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Six Sigma Approach in Resolving Tapeless QFN Top Backetching Defect

Ernani Padilla
Back-End Manufacturing & Technology, STMicroelectronics, Inc., Calamba City, Laguna, Philippines 4027

Abstract— *VPLGA (Very thin Plastic Land Grid Array) or Tapeless QFN-mR (Quad Flat No leads – Multi Row) has a lot of gain in comparison with similar package HVQFN which includes cheaper leadframe cost, capable for multi-row leads, copper wire compatible, no tape and faster sawing speed at package singulation. Product application is on hard disk drives. However, leadframe configuration no longer has barrier in the form of a tape at backside to prevent bottom plating from being disturbed thereby exposing the copper based on the leads and the pad during backetch process. This technical paper will use six sigma approach via DMAIC to address expose copper on all tapeless QFN packages. Statistical tools such as MSA, multi-vari chart, 2-proportion test, correlation and capability analysis was used to properly guide analysis and make tapeless QFN robust thereby reducing expose copper defect.*

Keywords— *Tapeless QFN backetch.*

I. INTRODUCTION

Assembly and packing trends and focus areas identified by ST Microelectronics Calamba were miniaturization, low cost, low development cost, fast prototyping, lead-pitch 0.3-0.5mm, large pin count range (2-200pins), flexible pin allocation(rerouting), excellent thermal and RF behavior, compatible with flip-chip technology, support (stacked) MCM technique and environmental friendly(green).

Tapeless QFN has the smallest board space, possibility of rerouting, opportunities for dual row, BGA and SiP and low cost.

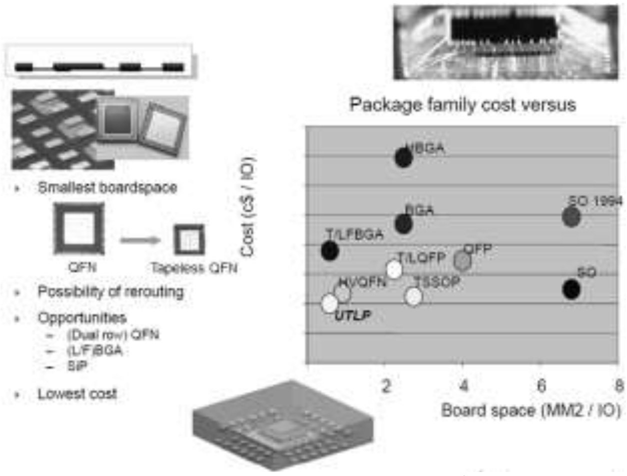


Figure 1. Tapeless QFN visual and package family vs. cost graph

Leadless technologies

Features	QFN	TFBGA	TAPP	Tapeless QFN	
Pitch 0.35 mm	x	✓	✓	✓	Package design features
Rerouting	x	✓	x	✓	
Dual row	x	✓	✓	✓	
No flash	x	✓	✓	✓	Ease of manufacturing
In-strip testing	x	x	✓	✓	
Plastic sawing only	x	x	✓	✓	
Package costs	✓	x	x	✓	
Reliability	✓	x	x	✓	

Table 1. Package feature comparison against tapeless QFN

1.1 Understanding Tapeless QFN Technology

1.1.1 Tapeless QFN leadframe manufacturing

Leadframe manufacturing starts with a three layer base material, Copper- Nickel-Copper wherein selective etching is possible. Patterning of the base metal Nickel-Palladium- Gold at top and bottom. Next is the top side copper etching followed by Nickel etching

1.2 Understanding frame etching process

Frame etching is the process of chemically removing copper between leads and heatsink areas through the use of an ammoniccal solution to complete the formation of metallization lines as shown below.

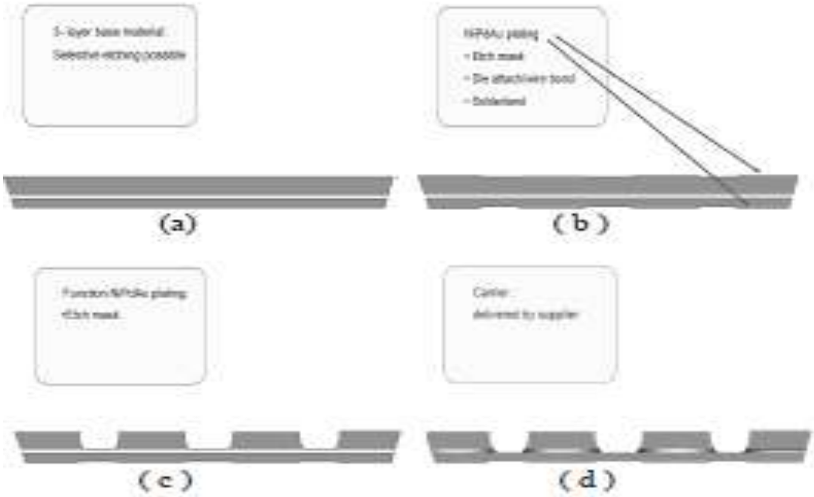


Figure 2. (a) Cu–Ni-Cu base material (b) patterning of base material (c) Copper etching (d) Nickel etching

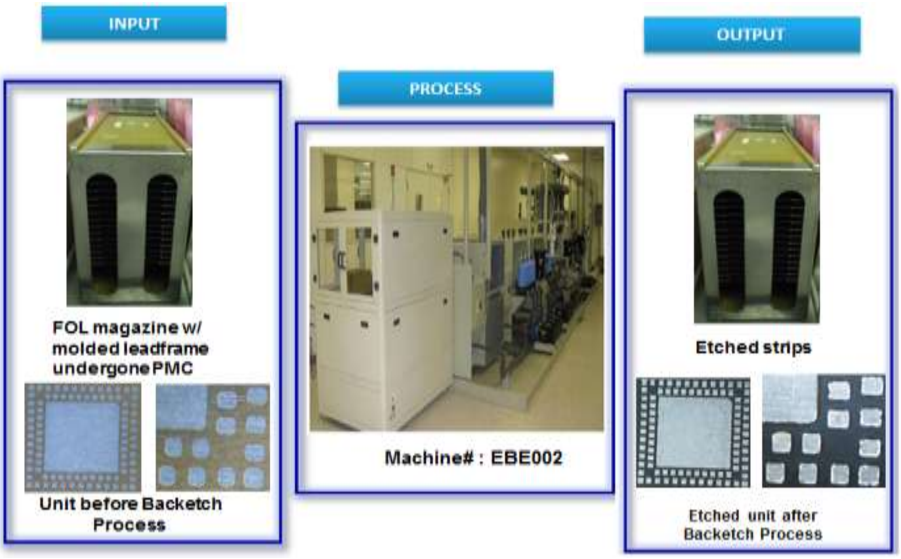


Figure 3. Frame etching or backetch process

1.3 Expose Copper Criteria

Criteria is to reject if exposed copper area is > 5% for die pad and 10% for lead area

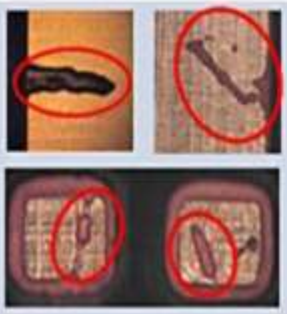
Defect Signature	Defect Callout	Specification Criteria (ADCS# 8260662)
	Exposed Copper	**Pad area:** Any exposed Copper on die pad that extends to more than 5% of die pad area. **Lead Area:** Any exposed Copper on lead that extends to more than 10% of lead area.

Figure 4. Expose copper defect signature

1.4 Defect failure mechanism

Expose copper is when the pad and lead plating is disturbed in the assembly process enough to expose the copper layer during backetch process.

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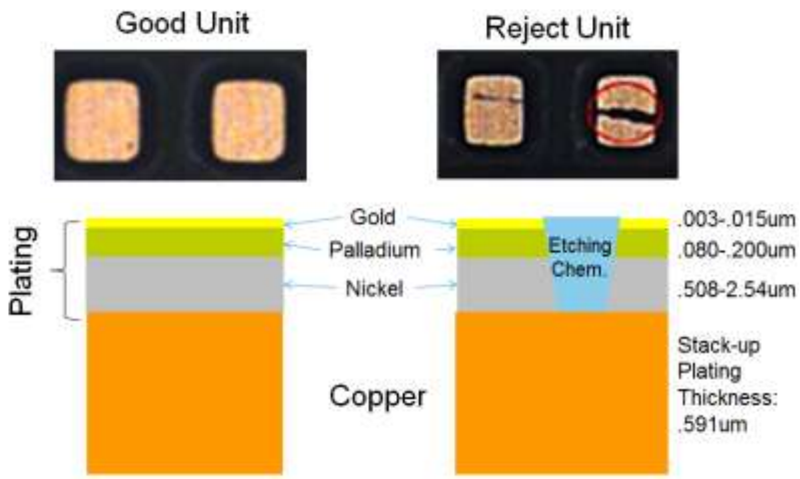

Figure 5. Comparison of good and unit with expose copper

II. MEASURE PHASE – ANALYSIS OF THE PRESENT SYSTEM

2.1 Tapeless QFN Assembly Yield Performance

Assembly yield of tapeless QFN is not meeting target of 99.50% for Q4'12.

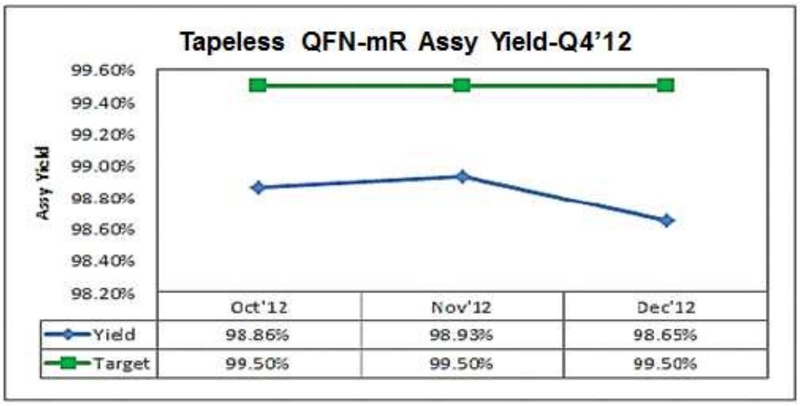

Figure 6. Tapeless QFN Assy yield Trend

2.1.1 Expose copper ppm

Expose copper is the top yield detractor at 15% contribution equivalent to 1770ppm in Q4'12 .

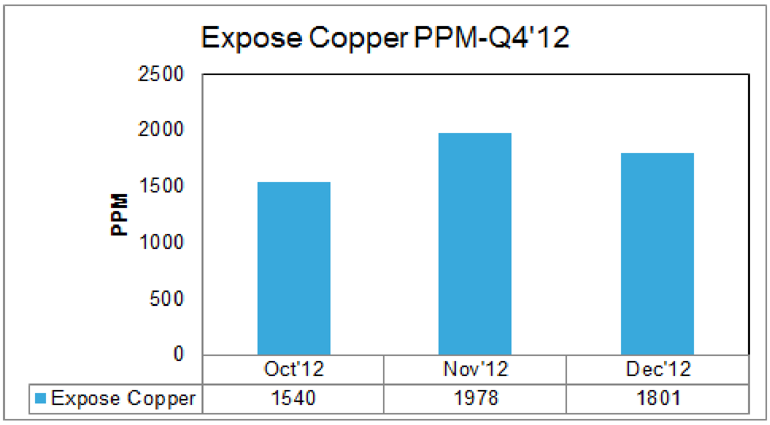

Figure 7. Expose Copper ppm Trend

2.2 Expose Copper Capability Analysis

Based from the capability analysis below expose copper is not in control. Process capability is 2.93 sigma level long term with current defect rate of 0.17%

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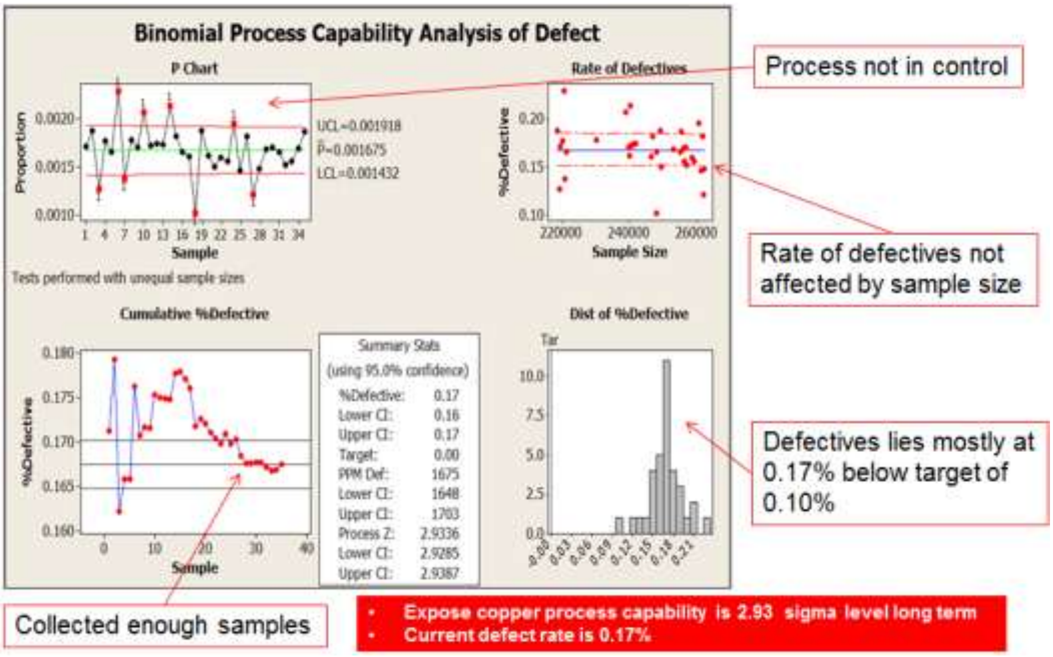
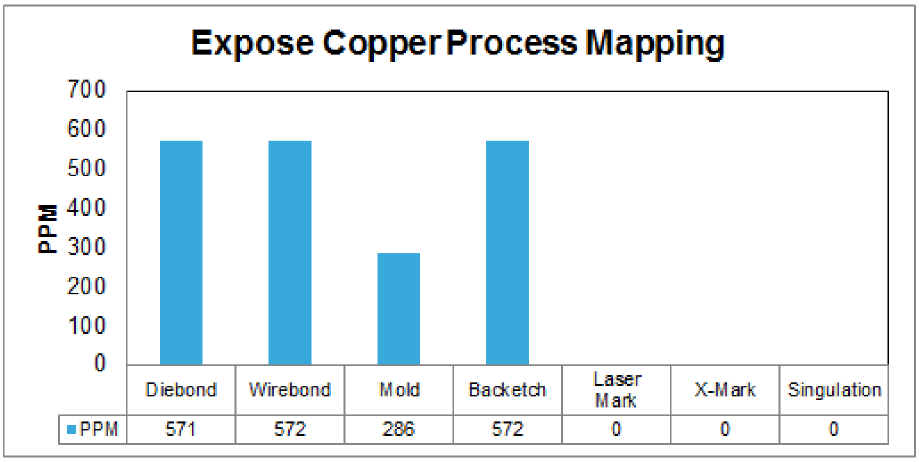


Figure 8. Expose copper capability

2.3 Expose Copper Process Mapping

As per mapping done in Jan'13, all main processes considered from die attach to frame etching is contributing to expose copper while process after frame etching did not contribute to expose copper. Problems by machine and handling related causing scratch on leadframe backside was immediately corrected as quick wins.



Process	PPM	Quick Win	When
Diebond	571	Fan-out Thermal Tape on all DB Machine	Feb'13
Wirebond	572	Provide WB jig for all lines	Jan'13
Mold	286		
Backetch	572	Handling OPI while automation is pending	Jan'13
Laser Mark	0		
X-Mark	0		
Singulation	0		

Figure 9. Expose copper mapping per process

2.4 Measurement System Analysis (MSA)

To check if rejection of expose copper is accurate an attribute MSA was conducted. Based from the MSA results, high percentage under each appraiser vs. std of 96.67-100% indicates good repeatability. High percentage under all appraisers of 96.67% indicates good reproducibility . Kappa of 0.991 is an indication of excellent agreement.

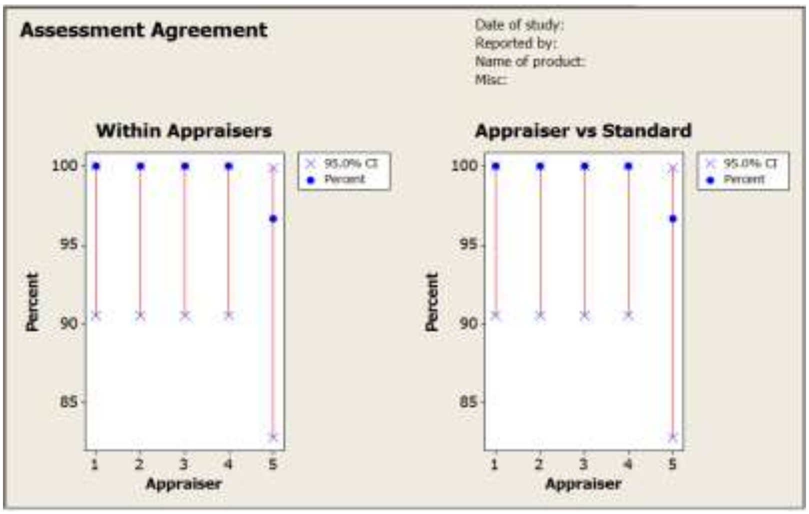


Figure 10. Assessment agreement

2.5 Problem Statement

High rejection rate of expose copper defect of 1770ppm on tapeless QFN-mR packages as of Q4’12.

2.5.1 Initial objective statement

To reduce expose copper from 1770ppm to 1000ppm by Apr’ 2013

Note: Objective was based on internal agreement to aggressively improve ppm surpassing the rule of 30% from entitlement of 1300ppm.

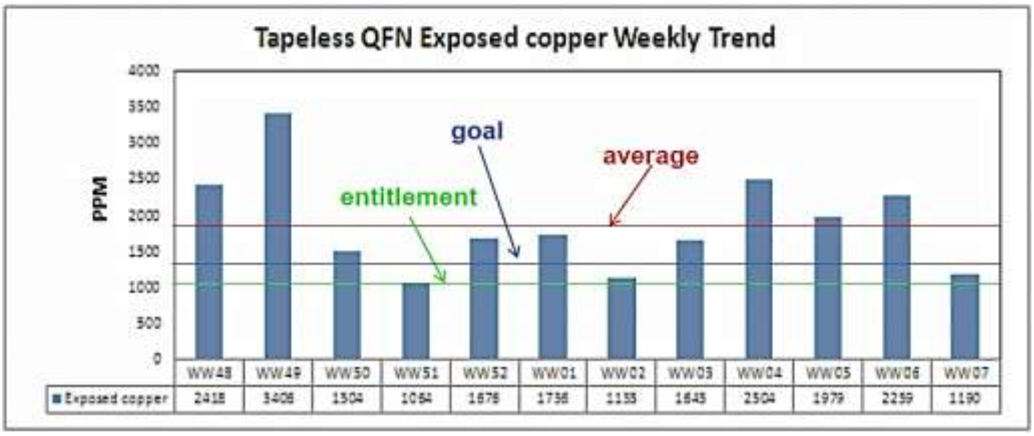


Figure 11. Tapeless QFN Expose copper goal setting reference

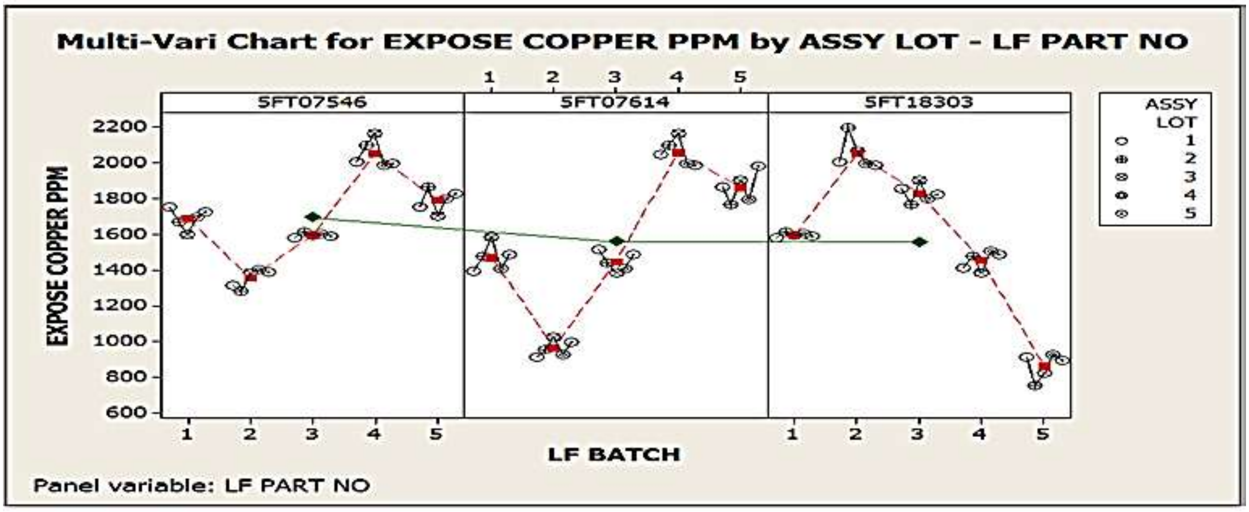
2.6 Identifying the Input Variables

Using an input output worksheet, there were 18 key process input variable (KPIV) identified which was further reduced to 9 after subjecting all items to a cause and effect prioritization matrix. Out of the 9, 5 has controls in place per FMEA leaving 4 for validation in the Analyze phase namely leadframe variation, diebond machine type, mold warpage and plating thickness. Details to be shown on the powerpoint presentation in the interest of space.

III. ANALYZE PHASE – Identification of Controllable Root causes

A multi-vari study was conducted to check graphically which among the 3 factors, leadframe part number, batch and assembly lot has the biggest variation to expose copper.

Process Function	Process Step	Practical Problem	Test Plan	Hypothesis Statement	Conclusion
Leadframe	Attaches the die to the leadframe using epoxy glue	Identify which factor has the highest variation to expose copper ppm	Multi-Vari Chart	Check graphical which among factors (leadframe part no, batch, lot) has biggest variation to expose copper ppm	Leadframe batch has the highest variation



Result I: The graph of the multi-vari shows that highest variation affecting expose copper is on leadframe batch to batch.
Next factor tested was to check if there is significant difference between two Diebond machine type with respect to expose copper using 2-proportion test.

Process Function	Process Step	Practical Problem	Test Plan	Hypothesis Statement	Conclusion
Diebond	Attaches the die to the leadframe using epoxy glue	Are units processed under DB A machine has lower defect rate as compared to DB B machine?	2-proportion	Ho: P DB A= P DB B Ha: P DB A < P DB B	No Significant difference

Power and Sample Size

```
Test for Two Proportions

Testing comparison p = baseline p (versus not =)
Calculating power for baseline p = 0.001
Alpha = 0.05


               Sample  Target
Comparison p     Size   Power  Actual Power
     0.00177    49021     0.9      0.900005

The sample size is for each group.
```

Test and CI for Two Proportions

```
Sample   X      N  Sample p
DBA     84  51000  0.001647
DBB     78  50000  0.001560


Difference = p (1) - p (2)
Estimate for difference:  0.0000870588
95% lower bound for difference:  -0.000327083
Test for difference = 0 (vs > 0):  Z = 0.35  P-Value = 0.365

Fisher's exact test: P-Value = 0.395
```

Practical Conclusion:

With P value of 0.395which is greater than 0.05, accept Ho, DB A and DB B has no significant difference in terms of expose copper rejection

Result 2: Based from the 2-proportion test there is no significant difference between diebond machine type with respect to expose copper

Another factor was to test if there is difference in using or not using metal plate in warpage rework during mold with respect to expose copper.

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Process Function	Process Step	Practical Problem	Test Plan	Hypothesis Statement	Conclusion
Mold	Warpage rework of strip manually pulled out from tool due to error	Are strip reworked using metal plate at bottom side has higher defectivity than w/o metal plate?	2-proportion	Ho: P w/ metal plate = P w/o metal plate Ha: P w/ metal plate > P w/o metal plate	No Significant difference

Power and Sample Size

```
Test for Two Proportions

Testing comparison p = baseline p (versus not =)
Calculating power for baseline p = 0.001
Alpha = 0.05


               Sample  Target
Comparison p    Size    Power  Actual Power
     0.00177   49021     0.9      0.900005

The sample size is for each group.
```

Test and CI for Two Proportions

```
Sample     X      N  Sample p
W/ PLATE  84  52500  0.001600
W/O PLATE 79  53000  0.001491


Difference = p (1) - p (2)
Estimate for difference:  0.000109434
95% lower bound for difference:  -0.000288435
Test for difference = 0 (vs > 0):  Z = 0.45  P-Value = 0.325

Fisher's exact test: P-Value = 0.354
```

Practical Conclusion:

With P value equal to 0.354, warpage rework with and without metal plate has no significance to expose copper defectivity rate

Result 3: There is no significant difference with and without using metal plate during warpage rework with respect to expose copper.
Then we conducted statistical testing to check if there is significant difference between plating thickness above and below the plating thickness specs of 0.591um.

Process Function	Process Step	Practical Problem	Test Plan	Hypothesis Statement	Conclusion
Leadframe plating	Plates bare copper base material at bottom of leadframe with Au, Pd and Ni	Are units having plating thickness > 591um has lower expose copper defect?	2-proportion	Ho: P thickness>591um = P thickness<591um Ha: P thickness<591um >P thickness>591um	Significantly different

Power and Sample Size

```
Test for Two Proportions

Testing comparison p = baseline p (versus not =)
Calculating power for baseline p = 0.001
Alpha = 0.05


               Sample  Target
Comparison p    Size    Power  Actual Power
     0.00177   49021     0.9      0.900005

The sample size is for each group.
```

Test and CI for Two Proportions

```
Sample    X      N  Sample p
T>591    84  52000  0.001615
T<591     6  53500  0.000112


Difference = p (1) - p (2)
Estimate for difference:  0.00150324
95% lower bound for difference:  0.00120393
Test for difference = 0 (vs > 0):  Z = 8.26  P-Value = 0.000

Fisher's exact test: P-Value = 0.000
```

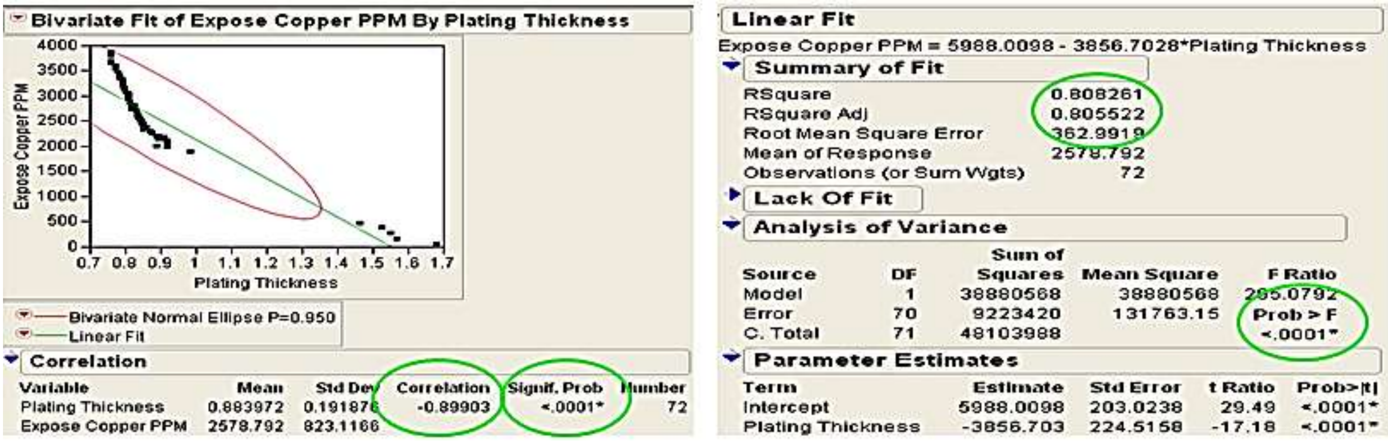
Practical Conclusion:

With P value equal to .000, plating thickness above 591um has lower expose copper defect compared to that with less than 591um

Result 4: There's a significant difference between plating thickness above and below 0.591um.

To further strengthen analysis on plating thickness another test was done to measure the strength of correlation of between plating thickness and expose copper reject.

Process Function	Process Step	Practical Problem	Test Plan	Hypothesis Statement	Conclusion
Leadframe plating	Plates bare copper base material at bottom of leadframe with Au, Pd and Ni	Is higher plating thickness has lower expose copper ppm and vice versa	Correlation , regression	Correlation is > 0.70 abs and P<0.05, means correlated For regression, R2 adj > 0.70 good correlation	High negative correlation and R2 adj, the higher the plating thickness the lower is the exp. cu. ppm



Practical Conclusion:

With P value equal to .0001 means plating thickness is significantly different with each other and correlation of 0.884 above 0.70 abs, plating thickness is negatively correlated to expose copper ppm. Based on the R2 adj, of 0.81, Plating thickness has high correlation to expose copper ppm

Result 4A: There is a strong correlation between reduction of expose copper and plating thickness increase

3.1 Plating Thickness Capability Study

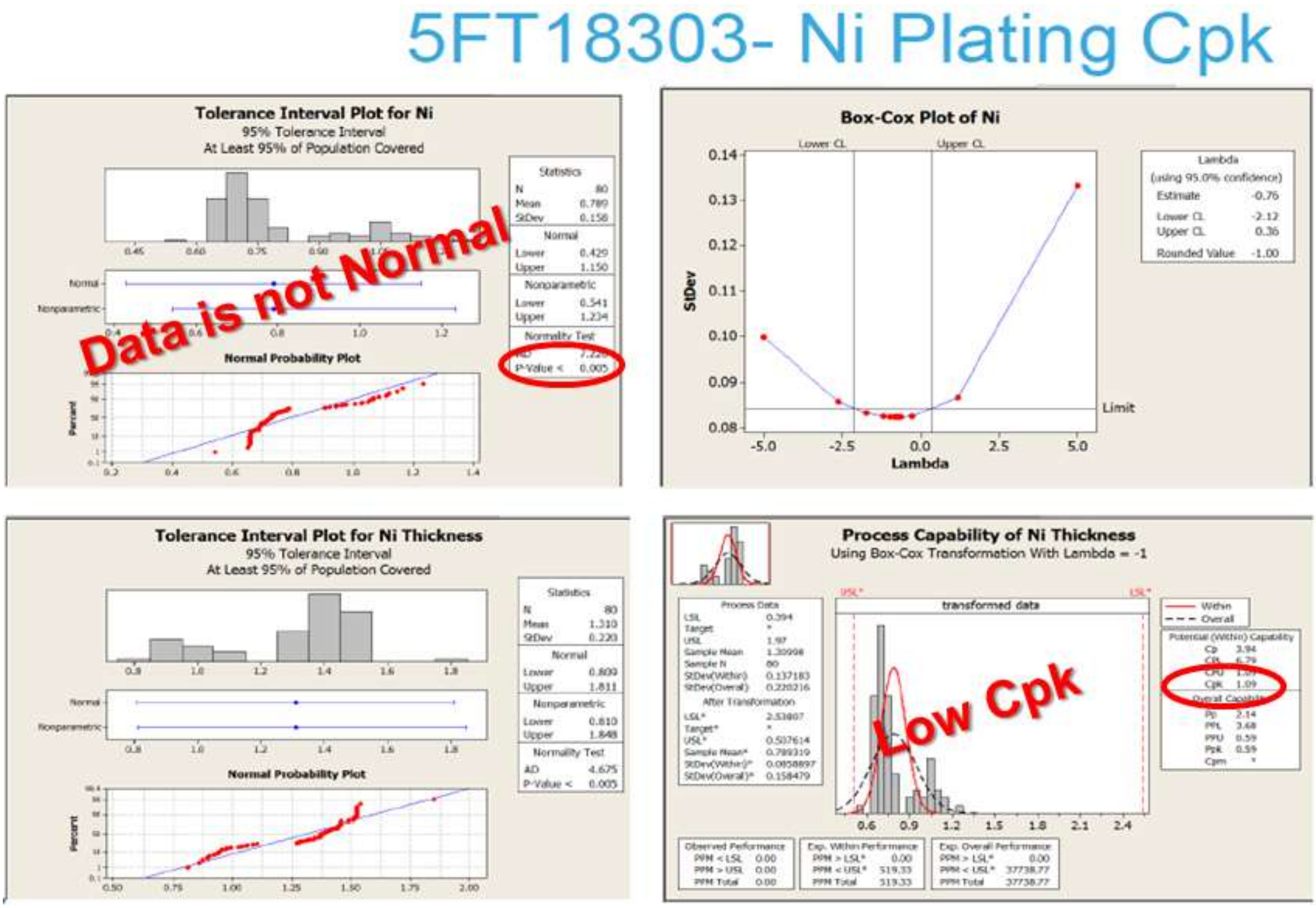
Consolidated supplier plating thickness record on c-of-c per batch for the 3 identified leadframe part number for tapeless QFN namely 5FT18303, 5FT07545, & 5FT07614. Compute for the Cpk for each of the plating layers namely, Au, Pd & Ni at bottom of leadframe per leadframe part number.

Table 2. Plating thickness specification for Tapeless QFN

	Top	Bottom		
Plating Layer	Ag	Au	Pd	Ni
Specs	3 - 8um	0.003-0.015um	0.080-0.200um	0.508-2.540um

3.2 Plating Thickness Summary Per Part No.

Example of capability analysis using box-cox is shown below for Ni plating on one of the part numbers.



Summarized results of Cpk, note that since data is not normal since distribution is skewed towards the lower specs and with Pvalue < 0.05, non-normal Cpk computation was performed using Box-Cox transformation wherein all part nos and plating layer is not meeting target of 1.67.

Table 3. Cpk summary table per part no. per plating layer

Non-normal Plating Thickness CPK Summary

Leadframe Type	Au Thickness	Pd Thickness	Ni Thickness
5FT18303	0.81	0.59	1.09
5FT07546	1.15	0.47	0.9
5FT07614	1.33	0.49	1.15

Cpk Criteria: >/=1.67

3.3 Plating Thickness Cross Section Verification

Cross section of good and reject unit of expose copper revealed readings marginally below specs at 571.66nm while reject shows for good units with 571

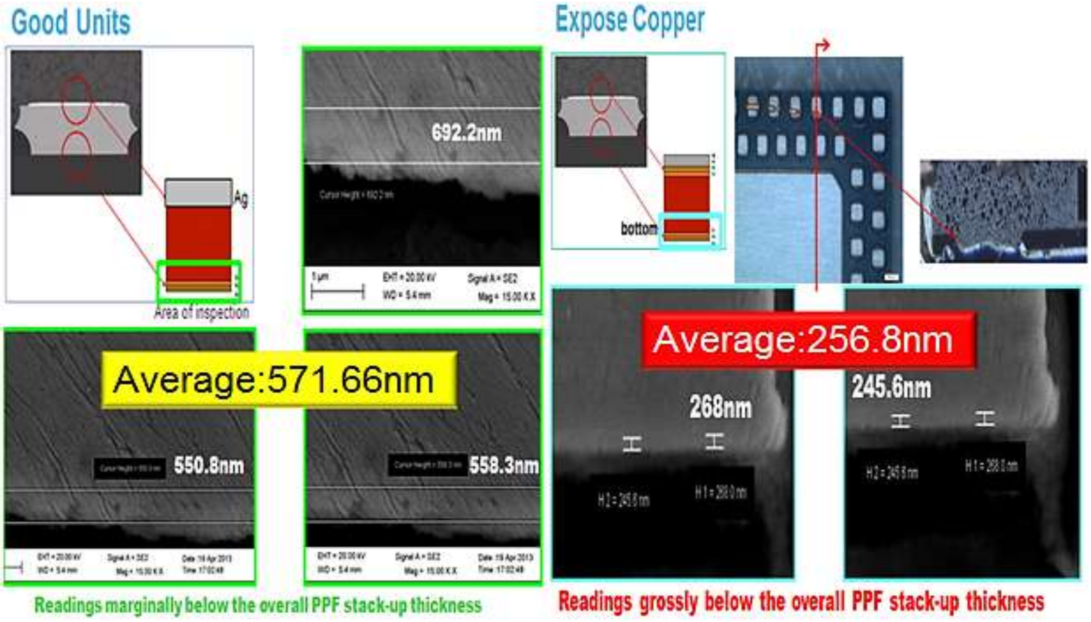


Figure 12. Cross section of expose copper

The reason why supplier is not meeting the nominal plating thickness due to plating material market price that will affect their manufacturing cost specially for gold and palladium.

Figure 13. Palladium, Gold and Nickel market price trend

Nickel has the lowest cost at $6.1497/lb but has the highest thickness layer among the 3 metals at 0.508-2.54um. It was mutually agreed to verify the effect of targeting nominal for Nickel to expose copper.

3.4 Final Objective Statement

To reduce tapeless QFN-mR expose copper ppm from 1770ppm to 110ppm by Apr.'13.

NOTE: Final objective was derived after the linear fit equation between expose copper and plating thickness in the correlation study.

IV. IMPROVE PHASE – SOLUTION FORMULATION

Based from the statistical validation, results shows that plating thickness is significant in reducing expose copper defect. However, plating thickness for all 3 layers cannot be implemented by supplier due to high metal price of gold and palladium and was agreed to put nickel layer to be target to nominal of the specs.

Table 4. Identified best solution

Ideal Solution	Potential Problem	Potential Cause	Counter Preventive Action	Validation Result	EP Level	Target Date	Responsible
Increase plating thickness	Under-etch copper	Reduce etch chemical penetration	Validate effect on under-etch against control	No change to under-etch ppm	EP5	Feb'13	Heidi V.
	Strip Warpage	Effect to CTE of leadframe	Validate effect on leadframe warpage against control	No difference in warpage	EP5	Feb'13	Jardin V.
	Increase leadframe price	Gold and Palladium increase cost	Target Nickel plating to nominal	Lower expose copper ppm	EP2	Mar'13	Nath R. / Nani P.

V. IMPROVE PHASE – SOLUTION IMPLEMENTATION

Below were the steps undertaken to have a close loop process in the implementation of the ideal solution.

Table 5. Solution implementation plan

Plan		Do											Check	Act	Status
Best Solution	Steps	Implementation Date(when)										Resp. (who)	Result Monitoring	Learning	
			1308	1309	1310	1311	1312	1313	1314	1315					
Increase plating thickness to nominal	Discuss with LF supplier the result of analyze phase	Plan										Ernani / Nath	Supplier acknowledge cross section	Understand loop holes in supplier quality control	done
		Actual													
	Request LF supplier to increase plating thickness	Plan										Ernani/ Nath	Only Nickel was target	Ni target to nominal is sufficient to	done
		Actual													
	Secure samples of increase Ni thickness for expose copper validation	Plan										Ernani/ Nath	Expose copper from 2037ppm (Q4'13) to 616ppm (Mar'13)	Initial data have favorable results to proceed with large scale	done
		Actual													
	Implement and fan-out for all LF part no.	Plan										Cpk Team	All three part no. of QFN-mR has nominal Ni plating	Supplier was convince with result triggering fanout	done
		Actual													
	Large scale validation and monitoring	Plan										Cpk Team	From 616ppm (Mar'13) to a low of 43ppm(Jun'13)	Drastic improvement was achieved	done
		Actual													
	Documentation	Plan										Cpk Team	Completed documentation of action	Will be reference for future QFN-mR packages	Update FMEA/ QIP
		Actual													

VI. CONTROL PHASE

5.1 Control - Results Evaluation

Revisiting the Nickel plating thickness capability after implementation of corrective action on all 3 leadframe part numbers reveals that all the data were stable and normal and with high Cpk values as compared to old.

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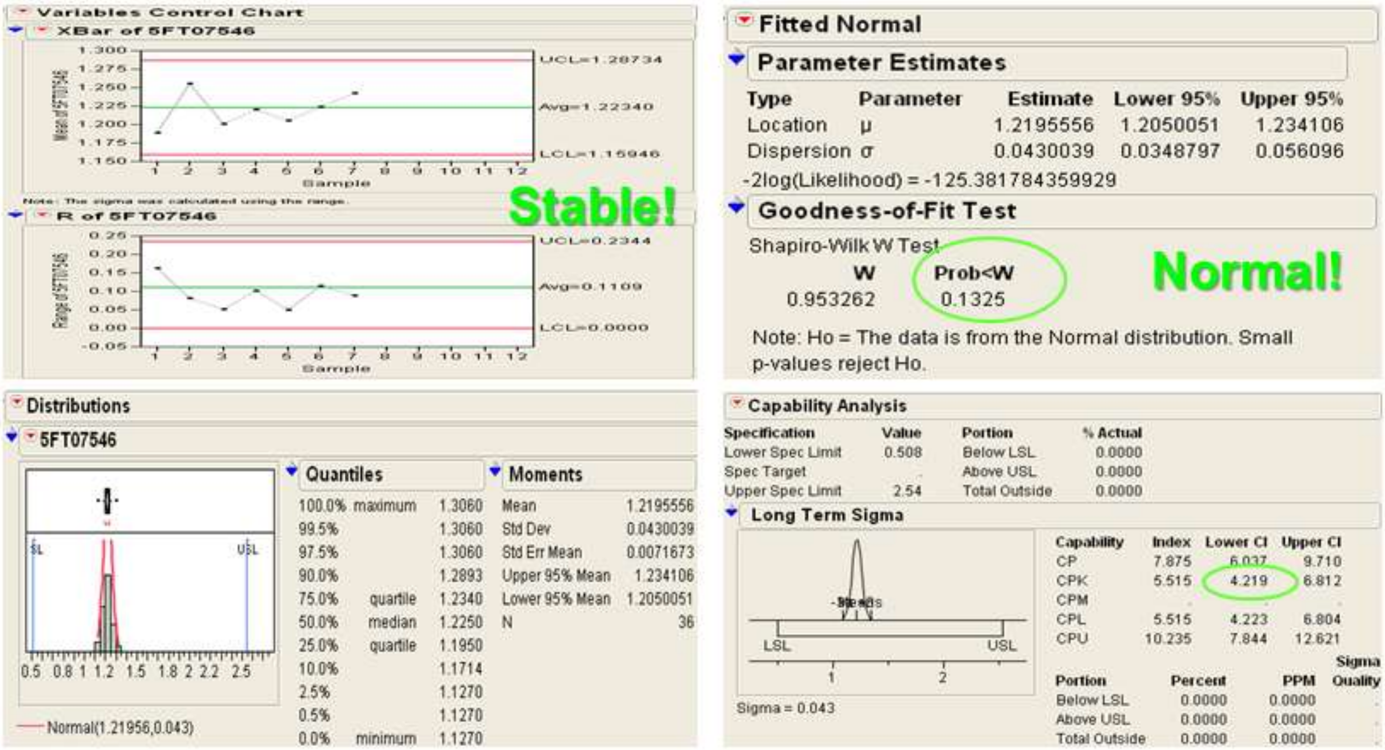
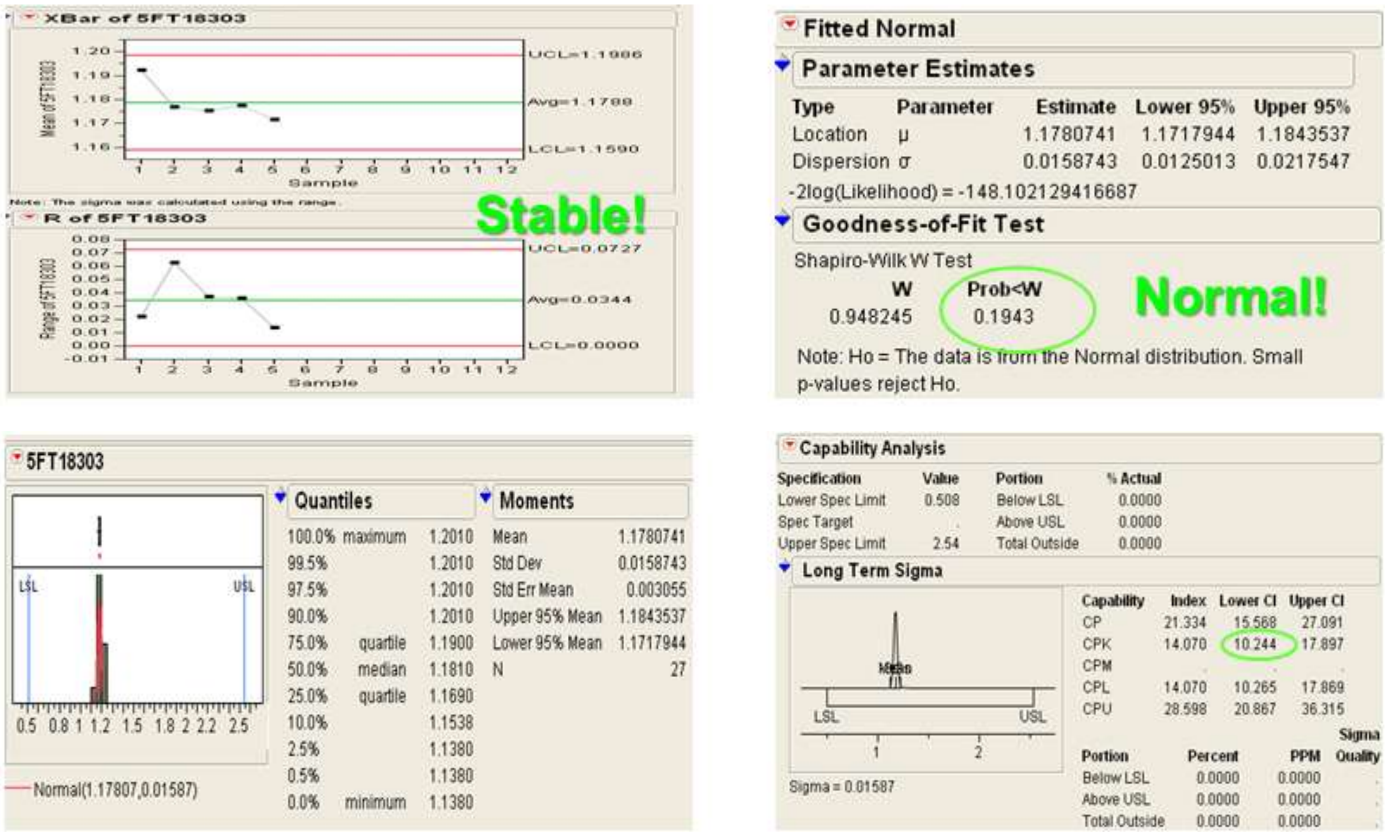


5FT07546 Ni Plating Thickness Cpk improved to 4.219



5FT18303 Ni Plating Thickness Cpk improved to 10.244

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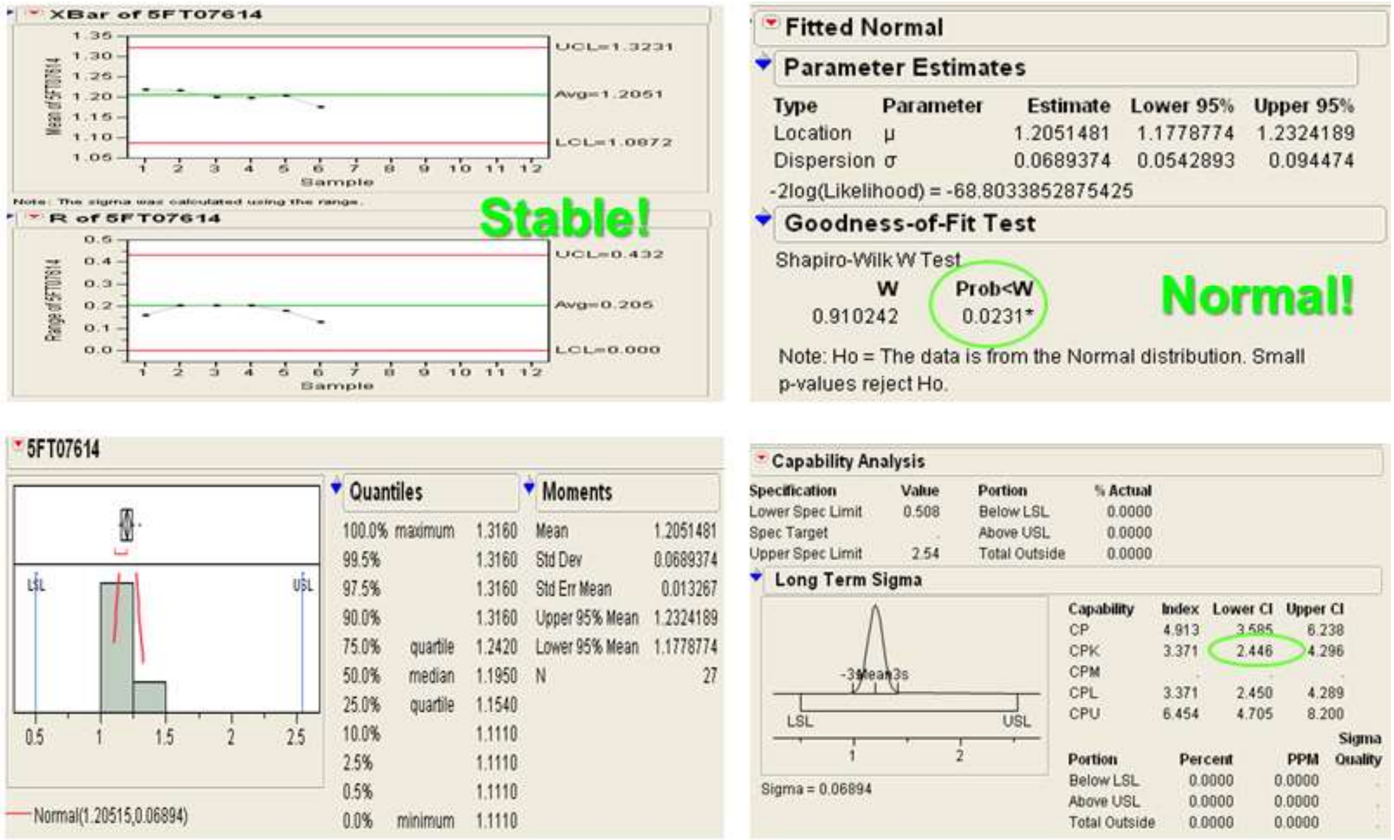

5FT07614 Ni Plating Thickness Cpk improved to 2.446

5.2 Description of Best Solutions

The solution of targeting the Nickel plating thickness to nominal resulted to high Cpk values for all leadframe part numbers which translated to the improvement of the expose copper ppm trend from 1770ppm(Q4'12) to best of 43ppm(Jun'13) translating to a savings of $34,500/annum due to yield improvement.

Table 6. Description of the best solution

Cause	Low Cpk for all plating(Au,Pd&Ni) thickness layer, capability at minimum of the specs		
Action	Target Nickel plating thickness to nominal by supplier	EP Level: 2	
BEFORE		AFTER	
Leadframe Part No	Cpk Old Ni Thickness	Leadframe Part No	Cpk New Ni Thickness
5FT18303	1.09	FT18303	10.244
5FT07546	0.9	5FT07546	4.219
5FT07614	1.15	5FT07614	2.446
Loss 1770	Expose Copper - 1770ppm	Gain	Expose Copper – 43ppm
Results		Results	$34,500 / annum

5.3 Tangible Benefits

QFN-mR expose copper ppm was significantly reduced from 1770ppm(Q4'12) to a low of 43ppm(Jun'13) or 97.85% defect improvement surpassing our objective of 110ppm.

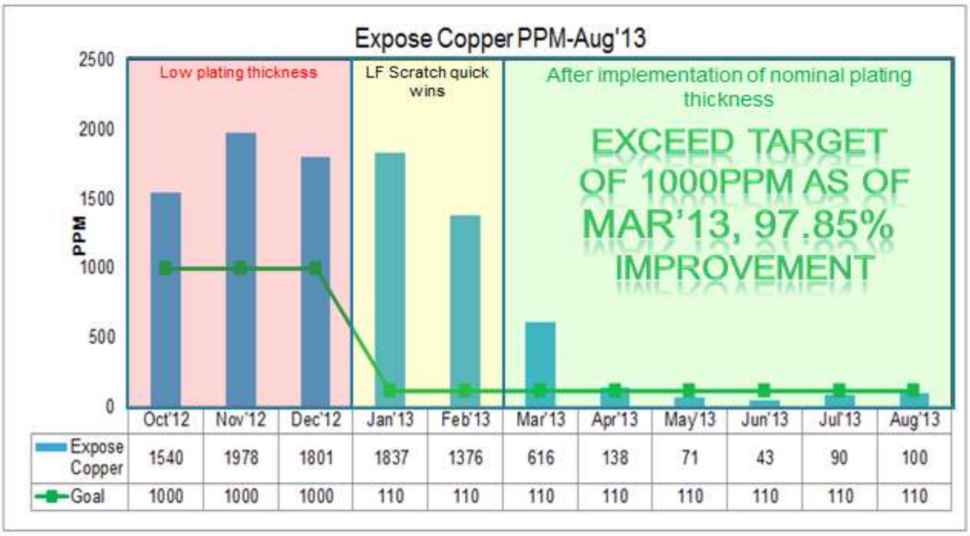

Figure 14. Expose copper ppm trend

Improvement on expose copper resulted to the improvement of 98.78% in Jan'13 to 99.35% in Oct'13. Annualized saving was computed at $34,500 as per IE.

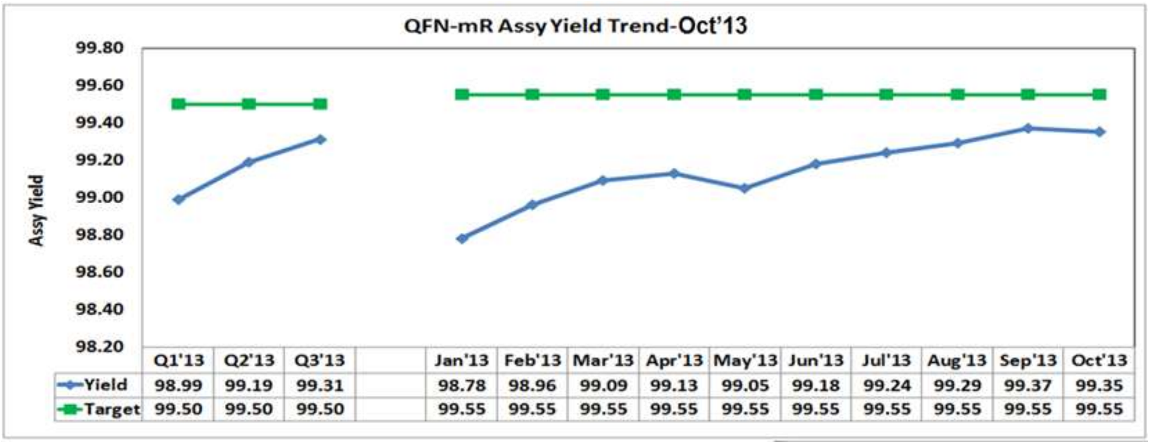

Figure 15. QFN-mR Assembly yield trend

5.4 Control - Standardization / Fan-Out

All leadframe part numbers of QFN-mR was agreed with supplier to maintain the nickel plating thickness to nominal. As such Cpk review of this items will be done quarterly with supplier.

5.5 Documentation and Deployment

Improvement on the expose copper was update on frame etching PFMEA and was also uploaded as a key action for the Quality Improvement Plan (QIP) wherein expose copper is one of the defects being monitored by Corporate.

5.6 Future Plans

Next focus is to organize focus teams based from the new QFN-mR top defect pareto to further improve Assembly yield as below. Note: NSOP/NSOL/Cut wire/Wafer Fab defects where not included as this is material related issue and is not within our control

Table 7. Package and Defect assignment for QFN-mR

Pkg	Owner	Defect	Owner	Target
QFN-mR (GB)	Conrado V.	Wireshort WB	Conrado V.	Q2'14
		Wireshort - Handling	Lester B.	Q2'14
		Epoxy on Lds	Noel C.	Q3'14
		Crumpled LF	Adrian E.	Q3'14

5.7 Acknowledgement

We bring back all the glory to God. Our family as our inspiration. Our respective departments colleagues in Assembly, Failure analysis and Supplier quality for their support. To our management team for their guidance. Special thanks to our mentor in statistics Mairel. Also this would not be possible if not for the support of our leadframe supplier.

5.8 Glossary of Terms

2-proportion test – Statistical tool to test significance for discrete data
Au - Gold
BGA – Ball grid array, a product porfolio in ST Calamba with substrate as carrier
Box Cox Transformation – statistical tool to convert non-normal data to normal data
Cpk – Capability Index
HVQFN – Heatsink Very thin Quad Flat No leads
LF - Leadframe
Ni – Nickel
NSOL – Non-stick on lead
NSOP – Non-stick on pad
Pd – Palladium
PFMEA – Process Failure Mode and Effect Analysis
QIP – Quality Improvement Plan