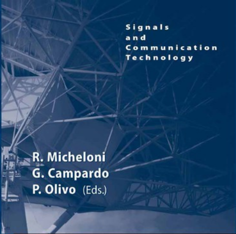

Signals and Communication Technology

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Memories in Wireless Systems

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Rino Micheloni · Giovanni Campardo ·
Piero Olivo (Eds.)

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ISBN: 978-3-540-79077-8 e-ISBN: 978-3-540-79078-5

Library of Congress Control Number: 2008930841

Originally published in Italian "Memorie in sistemi wireless", Edizioni Franco Angeli, 2005,
ISBN 13: 978-88-4646-779-9

Cover design: WMXDesign GmbH

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

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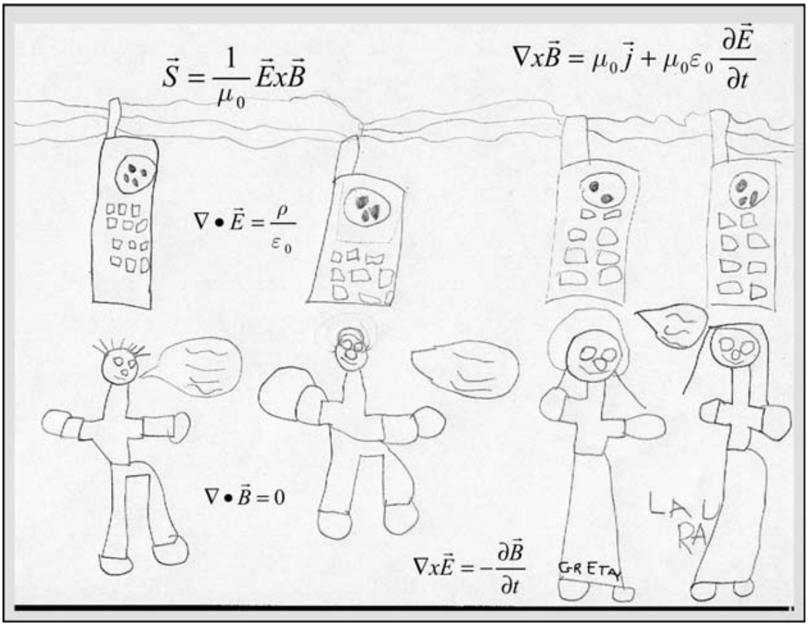

Original cover of the italian version. Laura and Greta Micheloni drawing

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About the Editors

Rino Micheloni (Senior Member, IEEE) was born in San Marino in 1969. He received the Laurea degree (*cum laude*) in nuclear engineering from the Politecnico di Milano, Milan, Italy, in 1994. In the same year, he was with ITALTEST, Settimo Milanese, Italy, working on industrial non-destructive testing reliability. In 1995 he joined the Memory Product Group, STMicroelectronics, Agrate Brianza, Italy, where he worked on an 8-Mb 3-V-only Flash memory, especially on the analog circuitry of the read path. He was the project leader of a 64-Mb 4-level Flash memory and, after that, he designed a 0.13-μm test chip exploring architectural solutions for Flash memories storing more than 2 bits/cell. Then he was the Product Development Manager of the NOR Multilevel Flash products for code and data storage applications. From 2002 to 2006 he led the NAND Multilevel Flash activities and the Error Correction Code development team. At the end of 2006 he joined Qimonda Flash GmbH, Unterhaching, Germany, as Senior Principal for Flash Design. Currently, he is with Qimonda Italy srl, Vimercate, Italy, leading the design center activities.

He is the author/co-author of more than 20 papers in international journals or conferences. He is co-author of Chapter 6 in "*Floating Gate Devices: Operation and Compact Modeling*", Kluwer Academic Publishers, 2004 and of Chapter 5 in "*Flash Memories*", Kluwer Academic Publishers, 1999. He is co-author of the books "*VLSI-Design of Non-Volatile Memories*", Springer-Verlag, 2005 and "*Memorie in sistemi wireless*", Franco Angeli, 2005. Mr. Micheloni was co-guest editor for the Proceeding of the IEEE, April 2003, Special issue on Flash Memory. He is author/co-author of more than 100 patents (79 granted in USA).

In 2003 and 2004 he received the STMicroelectronics Exceptional Patent Awards for US patent 6,493,260 "Non-volatile memory device, having parts with different access time, reliability, and capacity" and US patent 6,532,171 "Nonvolatile semiconductor memory capable of selectively erasing a plurality of elemental memory units" respectively. In 2007 he received the Qimonda Award for IP impact.

Giovanni Campardo was born in Bergamo, Italy, in 1958. He received the Laurea degree in nuclear engineering from the Politecnico of Milan in 1984. In 1997 he graduated in physics from the Universita' Statale di Milano, Milan.

After a short experience in the field of laser in 1984, he joined in the VLSI division of SGS (now STMicroelectronics) Milan, where, as a project leader, he designed the family of EPROM nMOS devices (512k, 256k, 128k and 64k) and a Look-up-table-based EPROM FIR in CMOS technology.

From 1988 to 1992, after resigning from STMicroelectronics, he worked as an ASIC designer, realizing four devices. In 1992 he joined STMicroelectronics again, concentrating on Flash memory design for the microcontroller division, as a project leader. Here he has realized a Flash + SRAM memory device for automotive applications and two embedded Flash memories (256k and 1M) for ST10 microcontroller family. Since 1994 he has been responsible for Flash memory design inside the Memory Division of SGS-Thomson Microelectronics where he has realized two double-supply Flash memories (2M and 4M) and the single-supply 8M at 1.8V. He was the Design Manager for the 64M multilevel Flash project. Up to the end of 2001 he was the Product Development Manager for the Mass Storage Flash Devices in STMicroelectronics Flash Division realizing the 128M multilevel Flash and a test pattern to store more than 2 bits/cell. From 2002 to 2007, inside the ST Wireless Flash Division, he had the responsibility of building up a team to develop 3D Integration in the direction of System-in-Package solutions. Now he is responsible for activities of CARD Business Unit, inside the Numonyx DATA NAND Flash Group.

He is author/co-author of more than 100 patents (68 issued in USA) and some publications and co-author of the books "*Flash Memories*", Kluwer Academic Publishers, 1999, and "*Floating Gate Devices: Operation and Compact Modeling*", Kluwer Academic Publishers, January 2004. Author of the book "*Design of Non-Volatile Memory*", Franco Angeli, 2000, and "*VLSI-Design of Non-Volatile Memories"*, Springer Series in ADVANCED MICROELECTRONICS, 2005, "*MEMORIE IN SISTEMI WIRELESS",* Franco Angeli Editore, collana scientifica, serie di Informatica, 2005.

He was the co-chair for the "System-In-Package-Technologies" Panel discussion for the IEEE 2003 Non-Volatile Semiconductor Memory Workshop, 19th IEEE NVSMW, Monterey, CA. Mr. Campardo was the co-guest editor for the Proceeding of the IEEE, April 2003, Special issue on Flash Memory.

He was lecturer in the "Electronic Lab" course at the University Statale of Milan from 1996 to 1998. In 2003, 2004 and 2005 he was the recipient for the "ST Exceptional Patent Award", respectively: US patent 5,949,713 titled "Non volatile device having sectors of selectable size and number", US patent 6,493,260 titled "Nonvolatile memory device, having parts with different access time, reliability, and capacity", and US patent 6,532,171, titled "Nonvolatile semiconductor memory capable of selectively erasing a plurality of elemental memory units". Mr. Campardo is a member of IEEE.

Piero Olivo was born in Bologna (Italy) in 1956. He graduated in electronic engineering in 1980 at the University of Bologna, where he received the PhD degree in 1987. In 1983 he joined the Department of Electronics and Computer Systems of the University of Bologna where he became associate professor of Electronic Instrumentation and Measurements in 1992. In 1994 he became full professor of Applied Electronics at the University of Catania (Italy). In 1995 he joined the University of Ferrara (Italy) where, since 2007, he is dean of the Engineering Faculty.

In 1986–1987 he was a visiting scientist at the IBM T.J. Watson Research Center. The scientific activity concerned several theoretical and experimental aspects of microelectronics, with emphasis on physics and reliability of electron devices and non-volatile memories as well as design and testing of integrated circuits. In particular he is author of the first paper describing and analyzing stress-induced leakage current (SILC) in thin oxides and of the first analytical theory of aliasing error in signature analysis testing techniques.

Introduction

If the inhabitants of the Western world were asked to name the technological innovation that most changed their habits, they would respond in a number of ways. Depending on their age and financial means, the answers might range from modes of transportation (aeroplane, train, or automobile) to information systems (PC, computing devices in general), from household appliances (refrigerator, washing machine) to systems of communication (telephone, radio, television). Actually, all the inventions mentioned deeply influenced the lifestyle habits of the 20th century and have become an integral part of our daily life, to the extent that we would be incapable of giving any of them up.

Few would probably have answered that the most significant invention is the mobile telephone. However, if they were asked which invention had managed to infiltrate their lives most rapidly, the answer would be nearly unanimous: over a short number of years, the mobile telephone has transformed from a status symbol for a select few to a system of the most widespread use, one that has accelerated the process of penetrating the market and the habits of the population at large to an extent that other technological innovations achieved only over the span of decades (e.g., automobiles, household appliances, television sets, etc.).

The astoundingly rapid penetration of mobile telephony into the market and into everyday habits has been accompanied by an equally swift (and necessary) technological evolution in the mobile telephones themselves: the reduction in size, the development of new services, the standard of reliability demanded, the short period of time required for the design of new systems, and the competition among the few manufacturers who have managed to survive in a fierce battle to win market share—all have driven over recent years technological development in the fields of integrated circuits, semiconductor memories, application software, and so on.

By limiting our observations to the field of semiconductor memories, which have now reached the complexity of outright electronic macrosystems, we can see how the evolution of mobile telephones has led to the rapid diffusion of nonvolatile memories such as flash, i.e., memories that can maintain information even in the absence of a power supply. The traditional flash NOR memories, used to store the code utilized by the mobile phone for its functioning, have been flanked by the flash NAND memories, which are utilized for the storing of images, music, etc.

The compact size of mobile phones then prompted the producers of integrated circuits and semiconductor memories to insert different components inside the same containers, thereby originating multichip systems containing different types of memory and control systems.

It is essential that the technological development of new electronic components be accompanied by advanced studies to optimize their software management, to be able to evaluate their functioning limits (which could invalidate the reliability of the system), and to implement specific error correction codes to guarantee the correct functioning of the system, even in the presence of malfunctions potentially arising over time.

In addition to the continuous development of these basic electronic components, scientific and technological research is currently being performed on nonvolatile memories based on innovative concepts in physics, as it is well understood that the technological evolution of the current flash memories cannot continue to infinity, and that over the span of a few years we will reach the technological limits that will render further increases in performance of these systems more and more costly and complex.

Thus, using these evaluations as our point of departure, we envisioned a book that would start with the mobile telephone taken as a complex electronic system, then would examine its various basic components and zero in on one in particular: the nonvolatile memory.

The book develops by following the thread of nonvolatile memory within the wireless system and aims to go in depth into several interdisciplinary issues that must be known and analyzed in order to guarantee not only the correct functioning of the system but also its reliability over the long term. An awareness develops of how the different disciplines—mathematics, mechanics, chemistry, computer science, and technology—all contribute to the creation of an industrial product.

The first chapter, "Hardware Platforms for Third-Generation Mobile Terminals," describes the main components of the cellular system, placing emphasis on the role of memories and their use inside the cell itself, taken as an example of the wireless system.

In the second chapter, "Nonvolatile Memories: NOR vs. NAND," the two types of flash memories, NOR and NAND, are compared, stressing the differences in their functioning in the memory cell.

The third chapter, "Nonvolatile Memories: New Concepts and Emerging Technologies," takes a look at the new types of nonvolatile memories that are starting to make their entry on the global market and that, it is believed, may replace flash memories in the near future.

The fourth chapter, "Memory Card," analyzes one of the primary applications of nonvolatile memories of the NAND type, in which the special characteristic of these memories in functioning as databanks is best utilized.

The fifth chapter, "Multichip," explores a new technology of assembling devices which enables the design of a complete system in a single package. This approach makes it possible to overcome many of the limits imposed by current technologies.

The sixth chapter, “SW Management of Flash Memories: Methods and Criticisms,” devotes itself to the problems of managing memories through software algorithms that best utilize the physical characteristics of the devices, with focus on the failure modes of the system and on the physics of the device itself.

The seventh chapter, “Error Correction Codes,” illustrates the ECC techniques that make it possible to identify the error and correct it in a flash memory. The use of a correction code implies knowledge of the principal failure modes in these types of devices.

In the eighth chapter, “Board Level Reliability,” the authors give a discussion of the different techniques and tests that enable control of the reliability of the component inserted inside the motherboard. This type of analysis involves knowledge not only of electronics but also of mechanics and chemistry.

Chapter Nine, “Reliability of Wireless Systems,” starts with a brief introduction to reliability techniques, then analyzes the primary types of failure of flash memories and of several electronic devices in the solid state, the aim of which is to show how the main reliability parameters can be determined.

The last chapter, Chapter Ten, “Reading a Datasheet,” describes a datasheet of a stacked device composed of several different memory types. The description illustrates the meaning and the genesis of the main parameters that characterize the different memories.

Our wish here is to contribute to the identification of some basic problems that cannot be disregarded when a system is being prepared for production and industrialization.

We would like to take this opportunity to thank all the authors who contributed to the drafting of the chapters in this book for their helpfulness and cooperation.

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Chapter 1
Hardware Platforms for Third-Generation Mobile Terminals

D. Bertozzi and L. Benini

1.1 Introduction

The development of the Internet has allowed access to multimedia content for an increasing number of users. Desktop PCs or laptop computers have been the traditional access terminals to this kind of information. However, the evolution of technologies for wireless network connectivity (e.g., IEEE Wireless LAN 802.11 standards, GPRS, third-generation mobile telephony) has paved the way for high-speed Internet and multimedia content access even for portable devices such as handheld computers and media-enabled mobile phones.

Consider, for example, *i-mode*, the wireless Internet access service of DoCoMo (Japan's largest mobile carrier), which plans to make the functionality offered by its mobile terminals even more pervasive: it ranges from traditional mobile telephony services, e-messaging, gaming, and Internet access to more advanced services such as bar code reading, audio/video multimedia streaming, payments, self-certification documents, remote control of home appliances or of electromechanical devices, and the purchase of tickets [1]. In essence, this is an embodiment of the concept of ubiquitous computing, where networked electronic devices are integrated at all scales into everyday objects and activities to perform information processing [2].

The development of new technologies for network access and the extension of services made available to mobile terminals pose tight computation requirements to these latter devices, in order to support new functionalities and to improve the quality of offered services [3].

One representative case study is the evolution of standards for video sequence encoding. Since the introduction of the H.261 standard in 1990, more advanced standards have been introduced: MPEG-1 video (1993), MPEG-2 video (1994), H.263 (1995, 1997), and MPEG-4 visual (1998). This development was driven by advances in compression technology and by the need to adapt to new applications

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R. Micheloni et al. (eds.), *Memories in Wireless Systems*,