Preface

Circuit theory is a discipline at the crossroad between physics, mathematics and system theory and provides basic knowledge in various fields of engineering, such as electronic devices and circuits, signal processing, control systems. The circuit theory core is the concept of *model*, i.e., a mathematical description of a physical system. Circuit theory treats circuits with a field-less approach and, contrary to general electromagnetic theory, neglects the electromagnetic propagation.

Circuit theory was developed later than electrical circuits, whose origin (neglecting the Greek discover of static electricity) dates back to the end of XVIII century. The first circuit theory laws were provided in the middle of XIX century and, up to the middle of XX century, the development of circuit theory was basically related to electrical circuits. During World War II, circuit theory received a strong boost due to the influence and growth of disciplines such as system theory, automatic controls and electronics. With the development of transistors and computers, the realization criteria and the potentialities of circuits underwent deep changes, concerned with both design (the semiconductor miniaturization made it possible to conceive ever more ambitious, complex and low-cost circuits) and the growing corpus of knowledge that circuit theory was called to provide and to rationalize. The devices made available by technology were described by models, first of elementary devices, such as transistors, and subsequently of circuit parts to be used as *building blocks* in broader architectures. The detailed behavior of the devices inside these blocks became unessential for the user and, as such, usually ignored.

Over the years, the need of both designing increasingly complex circuits (largely containing nonlinear devices) and checking their behaviors before concretely realize them required more and more the use of computer numerical simulations. In this perspective, the use of models is essential to provide to the computer a *systematic description* of the circuit structure, together with the electrical properties of its components; furthermore, models contributed to the formalization of *methods* suitable to be mapped into mathematical algorithms, in particular, for the treatment of large-size systems of algebraic equations and of systems of ordinary differential equations. The numerical solutions provided by computers in shorter and shorter

times made it possible to study complex circuits also in the absence of an analytical solution.

The circuit theory development had repercussions also outside the circuit field, in areas seemingly far from circuits, but where experimental observations displayed a strong similarity to physical behaviors observable in circuits. This led to formulate equivalent circuit models mimicking the observed phenomena. When World War II was still in full swing, for example, Hodgkin and Huxley formulated their circuit model for neurons, now head of a family of models.

In our vision, a circuit theory course must systematically show ideas and methods suitable to study both linear and nonlinear circuits, either passive or active. The presentation of concepts and fundamental methods of analysis must aim not only to allow their application in today's problems, but also to highlight their meaning and potential as tools to understand and address future developments. These needs were clearly expressed during the '60s of the last century, when Charles Desoer and Ernest Kuh adopted them as guidelines for their treatise "Basic Circuit Theory", which became a classic for university education. In 1969, at University of Genoa, Giuseppe Biorci adopted this text (in the original English version) for his course, and in 1972 he was the Editor of its Italian version. Among the university texts written with similar motivations in the following years, it should be definitely mentioned "Linear and Nonlinear Circuits", written by the previous authors and by Leon Chua about twenty years later. More recent books focused on circuits have downsized, in our opinion, this character. Even if the university programs strongly changed in the last decades, giving in some cases a larger space to information at the expenses of knowledge, there is still need of books providing not only a solid background to all students, but also a broader view to the most motivated among them. We strongly believe that circuit theory is a highly educational discipline, not only for Engineers. Indeed, students learn a quite large set of tools and, when dealing with a specific problem, they have to decide what subset of tools can be (or has to be) used to solve it. In our opinion, this capacity of solving non-trivial problems should remain one of the main elements of the scientific cultural baggage. It can certainly be aided and made more powerful by many practical skills, but cannot be replaced by them.

With these guidelines in mind, this book is structured in *multiple reading levels*: each part is split into two chapters (basic level and advanced level), with two independent levels of reading. Moreover, in the advanced level some suggested shortcuts provide simplified reading paths, left to the reader's choice. The basic chapters are aimed at newcomers to circuit theory, especially students taking a first course in the subject. Their organization is largely based on the experience ripened through a one-semester course, taught for several years, first at the Polytechnic University of Milan and then at the University of Genoa. Our goal with these parts is to explain the mathematics needed to handle circuits as clearly and simply as possible, and to show how it can be used to analyze/understand how a circuit works, also through many worked examples. A peculiar feature of this book is its emphasis on examples, showing how the proposed methods can be applied. The advanced chapters are aimed at both basic-level university students driven by

curiosity—in the belief that curiosity is the main driver for studying and learning—and higher-level students, up to Ph.D. students and young researchers that want to find a complete treatment of many mathematical aspects related to circuits. The theory is developed systematically, starting with the simplest circuits (linear, time-invariant and resistive) and providing food for thought on nonlinear circuits, potential functions, linear algebra, geometrical interpretations of some results. This is the subject of this volume. Circuits characterized by time-evolution/dynamics will be treated with the same spirit in a second volume. In our opinion, the multiple reading levels help teachers to adapt their course to best meet students' needs and background. In all cases, students should be assigned homework from the problems at the end of each chapter. They could also do computer projects based on circuit simulators and/or build real circuits during lab activities, e.g., to reproduce and check the results of some of the proposed examples. These aspects are left to the teacher experience and availability.

We are indebted to our friend Lorenzo Repetto, who carefully revised the preliminary version of this book reporting bugs and providing detailed comments, many of which were included in the present volume. We also want to remember our colleague and friend Amedeo Premoli, who passed away in 2014 and who shared our vision of circuit theory. The structure of this book reflects at least in part many discussions had in the past with him.

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February 2017   Marco Storace

Springer

Linear and Nonlinear Circuits: Basic & Advanced
Concepts
Volume 1
Parodi, M.; Storace, M.
2018, XXI, 273 p. 309 illus., 2 illus. in color., Hardcover