An Examination of Heavy Ion-Induced Persistent Visual Error Signatures in an Electronic Display Driver Integrated Circuit

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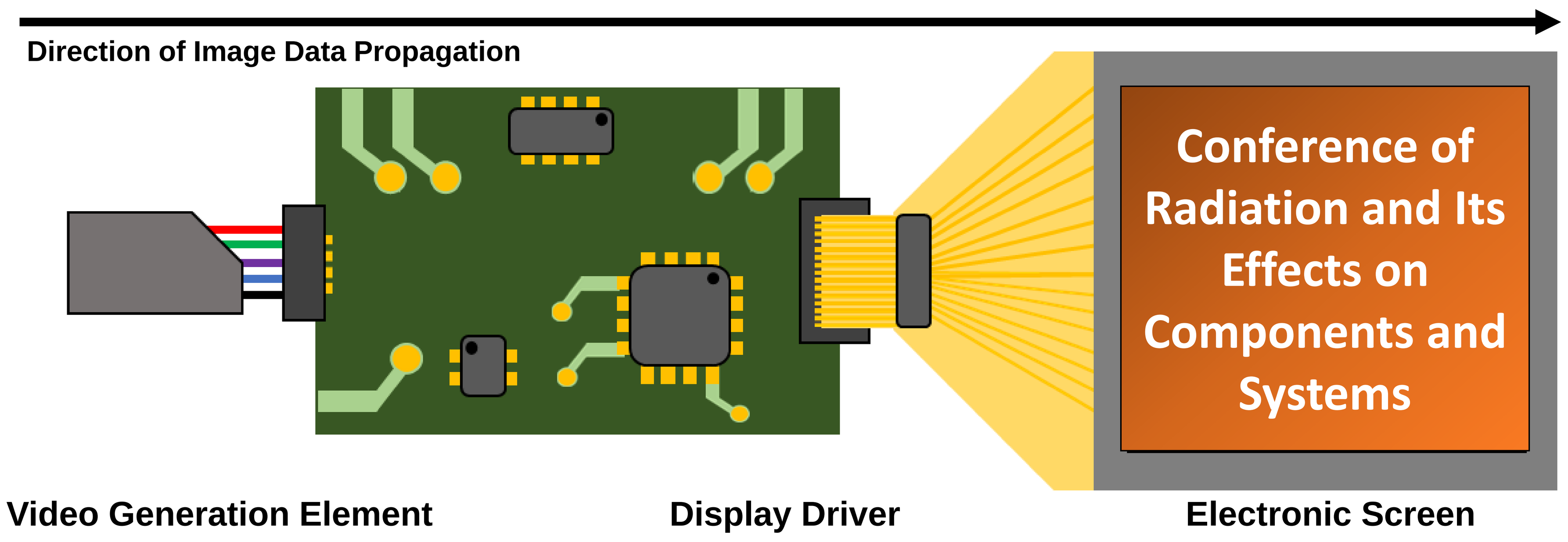
Abstract

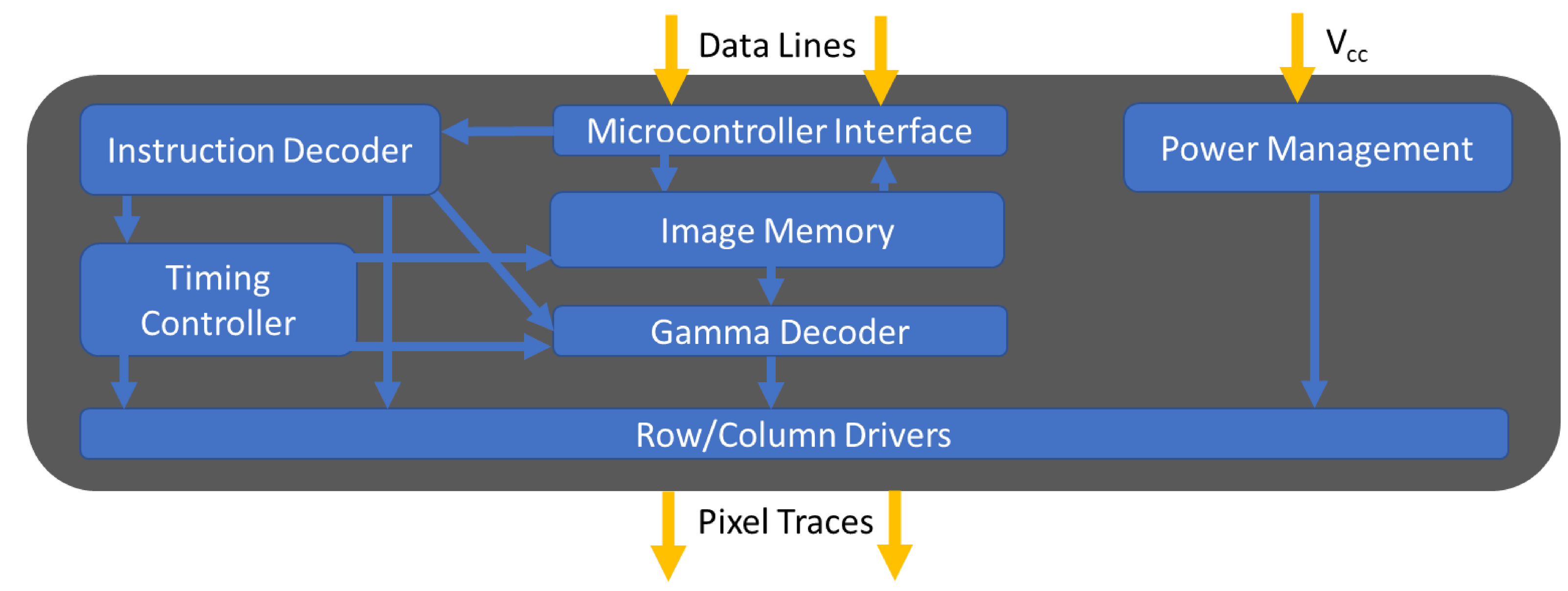
Given the ubiquity of electronic displays integration in human-based systems, the impending mission critical, space-based applications of electronic displays will necessitate SEE assessment of components unique to electronic displays. A commercially available DDIC designed to drive a small form factor organic light emitting diode (OLED) was visually monitored during heavy ion irradiation to catalogue radiation induced persistent visual error signatures that require manual intervention (i.e., power cycling) to return to nominal function. These error signatures were able to be reproduced via modification of configuration register values utilizing the instruction set intended for interfacing a microcontroller with the DDIC. This approach to emulation of heavy-ion induced errors on a table-top assists with human perception-based criticality analysis as well as development of mitigation techniques.

Integrated Electronic Displays



- Integrated electronic displays can be functionally decomposed into three components:
  - Video Generation Element – create image data for display (brightness, color, etc.)
  - Display Drivers – convert image data into temporal drive signals to drive screens
  - Electronic Screens – addressable arrays of optical emission/modulation pixels
- Screens & video generation elements have existing analogs amongst existing test data
  - Error states in the display driver can impact system behavior, require characterization

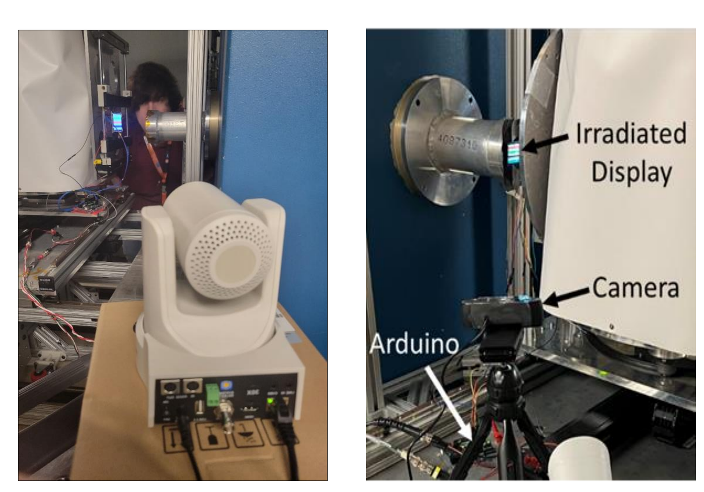
Electronic Display Driver Integrated Circuits (DDICs)



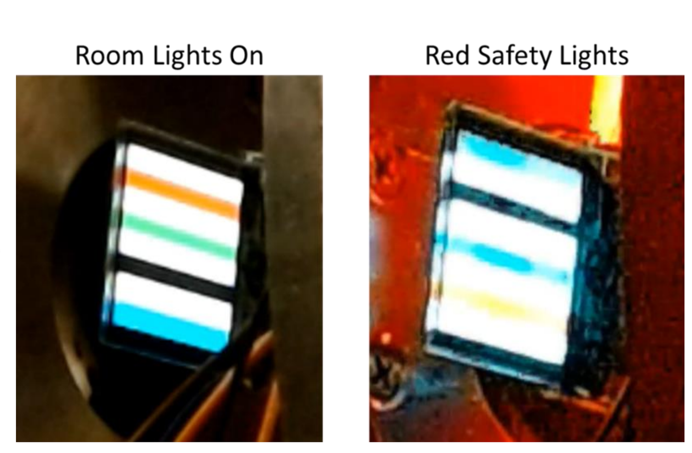
- Decomposition of a DDIC identifies SEE error sensitivities that present at a system level
  - Receiver for op commands & image data streamed from an off-board controller
  - Configuration registers & temporary memory for current image data
  - Control signal generation – timing circuits, DACs, Gamma correction,
  - Row/column drives systematically drive individual pixels based on control signals
- Configuration & instruction SEUs create operational errors, memory upsets impact pixels

Testing Approach

- Test Article: SSD 1351 COTS DDIC
  - Drives small form factor passive matrix OLEDs
- Heavy ion irradiation at Lawrence-Berkely National Laboratory Cyclotron – Neon from 16 MeV/u tune
  - Low LET to maximize range through DDIC die
- DDIC is interfaced with an off-board microcontroller
  - Nominal configuration and image data passed from controller affirms errors originate in DDIC



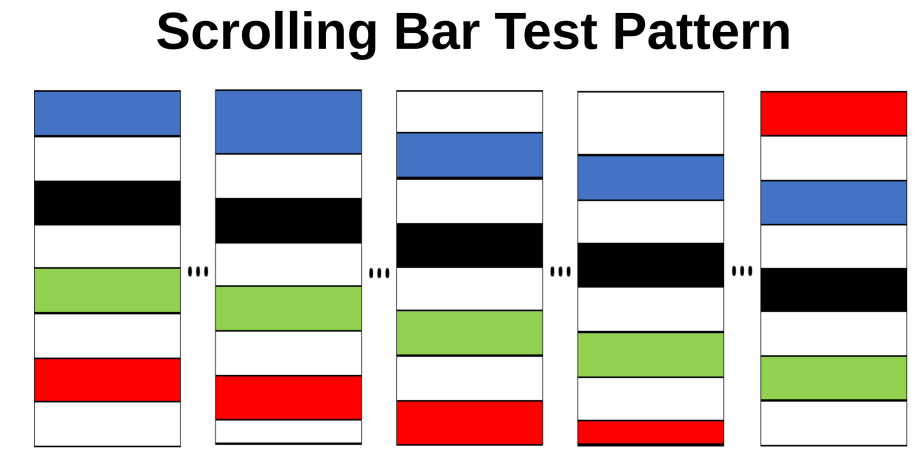
- Visual persistent errors require in-situ monitoring
  - Video feed to monitor the display visual output
  - Supply monitoring for resetting DDIC, clear errors
- Unique challenges for in-situ visual monitoring
  - Camera vs. display frame rate visual artifacts
  - Uncontrolled ambient lights (e.g. safety lights)

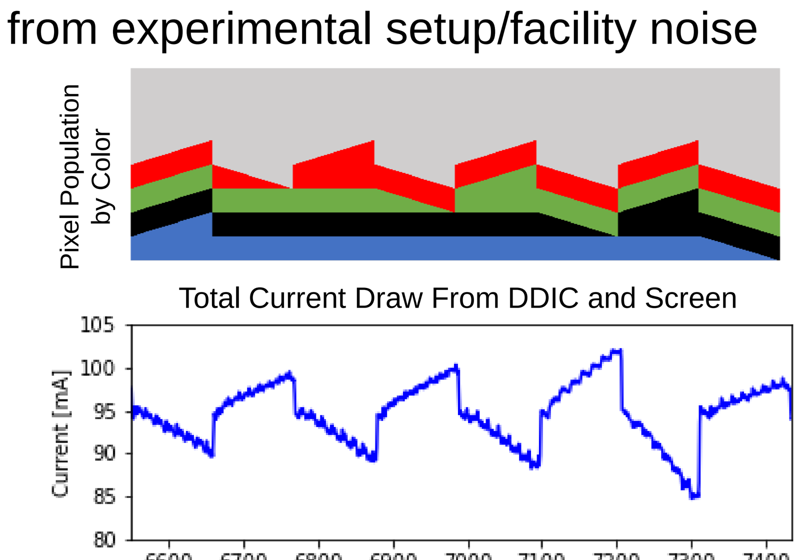


Test Pattern

- Custom test patterns can maximize data extraction from current & video monitoring
  - "Movement" needs to be slow compared to framerate of the monitoring camera
  - "Feature sizes" pattern should be large enough to be resolved via monitoring camera
  - Current draw from additive color emissive pixels varies based on color
- Test pattern in this work utilize colored bars separated by white regions slowly scrolling down - Each bar must be completely off the screen before appearing at the top
  - Modulates relative population of color pixels → pattern on monitored current draw
  - Simple geometry minimizes visual artifacts from experimental setup/facility noise

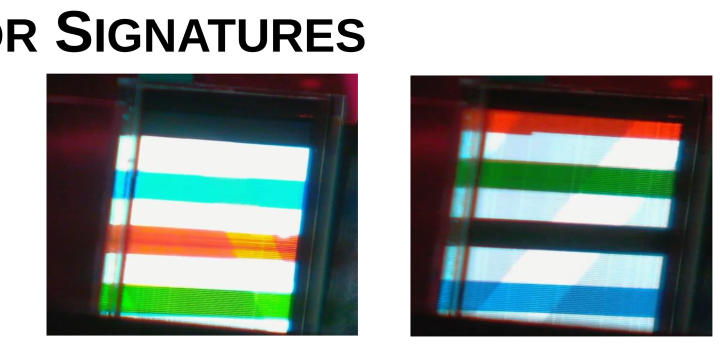
Scrolling Bar Test Pattern

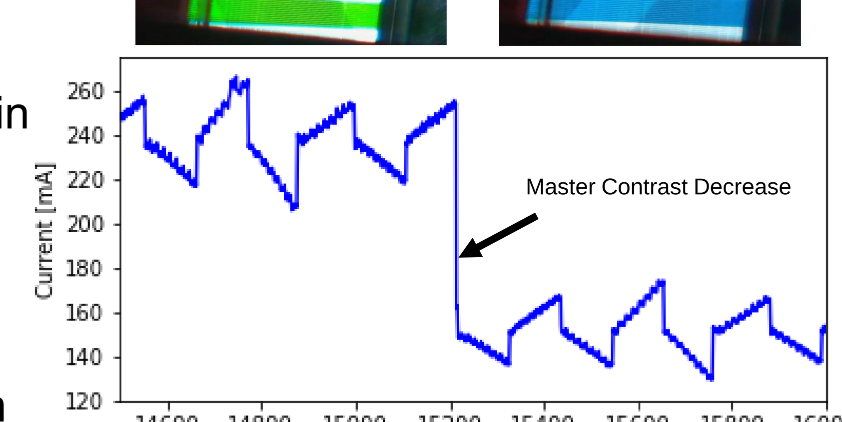


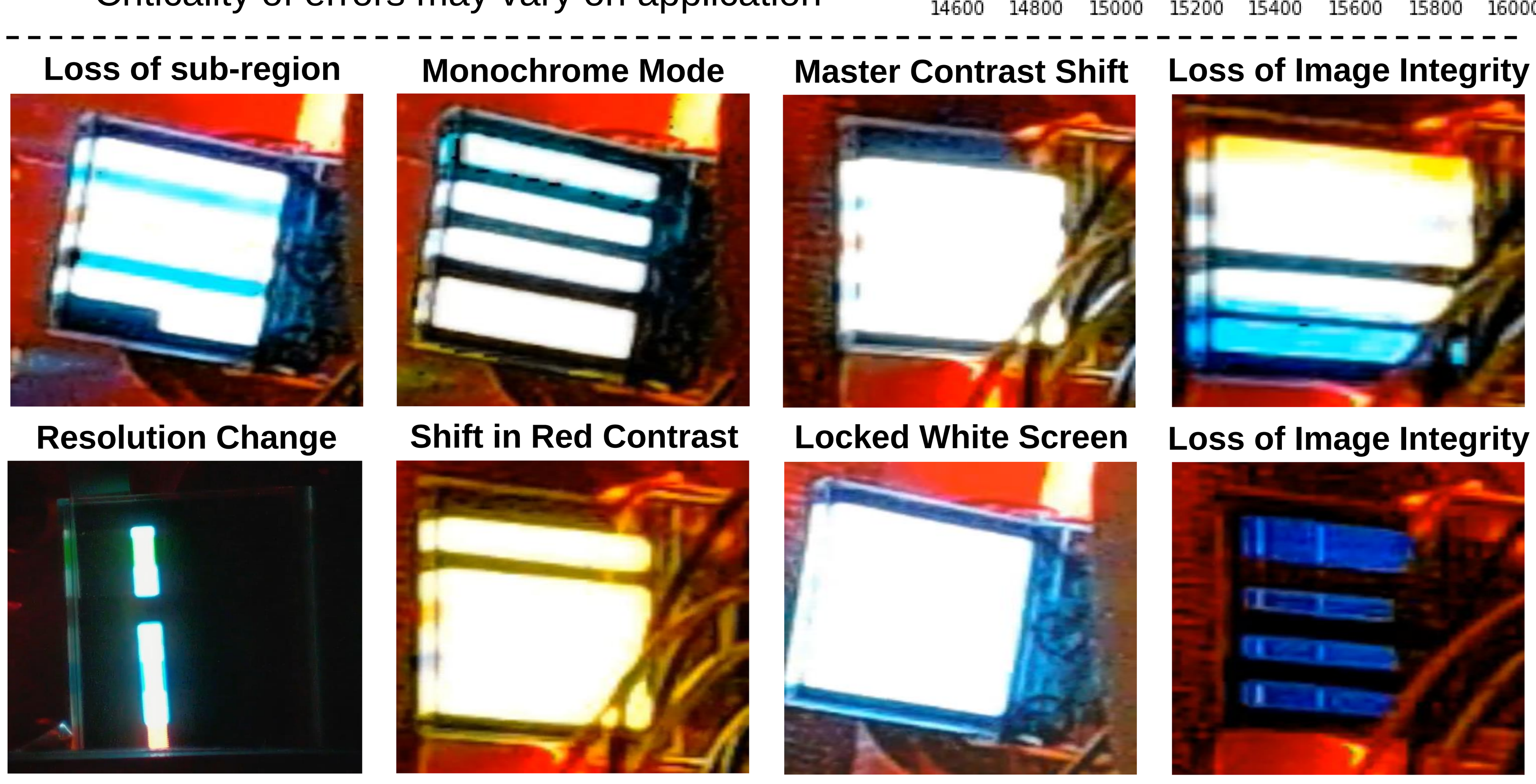


Persistent Visual Error Signatures

- Typical ConOps implies primary SEE concern is persistent visual errors requiring intervention
  - Individual "twinkling" pixels not a concern
- Combining current & visual monitoring allows for more in-depth evaluation of error modes
  - "Black screen" can be determined to be a in a "stow" configuration vs. loss of control
  - Observed brightness vs. current draw
- Various error signatures were catalogued to assess the gamut of error modes
  - Criticality of errors may vary on application



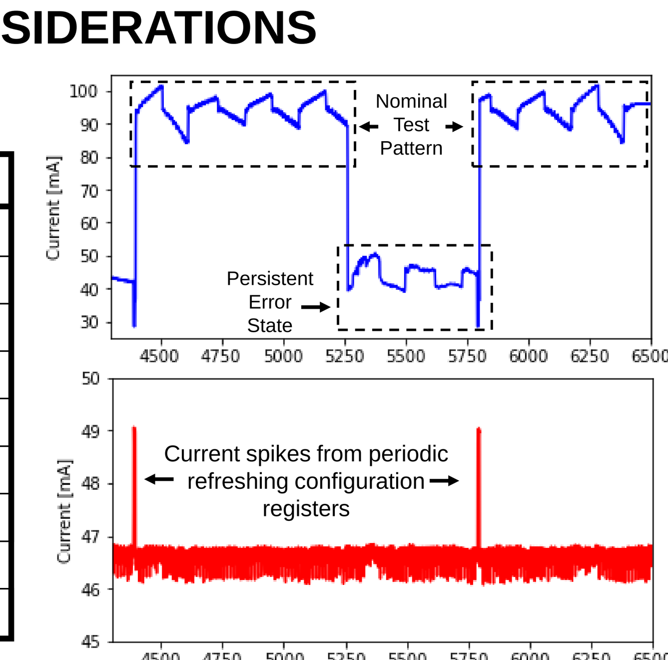




Error Mitigation and Considerations

Error Signatures Emulated via Configuration Registers

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 via modified instruction sets of the DDIC – "fault injection"
  - Allows for localization of error signatures to individual configuration registers
  - Methodology for predicting and criticality assessment of error signatures
- System-level mitigation techniques can be used to clear errors w/ minimal resource cost
  - Persistent errors due to configuration bits can be cleared with periodic configuration
  - Current monitoring can detect erroneous states for autonomous configuration/resets

Generalization of Results

- Required behavior for DDICs implies the existence of common error modes
  - Table-top testing of configuration registers allows for error investigation pre-rad
- Timing signals from DDICs constrains physical manipulation of an integrated display
  - Particle line-of-sight to DDIC can require poor placement of the screen for monitoring
- Test patterns can be observed on total current draw for small form factor display
  - Overhead from larger more complex DDICs potentially obfuscate total current draw
- SEE test routines that can refresh select configuration bits allows for isolation of select errors for counting and error rates – e.g. rates for errors that will require manual resets