Survival of the Fittest:
The Battle for the TV Market

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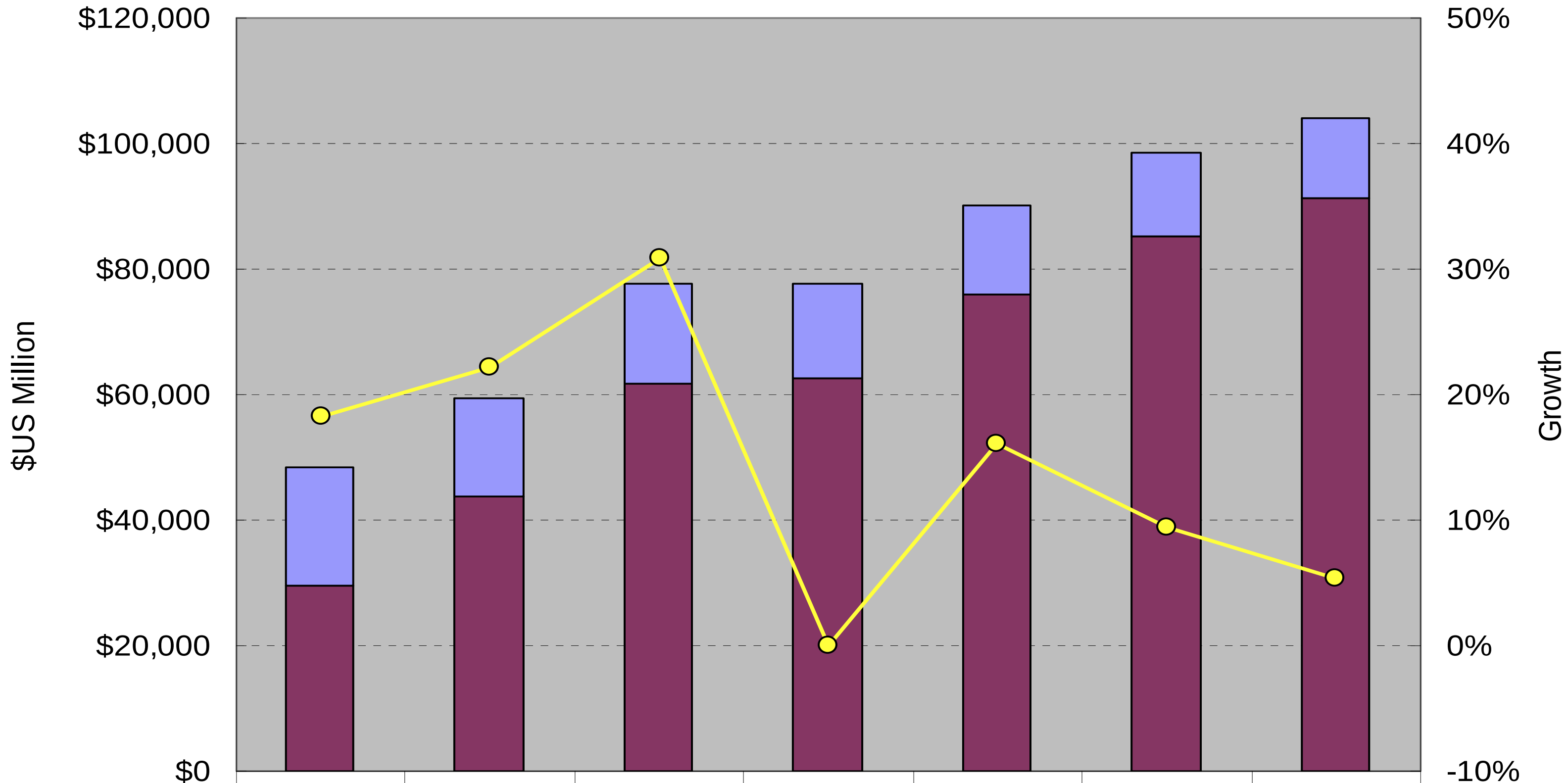
Outline

- Rapid Growth in FPD Market
  - Liquid Crystal Displays Dominate
  - TV Sales Reinvigorate PDPs
  - All Microdisplay RPTVs Gain Market Share
  - Rapid OLED Growth Stumbles
- Sales Forecasts for TV market
  - LCDs (<40”)
  - PDP (40-50”)
  - RPTV (>50”)
  - OLED (>2010)
- Performance
  - LCD vs PDP
- Costs
  - LCD and PDP
- Conclusion

Display Revenues by CRT & Flat Panel ($US Billions)

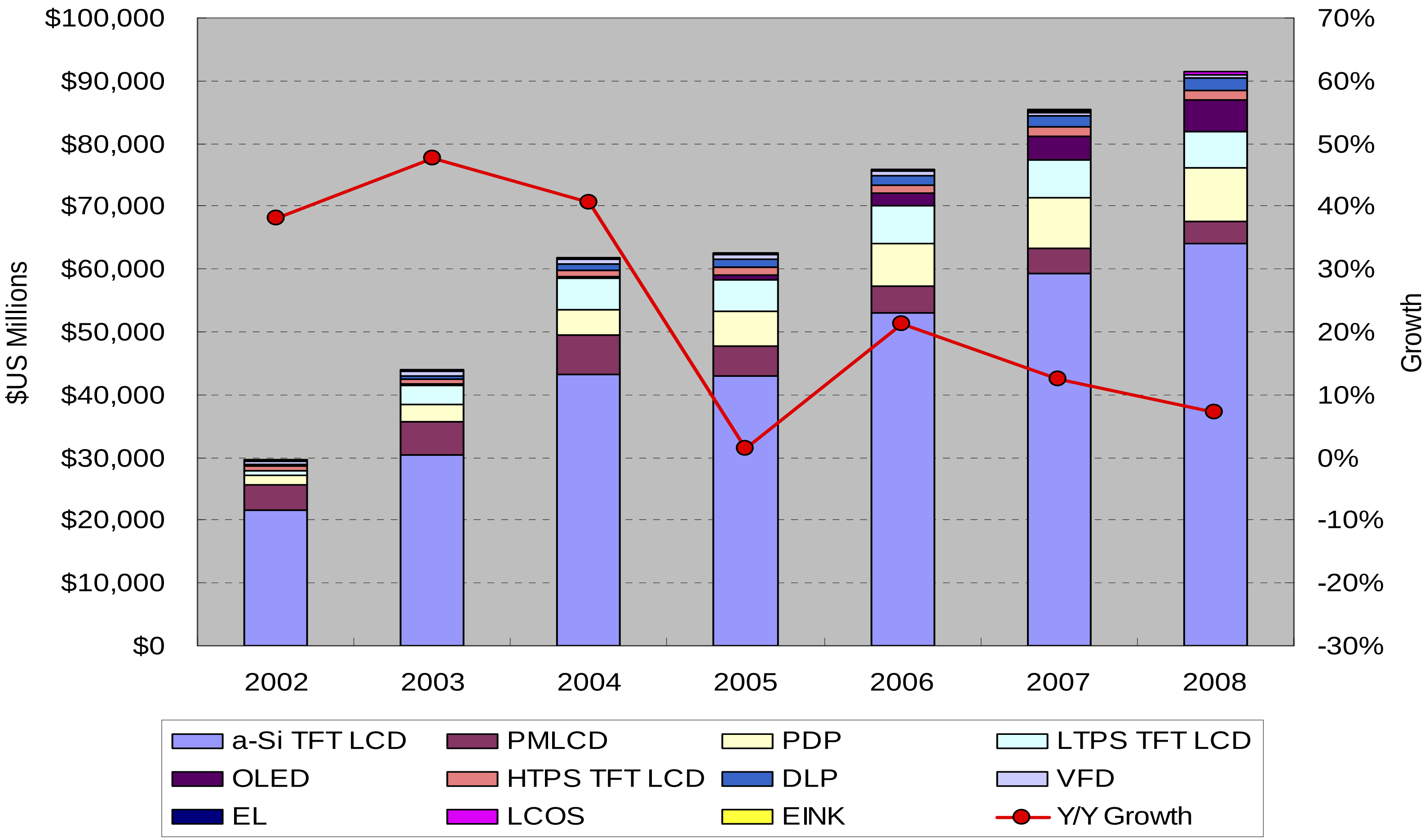
Total display revenues are forecast to grow from $59.3 B in 2003 to $103.9B by 2008. The CAGRs are: total displays 11.9%, FPDs 15.8% and CRTs –3.4%



	2002	2003	2004	2005	2006	2007	2008
CRT	$18,840	$15,428	$15,869	$15,009	$14,170	$13,304	$12,479
FPD	$29,691	$43,869	$61,705	$62,595	$75,939	$85,315	$91,446
Growth	18%	22%	31%	0%	16%	9%	5%

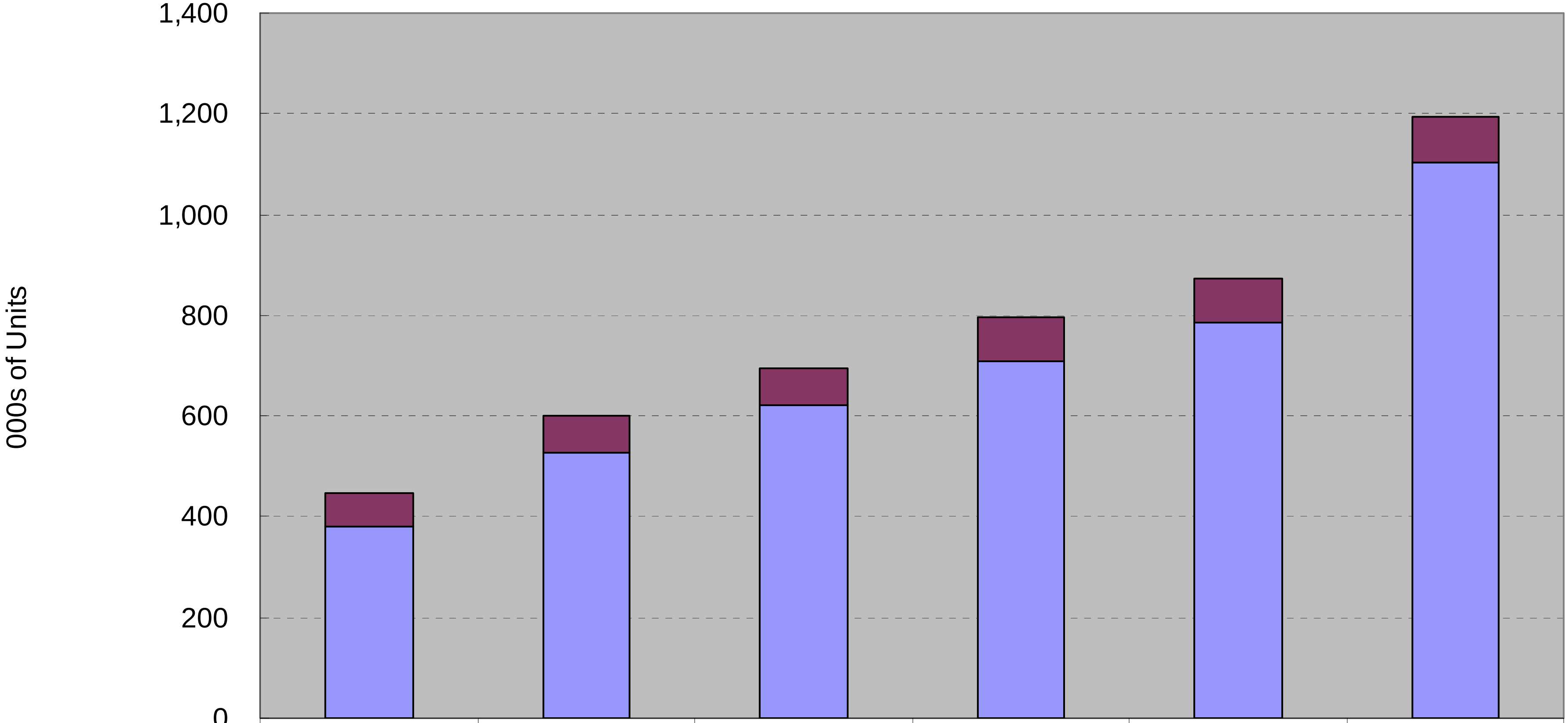
FPD Revenues by Technology ($US Millions)

a-Si TFT LCD is forecast to grow from a 69.5% share in 2003 to 69.9% in 2004, while PDPs grow from 6.4% to 6.7%, LTPS grows from 6.6% to 7.2% and PMLCDs drop from 11.9% to 9.9%. None of the other technologies have greater than a 1.4% share.



PDP Shipments by Application

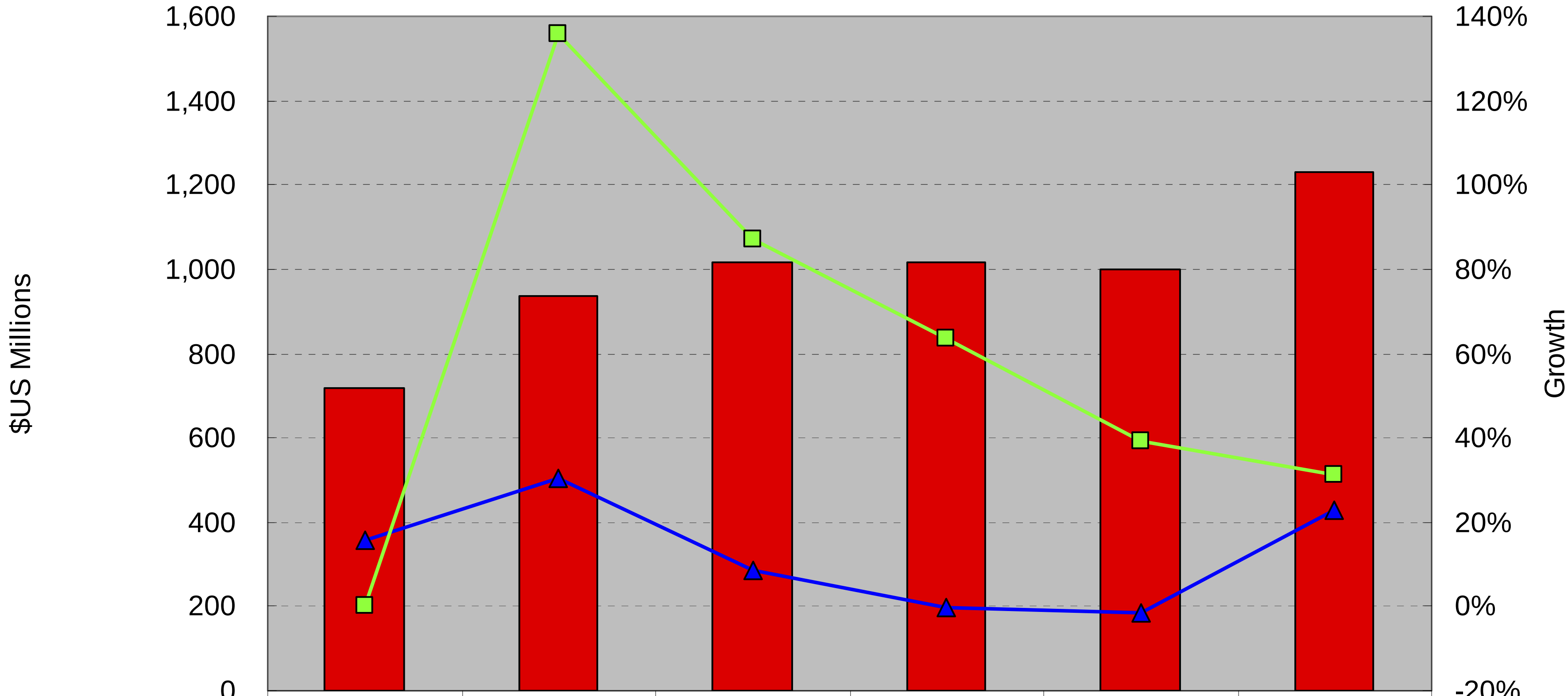
- TV module shipments surged on seasonal strength supported by lower prices. Public display shipments also continued to grow however.



	Q3'03	Q4'03	Q1'04	Q2'04	Q3'04	Q4'04
Public Display	68.7	76.5	73.0	88.7	85.9	92.5
TV	379.4	525.4	621.6	707.7	787.2	1,101.6

PDP Revenues, Q/Q and Y/Y Growth

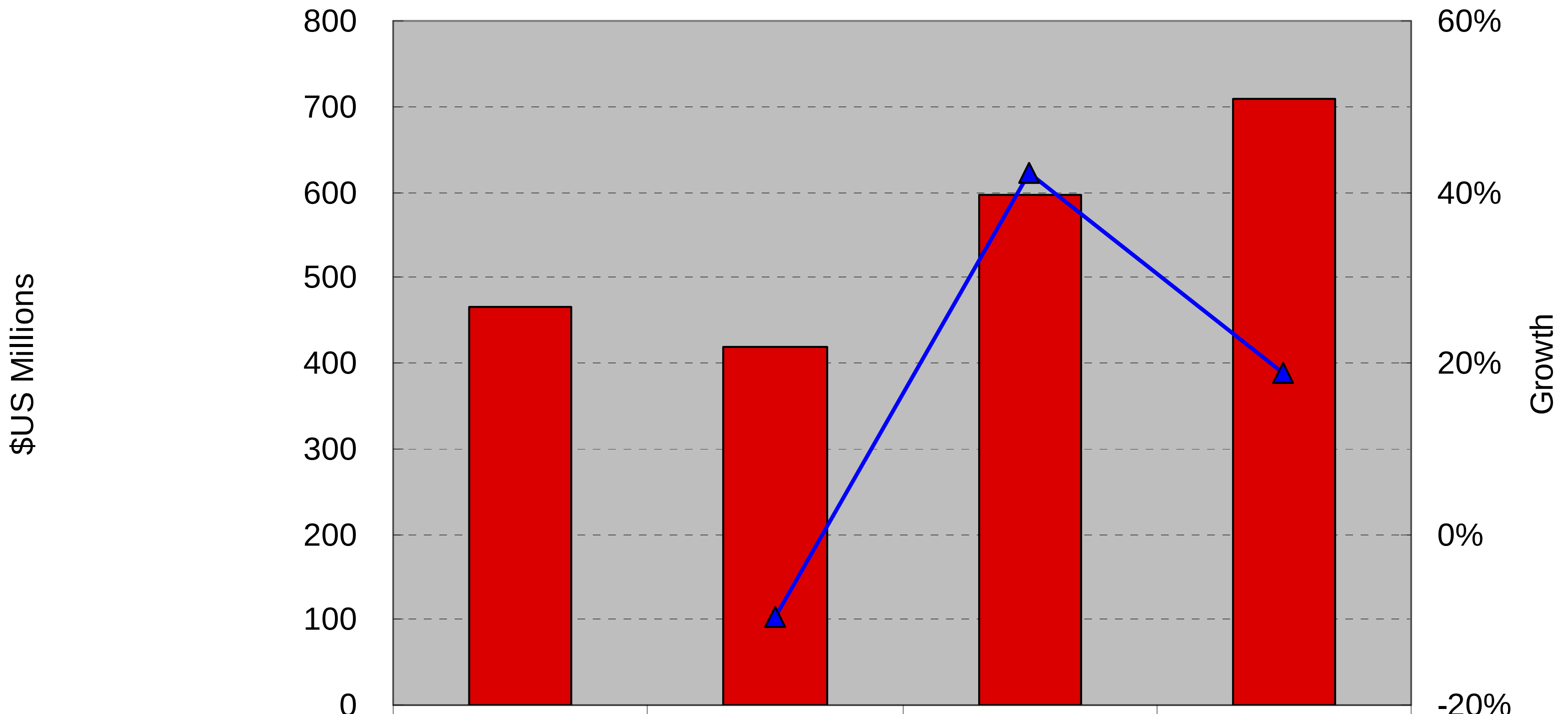
- PDP module revenues rose 23% Q/Q and 31% Y/Y in Q4'04 on higher volumes. For 2004, PDP module revenues rose 51% to $4.3B.



	Q3'03	Q4'03	Q1'04	Q2'04	Q3'04	Q4'04
Revenues	$718	$937	$1,017	$1,015	$1,001	$1,228
Q/Q Growth	16%	31%	8%	0%	-1%	23%
Y/Y Growth	0%	136%	87%	64%	39%	31%

LCD RPTV Revenues and Growth

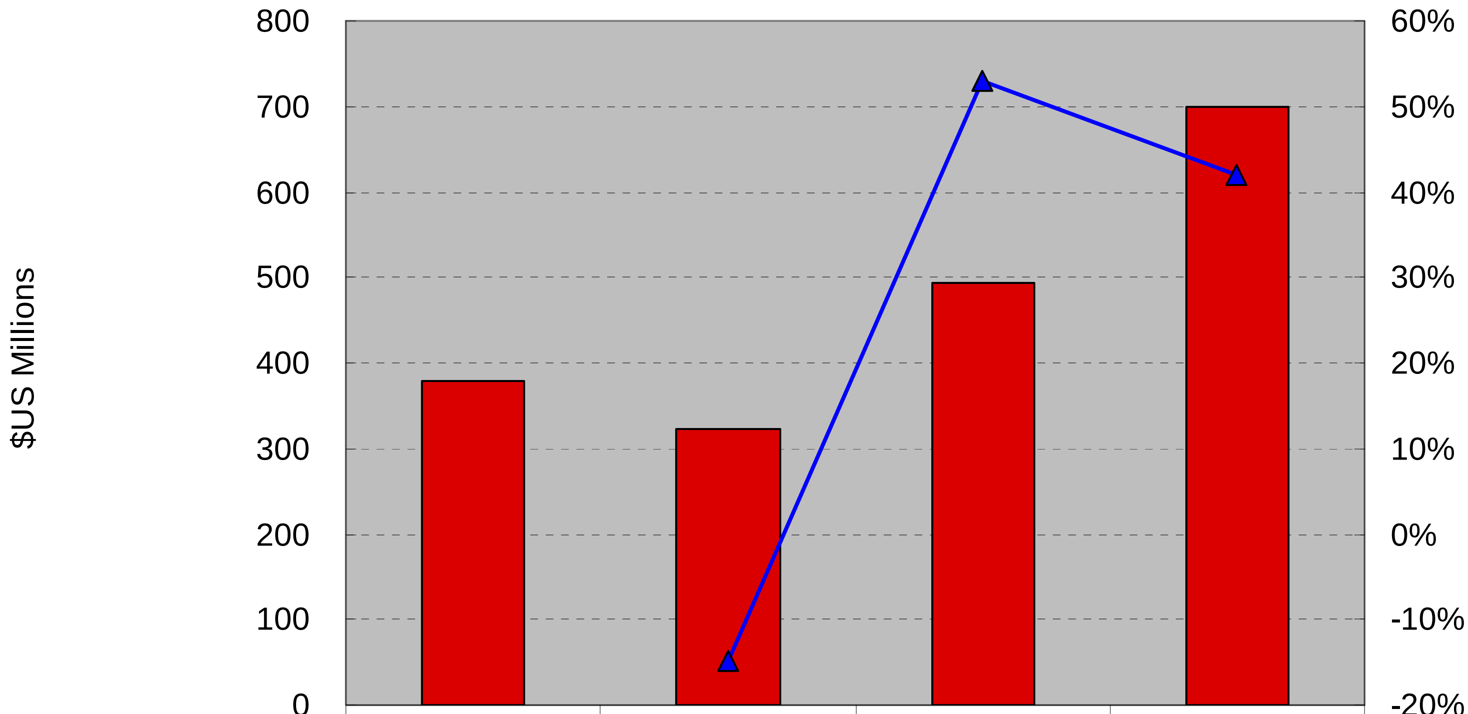
- Revenues for LCD RPTV grew by 42% in Q3’04 to $596M.
- We expect revenue growth to trail unit growth in Q4’04 as prices fall more aggressively to sell-through the significant Q3’04 sell-in growth.



	Q1'04	Q2'04	Q3'04	Q4'04
Revenues	$464.5	$419.2	$596.4	$709.3
Sequential Growth		-10%	42%	19%

DLP RPTV Revenues and Growth

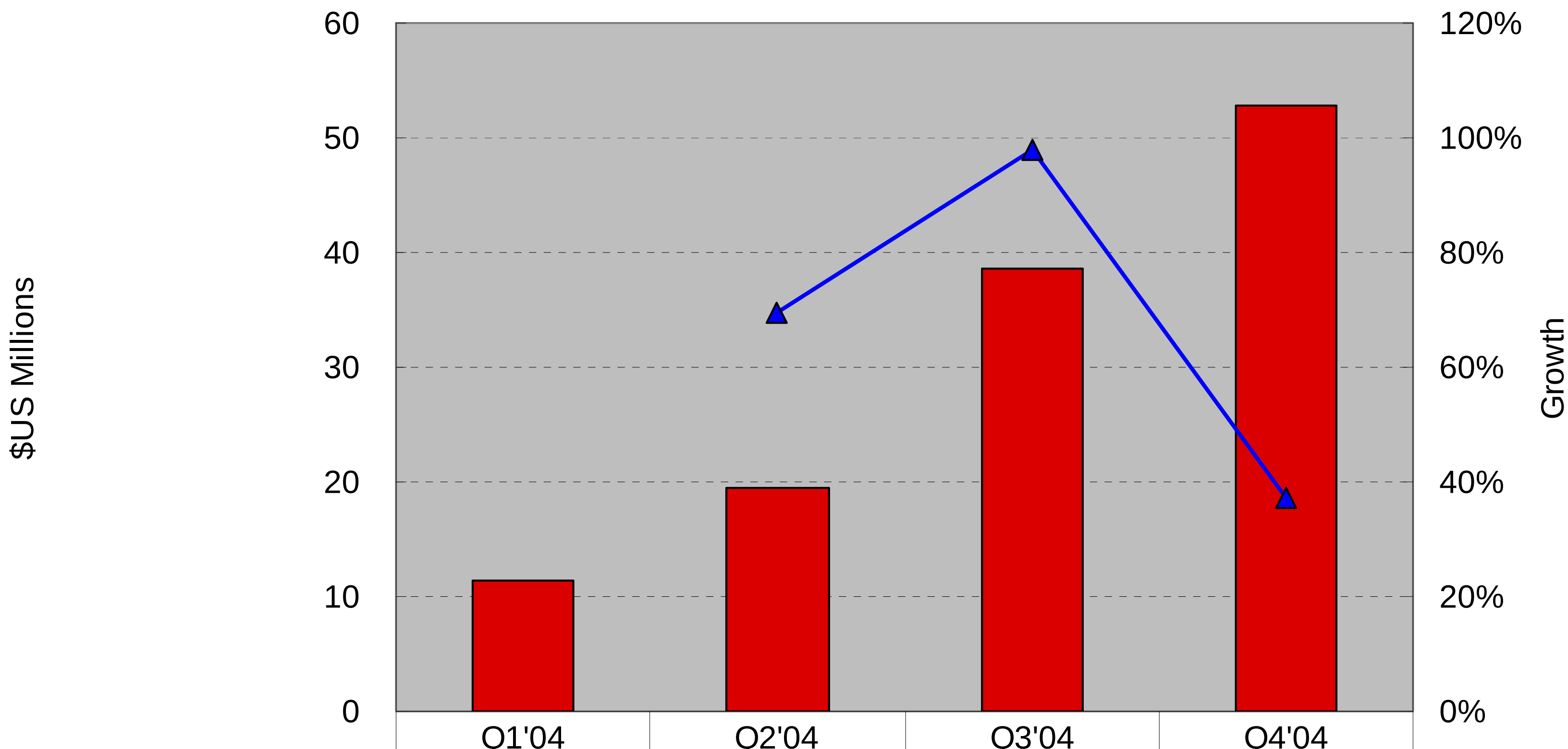
- Revenue growth kept pace with unit growth in Q3'04. Revenues grew by 53% to $493M for the quarter. We expect growth to remain robust in Q4'04 with a 42% rate of growth to $700M for that quarter.



	Q1'04	Q2'04	Q3'04	Q4'04
Revenues	$378.4	$322.3	$492.8	$699.9
Sequential Growth		-15%	53%	42%

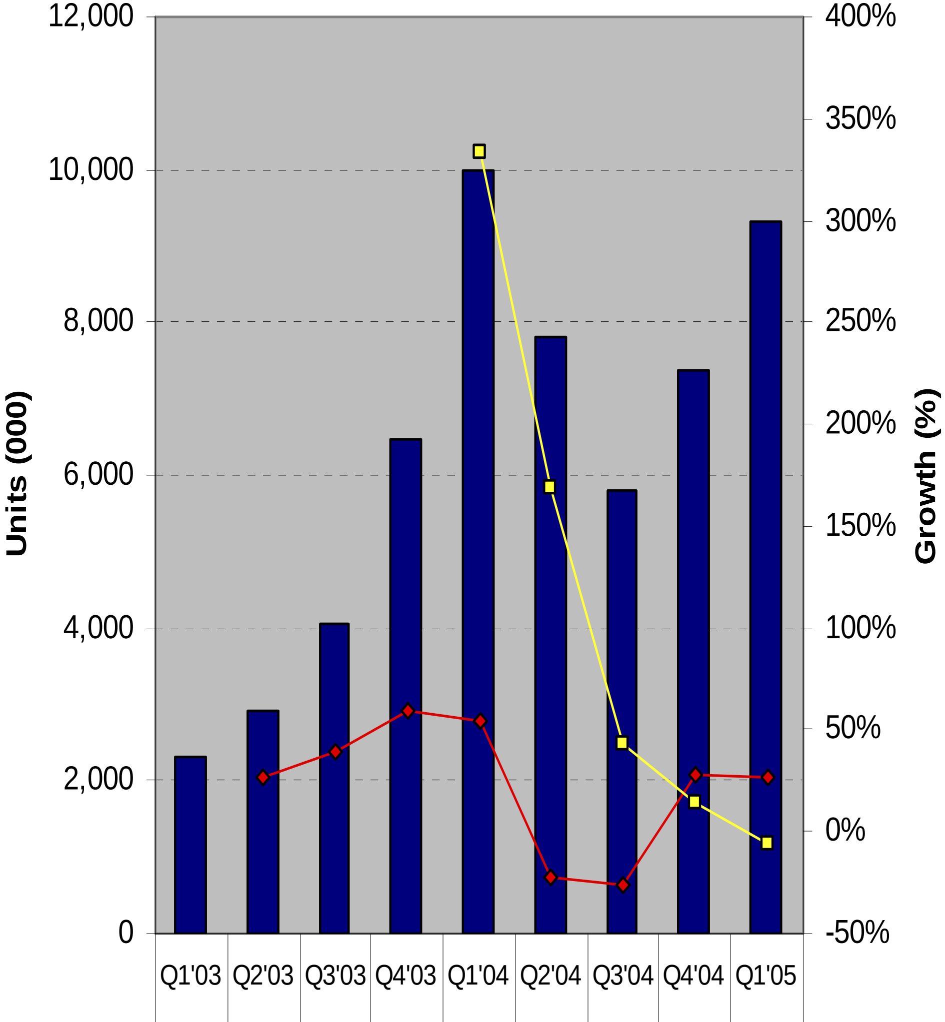
LCOS RPTV Revenues and Growth

- On a percentage basis, revenues did not outgrow units in Q3’04 as price pressures competing RP technologies applies downward pressure on LCOS RPTVs. We forecast unit growth to continue to outpace revenue growth as prices continue to fall.

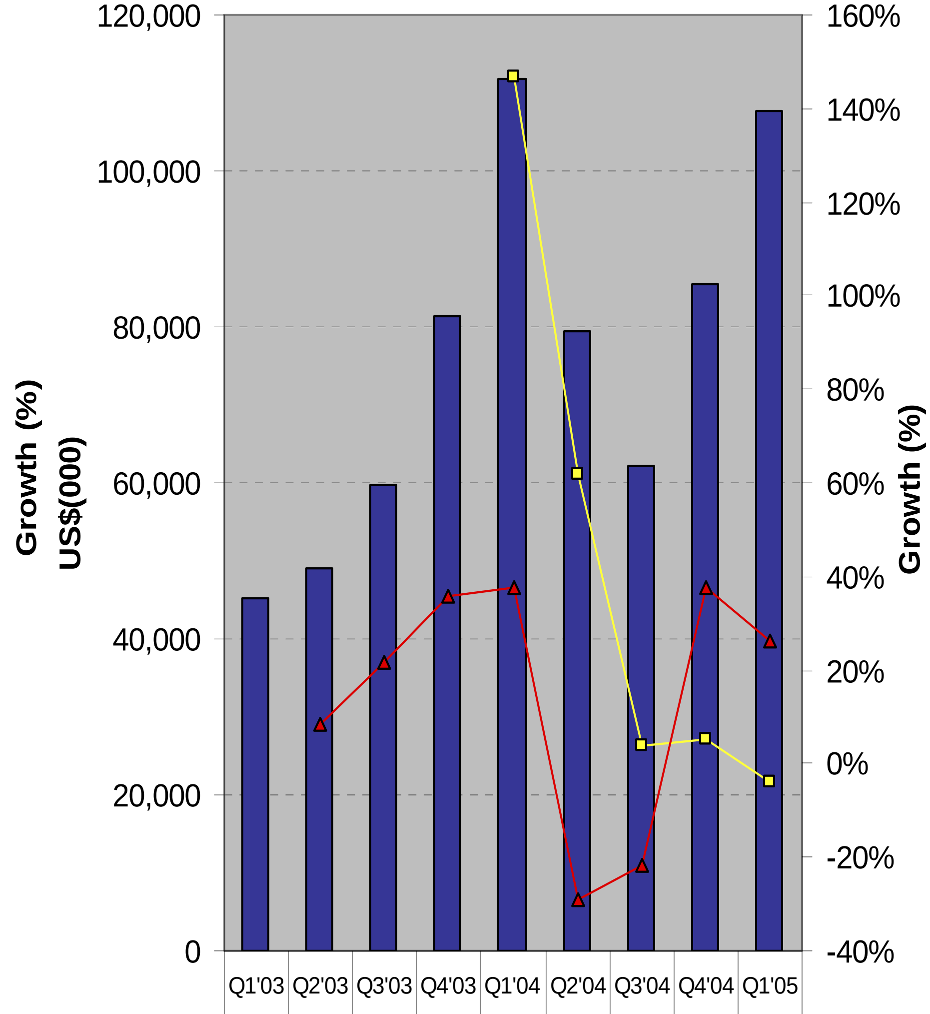


	Q1'04	Q2'04	Q3'04	Q4'04
Revenues	$11.5	$19.5	$38.5	$52.8
Sequential Growth		70%	98%	37%

OLED Shipments &Revenue

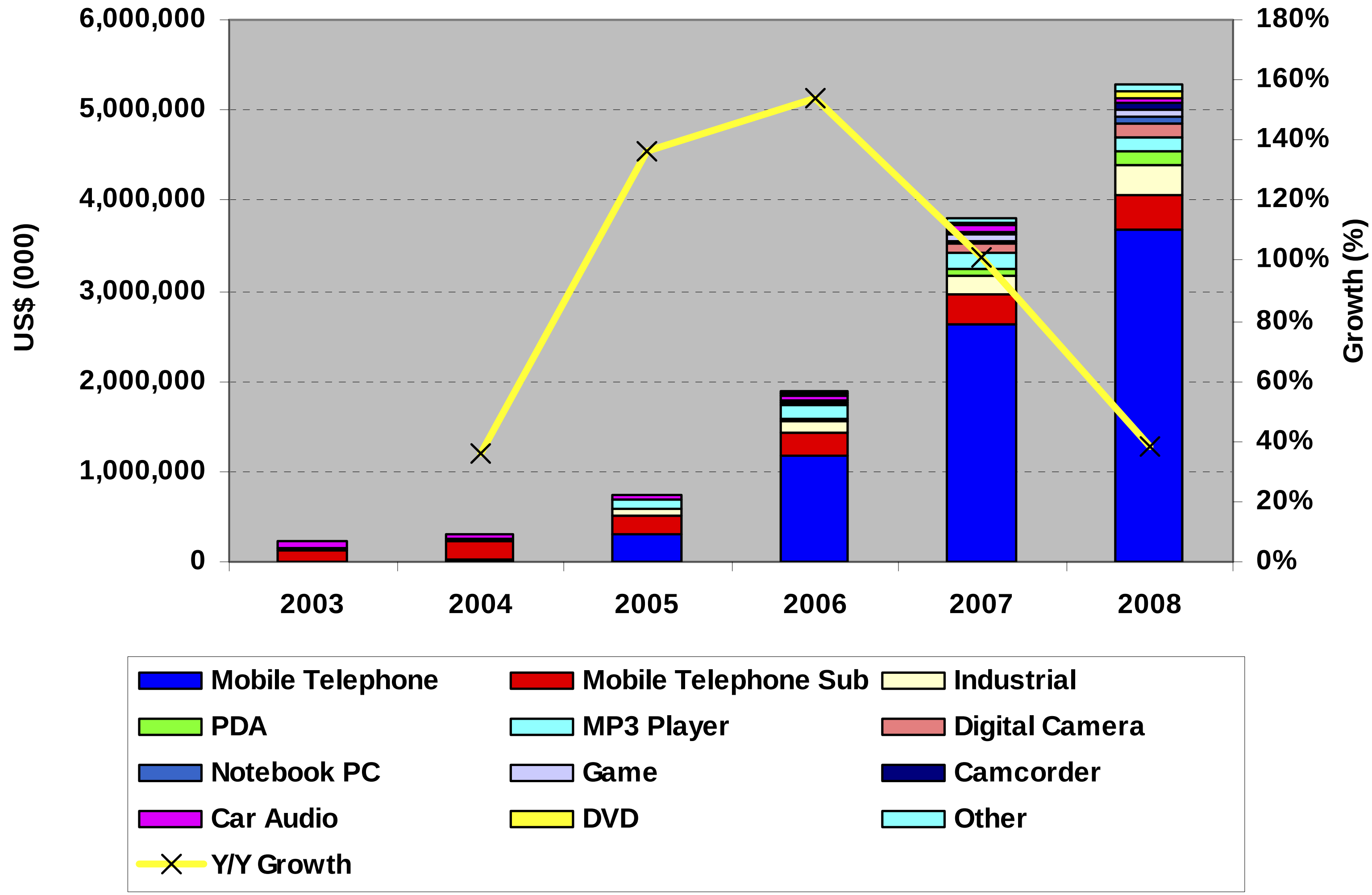


	Q1'03	Q2'03	Q3'03	Q4'03	Q1'04	Q2'04	Q3'04	Q4'04	Q1'05
Total	2,302	2,906	4,052	6,475	9,987	7,806	5,801	7,387	9,335
Y/Y growth					334%	169%	43%	14%	-7%
Q/Q Growth		26%	39%	60%	54%	-22%	-26%	27%	26%



	Q1'03	Q2'03	Q3'03	Q4'03	Q1'04	Q2'04	Q3'04	Q4'04	Q1'05
Total	45,33	49,10	59,83	81,24	111,8	79,53	62,07	85,41	107,6
Q/Q Growth		8%	22%	36%	38%	-29%	-22%	38%	26%
Y/Y Growth					147%	62%	4%	5%	-4%

OLED Revenue Forecast (US$000)

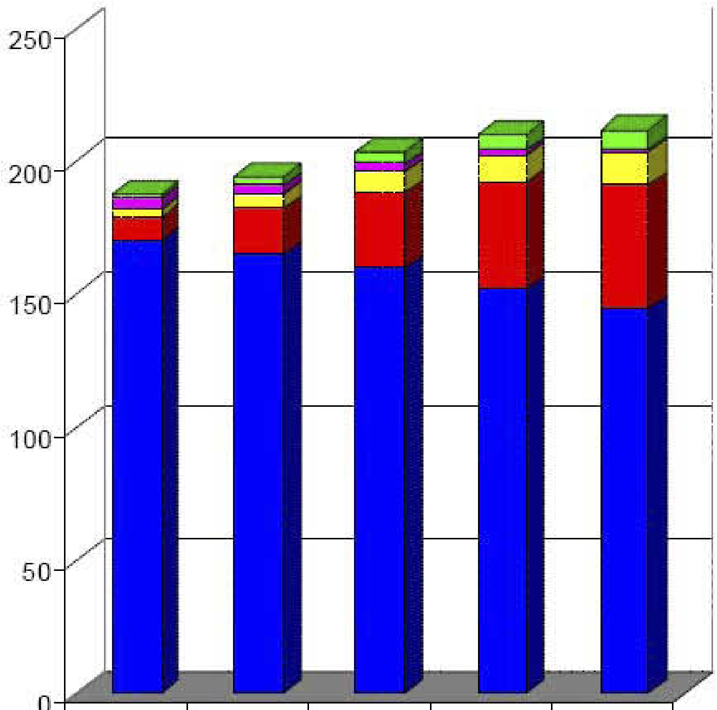


TV Shipments by Technology (Millions)

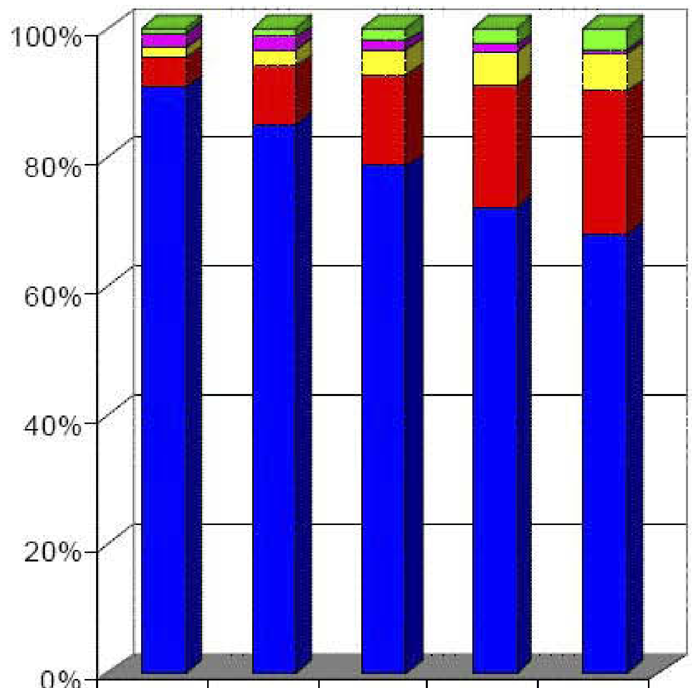
DISPLAYSEARCH

- CRTs and CRT RPTVs to decline, all other segments to grow at 40"+ CAGR. MD-RPTVs to overtake CRT RPTVs next year.

Tech.	CAGR
CRT	-4%
LCD	52%
PDP	44%
CRT RP	-25%
MD RP	46%
Total	3%



	2004	2005	2006	2007	2008
MD RPTVs	1.6	3.1	4.3	5.7	7.2
CRT RPTVs	4.1	3.6	2.8	2.1	1.3
PDPs	2.8	5.0	7.8	10.4	12.2
LCDs	8.8	17.5	28.9	39.9	46.8
CRTs	170.6	165.2	159.8	152.2	144.6



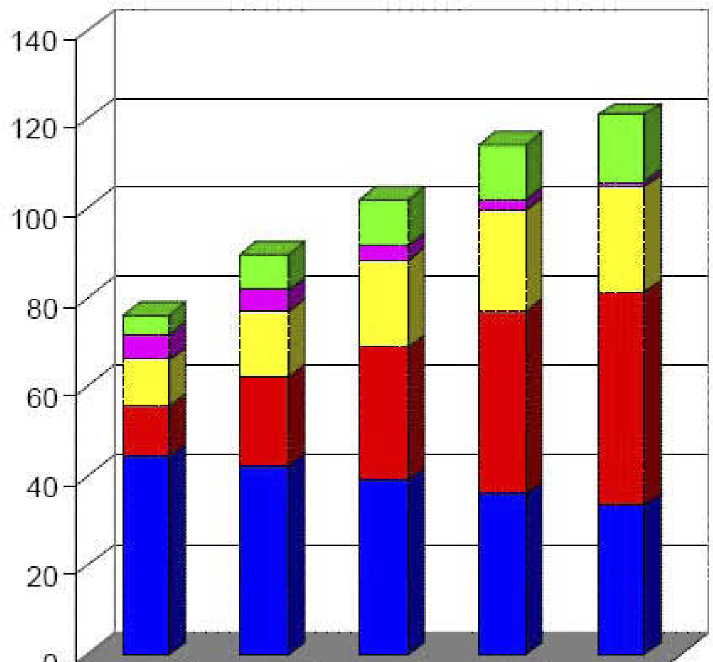
	2004	2005	2006	2007	2008
MD RPTVs	0.9%	1.6%	2.1%	2.7%	3.4%
CRT RPTVs	2.2%	1.8%	1.4%	1.0%	0.6%
PDPs	1.5%	2.6%	3.8%	4.9%	5.7%
LCDs	4.7%	9.0%	14.2%	19.0%	22.1%
CRTs	90.8%	85.0%	78.5%	72.4%	68.2%

TV Revenues by Technology

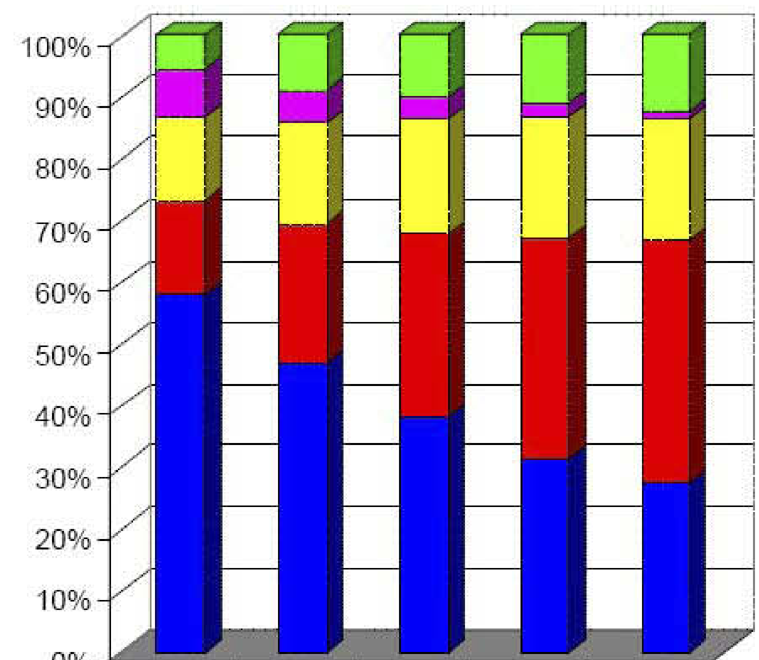
DISPLAYSEARCH

- Non-CRT technologies to occupy a majority of the market on a revenue basis from 2006.

	CAGR
CRTs	-7%
LCDs	42%
PDPs	24%
CRT RPTVs	-30%
MD RPTVs	37%
Total	12%



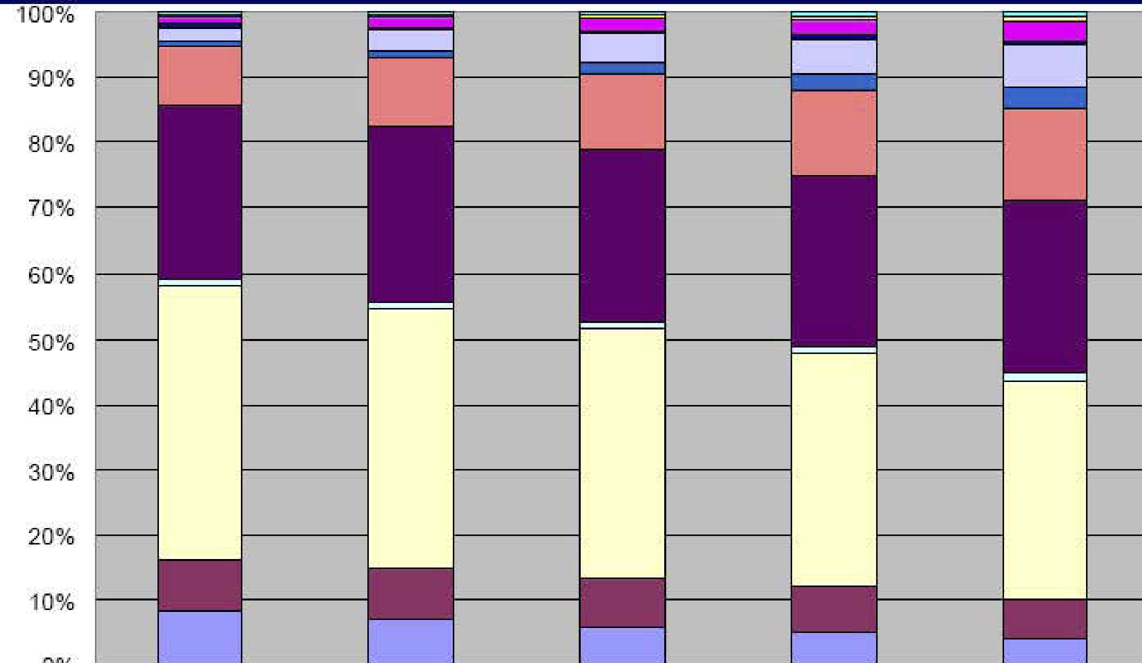
	2004	2005	2006	2007	2008
MD RPTVs	$4.2	$8.1	$10.2	$12.6	$14.9
CRT RPTVs	$5.9	$4.6	$3.4	$2.4	$1.4
PDPs	$10.1	$14.8	$19.3	$22.6	$23.6
LCDs	$11.7	$20.1	$30.1	$41.0	$47.9
CRTs	$44.1	$42.2	$39.1	$36.0	$33.3



	2004	2005	2006	2007	2008
MD RPTVs	5.5%	9.0%	10.0%	11.0%	12.3%
CRT RPTVs	7.8%	5.2%	3.3%	2.1%	1.2%
PDPs	13.3%	16.5%	18.9%	19.8%	19.5%
LCDs	15.4%	22.3%	29.5%	35.7%	39.5%
CRTs	58.0%	47.0%	38.3%	31.4%	27.5%

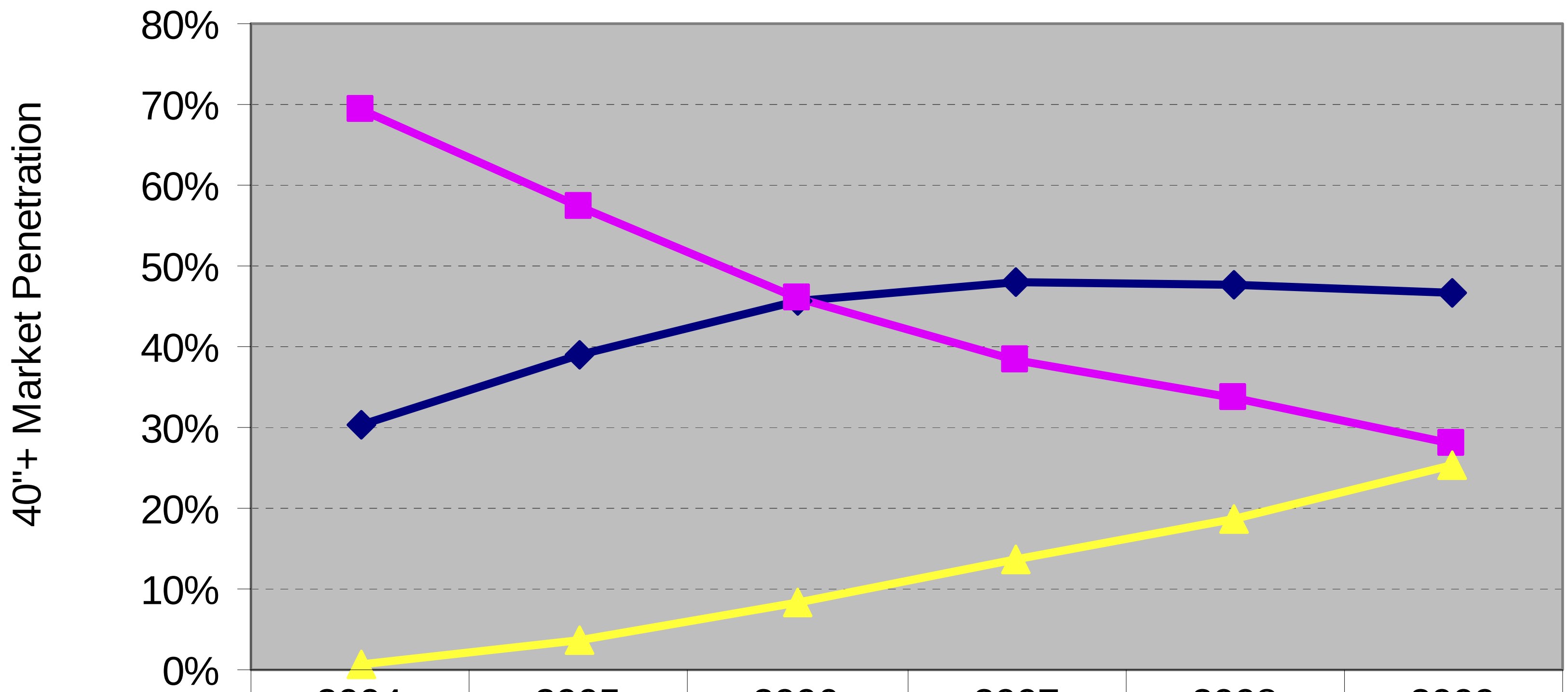
TV Shipments by Size (% Basis)

Size Category	CAGR
10"-14"	-13%
15"-19"	-5%
20"-21"	-2%
22"-24"	2%
25"-29"	3%
30"-34"	15%
35"-39"	45%
40"-44"	36%
45"-49"	4%
50"-54"	32%
55"-59"	14%
60"+	46%
Total	3%



	2004	2005	2006	2007	2008
60"+	0.2%	0.3%	0.4%	0.6%	0.8%
55"-59"	0.5%	0.5%	0.5%	0.6%	0.7%
50"-54"	1.1%	1.5%	1.9%	2.4%	3.0%
45"-49"	0.4%	0.4%	0.4%	0.4%	0.4%
40"-44"	2.2%	3.1%	4.3%	5.6%	6.6%
35"-39"	0.8%	1.2%	1.8%	2.4%	3.0%
30"-34"	9.2%	10.5%	11.8%	13.1%	14.4%
25"-29"	26.5%	26.7%	26.3%	26.1%	26.4%
22"-24"	0.9%	1.0%	1.0%	1.0%	0.9%
20"-21"	41.9%	39.7%	37.8%	35.8%	33.8%
15"-19"	8.0%	7.7%	7.5%	6.9%	5.8%
10"-14"	8.3%	7.3%	6.2%	5.2%	4.3%

Market Shares for Large-Screen TV (>40”)

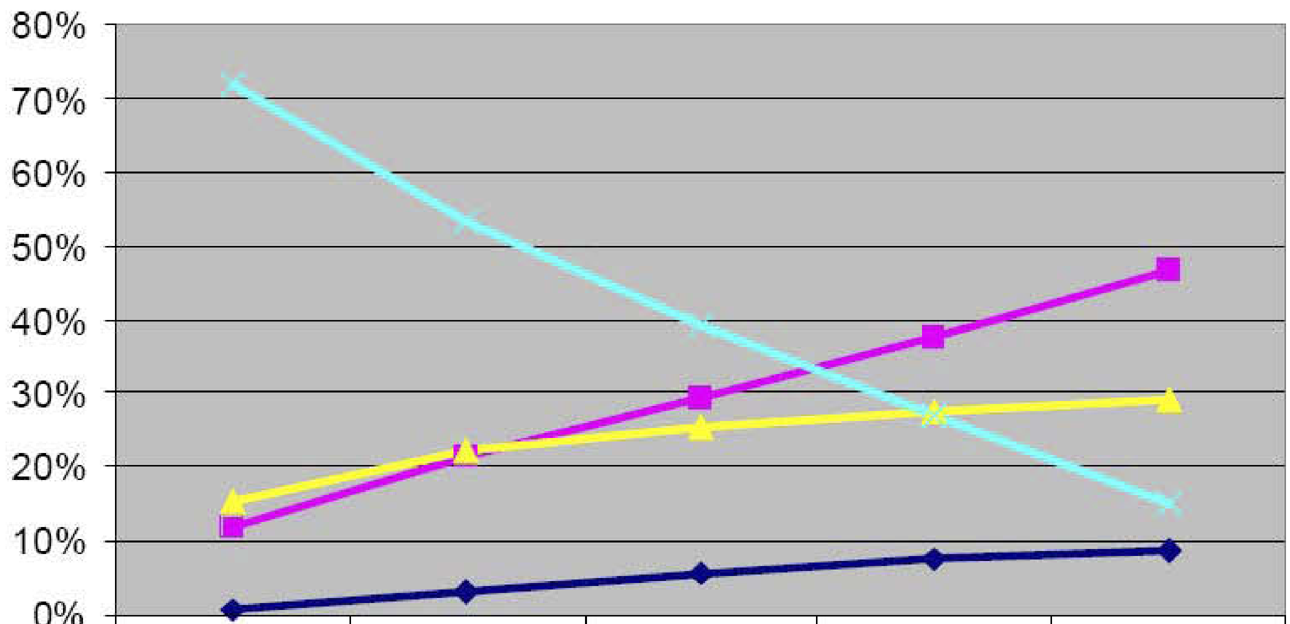


	2004	2005	2006	2007	2008	2009
PDPs	30%	39%	45.6%	48%	48%	47%
RPTVs	69%	57%	45.9%	38%	34%	28%
LCDs	1%	4%	8%	14%	19%	25%

RPTV Forecast by Technology

- Larger number of major brands along with:
  - Cost reduction and resolution improvement through SmoothPicture
  - Sony shifting some volume to LCOS

Should enable DLP to earn the top position in RPTVs.



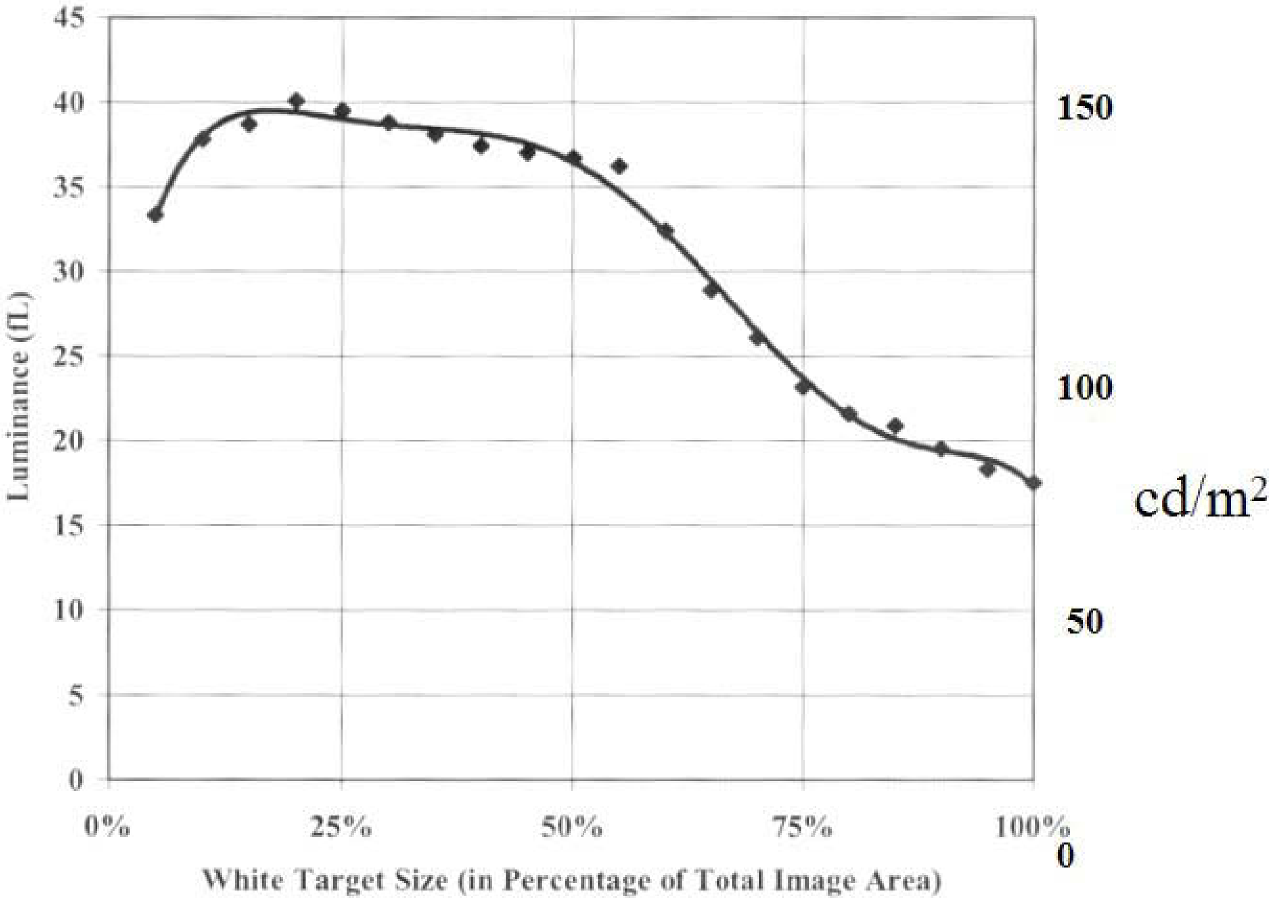
	2004	2005	2006	2007	2008
LCOS	1%	3%	6%	8%	9%
DLP	12%	21%	30%	38%	47%
LCD	15%	22%	26%	28%	29%
CRTs	72%	53%	39%	27%	15%

Performance: LCDs vs PDPs

- Brightness
- Contrast
- Viewing Angle
- Color
- Power Consumption
- Lifetime

Brightness Specs Can Be Misleading

Measurements on a PDP at NIDL (Sarnoff)



The Spec Sheet for this panel claims 560 cd/m^2

Brightness Measurements

Luminance of FPD TVs

Device		全画面白最大輝度 Full Area Max White (cd/m2)				ピーク最大輝度 Peak Max White (cd/m2)			
		'03 / 9	'04 / 3	'04 / 7	'05 / 3	'03 / 9	'04 / 3	'04 / 7	'05 / 3
LCD		32"	17"~ 32"	32"~ 45"	32"~ 46"	32"	17"~ 32"	32"~ 45"	32"~ 46"
		420 ~ 500	370 ~ 525	340 ~ 510	380 ~ 510	420 ~ 500	370 ~ 525	340 ~ 510	380 ~ 510
PDP		42"		42"~ 55"	42"~ 50"	42"		42"~ 55"	42"~ 50"
		71 ~ 100		55 ~ 80	55 ~ 70	320 ~ 400		250 ~ 400	250 ~ 330
CRT	20"	~ 140				~1500			
	32"	~110				~ 500			

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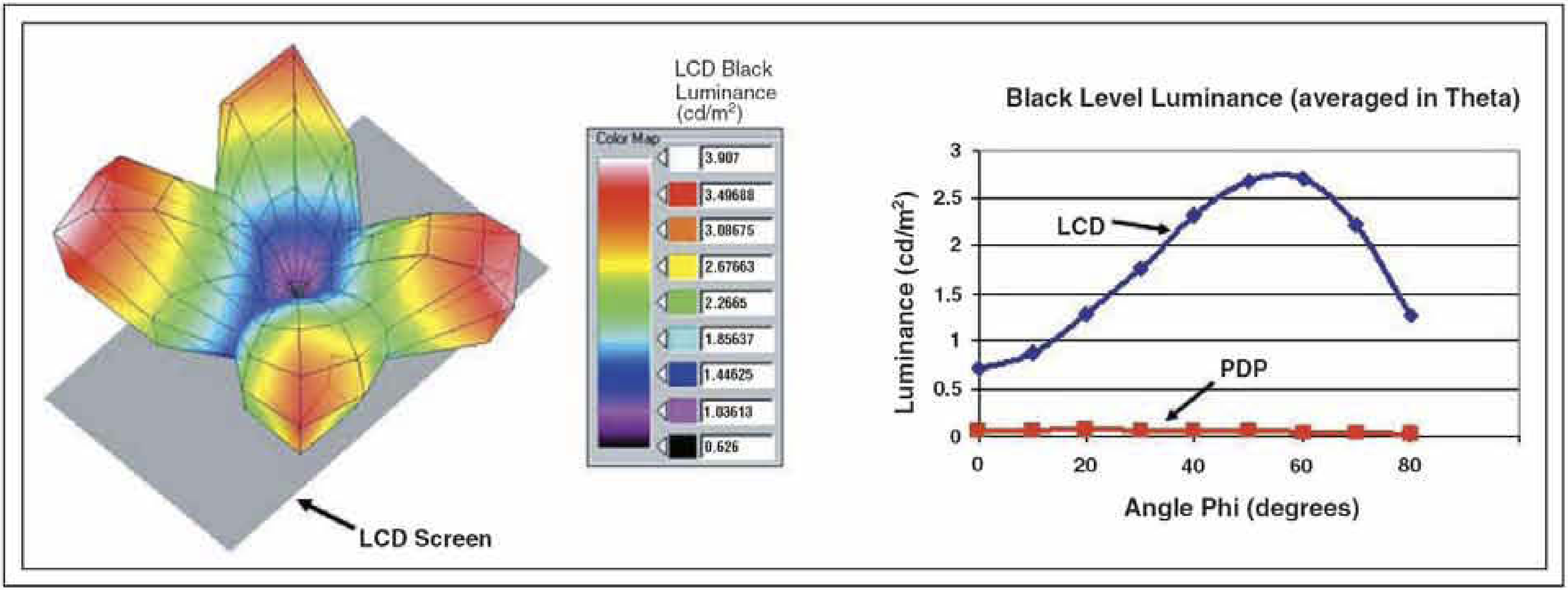
Black Levels



Source: Larry Weber

Contrast Measurements

Max Contrast (Dark Room)

Device		Full Area Max White (: 1)				Small Area Max White (Peak Brightness) (: 1)			
		’03 / 9	’04 / 3	’04 / 7	’05 / 3	’03 / 9	’04 / 3	’04 / 7	’05 / 3
LCD		32“	17“~ 32”	32“~ 45”	32“~ 46”	32“	17“~ 32”	32“~ 45”	32“~ 46”
		500 ~ 1390	260 ~ 1550	530 ~ 1300	500 ~ 1520	500 ~ 1390	260 ~ 1550	530 ~ 1300	500 ~ 1520
PDP		42“		42“~ 55”	42“~ 50”	42“		42“~ 55”	42“~ 50”
		180 ~ 550		120 ~ 380		640 ~ 2500		520 ~ 1750	860 ~ 2900
CRT	20”	5000 ~				10000 ~			
	32”								

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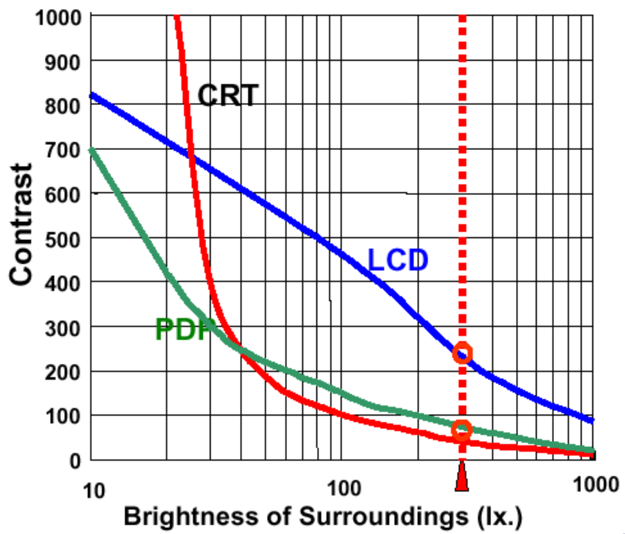
Contrast Ratio in Bright Rooms

CONTRAST COMPARISON of LCD VS CRT/PDP

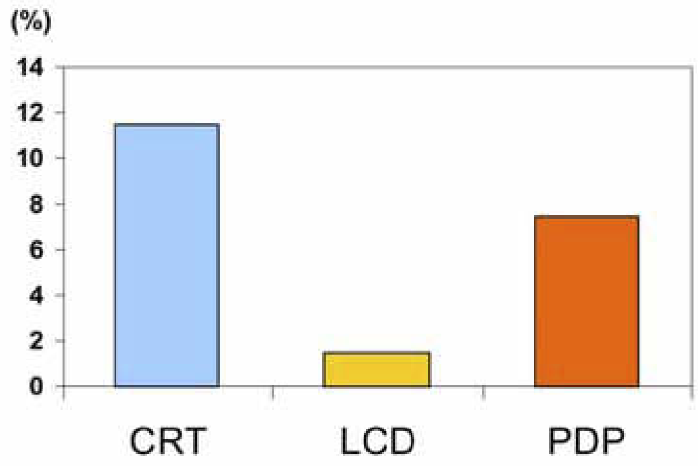
The brightness of a common household living room is about 300 lux. In case of the room exposed to the afternoon sun is about 1,500 lux.

With CRT TVs, when it gets brighter than around 30 lux, the contrast ratio dramatically decreases.

However, LCDs maintain high-contrast pictures in bright situations, even reducing eye stress for difficult screen viewing in outside light or with light reflection.

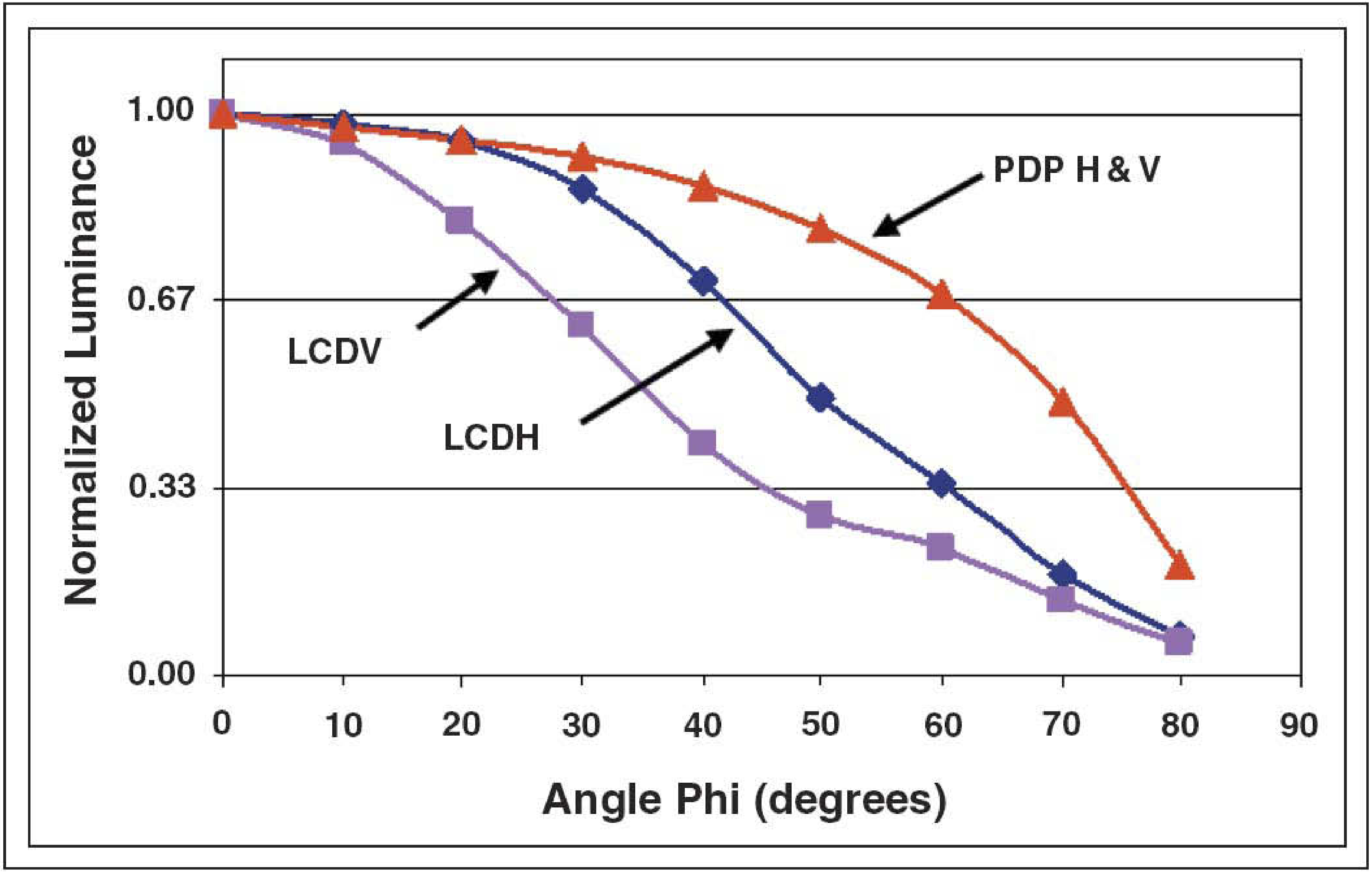


Reflection Ratio Comparison



Source:
Hiroshi Take
(SID 2003)

Viewing Angle: Luminance

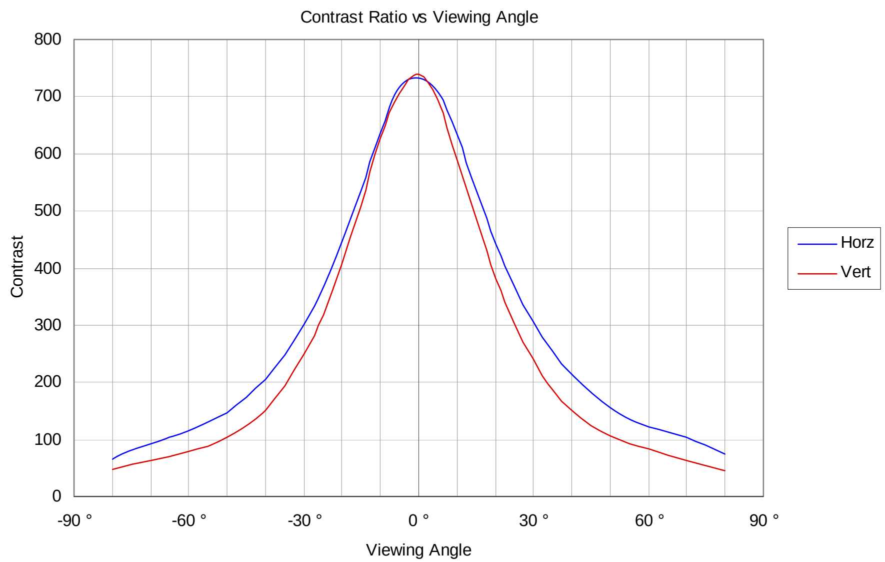


Source: Larry Weber

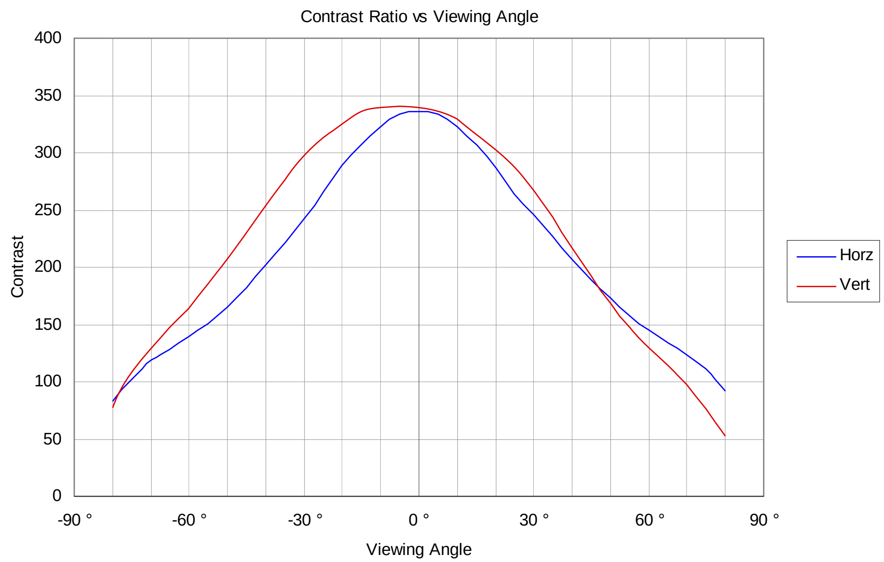
Viewing Angle: Contrast

- Viewing angle performance is a critical quality factor for LCD TV, because unlike laptop displays, LCD TVs are viewed from many different angles.
- This is an area where the LCD industry has focused much effort.
- Though manufacturers tout 170+ viewing angles – There is no one metric for viewing angle performance.

Sample Results – Contrast vs Viewing Angle



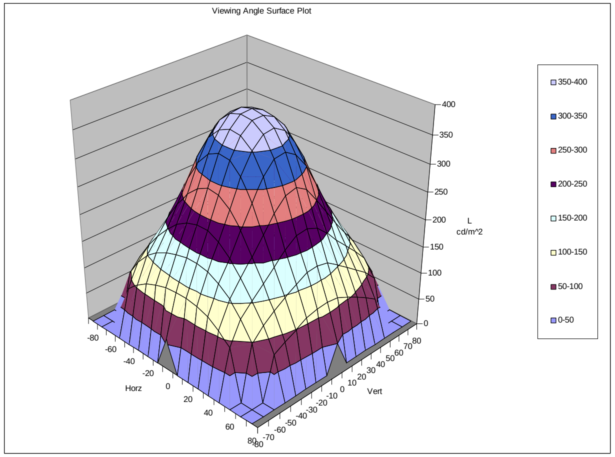
Model A (VA)



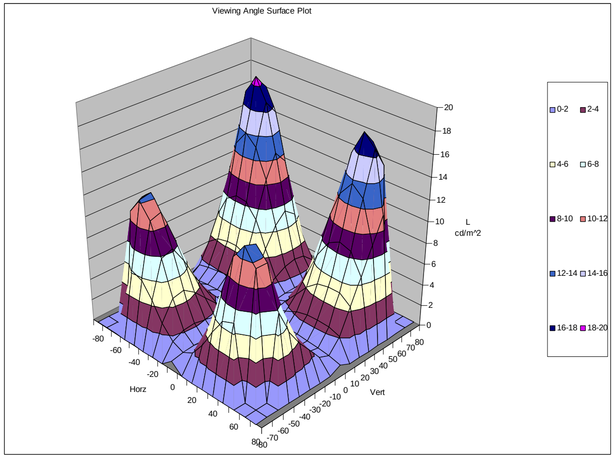
Model B (IPS)

Source: Mike Wilson (Westar)

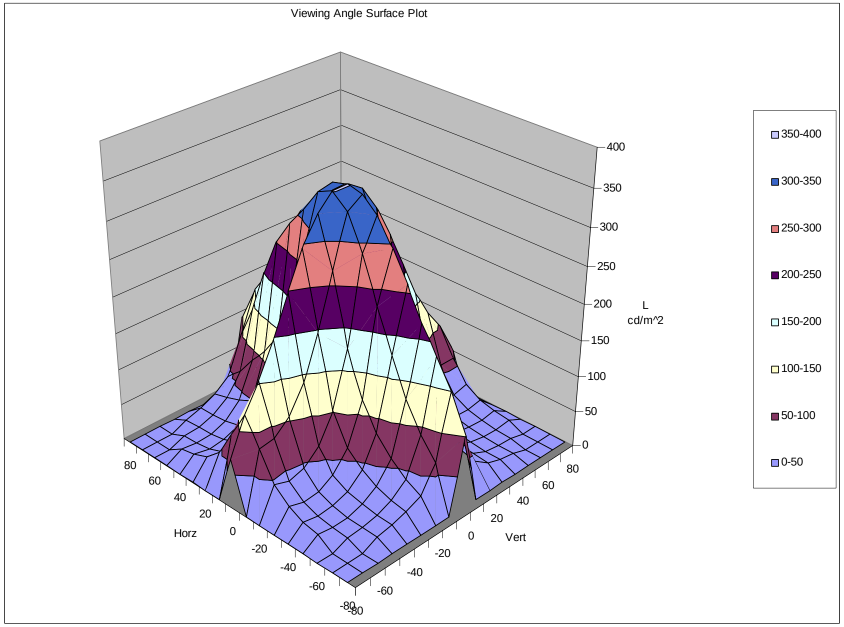
Viewing Angle: Contrast



White Luminance



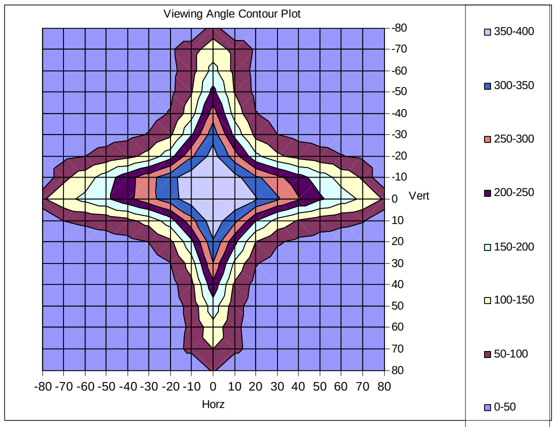
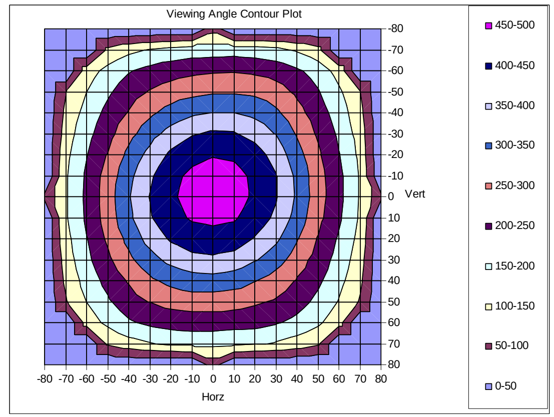
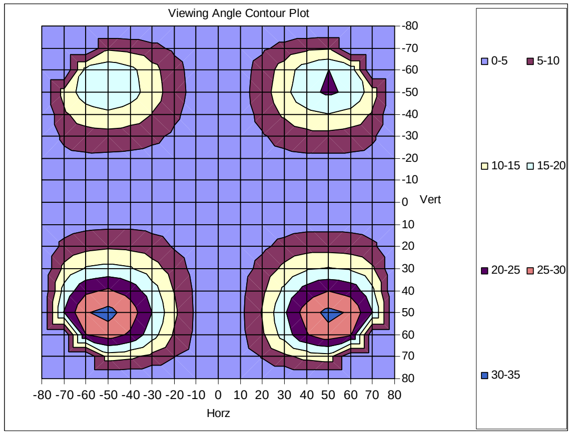
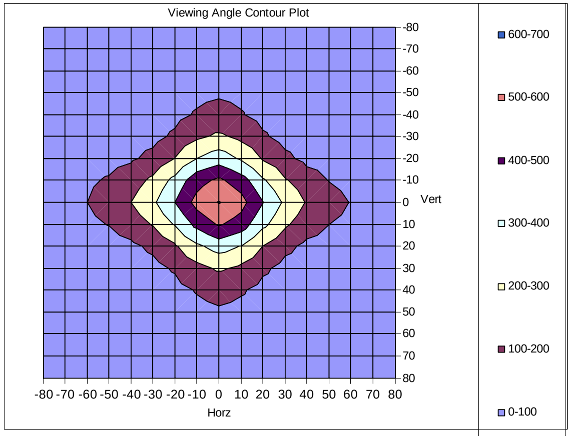
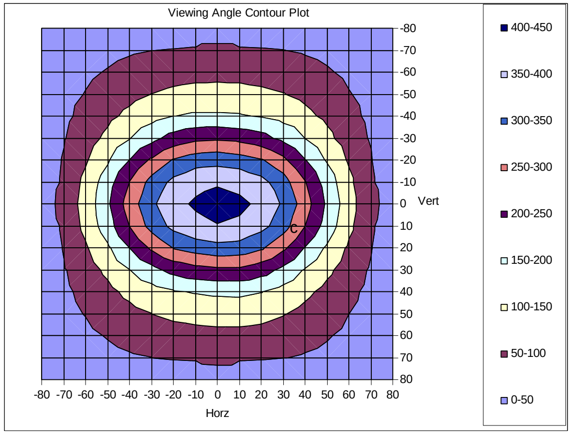
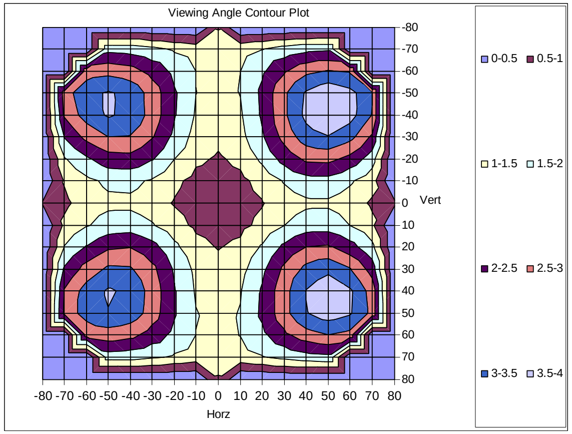
Black Luminance



Contrast

Source: Mike Wilson (Westar)

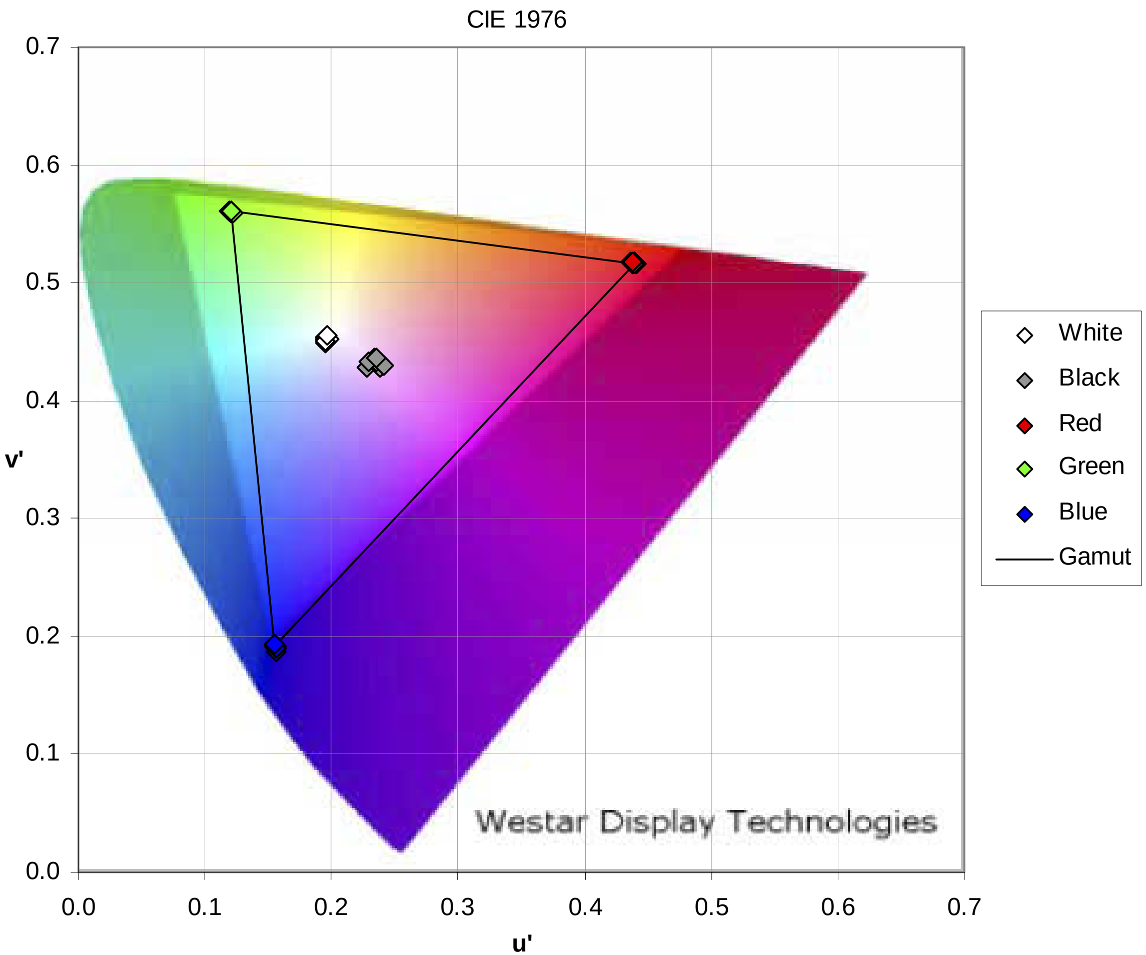
Viewing Angle Variation

	Contrast Ratio	Brightness	Black Level
IPS			
VA			

Source: Mike Wilson (Westar)

Color Gamut

- Color gamut is the range of possible colors that can be displayed.
- Typically this is expressed as a percentage of the NTSC color primaries.



Color gamut ranged from 77.7% to 86.2% of NTSC

Source: Mike Wilson (Westar)

Typical Color Gamuts Relative to NTSC*

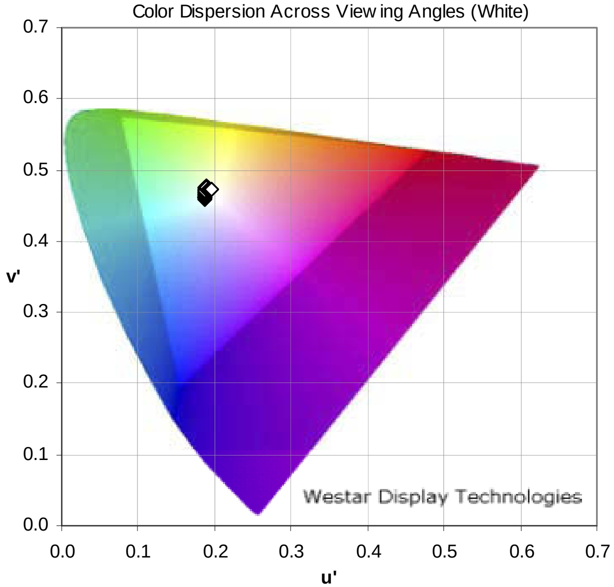
	Red		Green		Blue		Relative gamut
	x	y	x	y	x	y	
Saturated	.735	.265	.074	.834	.174	.005	155%
NTSC	.67	.33	.21	.71	.14	.08	100%
EBU	.64	.34	.29	.60	.15	.06	71%
CRT	.625	337	.288	.603	.151	.063	69%
PDP	.648	.347	.242	.708	.147	.067	93%
Typical transmissive LCD	.603	.331	.340	.566	.150	.130	50%
High quality LCD	.638	.340	.292	.611	.146	.085	70%
Reflective LCD	.42	.33	.33	.42	.21	.28	7%
Projector	.65	.35	.31	.67	.15	.04	73%
OLED-Small molecule	.65	.34	.30	.63	.17	.17	63%
OLED-Polymer	.68	.31	.35	.61	.15	.12	70%

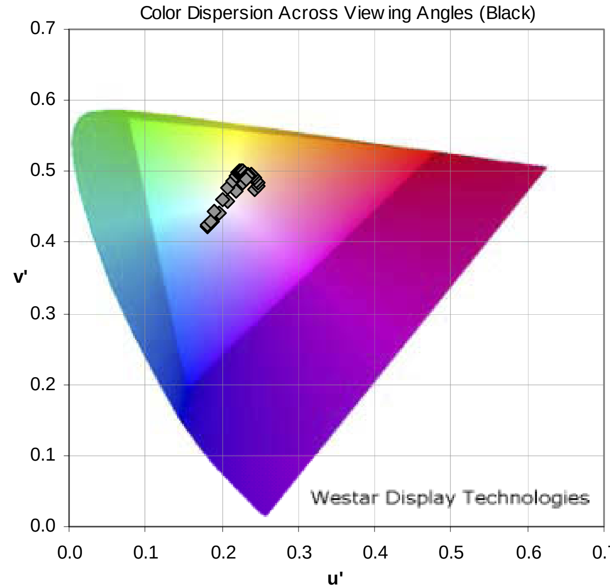
*Measured in (x,y) space

The use of LED backlights could enable LCDs to overtake PDPs

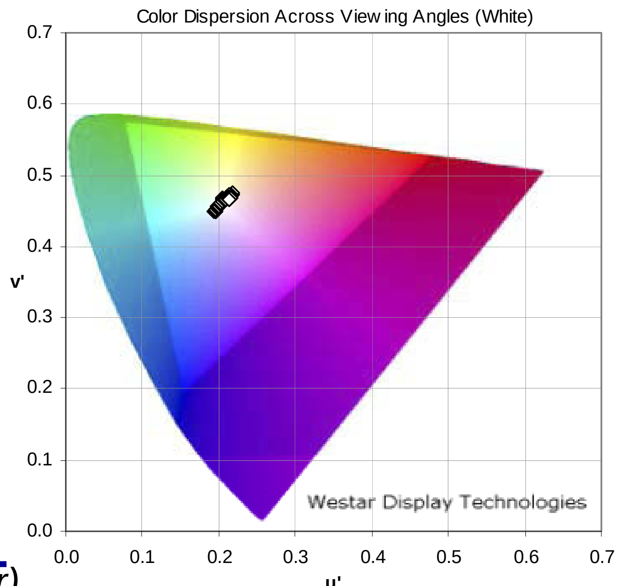
Color Shift with Viewing Angle

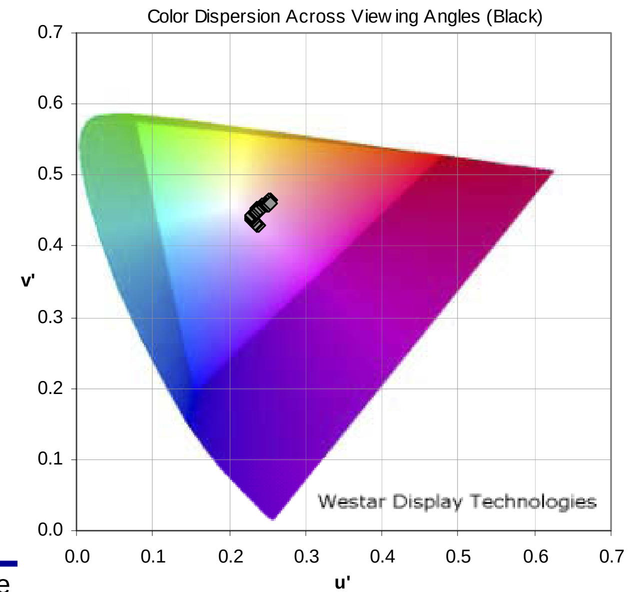
Model B (IPS)





Model A (VA)





Source:

Mike Wilson (Westar)

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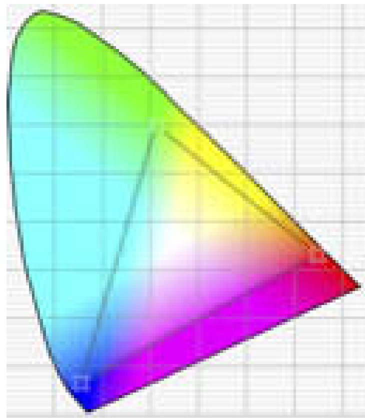
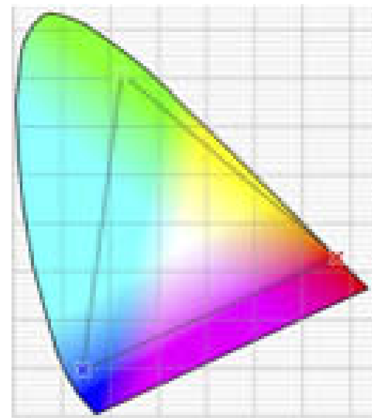
Color Gamut Standards

TV Standards

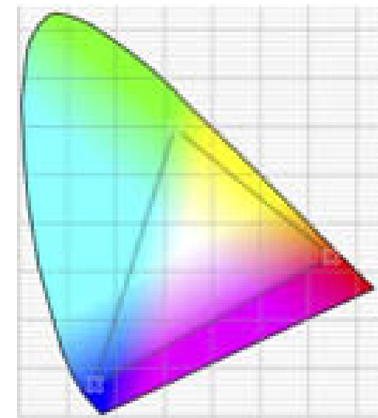
PAL/SECAM



NTSC

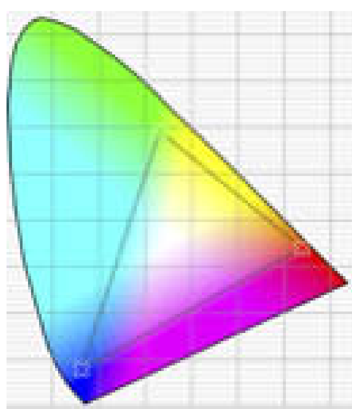


HDTV/sRGB

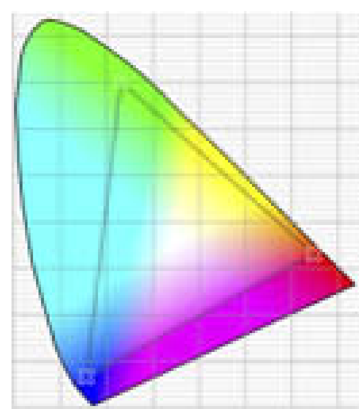


Other Standards

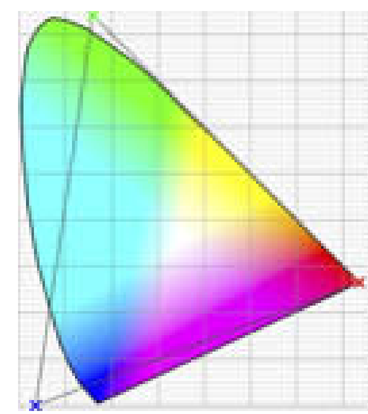
SMPTE C



Adobe RGB



ProPhoto RGB



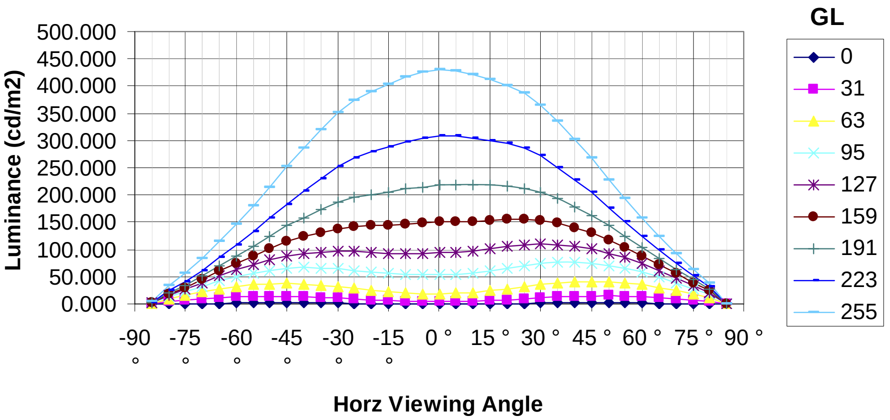
Source: Boscarel

Gray-Scale Inversion

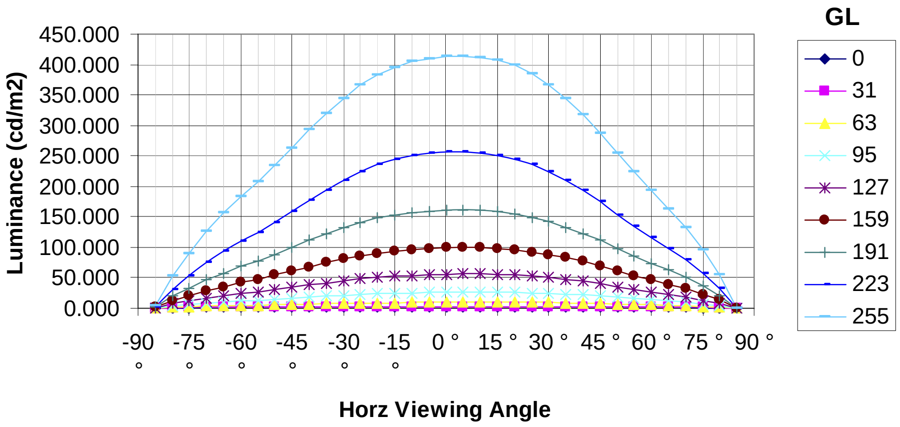
Inversion is another measure of viewing angle performance.

Inversion, or reversal of gray-scale is an objectionable artifact seen on many early LCD displays.

Sample Results – Gray Scale Inversion



Model A (VA)



Model B (IPS)

Source:

Mike Wilson (Westar)

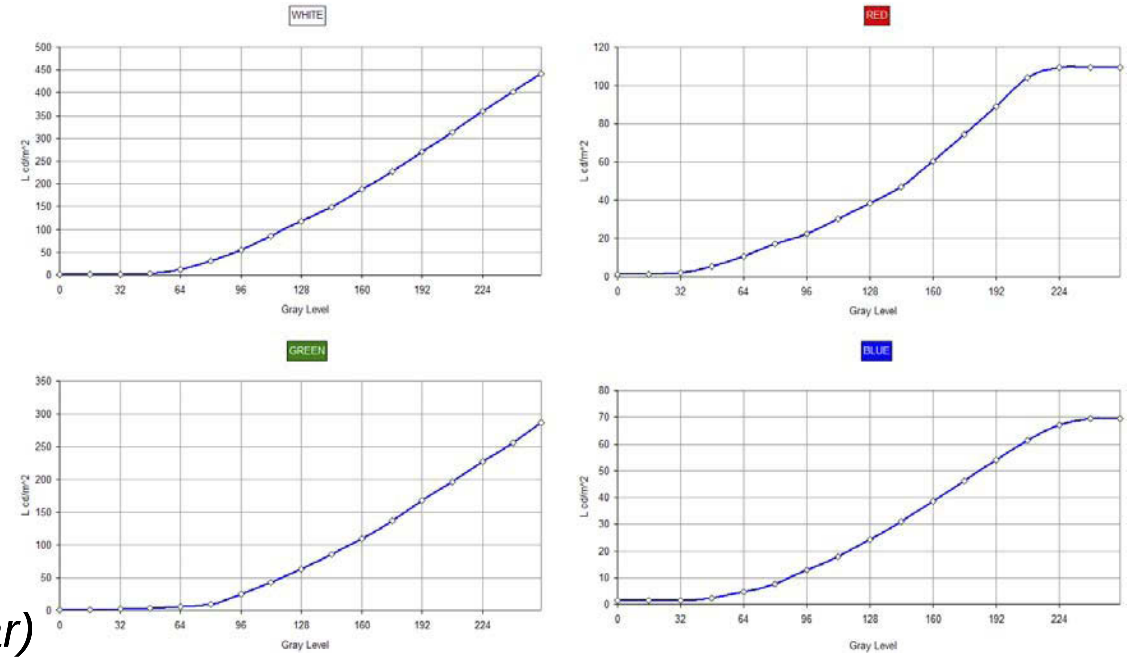
The good news… no inversions

Gray Scale Control for RGB&W

LCD Color Shifts at 10% Intensity

Property	A	B	C	D	E	F
White shift	0.004	0.016	0.021	0.016	0.026	0.012
Red shift	0.034	0.039	0.029	0.027	0.026	0.023
Green shift	0.009	0.009	0.009	0.006	0.006	0.020
Blue shift	0.023	0.013	0.018	0.005	0.008	0.014

The color balance
can be modified
by control electronics

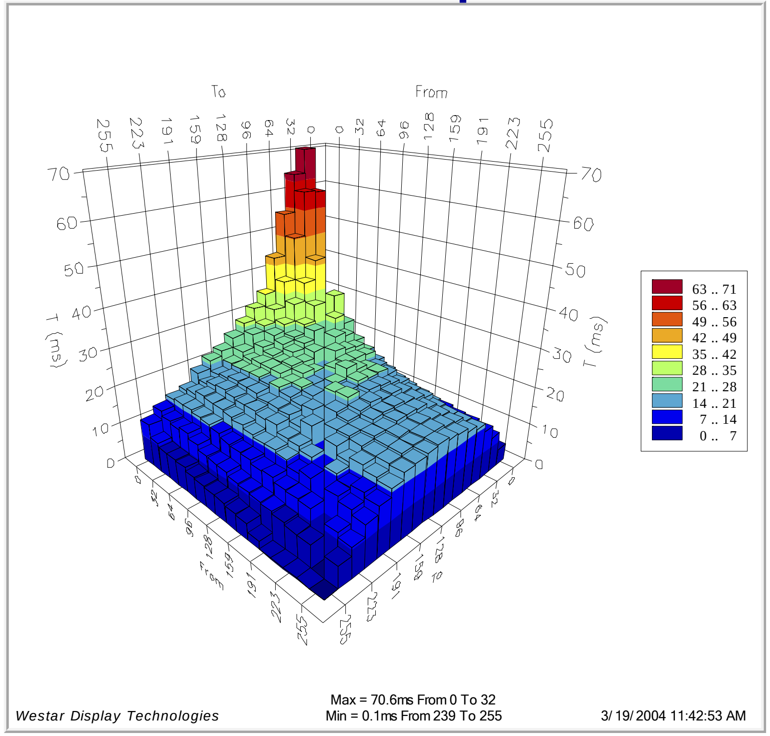


Source: Mike Wilson (Westar)

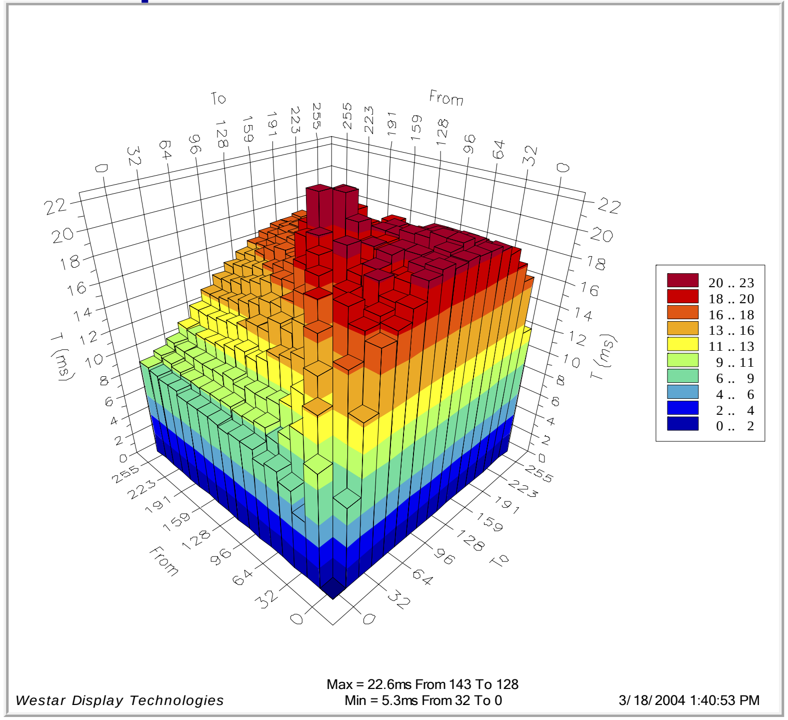
Response Time

- Response times directly impact the quality of motion video. Slow response times result in blurred edges.
- Gray-to-gray response is much slower for LCD than black to white.

Sample Results – Gray-Level Response Time



Model A (VA)



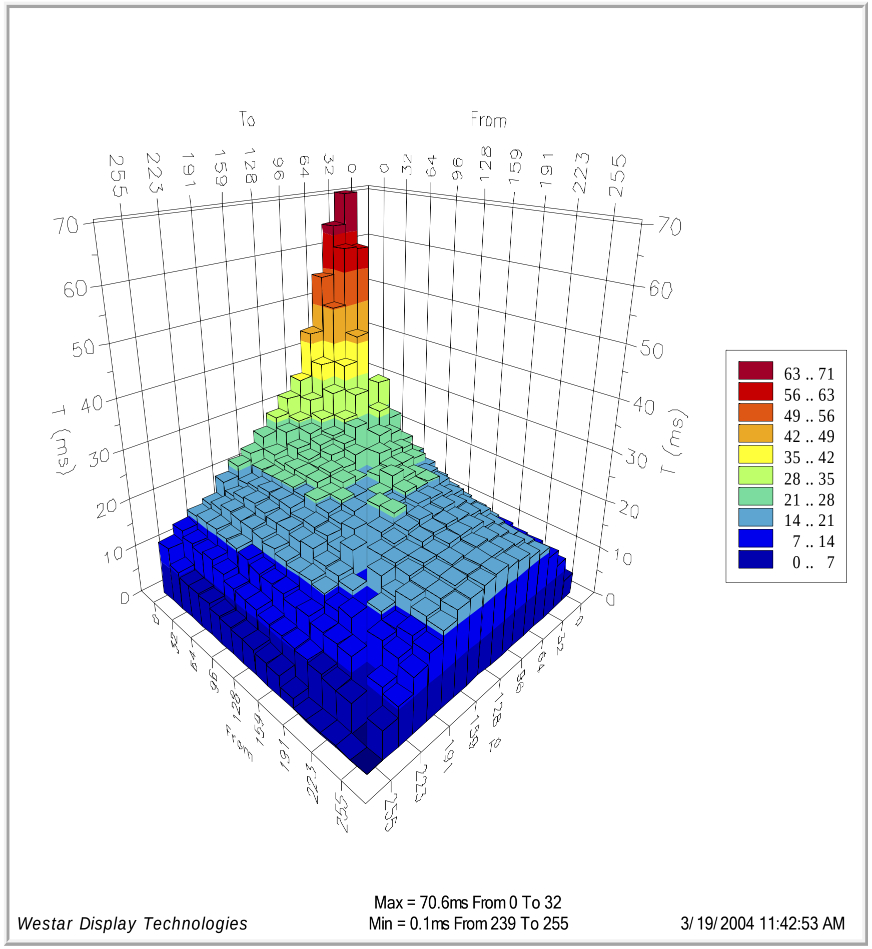
Model B (IPS)

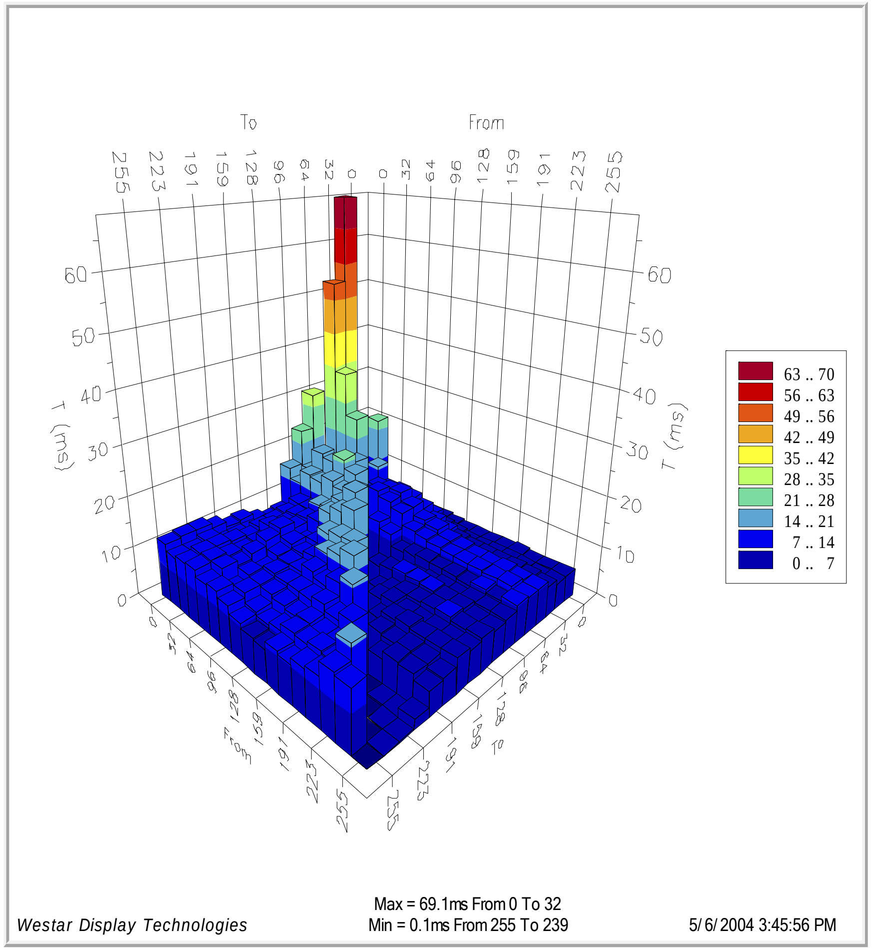
Source:

Mike Wilson (Westar)

Over-Drive

Most LCD TVs use over-drive to reduce gray-to-gray response time.

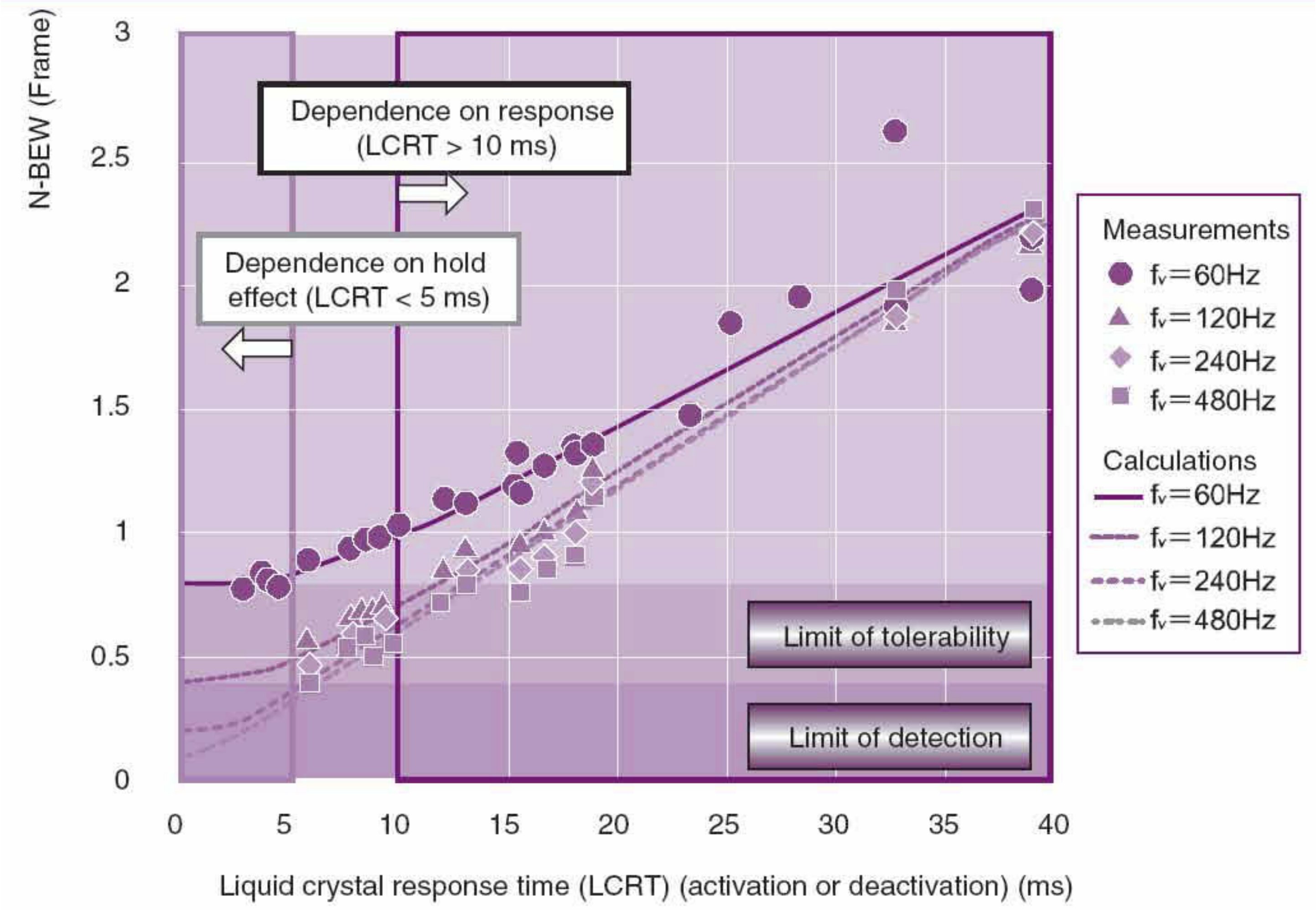




Source: Over-drive Off Over-drive On

Mike Wilson (Westar)

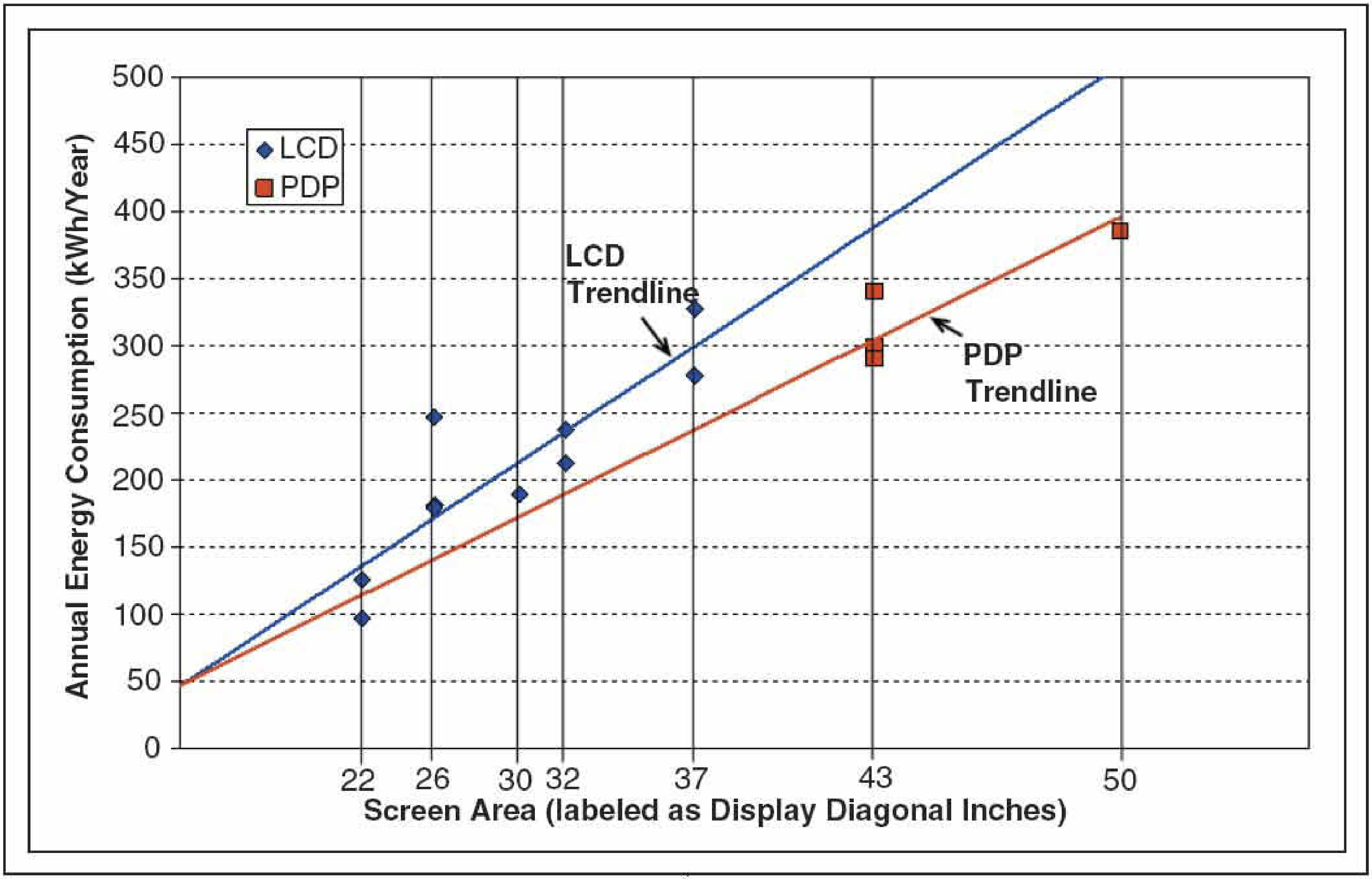
Blurring Edge Width Measurements



Can use flashing backlights or insert black sub-frames

Source: Hitachi

Power Consumption

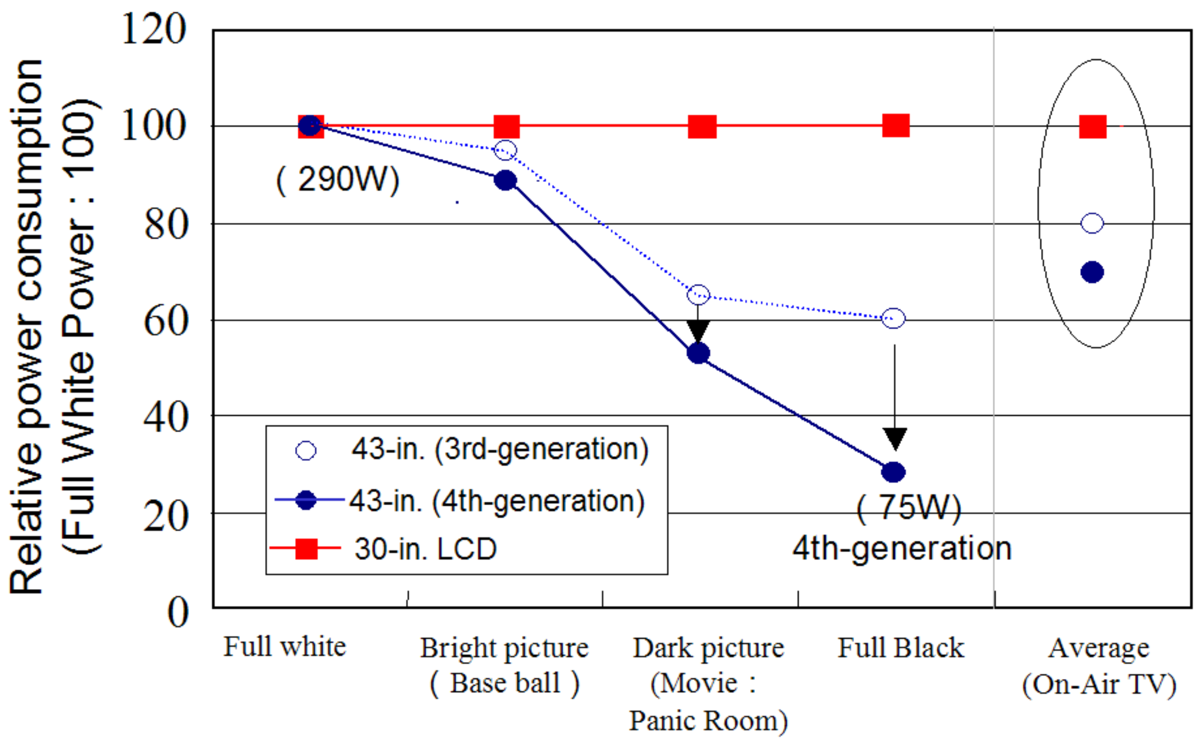


Source: Larry Weber

Emissive Displays Have an Advantage

Energy need only be supplied to each pixel as required,
but remember that switching currents on and off requires energy

PDP Power should be reduced by 30% for TV

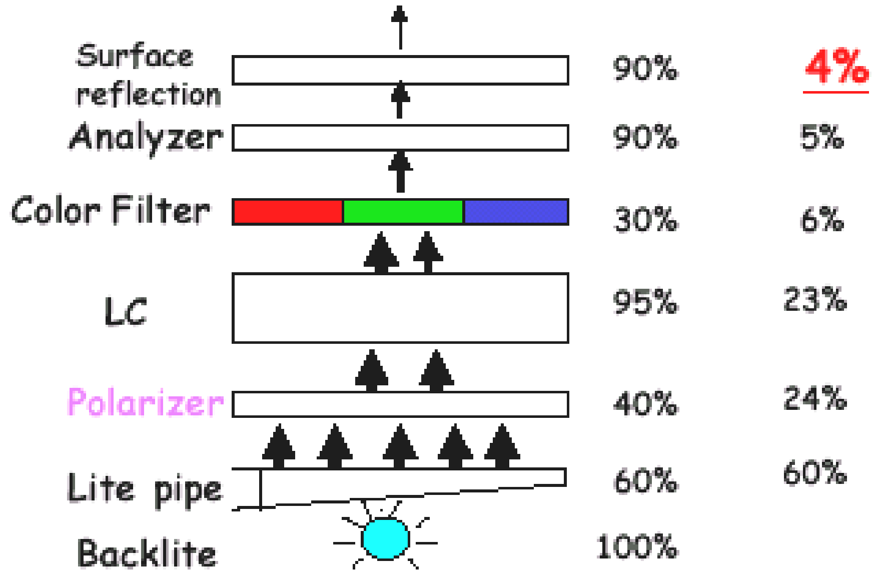


Source: Pioneer

Energy Flow in Liquid Crystal Display

Backlight efficiency
is ~15% (60 lm/W)

Transmission factor
is ~ 3%



Corrections: 1: TFT array blocks 20-50% of the light

2: Some of wrongly polarized light can be recycled

Overall efficiency is ~ 0.4% at ~1.6 lumen/Watt

Energy Flow in Plasma Display Panels

Desired step	Eff	Loss mechanisms	Total
	%		%
Wall power into discharge	75	Capacitive (reduced by partial energy recovery) Resistive	75
Discharge into electrons	35	Acceleration of ions	26
Electron excitation of Xe	60	Ionization Excitation of Ne Anode and wall collisions	16
UV production	60	IR radiation Ionization	9.5
Phosphor excitation	65	Escape through front plate Trapping	6.1
Visible light production	25	Quantum efficiency < 1 Frequency reduction	1.5
Visible light extraction	25	Wall losses in cell Passage through front plate	0.38

Efficacy has been ~ 1.5 lumen/Watt

Energy Flow in OLED

Stage	Efficiency	Loss Mechanisms	Total Eff.
Power to pixel	90%	Voltage conversion Line losses	90%
Over-voltage (8V/2.5V)	31%	Drive TFT photon energy mismatch	28%
Electron hole recombination	12%	Triplets, charge transport, charge imbalance	3.3%
Light extraction from optical stack	20%	Internal reflection absorption	0.67%
Absorption by electronic structures	80%	TFTs, bus lines electrodes	0.54%
Contrast enhancement	55%	Loss in polarizer or color filter	0.30%

Efficacy is ~ 1.2 lumen/Watt

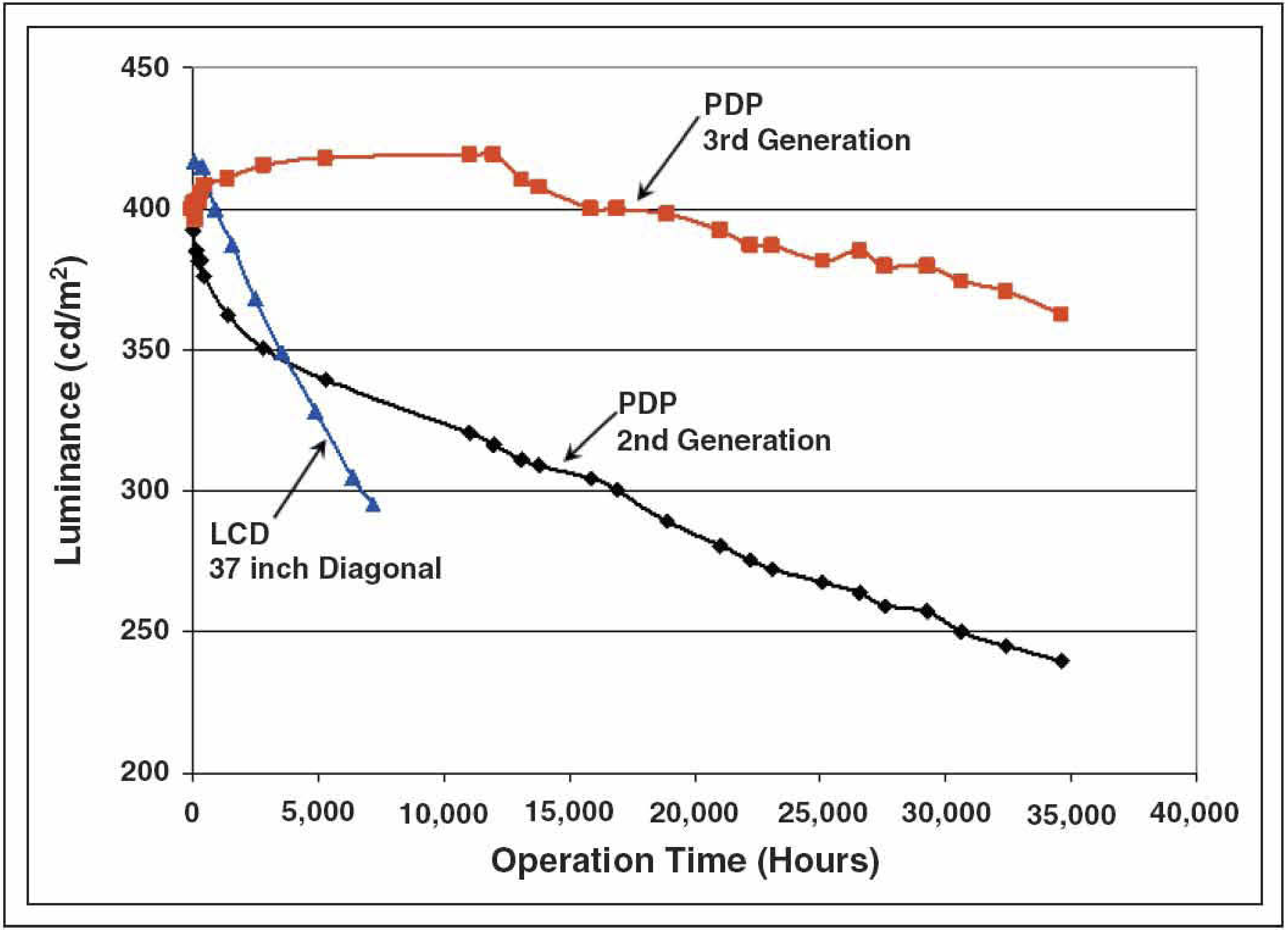
Single-Chip Projection

	Single Panel (0.82") 2 colors on panel at time 0.5 homogen. Scrolling, PCS	Single Panel (0.82") 3 colors on panel at a time 0.33 homogen. scrolling, PCS	Single Panel (0.82") MEMs no polarization necessary
lamp etendue coupling	64%	54%	60%
uv/ir losses	95%	95%	95%
polarization	50%	50%	100%
pcs+color gain	153%	153%	100%
color wheel or color quad	64%	96%	32%
color balance	91%	67%	91%
yellow notch	70%	70%	70%
pcs fresnel losses	85%	85%	100%
relay lenses	90%	80%	90%
pre-polarizer	100%	100%	100%
PBS-in	88%	88%	88%
LCoS Overfill (or MEMs)	90%	90%	90%
LCoS Reflectance (or MEMS)	65%	65%	65%
LCoS Duty Cycle (or MEMS)	77%	77%	90%
PBS-out	88%	88%	98%
Post-Polarizer	90%	90%	100%
Projection lens	85%	85%	85%
TOTAL	**3.87%**	**3.21%**	**4.04%**
LUMENS (150W)	**348**	**289**	**363**

Screen and mirror losses not included

Source: MicroDisplay Corp

Lifetime



Source: Larry Weber

But Don't Ignore the Slim & Flat CRT

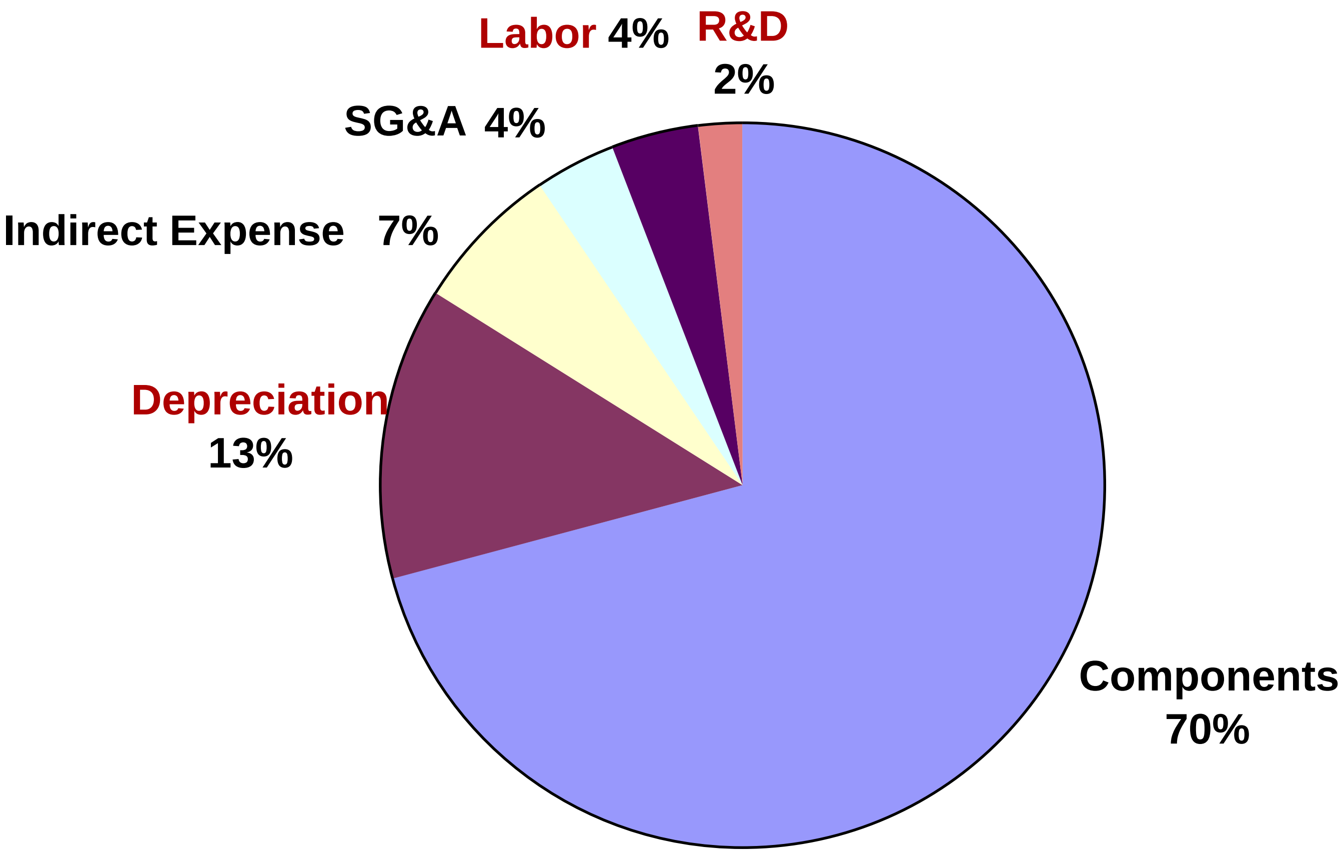
	Subject	Unit	CRT	Vixlim	LCD	Remark
Basic Spec.	Depth	mm	600	390	330(Stand)	SET standard
	Power consumption	W	150~170	160~170	160~170	
	Weight	Kg	55		26	
Quality	Image Brightness	Cd/m^2	300		320	Window 1%
	Contrast	-	5,000:1		600:1	
	Color Gamut	-	Natural		256	
	Color range	10^3	117 (75%)		111(71%)	NTSC (158, 100%)
	Reaction	-	μs		16ms	
	Viewing angle	Degree	180		170	

Source: Justin Lee (Samsung SDI)

Manufacturing Costs

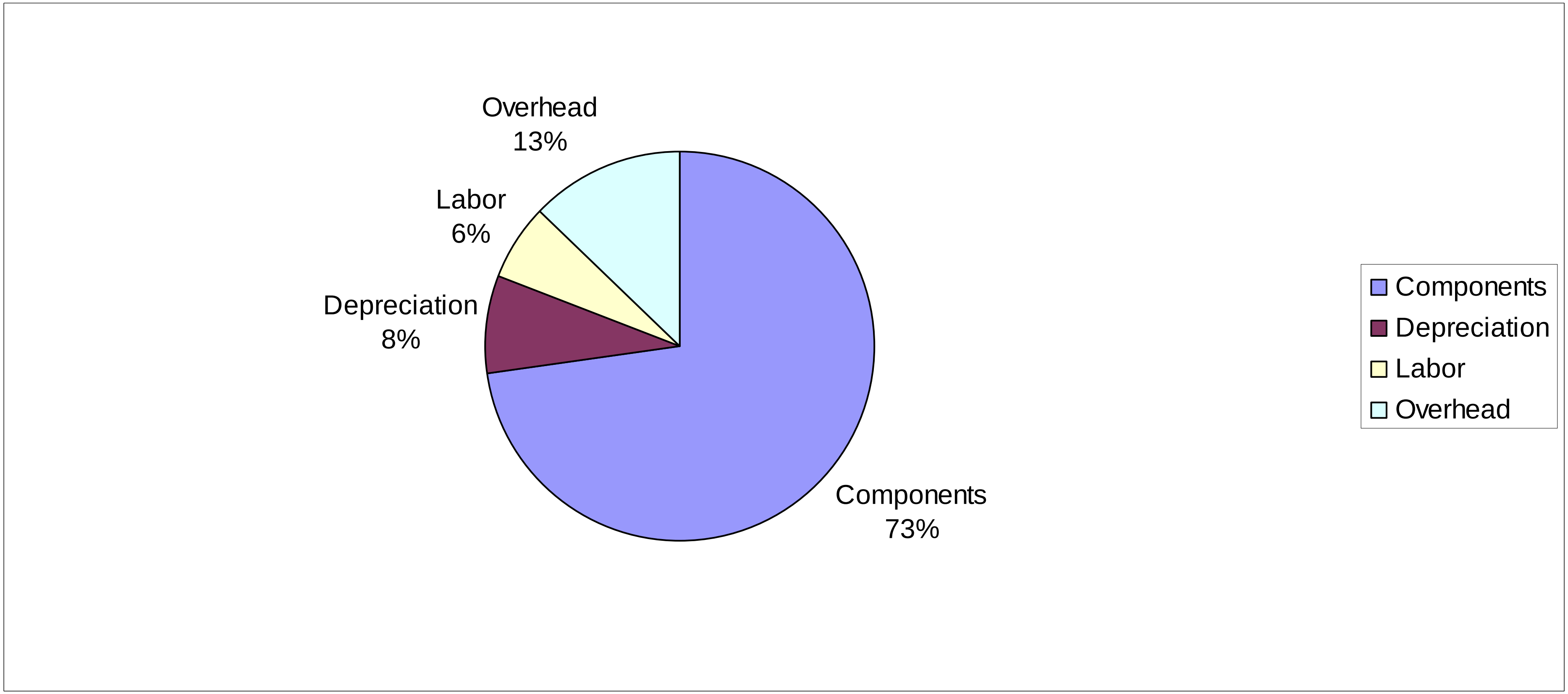
Large Area TFT LCD Cost Breakdown

The majority of cost is now in components



Future Gains Must Come from Component Costs

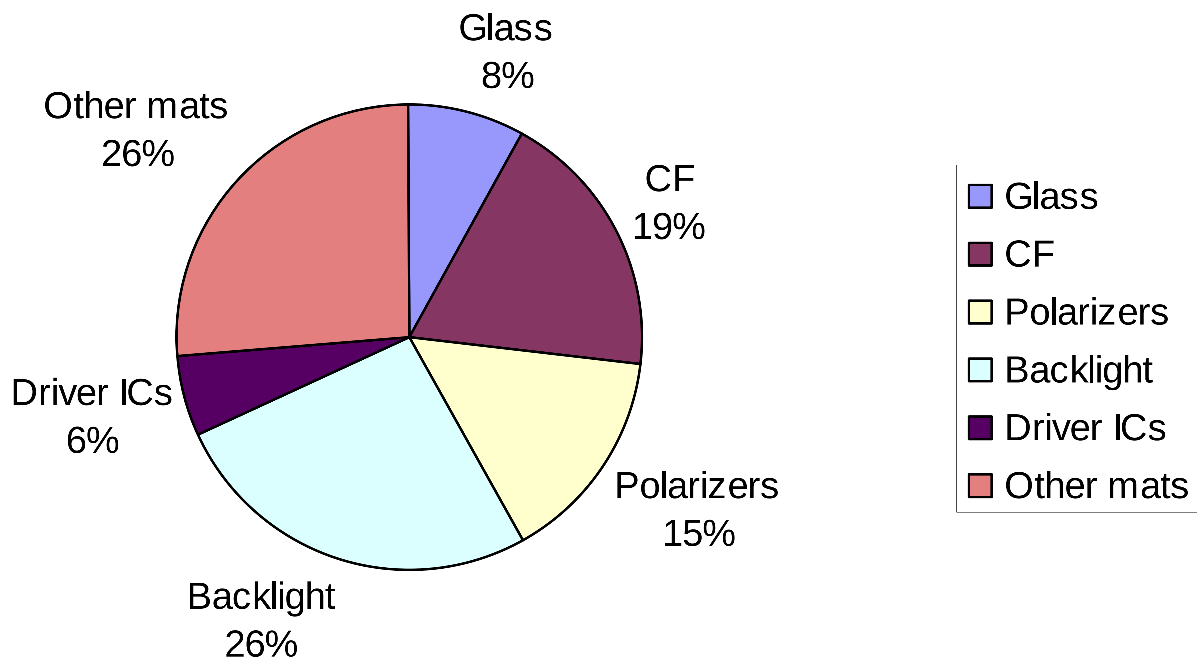
PDP Cost by Expense Type



Future Gains Must Come from Component Costs

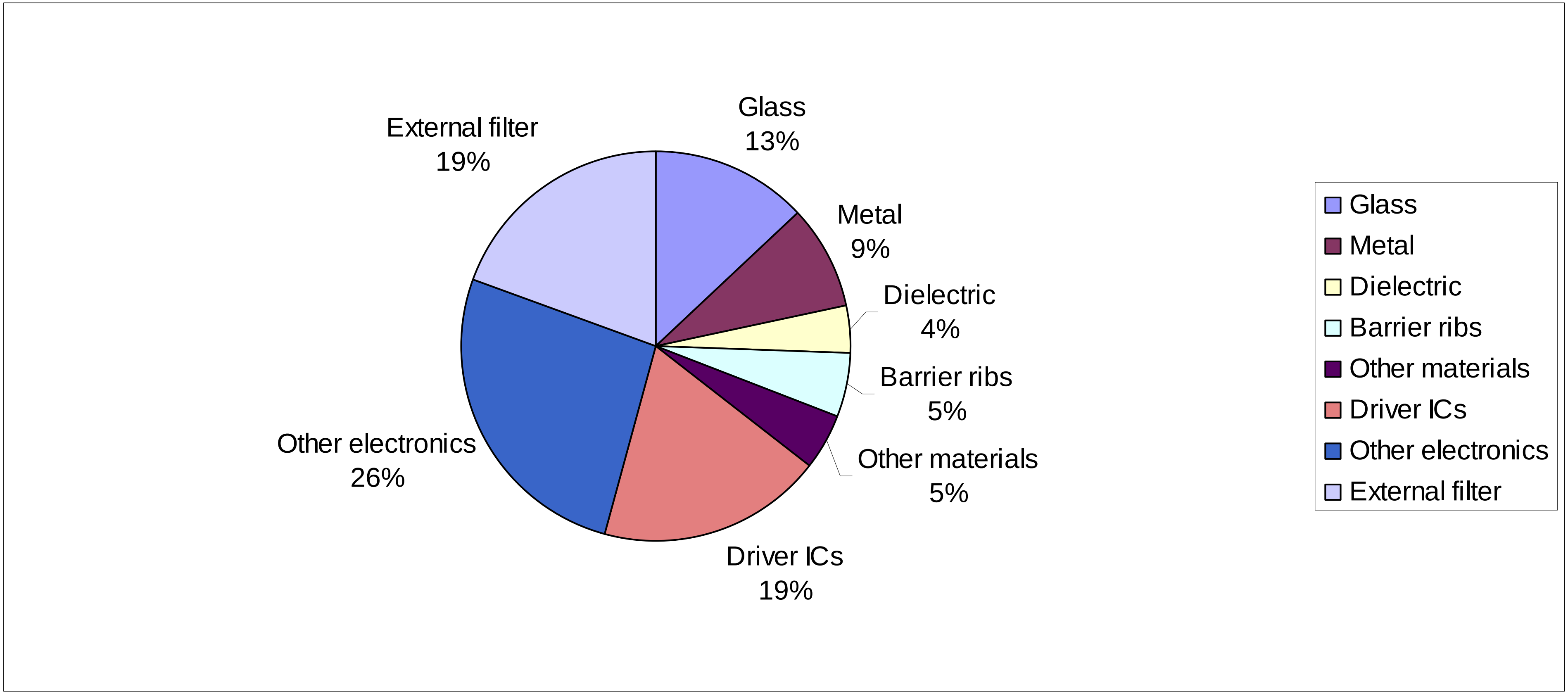
32" LCD TV Component Costs

Breakdown of Material/Component Costs
32" WXGA



Better backlight technology is critical to LCD-TV development

PDP Components and Materials



Reductions in cost of electronics and filter are essential

Reducing Costs of LCDs

- Further gains from larger substrates will be very difficult
  - First forecasts of costs for 8^{th} gen seem higher than 7^{th} gen
  - Equipment suppliers will focus on enabling material cost reductions
  - Less waste – additive rather than subtractive patterning
  - Thinner layers (in-cell polarizers?)
  - Repair of faults is critical at all stages
- Most gains must come from materials & components
  - Localized production
  - More efficient suppliers
  - More effective materials
  - Better design
    - -Improved backlights
    - -Eliminate the color filter
- We need better packaging for small displays

The Home Run – No Color Filter

Why?

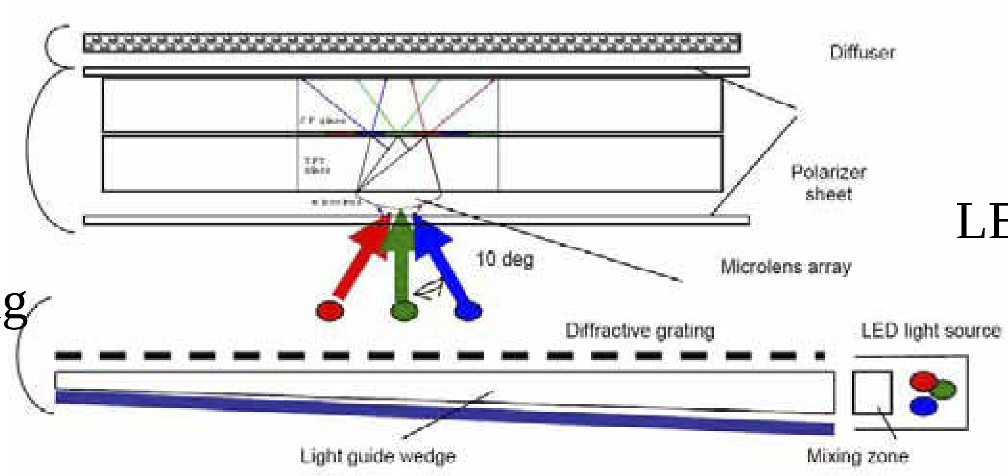
- ~4x increase in optical efficiency
- Avoid cost of patterning CF
- Reduce cost of backlight (perhaps by 75%)

How?

- Stacked films – difficult to manufacture & control light losses
- Microlens array – as in LCD projectors
- Field sequential color – as in DLP projectors

LCD with Micro-Lens Array

Structure



Diffraction grating to separate colors

LEDs to give narrower frequency spread

Need directed emission from light guide

13.3" XGA prototype

From IBM and IDTech

Authors recommend the use of a polarized light source

Source: IBM and IDTech (SID 2003 Int Symp, paper 43.1)

Field Sequential Color

Requirements

- Flashing backlights
  - Easier with LEDs
- Fast LCDs
  - OCB?
  - Ferroelectric?
  - Ultra-thin TN layers?
- Faster drive electronics
  - Talk nicely to TI

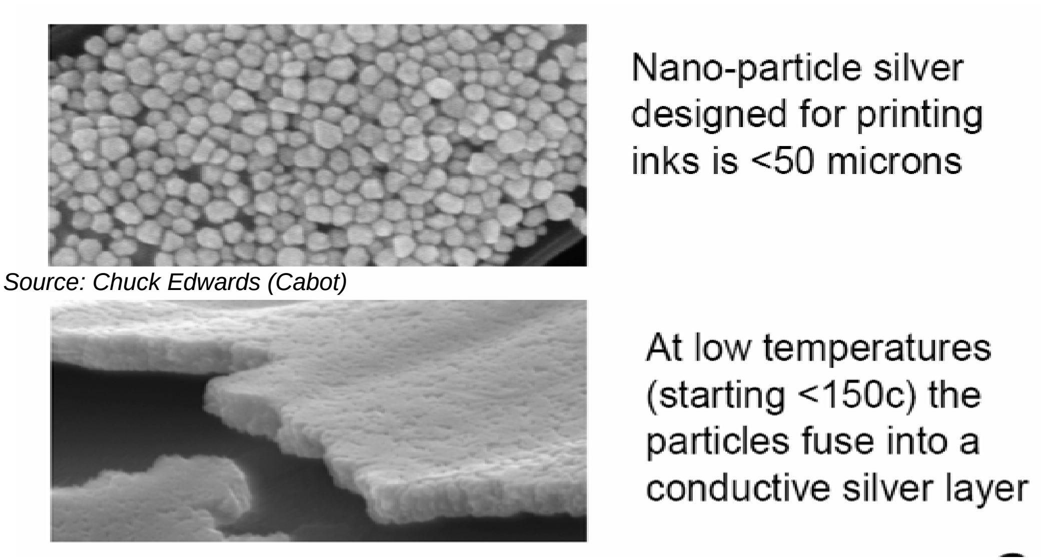
Small displays have been produced
by Samsung SDI & LGE
for phones and PDAs

Can this technology be implemented for large screens?

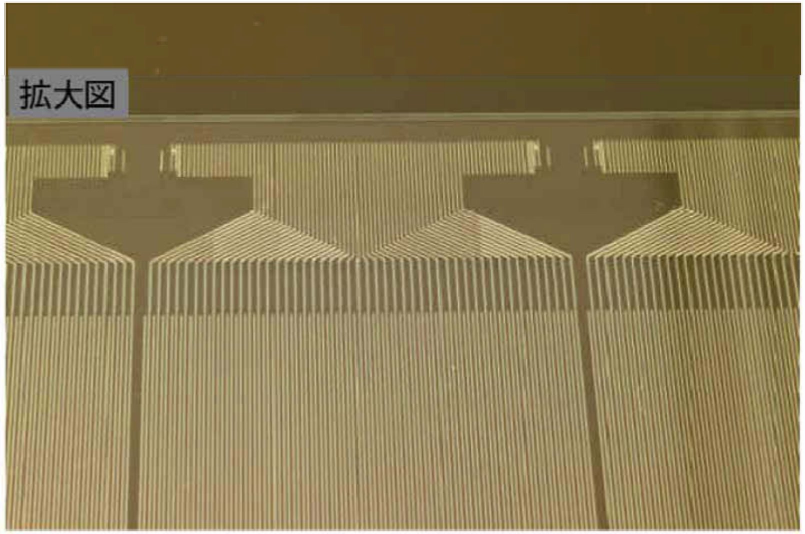
Cost Reduction for PDP

- Standardization of high-voltage electronics
  - Inevitable with high-volume and industry consolidation
  - Potential area of specialization for China or India or ….
- Increase in efficiency of panels
  - From 1.8 lumens/Watt to 5 lumens/Watt
- Improved printing techniques (ink-jet?)
    - Bus lines
    - Phosphors
    - Dielectrics
    - Barrier ribs????
- Closer collaboration between panel and set makers

Printing Bus Lines with Nano-Particle Inks



Source: Chuck Edwards (Cabot)



Source: Chuck Edwards (Cabot)

Source: Masaaki Oda (ULVAC)

Conclusion

Get ready for the battle of <$995 (H)DTVs

32” Slim CRT vs 32” LCD vs 42” PDP vs 50” RPTV

Probably at your local Walmart for Xmas 2006

For more details, see DisplaySearch reports