OLED Technology Evaluation for Space Applications

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Agenda

• Introduction
• Role of Displays in various Space Missions
• Display Technology Requirements for Space Applications
• AMOLED Technology Assessment
• Physical and Functional Improvements Recommended for the Use of AMOLED in Space Platforms
• Comparison of AMOLED Display Technology Against LCD Display Technology
• Conclusions and Recommendations
Introduction

- Significant commercial advancements in Organic Light Emitting Diode (OLED) display technology
  - OLED offers better performance than LCDs
  - Emerging applications due to flexible display screens
- Potential for next generation display technology for space applications
  - Evaluation of active matrix OLED (AMOLED)
  - Tested against various mission environmental requirements
Role of Displays in Various Space Missions

- Habitable volume limits the surface area suitable for incorporation of displays and controls for human rated spacecraft.
- Apollo-era displays consisted of many physical controls (switches, electro-mechanical indicators, rotary selectors, backlit indicators).

- Crew’s situational awareness shaped by the state of these controls.
- Available mature technology impacts spacecraft display and control design.
- Apollo Flight computer’s display consisted of:
  - Backlit push buttons and indicators
  - Alpha numeric gas discharge tubes
Role of Displays in Various Space Missions

Space Shuttle STS-101 Cockpit with MEDS Upgraded Displays
Role of Displays in Various Space Missions

• Space Shuttle relied on many physical controls similar to that of the Apollo-era (electro-mechanical, rotary selectors and switches, etc.)
  - Monochrome CRT based for cockpit displays
  - CRTs used for viewing CCTV motion imagery (Initially black & white, later upgraded to color)
• Advances in LCD technology made it possible to eliminate a number of electro-mechanical indicators and replace monochrome CRTs with daylight-readable color-capable LCD panels in the Multifunction Electronic Display Systems (MEDS) upgrade
• Shuttle Program introduced use of Laptop computers with LCD displays
Role of Displays in Various Space Missions

- Apollo and Space Shuttle vehicles were launched as complete vehicles and their display and control capabilities were not expected to evolve during their mission.
- International Space Station’s (ISS) displays and controls have evolved as elements added to the vehicle.
  - Technology advances in computers, networks and display panels made it possible to build display and control systems that evolve.
  - Today, ISS’s displays and controls are primarily laptop computers and video monitors that utilize LCD panel display technology.
Role of Displays in Various Space Missions

• Future human rated spacecraft will require multi-function displays
• LCD or AMOLED technology, in combination with computational and networked resources will aggregate functionality:
  ▪ Monitoring vehicle status
  ▪ Viewing checklists and maintenance procedures
  ▪ Commanding vehicle systems
  ▪ Communicating with other vehicles and terrestrially located personnel
  ▪ Providing social interaction with family
  ▪ Consulting with medical experts
  ▪ Training and entertainment
Display Technology Requirements for Space Applications

• Typical Optical Requirements
  ▪ To be tailored for the specific application

<table>
<thead>
<tr>
<th>Optical Requirement</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over Environment</td>
<td>Temperature range from -25°C to +65°C</td>
</tr>
<tr>
<td>Chromaticity</td>
<td></td>
</tr>
<tr>
<td>Luminance</td>
<td>0.1fL to 100fL (1000:1 dimming ratio)</td>
</tr>
<tr>
<td>Contrast Ratio</td>
<td>Dark Ambient 20:1; High Ambient 3:1</td>
</tr>
<tr>
<td>Luminance Non-Uniformity</td>
<td>&lt;40%</td>
</tr>
<tr>
<td>Light Leakage</td>
<td>no discernible light leakage</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>2.2% specular reflectance; 0.25% diffuse reflectance</td>
</tr>
<tr>
<td>Long Term Image Retention</td>
<td>No long term image retention is allowed</td>
</tr>
<tr>
<td>Response Time</td>
<td>Transition from any gray level to any other gray level within 17ms</td>
</tr>
</tbody>
</table>

Chromaticity at Design Eye Position

<table>
<thead>
<tr>
<th>Color</th>
<th>u'</th>
<th>v'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>0.385</td>
<td>0.540</td>
</tr>
<tr>
<td>Green</td>
<td>0.010</td>
<td>0.570</td>
</tr>
<tr>
<td>Blue</td>
<td>0.200</td>
<td>0.075</td>
</tr>
<tr>
<td>White</td>
<td>0.200</td>
<td>0.490</td>
</tr>
</tbody>
</table>

Chromaticity Variance

<table>
<thead>
<tr>
<th>Color</th>
<th>Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>0.03</td>
</tr>
<tr>
<td>Green</td>
<td>0.03</td>
</tr>
<tr>
<td>Blue</td>
<td>0.08</td>
</tr>
<tr>
<td>White</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Display Technology Requirements for Space Applications

- Typical Environmental Requirements
  - To be tailored for the specific application

<table>
<thead>
<tr>
<th>Environmental</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature range</td>
<td>-25° C to +65° C</td>
</tr>
<tr>
<td>Ambient Pressure</td>
<td>Ambient pressure environment ranging from 1.93E-6 psi (1 x 10E-4 torr) to 15.2 psi (786.1 torr) for not less than 144 hours</td>
</tr>
<tr>
<td>Humidity</td>
<td>Humidity test in accordance with MIL-STD-810 Method 507.4</td>
</tr>
<tr>
<td>Random Vibration</td>
<td>Composite of &gt; 10 Grms</td>
</tr>
<tr>
<td>Acceleration</td>
<td>20 G constant acceleration for 5 minutes in each direction for each axis</td>
</tr>
<tr>
<td>Shock</td>
<td>20 G terminal sawtooth shock pulse of 11ms duration two times in each axis, as shown in Figure 30 (MIL-STD-810, Method 516, Procedure 1)</td>
</tr>
<tr>
<td>Ozone</td>
<td>Operate after exposure to 3 to 6 ppm, total oxidant concentrations may reach 60 ppm for 1 to 3 hours in any 24 hour period</td>
</tr>
<tr>
<td>Fungus</td>
<td>Operate after exposure to requirements specified in MIL-HDBK-454, requirement 4, Fungus Inert Materials, Table 4-I Group I</td>
</tr>
<tr>
<td>Sand &amp; Dust</td>
<td>Operate after exposure to 140-mesh silica flour with particle velocity up to 500 feet per minute and a particle density of 0.25 grams per cubic feet (MIL-STD-810F, Method 510.4, Procedure 1)</td>
</tr>
<tr>
<td>Salt Fog</td>
<td>Operate after exposure to salt fog test per MIL-STD-810F, Method 509.4, with 4 alternating 24 hour periods of salt fog exposure and drying periods</td>
</tr>
</tbody>
</table>
AMOLED Technology Assessment

- Test Articles
  - Two 4.3” AMOLED displays
    - AZAMOLED043A
      » Non-touch screen
        • AZ Displays, Inc.
    - AZAMOLED043A-T
      » Touch screen
        • AZ Displays, Inc.

- Technology Assessment
  - Thermal Performance
  - Chromaticity and Emission Spectra
  - Viewing Angle
  - Image Retention
  - Environmental Performance Testing
    - EMI Testing
    - Thermal Vac Testing
    - Radiation Testing

4.3” AMOLED Display Environmental Test Pattern
AMOLED Technology Assessment

• Thermal Performance
  - Excellent chromaticity performance over temperature; very little primary color shift
  - Normalized luminance changes over temperature; would need compensation to reduce secondary color shift over temperature
AMOLED Technology Assessment

- Chromaticity and Spectra
  - ~115% NTSC color space coverage
  - Saturated pure primary colors
    - Red, Green, Blue
  - Relatively narrow emission color peaks
  - Easily satisfies color space for typical high performance avionics color targets
AMOLED Technology Assessment

- **Wide Viewing Angle**
  - Symmetric luminance roll-off from any viewing angle
  - Supports varied mounting positions in the space craft
    - Forward panel, side panels, overhead panel or center pedestal mounting is possible
AMOLED Technology Assessment

- Superb Cold Temperature Performance: -40º C
  - Cold temperature heater is not needed
  - Instantly available dynamic response
    - No LCD-like sluggishness
  - Secondary colors may need temperature compensation, depending on color performance requirements
AMOLED Technology Assessment
Environmental Testing

- Electromagnetic Testing
  - Radiated Emissions (Hardware EMI noise emitted)
  - Radiated Susceptibility (Upset hardware)
    - Frequency Band
      » 30 MHz to 18 GHz at each V/M setting
    - At 25, 50, and 75 V/M
  - Test Results – PASSED both:
    - Radiation Emission Test
    - Radiation Susceptibility at all V/M levels
AMOLED Technology Assessment
Environmental Testing

- Thermal Vacuum Testing
  - Habitat Pressures: 10, 8 and 4 psi
  - Thermal Cycling at each habitat pressure
    - 1-Thermal Cycle from -20\(^\circ\) F to +120\(^\circ\) F
  - Rapid Depressurization
    - Ambient to vacuum
    - First @1 psi/min, and then at 2 psi/min
  - Optical Equipment Used
    - Colorimeter
    - Luminance Meter
    - Spectral Irradiance Meter
AMOLED Technology Assessment
Environmental Testing

• Thermal Vacuum Testing
  ▪ Test Results
    – No issues at the three different habitat pressures or rapid depressurization
    – For thermal *cycling*, the AMOLED is sensitive to temperatures
      » Luminance changed as current changed due to temperature
      » Color shift as well—7000K to 9000K
AMOLED Technology Assessment
Environmental Testing

- Proton Radiation Testing
  - Test Conditions
    - 600 rads(Si)
      » Total dose for 10 years inside ISS
    - 6K rads(Si)
      » Total dose for 10 years outside ISS
  - Test Results
    - At 600 rads(Si)
      » No issues
    - From 600 rads(Si) to 6K rads(Si)
      » Permanent degradation of display noted with no success of annealing it
Physical and Functional Improvements Recommended for the Use of AMOLED in Space Platforms

- Cockpit displays need AMOLED panels that range from 12” to 20”
  - AMOLED panel manufacturers currently target the profitable high-performance smart phone and large-area TVs
  - Current selection of AMOLED displays are either too small or too large to be viable for use as cockpit mounted displays
  - Smaller sized currently available OLED displays would be useful for:
    - Helmet mounted displays for space suits
    - Incorporation into windows as Heads Up Displays (HUD)
    - Mobile devices that crew could utilize at any location inside a cabin

- Space platforms could be enhanced by the incorporation of touch screen technology compatible with gloved and ungloved hands
## Comparison of AMOLED Display Technology Against LCD Display Technology

<table>
<thead>
<tr>
<th>Category</th>
<th>LCD</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Luminance</td>
<td>Mature</td>
<td>Mature, better color saturation</td>
</tr>
<tr>
<td>Luminance</td>
<td>Mature and can always increase by applying more power to the backlight</td>
<td>Mature, but limited by OLED Technology, which continues to make rapid progress</td>
</tr>
<tr>
<td>Thermal Vibration</td>
<td>Mature</td>
<td>Mature</td>
</tr>
<tr>
<td>Vibration</td>
<td>Mature</td>
<td>Mature, no cell gap issues as with LCDs</td>
</tr>
<tr>
<td>Other Environments</td>
<td>Mature</td>
<td>Mature</td>
</tr>
<tr>
<td>Radiation</td>
<td>Mature, but components around LCD must be tested</td>
<td>More evaluation is needed, and components around OLED must be tested</td>
</tr>
<tr>
<td>Reliability</td>
<td>Mature and proven history in Space</td>
<td>Industry is rapidly improving operating life. Still testing in Space environments</td>
</tr>
<tr>
<td>Weight</td>
<td>Acceptable</td>
<td>Offers <strong>weight reduction</strong> and shallower display depth, via the removal of the backlight and associated heat sink</td>
</tr>
<tr>
<td>Power</td>
<td>Acceptable</td>
<td>Offers <strong>power reduction</strong> with the removal of backlight</td>
</tr>
</tbody>
</table>
Conclusions and Recommendations

• Moderate brightness levels
  - For display brightness levels in the vicinity of 120 fL, the AMOLED display may be a suitable candidate for human space flight use

• Extremely high brightness levels
  - OLED displays suffer from emitter life degradation and from thermal management challenges, particularly for long duration operation at high luminance levels
  - For extremely bright displays requiring 200 fL, and very long lifetimes, currently an LCD may be a better choice
Conclusions and Recommendations

- During EMI testing, the AMOLED display operated nominally with no anomalies detected.
- During TVAC testing, the AMOLED display is found to be sensitive to temperature changes.
  - AMOLED displays need a controlled *operating* temperature range to ensure luminance and color shifts are minimized.
    - A temperature compensation system designed into the OLED drive electronics would reduce color shifts due to ambient temperature variations.
Conclusions and Recommendations

- Proton radiation testing showed the AMOLED display is suitable for use inside a spacecraft when the total dose does not exceed 600 rads(Si)
  - When AMOLED displays are used externally, the display will begin to darken, as the total dose exceeds 600 rads(Si) and approaches 6K rads(Si), which represents 10-years of exposure outside the ISS
    - Permanently affecting its optical properties

- Heavy ion testing must be performed to determine suitability of OLED technology for use beyond low Earth orbital applications
Conclusions and Recommendations

• OLED technology has made impressive advances in lifetime and environmental robustness
  - AMOLED technology show promise for continued future advances in luminance, power efficiency, and lifetime
  - The evaluation results of an AMOLED display suggest that the technology’s benefits of low power, light weight and thin size, combined with excellent optical performance, makes OLED technology a potential candidate for future human space missions