

The Past, Present & Future of LCDs: The Black Swan Matures & Prospers

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World of 1967: Color TV gaining market share

Model CT608C
Genuine Walnut Veneer Cabinet
Private Listening Earphone Included. Cabinet superbly fashioned of fine quality Genuine Walnut Veneers and Select Hardwoods with Oil Walnut finish. 18 1/2" high, 27 1/2" wide, 16 1/2" deep.*

20" RECTANGULAR
COLOR TV
20" picture, measured diagonally, 227 sq. in.
the super compact series
1967 Motorola (USA)

Console Model CU622C
Contemporary Styling
Cabinet of Genuine Walnut Veneers and Walnut Solids with Oil Walnut finish. 29" high, 29" wide, 17 1/2" deep.

Model CT607C
Private Listening Earphone Included
Durable Metal cabinet covered with attractive scuff-resistant Vinyl with Walnut grain finish or Mahogany grain finish. 17 1/2" high, 25 1/2" wide, 20" deep. (Depth includes tube cap.)

Model CT606C
Private Listening Earphone Included
Durable Metal cabinet in attractive Metallic Brown color. 17 1/2" high, 25 1/2" wide, 20" deep. (Depth includes tube cap.) This model also available with Golden Satellite Remote Control Tuning as Model RT606C at extra cost.

Console Model CU615C
Built-in Swivel Base
Contemporary cabinet of Select Hardwood Veneers and Solids with an applied Walnut grain finish or an applied Mahogany grain finish. 30" high, 27 1/2" wide, 17" deep.*

Console Model CU612C
Italian Provincial Styling
Cabinet of Select Hardwood Veneers and Solids with an applied Mediterranean Mahogany grain finish. 29 1/2" high, 28 1/2" wide, 17 1/2" deep.*

Console Model CU613C
French Provincial Styling
Cabinet of Select Hardwood Veneers and Solids with an applied French Provincial Fruitwood grain finish. 29 1/2" high, 28 1/2" wide, 17 1/2" deep.*

Console Model CU611C
Early American Styling
Cabinet of Select Hardwood Veneers and Solids with an applied Midwest Maple grain finish. 31 1/2" high, 28 1/2" wide, 17 1/2" deep.*

Console Model CU610C
Contemporary Styling
Cabinet of Select Hardwood Veneers and Solids with an applied Mahogany grain finish or an applied Mahogany grain finish. 29 1/2" high, 28 1/2" wide, 17 1/2" deep.*

Model CU605C
Durable Metal cabinet in attractive Metallic Brown color. 17 1/2" high, 25 1/2" wide, 20" deep. (Depth includes tube cap.)

All models have a power transformer chassis, precision crafted with modern hand and die soldering for circuit connections of high reliability. Automatic Degasser. Required 24,000 volts of picture power (factory adjusted). Tint Control. Color

Today's LCD success was a black swan* in 1967

**** a high impact event that is extremely difficult to predict***



<http://lucaatalla.files.wordpress.com/2009>

First Commercial LCDs – 1971

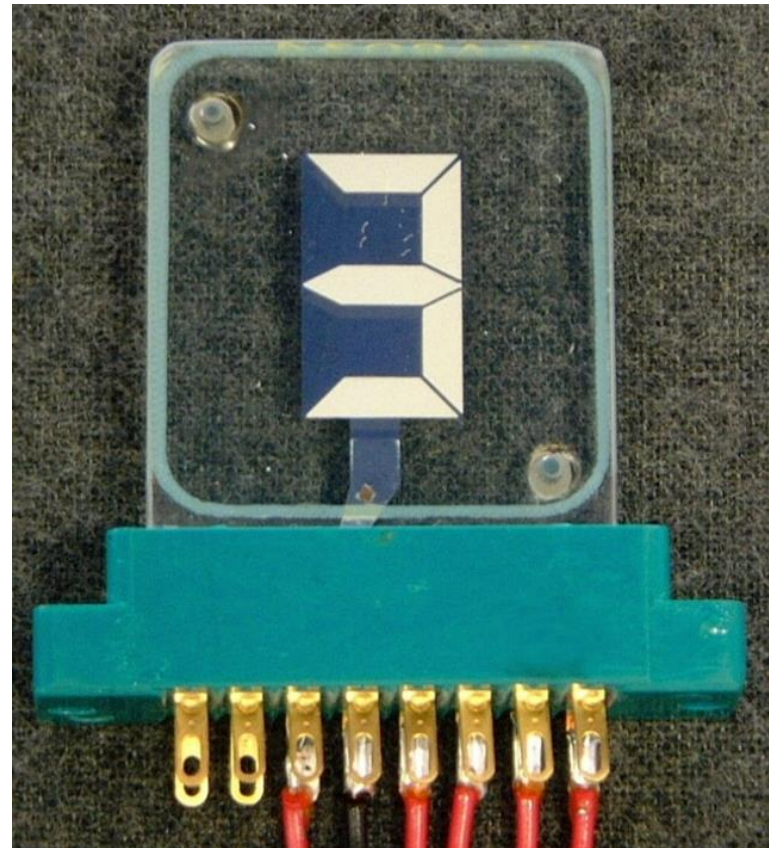
Current driven

Scattering mode

0.75" high

7-segment numeric

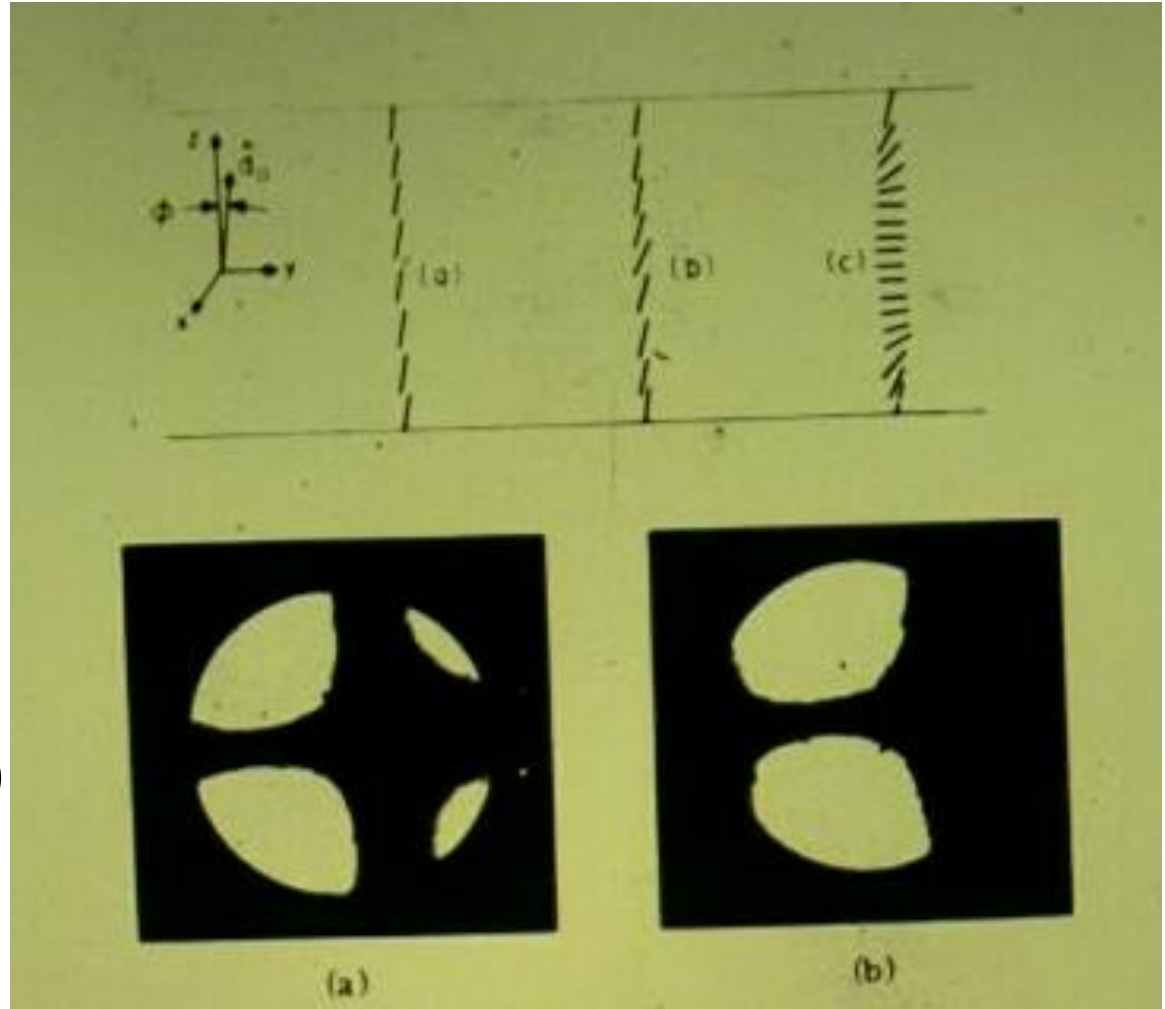
**Product of
RCA Solid State Division**



Courtesy of Dr. Sun Lu, Landmark Technologies

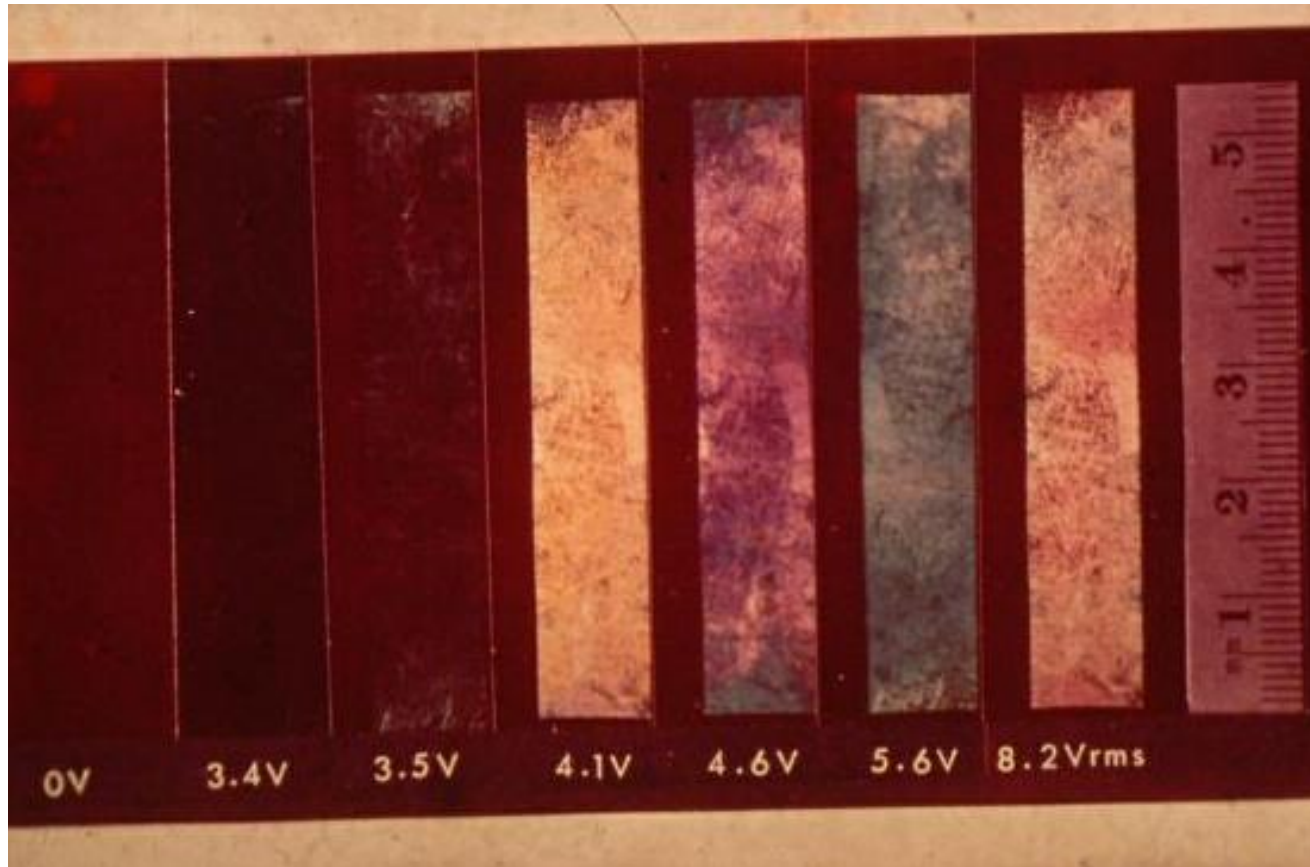
Vertically aligned nematic (VAN) LCD

Edge view



Conoscopic view
(converging light)

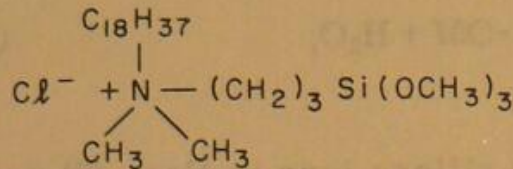
VAN LCD photos - 1971*



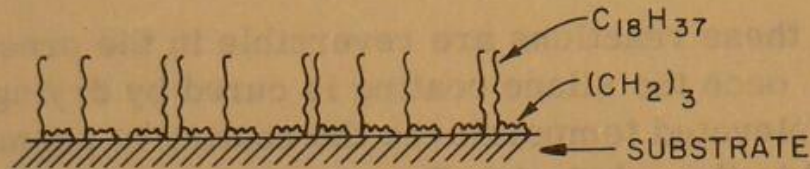
***F.J. Kahn, IEEE Device Research Conference, Ann Arbor, June 30, 1971;
US Patent 3,694,053, filed June 22, 1971**

Coupling agents align liquid crystals

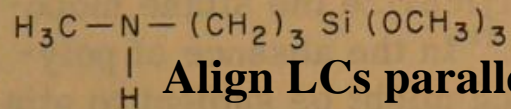
(a) N,N-dimethyl-N-octadecyl-3-aminopropyltrimethoxysilyl chloride (DMOAP)



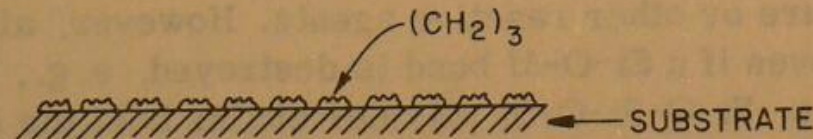
Align LCs normal to surface



(b) N-methyl-3-aminopropyltrimethoxysilane (MAP)

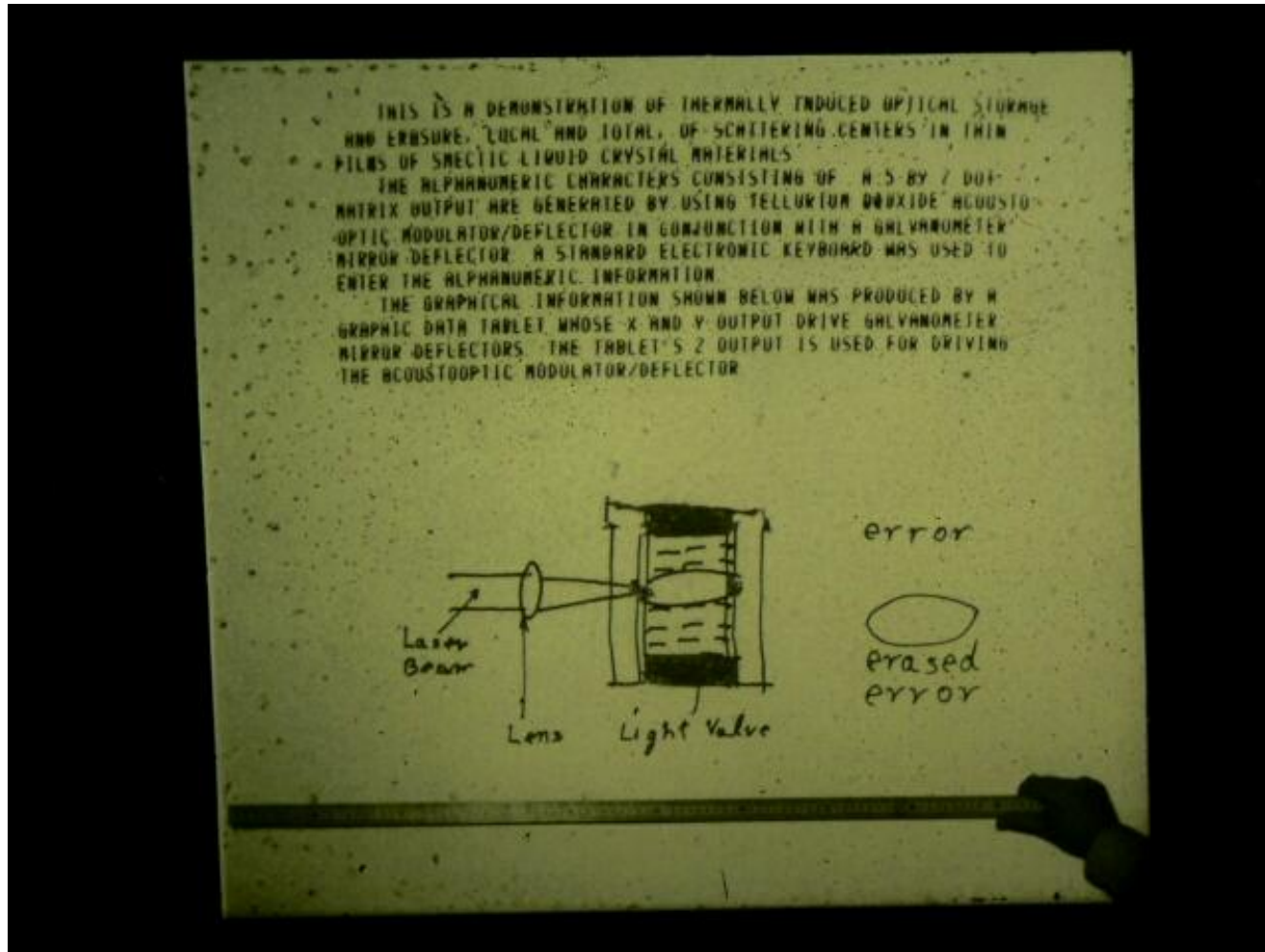


Align LCs parallel to surface



F. J. Kahn, *Appl. Phys. Lett.* **22**, 386-389 (1973)

Laser (thermal) Smectic LC Light Valve Projector 12.25 Mpixel (1973)



The dark gray LCD swan

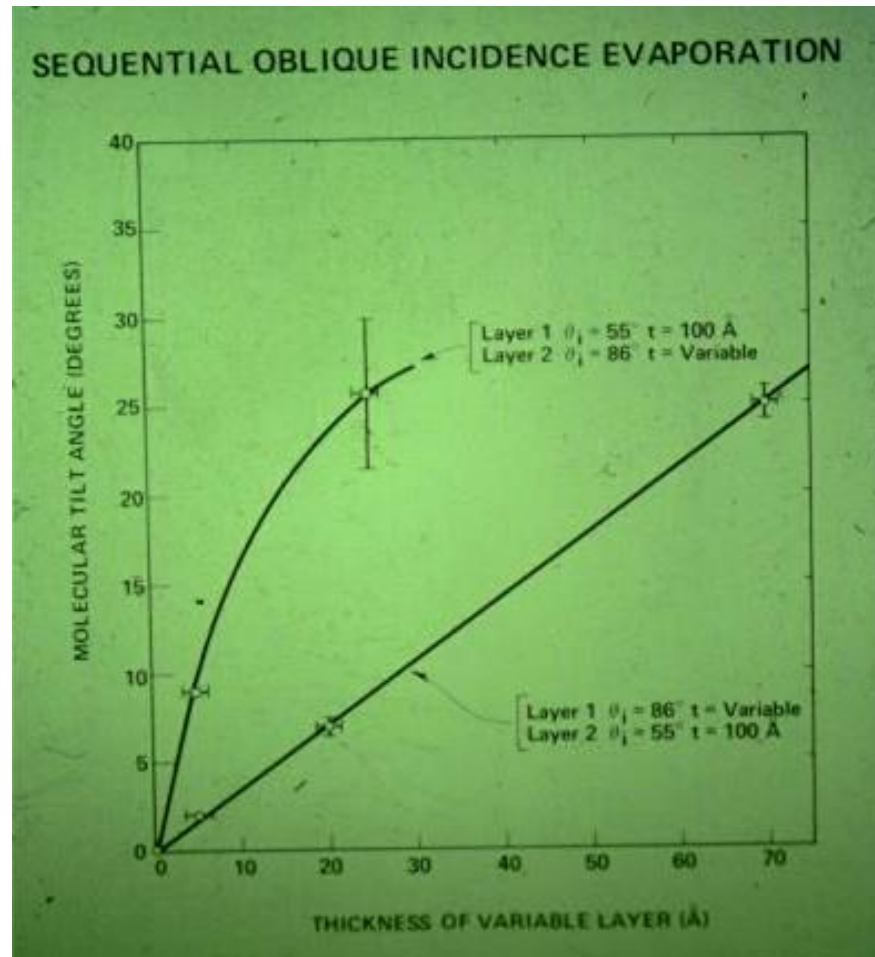


High reliability calculator display prototype (1974)



Demonstrated to William Hewlett and David Packard, May 1974

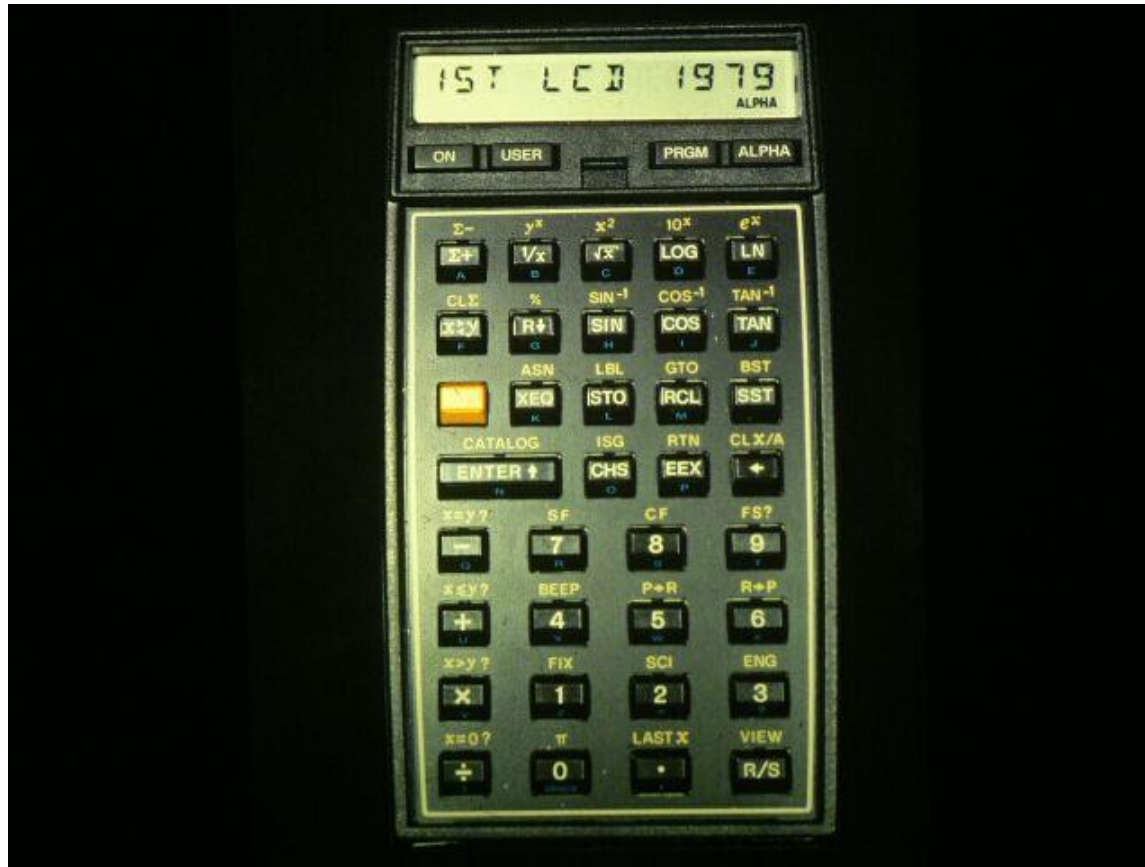
Precision alignment control for calculator LCDs



The first HP calculators used LEDs

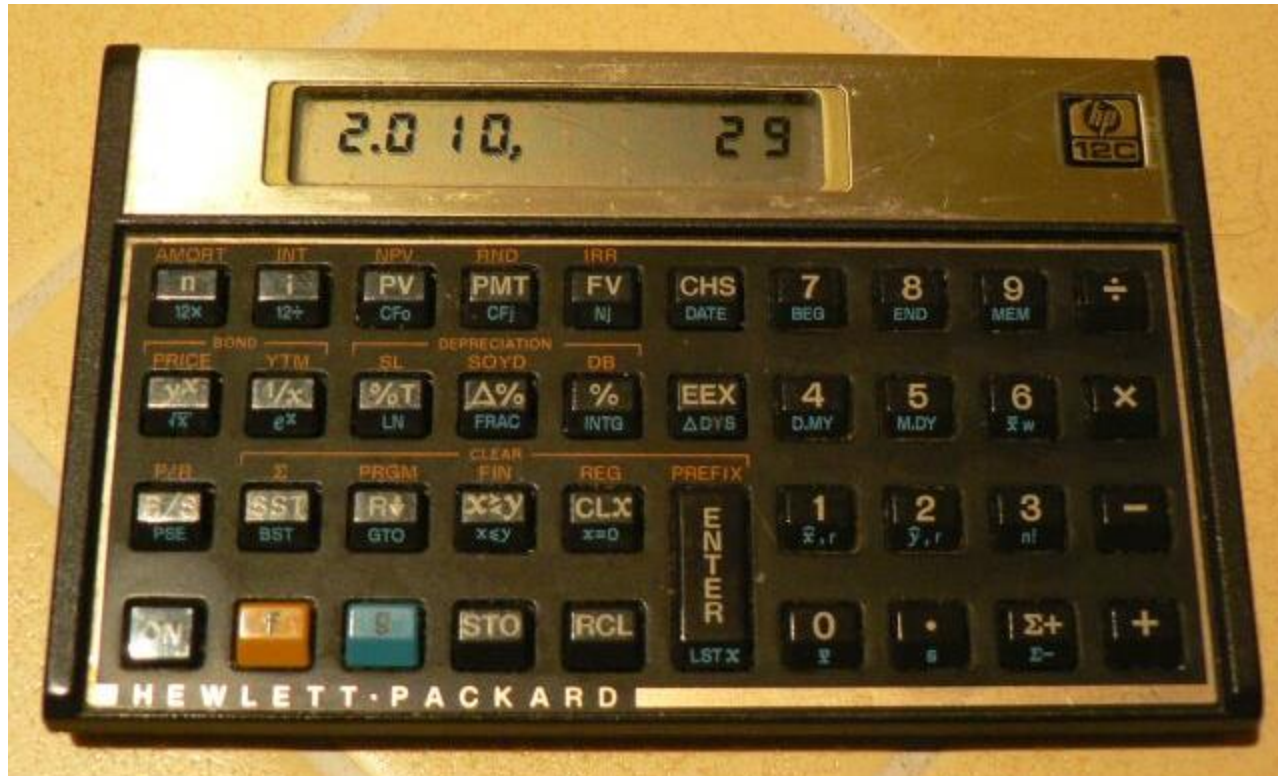


The first HP LCD calculator (1979)



“The alpha-numeric LCD screen of the HP-41C revolutionized the way a calculator could be used.”
(Wikipedia)

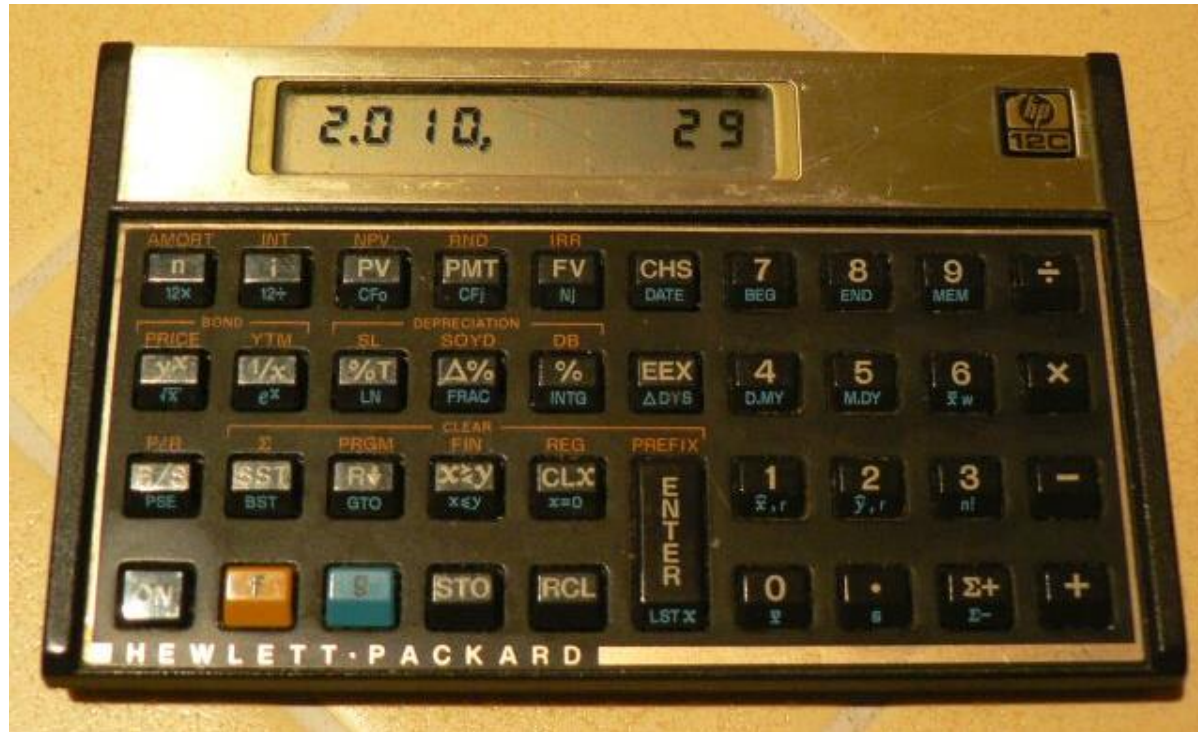
HP12c Financial Calculator (1981-)



“the oldest consumer electronic device still in production” and
”still HP’s best selling calculator” (Hewlett-Packard, Jan. 2004)

http://articles.chicagotribune.com/2004-01-10/business/0401100187_1_calculator-best-selling-device

HP12c Financial Calculator (1981-)



Still selling today, 35 yrs after introduction,
42 years after tech demo to Hewlett & Packard.
Amazon \$63.85, March 2016)

On the future of LCDs (1985)

Advances “will occur sooner, with higher performance, and at lower cost, than most of us expect today.” (F.J. Kahn)

THE FUTURE OF LIQUID CRYSTAL DEVICES

- LARGER AREA
- HIGHER RESOLUTION
- FULL COLOR
- HIGHER SPEED
- MORE DIVERSIFIED APPLICATIONS SUCH AS DISPLAY, PRINTING, OPTICAL PROCESSING, OPTICAL STORAGE, AND OPTICAL COMMUNICATIONS
- WILL OCCUR SOONER, WITH HIGHER PERFORMANCE, AND AT LOWER COST, THAN MOST OF US EXPECT TODAY



Greyhawk Softplot (1986)

40" D, 7.5 Mpixels



Display of the Year, *Electronic Products Magazine*, 1986

Greyhawk Large Area Display (1988)

144 inch D, 37.5 Mpixels



Close-up view of “print-quality” image detail



Ilford/Greyhawk Digital Photomager for short-run color printing



**Prints up to 200 full-color 35 mm slides,
overhead transparencies or 8.5x11”
prints per hour.**

← 35 mm slide example

DuPont/Greyhawk SeriFLASH printed circuit board exposure system

DuPont Electronics

Introducing the SeriFLASH™ Projection Direct Imager — for high productivity and improved yields.

DU PONT SERIFLASH

- DEVELOPED AND MANUFACTURED BY GREYHAWK
- ARTWORKLESS PHOTO RESIST EXPOSURE SYSTEM FOR HIGH THROUGHPUT PRINTED CIRCUIT BOARD MANUFACTURE
- USES TWO 4"X4" LASER THERMAL LIGHT VALVES AS PHOTOMASKS TO PRINT AND WRITE SIMULTANEOUSLY
- PRINTS .004" MINIMUM FEATURES ON 24"X24" RESIST AREA
- 4 PCB/MINUTE THROUGHPUT
- LINE EDGE PRECISION +/- 10%
- REGISTRATION +/- .001"
- PRINTS 10,000 X 10,000 FEATURES ON HIGH RES MEDIA

GREYHAWK

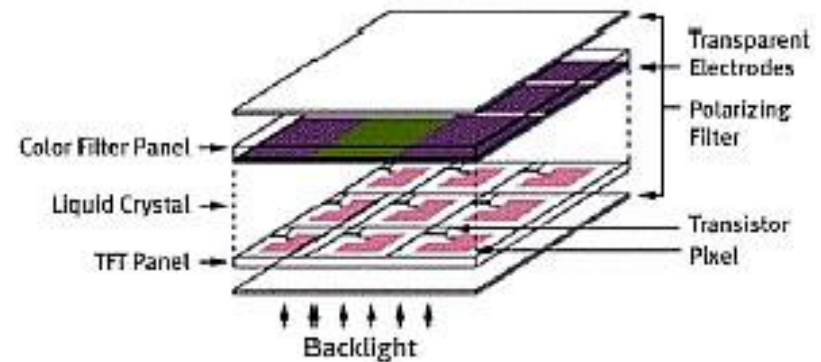
DU PONT

Two Earthquakes: October 1989



Paul Buckley, Wordpress

**Loma Prieta quake
shakes California.**



Videocraft.in

**TFT LCDs from Sharp
shake and transform
display world.**

TFT LCDs - The Great Market Enabler

41.1

Historical Review of our LCDs

The timeline illustrates the progression of Sharp's LCD technology through various product categories over time:

- 1973:** DSM-LCD Calculator [EL805]
- 1979:** TN-LCD <dot matrix> Electric Translator [IQ3000]
- 1980:** Wrist Watch
- 1987:** STN-LCD Word Processor
- 1987:** TFT-LCD LCD-TV
- 1989:** (Marked by a vertical red line)
- 1992:** Viewcam
- 1992:** Car navigation
- 1993:** PDA [Zaurus]
- 1995:** LCD-TV [Window]
- 1996:** DSC
- 1998:** Rear PJ
- 1998:** Cellular Phone
- 1998:** PDA [Color Zaurus]
- 1998:** LCD Desk-top PC
- 1998:** Note-book PC
- 1998:** Pocket Game
- 2000:** VA-LCD LCD-TV
- 2001:** AQUOS LCD-TV [AQUOS]
- 2004:** Kameyama Plant 1 45V
- 2005:** Kameyama Plant 2 65
- 2007:** Kameyama Plant 2 108-in
- 2008:** XS1 : 2.3cm^t
- 2009:** Sakai Plant LED-AQUOS UV²A

SHARP

SID International Symposium, 26th May, 2010

White LCD swan continues to ascend



HDTV comparison *(at constant pixel density)*

Potential future HDTVs ~8K: 7680x4320
33 Mpixels
with Greyhawk “print-quality” definition
(>37 Mpixels, wall-size, 8K class)

NHK Japan:

4K broadcasting, June 2014

8K test broadcasting, 2016

widespread, 2020 Tokyo Olympics

2K: 1920x1080

Today's HDTVs
(2 Mpixels)



BOE (China) UHD 10K 82in LCD

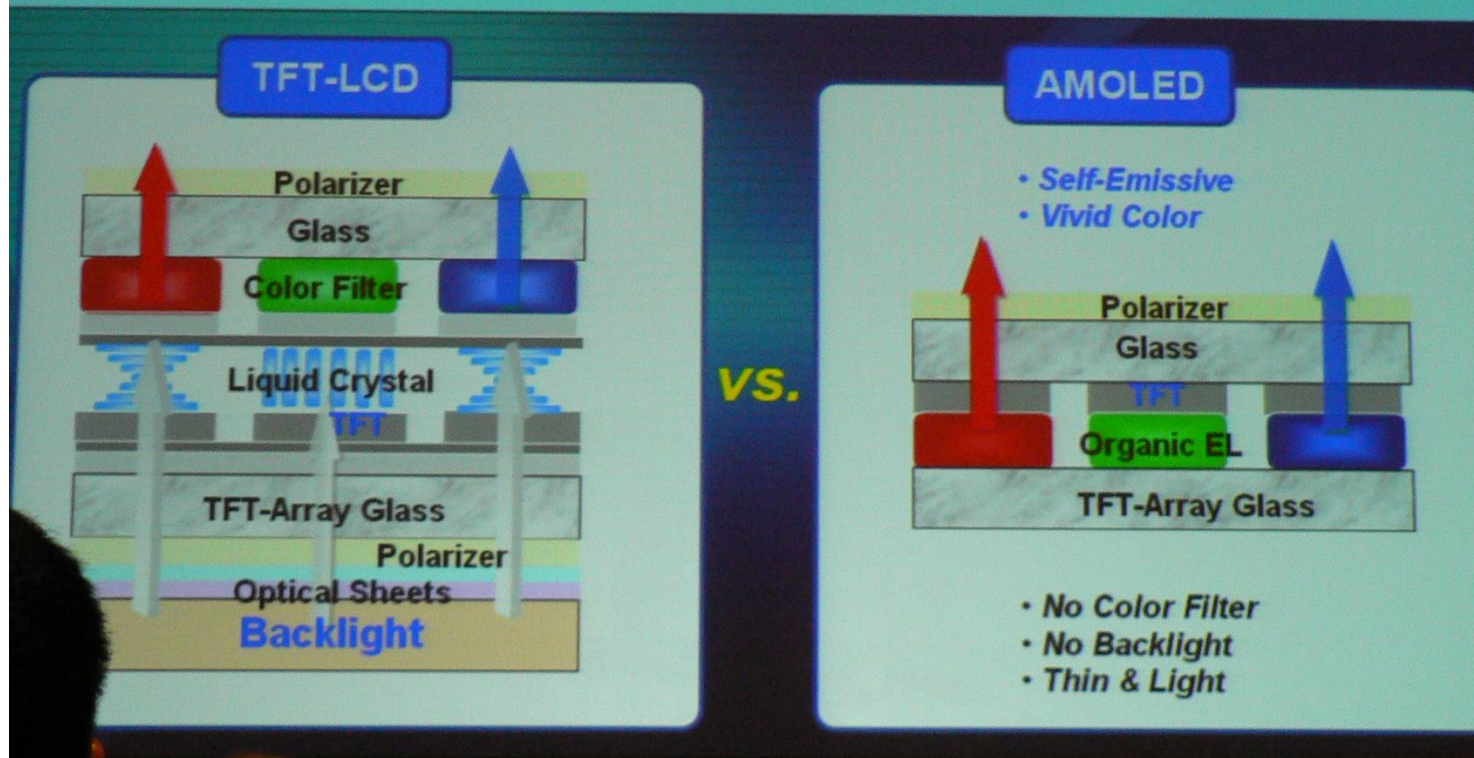
Best of show – Display Week 2015



Information Display

AMLCD vs. AMOLED Structures

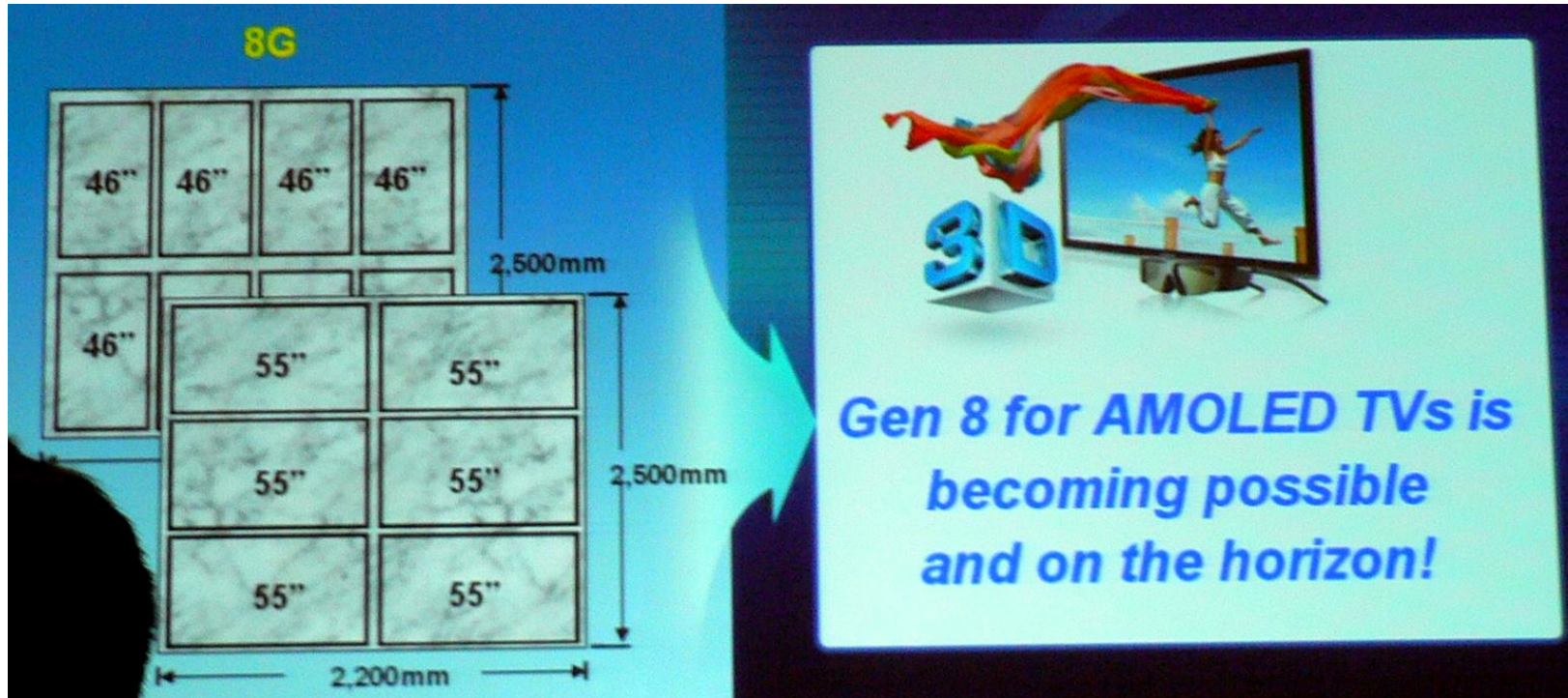
- Fundamentally Simpler Structure than TFT-LCDs
 - AMOLEDs should have Lower Cost
- Better display performance compared to TFT-LCDs
 - But they have not taken over ... , **(at least, not yet!)**



S. Kim, Samsung, SID 2010

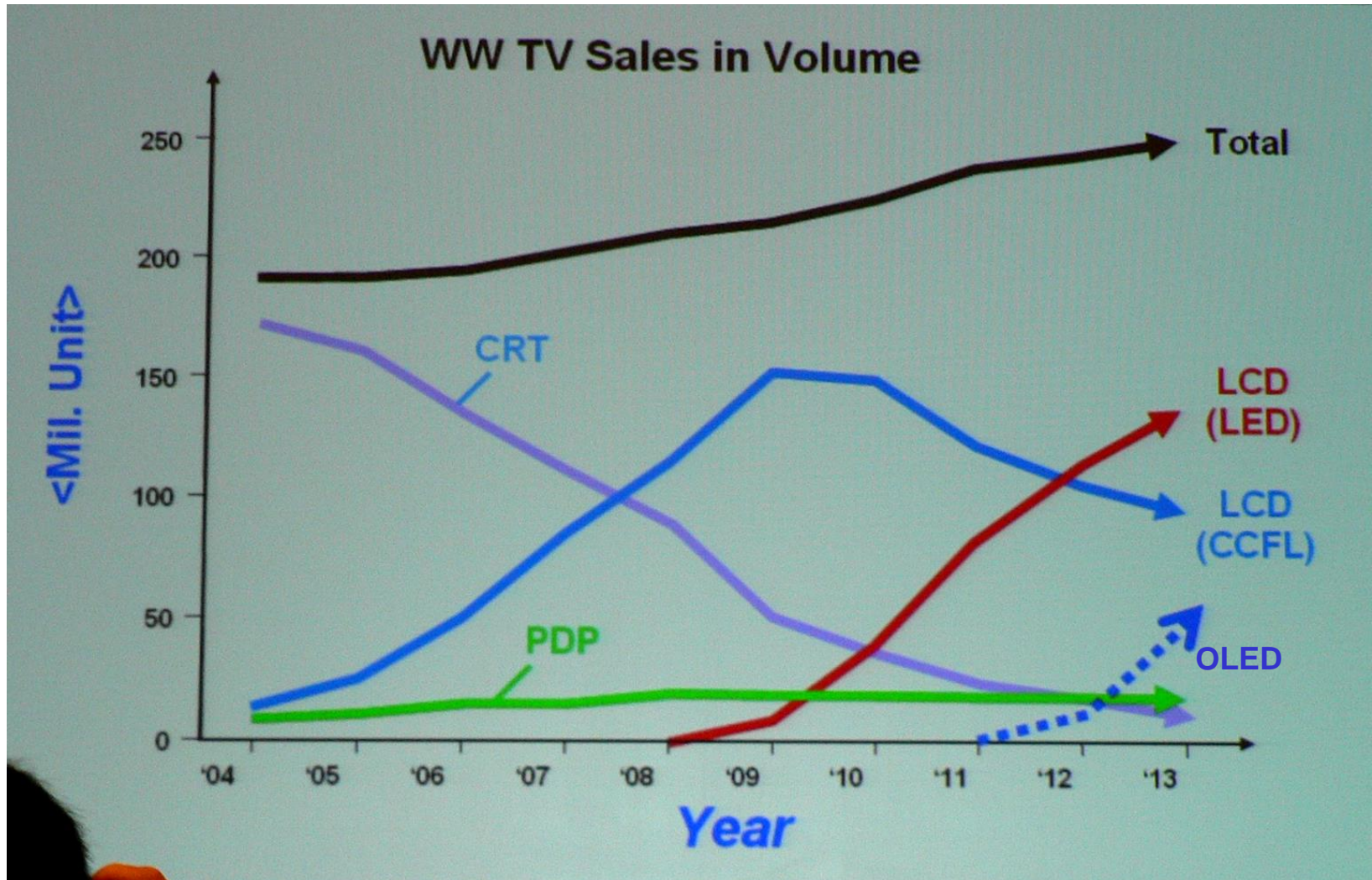
Samsung's AMOLED-TV Vision

Targets mainstream technology for “Premium TVs”
in Gen 8 production facility by 2015



S. Kim, Samsung, SID 2010

World wide TV market View 2010 (units)



S. Kim, Samsung, SID 2010

China Rising, How Fast?

Large Area TFT LCD/OLED Shipment Shares by panel makers, unit base

Shipment Share	Year		
Supplier	2014	2015	2016
AUO	16.2%	15.2%	14.6%
BOE	8.4%	12.0%	15.7%
CEC-Panda	1.7%	1.7%	1.6%
China Star	3.4%	3.7%	4.4%
CPT	0.8%	1.1%	1.0%
HannStar	0.4%	0.6%	1.0%
Hydis	0.0%		
InfoVision	1.7%	1.9%	1.9%
Innolux Corp.	19.3%	17.7%	16.3%
Japan Display	0.2%	0.2%	0.2%
LG Display	23.7%	23.4%	22.1%
Mitsubishi	0.2%	0.1%	0.2%
NLT	0.1%	0.1%	0.1%
Panasonic LCD	1.0%	1.3%	1.1%
Samsung	19.8%	17.9%	17.6%
Sharp	2.9%	2.8%	2.1%
Tianma	0.2%	0.2%	0.2%
Total	100.0%	100.0%	100.0%

Shipment Share	Year		
Region	2014	2015	2016
Japan	4.3%	4.6%	3.6%
China	15.4%	19.5%	23.7%
Taiwan	36.7%	34.6%	32.9%
Korea	43.6%	41.3%	39.7%
Total	100.0%	100.0%	100.0%

Source: IHS

© 2015 IHS

Large Area TFT LCD/OLED Shipment Shares by panel makers, Area base

Display Area Share	Year		
Supplier	2014	2015	2016
AUO	14.7%	13.3%	12.1%
BOE	5.5%	9.3%	13.1%
CEC-Panda	1.3%	1.6%	1.7%
China Star	5.4%	6.1%	7.3%
CPT	0.1%	0.2%	0.1%
HannStar	0.1%	0.1%	0.2%
Hydis	0.0%		
InfoVision	0.4%	0.3%	0.2%
Innolux Corp.	18.6%	16.3%	15.1%
Japan Display	0.0%	0.1%	0.0%
LG Display	24.5%	24.9%	23.3%
Mitsubishi	0.0%	0.0%	0.0%
NLT	0.0%	0.0%	0.0%
Panasonic LCD	1.0%	1.3%	1.0%
Samsung	22.5%	21.5%	21.9%
Sharp	5.8%	4.9%	3.9%
Tianma	0.1%	0.1%	0.1%
Total	100.0%	100.0%	100.0%

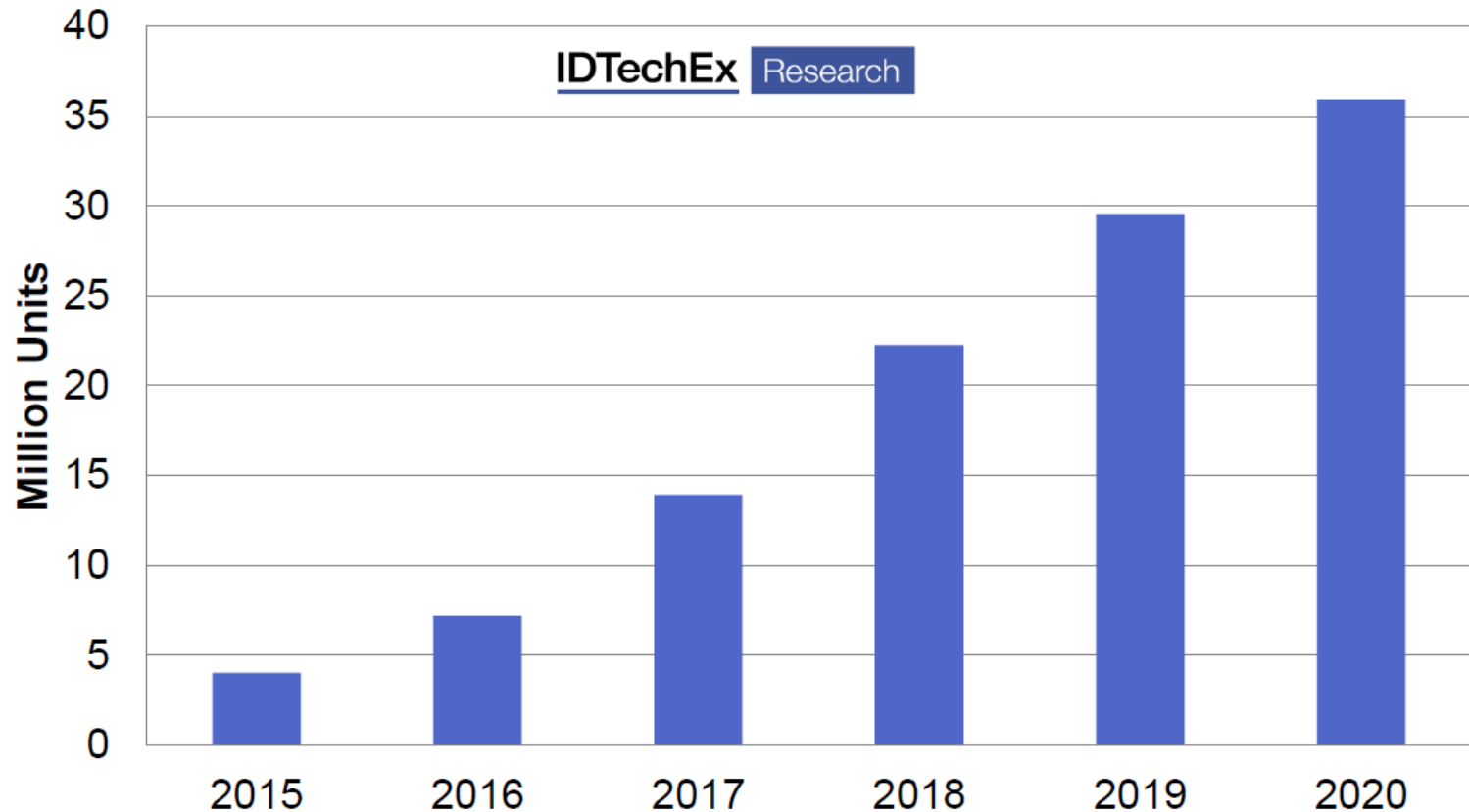
Display Area Share	Year		
Region	2014	2015	2016
Japan	6.8%	6.3%	5.0%
China	12.7%	17.4%	22.4%
Taiwan	33.5%	29.9%	27.4%
Korea	47.0%	46.5%	45.2%
Total	100.0%	100.0%	100.0%

Source: IHS

© 2015 IHS

Quantum Dot LCD TVs: OLED performance, LCD prices

LCD TV with Quantum Dots



Sri Peruvemba,, Marketer International

2016 OLED Status: TVs struggle; Small area OLEDs succeed

**LGD OLED TVs introduced but continue to struggle
due to high price, low yields, low production volume.**

LGD operates Gen 8 OLED production facility.

Others adding this capability

Panasonic's impressive & pricey OLED TV uses LGD panels.

**Major success: small area OLEDs for SmartPhones
(Samsung) and watches (Apple)**

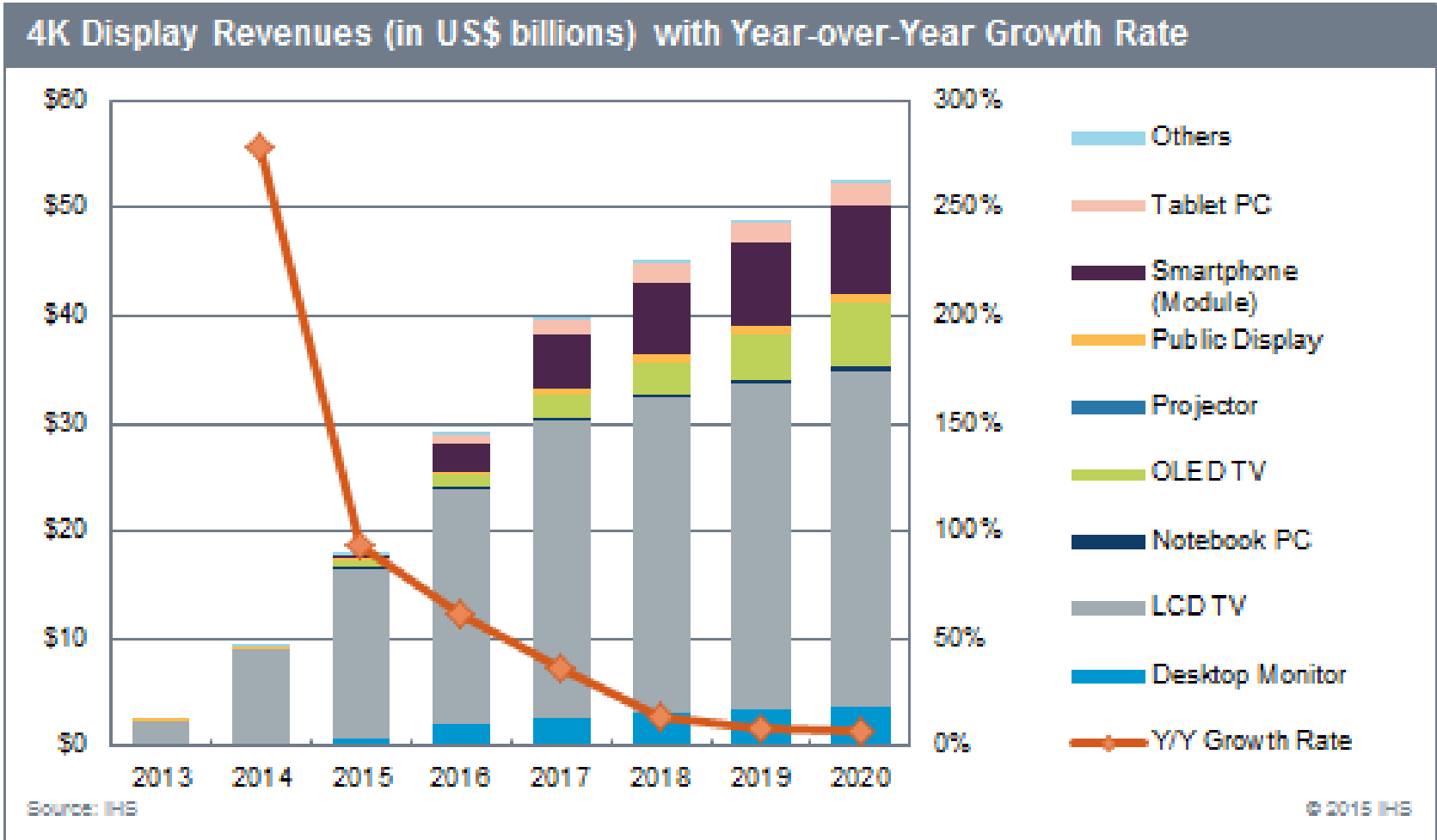
Apple 2017 next gen iPhone:

Samsung to supply flexible OLEDs says ETNews.

**LGD, Sharp/Foxconn, Japan Display, others are
potential second sources.**



4K LCDs dominate beyond 2020!



Total LCD Market Dominance Continues

- **WW display market**
 - **2015: \$116B** (Marketsandmarkets)
 - **Mostly LCD TV panels** (Research MOZ, Kahn Intl)
 - **4K displays, Major growth 2015 to 2020** (IHS)
 - **Mostly 4K LCD TV panels (~\$32B 2020)** (IHS)
- **WW OLED market (<< LCDs through 2022)**
 - **2015: \$13B** (LG/IHS)
 - **2022: \$29.1B** (LG/IHS)

Potential future improvements to extend LCD dominance

Evolutionary

- Higher production throughput
- Lower cost backlight structures and LEDs
- Lower cost materials, e.g., thinner glass, polarizers
- Higher image quality, e.g., QD LCDs
- Higher information content
- Larger area, lower weight per unit area

Revolutionary

- New faster LC effects
- Elimination of color filters: >3X brighter
- Flexible and/or rollable substrates
- Smart and interactive panels
- Full wall displays



Conclusions

**The LCD Black Swan is now a soaring, ascending White Swan.
LCDs are the world's most successful display industry.
Continuous improvement & high R&D expenditures
continue to protect LCD dominance.**

OLEDs are the most likely potential competitor.

**OLED TVs sales now limited by price, production and yield.
Major OLED markets: small area for SmartPhones, watches, autos.
Potential mainstream competition with LCDs in 2021 - 2025.**

**I have enjoyed surfing the liquid crystal wave for 49 years.
I thank the 1000s of people who have helped me stay afloat
and you for your attention this morning.**

