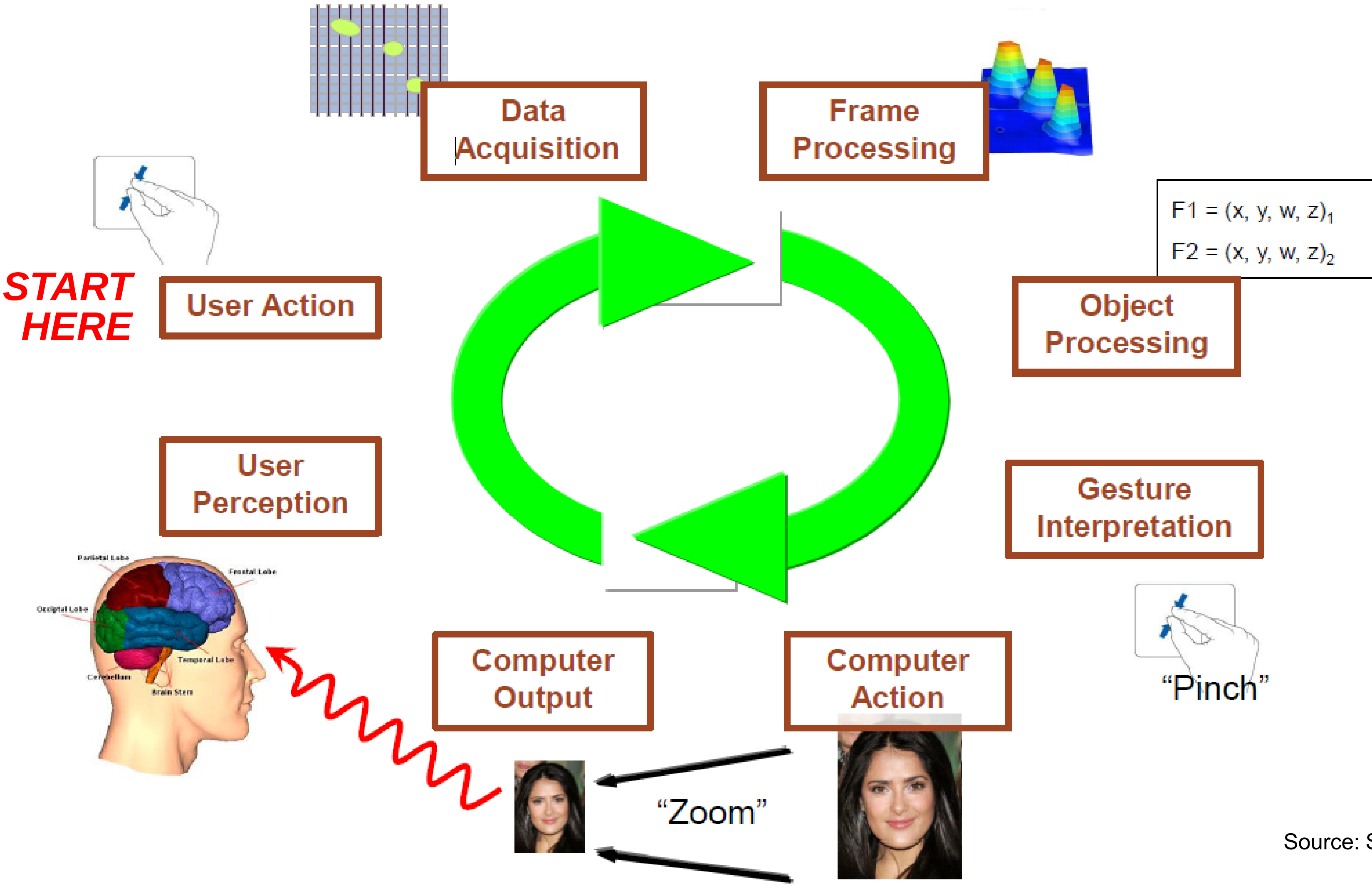
Proximity detection
- LCD screen wake up

Multi Finger gestures
- Pinch for zoom
- 2 Finger rotate (photo rotate)
- Two finger flick
- Bring up new menu
- Simple games



Source: Synaptics

Human in the Loop



Source: Synaptics

Touch System…2

- **Controller output data**
  - Windows (USB): HID packets
  - Android (I2C or SPI): Vendor-defined format

- **OS processing**
  - Built-in gesture recognition
  - Custom gestures

- **Middleware example**
  - MyScript (formerly Vision Objects) in Samsung Galaxy Notes

P-Cap Advantages & Disadvantages

P-Cap Advantages	P-Cap Disadvantages
Unlimited, robust multi-touch (if properly implemented)	Still relatively high cost, although it is dropping – especially in notebook sizes
Extremely light touch (zero pressure)	Touch object must have some amount of capacitance to ground (or active stylus)
Enables flush touch-surface (no bezel)	Challenging to integrate ("tuning")
Very good optical performance (especially compared with resistive)	Difficult to scale above 32" with invisibility
Extremely smooth & fast scrolling (if properly implemented)	No absolute pressure-sensing; only relative finger-contact area
Durable touch surface not affected by scratches and many contaminants	
Can be made to work with running water on the surface	
Can be made to work through extremely thick glass (~20 mm)	
Can be sealed to NEMA-4 or IP65	

Module Suppliers (Discrete & Embedded)

Supplier	Share
Samsung Display	13.1%
TPK	8.9%
O-film	7.8%
GIS	5.6%
ECW EELY	4.8%
Japan Display	4.4%
Sharp	4.0%
Truly	3.0%
Others	3.0%
Melfas	3.0%
LG Display	2.7%
SMAC	2.5%
Iljin Display	2.3%
ALPS Electric	2.1%

Supplier	Share
LG Innotek	2.0%
Wintek	2.0%
Laibao	1.7%
EACH	1.6%
Lcetron	1.6%
Top Touch	1.6%
Mutto Optronics	1.5%
ELK	1.5%
Synopex	1.4%
Young Fast	1.3%
Digitech Systems	1.3%
Panasonic	1.1%
Goworld	1.1%
JTouch	1.0%

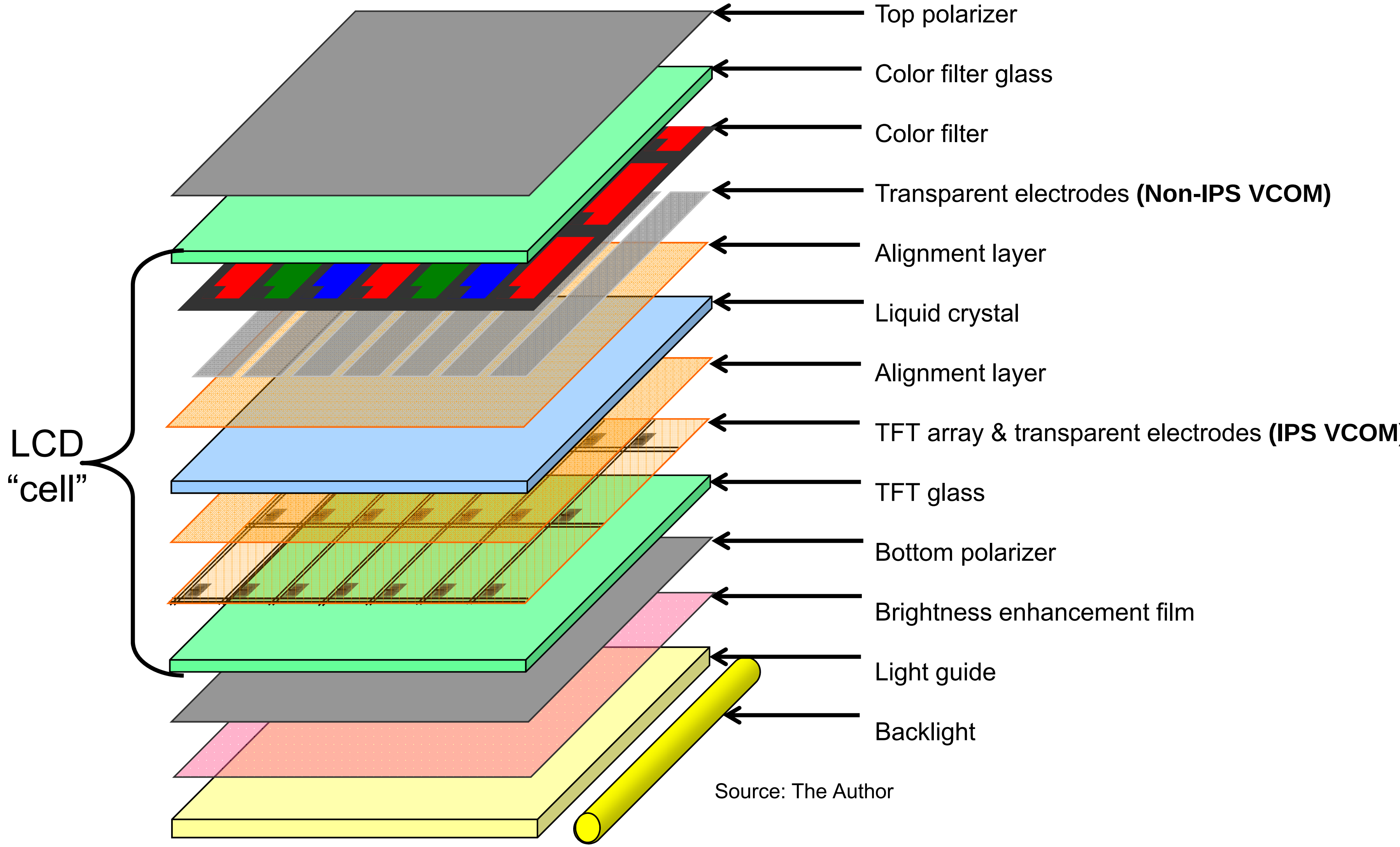
- 35% of suppliers account for 88% of units

Source: DisplaySearch Touch-Panel Market Analysis Report 1Q-2014

Embedded Touch

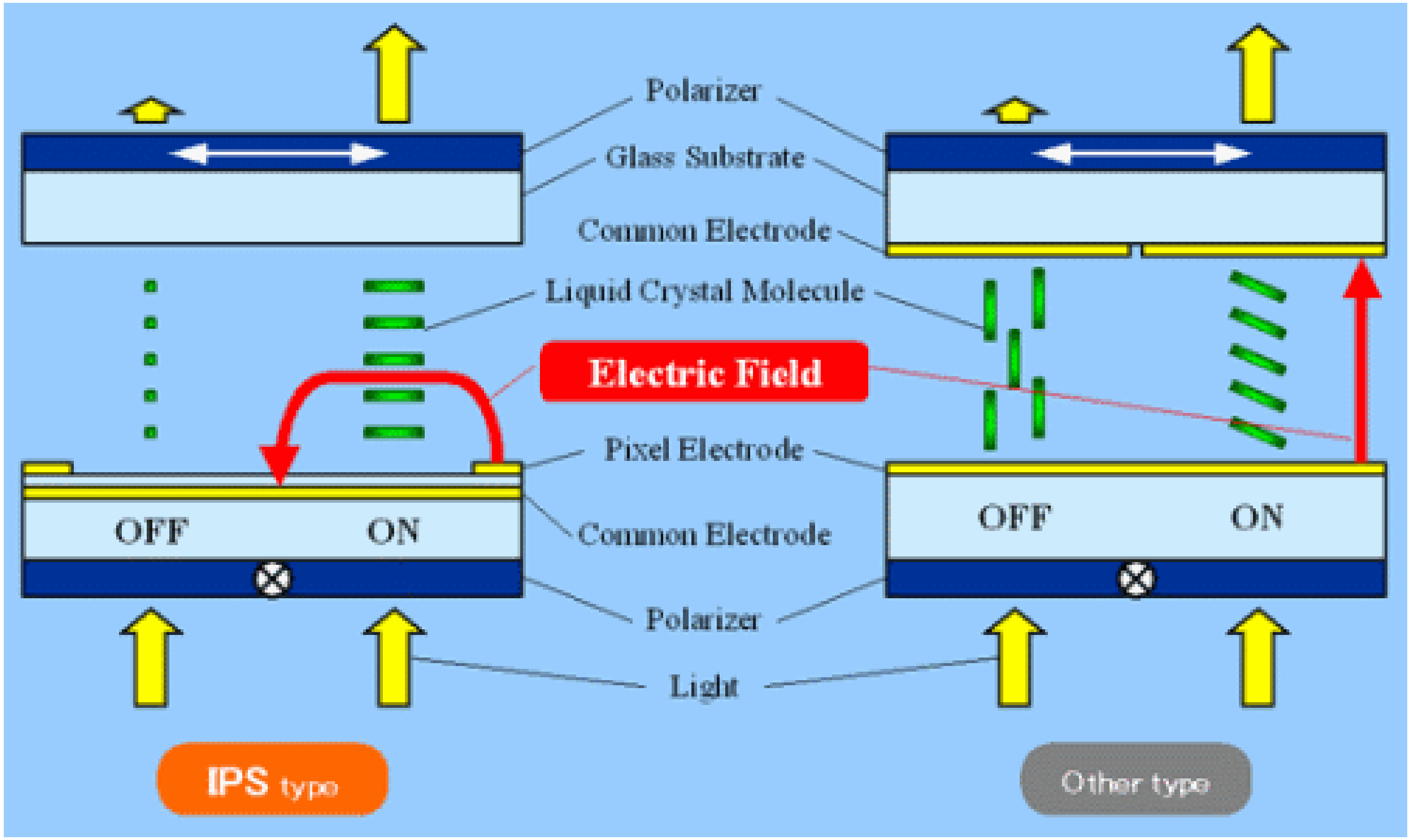
- LCD Architecture Refresher
- Embedded Terminology
- Early Embedded Failures
- On-Cell P-Cap
- Hybrid In-Cell/On-Cell P-Cap
- In-Cell P-Cap
- Summary of Sensor Locations
- Integrating the Touch Controller & Display Driver
- Discrete Touch vs. Embedded Touch

LCD Architecture Refresher



Source: The Author

IPS vs. Other LCD Architectures



Source: Presentation Technology Reviews

Embedded Touch Terminology…1

- **Key defining characteristic**
  - Touch capability is provided by a <u>display manufacturer</u> instead of a <u>touch-module manufacturer</u>
    - Touch-module manufacturers can’t do in-cell or on-cell
- **Marketing Terminology Alert!**
  - Some display manufacturers call all their embedded touch “in-cell”, even though they may be supplying hybrid or on-cell
  - Some display manufacturers use a brand name to encompass all their embedded touch products
    - For example, “Touch On Display” from Innolux
  - Some display manufacturers direct-bond or air-bond an external touchscreen to their display and call it “out-cell”

Embedded Touch Terminology…2

Term	Integration Method
In-Cell	Touch sensor is **physically inside the LCD cell** Touch sensor can be: • Capacitive electrodes (same as p-cap) • Light-sensing elements (rare)
On-Cell	Touch sensor is **on top of the color-filter glass (LCD) or the encapsulation glass (OLED)** • Capacitive electrodes (same as p-cap)
Hybrid (In-Cell/ On-Cell)	Touch sensor has **sense electrodes on top of the color-filter glass <u>and</u> drive electrodes inside the cell** • <u>IPS LCD</u>: Segmented Vcom electrodes on the TFT glass • <u>Non-IPS LCD</u>: Segmented Vcom electrodes on the underside of the color filter glass

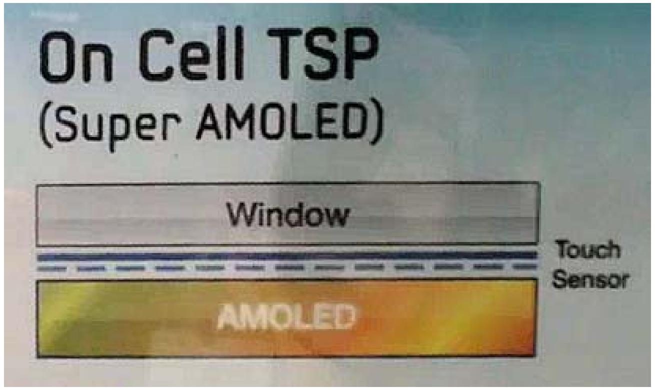
Early Embedded Methods All Failed

- **Attempts to develop embedded touch in 2003-2011 were all trying to invent something new while leveraging the LCD design**
  - “Pressed” capacitive, first mass-produced by Samsung in 2009
  - Light-sensing, first mass-produced by Sharp in 2009
  - Voltage-sensing (“digital switching”), first mass-produced by Samsung
- **But none of them was really successful**
  - Insufficient signal-to-noise ratio for robust operation
  - The need to press the display surface, which prevented the use of a protective cover-glass
  - The unreliability of pressing the display very close to the frame, where the color-filter glass has little ability to move

First Successful Embedded Touch: OLED On-Cell P-Cap

- **Samsung S8500 Wave mobile phone with Super AMOLED on-cell p-cap touch (Feb. 2010)**
  - 3.3-inch 800x480 (283 ppi) AM-OLED
  - "Super AMOLED" is Samsung's (odd) branding for on-cell touch
  - Sunlight readable
    - AR coating & no touchscreen overlay

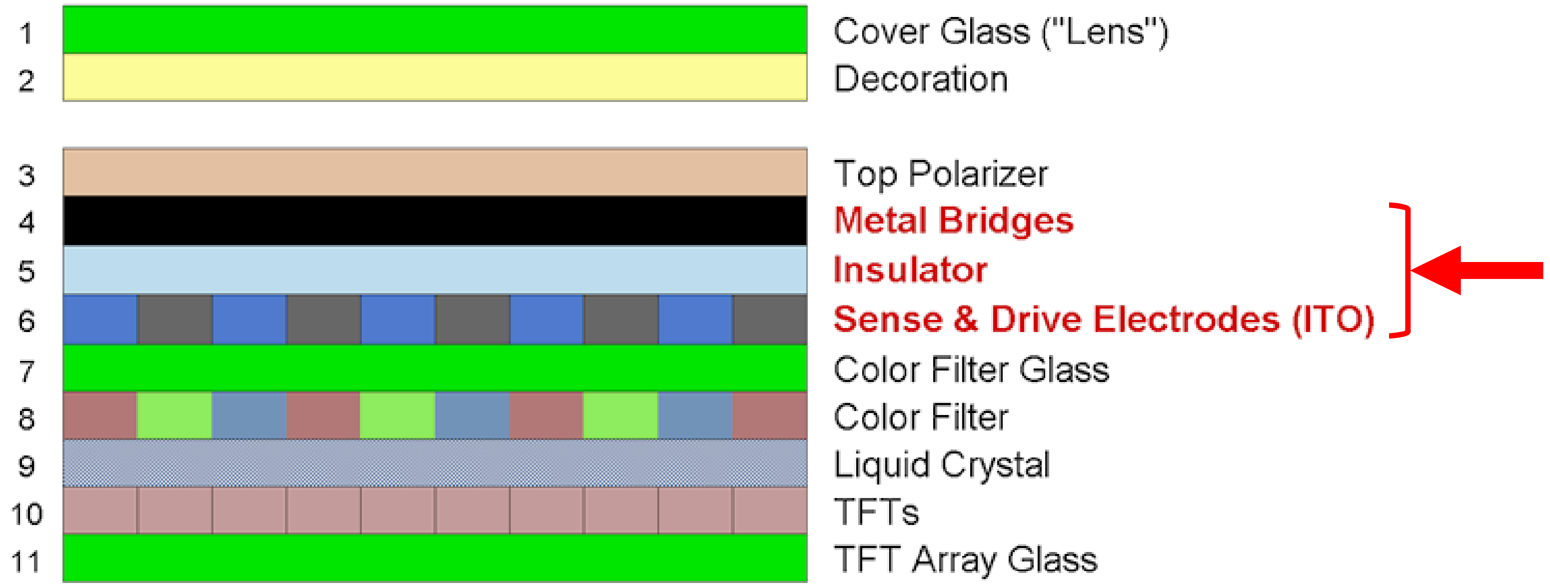
Window = direct-bond cover-glass



Source: Samsung booth graphic at Mobile World Congress 2010

Source: Samsung

On-Cell P-Cap



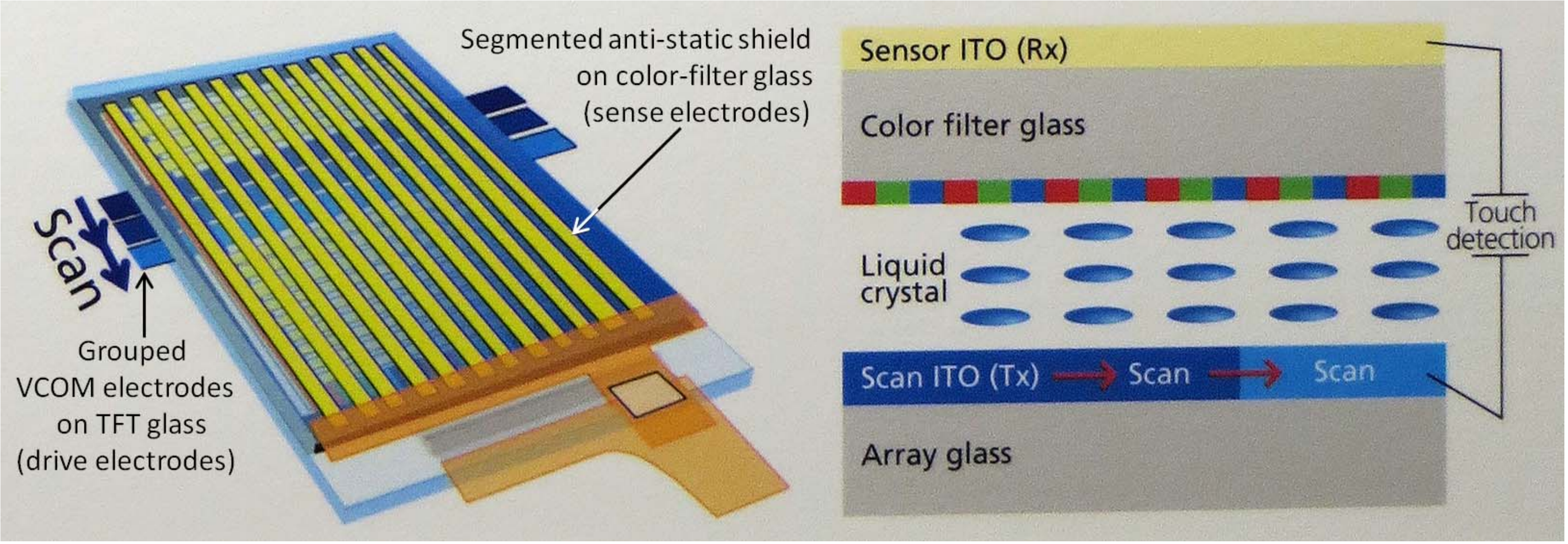
Source: The author

Principle

- ITO P-cap electrode array is deposited on top of the color filter glass (under the top polarizer)
  - Exactly the same function as discrete (standalone) p-cap
  - Shown above is one ITO layer with bridges; it could also be two layers with a dielectric instead

The Display-Makers Quickly Got the Idea

- **Don't try to invent something new; figure out how to apply what already works (p-cap)!**
- **The result: Sony's (JDI) "Pixel Eyes" hybrid in-cell/on-cell mutual capacitive**
  - First successful high-volume embedded touch in LCD



Source: Japan Display; annotation by the author

First Phones with Hybrid In-Cell/ On-Cell Mutual-Capacitive (May 2012)

- **Sony Xperia P and HTC EVO Design 4G** *(not the iPhone 5)*

Source: Sony

Source: HTC

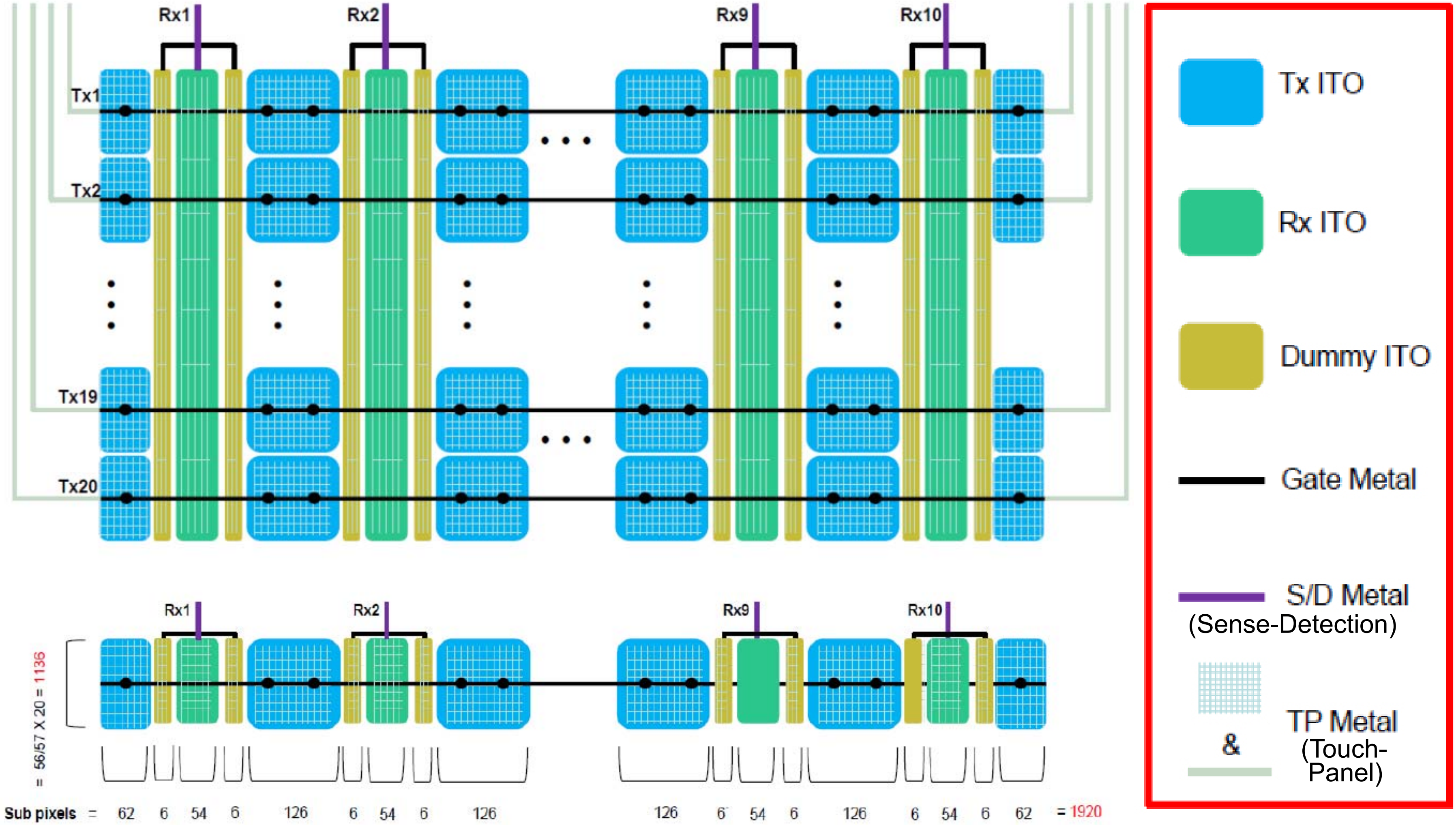
- **Similar LCDs**
  - 4-inch 960x540 LTPS (275 ppi) with different pixel arrays
- **Same touch solution**
  - Synaptics ClearPad 3250 (four touches)
- ***<100 µm thinner than one-glass solution!***

Apple iPhone 5: First Fully In-Cell Mutual Capacitive (Sept. 2012)

- **Structure**
  - Both sense and drive electrodes are in the TFT array, created by switching existing traces so they become multi-functional
  - Apple has said they may change to Innolux "Touch On Display" (TOD, Innolux's brand name for ALL of their embedded touch structures) in iPhone 6
    - That doesn't actually tell us anything, since TOD includes all three embedded structures…

Source: CNET

Apple's iPhone-5 Electrode Structure



Source: BOE Technology Group's Central Research Institute

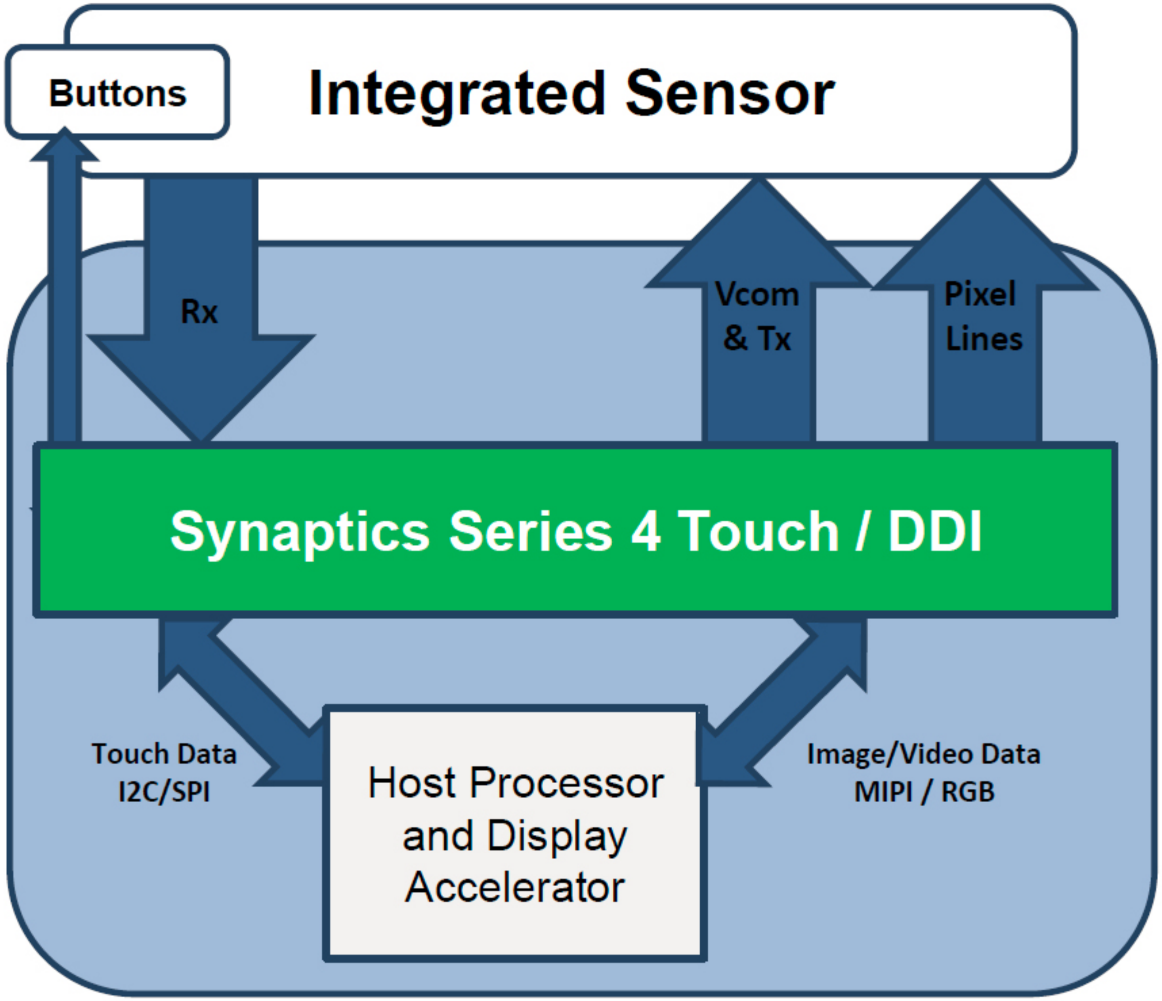
Other In-Cell Electrode Structures (Based On Patents)

- **Apple & Samsung**
  - Drive electrodes are segmented VCOM
  - Sense electrodes are metal overlaid on the CF black matrix
- **Apple & Samsung**
  - Drive electrodes are ITO stripes deposited on top of a dielectric layer over the color filter material
  - Sense electrodes as above
- **Sharp**
  - Both drive & sense electrodes are deposited on the bare CF-glass, before the black matrix and color-filter material are applied
- **LG Displays**
  - Self-capacitive method using just segmented VCOM

Summary of Sensor Locations

Sensor Location	Key Advantages	Key Disadvantages
Discrete sensor (separate glass)	Industry standard Glass or PET Easy to add shield layer Display unconstrained	Thickness & weight
Top of cover-glass	None	Impractical
Bottom of cover-glass (OGS = G2)	Good for sensing Widest sensing area Display unconstrained	Complex lens (yield) Limited durability
Top of polarizer	None	Impractical
Top of CF glass (1 or 2 layers)	Simple display integration Lower cost (1 layer)	2-sided CF process Limited to display size
Both sides of CF glass (hybrid for non-IPS)	Slightly thinner Slightly lower cost	2-sided CF process Limited to display size Requires display integration
Top of CF glass and in TFT array (hybrid for IPS)	Highest performance Slightly thinner Slightly lower cost	2-sided CF process Limited to display size Requires display integration
In cell (on TFT array for IPS; split between TFT and CF for non-IPS)	High performance Thinnest Potentially lowest cost	Limited to display size Requires display integration Complex design

Integrating the Touch Controller and the Display Driver IC…1



Integrating the Touch Controller and the Display Driver IC…2

- **Advantages**
  - Full synchronization of touch and DDI
  - Can work with any sensor (discrete, OGS, on-cell, in-cell, hybrid)
  - Reduced latency
    - 70 ms to 20 ms
  - Capable of user-input and feedback without CPU involvement
    - Done by programming the display configuration blocks of flash memory
    - Overlay capability plus image fade-in/out, animation, translation, etc.
  - Can support wake-on-touch
    - Can display sprites or graphics for log-in screen
- **Disadvantages**
  - Design is LCD-specific (resolution & pixel layout)
  - Substantial NRE; appropriate only for high-volume

Comparison of Discrete (e.g., OGS) Touch with Embedded Touch…1

- **Cost: Is embedded touch really "free"?** ***No!***
  - Barrier to entry
    - There is much more intellectual property (IP) on embedded touch layer-structure & driving; making sure you don't infringe costs money
  - Development cost
    - Embedded touch is much more complex to develop than OGS
    - High volume is required (5M) to make it practical
  - Cover glass, decoration & bonding
    - Similar to discrete (OGS), but embedded cover-glass is just glass & decoration (no ITO), so it's easier to manufacture
    - Sheet-type OGS may not be as strong as plain cover-glass
  - Touch controller
    - No integration = same cost (but performance is poor)
    - Linked to TCON for timing control = same cost (slightly different chip)
    - Integrated with TCON = saves \$1-\$2 in material cost
      - BUT, it adds LCD-specific chip-development cost (amortized NRE)

Comparison of Discrete (e.g., OGS) Touch with Embedded Touch…2

- **Cost (continued)**
  - FPC to connect electrodes
    - On-cell and hybrid = same
    - In-cell = none if touch controller is COG; saves another $1-$2
  - Electrode material
    - Discrete OGS currently uses ITO; could move to printed metal-mesh, which could save $10+ in tablet size (once sensor competition gets real)
    - On-cell = same as discrete ITO
    - Hybrid = only half as much added ITO (little material cost-difference)
    - In-cell = no added ITO

Comparison of Discrete (e.g., OGS) Touch with Embedded Touch…3

- **Performance**
  - On-cell = same as discrete or worse
    - If you build the color-filter first (focus on LCD yield) then you can't use high-temperature ITO so touch performance is worse
    - If you build the touch electrodes first for good performance, then you can't thin the color-filter glass
  - Hybrid = same
  - In-cell = worse, but should improve to be same as SNR goes up
- **Thickness**
  - Embedded is typically 100 µm thinner than discrete OGS
  - But <u>the thickness variation between smartphone models with embedded touch is ~1.0 mm due to other features</u>, so 0.1 mm doesn't mean that much to the consumer (it's mostly marketing!)

Comparison of Discrete (e.g., OGS) Touch with Embedded Touch…4

- **Weight**
  - Embedded = discrete (same number of sheets of glass)
- **Power consumption**
  - On-cell & hybrid = same as discrete
  - In-cell with integrated touch & TCON = probably lower, but touch power consumption is much lower than LCD power-consumption, so the decrease isn't very significant
- **Off-screen icons**
  - Discrete = no problem
  - Embedded = <u>requires additional circuitry</u>

Embedded Touch Conclusions…1

- Embedded touch isn’t a clear win in either cost or technology; *it’s all about who gets the touch revenue!*
- The driving force in embedded touch is the display-makers’ need to add value in order to increase their *profitability*
- Embedded touch provides *little advantage* to the end-user (consumer)

Embedded Touch Conclusions…2

- It's not clear that embedded touch will offer ***significant cost-savings*** to the device OEM, since OGS can be further cost-reduced with ITO-replacement materials
- The display-makers will take some market share with embedded touch in high-volume products (DisplaySearch says 25% in 2018) but ***embedded touch is unlikely to become dominant*** because the touch-panel makers won't let their business be destroyed

Large-Format P-Cap

- ❖ Introduction
- ❖ ITO Electrodes
- ❖ Wire Electrodes
- ❖ Metal Mesh Electrodes
- ❖ Applications

Introduction

- **Large-format touch is a much more wide-open space than consumer-electronics touch**
  - Multi-touch infrared (IR) has replaced traditional (single-touch) IR
  - Camera-based optical has dropped substantially with the exit of NextWindow (SMART Technologies) from the market
  - Startup: **Sentons** is taking a new approach to bending-wave
  - Startup: **RAPT** is taking a new approach to in-glass optical
  - P-cap with metal mesh is a threat to all other large-format touch technologies
    - Commonality of user experience (UX) with the 3 billion p-cap units shipped since 2007 may be the driving force
    - Cost and complexity (as always) are the impediment

ITO Electrodes

- **3M has managed to get ITO electrodes to work in a 46-inch display (larger than any other with ITO)**
  - They won’t disclose their secret sauce

Source: Photo by Author

Wire Electrodes…1

- **One more sensor variation: 10-micron wires between two sheets of PET or glass**
  - Commonly used for large-format touchscreens
  - Two main suppliers: Visual Planet & Zytronic, both in the UK

9 floor-to-ceiling Visual Planet touchscreens in the University of Oregon Alumni Center

Source: The University of Oregon

Wire Electrodes…2

- **Zytronic's new multi-touch large-format p-cap**
  - Previous Zytronic products were self-capacitive (2-touch max)
    - Binstead's frequency-variation patent was the basis of sensing
  - New product is mutual-capacitive with very dense electrode pattern
    - Traditional measurement of capacitance reduction caused by finger
    - ~1.5 mm electrode spacing in 6 mm x 6 mm cell
      - Density reduces visibility because the human visual system sees a more uniform contrast
    - 10-micron insulated copper wires allow crossover ("single layer")
      - 100's Ω/m at 10 μm
    - Can be applied to glass or film (including curved surfaces)
    - Initial controller handles all sizes up to 72"; 100"+ possible
    - Minimum 10 touches with palm rejection

Wire Electrodes…3

- **Jeff Han from Perceptive Pixel (acquired by Microsoft in mid-2012) showed an 82” at CES 2012 (with active stylus) and a 72” at Digital Signage Expo (DSE) 2012**
  - Metal electrodes (not ITO) – although Jeff wouldn’t talk about the electrode material or who is manufacturing the touchscreens

Source: Photos by Author

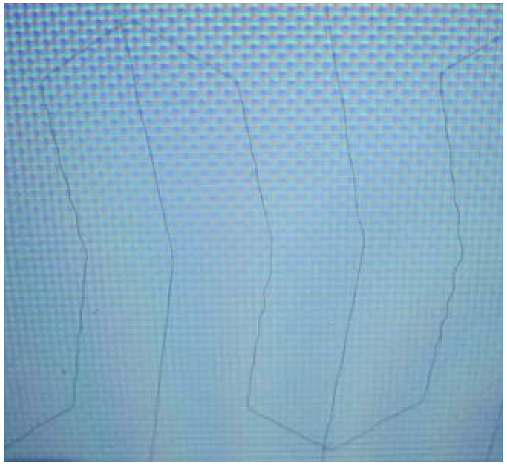
Wire Electrodes…4

- Both the 72” & 82” look much better than the traditional Zytronic zig-zag 10-micron wire pattern

72” at DSE 2012

72” at DSE 2012

Zytronic wires



Source: Photos by Author

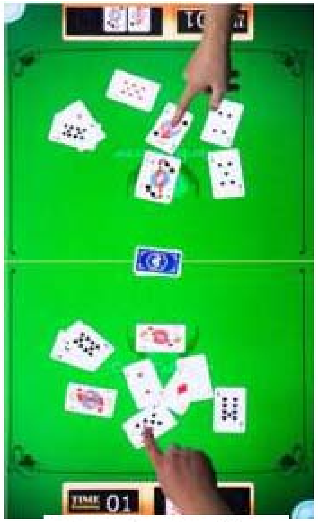
Metal-Mesh Electrodes

- **“Invisible” metal-mesh electrodes are the biggest threat & opportunity in large-format p-cap**
  - Many suppliers are working on this
  - Few (if any) have made formal product announcements
  - Display sizes of 42” to 55” are frequently mentioned
  - There are significant challenges
    - Total number of connections is large (~250 + ~150 = 400 for 55”)
    - Multiple ganged controllers are required
    - Longer electrodes means slower sensing (larger RC time-constant)
    - Much larger number of electrodes takes longer to sense
    - Number of suppliers able to print on 1,200 mm web is limited

Applications…1

❖ Large-format multi-touch applications

Education



Gaming Tables

Advertising

Digital Signage

Industrial Control

Vending

Source:
Zytronic

Applications…2

❖ **Applications for <u>curved</u> large-format touchscreens**

Source:
Zytronic

Applications…3

- **BUT, stepping back from a technology focus, is the large-format touch market likely to start shrinking?**
  - Interactive media walls – touch is very necessary
    - **MultiTaction** makes the best vision-based touch today (author's opinion)
  - Point-of-information – touch still seems necessary
  - Digital signage – interaction via smartphone
  - Education – interaction via tablets (including multi-user!)
  - TV – interaction via mobile & motion-based devices
  - Horizontal home-gaming tables – will they ever exist?
  - Other large-format applications??

Stylus Technologies

- History
- Use Cases
- Passive Stylus
- Electromagnetic Resonance (EMR) Stylus
- Active P-Cap Stylus
- Prediction
- Other Active Stylus Technologies

Stylus History…1

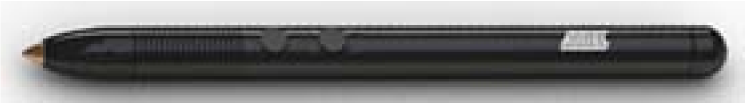
- **Microsoft Tablet PCs, PDAs, and early smartphones (e.g., Trio) always had styli (1989 to 2007), so why are we so finger-focused now?**
  1. Steve Jobs and the iPhone in 2007 – “Who needs a stylus?”
  2. Microsoft’s failure to make the stylus-based Tablet PC a success with consumers caused them to de-emphasize the stylus and focus on finger-touch in Windows 7; that has continued and become even stronger in Windows 8

Stylus History…2

- **Is the stylus coming back into the consumer space?**

YES!

- All the major p-cap controller suppliers support active & passive
- PC OEMs want to differentiate their products from Apple's
- Legacy Windows software on a Win8 tablet needs a stylus
- Android (in Ice Cream Sandwich) supports stylus messages
- Samsung has shipped >15M Galaxy Notes in two sizes
- Consumption isn't enough; a stylus is great for creation

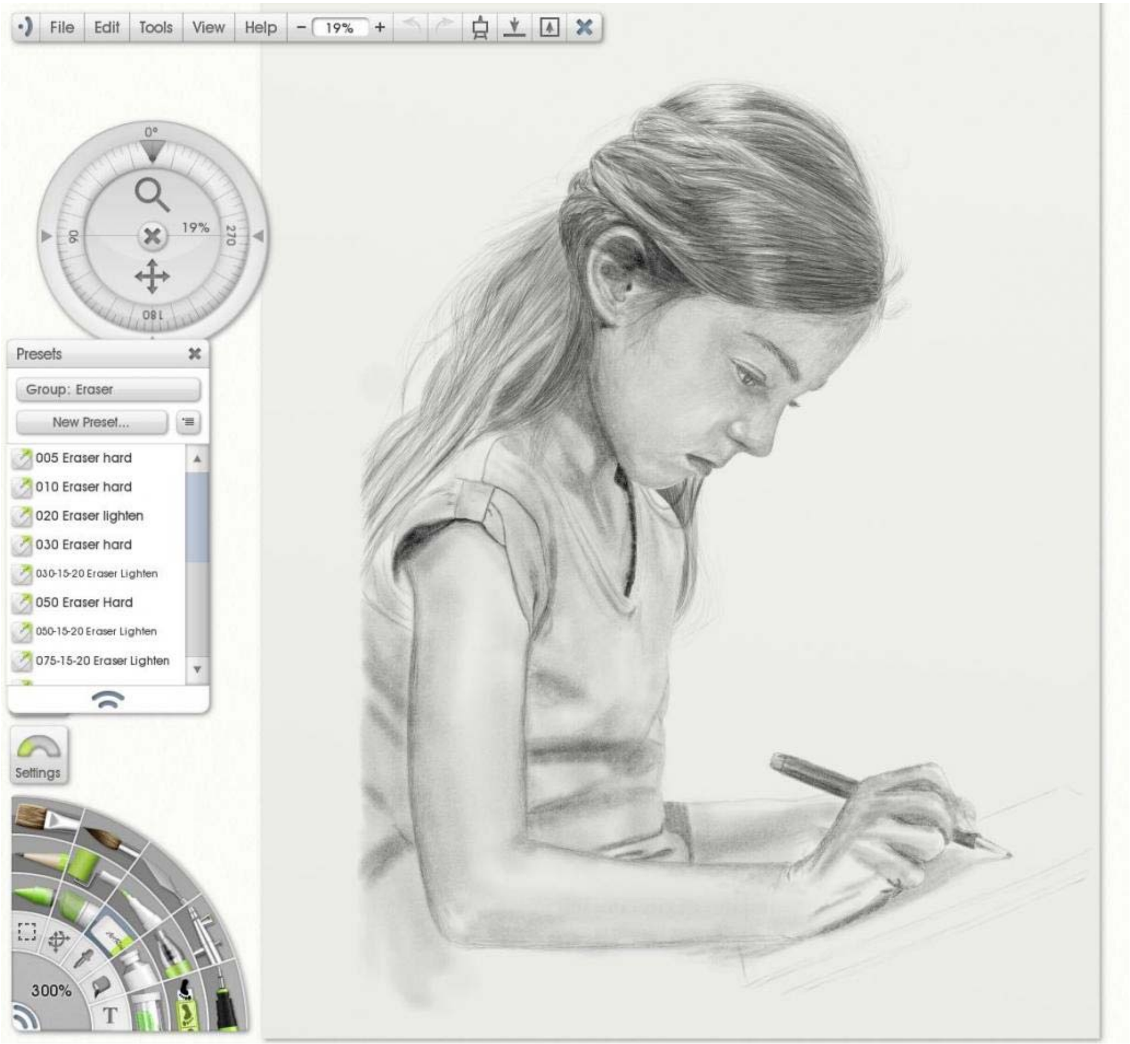


Source: Atmel

Stylus Use-Cases…1

- **Taking notes (in both Windows and Android)**
  - Notes are automatically converted into text in background; being able to search your “ink” notes is very powerful
- **Annotating documents**
  - Typically Office or PDF
- **Quick sketches**
  - Typical whiteboard-type sketches
- **Precision pointing device, e.g. with Windows 8 Desktop**
  - When you’re trying to select tiny UI elements
- **Artistic drawings**
  - It’s unbelievable what a real artist can do…

Stylus Use Cases…2



Created with an N-Trig active stylus on a Fujitsu Lifebook using ArtRage software

Passive Stylus…1

- **A passive stylus can be any <u>conductive</u> object**
  - Metal rod
  - Conductive plastic
  - Ballpoint pen
  - #2 pencil (shown at CES 2014)
  - Long fingernail
  - And those horrible 7 mm conductive-rubber-tipped styli
    - Needed for backwards compatibility with early tablets with low SNR
- **Tip diameter**
  - State of the art is 1.5 to 2.0 mm
    - Next generation is 1.0 mm
  - Essentially every controller supplier supports this now
    but not many have made it out into shipping products yet

Passive Stylus…2

- **Advantages**
  - Extremely low cost
  - Easily replaceable
  - Can be made any size and comfort level by low-tech methods
  - Improves as SNR increases
- **Disadvantages**
  - No hover that meets Microsoft's specification
  - There's no OS support (yet) for differentiating between finger & stylus
  - No pressure-sensing, so art and handwriting aren't as good
  - Resolution can't be better than a finger

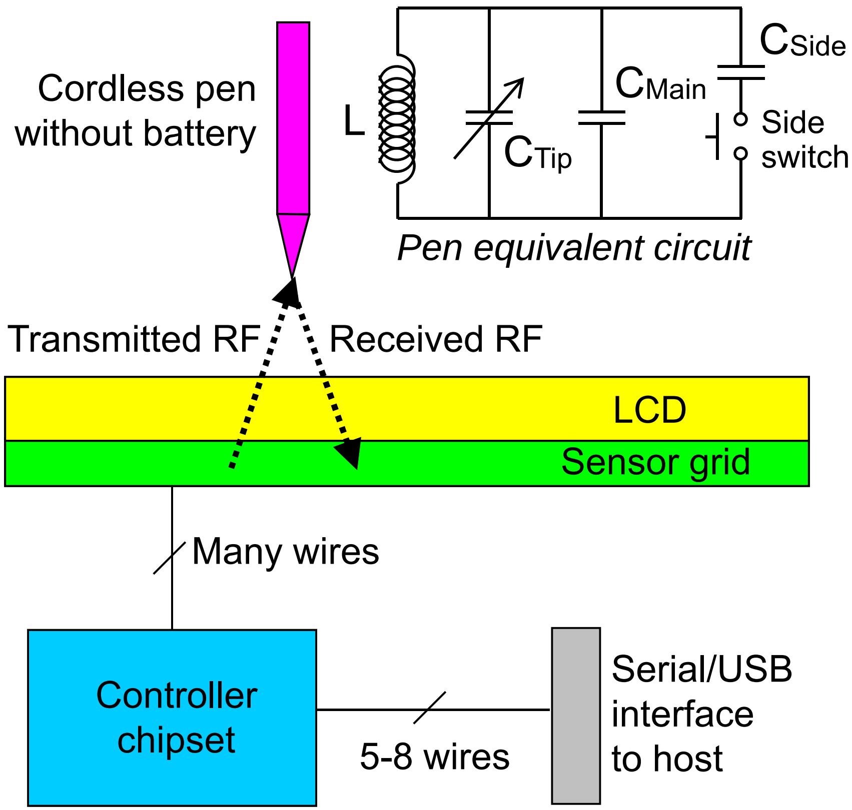
Electromagnetic Resonance (EMR) Stylus…1

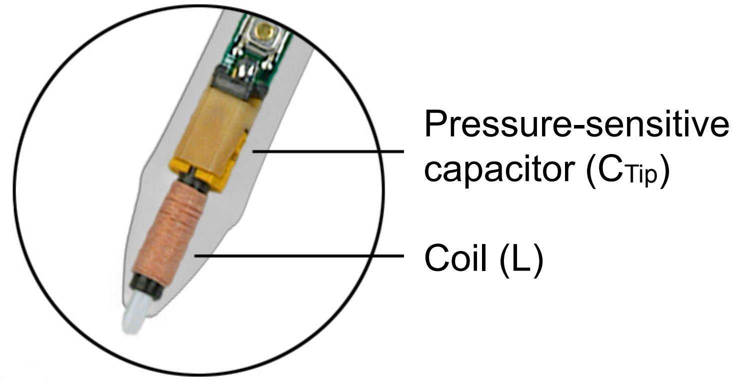
- **Key characteristics**
  - Second sensor under the LCD
  - Batteryless electronic stylus

Source: Wacom

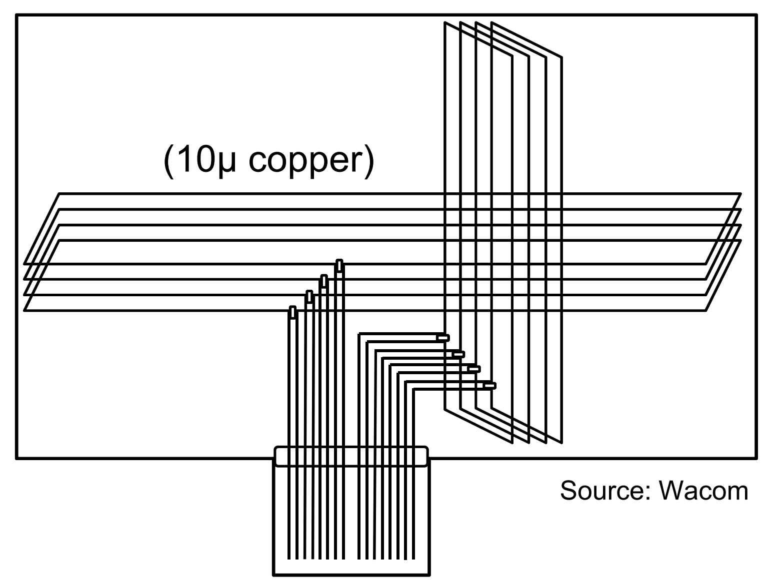
EMR Stylus…2

Source: Wacom





Sensor grid schematic



Source: Wacom

EMR Stylus…3

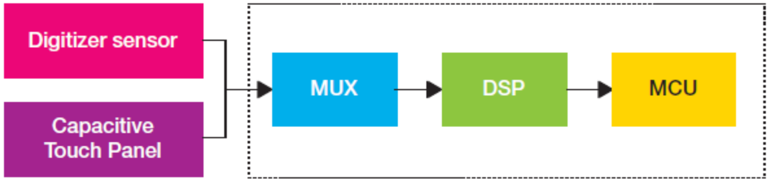
- Variations
  - Sensor substrate (rigid FR4 vs. flexible 0.3 - 0.6 mm PET)
  - Pen diameter (3.5 mm “PDA pen” to 14 mm “executive” pen)
- Size range
  - 2” to 14”
- Controllers
  - Proprietary
- Advantages
  - Very high resolution (1,000 dpi)
  - Pen “hover” (mouseover = move cursor without clicking)
  - Sensor is behind LCD = high durability & no optical degradation
  - Batteryless, pressure-sensitive pen

14”

2”

Controller for 10.4”

Source: Wacom



Single controller can run both pen digitizer & p-cap finger touch

EMR Stylus…4

- **Disadvantages**
  - Electronic pen = disables product if lost; relatively expensive
  - Difficult integration requires lots of shielding in mobile computer
  - Sensor can't be integrated with some LCDs
  - Single-source for mobile CE devices (Wacom) = relatively high cost
- **Applications**
  - Phablets and tablets
  - E-book readers
  - Opaque desktop graphics tablets
  - Integrated tablet (pen) monitors
- **Suppliers**
  - Wacom, Hanvon, Waltop, UC-Logic/Sunrex, KYE

Wacom "Bamboo" Tablet

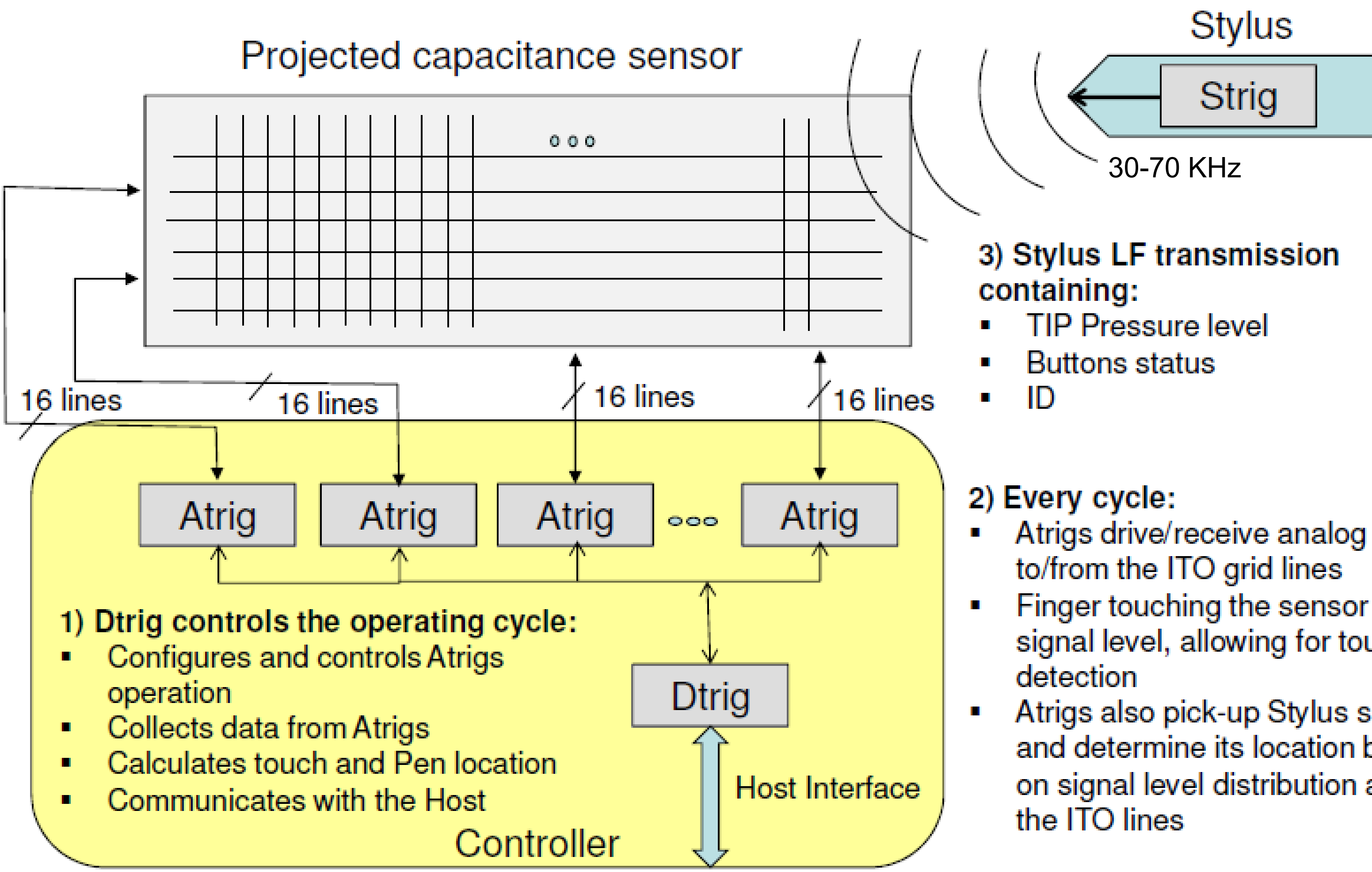
EMR Stylus…5

- **Samsung Galaxy Note sketching demo at CES 2012**

The Galaxy Notes use both a p-cap touchscreen AND a Wacom EMR stylus (2 sensors!)

Source: Photos by Author

Active P-Cap Stylus…1



1) Dtrig controls the operating cycle:

- Configures and controls Atrigs operation
- Collects data from Atrigs
- Calculates touch and Pen location
- Communicates with the Host

3) Stylus LF transmission containing:

- TIP Pressure level
- Buttons status
- ID

2) Every cycle:

- Atrigs drive/receive analog signal to/from the ITO grid lines
- Finger touching the sensor affect signal level, allowing for touch detection
- Atrigs also pick-up Stylus signal and determine its location based on signal level distribution across the ITO lines

Source: N-Trig

Active P-Cap Stylus…2

- **Variations**
  - One-way digital RF transmission from stylus to p-cap sensor, with both sense & drive electrodes acting as antennas
    - N-Trig has by far the most-developed user experience
  - Two-way transmission between stylus and p-cap sensor
    - Stylus receives p-cap sensor drive-signal, amplifies it, adds digitally encoded stylus information, and transmits it back to sensor
    - Atmel was the first to put this into production, but their user experience is still very immature
  - Stylus generates intense e-field at tip
    - E-field adds capacitance to p-cap sensor operating as usual (finger subtracts capacitance)
    - Unclear if anyone is actually doing this…

Active P-Cap Stylus…3

- **Advantages**
  - Uses existing (single) p-cap sensor
  - Pen “hover” (mouseover = move cursor without clicking)
  - Stylus tip can be very small (< 1 mm)
  - High resolution and accuracy

- **Disadvantages**
  - Stylus requires power source (battery or super-capacitor), which requires charging contacts in stylus-garage and charging circuit in host computer
  - Stylus technology is unique to each p-cap controller supplier
    - Total lack of interoperability will probably prevent active stylus from ever becoming mainstream
    - OEMs’ desire to obtain high margin on accessories makes the problem even worse

Active vs. Passive Stylus Summary

- **This battle's been going on since the 1990s…**

Passive ← versus → **Active**

Passive:
- Very low-cost
- "Good enough"
- Improves as SNR increases
- #2 pencil is the gold standard
- "Artificial finger" in Windows
- More flexibility in Android

Active:
- More expensive
- Pressure-sensing
- Hover (required for Windows)
- Higher resolution
- Customizable features

P-cap (powered):
- **N-Trig** leads
- Others following
- **NO** interoperability

EMR (batteryless):
- **Wacom** leads
- Others insignificant
- 2nd sensor

Cost in high-volume is surprisingly close

Prediction

- **Passive stylus is going to win (become mainstream)**
  - Being “good enough” is very important in the touch industry!
  - It’s the lowest-cost solution
  - However…
    - There is still some chicken-and-egg regarding good support for stylus in application software
    - Some OEMs haven’t bought into the need for a stylus yet (more chicken-and-egg)
- **Active stylus will remain a niche**
  - Active stylus’ total lack of interoperability and very high price as a replacement accessory will prevent it from ever becoming mainstream

Other Active-Stylus Technologies

- **Combination ultrasonic & infrared**
  - Used in many clip-on and clipboard-style digital note-taking accessories; also available for iPad
- **Embedded CMOS-camera stylus by Anoto**
  - Widely licensed for digital-pen note-taking accessories and form-filling applications
  - Used by LG Displays in large-format touch
  - Used in Panasonic 4K 20” professional tablet shown at CES 2013
- **Infrared LED light-pen**
  - Used by iDTI in their light-sensing in-cell touch monitor
- **Visible laser-pointer**
  - Used by isiQiri in large-format touch
  - Also works with iDTI light-sensing in-cell touch

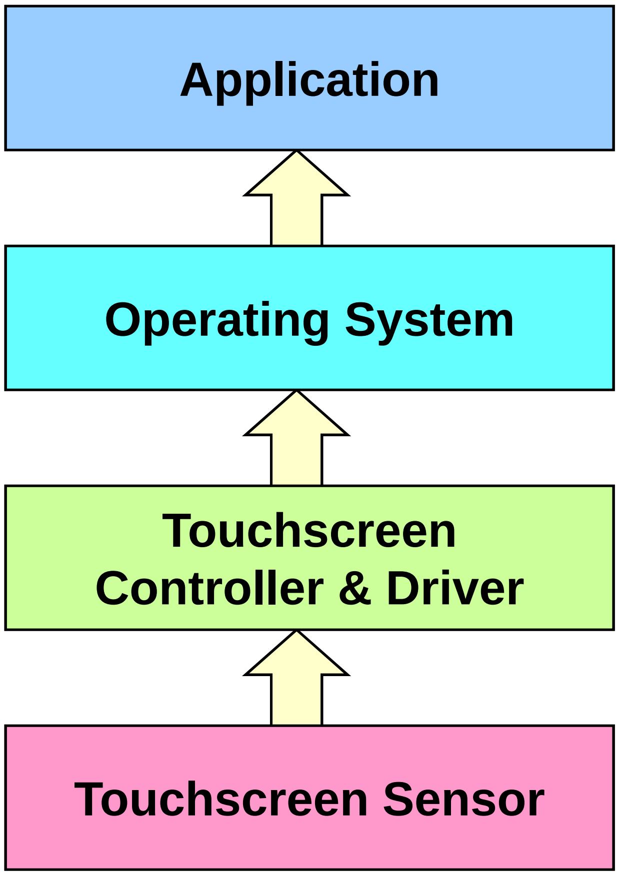
Software

- Multi-Touch
- OS Application-Development Support
- Middleware

Multi-Touch

- ***Multi-touch*** is defined as the ability to recognize two or more simultaneous touch points
- Multi-touch was invented in 1982 at the University of Toronto *(not by Apple in 2007!)*
- "Pinching" gestures were first defined in 1983 *(not by Apple in 2007!)*
- Windows 7 (2009) & Windows 8 (2012) both support multi-touch throughout the OS and are architected to support an "unlimited" number (~100) of simultaneous touch points

Multi-Touch Architecture



Capable of decoding multiple streams of moving points and taking actions in response

Capable of delivering multiple streams of moving points (and acting on a defined subset of them)

Capable of delivering sets of simultaneous points to the OS

Capable of sensing multiple simultaneous points

Source: The author

Why Multi-Touch Has Become So Important…1

- **Apple**
  - Apple established multi-touch as a "must-have" for coolness. The result is that people of all ages expect every display they see to be touchable with multiple fingers
- **Gaming**
  - Gaming is a natural for multi-touch. Try playing air hockey without multi-touch…
- **Unintended touches**
  - One of the major values of multi-touch is to allow the system to ignore unintended touches ("palm rejection", "grip suppression", etc.). As desktop screens become more horizontal (recline) this will become even more important.

Why Multi-Touch Has Become So Important…2

- **Multi-user collaboration**
  - When two people want to collaborate on a large screen (e.g., a student and teacher on an interactive "whiteboard" LCD), multi-touch is essential
    - Identifying which touch belongs to which user is still unsolved
    - It IS currently possible to uniquely identify multiple simultaneous styli

How Many Touches Are Enough?...1

- **The industry has multiple answers**
  - Microsoft settled for 5 touches in Win8 (they wanted 10)
    - But now under pressure from OEMs they have buckled and reduced it to TWO touches for All-in-One desktops (BIG mistake!)
  - The p-cap touchscreen suppliers under 30” either say “10” or “as many as possible” (e.g., 3M’s p-cap supports 60+ touches)
  - The large-format touchscreen suppliers say that 40 is enough
- **In practice it depends on the hardware and controller firmware implementation**
  - Ideally the touchscreen should ***ignore*** all other touches beyond however many the product is guaranteeing
  - This is usually called “***palm rejection***” and its implementation is absolutely critical to the user experience

How Many Touches Are Enough?...2

- **The answer actually depends on the application**
  - For a small mobile device, 2-5 (one hand) are enough
  - For a single-user app on any device (even an 82” screen), it’s hard to see why more than 10 (two hands) are needed
  - For a multi-user app, it depends…
    - For a 55-inch gaming table, 40 (8 hands) is not unreasonable
      - The key touchscreen specification is probably response time (latency)
    - For a 65-inch interactive “whiteboard” LCD, 20 (4 hands) is probably enough, although an argument can be made for 40
      - BUT, the key touchscreen specifications are entirely different: minimum stylus tip size, pre-touch, jitter, ink-lag, etc., can all be critical

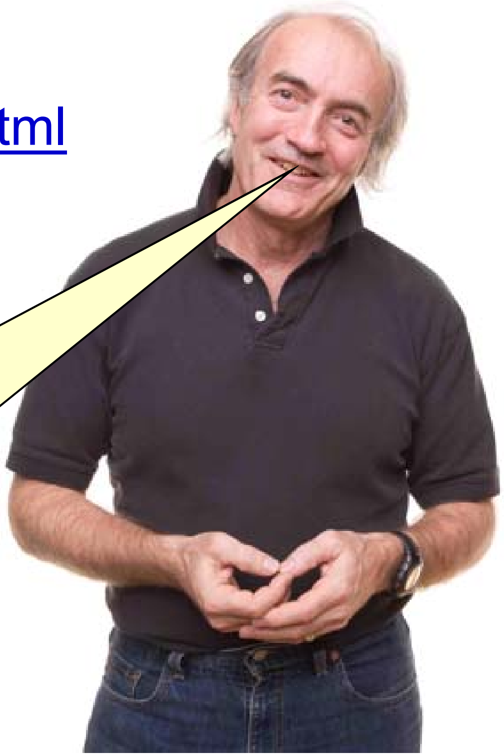
Source: FlatFrog

From a video of a very cool multi-player game on the FlatFrog website

#1 Reference On Multi-Touch

- **“Multi-Touch Systems that I Have Known and Loved”**
  - www.billbuxton.com/multitouchOverview.html

“If you can only manipulate one point … you are restricted to the gestural vocabulary of a fruit fly. We were given multiple limbs for a reason. It is nice to be able to take advantage of them.”



Bill Buxton, 2008
Principal Researcher,
Microsoft Research

For Windows, the "Logo" Is the Starting Point

- **A set of touch performance standards designed to ensure a high-quality user experience**
  - 5 touch-point minimum
  - Touchscreen jitter
  - Extra input behavior
  - High-resolution timestamp
  - Input separation
  - Noise suppression
  - Physical input position
  - Reporting rate
  - Response latency
  - Cold boot latency
  - Touch resolution
  - User experience
  - Pre-touch
  - Pen tests

Windows 8 Touch

- **The Win8 Touch Logo specification is based on p-cap**
  - Win7 spec was based on optical, which had little relevance
  - Win8 spec creates a common touch capability for mobile phones, tablets, notebooks, and desktops
    - This may be very significant for multi-platform applications!
- **Basic spec requirements**
  - Minimum of 5 simultaneous touches; must ignore an additional 5
  - Tablets must be zero-bezel; otherwise 20 mm border minimum
  - Respond to first touch in < 25 ms
  - Subsequent touches must be < 15 ms at 100 Hz for all touches
  - Better than 0.5 mm accuracy with < 2 mm offset from actual location
  - No jitter when stationary; < 1 mm when moving 10 mm
  - Pre-touch < 0.5 mm
  - **Finger separation** >= 12 mm horizontal/vertical, 15 mm diagonal
    - But on-screen keyboards and normal human behavior violates this!

Windows 8 Touch Application Development

Windows 8

- **There are multiple development environments commonly used in Windows 8, each of which handles touch differently**
  - Native C++ (Win32/COM)
  - Managed environment (.NET Framework)
  - Silverlight & WPF (Windows Presentation Foundation)
  - Adobe Flash
  - Modern (Win-8) using C# and XAML or HTML5 and JavaScript
    - Modern apps today only represent one aspect of business computing: reporting/dashboards, with moderate-to-light data updating
- **From my perspective…**
  - As a hardware person, I find the level of detail required to do anything significant in touch software to be excruciating

Android Touch Application Development

- **Android has an extensive and growing API for touch & stylus**
  - I hear complaints about the degree of bugginess
  - From what I can tell, the level of tediousness is a little better than Windows
  - The Android API supports up to 256 touches, but the actual number depends on the hardware & firmware implementation in the device – 2 to 5 isn't unusual
  - Fragmentation of Android (different versions from each OEM) appears to make developing a robust run-on-anything Android touch application very difficult
- **The language decision is easy – it's Java or nothing**

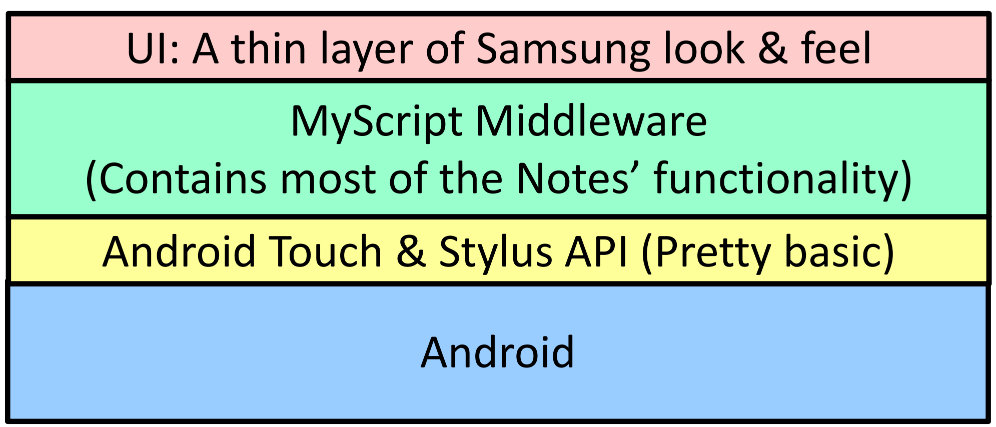
iOS Touch Application Development

iOS 7

- **iOS seems to have the most constrained touch application development environment**
  - But it’s not any easier than Android -- in the chapter on touch in “Programming iOS 5” (an O’Reilly book), the words “messy” and “tricky” seem to occur a lot
- **The language decision is easy – it’s Objective-C or nothing**

Middleware…1 (Consumer Electronics)

- **The best example of middleware in CE devices is from MyScript (formerly “Vision Objects”)**
  - This is what makes the Samsung Galaxy Notes possible
  - Extremely powerful, configurable capabilities
    - Note-taking, handwriting recognition, mathematics (including equations), music notation, even “ink as a data-type” (same concept as in Windows, stores both ink and ASCII text)



Source: The author

Samsung Galaxy Notes’ software stack

Middleware…2 (Large-Format / Commercial)

- **The best middleware for large-format applications (in the author's opinion) is Snowflake**
  - Good starting point for commercial applications
  - Includes 30+ multi-touch apps (entertainment, presentation, creativity, media-browsing, etc.)
  - Includes an SDK
  - Runs on Win 8/7/Vista/XP, Mac OS X Lion & Snow Leopard, and Linux Ubuntu
- **Snowflake simplifies handling…**
  - Touch & gesture events, audio, video, images
  - PDFs, 3D, on-screen keyboards, web browsing
  - Multiple languages, QuickTime integration, etc.

Middleware…3

❖ **Snowflake home screen**

Source: NuiTeq

Middleware…4

- **Other alternative “middleware” for large-format**
  - Omnitapps
    - Less complete, Windows only, no SDK, more for product marketing
  - Intuilab
    - Commercial multi-touch application platform with Kinect, RFID, etc.
  - GestureWorks (Ideum)
    - Robust Flash multi-touch development environment
  - 22 Miles
    - Sales productivity application for iOS, Android, Windows & Mac
  - Sotouch
    - Application platform for wayfinding and presentations
  - Fingertapps (Unlimited Realities)
    - Multi-touch demo software

Conclusions

- Future Trends & Directions
- Suggested Reading on Touch
- Recommended Conferences & Trade Shows on Touch

Future Trends & Directions…1

- **P-cap is here to stay**
  - It is totally dominating consumer electronics
  - Consumer p-cap is getting much closer to meeting commercial application requirements
    - For example, glove-touch and water-resistance
  - P-cap's capabilities are becoming increasingly attractive in commercial applications
    - Curved touch-panels, particularly in automotive
    - Light touch expected by ALL touch-panel users
    - Flat-bezel in customer-facing applications
    - Multi-touch wherever images are viewed (e.g., photo-printing kiosk)
  - The forecasts for commercial penetration of p-cap are MUCH too conservative

Future Trends & Directions…2

- **ITO-replacements are going to have an increasingly significant impact**
  - Performance increase
  - Sensor cost reduction (including CAPEX)
  - Printed metal-mesh is going to win

- **Embedded touch will become significant in phones, but not in tablets and larger-screen devices**
  - On-cell will beat in-cell
  - Embedded touch isn't "free", and it reduces feature flexibility
  - Display makers aren't being totally successful competing with the full capability of touch-module makers

Future Trends & Directions…3

- **Many p-cap enhancements have been completed from an R&D viewpoint but haven't been widely sold yet**
  - Hover
  - Glove-touch
  - Water resistance
  - Improved interference-resistance
  - Fine-tipped passive stylus

- **Some enhancements are still under development**
  - Latency reduction
  - True (absolute) pressure-sensing
  - Software integration (running touch algorithms on the host GPU)

Future Trends & Directions…4

- **The biggest remaining problem is that touch still doesn't "just work!" all the time**
  - Missed touches
  - Unintended touches
- **The #1 reason is poor programming, not poor touchscreens (author's opinion)**
- **Touch is continuing to evolve**
  - P-cap controller-makers are continuing to innovate
  - Touch startups are plentiful (5+ mentioned today)
  - The battle between the display-makers and the touchscreen-makers is continuing with no clear winner in sight

Future Trends & Directions…5 (Going Beyond Touch)

- **Intel RealSense™**
  - “Bringing human senses to your devices”
- **User-facing 3D camera use-cases**
  - Entertainment and gaming
  - Interactive reality books
  - Immersive collaboration & creation
  - Object capture
  - Control and navigation
  - Broad enabling of 3D in applications

- **World-facing 3D camera**
  - Google “Intel CES 2014”
- **Download Intel’s Perceptual Computing SDK**

Suggested Reading on Touch…1

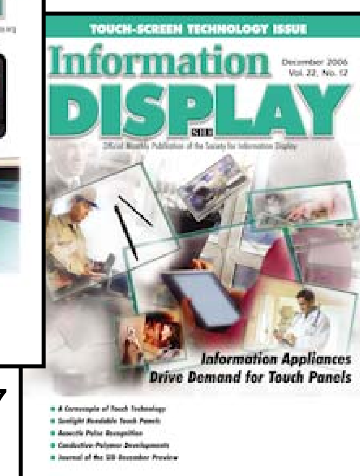
http://www.informationdisplay.org/IDArchive.aspx (2005-2014)

September 2012

March 2011

March 2010

December 2007



December 2006

Even the oldest issue still contains useful information (e.g., on surface capacitive)

Suggested Reading on Touch…2

Touch Panel

Veritas et Visus

June 2012 Vol 6 no 8

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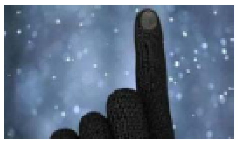
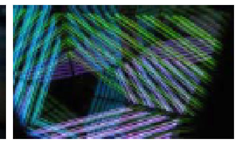

Alice Ning, p12


MIT, p21


DNP, p44

The *Touch Panel* is focused on bringing news and commentary about the activities of the companies and technologies related to touch screens and related technologies for the displays industry. The *Touch Panel* is published electronically 10 times annually by Veritas et Visus, 3305 Chelsea Place, Temple, Texas, USA, 76502. Phone: +1 254 791 0603. http://www.veritasetvisus.com

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1

At $49/year for 10 issues,
this is an excellent value
as a source of touch news
and touch-conference reports

www.veritasetvisus.com

Suggested Reading on Touch…3

News | **32** new results for **touch-screen**

[Califone Intros **Touchscreen** MP4 Player for Education]
T.H.E. Journal
Designed for education, Califone's new **touchscreen** media player supports individual and small group digital learning activities.
See all stories on this topic »

["New" Tactile iPhone 5 **Touchscreen** Rumor Recycles "Haptic ...]
The iPhone 5 News Blog (blog)
iPhone 5 rumors die hard — and seem to come around and again and again. This time, it's the "new" tactile iPhone 5 **touchscreen**. The new story was spurred ...
See all stories on this topic »

[Nintendo Wii U Console and **Touchscreen** Controller: Hands-on ...]


IBTimes.co.uk

IBTimes.co.uk
Nintendo Wii U release date: Christmas 2012. Price: £279.99 (unconfirmed). Rating: Very playable.
See all stories on this topic »

[Tactus reveals pop-up **touch-screen** keyboard]
ITWeb
Tactus reveals pop-up **touch-screen** keyboardTactus Technology has unveiled a new technology that brings the feedback of touching something back to a ...

Use Google Alerts to track your favorite touch keywords

News | **5** new results for **"touch technology" OR "multi-touch"**

[Nintendo Explains Choice for Single-Touch Wii U GamePad ...]


Nintendo World Report

Nintendo World Report
Nintendo of America President Reggie Fils-Aime explained the company's stance on using single-touch functionality as opposed to **multi-touch** functionality with ...
See all stories on this topic »

[HP boosts thin client capabilities]
ITWeb
HP is enabling customers to expand the use of thin clients for **multi-touch** business applications, such as self-service banking and digital signage kiosks, ...
See all stories on this topic »

[Philips Exhibits Innovative Digital Signage Displays at ...]


Digital Signage Connection (press

Digital Signage Connection (press release)
The Infrared Sensing **Multi-Touch technology** allows for multiple simultaneous touch points at the same time. This technology is ideal for large screen digital ...

Suggested Conferences and Shows on Touch & Interactivity…1

- **SID's Display Week (San Jose, CA, 5/31- 6/5, 2015)**
  - Exhibits, Symposium Touch Papers on Thursday, Sunday Short Course, Monday Technology Seminars, Tuesday Exhibitors' Forum, Wednesday Touch-Gesture-Motion Conference
- **IHS' Touch-Gesture-Motion conferences (USA & Europe)**
- **Touch China (Shenzhen, China)**
- **C-Touch (Shenzhen, China; <u>not</u> Shanghai)**
- **Computex (Taipei - consumer electronics products)**
- **InfoComm (USA - large-format commercial products)**
- **DisplaySearch Emerging Display Technologies (USA)**
- **FPD International (Japan)**
- **ACM's SIGGRAPH (USA)**
- **ACM's Interactive Tabletops & Surfaces (USA)**

Suggested Conferences and Shows on Touch & Interactivity…2

- **Shows with commercial touch applications**
  - National Retail Federation (NRF-USA)
  - Healthcare Information Management Systems Society (HIMSS-USA)
  - Global Gaming Expo (G2E-USA & G2E-Asia)
  - Digital Signage Expo (DSE-USA)
  - Customer Engagement Technology World (CETW-USA) (Formerly "KioskCom")
  - Integrated Systems Europe (ISE-Europe)

Thank You!

File Download: **www.walkermobile.com/SID_2014_Short_Course_S1.pdf**

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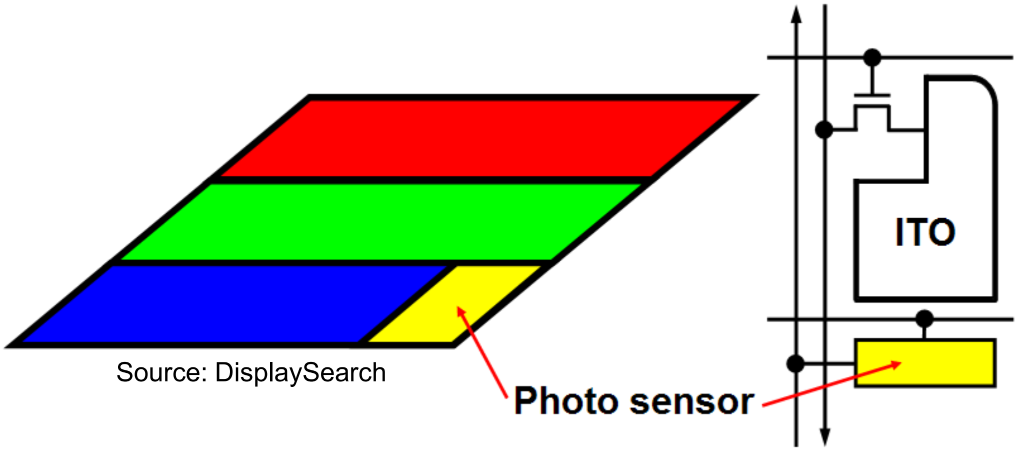
Santa Clara, CA 95054	408-765-19 fax	

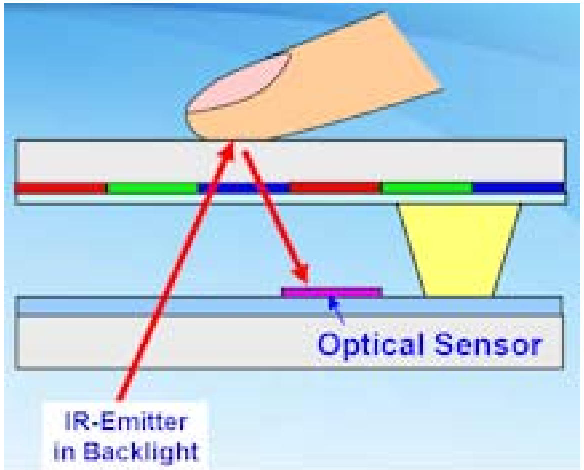
Appendix A
Historical Embedded Touch

- In-Cell Light-Sensing
- Pressed Capacitive
- In-Cell Voltage Sensing
- In-Cell Self-Capacitive

In-Cell Light-Sensing



Source: DisplaySearch



Source: Samsung

❖ Principle

- ✦ Photo-sensor added in each pixel (rare) or group of pixels (4 to 16)
  - IR sensor (aSi or aSiGe) added to TFT array
  - IR emitters added to backlight
  - Does not depend on ambient light (as in original design from 2003)
- ✦ Works with finger or light-pen; can work as a <u>scanner</u>
- ✦ Adding a cover-glass to protect the surface of the LCD reduces touch sensitivity because the finger is further away from the sensors

First Product with In-Cell Light-Sensing

- **Sharp's PC-NJ70A netbook (5/09)**
  - Optical in-cell touch in 4" CG-silicon 854x480 touchpad LCD (245 dpi)
    - 1 sensor per 9 pixels
    - LED backlight
    - Stylus & 2-finger multi-touch
    - Scanning (object recognition)
    - Japan-only; $815
  - Problems
    - Required adding IR emitters into backlight
    - **S L O W** (25% of typical touchpad speed)
    - Short battery life

Source: Sharp

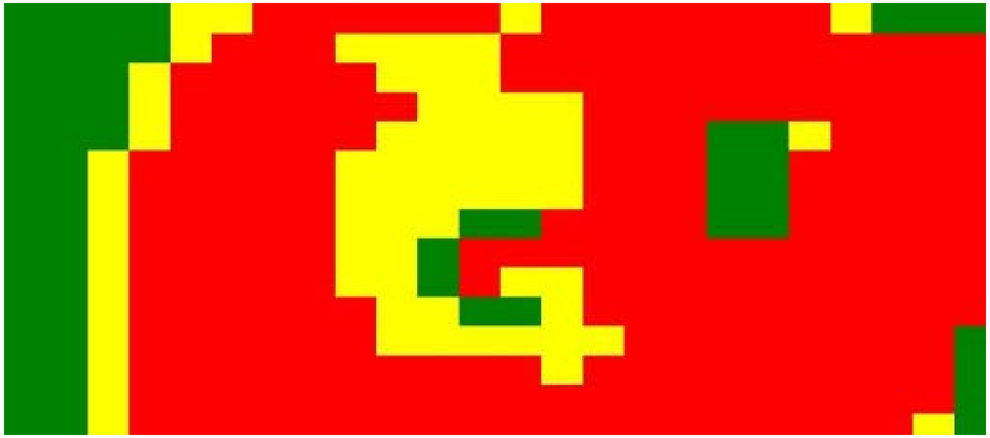
Second Product with In-Cell Light-Sensing

- **Samsung SUR-40 (PixelSense)**
  - aSiGe sensor is 15X more sensitive than aSi, but that means the touch-screen is **15X more sensitive to ambient IR**

Maximum Surface-2 lighting for acceptable performance

Lighting Type	Max Lux
Compact Fluorescent	600
Cool White LED	560
Vapor Lamps	530
Sunlight (filtered through window)	400
Metal Halide	370
Warm White LED	300
Sunlight (direct)	160
Halogen	60
Incandescent	50

Example Output



Environmental Lighting Optimizer Output

Unique Product with In-Cell Light-Sensing

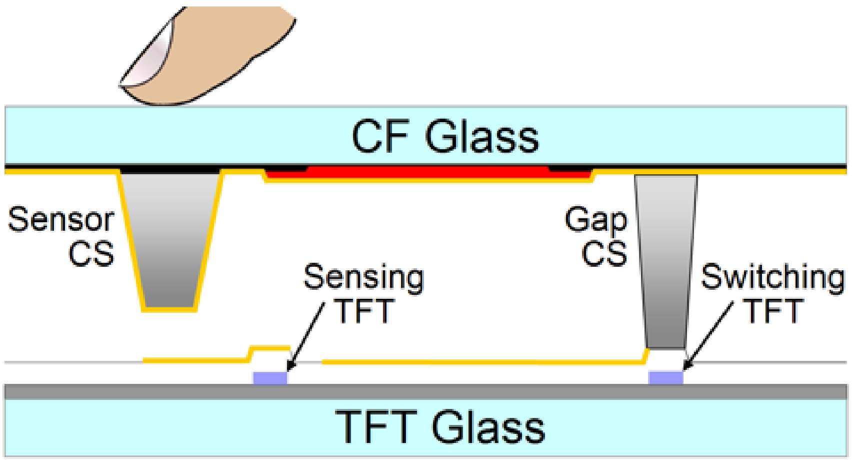
- **Integrated Digital Technologies light-pen monitor**
  - 21.5” in-cell light-sensing monitor with IR light-pen
  - Supports two-touch with two pens
  - Backplane by Taiwan CPE

Source: IDTI

Source: Photo by author

In-Cell "Pressed" Capacitive

Also called "Charge Sensing"



Source: LG Display

Principle

- Pressing the LCD changes the dielectric constant of the liquid crystal, which changes the capacitance between the conductive column spacer (CS) and the flat electrode in the TFT array. Electrode pairs can be in one pixel or in a group of pixels.
- Works with any touch object within damage limits of top polarizer
  - Human body capacitance and dimensional change between electrodes are NOT relevant factors
  - Requires deflecting the LCD surface (<u>cannot add a cover glass</u>)

First Product with In-Cell Pressed-Capacitive…1

- **Samsung ST10 camera with 3” 480x320 transflective TFT with in-cell pressed-capacitive touch (4/09)**
  - First use of any in-cell touch in a commercial product
  - Works with finger or stylus, but with visible pooling
  - Surface hardness = low
  - Touch-screen includes electrostatic haptic feedback
  - Camera includes MP3, PMP & text-viewer functions
  - One sensor per 8 pixels (60x40 sensing matrix)

Source: Samsung

First Product with In-Cell Pressed-Capacitive…2

- **Excerpt from Samsung ST-700 digital camera manual**

Touching

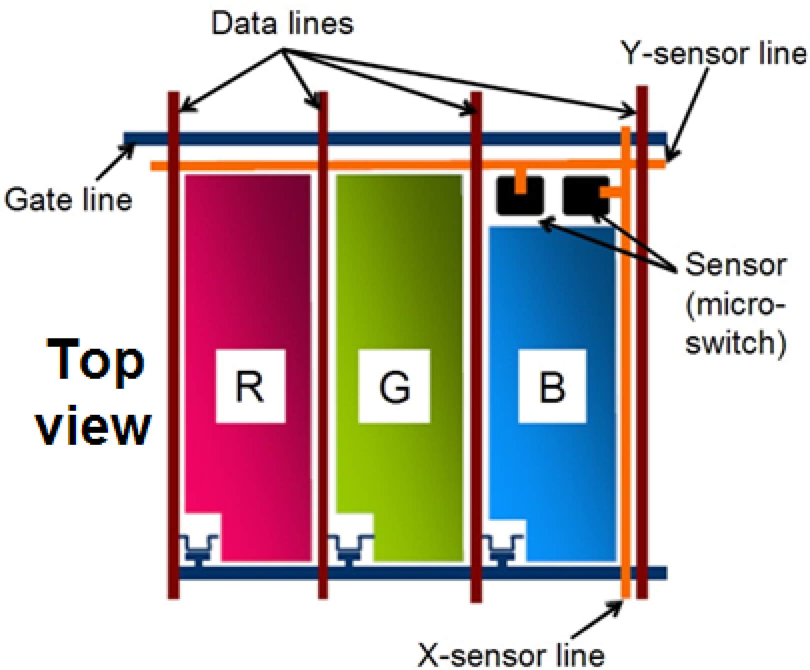
Touch an icon to select a menu or option.

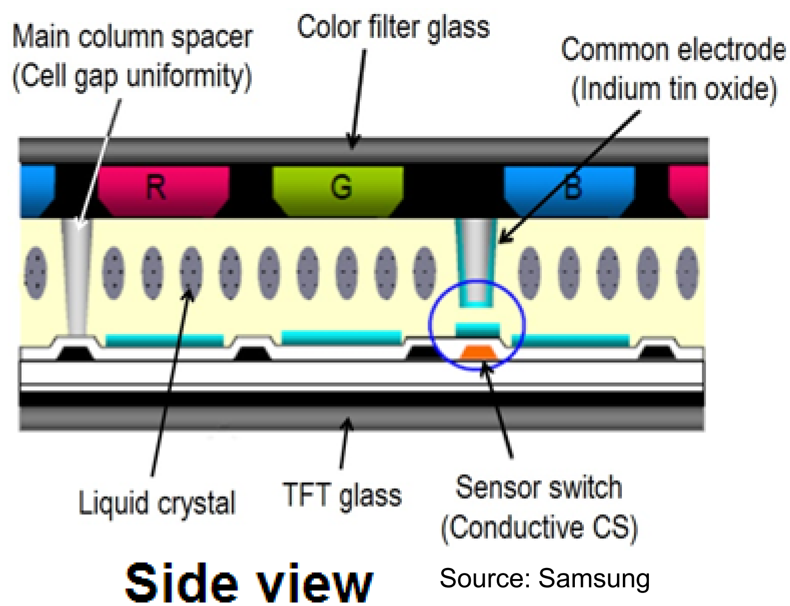
Flicking

Gently flick the touch pen across the screen.

- Do not use sharp objects, such as pens or pencils, to touch the screen. You can damage the screen.
- The touch screen may not recognize your inputs if you touch multiple items at the same time.
- The touch screen may not recognize your inputs if you touch the screen with your finger.
- When you touch or drag the screen, discolorations may occur. This is not a malfunction, but a characteristic of the touch screen. Touch or drag lightly to minimize the effect.
- The touch screen may not work properly if you use the camera in extremely humid environments.
- The touch screen may not work properly if you apply screen protection film or other accessories to the screen.

In-Cell Voltage-Sensing (also Called "Switch-Sensing" and "Resistive")

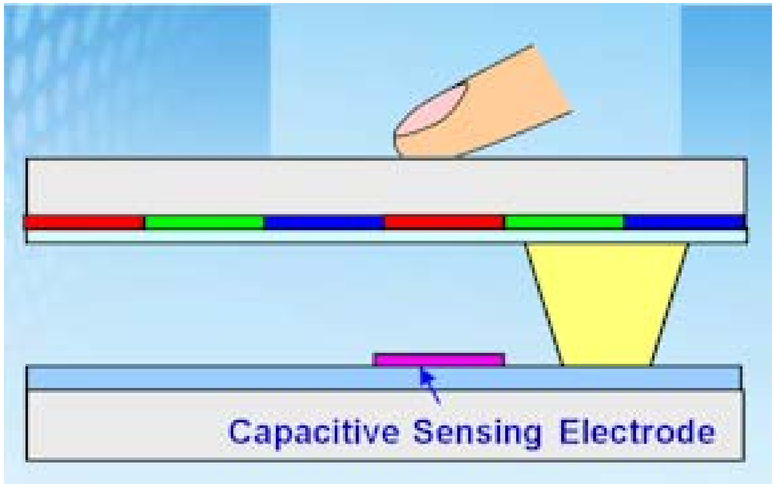




- **Principle**
  - Pressing LCD surface closes X & Y micro-switches in each pixel or group of pixels
  - Requires deflecting the LCD surface (cannot add a cover glass)
  - Works with any touch object within damage limits of top polarizer

In-Cell Self-Capacitive

- **Principle**
  - A single electrode per sensing element in the TFT array is connected to a reference capacitor. When a finger touches the LCD, the voltage at the electrode changes due to the capacitive coupling of the user's body-capacitance to ground.
  - Works only with finger; no pressure is required
  - Adding a cover glass reduces touch sensitivity; reduction in SNR can make touch non-functional in noisy environments



Source:
Drawing = Samsung & Author;
Information = Toshiba Mobile Display