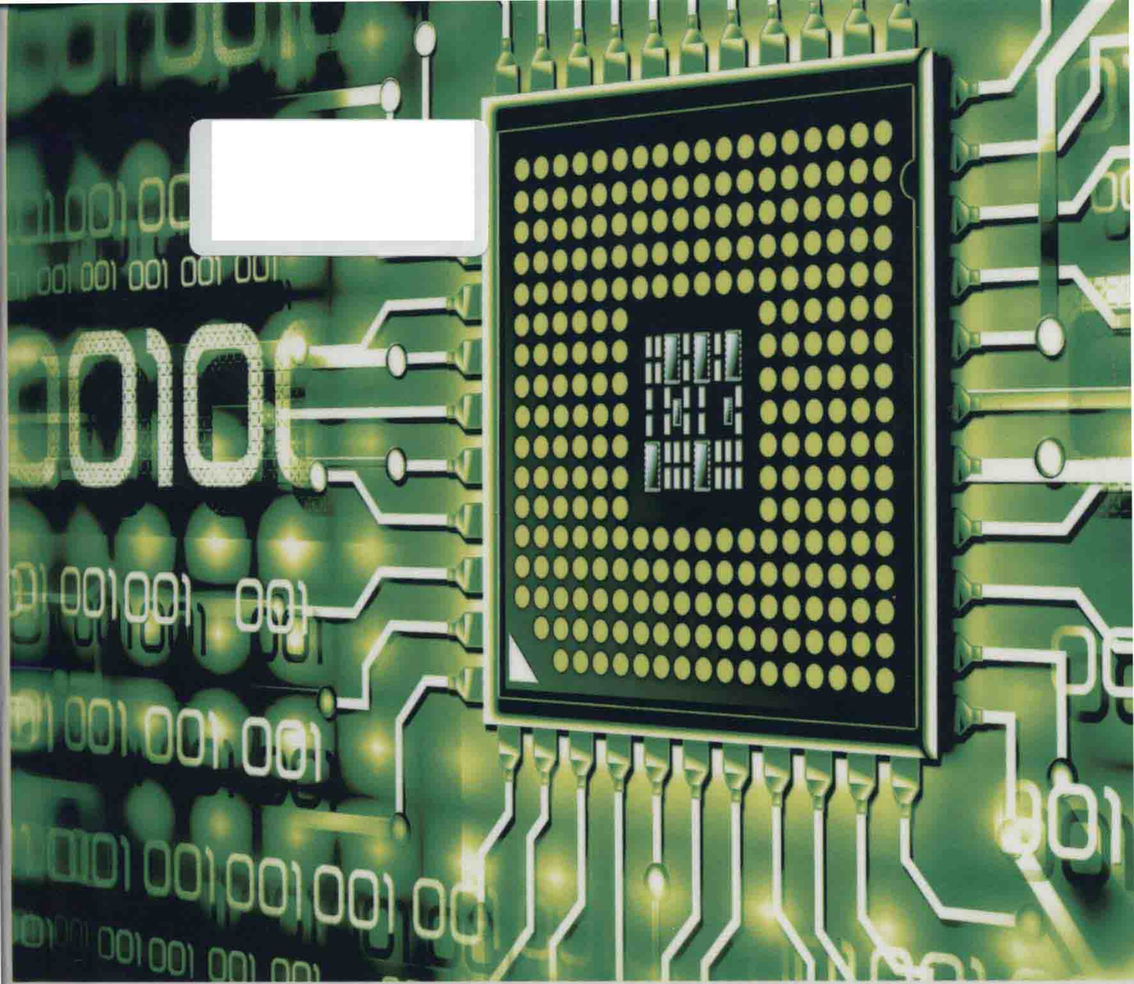

Embedded Mechatronic Systems 2

Edited by
Abdelkhalak El Hami
Philippe Pougnet

Analysis of Failures, Modeling, Simulation and Optimization

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Preface

Electronics are increasingly used in controlled and embedded mechanical systems. This leads to new mechatronics devices which are lighter, smaller and use less energy. However, this mechatronics approach which enables technological breakthroughs must take into account sometimes contradictory constraints such as lead-time to market and cost savings. Consequently, implementing a mechatronic device and mastering its reliability are not always entirely synchronized processes. For instance, this is the case of systems that function in harsh environments or in operating conditions which cause failures. Indeed, when the root causes of such defects are not understood, they can be more difficult to control. This book answers to these problems. It is intended for stakeholders in the field of embedded mechatronics so that they can reduce the industrial and financial risks linked to operational defects. This book presents a method to develop mechatronics products where reliability is an ongoing process starting in the initial product design stages. It is based on understanding the failure mechanisms in mechatronic systems. These failure mechanism are modeled to simulate the consequences, and experiments are carried out to optimize the numerical approach. The simulation helps to reduce the time required to anticipate the causes of these failures. The experiments help to refine the models which represent the systems studied.

This book is the result of collaborative research activities between private (big, intermediate and small businesses) and public sector agents (universities and engineering schools). The orientations of these research works were initiated by the Mechatronics Strategical Branch of the Mov'eo competitive cluster (*Domaine d'Action Stratégique*) to meet the need to have reliable mechatronics systems.

This book is directed at engineers and researchers working in the mechatronics industry as well as at Masters or PhD students aiming to specialize in experimental investigations, in experimental characterization of physical or chemical stresses, in failure analysis, and in failure mechanism modeling to simulate the consequences of causes of failure and wanting to use statistics to assess reliability. These subjects match the needs of the mechatronics industry.

It is organized into two volumes. Volume 1 looks at trials and multi-physical modeling of defects which show weaknesses in design and the creation of meta-models for optimizing designs. Volume 2 presents the statistical approach for optimizing designs for reliability and the experimental approach for characterizing the evolution of mechatronic systems in operation.

Chapter 1 of this volume discusses a methodology for carrying out highly accelerated life tests (HALT) in a humid environment. The principle is to subject the device under test (DUT) to humid air. The ability of the HALT chamber to vary the temperature while applying vibrations enhances the penetration of humidity into the DUT, especially in the case of a failure of water-tightness. Depending on the temperature, this humidity may be in the form of steam or frost on electronic circuit boards and highlight the weaknesses in the assembly or interconnections and failure of water-tightness. Electromagnetic disturbances are also sources of failures. Weaknesses in the design of circuits and components are checked by ensuring the electromagnetic compatibility (EMC) through a characterization of the disturbances produced and the emissions before and after the highly accelerated tests.

Chapter 2 describes how to conduct life tests on high-frequency power transistors under operational conditions. The originality of this test is to follow the performance of the component in an automated way over thousands of hours while applying electric and thermal stresses. The test examines high power components in pulsing mode and tracks deviations by *in-situ* static and dynamic electric characterizations. The lifecycle results obtained for high-power laterally diffused metal oxide semiconductor (LDMOS) transistors are presented.

Chapter 3 presents the methodology for analyzing failures of mechatronic systems. The advantages and disadvantages of different techniques of opening the resin and ceramic casings are described as well as the precautions to be used to preserve the operational and structural integrity of the component. The technique of detecting and locating defects by photon emission microscopy (PEM) is combined with the optical-beam-induced resistance change (OBIRCH) technique to guide the analysis and determine the cause of the failure. Four case studies of failure analysis are presented: a defective IGBT-power component after the test, a metal oxide semiconductor field effect transistor (MOSFET) damaged by the electrical overvoltage stress test, a GaN technology transistor damaged during reliability testing and a LDMOS component damaged during life test. The results of these analyses are presented, helping to identify the cause of the defects (X-ray analysis, electrical analysis, optical microscopy analysis, thermal analysis, photon emission analysis, transmission electron microscopy analysis).

Chapter 4 examines the phenomenon of thermal transfer linked to the dissipation of heat in a power module and its effects. During the assembly of a mechatronic module, defects can appear in the form of voids in the interconnection material (ICM). By trapping thermal energy, these defects are transformed into potential sources of failure in the module. The goal of this study is to determine the influence of such imperfections on reliability by using the maximum temperature parameters of the chip and the thermo-mechanical constraints at the interfaces as indicators.

Chapter 5 describes modeling using the finite element method of the behavior of electronic circuit boards which are stressed by temperature cycles, vibrations and electric loads. The electric, thermal and mechanical behavior of a mechatronic structure is presented. Details of two types of coupling of physical phenomena are given.

The first is strong coupling: it uses finite elements with all degrees of freedom necessary for an electro-thermo-mechanical study. The second is weak coupling: it consists of decoupling the three physical phenomena, with a sequential calculation. This method is applied to the electronic circuit board of an engine control unit and to a radar power amplifier. Understanding the mechanical behavior of electric circuit boards requires the modeling of several physical phenomena. A multi-physical model is presented which takes into account the interdependencies and interactions between various physical phenomena: electric, thermal and vibratory.

In Chapter 6, several methods are proposed to optimize the structure of mechatronic systems from a reliability point of view. These methods use know-how and skills in deterministic and stochastic modeling. The goal is to associate numerical modeling by the finite element method describing the physical behavior of the mechatronic system with a stochastic behavior model. The results of numerical modeling are used to build a meta-model by surface response. By using this meta-model, the level of control factors is adjusted, the sensitivity of the mechatronic system to sources of variability is reduced (noise factors) and the system's response to its target (objective) is determined.

Chapter 7 presents a method based on probabilistic approaches allowing the optimization of the design of embedded mechatronic systems taking into account uncertainties. These uncertainties are due to unknown properties of the materials, the geometric dimensions and the fluctuations of load. The deterministic optimization does not take uncertainties into account and does not ensure a reliable design. The rational process for optimizing embedded systems consists of considering the spread of uncertainties in multi-physical behavior (electrical, thermal, mechanical, etc.) by using a probabilistic model of the variables of input parameters. The reliability optimization is an approach which attempts to find the best design using a compromise between reducing the objective function (cost, weight, etc.) and ensuring reliability.

Chapter 8 presents a study of the reliability of a powerful radiofrequency amplifier made of gallium nitride components for

RADAR applications. The technology of the AlGaN/GaN high-electron-mobility transistor (HEMT) is studied. In order to determine the parameters which influence reliability, electric characterizations, ageing tests and physical analysis are combined. The results show that temperature is the most significant parameter determining ageing and that the gate contact is the most sensitive element. A component model integrating reliability from the design phase of the amplifiers is presented.

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