Presented at Bay Area SID, Sep'23rd 2015

http://www.sid.org/Chapters/Americas/BAChapter/Archives/BA2015SeminarArchive.aspx

Market, Technologies, Insights & Opportunities

PORTABLE & IOT DISPLAYS, CHALLENGES & OPPORTUNITIES – PART 1

Agenda

- Internal Panel Display Revenue growth
- Technology Progression
- Challenges
- Opportunities : Value in solving the Challenges
- IoT Devices : What those displays will need
- Looking ahead into 2016, 2017, …

Warning : LCD-centric content ahead, your mileage may vary

Panel Industry Revenue

- Revenue*
  >$100 billion
  – 2012 : >$15bil loss
  – 2014 : Break Even
- Japan LCD makers losing share, China gaining faster

(*Source : DisplaySearch Industry Report 2013)

Global Large-Sized LCD Panel Market Share Forecast for Suppliers (Market Share Percentage Based on Shipment Volume)

Rank	Company	Country	Q1 '12 Shipments (Thousands of Units)	Q1 '12 Market Share	Q4 '11 Shipments (Thousands of Units)	Q4 '11 Market Share	Q/Q Growth
1	LG Display	South Korea	44,535.6	28.1%	44,287.4	27.0%	0.6%
2	Samsung	South Korea	36,168.0	22.8%	39,149.1	23.9%	-7.6%
3	Chimei Innolux	Taiwan	27,360.6	17.3%	29,912.5	18.2%	-8.5%
4	AUO	Taiwan	27,328.0	17.2%	26,857.0	16.4%	1.8%
5	BOE	China	7,135.0	4.5%	6,018.0	3.7%	18.6%
6	Sharp	Japan	4,450.6	2.8%	5,325.5	3.2%	-16.4%
7	IVO	China	4,175.0	2.6%	3,529.0	2.2%	18.3%
8	Panasonic LCD	Japan	2,165.0	1.4%	3,200.0	2.0%	-32.3%
9	CPT	Taiwan	1,523.0	1.0%	2,145.0	1.3%	-29.0%
10	HannStar	Taiwan	1,095.0	0.7%	1,001.0	0.6%	9.4%
	Others		2,635.2	2.0%	2,509.2	2.0%	5.0%
	Grand Total		158,571.0	100%	163,933.9	100%	-3.3%

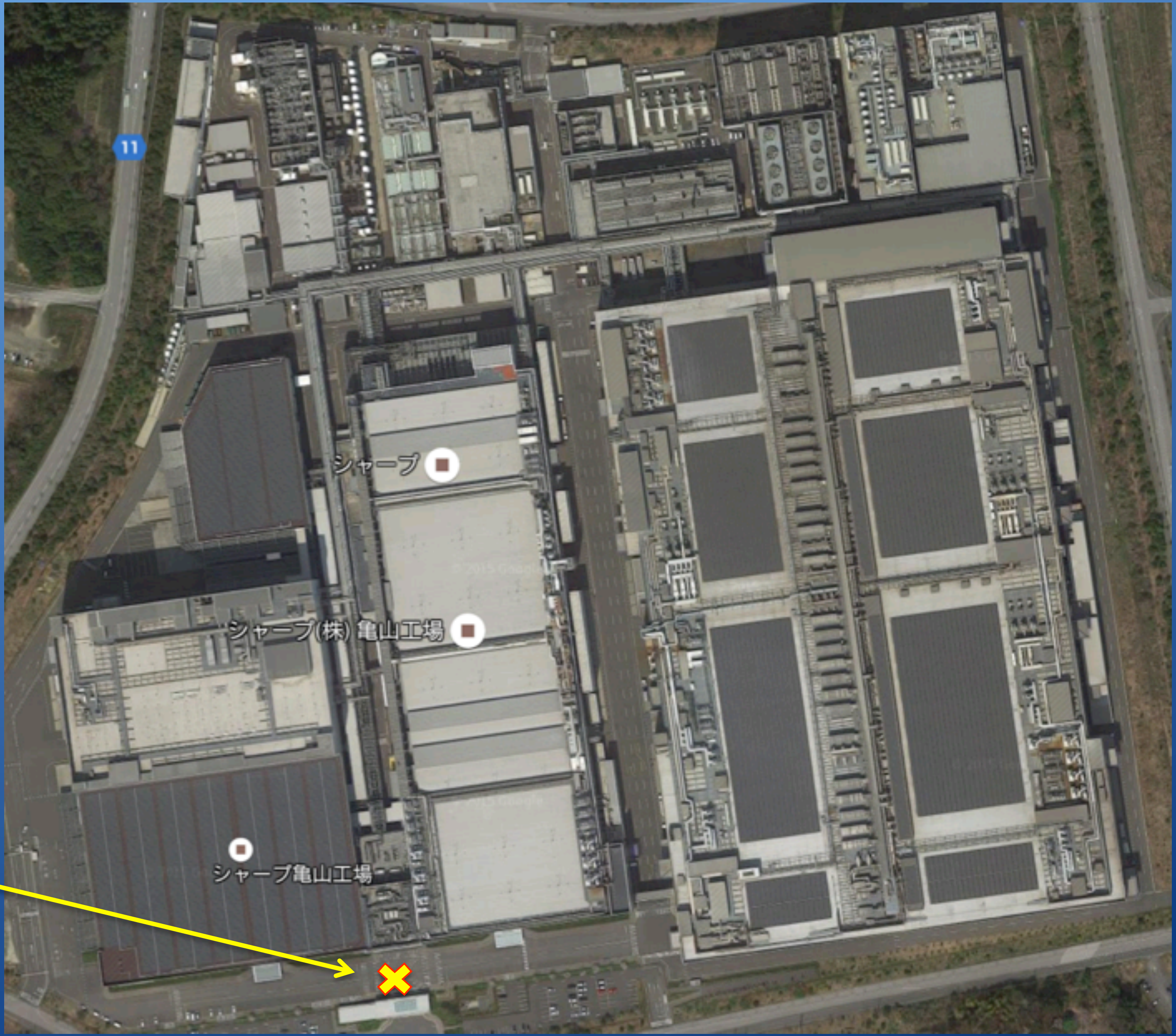
Source: IHS iSuppli Research, May 2012

>10yr Foundry Investments ➔ Intensely competitive
50~75% of LCD Cost = Depreciation*

What do “Billion Dollar” LCD Fab’s look like ?

- Let’s pick two orthogonal examples : Sharp, BoE

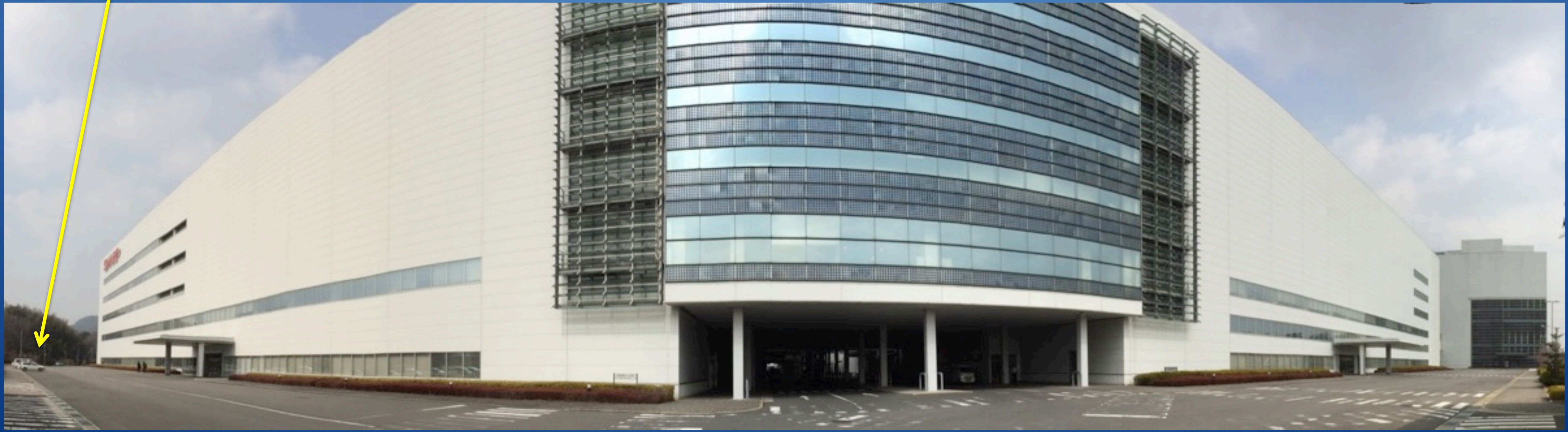
Sharp Kameyama Fab (Mei Prefecture)



Imagine
You are Here

Sharp Kameyama

Speck = Car



BoE LCD Fabs

BoE #4 BeiJing
(Gen4-5)

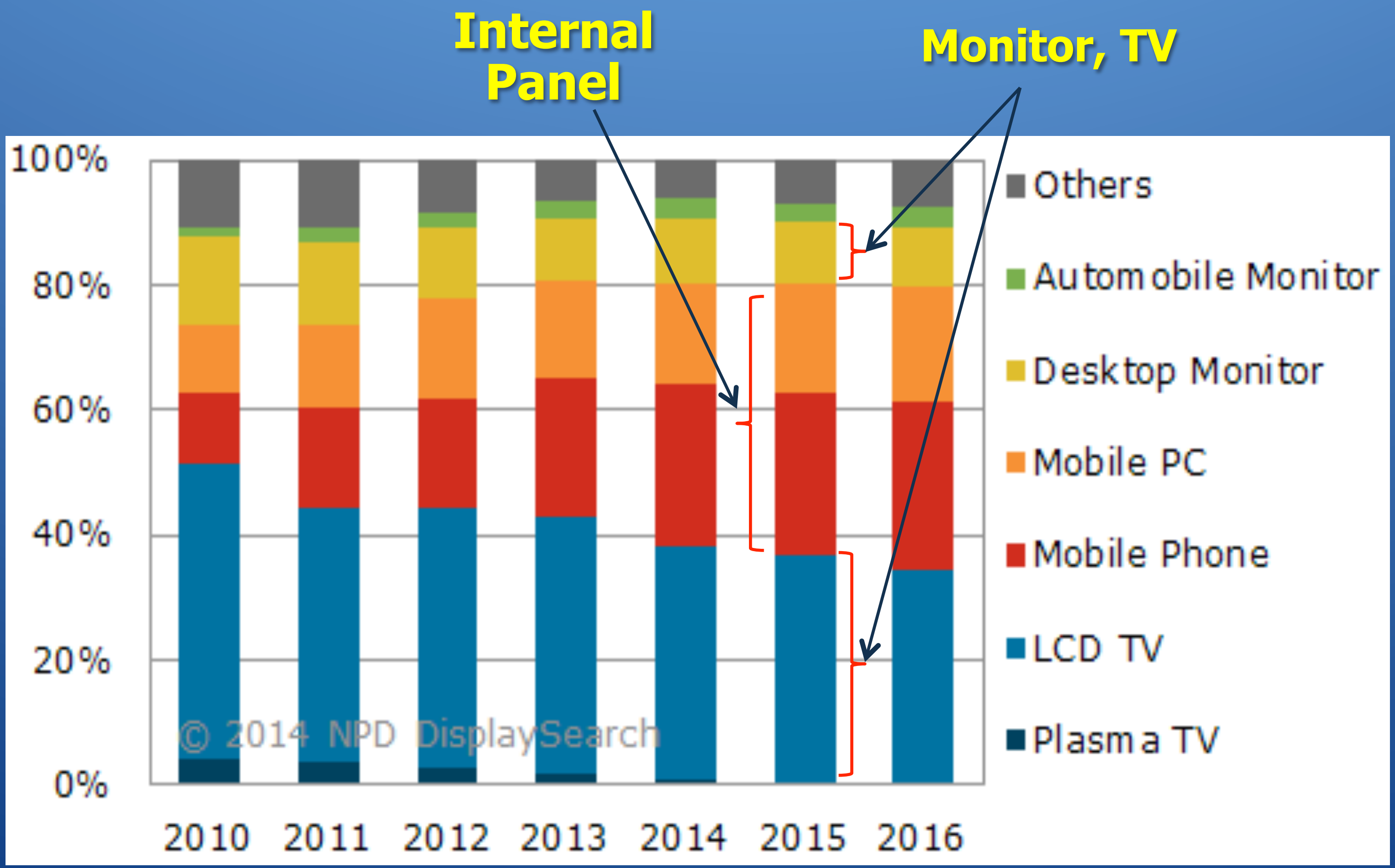
BoE #7 HeFei (Gen8)

China is investing in yet more TFT Fabs …

April 2015 : "BOE to splash RMB 70 billion (~$10bil) on new display fabs"

"planned to build a new 10.5 TFT-LCD fab in Hefei, Anhui and an 8.5G fab for the production of new type of displays"

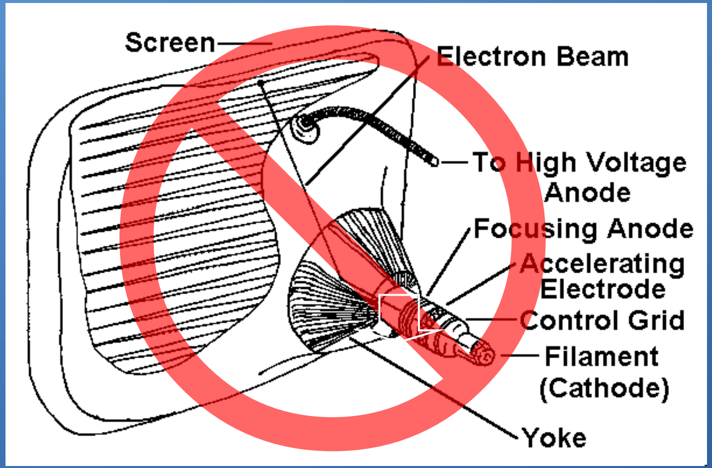
Panel Industry Growth

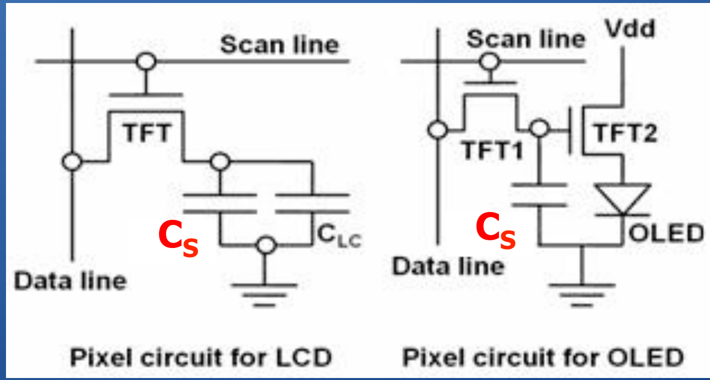


Source : NPD DisplaySearch 2014

Display Technology has changed

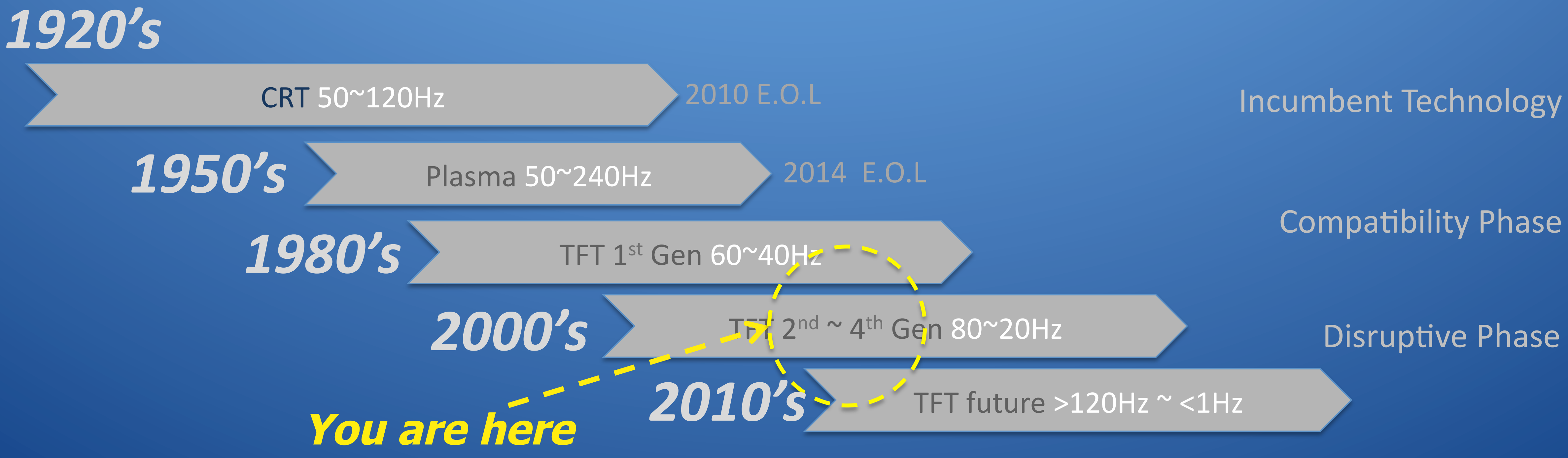
- CRT 50/60Hz Screen Refresh
  - 1920's Technology
- TFT = Charge-Hold Device
  - 2~7 transistors per pixel
  - Used for LCD, OLED, MEMS, eInk…
  - DRAM-like storage capacitor Cs
  - No phosphor





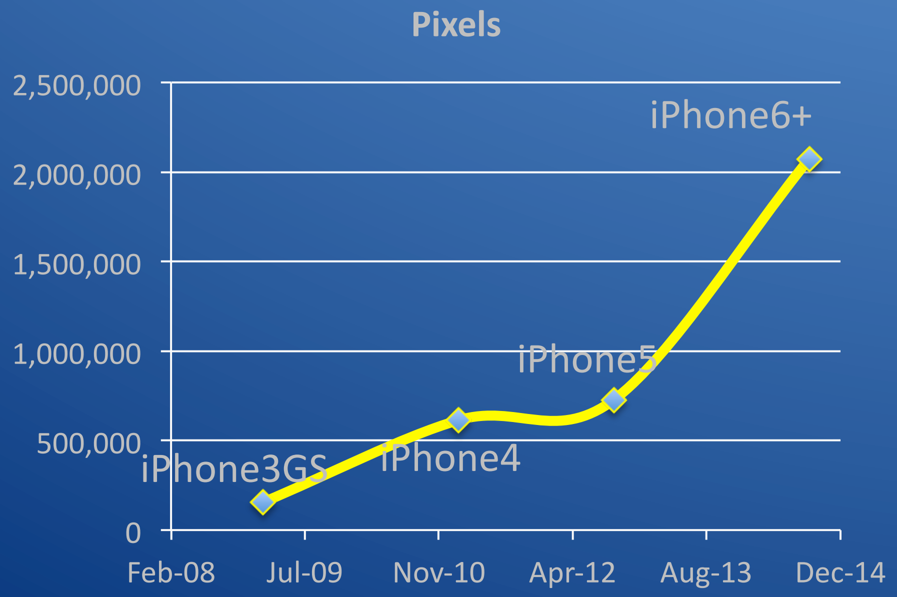
Realization : Not driving a CRT, so why do Fixed 60Hz Refresh ? ➔ sDRRS & G-SYNC

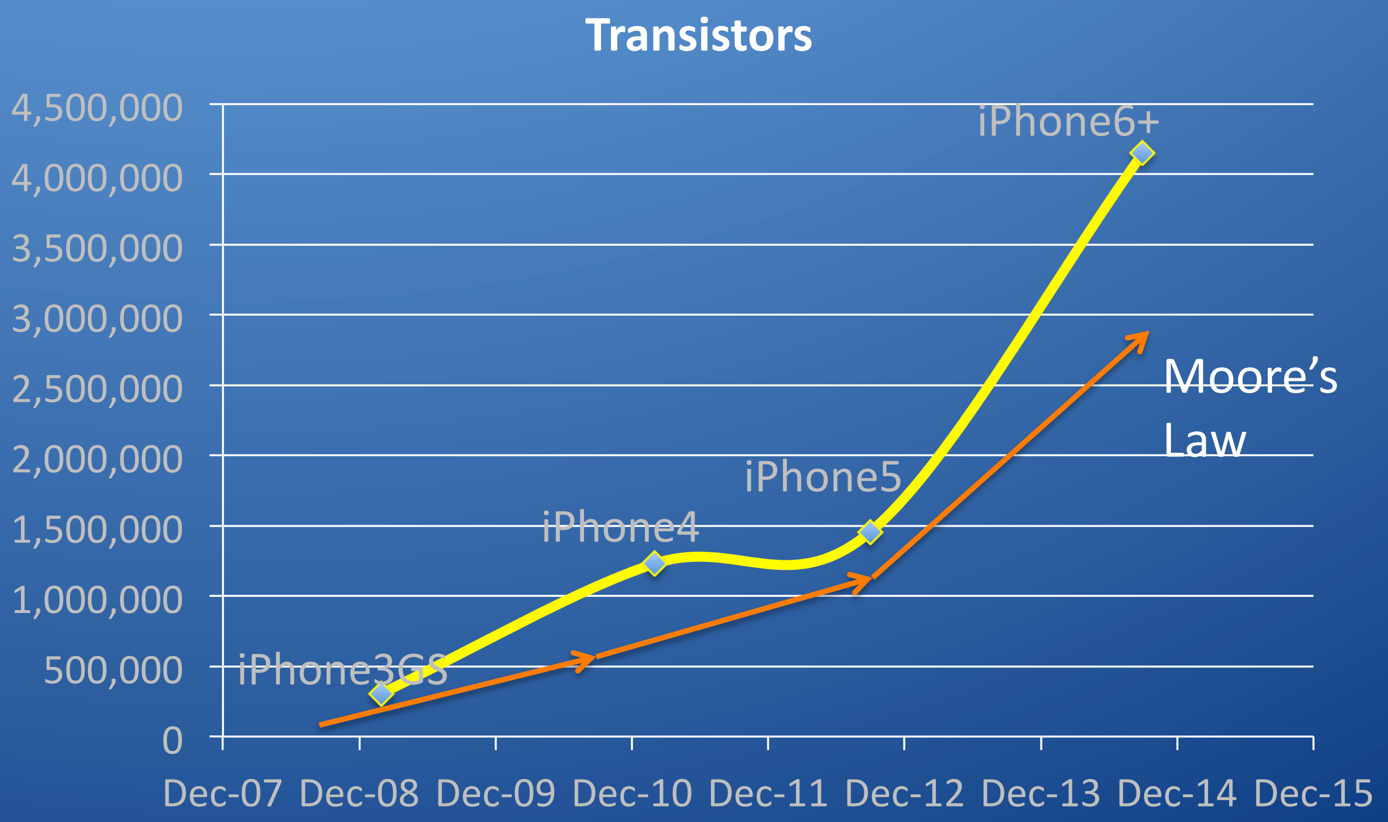
Display Technologies : TFT is the Medium



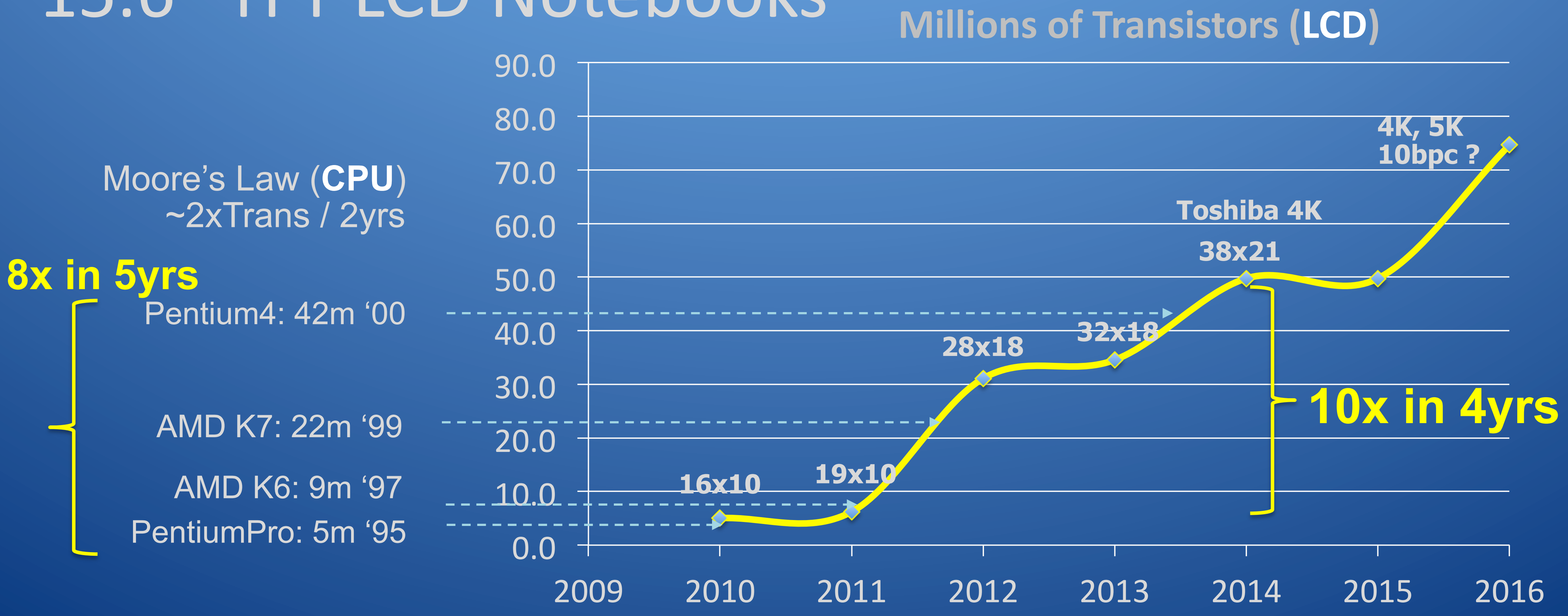
- Key Technologies : IGZO, LTPS, Blue-Phase, Polymer …
- OLED & LCD Resolution driving TFT transistor count on the Glass

TFT Dynamics : SmartPhone Pixels / Transistors



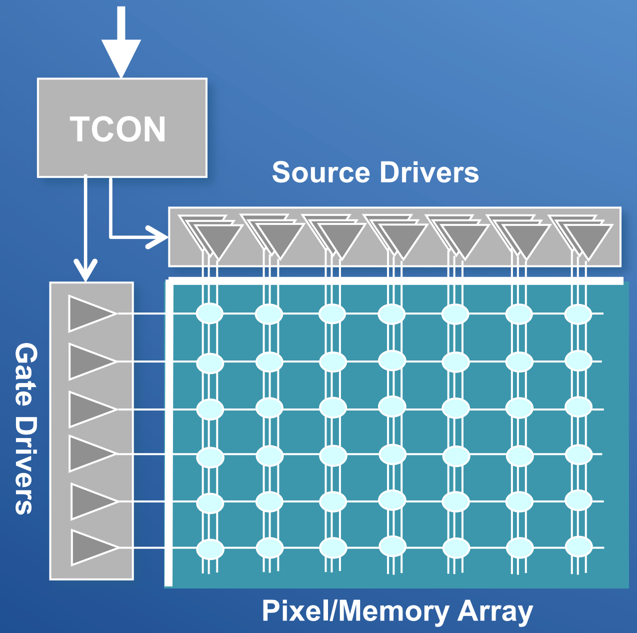


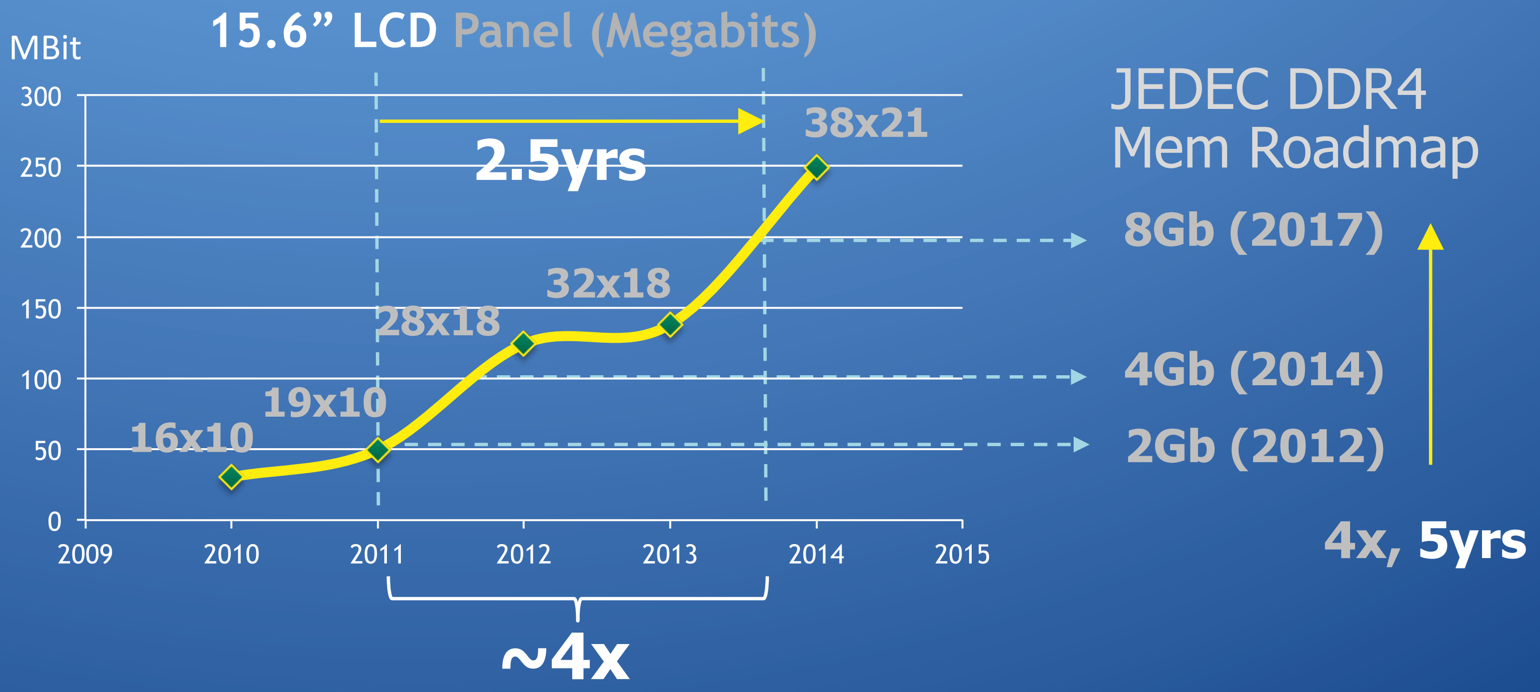
15.6” TFT LCD Notebooks



TFT on Glass : growing **faster** than Moore’s Law

LCD by Memory bit

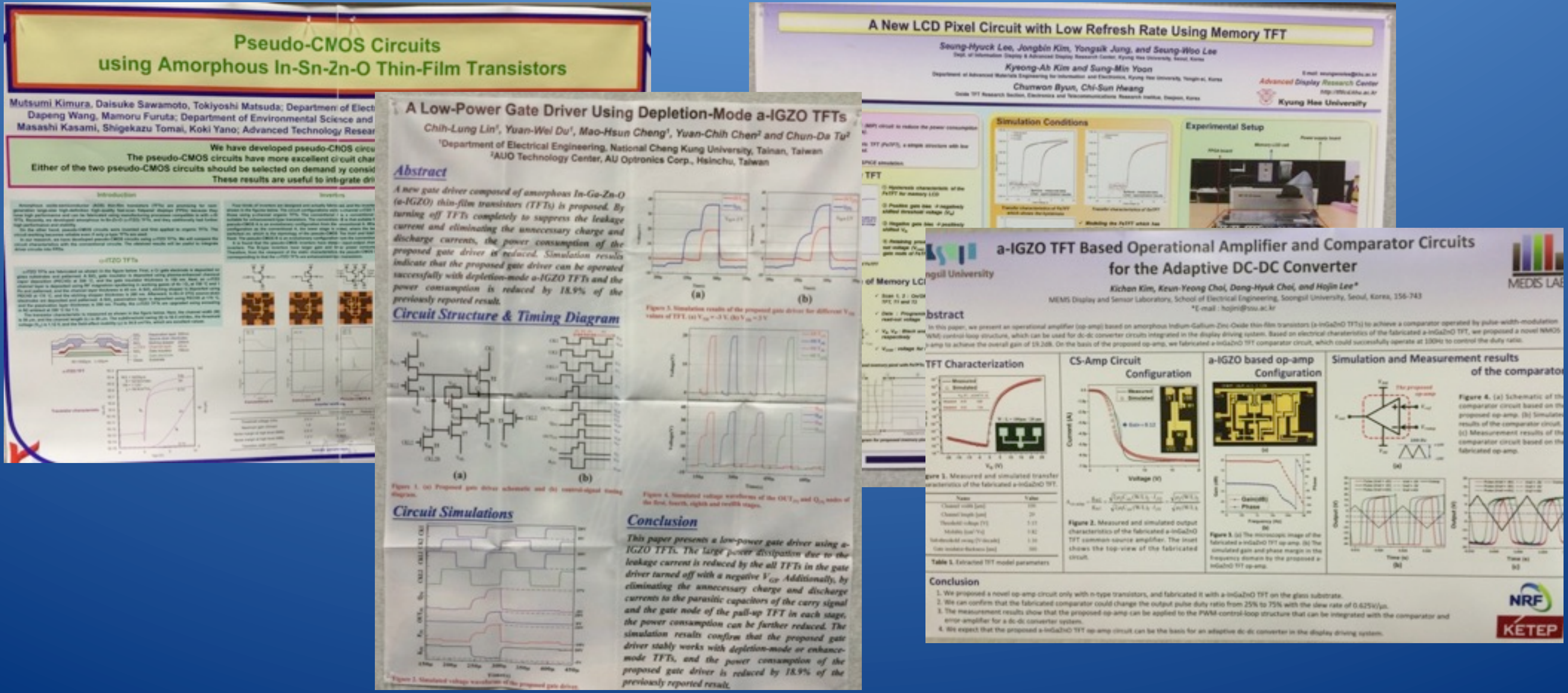




- LCD growing **twice as fast as DRAM**, in Memory Density, based on JEDEC roadmap
- Combination of resolution, color depth, sub-pixels, T/C cell

TCON is the new MCH "Memory Controller Hub" for Pixels

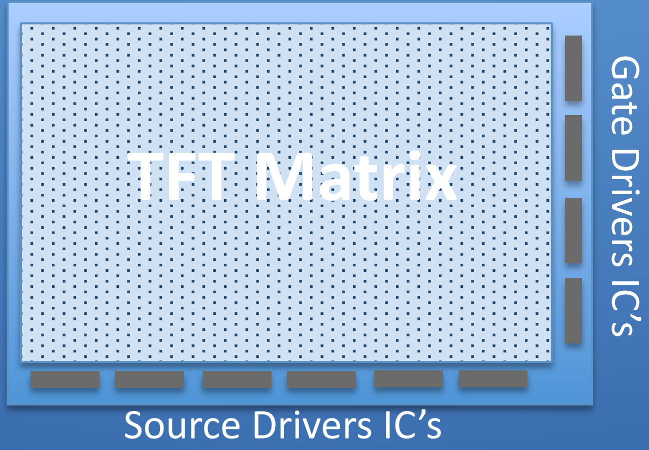
SID Display Week – the revolution is happening, right in front of us



Logic on TFT Glass = Revolutionary IoT Enabler

Sharp: Zero-Bezel Round LCD

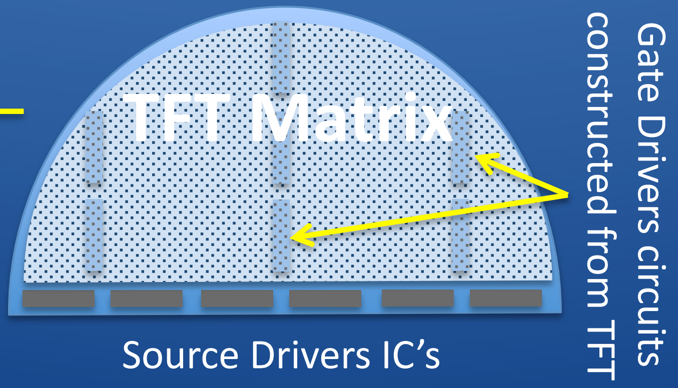
Old Tech : Panel restricted to Rect Bezel



JDI : RGBW Reflective, SRAM Memory-In-Pixel, 0.000130/160 W

Sharp: Source/Gate Driver-On-Glass

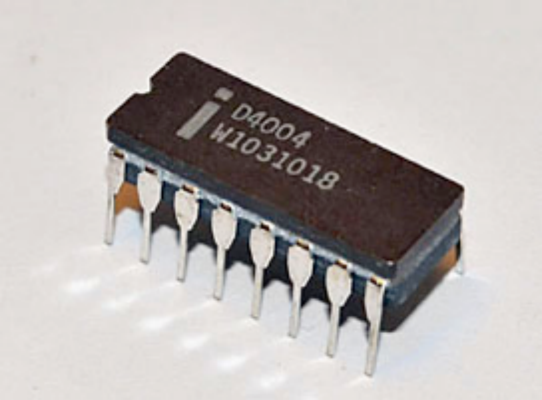
New Generation: Panel is Any Shape



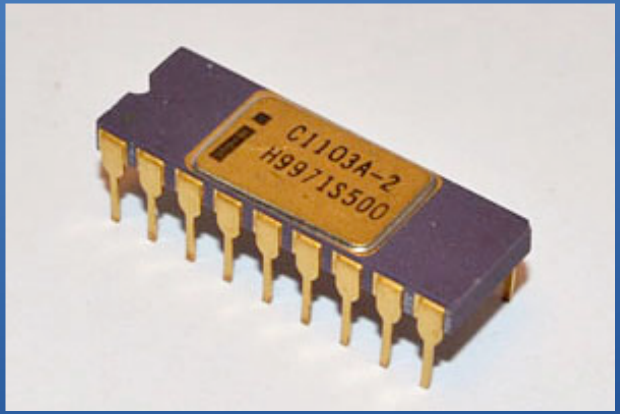
Sharp : Reflective, SRAM Memory-In-Pixel, 0.000010/16 W

But wait a minute …

- Rapid growth in Transistor gate count & dynamic Random Access Memory, when was the last time that occurred … ?



Microprocessor, Intel 4004

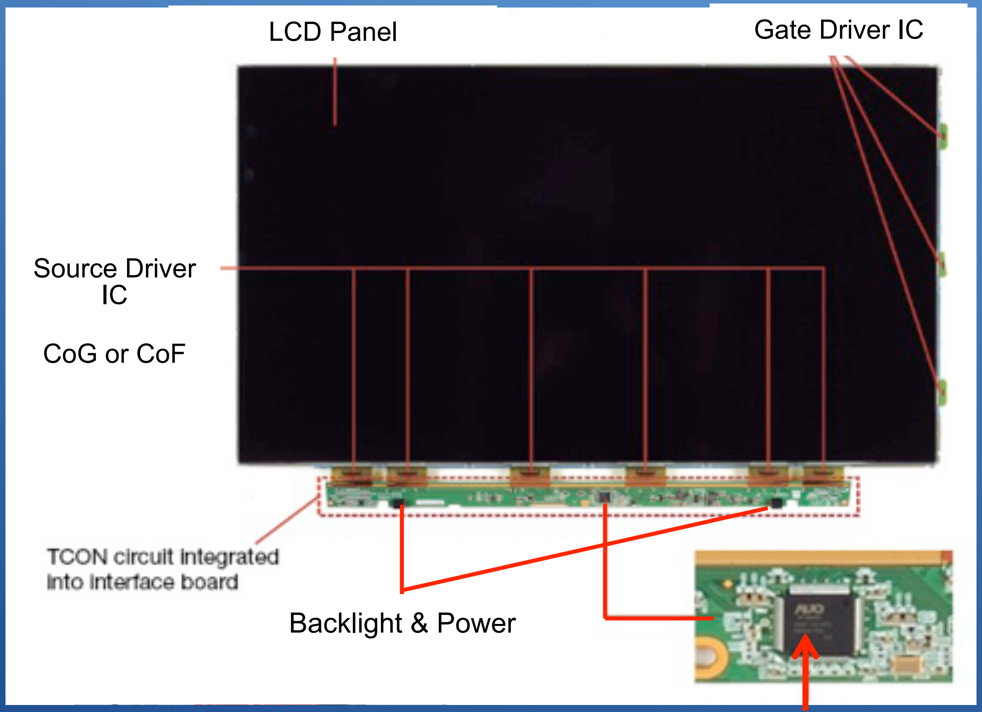


Dynamic RAM, Intel 1103

1971 : *"Announcing a new era in integrated electronics"*

Recap : Internal/Embedded Panel

Hybrid, Notebook, All-in-One



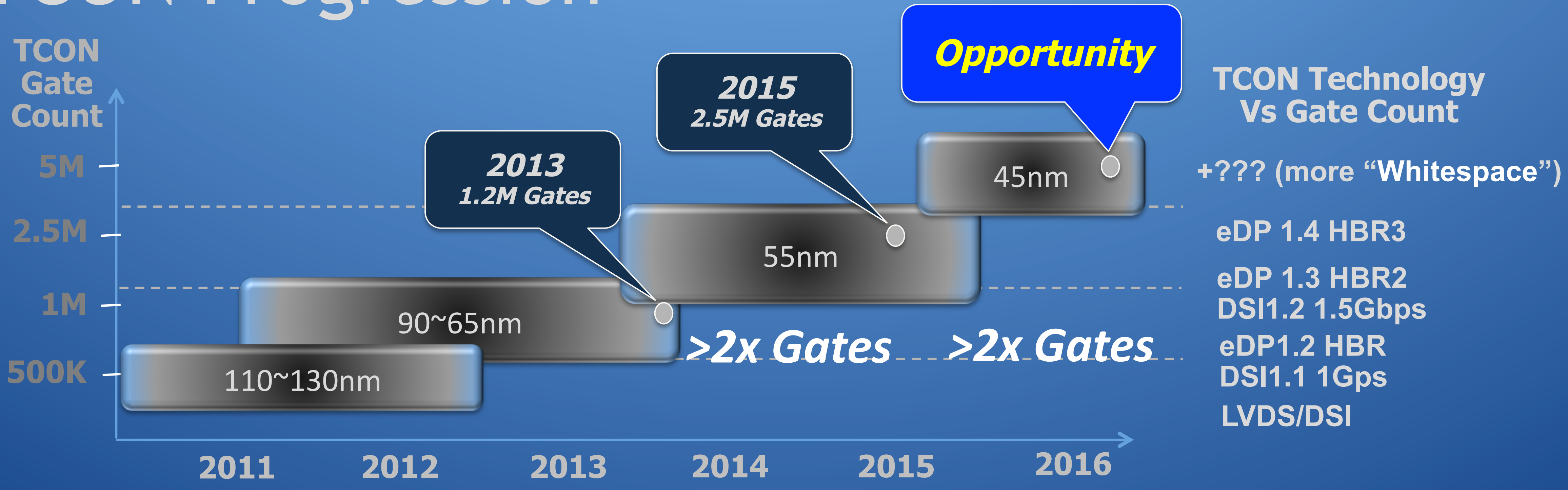
Timing Controller : TCON
< 10x5 mm (VESA) CoG or CoF Drivers

Tablet, Smartphone

TCON + Drivers
Single Chip : "DDIC"
Chip-on-Glass (CoG)

What is a **TCON** ? http://www.apple.com/imac-with-retina (TCON at offset 1:00min)

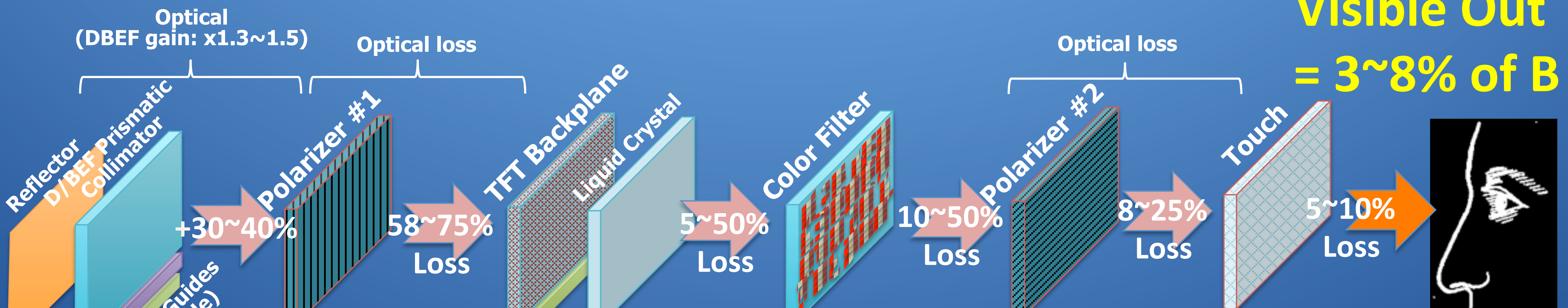
TCON Progression



- TCONs have lagged other Semiconductors due to Driver/Glass signaling
  - Required older Analog-friendly Si processes
- But every Year : Vendors ➔ 2x Gate count increase, plenty of Process runway

TCON Vendors **add digital value**, closer to the "Glass"

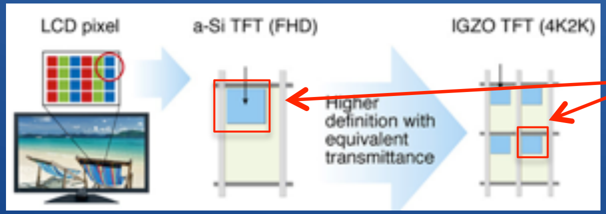
Step Back – Recap of Normal LCD Stack



TFT Aperture Ratio

Light In

= B

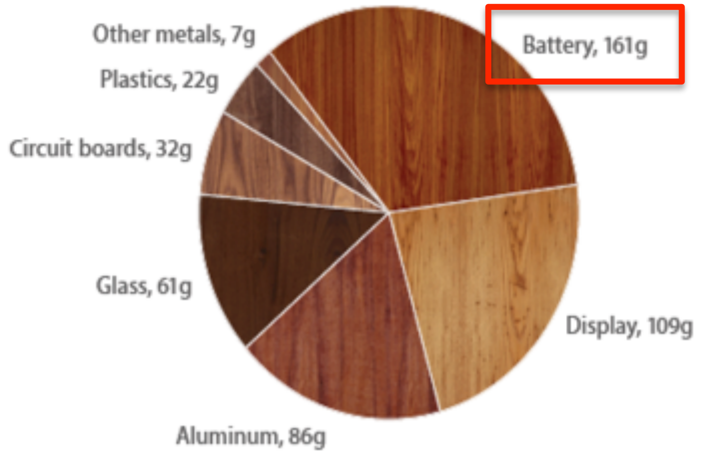


Power savings:
LTPS = 25%
IGZO = 40%

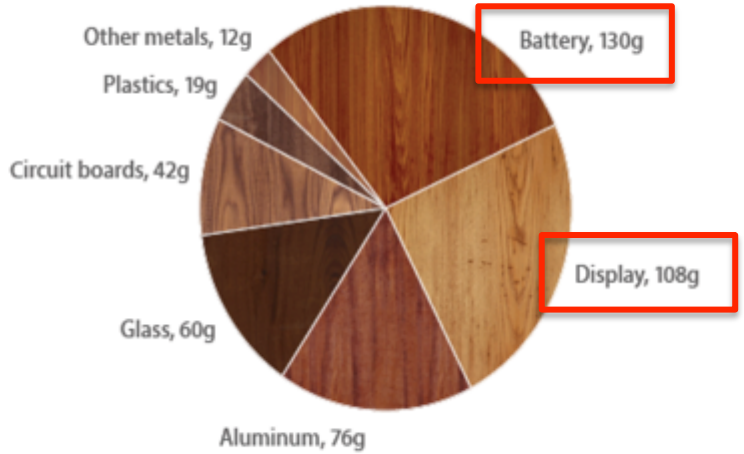
Aperture Ratio: Opaque TFT+Cap
Vs Transmissive area

By Weight, By Power – most important is …

Material Use for iPad Air (Wi-Fi + Cellular)



Material Use for iPad Air 2 (Wi-Fi + Cellular)



Power Consumption for iPad Air (Wi-Fi + Cellular)

Mode	100V	115V	230V
Sleep	0.15W	0.14W	0.16W
Idle—Display on	3.17W	3.20W	3.62W
Power adapter, no-load	0.043W	0.042W	0.048W
Power adapter efficiency	84%	84%	80%

Power Consumption for iPad Air 2 (Wi-Fi + Cellular)

Mode	100V	115V	230V
Sleep	0.22W	0.22W	0.26W
Idle—Display on	3.13W	3.14W	3.21W
Power adapter, no-load	0.09W	0.09W	0.09W
Power adapter efficiency	80%	81%	80%

Source : http://www.apple.com/environment/reports/

iPad BOM Cost Analysis – Value of Display IP

iPad 2 (2nd gen) — *Cost of Retina* ☹ → iPad Retina (4th gen)

Component	Estimate
Display 9.7" 1024x768 IPS	$57
Touchscreen	$40
32GB Flash, 2GB DRAM	$67
Processor A5	$14
Battery 43WHr	$23
Cameras 4MP+1.2MP	$12
Audio, … etc	$35
Enclosure, PCB's, Cables	$42
Assembly & Test	$5
BOM Cost	$295
MSRP 32GB WiFi No-3G	$599
Thickness	13.4mm
Weight	680g

iPad Retina (4th gen)

Component	Estimate
Display 9.7" 2048x1536 (LG A-Si IPS)	$87
Touchscreen	$40
64GB Flash, 2GB DRAM	$67
Processor A5X	$23
Battery 32.9WHr	$32
Cameras 8MP+1.2MP	$12
Audio, … etc	$35
Enclosure, PCB's, Cables	$42
Assembly & Test	$5
BOM Cost	$343
MSRP 64GB WiFi no-3G	$599
Thickness	7.1mm
Weight	650g

iPad 2 Air

Component	Estimate
Display 9.7" 2048x1536 (**Sharp IGZO**)	$77
Touchscreen	$38
64GB Flash, 2GB DRAM	$45
Processor A8X	$22
Battery 27.6WHr	$15
Cameras 8MP+1.2MP	$11
Audio, Sensors, Power, WiFi/GPS, Misc	$35
Enclosure, PCB's, Cables	$42
Assembly & Test	$5
BOM Cost	$290
MSRP 64GB WiFi no-3G	$599
Thickness	6.1mm
Weight	437g

Wow !

Display IP => Thinner, cheaper, lighter, faster

Source : IHS Technology & iSuppli reports

Conclusion

- Solving mobile platform challenges with TFT Display Technology improvements (e.g. IGZO) enabled:
  - Platform paradigm shift
  - Enhanced usability
  - BOM cost & profitability improvements

Looking 1yr ahead

2016 : The new wave of UHD Content/Displays

CinemaCon : Launched April 23rd 2015
DC Cinema Today: *"Dolby Showcases End-to-End Innovation for Cinema"*
"Dolby Impresses CinemaCon with 1,000,000:1 HDR"

The Hollywood Reporter: *"previously reported … both **Star Wars: The Force Awakens** and Kosiniski's upcoming **Tron** sequel will be released in **Dolby Vision**"*

Technicolor June 2014 : … plays back on legacy SDR TVs and new HDR TVs coming to market.

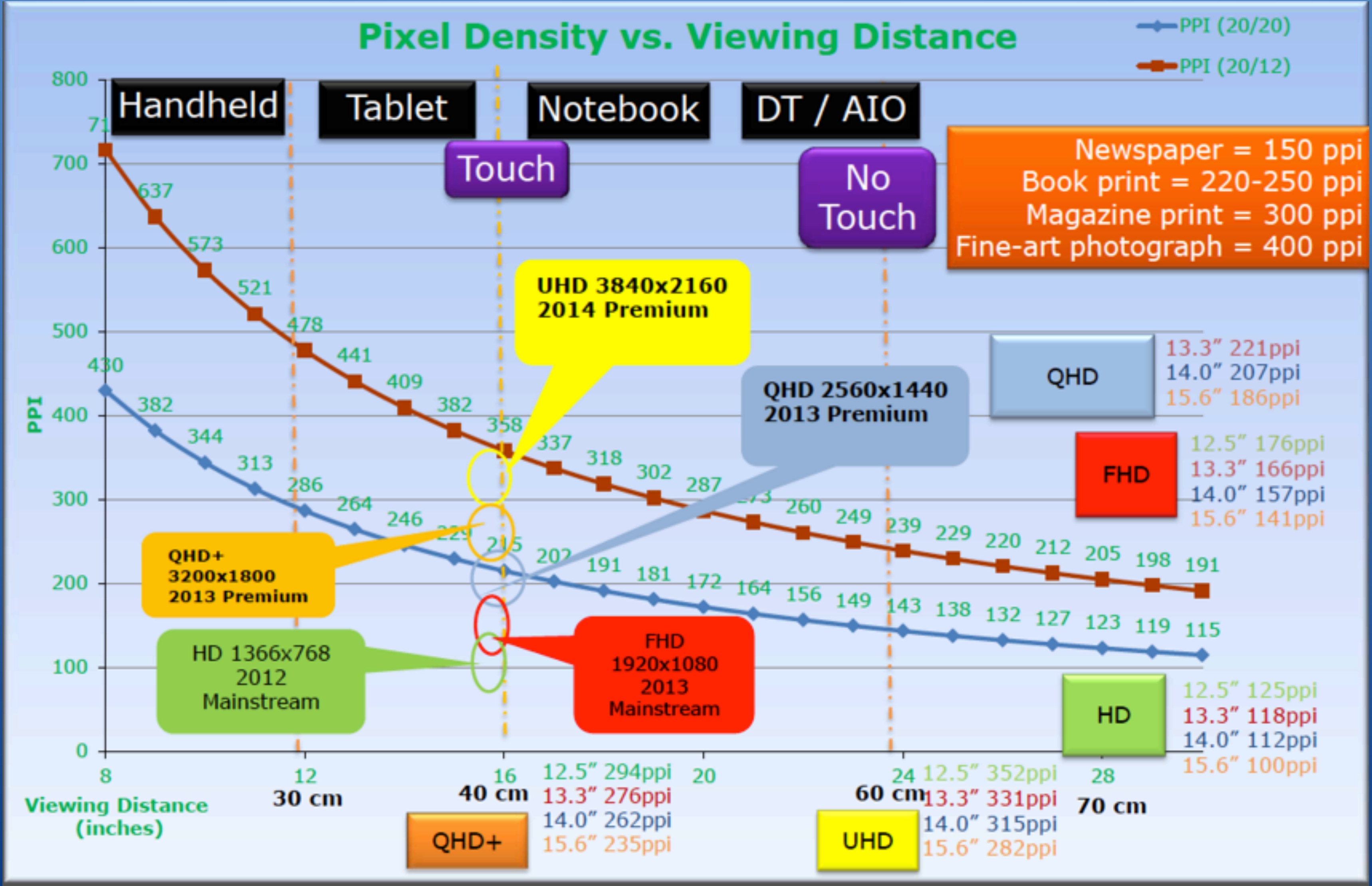
Amazon http://www.digitaltrends.com/home-theater/amazon-will-bring-hdr-this-year-transparent-bosch/

Netflix http://www.wired.com/2015/03/netflix-will-remake-image-tv/

BD-UHD Launch : Sep'2015 (Samsung IFA, Berlin)
TV's & Players : Xmas'15 ~ CES'16

http://www.extremetech.com/extreme/213396-samsung-launches-first-the-worlds-first-4k-blu-ray-player

4K who cares ? Pixels Per Inch maxed out ?



Intel IDF 2013

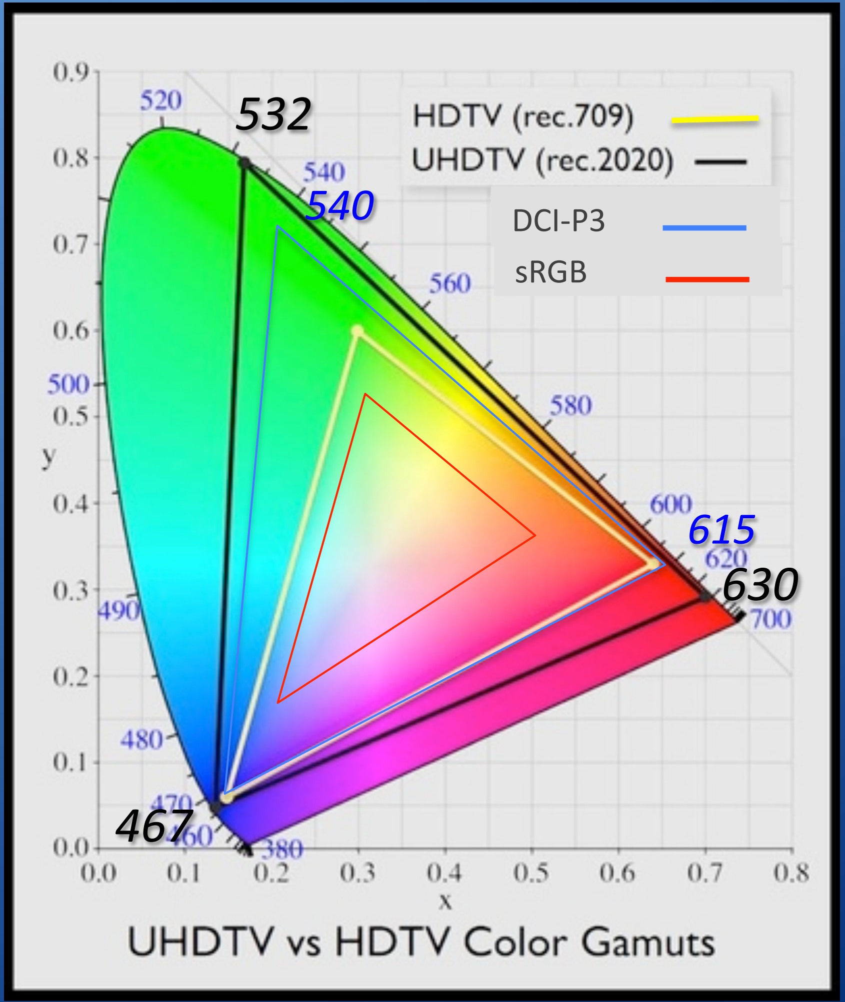
“UHD” : **not** just 4K

“UHD” Content = HDR Localized Highlights

- HDR requirement : 10% localized highlight 750~1000nits
- Background max : 400 nits

"UHD" Content = Color Gamut Advancement

- Today : sRGB (~72% NTSC)
  - Portable devices mostly LCD (60~72%)
  - Internet & HD content
- First step : DCI-P3 (~110% NTSC)
  - Movie camera, content, cinema
  - Backwards/forward compatible
- Longer Goal : BT2020 (~150% NTSC)
  - "Superset" container
  - Fully contains DCI-P3
  - Fully contains NTSC / sRGB



"UHD" Content = 10x Bandwidth & Power

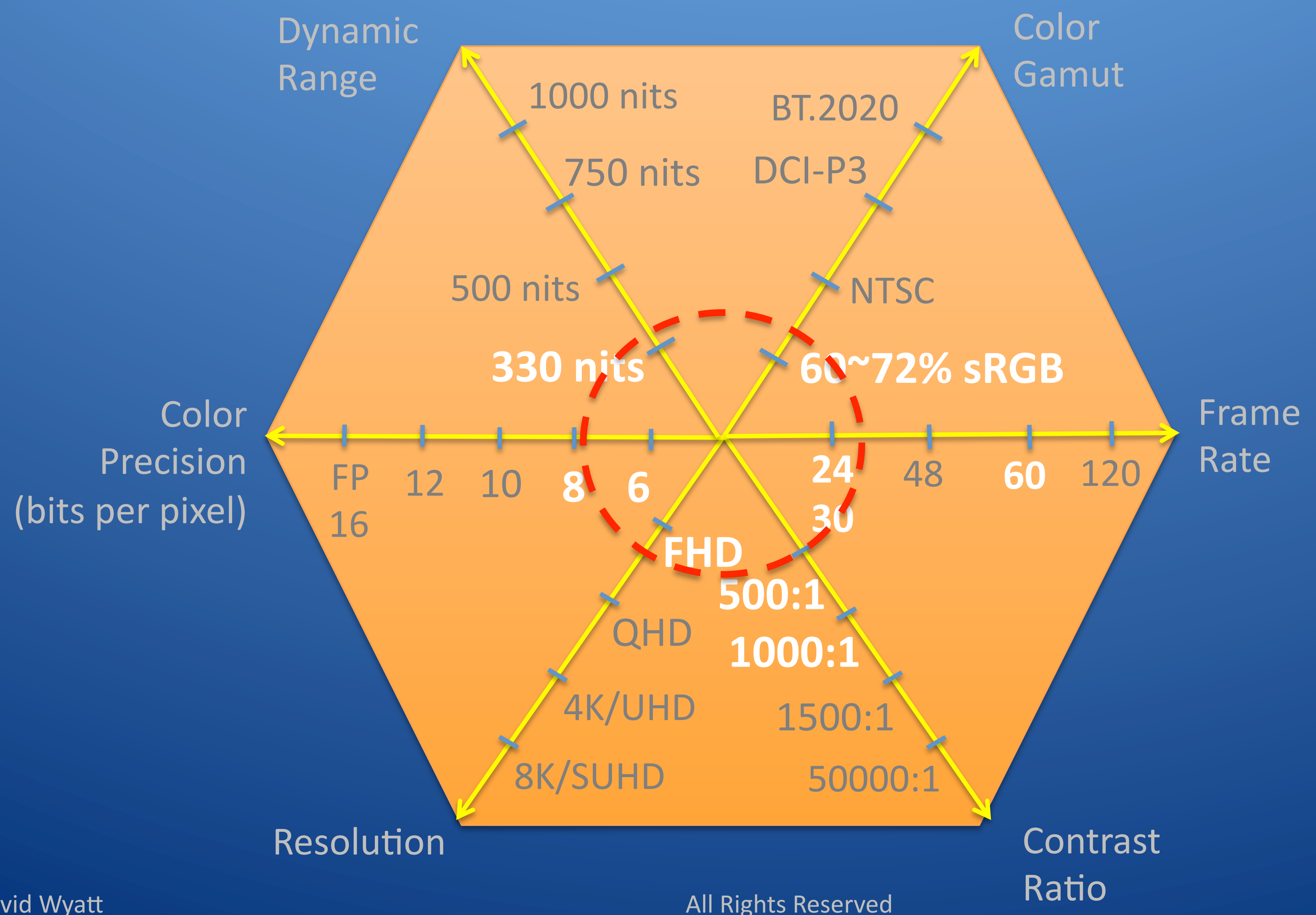
- BluRay (FHD) ➔ BluRayUHD (4K)
  - More Pixels (4x)
  - 30 ➔ 60fps (2x)
  - 18/24bit ➔ 30/36 bit per pixel (1.25~1.5x)

  ➔10~12x Bandwidth (20x for 4K-Stereo3D)

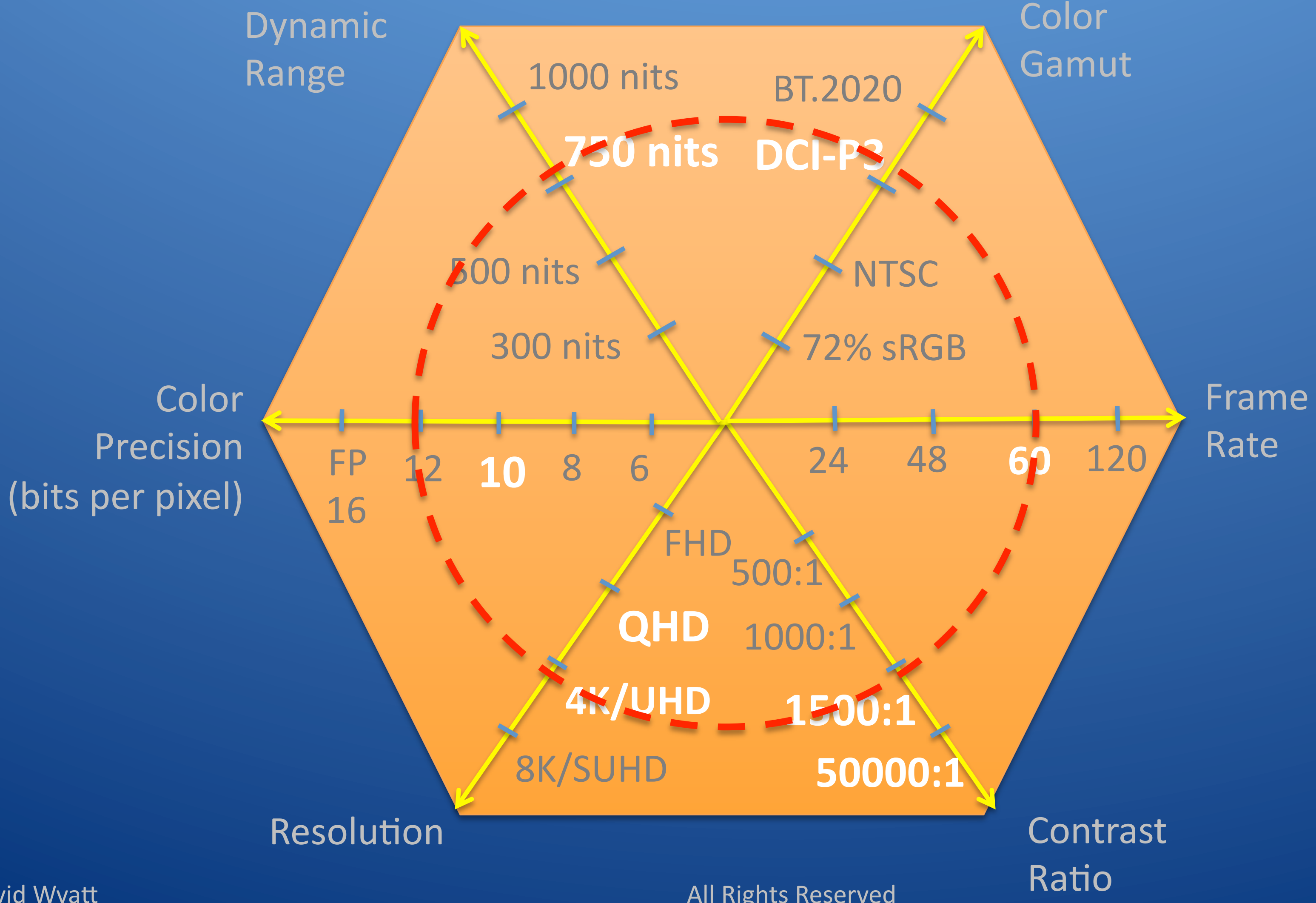
- Reminder : Power = $VI_L + akV^2F$
  - So if F(frequency) or a(activity) = 4x increase, Power increase = Linear
  - But higher F also requires higher Voltage = Cubic increase in power

Opportunity : Efficiency improvements

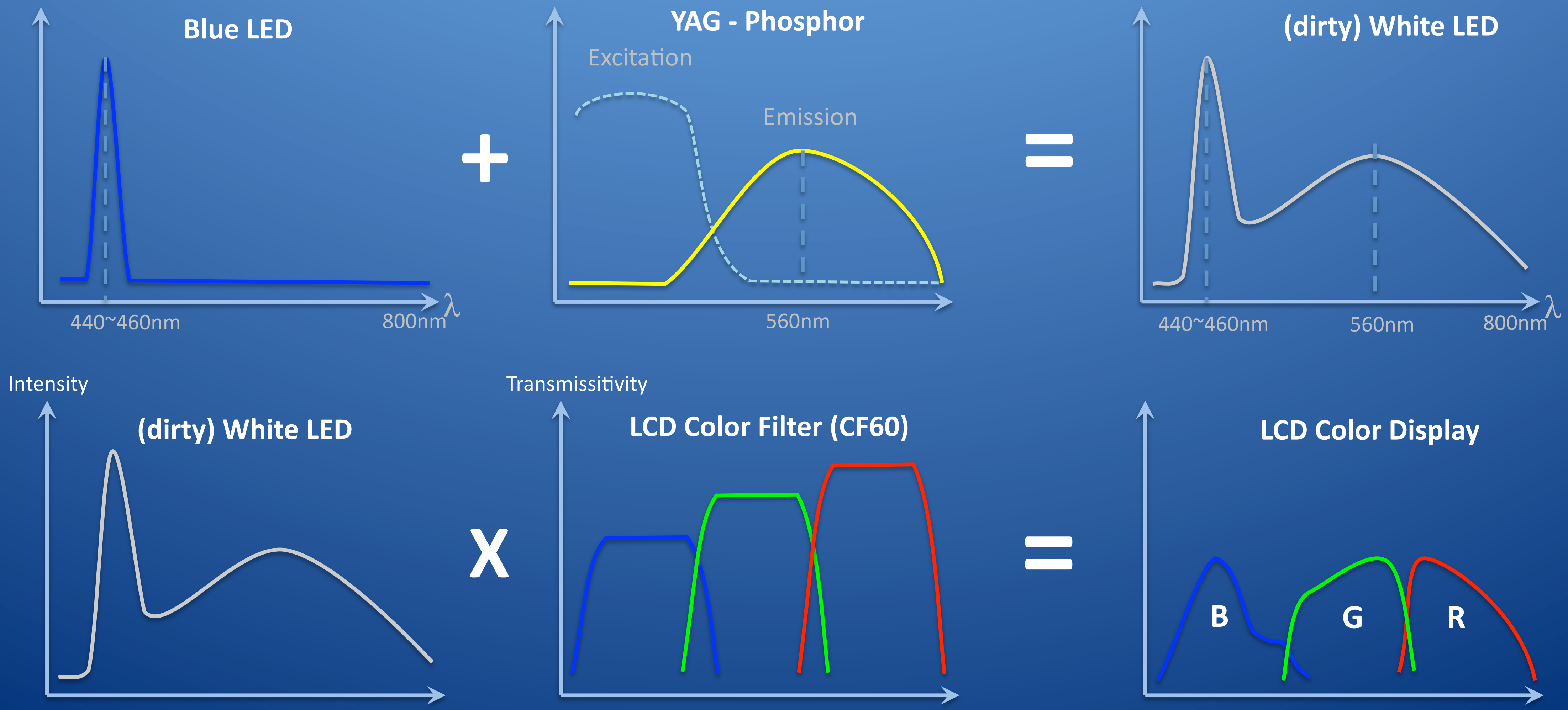
Today's Portable Display Experience



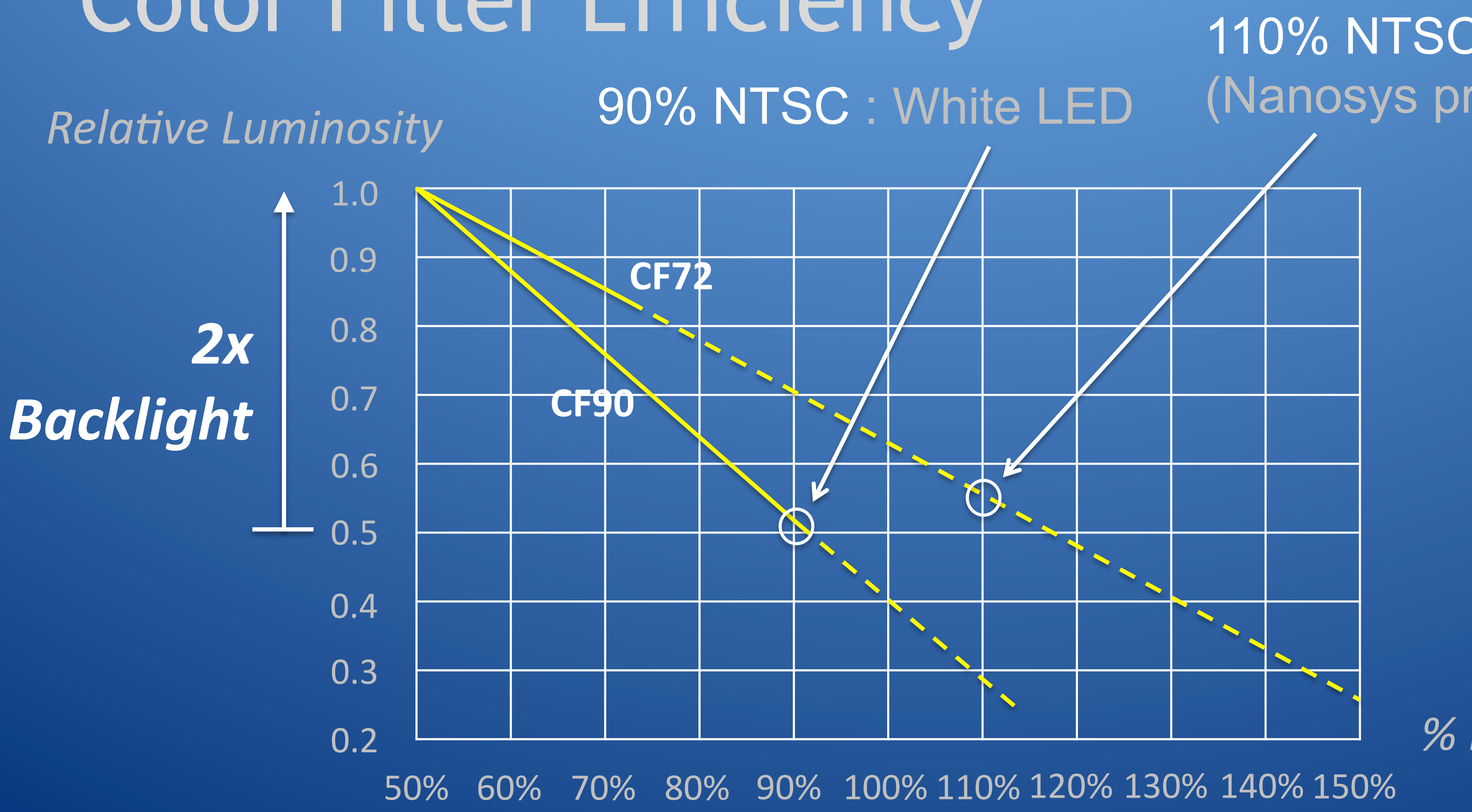
2016 “UHD” Display Experience



LCD Recap – White LED Backlight



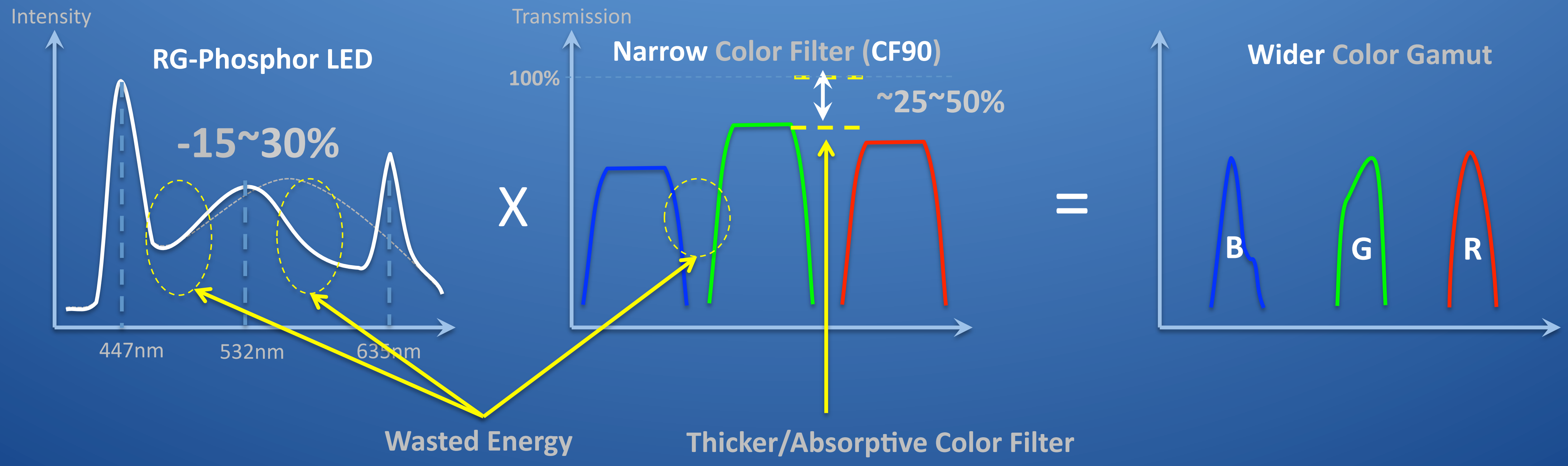
Color Filter Efficiency



Match Original Brightness + Wide Gamut → 2x Backlight

“Wide Gamut” LED

Example : Nichia NS2W266F-HG



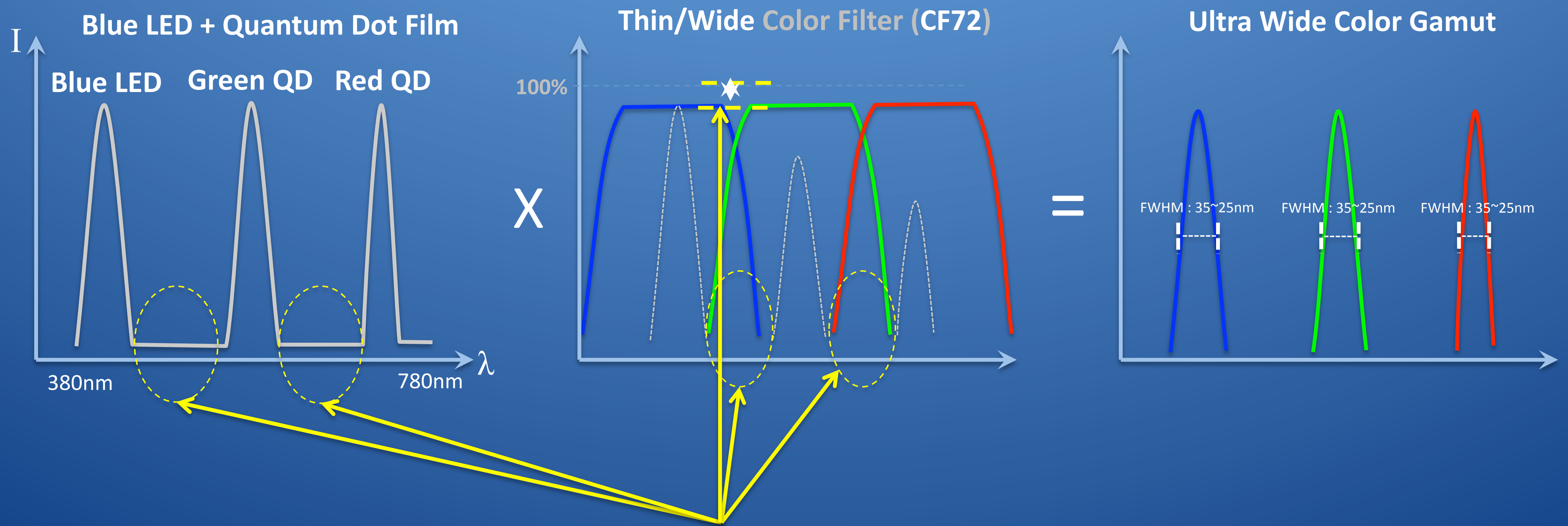
Total Backlight Power Increase : 1.8~2.4x

Example 9.7” Retina Tablet

LGD LP097QX1 $87	Today : Max 440 cd/m²	HDR-Only: 750 cd/m²	10% 750 cd/m² + 90% 400 @ P3
Contrast Ratio	1000:1	1000:1	>50,000:1 (Regional Backlight)
Color Space (% NTSC)	94.4%	94%	110%
#LEDs (3.0mm x 0.4)	2x 42pcs = 84pcs 49pcs (4.2mm)	143 pcs (1.7x) 83pcs (4.2mm)	184pcs (2.2x) 108pcs (4.2mm)
LED BOM Cost	$13.27	$22.60 (+$9.33)	$29.20 (+$16.64)
Backlight Bar	2 S-edge (49pcs @3m) ✓	2 S-edge (35pcs @4m) ✗ 2 L-edge (46pcs @4m) ✓	2 L-edge (46pcs @4m) ✗ 2L + 2S (162pcs @4m) ✓ (4 edges !)
B/L Power (max)	4.4W	8.9W*	11.6W*
Battery Life (Video, 42.5WHr)	400nits 5.57Hrs 200nits 10 Hrs 4.25	4.08 Hrs	3.22 Hrs
Battery Cost (10Hrs)	$31	$72 (+$41)	$91 (+$43)
Total BOM Cost Adder	~	>$50	>$60

NB : IGZO 25~30% more efficient, only 2 edge backlight

Quantum Dot



Wasted energy minimized = +20~30% Efficiency Improvement …

… but : $$$ Cost, Thickness, Thermal/O_2 Stability, Heavy Metals : Cd

Conclusion

- Tsunami of UHD content in 2016
  - UHD not just about 4K: More Pixels, it's about HDR/WCG: Better Pixels
- Compelling experience, very-high WAF* for new product sales
  - We're all going to want to see this on Mobile/Portable Platforms
  - LCD technology needs revolutionary improvements to get there
- Opportunities :
  - Brightness, Wider Color Gamut, Color Depth, Bandwidth, Power
  - Revolutionizing the Light source itself

* - "Wife Acceptance Factor"

Looking >1yrs ahead

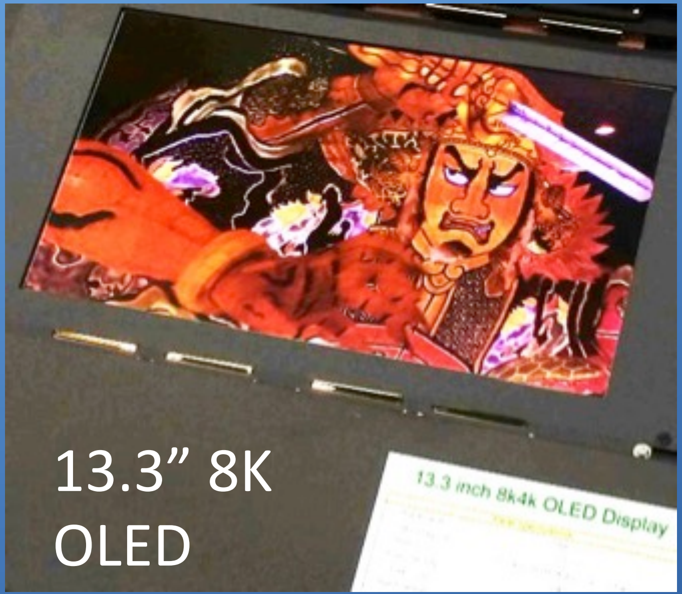
8K – Super Vision

- Goal : Broadcast 2020 Olympics in 8K
- NHK & Government
- BT2020 Color Space
- HDR

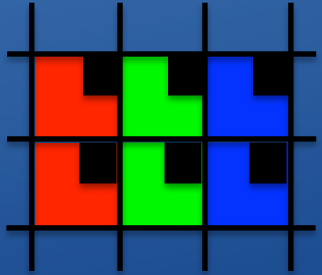
Live color grading in 8K, Astrodesign Tokyo

What PPI/Res Limit ?

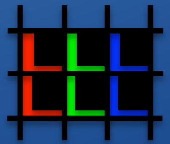
- OLED 8K 13.3”
  - SID San Diego 2014
- Challenges :
  - OLED: power distribution across TFT matrix
    - Voltage droop
  - LCD : Aperture ratio
    - TFT storage cap size based on leakage
    - How can LCD keep up with OLED ?
      - Remove Storage Cap ?



LCD Aperture Ratio Example
Mask & Opaque Storage Cap vs Transmission



4K : ~30% loss

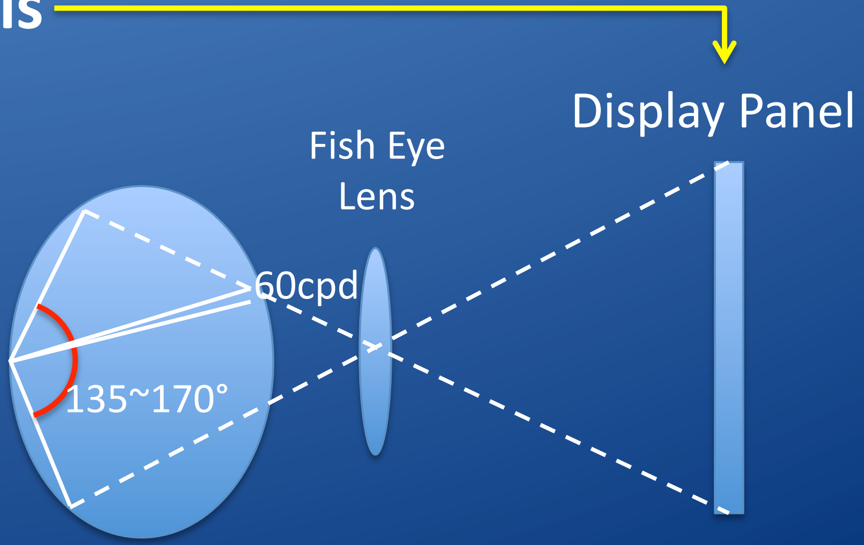


8K : ~80% loss

4K, 8K too much ? … along comes VR

Ideal Head Mounted VR Display (SOL)

- 20/20 human acuity : ~60 CPD* (cycles per degree) at fovea
  - Apply Nyquist rule : 1 Pixel = 2x cycles
- Human field of view: about 170° × 135°
  - – 10,200 × 8,100 cycles ***per eye***
  - ➔Or a single Display Panel of **40K x 16K pixels**



- Independent of panel size or PPI
  - – 5-7" for practical reasons (bulk, weight)

*Michael Deering, 2nd *Int'l Immersive Projection Tech Wkshp*, 1998
*Barten, Peter G, Contrast Sensitivity of the Human Eye

Ideal Head Mounted VR Display (SOL)

- Has a Color Gamut equal to CIE 1931 color gamut
  - BT.2020 only surface colors, doesn't cover radiated e.g. Neon signs
  - Matches exactly what your eye will see "crossing the uncanny valley"
- Has a High-Dynamic Range of 10^{14}:1
  - Human vision spans from 10^{-6} nits to 10^{8} nits (not incl. looking at Sun)
  - However: enclosure allows operating at a fraction of this range
- Should operate at same brightness as indoors/daylight
  - Avoid the after-shock of removing VR headset

Disruptive Technologies

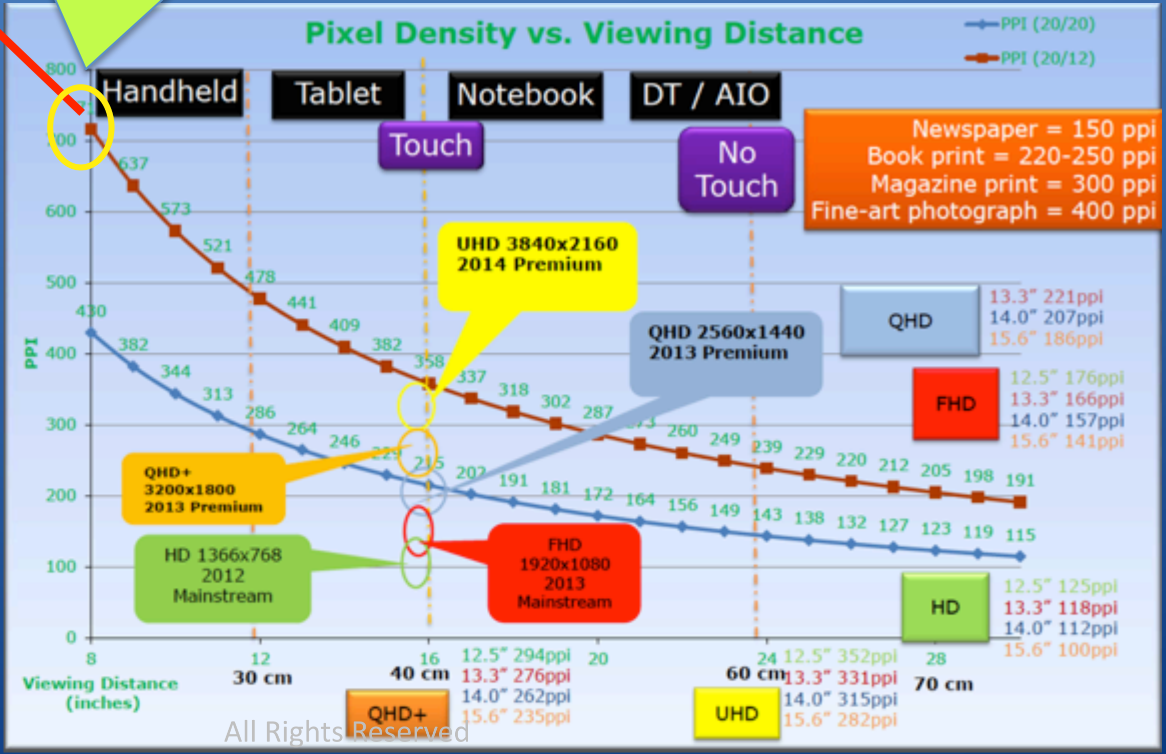
Light Field ?

VR / HMD (SOL)

40Kx16K
5.5~8" Screen

Sharp LCD, Nov'14
http://www.ubergizmo.com/2014/11/sharp-unveils-4-1-inch-igzo-display-with-700-ppi/

Nov'14 700ppi 4.1" QHD



Looking ahead >1yrs IoT

IoT Digital Signage – Everywhere

LED Signage everywhere - Power Consumption ?
Time for : Electrowetting, eInk, Reflective-LCD

Power Matters for Portable / IoT Devices

- It drives Usability, Battery, Weight, Form-factor, Cost

- Green-tech is not just a fashion
  - Now a voter & lobbyist magnet

  ➔Enter the regulators, lawyers

California Energy Commission

- 36mil Personal Computers (PC's) in California
  - 9.6m Desktop, 3.6m AIO Desktop & 23m Notebooks
- Current statewide PC computing energy use in 2013

  is between 4-7 TWH = city of Los Angeles!
- CEC targeting wasted energy
- Proposal to reduce PC energy, takes effect Jan'17 & Jan'18

  http://www.energy.ca.gov/appliances/2014-AAER-2/prerulemaking/

Case Example : Tokyo Central Station

- Tokyo Central upgraded walkways to LCD Based digital signage
- JR had to install additional sub-station & transformer to handle the load
- Cost overrun : $Millions

Personal IoT Example – Display Matters

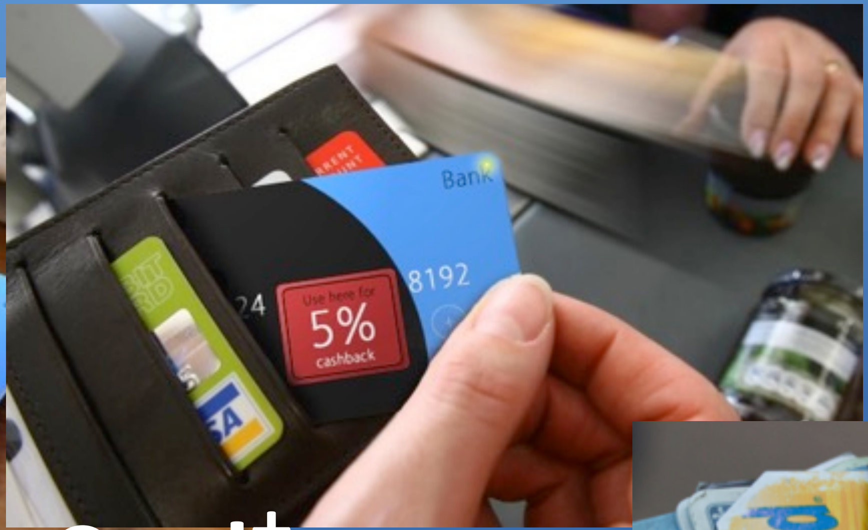
There's an App for that

©BenGuild http://benguild.com/2015/06/06/low-battery-for-ios-apple-watch/

OLED = 1 day

LCD = 7~10 days

IoT : Close & Personal



Card+

COIN

PLASTC

0.8mm thick

Battery-life in months/years

Challenges Recap

- UHD
  - Spectral Purity, Color, Brightness, Power, Cost, Bandwidth
- LCD + 4K / 8K
  - Backlight Source : >2x Brightness, >4x Color Gamut
  - Color Filter & Aperture Ratio Transmissitivity
  - Power, Brightness challenges for Mobile/Handheld Platforms
- IoT
  - Power, color, thinness, flexibility, weight, daylight viewing

Opportunities – what is needed is …

- Better quality light source (other than Blue + Yellow = dirty-white)
- More efficient LCD optical stack (than absorption polarizers)
- More efficient Color Filtering (than lossy absorption filter)
- Higher Dynamic Range (SMPTE:2084 10bit + PQ, 12bit, 16bit Float)
- Wide color depth 10bpc (more than 8bits per component)
- Localized highlight control (edge-lit regional backlight)
- More-efficient Sub-Pixels : RGBY (Sharp), RGBC (AuO), … ?
- Smarter, lower-power, more-colorful displays
  - Memory & Transistor Circuits in Pixel

Summary

- Displays Everywhere
- Growth in Pixels unstoppable, and Better Pixels are coming
- 2016 = UHD Tsunami, consumer demand for UHD portable displays
- Brightness & Color matter, so does Power
- Solving these challenges is valuable and enables IoT usage models

- TFT Everywhere : TCON = MCH ? LCD Foundries = the next Intel(s) ?
  – Moore’s Law was the foundation of many Business Models

Backup

TFT Backplane (OLED/LCD)

Claimed : Simplest. Cheapest

Best High Refresh Range

Best Low Refresh Range

	A-Si Amorphous Si	LTPS Low-Temp Poly Si	IGZO Oxide
Electron Mobility (higher=better)	**Ok** (<1 cm^2/V-sec))	**Best** (>100)	Better (>10 cm^2/V-sec)
Off Leakage Current (lower=better)	Ok (10^{-12})	Better (10^{-14})	**Best** (10^{-15})
Deposition Process (lower=better)	350°C	600°C	Room Temp
Process Complexity	Low (4~5 steps)	High (5~11 steps)	Low (5~7 steps)
Pixel Complexity	High (4T/5T + 1/2C)	High (5T + 2C)	Lo/Hi (2/6T+1/2C)
Process Scalability	Gen10 (2.8mx3.1m)	Gen5 (1.1mx1.2m)	Gen10 (2.8mx3.1m)
Mura (Uniformity)	Good	Ok : Inter-column	Ok : Regional
Driver Integration (cost/low profile)	Partial	Yes	Yes
Practical DPI (backlight, power, speed)	<300ppi	>500ppi	>500ppi
Practical High Ref (w/o overdrive)	<80Hz	<120Hz	>80Hz
Practical Low Ref (w/o flicker)	>45Hz	>30Hz	>20Hz
Practical Application	Under 300ppi	Panels ≤10”	Panels ≥7”

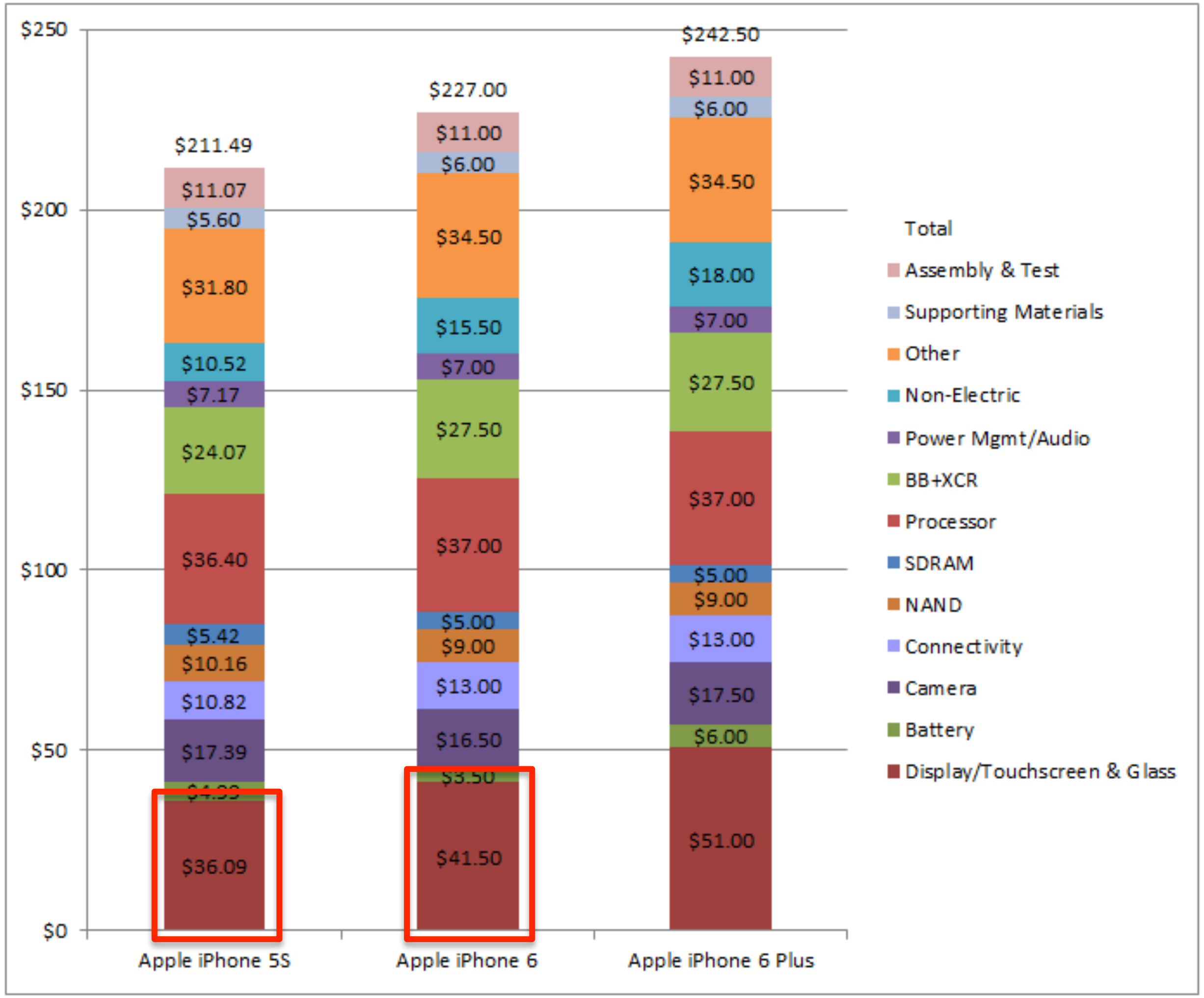
iPhone BOM Cost

Preliminary iPhone 5 Bill of Materials and Manufacturing Cost Estimate Based on Virtual Te
(Costs in U.S. Dollars)

Components / Hardware Elements	iPhone 5 Hardware Comments	iPhone 5 Mo 16GByte	 32GByte
Pricing without Contract		**$649**	**$749**
Total BOM Cost		**$199**	**$209**
Manufacturing Cost		**$8.00**	**$8.00**
BOM + Manufacturing		**$207**	**$217**
Major Cost Drivers			
Memory			
NAND Flash		$10.40	$20.80
DRAM	1GByte LPDDR2	$10.45	$10.45
Display & Touchscreen		$44.00	$44.00
Processor	A6 Processor	$17.50	$17.50
Camera(s)	8 Megapixel + 1. 2 Megapixel	$18.00	$18.00
Wireless Section - BB/RF/PA	Qualcomm MDM9615+RTR8600+Front End*	$34.00	$34.00
User Interface & Sensors		$6.50	$6.50
BT / WLAN	BTv4.0 + Dual-Band Wireless-N	$5.00	$5.00
Power Management		$8.50	$8.50
Battery	Assumed 1800mAh	$4.50	$4.50
Mechanical / Electro-Mechanical		$33.00	$33.00
Box Contents		$7.00	$7.00

* - Assumed

Source: IHS iSuppli Research, September 2012



teardown.com

iPad BOM

2. 일반 사양

1) 대각 크기 : 9.7"
2) 표시 영역 : 196.608(H)×147.456(V) [mm]
3) 화소 수 : 2048 × RGB × 1536 pixels, R
4) 화소 피치 : 192(H) X 192(V) [㎛]
5) 모듈 크기 : 208.881(H)×167.123(V)×2.68
6) 표시 모드 : Transmissive & Normally Black
7) 칼라 수 : 16,777,216 Colors (8 bit)
8) 시야각 : 80º/80º/80/80º(CR > 10) Typ.
9) 주시야각 : 6시 방향
10) 공급 전압 : 3.3 [V]
11) 모듈 무게 : 134g(협의 中) (Max.)
12) 표면 처리 : Glare, Anti-reflective treatment
13) 백라이트 : White LED 2 array(42ea x2)
14) 인터페이스 : eDP 4lane
15) 소비 전력 : 6W(Typ.) [1W(Logic, Typ.) + 4.

인쇄된 표준은 최신본이 아닐 수

1

New iPad Preliminary Bill of Materials (BOM) Cost Analysis

	iPad 2		New iPad (3rd Generation)				
	WiFi	WiFi + 3G	WiFi			WiFi	
Components / Hardware Elements	16GB	16GB3	16GB6	32GB7	64GB8	16GB9	32G
Retail Pricing (As of March 2012)	$399.00	$529.00	$499.00	$599.00	$699.00	$629.00	$729
Total BOM Cost	$236.95	$262.55	$306.05	$322.85	$356.45	$347.55	$364
Manufacturing Cost	$8.15	$8.45	$10.00	$10.00	$10.00	$10.75	$1
BOM + Manufacturing	$245.10	$271.00	$316.05	$332.85	$366.45	$358.30	$375
Major Cost Drivers							
Memory							
NAND Flash	$16.80	$16.80	$16.80	$33.60	$67.20	$16.80	$3
DRAM	$7.60	$7.60	$13.90	$13.90	$13.90	$13.90	$1
Display & Touchscreen							
Display	$57.00	$57.00	$87.00	$87.00	$87.00	$87.00	$8
Touchscreen	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$4
Processor	$14.20	$14.20	$23.00	$23.00	$23.00	$23.00	$2
Camera(s)	$4.10	$4.10	$12.35	$12.35	$12.35	$12.35	$1
Wireless Section - BB/RF/PA (Module)		$25.60				$41.50	$4
User Interface & Sensors & Combo Module (WLAN/BT/FM)	$15.35	$15.35	$15.00	$15.00	$15.00	$15.00	$1
Power Management	$5.85	$5.85	$10.00	$10.00	$10.00	$10.00	$1
Battery	$22.75	$22.75	$32.00	$32.00	$32.00	$32.00	$3
Mechanical / Electro-Mechanical / Other	$47.80	$47.80	$50.50	$50.50	$50.50	$50.50	$5
Box Contents	$5.50	$5.50	$5.50	$5.50	$5.50	$5.50	$

Source: IHS iSuppli Research, March 2012

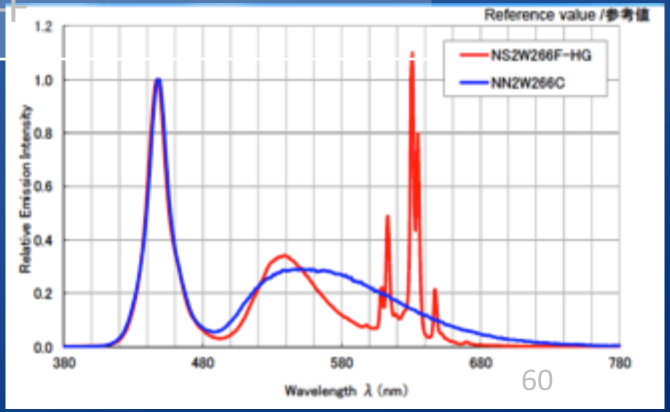
October 2014		Apple iPad Air 2					
		WiFi + Cellular			WiFi		
Components / Hardware Eleme	iPad Air Hardware Comments	16GB	64GB	128GB	16GB2	64GB2	128GB2
	Retail Pricing	$629	$729	$829	$499	$599	$699
Total BOM Cost		$305	$325	$352	$270	$290	$317
Manufacturing Cost		$6.00	$6.00	$6.00	$5.00	$5.00	$5.00
BOM + Manufacturing		$311	$331	$358	$275	$295	$322
Major Cost Drivers							
		$6.75	$27.00	$54.00	$6.75	$27.00	$54.00
	3 LPDDR3	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00
	536 IPS Mode LCD	$77.00	$77.00	$77.00	$77.00	$77.00	$77.00
	GF2	$38.00	$38.00	$38.00	$38.00	$38.00	$38.00
	rocessor + M8 Co- Price includes M8 rocessor	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00
	P + 1.2MP	$11.00	$11.00	$11.00	$11.00	$11.00	$11.00
	ns Qualcomm						

		Wi-Fi + Cellular				Wi-FI			
ents		16GB	32GB	64GB	128GB	16GB2	32GB3	64GB4	128GB5
		$629	$729	$829	$929	$499	$599	$699	$799
		51%	56%	60%	61%	45%	53%	58%	59%
		$304	$313	$325	$355	$269	$278	$290	$320
		$6	$6	$6	$6	$5	$5	$5	$5
		$310	$319	$331	$361	$274	$283	$295	$325
		$9.20	$18.00	$30.00	$60.00	$9.20	$18.00	$30.00	$60.00
		$10.50	$10.50	$10.50	$10.50	$10.50	$10.50	$10.50	$10.50
Display	9.7" 2048 x 1536	$90.00	$90.00	$90.00	$90.00	$90.00	$90.00	$90.00	$90.00
Touch Screen	COP Film Sensor	$43.00	$43.00	$43.00	$43.00	$43.00	$43.00	$43.00	$43.00
Processor	64-Bit A7 Processor + M7 Co-Processor	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00

LED Efficiency – Nichia case example

	Flux	Intensity	Efficiency	Size	Example	Est. Cost
Standard W-LED	~8 lm	~2.5 cd	110~135 lm/W	3.0x0.85x0.4	NSSW306-F	$0.132
Single RG-LED	~6.8 lm	~2.3 cd	110~120 lm/W	3.0x0.85x0.4	NSSW306-F	
Standard W-LED	~9.5 lm	~2.8 cd	140~165 lm/W	3.0x0.85x0.6	**NSSW306-F**	$0.158
Single RG-LED	~8.1 lm	~2.7 cd	140~ lm/W	3.0x0.85x0.6	NSSW306-HG	
Double W-LED	16.4 lm	4.5 cd	125~155 lm/W	4.2x1.0x0.6	**NSSW266-F**	$0.268
Double RG-LED	14.5 lm	4.5 cd	120~145 lm/W	4.2x1.0x0.6	NSSW266-F	

Source : http://www.nichia.co.jp/en/product/led_search.html?op=cond=application=%27LCD%20Backlighting%27



Nanosys QD Proposal

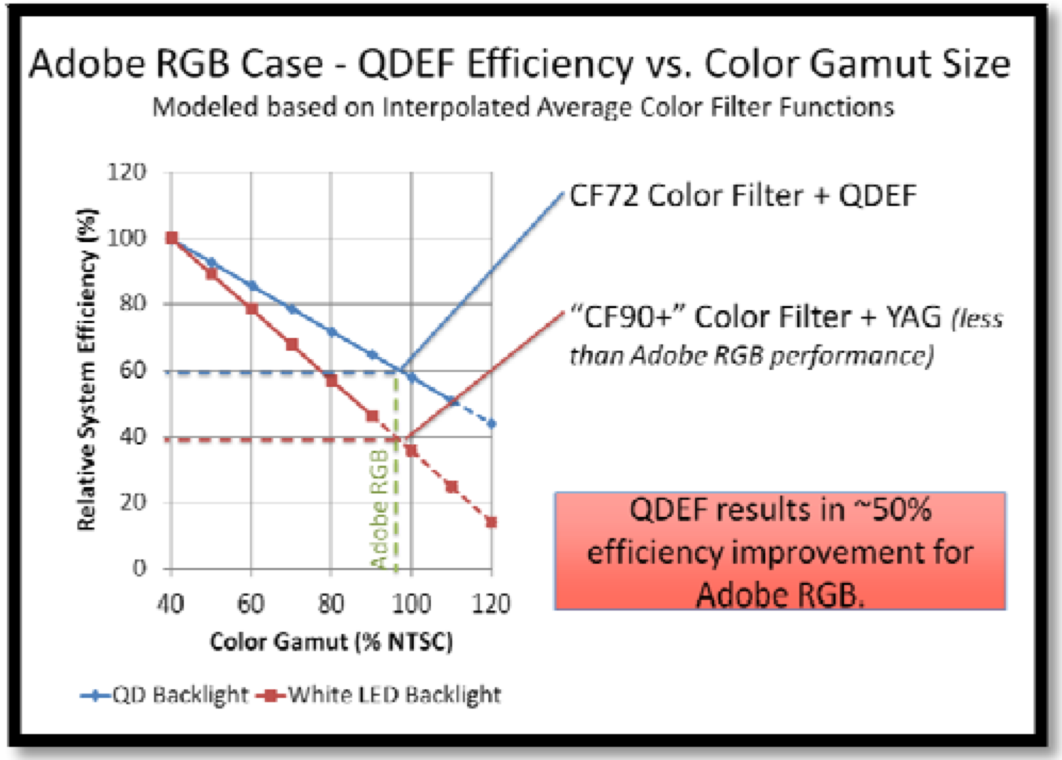


Figure 5. Modeling analysis showing relative LCD system efficiency. The Adobe RGB color gamut can be achieved using QDEF or highly saturated color filters; the QDEF displays are approximately 50 percent more energy-efficient than displays using the more saturated (CF90+) color filters.

https://www.nanosysinc.com/s/high-efficiency-lcds-using-quantum-dot-films.pdf