

Preface

Complementary metal-oxide semiconductor (CMOS) technology is the leading electronics technology and will continue to be for the next few years. The metal-oxide-semiconductor field-effect transistor (MOSFET) is the basic building block in CMOS technologies and, as a consequence, the predominant device of integrated circuits. Therefore, MOSFET modeling plays an important role in interfacing the circuit design community with the device and technology community.

In order to be of practical usefulness for circuit designers, MOSFET models should be compact, *i.e.*, they should provide efficient and accurate algorithms to calculate charges, currents, and their derivatives. The compact modeling of MOS transistors for integrated circuit design has, for many years, been driven by the needs of digital circuit simulation. However, the trend which started in the late 1970's toward mixed analog-digital design generated the necessity for MOSFET models appropriate for analog and radio-frequency (RF) design as well. As a result, two types of advanced models are currently considered as adequate for circuit analysis and design, inversion charge and surface potential-based models. In the former approach, currents and charges are expressed in terms of the inversion charge densities at the source and drain ends of the transistor channel. In the latter, drain current and charges are related to the surface-potential at the ends of the channel.

This book provides both an overview of the basic physics theory required to build compact MOSFET models and a unified treatment of inversion-charge and surface-potential models. The text presents a fresh view of compact modeling, having completely abandoned the regional modeling approach. Regional models are presented as asymptotic cases of the all-region model, with the main objective of developing the understanding of the reader regarding transistor operation in that particular region. Compact expressions for hand analysis or for automatic

synthesis, valid in all the operating regions, are presented throughout the book. Most of the accurate expressions for computer simulation used in the new generation compact models are derived.

The book starts with a short introduction to MOSFET transistor modeling. Chapter 2 presents the two- and three-terminal MOS structures. Because it forms the basis of MOS compact models, the equivalent capacitive circuit of the MOS structure is carefully derived. A rigorous definition of pinch-off based on charge is given. Chapter 2 includes a thorough treatment of the unified charge control model (UCCM) which is at the center of the so-called charge-based models. The long-channel MOSFET theory is the subject of Chap. 3. Compact drain current models based on either surface potential or inversion charge are rigorously derived from the exact Pao and Sah double-integral formula. The chapter finishes with the introduction of a current-based model appropriate for design and parameter extraction.

In Chap. 4, the basic long-channel theory is extended to obtain practical compact models. Of particular relevance is the definition of saturation in terms of charge. Several small-dimension effects are presented and compact models are developed for them. Chapter 5 deals with stored charges and capacitive coefficients, taking into account short-channel effects. The complete small-signal model for quasi-static operation is presented.

The book strongly emphasizes the modeling of fluctuations, introducing a unified approach for both space (matching) and time (noise) fluctuations. Chapter 6 is dedicated to mismatch modeling and Chap. 7 aims at giving the reader an in-depth understanding of thermal and low-frequency noise modeling.

Non-quasi-static models for high-frequency applications are developed in Chap. 8. Compact models for gate and bulk currents originating from tunneling and high-field effects are developed in Chap. 9. Advanced MOSFET structures with their specific models are presented in Chap. 10. A simple but accurate procedure for parameter extraction is introduced in Chap. 11. The approaches taken by the developers of the main next generation compact models are summarized in Chap. 12. Finally, some fundamental concepts essential for the

development of the theory behind MOS transistors are summarized in the appendices.

This textbook has been organized to fulfill the needs of several types of audience. It is intended as a key reference on MOSFET modeling for graduate courses as well as senior level courses. For short courses, different selections of topics are recommended. A course emphasizing general principles should be based on Chaps. 1 to 5. A course for digital designers may cover Chaps. 1 to 6 and Chap. 9, plus selected sections from Chap. 10. Since RF circuits are the most demanding regarding models, a course for RF designers should cover the complete book, with the possible exception of Chap. 10 on advanced MOS structures.

The authors would like to acknowledge those individuals who contributed to the writing of this book and to the research on which it is based. We are very grateful to Professor Chih-Tang Sah, who kindly requested that we write this book. A book chapter about the all-region one-equation MOS transistor that we wrote several years ago was the first step on this path. We are indebted to Professor Edgar Sánchez-Sinencio, who invited us to write that chapter.

We are also very grateful to our former and current students who developed the research on MOS modeling: Dr. Ana Isabela Araújo Cunha, who made the first and fundamental contributions to the charge-based modeling approach in our group; Dr. Oscar da Costa Gouveia Filho, who developed the computer-implemented model, the Advanced Compact MOSFET (ACM) model; Dr. Alfredo Arnaud, who started our work on the unified modeling of fluctuations (noise and mismatch) and its application to low-power circuit design; Hamilton Klimach, who has been developing the modeling and characterization of mismatch in MOSFETs; Viriato Correa Pahim, who contributed to the comparison between the inversion charge and surface potential approaches and also to noise modeling; Márcio Bender Machado, for improving the parameter extraction methodology.

We thank Dr. Siobhan Wiese, who reviewed the text to reduce the distance from our English to the language of her homeland. We are also very grateful to Paula Chakkour for preparing the figures.

Finally, the support of CNPq and CAPES, Brazilian agencies for scientific development, was invaluable to the research in our laboratory that resulted in this book.

Florianópolis, April 2006

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