QC FAILURE ELIMINATION: PREDICTING CURRENT SENSE TEST FAILURES THROUGH LINEAR REGRESSION

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ABSTRACT

Current monitoring capability from DrMos (Driver-Mosfet) or SPS (Smart power stage) devices has evolved with time, as well as its application requires tighter spec accuracy. The competition out there is to provide the most accurate current monitoring on an integrated system.

This case on current sensing linearity check was realized on top of the normal qualification process for a high-profile, high-market potential NPD for the company. New and unique challenges were faced by the team to release the new product in such a short period of time. It was interesting for the team to formulate new calculated test screens derived from existing tests that have minimal impact on test time but maximum impact on quality. Through the nature of the concerned test parameter, it was discovered that slopes using minimum and maximum values do not always represent the values in between.

This paper shows how the team used a basic slope formula that was further modified to introduce an effective screen, which led to adding value and protection for the manufacturer and the customer.

1. 0 INTRODUCTION

A typical semiconductor product flow will have wafer-level testing (sort) and package testing after assembly (final Test) as shown in Figure 1. In final test, having full test coverage with the least amount of test time is ideal. On the contrary, having more tests results in high test times, which slow down productivity and increase manufacturing costs.

Fig. 1. Typical Semiconductor Product Flow. Wafer sort and Final test are test screen steps within the process.

Device testing is critical to ensuring high-quality products are delivered to customers. It is always a challenge to balance adding more tests for better coverage while at the same time limiting the test time for productivity.

During development, the products' testability and test coverage are already defined by its Engineering and Design core team. Apart from including fundamental tests such as open-shorts, leakage, functional, active, and standby currents; timing and switching tests, and digital input and output levels, there are also special tests added based on best practices, including QC and EFAR screens.

Having QC sampling in the test flow further adds value and protection to customers. Any failure from a statistically sampled group means possible inconsistency and inaccuracy in the final test process. To solve QC sample failures, guard banding is one general approach, but engineers is not limited to this method alone. In this paper, we will share how we were able to find a distinct behavior from the QC sampling failing units, which were initially measured similarly within their population.

Our device, a smart power stage driver FET (Figure 2), has the capability of sensing current accurately and feeding this information back to its controller for a closed-looped, efficient system.

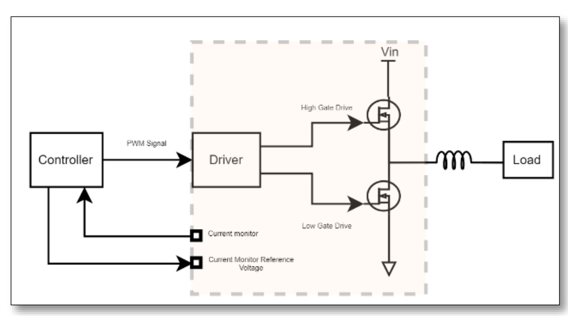


Fig.2. Smart Power Stage Driver FET. An integrated system which compose of a driver, high side FET and low side FET, which feeds back current monitor information back to the controller.

2. 0 REVIEW OF RELATED LITERATURE

Current monitoring or sensing has been one of the most important features in any power system design. This feature will allow several other important functionalities in the system, such as overcurrent protection, regulating the output, etc.

Below are some techniques, coming from several current-sense methods used in different applications:

2.1. Sense Resistor (Figure 3)

The simplest current monitoring/sensing technique. It utilizes the basic principle of Ohm's Law, which states the current flowing through a known resistance is directly proportional to the voltage applied.

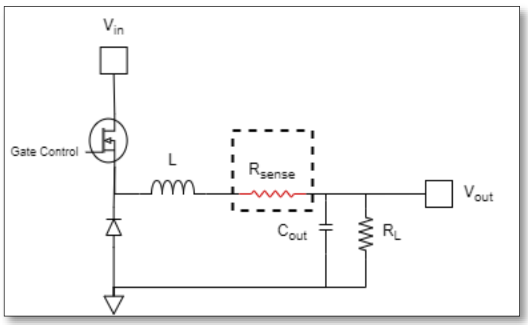


Fig. 3. Sense Resistor. A sense resistor will be connected in series with the load, and its voltage will be measured and then used to compute for the equivalent current flowing in the loop.

2.2 Inductor DCR (Figure 4)

This technique is very common for buck converters. It uses an RC network in parallel with the inductor as an addition to the sensor circuit.

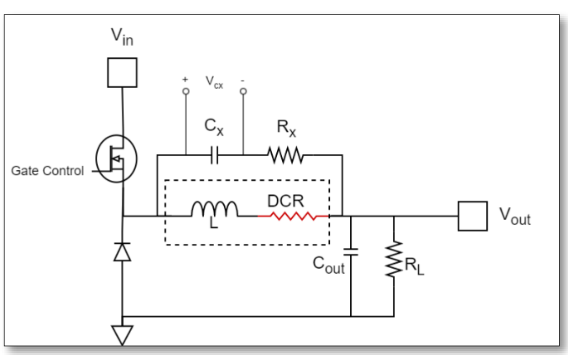


Fig. 4. Inductor DCR. The DC resistance of the inductor (DCR) and the voltage drop in the capacitor is used to determine the current IL

2.3 Integrated Current Monitor (Figure 5)

This method is more commonly used for power MOSFETS with integrated gate drivers (called DrMOS). This is also the method for the device referred to in this paper.

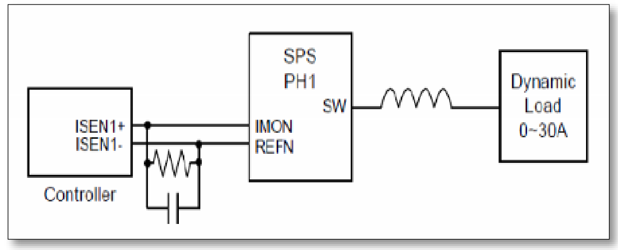


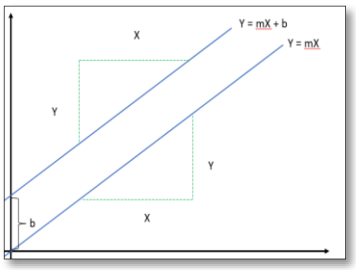
Fig. 5. Integrated Current Monitor.

The DrMOS has dedicated internal circuitry that outputs either current or voltage proportional to the actual load current. This current or voltage signal will then be fed into the system's PWM controller. This signal can also be referred to as Imon or Integrated current monitoring. Imon performance is guaranteed by independent ATE testing of high−side and low−side slope and offset. IMON output current accuracy is guaranteed within the IMON pin voltage range. The motivation for the IMON feature is to replace the industry standard output filter DCR sensing or output current sense using an external precision resistor. Both techniques are lossy and lead to reduced system efficiency. Inductor DCR sensing is also notoriously inaccurate for low-value DCR inductors. For the SPS module, parameters that can affect IMON accuracy are tightly controlled and trimmed at the MOSFET/IC production stage. The user can easily incorporate the IMON feature and accuracy, replacing the traditional current sensing methods in multi−phase VR applications.

The Imon output is usually specified on the datasheet as an accuracy parameter and is assumed to be linear. ie. 5mA/A +/- 5%.

2.4. Linear Regression

Moving to the topic of linearity (Figure 6), with the linear regression generic formula:



$$Y = mX + b$$

Where:

Y is the dependent variable,
X is the independent variable,
m for slope,
b for Y-intercept of constant

Fig. 6. Linear Regression Graph and Equation.

As the linear regression model finds the best linear relationship between the input (independent variables) and output (dependent variables) and is mostly used for predicting values, we will use the formula in a different manner. Assuming the ***b*** or y-intercept as zero, the formula can be rewritten as:

$$m = Y / X$$

This formula was frequently used in this project.

3.0 METHODOLOGY

3.1 Data Review

As qual lots were processed, yields were acceptable but QC failure was observed which needs to be addressed as part of the NPD release to production requirements. Its FT data logs were mostly the basis of the data analysis done.

Initially, a review of the FT reject Pareto is done as shown (Figure 7). Surprisingly, the failing parameter was not even in the top 10 failures.

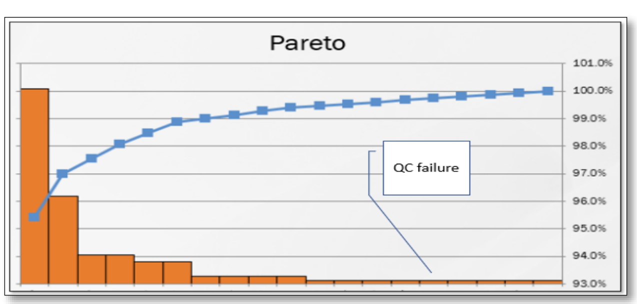


Fig. 7. Reject Pareto. QC failure was found on the top 15th but needs to be resolved. QC failure is in the Pareto because the process does in-line QC testing.

The next step is the review of the relationship between FT measurement and QC measurement through a parallel plot (Figure 8).

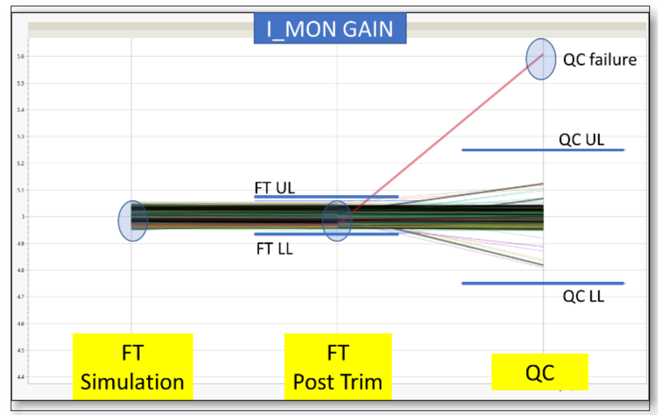


Fig. 8. FT to QC Parallel Plots. The failing QC units had passing FT readings.

Observation: Post trim measurement is equal to its simulated value and centered to its limits but retesting on QC flow, the value has shifted outside spec limit.

The third step in the process is the checking of the Trim codes relationship for Current monitoring test gain through a histogram (Figure 9).

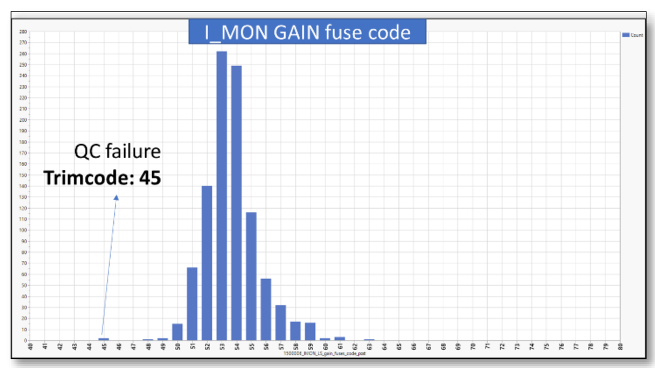


Fig. 9. Trim Code Histogram. The QC failing unit's trim code was an outlier in the trim code distribution, but the lot quantity was low; thus, to call this unit an outlier was still premature.

The final step is the checking of the current monitoring linearity from the available current monitoring test output. The current monitoring was measured in different loading conditions, such as 10A, 20A, and 30A. Linearity was calculated as slopes for 10A-20A, 20A, and 30A (Figure 10).

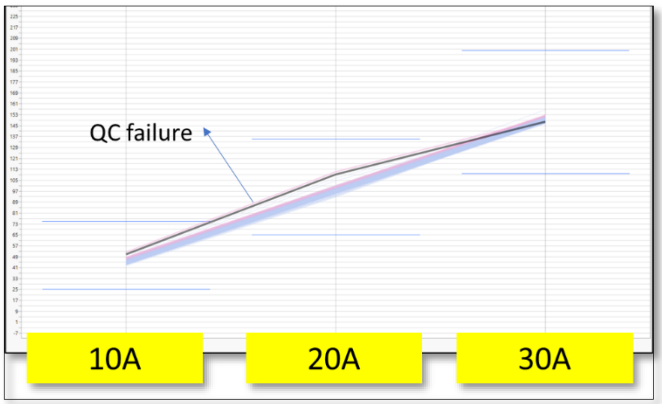


Fig. 10. Current Monitor Linearity Plot. A QC failure shows a different response from the population.

Observation: A QC failing unit is observed to have a different slope response compared to the population. But there were also other units that had this unusual linear response; these units were revalidated during the lot retest or 100% rescreen.

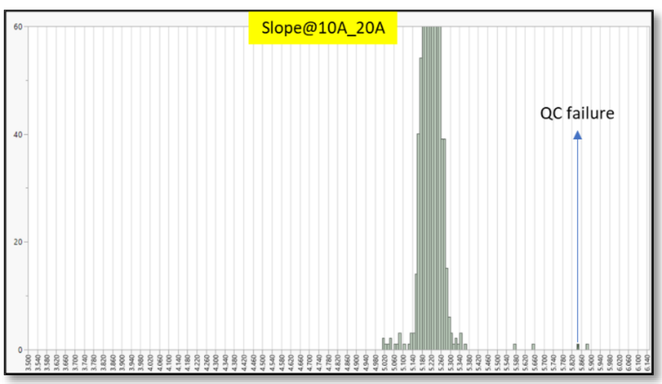


Fig.11. Slope Distribution. Distribution of slopes between 20A and 10A.

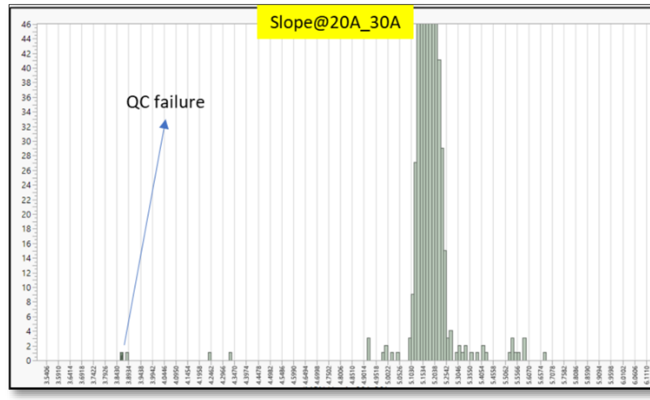


Figure 12 Slope Distribution. Distribution of slopes between 30A and 20A.

Observation: By plotting the distribution of slopes 10A_20A and slopes 20A_30A, the QC failure shows as an obvious outlier (Figures 11 and 12). This brought us closer to finding a solution.

3.2 Data Validation

Theory: Based on the observed linear response of the QC failing unit, an outlier slope tends to be a potential QC failure.

Experiment: The tested lot was subjected to QC rescreening to test all units, including the other unit with an outlier slope in the I_MON linear response. The 1:1 data is traced thru die-level traceability (Figure 13).

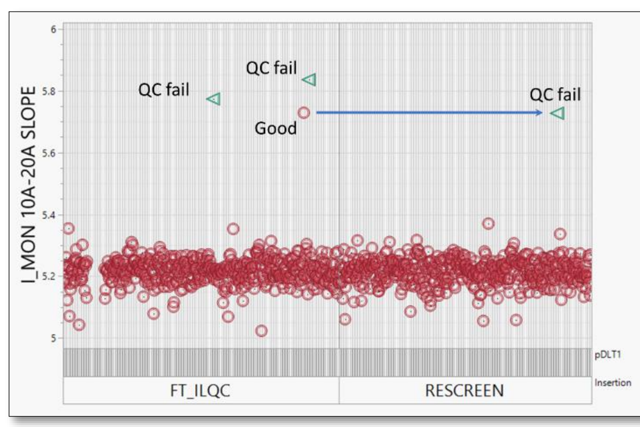


Fig.13. FT_ILQC Rescreen Run Chart. Units caught at FT are potential QC failures.

Observation: The previously good unit had resulted as QC fail on the current monitoring test.

Conclusion: The experiment resulted as expected: that the outliers from the distributions are indeed QC failures after performing a 100% retest.

3.3 Optimization and Implementation

Based on the completed experiment, unique responses from the potential failures surfaced and were identified; hence, additional calculation tests can be formulated to further isolate and screen out the failures. By using the slope equation derived from the linear regression:

$$m = Y / X$$

Taking the ratio between two slopes from the same line (Figure 14), the ideal quotient should have a value of 1 (one) if both slopes have the same value.

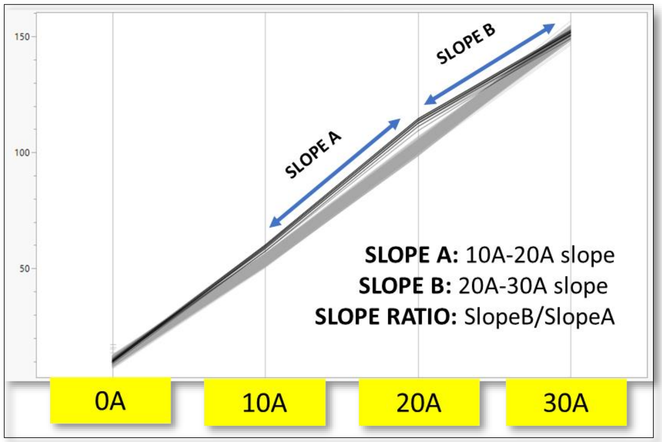


Fig. 14. Current Monitoring Output Linear Response. Where slope A is the slope between 10A and 20A and slope B is the slope between 20A and 30A.

Slope A = $Y_{20A} - Y_{10A}$ / 20A-10A.
Slope B = $Y_{30A} - Y_{20A}$ / 30A-20A.
Slope Ratio = Slope B / Slope A

Case 1:
If slope A and slope B have the same value, then the quotient is close or equal to 1.
Example:
Slope A = 5
Slope B = 5, then
Slope ratio = 5/5 = 1

Case 2:
If slope A is greater than slope B, then the quotient is less than 1.
Example:
Slope A = 5.5
Slope B = 5, then
Slope ratio = 5/5.5 = 0.9091

Case 3:
If slope A is lesser than slope B, then the quotient is more than 1.
Example:
Slope A = 5
Slope B = 5.5, then
Slope ratio = 5.5/5 = 1.1

4.0 RESULTS AND DISCUSSION

With the limits set based on the qual the lot's data, a new screen was introduced and found effective. The distribution of current monitoring slope checks showed outliers were getting screened out (Figure 15).

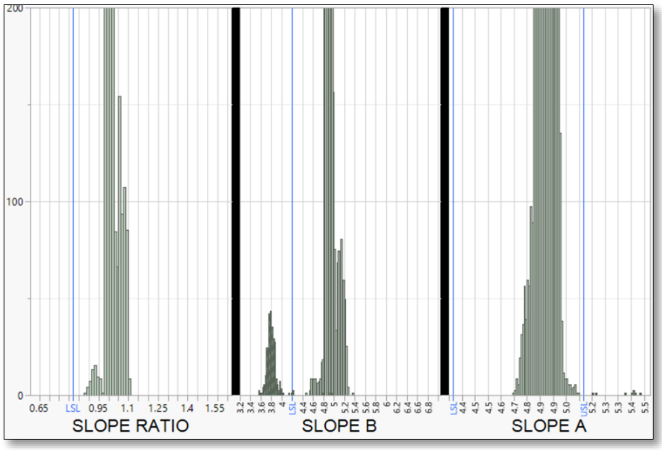


Fig.15. Current Monitor Slope Check Distributions. The slope ratio is the ratio between slope B and slope A.

The new product, together with its test solution, was released to production. Safe launch lots were then monitored to check the effectiveness of the new screen (see Figure 16).

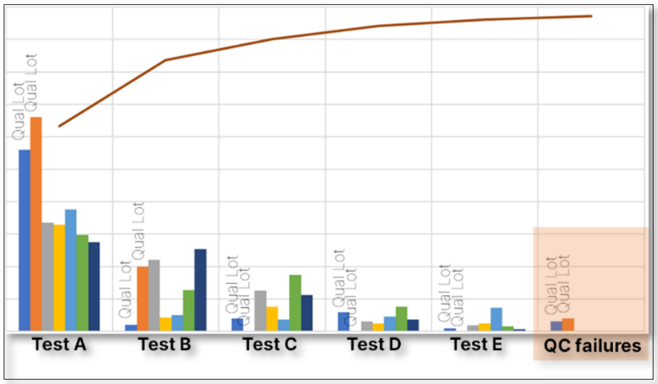


Fig.16. Safe Launch Lots Reject Pareto. After the qual lots, there were no QC failures observed on the succeeding lots.

While there were minimal losses from the new screen/s added in the final test, the safe launch lots resulted in zero QC failures.

5.0 CONCLUSION

In this study, we were able to identify the unique characteristics of QC rejects from their population by using their slopes. Simple graphical methods such as parallel plots, FT vs. QC using die level traceability (DLT), and histogram or distribution plots can visually identify an obvious separation between rejects and their population. But the stronger screen that was adopted was to take the ratio from two slopes that were on the same line. When their values are the same, the ideal result is equal to 1 (one), and not, if their values are different.

The tests added were calculated tests coming from existing datalog parameters, so the test time increase was minimal. These tests were considered effective screens based on the safe launch lot monitoring and resulted in zero QC failures; hence, quality and test coverage were amplified.

6.0 RECOMMENDATIONS

In implementing tests that involve slopes, one is not only limited to plotting two extreme points that would assume the linearity of the points in between. Validation of points from different ranges is also recommended.

Before adding new test screens, check if existing datalog tests can be reused to formulate new tests.

7.0 ACKNOWLEDGMENT

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