RF and Microwave Measurements
device characterization, signal integrity and spectrum analysis

RF and microwave measurements are common to many disciplines and engineering areas: device and PCB characterization and testing, EMI and EMC, and signal integrity, during design, prototyping and production phases.

Measurement setups and procedures are more and more complex and demanding in terms of accuracy, performance, flexibility. Methods and techniques are often borrowed from other domains, including signal processing and probability theory.

Mastering the whole process has thus become challenging for the variety and breadth of the required skills and experience.

This book attacks the problem from two sides: reviewing circuits and transmission lines, signal analysis, random processes and statistics, and then considering the main experimental setup elements (cables, connectors and PCBs). Two chapters are for the Spectrum Analyzer and the Vector Network Analyzer, their settings, operation, calibration and verification.

The objective is supporting R&D and test engineers, academic staff and students: references were thoroughly examined and practical examples conceived to support theory and allow autonomous repetition and verification.

Andrea Mariscotti in 1992 began his service as an Italian army officer in charge of quality control and EMC testing of military devices, and since then continued working in the EMC sector, applied to equipment and systems, in particular for naval and railway applications: signals, signaling and telecommunication systems, rolling stock, electrical and power equipment.

Based for about 20 years at the University of Genova, he has lectured and carried out research in electrical system simulation, power quality, EMI/EMC, electrical and electromagnetic measurements, analog circuits and design of sensors and instrumentation.

Presently on leave, he cofounded ASTM, where he is responsible for measurement and testing services and the development of new products.

Mariscotti

RF and Microwave Measurements

First edition

ASTM   **ASTM**

RF and Microwave Measurements

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Preface

This is a book of applied theory. Basic theory and techniques are concentrated mostly in the first four chapters, where definitions, formulas and references are collected aiming at giving a thorough overview of the most relevant topics: circuit theory, material properties, transmission lines, signal analysis and spectral analysis, including random processes, probability and statistics. The central chapters 5, 6 and 7 deals with three important elements of setups and experiments: cables, printed circuit boards and connectors. The influence on the overall measurement, their modeling and characterization are discussed, keeping an eye on applicable standards. The last four chapters cover advanced aspects of scattering parameters, differential lines and mixed modes, and the use and performance of spectrum analyzer and vector network analyzer.

The subdivision of topics in an ordered and structured scheme was not trivial, trying to have the talk flowing naturally avoiding the rigidity of textbooks, that are however an example of clearness and organization: it's like when you step into your colleague's office asking for help and he/she knows where to start from with explanations and suggestions, that is not from the basic theory. On the other hand, the support we are looking for is partly theoretical and partly practical: it shall work, it shall be accessible and we need the possibility of demonstrating its correctness with a bit of theory. The first edition contains the result of a thorough literature search for reliable and accurate information with examples spread over the chapters.

A major challenge is that of achieving a balanced and comprehensive presentation of complex and articulated subjects such as signal integrity, high frequency design, interconnects, device characterization, metrology and electrical measurements, where hardware and instrument performance, calibration, statistics and signal processing have equal dignity and relevance. At some point a decision was taken, to go or not to go for a topic, to extend more or less a chapter, selecting references and examples, using cross-references and indexing to guide the reader through the chapters.

The experimental side is the true reason of this book. When it comes to do something, that shall work and that shall be the best solution to our problem, we face with the problem of spotting out and obtain the right materials and components, making trade-offs for what is desirable, what is available, and what is cheap enough, and then using them correctly.

During production personnel is well trained and procedures are optimized and executed routinely. During design and prototyping or when unusual requests come from other departments or customers, there may be concepts, methods, setups that we do

not master for several reasons. When considering modern technologies employed in complex products, the skills and background required to designers and technicians are rarely covered by a single university curriculum. Moreover, it is often necessary to possess previous knowledge and experience to select the most promising approaches and to decide what is needed in terms of instrumentation, methods, setups and support. For this reason the focus of this book is on applied theory, using e.g. statistics, signal and spectral analysis to evaluate the consistency and the uncertainty of measurements, to improve test setups, to use at best the available instruments, to judge on the applicability of a specific technique or if it is preferable to others. Simple rules of thumb are attractive, but may have short legs.

Often we have collected so many books, papers, application notes and then stuck on the implementation, trying to understand which formula is really applicable to our case and under which circumstances, which degree of approximation is tolerable, writing code and using experimental data for confirmation. We need to become soon experts to understand and discriminate the many sources of information, spotting out the original, the most reliable, those balancing theory and practice, where good reusable results are available. The process is time consuming and requires many trial-and-error attempts. In these moments we would like to ask our skilled and experienced colleague exactly the right question, straight to the problem, and not listening to a whole course back from the basics; for this reason the introductory material is kept to a minimum, conveniently pointing at good references.

This book is for engineers, technicians and students approaching problems of signal integrity, device characterization and product testing in the field of weak RF signals, mixing experimental techniques and data processing, relying on rigorous methods with only a fraction of the complexity of the theory behind, but with the backup of good references for further reading, possibly down to the page or section number, maybe niggling, but saving reader's time from generic citations. I hope to have hit the target, giving readers clear usable material.

Feedback on errors, questions, as well as suggestions for new problems and additional references are warmly welcome.

Chiasso, August 2015

Do, or do not. There is no try.

–Star Wars, The Empire strikes again

Contents

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