Non-Visual Color Differentiation of LEDs on ICT

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Project Definition

Project Name: Non-Visual LED Color Differentiation on ICT

Team Leader: Benjamin Scott

Objective: Catch if a Wrong Color LED Has Been Placed on the Board

Scope: Red, Amber, and Green LEDs of a Display Module PCBA

Resources: Keysight i3070 In-Circuit Tester

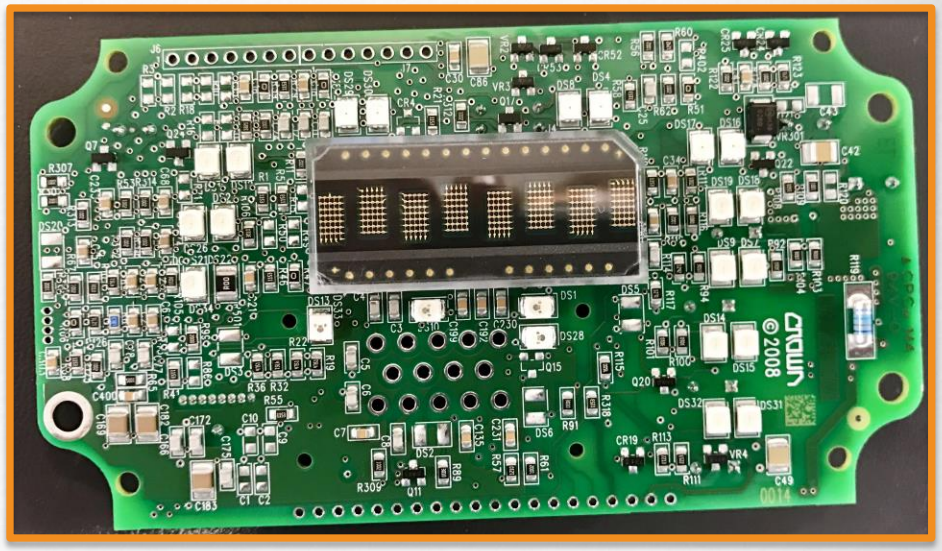
Figure 1:
Assembled Display Module

Problem Statement: Identify and optimize the In-Circuit Test of SMT LEDs on Display PCBAs to reliably differentiate between different LED colors. The previous diode test limits had an overlap between red and amber LEDs, allowing nonconforming parts to pass ICT.

Considerations

- Fixture is in production.
- ICT is off-line
- LEDs are on the bottom side of the PCBA
    - 23 LEDs placed
    - Limited space in fixture for light pipes
- Prior projects show difference between voltage drop of Green and Red/Amber LEDs on other PCBAs
    - Can voltage drop help discern Red and Amber LEDs?
    - Red and Amber are from same vendor and same die material.

Figure 2: Display PCBA



Measurement Definition

PROCESSES THINKING:

- Boards tested at ICT and continue on if passing. To test each LED, a constant voltage and current are applied to each LED and the forward voltage drop is measured. Manufacturers claim the forward voltage is distinct for each LED semiconductor material/mixture (i.e. color).
    - Can we prove that there is a difference between materials? Between material ratios?

CURRENT PERFORMANCE:

- Before containment: 94.9% FPY for month prior to issue; false passing boards were not contained at ICT. Containment put in place that prevents false passing, but issues with false failures persist.

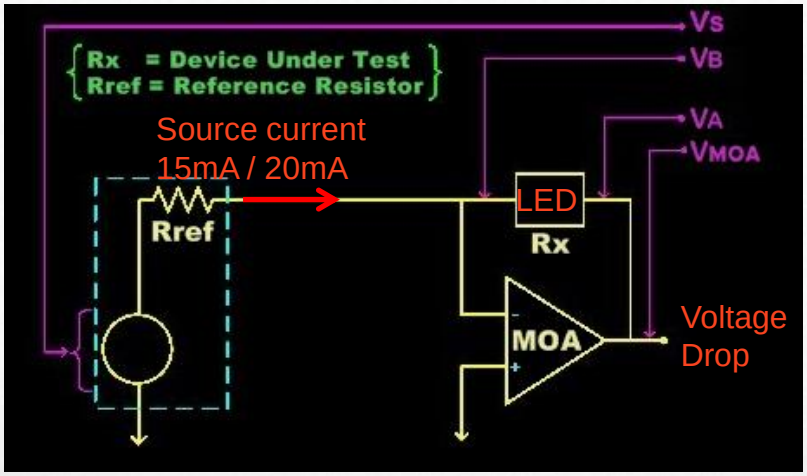
MEASURMENTS:

- Metric: LED Forward Voltage at a constant current
- Initially tested with 4V compliance limit @ 15mA, datasheets specified to test with 20mA, therefore data was collected for both settings.

LIKELY SUSPECTS:

- The inputs inspected were forward current and forward voltage. All other factors either cannot be controlled, are impractical to control, or are outside the scope to control.
    - LED theory states voltage has minimal impact on voltage drop so long as voltage is higher than the forward voltage drop

Figure 3: MEASUREMENT CIRCUIT

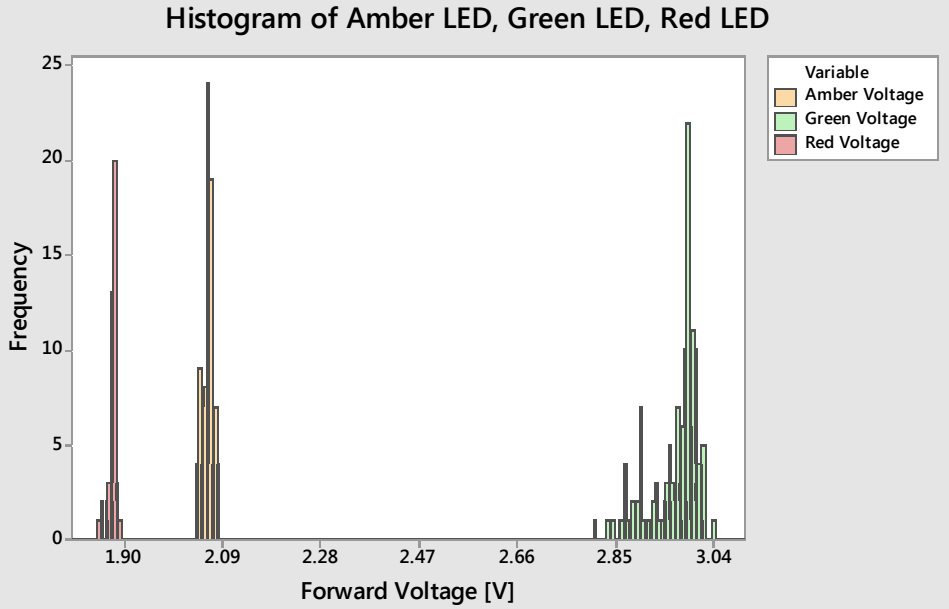


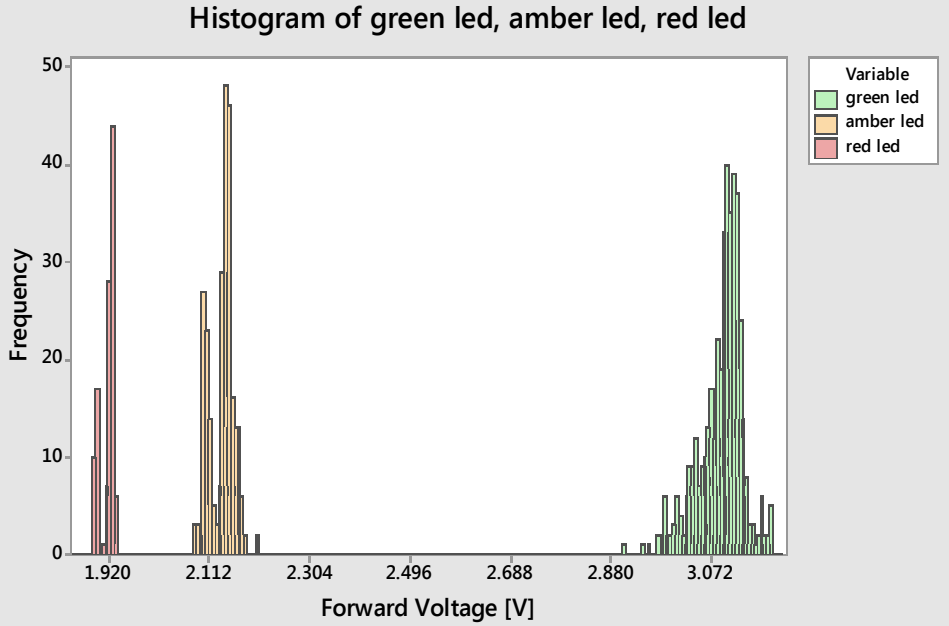
Conclusion: Collect data for both settings. Check for difference between distributions per setting

Analyze

- Sharp distinction between semiconductor mixtures (red/amber vs green) for both test settings.
- **Top**- Figure 4: Histograms from LEDs tested at 15mA.
    - Appear to be normal Distributions, but had a large fallout at a trial run.
        - Unable to distinguish red and amber.

- **Bottom** – Figure 5: Histograms from LEDs tested at 20mA
    - Distinct splits within red and amber distributions.
    - Statistically determined that each peak could be from separate distributions, used those distributions to reset limits.





Analyze

- Only the input current could be controlled to affect distributions and separation of means.
- Issue was thought to be the limits alone. Assumed the distributions at 15mA were normal enough to set statistical limits. The number of false failures between red and amber LEDs greatly exceeded the predicted probability (predicted to be less than 1 in 1 billion).
- Distributions of red and amber LEDs were each bimodal at 20mA. Some evidence seen at 15mA, but not enough to statistically justify two separate distributions per color.
- Each color LED produces a specific forward voltage within a specific range so long as the applied current and voltage are held constant. Thus changes in color correlate to a change in forward voltage when an incorrect LED is placed on the board, allowing limits to be set within the range.
- **SUMMARY:**

The display boards with incorrect LEDs passed through ICT because the limits for each color was wider than the range for the correct color. The issue was complicated by not testing the LEDs at the optimal current, leaving the LED in a forward voltage range with a much smaller gap between each color.

- As the current increases, there is increased separation between forward voltage for most colors (up to a certain point, somewhere between 40-50mA); but ICT and LED can be damaged by excessive current. Multiple vendors suggest testing at 20mA.

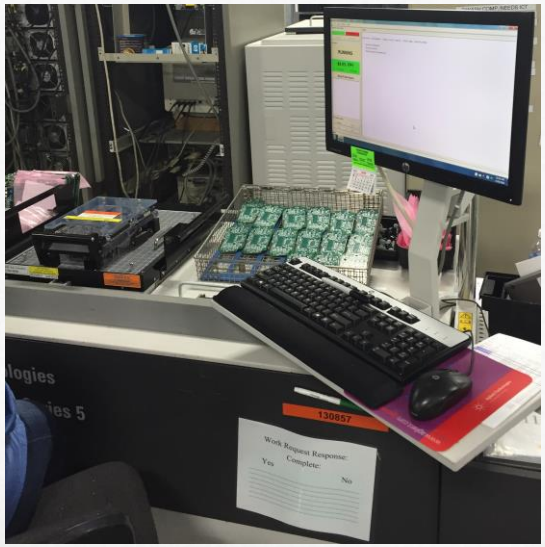
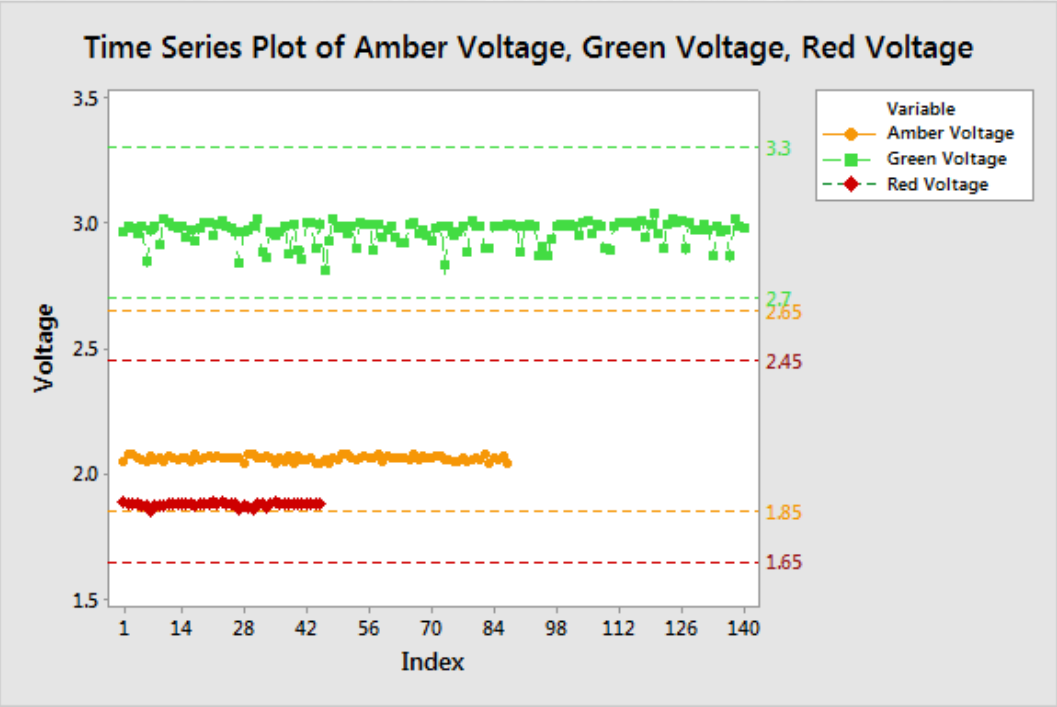


Figure 6: Display PCBA Testing

Conclusion: LED limits were too wide and the LEDs were not tested under optimal conditions for distinguishing LED colors with forward voltage drop.

Analyze

Figure 7: Original Test Parameters (Before Containment)



Probability False Fail:

Red 99.98%

Amber 99.98%

Green 0.035%

Figure 8: New Test Parameters

Probability of False Failure:

Red 11.4905E-8 %

Amber 0.001061%

Green 1.6321E-18%

Experiments and Improvements

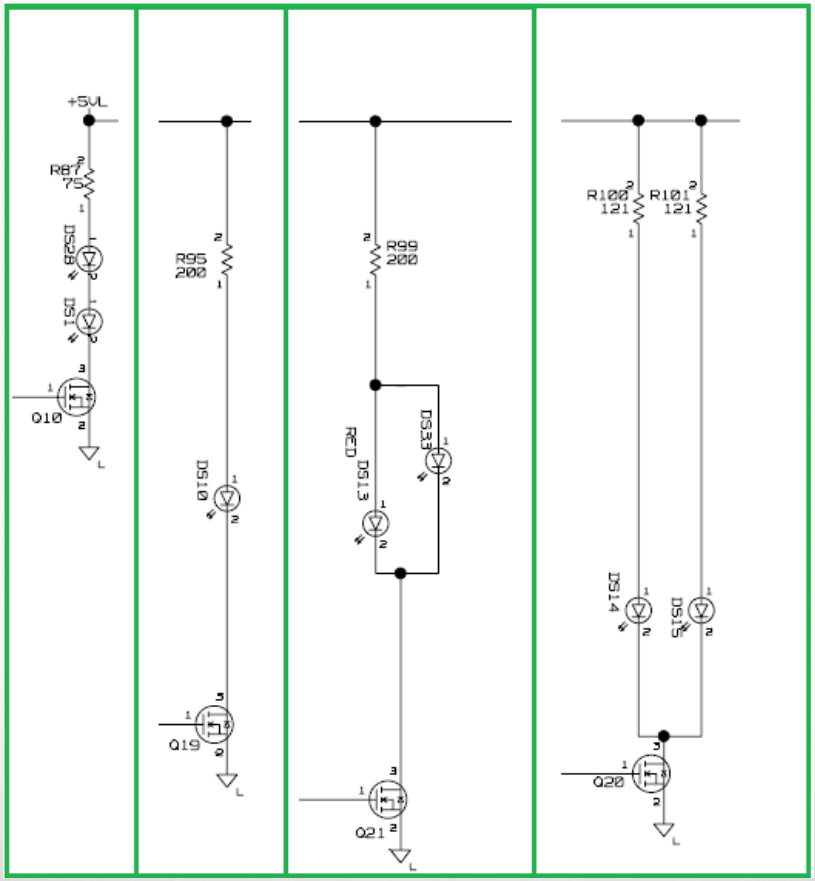
- Limits Set for each LED, testing the LEDs with 4V at 20mA.

Experiment Conditions:

- Incorrect LEDs were placed for every color and topology on the board (i.e. parallel, series, single).
    - The ICT was able to call out any misplaced LED independent of topology, and the forward voltages of the misplaced LEDs were in the typical range for the color that was placed on the board.
- A trial run of 30 new boards were ran, with 30/30 passing. Boards were then powered up at a benchtop to ensure only correct LEDs passed.
    - A secondary run the same boards was done at 15mA, with all 30 passing
    - A full Pilot Test was deemed unnecessary due to data collected to set limits could be observed for compliance and control.

Figure 9:
LED TOPOLOGY EXAMPLES
From Left to Right:

Series LEDs
Single LEDs
Parallel LEDs
Single LEDs with one FET



Process Control

Figure 10: Failure Data from One Month Post Improvement

Color	Failure*	# Boards	# Failed LEDs	FPY LED	DPMO LED	Sigma Level
red	Uncertain	226	2	99.4949%	5050.505	4.07
Amber	Real	202	1	99.9328%	672.043	4.71
Amber	Uncertain	202	6	99.5968%	4032.258	4.15
Amber	Total	202	7	99.5296%	4704.301	4.1
Green	Real	457	6	99.8896%	1104.159	4.56
All	Real	659	7	99.9496%	503.8871	4.79
All	Uncertain	428	8	99.9094%	905.7971	4.62
All	Total	885	15	99.9187%	813.1844	4.65

***** Failure refers to whether failures were real defects or of uncertain legitimacy. Failures of uncertain legitimacy were assumed to be false calls that could be addressed with limits.

SUSTAINABILITY

- There may be issues between LED lots, as seen in the measurement distributions from the Analyze Phase.
    - Lot based issues are outside of control and are addressed as they appear.
- Per the initial goal, incorrectly placed LEDs are detected. A small number of false failures may occur since certain factors were not addressed, such as solder, flux, moisture, ambient conditions, and more.
- Incorrect LED placement will be detected and the issue can be contained with the first board tested from that batch. False failures will be detected from the failure database and will be set aside for test engineers to observe.
- Financial benefits were present based on the rework needs.
    - Over the past number of months, the issue has been limited to a few lot-lot issues.

Conclusion: ICT should ONLY be used for containment, not as preventative feedback. Feedback in-line with SMT would yield better savings and less rework. DPMO rates may not be suitable for high volume environments.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