



LCD In-Cell Touch

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Agenda

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<begin> A Commercial...

❑ Bay-Area SID Chapter

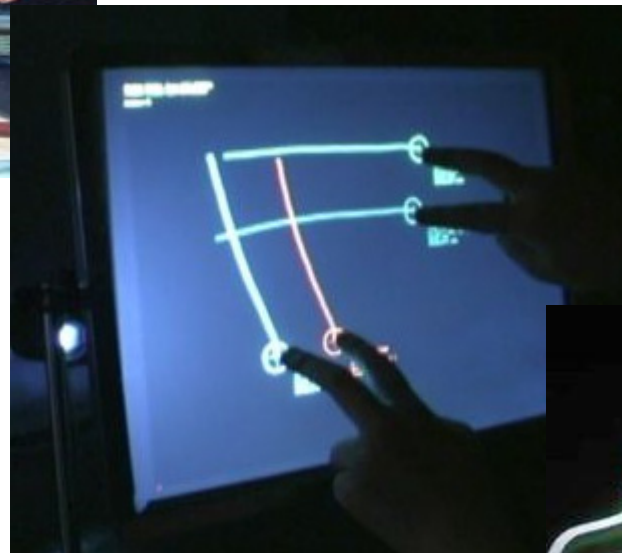
This Chapter needs your help!
We need people who...

- Have some time available
- Want to get involved

*If you're interested, please contact me
or Dave Armitage after the presentation*

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Multi-Touch



2 → 4 → 10

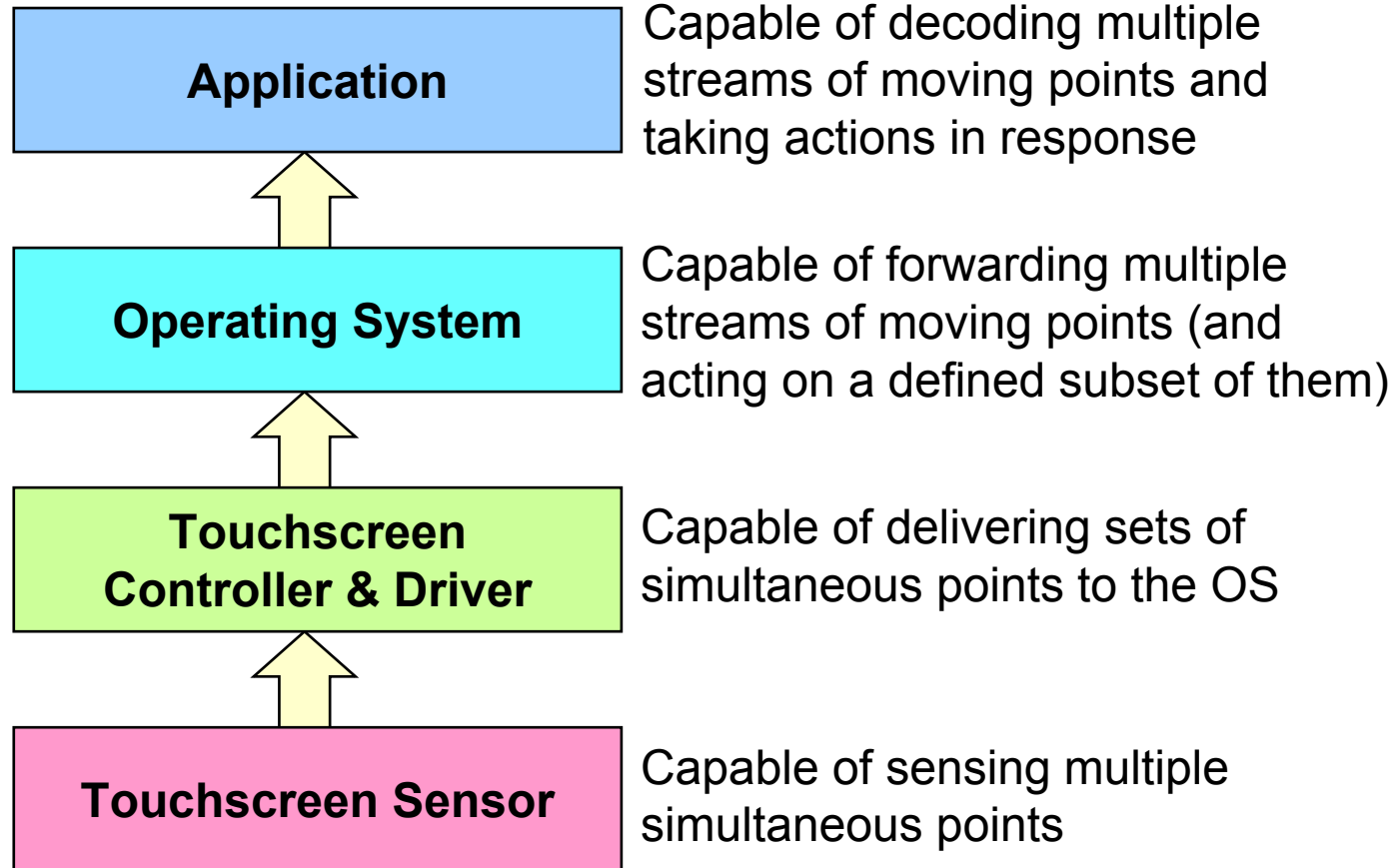


Sources: Engadget, Do Device
and Good Times & Happy Days

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 of simultaneous touch points

Multi-Touch Architecture



Multi-Touch Technologies

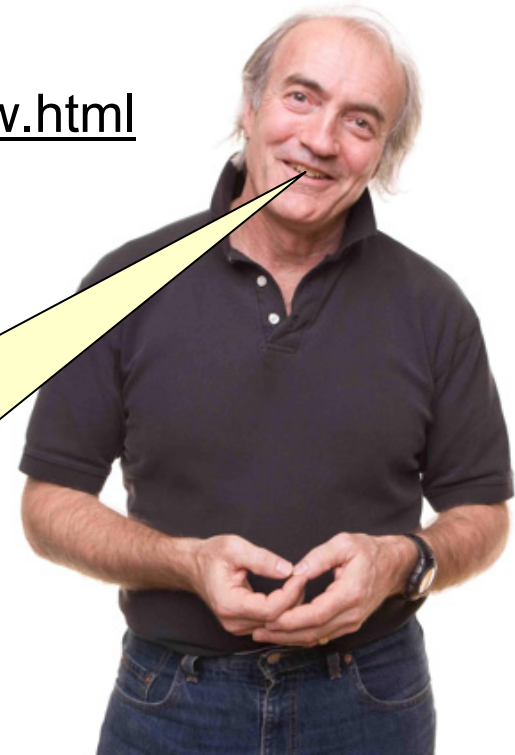
Touch Technology	Multi-Touch Capable? (#)	Win-7 Logo Capable?	Commercial MT Product Example
Projected Capacitive	Yes (unlimited)	Yes	<i>Apple iPhone; Dell Latitude XT</i>
Digital Resistive	Yes (unlimited)	Yes	<i>JazzMutant Music Controller</i>
LCD In-Cell (all forms)	Yes (unlimited)	Yes	<i>Sharp Netbook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

#1 Reference On Multi-Touch

❑ “Multi-Touch Systems that I Have Known and Loved”

◆ www.billbuxton.com/multitouchOverview.html

“If you can only manipulate one point ... you are restricted to the gestural vocabulary of a fruit fly. We were given multiple limbs for a reason. It is nice to be able to take advantage of them.”



Bill Buxton, 2008
Principal Researcher,
Microsoft Research

LCD In-Cell Touch



Source: TMD

Three Different Technologies Used In LCD In-Cell Touch

❑ Light-sensing or “optical”

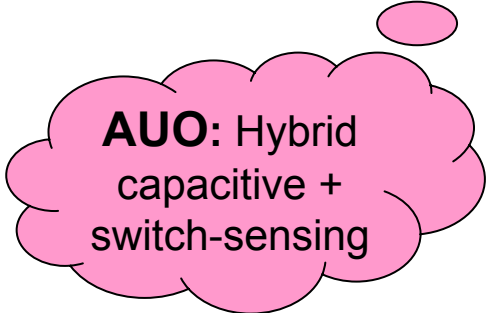
- ◆ Addition of a photo-transistor (photocell) into each pixel
- ◆ Works with finger, stylus, light-pen or laser pointer; also works as a scanner

❑ Switch-sensing or “voltage-sensing” or “resistive”

- ◆ Addition of micro-switches for X & Y into each pixel
- ◆ Works with finger or stylus, within damage limits of LCD

❑ Capacitive-sensing or “charge-sensing”

- ◆ Addition of electrodes into each pixel for capacitive sensing
- ◆ Works with finger-only, within damage limits of LCD



AUO: Hybrid
capacitive +
switch-sensing

Three Different Physical Integration Methods Used In LCD “In-Cell” Touch

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

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"

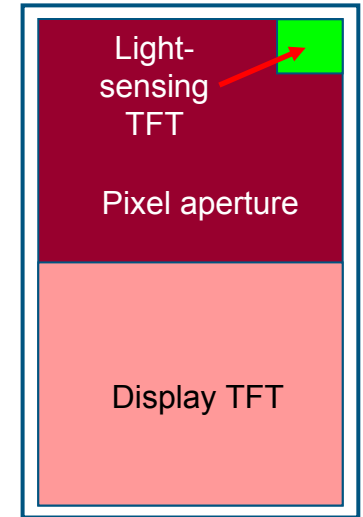
Light-Sensing...1

□ Principle

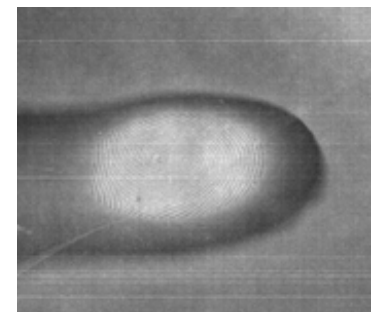
- ◆ Photo-transistors see shadow of finger in bright light or reflection of backlight on finger in dim light

□ History

- ◆ TMD was first to announce the concept on 4/03
 - First to auto-switch between shadow & reflection
 - No announced commercialization date
- ◆ 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



(Conceptual illustration)

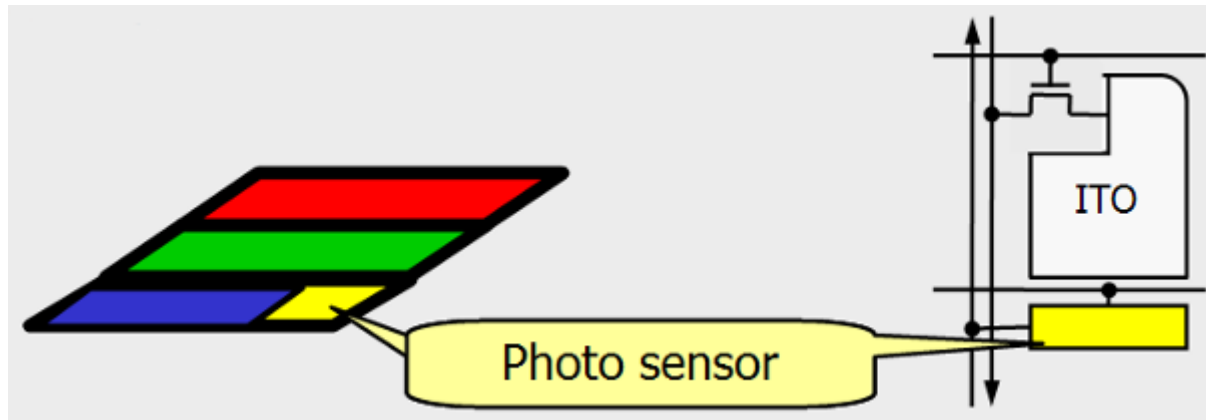


Sample captured image on
2.6" VGA (300 ppi)

Source: Sharp

Light-Sensing...2

□ Another conceptual illustration



Source: DisplaySearch

□ Size range

- ◆ 3" to 3x"
 - AUO is working on 30"- 40" with 1 sensor/9 pixels (finger-resolution)
- ◆ Technically there is no upper size limit

Light-Sensing...3

❑ Suppliers

- ◆ AUO, CMO, CPT, LGD, Samsung, Sharp, Sony, TMD...
 - AUO says they've been in "mass production" on 3" & 4.3" in-cell optical since 2008, but there's no sign of any end-user products...

❑ Advantages

- ◆ Integration, size, thickness, weight, ID
- ◆ Unlimited multi-touch (controller-dependent)
- ◆ Conceptually high performance
 - Low parallax error (assuming no cover glass)
 - Very accurate & linear touch-point data
 - Potentially higher resolution than LCD through interpolation
- ◆ Can work as a scanner
- ◆ Capable of detecting the difference between hover & touch
 - Problematic in low ambient

Light-Sensing...4

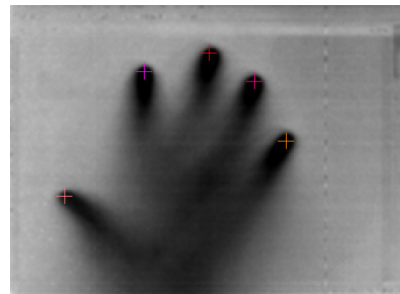
❑ Disadvantages

- ◆ Touching a black image doesn't work in low ambient light
- ◆ 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
- ◆ Smaller aperture causes light loss (inefficient)
- ◆ Significant processing power is required due to image processing in every sensing cycle
- ◆ Cost (?) – rumors of significant cost problems...

Light-Sensing...5

❑ Potential solutions to the “can’t touch black” problem

- ✦ Add an IR light source (e.g., backlight LEDs), and make in-pixel light sensors IR-sensitive
 - IR goes through the LCD and reflects off the finger
 - Sharp did this in their netbook “touchpad LCD”
- ✦ 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 a [small-medium?] LCD manufacturer in 2009, which will probably prevent all others from using the idea



Source: Planar

Light-Sensing...6

❑ Controller functions

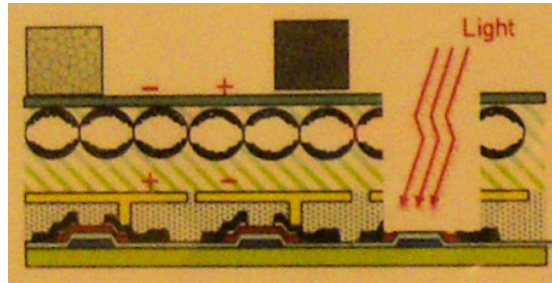
- ◆ Too much horsepower required for on-glass silicon
 - Analog-to-digital conversion
 - Position determination
 - Image processing & motion recognition (phone vs. Windows)

❑ Applications

- ◆ Mobile devices are clearly the initial target
- ◆ LGD & e-Ink showed an e-book reader with in-cell optical touch at SID 2009
- ◆ AUO & SiPix announced a similar concept at Display Taiwan 2009



Source: AUO



Source: LGD



Source: Sharp

Light-Sensing...7

First use of in-cell optical touch in a commercial product...?

❑ 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
 - Needed IR from backlight
 - **S L O W** (25% of typical touchpad speed)



Source: Sharp

Light-Sensing...8



Source: AkihabaraNews.com

Light-Sensing...9



Source: NetbookChoice.com



Source: AkihabaraNews.com



Source: Sharp

Standard retractable
PDA-style pen

Switch-Sensing...1

❑ Principle

- ◆ Pressing LCD surface closes micro-switches in each pixel

❑ Size range

- ◆ 3" to 26" (AUO's stated maximum)
- ◆ Limited by RC-loading of (and space for) connecting traces

❑ Suppliers

- ◆ AUO and Samsung

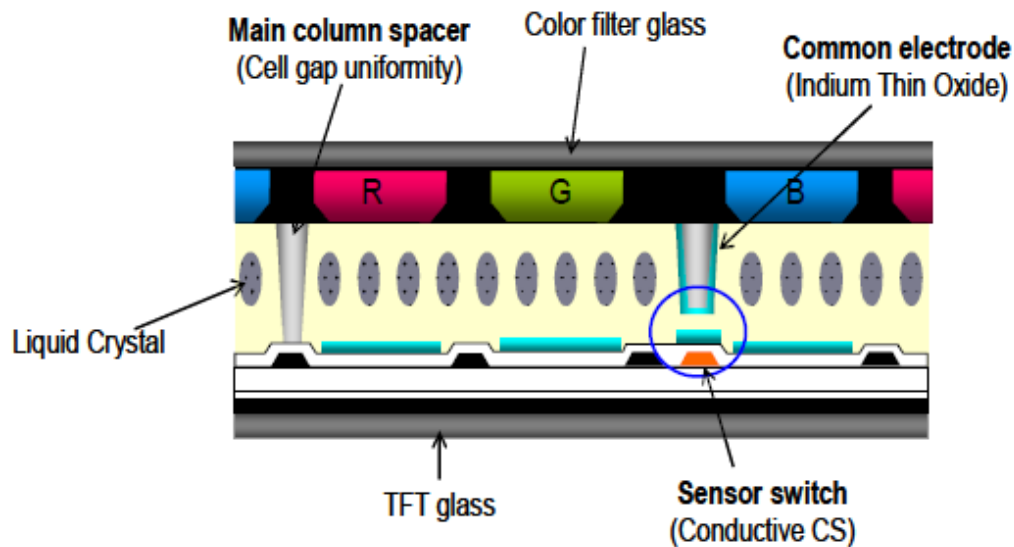
❑ Controller

- ◆ Relative simplicity potentially allows integration into LCD driver
- ◆ Needs "isolated drive & scan", like Stantum's digital resistive

Switch-Sensing...2

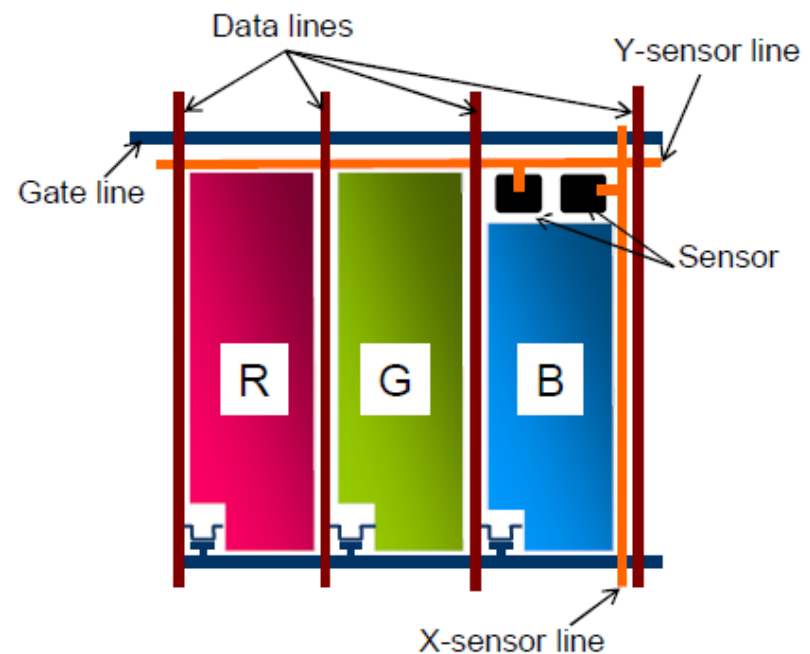
- ❑ Samsung's design (AUO's is very similar)

Side view



Source: Samsung

Top view



Switch-Sensing...3

❑ Advantages

- ◆ Integration, size, thickness, weight, ID
- ◆ Unlimited multi-touch (controller-dependent)
- ◆ Low parallax error; very accurate & linear data; can be same resolution as LCD
- ◆ Totally independent of ambient, back or front-lighting
- ◆ Simplest controller of the three in-cell types

Switch-Sensing...4

❑ Disadvantages

- ◆ Switch-sensing definitely 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

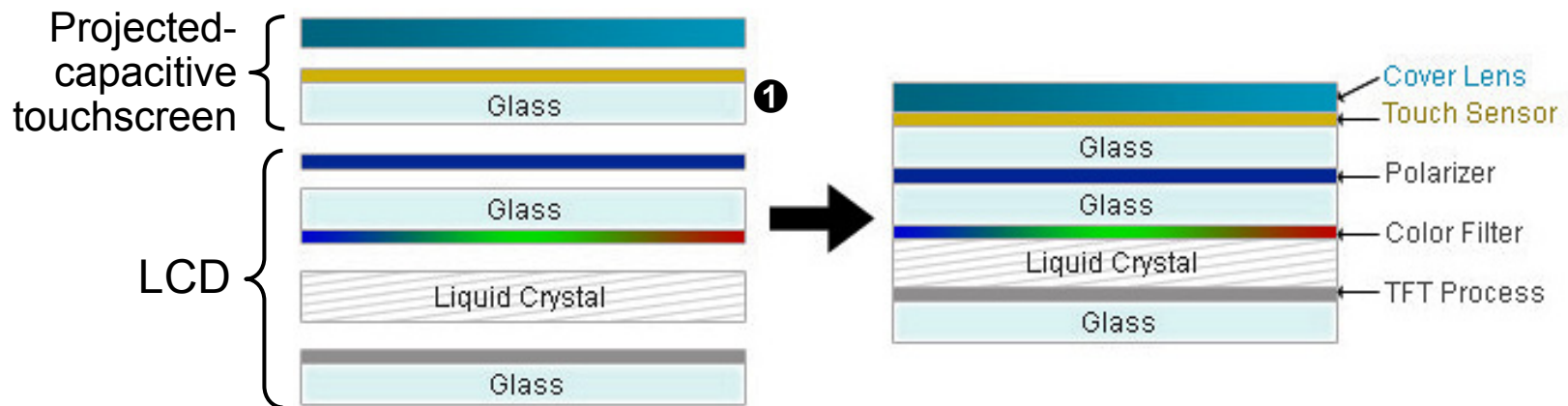
❑ Applications

- ◆ Mobile is clearly the initial target; others TBD

Capacitive-Sensing...1

❑ Out-cell

- ◆ Laminated capacitive or resistive touchscreen



❶ Touch sensor construction

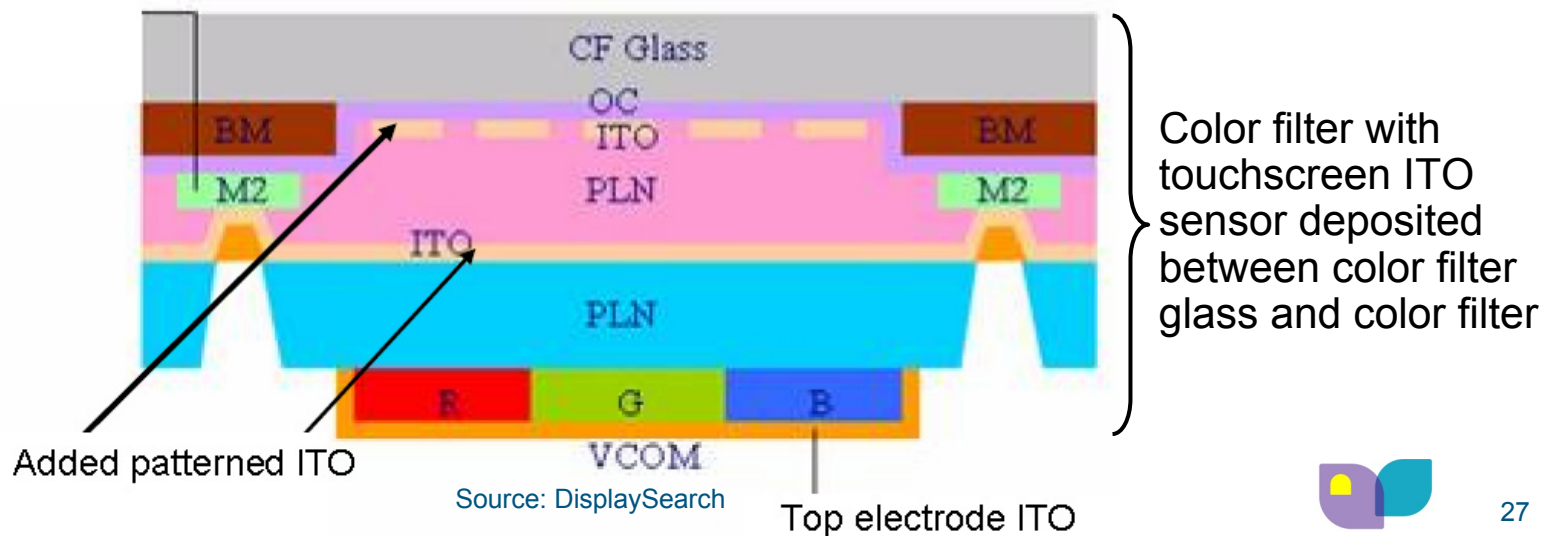
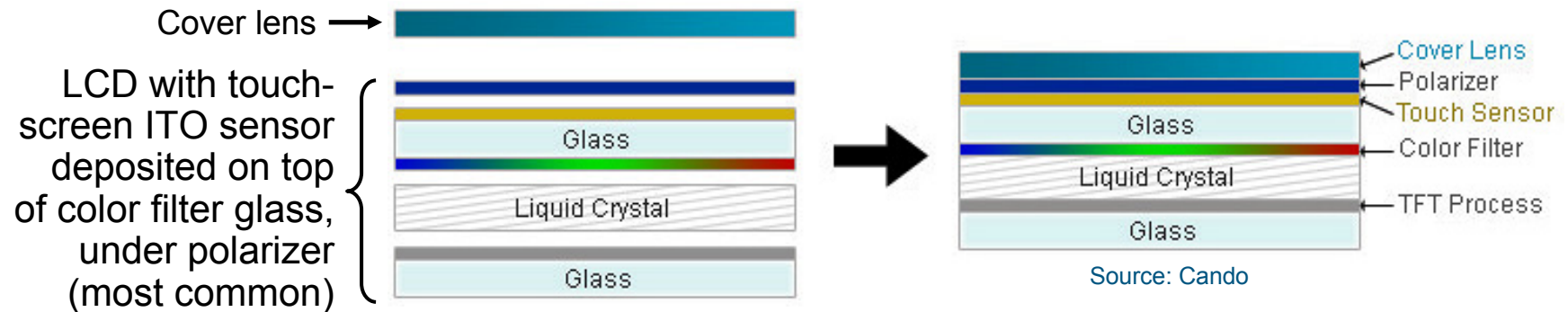


Source: Cando

Capacitive-Sensing...2

❑ On-cell

◆ Capacitive touchscreen sensor on color filter glass



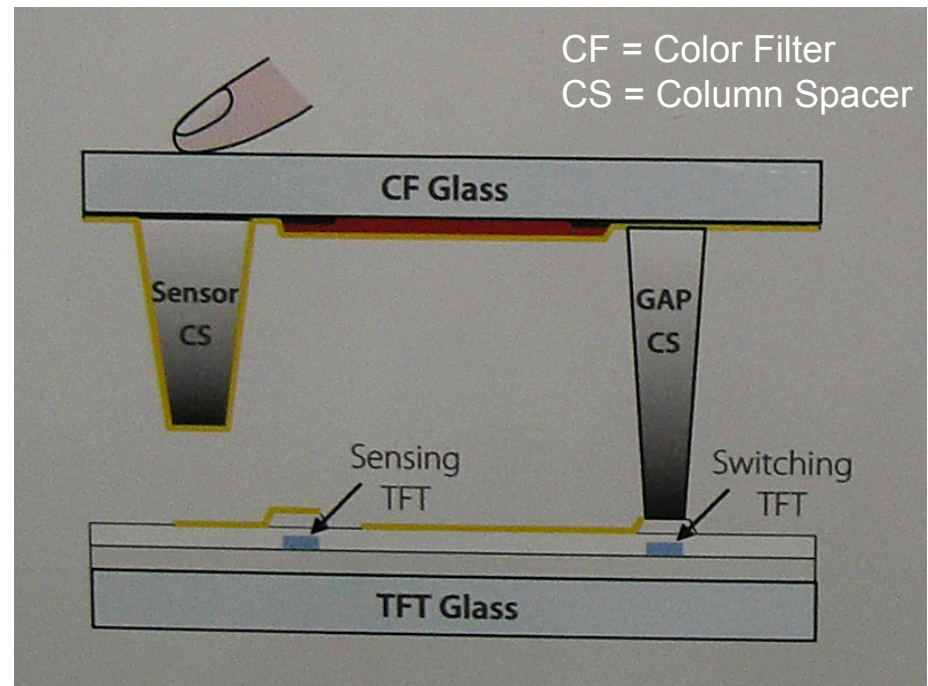
Capacitive-Sensing...3

❑ In-cell

- ◆ Capacitive-sensing ITO electrodes added inside the LCD cell

❑ Principle

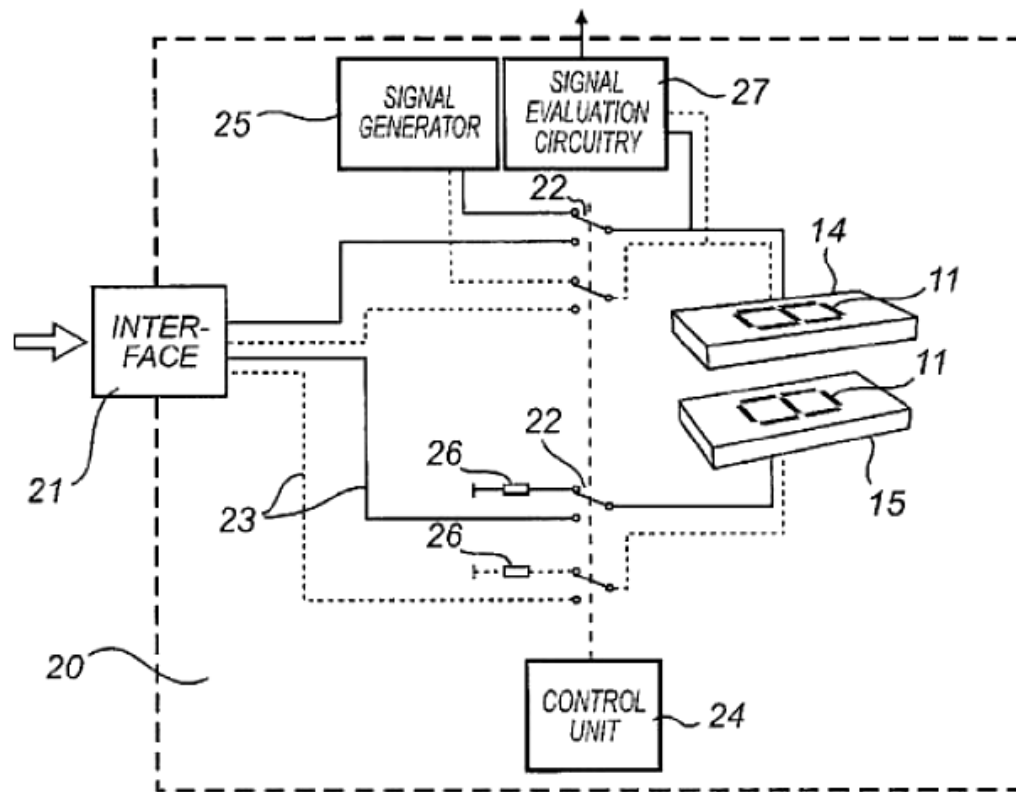
- ◆ Body capacity to ground changes capacitance between sensor CS and bottom electrode
- ◆ No pressure is required
- ◆ Similar to projected capacitive



Source: LG Display

Capacitive-Sensing...4

❑ A different in-cell design: Integritouch (Sweden)



- ◆ Integritouch's patented method of switching the LCD's existing internal electrodes to become projected-capacitive touch-screen electrodes during the refresh cycle
- ◆ Patent WO **2005/036510**
- ◆ No real traction to date
 - LCD fab's N.I.H.?
 - Are there enough significant advantages?

Capacitive-Sensing...5

❑ **Size range**

- ◆ 3" to 24"
- ◆ AUO has demoed 12" & 15"; they say their maximum will be 24"

❑ **Controller**

- ◆ Same concept as standard “all points addressable” projected-capacitive controllers, but unique to each LCD manufacturer
- ◆ Some controller suppliers are partnering with LCD manufacturers (e.g., AUO/Cando & Cypress)

❑ **Advantages (in-cell & on-cell)**

- ◆ Integration, size, thickness, weight, ID
- ◆ Unlimited multi-touch (controller-dependent)
- ◆ Totally independent of ambient, back or front-lighting
- ◆ Potentially higher resolution than LCD through interpolation

Capacitive-Sensing...6

❑ Disadvantages (in-cell & on-cell)

- ◆ Finger-touch only; no stylus
- ◆ In-cell capacitive sensing won't work well with a cover glass, so the LCD can easily be damaged
- ◆ 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 reasonable performance
 - Same as in-cell optical
- ◆ Smaller aperture ratio causes light loss (inefficient)
- ◆ Liquid-crystal pooling can be visually distracting

Capacitive-Sensing...7

□ Applications

- ◆ Mobile phones, netbooks & notebooks; maybe monitors & AiOs

□ Suppliers

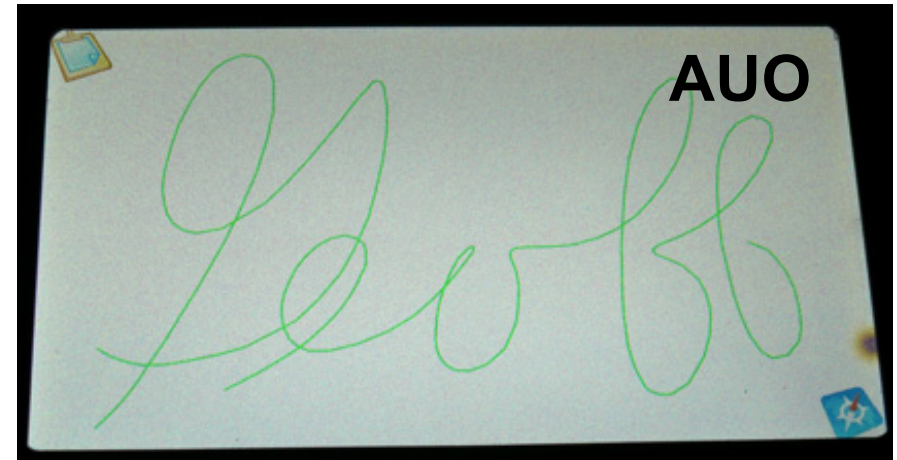
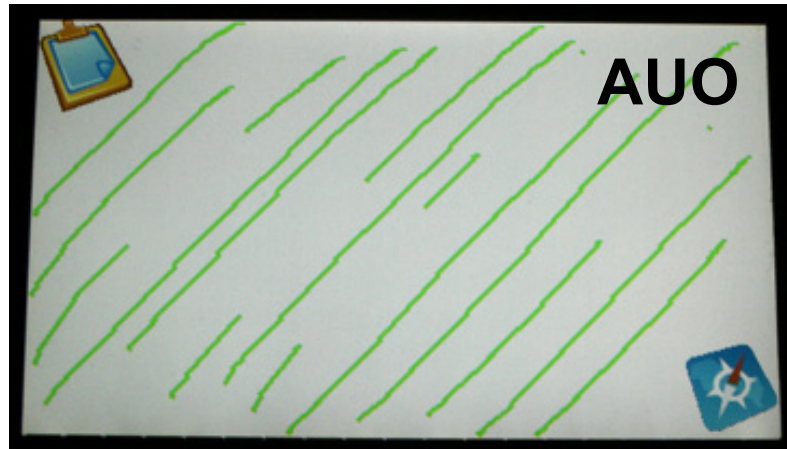
- ◆ AUO, CMO, CPT, LGD...
 - At LCD fab for in-cell
 - At color filter fab (e.g., AUO/Cando) for on-cell



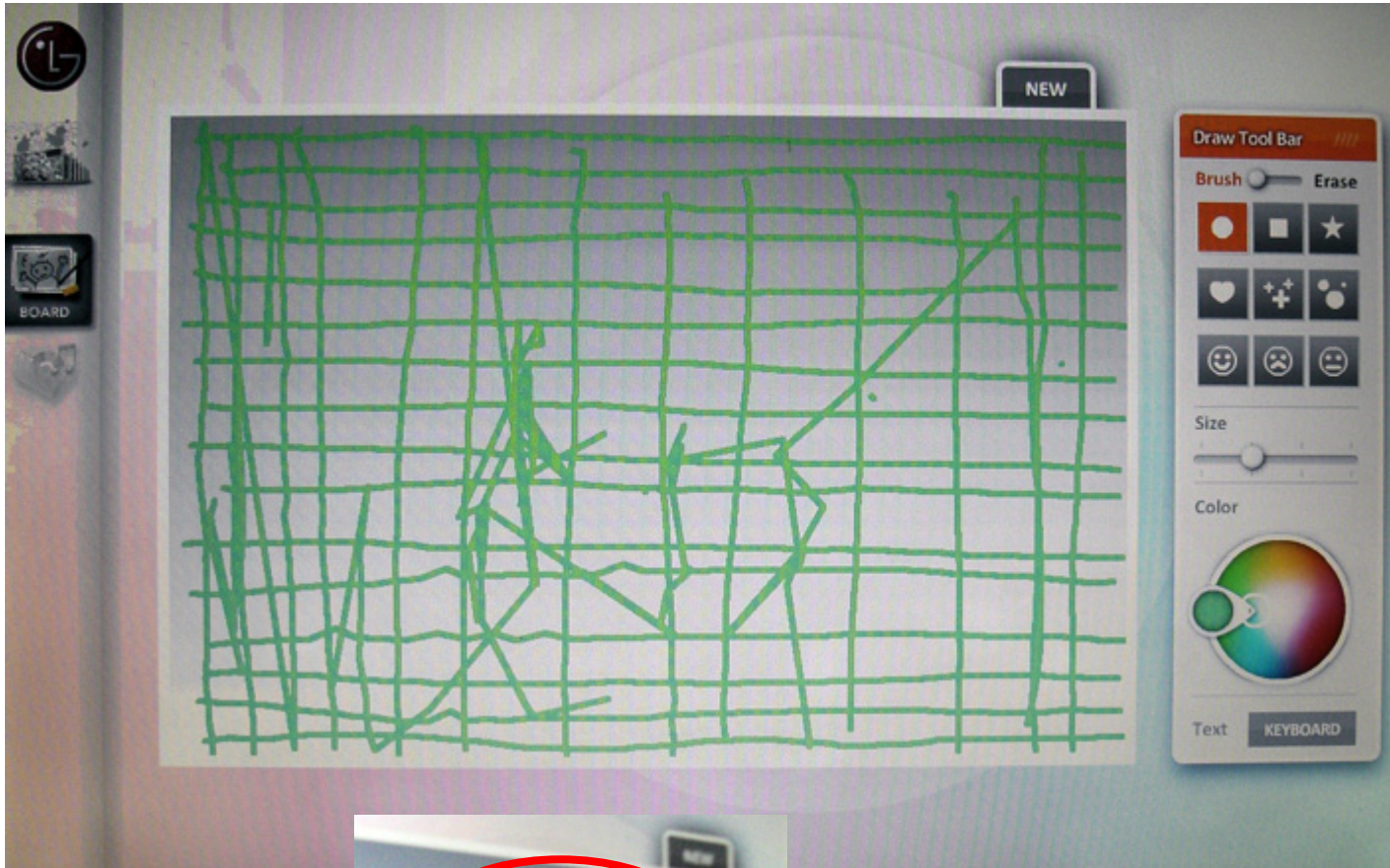
Source: AUO

Capacitive-Sensing...8

Photos taken at FPD 2008 in Yokohama

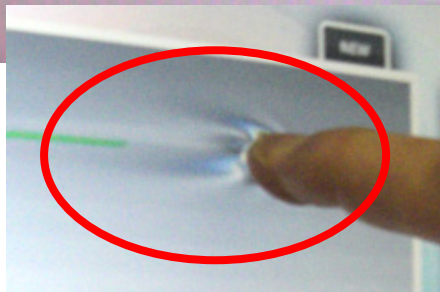


Capacitive-Sensing...9



**LG Display
13.3" in-cell
capacitive
At SID 2009**

Attempt to
draw a grid
of straight
lines...



Lots of pooling and ink lag!



Technology Comparison

Technology Comparison

Characteristic	Optical	Switch	Capacitive (in-cell & on-cell)
Size limit	Unlimited	26"	24"
Input device	Finger, stylus, light-pen	Finger, stylus	Finger
Touch force required	None	Some	None
Cover glass possible	Yes	No	No
Durability	High with cover glass	Low	Low
True flush surface ("zero bezel")	Yes with cover glass	No	No
Transmissivity loss	Aperture	Aperture	Aperture plus ITO (on-cell)
EMI sensitivity	None	None	High
Ambient light sensitivity	High	None	None
Flexible substrate	Yes	No	No
Controller complexity	High	Low	High

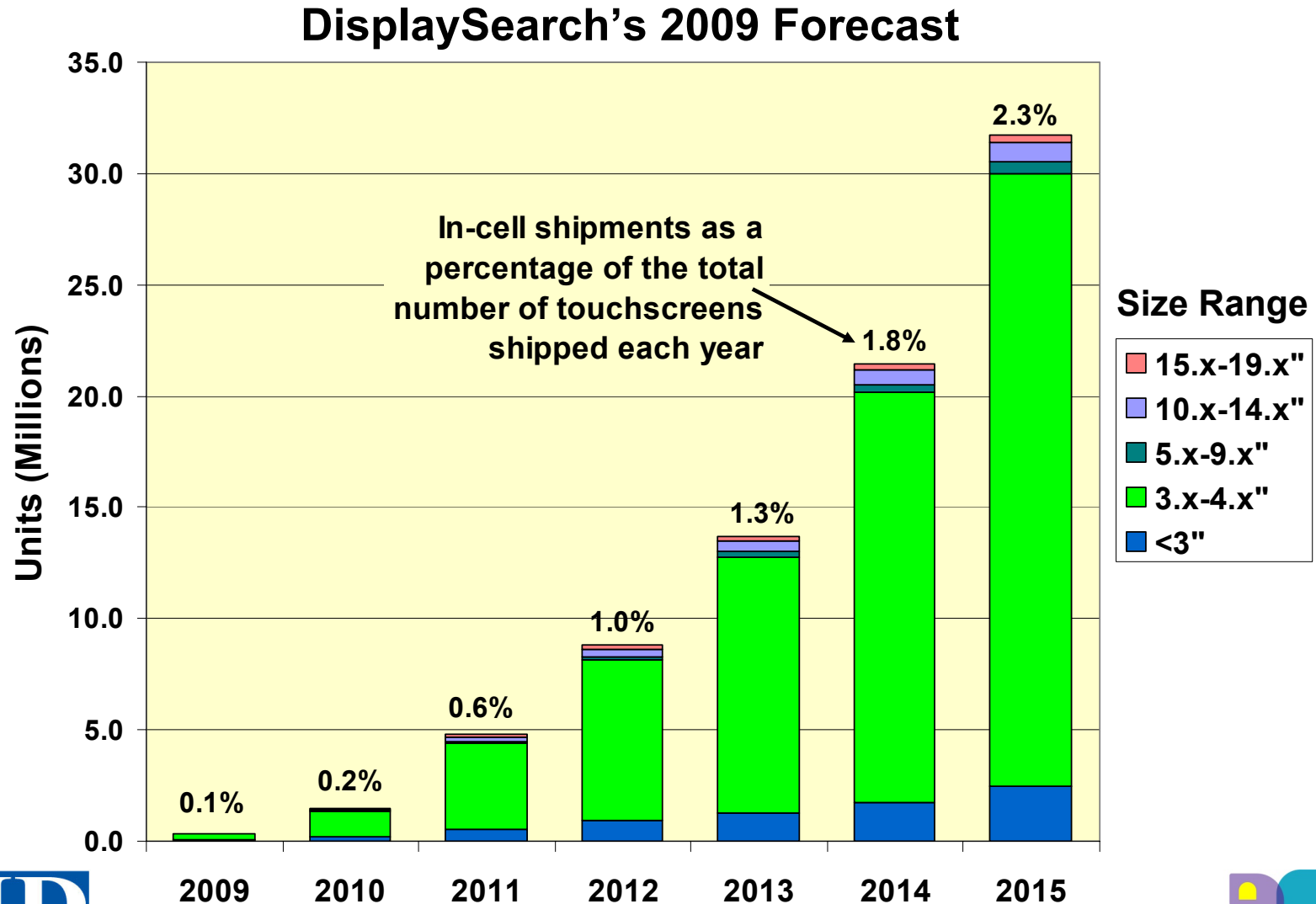
Red-yellow-green color ratings are relative within the three in-cell technologies, not within all touch technologies

Touch Market



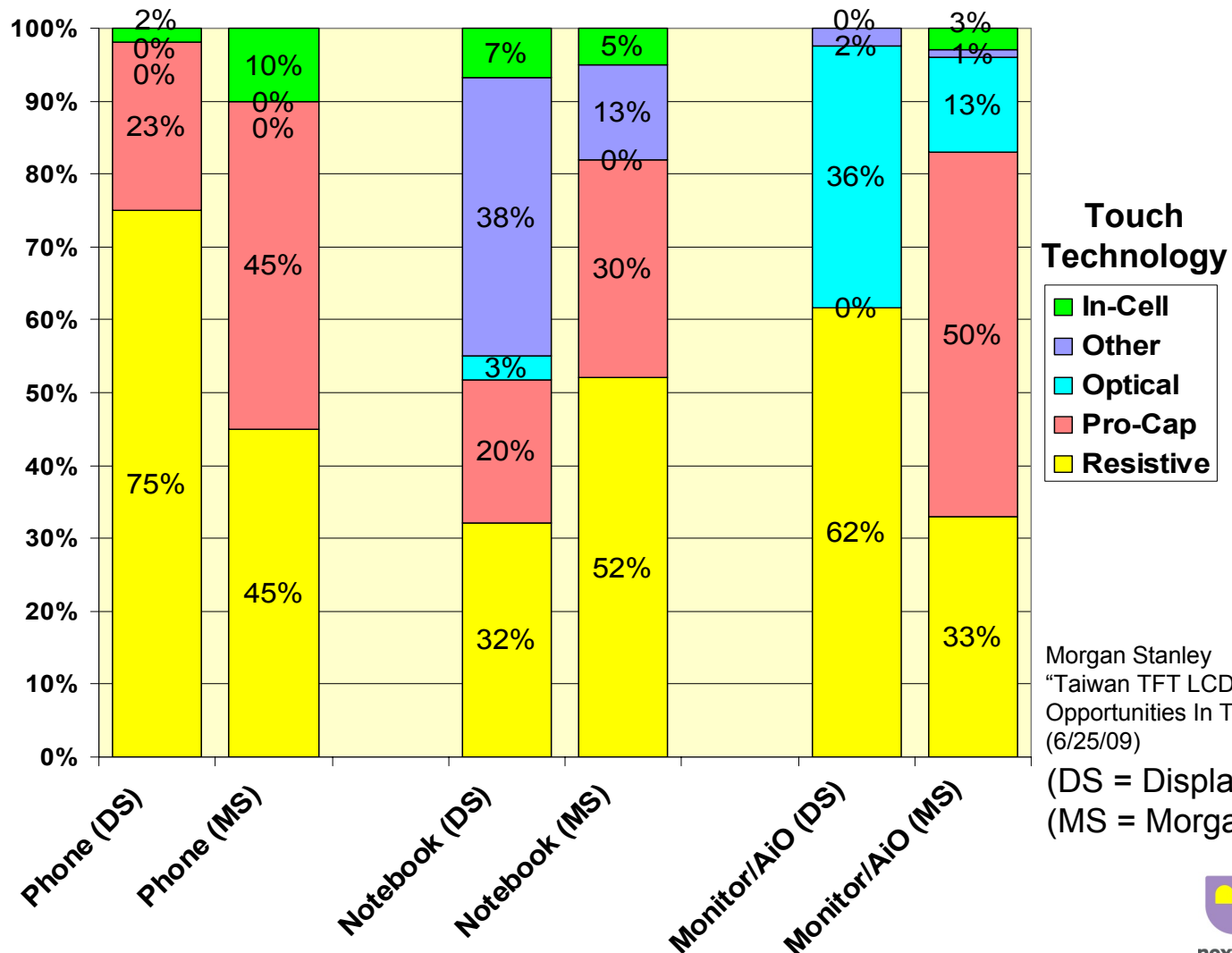
Source: Gizmodo

LCD In-Cell Forecast by Screen Size



Touch Technology Forecasts for Phones, Notebooks & Monitors/AiOs

DisplaySearch's & Morgan Stanley's Forecast for 2013





Source: CG4TV

Conclusions

There Is No Perfect Touch Technology!

Technology	Major Advantage	Major Flaw
Analog Resistive	Low cost	Low durability
Digital Resistive	Multi-touch	Low resolution
Surface Capacitive	Touch sensitivity	High drift
Projected Capacitive	Multi-touch	Finger-only
Surface Acoustic Wave	Durability	Hard to seal
Traditional Infrared	Reliability	High cost
Waveguide Infrared	Low cost	Contamination
Camera-Based Optical	Scalability	Profile height
Acoustic Pulse Recognition	Any touch-object	No touch & hold
Bending Wave	Any touch-object	No touch & hold
Force Sensing	3D substrate	No multi-touch
Vision-Based Optical	Multi-touch	Rear projection
LCD In-Cell (Optical)	Integration	Sensitivity
LCD In-Cell (Capacitive)	Integration	Durability
LCD In-Cell (Switch-Sense)	Integration	Durability



Thank You!



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Source: Vissumo

Appendix

2008 Overall Touch Market

Technology	2008					
	Small-Med (<10")		Large-Area (>10")		TOTAL	
	Revenue	Units	Revenue	Units	Revenue	Units
Resistive	\$1,140M	325M	\$684M	40M	\$1,824M	365M
Surface acoustic wave	\$4.7M	0.1M	\$185M	2.8M	\$190M	2.9M
Surface capacitive	\$0.2M	0M	\$168M	2.0M	\$168M	2.0M
Infrared	\$4.5M	0.1M	\$128M	1.0M	\$133M	1.2M
Mainstream	\$1,150M	325M	\$1,165M	46M	\$2,315M	371M
Emerging	\$462M	31M	\$55M	0.8M	\$517M	32M
TOTAL	\$1,612M	356M	\$1,220M	47M	\$2,832M	403M

	Revenue	Units
Small-Medium	57%	88%
Large-Area	43%	12%
TOTAL	100%	100%

	Revenue	Units
Mainstream	82%	92%
Emerging	18%	8%
TOTAL	100%	100%

All market size charts are based on DisplaySearch's 2009 "Touch-Panel Market Analysis" with adjustments

2008 Touch Market By Technology

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

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

2008 Touch Market By Application

Application	2008 Revenue	2008 Share
Mobile Phone	\$ 801M	28.3%
Other	\$ 311M	11.0%
Retail/POS	\$ 222M	7.8%
Point of Information/Check-In	\$ 211M	7.5%
ATM/Financial	\$ 180M	6.4%
Factory/Industrial	\$ 172M	6.1%
Portable Navigation Device	\$ 151M	5.3%
Automobile	\$ 145M	5.2%
Game – Portable	\$ 139M	4.9%
Medical	\$ 101M	3.6%
Game – Casino	\$ 77M	2.7%
PMP/MP3 Player	\$ 70M	2.5%
Ticketing	\$ 46M	1.6%
Digital Still Camera/Camcorder	\$ 44M	1.5%
Printer/Office	\$ 43M	1.5%
Notebook PC	\$ 36M	1.3%
Desktop/PC Monitor	\$ 33M	1.2%
Education/Training	\$ 30M	1.1%
Digital Picture Frame	\$ 6M	0.2%
PDA	\$ 6M	0.2%
Mini-Notebook	\$ 7M	0.2%
TOTAL	\$2,832M	100%