Preface

Due to the huge challenges in the continuous scaling of technology, there is a need to search for alternatives that are compatible with CMOS and can provide high performance in nanoscale dimension, especially in memories due to the enormous data storage required for many applications. Memristor-based technology offers a feasible solution for post-CMOS memories and reconfigurable analog modules, which are essential in modern electronics and systems-on-chip (SOC). The history of memristor goes back to 1971 and 1976 when L. Chua, the father of nonlinear circuits, postulated the existence of passive circuit elements and their promising applications. Recently in 2008, HP Lab recognized practically the first memristor based on nanoscale titanium dioxide films though their Nature paper. Thus, mem-elements such as memristor, memcapacitor, and meminductor have become very vital components in many applications, due to their unique behaviors which cannot be obtained using other conventional elements, so modeling of these elements has become necessary.

This book tries to study the modeling and analysis of these elements in analog and digital designs as well as their new fundamentals in the circuit theory. The literature survey includes the main properties of memristor, mathematical representations (ideal, generic, and extended), physical models, types, and some applications. A generalized mathematical class of mem-elements are discussed and validated through different emulator circuits with experimental results. The concept of fractional-order elements have been extended to cover the memristor model with its basic characteristics such as step and sinusoidal responses.

Memristor-based oscillators are considered one of the nonlinear analog blocks required for many applications such as chaotic memristor oscillators and artificial neuron networks. Realizations of memristor-based oscillators have been discussed via replacing resistors with memristors to achieve oscillation, or by replacing capacitors with memristors to construct relaxation reactance-less oscillators. The advantages of such oscillators are related to low frequency, nanoscale, and simple designs and can be used in neuromorphic systems. Different topologies of memristor-based relaxation oscillators have been discussed, either symmetric or asymmetric types, with analytical formulas of oscillation frequency and conditions for oscillations derived. The analyses of these oscillators are introduced with their numerical simulations, and verified using PSPICE circuit simulations showing great matching. Moreover, many fundamentals are also discussed such as the effect of boundary dynamics, series and parallel connections, as well as power analysis in memristor-based circuits.

Recently, there are huge concerns regarding memristors in digital signal processing (DSP) circuits to enhance the performance and realize very high density nonvolatile memories in neural networks. This can be achieved by mapping the high/low logic into the memristors' high/low resistances. Recently, the potential to divide the memristance levels to build multilevel digital circuits, such as ternary and redundant circuits, are discussed. The concepts have been initiated by designing a half-ternary adder based on the memristor, then the concept is generalized for redundant half adder, full adder, and N-bit adder circuits. The advantages of such circuits is that the speed is independent on the operand, and parallel processing can be handled efficiently. Moreover, a general approach to build digital functions using mixed memristor-transistor circuits are investigated, such as multipliers.

Similarly, the basic definitions of memcapacitor and meminductor are introduced with their step response with the settling time formulas, sinusoidal response, power and energy calculations, and the effect of boundary dynamics. Then, the boundary dynamics under sinusoidal excitations are used as bases to analyze any periodic signal by Fourier series expansion. Moreover, the analytical analyses of series and parallel connections as well as resistive-less memcapacitor-based relaxation oscillator are discussed with closed-form expressions for oscillation frequency and conditions for oscillation. Different memcapacitor and meminductor emulators are summarized with their mathematical modeling, numerical simulation, and verified using PSPICE simulations.

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