Agenda…1

- **Touch-Screen Market** [4]
- **Automotive Application Requirements** [2]
- **Dominant Technology** [16]
  - Analog Resistive
    - Sunlight Readability
- **Potential Technologies** [19]
  - Projected Capacitive
  - Digital (“Matrix”) Resistive
  - LCD In-Cell (Optical, Contact-Closure & Capacitive)

[ ] = Number of actual content slides in each section
Agenda...2

- **Unlikely Technologies** [8]
  - Acoustic Pulse Recognition (APR - Elo)
  - Traditional Infrared
  - Waveguide Infrared (RPO)
  - Camera-Based Optical

- **Disqualified Technologies** [7]
  - Dispersive Signal Technology (DST - 3M)
  - Vision-Based Optical
  - Force Sensing (Vissumo)
  - Surface Capacitive
  - Surface Acoustic Wave

- **Conclusions & Predictions** [4]

Total = [60]
Course Coverage

- **This tutorial covers...**
  - Transparent touch on top of a display (usually an LCD)

- **This tutorial doesn’t cover...**
  - Opaque touch
  - Haptics (tactile feedback)
  - Vision-based gestures (“3D touch”) for HUDs
  - Ergonomics
## 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><strong>$1,150M</strong></td>
<td><strong>325M</strong></td>
<td><strong>$1,165M</strong></td>
</tr>
<tr>
<td>Emerging</td>
<td>$462M</td>
<td>31M</td>
<td>$55M</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$1,612M</strong></td>
<td><strong>356M</strong></td>
<td><strong>$1,220M</strong></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>

Market size estimates are based on DisplaySearch’s 2009 “Touch-Panel Market Analysis” with adjustments for errors and inappropriate inclusions.
# 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>
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<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 for errors and inappropriate inclusions.
2008 Automotive & Portable Navigation Device Touch-Screen Market Size

- **2008 automotive touch-screen sales (100% resistive)**
  - Units = 15M  (22% glass-glass, 78% film-glass)
    - 4.6% of total resistive; 3.7% of total touch-screen market
  - Revenue = $110M
    - 6.0% of total resistive; 3.9% of total touch-screen market
  - ASP = $7.37
    - This average selling price (ASP) should be about 2X-3X higher; DisplaySearch’s revenue estimate is probably incorrect.

- **2008 portable navigation device sales (100% resistive)**
  - Units = 43M  (99.7% film-glass)
    - 12% of total resistive; 11% of total touch-screen market
  - Revenue = $155M
    - 8.4% of total resistive; 5.5% of total touch-screen market
  - ASP = $3.62
    - This ASP is about right for a 3” to 4” touch screen on an aftermarket device ($1/inch).

Data from DisplaySearch 2009 “Touch-Panel Market Analysis”
Automotive & Portable Navigation Device Touch-Screen Forecast

DisplaySearch forecasts that Automotive remains 100% resistive through 2015, and Portable is only 1% projected capacitive in 2015.

Data from DisplaySearch 2009 “Touch-Panel Market Analysis”
Automotive Application Requirements
Automotive Applications Can Be Difficult!

*Note: Focus here is the center-stack (CSE) “navi-radio” application*

- **Temperature**
  - -30°C to +85°C operating
  - -40°C to +95°C storage

- **Light management**
  - Sunlight readability
    - Relaxed requirement for rear-seat entertainment (RSE)

- **Crashworthiness**
  - Top surface can’t be glass (DOT)

- **Cost**
  - Especially important for dealer-installed vs. OEM-installed

- **Vibration**
  - Cables & connectors
Automotive Applications Can Be Difficult...2

- **Industrial design**
  - Narrow frame borders & flush surface

- **Usability**
  - Use with gloves

- **Off-angle viewing**
  - Polarizer used for sunlight viewability can be a problem
  - Optical bonding is still too expensive

- **Flammability**
  - Gaskets

- **Humidity**
  - Condensation freezing into ice crystals

- **ISO quality requirements**
  - Difficult for a small or inexperienced company to meet
Dominant Technology: Analog Resistive

Source: Engadget
Analog Resistive

Source: Bergquist

Source: Elo TouchSystems
Analog Resistive…2

- **Types**
  - 4-wire (low cost, short life) – mobile devices & automotive
  - 5-wire (higher cost, long life) – stationary devices

- **Constructions**
  - Film (PET) + glass (previous illustration) is the most common
  - Glass + glass is the most durable; automotive is primary use
  - Film + film is the thinnest; sometimes used in cellphones
  - Others…

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

(50-µM glass) Source: Schott
Analog Resistive...3

4-Wire Construction

X-Axis

Voltage gradient applied across glass

Voltage measured on coversheet

Bus bar

Y-Axis

Voltage measured on glass

Voltage gradient applied across coversheet

Equivalent circuit
Analog Resistive...4

5-Wire Construction

X-Axis

Voltage gradient applied across glass

Contact point on coversheet is a voltage probe

Linearization pattern

Y-Axis

Voltage gradient applied across glass

Contact point on coversheet is a voltage probe

Equivalent circuit
Analog Resistive…5

- **Size range**
  - 1” to ~26”

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

- **Advantages in automotive**
  - 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

Source: Liyitec

Source: Hampshire
Analog Resistive...6

- **Disadvantages in automotive**
  - Film-glass is not durable (PET top surface is easily damaged)
  - Poor optical quality (10%-20% light loss)
  - No multi-touch (unimportant in automotive?)

- **Applications**
  - Wherever cost is #1
  - Mobile devices & automotive
  - Point of sale (POS) terminals
Analog Resistive…7

- **Automotive suppliers**
  - **Film-glass**: Shenzhen TopTouch, Nanjing Wally, Panasonic, Fujitsu, DMC, Gzyulian, SMK, A-Touch, Gunze…
  - **Glass-glass**: Hosiden, Shoei, SMK, Micro Technology, TechnoPrint…
  - 60+ total suppliers for analog resistive

- **General 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
  - Substantial price reductions in analog resistive in 2008
    - Some competitors dropped out
Automotive market trends

- Performance of film-glass materials has steadily increased such that film-glass is seriously challenging the dominance of glass-glass in OEM applications.
- Cost pressure in dealer-installed applications has focused this market almost exclusively on film-glass.
- Top-glass is typically 0.2 mm (0.15 – 0.4 mm), so resolution is lower than film-glass, but applications are moving towards higher resolution (graphics & higher data-density).
  - Implication is towards stylus use, but there’s hesitation because the stylus must be supplied and stored.
Sunlight Readability of Resistive Touch-Screens
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!

<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>
</tbody>
</table>
Circular Polarizer Principal

**Combination is Equivalent to a Circular Polarizer**

- Unpolarized Light
- Linear-Polarized Light (Horizontal)
- Linear-Polarized Light (Vertical)
- Right-Circular Polarized Light
- Left-Circular Polarized Light

**Reflection**

**Quarter-Wave Retardation Film**

**Linear Polarizer**

**Reflecting Surface**

**Reflection is blocked**

**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>Layer</th>
<th>Description</th>
<th>Equivalent to</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>Total Reflectivity</th>
</tr>
</thead>
<tbody>
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<td>2%</td>
<td>20%</td>
</tr>
<tr>
<td>5 AR coatings</td>
<td></td>
<td></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></td>
<td></td>
<td>0.5%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.5%</td>
<td>0.5%</td>
<td>1.7%</td>
</tr>
</tbody>
</table>
Touch-Screen Surface Reflections: The Ultimate Solution

Note: Drawing is not to scale!

Reference:
General Dynamics
Itronix DynaVue
http://www.ruggedpcreview.com/3_technology_itronix_dynavue.html

<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 +</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>
1% Is Good Enough

- **Rule-of-thumb for approximating extrinsic contrast**

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

- 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

With ANR
Potential Technologies

- Projected Capacitive
- Digital (“Matrix”) Resistive
- LCD In-Cell
Projected Capacitive

“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

“10 fingers, 2 palms and 3 others”

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

- **Size range**
  - 2” to 100”+
  - (ITO up to ~24”; wires up to 100”+)

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

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

Source: Verifone
Source: Mildex
## Projected Capacitive Suppliers (5/09)

<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>
</tr>
<tr>
<td>Broadcom</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>EETI (eGalax)</td>
<td>Taiwan</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Elan Microelectronics</td>
<td>Taiwan</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Focal Tech Systems</td>
<td>China</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Microchip Technology</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Pixcir Microelectronics</td>
<td>China</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>RISIN Technology</td>
<td>Taiwan</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Silicon Integrated Systems (SIS)</td>
<td>Taiwan</td>
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<td>No</td>
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<tr>
<td>Texas Instruments</td>
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<td>Alps</td>
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<td>Cando (AUO)</td>
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<td>Digitech</td>
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<tr>
<td>Emerging Display Technology</td>
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<td>HannStar Display</td>
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<td>Innolux</td>
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<td>No</td>
<td>Yes</td>
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<tr>
<td>iTouch Electro-Optical</td>
<td>China</td>
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<td>Yes</td>
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<td>J-Touch</td>
<td>Taiwan</td>
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<td>Yes</td>
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<td>Nissha Printing</td>
<td>Japan</td>
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<td>Yes</td>
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<td>Panasonic Electric Devices (PED)</td>
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<td>QuickTouch Technology</td>
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<td>Sintek Photronic</td>
<td>Taiwan</td>
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<td>Young Fast Optoelectronics</td>
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<td>N-trig</td>
<td>Israel</td>
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<td>Yes</td>
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<td>Synaptics</td>
<td>USA</td>
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<td>Yes</td>
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<tr>
<td>Zytronic</td>
<td>UK</td>
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</tr>
</tbody>
</table>

China = 5  
Israel = 1  
Japan = 3  
Korea = 3  
Taiwan = 13  
UK = 1  
USA = 9  
Controller Only = 12  
Sensor Only = 17  
Controller & Sensor = 4
Sunlight Readability Comparison

*Note: Drawing is not to scale!*

**Touch Screen**

- **S1**
  - 1 - Protective Film
  - 2 - Glass
  - 3 - ITO Coatings
    - 0.5% 1% 0.5% 2% 5%
  - Circular polarizer -- -- -- (N/A) 0.9%
  - Optical bonding + one AR coating 0.5% 0% 0% 0.5% (N/A)

- **S2**
  - 4 - Dielectric (Insulator)
  - 5 - LCD Top Polarizer
  - 6 - LCD Cell
  - 7 - LCD Bottom Polarizer

- **S3**
  - 8 - Backlight

**LCD**

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

Segmented type (for vertical applications)

- Touch Sensor: Single-layer (shown) or two-layer matrix
- Opaque switch panel (the original purpose of digital resistive)
- Multi-Touch Controller

Source: Apex
Digital Resistive...2

All points addressable (APA) type (competes with projected capacitive)

![Diagram of touch sensor system with drive lines, sense lines, and track intersection.]

Multi-Touch Controller

Output to host computer

Source: Stantum

Source: Wintel
Digital Resistive...3

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

- **Constructions**
  - Same as analog resistive

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

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

Source: J-Touch
Digital Resistive…4

- **Size range**
  - 3” – 22”
  - Tradeoff between number of connections and resolution

- **Advantages in automotive**
  - Works with any touch object (especially stylus in Asia!)
  - Simple, familiar technology
  - Unlimited multi-touch (unimportant in automotive?)

- **Disadvantages in automotive**
  - Poor durability (PET top surface) and poor optical performance
  - Low resolution (except new hybrid analog-digital)
  - More expensive than analog resistive

Source: Stantum
LCD In-Cell Touch: Three Different Technologies

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

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

- **Capacitive or “charge-sensing”**
  - Addition of electrodes into each pixel for capacitive sensing
  - Works with finger-only, within damage limits of LCD
## LCD In-Cell Touch: Three Different Integration Methods

<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:  
- Light-sensing phototransistors (optical)  
- Micro-switches (contact-closure or “resistive”)  
- Capacitance-sensing electrodes (capacitive) |
| **On-cell** | Touch sensor is an X-Y array of ITO conductors on the top surface of the color filter substrate  
- Capacitive-only |
| **Out-cell** | Standard touchscreen laminated directly on top of the LCD during manufacture  
- Key difference: An additional piece of glass is required  
- Typically only analog resistive or projected capacitive  
- 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* |
LCD In-Cell Touch: Fundamental Issues

LCD design changes
- Modifying the backplane or frontplane of a single LCD to add in-cell touch costs >$1M 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
- Almost all OEMs have multiple sources for their LCDs; in-cell introduces a big new source of potential incompatibility

Choice of touch technologies
- Different applications require different touch technologies; it’s almost never “one size fits all”
# Light-Sensing

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

- **Size range**
  - 3” to 32” (so far)

- **Advantages in automotive**
  - Integration, size, thickness, weight, ID, cost (?)
  - Low parallax error & high resolution
  - Multi-touch (unimportant in automotive?)

- **Disadvantages in automotive**
  - Touching a black image doesn’t work at all in low light
  - A cover-glass is desirable to protect the LCD, but using a cover-glass reduces touch sensitivity due to spacing
    - Harder LCD top-polarizer may solve this problem.

Source: Sharp
Contact-Closure Sensing

- **Principle**
  - Pressing on the LCD causes micro-switches in each pixel to make contact

Source: Samsung
Contact-Closure Sensing…2

- **Size range**
  - 3” to 26”

- **Advantages in automotive**
  - Same as capacitive-sensing

- **Disadvantages in automotive**
  - Won’t work with a cover glass, so the LCD is easily damaged
    - AUO’s current spec is only 100K touches at <40 grams!
    - Harder LCD top-polarizer may solve this problem
  - Liquid-crystal pooling can be visually distracting

[Image of an LG Display 13.3” in-cell capacitive (SID 2009)]
Capacitive Sensing

Principle

- Pressing on LCD changes capacitive between added electrodes in each pixel
- This technology requires significant change to the LCD’s backplane and frontplane
- IP exists on using the existing internal electrodes for this purpose, but nobody has demoed it at a show yet

Source: LG Display
Capacitive Sensing…2

- **Size range**
  - 3” to 24”

- **Advantages in automotive**
  - Same as light-sensing
  - PLUS, total independence from ambient, back or front-lighting

- **Disadvantages in automotive**
  - Finger-touch only; no stylus
  - Won’t work with a cover glass, so the LCD is easily damaged
    - Harder LCD top-polarizer may solve this problem
  - Demonstrated performance to date has been exceptionally poor
  - Liquid-crystal pooling can be visually distracting
# Summary of Dominant & Potential Touch Technologies

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Analog Resistive</th>
<th>Digital Resistive</th>
<th>Projected Capacitive</th>
<th>LCD In-Cell Optical</th>
<th>LCD In-Cell Contact-Closure</th>
<th>LCD In-Cell Capacitive</th>
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</thead>
<tbody>
<tr>
<td>Environmental Resistance</td>
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<td>✔</td>
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<td>⬇️</td>
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<td>Sunlight Readability</td>
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<td>Curved Surface</td>
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<td>Ease of Integration</td>
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<td>Cost</td>
<td>⭩</td>
<td>✔️</td>
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<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>

- Best
- OK
- Worst
Unlikely Technologies

- Acoustic Pulse Recognition (APR - Elo)
- Traditional Infrared
- Waveguide Infrared (RPO)
- Camera-Based Optical
Acoustic Pulse Recognition (APR)

- Plain glass sensor with 4 piezos on the back edges
- Table look-up of bending-wave “acoustic signatures”

Elo’s “Zero-Bezel” APR with capacitive buttons & scroll-wheel in lower-right corner (SID 2009)
Acoustic Pulse Recognition (APR)…2

- **Size range**
  2.8” to 52”

- **Advantages in automotive**
  - Works with any touch object
  - Very durable & transparent touch sensor
  - Resistant to surface contamination
  - Completely flush top surface (“Zero-Bezel”)

- **Disadvantages in automotive**
  - Bending waves in glass behave differently above 50°C
  - Plastic film laminated on surface radically changes characteristics
  - Control of mounting method in bezel is critical
  - Sole-source (Elo TouchSystems)

“Zero-Bezel” monitor (entire front surface is one sheet of glass)
Traditional Infrared

Edge of active display area

Opto-matrix frame inside bezel

Photoreceptors

LEDs create grid of infrared light

Inside and outside edges of infrared transparent bezel

Source: Elo TouchSystems

Source: IBM
Traditional Infrared...2

- **Size range**
  - 8” to 150”

- **Advantages in automotive**
  - Works with any touch object
  - High durability, optical performance and sealability
  - Only solution for glass-free mainstream touch (acrylic substrate)

- **Disadvantages in automotive**
  - High cost
  - Profile height (IR transceivers project above touch surface)
  - Surface obstruction or hover can cause a false touch
Waveguide Infrared

Principle

Light Source
Transmit Side Waveguides

LCD Display
Free Space IR Grid for Shadow Detection

Receive Side Waveguides

Light Detector (ASIC)

Implementation (3.5”)

IR LED

Line-scan optical sensor

Substrate
Parabolic reflector
Light path (white)
Waveguides
Light path (uses TIR in substrate)

Source: RPO
Photo source: RPO; Annotation by author
Waveguide Infrared...2

- **Size range**
  - 3” to 14”

- **Advantages in automotive**
  - Works with any touch object
  - High resolution
  - Relatively low profile height (0.7 mm)

- **Disadvantages in automotive**
  - Sole-source (RPO, a startup in Australia)
  - Surface obstruction or hover can cause a false touch
Two line-scan optical sensors detect the presence of fingers by seeing interruptions (shadows) in the infrared backlighting produced by two IR-LEDs reflected from retro-reflectors around the periphery.
Camera-Based Optical...2

- **Size range**
  - 12” to 120”

- **Advantages in automotive**
  - Works with any touch object

- **Disadvantages in automotive**
  - Profile height (~3 mm)
  - Border width in smaller sizes
  - Surface obstruction or hover can cause a false touch

Source: NextWindow

Source: HP TouchSmart all-in-one computer
Source: HP
Disqualified Technologies

- Dispersive Signal Technology (DST - 3M)
- Vision-Based Optical
- Force Sensing (Vissumo)
- Surface Capacitive
- Surface Acoustic Wave (SAW)
Dispersive Signal Technology

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

- **Size range**
  - 32” to 46” (3M will probably expand into larger sizes)

- **Reason for disqualification**
  - Minimum size
**Vision-Based Optical**

**Principle (simplest version)**

- **Frustrated Total Internal Reflection (FTIR)**

  - **LED**
  - **Baffle**
  - **Diffuser**
  - **Acrylic Pane**
  - **Scattered Light**
  - **Projector**
  - **Video Camera**

**Size range**
- As described, ~32” and up

**Reason for disqualification**
- Requires rear projection

Source: Jeff Han, NYU & 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
Vision-Based Optical…3

One Exception: “Digital Dash” Concept

Rear projection in an automotive display…

Source: www.digital-dash.com
Force Sensing

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

- **Size range**
  - 5”-48”

- **Reason for disqualification**
  - Doesn’t work with vibration < 10 Hz

Source: QSI
Surface Capacitive

- **Size range**
  ✦ 6.4” to 32”

- **Reason for disqualification**
  ✦ Requires stable ground
  (not suitable for mobile environment)
Surface Acoustic Wave (SAW)

- **Size range**
  - 6” to 52”
- **Reasons for disqualification**
  - Border width, touch-force, contamination, integration

Diagram showing:
- Glass substrate
- Y-axis transmitting transducer
- Y-axis receiving transducer
- X-axis receiving transducer
- X-axis transmitting transducer
- Edge of Active Area
- Array of reflectors (45°)
- Rayleigh wave

Source: Onetouch

Amplitude graph showing:
- Transmit Burst
- Touch Effect
- Width Checked
- Threshold
- Time proportional to distance
- Time

Logo: Society for Information Display (SID)
Conclusions & Predictions

Source: CG4TV
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
## 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)</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 (capacitive)</td>
</tr>
<tr>
<td>Absence of light</td>
<td>Camera-based optical, Infrared (all forms), LCD in-cell (optical)</td>
</tr>
<tr>
<td>Presence of light</td>
<td>LCD in-cell (optical) in low ambient</td>
</tr>
<tr>
<td>Image</td>
<td>Vision-based optical</td>
</tr>
<tr>
<td>Sound</td>
<td>Acoustic Pulse Recognition (APR)</td>
</tr>
<tr>
<td>Bending waves</td>
<td>Dispersive Signal Technology (DST)</td>
</tr>
<tr>
<td>Force</td>
<td>Force sensing</td>
</tr>
<tr>
<td>Resistance (contact closure)</td>
<td>LCD in-cell (resistive)</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>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>Low resolution</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>Touch sensitivity</td>
<td>High drift</td>
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<tr>
<td>Projected Capacitive</td>
<td>Multi-touch</td>
<td>Finger-only</td>
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<tr>
<td>Surface Acoustic Wave</td>
<td>Durability</td>
<td>Hard to seal</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>
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<tr>
<td>Camera-Based 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>Bending Wave</td>
<td>Any touch-object</td>
<td>No touch &amp; hold</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>3D substrate</td>
<td>No multi-touch</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>Multi-touch</td>
<td>Rear projection</td>
</tr>
<tr>
<td>LCD In-Cell (Optical)</td>
<td>Integration</td>
<td>Sensitivity</td>
</tr>
<tr>
<td>LCD In-Cell (Capacitive)</td>
<td>Integration</td>
<td>Durability</td>
</tr>
<tr>
<td>LCD In-Cell (Resistive)</td>
<td>Integration</td>
<td>Durability</td>
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</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>
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<tr>
<td>Mobile Devices</td>
<td>Analog Resistive</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>POS Terminals</td>
<td>Analog Resistive</td>
<td>Traditional Infrared</td>
</tr>
<tr>
<td>Kiosks</td>
<td>Surface Acoustic Wave</td>
<td>Surface Capacitive</td>
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<tr>
<td>Casino Gaming</td>
<td>Surface Capacitive</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>Consumer Notebooks</td>
<td>Projected Capacitive</td>
<td>Camera-Based Optical</td>
</tr>
<tr>
<td>Consumer AiOs and Monitors</td>
<td>Camera-Based Optical</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>Interactive Digital Signage</td>
<td>Camera-Based Optical</td>
<td>Traditional Infrared</td>
</tr>
</tbody>
</table>
Thank You!

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Product Marketing Manager
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Pleasanton, CA 94566
1-925-272-4529
gwalker@nextwindow.com
Appendix: Multi-Touch

Sources: Engadget, Do Device and Good Times & Happy Days
Multi-Touch: Past, Present & Future

- **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 (to be released 10/22/09) will support multi-touch throughout the OS.
- Multi-touch’s primary value is likely to be in the consumer market rather than in enterprise or verticals.
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>Digital Resistive</td>
<td>Yes (unlimited)</td>
<td>Probably</td>
<td>JazzMutant Music Controller</td>
</tr>
<tr>
<td>Projected Capacitive</td>
<td>Yes (unlimited)</td>
<td>Yes</td>
<td>Apple iPhone Dell Latitude XT</td>
</tr>
<tr>
<td>LCD In-Cell (all forms)</td>
<td>Yes (unlimited)</td>
<td>Yes</td>
<td>Products in development (2009)</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>Yes (unlimited)</td>
<td>Yes</td>
<td>Microsoft Surface</td>
</tr>
<tr>
<td>Camera-Based Optical</td>
<td>Yes (~8)</td>
<td>Yes</td>
<td>HP TouchSmart</td>
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<tr>
<td>Traditional Infrared (&quot;XYU&quot; IR from Elo)</td>
<td>Yes (~4)</td>
<td>Yes</td>
<td>Products in development (2009)</td>
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<tr>
<td>Surface Acoustic Wave (&quot;XYU&quot; SAW from Elo)</td>
<td>Yes (2)</td>
<td>Probably</td>
<td>Products in development (2010)</td>
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<tr>
<td>Waveguide Infrared</td>
<td>Yes (2)</td>
<td>Probably</td>
<td>Products in development (2010)</td>
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<td>Acoustic Pulse Recognition (APR)</td>
<td>Future (2)</td>
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<td>Technology in development (2010)</td>
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<td>Dispersive Signal Technology (DST)</td>
<td>Future (2)</td>
<td>Maybe</td>
<td>Technology in development (2011?)</td>
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<tr>
<td>Analog Resistive</td>
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<td>No</td>
<td>--</td>
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<tr>
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<td>No</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Force Sensing</td>
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<td>No</td>
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“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