



Embedded Mechatronic Systems 2

Edited by
Abdelkhalak El Hami
Philippe Pougnet

***Analysis of Failures, Modeling, Simulation
and Optimization***

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Volume 2

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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 Strategic 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 AlGa_N/Ga_N 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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Contents

PREFACE	xiii
CHAPTER 1. HIGHLY ACCELERATED TESTING	1
Philippe POUGET, Pierre Richard DAHOO and Jean-Loup ALVAREZ	
1.1. Introduction	1
1.2. Load characteristics of the Super HAT equipment	3
1.3. Description of the Super HAT system.	4
1.3.1. System configuration	4
1.3.2. Control and monitoring system	5
1.3.3. Test profiles.	7
1.3.4. Utility operating conditions	8
1.4. Application.	9
1.4.1. Device under test.	10
1.4.2. Mounting of the DUT on the HAT vibration table	11
1.4.3. Testing for operating temperature limits	12
1.4.4. Testing for weaknesses due to rapid temperature changes	13
1.4.5. Testing for random vibration limits	14
1.4.6. Testing for limits due to the combined stresses of rapid temperature changes and random vibrations	16
1.4.7. Testing for limits due to the combined stresses of rapid temperature changes, random vibrations and moisture.	17

1.4.8. Testing for weaknesses to rapid thermal variations, random vibrations and moisture	17
1.4.9. Test for weaknesses in electromagnetic compatibility functions to thermal stresses	19
1.5. Conclusion	20
1.6. Bibliography	21
 CHAPTER 2. AGING POWER TRANSISTORS IN OPERATIONAL CONDITIONS	 23
Pascal DHERBECOURT, Olivier LATRY, Karine DEHAIS-MOURGUES, Jean-Baptiste FONDER, Cédric DUPERRIER, Farid TEMCAMANI, Hichame MAANANE and Jean-Pierre SIPMA	
2.1. Introduction	23
2.2. Aging microwave power electronic components under operational conditions	24
2.2.1. Definition of the specifications for the realization of the workbench	24
2.2.2. Applying stresses and measuring aging process parameters	26
2.2.3. <i>In situ</i> I-V static characterization in pulse mode	28
2.2.4. Description of the in situ S-pulsed parameters measures	31
2.2.5. Setup developed to study transistor behavior in extreme cold start conditions	31
2.3. Application to the study of microwave power transistors	33
2.3.1. Reliability study of microwave LDMOS 330 W power transistor in operational conditions	33
2.3.2. Accelerated aging by overvoltage on LDMOS 330 W transistor	35
2.3.3. Low temperature endurance tests on 330 W LDMOS transistors	41
2.4. Conclusion	47
2.5. Bibliography	47
 CHAPTER 3. PHYSICAL DEFECTS ANALYSIS OF MECHATRONIC SYSTEMS	 49
Christian GAUTIER, Eric PIERAERTS and Olivier LATRY	
3.1. Introduction	49

3.2. Equipment and methodology for analyzing failure in mechatronic systems	51
3.2.1. Opening ceramic and resin casings	51
3.2.2. Equipment and technique for detecting and locating defects	54
3.3. Analysis of physical defects.	57
3.3.1. Analysis of an IGBT component after a highly accelerated test	57
3.3.2. Analysis of a MOSFET component after electrical surge tests.	62
3.3.3. Analysis of a GaN50W–HEMT component after the reliability test	65
3.3.4. Analysis of an LDMOS component after a High Temperature Operating Life Test (HTOL).	72
3.4. Conclusion.	75
3.5. Bibliography.	76

CHAPTER 4. IMPACT OF VOIDS IN

INTERCONNECTION MATERIALS 79

Pierre Richard DAHOO, Malika KHETTAB, Christian CHONG,
Armelle GIRARD and Philippe POUGET

4.1. Introduction	79
4.2. Thermal transfer and thermo-elasticity	82
4.2.1. Conduction	83
4.2.2. Convection	83
4.2.3. Radiation	84
4.2.4. Equation of heat diffusion	84
4.2.5. Thermo-mechanics and thermo-elasticity	85
4.3. Description of the numerical method	91
4.4. Simulation of thermal and thermomechanical effects in the interconnection material of an electronic module.	93
4.4.1. Variation of the temperature and strain in the presence of a void defect	96
4.4.2. Maximum temperature as a function of the voltage or the size of the defect.	97
4.4.3. Study of the effect of void defects in size and position in the ICM	99

4.4.4. Study of the effect of the disposition of void defects in the ICM	100
4.4.5. Thermomechanical effects on materials of a mechatronic power module.	101
4.4.6. Analysis of results	103
4.5. Conclusion	103
4.6. Bibliography	104

CHAPTER 5. ELECTRO-THERMO-

MECHANICAL MODELING 107

Abderahman MAKHLOUFI, Younes AOUES and
Abdelkhalak EL HAMI

5.1. Introduction	107
5.2. Theory of electro-thermo-mechanical coupling	108
5.2.1. Heat dissipation equations	108
5.2.2. Electrothermal phenomena	112
5.2.3. Numerical formulation of electro- thermo-mechanical coupling.	114
5.3. Simulation of electro-thermo-mechanical behavior using the finite element method	120
5.3.1. Strong coupling of electro-thermo- mechanical modeling	120
5.3.2. Weak coupling of electro-thermo- mechanical modeling	122
5.4. Example of an electro-thermo- mechanical simulation of an HBT transistor.	123
5.4.1. General model of the HPA	123
5.4.2. Local model of the HBT transistor	128
5.5. Modal analysis of mechanical components.	131
5.5.1. Equations for the vibratory problem	131
5.5.2. Variational formulation	132
5.5.3. Approximation by finite elements.	133
5.5.4. Resolution in the frequency domain	135
5.6. Stochastic modal analysis of structures	136
5.7. Numerical identification of the elastic parameters of electronic components	137
5.8. Example of modeling and simulation of the vibratory behavior of mechatronic components.	139

5.9. Conclusion	148
5.10. Lists of abbreviations and symbols.	148
5.11. Bibliography	150
CHAPTER 6. META-MODEL DEVELOPMENT	151
Bouzid AIT-AMIR, Philippe PUGNET and Abdelkhalak EL HAMI	
6.1. Introduction	151
6.2. Definition of a meta-model	152
6.3. Selection of factors: screening	152
6.4. Creation of a design of experiment	155
6.4.1. Central composite (CC) designs.	155
6.4.2. Box–Behnken designs.	158
6.4.3. D-optimal designs	159
6.4.4. Doehlert designs	159
6.4.5. Designs using Latin hypercube sampling (LHS)	161
6.5. Modeling of the response surface: PLS regression and Kriging	163
6.5.1. PLS regression	163
6.5.2. Kriging.	165
6.5.3. Model comparison	168
6.6. Sensitivity analysis of the model: variance decomposition and Sobol criterion	171
6.6.1. Principle	171
6.6.2. Application of Kriging to a model	173
6.7. Robust design	174
6.8. Conclusion	179
6.9. Bibliography	179
CHAPTER 7. OPTIMIZING RELIABILITY OF ELECTRONIC SYSTEMS	181
Younes AOUES, Abderahman MAKHLOUFI and Abdelkhalak EL HAMI	
7.1. Introduction	181
7.2. Probabilistic and multi-physics modeling.	183
7.2.1. Structural reliability methods	185
7.2.2. Monte Carlo simulations method	189
7.2.3. Probabilistic modeling of a solder joint under thermal fatigue.	191

7.3. Reliability-based optimization methodology	198
7.3.1. Reliability index approach (RIA) for reliability-based optimization	200
7.3.2. Sequential optimization and reliability assessment (SORA) approach	201
7.3.3. Reliability optimization using a response surface	203
7.4. Reliability-based optimization of material layers of heterojunction bipolar technology (HBT) power modules	204
7.4.1. Finite element model of the HPA board	206
7.4.2. Formulation of the deterministic and reliability- based optimization problem for the HPA	207
7.4.3. Main results	211
7.5. Conclusion	213
7.6. Bibliography	214
 CHAPTER 8. HIGH-EFFICIENCY ARCHITECTURE FOR POWER AMPLIFIERS.	 217
Farid TEMCAMANI, Jean-Baptiste FONDER, Cédric DUPERRIER and Olivier LATRY	
8.1. Introduction	217
8.2. Main reliability parameters	218
8.3. Methodology	218
8.4. Aging tests	220
8.4.1. Test protocol	220
8.4.2. Impact of pulsed RF signal on the idle current I_{D0}	222
8.5. Other results	223
8.5.1. Performance monitoring	223
8.5.2. RF characterizations	224
8.5.3. Direct Current (DC) measurements	225
8.6. Origin of degradations: discussion	228
8.7. Physical analysis	229
8.7.1. Description	229
8.7.2. Visual inspection	230
8.7.3. Localization of defects by non-destructive techniques	231
8.7.4. Degradation microstructural analysis: TEM and FIB	232