

# RF Test Gage R&R Improvement

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## Abstract

Advanced cell phone architectures require high performance multi-throw RF switches. Reliably measuring the very low RF power levels of the third harmonic signal of these switches is a significant challenge. This paper discusses the use of Gage studies to identify and measure the sources of variation in RF probe measurements. Tester Gage study results are presented. Evaluations of factors including test instrument repeatability, probe card wear, probe tip planarity, probe pressure, and probe placement within the bond pad are presented. The data indicated the repeatability of the test instrumentation was very good. However, the reproducibility needed improvement. The most significant factor in achieving reproducible RF measurements is sufficient probe contact. A method to provide probe operators feedback of sufficient probe contact was developed and implemented. As a result, the Gage study passed. Further, the percentage of die requiring re-test was reduced significantly.

## INTRODUCTION

State of the art multi-throw RF switches need to meet third harmonic performance specifications in the range of -30 to -40 dBm power at RF frequencies in the range of 824 to 915 MHz. -30 and -40 dBm correspond to 1uW and 100nW of power respectively. To provide known good switch die for Skyworks Front End Modules (FEM), the Skyworks pHEMT wafer fab performs RF probe testing on all switch die. Reliably making these low power measurements at high frequencies in a probe test environment requires advanced test instruments and rigid production discipline. The Skyworks Quality System requires Gage studies be performed on all measurement equipment. Further, Skyworks customers can and do request measurement system Gage study results.

## DISCUSSION

### Gage Study

A Gage study for third harmonics was performed. A production wafer was taken from the line after RF test. The data was reviewed and 21 functional die were selected which had a range of third harmonic performance from very good to very bad. Four operators, one from each shift, measured the die three times each. All 21 die were tested, then the

setup was taken apart, put back together and the die tested again. Each of the four operators did this three times each. This maximized variation by requiring all electrical connections between the tester and the prober to be remade, the probe card to be reset, and the probe pressure adjusted each time. The top level results of the Gage study are shown in Figure 1. The total Gage study result was 14%, which is marginally passing. Results of less than 10% are considered acceptable. Results between 10% and 30% are marginal. Results greater than 30% are unacceptable. The repeatability portion of the Gage study indicates the amount of variation due to the measurement equipment. This result was very good at 0.5%. The reproducibility portion of the Gage study indicates the amount of variation due to the operator. This result was marginal at 13.5%.

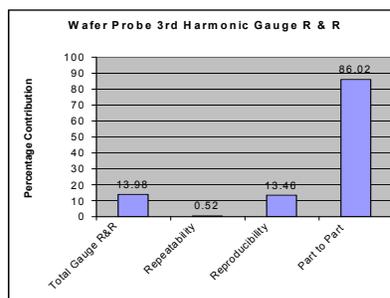


Figure 1  
Third Harmonic  
Gage R&R Results

The third harmonic variation was analyzed by operator (shift). Systematic differences between operators were observed (Figure 2). Further, the difference between operators was larger for better performing parts. We look at it as you can make a good part bad, but you can't make a bad part good. Note the data is shown in dBc. This is the third harmonic power level relative to the input power.

$$\text{dBc} = \text{input power (dBm)} - \text{measured 3F0 (dBm)}$$

The test engineering group met to discuss possible reasons for the reproducibility results. The team listed the factors listed in Table 1 as possible sources of test result variation than can be influenced by the operator.

Table 1 List of Potential Factors Influencing Reproducibility

- ✓ Probe pressure/planarity

- ✓ Probe wear
- ✓ Probe cleanliness
- ✓ Probe placement on bond pad

Table 1 Third Harmonic in (dBc) Results by Shift

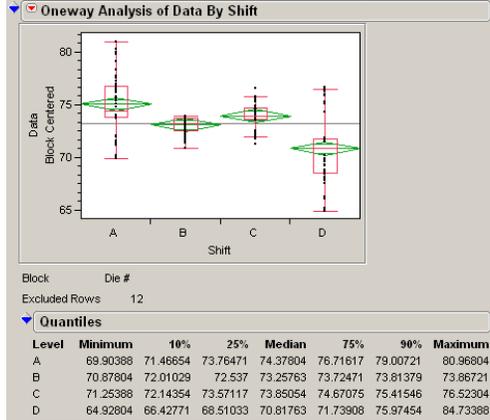
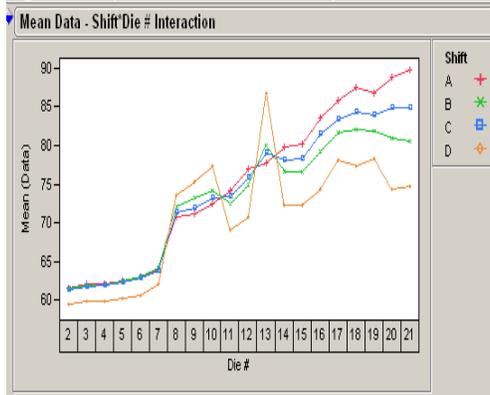


Figure 2 Graphs of Third Harmonics By Part and Shift



The hypothesis is that variations in these factors could change the third harmonic measurement by changing the impedance of the path from probe tip to each bond pad. Experiments were run to evaluate probe tip wear, probe placement within the bond pad, and probe pressure. We did not run a probe tip cleanliness experiment because we could not think of a way to dirty probe tips in a controlled manner.

#### Probe Pressure Evaluation

To evaluate the effect of probe pressure, the third harmonics were measured on the same die on the same wafer using four different probe pressure settings. A new, never been used before, probe card was used to make the measurements. This eliminated any variation due to a worn or non-planar probe card. The four probe settings were 0, 0.1, 0.2, and 0.3 mil over travel. The “zero” pressure was when the experienced operator believed all probes were touching the bond pads. The results are shown in Figure 3. The “zero” over travel setting resulted in highly variable results. The 0.1, 0.2, and 0.3 mil over travel reading resulted in reproducible measurements (Figure 4). The data shows with

a new, planar probe card, an over travel of .1 mils is sufficient to obtain reproducible 3rd harmonic measurements. By inference, maintaining probe planarity is critical to obtaining consistent measurements.

Figure 3 Third Harmonics by Probe Pressure

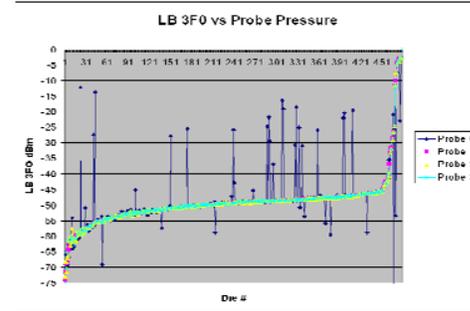
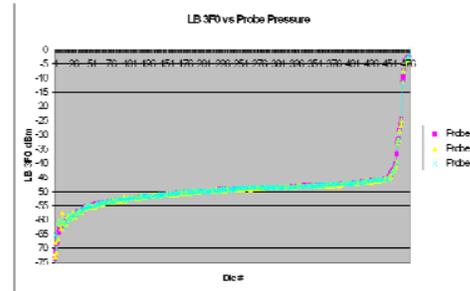


Figure 4 Third Harmonics by Probe Pressure



#### Probe Placement Within The Bond Pad

The placement of the probe tip within the bond pad was identified as a possible source of variation in third harmonic results. To evaluate this effect, 94 die on a production wafer measured with deliberate placement of the probe in the center and opposite corners of the bond pad (Figure 5). A newer probe card was used to make these measurements to reduce any variation due to probe tip wear. The probe card had been used for only 95,000 touches. We routinely achieve probe life in the 500,000 to 2,000,000 touches. The delta of the measurements from center placement to the corner measurements was calculated. A statistically significant difference of 0.14 dBm between the probe placements was observed (Figure 7). However, the difference was small, so in practice it is irrelevant (Figure 6). Probe placement within the bond pad is not the cause of the marginal reproducibility results of the Gage study.

Figure 5 Illustration of Probe Tip Placement Within a Bond Pad

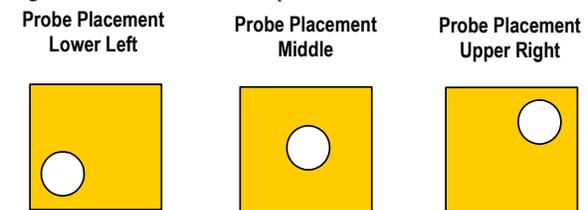


Figure 6 Third Harmonics By to Probe Placement within The Bond

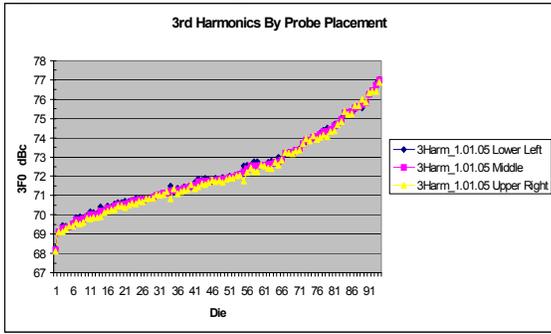
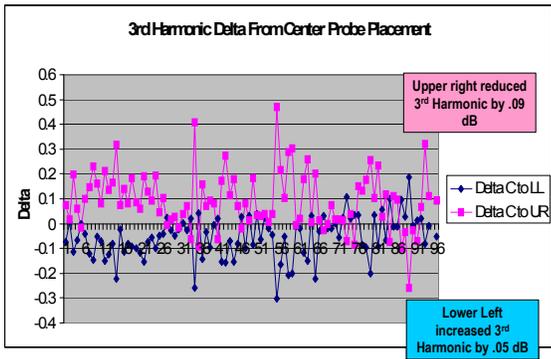


Figure 7 Differences in Third Harmonics Due to Probe Placement Within The Bond Pad



Probe Wear

The 1 mil diameter probe tips used for RF test are very small and fragile. During usage, the probe tips wear and change from sharp to dull. The probe marks left by a new probe tip are narrower and deeper than a dull tip, which tends to be wide and push more of the bond pad metal. This wear effect was identified as a possible source of variation in third harmonic results. To evaluate this effect, two probe cards were utilized. A newer card with 95,000 touches and an older card with 1,160,000 touches were used. Figure 8 shows the third harmonic results sorted from best to worst. Figure 9 shows the point by point difference between the two probe cards. There was no statistically significant difference observed between an old and new probe card. Probe tip wear is not the cause of the marginal Gage study result for reproducibility.

Figure 8 Third Harmonics vs Probe Tip Wear

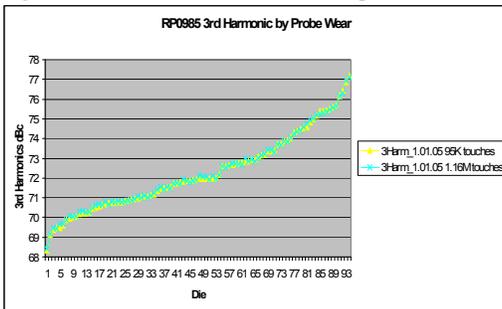
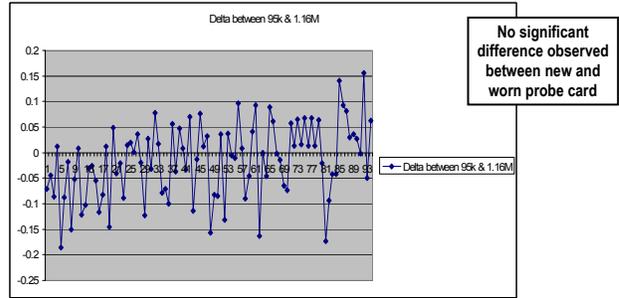


Figure 9 Difference in Third Harmonics Due to Probe Tip Wear



Improving Control of Probe Pressure

The operator is responsible for setting probe pressure using our EG4090 and EG2001 automatic probers. To ensure adequate probe pressure, the test engineering group at Skyworks developed a visual system to aid the operators. A wafer map is generated real time as the wafer is being tested. The map indicates passing die, functional die that fail, and non-functional die. Functional die are those which pass a minimal functional screen but do not pass the high performance specifications. The non-functional die fail the minimal screen. When die fail the functional screen, some special cause is at work. For example, an out of control process step, equipment failure, or operator error. The limits have been chosen such that poor probe contact is reported as non-functional die. When an operator sees excessive non-functional die, the probe pressure is one of the items to be checked (Figure 10). Typically, when probe pressure is insufficient, an abnormal pattern in the data is revealed.

Repeat of Gage Study For Third Harmonics

The Gage study was repeated with carefully controlled probe pressure. Once again, four operators were used in the study each repeating their measurements three times with the set up being redone after each measurement. The results showed the reproducibility improved from 14% to less than 1%. See Figure 11 and 12.

The range each of the twelve readings was calculated (4 operators, 3 times each) for each of the test data points. The range was then plotted as a function of the third harmonic performance. Figure 13 shows the range of measurements increases with increasingly better third harmonic performance. At -40dBm (100nW), the range of 12 repeated readings was <0.5 dB. Above -50 dBm (10nW), the range of measurements increases. This is likely due to reaching the noise floor of the test hardware.

Re-Test Rate

After learning the significant contribution to variation in probe results that is caused by probe pressure control and implementing the visual aid for operators to recognize insufficient probe pressure, the need for re-test decreased (Figure 14).

Figure 10 Wafer Map Showing Atypical Pattern Due to Probe Pressure. Blue color is for failing die

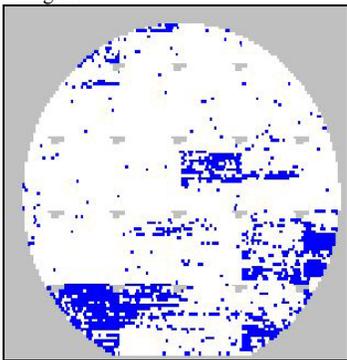
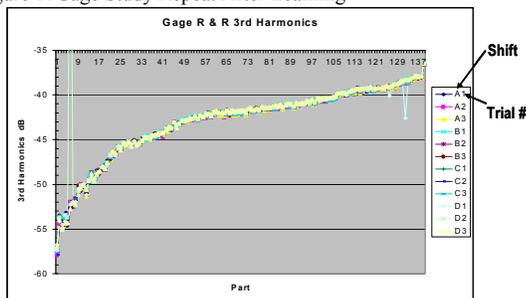


Figure 11 Gage Study Repeat After Learning



The 3<sup>rd</sup> Harmonic Measurements were both repeatable and reproducible. Each die was measured 12 times. 4 operators (on 4 shifts) measured each part 3 times. The Average range of the 12 measurements for 139 die was 0.48 dBm.

Figure 12 Gage Study Repeat After Learning

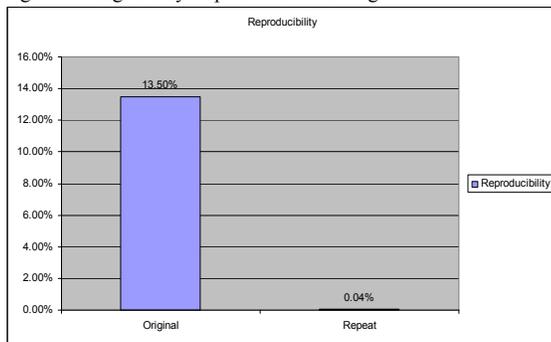


Figure 13 Range of 12 Repeated Measurements vs Performance

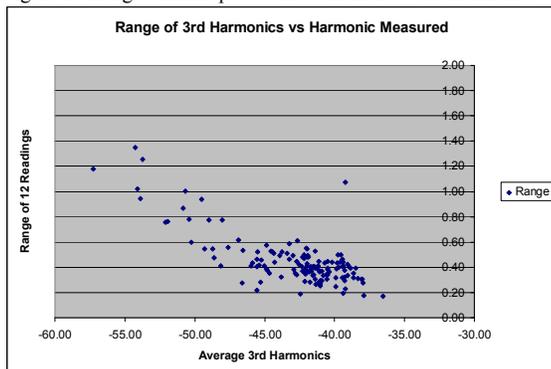
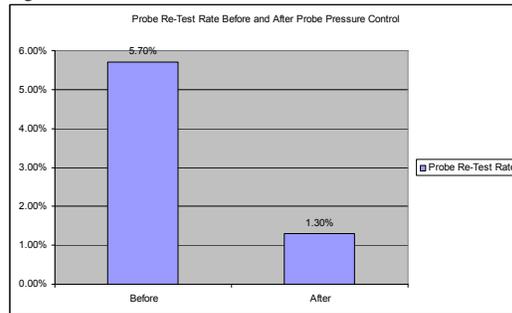


Figure 14 RF Probe Re-Test Rate Before and After Probe Pressure Control



### CONCLUSIONS

It was shown that Gage studies are a useful tool to identify and reduce variation in RF test results. Probe placement and probe wear were observed to be insignificant factors in third harmonic measurement results. Insufficient probe pressure was identified as a plausible explanation for marginal reproducibility of the third harmonic measurement in our initial Gage study. A repeat of the gage study passed with careful attention to probe pressure. A method to provide probe operators feedback of sufficient probe contact was developed and implemented. As a result, the percentage of die requiring re-test was reduced significantly.

### ACKNOWLEDGEMENTS

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### ACRONYMS

- RF: Radio Frequency
- pHEMT: Pseudomorphic High Electron Mobility Transistor
- Gage R&R: Gage Repeatability and Reproducibility