



Presented at Bay Area SID, Sep'23rd 2015

<http://www.sid.org/Chapters/Americas/BACChapter/Archives/BA2015SeminarArchive.aspx>

Market, Technologies, Insights & Opportunities

PORTABLE & IOT DISPLAYS, CHALLENGES & OPPORTUNITIES – PART 1

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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

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

(*Source : DisplaySearch Industry Report 2013)

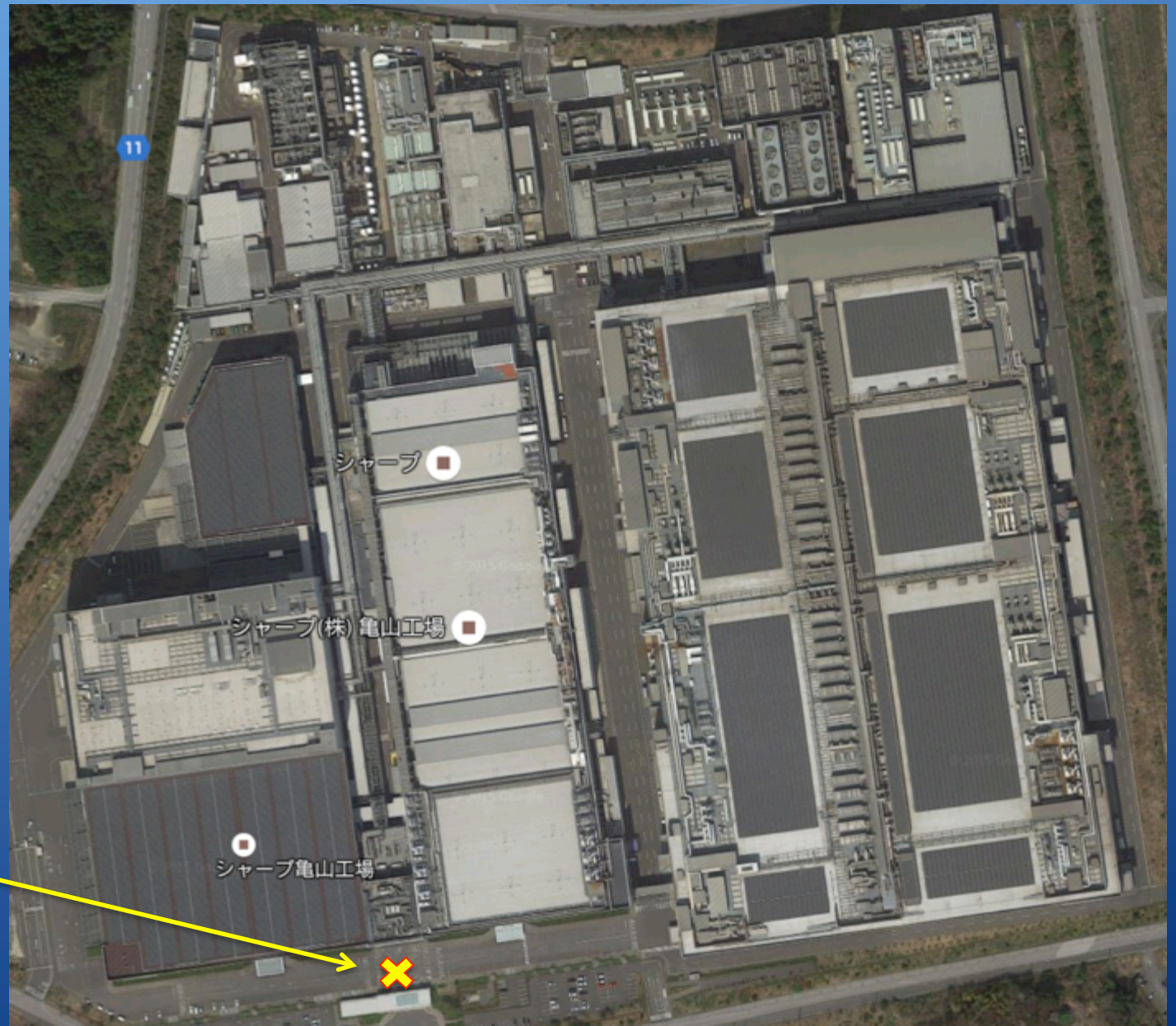
>10yr Foundry Investments → Intensely competitive
50~75% of LCD Cost = Depreciation*

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)



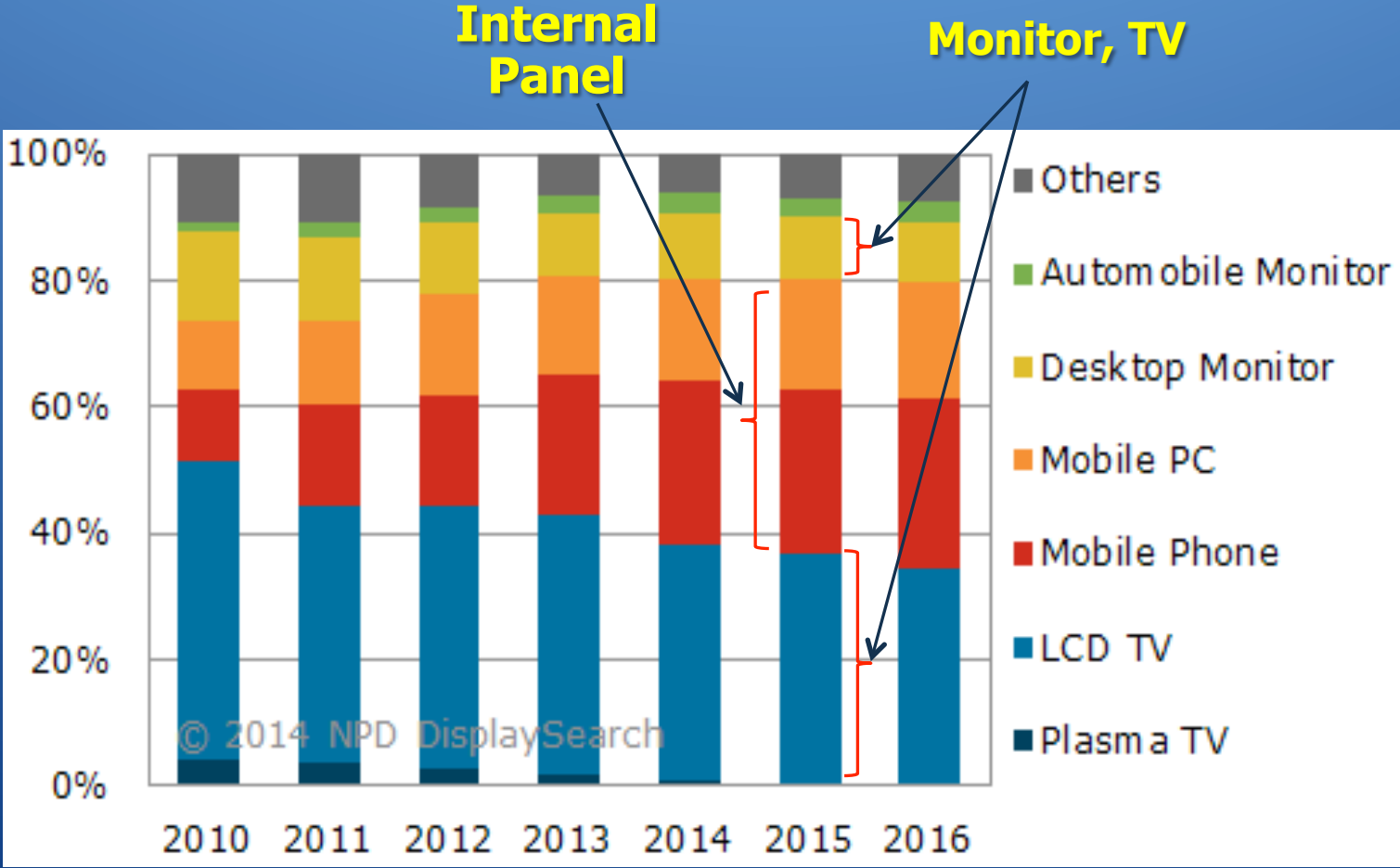
China is investing in yet more TFT Fabs ...

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”



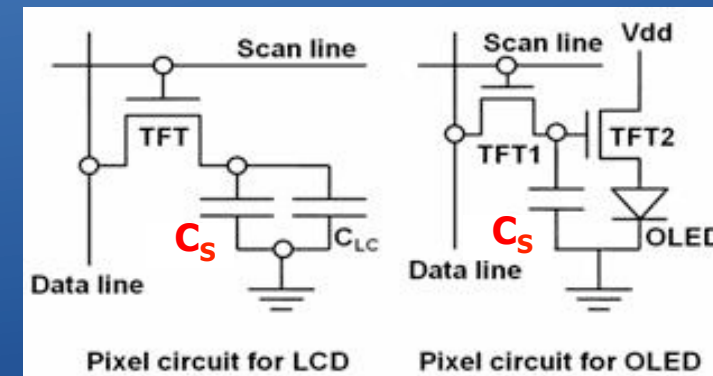
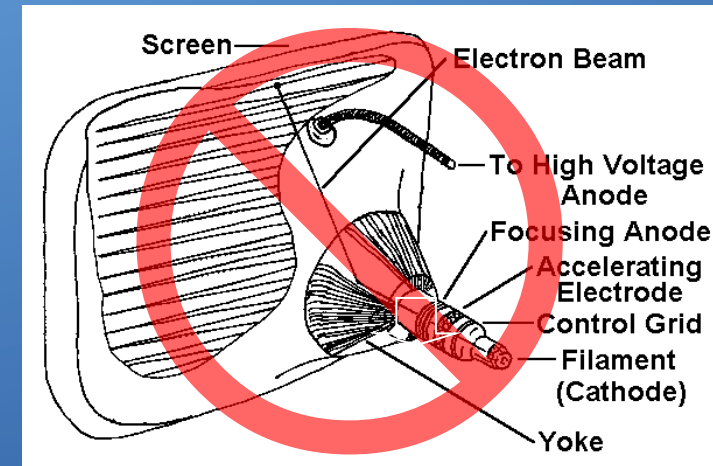
Panel Industry Growth



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 C_s
 - No phosphor



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

Display Technologies : TFT is the Medium

1920's

CRT 50~120Hz

2010 E.O.L

Incumbent Technology

1950's

Plasma 50~240Hz

2014 E.O.L

Compatibility Phase

1980's

TFT 1st Gen 60~40Hz

2000's

TFT 2nd ~ 4th Gen 80~20Hz

Disruptive Phase

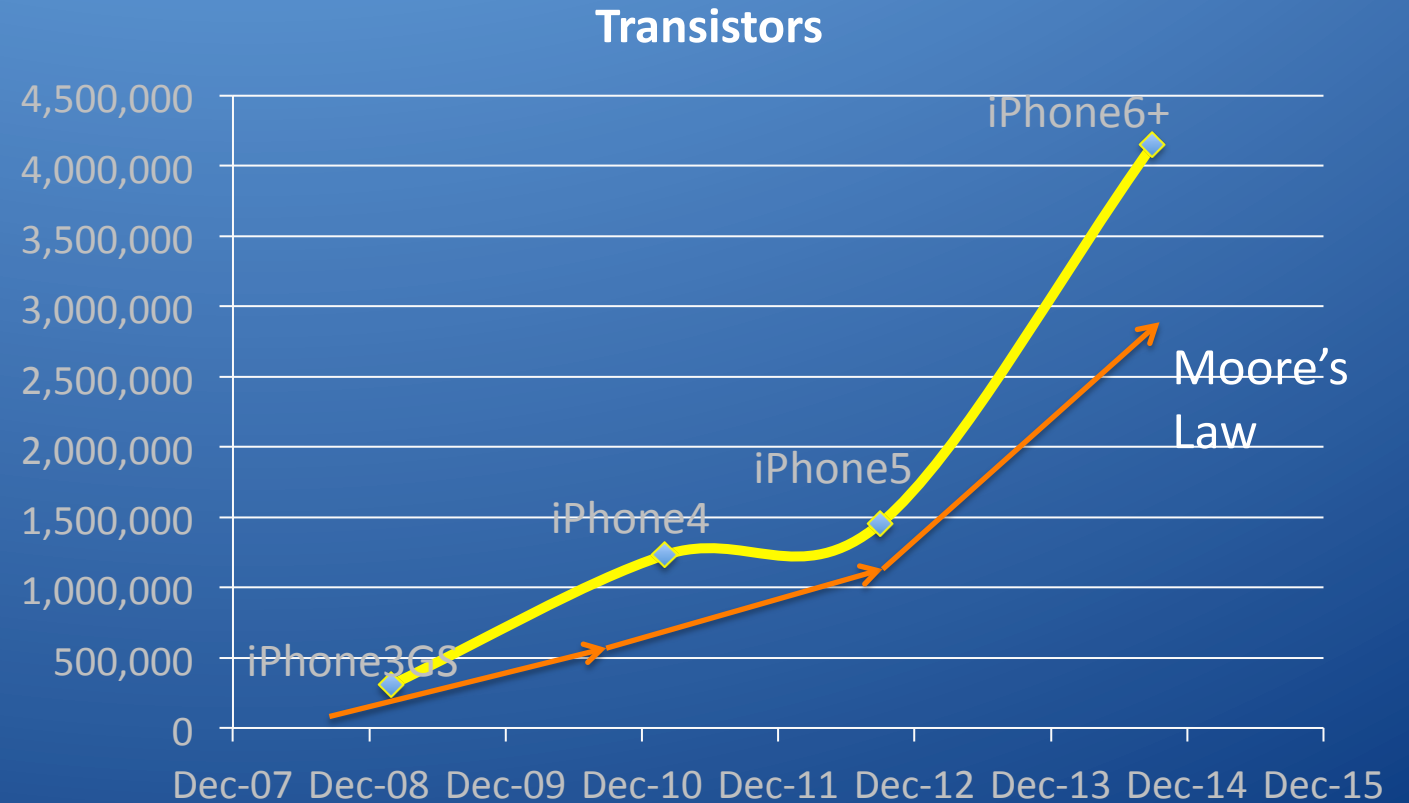
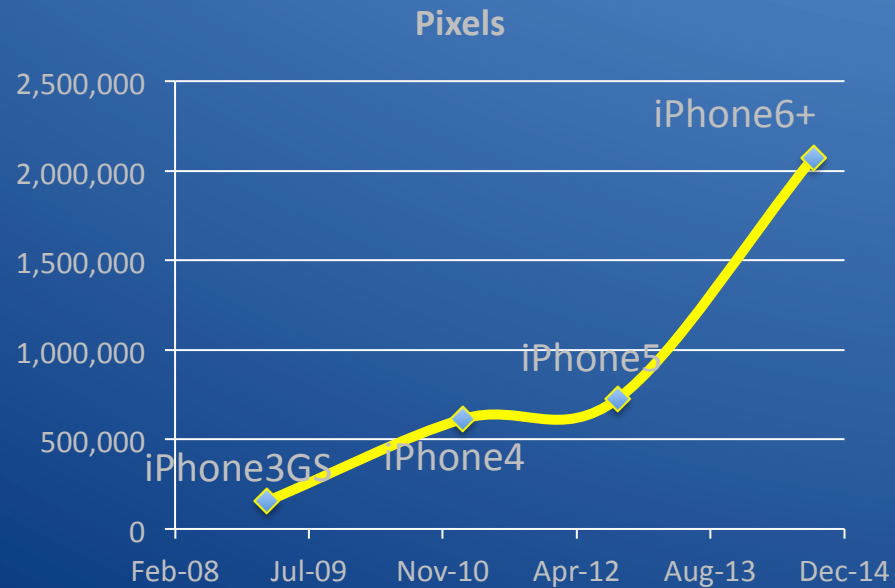
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2010's

TFT future >120Hz ~ <1Hz

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

TFT Dynamics : SmartPhone Pixels / Transistors



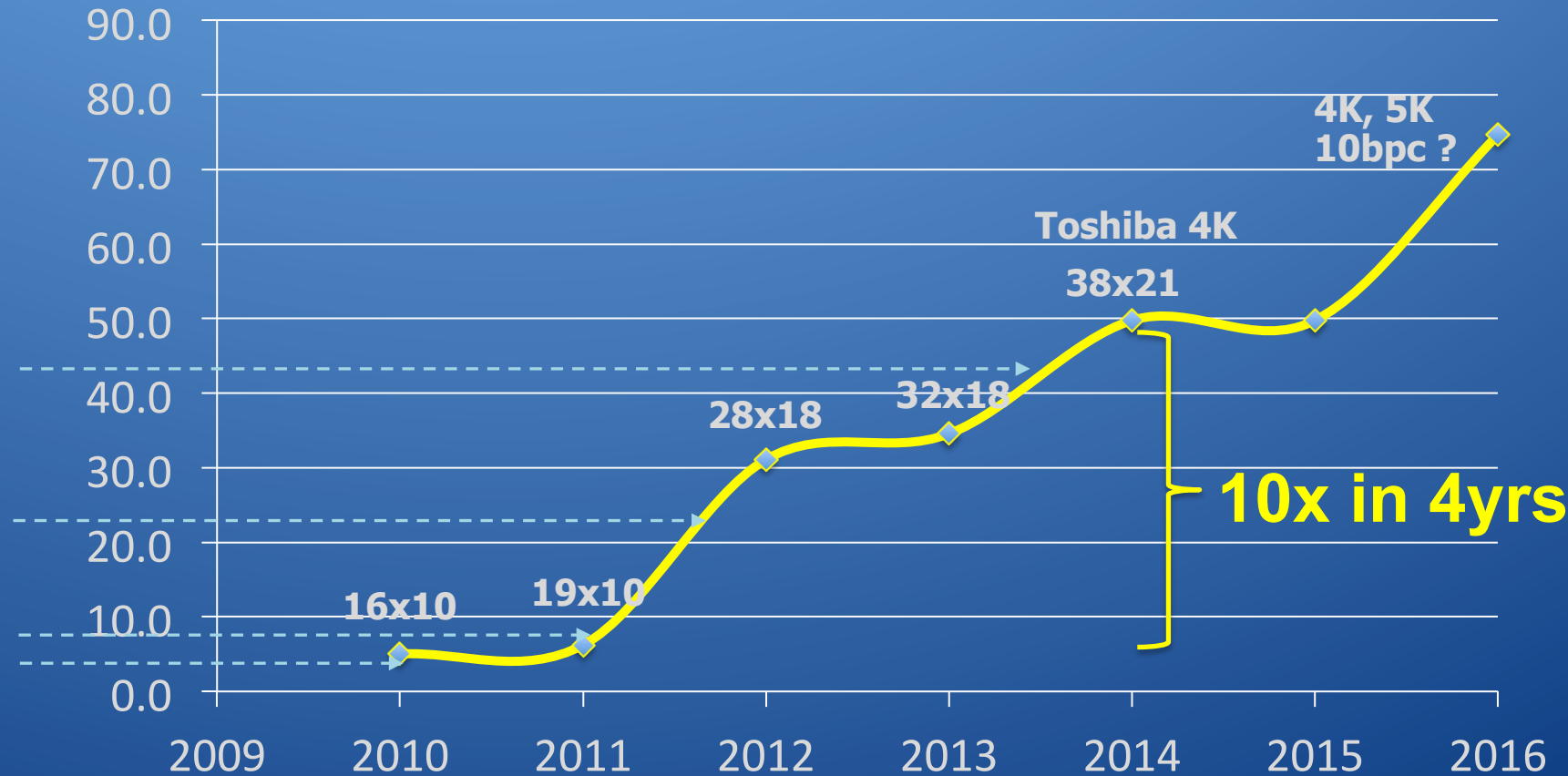
15.6" TFT LCD Notebooks

Millions of Transistors (LCD)

Moore's Law (CPU)
~2xTrans / 2yrs

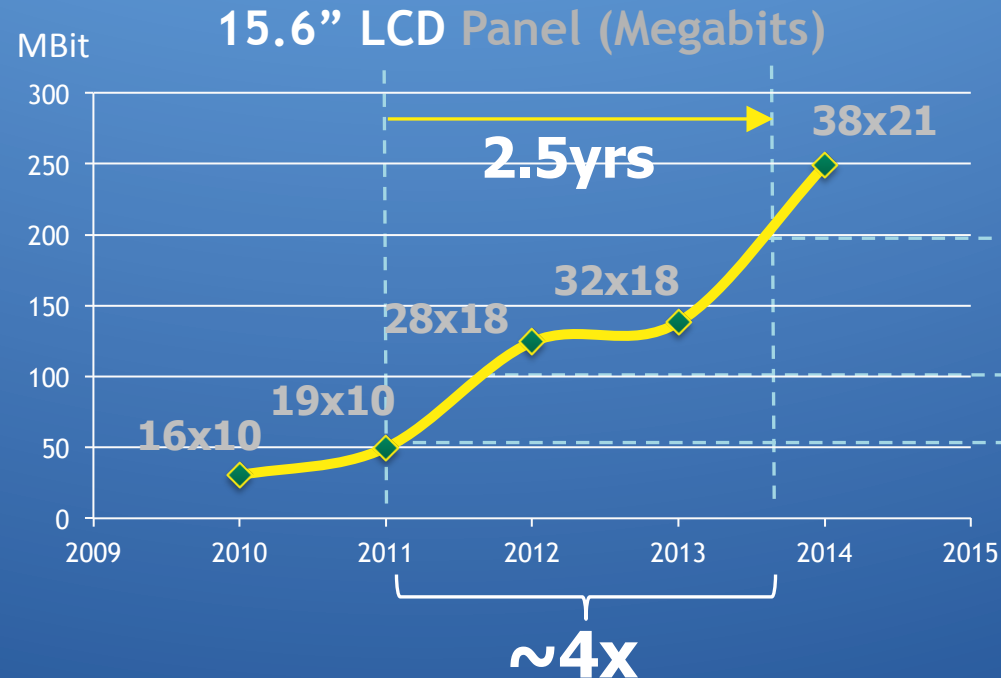
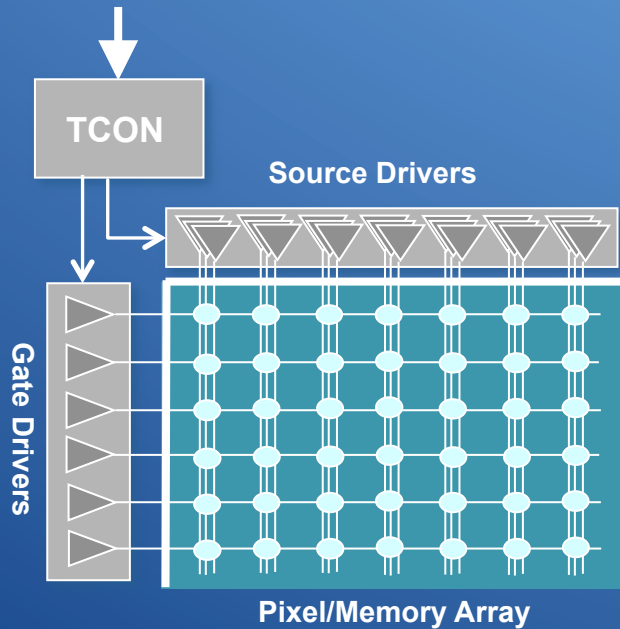
8x in 5yrs

- Pentium4: 42m '00
- AMD K7: 22m '99
- AMD K6: 9m '97
- PentiumPro: 5m '95



TFT on Glass : growing faster than Moore's Law

LCD by Memory bit



JEDEC DDR4 Mem Roadmap

8Gb (2017)

4Gb (2014)

2Gb (2012)

4x, 5yrs

- 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

Pseudo-CMOS Circuits using Amorphous In-Sn-Zn-O Thin-Film Transistors

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We have developed pseudo-CMOS circuits with more excellent characteristics than conventional CMOS circuits. Either of the two pseudo-CMOS circuits should be selected on demand by considering the characteristics of the TFTs. These results are useful to integrate display drivers on a single substrate.

Introduction

Amorphous In-Sn-Zn-O thin-film transistors (TFTs) are promising for low-power and high-performance applications. However, their performance is still lower than that of crystalline silicon TFTs. In this paper, we propose pseudo-CMOS circuits using amorphous In-Sn-Zn-O TFTs. The proposed pseudo-CMOS circuits are compared with conventional CMOS circuits. The results show that the proposed pseudo-CMOS circuits have more excellent characteristics than conventional CMOS circuits. The results are useful to integrate display drivers on a single substrate.

Simulation Results

Figure 1 shows the simulated voltage waveforms of the proposed gate driver. The results show that the proposed gate driver has more excellent characteristics than conventional CMOS circuits. The results are useful to integrate display drivers on a single substrate.

A Low-Power Gate Driver Using Depletion-Mode a-IGZO TFTs

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Abstract

A new gate driver composed of amorphous In-Ga-Zn-O (a-IGZO) thin-film transistors (TFTs) is proposed. By turning off TFTs completely to suppress the leakage current and eliminating the unnecessary charge and discharge currents, the power consumption of the proposed gate driver is reduced. Simulation results indicate that the proposed gate driver can be operated successfully with depletion-mode a-IGZO TFTs and the power consumption is reduced by 18.9% of the previously reported result.

Circuit Structure & Timing Diagram

Figure 1. (a) Proposed gate driver schematic and (b) corresponding timing diagram.

Figure 2. Simulated voltage waveforms of the O₁T₁ and O₂T₁ nodes of the first, fourth, eighth and twelfth stages.

Circuit Simulations

Figure 3. Simulated voltage waveforms of the proposed gate driver.

Conclusion

This paper presents a low-power gate driver using a-IGZO TFTs. The large power dissipation due to the leakage current is reduced by the all TFTs in the gate driver turned off with a negative V_{GS}. Additionally, by eliminating the unnecessary charge and discharge currents to the parasitic capacitors of the carry signal and the gate node of the pull-up TFT in each stage, the power consumption can be further reduced. The simulation results confirm that the proposed gate driver stably works with depletion-mode or enhancement-mode TFTs, and the power consumption of the proposed gate driver is reduced by 18.9% of the previously reported result.

A New LCD Pixel Circuit with Low Refresh Rate Using Memory TFT

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 Kyeong-Ah Kim and Sung-Min Yoon
 Department of Advanced Materials Engineering for Information and Electronics, Kyung Hee University, Yongsin, Korea
 Chumwon Byun, Chi-Sun Haeng
 Display TFT Research Center, Electronics and Telecommunications Research Institute, Daejeon, Korea
 Kyung Hee University

Simulation Conditions

Figure 4. (a) Measured and simulated transfer characteristics of the fabricated a-IGZO TFT. (b) Measured and simulated output characteristics of the fabricated a-IGZO TFT.

Experimental Setup

Figure 5. Measured and simulated transfer characteristics of the fabricated a-IGZO TFT.

a-IGZO TFT Based Operational Amplifier and Comparator Circuits for the Adaptive DC-DC Converter

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Abstract

In this paper, we present an operational amplifier (op-amp) based on amorphous Indium-Gallium-Zinc-Oxide thin-film transistors (a-IGZO TFTs) to achieve a comparator operated by pulse-width-modulation (PWM) control loop structure, which can be used for dc-dc converter circuits integrated in the display driving system. Based on electrical characteristics of the fabricated a-IGZO TFT, we proposed a novel NMOS op-amp to achieve the overall gain of 19.2dB. On the basis of the proposed op-amp, we fabricated an a-IGZO TFT comparator circuit, which could successfully operate at 100kHz to control the duty ratio.

TFT Characterization

Figure 1. Measured and simulated transfer characteristics of the fabricated a-IGZO TFT.

Name	Value
V _{GS} (V)	1.0
V _{DS} (V)	2.0
Threshold voltage (V)	1.11
Mobile Ion ⁺ (V)	1.42
Ion (mA/V)	1.16
Ion (mA/V)	1.16

CS-Amp Circuit Configuration

Figure 2. Measured and simulated output characteristics of the fabricated a-IGZO TFT common-source amplifier. The inset shows the top-view of the fabricated circuit.

a-IGZO based op-amp Configuration

Figure 3. (a) The micrograph image of the fabricated a-IGZO TFT op-amp. (b) The simulated gain and phase margin in the frequency domain by the proposed a-IGZO TFT op-amp.

Simulation and Measurement results of the comparator

Figure 4. (a) Schematic of the comparator circuit based on the proposed op-amp. (b) Simulated results of the comparator circuit. (c) Measurement results of the comparator circuit based on the fabricated op-amp.

Conclusion

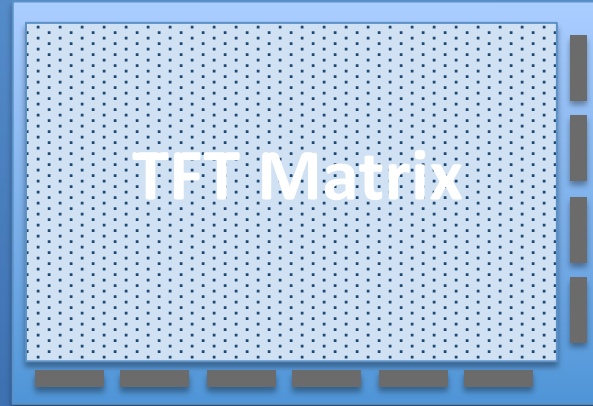
- We proposed a novel op-amp circuit only with n-type transistors, and fabricated it with a-IGZO TFT on the glass substrate.
- We can confirm that the fabricated comparator could change the output pulse duty ratio from 25% to 75% with the slew rate of 0.625V/μs.
- The measurement results show that the proposed op-amp can be applied to the PWM control loop structure that can be integrated with the comparator and error amplifier for a dc-dc converter system.
- We expect that the proposed a-IGZO TFT op-amp circuit can be the basis for an adaptive dc-dc converter in the display driving system.

Logic on TFT Glass = Revolutionary IoT Enabler

Old Tech : Panel restricted to Rect Bezel



Sharp: Zero-Bezel Round LCD



TFT Matrix

Gate Drivers IC's

Source Drivers IC's

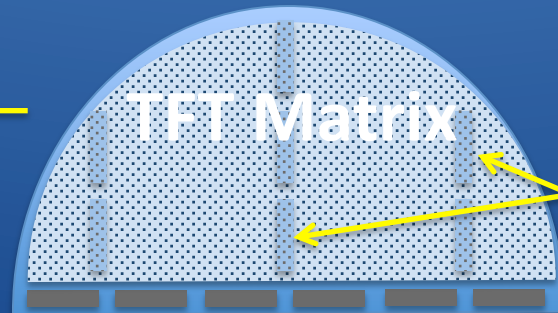


JDI : RGBW Reflective, SRAM Memory-In-Pixel, 0.000130/160 W

New Generation: Panel is Any Shape



Sharp: Source/Gate Driver-On-Glass



TFT Matrix

Gate Drivers circuits constructed from TFT

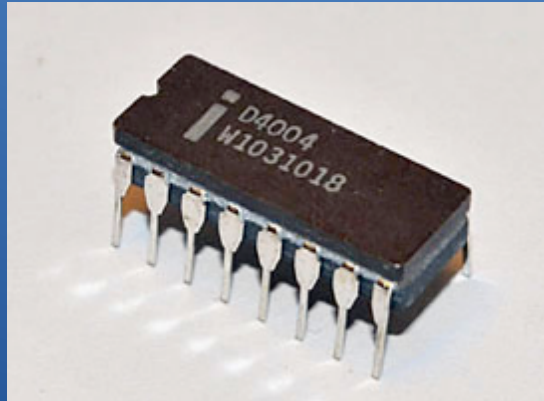
Source Drivers IC's



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

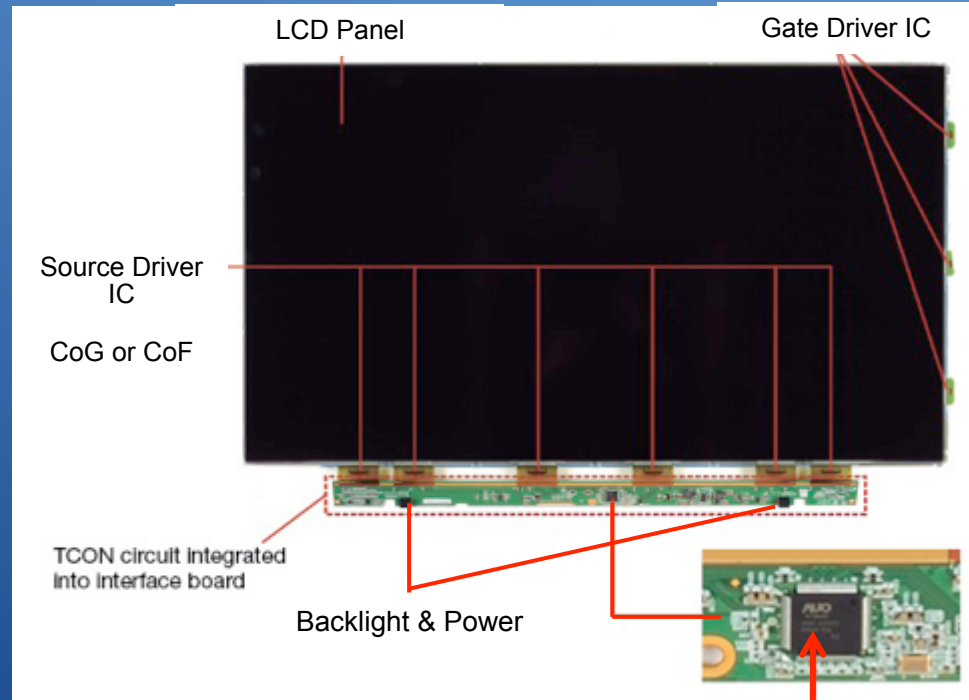


Dynamic RAM, Intel 1103

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

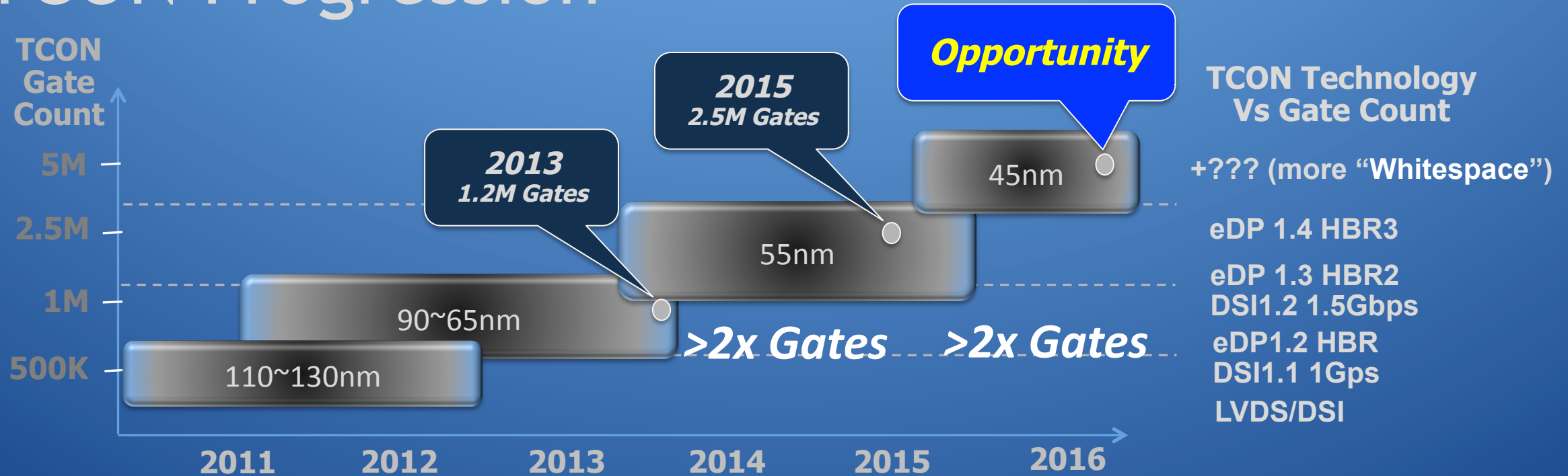


TCON + Drivers
Single Chip : "DDIC"
Chip-on-Glass (CoG)

Backlight & Power

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

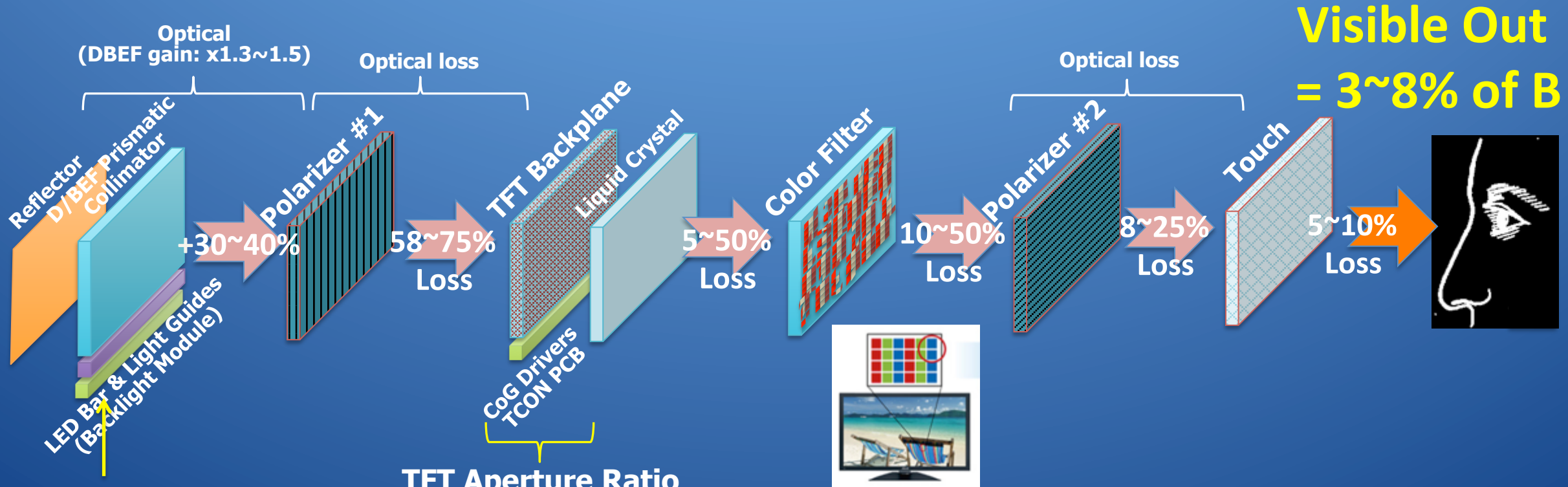
TCON Progression



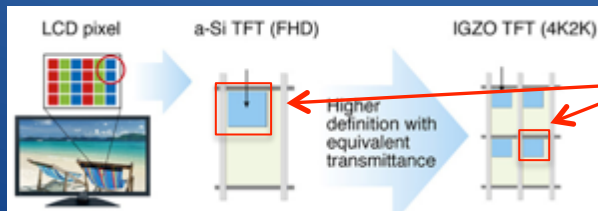
- TCONs have lagged other Semiconductors due to Driver/Glass signaling
 - Required older Analog-friendly Si processes
- But every Year : Vendors → 2x Gate count increase, plenty of Process runway

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

Step Back - Recap of Normal LCD Stack



Light In = B

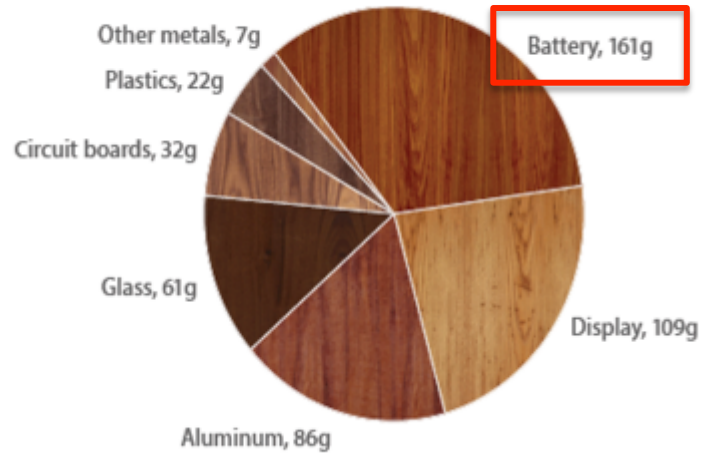


Power savings:
 LTPS = 25%
 IGZO = 40%

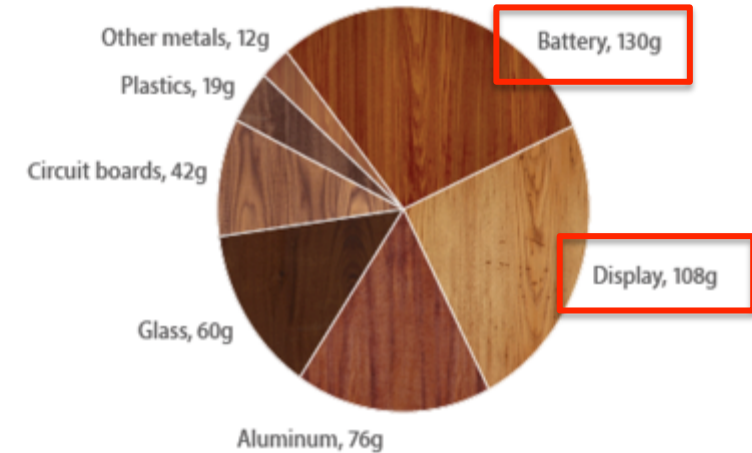
Aperture Ratio: Opaque TFT+Cap Vs Transmissive area

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)

iPad 2 Air

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

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

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 !

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/>

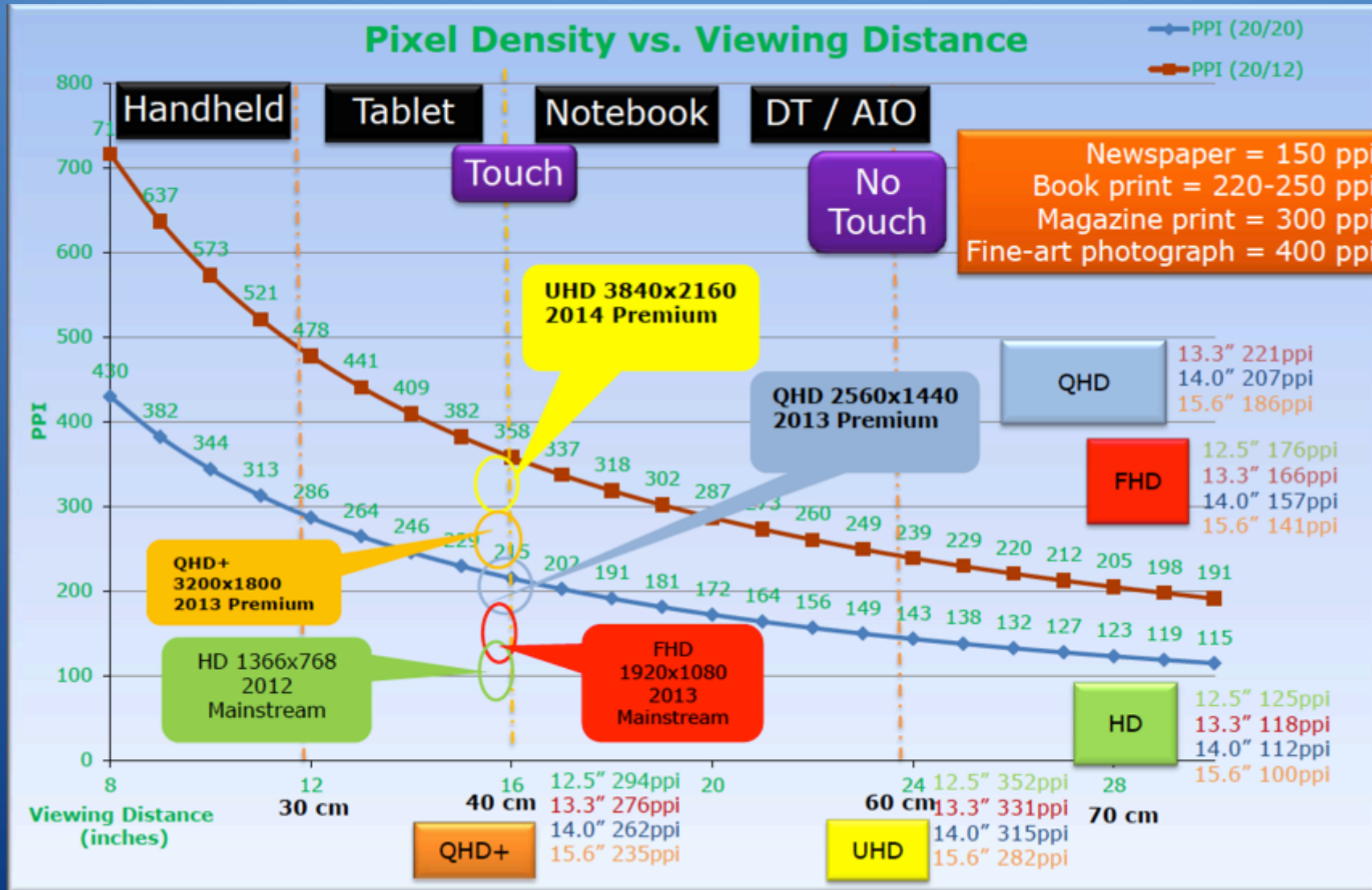
Netflix <http://www.wired.com/2015/03/netflix-will-remake-image-tv/>



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



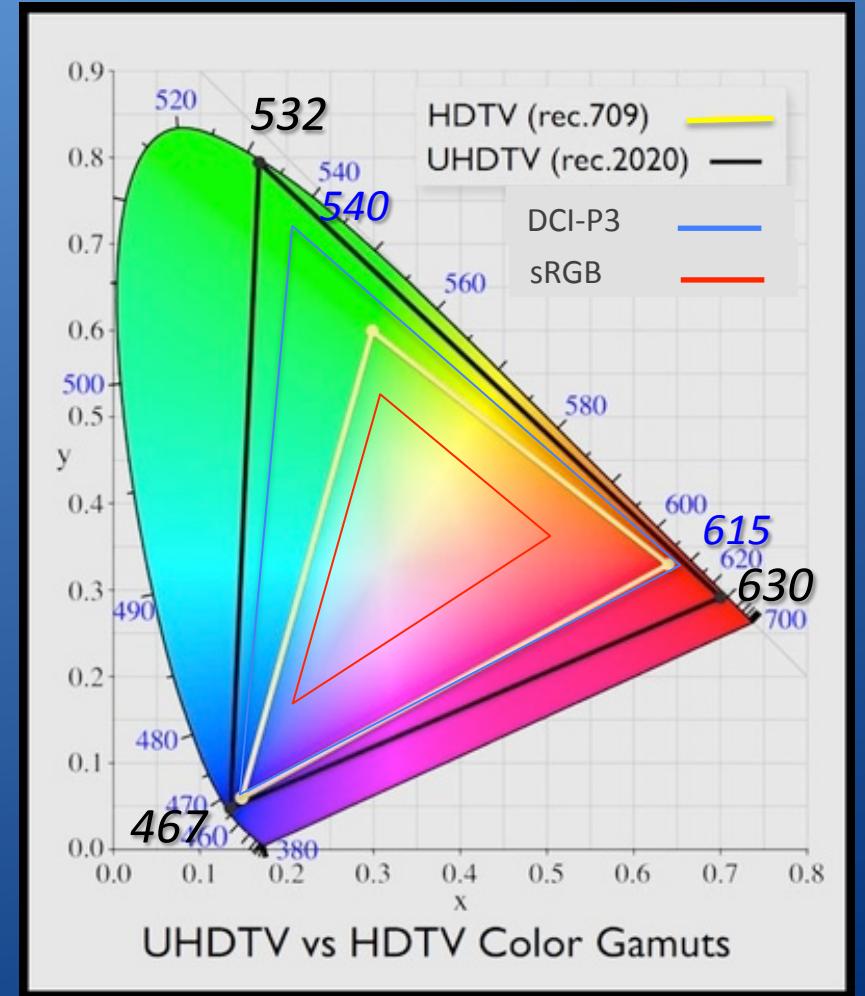
“UHD” Content = HDR Localized Highlights



- 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



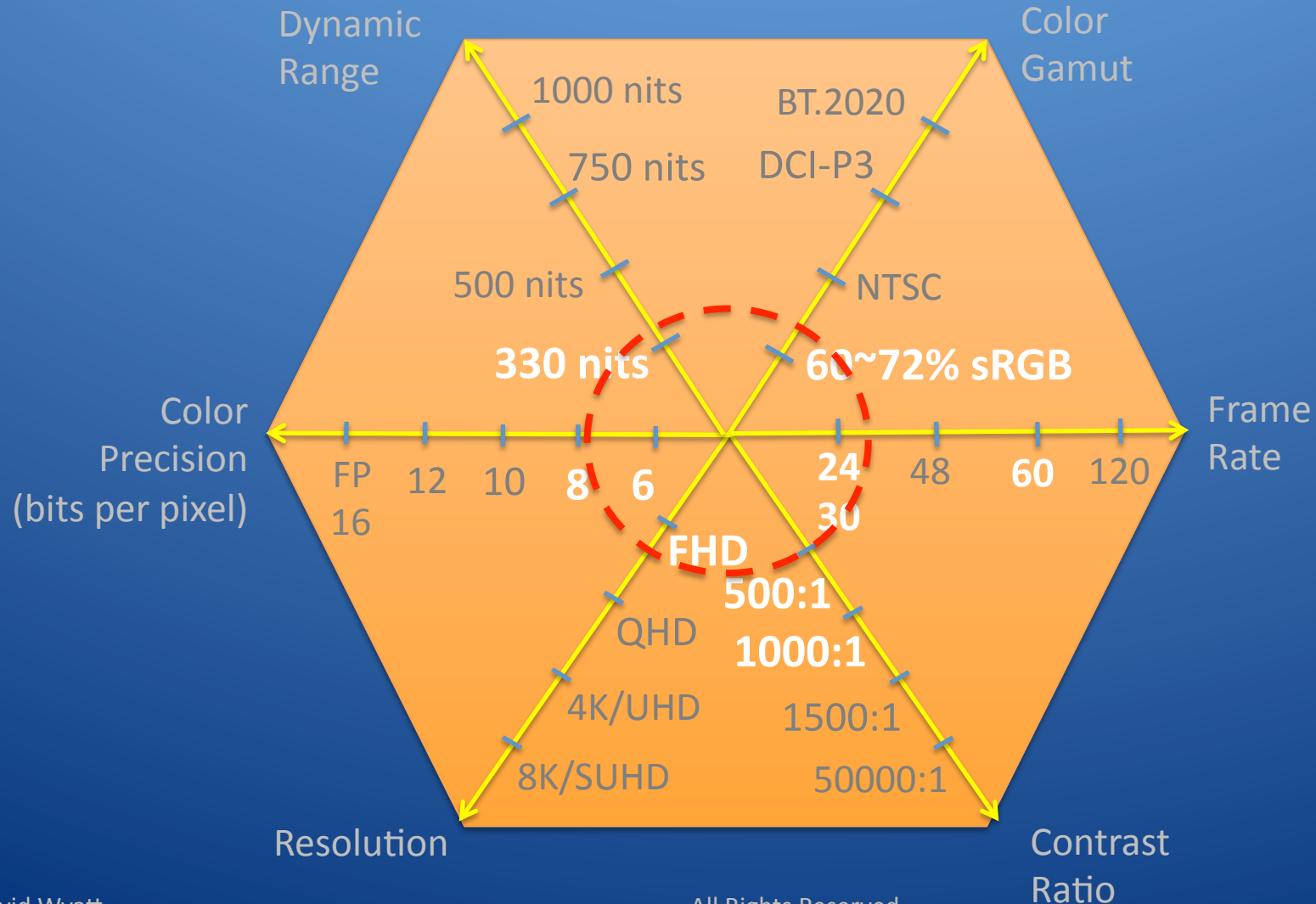
“UHD” Content = 10x Bandwidth & Power

- 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

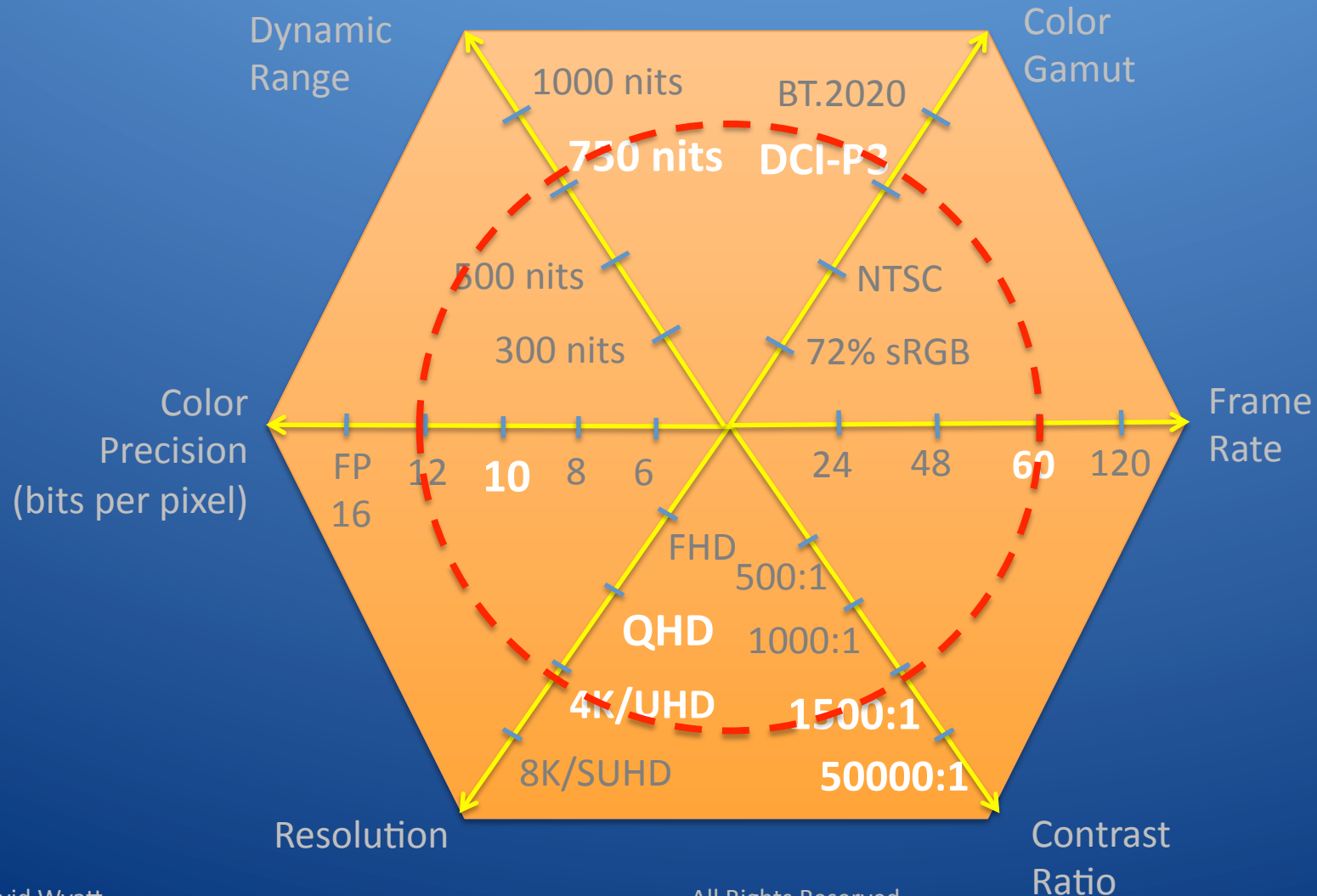


Opportunity : Efficiency improvements

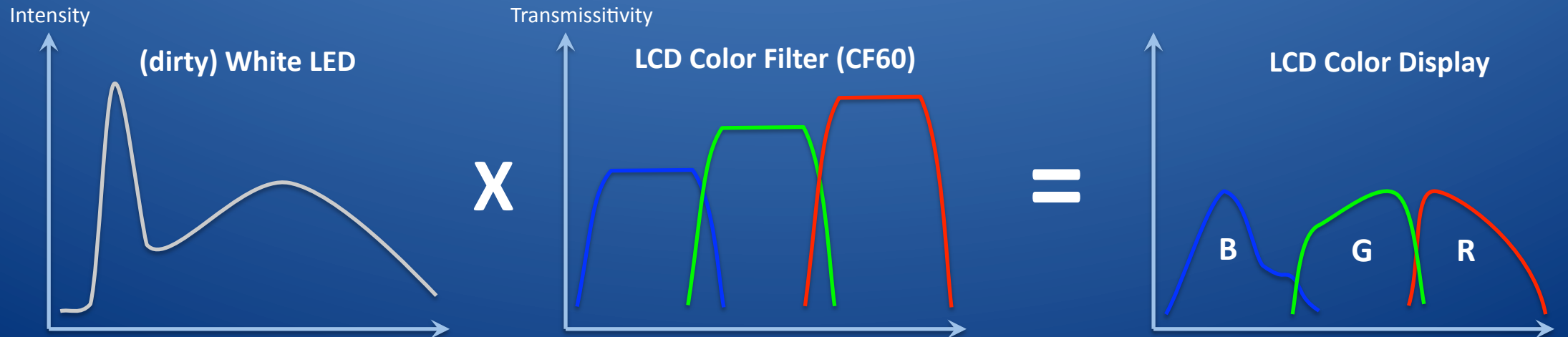
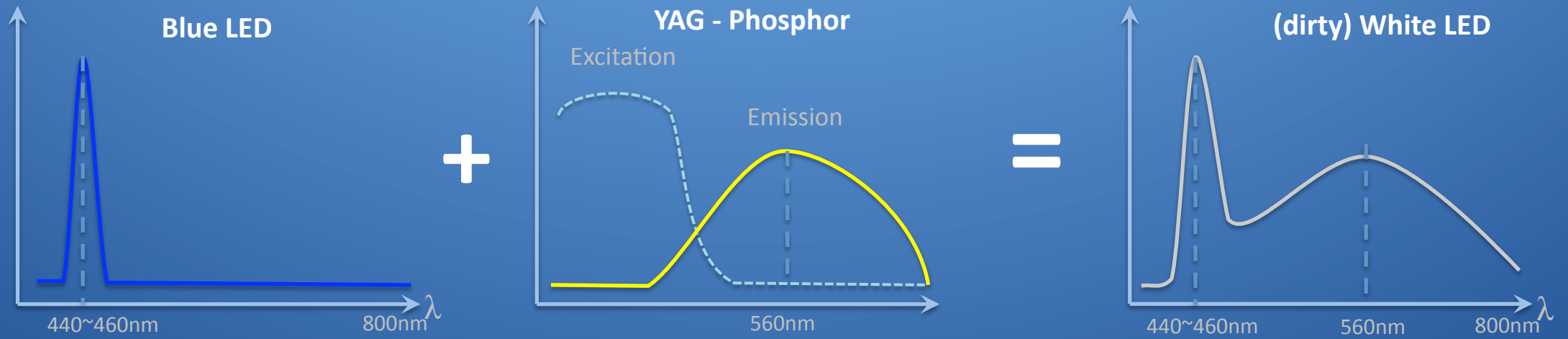
Today's Portable Display Experience



2016 "UHD" Display Experience



LCD Recap – White LED Backlight



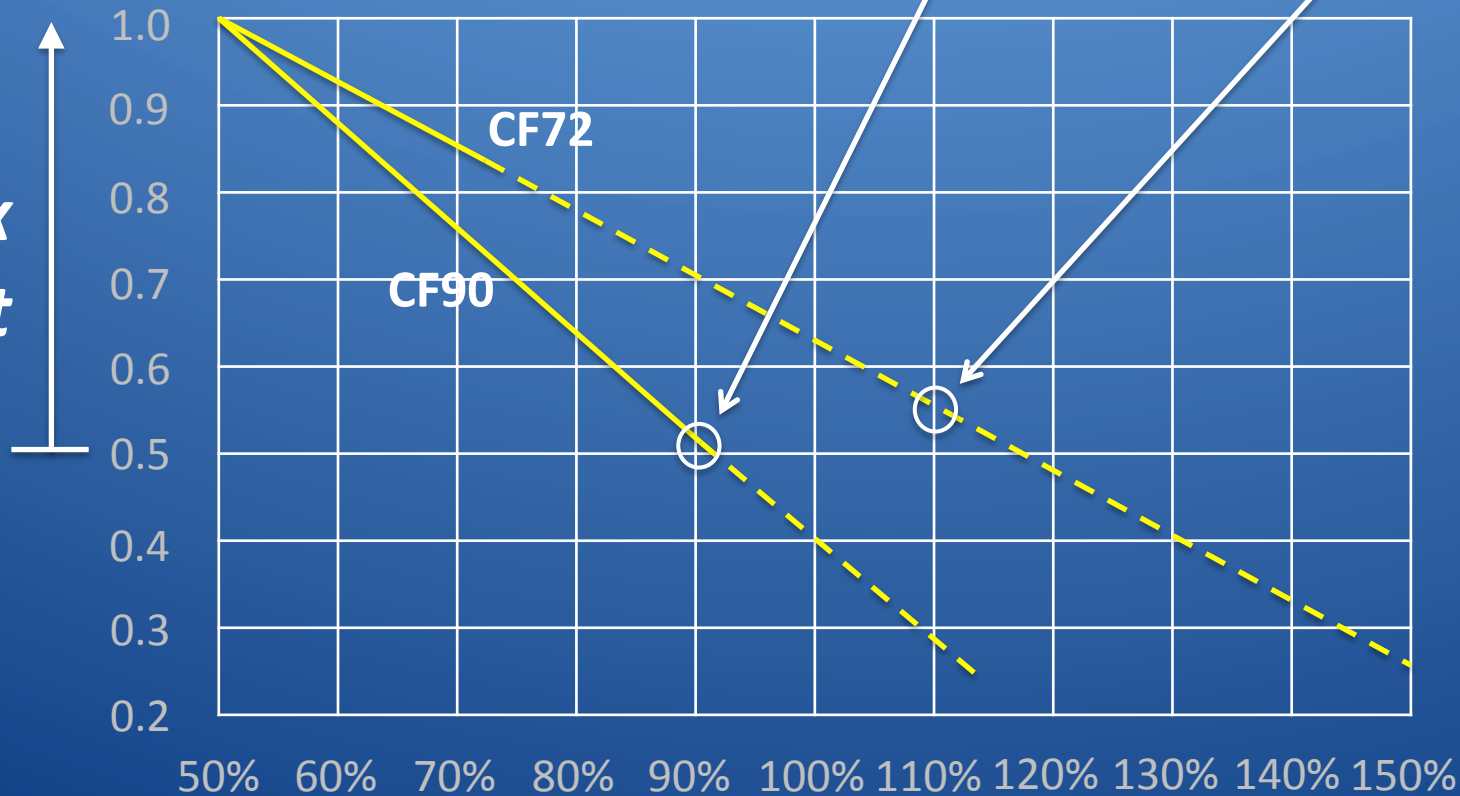
Color Filter Efficiency

110% NTSC : Blue LED + QD
(Nanosys proposal)

90% NTSC : White LED

Relative Luminosity

2x
Backlight

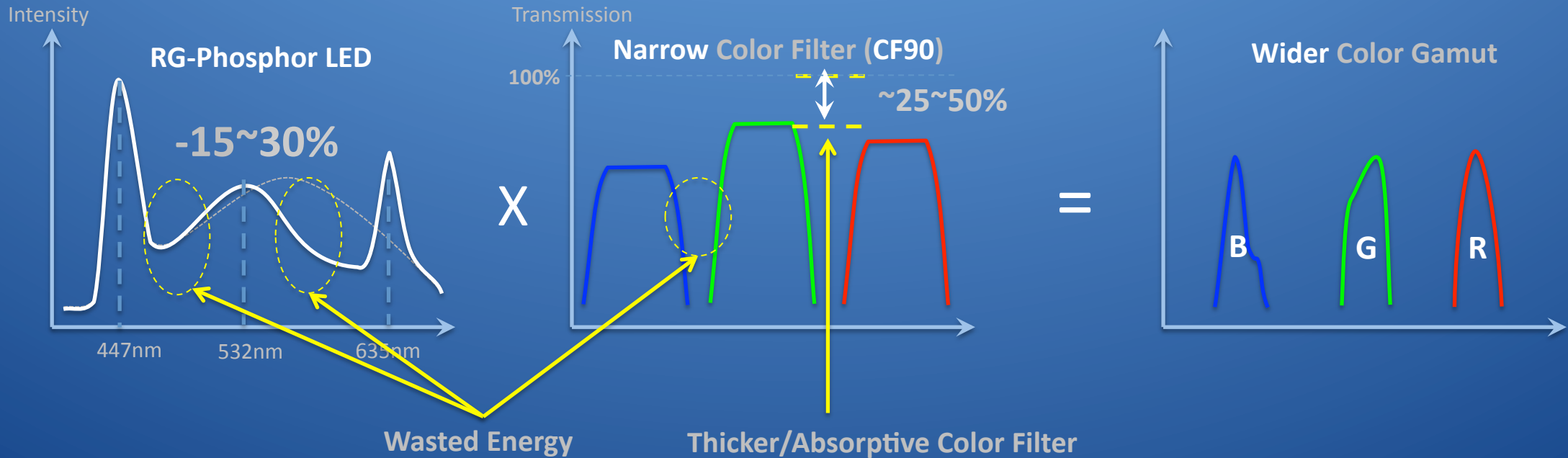


% NTSC

Match Original Brightness + Wide Gamut → 2x Backlight

“Wide Gamut” LED

Example : Nichia NS2W266F-HG

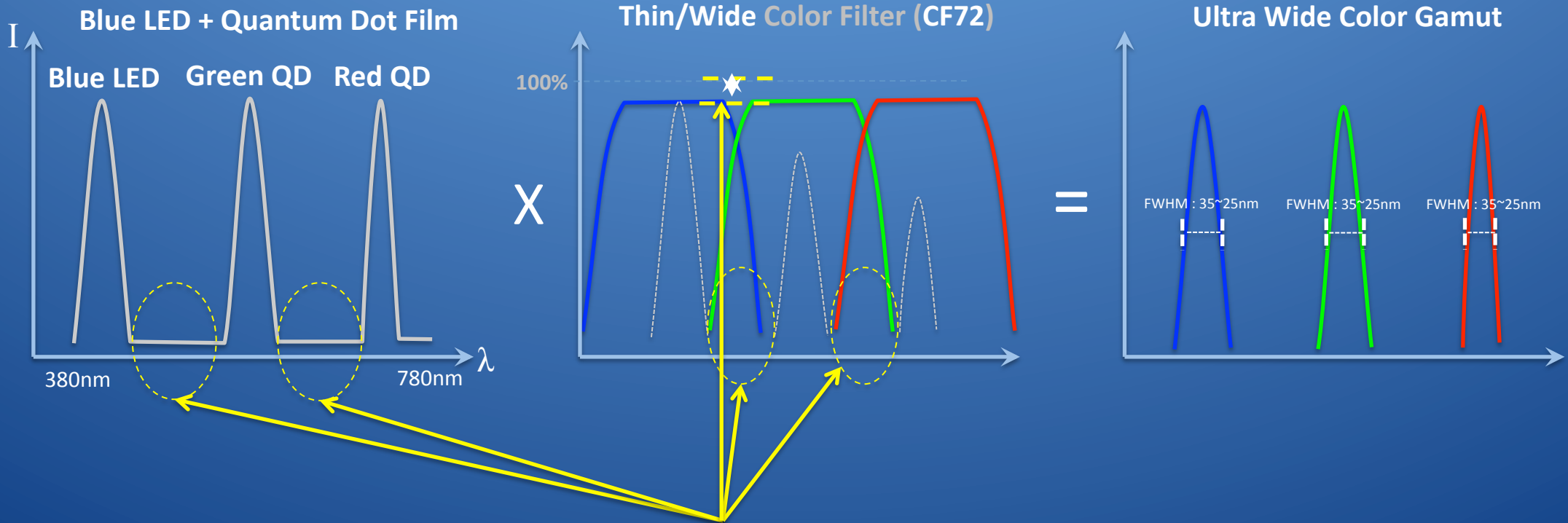


Total Backlight Power Increase : 1.8~2.4x

Example 9.7" Retina Tablet

LGD LP097QX1 \$87	Today : Max 440 cd/m ²	HDR-Only: 750 cd/m ²	10% 750 cd/m ² + 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

Quantum Dot



**Wasted energy minimized = +20~30% Efficiency Improvement ...
... but : \$\$\$ Cost, Thickness, Thermal/O₂ 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

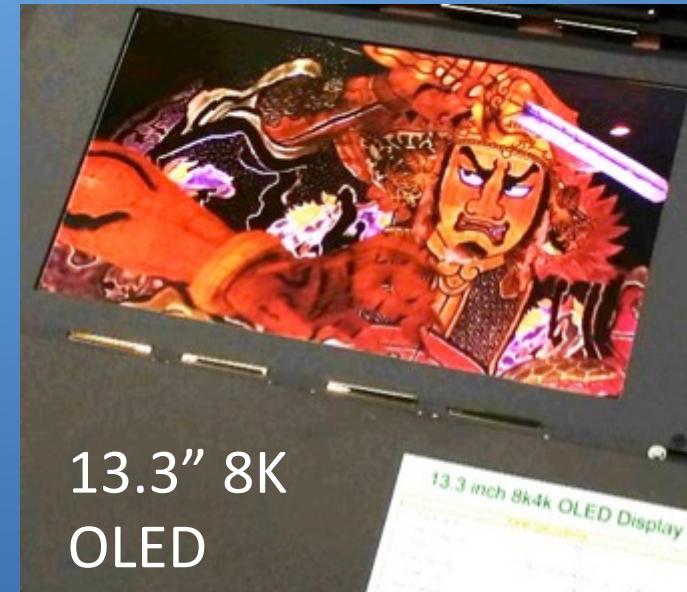
- Goal : Broadcast 2020 Olympics in 8K
- NHK & Government
- BT2020 Color Space
- HDR



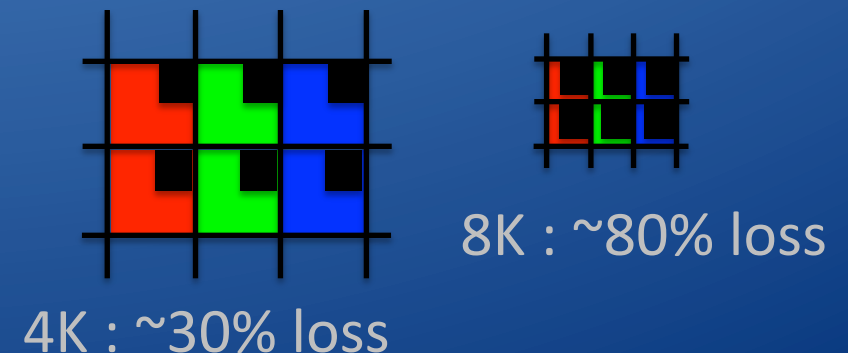
Live color grading in 8K, Astrodesign Tokyo

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



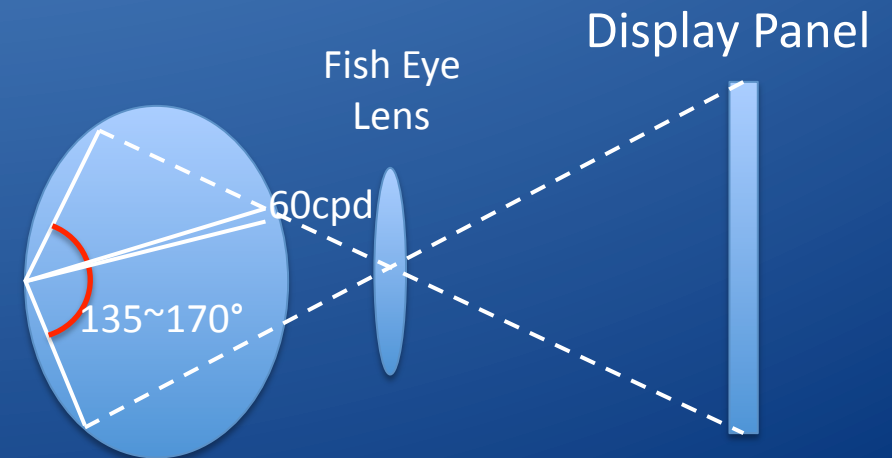
4K, 8K too much ? ... along comes VR



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 $170^\circ \times 135^\circ$
 - $10,200 \times 8,100$ 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 ?

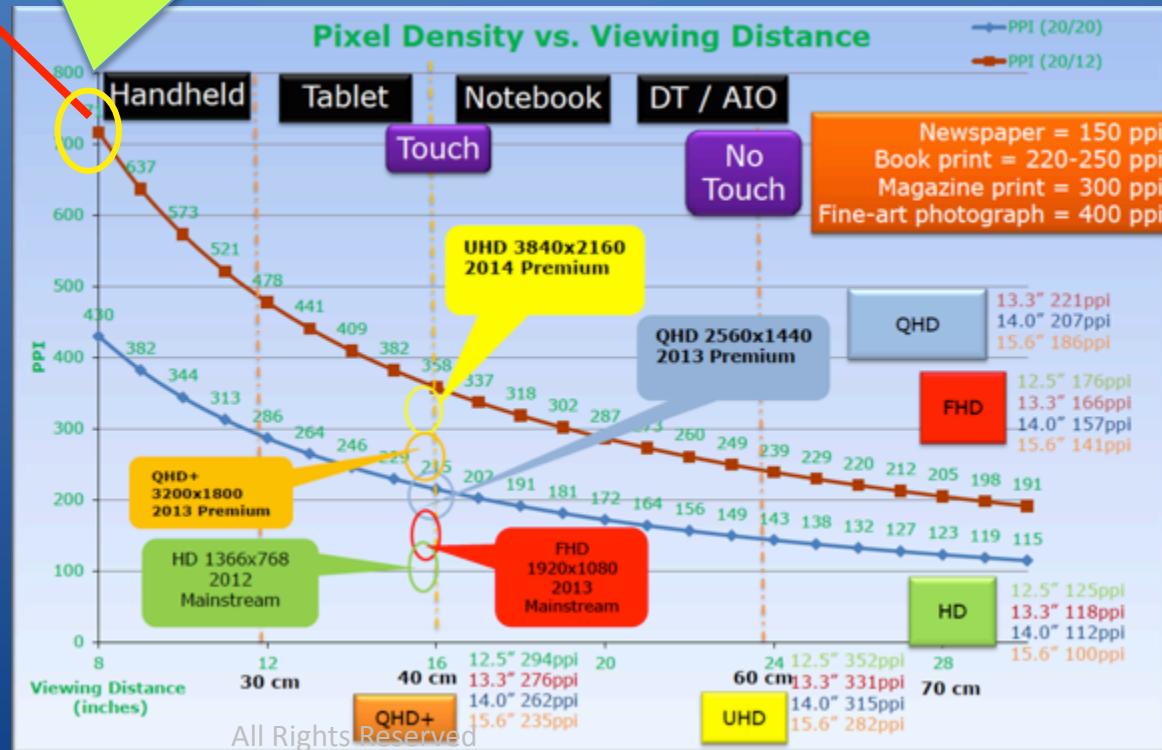
VR / HMD (SOL)

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

PLASTIC



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 Transmissivity
 - 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"

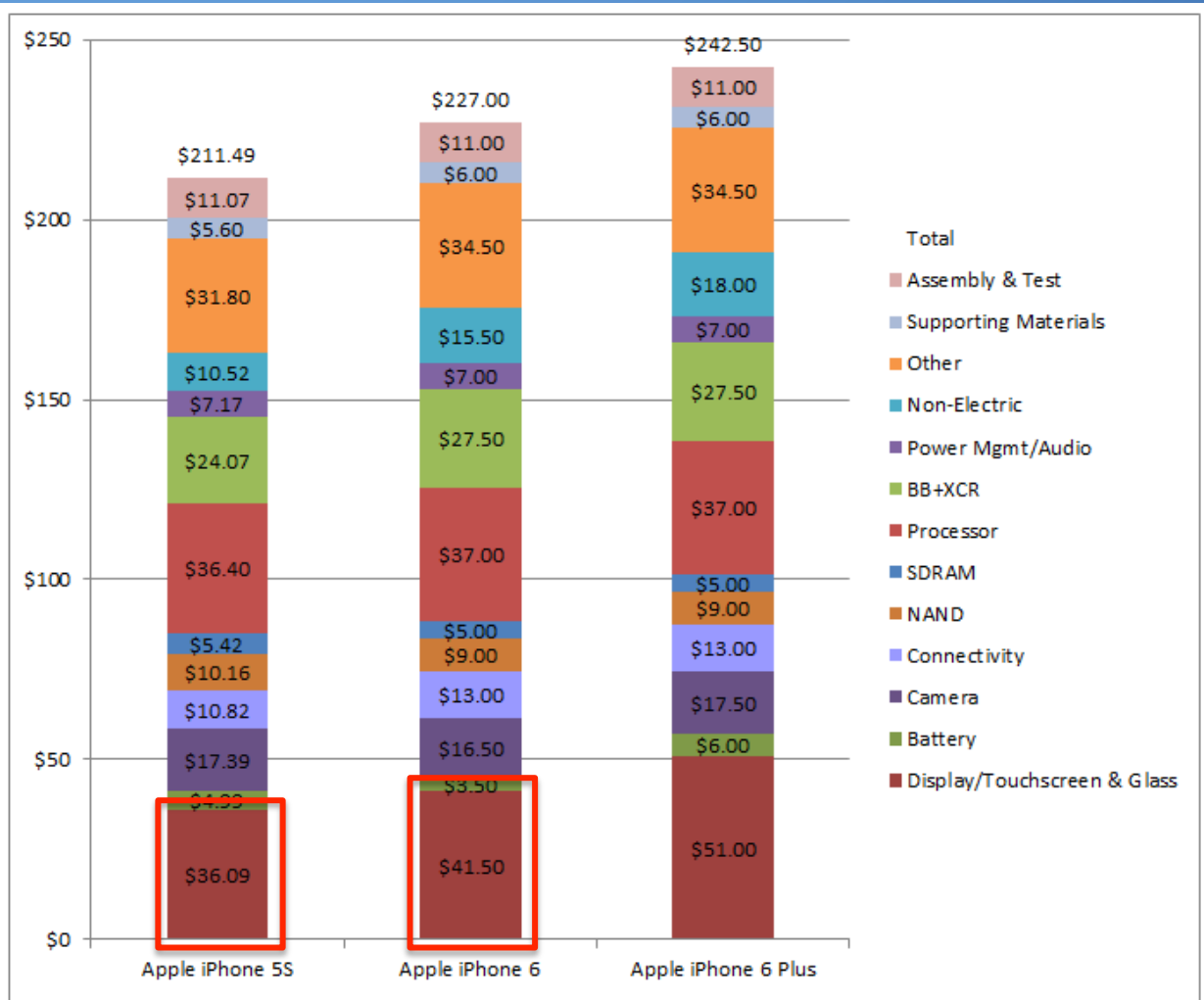
iPhone BOM Cost

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

Components / Hardware Elements	iPhone 5 Hardware Comments	iPhone 5 Model	
		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



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) [μm]
- 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 : 80°/80°/80/80°(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

Components / Hardware Elements	iPad 2		New iPad (3rd Generation)				
	WiFi	WiFi + 3G	WiFi			WiFi	
	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	\$725
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	\$10
BOM + Manufacturing	\$245.10	\$271.00	\$316.05	\$332.85	\$366.45	\$358.30	\$379
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							
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

Components / Hardware Elements	iPad Air Hardware Comments	Apple iPad Air 2					
		WiFi + Cellular			WiFi		
		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							

LPDDR3	\$6.75	\$27.00	\$54.00	\$6.75	\$27.00	\$54.00
536 IPS Mode LCD	\$18.00	\$18.00	\$18.00	\$18.00	\$18.00	\$18.00
GF2	\$77.00	\$77.00	\$77.00	\$77.00	\$77.00	\$77.00
Processor + M8 Co-processor	\$38.00	\$38.00	\$38.00	\$38.00	\$38.00	\$38.00
Price includes M8 processor	\$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
Qualcomm						

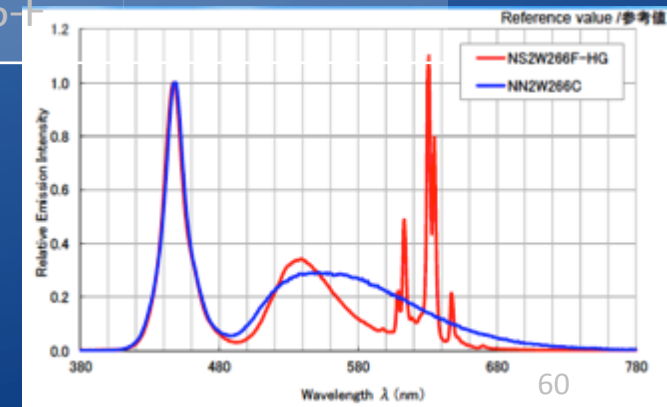
Components	Wi-Fi + Cellular				Wi-Fi			
	16GB	32GB	64GB	128GB	16GB2	32GB3	64GB4	128GB5
	\$629	\$729	\$829	\$929	\$499	\$599	\$699	\$799
	51%	56%	60%	61%	45%	53%	58%	59%
	\$304	\$313	\$325	\$355	\$269	\$278	\$290	\$320
	\$6	\$6	\$6	\$6	\$5	\$5	\$5	\$5
	\$310	\$319	\$331	\$361	\$274	\$283	\$295	\$325

Display	9.7" 2048 x 1536	\$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
Processor	64-Bit A7 Processor + M7 Co-Processor	\$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

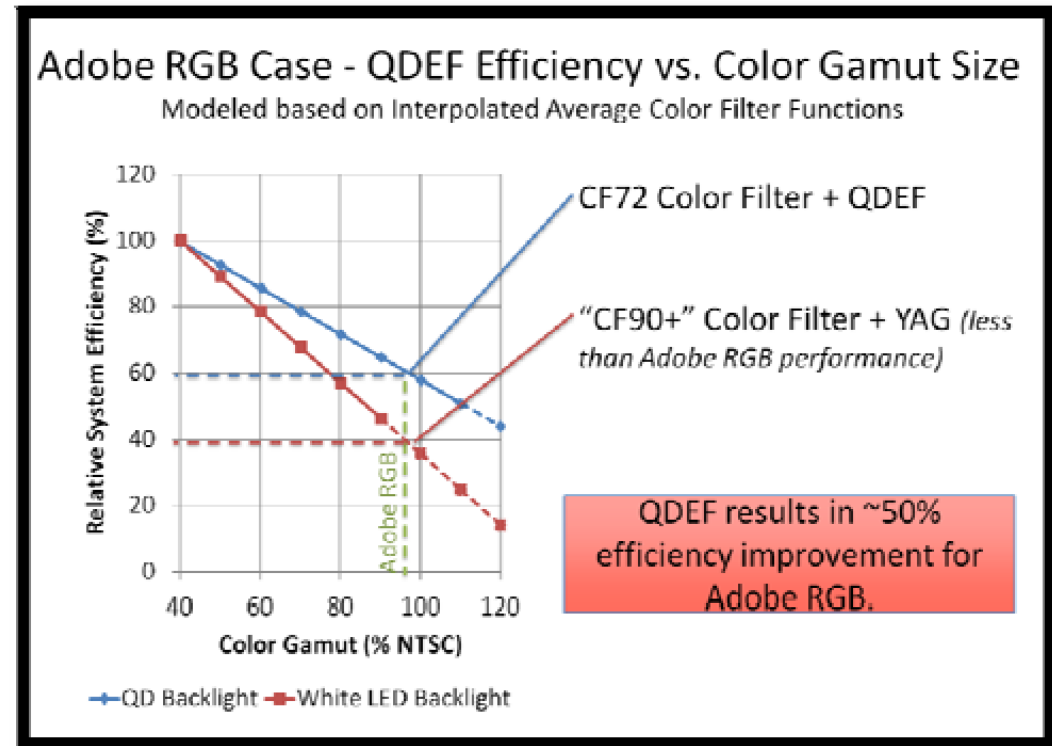


Figure 5. Modeling analysis showing relative LCD system efficiency. The Adobe RGB color gamut can be achieved using QDEF or highly saturated color filters; the QDEF displays are approximately 50 percent more energy-efficient than displays using the more saturated (CF90+) color filters.

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