Embedded Touch Terminology…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 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 and drive electrodes inside the cell** • IPS LCD: Segmented Vcom electrodes on the TFT glass • Non-IPS LCD: Segmented Vcom electrodes on the underside of the color filter glass

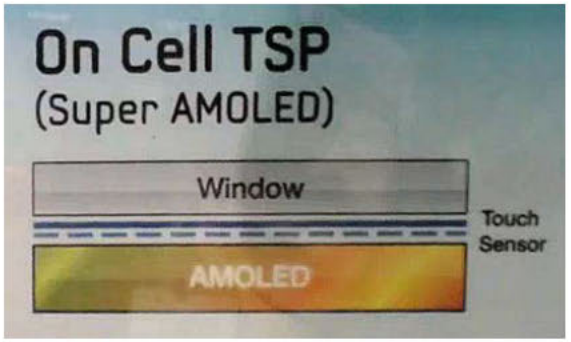
Early Embedded Methods All Failed

- **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

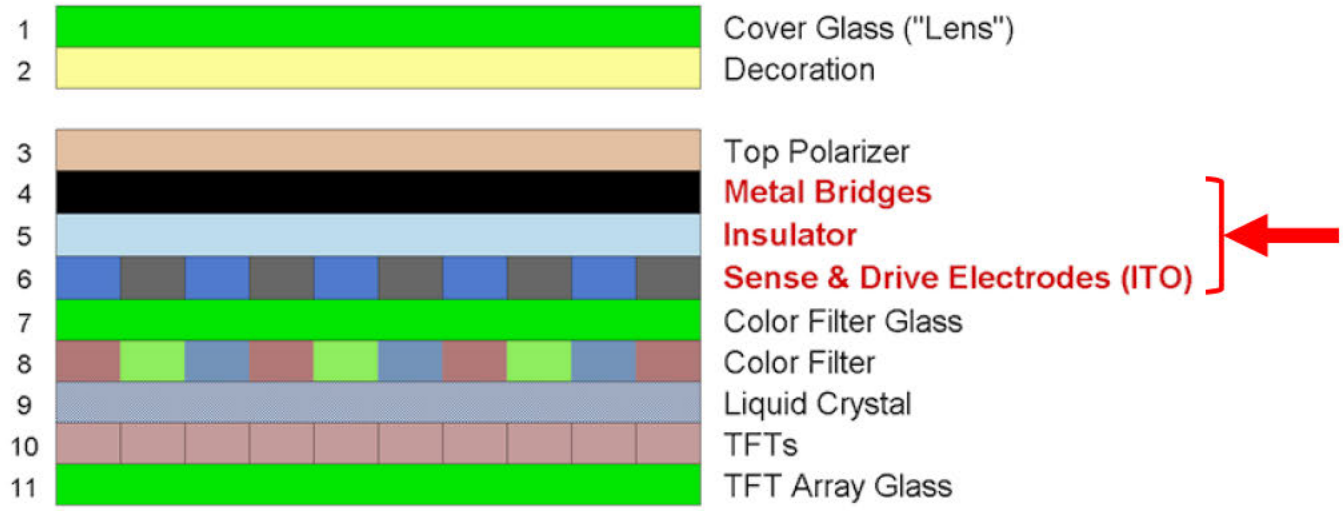
Window = direct-bond cover-glass



Source: Samsung booth graphic at Mobile World Congress 2010

Source: Samsung

On-Cell P-Cap



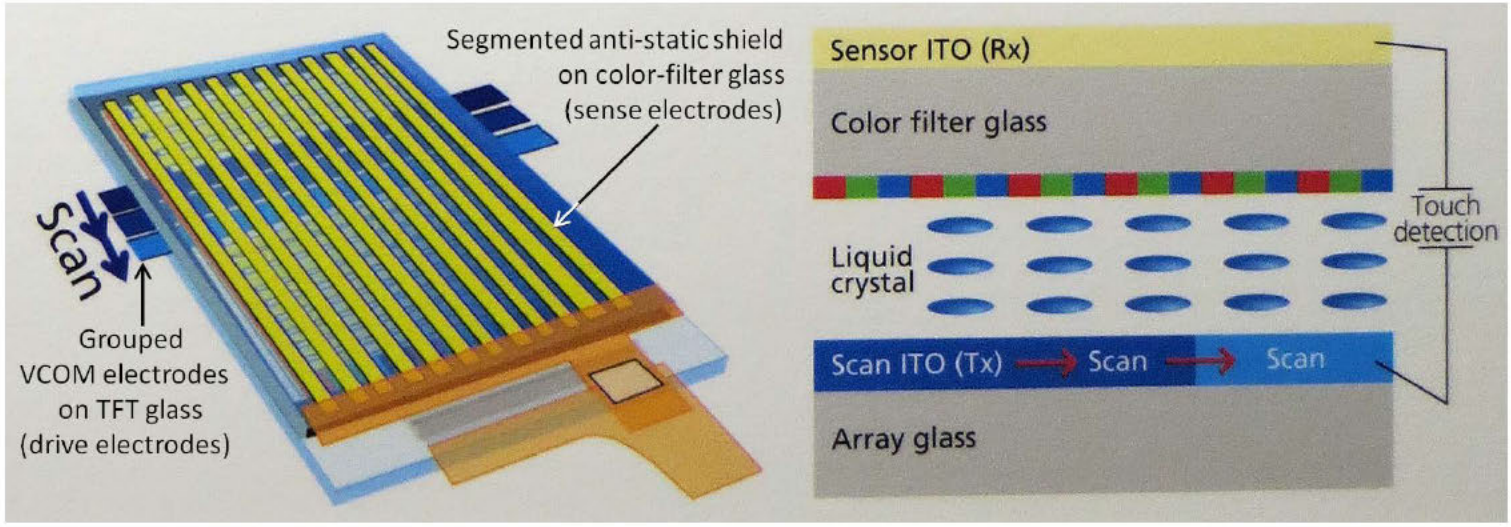
Source: The author

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

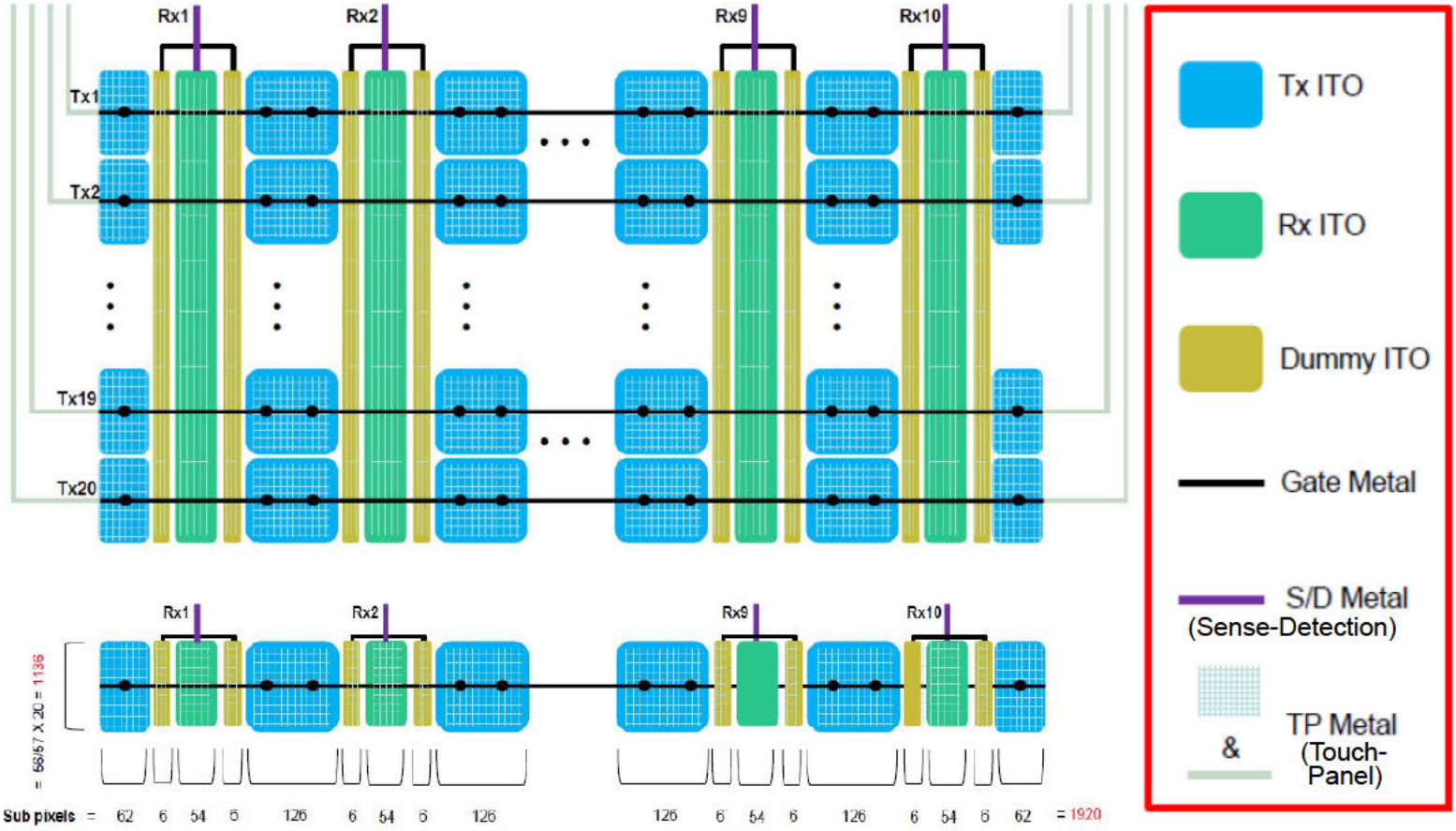
- **Similar LCDs**
  - 4-inch 960x540 LTPS (275 ppi) with different pixel arrays
- **Same touch solution**
  - Synaptics ClearPad 3250 (four touches)
- ***<100 µm thinner than one-glass solution!***

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

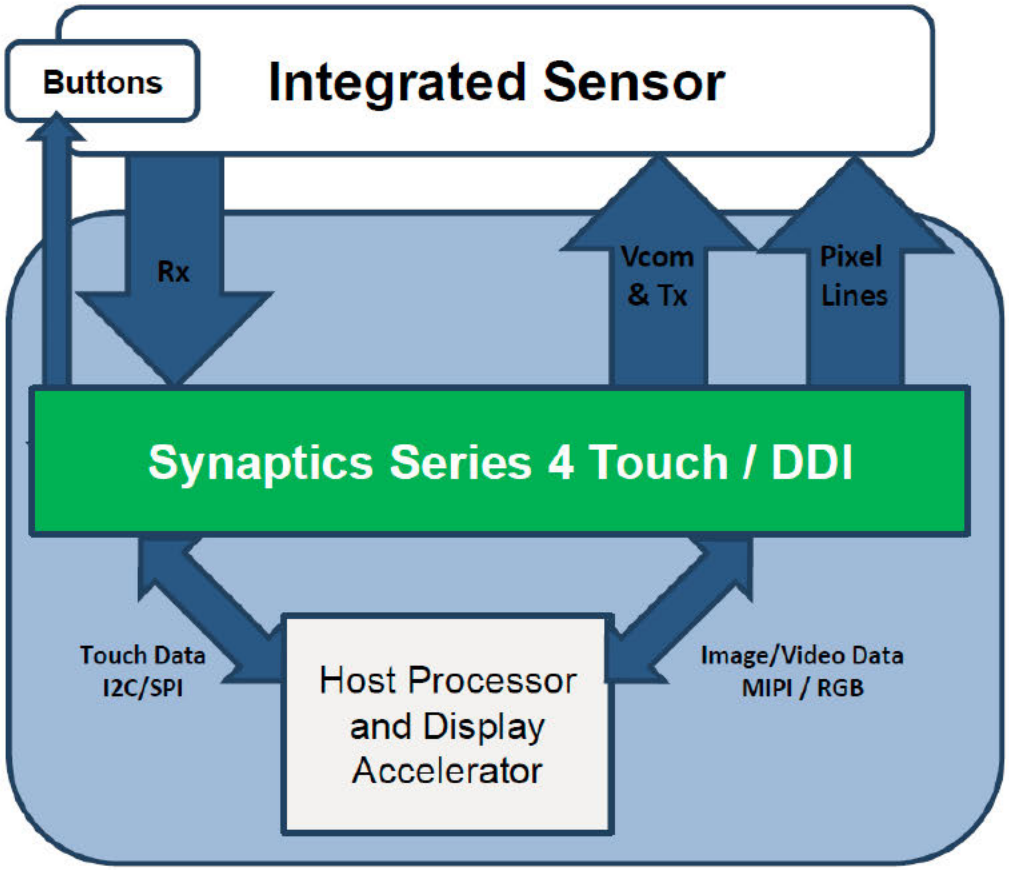
Other In-Cell Electrode Structures (Based On Patents)

- **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 the thickness variation between smartphone models with embedded touch is ~1.0 mm due to other features, 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 = requires additional circuitry

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

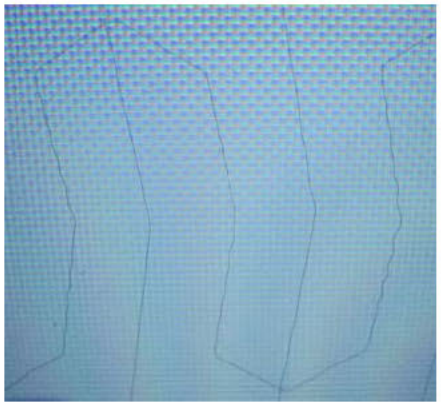
Wire Electrodes…4

- **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!

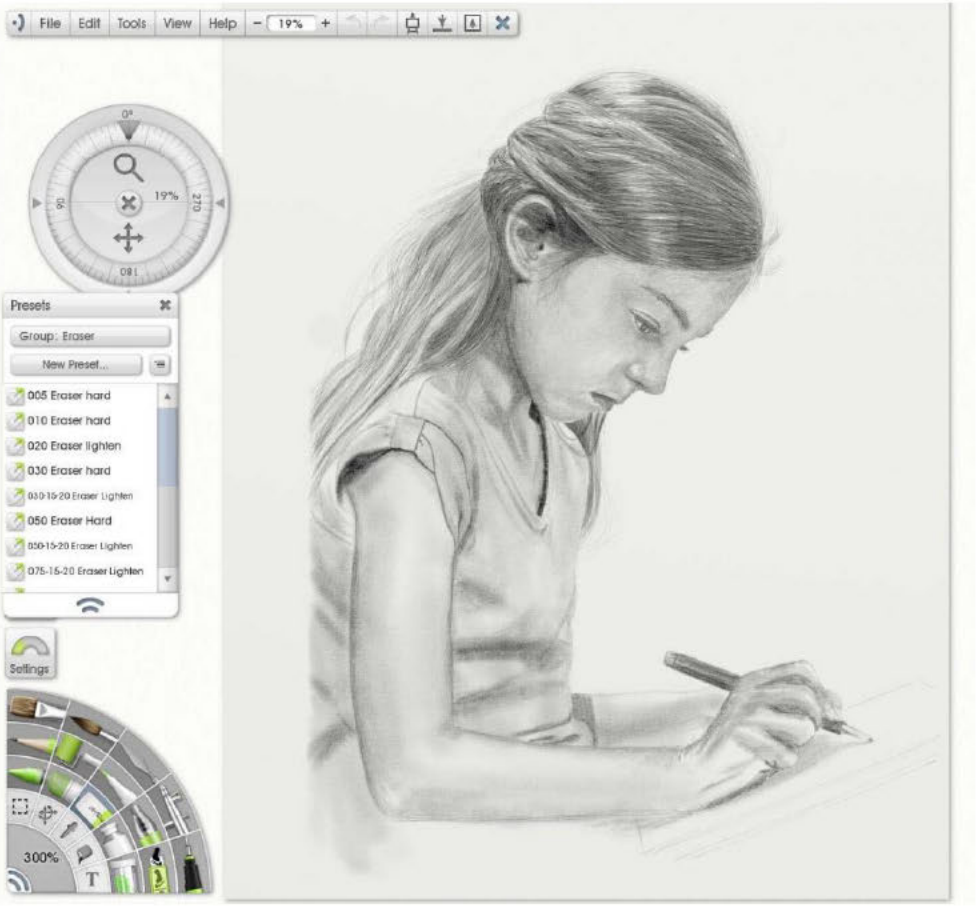
- All the major p-cap controller suppliers support active & passive
- PC OEMs want to differentiate their products from Apple's
- Legacy Windows software on a Win8 tablet needs a stylus
- Android (in Ice Cream Sandwich) supports stylus messages
- Samsung has shipped >15M Galaxy Notes in two sizes
- Consumption 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 conductive 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

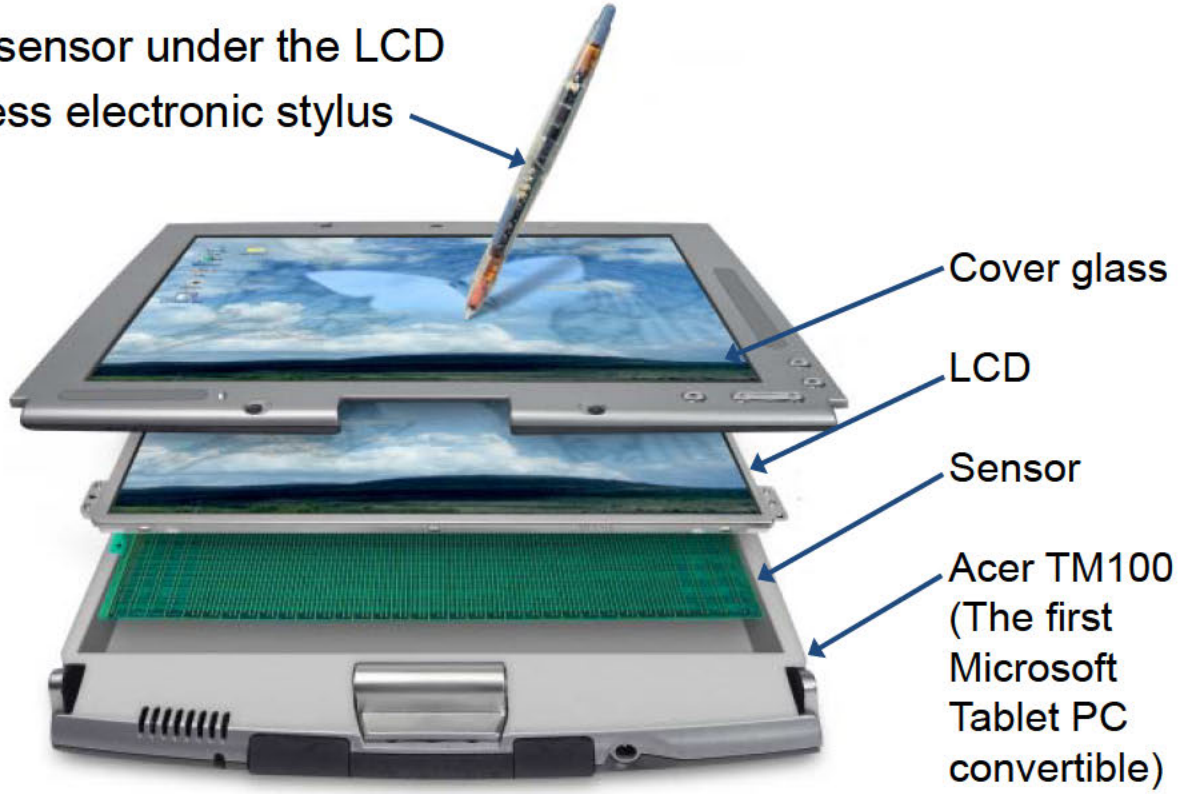
Passive Stylus…2

- **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

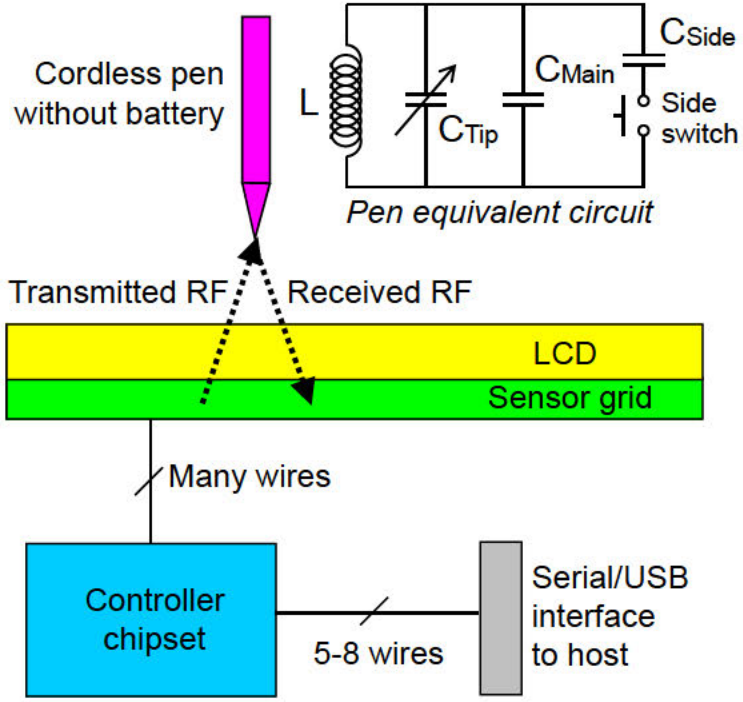
- **Key characteristics**
  - Second sensor under the LCD
  - Batteryless electronic stylus

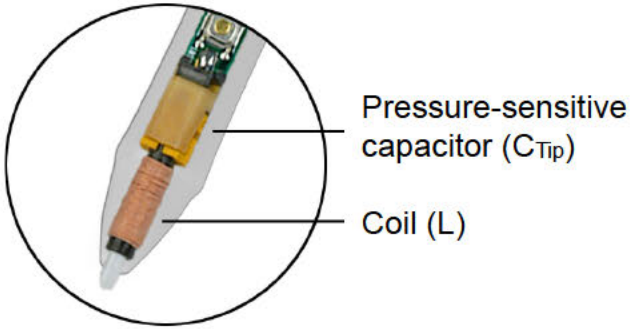


Source: Wacom

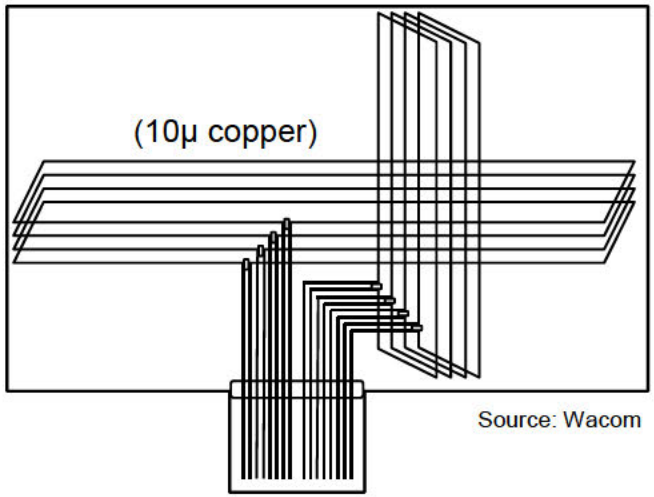
EMR Stylus…2

Source: Wacom





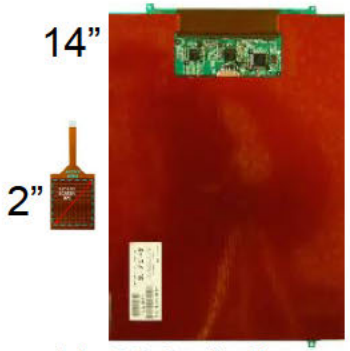
Sensor grid schematic

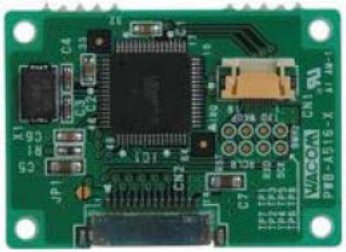


Source: Wacom

EMR Stylus…3

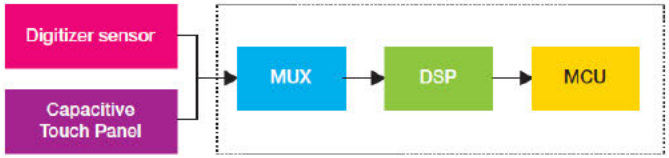
- **Variations**
  - Sensor substrate (rigid FR4 vs. flexible 0.3 - 0.6 mm PET)
  - Pen diameter (3.5 mm “PDA pen” to 14 mm “executive” pen)
- **Size range**
  - 2” to 14”
- **Controllers**
  - Proprietary
- **Advantages**
  - Very high resolution (1,000 dpi)
  - Pen “hover” (mouseover = move cursor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





Controller for 10.4”

Source: Wacom



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

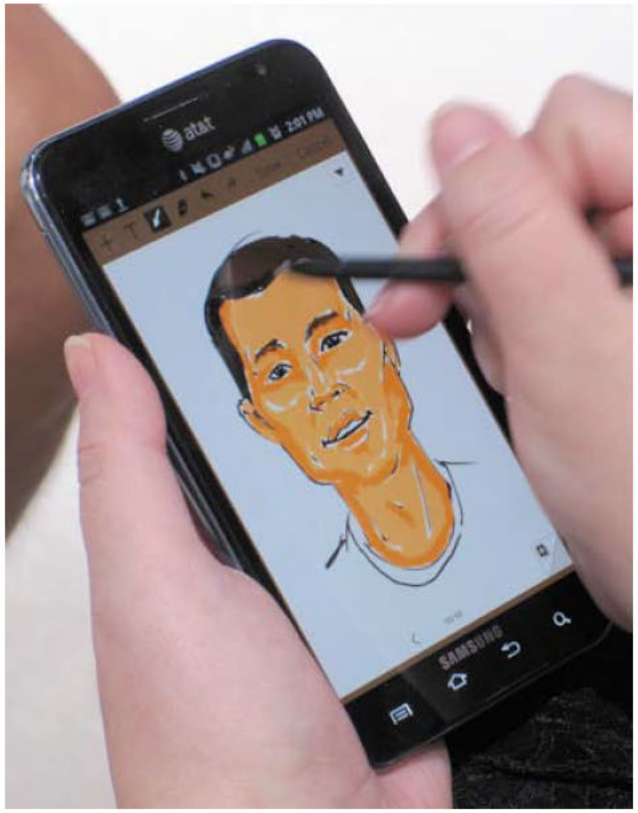
EMR Stylus…4

- **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

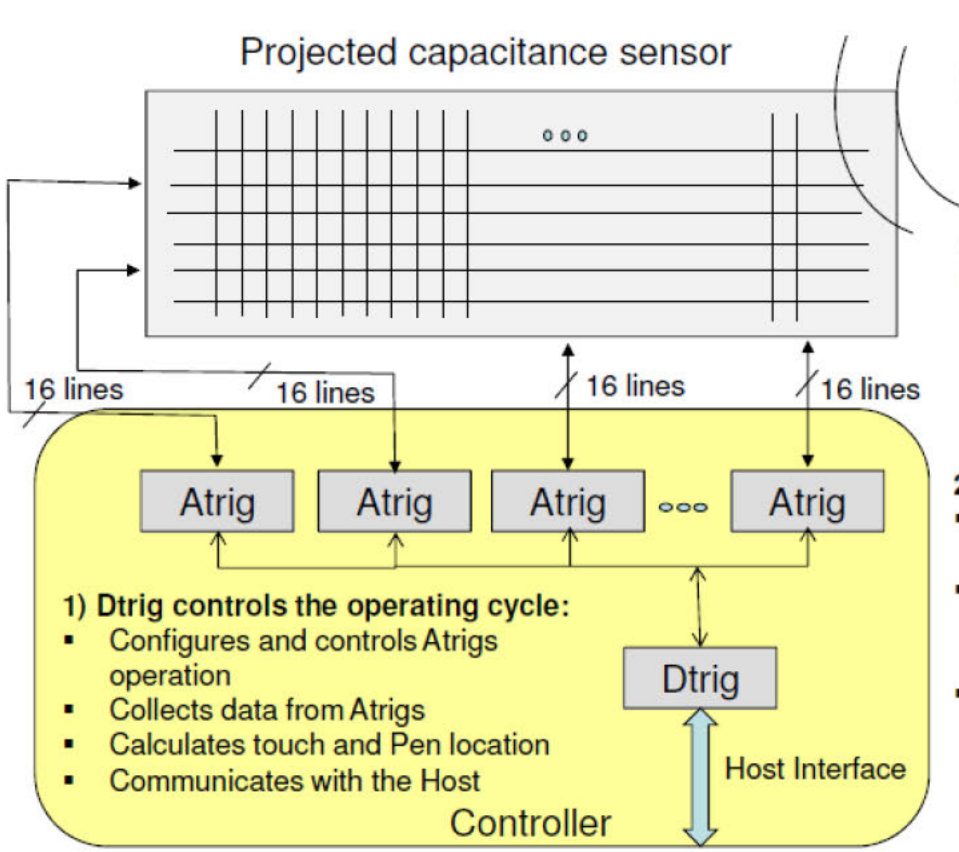
- **Samsung Galaxy Note sketching demo at CES 2012**

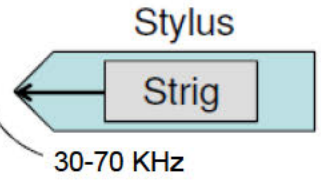


The Galaxy Notes use both a p-cap touchscreen AND a Wacom EMR stylus (2 sensors!)

Source: Photos by Author

Active P-Cap Stylus…1





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…

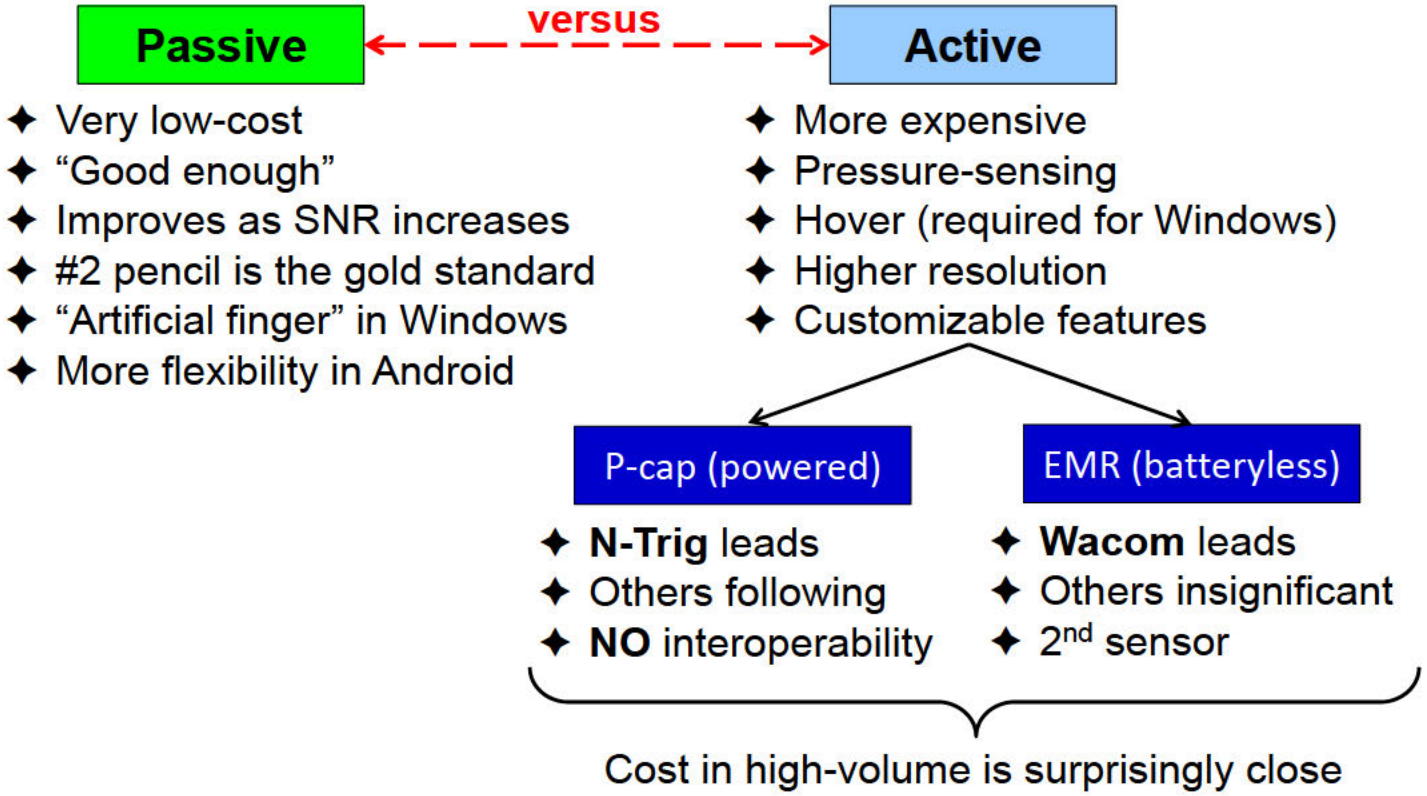
Active P-Cap Stylus…3

- **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…**



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

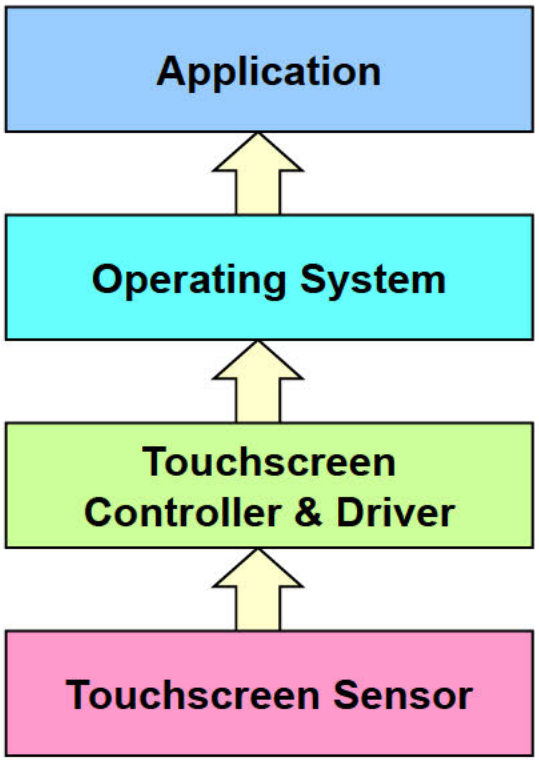
Software

- 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

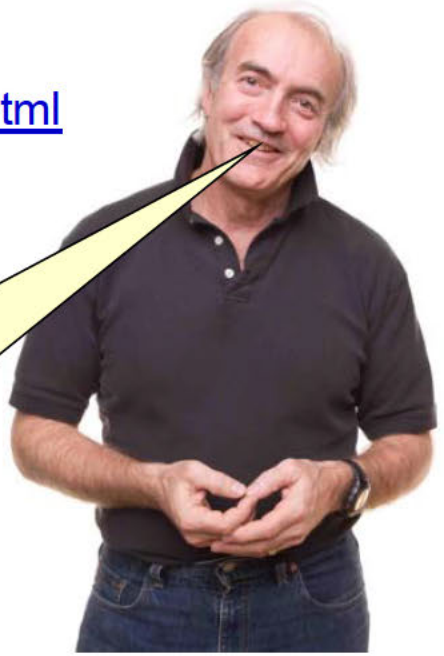
From a video of a very cool multi-player game on the FlatFrog website

Source: FlatFrog

#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

- **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**

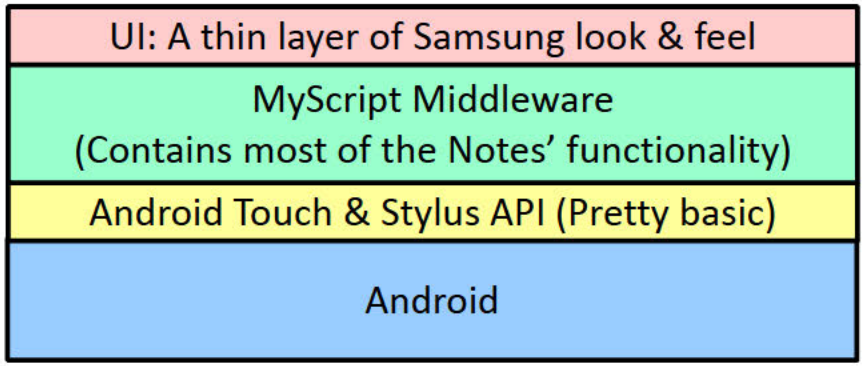
iOS Touch Application Development

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

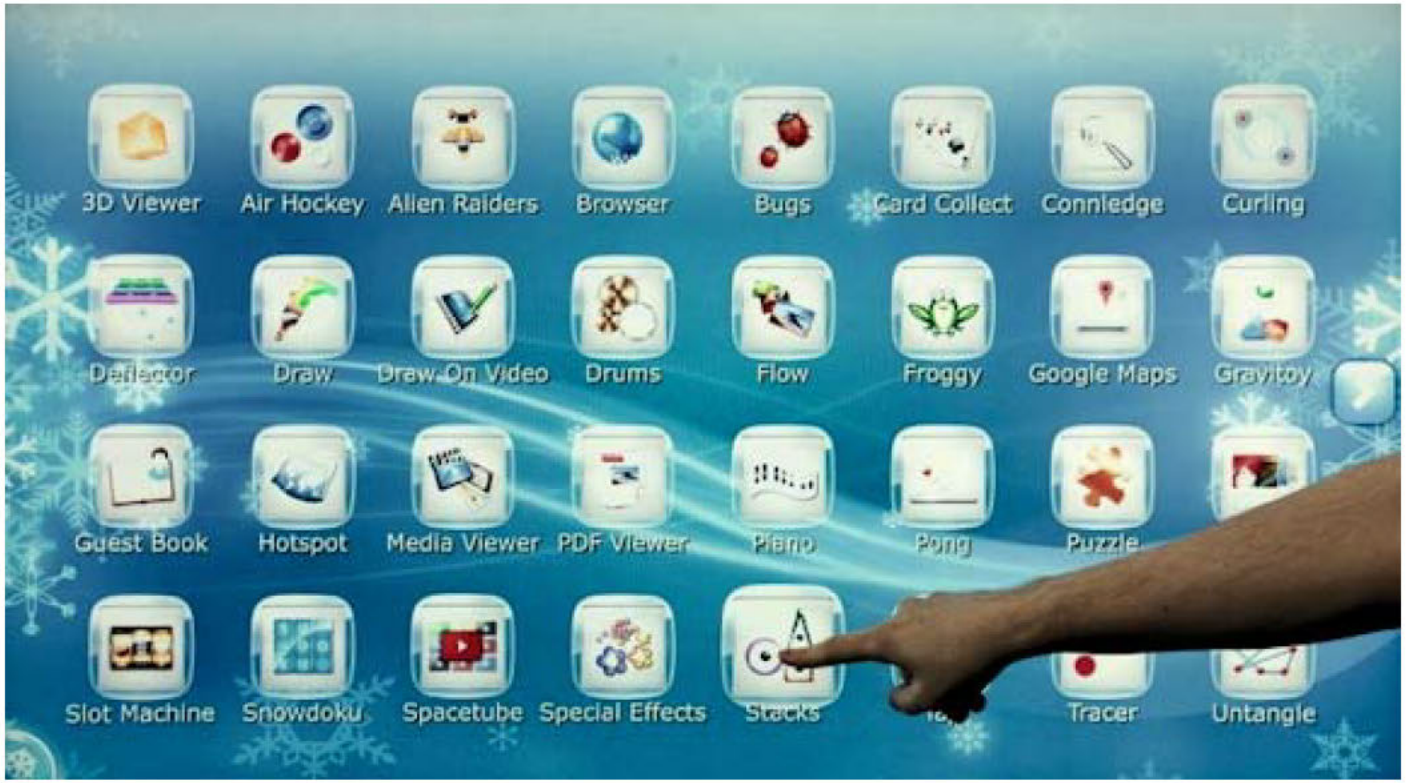
Samsung Galaxy Notes' software stack

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

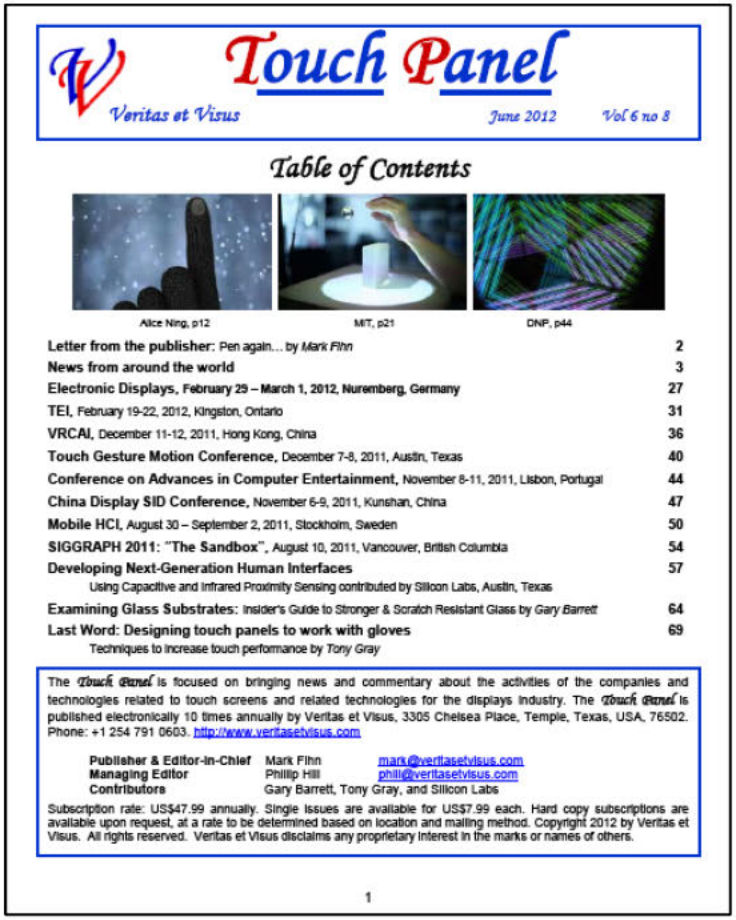
March 2010

December 2007

December 2006

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

Suggested Reading on Touch…2



Touch Panel

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Table of Contents

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


IBTimes.co.uk

[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 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 »


Nintendo World Report

[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 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 ...


Digital Signage Connection (press

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; not 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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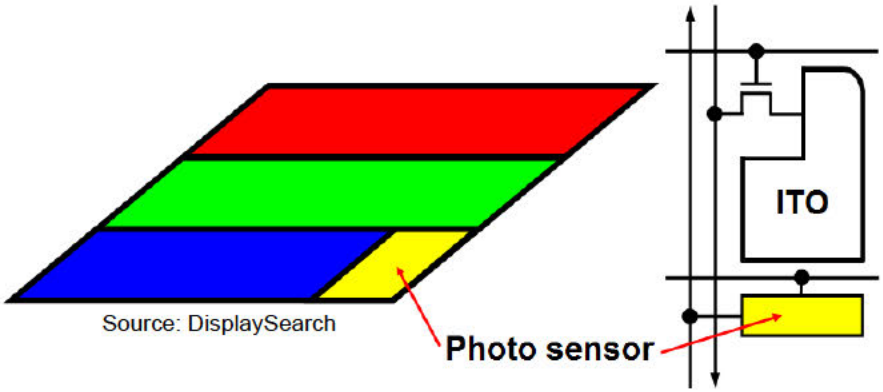
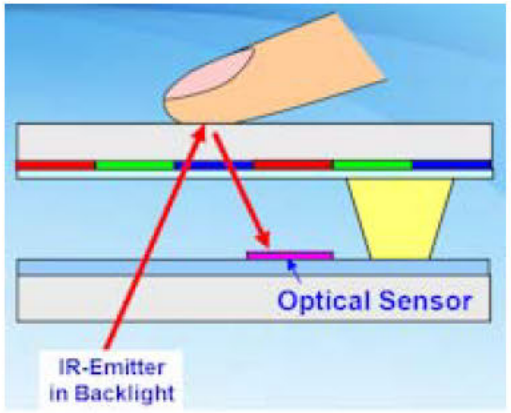
Appendix A
Historical Embedded Touch

- 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 scanner
- 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

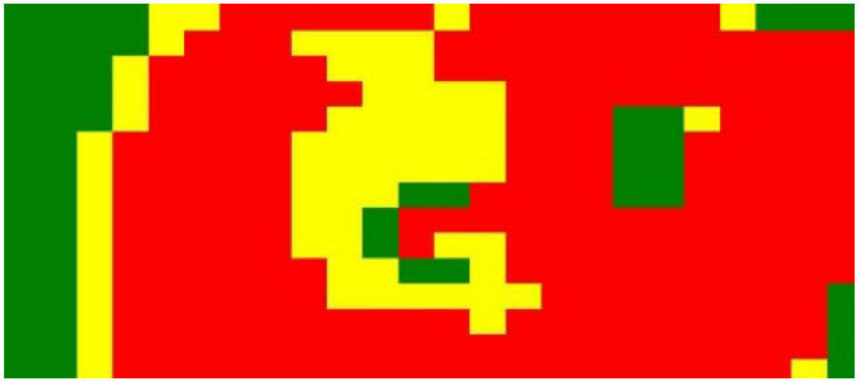
Second Product with In-Cell Light-Sensing

- **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

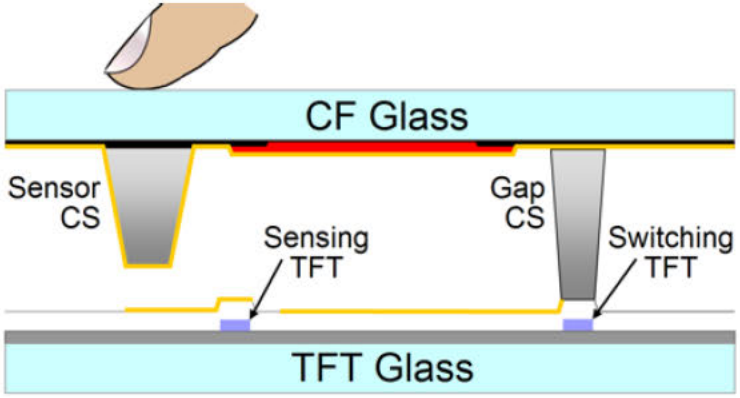
- **Integrated Digital Technologies light-pen monitor**
  - 21.5” in-cell light-sensing monitor with IR light-pen
  - Supports two-touch with two pens
  - Backplane by Taiwan CPE

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 (cannot add a cover glass)

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

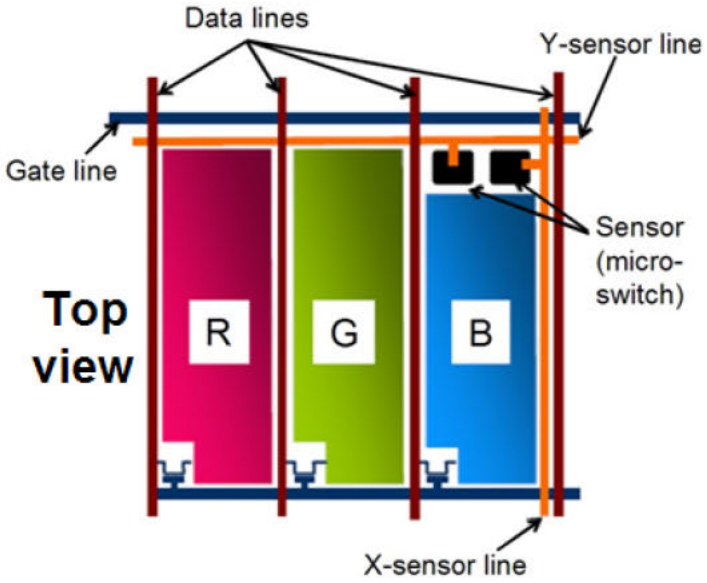
Touch an icon to select a menu or option.

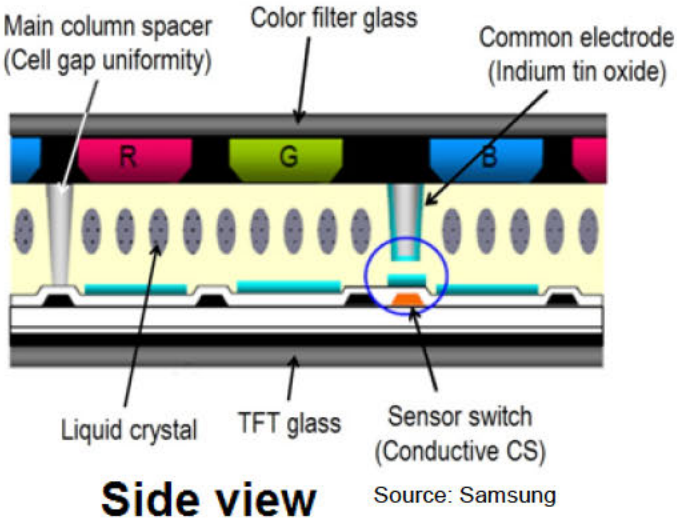
Flicking

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")

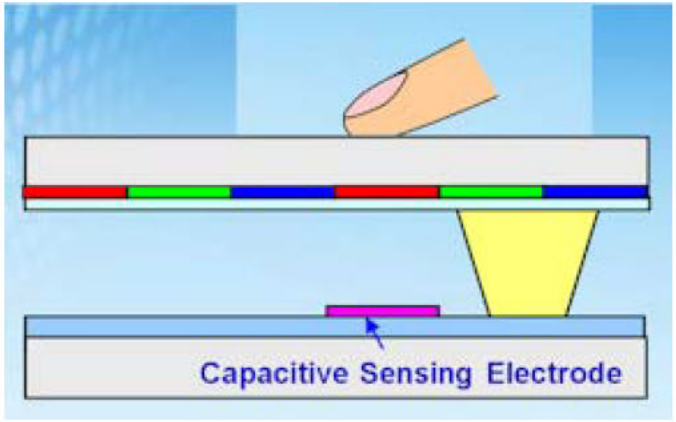




- **Principle**
  - Pressing LCD surface closes X & Y micro-switches in each pixel or group of pixels
  - Requires deflecting the LCD surface (cannot add a cover glass)
  - Works with any touch object within damage limits of top polarizer

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

Part 2: Fundamentals of Touch Technologies other than Projected Capacitive

Geoff Walker
Senior Touch Technologist
Intel Corporation

Updated October, 2013

Agenda…1

- This tutorial course covers all touch technologies except projected capacitive
- Because of its dominance, projected capacitive has been split off into a separate tutorial course entitled "Fundamentals of Projected-Capacitive Touch Technology"
- Related materials such as "ITO Replacement Materials", "Embedded Touch", and "Software" have been updated and moved into the P-cap tutorial

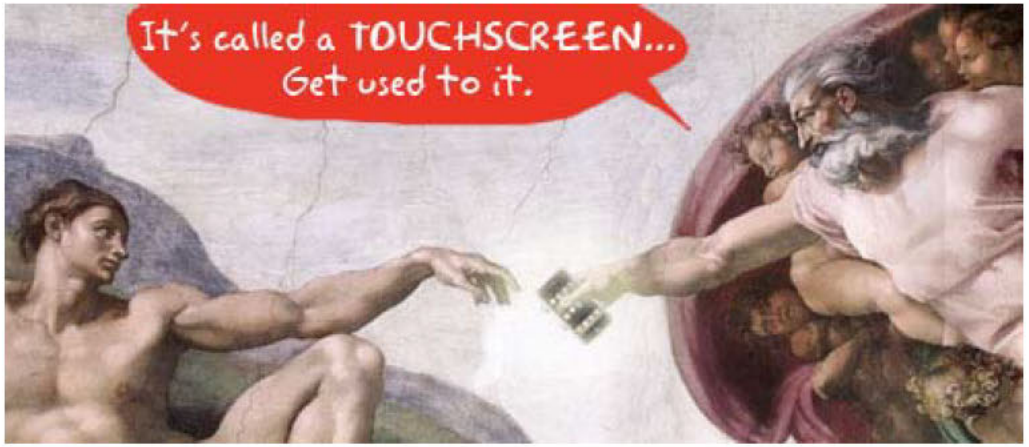
Agenda…2

- **Introduction**
- **Capacitive (1)**
  - 1B - Surface Capacitive
- **Resistive (2)**
  - 2A - Analog Resistive
  - 2B - Analog Multi-Touch Resistive (AMR)
  - 2C - Digital Multi-Touch Resistive
- **Acoustic (3)**
  - 3A - Surface Acoustic Wave (SAW)
  - 3B - Acoustic Pulse Recognition (APR by Elo Touch Solutions)
  - 3C - Dispersive Signal Technology (DST by 3M Touch Systems)

Agenda…3

- **Optical (4)**
  - 4A - Traditional Infrared
  - 4B - Waveguide Infrared (DVT by RPO)
  - 4C - Multi-Touch Infrared
  - 4D - Camera-Based Optical
  - 4E - Planar Scatter Detection (PSD by FlatFrog)
  - 4F - Vision-Based
- **Other Touch Technologies (5)**
  - 5 - Force-Sensing
- **Conclusions**
  - Touch Technology vs. Application
  - Usability, Performance, and Integration Characteristics
  - Touch Technology Primary Advantages and Flaws
  - Predictions for the Future

Introduction



Source: Gizmodo

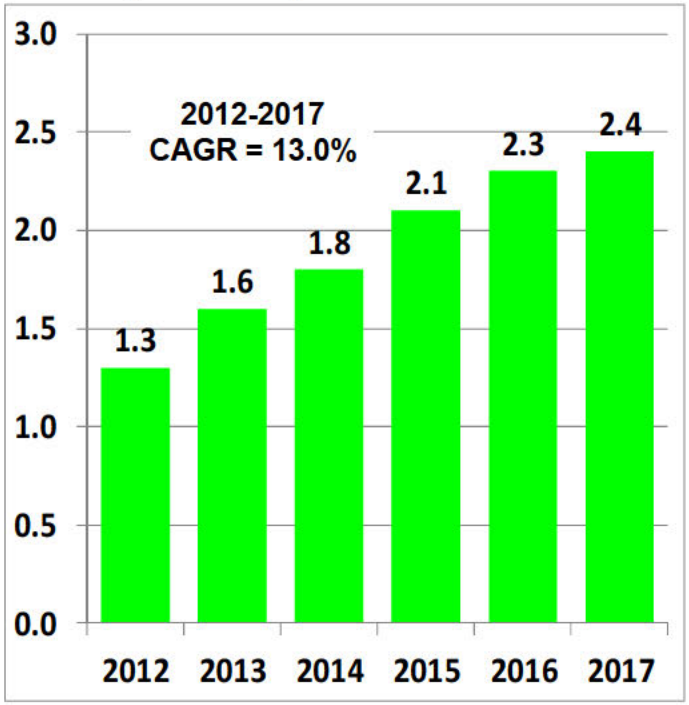
(Michelangelo's "The Creation Of Adam", in the Sistine Chapel, 1511)

Two Basic Categories of Touch

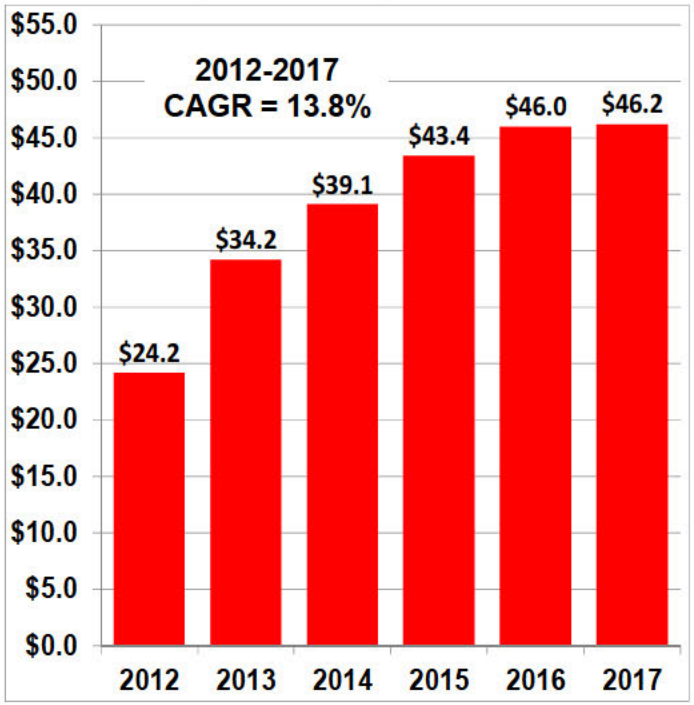
- **Opaque (non-transparent) touch**
  - Dominated by the controller chip suppliers
    - Atmel, Cypress, Synaptics, etc.
    - One technology (projected [self] capacitive)
    - Sensor is typically developed by the device OEM
  - Notebook touchpads are the highest-revenue application
    - Synaptics, Alps and ELAN have the majority of the market
    - Sensors are all two-layer projected capacitive
  - *There is no further discussion of opaque touch in this course*
- **Transparent touch on top of a display**
  - Dominated by the touch module manufacturers (150+ worldwide)
  - 6 fundamental technologies with ~20 types

Overall Touchscreen Market 2012-2017

Units (Billions)



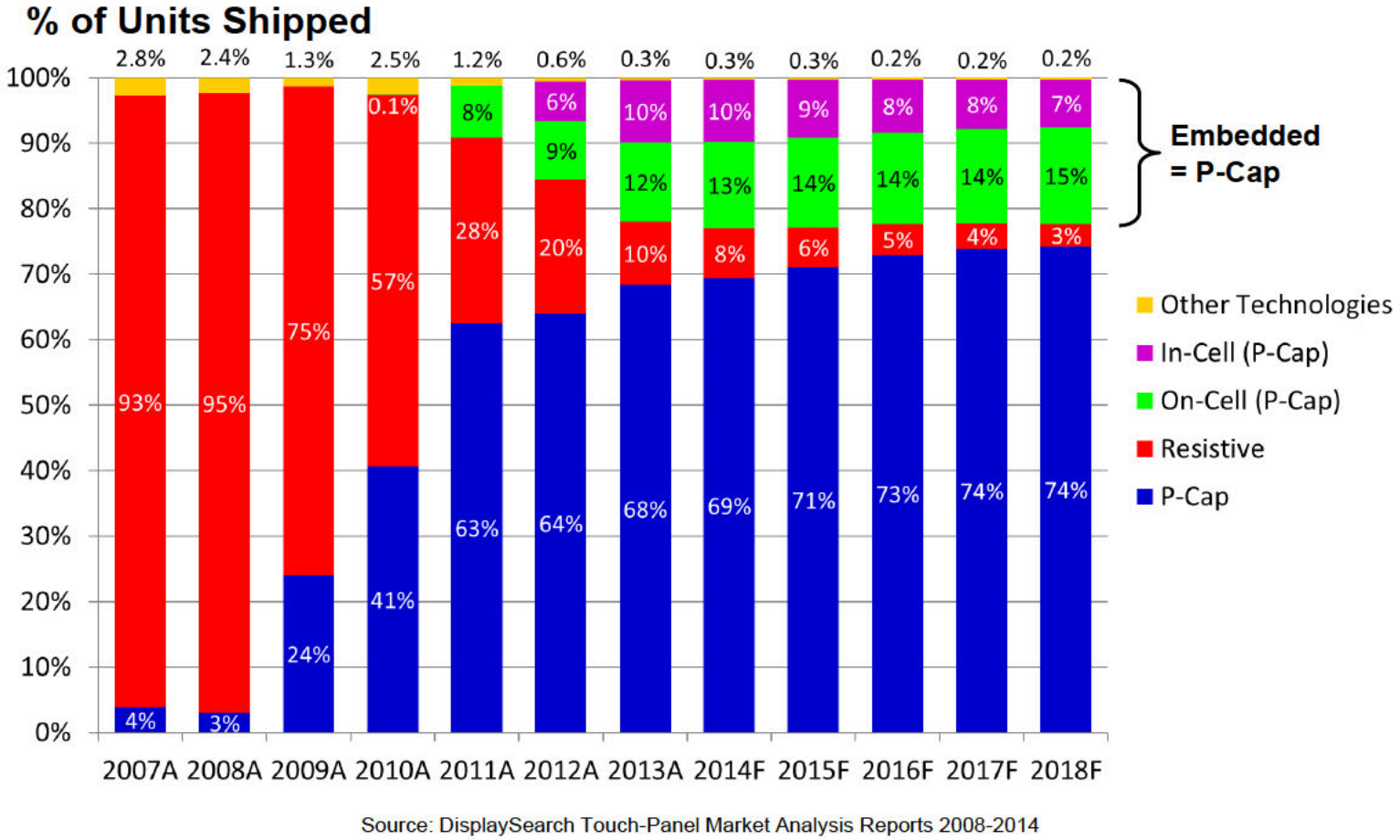
Revenue ($Billions)



Source: DisplaySearch Quarterly Touch-Panel Market Analysis Report (June 2013)

Touch in 2007 was 308M units & $1.3B…

Touchscreen Market 2007-2018 by Technology (Units)



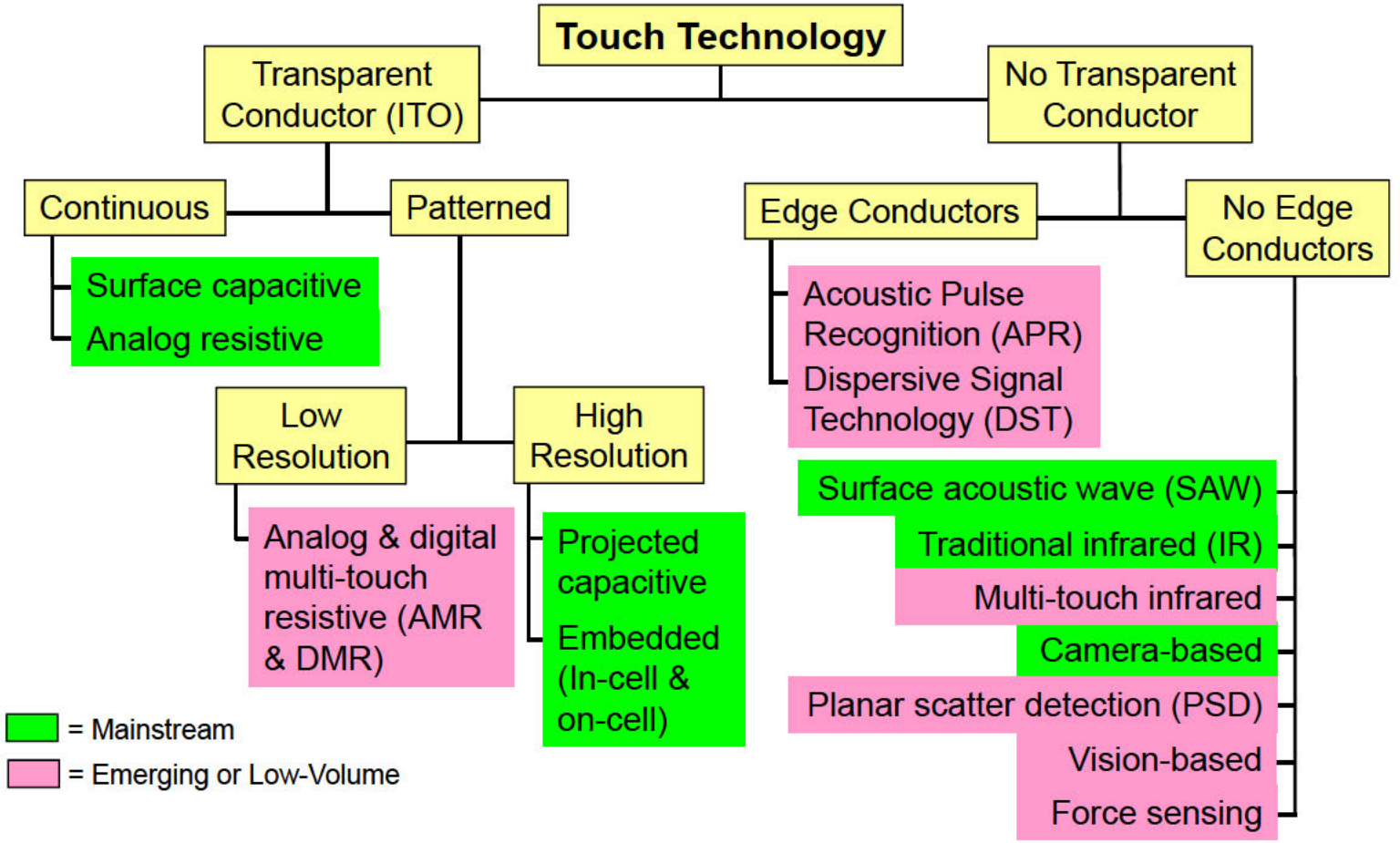
Source: DisplaySearch Touch-Panel Market Analysis Reports 2008-2014

Touch Technologies by Size & Application

#	Touch Technology	Mobile (2" – 17")	Stationary Commercial (10" – 30")	Stationary Consumer (10" – 30")	Large-Format (>30")
1A	Projected Capacitive	M	M	L	L
1B	Surface Capacitive		M		
2A	Analog Resistive	M	M	L	
2B	Analog Multi-Touch Resistive (AMR)	E		E	
2C	Digital Multi-Touch Resistive (DMR)	E			
3A	Surface Acoustic Wave (SAW)		M		L
3B	Acoustic Pulse Recognition (APR)	E	L		
3C	Dispersive Signal Technology (DST)				L
4A	Traditional Infrared (IR)		M		M
4B	Multi-Touch Infrared	E	E	E	E
4C	Camera-Based Optical			M	M
4D	Planar Scatter Detection (PSD)				E
4E	Vision-Based (In-Cell Optical)				E
5	Embedded (In-Cell/On-Cell Capacitive)	M			E
6	Force Sensing		E		

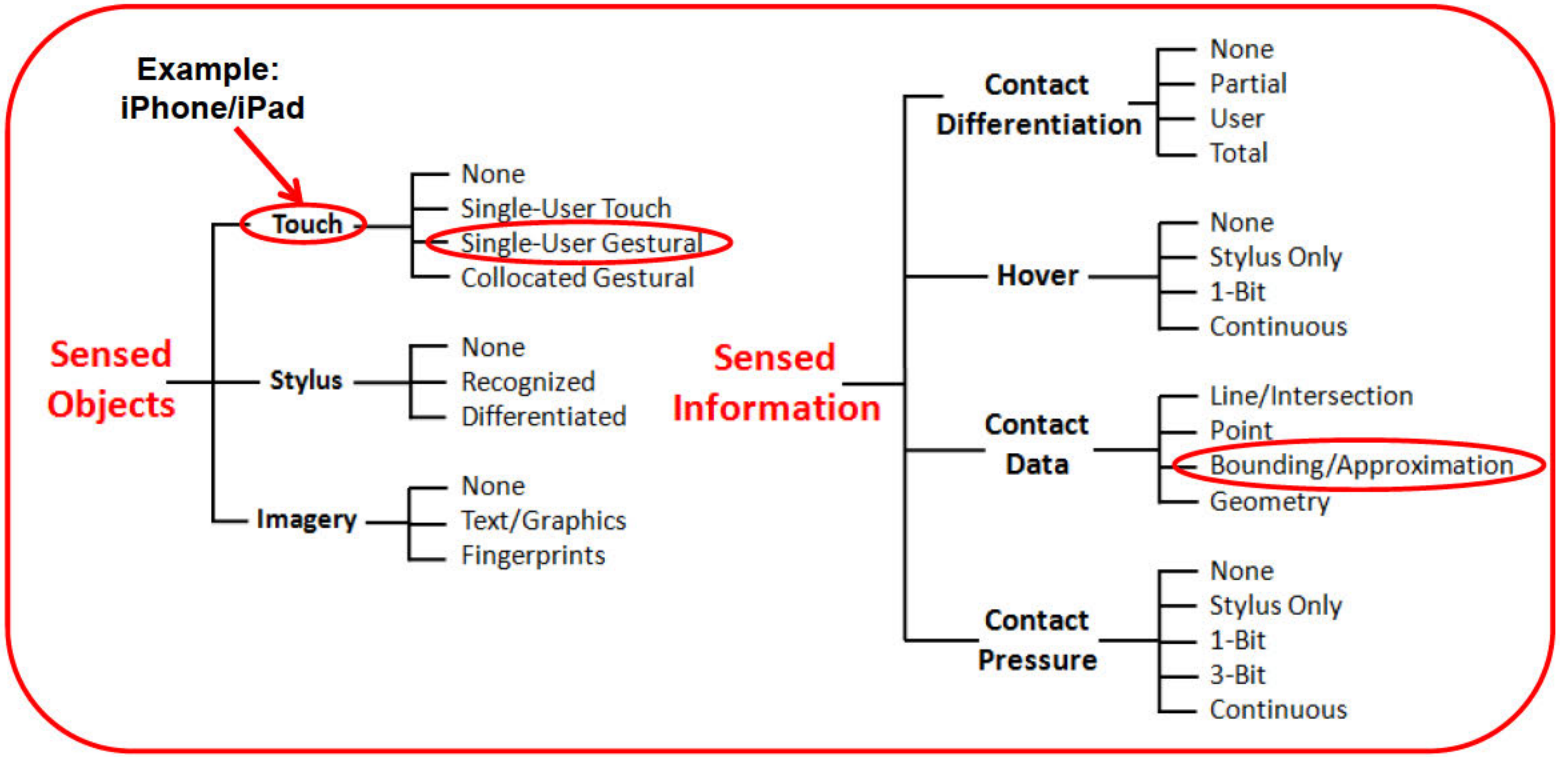
M = Mainstream L = Low-volume E = Emerging

Touch Technologies by Materials & Process



A Simple Touch Isn't Simple…1

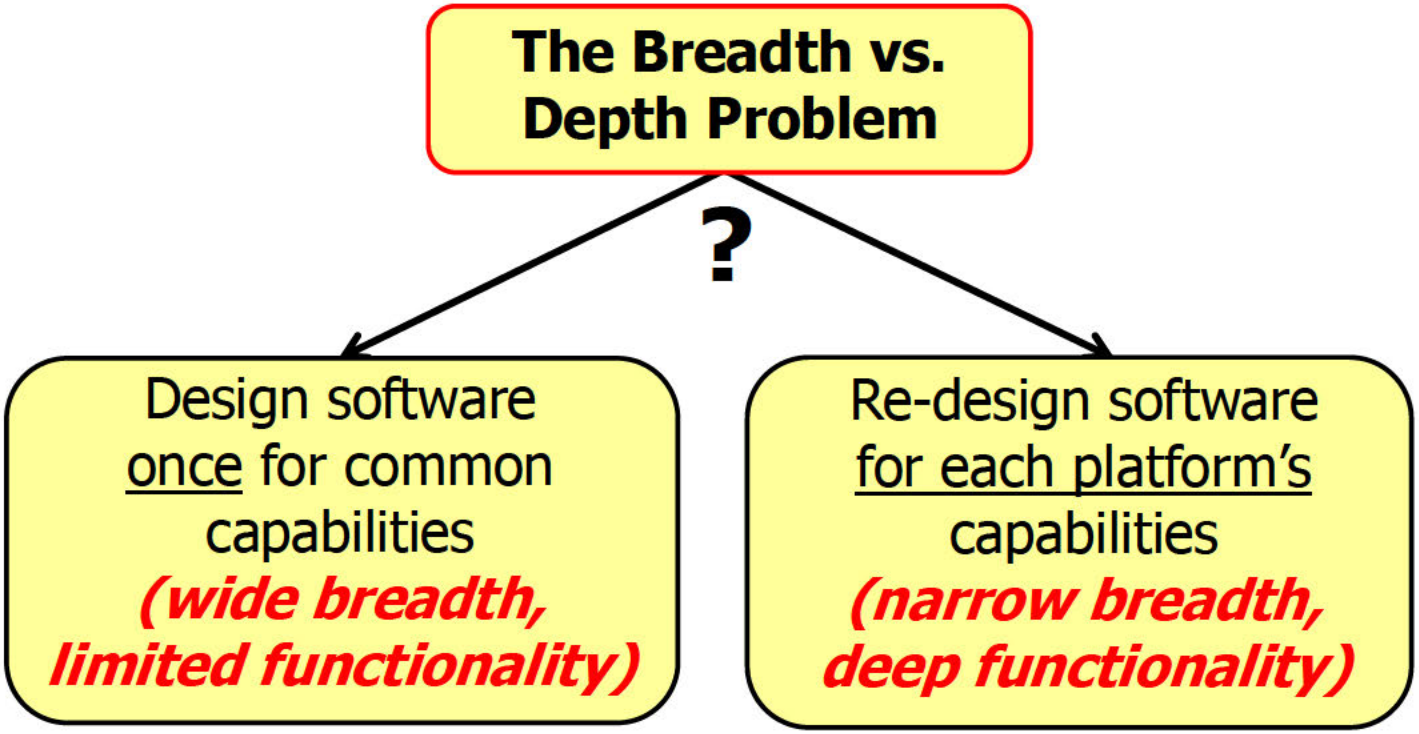
- Touch classification from the University of Toronto



Source: Daniel Wigdor

A Simple Touch Isn't Simple…2

- It's far more complex than just "how many touches?"



Touch Is An Indirect Measurement

- **This is one reason why there are so many technologies**

Touch Technology	What's Being Measured
Projected capacitive, Embedded (capacitive)	Change in capacitance
Surface capacitive	Current
Resistive (all forms) & Embedded (voltage-sensing)	Voltage
Surface acoustic wave	Ultrasonic wave amplitude
Acoustic Pulse Recognition & Dispersive Signal Technology	Bending waves
Infrared & camera-based (all forms), Planar Scatter Detection	Absence or reduction of light
Vision-based	Change in image
Embedded (light-sensing)	Presence of light
Force sensing	Force

The ideal method of sensing touch has yet to be invented!

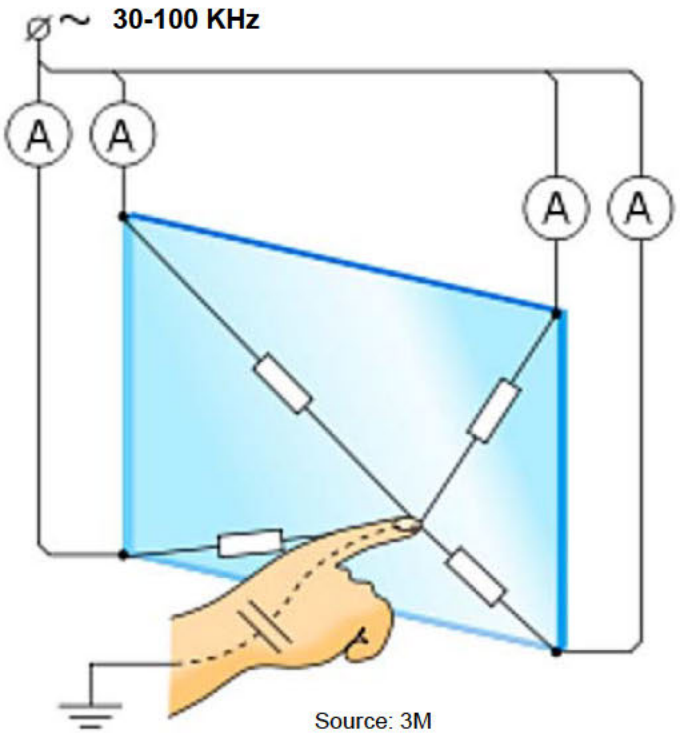
Capacitive Touch Technologies other than Projected Capacitive

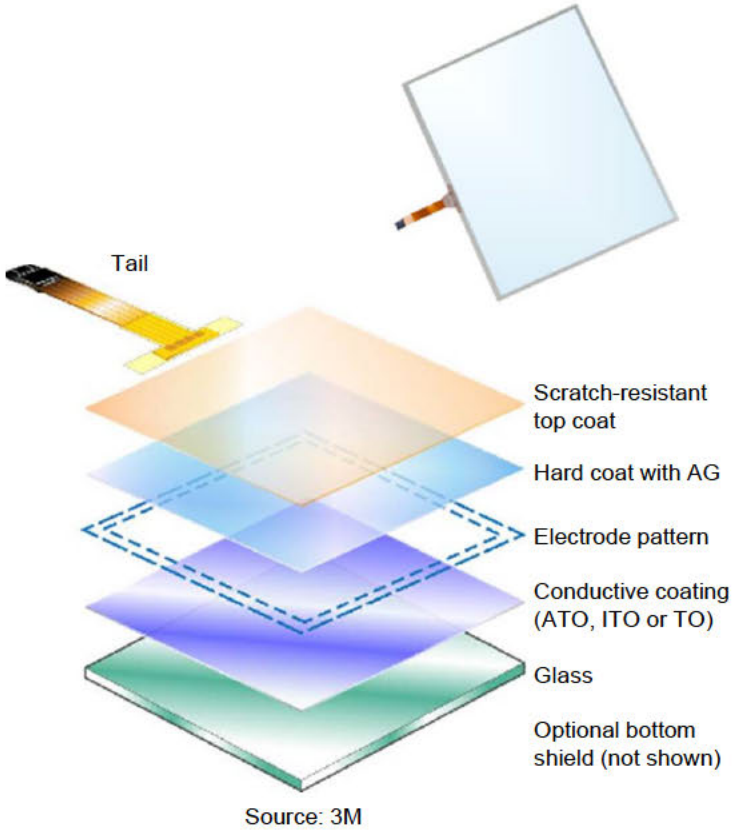
- Surface Capacitive

Source: 3M

Surface Capacitive

Surface Capacitive…1

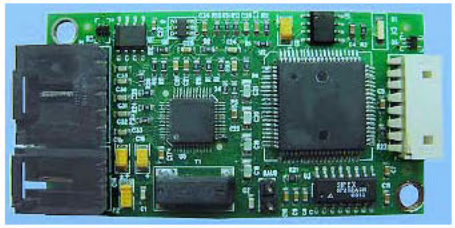




Surface Capacitive…2

- **Variations**
  - Rugged substrate
- **Size range**
  - 6.4” to 32”
- **Controllers**
  - 3M, Microchip (Hampshire), eGalax, and Digitech
- **Advantages**
  - Excellent drag performance with extremely smooth surface
  - Much more durable than analog resistive
  - Resistant to contamination
  - Highly sensitive (very light touch)

Source: 3M



Source: Interactive Systems