Climatic Reliability of Electronics:

Prediction of PCB Failure under Humidity using Predictive Analytics

A thesis submitted to the technical University of Denmark for the degree of doctor of philosophy in the department of mechanical engineering

By

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Abstract

This PhD project is supported by the IFD (Innovation Fund Denmark) through the ELMAC (Electronic Systems Manufactured for Climate) and by CELCORR (Centre for Electronic Corrosion) via the CreCon (Consortium for Climatically Reliable Electronics) at DTU. Humidity caused corrosion failures in electronics is an important contributor to the robustness and reliability issues due to several external and inherent factors related to electronics. External factors include wide-spread use of electronics today exposing them to all climatic conditions, while inherent factors include the multi-material use in electronics, miniaturization, and manufacturing process related contributions. Corrosion occurrence in electronics under humid conditions is a multi-parameter effects involving many factors. Hence, it is important to understand combined effects of various parameters and their relative importance in relation to the failure mechanisms. The motivation of this project is to investigate the possibility of using predictive analytics approaches based on statistical, probabilistic, and ML (machine learning) techniques to forecast PCB failures based on multiparameter experimental test data. Such approach not only provide models based on multi-parameters effects, but also can determine the relative contribution of different factors or multiple factors based on the statistical analysis. The research in this thesis also focused on the investigation of critical factor effects such as pitch distance, contamination level, voltage, temperature, humidity, contamination type, and their interactions on SIR (Surface Insulation Resistance) reduction and LC (Leakage Current), besides dendrite formation and ECM (Electrochemical Migration) on PCB surfaces under various corrosive conditions created of a combination of diverse factors/ levels.

Chapter 1 provides a background to the climatic reliability of electronics, the motivation and research objectives for this PhD project, and the structure of the current PhD thesis. Chapter 2 reviews critical factors influencing climatic reliability issues and failures on PCB surfaces and literature review. Additionally, PCB testing with common failure mechanisms and data analytics focusing on predictive analytics is described. Chapter 3 summarizes the materials, experimental works done in this thesis, and predictive methods are employed in the PhD project. Chapter 4 contains a summary of appended papers with highlights and important outcomes. The research results of investigations and predictions are brought in chapters 5-7 from research papers published in peer-reviewed journals or in the form of a

draft for publication in the journals. The first paper (chapter 5) investigates the critical factors' effect and their interactions to forecast leakage current (LC) and time to failure (TTF) due to ECM on PCB surfaces under humidity conditions with a focus on the first branch of predictive analytics, i.e., statistical analysis. The second paper (chapter 6) focuses on TTF prediction on PCBs under humidity conditions using probabilistic analysis as the second branch of predictive analytics. The third paper (chapter 7) concentrates on using ML algorithms as the third branch of predictive analytics and creating a comprehensive ML investigation for forecasting PCB failure and LC values based on the training input conditions mixed from five numerical and one categorical factor of experimental data results. Eventually, chapters 9-10 provide the overall discussion, conclusions, and suggestions for future works.

Overall, the principal results of this PhD project are categorized into three types of empirical investigations in three individual papers, each focusing on a separate branch of predictive analytics. Based on the advantages and disadvantages of each predictive model, one can select all or one of them according to the experimental dataset, which includes; the number of factors/levels/conditions, and also responses, limitations, and accuracy of prediction models. In addition, the investigations of this project thoroughly explained the mathematical simulation of the general leak current behavior, the importance and numerical influence of each changeable factor and their interactions on numerical responses (LC and TTF values), and the correlation of the responses at various corrosive conditions on PCB surfaces. An overall analysis of three approaches are provided in overall discussion section.