CHAPTER 4

TEST DEFECT AND METHODOLOGY

4.1 Product Background

4.2 Type of Defect and Test to Detect Defects

4.3 Methodology

4.4 Data Collection

4.1 Product Background

The MCM69R736C/738C/818C is a 4 megabit synchronous late Fast Static Random Access Memory (FSRAM) designed to provide high performance in secondary cache and ATM switch, Telecom, and other high speed memory applications. FSRAM is a read or write in which the data are latched and retained. The MCM69R818C (organized as 256k words by 18 bits) and the MCM69R736C (organized as 128K words by 36 bits) are fabricated in the company's high performance silicon gate BiCMOS technology (Company product handbook).

4.2 Type of Defects and Test to Detect Defects

To detect and to test the defects or faults in a devices one needs to know the types of defects that one may encounter, i.e. one needs to model how faults or defect occur and impact on circuits (Company product handbook). Basically, there are four types of reject bins i.e. bin 5, 6, 7 and 8, the detail description is presented in following session.

4.2.1 Margins or Pattern Failure

There are many types of defects that are classified under margin or pattern failure and these defects are sorted into bin 5. The defects are levels, high core power supply voltage (Vdd) pattern, low Vdd, impedance, joint test action group (JTAG) or etc.

To determine whether a given chip performs correctly according to specifications, a sequence of test input stimuli are applied and the output responses sampled. If the sampled response differs from the response expected from a good device, then the device is declared faulty. The test stimuli are called the test pattern or test vector. The test pattern must be so chosen that for every modeled fault at least one input will produce a response that differs from the corresponding good response. The goodness of a test pattern is measured by its test time and fault coverage. The test time is the time required testing the whole test pattern. Fault coverage is expressed as the ratio of the number of faults detected by input test patterns to the number of possible faults the device has. The fault coverage is determined by the efficiency and length of the test patterns.

4.2.2 Parametric Failure

A parametric test is a test that measures DC and AC conditions of a chip, such as maximum current, leakage, and output drive. Parametric failures to be sorted under bin 6, type of defects are data retention test (DRET), walk 1/0, current and etc.

Parametric testing is used to ensure that the device meets its performance specifications. Parametric testing consists of DC parametric testing and AC parametric testing.

a) DC Parametric Testing

These are tests in which steady-state voltages and currents are applied to certain I/Os (input output) of the device and corresponding voltages and currents are measured at other I/Os. These tests are used to measure input/output levels (V_{IL}, V_{IH}, V_{OL}, V_{OH}, I_{OL}, I_{OH}, refer detail in acronyms), static and dynamic supply current levels (I_{CC}, I_{DD}, refer detail in acronyms), leakage (tristate, input, pull-up, pull down), etc. These tests may be performed at both wafer probe and final test.

b) **AC Parametric Testing**

These tests are used to measure the frequency-dependent characteristics of the circuit. These characteristics include propagation delay (time interval from input signal application to output response), setup/hold times (verifies valid signal before/after assertion of second signal), clock frequencies (verifies duty cycle, period), signal timing (verifies signal edge placement), etc. These tests are usually not done at wafer probe due to the poor electrical environment of a standard probe card.

4.2.3 Nominal March Failure

V_{REG} (Voltage register) tests, leakage, GHKH (cycle time) and etc. are the defects categorize under bin 7 reject bin or nominal march failure.

Here, a functional test is performed to verify that a circuit performs its intended function. This is sometimes termed truth-table verification for digital circuits. Functional testing includes two type of testing: -

a) Standard speed functional testing verifies that the device behavior is correct, using static settled-state measurement, and

b) At-speed functional testing verifies behavior at rated circuit signal timing.

Functional testing at wafer probe is done at reduced clock speed due to the limitation of the needle-type epoxy ring probe cards, it is used primarily to determine whether the circuit behavior correct. The final test for a packaged device usually incorporates a full at-speed functional test to ensure device behavior over the full rated speed range.

In functional testing, the fault at each internal node must be propagated to external I/O pins such that it can be detected. The test pattern may be very difficult to generate as the number of internal nodes may be very large and the external I/O pins are limited.

4.2.4 Shorts and Opens Failure

A short fault is defined as an electrical short circuit between two nodes that are supposed to be electrically isolated. An open fault represents a failure that causes a line or wire in the circuit to be broken. This type of rejects is classified under bin 8 reject bin.

A continuity testing was applied here to detect this shorts and opens defect. Testing is performed to ensure that all device pins are actually connected to the device. On the surface, it may seem redundant to perform a separate test for open circuit pins, after all, a circuit with missing connections is bound to fail logic function subtests and be rejected. However, a circuit may fail functional tests for the following reasons:

- Failure to meet Vin/Vont specifications
- Failure to meet timing specifications
- Inability to perform the require logic function
- Open circuited pins

Knowledge of open circuit failures points directly towards errors in attaching bonding wires or to package stresses that tone away the bonds. It may also point to mistakes in aligning wafer probers or package handlers to the testers. In short, testing for open pins provides invaluable information about integrity of the test equipment and about quality of the assembly line.

Separate testing for open circuits is invariably performed and is almost always placed first in the testing sequence. Tests for pins that are internally shorted together. Like open pins, shorted pins point to specific errors in test equipment setup or in device packaging.

4.3 Methodology

Following displayed a series of statistical analysis tools that will be used in data analysis in Chapter 5.

4.3.1 Box and Whisker Plots

The box-and-whisker plot is a graphical procedure that uses five statistical measures: the minimum, the 25th percentile, the median, the 75th percentile, and the maximum value. The inner box shows the numbers that span the range from 25th to the 75th percentiles. A line is drawn through the box at the median (William L.Carlson et al, 1997). All five of the statistical measures can be obtained by computer software package such as SPSS. The graph display shows central tendency, dispersion, the degree of asymmetry and the shape of the distributions, either positive or negative skewed.

4.3.2 Homogeneity of Variance Test

Although the one-way analysis of variance is relatively robust to the assumption of equal group variances, large departures from this assumption may seriously affect the α level and the power of test. Therefore, various procedures have been developed to test the assumption of homogeneity of variance, such as Bartletts's test (Douglas C. Montgomery, 1997). However, the test was not available in SPSS package. In SPSS package, Levene test was used to test for the equality of group variances. The results of a hypothesis test is to state that the null hypothesis was or was not rejected at a specified α-value (0.05 was set in this study) in this statistical software package. This decision rule has been reformulated to p-value. The p-value is the probability that test statistic will take on a value that is at least as extreme as the observed value of the statistic when the null hypothesis H_0 is true.

The critical region is $Z_p = \frac{\overline{X} - \mu_0}{\sigma / \sqrt{n}}$. Then, Z_p is used with the normal table to obtain the probability of the sample mean, $\overline{X}$, given H_0. If p is less than the probability of type 1 error α, H_0 is rejected and H_1 is accepted (William L.Carlson et al, 1997)

4.3.3 Analysis of Variance (ANOVA)

Analysis of variance, commonly referred to as ANOVA, is a statistical technique that seeks to determine whether differences in the values of a variable can be explained by categorization of the observations (Thad W. Mirer, 1995). It is a test used to deal with testing whether k samples come from a population with the same mean.

In the analysis-of-variance procedure, it is assumed that whatever variation exists between the aggregate averages is attributed to variation among the observation called within-group variation and variations among the group means are called the between-group variation (Ronald E. Walpole et al, 1993 and Douglas C. Montgomery, 1997). The total corrected sum of squares is used as a measure of overall variability in the data.

$$\text{SST} = \sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij} - \bar{y}_{..})^2$$

where $\bar{y}_{..} = \dfrac{\sum_{i=1}^{a}\sum_{j=1}^{n} y_{ij}}{n}$ is called the grand mean

y_{ij} = i_{th} observation in group j

n = number of observations in group j

a = number of groups

And $SS_T = SS_{Treatments} + SS_E$ where $SS_{Treatments}$ is called the sum of squares due to treatments (i.e., between treatments), and SS_E is called the sum of squares due to error (i.e., within treatments). There are an = N total observations; thus, SS_T has N-1 degrees of freedom. There are a levels of the factor, so $SS_{Treatments}$ has a-1 degrees of freedom. Finally, within any treatment there are n replicates providing n-1 degrees of freedom with which to estimate the experimental error.

$$SS_{Treatments} = n\sum_{i=1}^{a}(\bar{y}_{i.} - \bar{y}_{..})^2$$

$$\text{SSE} = \sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij} - y_{i.})^2$$

Since the degrees of freedom for $SS_{Treatments}$ and SS_E add to N-1, the total number of degrees of freedom, Cochran's theorem implies that $SS_{Treatments}/\sigma^2$ and SS_E/σ^2 are independently distributed chi-square random variables. Therefore if the null hypothesis of no difference in treatment means is true, the ratio is distributed as F with

$$F_0 = \frac{SS_{Treatments}/(a-1)}{SS_E/(N-a)} = \frac{MS_{Treatments}}{MS_E}$$

a-1 and N-a degrees of freedom. Above equation is the test statistic for the hypothesis of no differences in treatment means. Null hypothesis will be rejected and conclude that there are differences in the treatment means if $F_0 > F_{\alpha,a-1,N-a}$.

4.3.4 Assumption of the Analysis of Variance

The analysis-of-variance technique makes certain assumptions about the data being investigated. There are three major assumptions in the analysis of variance:

The first assumption, normality, states that the values in each group are normally distributed. The analysis-of-variance test is "robust" against departures from the normal distribution; that is, as long as the distributions are not extremely different from the normal distribution, the level of significance of the analysis-of-variance test is not greatly affected by lack of normality.

The second assumption, homogeneity of variance, states that the variance within each population should be equal for all populations ($\sigma_1^2 = \sigma_2^2 = ... = \sigma_c^2$).

This assumption is needed in order to combine or pool the variances within the groups into a single "within-group". If there are equal sample sizes in each group, inferences based upon the F distribution may not be seriously affected by unequal variances. If, however, there are unequal sample sizes in different groups, unequal variances from group to group can have serious effects on drawing inferences made from the analysis of variance.

The third assumption, independence of errors, refers to the difference of each value from its own group mean. The assumption is that these should be independent for each value. That is, the error for one observation should not be related to the error for any other observation.

4.3.5 Non-parametric Methods in the Analysis of Variance:- Kruskal-Wallis Test

When the normality assumption and homogeneity-of-variance is violated, alternatives to the analysis-of-variance F test are Kruskal-Wallis test. The test is a non-parametric procedure for testing the equality of means in the one-factor analysis of variance when the experimenter wishes to avoid the assumption that the samples were selected from normal distribution (Ronald E. Walpole et al, 1993).

The Kruskal-Wallis test, also called the Kruskal-Wallis H test, is a generalization of the rank-sum test to the case of k>2 samples. The Kruskal-Wallis procedure is most often used to test whether c independent sample groups have been drawn from populations possessing equal medians. That is,

$H_0 : \quad M_1 = M_2 = M_3 = ... = M_C$

$H_1 :$ Not all M_j's are equal (where j = 1,2...c)

The Kruskal-Wallis procedure for testing H_0 is really quite simple, involving considerably fewer computations than the analysis of variance. The first step is to rank the entire set of $n = \sum_{i=1}^{k} n_i$ observations (from smallest to largest). If any values are tied, they are assigned the average of the ranks they would otherwise have been assigned if ties had not been present in the data. Then the rank sum, $R_{.j}$, is calculated for each sample.

The Kruskal-Wallis statistic, H, is defined as

$$H = \left[\frac{12}{n(n+1)} \sum_{j=1}^{c} \frac{T_j^2}{n_j} \right] - 3(n+1)$$

where n is the total number of observations over the combined samples,

i.e.,

$n = n_1 + n_2 + ... + n_c$

n_j is the number of observations in the j_{th} sample; j = 1,2,....c

T_j^2 is the square of the sum of the ranks assigned to the j_{th} sample

For any selected level of significance α, the decision rule would be to reject the null hypothesis if the computed value of H > χ_α^2 with c-1 degrees of freedom; otherwise, accept H_0.

4.3.6 Multiple Comparisons: Tukey's Test

The analysis of variance was used to determine whether there was a difference in the mean over several groups. Once differences in the means of the groups are found, it is important that we determine which particular groups are different (Douglas C. Montgomery, 1997).

The Tukey's test enables us to simultaneously examine comparisons between all pairs of groups. The procedure requires the use of $q_\alpha(a, f)$ to determine the critical value for all pairwise comparisons, regardless of how many means are in the group. Thus, Tukey's test declares two means significantly different if the absolute value of their sample differences exceeds

$$T_\alpha = q_\alpha(a, f) S_{\bar{y}_i \cdot}$$

$$\text{where } S_{\bar{y}_i \cdot} = \sqrt{\frac{MS_E}{n}}$$

4.3.7 Histogram

A Histogram consists of vertical bars constructed on a horizontal line marked off with intervals for the variable being displayed. The heights of the bars are proportional to the number of observations in that interval (William L. Carlson et al, 1997)

4.3.8 Pareto Charts

The Pareto chart is a bar chart that displays the frequency of defect causes. The bar at the left indicates the most frequent cause and bars to its right indicate causes in decreasing frequency. Using Pareto charts, the analyst can quickly identify the factors that are most often involved in process failure.

4.4 Data Collection

Six months' data (July - Dec 1999) was collected from the TPROTO database.

a) To minimize bias, data were collected only on lots in excess of 200 units. A small lot size may effect in two ways.

   i) No reject is found thereby resulting in 0 dppm (defective part per million) for that lot.

   ii) Rejects are found resulting in a relatively high dppm for that lot.

b) Data collection including following variables:

   i) Temperature, TOS (room), TLO (low), THI (high)

   ii) Tester (KLM53, KLM55, KLM57 and KLM58)

   iii) Type of defect (bin 4, 5, 6 ,7 and 8)

   iv) Quantity good (bin1,2,3 and 4)

   v) Input quantity

   vi) Output quantity

   vii) Yield = output quantity/ input quantity x 100%

   viii) Day of production (Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday)