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

It’s called a TOUCHSCREEN...
Get used to it.

Source: Gizmodo

(Michelangelo's "The Creation Of Adam", in the Sistine Chapel, 1511)
# Status of Touch Technologies
## By Size & Application

<table>
<thead>
<tr>
<th>Touch Technology</th>
<th>Mobile (2” – 17&quot;)</th>
<th>Stationary Commercial (10” – 30&quot;)</th>
<th>Stationary Consumer (10” – 30&quot;)</th>
<th>Large-Format (&gt;30&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Capacitive</td>
<td>A</td>
<td>A</td>
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<tr>
<td>Surface Capacitive</td>
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<tr>
<td>Analog Resistive</td>
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<tr>
<td>Analog Multi-Touch Resistive (AMR)</td>
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<tr>
<td>Digital Multi-Touch Resistive</td>
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<tr>
<td>Surface Acoustic Wave (SAW)</td>
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<tr>
<td>Acoustic Pulse Recognition (APR)</td>
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<td>Dispersive Signal Technology (DST)</td>
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<tr>
<td>Traditional Infrared (IR)</td>
<td></td>
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<td>A</td>
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<tr>
<td>Multi-Touch Infrared</td>
<td>A</td>
<td></td>
<td>E</td>
<td>E</td>
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<tr>
<td>Camera-Based Optical</td>
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<td></td>
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<td>A</td>
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<tr>
<td>Planar Scatter Detection (PSD)</td>
<td></td>
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<td>E</td>
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<tr>
<td>Vision-Based (In-Cell Optical)</td>
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<td>D</td>
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<tr>
<td>Embedded (In-Cell/On-Cell Capacitive)</td>
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<tr>
<td>Force Sensing</td>
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<td>D</td>
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</tbody>
</table>

**Legend:**
- **A** = Active
- **L** = Legacy
- **E** = Emerging
- **D** = Dead/Dying
Touch Penetration
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


Daria Loi – User Experience Innovation Manager at Intel Corporation

Study released to the public on January 28, 2013
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

❖ 6 to 32 touches
❖ 32” to 103”

Source: Author

LED_A LED_B

= IR emitter
= IR receiver

Source: Author
Multi-Touch Infrared...3

❖ “PulseIR” (Image Display Systems) method

❖ 2 to 40 touches
❖ 5” to 103”

Source: Author
Multi-Touch Infrared…4

❖ “TimeLink” method

- 10 to 48 touches
- 15” to 100”
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
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)
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 lower 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 higher than ITO
  - Highly flexible – bend radius typically 4 mm

- **Optical problems have been solved**
  - Invisible mesh, with no moiré pattern
Metal Mesh Example
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”
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?)
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*

**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

Source: The Author
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*)
  - 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

Both sense and drive electrodes are in the TFT array, 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*

<table>
<thead>
<tr>
<th>Lighting Type</th>
<th>Max Lux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact Fluorescent</td>
<td>600</td>
</tr>
<tr>
<td>Cool White LED</td>
<td>560</td>
</tr>
<tr>
<td>Vapor Lamps</td>
<td>530</td>
</tr>
<tr>
<td>Sunlight (filtered through window)</td>
<td>400</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>370</td>
</tr>
<tr>
<td>Warm White LED</td>
<td>300</td>
</tr>
<tr>
<td>Sunlight (direct)</td>
<td>160</td>
</tr>
<tr>
<td>Halogen</td>
<td>60</td>
</tr>
<tr>
<td>Incandescent</td>
<td>50</td>
</tr>
</tbody>
</table>

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
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 has been used in commercial applications continuously since the early 1990s

- Sales automation, healthcare, insurance inspections, etc.

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

Photo by Author
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 needs 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
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

Fujitsu Detachable

Lenovo Double-Hinge

All N-Trig!
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
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)
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
“Adaptive configuration” example (N-Trig)

Touch should always work!

Finger-Touch Detection

One Finger Only?

Noise Level?

Reduce Touch Report-Rate

Single-Touch Operation

Normal Operation: Multi-Touch With Frequency-Hopping

Medium

Medium-High

Yes

No

Extreme

No

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
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)
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.
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
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
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
More use of USB interfaces, less use of I²C

- 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
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
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
True “single-layer” sensor (continued)

- A true single-layer sensor has one layer of ITO and nothing else

- 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

(Conceptual drawing)
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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Roadmap not reflective of exact launch granularity and timing – please refer to ILU guidance

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