Meta-Smith Charts and Their Potential Applications

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Danai Torrungrueng
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ABSTRACT

This book presents the developments and potential applications of Meta-Smith charts, which can be applied to practical and useful transmission line problems (e.g., *metamaterial* transmission lines and *nonreciprocal* transmission lines). These problems are *beyond* the capability of the standard Smith chart to be applied effectively. As any RF engineer is aware, a key property of the Smith chart is the insight it provides, even in very complex design processes. Like the Smith chart, Meta-Smith charts provide a useful way of visualizing transmission line phenomenon. They provide useful physical insight, and they can also assist in solving related problems effectively. This book can be used as a companion guide in studying "Microwave Engineering" for senior undergraduate students as well as for graduate students. It is also recommended for researchers in the RF community, especially those working with periodic transmission line structures and metamaterial transmission lines. Problems are also provided at the end of each chapter for readers to gain a better understanding of material presented in this book.

KEYWORDS

Smith Chart, Meta-Smith Charts, transmission line, metamaterial transmission line, nonreciprocal transmission line, periodic transmission line structure, exponentially tapered nonuniform transmission line, conjugately characteristic-impedance transmission line, bi-characteristic-impedance transmission line, negative characteristic resistance, nonnegative characteristic resistance, RF circuit

This book is dedicated to
imagination and creativity.

The constant support of my family,
in particular my mom and dad,
is deeply appreciated.

Contents

Foreword I

Metamaterial microwave circuits and related printed structures have gained significant interest in recent years. Their wave slow-down properties have led to smaller matching circuits, microwave filters, feed networks and antenna arrays. Nonreciprocal propagation is another characteristic in some of these structures. With the growing interest in using metamaterials, Smith charts that can be used for designing related RF components are badly needed.

This book is a well-written text with useful problems at the end of each chapter to serve as a guide for students and instructors in using the proposed meta-charts (appropriately meaning the next-chart or after-chart upon translating the Greek word meta). The book presents meta-charts for exponentially tapered (varying characteristic impedance as a function of position along the transmission line), nonreciprocal lossless, and nonreciprocal lossy transmission lines, among others. Several applications are given, including the standard single and double stub tuners.

This is a well-written and easy-to-follow book. With the increasing use of metamaterials in design, it can be an important companion to any microwave engineering text and to users of commercial and research computational tools.

John L. Volakis
R.&L. Chope Chair Professor
The Ohio State University

Foreword II

Dramatic enhancements in technologies for manipulating materials and their properties are spurring innovations in many engineering disciplines, including those involving microwave and electromagnetic systems. The creation of new antennas, enhanced transmit and/or receive circuit devices such as switches, filters, mixers, and amplifiers, and the integration of these systems into smaller and smaller packages are all subjects of extensive current research. Achieving operation over wider bandwidths, electronically adaptable ("software defined") performance, and platform conformal integration, all at reduced cost and manufacturing complexity, are among the potential gains enabled by material innovations. I believe that the future will see our present time as the beginning of a revolution in RF technologies and the capabilities they provide due to the new materials that are currently being investigated.

While system components will be the drivers of this future, innovations in engineering design procedures will also be necessary in order to understand and to utilize the new "tools" in the engineer's toolbox that will be available. The Smith chart is one of the most fundamental tools in RF design, and accompanies the basic transmission line structures that provide connections between RF devices. As any RF engineer is aware, a key property of the Smith chart is the insight it provides in even complex design processes. Enhancement of Smith charts into "Meta-Smith charts" to enable their continued use even with transmission lines that are nonreciprocal or contain metamaterials keeps this insight available for designs using future materials. Prof. Torrungrueng makes a valuable contribution with this volume whose benefits will be realized at present, but even more so as the metamaterial revolution continues.

Joel T. Johnson
Professor, Electrical and Computer Engineering
The Ohio State University

Preface

The Smith chart was developed in early 1937 by Phillip H. Smith. In early 1939, an article on the Smith chart was first published in the *Electronics* magazine. Radio-frequency (RF) engineers have found that the Smith chart is much more than merely a graphical tool; not only does it allow the user to gain more physical insight when visualizing transmission line (TL) phenomenon, but also assists in solving associated problems effectively. Although powerful computers are used as the dominant design tool nowadays, the Smith chart still remains widely in use. It has come to provide the basis for both modern computer and measurement instrument displays.

I became impressed with the usefulness of the application of the Smith chart whilst studying courses on antennas and frequency-selective surfaces with the late Prof. Dr. Ben A. Munk during my graduate studies at The Ohio State University [1], [2]. Prof. Munk had shown that use of the Smith chart can provide a physical understanding of many associated complex phenomena. In 2002, while preparing my lecture notes on the transmission line theory from Chapter 2 in [3] (see Problem 2.29), I asked myself the question: "Can a graphical tool, like the Smith chart, be applied for nonreciprocal lossless transmission lines?" The author found that the answer to this question was "No", and so I started developing a new graphical tool for nonreciprocal lossless transmission lines. In 2004, the first journal paper on the new graphical tool, called a generalized *ZY* Smith chart or "*T-Chart*", was published [4]. I and my team have continued developing the theory of T-Charts, including their practical applications [4-10].

In the references [4-10], the authors employed the terminology "T-Charts" for graphical tools associated with conjugately characteristic-impedance transmission lines (CCITLs) and bi-characteristic-impedance transmission lines (BCITLs). These transmission lines are discussed in detail later in this book. It should be pointed out that a nonreciprocal lossless TL in [4] is an example of CCITLs. In this book, the new terminology "*Meta-Smith charts*" is used instead of "T-Charts" to make readers, who are familiar with the Smith chart, see the originality and generality of the proposed graphical tools: the Meta-Smith charts. Note that the Greek word *meta* means *beyond*. The Meta-Smith charts can be applied to more practical and useful TL problems; i.e., CCITLs and BCITLs, *beyond* the capability of the Smith chart. Another reason for using this new terminology is that the Meta-Smith charts can be applied to analyze *metamaterial TLs*, where the Smith chart cannot be employed effectively. It will be shown in the book that the Smith chart is a special case of the Meta-Smith charts.

This book is organized into five chapters and five appendices. Chapter 1 provides the essential transmission line theory. Both uniform and nonuniform transmission lines are discussed in this chapter. The material covered in this chapter will serve as an essential grounding in understanding subsequent material in the book. Chapters 2 and 3 give the theories of CCITLs and BCITLs respectively, including practical examples. These two chapters will serve as the necessary background in developing the Meta-Smith charts for CCITLs and BCITLs in Chapter 4. Chapter 5 provides several applications of the Meta-Smith charts for solving practical problems associated with CCITLs and BCITLs. Finally, five appendices are also provided to supplement material in the chapters discussed earlier. In this book, the Meta-Smith charts are applied to analyze and design passive circuits only. However, they can also be applied for problems associated with active circuits. Due to the fact that the Meta-Smith charts depend on parameters of CCITLs and BCITLs, computerized Meta-Smith chart programs are indispensable, and they are developed to generate plots of the Meta-Smith charts.

This book can be used as a companion guide in studying "Microwave Engineering" for senior undergraduate students as well as for graduate students. It is also recommended for researchers in the RF community, especially those working with periodic TL structures and metamaterial TLs. Problems are also provided at the end of each chapter for readers to gain a better understanding of material presented in this book. For convenience in usage of Meta-Smith charts, a computerized Meta-Smith chart program, developed in Java, can be accessed via `http://www.meta-smithcharts.org/`.

I hope that the Meta-Smith charts will be used extensively by students, professors and researchers in the RF community in the near future to develop a physical understanding of many sophisticated phenomena of complex transmission lines and related problems. Useful suggestions and comments from readers are welcome, and they can be submitted by e-mail to the author via `dtg@asianust.ac.th` (cc: `torrungd@hotmail.com`).

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BIBLIOGRAPHY

[1] B. A. Munk, *Frequency Selective Surfaces, Theory and Design*. New York: Wiley Interscience, 2000. xvii

[2] B. A. Munk, *Finite Arrays and FSS*. New York: Wiley Interscience, 2003. xvii

[3] D. M. Pozar, *Microwave Engineering*, 2nd ed. New Jersey: Wiley, 1998. xvii

[4] D. Torrungrueng and C. Thimaporn, "A generalized *ZY* Smith chart for solvingnon reciprocal uniform transmission line problems," *Microwave and Optical Technology Letters*, vol. 40, no. 1, pp. 57–61, Jan. 2004. DOI: 10.1002/mop.11284 xvii

[5] D. Torrungrueng, P.Y. Chou, and M. Krairiksh, "An extended ZY T-chart for conjugatelycharacteristic-impedance transmission lines with active characteristic impedances," *Microwave and Optical Technology Letters*, vol. 49, no. 8, pp. 1961–1964, Aug. 2007. DOI: 10.1002/mop.22626

[6] D. Torrungrueng, P.Y. Chou, and M. Krairiksh, "A graphical tool for analysis and designof bi-characteristic-impedance transmission lines," *Microwave and Optical Technology Letters*, vol. 49, no. 10, pp. 2368–2372, Oct. 2007. DOI: 10.1002/mop.22801

[7] D. Torrungrueng, P.Y. Chou, and M. Krairiksh, "Erratum: A graphical tool for analysis and design of bi-characteristic-impedance transmission lines," *Microwave and Optical Technology Letters*, vol. 51, no. 4, pp. 1154, Apr. 2009. DOI: 10.1002/mop.24260

[8] D. Torrungrueng and C. Thimaporn, "Applications of the ZY T-chart for nonreciprocal stub tuners," *Microwave and Optical Technology Letters*, vol. 45, no. 3, pp. 259–262, May 2005. DOI: 10.1002/mop.20789

[9] D. TorrungruengandC. Thimaporn, "Application of the T-chart for solving exponentially tapered lossless nonuniform transmission line problems," *Microwave and Optical Technology Letters*, vol. 45, no. 5, pp. 402–406, Jun. 2005. DOI: 10.1002/mop.20836

[10] D. Torrungrueng, C. Thimaporn, and N. Chamnandechakun, "An application of the T-chart for solving problems associated with terminated finite lossless periodic structures," *Microwave and Optical Technology Letters*, vol. 47, no. 6, pp. 594–597, Dec. 2005. DOI: 10.1002/mop.21239

List of Abbreviations

BCITL	Bi-Characteristic-Impedance Transmission Line
CCITL	Conjugately Characteristic-Impedance Transmission Line
ETLNUTL	Exponentially Tapered Lossless Nonuniform Transmission Line
NCR	Negative Characteristic Resistance
NNCR	Nonnegative Characteristic Resistance
NRI	Negative Refractive Index
NRLSUTL	Nonreciprocal Lossy Uniform Transmission Line
NRLUTL	Nonreciprocal Lossless Uniform Transmission Line
OC	Open-Circuited
RF	Radio-Frequency
RHS	Right-Hand Side
RLSUTL	Reciprocal Lossy Uniform Transmission Line
RLUTL	Reciprocal Lossless Uniform Transmission Line
SC	Short-Circuited
TL	Transmission Line

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