Multi Primary Color:
The Optimal Wide-Gamut Solution for LCD TV
Contents

• The need for wide gamut
• Gamut expansion possibilities
• Multi primary principles
• Implementation in LCD
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Need of wide gamut in LCD TVs

- Old TV standards (REC-709, EBU, S\textsubscript{RGB}..) were created based on CRT phosphors limitation.
- Natural objects and cinema are significantly more colorful than standard TVs.
- Competitive new display technologies (Plasma, projection) are not limited to RGB phosphors gamut. Plasma has \sim 90\% NTSC gamut.
- Traditional LCD “problems” that differentiated panels and brands like contrast ratio, brightness, viewing angle and motion blur are widely solved. Appearance and color are the new differentiators, and the competition is on.
- Together with wide gamut displays technology, new wide gamut TV standards emerge.
Real surface (Pointer) colors gamut
Seeing Color – Around Us, At Movies and On TV

Film and HDTV (“Rec. 709”) Gamuts
Gamut expansion possibilities

• Expand the RGB triangle by modification of color filters and/or backlight
  – Narrow spectrum color filters
  – Modify backlight
    • Wide gamut CCFL
    • LED

• Add additional color primaries and “widen” gamut shape – the multiprimary approach.
• The RGB triangle can be expanded
• However, it is still a triangle
• Therefore, it cannot contain both yellow and turquoise regions

• Coverage of yellows → poor cyans
• Coverage of cyans → poor yellows
Narrow Spectrum RGB Filters, standard backlight

- Maximum “practical” expansion: 72% NTSC →~85% NTSC (not sufficient)
- Brightness decrease by >30%
Wide (color) gamut CCFL
WG CFL, WCG CCFL

Regular CCFL
WG CCFL
Commercial WG CCFL TV

WG CCFL TV Spectrum

Intensity (AU)

Wavelength (nm)

CIE

WG CCFL TV

REC-709

x

y
Commercial WG CCFL TV

Green?

Excellent Cyan

Low Blue Saturation

Yellow Deficient

Excellent Red

CIE

WG CCFL TV

REC-709
WG CCFL TV Properties

- Wide color gamut ~90% NTSC
- Excellent red and cyan colors
- Low saturation blue
- Yellow deficient
- Lower lifetime
- Low efficiency (~75-80% of regular CCFL)
  - Additional lamps
  - Expensive brightness enhancement films
  - Increase input power (reduce further lifetime)
  - Increased power consumption
LED Backlight

Graph showing relative intensity vs. wavelength in nm.

- Blue peak at approximately 480 nm
- Red peak at approximately 680 nm
- Green peak at approximately 580 nm

Wave Length in nm:
380 480 580 680 780

Relative Intensity:
0.2 0.4 0.6 0.8 1.0
Typical LED BL Gamut

- **Good Green(*)**: Careful color processing needed to avoid “unnatural” greens
- **Excellent Cyan**
- **Excellent Red**
- **Yellow Deficient**
LED BL Properties

- Wide color gamut ~100% NTSC
- Excellent red and cyan colors
- Long lifetime
- Yellow deficient
- Low efficiency (~50% of regular CCFL)
  - High power consumption
- Expensive (backlight unit cost ~X2.5-X3 of CCFL backlight)
- In the next few years applicable only to high end professional monitors and small commercial displays.
Multi Primary Technology

RGB

RGBY

RGBYC
Multi Primary Technology

- Use of 4 to 6 color filters to get 4 to 6 primary colors
  - 4 or 5 primaries are generally more cost effective.
- Increase color gamut
- Increase brightness
- Low cost, best appearance and most efficient wide gamut method
Multi primary basic requirements

• Genoa implemented multi primary in projection (single and multiple panels) and LCD displays

• Requires certain modifications
  – TFT and color filters array in LCD displays
  – Color wheel in single panel projection displays
Multi primary principles

• Adding more primaries to RGB (usually yellow and cyan for 5 primaries or just yellow for 4 primaries) allows:
  – Better utilization of the backlight spectrum
  – Boost of luminance using spectral overlap of color filters – enhanced brightness
  – Enhancing color gamut in perception-sensitive area (like yellow)

• High efficiency, cinema-like appearance.
Extended RGB vs. Multi Primary

Adding yellow (and cyan) allows flexibility in the design of the color gamut, thus it may fit better the color gamut of film.
Efficiency Increase

- **RGB**
  - Intensity vs. Wavelength
  - Peaks at different wavelengths for R, G, B

- **RGBYC**
  - Intensity vs. Wavelength
  - Expanded spectrum with additional peaks for Y and C

- **Comparison**
  - Graphs showing intensity variation with wavelength for RGB and RGBYC
Efficiency Increase

- In RGB displays, the red part of the light passes only through the red filter, the green part through the green filter and the blue through the blue filter.
- In a multi primary display, for example in a 5 primaries display, the red part of the light passes through the red and yellow filters, the green part through the green, cyan and yellow filters and the blue part through the blue and cyan filters.
Multi primary color conversion (MPC) – Keshet™ chip
Keshet™ chip

- Developed and fully tested for Philips single panel LCoS projection TV.
- Supports 1080p, 4 - 6 primaries.
- Implemented successfully in many projection and LCD displays
Implementation in LCD

- Pixels layout
  - New TFT
  - Existing TFT
- Color filters
- LCD prototypes
- Performance
Many possible configurations.

- New TFT for full resolution
- Existing TFT for fast prototyping and TV only application, using advanced spatial processing - Pixcale™
New TFT examples

RGB
RGBY
RGBYC
RGBYCM

Configuration based on price/performance optimization
Existing TFT (Pixcale™) examples

- RGB display
- 4 primaries (RGBY) display on standard TFT backplane
  - Stripe configuration
- 5 primaries (RGBYC) display on standard TFT backplane
  - Staggered configuration
Color Filters

• **Requirements**
  – New Yellow, Cyan (Magenta) filters
  – Extended saturation RGB filters
  – Good contrast ratio
  – Cost effective manufacturing process

• **Achievements**
  – Multi primary color filters meeting the above requirements were developed by several companies.
    • Panel makers with internal color filter manufacturing
    • Color filter makers (more than one company)
    • One color filters company, DNP from Japan, publicly announced multiprimary color filters availability.

• **Multi primary color filters available**
LCD prototypes

• Company “A”: 5 primaries, new TFT, 18”, VGA resolution (CES 2005)
• Company “B” (CMO): 4 and 5 primaries, Pixcale™, 14”, VGA resolution (FPD Yokohama 2005)
• Company “C”: 4 and 5 primaries, Pixcale™, 32”, WXGA resolution, demonstrated in SID 2006 and FPD Taipei 2006.
32” panels configuration and performance

<table>
<thead>
<tr>
<th>Display</th>
<th>Backlight</th>
<th>Gamut</th>
<th>Relative Brightness</th>
</tr>
</thead>
<tbody>
<tr>
<td>RGB (3p)</td>
<td>Normal CCFL</td>
<td>72% NTSC</td>
<td>100</td>
</tr>
<tr>
<td>RGBY (4p)</td>
<td>WG CCFL</td>
<td>95% NTSC</td>
<td>95</td>
</tr>
<tr>
<td>RGBCY (5p)</td>
<td>Normal CCFL</td>
<td>92% NTSC</td>
<td>115</td>
</tr>
<tr>
<td>RGBCY (5p)</td>
<td>WG CCFL</td>
<td>110% NTSC*</td>
<td>&gt;80</td>
</tr>
</tbody>
</table>

* We believe that this value represents the highest NTSC ratio ever achieved with CCFL backlight and high efficiency. 115% NTSC and higher can be also obtained.
32” panels gamut

The multi primary gamut have the correct shape in addition to the “large number”
Wide gamut displays comparison - 90+% NTSC Displays

<table>
<thead>
<tr>
<th></th>
<th>RGB, WG CCFL</th>
<th>MPC, normal CCFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamut coverage</td>
<td>“Poor yellow”</td>
<td>“Good yellow”</td>
</tr>
<tr>
<td>Brightness efficiency</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>CCFL lifetime</td>
<td>Moderate(*)</td>
<td>High</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

(*) – If low brightness efficiency is compensated by increased lamp current, lifetime will decrease significantly
<table>
<thead>
<tr>
<th>Gamut coverage</th>
<th>LED BL</th>
<th>MPC, WG CCFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-105% NTSC, yellow deficient</td>
<td>110-120% NTSC, good yellow</td>
<td></td>
</tr>
<tr>
<td>Brightness efficiency</td>
<td>Very low</td>
<td>High</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
32” panels TV integration

The 32” panels were successfully integrated in two TV sets (as of May 2006) and are planned to be integrated in additional sets.

The 32” were demonstrated to at least 7 TV brands, compared with the best TV sets available today (including the newest models of WCG CCFL), and every time were found significantly superior.
Quixel Research
Custom Research Studies

Genoa Color Comparison Study 2006, main findings

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Quixel Research
Custom Research Studies

“X” – Multi primary panel
“Y” – Premium brand 32” TV
Number of respondents: 251
Number of video clips: 6
Number of still images: 7
Gender

- Male: 45%
- Female: 55%

n=251
Age Range

n=251

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Totals</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 21</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>22 to 29</td>
<td>57</td>
<td>22.71%</td>
</tr>
<tr>
<td>30 to 39</td>
<td>58</td>
<td>23.11%</td>
</tr>
<tr>
<td>40 to 49</td>
<td>69</td>
<td>27.49%</td>
</tr>
<tr>
<td>50 to 59</td>
<td>41</td>
<td>16.33%</td>
</tr>
<tr>
<td>60+</td>
<td>26</td>
<td>10.36%</td>
</tr>
</tbody>
</table>
On an Overall Basis, 230 of 251 Respondents Preferred the Genoa Panel

Q14a. Now I’d like you to rate your overall preference between the two LCD TVs you just watched, again, relative to the picture quality. n=251
160 Respondents Were Willing to Pay at Least $200 More for the Genoa Panel or $264 More on Average

Q15. Currently, the average price you would pay in a store for a 32” LCD TV, that is the same size TV you were just comparing, is $1499. When thinking about the TVs you just compared, how much more would you pay for X TV over Y TV? n=251
## Summary

<table>
<thead>
<tr>
<th></th>
<th>RGB WG CCFL</th>
<th>RGB LED</th>
<th>Multi primary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamut “value”</td>
<td>○</td>
<td>◎</td>
<td>◎</td>
</tr>
<tr>
<td>Gamut shape and yellow coverage</td>
<td>X</td>
<td>△</td>
<td>◎</td>
</tr>
<tr>
<td>Brightness efficiency</td>
<td>X</td>
<td>X</td>
<td>◎</td>
</tr>
<tr>
<td>Cost</td>
<td>○</td>
<td>X</td>
<td>◎</td>
</tr>
</tbody>
</table>

○ - excellent  ◎ - good  △ - fair  X - worst
Summary

Wide Gamut LCD is a reality.

WG CCFL and LED BL techniques are currently used.

Multi primary technology, as provided by Genoa, enables the best appearance at the lowest cost and lowest power consumption.
Some Frequently Asked Questions

• The camera has only 3 sensors (RGB). Therefore, display should have also only 3 primaries. Correct?
• Video and DVD data is within the Rec-709 gamut. How do you display this on the wide gamut display.
• Are the colors natural?
• In multi primary displays the RGB primaries intensity is much lower than in RGB. Why this does not effect the image?
Camera, 3 sensors...

Common notions:

“Cameras use RGB sensors to capture the image and thus their gamut is limited”

“The RGB signals from cameras are always positive so the gamut is enclosed by a triangle”

WRONG!
• Do cameras have “restricted gamut”?  
  – Cameras usually have three color sensors: red, green and blue

• However, all colors may be captured using three color sensor device  
  – Humans use three-sensor device (the eye) to view all colors. The spectral response of the eye sensors is very broad.  
  – Cameras can capture and discriminate monochromatic light (lasers), the colors of which are outside the Rec. 709 gamut
The Opponent Colors Model

- **L** (Luminance signal)
- **M** (Red - Green signal)
- **S** (Blue - Yellow signal)
Example

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>M</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.15</td>
<td>-.43</td>
<td>-2.07</td>
</tr>
<tr>
<td>2</td>
<td>1.96</td>
<td>-.32</td>
<td>-1.96</td>
</tr>
</tbody>
</table>

Camera color processing (similar to “eye color processing” enables wide gamut colors capture and discrimination)
Video data...

Q: Video and DVD data is within the Rec. 709 gamut. How do you display this on the wide gamut display.

A: Video data...
Material Encoding

- In the encoding process, the color information is usually compressed into the reference triangle (rarely clipped)
- YCC space (DVD & broadcast) may contain color information beyond the RGB gamut (negative values)
- The extended color information is clipped out by the TV after the transformation to RGB

Data analysis of a video frame
Video data

- “Out of gamut data” that is clipped in the RGB TV is displayed in the multiprimary TV
- “In gamut data” is mapped to the wide gamut display envelope to give the most preferred image
Natural image…

Q: Is the image natural?
A:
- TV images are generally NOT NATURAL (for example 12,000K white temperature, where natural white temperatures are 2700-5500K).
- However, Genoa demonstrated in FPD Yokohama 2005 and CES 2006 the capability of very accurate colors reproduction (by displaying images captured in real time by video camera). “Out of gamut” colors that can not be displayed on RGB TVs were accurately displayed on the multiprimary display.
The red and the green primaries in the multi-primary display have a lower relative luminance with respect to that of the red and the green in the RGB gamut (Rec. 709).
Film and REC-709 3D gamut

White temperature:

- Film – 5500K
- TV – 6500K
Film and REC-709 3D gamut

White temperature:

• Film – 5500K
• TV – 6500K
Film and Multi-Primary 3D gamut

White temperature:

• Film – 5500K
• TV – 10000K
Red and green natural images luminance

The reflectance of saturated green and blue real object colors is much lower than 100%

Only the red reflectance is close to 100%

Therefore, green may have much lower luminance than the Rec. 709 requirement
Red reflectance near 100% in the pass band implies that required luminance may be closer to that of Rec. 709
Red, green and blue intensity

- The green intensity in the RGB display is high because it is needed in order to produce bright white and yellow.
- In practice, the green itself should not be so bright.
- In the multi-primary display there is a yellow primary, and the green need not to be so bright.
- The green primary can be made more saturated (and less bright) increasing the color gamut.
- The red primary intensity and saturation trade-off should be optimized carefully.
- Genoa has acquired extensive experience regarding this optimization.
- The 3d multi-primary gamut is adjusted to approximately match 3D cinema gamut.