



Update on Radiation Testing of Electronic Display Technologies

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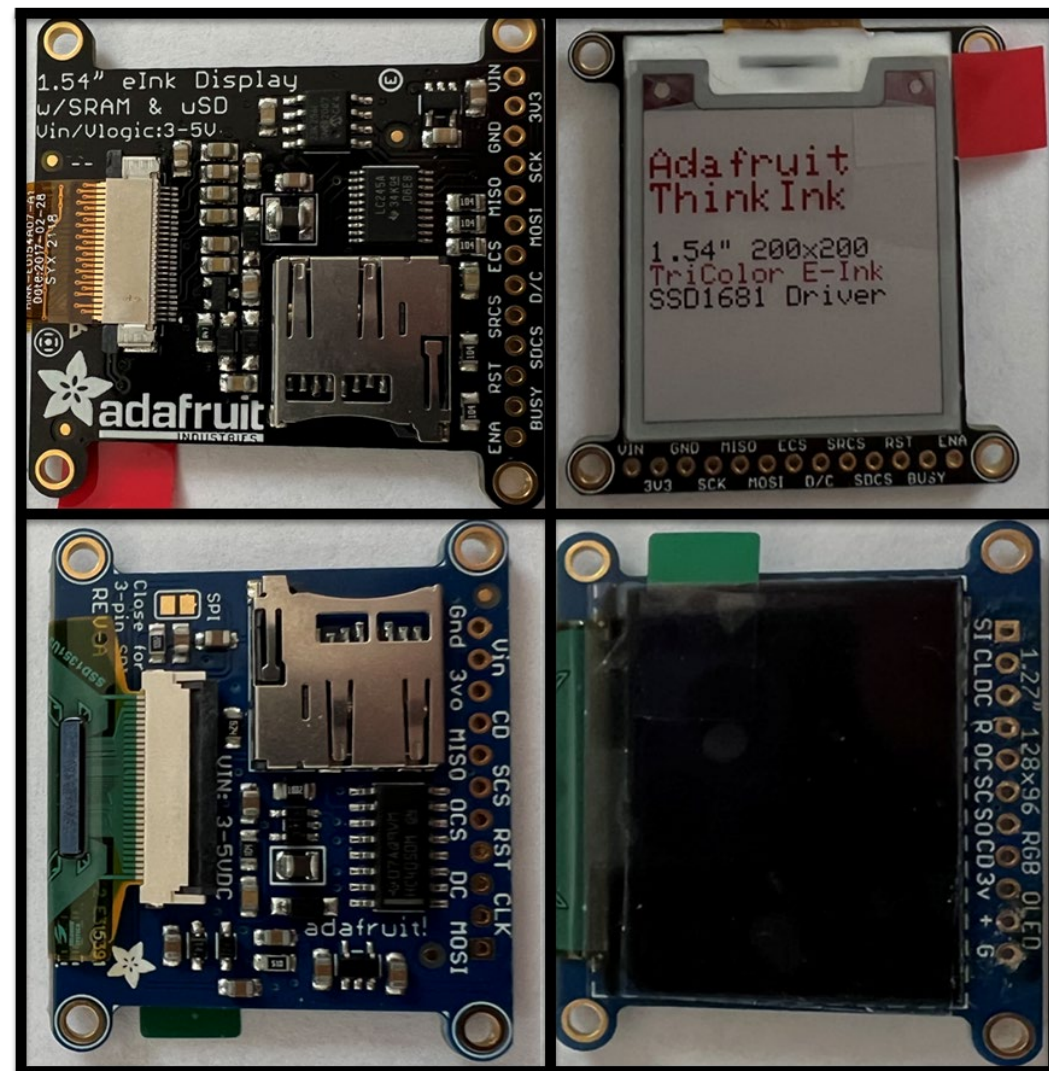
Acronyms



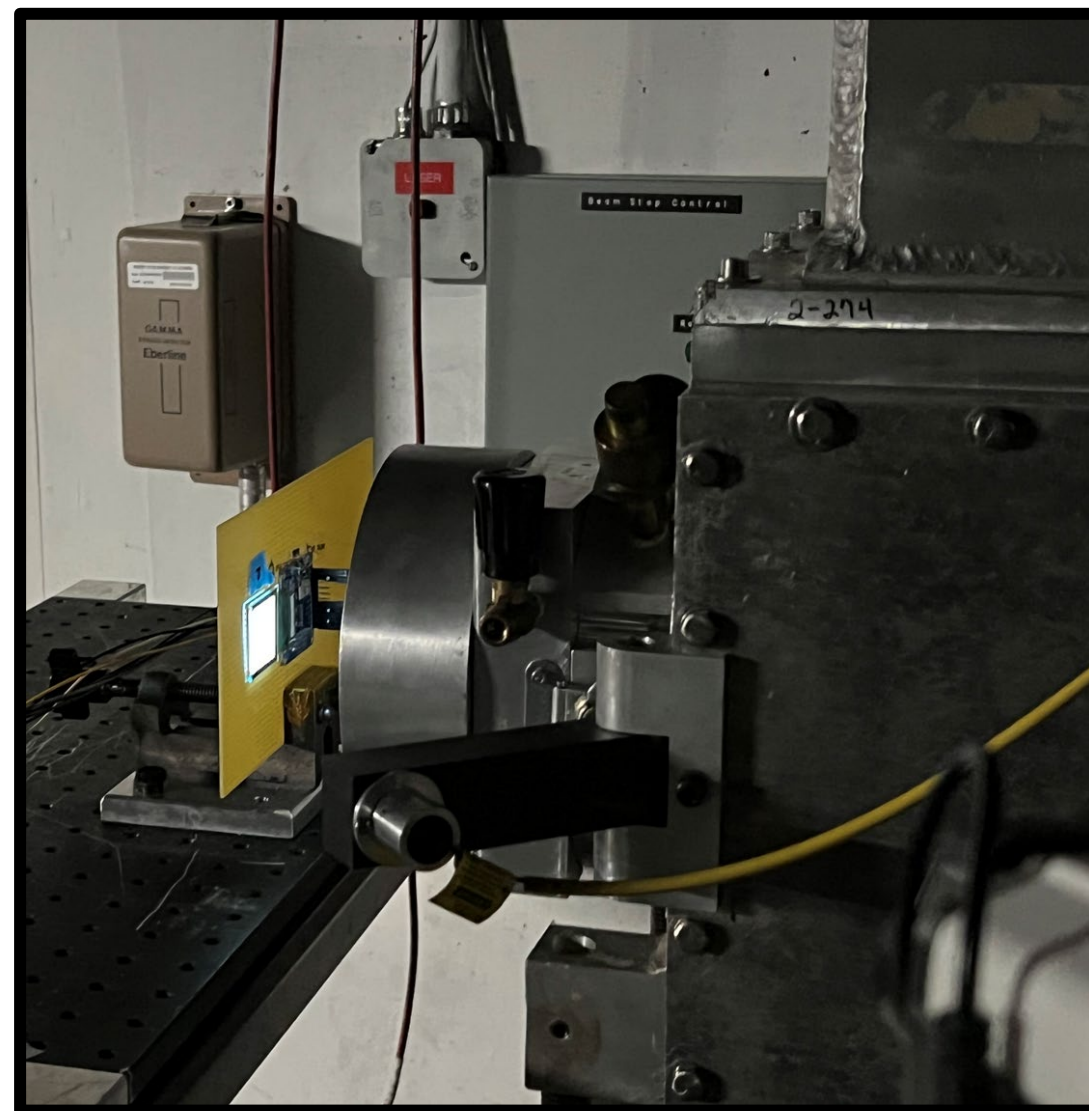
Abbreviation	Definition
2REDPANDAS	Radiation tolerant and Reliable Electronic Displays: a Preliminary Assessment Necessary for Deep-spaceflight Applications
AES	Advanced Exploration Systems
COTS	Commercial Off The Shelf
DDIC	Display Driver Integrated Circuit
EEEE	Electrical, Electronic, Electromechanical, Electro-optical
E-Ink	Electronic Ink
GSFC	Goddard Space Flight Center
HEO	Human Exploration and Operations
JSC	Johnson Space Center
LARC	Langley Research Center
LCD	Liquid Crystal Display
LET	Linear Energy Transfer
NEPP	NASA Electronic Parts and Packaging
OLED	Organic Light Emitting Diode
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEU	Single Event Upset
SEL	Single Event Latch-up
TFT	Thin Film Transistor

- **2021 Polaris Project – two year AES-HEO funded project managed by early careers**
 - Address the knowledge gap for radiation-tolerant displays for future manned missions
 - Work being continued as “Radiation Tolerant Displays” Program at JSC
- **Cross-Center Collaboration:**
 - JSC: **Justin Bautista, Tyler Garrett, Geraldo Cisneros**, Brian Schwing, Razvan Gaza
 - GSFC: **Landen Ryder**, Ed Wyrwas, Michael Campola, Jonny Pellish, Wesley Powell
 - LARC: **Sharon Xu**, Lisa Simonsen
- **Testing displays requires techniques not associated with typical EEEE parts**
 - On-site optical characterization of human-centric metrics for assessment of dose degradation
 - In-situ visual monitoring of displays for error signature during irradiation
 - Development of quantitative analysis techniques for bounding system level performance

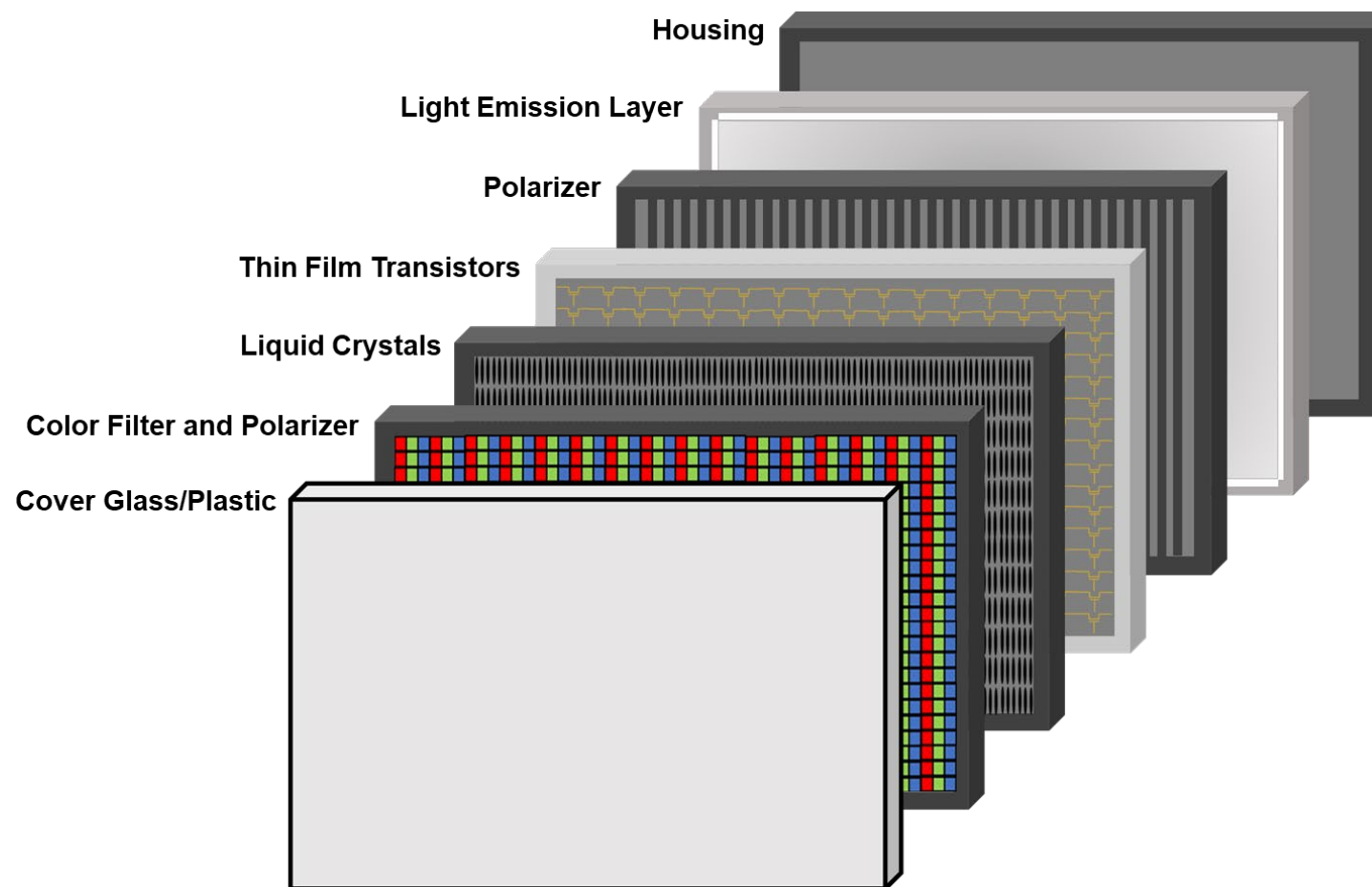
- COTS LCDs, LEDs, OLED, and E-Ink displays
- Display candidates for testing
 - Small footprint to optimize beam overlap
 - Modifiable packaging for radiation testing
 - Compatibility with common microcontrollers
 - Public facing software libraries for prototyping
 - No additional thermal mitigation required
- Results will be “generalizable” to larger displays
 - Pixel degradation will be normalized, per pixel
 - Duplicate ICs often required for larger displays, susceptibility will scale with number of ICs



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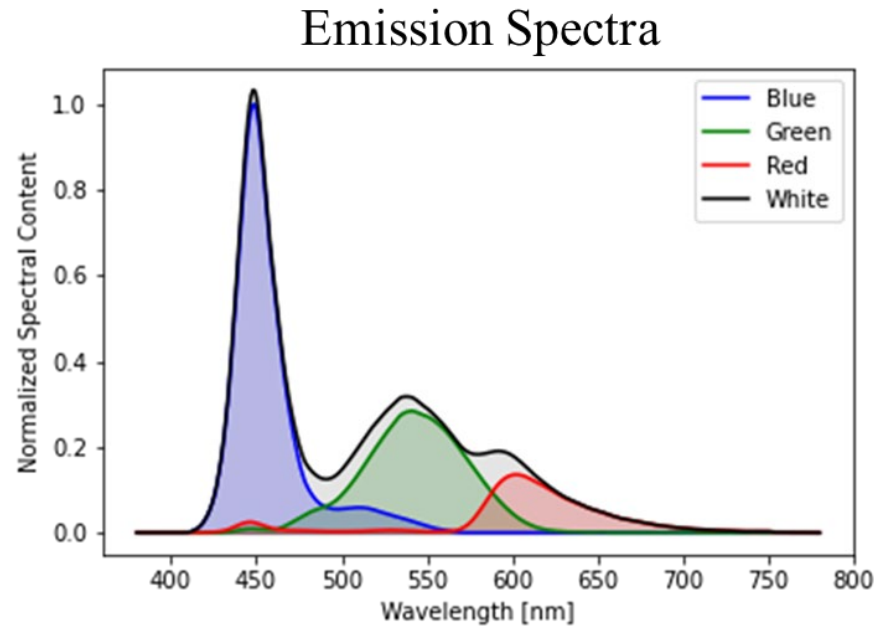


Electronic Display Screens



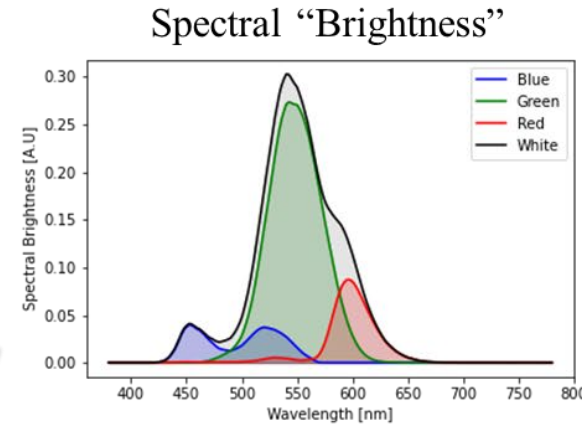
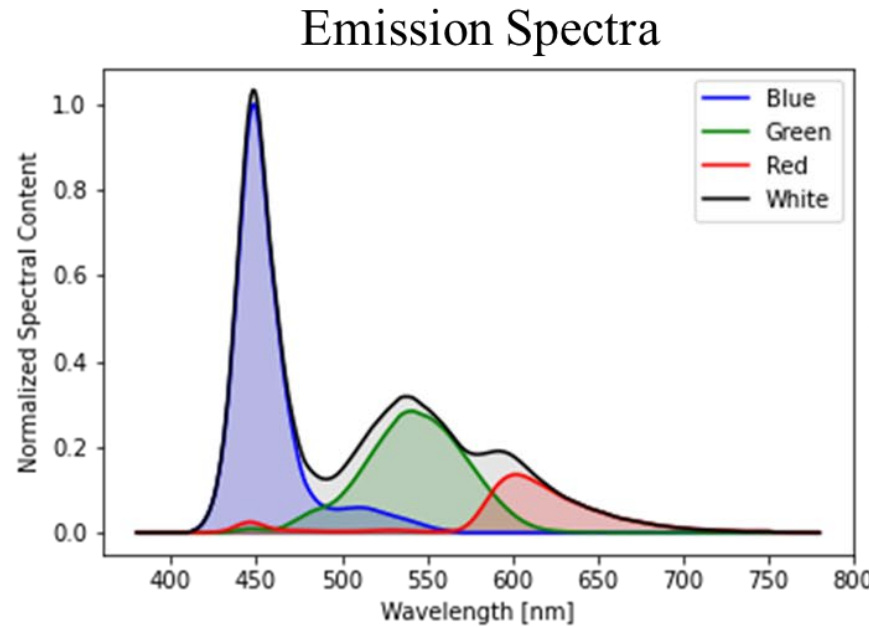
- **Electronic display screens are built from a stack of layers that can be susceptible to degradation**
 - Stack integration requires system-level testing, aggregates sensitivities from the individual layers

Human-Centric Optical Characterization

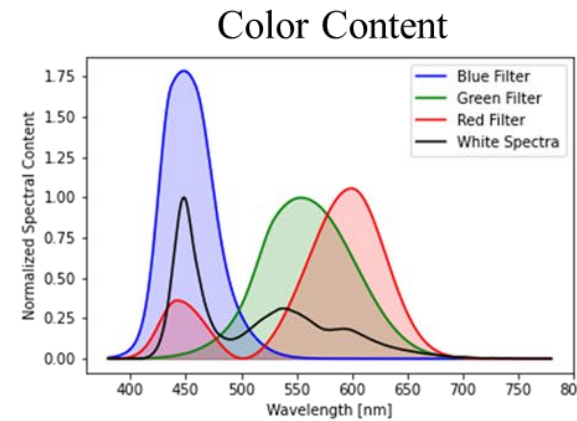


- Traditional EEEE optical testing monitors degradation at discrete wavelengths, spectra

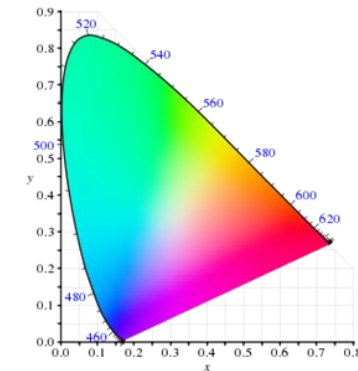
Human-Centric Optical Characterization



Contrast Ratio
Luminous Intensity

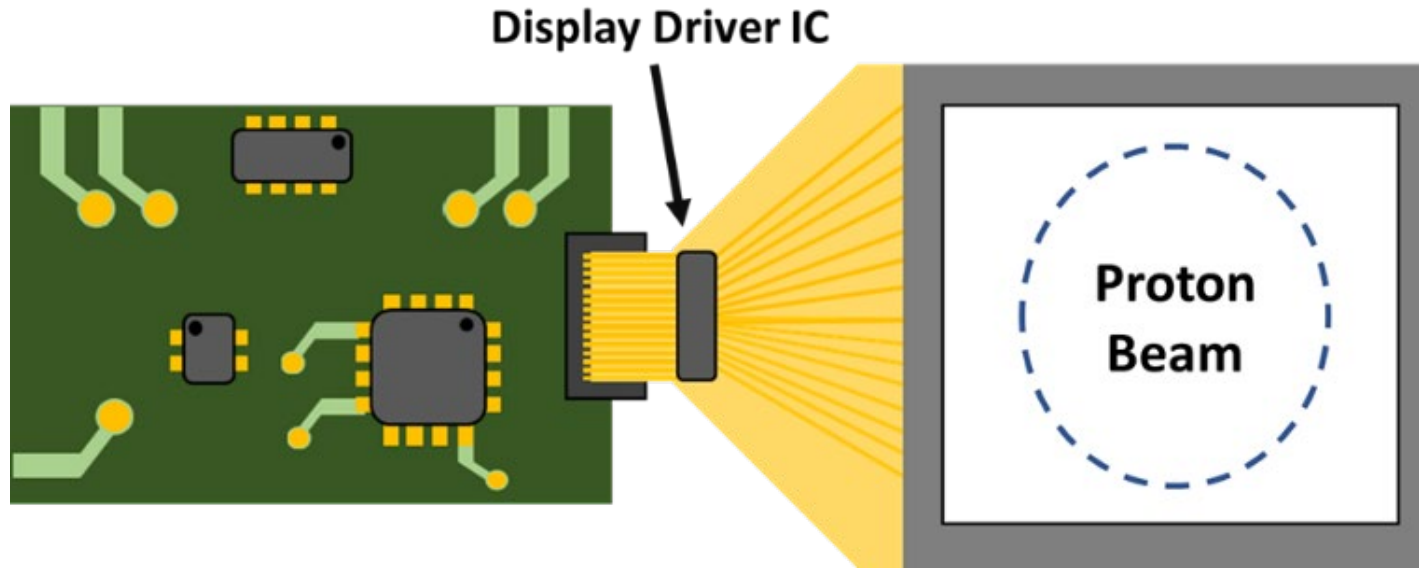


Color Space Coordinates



- Traditional EEEE optical testing monitors degradation at discrete wavelengths, spectra
- Sensitivity of the human eye acts as spectral weight for human perception
 - Conversion of optical spectra to luminous intensity (brightness) and color quantities

Proton Test Campaign – TID and DD



- 64 MeV proton irradiation at UC Davis Crocker National Lab's 76" Cyclotron
- Units configured to irradiate display screens, avoid support electronics
 - Facility provided apertures used confine exposure region to a region of the screen, cameras to monitor displays for irregular behavior during irradiation
- 3D printed light-tight box - consistent placement of display to handheld spectrometer

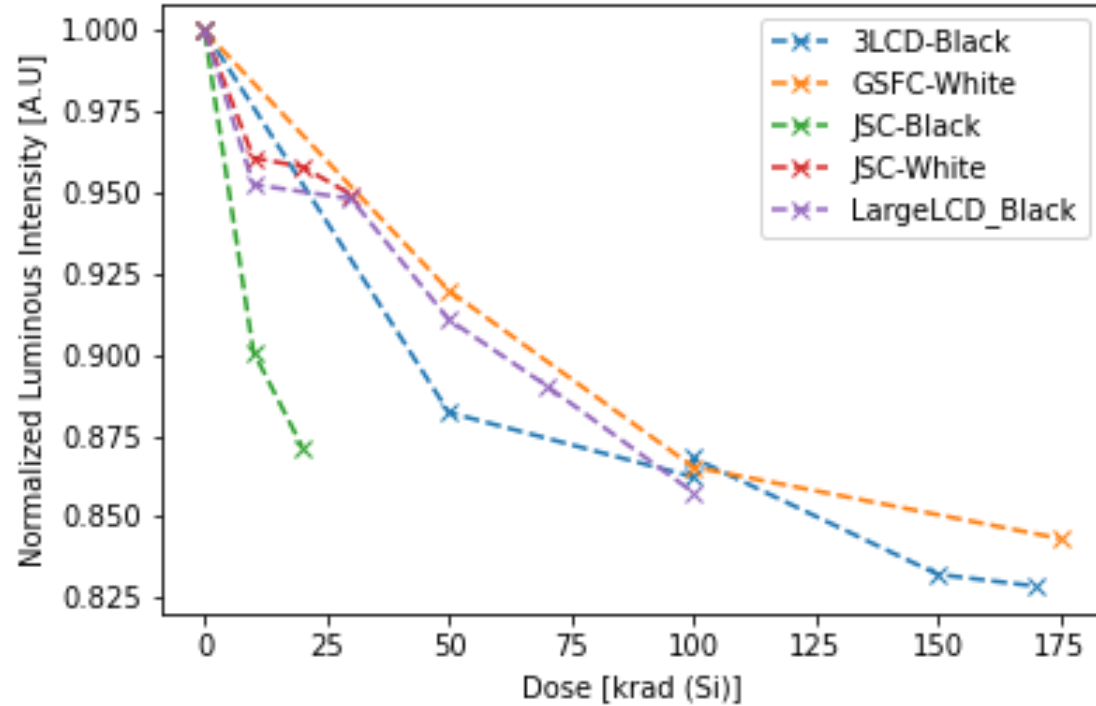
Devices Under Test – Proton Testing



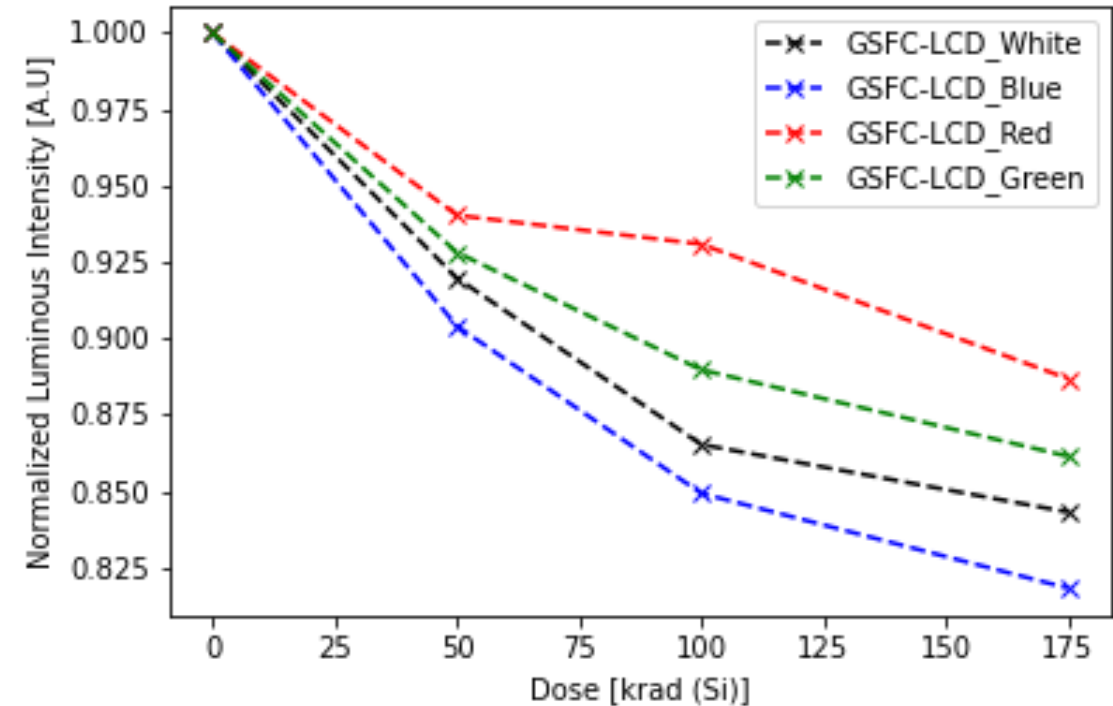
Qty	Part Number	Pixel Technology	Drive Technology	DUT Labels	Irradiation Condition
4	Product ID: 1431	OLED	Passive Matrix	GSFC-Black	Black Screen
				GSFC-Grounded	Pins Grounded
				JSC-Black	Black Screen
				JSC-White	White Screen
4	Product ID: 2478	TFT-LCD	Active Matrix	3LCD-Black	Black Screen
				GSFC-White	White Screen
				JSC-Black	Black Screen
				JSC-White	White Screen
1	Product ID: 2050	TFT-LCD	Active Matrix	LargeLCD-Black	Black Screen
1	KWM-30881CBB	Blue LED	Simple Conductor	BLED	Pins Grounded
3	KWM-20882XWB	White LED	Simple Conductor	WLED	Pins Grounded
2	Product ID: 4196	Monochrome e-Ink	Passive Matrix	M-eInk	Checkerboard and Text
2	Product ID: 4868	Tricolor e-Ink	Passive Matrix	T-eInk	Checkerboard and Text

LCD Luminosity Degradation

White Screen Luminosity

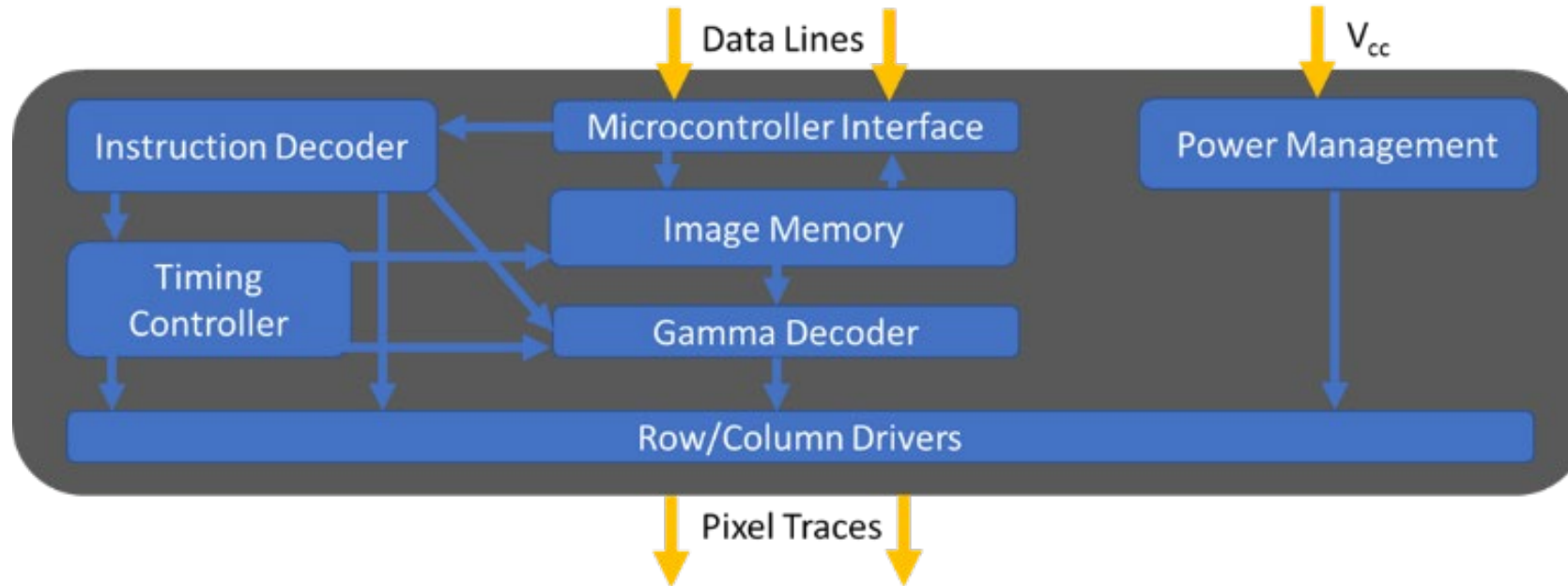


Sub-Pixel Screen Luminosity



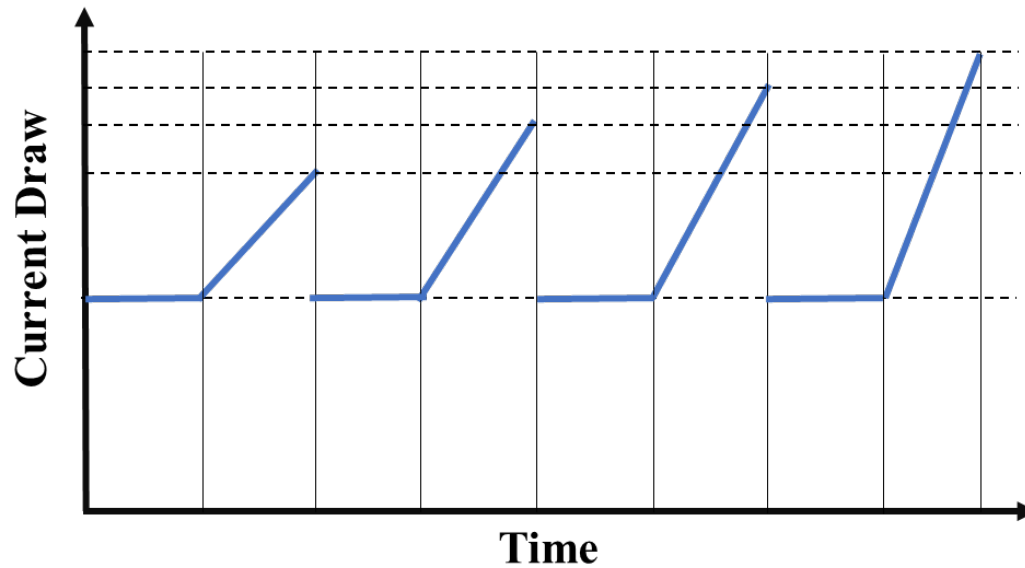
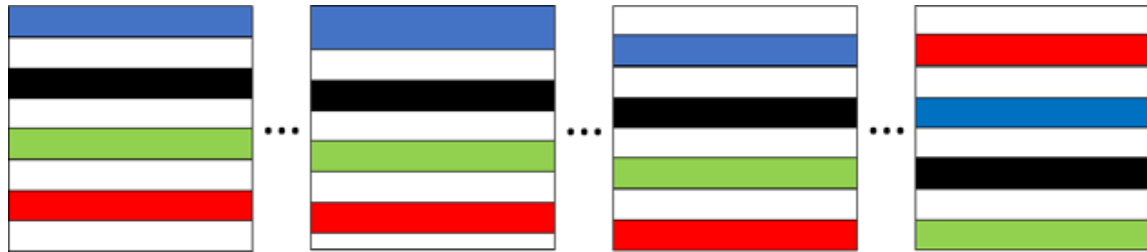
- **Decrease in white luminosity as a function of dose: ~10% loss of brightness @ 100 krad**
- **Monitoring sub-pixel luminosity demonstrates color-dependent degradation “rates”**
 - Color mixing means there is not going to be consistent degradation in display brightness
 - Monitoring blue pixels would be most conservative approach
 - Utilizing red pixels provides most consistent luminosity for the display over mission duration

Single Event Effects Measurements



- **Heavy ion testing was in air at Lawrence Berkley National Lab's 88" Cyclotron**
- **OLED display configured to irradiate DDIC without hitting off-board microcontrollers**
 - Test setups include remote power cycling to clear persistent error states between runs
- **Power supplies/cameras were monitored to identify error signatures**
 - Pixel/Line/Screen dropouts were captured via camera monitoring
 - Current draw can be used differentiate errors (Functional Interrupts vs. Latch Up)

Single Event Test Pattern



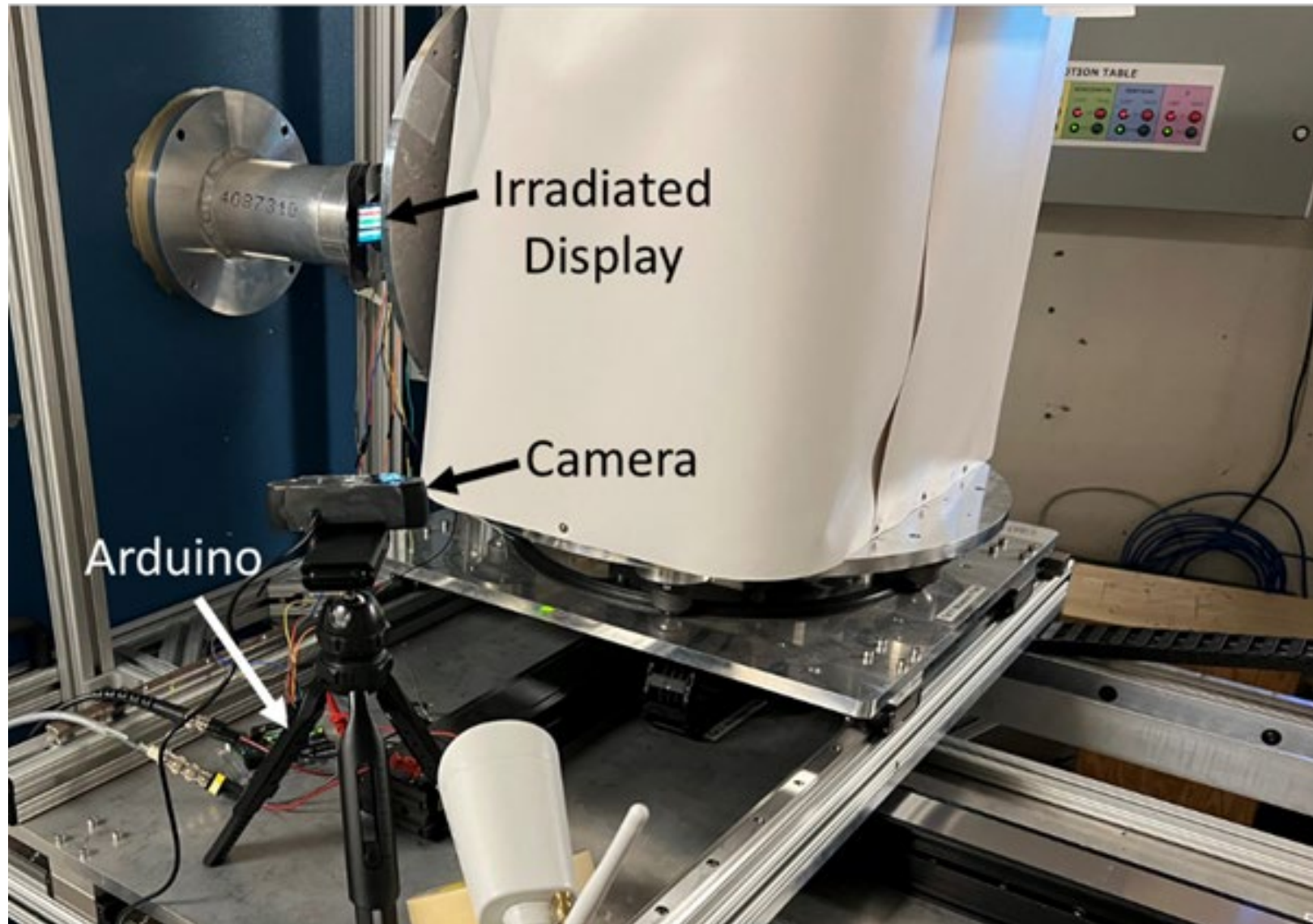
Microcontroller Test Routine 1: Typical Microcontroller Driving Behavior

```
// Configuration register initialization
ConfigBits ← ScreenResolution;
ConfigBits ← RefreshRate;
...
InitializeDDIC(ConfigBits);

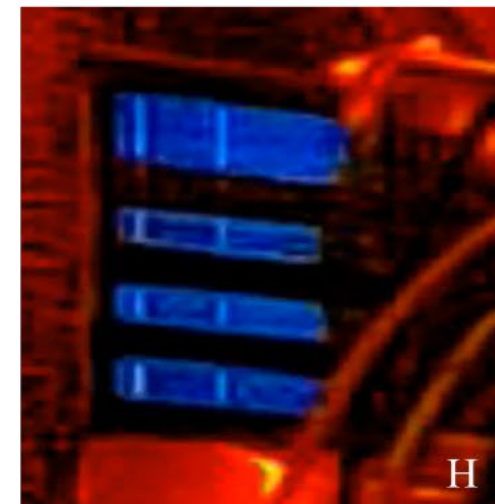
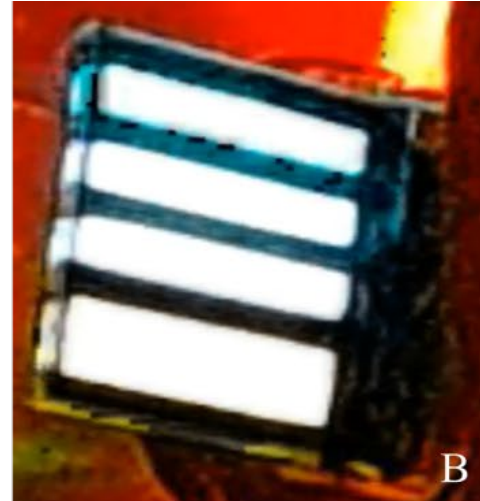
while True do
    // Image data updates every loop iteration
    UpdatedBlueVertices ← UpdateVertices(CurrentBlueVertices, dt);
    UpdatedBlackVertices ← UpdateVertices(CurrentBlackVertices, dt);
    UpdatedGreenVertices ← UpdateVertices(CurrentGreenVertices, dt);
    UpdatedRedVertices ← UpdateVertices(CurrentRedVertices, dt);
    ImageArray ← ConstructImage(UpdatedVertices);
    TransmitToDDIC(ImageArray);
    SleepUntilNextImageUpdate(dt);
end
```

- **Test pattern of white screen with scrolling bars from top to bottom of the screen**
 - Roll over behavior gives unique current draw signature that can be mapped to state of test pattern for extraction of SEE error signatures (e.g. movement of plateaus vs. slopes)

Heavy Ion Testing Setup - LBNL



Cataloguing Persistent Visual Error Signatures

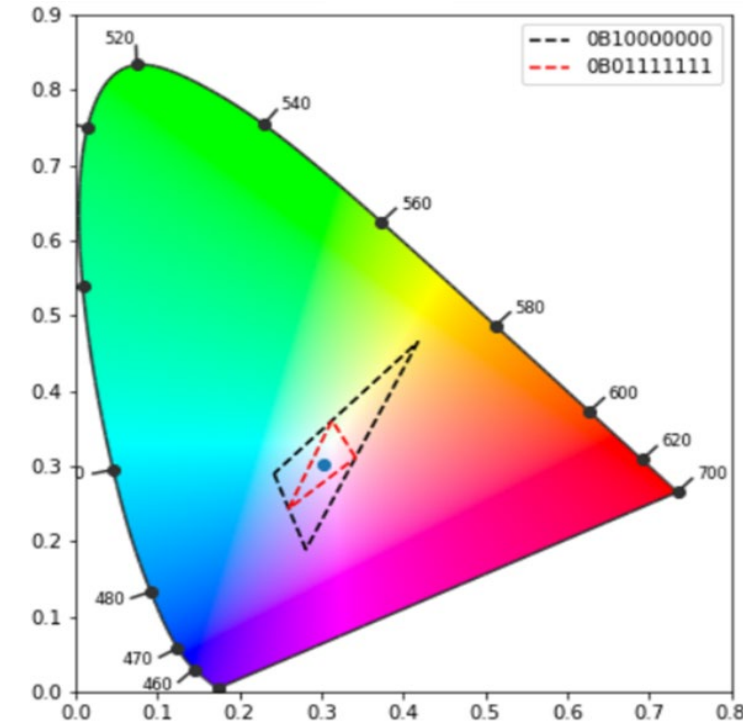
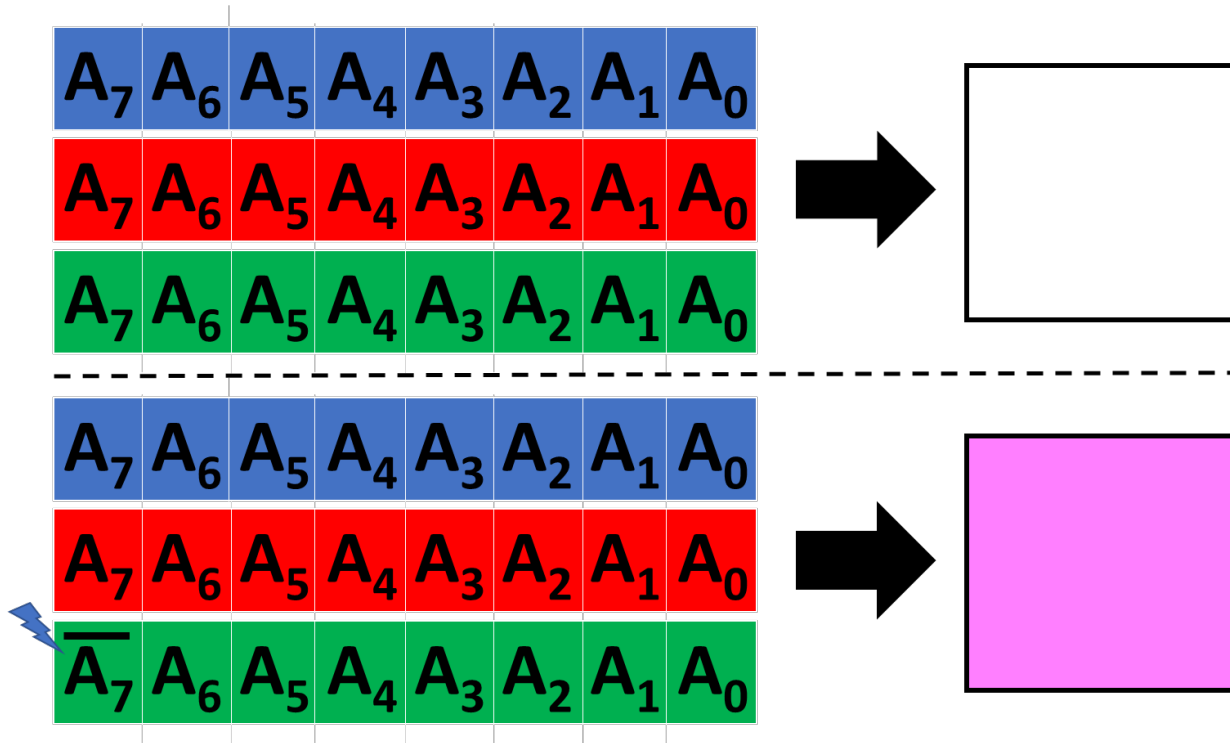


Cataloguing Persistent Visual Error Signatures

Error Signature	Command Set
Overall Brightness	Master Contrast Current Control
Changing Color Mixing	Set Contrast Current for Color A,B,C
Inverted Colors	Set Display Mode
Scrolling Direction of Color Bars	Horizontal Scroll
Speed of Scrolling Color Bars	Set Front Clock Divider
Loss of Screen Segment	Set Multiplex Ratio or Set Display Offset
White Screen	Set Display Mode
Black Screen	Set Display Mode or Set Sleep Mode
Static Image	Set Command Lock

- **Error signatures emulated on benchtop via modification of command instructions used to interface with the DDIC – localizes errors to configuration bits for the display control**
 - Allows for human-based criticality evaluation, development of error mitigation approaches

Mitigation Considerations – Register “Bit Structures”



- **DDICs utilize master contrast controls to set the dynamic range of subpixel luminosity**
 - Calibration controls used to ensure accuracy for color mixing, overall screen luminosity
- **SEUs in contrast control registers can significantly alter the color mixing depending on location**
 - “Bit structure” of registers maps to sensitivity of the registers to single bit flips

- **Deliverables**

- Posters/Papers at NSREC and RADECS for Proton and Single Event Effects Data and Analysis
- Presentation at IEEE Space Computing Conference

- **Preliminary test campaigns results yielded useful results**

- No pixel technology shows significant degradation at mission dose ranges
- Persistent visual SEEs were observed at low LET values in a COTS DDIC, requires resets
- Reproduction of radiation-induced degradation on benchtop for human-based criticality assessment

- **Develop the body-of-knowledge, testing capabilities for future manned mission needs**

- Broad characterization of technologies sensitivities – “Should we use LCDs or OLEDs?”
- Impact of design features on radiation tolerance – “Edge-coupled or back-lite LCD screens?”
- Refine techniques for radiation testing of displays – “We have already bought these displays, so...”