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Using the Monte Carlo Simulation to Predict the Assembly Yield

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Abstract**—**Electronics Products that achieve high levels of integrated communications, computing and entertainment, multimedia features in small, stylish and robust new form factors are winning in the market place. Due to the high costs that an industry may undergo and how a high yield is directly proportional to high profits, IC (Integrated Circuit) manufacturers struggle to maximize yield, but today's customers demand miniaturization, low costs, high performance and excellent reliability making the yield maximization a never ending research of an enhanced assembly process. With factors such as minimum tolerances, tighter parameter variations a systematic approach is needed in order to predict the assembly process. In order to evaluate the quality of upcoming circuits, yield models are used which not only predict manufacturing costs but also provide vital information in order to ease the process of correction when the yields fall below expectations.

For an IC manufacturer to obtain higher assembly yields all factors such as boards, placement, components, the material from which the components are made of and processes must be taken into consideration. Effective placement yield depends heavily on machine accuracy and the vision of the system which needs the ability to recognize the features on the board and component to place the device accurately on the pads and bumps of the PCB. There are currently two methods for accurate positioning, using the edge of the package and using solder ball locations also called footprints. The only assumption that a yield model makes is that all boards and devices are completely functional.

This paper will focus on the Monte Carlo method which consists in a class of computational algorithms (information processed algorithms) which depends on repeated random samplings in order to compute the results. This method utilized in order to recreate the simulation of placement and assembly processes within a production line.

Keywords**—**Monte Carlo simulation, placement yield, PCB characterization, electronics assembly

I. Introduction

IC manufacturers have for some time, struggled with the imposed market trend to increase functionality of devices and at the same time miniaturize them, which is constantly challenging the assembly yield [1], [2]. This market trend has obliged circuit designers to decrease the pitch size *(distance between 2 adjacent leads)*, increase densification of the PCB, develop new printing paste mixtures and use advanced placement machines in order to obtain a high yield. Due to the complexity of this new process, the existence of error during the production process can not be tolerated, given that it would lessen the yield percentage, sacrificing the projected revenue for the product.

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Process parameters that affect the assembly include placement and board interaction across the production line. Placement yield consists on placement machine accuracy, substrate tolerances and the vision of the system. Effective placement yield also depends on the machines ability to recognize the features across the board and the component being picked and the accuracy to align the component on the bumps and pads of the printed circuit board. There are two methods which can be used for accurate positioning, the first method works with the edge of the package and the second which uses the solder ball locations or footprints across the board.

Placement machines use Fiducial on the board as a reference during the component placement procedure (Fig. 1). Any deviation in the location of the fiducials may affect the placement accuracy and subsequently yield. Also, deviations within pad location on the substrate may also affect the assembly yields and long term reliability of the assembly.

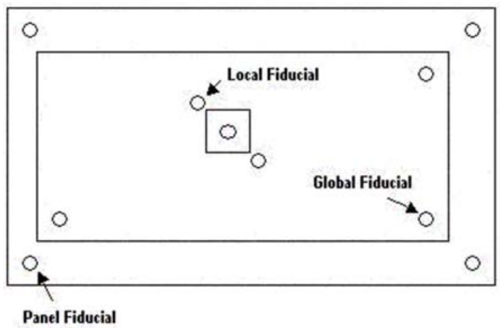

Fig. 1 Fiducial Marks on a Printed Circuit Board

For IC manufacturers to maximize the yield throughout this complex process, a Monte Carlo analysis is performed before the first production run. This computer analysis program projects the assembly yield output based on the current parameters set on the production line such as, size, pitch & thickness of electrodes, inter-chip distance, adhesive parameters and misalignments enabling all stacking parameters to be evaluated [3]–[5]. Within this study, the following objectives are attempted:

- Gain knowledge on the different processes that revolve around the production of an electronic component.
- Demonstrate the offset in pad location that exists between printed circuit boards of the same manufacturer.
- Run a Monte Carlo simulation in order to predict the area of coverage within a printed circuit board.

I. Methodology Used to Determine the Yield

The Monte Carlo based simulation approach is broadly used to simulate a process or a system whose parameter variations can be analyzed via probability distributions. The main components of a Monte Carlo simulation method includes a random number generator as a source of the random numbers and the generation of a probability distribution function for defining the various aspects of the system. A random number can be defined as a numerical quantity that is selected from a uniform distribution of numbers between some limits. Nevertheless, this simulation can not guarantee a precise solution to the problem, but the solutions obtained from the model are relatively close to the real solution.

This method is able to forecast the performance any given scenario, therefore it has become a very accepted tool within the industry, since engineers are able to observe the possible outcomes of certain production profiles without any actual change to the profiles that are currently in use. Once the method has delivered the outcome of the desired profiles, the data is inserted into probability distribution formulas that give engineers an insight on possible defects that may arise if the tested profile is applied to the current production line. This method has reduced time and costs when new components that require modifications to the production line are developed, since possible defects that may arise during the production are tackled before production even starts.

Within this model the random variable has to be identified and then use the random number to obtain a sample. We can define a random variable as a measurable quantity associated with an experiment. Variables however cannot be predicted and they can only acquire a value after the experiment has been conducted, which can then be used in the probability distribution.

The primary components of a Monte Carlo simulation method includes a random number generator as a source of random numbers uniformly distributed between 0 & 1, a probability distribution function (PDF) for defining the system, and sampling techniques for sampling the specified PDF. The yield calculation procedure consists of generating random numbers based on the characteristics of input variables which are normally distributed and using these numbers to simulate random pad locations and pad sizes. For a random variable with known distributions, its probability can be easily estimated using the probability density function or cumulative probability function.

Assuming the cumulative distribution of a random variable X is F(X), for any real number a, F(a) can be defined as the probability of X< a

$$F(a) = P\{X \le a\} = \int_{-\infty}^{a} f(X)\,dx \qquad (1)$$

We can infer from (1) that for any two real numbers a & b the probability when a < X < b is

$$P(a \le X \le b) = \int_{a}^{b} f(X)\,dx = F(b) - F(b) \qquad (2)$$

and a cumulative probability density function that has the characteristics of (3) and (4):

$$\lim_{a\to\infty} F(a) = \lim_{a\to\infty} \int_{a}^{\infty} f(x)\,dx = 1 \qquad (3)$$

$$\lim_{a\to\infty} F(a) = \lim_{a\to\infty} \int_{-\infty}^{a} f(x)\,dx = 0 \qquad (4)$$

From (3) and (4) we can get a random number F(x) which is uniformly distributed within (0,1), therefore first generate a number “r” from the uniform distribution and then let F(x) equal to r, so that we can obtain the value of x.

Using Monte Carlo’s random sampling we understand that X is a function of “y” making it a quality variable, while “x” is a function of several “y” which can influence the value of x. if these “y” follow the distribution then “x” should be normally distributed. If x is within a normal distribution, then the expected value will be the average of the expected sample, as well for the variance.

In this case, the experimental errors are a combination of several sources of error (pad location and pad size). We can conclude that the experiment should be normally distributed in order to apply the probability density function (PDF). A PDF of a random variable is a function that describes the density of probability at each point in the sample space or set of all possible outcomes.

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[\frac{-(x-\mu)^2}{2\sigma^2} \right] \qquad (5)$$

Normalizing the data with

$$Z = \frac{x-\mu}{\sigma}, \quad X = \mu + Z\sigma \qquad (6)$$

Once normalized each value will have the same opportunity to be picked and at the same time using this chart to convert the normal distribution into a uniform distribution (Fig.2).

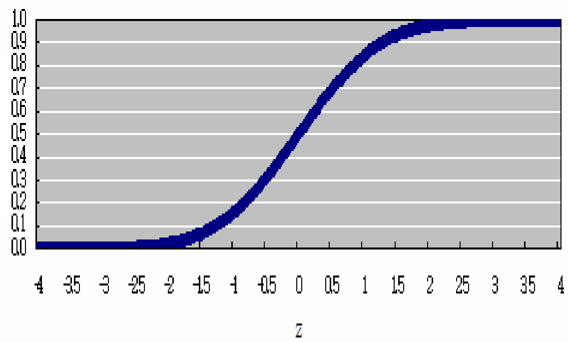

Fig. 2 Accumulative Probability of the Normal Distribution

II. PCB Characterization

In order to obtain the precise coordinate of the pad on the printed circuit board, a three-dimensional measuring machine had to be used. The machine had to be calibrated every time a new PCB was placed for measurements. The fiducial mark on the printed circuit board was set as the origin or (0,0). From the origin, the X and Y axis were shifted until the laser pointer was in the center of the pad that was chosen for the evaluation. Each measurement varied in 1 millimeter or a hundredth of a millimeter. The following measurements were obtained from the machine:

TABLE I The data obtained from the measuring machine

PCB #	X Coordinate	Y Coordinate
1	115.425	81.180
2	115.917	80.042
3	116.345	79.988
4	117.908	78.165
5	117.564	78.396
6	116.990	79.765
7	117.180	79.223
8	115.958	80.226
9	115.783	80.776
10	116.183	80.147
11	116.957	78.724
12	117.785	79.870
13	115.850	80.150
14	116.283	78.302
15	115.930	77.870
Mean	116.537	79.522
Std Dev	0.796364346	1.01143865

III. Crystal Simulation

Crystal Ball is spreadsheet-based application for predictive modeling which relies on Monte Carlo simulations. For this experiment, Crystal Ball version 7.2 was used on a computer running Windows XP and Microsoft Office 2003 (Fig. 3 and Fig. 4). The table presented on the previous page was inputted into Excel (Fig. 5). Once the data was in Excel, Crystal Ball was executed to run Monte Carlo simulations based on 10,000 trials. A normal distribution was used to analyze the values obtained from the trials since it not only clusters the data around the mean but enables us to obtain the probability and frequency of the happening of each event. The forecasted outputs and probabilities were then set to our defined area of coverage requirement, which in this case was 95%, discarding anything below 95% or above 100% (Fig. 5).

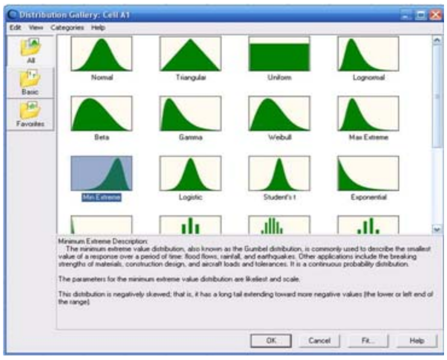

Fig. 3 Crystal Ball's Distribution Gallery Menu

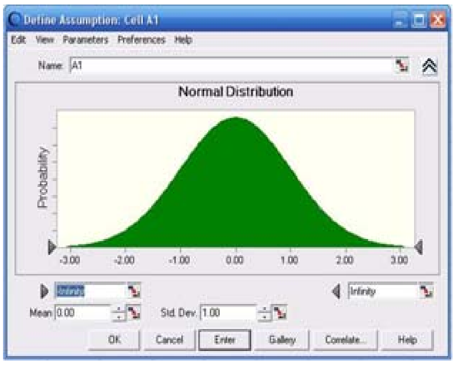

Fig. 4 Crystal Ball's Normal Distribution Parameter Setting Screen

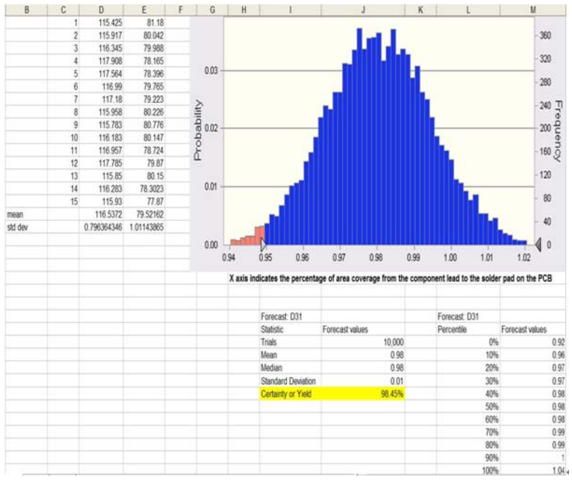

Fig. 5 Results Obtained from the simulations

IV. Recommendations

Based on the results from the simulations ran on the printed circuit boards some recommendations can be made regarding the yield percentage and parameters that might influence the percentage of coverage.

After running a simulation on 10,000 trials and setting our area of coverage percentage to 95% we were able to achieve a yield of 98.45%. Obtaining this high yield percentage on 10,000 components seems profitable, but when this setup is taken to a high volume production the numbers of defective components would rise significantly. In order to improve this yield percentage, processes such as component layout, solder paste mixture, size and shape of contact pads, the type of leads used and the reflow profile should be revised in order to optimize the entire process; where a second simulation should be made to ensure that the setup is suitable for high volume production.

V.Conclusion

In order to achieve high assembly yields proper selection of process parameters are vital to produce high volumes of products with minimum number of defects. Rework on components is not only expensive but can lead to reliability problems which in the end affect the sales volume, due to the loss of confidence that this mishap produces between vendor and client. It is clear that as technology develops, new manufacturers and suppliers will rise with competitive products which might reduce production costs, therefore including them in upcoming production lines; but if not observed meticulously during the first stages of the production run it may have devastating effects on a company's expected revenue.

Within this research, a concise analysis was made on the development of an electronic product. Due the wide scope if this subject, only the most relevant areas were discussed, focusing on the parameters that affect the assembly yield and how The Monte Carlo Simulation can be sought as an alternative in order to predict the assembly yield of a particular component. The Monte Carlo method proved to be efficient at predicting the assembly yield of our test subjects, making it a powerful utility which could be used within the Electronics Industry, since it not only has a shorter run time, but also has the capacity of distributing the probability of occurrence of each event among the normal distribution graph. With this advantage, decisions can be taken with confidence, since the output of the graph shows the range of different results for each forecast or certainty desired by the user, of achieving results within the specified range which in the end may lead to the development of higher quality components.

A determining factor that emerged during our research worth mentioning was the offset that occurs within the location of each solder pad. The ability of a printed circuit board manufacturer to precisely place every solder pad on a specific section within a printed circuit board or repeatability is one of the main issues of why a 100% area coverage may not be achieved. As stated previously, during the measurements that were taken from the 15 specimens, an offset of a millimeter or hundredth of a millimeter was present at all times. This slight deviation of millimeters is critical within a production line, given that the automated machines that work during the solder paste deposition and the assembly stages, guide themselves with the aid of the fiducial marks within a PCB. Any deviation in the location of the pad with respect to the fiducial mark is not corrected by the machine, affecting the placement accuracy and subsequently the yield. Also, deviations within pad location on the substrate may also affect the assembly yields and long term reliability of the assembly.

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