Agenda: Part 1

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  - Surface Acoustic Wave (SAW)
  - Surface Capacitive
  - Traditional Infrared (IR)
- Electromagnetic Resonance (EMR) Pen Digitizer [4]
- Emerging Touch Technologies Without Multi-Touch [13]
  - Acoustic Pulse Recognition (APR - Elo)
  - Dispersive Signal Technology (DST - 3M)
  - Force Sensing (Vissumo)

[ ] = Number of content slides in each section
Agenda: Part 2

- Multi-Touch [9]
- Emerging Touch Technologies With Multi-Touch [58]
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  - LCD In-Cell (Optical, Switch & Capacitive)
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  - Vision-Based Optical
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- Appendix [9]
  - Sunlight Readability of Resistive Touchscreens
About NextWindow

NextWindow
- Founded in 2000 by CTO and private investors
- 100 employees, 45 in engineering

Brief history
- 2003: First product to market (optical touch for large displays)
- 2005: Entered USA market
- 2006: First major volume contract signed (HP TouchSmart AiO)
- 2008: Entered Taiwan market with ODM focus
- 2009: Engaged with many PC OEMs & ODMs on Win-7 products

Global presence
- HQ in New Zealand; offices in USA, Taiwan and Singapore
- Manufacturing in China, Thailand and Malaysia

Currently focused on two touch-screen markets
- Windows-7 consumer monitors and all-in-one computers
- Large-format display applications such as interactive digital signage
Introduction

Source: Elo TouchSystems
Two Basic Categories of Touch

- **Opaque touch**
  - Dominated by the controller chip suppliers
    - Atmel, Cypress, Synaptics, etc.
    - One technology (projected capacitive)
    - Sensor is typically developed by the device OEM
  - Notebook touchpads are the highest-revenue application
    - Synaptics ~60% share; Alps ~30% share; Elan ~10% share
    - Sensors are all two-layer projected capacitive
  - *There is no further discussion of opaque touch in this tutorial*

- **Transparent touch on top of a display**
  - Dominated by the sensor manufacturers (100+ worldwide)
  - 13 technologies
# 2008 Touchscreen Market by Size and Type of Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Small-Med (&lt;10”)</th>
<th>Large-Area (&gt;10”)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Revenue</td>
<td>Units</td>
<td>Revenue</td>
</tr>
<tr>
<td>Resistive</td>
<td>$1,140M</td>
<td>325M</td>
<td>$684M</td>
</tr>
<tr>
<td>Surface acoustic wave</td>
<td>$4.7M</td>
<td>0.1M</td>
<td>$185M</td>
</tr>
<tr>
<td>Surface capacitive</td>
<td>$0.2M</td>
<td>0M</td>
<td>$168M</td>
</tr>
<tr>
<td>Infrared</td>
<td>$4.5M</td>
<td>0.1M</td>
<td>$128M</td>
</tr>
<tr>
<td><strong>Mainstream</strong></td>
<td>$1,150M</td>
<td>325M</td>
<td>$1,165M</td>
</tr>
<tr>
<td>Emerging</td>
<td>$462M</td>
<td>31M</td>
<td>$55M</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>$1,612M</td>
<td>356M</td>
<td>$1,220M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>Revenue</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small-Medium</td>
<td>57%</td>
<td>88%</td>
</tr>
<tr>
<td>Large-Area</td>
<td>43%</td>
<td>12%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>Revenue</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainstream</td>
<td>82%</td>
<td>92%</td>
</tr>
<tr>
<td>Emerging</td>
<td>18%</td>
<td>8%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Market size estimates are based on DisplaySearch’s 2009 “Touch-Panel Market Analysis” with adjustments.
2008 Touchscreen Market by Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>2008 Revenue</th>
<th>2008 Share</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Resistive **</td>
<td>$1,824M</td>
<td>64%</td>
<td>30% = stationary</td>
</tr>
<tr>
<td>Projected Capacitive</td>
<td>$470M</td>
<td>17%</td>
<td>3% = stationary</td>
</tr>
<tr>
<td>Surface Acoustic Wave (SAW) **</td>
<td>$190M</td>
<td>6.7%</td>
<td>Most &gt; 10”</td>
</tr>
<tr>
<td>Surface Capacitive **</td>
<td>$168M</td>
<td>5.9%</td>
<td>Most &gt; 10”</td>
</tr>
<tr>
<td>Traditional Infrared **</td>
<td>$133M</td>
<td>4.7%</td>
<td>Most &gt; 10”</td>
</tr>
<tr>
<td>Optical</td>
<td>$40M</td>
<td>1.4%</td>
<td>All &gt; 10”</td>
</tr>
<tr>
<td>Acoustic Pulse Recognition (APR – Elo)</td>
<td>$2M</td>
<td>0.1%</td>
<td>All &gt; 10”</td>
</tr>
<tr>
<td>Dispersive Signal Technology (DST – 3M)</td>
<td>$2M</td>
<td>0.1%</td>
<td>All &gt; 30”</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>$2M</td>
<td>0.1%</td>
<td>All &gt; 30”</td>
</tr>
<tr>
<td>Force Sensing (Vissumo)</td>
<td>$1M</td>
<td>0%</td>
<td>Start-up</td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>0</td>
<td></td>
<td>No controllers</td>
</tr>
<tr>
<td>Waveguide Infrared (RPO)</td>
<td>0</td>
<td></td>
<td>No customers</td>
</tr>
<tr>
<td>LCD In-Cell (all forms)</td>
<td>0</td>
<td></td>
<td>No shipments</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$2,832M</strong></td>
<td><strong>100%</strong></td>
<td></td>
</tr>
</tbody>
</table>

- 4 mainstream touch technologies** ........ 82%
- #2 new kid on the block (pro-cap) ........ 17%
- Remaining emerging technologies .......... 1%

Market size estimates are based on DisplaySearch’s 2009 “Touch-Panel Market Analysis” with adjustments
Why There Are So Many Touch Technologies

Source: Elo TouchSystems
Why There Are So Many Touch Technologies

1. Proliferation of touch
2. Touch is an indirect measurement
3. There is no perfect touch technology
4. The drive for fundamental intellectual property
5. Vertical integration

Source: Gizmodo
Proliferation of Touch

- Self-service eliminates humans & saves $$
- Increasing display ubiquity & decreasing display cost
- Simplification of the user interface
- Hand-eye coordination
- Shrinking device size
- Global hardware simplification
- Increased awareness of value
- Viral behavior (the iPhone effect)

Source: Apple
## Touch Is An Indirect Measurement

<table>
<thead>
<tr>
<th>What’s Being Measured</th>
<th>Touch Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>Resistive (all forms), LCD in-cell (voltage)</td>
</tr>
<tr>
<td>Current</td>
<td>Surface capacitive</td>
</tr>
<tr>
<td>Time delay</td>
<td>Surface acoustic wave</td>
</tr>
<tr>
<td>Change in capacitance</td>
<td>Projected capacitive, LCD in-cell (charge)</td>
</tr>
<tr>
<td>Absence of light</td>
<td>Optical, Infrared (all forms), LCD in-cell (light) in high ambient</td>
</tr>
<tr>
<td>Presence of light</td>
<td>LCD in-cell (light) in low ambient</td>
</tr>
<tr>
<td>Image</td>
<td>Vision-based optical</td>
</tr>
<tr>
<td>Bending waves</td>
<td>Acoustic Pulse Recognition (APR), Dispersive Signal Technology (DST)</td>
</tr>
<tr>
<td>Force</td>
<td>Force sensing</td>
</tr>
</tbody>
</table>

The ideal method of detecting touch has yet to be invented!
## There Is No Perfect Touch Technology

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Analog Resistive</th>
<th>Projected Capacitive</th>
<th>APR</th>
<th>Waveguide Infrared</th>
<th>Traditional Infrared</th>
<th>Digital Resistive</th>
<th>LCD In-Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stylus Independence</td>
<td>✔</td>
<td>🕳️</td>
<td>🍀️</td>
<td>✔</td>
<td>🕳️</td>
<td>✔</td>
<td>🕳️</td>
</tr>
<tr>
<td>Multi-Touch</td>
<td>🕳️</td>
<td>🍀️</td>
<td>🍀️</td>
<td>✔</td>
<td>✔</td>
<td>🍀️</td>
<td>🍀️</td>
</tr>
<tr>
<td>Durability</td>
<td>🕳️</td>
<td>🍀️</td>
<td>🍀️</td>
<td>🍀️</td>
<td>🍀️</td>
<td>🕳️</td>
<td>✔</td>
</tr>
<tr>
<td>Optical Performance</td>
<td>🕳️</td>
<td>✔</td>
<td>🍀️</td>
<td>🍀️</td>
<td>🍀️</td>
<td>🕳️</td>
<td>🕳️</td>
</tr>
<tr>
<td>Flush Surface</td>
<td>✔</td>
<td>🍀️</td>
<td>🍀️</td>
<td>✔</td>
<td>🕳️</td>
<td>✔</td>
<td>🍀️</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>🍀️</td>
<td>✔</td>
<td>🍀️</td>
<td>✔</td>
<td>🕳️</td>
<td>✔</td>
<td>🕳️</td>
</tr>
<tr>
<td>Stable Calibration</td>
<td>🕳️</td>
<td>🍀️</td>
<td>🍀️</td>
<td>🍀️</td>
<td>🍀️</td>
<td>🕳️</td>
<td>🕳️</td>
</tr>
<tr>
<td>Narrow Borders</td>
<td>✔</td>
<td>✔</td>
<td>🍀️</td>
<td>✔</td>
<td>🕳️</td>
<td>✔</td>
<td>🕳️</td>
</tr>
<tr>
<td>Substrate Independence</td>
<td>✔</td>
<td>🍀️</td>
<td>🍀️</td>
<td>✔</td>
<td>🕳️</td>
<td>✔</td>
<td>🕳️</td>
</tr>
<tr>
<td>Cost</td>
<td>🍀️</td>
<td>🕳️</td>
<td>✔</td>
<td>✔</td>
<td>🕳️</td>
<td>✔</td>
<td>🕳️</td>
</tr>
</tbody>
</table>

### Example: Selecting the touch technology for a smartphone

- **Best**
- **OK**
- **Worst**
The Drive For Fundamental Intellectual Property

The fundamental intellectual property (IP) on all four of the traditional touch technologies has expired.
- New patents tend to be on enhancements.

Companies trying to establish a sustainable competitive advantage create new touch technologies.

"Cross-beam" light paths increase resolution and fault-tolerance in infrared touchscreens (Elo).

e.g., Touchco, SiMa Systems, FlatFrog & others...
LCD in-cell touch
- When touch was insignificant, LCD manufacturers ignored it
- Now that it’s becoming more significant, LCD manufacturers want to incorporate it into their products

Three types
- Light-sensing: Photo-transistor in every or some pixels
  - Can’t sense touch on a dark on-screen object in low light
- Voltage-sensing: Micro-switches in each pixel
  - User must press the surface of the LCD (poor durability)
- Charge-sensing: Capacitive ITO electrodes in or on the cell
  - Standard shortcomings of projected capacitive (e.g., no stylus)

“There is no perfect touch technology”
Touch & Flexible Displays

Source: Cambrios
## Touch Technologies & Flexible Displays

<table>
<thead>
<tr>
<th>Touch Technology</th>
<th>Applicability</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pro-Cap &amp; On-Cell (Charge)</td>
<td>High</td>
<td>Single flexible substrate; may need <strong>ITO replacement</strong></td>
</tr>
<tr>
<td>Pen Digitizer</td>
<td>High</td>
<td>Flexible sensor behind display</td>
</tr>
<tr>
<td>In-Cell (Light)</td>
<td>High</td>
<td>Involves only LCD backplane</td>
</tr>
<tr>
<td>Analog &amp; Digital Resistive</td>
<td>Medium</td>
<td>Film-film construction; may need <strong>ITO replacement</strong></td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>Low</td>
<td>Might be possible; may need <strong>ITO replacement</strong></td>
</tr>
<tr>
<td>Surface Acoustic Wave (SAW)</td>
<td>Low</td>
<td>Unlikely due to need for flexible reflectors</td>
</tr>
<tr>
<td>In-Cell (Charge &amp; Voltage)</td>
<td>None</td>
<td>Depends on frontplane-to-backplane spacing</td>
</tr>
<tr>
<td>Bending Wave (APR &amp; DST)</td>
<td>None</td>
<td>Requires rigid substrate</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>None</td>
<td>Requires rigid substrate</td>
</tr>
<tr>
<td>Optical</td>
<td>None</td>
<td>Light travels in a straight line</td>
</tr>
<tr>
<td>Infrared (All types)</td>
<td>None</td>
<td>Light travels in a straight line</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>None</td>
<td>Rear-projection only</td>
</tr>
</tbody>
</table>
Examples of Flexible Touch...1

ASU-FDC: Pen substrate, Wacom pen digitizer; Epson display controller also supports resistive touch, but it’s not implemented in this particular prototype

QUE/PlasticLogic: Flexible screen in a rigid device; flexible projected capacitive
Examples of Flexible Touch...2

Bridgestone: Flexible resistive? (10.7”, 5.8 mm thick)

AUO & SiPix: Potentially flexible pro-cap touchscreen on a glass-substrate e-book reader (reflectivity 33% → 27%)

(Same screen in Jinke A6 & A9 readers)
Examples of Flexible Touch...3

Concept shown by LG Display at SID 2009

Concept
Flexible Touch E-Book display using SW TFT and Photo-Sensor array on a thin metal foil and electrophoretic e-Ink film

Features
• Slim and Light display using thin stainless steel substrate & E-Ink film
• Low power consumption and Portable display
• Excellent readability with wide viewing angle
• Low temperature process and device development for flexible display
• In-Cell Type Touch Panel using Photo Sensor

✧ 2 sensors per 10x12 pixels (dpi = 174)
✧ What about touching a black object?
ITO Replacements…1

- **Why replace ITO?**
  - Brittle & inflexible
  - Highly reflective (IR = 2.6) & tinted yellow
  - Costly to pattern & needs high temperature processing
  - Relies on “environmentally questionable” Chinese zinc mines*

- **Replacement material objectives**
  - Better in all of the above characteristics
  - Higher transmissivity & same resistivity
  - Solution processing (no vacuum sputtering)
  - Same or lower cost than ITO

- **Three main replacement candidates**
  - Metal nano-wires
  - Carbon nanotubes
  - Conductive polymers

* 63% of estimated 2007 production of indium
ITO Replacements...2

- **Metal nano-wires**
  - **Cambrios**
    - Synthesis of inorganic material (e.g., silver) from soluble precursors, followed by assembly of the resulting materials into nanostructures.
    - Cambrios has been coating rolls of PET with their material (“ClearOhm”) in a roll-to-roll production facility since early 2007.
    - Cambrios is working with all the Japanese resistive suppliers, but has signed an exclusive agreement for pro-cap with Nissha.
  - **Others**
    - Sigma Technologies, Nanoco, university research.

Source: Nikkei Business Publications
ITO Replacements...3

Cambrios Sample TC Film
AG / PET / Clr HC / TC

Transmission, %
Wavelength, nm

Source: Cambrios
ITO Replacements…4

- Carbon nanotubes
  - Unidym
    - Merged with Carbon Nanotubes Inc. (CDI) in 2007; IP leader
    - Targeting touch-screens first, then displays and photovoltaics
    - Not yet meeting transmissivity & resistivity targets
  - Eikos
    - Mostly funded through government contracts on conductive polymeric coatings and films (e.g., ESD film, EMI shield, etc.)
    - Good progress on transmissivity & resistivity but… no momentum
  - Others
    - Canatu, RQMP, DuPont
ITO Replacements…5

- Conductive polymers (PEDOT/PSS)*
  - Fujitsu
    - The only commercialized replacement so far
    - First announced in 2003; first production in 2008
    - 5X – 10X touch-screen lifetime
    - Roll-to-roll film manufacturing
    - BUT, conventional wisdom is that PEDOT has inferior transparency and degrades under UV…
  - Others
    - Agfa, Kent Displays, National Starch, university research

* poly(ethylene dioxythiophene) / poly(styrene sulfonate)
ITO Replacements…6

Realities

- The indium supply is not really an issue
- ITO used in LCDs is < 1% of cost (~$4 for a 40” display)
- LCD makers are very reluctant to make changes in fabs
- Touch-screens provide several good reasons to switch from ITO to an alternative, but the market is relatively small
  - 500M cellphone touch-screens only need about $5M of ITO
- Flexible displays are probably the biggest opportunity for ITO replacements, but there’s still no killer app

Conclusion

- Replacing ITO is unlikely to be a quick activity
Mainstream Touch Technologies

- Analog Resistive
- Surface Acoustic Wave (SAW)
- Surface Capacitive
- Traditional Infrared (IR)

*Note: SAW & IR support multi-touch*
Analog Resistive

Source: Engadget
Analog Resistive...1

Source: Elo TouchSystems

Source: Bergquist
Analog Resistive...2

- **Types**
  - 4-wire (low cost, short life) is common in mobile devices
  - 5-wire (higher cost, long life) is common in stationary devices

- **Constructions**
  - Film (PET) + glass (previous illustration) is the most common
  - Film + film (used in some cellphones) can be made flexible
  - Glass + glass is the most durable; automotive is the primary use
  - Film + film + glass, others…

- **Options**
  - Surface treatments (AG, AR, AS), rugged substrate, dual-force touch, high-transmissivity, surface armoring, many others…

Source: Schott
Analog Resistive…3

4-Wire Construction

X-Axis

Voltage gradient applied across glass

Bus bar

Y-Axis

Voltage gradient applied across coversheet

Voltage measured on coversheet

Voltage measured on glass

Equivalent circuit
Analog Resistive...4

5-Wire Construction

X-Axis

Contact point on coversheet is a voltage probe

Linearization pattern

Voltage gradient applied across glass

Y-Axis

Contact point on coversheet is a voltage probe

Voltage gradient applied across glass

Equivalent circuit
Analog Resistive…5

- **Size range**
  - 1” to ~24” (>20” is rare)

- **Controllers**
  - Many sources
  - Single chip, embedded in chipset/CPU, or “universal” controller board

- **Advantages**
  - Works with finger, stylus or any non-sharp object
  - Lowest-cost touch technology
  - Widely available (it’s a commodity)
  - Easily sealable to IP65 or NEMA-4
  - Resistant to screen contaminants
  - Low power consumption

Source: Liyitec

Source: Hampshire
Analog Resistive...6

- **Disadvantages**
  - Not durable (PET top surface is easily damaged)
  - Poor optical quality (10%-20% light loss)
  - No multi-touch

- **Applications**
  - Mobile devices
  - Point of sale (POS) terminals
  - Wherever cost is #1

- **Market share**

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>64%</td>
</tr>
<tr>
<td>Volume</td>
<td>91%</td>
</tr>
</tbody>
</table>
Analog Resistive…7

- **Suppliers**
  - Nissha, Young Fast, J-Touch, Gunze, Truly Semi, Fujitsu, EELY, Elo TouchSystems, SMK, Swenc/TPO, eTurboTouch…
  - 60+ suppliers

- **Market trends**
  - Analog resistive is losing share (1st time!) to projected capacitive in the mobile market
    - First significant challenge to analog resistive’s dominance
  - Analog resistive is still very important in mobile phones in Asia
    - It supports a stylus; projected capacitive doesn’t (yet!)
Surface Acoustic Wave

Source: Kodak
Surface Acoustic Wave...1

Source: Onetouch

Source: A-Touch
Surface Acoustic Wave...2

Source: Elo TouchSystems
Surface Acoustic Wave…3

- **Variations**
  - Ruggedization, dust-proofing, surface treatments, etc.

- **Size range**
  - 6” to 52” (but some integrators won’t use it above 32”)

- **Controllers**
  - Mostly proprietary

- **Advantages**
  - Clear substrate (high optical performance)
  - Very durable
  - Can be vandal-proofed with tempered or CS glass
  - Finger, gloved hand & soft stylus activation
Surface Acoustic Wave...4

- **Disadvantages**
  - Very sensitive to any surface contamination, including water
  - Requires “soft” (sound-absorbing) touch object
  - Can be challenging to seal
  - Relatively high activation force
  - Projects slightly above touch surface (1 mm) so can’t be flush

- **Applications**
  - Kiosks
  - Gaming

- **Market share**

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>7%</td>
</tr>
<tr>
<td>Volume</td>
<td>1%</td>
</tr>
</tbody>
</table>

Source: Euro Kiosks Network
Surface Acoustic Wave…5

- Suppliers
  - Elo TouchSystems, General Touch, Shenzhen Top-Touch, Leading Touch, Shenzhen KeeTouch…
  - 10+ suppliers

- Market trends
  - Price is dropping as Taiwanese and Chinese vendors enter the market now that Elo TouchSystems’ key patent has expired
    - Elo still has >50% of this market
  - SAW’s growth is matching the market
Surface Acoustic Wave...6

Elo’s “XYU” multi-touch SAW (demoed at SID 2009; launched 12/09)

Photo by Geoff Walker
### SAW vs. Optical Technology Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>SAW</th>
<th>Optical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touch force</td>
<td>80 grams</td>
<td>Zero</td>
</tr>
<tr>
<td>Touch object</td>
<td>Soft</td>
<td>IR-opaque</td>
</tr>
<tr>
<td>Maximum number of touches</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Sensitivity to contamination</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Profile height</td>
<td>1 mm</td>
<td>2-3 mm</td>
</tr>
<tr>
<td>Border width</td>
<td>Large</td>
<td>Medium</td>
</tr>
<tr>
<td>Mounting &amp; bezel</td>
<td>Complex</td>
<td>Medium</td>
</tr>
<tr>
<td>Power consumption</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Occlusions &amp; ghost touches</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sales volume</td>
<td>Just starting</td>
<td>&gt; 1M</td>
</tr>
<tr>
<td>Sole-source</td>
<td>Yes (Elo)</td>
<td>No</td>
</tr>
<tr>
<td>Cost</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

✧ SAW & optical will compete in consumer desktops
Surface Acoustic Wave...8

Special Case: Fujitsu Lab’s Mobile SAW Prototype (2007)

Enabling Technology:
Thin-film piezo transducers that are only 2 microns thick. The transducers are sandwiched in an electrode structure consisting of an array of V-shaped electrodes, all around the screen.

Source: Fujitsu Labs
Surface Capacitive

Source: 3M
Surface Capacitive...1

- Scratch-resistant top coat
- Hard coat with AG
- Electrode pattern
- Conductive coating (ATO, ITO or TO)
- Glass
- Optional bottom shield (not shown)

Source: Elo TouchSystems
Source: 3M

Tail
Surface Capacitive…2

- **Variations**
  - Rugged substrate

- **Size range**
  - 6.4” to 32”

- **Controllers**
  - 3M, Hampshire, eGalax, Digitech and Billabs (ISI)

- **Advantages**
  - Excellent drag performance with extremely smooth surface
  - Much more durable than analog resistive
  - Resistant to contamination
  - Highly sensitive

Source: 3M

Source: Billabs
Surface Capacitive…3

- Disadvantages
  - Finger-only
  - Calibration drift
  - Susceptible to EMI (no mobile use)
  - Moderate optical quality (85% - 90% transmissivity)

- Applications
  - Regulated (casino) gaming
  - Kiosks
  - ATMs

- Market share

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
</tr>
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<tbody>
<tr>
<td>Revenue</td>
<td>6%</td>
</tr>
<tr>
<td>Volume</td>
<td>&lt;1%</td>
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</tbody>
</table>

Source: 3M
Surface Capacitive…4

- **Suppliers**
  - 3M, DanoTech, Elo TouchSystems, EELY, DigiTech, eTurbo, Optera, Touch International, Higgstec…
  - 16+ suppliers (dominated by 3M)

- **Market trends**
  - Surface capacitive isn’t growing with the touch market
    - No multi-touch capability; other significant disadvantages
    - Casinos (major market) are starting to experiment with other touch technologies
  - Price is dropping as Taiwanese and Chinese suppliers enter the market now that 3M’s key patent has expired
A New Spin: Wacom’s RRFC
Surface Capacitive Technology

How it works

- AC voltage on 2 adjacent corners; DC voltage on other 2 corners
  - Creates ramp-shaped electrostatic field across surface
- Controller switches signals around all 4 corners, creating 4 ramp fields vs. single flat field in standard capacitive
  - Current flow is measured in each case
- Resulting signal representing touch event is independent of all capacitance effects except those due to finger touch
- Controller does additional digital signal processing to compensate for factors that affect accuracy and drift

RRFC = Reversing Ramped Field Capacitive

Source: Wacom
(Trademark = CapPLUS)
Wacom’s RRFC Technology...

- **Advantages**
  - Solves all the problems of traditional surface capacitive
    - Works in mobile & stationary devices (3” to 46”)
    - Unaffected by grounding changes, EMI, variations in skin dryness & finger size, temperature, humidity, metal bezels, etc.
    - Works through latex or polypropylene gloves
    - Allows 4X thicker hardcoat for improved durability
    - Screen works outdoors in rain and snow
  - Uses same ASIC as Wacom’s EMR pen digitizer, so dual-mode input is lower cost & more efficient (e.g., in Tablet PC)

- **Disadvantages**
  - No multi-touch
  - Sole-source supplier
Traditional Infrared
Traditional Infrared…1

Source: Elo TouchSystems
Traditional Infrared...2

- **Variations**
  - Bare PCA vs. enclosed frame; frame width & profile height; enhanced sunlight immunity; force-sensing

- **Size range**
  - 8” to 150”

- **Controllers**
  - Mostly proprietary, except IRTouch

- **Advantages**
  - Scaleable to very large sizes
  - Multi-touch capable (2-4 touches)
  - Can be activated with any IR-opaque object
  - High durability, optical performance and sealability
  - Doesn’t require a substrate
Traditional Infrared...3

- **Disadvantages**
  - Profile height (IR transceivers project above touch surface)
  - Bezel must be designed to include IR-transparent window
  - Sunlight immunity can be a problem in extreme environments
  - Surface obstruction or hover can cause a false touch
  - Low resolution
  - High cost

- **Applications**
  - POS
  - Kiosks
  - Large displays (digital signage)

- **Market share**

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
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<tbody>
<tr>
<td>Revenue</td>
<td>5%</td>
</tr>
<tr>
<td>Volume</td>
<td>&lt;1%</td>
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</tbody>
</table>
Traditional Infrared...4

- **Selected suppliers**
  - Elo TouchSystems, IRTouch, Minato, Nexio…
  - 10+ suppliers

- **Market trends**
  - Interest in IR is re-awakening as Asian vendors bring down prices, large displays become more common, and digital signage becomes more affordable
  - IR is growing, but isn’t keeping up with the market

50” plasma display with infrared touch-screen from Netrax
Elo’s “XYU” multi-touch traditional infrared (two-touch version first shown in 2008; launch expected in 2010)
Traditional Infrared...6

- **Special Case:** Neonode cellphone implemented with traditional infrared touch
  - Same battery life as iPhone
  - Low profile height (~1.7mm)
  - Finger-only
  - No multi-touch

- **Neonode couldn’t complete in the cellphone market and went bankrupt in 2009**

Source: Neonode & Pen Computing
Electromagnetic Resonance (EMR) Pen Digitizer

Source: Wacom
EMR Pen Digitizer…1

Cordless pen without battery

Transmitted RF

Received RF

Pen equivalent circuit

Pressure-sensitive capacitor ($C_{\text{Tip}}$)

Coil (L)

Sensor grid schematic

Source: Wacom

Sensor grid schematic

Source: Wacom

Controller chipset

Serial/USB interface to host

many wires

5-8 wires

Source: Wacom

5-8 wires

Source: Wacom

Pressure-sensitive capacitor ($C_{\text{Tip}}$)

Coil (L)

Sensor grid schematic

Source: Wacom

Pen equivalent circuit
EMR Pen Digitizer…2

- **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

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

Source: Wacom
EMR Pen Digitizer…3

- **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 = relatively high cost

- **Applications**
  - Tablet PCs
  - Opaque desktop graphics tablets
  - Integrated tablet (pen) monitors
  - E-book readers
  - Smartphones… but zero traction

- **Market share**
  - 100% share in Tablet PCs
    - Failed challengers: FinePoint/InPlay, Aiptek, Acecad, KYE, Synaptics, UC-Logic, Wintime
  - Majority share in graphics tablets & tablet monitors
EMR Pen Digitizer…4

- **Suppliers**
  - Wacom, Hanvon, Waltop, UC-Logic/Sunrex

- **Market trends**
  - Microsoft significantly de-emphasized the pen in Windows 7, so Wacom is selling into Tablet PCs against a headwind
  - Pen in general is undergoing a lessening of importance
    - iPhone and many imitators
    - Tablet PCs still a niche
    - iPad… doesn’t have a pen!
  - E-book readers are a natural fit if annotation is important…
  - E-Ink 9.7” Prototype EMR Kit
Emerging Touch Technologies

*Without Multi-Touch*

- Acoustic Pulse Recognition (APR - Elo)
- Dispersive Signal Technology (DST – 3M)
- Force Sensing (Vissumo)
“Zero-Bezel”

Single piece of glass (no bezel); black margin is fired-on glass frit on underside

Acoustic Pulse Recognition (APR)

Source: Elo TouchSystems
Acoustic Pulse Recognition (APR)...

- Plain glass sensor with 4 piezos on the edges
- Table look-up of bending wave samples ("acoustic touch signatures")

Source: Elo TouchSystems
Acoustic Pulse Recognition (APR)…2

- **Variations**
  - “Stationary APR” from 10” to 52” with controller board
  - “Mobile APR” from 2.8” to 10” with controller ASIC

- **Size range**
  2.8” to 52”

- **Controllers**
  - Proprietary

- **Advantages**
  - Works with finger, stylus or any other touch object
  - Very durable & transparent touch sensor
  - Resistant to surface contamination; works with scratches
  - Totally flush top surface (“Zero-Bezel”)
  - Very simple sensor (plain glass + 4 piezoelectric transducers)
Acoustic Pulse Recognition (APR)…3

- **Disadvantages**
  - No “touch & hold”; no multi-touch
    (both are under development & should appear in 2010)
  - Requires enough touch-force (tap) to generate sound
  - Control of mounting method in bezel is critical

- **Applications**
  - POS, kiosks, gaming, mobile devices

- **Market share**
  - <1% (first production in Elo monitors was at the end of 2006)

- **Supplier**
  - Elo TouchSystems (sole source)

- **Market trends**
  - Elo has begun shipping APR to mobile device OEMs
Acoustic Pulse Recognition (APR)…4

Elo’s “Zero-Bezel” APR with capacitive buttons & scroll-wheel in lower-right corner (SID 2009)
Breaking News!

- Elo (Tyco Electronics) purchased Sensitive Object (www.sensitive-object.com) on 1/27/10 for $62M (wow!)
- Sensitive Object’s technology is so similar to APR that the two companies cross-licensed in July, 2007

Source: Sensitive Object
Dispersive Signal Technology (DST)

Source: 3M
Dispersive Signal Technology…1

- Plain glass sensor with 4 piezos in the corners
- Real-time analysis of bending waves in the glass ("time of flight" calculation)

Source: 3M
Dispersive Signal Technology...2

- Variations
  - None

- Size range
  - 32” to 46” (3M is likely to expand into larger sizes)

- Controller
  - Proprietary

- Advantages
  - Very simple sensor (plain glass + 4 piezoelectric transducers)
  - Works with finger, stylus or any other touch object
  - Very durable & transparent touch sensor
  - Operates with static objects or scratches on the touch surface
  - Fast response; highly repeatable touch accuracy; light touch
Dispersive Signal Technology…3

- **Disadvantages**
  - No “touch & hold”; no multi-touch
  - Control of mounting method in bezel is critical

- **Applications**
  - Interactive digital signage; point-of-information (POI)

- **Market share**
  - < 1%

- **Supplier**
  - 3M (sole source)

- **Market trends**
  - DST still has a relatively low market profile due to 3M’s very conservative rollout
  - 3M avoids cannibalizing their surface-capacitive sales (<32”)
### APR vs. DST Technology Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>APR</th>
<th>DST</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size range</td>
<td>2.8”-52”</td>
<td>32”-46”</td>
<td>3M surface capacitive is 5.7”-32”</td>
</tr>
<tr>
<td>Methodology</td>
<td>Table lookup</td>
<td>Real-time</td>
<td></td>
</tr>
<tr>
<td>Measurement</td>
<td>Bending waves</td>
<td>Bending waves</td>
<td></td>
</tr>
<tr>
<td>Multi-touch</td>
<td>Under development</td>
<td>Gestures announced</td>
<td>3M’s “multi-touch gestures” only work with two moving points</td>
</tr>
<tr>
<td>Touch &amp; hold</td>
<td><strong>Under development</strong></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Activation force</td>
<td>Moderate</td>
<td>Light</td>
<td></td>
</tr>
<tr>
<td>Controller</td>
<td>Chip (mobile)</td>
<td>Board (fixed)</td>
<td></td>
</tr>
<tr>
<td>Mounting</td>
<td>Critical</td>
<td>Critical</td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>In monitors; components for mobile devices</td>
<td>In monitors</td>
<td>Neither technology has reached the “drop-in touch-screen” component state yet</td>
</tr>
<tr>
<td>Others</td>
<td>Similar</td>
<td>Similar</td>
<td>Performance, materials, surface treatment, interface, etc.</td>
</tr>
</tbody>
</table>
Force Sensing
Force Sensing...1

- **Principle**
  - Suspend the touch-screen from force-sensors (strain gauges or piezos) such that movement is constrained to only the z-axis

- **Variations**
  - **Vissumo**: “Beam-mounted” sensors
  - **IBM “TouchSelect”**: Strain gauges (early 1990s, unsuccessful)
  - **F-Origin**: On life-support

- **Size range**
  - 5”-48”

- **Controller**
  - Proprietary
Advantages
- Complete substrate design freedom – no other touch technology can handle three-dimensional substrates with embedded moving objects

Disadvantages
- No vibration under 10 Hz; no rapid-fire touches (>200 ms required between touches); no multi-touch

Applications
- 3D architectural applications

Market share
- <<1% (Vissumo is still a startup)
Market trends

- Vissumo’s “architectural” focus (e.g., a 3D elevator control panel made of steel, glass & stone containing an embedded LCD with “soft keys” and a speaker) is strongly differentiated with some unique capabilities
Vissumo’s Amazing Demo Box

- Glass-covered LCD integrated into touch panel with “soft keys” printed on back of glass.
- Raised, marble touch surface with toggle switches penetrating touch panel.
- “Snap-dome” keys attached to touch panel; removable padded and textured keys; speaker attached with holes through the touch panel.
- Motor attached to and penetrating touch panel with printed speed control keys and push-pull control lever.

4 strain gauges supporting one touch panel.
Multi-Touch

Sources: Engadget, Do Device and Good Times & Happy Days
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 *(released 10/22/09)* supports multi-touch throughout the OS.
- Windows 7 is structured to support an unlimited number *(100?)* of simultaneous touch points.
Multi-Touch Architecture

- **Application**: Capable of decoding multiple streams of moving points and taking actions in response
- **Operating System**: Capable of forwarding multiple streams of moving points (and acting on a defined subset of them)
- **Touchscreen Controller & Driver**: Capable of delivering sets of simultaneous points to the OS
- **Touchscreen Sensor**: Capable of sensing multiple simultaneous points
## Multi-Touch Technologies

<table>
<thead>
<tr>
<th>Touch Technology</th>
<th>Multi-Touch Capable? (#)</th>
<th>Win-7 Logo Capable?</th>
<th>Commercial MT Product Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Capacitive</td>
<td>Yes (unlimited*)</td>
<td>Yes</td>
<td><strong>Apple iPhone; Dell Latitude XT</strong></td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>Yes (unlimited*)</td>
<td>Yes</td>
<td><strong>JazzMutant Music Controller</strong></td>
</tr>
<tr>
<td>LCD In-Cell (all forms)</td>
<td>Yes (unlimited*)</td>
<td>Yes</td>
<td><strong>Sharp Netbook</strong></td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>Yes (unlimited*)</td>
<td>Yes</td>
<td><strong>Microsoft Surface</strong></td>
</tr>
<tr>
<td>Optical</td>
<td>Yes (4)</td>
<td>Yes</td>
<td><strong>HP TouchSmart</strong></td>
</tr>
<tr>
<td>Traditional Infrared (&quot;XYU&quot; IR from Elo)</td>
<td>Yes (4)</td>
<td>Yes</td>
<td>Products in development (2010)</td>
</tr>
<tr>
<td>Surface Acoustic Wave (&quot;XYU&quot; SAW from Elo)</td>
<td>Yes (2)</td>
<td>Yes</td>
<td>Products in development (2010)</td>
</tr>
<tr>
<td>Waveguide Infrared (RPO)</td>
<td>Yes (2)</td>
<td>Yes</td>
<td>Products in development (2010)</td>
</tr>
<tr>
<td>Bending Wave (DST – 3M)</td>
<td>Future (2)</td>
<td>Maybe</td>
<td>Technology in development (2010?)</td>
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<tr>
<td>Analog Resistive</td>
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<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>No</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>No</td>
<td>No</td>
<td>--</td>
</tr>
</tbody>
</table>

* Controller-dependent, not sensor-dependent
A set of touch performance standards designed to ensure a high-quality user experience

- Test 1: Sampling Rate
- Test 2: Single-Touch Taps in 4 Corners
- Test 2: Single-Touch Taps in 5 Other Locations
- Test 4: Double Taps
- Test 5: Multi-Touch Points
- Test 6: Press and Tap
- Test 7: Straight-Line Accuracy
- Test 8: Maximum Touch Lines
- Test 9: Multi-Touch Straight Lines
- Test 10: Line Accuracy Velocity
- Test 11: Single-Touch Arcs
- Test 12: Pivot
- Test 13: Multi-Touch Arcs
- Test 14: Ghost Point Test
What’s So Hard About Multi-Touch with Analog-Type Sensors?

Keeping the right X with the right Y when going through occlusion

Source: Elo TouchSystems
What’s So Hard About Multi-Touch with *Digital-Type* Sensors?

Designing a controller that can put out enough points fast enough

Source: Techdu.de
How Many Touches Are Enough?

- Why multi-touch will probably expand beyond two touches
  1. Most research on multi-touch is being done with vision-based hardware because it’s easy to develop the hardware yourself
     - Vision-based touch supports an unlimited number of touches
     - All other multi-touch-capable technologies are difficult to build & buy
  2. Projected capacitive (currently the #2 touch technology!) also supports an unlimited number of touches
  3. Number of touches is one way for a touch technology vendor to differentiate themselves
  4. ISVs are creative; they’ll find ways to use more touches ("If you build it, they will come")
An Anomaly: Multi-Touch Gestures on Non-Multi-Touch Screens

- **Elo TouchSystems: “Resistive Gestures”**
  - Capable of sensing two-finger gestures on standard analog resistive touch-screens
  - Fingers must be moving to sense two points; two static touches don’t work

- **3M: “Multi-Touch Gestures on DST”**
  - Same capability & restriction as above on Dispersive Signal Technology (DST) touch-screens

- **It’s not true multi-touch, but is it good enough?**
  - Gestures are HOT, so device manufacturers want them
  - Today, multi-touch is mostly used to enable two-finger gestures
  - For mobile devices, pro-cap is ~3X the cost of analog resistive, so enabling gestures on analog resistive is attractive
“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
Emerging Touch Technologies

*With Multi-Touch*

- Projected Capacitive
- LCD In-Cell
- Optical
- Digital Resistive
- Waveguide Infrared (RPO)
- Vision-Based Optical
Projected Capacitive

Source: Apple
"Perimeter scan" or "non-imaging" type (NB touchpad)

- X-axis and then Y-axis electrodes are scanned sequentially, looking for point of maximum capacitance to ground
- Ghost points are a problem with 2 touches
Projected Capacitive...2

“Imaging” or “all points addressable” type (Apple iPhone)

Output is an array of capacitance values for each X-Y intersection
Projected Capacitive…3

Raw data including noise

Filtered data

Gradient data

Touch region coordinates and gradient data

“10 fingers, 2 palms and 3 others”

Source: Apple Patent Application #2006/0097991
Projected Capacitive...4

Why “Projected”?  

- A finger “steals charge” from the X-electrode, changing the capacitance between the electrodes.
- E-field lines are “projected” beyond the touch surface when a finger is present.
Technology variations

- Single-layer sensor (no crossovers)
  - “Self capacitance” (Apple’s term)
  - Rarely used with displays due to low resolution

- Two-layer sensor (X-Y grid)
  - “Peripheral scan” or “non-imaging” (Synaptics ClearPad™)
  - Not commonly used with displays due to limited number of touches

- Two-layer sensor (X-Y grid)
  - “All points addressable” or “imaging” or “mutual capacitance” (Apple’s term)
  - Most common configuration
  - Supports unlimited number of touches (controller-dependent)
Projected Capacitive...6

- **Sensor variations**
  - Wires between two sheets of glass (Zytronic)
  - Wires between one piece of PET and one piece of glass (Zytronic)
  - Wires between two sheets of PET (Visual Planet)
  - ITO on two pieces of glass
  - ITO on both sides of one sheet of glass
  - ITO on two pieces of PET (Touch International)
  - ITO on one piece of PET and one piece of glass
  - ITO in two layers on one piece of glass with dielectric (TPK)

- **Wires vs. ITO**
  - Wires: Visible, acceptable for intermittent use
  - ITO: Invisible, needed for continuous use
Projected Capacitive…7

- **Size range**
  - 2” to 100”+
    - ITO up to 22”; wires up to 100”+

- **Advantages**
  - Very durable (protected sensor)
  - High optical quality (ITO)
  - Unlimited multi-touch
  - Unaffected by debris or contamination
  - Enables “zero-bezel” industrial design
  - Works with curved substrates (on PET)

- **Disadvantages**
  - Finger or tethered pen only
  - High cost (dropping as usage increases)
  - Difficult to integrate due to noise sensitivity

LG-Prada mobile phone with Synaptics’ projected-capacitive touch-screen; launched 3 months before iPhone
Projected Capacitive...8

- **Applications**
  - **Consumer devices**
    - Smartphones
    - Netbooks, notebooks, Tablet PCs
    - Apple AiOs (2010)
    - Almost any consumer device < 10”
  - **Vertical-market devices**
    - Signature-capture & other POS terminals
    - “Through-glass” interactive retail signage

- **Market share**

<table>
<thead>
<tr>
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<td>Revenue</td>
<td>17%</td>
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<td>Volume</td>
<td>8%</td>
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</table>

Source: Verifone

Source: Mildex

Demy Digital Recipe Reader (CES 2010)
Projected Capacitive...9

Gunze’s “Direct Printing Technology” (DPT) for large-area capacitive touchscreens (shown at SID 2009)

- Flexible pro-cap sensor
- Printed silver conductors, 0.5 ohm/sq.
- Roll-to-roll, maximum size 50”
- < 1 mm resolution
- 78% transmissivity with 20µ/300µ line/space

Source: Gunze
Projected Capacitive...10

3M 22”
10-touch pro-cap touchscreen monitor
(CES 2010)
# Projected Capacitive Suppliers!

<table>
<thead>
<tr>
<th>Pro-Cap Vendor</th>
<th>Country</th>
<th>Controller</th>
<th>Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altera</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Analog Devices</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Atmel (Quantum)/ST Micro</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
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<td>Avago</td>
<td>USA</td>
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<td>Broadcom</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>EETI (eGalax)</td>
<td>Taiwan</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Focal Tech Systems</td>
<td>China</td>
<td>Yes</td>
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<tr>
<td>Melfas</td>
<td>Korea</td>
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<td>Microchip Technology</td>
<td>USA</td>
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<td>Pixcir Microelectronics</td>
<td>China</td>
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<td>RISIN Technology</td>
<td>Taiwan</td>
<td>Yes</td>
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<td>Silicon Integrated Systems (SIS)</td>
<td>Taiwan</td>
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<td>No</td>
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<td>Texas Instruments</td>
<td>USA</td>
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<td>Alps</td>
<td>Japan</td>
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<tr>
<td>Cando (AUO)</td>
<td>Taiwan</td>
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<td>Digitech</td>
<td>Korea</td>
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<td>Emerging Display Technology</td>
<td>Taiwan</td>
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<td>Yes</td>
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<td>HannStar Display</td>
<td>Taiwan</td>
<td>No</td>
<td>Yes</td>
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<table>
<thead>
<tr>
<th>Pro-Cap Vendor</th>
<th>Country</th>
<th>Controller</th>
<th>Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innolux</td>
<td>Taiwan</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>iTouch Electro-Optical</td>
<td>China</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>J-Touch</td>
<td>Taiwan</td>
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<td>Yes</td>
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<td>Nisssha Printing</td>
<td>Japan</td>
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<td>Panasonic Electric Devices (PED)</td>
<td>Japan</td>
<td>No</td>
<td>Yes</td>
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<td>Panjit (Mildex)</td>
<td>Taiwan</td>
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<td>QuickTouch Technology</td>
<td>China</td>
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<td>Sintek Photronic</td>
<td>Taiwan</td>
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<td>Touch International</td>
<td>USA</td>
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<td>TPK</td>
<td>China</td>
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<td>Wintek</td>
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<td>Young Fast Optoelectronics</td>
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<td>Cypress</td>
<td>USA</td>
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<td>Elan Microelectronics</td>
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<td>N-trig</td>
<td>Israel</td>
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<td>Synaptics</td>
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<td>Wacom</td>
<td>Japan</td>
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<td>Yes</td>
</tr>
<tr>
<td>Zytronic</td>
<td>UK</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

China = 5  
Israel = 1  
Japan = 4  
Korea = 2  
Taiwan = 13  
UK = 1  
USA = 10  
Controller Only = 13  
Sensor Only = 17  
Controller & Sensor = 6  
(“module”)
Projected Capacitive…12

- Market trends
  - Extremely strong worldwide interest
  - Rapidly increasing number of suppliers (>250% in last year)
  - Rapidly dropping prices (>50% in last 18 months)
  - Upper size limit expanding from 8” to 22”
  - OEMs’ desire for multi-touch is a key driving force, along with durability and high optical performance
  - The first significant challenge to analog resistive in mobile devices

Source: Apple

The iPod Touch
“3D” Projected capacitive: Proximity detection

- Mitsubishi 5.7” prototype
  - Hover (mouseover) function
  - Finger speed can be measured by rate of change in capacitance
  - Proximity state: Priority to sensitivity, not resolution; slow response
  - Contact state: Priority to resolution, not sensitivity; fast response

Source: TechOn
Special Case: Several Tablet PCs with N-trig’s DuoSense™ finger-and-pen digitizer

- Projected capacitive sensor with analog-to-digital chips around edge of screen to minimize noise from long analog traces

- Electrostatic digitizer using electronic pen charged by coil around periphery of sensor or powered by battery

Source: Dell
Projected Capacitive…15

N-trig’s Finger-and-Pen Digitizer Architecture

- Cordless pen without battery
- E-field
- Transparent conductors (X-Y sensor grid)
- Excitation coil
- Controller chipset
- Frame (same mechanical outline dimensions as LCD)
- Digitizer (and LCD) active area
- Serial interface to host

LCD In-Cell

Source: TMD
# Three Different Physical Integration Methods Used In LCD “In-Cell” Touch

<table>
<thead>
<tr>
<th>Term</th>
<th>Integration Method</th>
</tr>
</thead>
</table>
| **In-Cell** | Touch sensor is *physically inside the LCD cell*  
  Touch sensor can be:  
  - Photo-transistors (light-sensing)  
  - Micro-switches (voltage-sensing)  
  - Capacitive electrodes (charge-sensing) |
| **On-Cell** | Touch sensor is an X-Y array of ITO conductors  
  *on the top or bottom surface of the color filter substrate*  
  - Capacitive-only *(1)* |
| **Out-Cell** | Standard touchscreen *laminated directly on top of the LCD* during manufacture  
  - Key difference: An additional piece of glass is required  
  - Typically only projected capacitive or analog resistive  
  - New term coined by AUO – *Since this term hasn’t entered common usage yet, some LCD manufacturers still refer to this configuration as on-cell* *(2)* |

---

*(1)* CMO persists in labeling their on-cell capacitive (on top of the color filter glass) as “in-cell” capacitive.

*(2)* LGD’s 6.4-inch “on-cell capacitive” at SID 2009 was actually a laminated cover-glass with ITO patterning on the under-side (out-cell).
Three Different Technologies Used In LCD “In-Cell” Touch

- **Light-sensing or “optical”**
  ✦ Addition of a photo-transistor (photocell) into some or all pixels
  ✦ Works with finger, stylus, light-pen or laser pointer; also works as a scanner

- **Voltage-sensing or “switch-sensing” or “resistive”**
  ✦ Addition of micro-switches for X & Y into each pixel
  ✦ Works with finger or stylus, within damage limits of LCD

- **Charge-sensing or “capacitive-sensing”**
  ✦ Addition of electrodes **on** or **in** cell for capacitive sensing
  ✦ In-cell = works with finger or stylus, within damage limits of LCD
  ✦ On-cell = works with finger-only; allows cover-glass
Theoretical Advantages of In-Cell

- Minimal or no added size, thickness or weight
- Unlimited multi-touch functionality (controller-dependent)
- Very high performance
  - Low parallax error
  - Very accurate and linear touch-point data
  - Potentially higher resolution than the LCD
- Much lower cost for the touch function

In reality, all of these advantages have turned out to be compromised to some degree
Who’s Working On What

<table>
<thead>
<tr>
<th>LCD Manufacturer</th>
<th>Light-Sensing</th>
<th>Voltage-Sensing</th>
<th>Charge-Sensing (in-cell or on-cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUO</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Chi Mei Innolux</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>CPT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HannStar</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>LGD</td>
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<td>NEC</td>
<td></td>
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<tr>
<td>Samsung</td>
<td>✓</td>
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<td>✓</td>
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<tr>
<td>Seiko-Epson</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sharp</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Sony</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMD</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

= Primary  = Secondary
- Bold = Most significant manufacturers
Light-Sensing…1

- **Principle**
  - Photo-transistors see shadow of finger in bright light or reflection of backlight on finger in dim light

- **History**
  - TMD was first to announce the concept on 4/03
    - First to auto-switch between shadow & reflection
  - Sharp announced the same concept on 8/07
    - Sharp has one product in current production
  - Planar published a paper on 8/07 with AUO showing a prototype of the same concept
  - LG.Philips announced the same concept in an automotive LCD at FPD/International on 10/07

Sample captured image on 2.6" VGA (300 ppi)
Source: Sharp
Light-Sensing...2

- Another conceptual illustration

- Variations
  - Number of pixels per sensor

- Size range
  - 3” to 20” (limited by need for LTPS or CG silicon backplane)

- Applications
  - Mobile devices are the initial target

Source: DisplaySearch
Source: Sharp
Light-Sensing...3

Disadvantages

- Touching a black image doesn’t work in low ambient light
- Using a photo-sensor to reliably detect touch over the range of full sunlight to total darkness is very difficult
  - Touching object shadow vs. proximate object shadow
  - Reflection from backlight vs. reflection from external light source
- Putting a light-sensor in every pixel consumes too much of the aperture (reducing efficiency) and requires too much processing power
  - But scanning resolution and ink quality are too low if light-sensors are added to only every ninth pixel (for example)
- The LCD’s display function and the touch function tend to interfere with each other (“severe EMI problems”)
  - Speeding up the touch function makes it worse
Disadvantages (continued)

- The amount of processing power needed to operate the touch function results in high power consumption
  - Analog-to-digital conversion
  - Position determination
  - Image processing
  - Gesture/motion recognition

- A cover-glass is desirable to protect the LCD, but a cover-glass reduces touch sensitivity due to the spacing between the finger and the photo-transistor
  - Optical bonding helps (at additional cost & lower yield)
  - Harder LCD top-polarizer is the best solution to this problem
Potential solutions to the “can’t touch black” problem

- Add an IR light source (e.g., backlight LEDs), and make the light sensors IR-sensitive
  - IR goes through the LCD and reflects off the finger
  - But this increases power consumption...
- Add IR edge-lighting on a cover glass and use FTIR
  - Planar created IP on this idea\(^{(1)}\) in 2004-2007, then sold it to an unidentified buyer in 2009, which will probably prevent all others from using the idea

Light-Sensing…6

- 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 (shape recognition)
    - Touch surface = ??
    - Japan-only; $815

- Problems
  - Need IR from backlight
  - **S L O W** (25% of typical touchpad speed)
  - Short battery life

First use of in-cell light-sensing touch in a commercial product

Source: Sharp
Voltage-Sensing…1

- **Principle**
  - Pressing LCD surface closes micro-switches in each pixel
  - Same principle as emerging “digital resistive” touch technology

- **Size range**
  - 3” to 26” (AUO’s stated maximum)
  - Limited by RC-loading of (and space for) connecting traces

- **Controller**
  - Needs “isolated drive & scan”, like Stantum’s digital resistive

- **Applications**
  - Mobile devices are the initial target
Voltage-Sensing...2

- Samsung’s design (AUO’s is very similar)

Source: Samsung
Advantages

- All the theoretical advantages of in-cell...
- The relative simplicity of the controller compared with that for light-sensing and charge-sensing) potentially allows integration directly into the LCD driver
- Total independence from ambient, back or front-lighting
- Optimum for use with a stylus, since sub-pixel resolution can be achieved by inter-pixel interpolation
Disadvantages

- Voltage-sensing won’t work with a cover glass, so the LCD can easily be damaged
  - AUO’s current spec is only 100K touches at <40 grams! – although it’s unclear if it’s limited by the LCD surface or the ITO cracking
  - Typical resistive touchscreen spec is 1M touches (4-wire) or 30M touches (5-wire) at ~80 grams
  - Harder LCD top-polarizer may solve this problem
- Finite (non-zero) activation force, which can make multi-touch gestures more difficult to perform
- Smaller aperture causes light loss (inefficient)
- Liquid-crystal pooling can be visually distracting
Charge-Sensing...1

- **In-cell**
  - Capacitive-sensing ITO electrodes added inside the LCD cell (sometimes called “pressed capacitive”)

- **Principle**
  - Pressing the LCD brings the two electrodes closer together, which changes the capacitance between them
  - Requires touching the LCD surface
  - Works with finger, fingernail or stylus

Source: LG Display
Charge-Sensing…2

- **On-cell**
  - Projected-capacitive X-Y electrode array added on top of the color filter glass, under the top polarizer

- **Principle**
  - Same as standard projected capacitive
  - Works only with finger
  - Cover-glass (0.5 mm) can be added on top of polarizer

Source: LG Display
Charge-Sensing...3

- **Size range**
  - 3” to 24” (limited by RC-loading of traces and by space required)
  - Only current products on market are 3.0” and 4.3” from AUO

- **Applications**
  - Mobile devices are the initial target

- **Advantages (in-cell & on-cell)**
  - All the theoretical advantages of in-cell...
  - Cover-glass can be added to protect the LCD surface (on-cell)
  - Well-understood projected capacitive technology (on-cell)
  - CF fabs can be modified to support manufacturing (on-cell)
Disadvantages (in-cell & on-cell)

- Finger-touch only; no stylus (problem on Asian cellphones)
- All forms of capacitive sensing are subject to electrical noise; successful integration into the LCD can be very difficult, especially as the LCD size increases
- Significant processing power is required in the controller in order to achieve acceptable performance
  - But algorithms are more well-developed due to wide use of pro-cap
- Lower touch resolution than light-sensing or voltage-sensing
- Smaller aperture ratio (in-cell) or X-Y electrode array (on-cell) causes light loss (inefficient)
- In-cell charge-sensing won’t work with a cover glass, so the LCD can easily be damaged
- Liquid-crystal pooling (in-cell) can be visually distracting
Charge-Sensing...5

LG Display 13.3” in-cell capacitive (SID 2009)

Attempt to draw a grid of straight lines...

Lots of pooling and ink lag!
## LCD In-Cell Technology Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Light-Sensing</th>
<th>Voltage-Sensing</th>
<th>Charge-Sensing (In-cell)</th>
<th>Charge-Sensing (On-cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size limit</td>
<td>20”</td>
<td>26”</td>
<td>24”</td>
<td>24”</td>
</tr>
<tr>
<td>Touch object</td>
<td>Finger, stylus, light-pen</td>
<td>Finger, stylus</td>
<td>Finger, stylus</td>
<td>Finger</td>
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<tr>
<td>Touch force</td>
<td>None</td>
<td>Some</td>
<td>Some</td>
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<tr>
<td>Touch resolution</td>
<td>Medium</td>
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<tr>
<td>Cover glass</td>
<td>Yes</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Durability</td>
<td>High with cover-glass</td>
<td>Low</td>
<td>Low</td>
<td>High with cover-glass</td>
</tr>
<tr>
<td>True flush surface (“zero bezel”)</td>
<td>Yes with cover-glass</td>
<td>No</td>
<td>No</td>
<td>Yes with cover-glass</td>
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<td>Transmissivity loss</td>
<td>Aperture</td>
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<td>Aperture</td>
<td>ITO</td>
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<td>External EMI sensitivity</td>
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<td>High</td>
</tr>
<tr>
<td>Internal EMI sensitivity</td>
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<td>High</td>
</tr>
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<td>Ambient light sensitivity</td>
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<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Flexible substrate</td>
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<td>No</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Controller complexity</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Red-yellow-green color ratings are relative within the in/on-cell technologies, not within all touch technologies.
Fundamental Issues

- **LCD design changes**
  - Modifying the backplane or frontplane of a single LCD to add in-cell touch costs $1M-$2M or more due to masking.
  - If touch isn’t required in every LCD, will LCD manufacturers be willing to make touch & non-touch versions of many different LCDs?

- **OEM second-sourcing**
  - Each LCD-maker is defining their own touch architecture and interface which introduces a big new source of potential incompatibility.

- **Choice of touch technology**
  - Different applications require different touch technologies; it’s almost never “one size fits all”
Opportunities

- **Hybrid technologies**
  - It may be possible to combine multiple in-cell technologies to produce enhanced touch & stylus performance (for example)
  - AUO is experimenting in this area

- **Multi-color subpixel structures**
  - RGBW structure could enable the light-sensor to be located in the white pixel, which would improve sensing performance while reducing shadowing and power consumption problems

*The bloom is definitely off the rose with regard to in-cell; only on-cell and out-cell still look promising*
This picture was drawn on a 46" LCD equipped with a NextWindow optical touch-screen by a visitor to the AETI Exhibition in London on January 24, 2006.

Source: NextWindow
Optical...1

LED reflecting directly into the optical sensor

Touch Point

Optical Sensor Pixel Position

Light Intensity

Society for Information Display

NextWindow
Optical...2

- **Variations**
  - OEM
  - Bezel-integrateable
  - Strap-on (aftermarket)

- **Size range**
  - 15” to 120”

- **Controllers**
  - Proprietary

Source: NextWindow
Optical…3

- **Advantages**
  - Stylus independence (ADA-compliant)
  - Superior drag performance
  - Scalability to large sizes
  - Multi-touch (dependent on # of sensors)
  - Object size recognition

- **Disadvantages**
  - Profile height (~3 mm on a 19” screen)
  - The “fly on the screen” problem (susceptibility to contaminants)

- **Applications**
  - Consumer touch monitors & AiOs (market leader)
  - Interactive digital signage; education
Optical...4

- **Market share**
  - 2008
    - Revenue: 1%
    - Volume: <1%

- **Suppliers**
  - NextWindow, Quanta, Lumio, Xiroku, eIT (XYFer)

- **Market event**
  - NextWindow shipped more than a half-million touchscreens in 2009 to Asus, Dell, HP, Lenovo, Medion, NEC, Samsung & Sony

- **Market trends**
  - Touch on the consumer desktop is just starting
  - The market is just becoming aware of optical touch
  - NextWindow is the leader
Digital ("Matrix") Resistive
Digital Resistive...1

Segmented type (for vertical applications)

Opaque switch panel (the original purpose of digital resistive)

Multi-Touch Controller

Touch Sensor:
Single-Layer (shown) or Two-Layer Matrix

Source: Apex
Digital Resistive...2

All Points Addressable (APA) type (competes with projected capacitive)

Source: Wintek
Digital Resistive...3

3.74” x 2.12”
(128 pixels/inch)

64 x 36 sensing lines
= 1.5 mm squares
= 4.8 pixels/square

Display and
digital resistive
sensor by Wintek;
controller by
Stantum
(SID 2009)
Digital Resistive...4

9” slate
digital resistive
touchscreen by
Stantum
(SID 2009)
Digital Resistive...5

- **Types**
  - Segmented, for vertical-market applications
  - All points addressable [APA], competes with pro-cap

- **Constructions**
  - PET + Glass, PET + PET, etc. (same as analog resistive)

- **Variations**
  - Traditional
    - Simple switch (Stantum, AD Semi, Wintek)
  - New concept
    - Hybrid analog-digital
      - (SiMa Systems, J-Touch)

- **Options**
  - Technically same variety as analog resistive, but less demand

Source: J-Touch
Digital Resistive...6

- **Size range**
  - 3” – 17”
  - Tradeoff between number of connections and resolution

- **Controllers**
  - Single-touch – many sources
  - Multi-touch – proprietary & emerging

- **Advantages**
  - Unlimited multi-touch
  - Simple, familiar technology
  - Lower cost than pro-cap

- **Disadvantages (mostly the same as analog resistive)**
  - Poor durability (PET top surface) & poor optical performance
  - Low resolution (except new hybrid analog-digital)
  - More expensive than analog resistive

Source: Stantum
** Digital Resistive...7

- **Applications**
  - Fixed touch-location devices (e.g., button panels)
  - Multi-touch music controllers (JazzMutant/Stantum**)
  - Mobile devices

- **Market share**
  - Just starting

- **Suppliers**
  - Many suppliers for single-touch, but no standouts
  - Stantum (leader), SiMa Systems, AD Semi, J-Touch, Wintek

- **Market trends**
  - Suppliers are gearing up to compete against pro-cap

** See US patent application 2007-0198926

Source: Jazz Mutant
Optical Waveguide Infrared

Source: RPO
Waveguide Infrared... 1

Principle

Light Source

Transmit Side Waveguides

LCD Display
Free Space IR Grid for Shadow Detection

Receive Side Waveguides

Source: RPO

Light Detector (ASIC)

Traditional Infrared
Waveguide Infrared...2

RPO’s actual construction (3.5” screen)

- IR LED
- Parabolic reflector
- Substrate
- Waveguides
- Light path (white)
- Light path (uses TIR in substrate)
- Line-scan optical sensor

Photo source: RPO; Annotation by author
Waveguide Infrared...3

- **Variations**
  - None yet

- **Size range**
  - 3” to 14”

- **Controller**
  - Proprietary

- **Advantages**
  - Much lower cost than traditional IR
  - Very low profile height (0.7 mm)
  - Higher resolution (depending on waveguide channel width)
  - Much less pre-touch (IR is only 200µ above substrate)
  - Works with a finger, stylus or any other touch object
  - Object size recognition
  - Limited multi-touch

Source: RPO
Waveguide Infrared...4

- **Disadvantages**
  - Can’t be scaled easily to large sizes (border width)
  - Power consumption (positioned as = to light loss of resistive)
  - The “fly on the screen” problem (IR is only 200µ above substrate)

- **Applications**
  - Mobile devices & automotive (maybe)

- **Market share**
  - Not in a shipping device yet as of 01/10, although RPO says they now have a committed OEM

- **Suppliers**
  - RPO (Australian startup; sole source)
Market events

- RPO...
  - Announced IR optical-waveguide touch at SID 2007
  - Showed improved performance at SID 2008
  - Showed larger sizes at SID 2009
  - Hooked their first OEM in late summer 2009

Market trends

- RPO may benefit from the general increase in interest in infrared, as well as from the growing interest in alternative touch technologies for mobile
Vision-Based Optical

Source: Perceptive Pixel
Vision-Based Optical…1

Principle (simplest version)

Frustrated Total Internal Reflection (FTIR)

Multiple touch points;
Image taken without a diffuser
(Source: Perceptive Pixel)

Source: Perceptive Pixel
Vision-Based Optical...2

Microsoft Surface

1 – Screen with diffuser
2 – IR LED light source
3 – Four IR cameras
4 – DLP projector
5 – Vista desktop

Source: Popular Mechanics

Projector resolution
1024x768

Touch resolution
1280x960
Variations
- IR injected into the cover glass; touch points seen via FTIR
- IR illuminates underside of cover glass; touch points reflect IR

Size range
- As described, 30” and up

Substrates
- Glass or acrylic

Advantages
- Combination touch-screen and rear-projection screen
- Alternative to IR and projected-capacitive for rear projection
- Unlimited multi-touch (MS Surface spec is 52 touches max)
Vision-Based Optical...4

- **Disadvantages**
  - As described, for use with rear-projection only
  - Finger-only (FTIR) or IR-reflecting object (Surface)

- **Applications**
  - Interactive “video walls”; digital signage; high-end retail

- **Market share**
  - << 1%

- **Suppliers**
  - Microsoft (Surface)
  - Perceptive Pixel (Jeff Han’s famous videos)
  - GestureTek
  - “TouchKit” by NORTD (www.labs.nortd.com)
    - Open-source, multi-touch screen-developer kit

Source: NORTD
Vision-Based Optical...5

- **Market event**
  - The emergence of Microsoft’s Surface product as an actual, for-sale, shipping product rather than just a research platform

- **Market trends**
  - Because a vision-based optical touch system can be assembled very easily, it’s the most common platform used for research
  - Research therefore tends to explore applications that make use of many touch points, which may bias the market towards the four (out of 13) technologies that provide “unlimited” touches:
    - Projected Capacitive
    - Digital Resistive
    - Vision-Based Optical
    - LCD In-Cell
Comparing Touch Technologies
## 13 Usability Characteristics

<table>
<thead>
<tr>
<th>Desirable Characteristic</th>
<th>Touch Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analog Resistive</td>
</tr>
<tr>
<td>Touch with any object</td>
<td>H</td>
</tr>
<tr>
<td>No unintended touch</td>
<td>H</td>
</tr>
<tr>
<td>Multi-touch</td>
<td>L</td>
</tr>
<tr>
<td>Touch &amp; hold</td>
<td>H</td>
</tr>
<tr>
<td>High durability</td>
<td>L</td>
</tr>
<tr>
<td>High sensitivity (light touch)</td>
<td>M</td>
</tr>
<tr>
<td>Fast response &amp; drag</td>
<td>M</td>
</tr>
<tr>
<td>Stable calibration</td>
<td>M</td>
</tr>
<tr>
<td>Very smooth surface</td>
<td>L</td>
</tr>
<tr>
<td>No liquid crystal pooling</td>
<td>H</td>
</tr>
<tr>
<td>Resistant to contaminants</td>
<td>H</td>
</tr>
<tr>
<td>Works in rain, snow &amp; ice</td>
<td>H</td>
</tr>
<tr>
<td>Works with scratches</td>
<td>L</td>
</tr>
</tbody>
</table>
# 13 Performance Characteristics

<table>
<thead>
<tr>
<th>Desirable Characteristic</th>
<th>Touch Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analog Resistive</td>
</tr>
<tr>
<td>High optical performance</td>
<td>L</td>
</tr>
<tr>
<td>High resolution</td>
<td>H</td>
</tr>
<tr>
<td>High linearity</td>
<td>H</td>
</tr>
<tr>
<td>High accuracy &amp; repeatability</td>
<td>H</td>
</tr>
<tr>
<td>Low power consumption</td>
<td>H</td>
</tr>
<tr>
<td>Insensitive to vibration</td>
<td>H</td>
</tr>
<tr>
<td>Insensitive to EMI &amp; RFI</td>
<td>H</td>
</tr>
<tr>
<td>Insensitive to ambient light</td>
<td>H</td>
</tr>
<tr>
<td>Insensitive to UV light</td>
<td>L</td>
</tr>
<tr>
<td>Touch-object size recognition</td>
<td>L</td>
</tr>
<tr>
<td>Measures Z-axis</td>
<td>L</td>
</tr>
<tr>
<td>Handwriting recognition</td>
<td>H</td>
</tr>
<tr>
<td>Works with bi-stable reflective</td>
<td>H</td>
</tr>
</tbody>
</table>
# 13 Integration Characteristics

## Desirable Characteristic

<table>
<thead>
<tr>
<th>Integration</th>
<th>Touch Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate independence</td>
<td>M M L H L H H H L L L</td>
</tr>
<tr>
<td>Scalable</td>
<td>M L M H M M L H H H L L</td>
</tr>
<tr>
<td>Easy integration</td>
<td>H M L L M M M H L L M H H H</td>
</tr>
<tr>
<td>Flush surface (low profile)</td>
<td>M M M H M L M L H H M H M M</td>
</tr>
<tr>
<td>Narrow border width</td>
<td>H M M H L L M L H H M H H H</td>
</tr>
<tr>
<td>Thin and light</td>
<td>H H L H L L M L L L H H H</td>
</tr>
<tr>
<td>Easy to seal</td>
<td>H H H H L L M L H H M M</td>
</tr>
<tr>
<td>Can be vandal-proofed</td>
<td>L L M H H M M L H H L L L</td>
</tr>
<tr>
<td>Works on curved surface</td>
<td>M M L H L L L L L L H L H</td>
</tr>
<tr>
<td>Can be laminated to LCD</td>
<td>H H H H M M H H L L L H H</td>
</tr>
<tr>
<td>HiD (Plug &amp; Play) interface</td>
<td>L L L L L L H L H L L L L</td>
</tr>
<tr>
<td>Simple controller</td>
<td>H M L L L L M M L H L H M M</td>
</tr>
<tr>
<td>Controller chip available</td>
<td>H H L H H L H L H L L L L</td>
</tr>
</tbody>
</table>
## Touch Technology vs. Screen Size

<table>
<thead>
<tr>
<th>Touch Technology</th>
<th>Small 2&quot; – 10&quot;</th>
<th>Medium 10&quot; – 30&quot;</th>
<th>Large 30&quot; – 150&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Resistive</td>
<td>High</td>
<td>Medium</td>
<td>X</td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>High</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>Low</td>
<td>High</td>
<td>X</td>
</tr>
<tr>
<td>Surface Acoustic Wave</td>
<td>X</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Traditional Infrared</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Projected Capacitive</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Optical</td>
<td>X</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>APR</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>DST</td>
<td>X</td>
<td>X</td>
<td>High</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Waveguide Infrared</td>
<td>High</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>X</td>
<td>X</td>
<td>High</td>
</tr>
<tr>
<td>LCD In-Cell (Light)</td>
<td>Medium</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>LCD In-Cell (Voltage)</td>
<td>Medium</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>LCD In-Cell (Charge)</td>
<td>Medium</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>LCD On-Cell (Charge)</td>
<td>High</td>
<td>Medium</td>
<td>X</td>
</tr>
</tbody>
</table>

Market penetration and/or applicability:
- **High**
- **Medium**
- **Low**
- **X (None)**
## Touch Technology vs. Application

<table>
<thead>
<tr>
<th>Application</th>
<th>Example</th>
<th>Touch Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiosk Point of Info (POI)</td>
<td>Museum information</td>
<td>O      X       O</td>
</tr>
<tr>
<td>Kiosk Commerce</td>
<td>Digital photo printing</td>
<td>X      O      X</td>
</tr>
<tr>
<td>Kiosk Ruggedized</td>
<td>Gas pump</td>
<td>X      X      O</td>
</tr>
<tr>
<td>Point of Sale (POS)</td>
<td>Restaurant; lottery</td>
<td>O      X      O</td>
</tr>
<tr>
<td>Office Automation</td>
<td>Office monitor</td>
<td>O      O      X</td>
</tr>
<tr>
<td>Industrial Control</td>
<td>Machine control</td>
<td>O      O      X</td>
</tr>
<tr>
<td>Medical Equipment</td>
<td>Medical devices</td>
<td>O      X      O</td>
</tr>
<tr>
<td>Healthcare</td>
<td>Patient info monitor</td>
<td>O      X      O</td>
</tr>
<tr>
<td>Military Fixed &amp; Mobile</td>
<td>Submarine console</td>
<td>O      X      O</td>
</tr>
<tr>
<td>Training &amp; Conference</td>
<td>Boardroom display</td>
<td>O      X      O</td>
</tr>
<tr>
<td>Legal Gaming</td>
<td>Casino machine</td>
<td>X      X      X</td>
</tr>
<tr>
<td>Amusement Gaming</td>
<td>Bar-top game</td>
<td>X      X      O</td>
</tr>
<tr>
<td>In-Vehicle</td>
<td>GPS navigation</td>
<td>O      X      O</td>
</tr>
<tr>
<td>ATM Machine</td>
<td>ATM machine</td>
<td>X      O      O</td>
</tr>
<tr>
<td>Mobile Device</td>
<td>Smartphone</td>
<td>O      X      O</td>
</tr>
<tr>
<td>Appliance</td>
<td>Refrigerator door</td>
<td>O      X      O</td>
</tr>
<tr>
<td>Architectural</td>
<td>Elevator control</td>
<td>X      O      X</td>
</tr>
<tr>
<td>Consumer AiO &amp; Monitor</td>
<td>HP TouchSmart</td>
<td>O      X      X</td>
</tr>
<tr>
<td>Music Controller</td>
<td>Jazz Mutant</td>
<td>O      X      O</td>
</tr>
<tr>
<td>Digital Signage</td>
<td>Thru-window store</td>
<td>X      X      O</td>
</tr>
</tbody>
</table>
Conclusions

Source: CG4TV
There Is No Perfect Touch Technology!

<table>
<thead>
<tr>
<th>Technology</th>
<th>Major Advantage</th>
<th>Major Flaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Resistive</td>
<td>Low cost</td>
<td>Low durability</td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>Multi-touch</td>
<td>Connections</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>Touch sensitivity</td>
<td>High drift</td>
</tr>
<tr>
<td>Projected Capacitive</td>
<td>Multi-touch</td>
<td>Finger-only</td>
</tr>
<tr>
<td>Surface Acoustic Wave</td>
<td>Durability</td>
<td>Soft touch object</td>
</tr>
<tr>
<td>Traditional Infrared</td>
<td>Reliability</td>
<td>High cost</td>
</tr>
<tr>
<td>Waveguide Infrared</td>
<td>Low cost</td>
<td>Contamination</td>
</tr>
<tr>
<td>Optical</td>
<td>Scalability</td>
<td>Profile height</td>
</tr>
<tr>
<td>Acoustic Pulse Recognition</td>
<td>Any touch-object</td>
<td>No touch &amp; hold</td>
</tr>
<tr>
<td>Dispersive Signal Technology</td>
<td>Any touch-object</td>
<td>No touch &amp; hold</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>3D substrate</td>
<td>Vibration</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>Multi-touch</td>
<td>Rear projection</td>
</tr>
<tr>
<td>LCD In-Cell (Light)</td>
<td>Integration</td>
<td>Sensitivity</td>
</tr>
<tr>
<td>LCD In-Cell (Charge)</td>
<td>Integration</td>
<td>Durability</td>
</tr>
<tr>
<td>LCD In-Cell (Voltage)</td>
<td>Integration</td>
<td>Durability</td>
</tr>
</tbody>
</table>
# A Prediction of Which Technologies Will Win in the Next Five Years

<table>
<thead>
<tr>
<th>Application</th>
<th>Winning Technology</th>
<th>Runner-Up Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive</td>
<td>Analog Resistive</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>Casino Gaming</td>
<td>Surface Capacitive</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>Consumer AiOs and Monitors</td>
<td>Optical</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>Consumer Notebooks</td>
<td>Projected Capacitive</td>
<td>Optical</td>
</tr>
<tr>
<td>Interactive Digital Signage</td>
<td>Optical</td>
<td>Traditional Infrared</td>
</tr>
<tr>
<td>Kiosks</td>
<td>Surface Acoustic Wave</td>
<td>Surface Capacitive</td>
</tr>
<tr>
<td>Mobile Devices</td>
<td>Projected Capacitive</td>
<td>Analog Resistive</td>
</tr>
<tr>
<td>POS Terminals</td>
<td>Analog Resistive</td>
<td>Traditional Infrared</td>
</tr>
</tbody>
</table>
Thank You!

Geoff Walker
Product Marketing Manager
NextWindow
7020 Koll Center Parkway, Suite 138
Pleasanton, CA 94566
1-408-506-7556 (mobile)
gwalker@nextwindow.com
Appendix

Sunlight Readability of Resistive Touchscreens
Common Solutions For Sunlight Readability

1 Active enhancement
   ✦ Boost the LCD backlight intensity to 1000+ nits
      ● High power consumption
      ● Thick, hot & heavy

2 Passive enhancement
   ✦ Add brightness enhancement films
      ● Limited to 2X increase in brightness (not enough)
      ● Reduces the LCD’s viewing angle

3 Controlling reflections
   ✦ Reflected light reduces contrast (that’s the real problem)
   ✦ Controlling reflected light is the most effective solution
Touch-Screen Surface Reflections

**Note:** Drawing is not to scale!

![Diagram of touch-screen surface layers](image)

<table>
<thead>
<tr>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>Total Reflectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>No enhancement</td>
<td>4%</td>
<td>5%</td>
<td>5%</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>5 AR coatings</td>
<td><strong>0.5%</strong></td>
<td><strong>2.5%</strong></td>
<td><strong>1%</strong></td>
<td><strong>0.5%</strong></td>
<td><strong>0.5%</strong></td>
</tr>
</tbody>
</table>
Circular Polarizer Principle

Combination is Equivalent to a Circular Polarizer

Principle: Modify the polarization of reflected light so it can’t escape back through the polarizer.
Touch-Screen Surface Reflections with Circular Polarizer

Note: Drawing is not to scale!

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>Total Reflectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>No enhancement</td>
<td>4%</td>
<td>5%</td>
<td>5%</td>
<td>4%</td>
<td>2%</td>
<td>20%</td>
</tr>
<tr>
<td>5 AR coatings</td>
<td>0.5%</td>
<td>2.5%</td>
<td>1%</td>
<td>0.5%</td>
<td>0.5%</td>
<td>5%</td>
</tr>
<tr>
<td>Circular polarizer + 3 AR coatings</td>
<td><strong>0.5%</strong></td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.5%</td>
<td>0.5%</td>
<td><strong>1.7%</strong></td>
</tr>
</tbody>
</table>
Touch-Screen Surface Reflections: The Ultimate Solution

**Note:** Drawing is not to scale!

<table>
<thead>
<tr>
<th>Layer</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>Total Reflectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>No enhancement</td>
<td>4%</td>
<td>5%</td>
<td>5%</td>
<td>4%</td>
<td>2%</td>
<td>20%</td>
</tr>
<tr>
<td>5 AR coatings</td>
<td>0.5%</td>
<td>2.5%</td>
<td>1%</td>
<td>0.5%</td>
<td>0.5%</td>
<td>5%</td>
</tr>
<tr>
<td>Circular polarizer +</td>
<td>0.5%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.9%</td>
</tr>
<tr>
<td>relocated retardation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>film + 1 AR coating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reference:
General Dynamics
Itronix DynaVue
http://www.ruggedpcreview.com/3_technology_itronix_dynavue.html
1% Is Good Enough

- Rule-of-thumb for approximating extrinsic contrast

\[ \text{Contrast Ratio (CR)} = 1 + \left( \frac{\text{Display Brightness}}{\text{Reflected Light}} \right) \]

- In 10,000 nits ambient light, 1% reflected light = 100 nits
- With a 500-nit automotive display, \( \text{CR} = 6 \), which is good enough for acceptable sunlight readability

<table>
<thead>
<tr>
<th>Contrast Ratio</th>
<th>LCD Outdoor Readability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Totally unreadable in sunlight</td>
</tr>
<tr>
<td>3-4</td>
<td>Adequately readable in shade; barely readable in sunlight</td>
</tr>
<tr>
<td>5.5-6</td>
<td>Military spec for minimum acceptable readability in sunlight</td>
</tr>
<tr>
<td>10</td>
<td>Definitely readable in sunlight; looks good</td>
</tr>
<tr>
<td>15</td>
<td>Outstanding readability; looks great</td>
</tr>
<tr>
<td>20</td>
<td>Totally awesome; excellent readability; can’t improve</td>
</tr>
</tbody>
</table>
Surface Treatments

- **Anti-Glare (AG)**
  - Changes specular reflections into diffuse reflections
  - Changes the form of reflected light but doesn’t reduce the amount
  - Formed by etching, abrasion or deposition

- **Anti-Smudge (AS)**
  - Minimizes the effect of skin oils on the touch panel’s top surface
  - Hydrophobic coating; can be combined with AG
Surface Treatments...2

- **Anti-Newton’s Ring (ANR)**
  - Prevents Newton’s rings from being formed by contact between the PET film and the glass substrate
  - Texture added underneath ITO coating on bottom of PET
  - Adds ~1/3 of the haze value of AG

Without ANR  ![Image](image1.png)  With ANR  ![Image](image2.png)
What About Projected Capacitive?

Note: Drawing is not to scale!

Touch Screen

1 - Protective Film
2 - Glass
3 - ITO Coatings
4 - Dielectric (Insulator)
5 - LCD Top Polarizer
6 - LCD Cell
7 - LCD Bottom Polarizer
8 - Backlight

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>Total Reflectivity</th>
<th>(Resistive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No enhancement</td>
<td>4%</td>
<td>5%</td>
<td>2%</td>
<td>11%</td>
<td>20%</td>
</tr>
<tr>
<td>3 AR coatings</td>
<td>0.5%</td>
<td>1%</td>
<td>0.5%</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>Circular polarizer</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>(N/A)</td>
<td>0.9%</td>
</tr>
<tr>
<td>Optical bonding +</td>
<td>0.5%</td>
<td>0%</td>
<td>0%</td>
<td>0.5%</td>
<td>(N/A)</td>
</tr>
<tr>
<td>one AR coating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>