Electromagnetic Field Interaction with Transmission Lines

Advances in Electrical Engineering and Electromagnetics

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Electromagnetic Field Interaction with Transmission Lines

From classical theory to HF radiation effects

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To Mojgan

To Victoria, Natalie and Anna

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Preface

The evaluation of electromagnetic field coupling to transmission lines is an important problem in electromagnetic compatibility. Customarily, use is made of the transmission line (TL) approximation which applies to uniform transmission lines with electrically-small cross-sectional dimensions, where the dominant mode of propagation is transverse electromagnetic (TEM). Antenna-mode currents and higher-order modes appearing at higher frequencies are neglected in the classical TL theory.

Since the development of the TL theory and the derivation of the so-called telegrapher's equations by Oliver Heaviside in the late 19th century, significant progress has been achieved in the understanding of wave propagation along transmission lines. In 1965, Taylor, Satterwhite and Harrison extended the classical TL equations to include the presence of an external electromagnetic field. Their field-to-transmission coupling equations – as well as their equivalent formulations derived later – have been successfully applied to solve a large range of problems dealing with EMP and lightning interaction with power and telecommunication lines.

The unabated increase in the operating frequency of electronic products and the emergence of sources of disturbances with higher frequency content (such as High Power Microwave and Ultra-Wide Band systems) have led to a breakdown of the TL approximation's basic assumptions for a number of applications. In the last decade or so, the generalization of the TL theory to take into account high frequency effects has emerged as an important topic of study in electromagnetic compatibility. This effort resulted in the elaboration of the so-called 'generalized' or 'full-wave' TL theory, which incorporates high frequency radiation effects, while keeping the relative simplicity of TL equations.

This book covers both the classical transmission line theory as well as its recent enhancements. It is intended for graduate students, researchers and engineers interested in the transmission line theory and electromagnetic field interaction with transmission lines, with special emphasis on high frequency effects. The text is organized in two main parts containing a total of seven chapters.

Part I presents the consolidated knowledge of classical transmission line theory and different field-to-transmission line coupling models.

Chapter 1 discusses the assumptions of the TL theory and presents the derivation of the field-to-transmission line coupling equations. Three different but completely equivalent approaches that have been proposed to describe the coupling of electromagnetic field coupling to transmission lines are also presented and discussed. Chapters 2 and 3, deal, respectively, with the specific cases of overhead multiconductor lines and buried cables. Various factors influencing the pulse propagation and crosstalk along multiconductor systems are discussed, and methods for the calculation of the line longitudinal and transverse line parameters are presented.

Part II presents different approaches developed to generalize the TL theory in order to include high frequency effects.

In Chapter 4, a TL-like pair of equations is derived under the thin-wire approximation for evaluating currents and potentials induced by external electromagnetic fields on a wire of a given geometric form above a perfect conducting ground. Based on perturbation theory, an iterative procedure is proposed to solve the derived coupling equations, where the zero-iteration term is determined by using the classical TL approximation. Chapter 5 presents an efficient hybrid method to compute high frequency electromagnetic field coupling to long, loaded lines including lumped discontinuities. Chapter 6 shows that the classical TL theory may be included in a more general model based on an integral formulation of the general full-wave problem. The derived general model is applied to conventional high-speed microelectronics, as well as to nanoelectronics applications. Chapter 7 deals specifically with high frequency electromagnetic field coupling to buried wires. Two approaches, one in the frequency domain based on the Pocklington's integral equation, and the other in the time domain using the Hallen integral equation, are proposed and discussed.

Although the chapters follow a logical order and a novice reader is advised to read the book sequentially, an effort has been made to make each chapter as independent of the others as possible. Therefore, readers interested in a particular aspect of the subject dealt with in one chapter do not need to consult other chapters of the book.

This book is the result of the authors' activities in the area of electromagnetic field-to-transmission line interactions. The authors are indebted to many individuals for their support, advice, and guidance. Special thanks are due to Michel Ianoz, Juergen Nitsch and Fred M. Tesche, and to all the authors of the chapters for their precious contributions.

Farhad Rachidi and Sergei Tkachenko