BALANCED MICROWAVE FILTERS
WILEY SERIES IN MICROWAVE AND OPTICAL ENGINEERING

Professor Kai Chang, Editor
Texas A&M University

A complete list of the titles in this series appears at the end of this volume.
BALANCED MICROWAVE FILTERS

Edited by
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To our families
Anna, Alba, and Arnau
Kai and Haide
Huizheng and Yi Hang
Carmen, Marta, Santos, Juan, and Lola

The editors would like to acknowledge the effort of many people directly or indirectly involved in the preparation and writing of this book, not only the chapter contributors but also the members of their respective groups, without whom this book had never been written.
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Differential, or balanced, transmission lines and circuits have been traditionally applied to low-frequency analog systems and to high-speed digital systems. As compared with single-ended signals, differential-mode signals exhibit lower electromagnetic interference (EMI) and higher immunity to electromagnetic noise and crosstalk. Consequently, a better signal integrity and a higher signal-to-noise ratio (SNR) can be achieved in differential systems. These aspects are especially critical in modern digital systems, where logic signal swing and noise margin have dramatically decreased and hence are less immune to the effects of noise and EMI. However, differential systems are implemented through balanced circuits and transmission lines (interconnects), representing further design and fabrication complexity as compared with single-ended systems. For this main reason, in radiofrequency (RF) and microwave applications, unbalanced structures have dominated the designs for decades, still being more common than differential circuits. Nevertheless, recent technological advances are pushing differential circuits into the RF and microwave frequency domain, and balanced lines and devices are becoming increasingly common not only in high-speed digital circuits but also in modern communication systems.

Despite the inherent advantages of differential signals over their single-ended counterparts, in a real scenario, perfect circuit symmetry cannot be guaranteed, and the applied signals may exhibit certain level of time skew. Therefore, the presence of common-mode noise due to cross-mode coupling (from the differential signals of interest) is almost
unavoidable. This common-mode noise is the source of most of the radiation and EMI problems in differential systems and may degrade the desired differential signals. Therefore, the design of differential lines and circuits should be preferably focused on suppressing the common mode and, at the same time, preserving the integrity of the differential mode within the frequency range of interest.

The increasing research activity devoted to the design of common-mode suppressed balanced transmission lines and microwave circuits (especially filters) in the last decade has motivated this book proposal. Filters are key components in any communication system, and the fact that balanced systems are increasingly penetrating into the high-frequency domain has focused the attention of many microwave researchers working on planar passive components on the design of balanced microwave filters, the main topic of this book. Efficient common-mode suppression preserving the integrity of the differential signals, compact dimensions, wideband and ultra-wideband differential-mode filter responses, multiband functionality and the implementation of more complex devices (e.g., balanced diplexers, power dividers, etc.) are some of the challenging aspects covered by this book. The subject is so wide and the research activity is so intense that this book has been conceived from contributions by the main relevant researchers and groups worldwide working on the topics covered by the different book chapters.

After an introductory chapter (Part I of the book), devoted to the fundamentals of balanced transmission lines, circuits, and networks, the book has been structured by grouping the chapters in further four parts. In Part II, the main strategies for common-mode suppression in balanced transmission lines are reviewed (Chapter 2). It is also shown in this part that these common-mode rejection filters can be applied to enhance the common-mode rejection level of balanced filters with limited common-mode suppression efficiency (Chapter 3).

Part III of the book is focused on the design of balanced filters exhibiting wideband and ultra-wideband differential-mode responses with inherent common-mode rejection. Several strategies to achieve this challenging objective (i.e., the intrinsic and efficient suppression of the common mode over the wide or ultrawide differential-mode transmission bands) are reviewed. The general idea behind the different considered approaches is the conception of filter topologies able to provide the required wide or ultra-wideband differential-mode responses (subjected to certain specifications) and, at the same time, efficient common-mode suppression in the region of interest. This selective mode transmission/suppression is typically achieved by using symmetry
properties and topologies providing opposite behavior for the differential (passband) and common (stopband) modes. Typically, circuit elements insensitive to the differential mode, but providing controllable transmission zeros for the common mode, are used. The different studied approaches/structures include branch-line topologies (Chapter 4), coupled line sections (Chapter 5), T-shaped structures (Chapter 6), multilayer and defect ground structures (Chapter 7), signal interference techniques (Chapter 8), multi-section mirrored stepped-impedance resonators (Chapter 9), metamaterial-inspired resonators (Chapter 10), and slotline resonators (Chapter 11).

In Part IV, several strategies to achieve narrowband and dual-band differential-mode filter responses with inherent common-mode suppression are reviewed. The challenge here is to achieve the maximum possible common-mode suppression covering the differential-mode band, or bands. Strategies based on coupled resonators implemented in planar technology are reviewed in Chapters 12 and 13, whereas in Chapter 14, dual-band balanced filters based on substrate integrated waveguide (SIW) technology are introduced.

Finally, in Part V of the book, different common-mode suppressed balanced circuits are studied for completeness. This includes power dividers/combiners (Chapter 15) and equalizers (Chapter 16).

To end this preface, the book editors would like to mention that the contents of this book have been determined in order to provide a wide and balanced overview of the international activity and state of the art in the field of balanced microwave filters and related topics. Nevertheless, the designated contributors for the different chapters have been given full freedom to conceive and structure their respective assigned chapters at their convenience. For this reason, and because the different book chapters are self-sustaining for easy reading, some (but few) overlapping between different parts of the book has been accepted by the book editors. Some aspects related to the terminology may also vary from chapter to chapter due to the same reason. It is the editors’ hope that the present manuscript constitutes a reference book in the topic of balanced microwave filters and some other passive devices and that the book can be of practical use to students, researchers, and engineers involved in the design/optimization of RF/microwave components and filters.

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PART 1

Introduction