Status and Future of Touch Technologies

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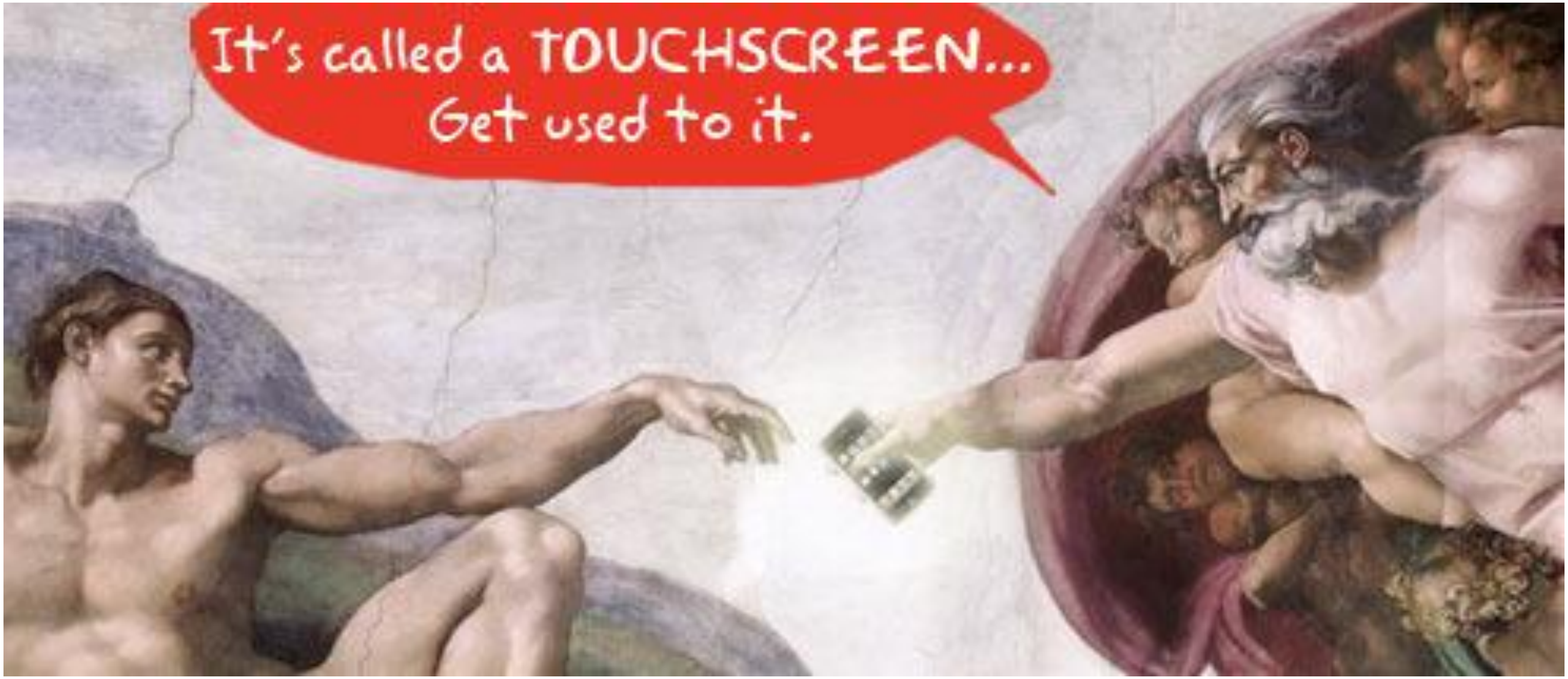
Agenda

- Status of Touch Technologies
- Touch Penetration
- Multi-Touch Infrared
- ITO-Replacement Materials
- Embedded Touch
- Stylus
- P-Cap Futures

Status of Touch Technologies

Status of Touch



Source: Gizmodo

(Michelangelo's "The Creation Of Adam“, in the Sistine Chapel, 1511)

Status of Touch Technologies By Size & Application

Touch Technology	Mobile (2" – 17")	Stationary Commercial (10" – 30")	Stationary Consumer (10" – 30")	Large-Format (>30")
Projected Capacitive	A	A	A	A
Surface Capacitive		L		
Analog Resistive	L	A	L	
Analog Multi-Touch Resistive (AMR)	D	D	D	
Digital Multi-Touch Resistive	D			
Surface Acoustic Wave (SAW)		A	D	A
Acoustic Pulse Recognition (APR)	D	A		D
Dispersive Signal Technology (DST)				L
Traditional Infrared (IR)		A		A
Multi-Touch Infrared	A		E	E
Camera-Based Optical			A	A
Planar Scatter Detection (PSD)				E
Vision-Based (In-Cell Optical)				D
Embedded (In-Cell/On-Cell Capacitive)	A			
Force Sensing		D		

A = Active L = Legacy E = Emerging D = Dead/Dying

Touch Penetration

Touch Penetration…1

- **What's left to penetrate?**
  - Mobile phones – DisplaySearch (DS) estimates 95% in 2018
  - Tablets – 100%
  - Ultrabooks – Intel requires touch on Ultrabooks™ on Haswell
  - Notebooks – **DS estimates 37% in 2018**
  - All-in-ones – It's a roller-coaster; DS estimates 23% in 2018
  - Monitors (consumer) – Very resistant; DS estimates <2% in 2018
  - Large-format – Interactive digital signage: **S..L..O..W** but exciting
  - Commercial – Touch has been there for 30+ years
  - Automotive – Already 20% in 2013 (design wins, not shipped cars)

Touch Penetration…2

- **What will it take to drive touch into notebooks?**
  - Lower cost
  - Touch apps that create consumer pull
  - Touch that's easier or more convenient than alternative input methods
  - Touch that feels natural and responds quickly (low latency!)
  - Touch that's fun and satisfying
  - Windows 8
- **Intel's user-testing of touch on clamshells produced very surprising results**

http://ultrabooknews.com/2013/01/28/digitizers-and-ultrabooks-what-people-want-design-recommendations-and-developer-tips-video-series/
Daria Loi – User Experience Innovation Manager at Intel Corporation
Study released to the public on January 28, 2013

Touch Penetration…3

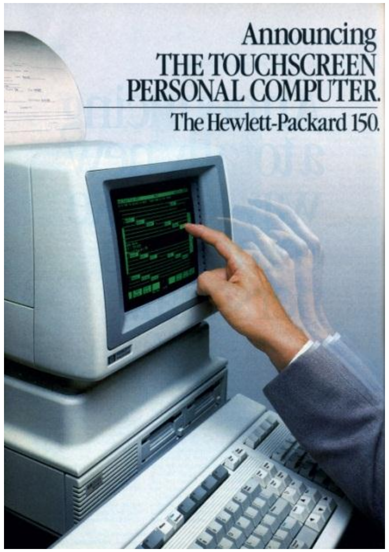
- **Intel is focused on reducing the cost of touch**
  - ITO-replacement materials
    - Top 3: metal mesh, silver nanowires, carbon nanotubes
    - It's not really about the **material**; it's about the **process**
  - Easier/simpler/higher-yield direct bonding (lamination to LCD)
  - Supply-chain improvements
  - Glass ➔ plastic (PMMA)
  - Alternative touch technologies for larger screens

Multi-Touch Infrared

Multi-Touch Infrared…1

- **Why it's interesting**
  - It's an example of how "multi-touch changes everything"
  - IR touch first appeared in **1972** (PLATO IV instructional terminal)
  - IR touch was used in HP's first microcomputer, the HP150, in **1983**
  - After 30+ years of stability, it's changed!

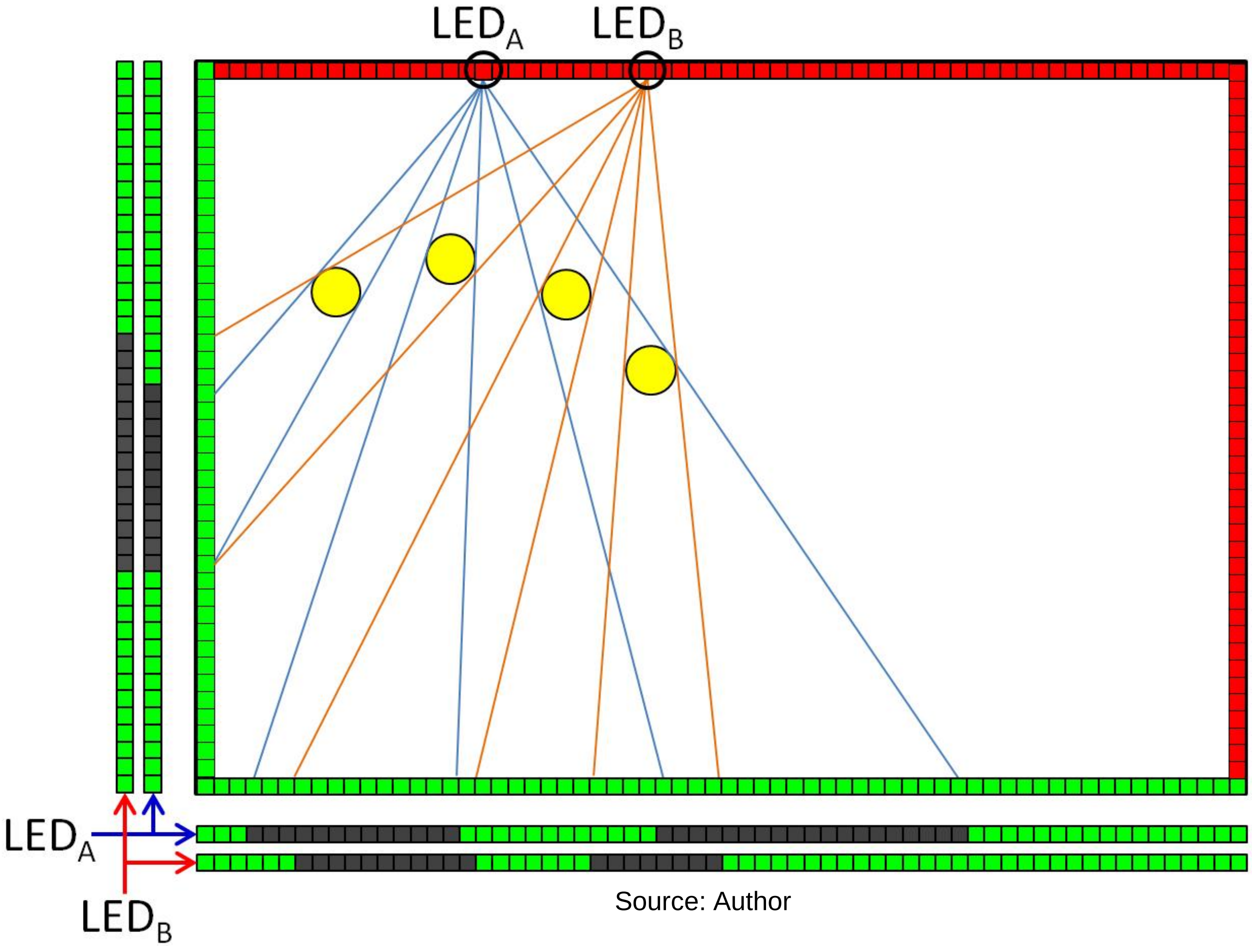
Source: University of Illinois



Source: VintageComputing.com

Multi-Touch Infrared…2

- **“PQ Labs” method**



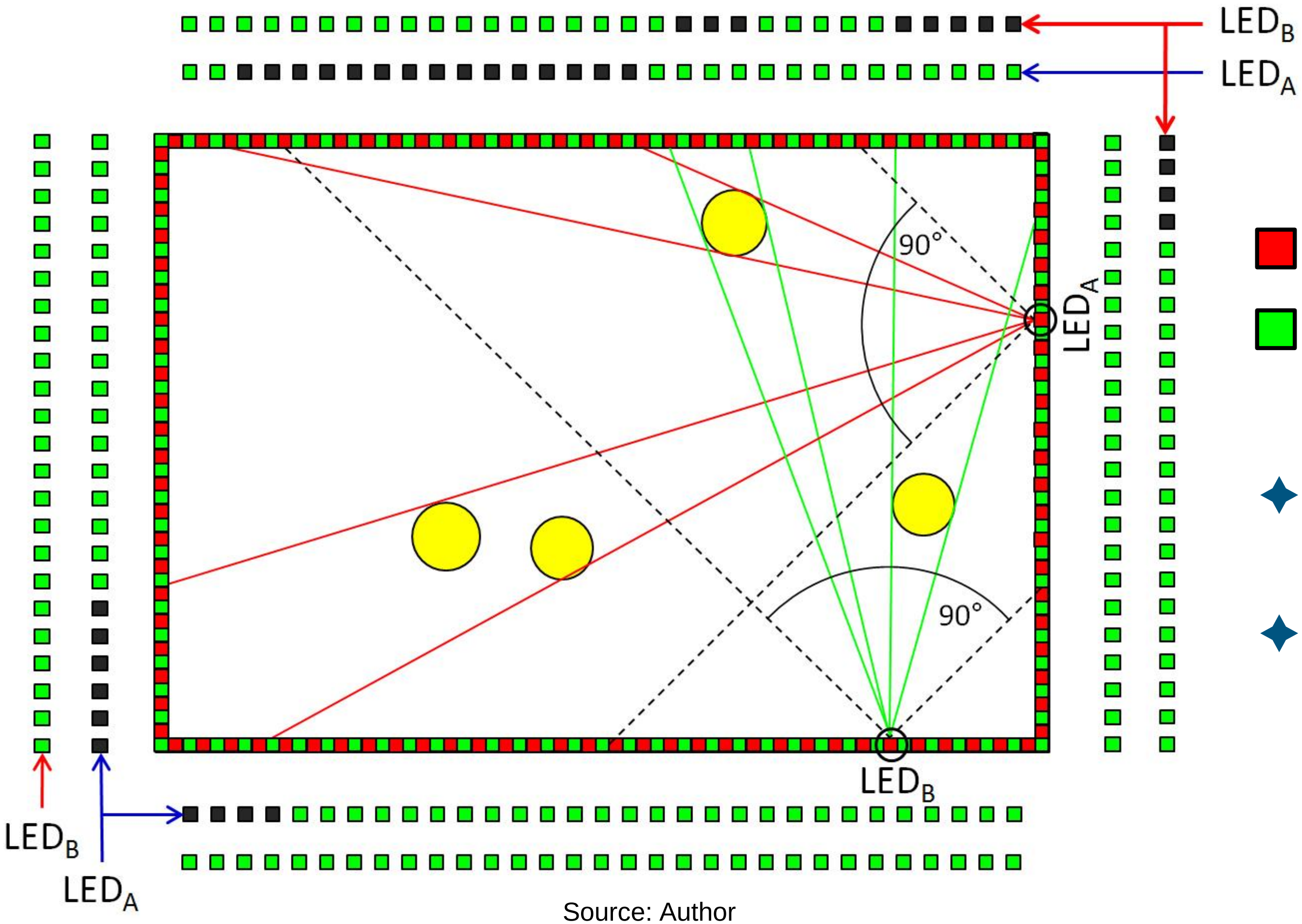
Source: Author

- = IR emitter
- = IR receiver

- 6 to 32 touches
- 32” to 103”

Multi-Touch Infrared…3

❖ **"PulseIR" (Image Display Systems) method**



= IR emitter

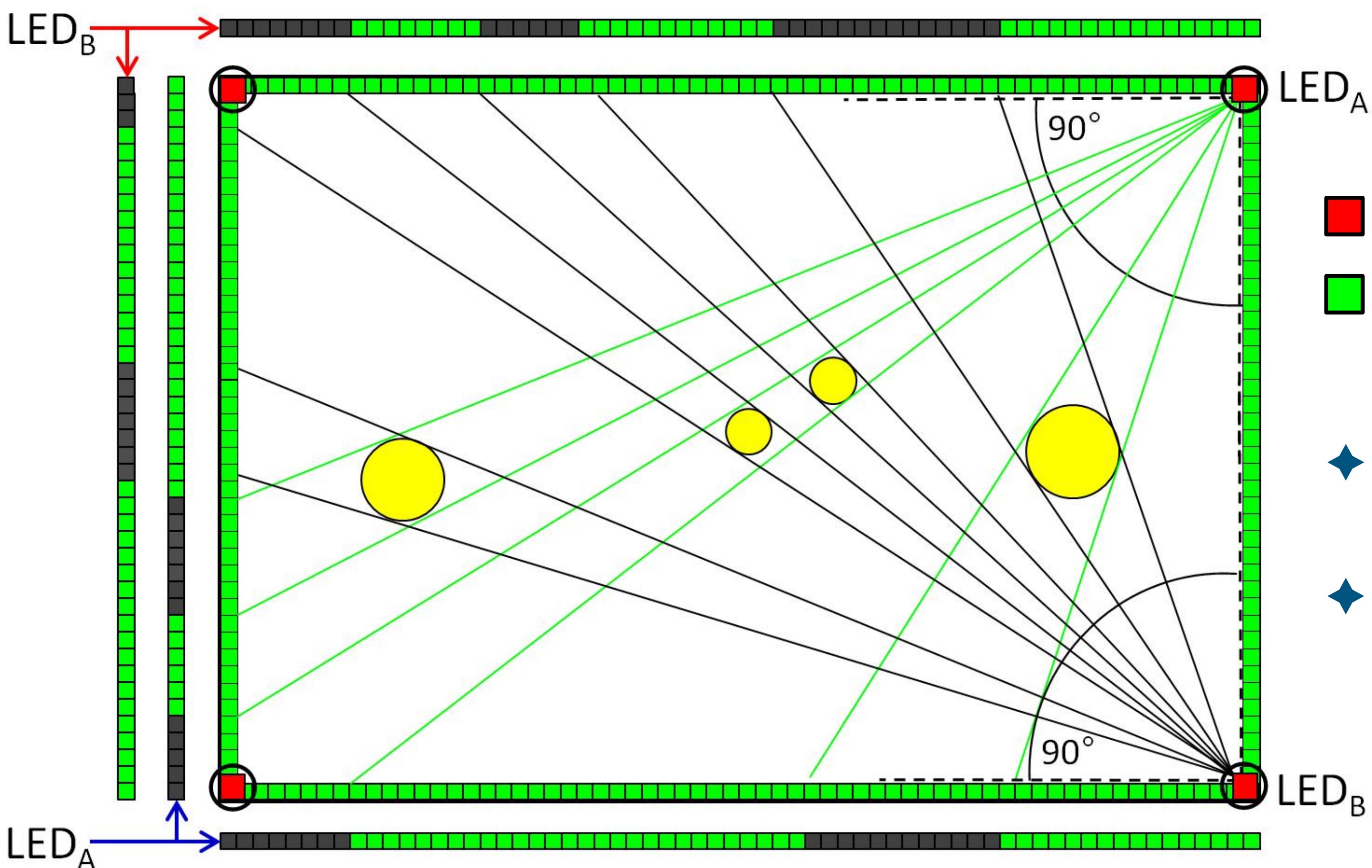
= IR receiver

- 2 to 40 touches
- 5" to 103"

Source: Author

Multi-Touch Infrared…4

- “TimeLink” method



Source: Author

- = IR emitter
- = IR receiver

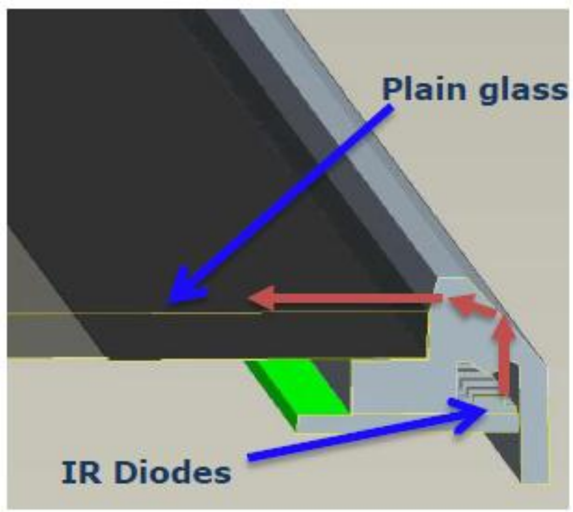
- 10 to **48** touches
- 15” to 100”

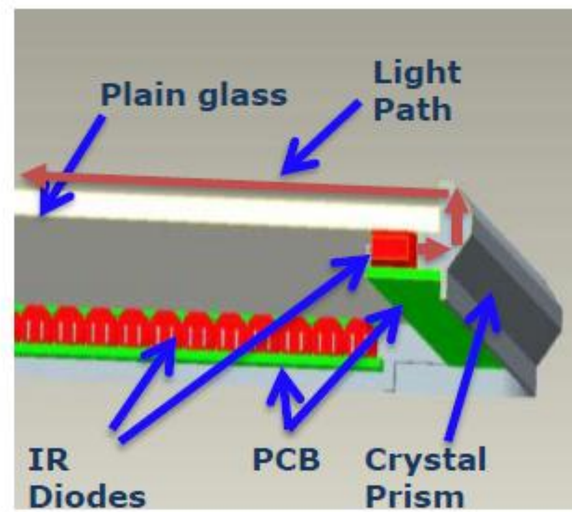
Multi-Touch Infrared…5

- **What's needed to move multi-touch infrared from "emerging" to "active"?**
  - Multi-user applications, starting with games!
  - A solution to the "Which user touched it?" problem
  - Success in **All-in-Ones**

Multi-Touch Infrared…6

- **General Touch's "Projected Infrared Touch" (PIT)**
  - Proprietary design using traditional opto layout (PQ Labs method)
  - Meets Win8 Logo
  - Bezel is a light-guide/prism (**2.5 mm high, 4 mm wide**) that allows IR emitters & receivers to be located under the cover-glass, outside the LCD frame (also reduces parallax due to no top PCB)





Source: General Touch

Multi-Touch Infrared…7

- **Additional PIT features**
  - 15” to 42” size range standard; over 42” is custom
    - First sizes to launch in 2Q-2013 are 21.5” & 23” (for **AiO**)
  - 2-touch for lowest cost; 5-touch for Win8; 10-touch for high-end
    - Only the controller changes
  - Entire surface is touch-active, including the 20 mm (MS) border
    - Active icons can be silk-screened in the border’s black matrix
  - Pre-touch meets the Win8 spec of 0.5 mm
    - Exceptionally low for any infrared touchscreen
  - Touch surface can be any material that meets surface flatness spec
    - Can be sealed to IP65

Now Four Touch Technologies with Win-8 Logo Appropriate for AiOs

- **P-cap**
  - What Win-8 touch was designed around
- **Camera-based optical**
  - The Win-7 touch winner, adapted for Win-8
- **Multi-touch infrared (PIT)**
  - Intelligent use of Microsoft’s “20-mm surround” guideline
- **Planar scatter detection**
  - Already shipping in 32”; makes sense in AiO-size

ITO-Replacement Materials

ITO Replacements…1

- **Why replace ITO?**
  - **Costly to pattern & needs high temperature processing**
  - Highly reflective (IR = 2.6) & tinted yellow; brittle & inflexible
  - Relies on potentially politically unstable Asian zinc mines*
- **Replacement material objectives**
  - **Solution processing (no vacuum, no converted LCD fab)**
  - Higher transmissivity & lower resistivity (better than ITO!)
  - Same or lower material cost than ITO
- **Six replacement candidates**
  - Metal mesh
  - Silver nanowires
  - Carbon nanotubes
  - Conductive polymers
  - Graphene
  - ITO inks

* 63% of estimated 2007 production of indium

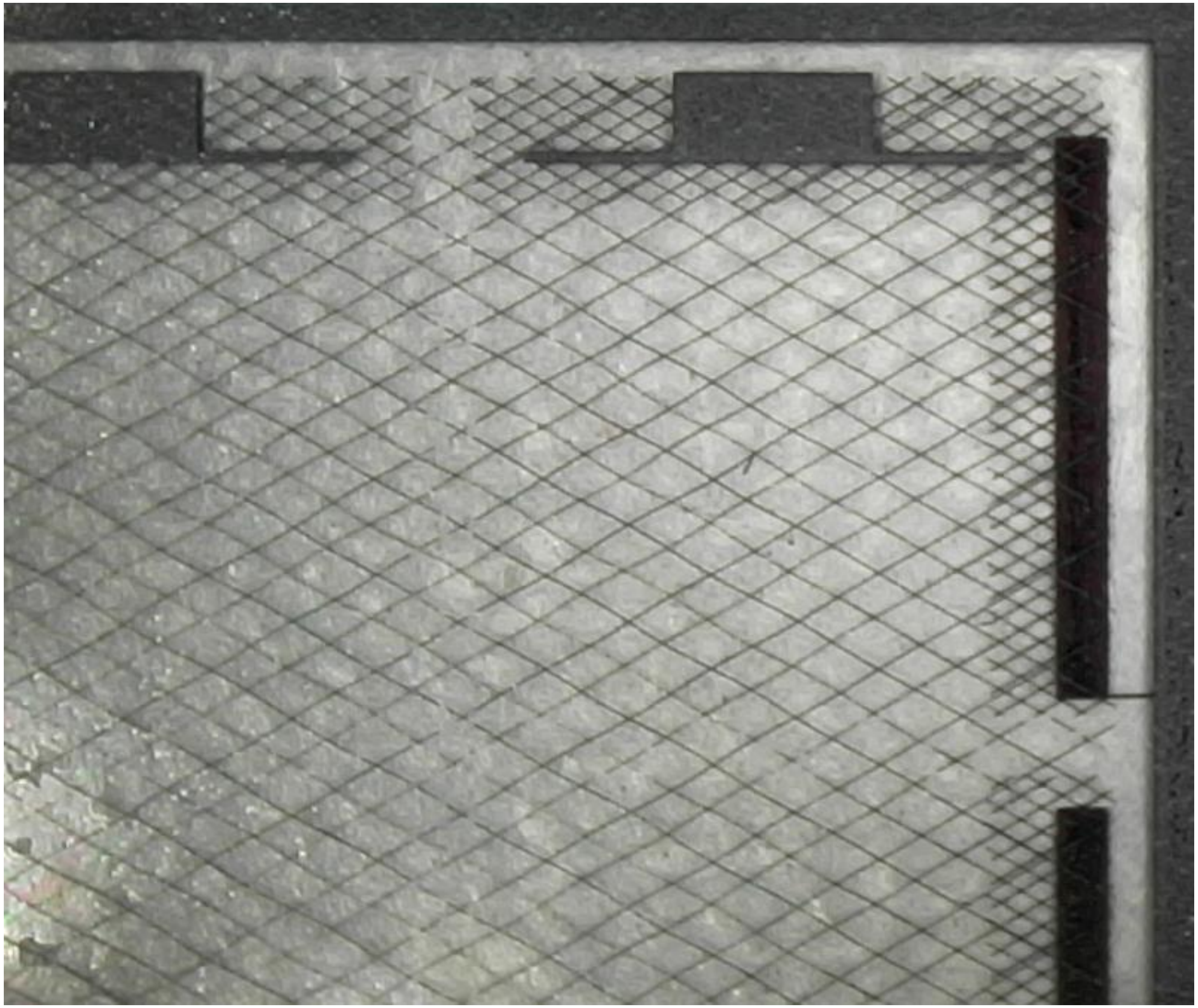
ITO Replacements…2

- **Metal mesh has started shipping in touchscreens, and it's looking better than silver nanowires**
  - **Atmel** (partnered with CIT in the UK) was the first to ship metal-mesh (XSense™) for a smartphone and a 7" tablet in 2H-2012
  - **FujiFilm** has started production of their silver-halide based metal-mesh product
  - **Unipixel** should start production of UniBoss™ this quarter
    - Metal mesh roll-to-roll printable in two passes (one for printing, one for plating) at room temperature
    - They're one of the very few suppliers using printing for patterning: almost everyone else uses photolithography
  - Many other companies are entering this market

ITO Replacements…3

- **Metal mesh has significant advantages**
  - Patterning via printing allows both operating and CapEx cost to be very low
    - Electrodes and border connections are printed simultaneously, which allows borders as narrow as 3 mm (typically 9 mm with ITO)
  - Sheet resistivity is <u>lower</u> than ITO (**under 10 ohms/square**)
    - Reduces p-cap charge time, which allows larger touchscreens
    - Increases SNR and linearity
  - Mesh pattern creates electrical redundancy, which improves yields
  - Transparency is <u>higher</u> than ITO
  - Highly flexible – bend radius typically 4 mm
- **Optical problems have been solved**
  - Invisible mesh, with no moiré pattern

Metal Mesh Example

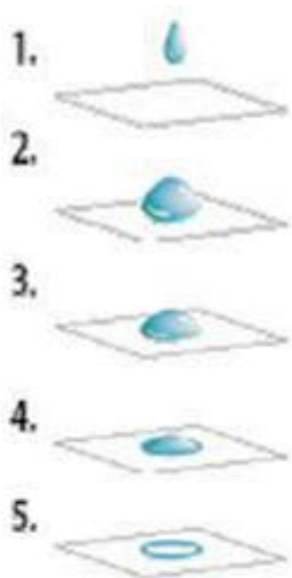


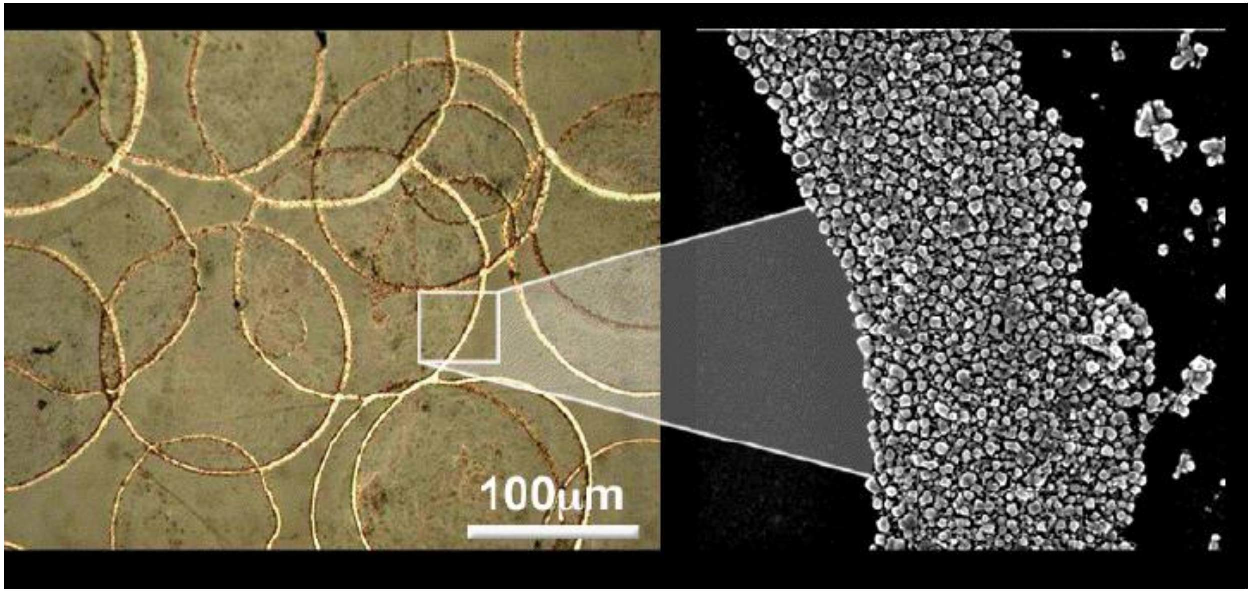
ITO Replacements…4

- **Predictions**
  - Most capital-intensive, fab-based, p-cap module suppliers will resist printed ITO replacements because they have to maintain a targeted return on their invested capital
    - ITO-replacements represent a competitive threat to them
  - An entirely new group of much less capital-intensive touch module suppliers will arise to compete with the existing suppliers
    - Printed sensor-film producers + film integrators
  - Five years from now, as much as 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)

ITO-Replacement Startup: ClearJet

- **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





Embedded Touch

Embedded Touch…1

- **Key defining characteristic**
  - Touch capability is provided by a display manufacturer instead of a touch-module manufacturer
    - 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…2

- **Summary of all p-cap constructions**
  - Embedded sensor
    - **Hybrid In-Cell** = Drive electrodes on TFT array, sense on top of CF glass
      - Example = HTC EVO Design, Sony Xperia S
    - **In-Cell** = Both electrodes on TFT array
      - Example = iPhone-5 & iPod Touch-5
    - **On-cell** = Both electrodes on top of color filter glass (or OLED glass)
      - Example = Samsung S1/2/3, Toshiba Excite 7.7
  - Glass-only sensor (two or more sheets of glass in total)
    - **(CG)G-DITO** = one glass with ITO on each side
      - Example = iPhone-1, iPad-1 & -2
    - **(CG)G-SITO** = one glass with ITO on one side with bridges
      - Example = Kindle Fire & HD, HTC Sensation, many others
    - **(CG)G1** = one glass with two layers of ITO on one side (w/dielectric)
      - Example = Samsung Wave II
    - **(CG)GG** = two sheets of glass with ITO on one side of each (example?)

Embedded Touch…3

P-cap constructions (continued)

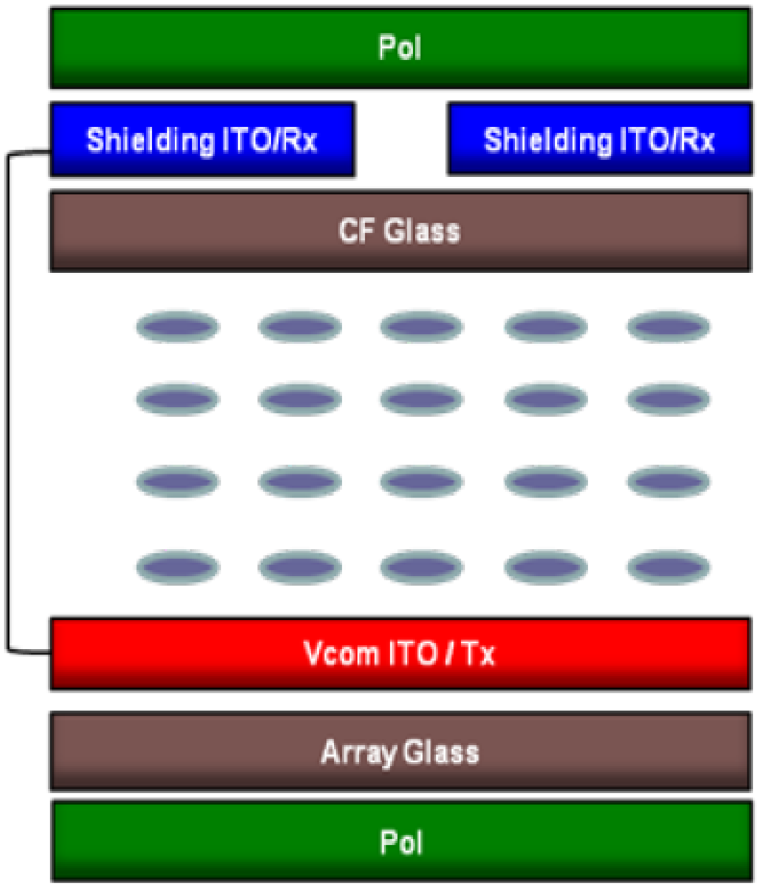
- Film-only sensor
  - **(CG)FF** = two single-sided ITO films
    - Example = Samsung Galaxy Tab 7/8.9/10, HTC One X
  - **(CG)F-DITO** or **(CG)F2** = one double-sided ITO film
    - Example = Apple iPad mini
  - **(CG)F1** = one film with two layers of ITO on one side (with dielectric)
    - Example = ?
- Glass and film sensor
  - **OGS** or **(CG)2** = cover-glass with ITO on one side with bridges
    - Example = Google Nexus 4 & 7, many others
  - **(CG)1F** = cover-glass with ITO on one side and one single-sided ITO film
    - Example = Microsoft Surface RT

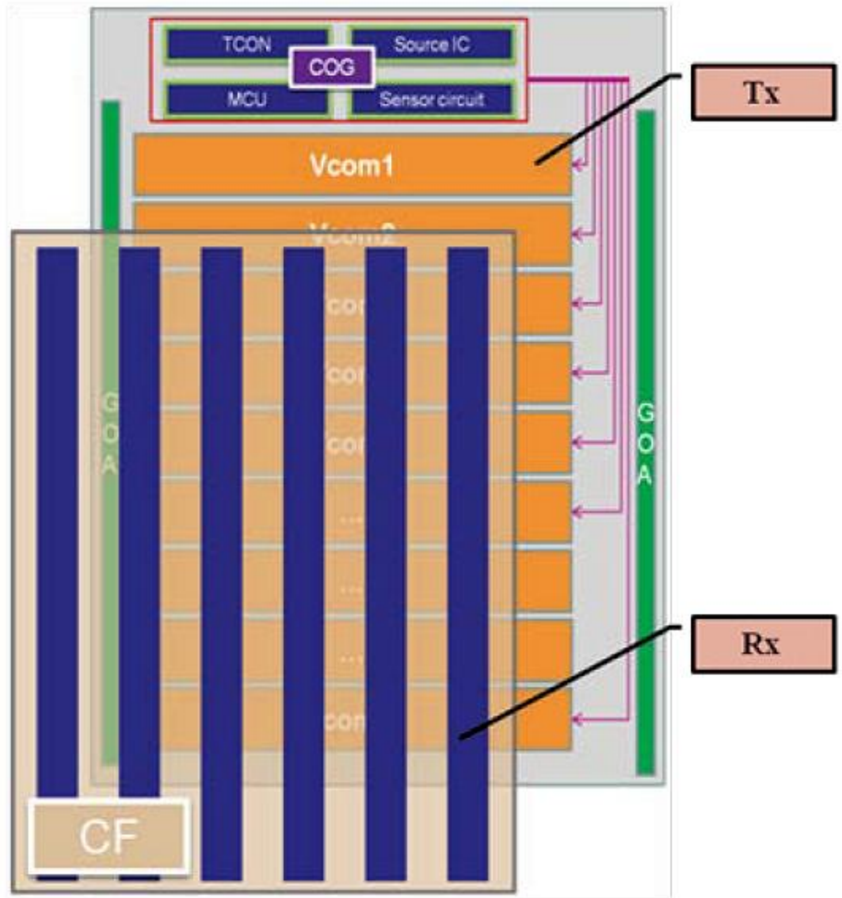
Hybrid In-Cell Mutual Capacitive for *IPS LCDs*

Source: The Author

- **Principle**
  - Electrodes arranged to provide true mutual-capacitance sensing in an IPS LCD while providing a high signal-to-noise ratio (>50 dB)
    - Existing ITO static-shield on top of color filter glass (under the polarizer) is segmented into sense electrodes
    - VCOM electrodes on TFT array are re-grouped into drive electrodes
    - Requires cooperation between touch controller & LCD driver for timing
  - First developed by JDI (Sony) & Synaptics

Hybrid In-Cell Mutual Capacitive for *IPS LCDs*…2





Source: BOE

First Phones Shipped with Hybrid In-Cell Mutual-Capacitive (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 (supports four touches)
- ***Same thickness as one-glass solution!***

Apple iPhone-5 In-Cell

Structure

- <u>Both sense and drive electrodes are in the TFT array</u>, created by switching existing traces so they become multi-functional
  - Required adding one layer (12-mask LTPS ➔ 13 masks)
- They're the only one using this structure; will Apple's patent block others?
  - Apple's yield problems are well-known
- Apple has said they may change to Innolux "Touch On Display" (Innolux's brand name for ALL of their embedded touch structures) in iPhone-6
  - Probably will be on-cell; maybe hybrid in-cell
  - Still touch by a display company, not by a touch module-maker!

Source: CNET

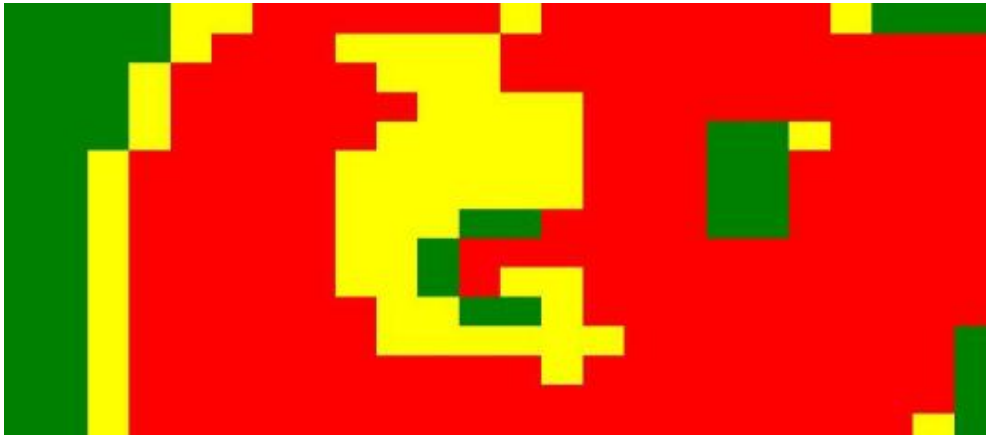
Say Goodbye to All Other Types of In-Cell Except Possibly Light-Sensing

- **"Pressed" capacitive**
  - Currently shipping in some Samsung cameras
- **Self capacitive & voltage-sensing ("digital switching")**
- **Here's one current problem with light-sensing**

Maximum SUR40 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

Source: Samsung

On the Other Hand, If You're Willing To Use a Light-Pen, It Works Great!

- **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 CPT

Source: IDTI

Source: Photo by author

Embedded-Touch Issues

- **Will fully in-cell mutual capacitive (both electrodes in the TFT array) ever happen?**
  - It's already happened in the iPhone-5, but nobody else has done it
- **Can the size limit of today's hybrid mutual-capacitive be expanded beyond 12"?**
  - Probably. The problem is sensing a larger number of electrodes faster. Metal mesh can help.
- **Is light-sensing in-cell touch ever going to be fully successful?**
  - Probably not. It's been 10 years and the problems aren't solved yet
- **Which is ultimately going to win, embedded or discrete touch?**
  - Embedded for high-volume, discrete for everything else

Stylus

Stylus…1

- **Tablet PCs, PDAs, and early smartphones (e.g., Trio) have 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

Stylus…2

- **Stylus has been used in commercial applications continuously since the early 1990s**
  - Sales automation, healthcare, insurance inspections, etc.

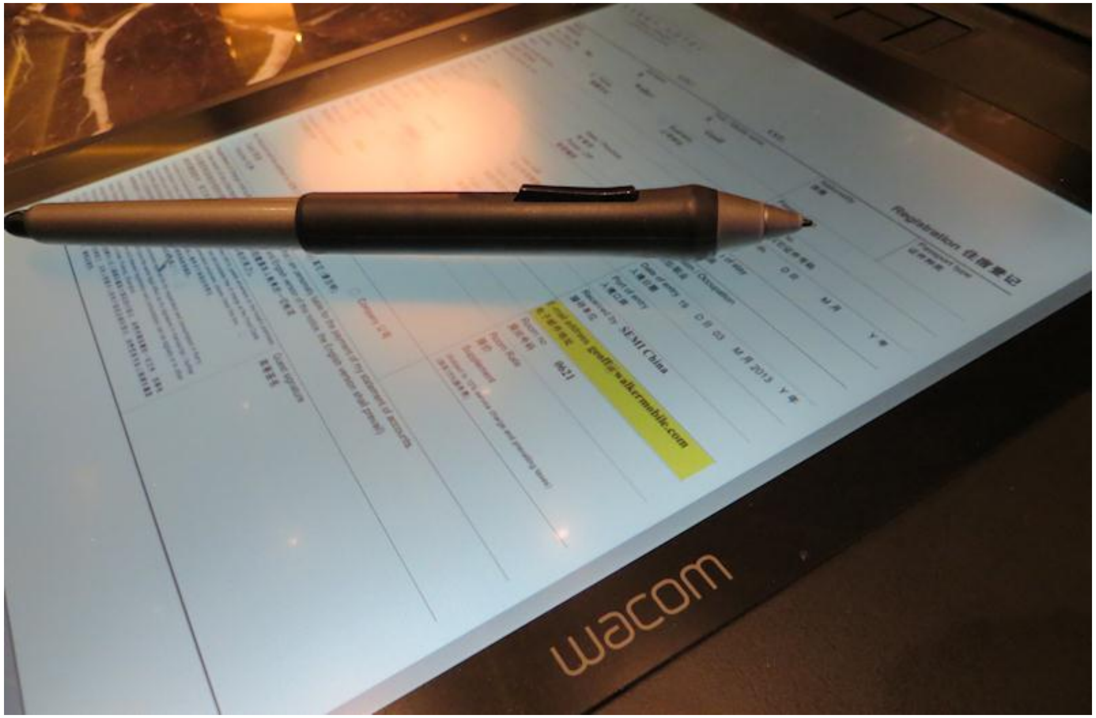


Photo by Author

Every check-in station at the Kerry Hotel in Shanghai has a stylus-equipped tablet display

Stylus…3

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

YES!

- All the major p-cap controller suppliers support active & passive
- Windows 8 has good support for active stylus (“MS Tablet PC”)
- PC OEMs want to differentiate their products from Apple’s
- Legacy Windows software on a Win-8 tablet <u>needs</u> a stylus
- Android (in Ice Cream Sandwich) supports stylus messages
- Samsung has shipped >15M Galaxy Notes I & II
- Consumption isn’t enough; a stylus is great for creation

Source: Atmel

Stylus…4

Passive vs. [N-trig] active stylus

- Passive stylus is basically an artificial finger with a small tip (2 mm)
  - It uses the p-cap electrodes for capacitive sensing, just like the finger
  - It has no more capability than the finger
  - It contains no electronics and is very low-cost (conductive plastic)
  - In Windows it uses the touch-digitizer interface (same as finger)

- P-cap active stylus is a radio transmitter with a very small tip (1 mm)
  - It uses the p-cap electrodes as a radio antenna [N-trig]
  - In Windows it has much more capability than the finger
    - "**Ink as a data type**" is the basis
    - Ink property records can contain stylus pressure, stylus angle, multiple text-translations of the ink, and much more
  - In Android, "ink as a data type" is up to the application developer
  - It contains electronics and a power source, so it costs more
    - AAAA battery, super-capacitor or custom rechargeable battery
  - In Windows it uses the pen-digitizer interface

Stylus…5

❖ Wacom (EMR) vs. [N-trig] p-cap active stylus

- Wacom uses a second sensor underneath the LCD that transmits RF to the stylus; the stylus stores and reflects the RF energy back to the sensor which switches from transmit into receive mode
  - No battery in the stylus; simple stylus electronics
  - Lower-cost stylus but additional sensor and separate controller
  - Inherent "palm rejection"

- P-cap active stylus transmits RF to the p-cap sensor which multiplexes capacitive-sensing and RF-receive (stylus) modes
  - Power source in the stylus; more complex stylus electronics
  - Uses the same sensor and controller as finger-touch
  - More complex "palm rejection"

Stylus…6

Sony Slider

Dell Convertible

All N-Trig!

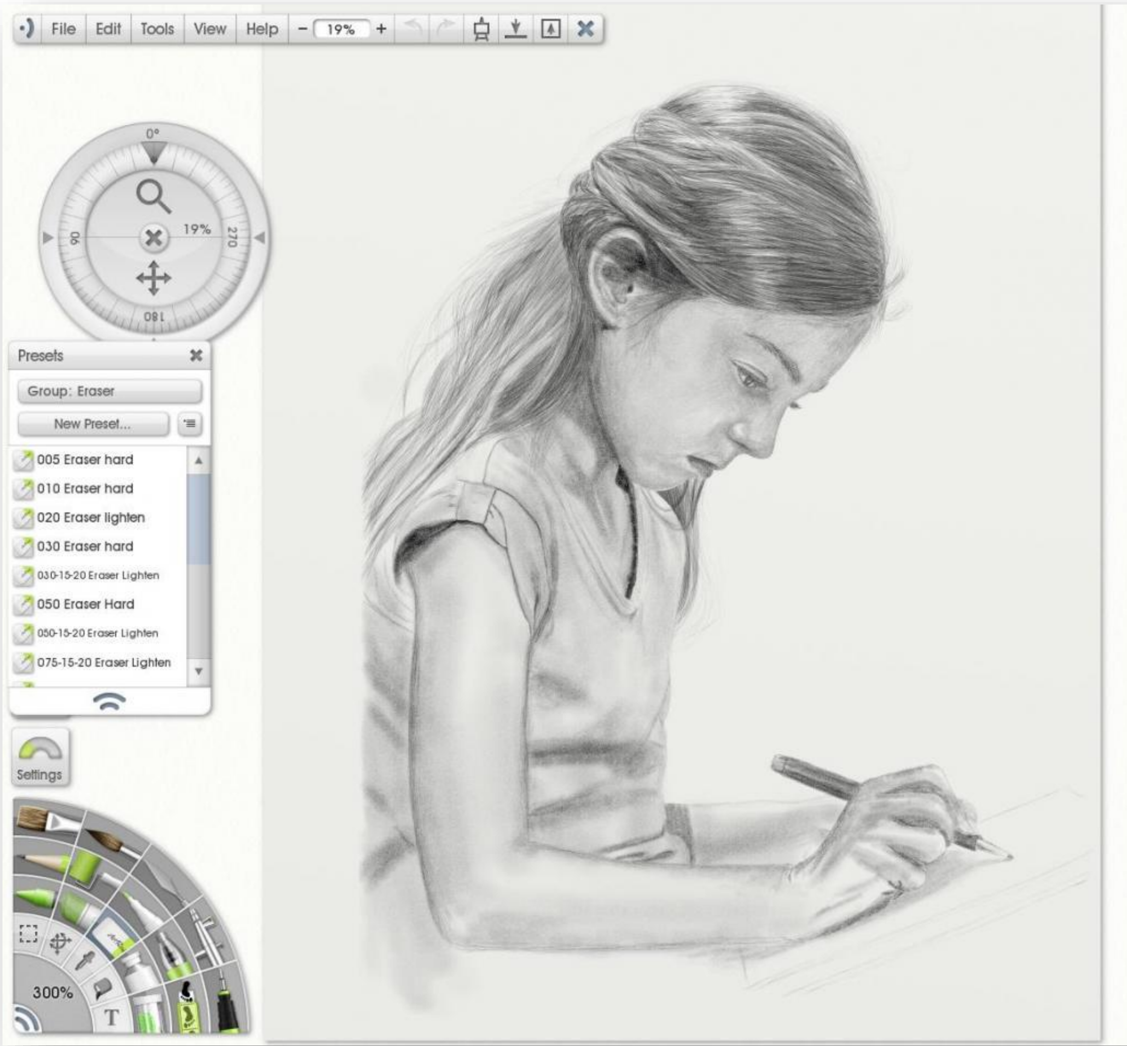
Fujitsu Detachable

Lenovo Double-Hinge

Stylus Use-Cases In Windows

- **Taking notes, typically with MS OneNote**
  - 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
- **Artistic drawings**
  - It’s unbelievable what a real artist can do…
- **Precision pointing device, e.g. with Windows 8 Desktop**
  - When you’re trying to select tiny UI elements

Stylus Use-Case #4…



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

P-Cap Futures

P-Cap Futures…1

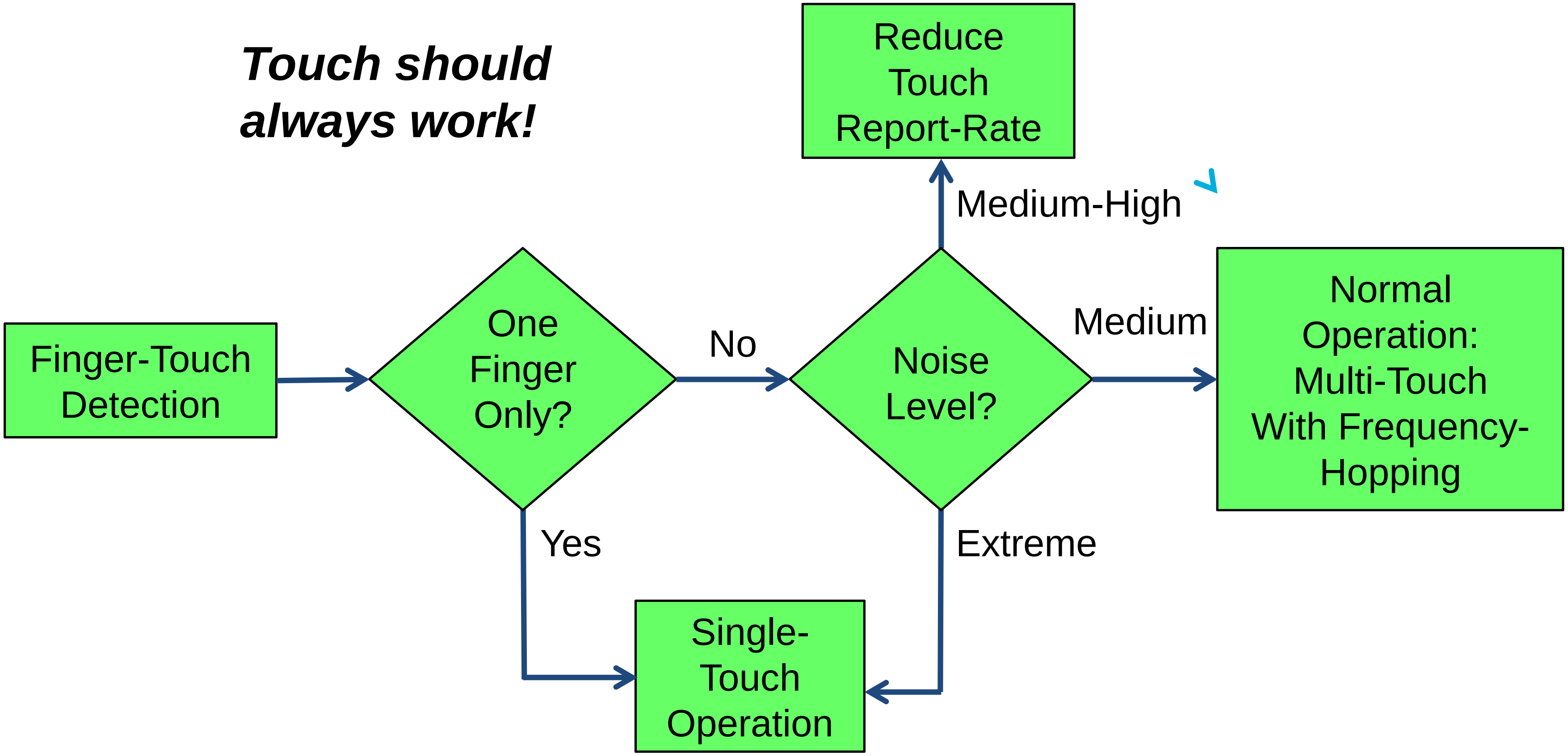
- **What we've already covered**
  - P-cap expanding into every application category
  - P-cap cost reduction
  - ITO replacements
  - Embedded p-cap (hybrid in-cell, true in-cell, and on-cell)

P-Cap Futures…2

- **Addition of self-capacitance (proximity) to existing mutual-capacitance (touch location)**
  - Provides finger-hover (hover to view choices, touch to select)
    - Pressure-sensing (press lightly to view choices, press harder to select) hasn’t been implemented successfully yet
  - Provides glove-touch
    - Glove causes finger to remain a constant distance above screen
  - Provides more information for “adaptive configuration”
    - Palm rejection
    - Adaptive noise-management

P-Cap Futures…3

- “Adaptive configuration” example (N-Trig)



P-Cap Futures…4

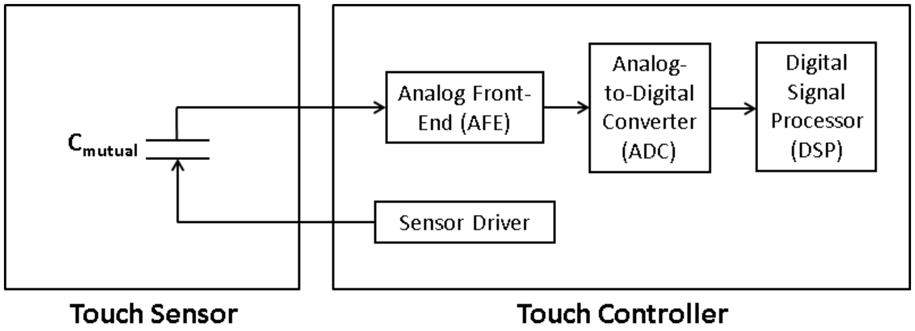
- **Moisture-resistance**
  - P-cap touchscreens already exist that can operate with running water on the surface
  - Water affects the shape of the e-field on the surface
  - Adaptive algorithms can adjust for the difference in field shape
  - The author believes the REAL issue is lack of demand from the consumer market

WaterSENSE® from UICO

(handheld shower spray)

P-Cap Futures…5

- **Much higher signal-to-noise (SNR) ratios**
  - Today's best SNR is around 50 dB, which supports a passive stylus with a 2-mm tip (still too large)
  - What's in the lab now is ~65 dB, which allows using a **#2 pencil** as a stylus (or just your fingernail, or a 10-penny [76 mm] nail)
    - I've seen three companies demonstrate this
    - This is the end of "finger-touch only"
  - Most work to increase SNR in the past has been done improving the performance of digital algorithms; now more work is being done to enhance the performance of analog front-ends (AFE)



P-Cap Futures…6

- **Haptics support**
  - A few touch controllers already supply signals to drive haptics transducers (e.g., Synaptics); doing so is relatively easy
  - The REAL problem is that haptic feedback in touch-displays larger than mobile-phone size has progressed very little
    - Haptics transducers (force-generators) are mostly still too big
    - Sophisticated force-generators (e.g., Senseg's Coulomb's force) don't create enough of a physical effect or work only with motion
    - Electro-elastic polymers (the author's best-bet for force-generators) haven't been made in larger sizes because there's no demand (chicken-and-egg)
    - There's no demand because nobody has a vision of what to do with haptic feedback in (for example) a notebook-size screen
    - Most of the current market for haptic feedback is in non-display devices such as headsets, game controllers, capacitive buttons, touchpads, medical simulators, robotics, etc.

P-Cap Futures…7

- **Lower latency**
  - Latency is the time between a touch and the response
    - Best examples are an object lagging behind your finger when you drag it, and ink lagging behind the stylus when you're drawing
    - Latency consists of the touchscreen response time plus the OS response time
  - Minor improvements
    - Optimize the software path
    - This was done in Android 4.0 as part of the "butter" effort
    - Windows is a much tougher nut to crack
  - Major improvements
    - Create a direct path between the touch controller and the display controller
    - Synaptics did this in their DDTI
    - Microsoft and the University of Toronto both published related papers

P-Cap Futures…8

- **Integration with the display controller (TCON)**
  - Synaptics is the leader in doing this; they acquired a TCON company in order to be able to do it right
  - First generation of embedded touch in smartphones (by JDI & Synaptics) uses a communication link between the touch controller and the TCON to coordinate the display and touch timing
  - Next generation (from Synaptics) uses an integrated chip
    - BUT, the chip is display-specific (resolution, pixel structure, etc.), so it's not really a general-purpose solution
  - Integration is the optimum solution for embedded (in-cell/on-cell) touch in high-volume displays

P-Cap Futures…9

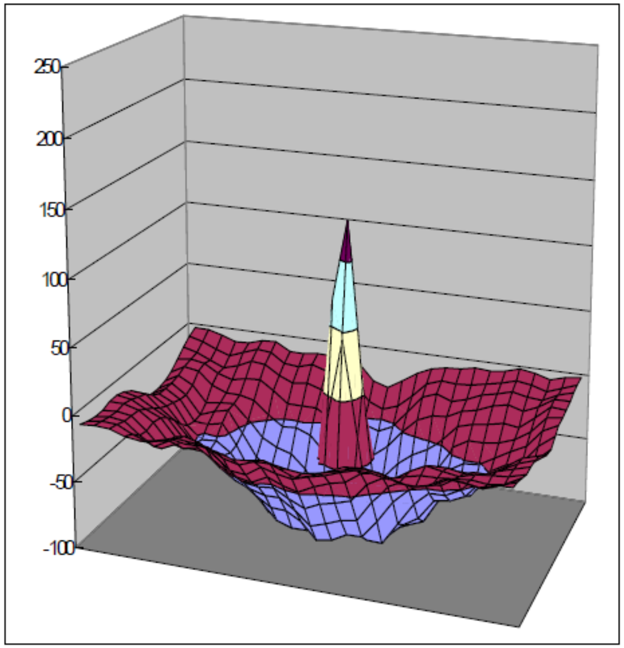
- **Integration of the digital portion of the touch controller as software running on the device CPU/GPU**
  - This has already happened in NVIDIA's "Direct Touch", but it wasn't widely used in actual devices
  - Mobile-phone OEMs are starting to push for it happen for real now
  - Benefits
    - Algorithm-writers 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 controller once it ships in a device; N-Trig is the exception
    - Cost-reduction by elimination of one micro
      - Even more cost reduction for large screens by elimination of slave chips

P-Cap Futures…10

- **More use of USB interfaces, less use of I^2C**
  - Partially driven by Microsoft, partially due a general "up-leveling" of touchscreen systems
- **Lower power consumption**
  - Motherhood & apple pie, but the author expects average power consumption to drop by 50% over the next three years
- **Higher scan & data-report rates**
  - Reduces latency and improves stylus performance
  - There's probably a practical limit (maybe 300 fps) but Microsoft has done experiments up to 1,000 fps
    - Current MS Win8 Logo spec is 100 fps per finger

P-Cap Futures…11

- **More common use of "cover-glass bending" algorithms**
  - When an air-bonded cover-glass is pressed hard enough, it touches the LCD surface. This adds capacitance at the touch point, but the finger pushing the glass reduces capacitance.
  - Cover-glass is getting thinner (currently 0.55 mm; next step is 0.4 mm)
  - Air-bonding is getting more popular due to the high cost of direct-bonding



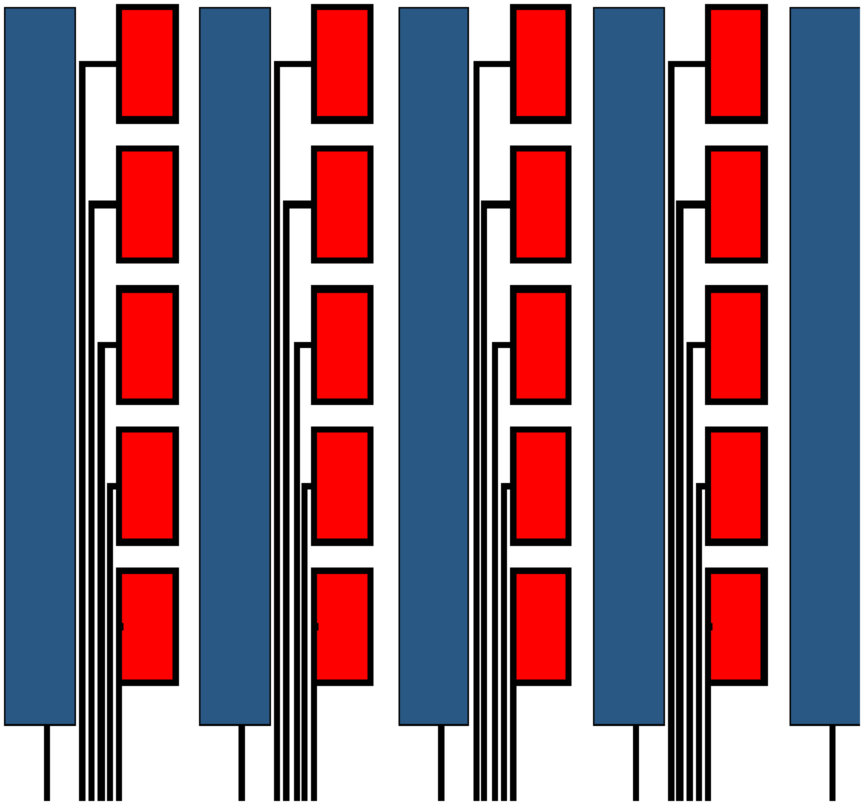
Source: Solomon Systech

P-Cap Futures…12

- **True "single-layer" sensor**
  - Rectangular-grid sensors (e.g., "bars & stripes" with wide transmitters and narrow sensors) are usually two layers and sometimes three layers
    - Most use two layers of ITO on two different surfaces
    - Some use one layer of ITO for the bars & strips but with bridges at the crossovers
  - Diamond-pattern (similar and symmetric rows and columns) with bridges are actually three layers
    - One layer of ITO with all diamonds but gaps at the crossovers
    - One layer of insulation (dielectric) at the crossovers
    - Another layer of ITO or metal on top of the insulators to form the bridges

P-Cap Futures…13

- **True "single-layer" sensor (continued)**
  - A true single-layer sensor has one layer of ITO and nothing else



(Conceptual drawing)

- Shown at SID 2012 by TouchTurns
- Advantage is lower cost
- Disadvantages are (a) it requires many connections, and (b) performance with a stylus may not be optimum

P-Cap Futures…14

- **P-cap combined with pressure-sensors**
  - Still an unrealized dream
  - Blackberry Storm (2 models!) failed with “press to select”
  - Nissha/Peratech (QTC) collaboration never shipped anything
  - The author knows of four startups working on pressure-sensing
    - NextInput
      - Uses an array of pressure-sensing piezo-capacitors under the LCD
      - Focused on consumer electronics applications
    - FloatingTouch
      - Mounts the LCD on pressure-sensing capacitors made using a 3M material
      - Focused on consumer electronics applications
    - F-Origin
      - Attaches the LCD to spring-arms mounted on piezo sensors
      - Focused on industrial applications
    - Tactonic Technologies
      - Offers a proprietary material with 5 grams minimum sensitivity
      - Focused mostly on industrial applications

Thank You!

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