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

Samsung Flexible OLED Display

LG's flexible and transparent OLED Display

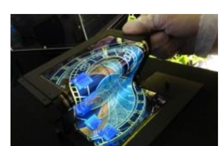
Curved

Foldable

Bendable

Rollable

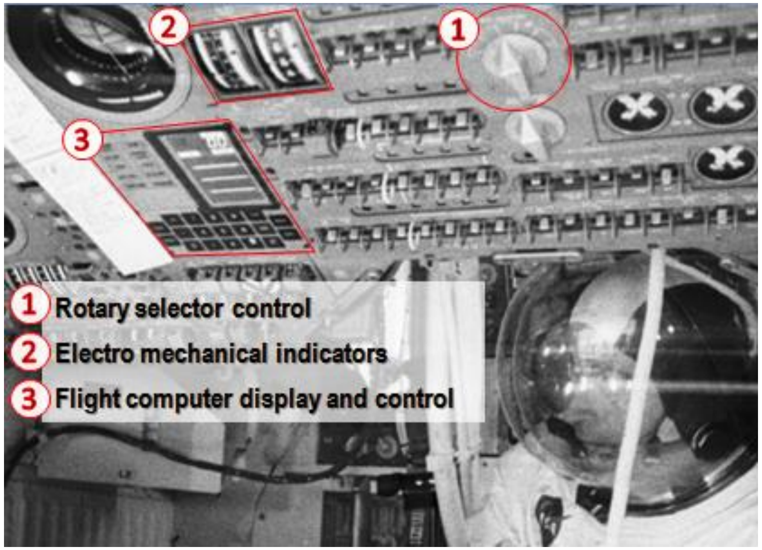
LG's curved OLED Display



Semiconductor Energy Laboratory's foldable OLED Display

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)



John W. Young working in the Apollo 10 Prime Crew Command Module

- 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

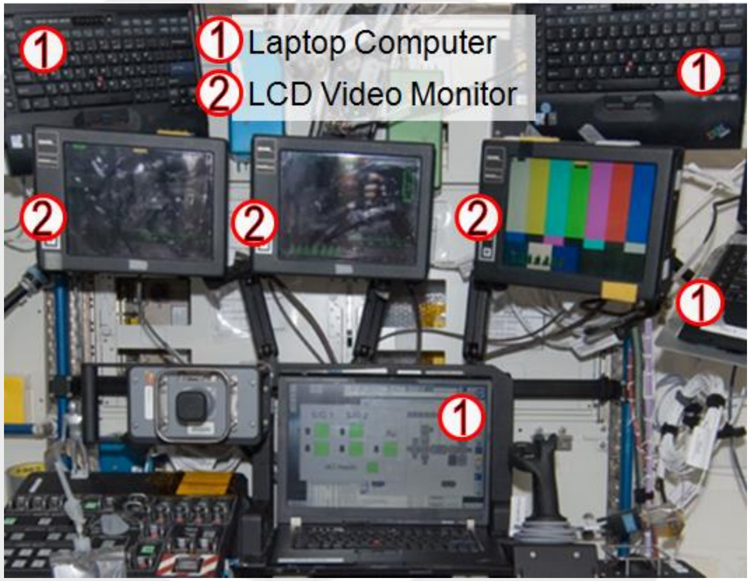
- Space Shuttle relied on many physical controls similar to that of the Apollo-era (electro-mechanical, rotary selectors and switches, etc.)
  - Monochrome CRT based for cockpit displays
  - CRTs used for viewing CCTV motion imagery (Initially black & white, later upgraded to color)

MEDS Display

- 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



ISS Robotics Workstation

  - 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

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

Chromaticity at Design Eye Position

Color	u'	v'
Red	0.385	0.540
Green	0.010	0.570
Blue	0.200	0.075
White	0.200	0.490

Chromaticity Variance

Color	Radius
Red	0.03
Green	0.03
Blue	0.08
White	0.03

Display Technology Requirements for Space Applications

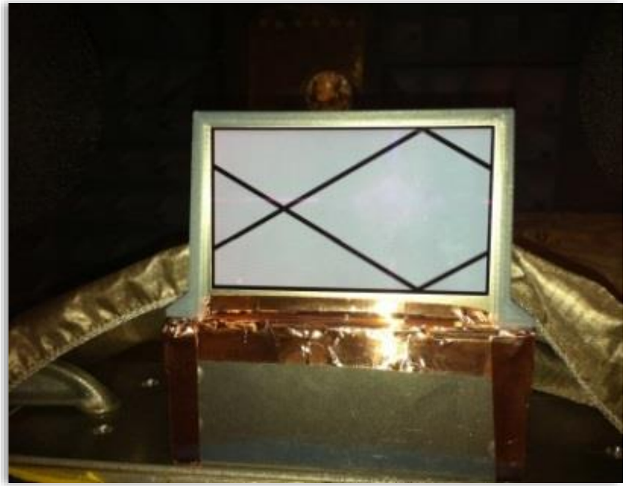
- Typical Environmental Requirements
  - To be tailored for the specific application

Environmental	Requirement
Operating temperature range	-25° C to +65° C
Ambient Pressure	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
Humidity	Humidity test in accordance with MIL-STD-810 Method 507.4
Random Vibration	Composite of > 10 Grms
Acceleration	20 G constant acceleration for 5 minutes in each direction for each axis
Shock	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)
Ozone	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
Fungus	Operate after exposure to requirements specified in MIL-HDBK-454, requirement 4, Fungus Inert Materials, Table 4-I Group I
Sand & Dust	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)
Salt Fog	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

AMOLED Technology Assessment

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

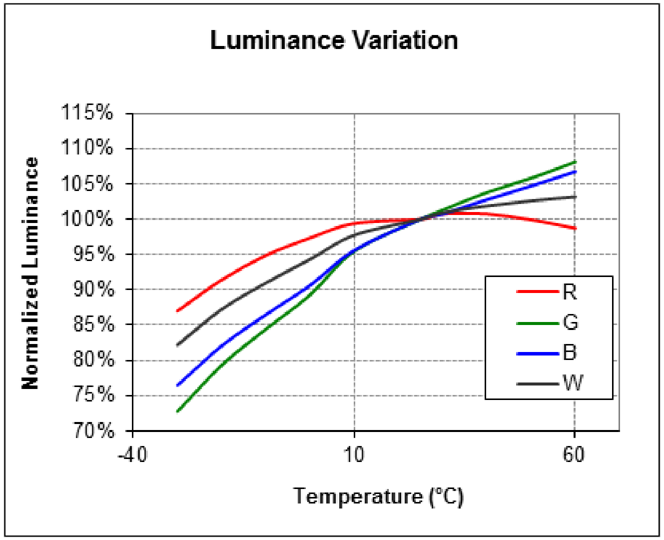
- Technology Assessment
  - Thermal Performance
  - Chromaticity and Emission Spectra
  - Viewing Angle
  - Image Retention
  - Environmental Performance Testing
    - EMI Testing
    - Thermal Vac Testing
    - Radiation Testing

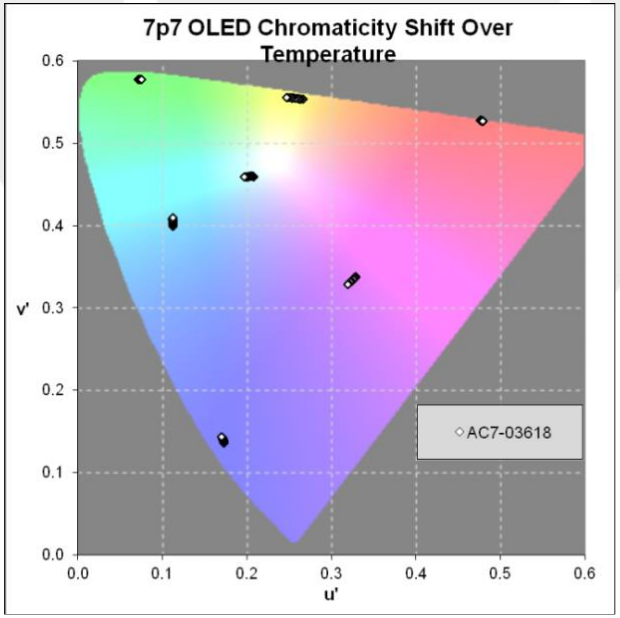


4.3" AMOLED Display Environmental Test Pattern

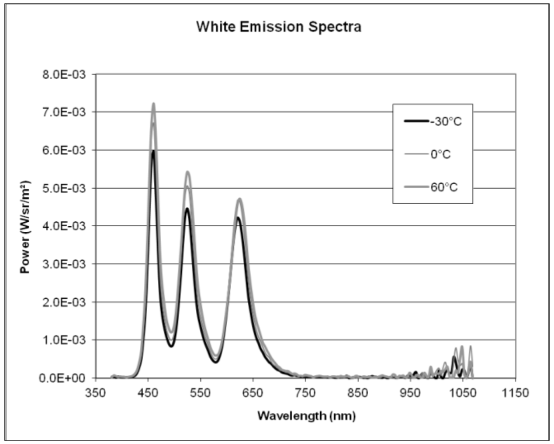
AMOLED Technology Assessment

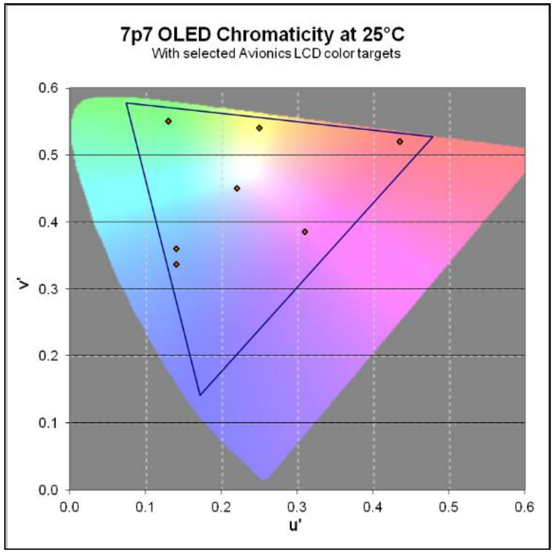
- Thermal Performance
  - Excellent chromaticity performance over temperature; very little primary color shift
  - Normalized luminance changes over temperature; would need compensation to reduce secondary color shift over temperature





AMOLED Technology Assessment

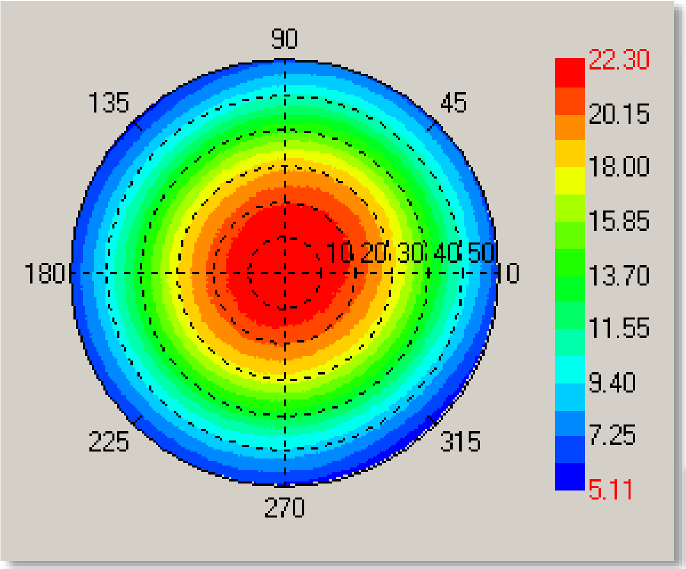




- Chromaticity and Spectra
  - ~115% NTSC color space coverage
  - Saturated pure primary colors
    - Red, Green, Blue
  - Relatively narrow emission color peaks
  - Easily satisfies color space for typical high performance avionics color targets

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



White Gray Level 128 Luminance (fL) over Viewing Angle

AMOLED Technology Assessment

- Superb Cold Temperature Performance: -40º C
  - Cold temperature heater is not needed
  - Instantly available dynamic response
    - No LCD-like sluggishness

AMOLED Cold Temperature Startup

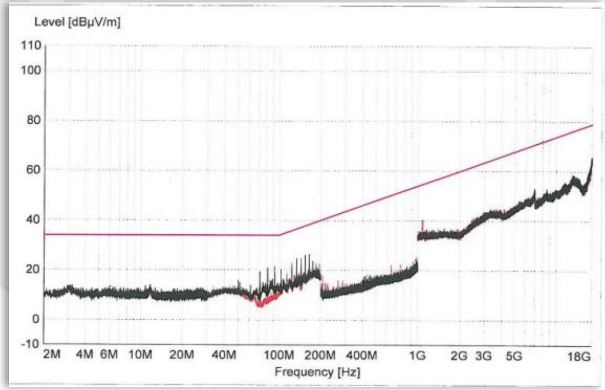
  - Secondary colors may need temperature compensation, depending on color performance requirements

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

JSC Bldg 14 EMI Test Facility

AMOLED Clamped to EMI Table



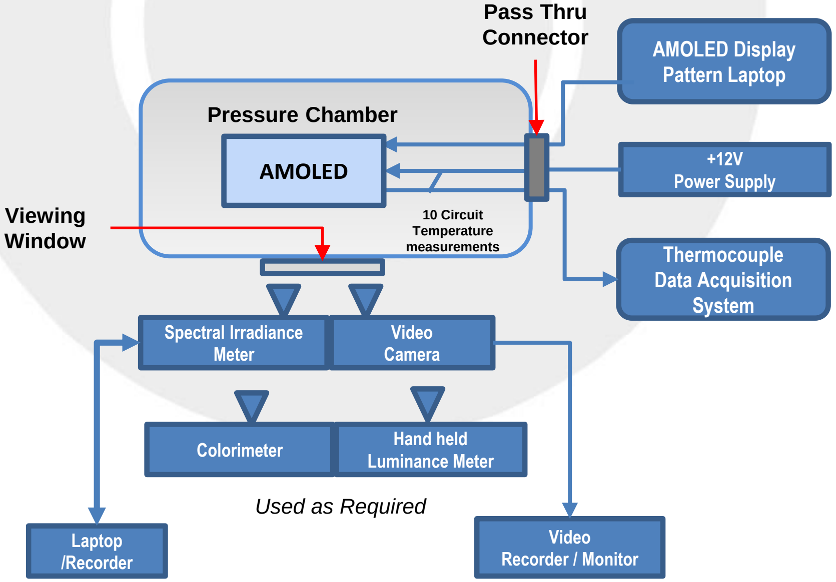
Radiation Emissions Test Spectrum

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^{o} F to +120^{o} 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

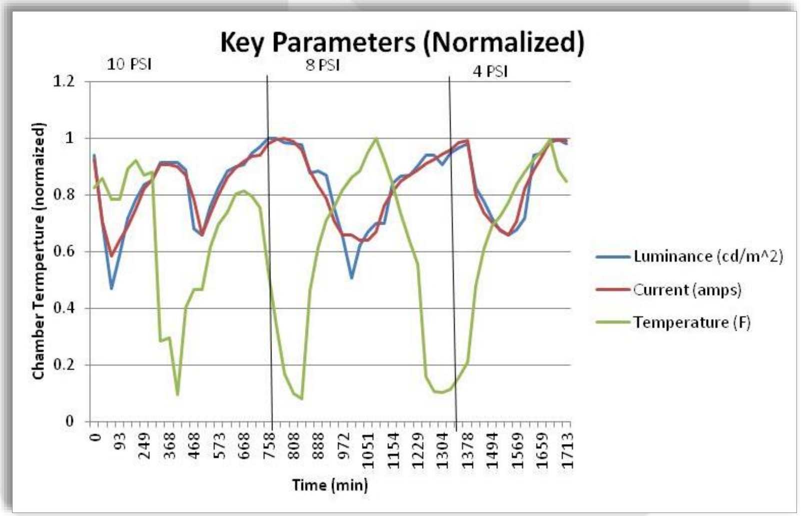


Thermal Vacuum Test Setup



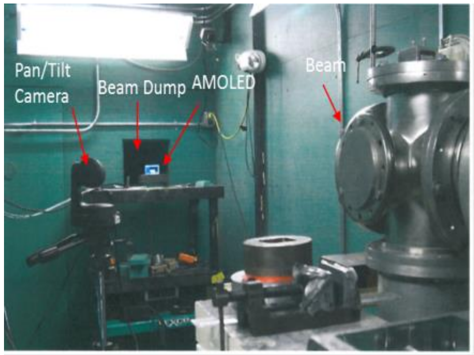
AMOLED Technology Assessment
Environmental Testing

- 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

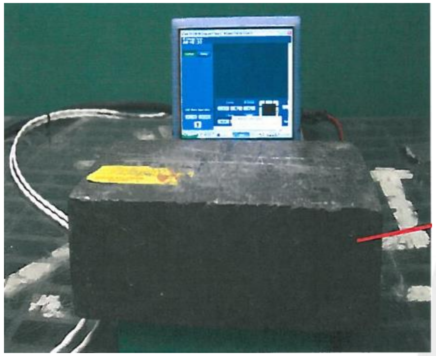


Current Draw as a Function of Temperature

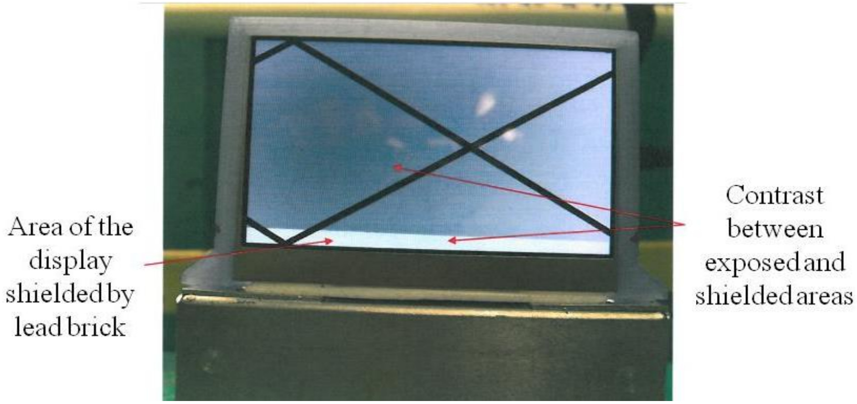
AMOLED Technology Assessment
Environmental Testing



AMOLED Inside Cave Indiana University Cyclotron Facility



Radiation Shielding



Display after proton testing up to 6K rads(Si)

- 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

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Comparison of AMOLED Display Technology Against LCD Display Technology

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

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

Shaping the Future of Aerospace