Color Logical Analysis Approach for LED Testing in Manufacturing

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Abstract

Complexity of test development for LED test and long LED test execution time in production are big challenges faced by the PCB manufacturing industry. This paper introduces a parallel multi-channel, multi-function color logical analysis (PMCMF-CLA) methodology to achieve zero additional test development and zero extra test execution time.

Traditional LED test includes two major tasks. 1. Development of test program to drive LED ON/OFF. 2. Test execution in production line. Test program development incurs a one-time cost for each type of DUT and it is a challenging job. The engineer needs knowledge of the device under test (DUT), and skills in test development. LED test execution contains several steps: driving LED on, waiting for LED to reach stable state, measuring LED, driving LED OFF. It would be ideal to save the effort of test development and time to run LED test in production.

In this case study, several PCB boards for desktop and laptop are studied. The number of LEDs varies from 0 to 20. The observation shows opportunity for zero additional test development. 70% to 80% of LEDs are lit at certain time during power-on test and functional test stage. Some LEDs are lit constantly. Some LEDs are turned ON or OFF according to time. The sampled ON and OFF forms a sequence of ON/OFF that provides information about not only whether LED is present, correct, and live, but also DUT functionality. This LED ON/OFF behavior presents an opportunity to have zero test development and zero extra test execution time.

PMCMF-CLA is a method to achieve LED coverage with zero additional LED ON/OFF test development and zero extra test execution time. PMCMF-CLA monitors multiple LEDs in parallel while other tests are running. Measurement of color (in the term of wavelength) and luminosity is recorded along with its sampled time. The sampled data forms color waveform that can be analyzed for various test purposes. For example, an expected LED has red color with certain luminosity. When it is detected in a color waveform, the information indicates the LED is present, correct and live. Color waveform analysis can be running in parallel while LED ON/OFF is monitored. Therefore, overall test execution time is almost the same as the test program that has no LED designated test.

Introduction

High volume PCB manufacturing is very sensitive to cost of test in production line. The key test objective is to achieve high test coverage that may be measured by PCOLA/SOQ [Ref Park02]. Test development effort for a special PCB and test execution time in production are two of factors that impact cost of test. Test development happens when a new product is about to be manufactured. Complexity of product impacts how much effort needed to develop test program. Once a test program is developed, it is executed in production line to verify product quality. The execution time of a test program has direct impact to throughput of a production line. The faster the test program runs, the lower the cost of test would be.

Traditional LED test approach contains two stages. The first one is to develop a program, called test, to turn LED under test ON or OFF. The complexity of test depends on design of PCB board to turn LED ON or OFF, and functionality provided by test equipment, called tester. To achieve quick time-to-market (TTM), it is desirable to generate such test automatically. Usually, it is a challenge to generate it automatically due to specialty of PCB design. Is there any way to save development effort? This is one of topics that will be discussed by later sections. The second stage is test program execution. Usually LED test execution contains four steps.

1. Run test to turn LED ON
2. Wait for LED under test to reach stable state, i.e. desired color and brightness

3. Measure LED color and brightness to decide whether the LED meets expected quality
4. Run test to turn LED OFF

Time for the four steps varies from 3 second to 30 second [Ref Yang]. Saving this execution time in high volume production will be desired. The following sections will discuss cases where test execution time can be saved to reduce overall test execution time.

In the following sections, challenges in board level LED test are discussed first. Then, several PCB boards are studied. A parallel multi-channel / multi-functional color logic analysis (PMCMF-CLA) is introduced. What PMCMF-CLA can cover and how it helps in reducing cost of test for high volume PCB manufacturing are also discussed.

Board Level LED Test Challenges

Two challenges are faced. One is complexity of test program development. Another one is test execution time.

The density of PCBAs is increasing due to an increasing number of devices added, while PCB size is decreasing due to the trend of compacting designs. Fewer and fewer test pads are available for manufacturing test. Without direct access to test pads to drive LED ON/OFF, the PCB design has to be studied carefully, such as board schematic, component data sheet, etc. For example, Figure 1 shows a commonly used circuit to control LED ON/OFF. To drive the LED, a special digital test program has to be developed. The digital test program controls the IC to pull the pin low or high to turn LED ON/OFF. Digital test development is complex. The data sheet of the IC needs to be studied thoroughly. Enough test pads must be available for the digital test, including any interference from neighboring components that needs to be highlighted etc. All these issues need to be studied carefully, and then only can the test program be developed and debugged. This entire process of studying, programming, and debugging takes a lot of time.

If there is test pad to drive LED ON/OFF, the current has to be controlled to safely drive LED ON/OFF without causing potential damage to any connected IC. In the case of Figure 1, current control is hard to drive LED ON/OFF to make sure that it does not harm the connected IC. To address all these concerns, a lot of time is needed. It impacts the Time-To-Production, a manufacturing criterion that is always required to be as short as possible. To make the situation more complicated, product design changes frequently during a new product introduction. Therefore, LED test development is a time consuming, complex task.

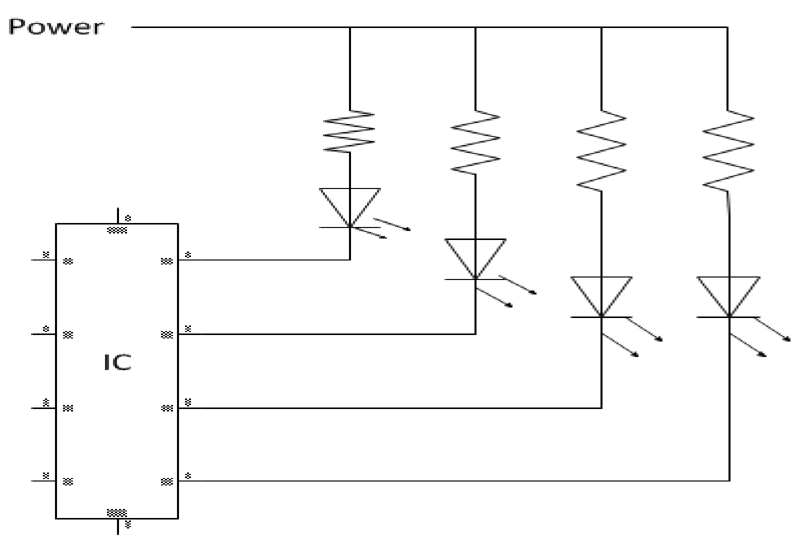

Figure 1: LED Control Circuit Example

As mentioned in the Introduction section, traditional LED test has four steps: turning the LED ON, waiting for LED to reach stable state, measuring color and luminosity, and turning LED OFF. The second step, the waiting step, is an interesting step to study.

Figure 2 shows an experiment that records LED color and luminosity. Each measurement has one pair of data, color (in terms of wavelength) and brightness (in terms of luminosity). At time *t1*, red color is detected. But the luminosity is only half value of the value at time *t2*. A stable luminosity is at *t2*. Therefore, at least, we need to wait at least 0.4 seconds before obtaining a stable measurement. This is a short delay for one LED test. But a typical high volume production line can assemble one hundred thousand products. That would cause a total of 40,000 seconds, or 666 minutes, or 11 hours. This test execution time is considered as one of test cost in production. It would be desirable to save this cost in the high volume production line.

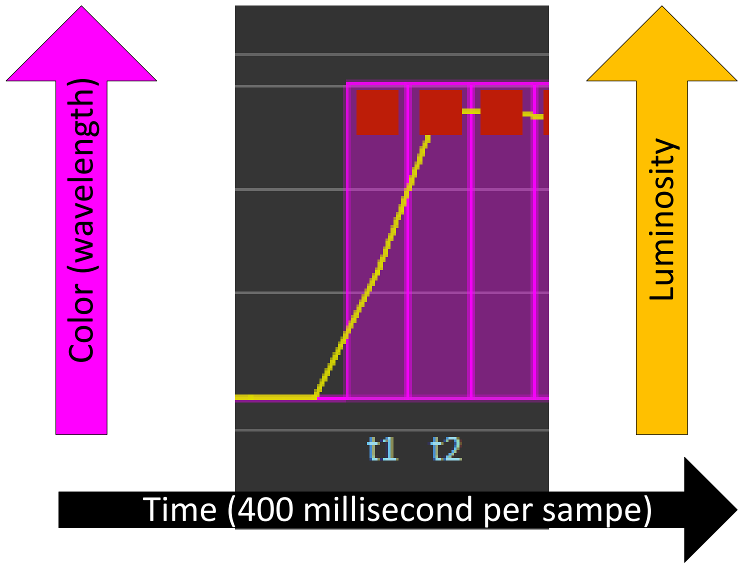

Figure 2: LED color & luminosity change while turning to LED ON

The following sections will explore potential solutions to address the above challenges.

Analysis of Printed Circuit Board under Test

In order to address the challenges discussed in the section Board Level LED Test Challenges, we would like to see whether there is any chance that the LED is turned ON during a non-LED designated test stage (non-LED designated test is a test that is not specifically designed for LED test purpose). If there is, it would present an opportunity to save effort to develop the LED test program. If the LED is monitored during the non-LED designated test stage, the monitored information about the LED may provide information on what LED tests are required at the board level. If the monitored LED data is processed in parallel with the non-LED designated test, the LED test execution time can be saved. This is motivation to select some PCB boards in high volume production for further study.

Four high volume PCB boards are studied to observe whether LED is ON during running time for non-LED designated test. Then, the LEDs are sorted into four categories: always ON along with power-on, ON happening at certain times during boot/BIST, ON happening at some time during functional test, and no-ON states.

Table 1: Summary of LED ON observation

	Laptop mother board I	Laptop mother board II	Laptop mother board III	Network router PCB board
Always ON along with power-on	1	1	0	2
ON during boot/BIST	4	3	0	4
ON during functional test	11	8	0	4
No-ON	4	5	0	0
Total LED having ON	16 (80%)	12 (70%)	0 (100%)	10 (100%)

Table 1 summarizes observations of LED ON during non-LED designated test for four PCB boards under the study. Each PCB under test has different number of LEDs (20, 17, 0, and 10). The number of ON LEDs for each PCB varies, 8 out of 20

(80%), 12 out of 17 (70%), 0 out of 0 (100%), and 10 out of 10 (100%). It indicates that quite high percentage of LEDs have ON happened at certain time during non-LED designated test stage. This provides opportunity to test LED without special test development effort designated to test these LEDs, and no extra test execution time to cover these LEDs if LED is monitored and data is processed in parallel with non-LED designated test execution.

PMCMF-CLA Approach

The PMCMF-CLA approach takes the opportunity of LED ON during PCB power-on and functional test, and parallel computing capability of modern CPU. Each LED has one sensor to monitor its color and luminosity, as illustrated by Figure 3. These sensors continuously measure and transmit color and luminosity measurement to the controller for processing.

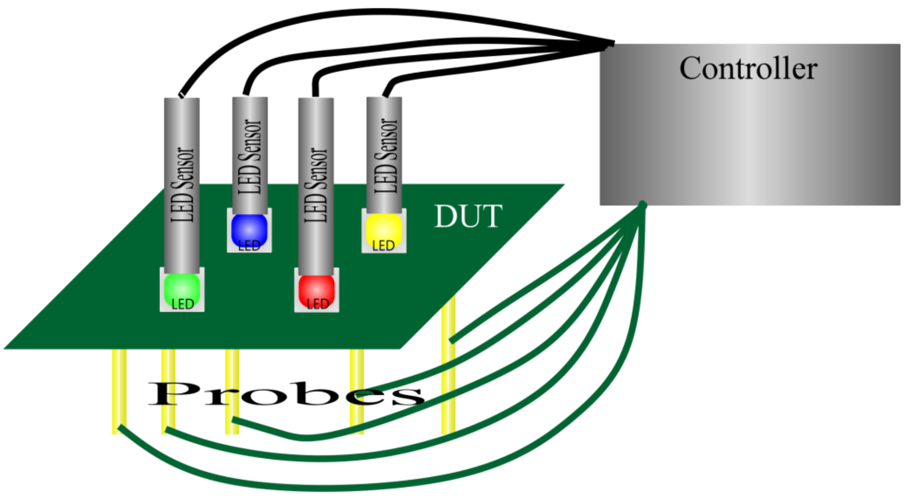

Figure 3: Parallel multi-channel, multi-function architecture

The controller has multi-tasking capabilities. While it executes power-on test and functional test, it also collects LED color and luminosity data transmitted by LED sensors. At the same time, the controller processes data according to what LED feature is to be tested. This parallel data handling capability helps to test LEDs without adding extra test time on non-LED designated tests.

Each sample contains information about color, luminosity, and time stamp of the sample, which can be represented by a 3-tuple, `<Color,Luminosity,TimeStamp>`. A color waveform is built on a collection of 3-tuple that is sorted on sampled time (`TimeStamp`). A bar chart is used to represent color in wavelength (nanometer). A line chart is used to represent brightness (luminosity and its unit value is relative). Figure 4 is a sample of color waveform. The bar chart has four colors due to four different color LEDs being used to walk through the sensor. For ease of understanding, a small square mark is labeled on each bar to indicate a detected color. A yellow line chart represents brightness. The higher the value, the brighter the LED is.

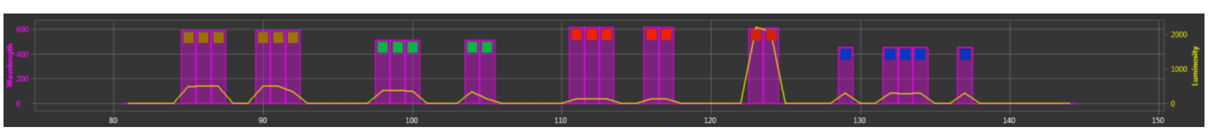

Figure 4: A color waveform sample

Color waveforms can be used to help test LEDs. This topic is discussed in the next section.

Features that can be tested by analyzing color waveform

The previous section shows how a color waveform is formed. This section discusses LED features that can be tested by analyzing color waveform. First, LED's PCOLA (see [Park02]) is discussed. Then, more features are explored.

Accordingly to [Park02], fundamental properties of a device on a PCB are <u>presence</u>, <u>correct</u>, <u>orientation</u>, <u>live</u> and <u>alignment (PCOLA)</u>. These properties form the starting point to investigate whether color waveform can help LED test.

Color waveform can test whether LED is present. A color sensor is assigned to monitor one LED. A color waveform is created for the monitored LED. If a color and luminosity are detected in the color waveform, it is reasonable to assume that the LED under test is present.

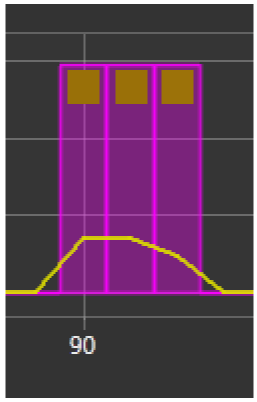

Figure 5: Color and Luminosity are detected in a waveform

Color waveform can be used to test whether the LED mounted on PCB is correct and as specified. Usually, it is expected that a correct LED means of a correct color and proper range of luminosity value. For a single-color LED, it is reasonable to assume that the LED under test is correct if a desired color and luminosity are detected. Figure 5 is an example for single color LED. For a multi-color LED, multiple colors are expected to appear in color waveform. Therefore, a sequence of colors needs to be detected. If several colors are detected in color waveform, it is reasonable to assume the LED is a correct LED. Color waveform in Figure 6 has red and blue color detected. It indicates that the LED under test is a multi-color LED (red and blue).

Figure 6 Red and Blue are detected in a color waveform

Can color waveform tell whether the LED under test has right orientation? The answer is no. If the LED is placed in a wrong orientation, it probably will not be turned ON. 'No ON' could have a lot of reasons. Therefore, no conclusion can be made for the question of whether the LED is in the correct orientation.

Color waveform can be used to test whether the LED under test is live. If color and luminosity are detected in a color waveform, it is reasonable to assume that the LED under test is live. Figure 7 is a color waveform that sees green color detected a number of times.

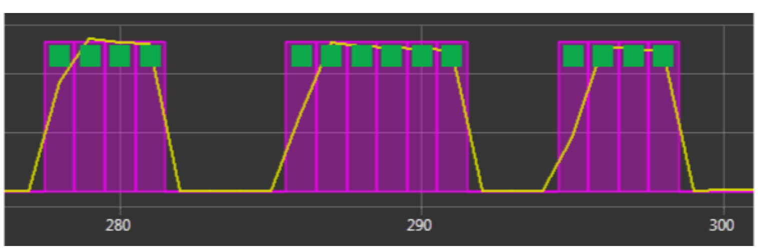

Figure 7: Green color is detected several times

Color waveform has information that indicates whether the LED under test has any alignment issue. Luminosity changes if LED is slightly misaligned. This luminosity change may indicate some alignment issue. If luminosity is within a desired range, it is reasonable to assume the LED under test is properly aligned. Figure 8 is an example for LED in proper alignment and slight misalignment position. The color is the same but luminosity is different.

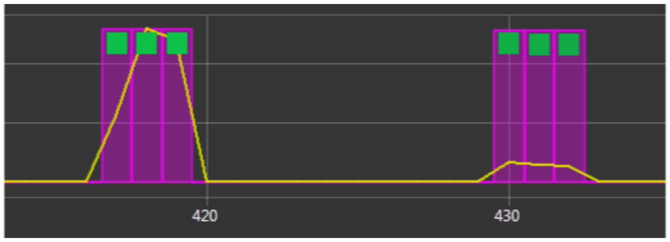

Figure 8: Alignment vs luminosity

There are more than PCOLA features that can be tested by color waveform. Here are some examples that cover some functionalities of PCBAs under test.

One common electronic product design is that an LED (power-on indicator) is used to indicate whether the product is powered on. During production test, the LED is expected to have a sequence of OFF, ON, OFF as the PCBA under test goes through from unpowered, to powered-on, and to unpowered again. If the sequence of OFF-ON-OFF is synchronized with actual operation of unpowered-powered-unpowered procedure, it will be reasonable to assume that power-on indicator works properly. Figure 9 is a color waveform collected from a PC monitor board's power-on indicator. The indicator is a blue LED, and its light is dim.

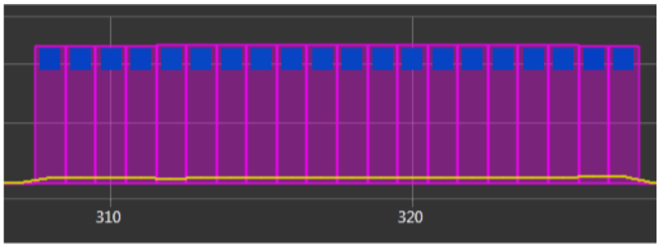

Figure 9: Color waveform of a power-on indicator

A PCBA under test has active and standby states. A multi-color LED is used as an indicator. One color indicates one state. A standby state shall have a lower brightness than an active mode. Color waveform can be used to capture such behavior when the PCBA under test goes through active and standby states. Figure 10 shows state changes captured by a color waveform.

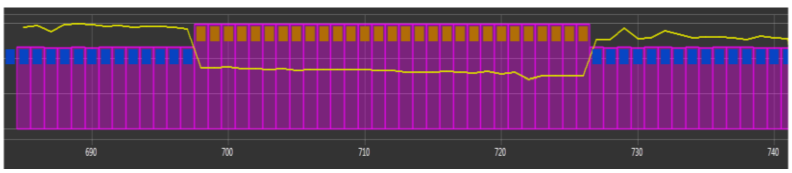

Figure 10: Color waveform of state change between active and standby

A flashing LED is often used to indicate a "busy" state. It is difficult to identify flashing activity if only color is measured. But, luminosity measurement varies. Figure 11 shows a color waveform for a flashing LED. When the color is correct, and the luminosity shows a high / low change sequence, it is reasonable to assume that the LED is flashing, and the PCBA under test is "busy".

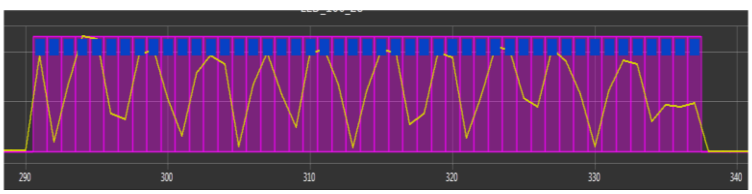

Figure 11: Color waveform of a flashing LED

The above are some examples for testing some features by analyzing color waveform. Color waveform data is collected while the DUT is under tested by running non-LED designated test. Analysis of color waveform is conducted in parallel by the controller. Therefore, for those LEDs that are ON during non-LED designated tests, zero test development effort and zero extra test execution time are achieved.

Conclusion

This paper proposes a color waveform approach to relieve efforts to develop complicated test programs to safely turn LEDs ON/OFF, and to increase LED coverage without increasing test execution time. It is easy to use in production to achieve quick-to-production goals. However, there is a limitation. It is limited by those LEDs that happen to be ON/OFF while non-LED designated tests are running. For those LEDs that are never ON, this remains a topic for further investigation.

References

[Park02] "Test Coverage: What Does It Mean when a Board Test Passes?", Kathy Hird, Ken Parker, Bill Follis, Proceedings International Test Conference 2002

[Yang] "LED Test Case Study", Yang Hua, Technique Report, Agilent Technologies, 2012

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Color Logic Analysis Approach For LED Test in PCBA Manufacture

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Objectives of Color Logic Analysis Approach (CLA) for LED Test

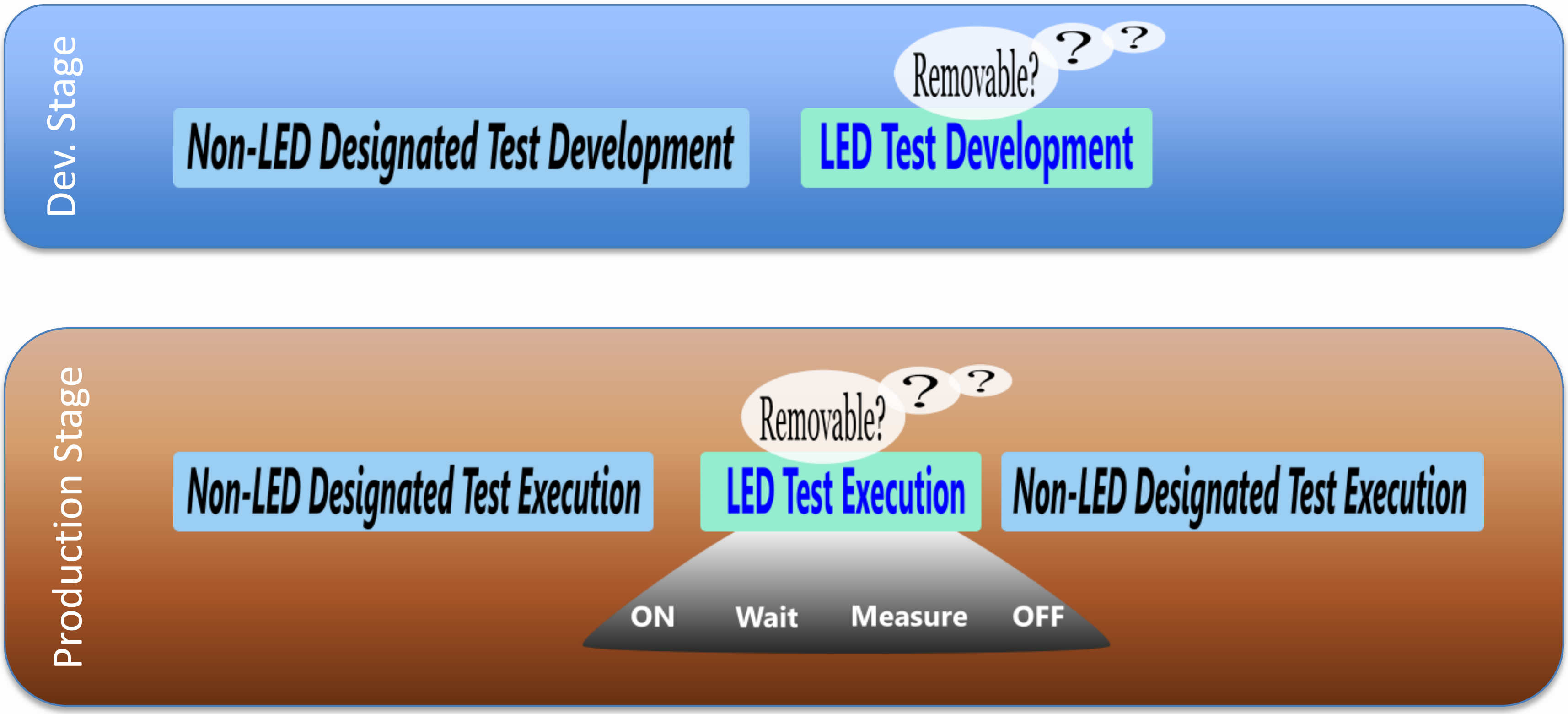
Zero Extra Test Development Effort

- Challenge – Limited access points
- Challenge – Limited test resources
- Challenge – Complexity of DUT

Zero Extra Test Execution Time

- Challenge – Test cost due to test execution time

LED Test in PCBA Manufacture Test Process and Area to Study



PCB Case Study and Zero Extra Test Cost Opportunity

	Laptop mother board I	Laptop mother board II	Laptop mother board III	Network router PCB board
Always ON along with power-on	1	1	0	2
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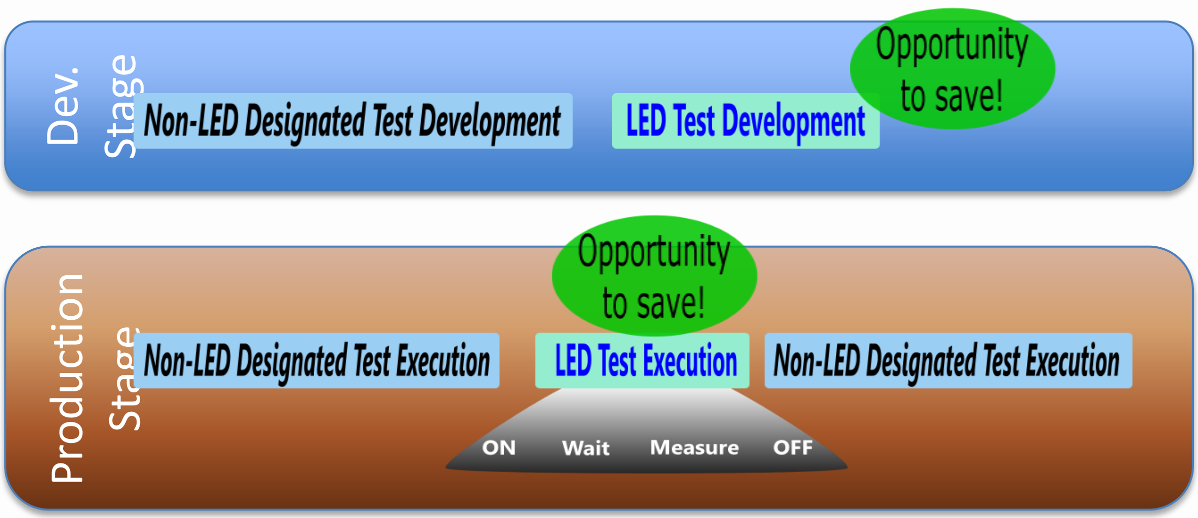
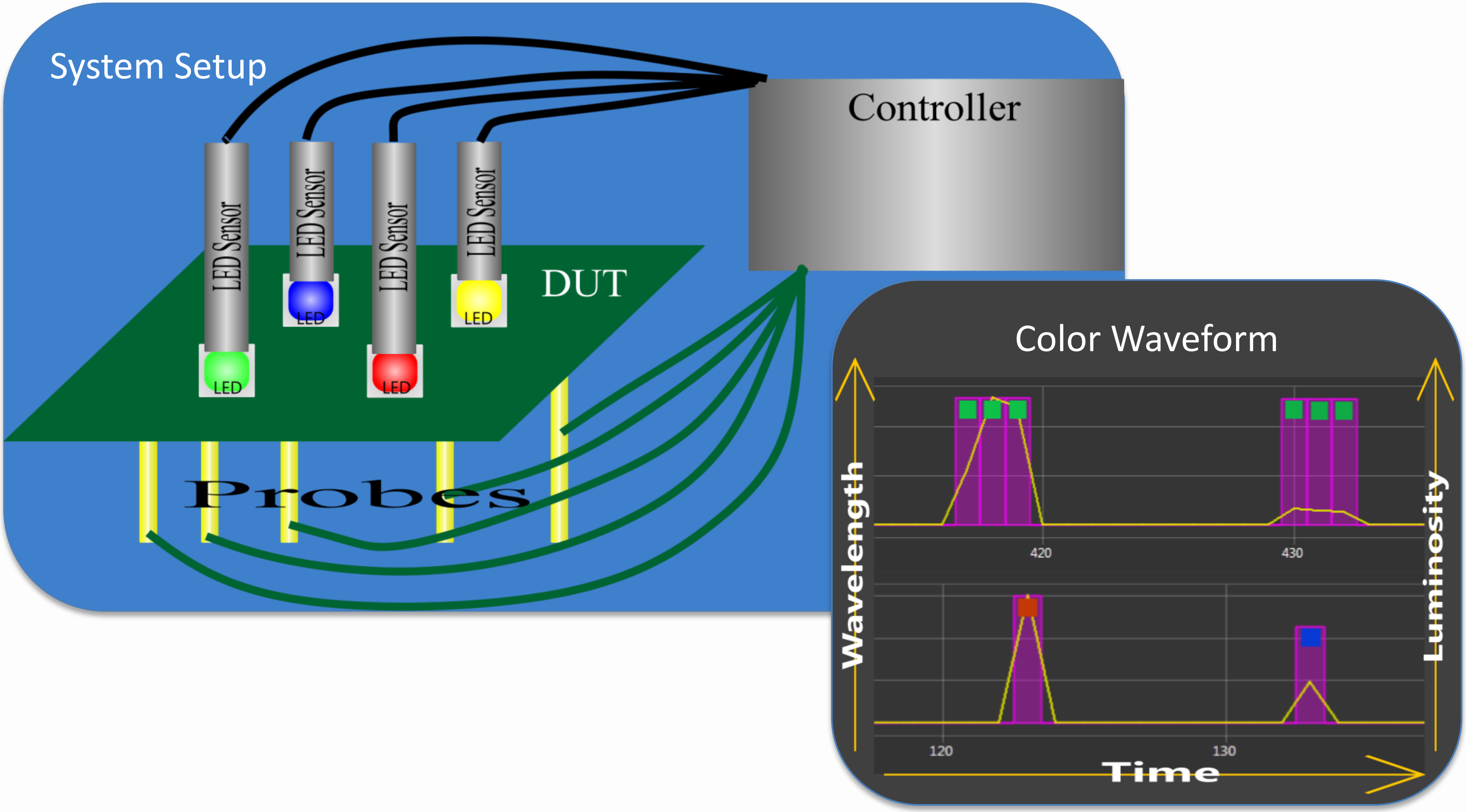
ON during functional test	11	8	0	4
No-ON	4	5	0	0
Total LED having ON	16 (80%)	12 (70%)	0 (100%)	10 (100%)

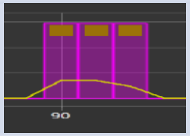


PMCMF-Color Logic Analysis Approach

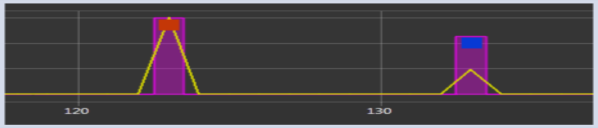


Color Logic Analysis Coverage - PCOLA

Presence
- YES

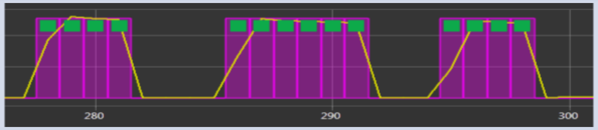


Correct
- YES

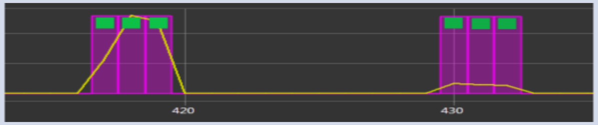


Orientation
- NO

Live
- YES

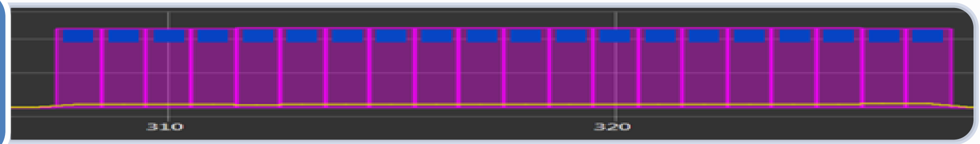


Alignment
- YES

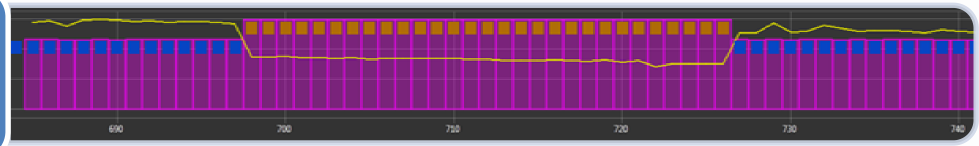


Color Logic Analysis Coverage – Beyond PCOLA

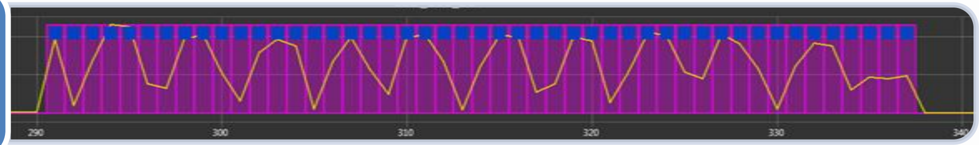
Power-on indicator



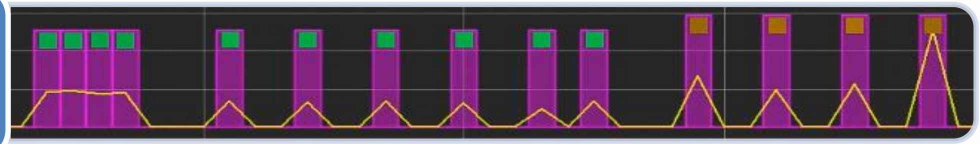
Multi-state indicator



Flashing indicator



etc.



Conclusion of Color Logic Analysis Approach

Zero Extra Test Development Effort	• Relieve efforts in LED test development
Zero Extra Test Execution Time	• Save test cost introduced by LED test execution
Opportunity in coverage beyond PCOLA	• Increase coverage not only PCOLA but also functionality
Has limitations	• LED is not tested if it has no chance being ON during non-LED designated test execution

Questions?