# Preface

This textbook is intended for a senior or graduate-level course in an Electrical Engineering curriculum on the subject of the analysis of Multiconductor Transmission Lines (MTL's). It will also be a useful reference on the subject for industrial professionals. The term MTL typically refers to a set of $(n + 1)$ parallel conductors that serve to transmit electrical signals between sources and loads. The dominant mode of propagation in a MTL is the Transverse ElectroMagnetic or TEM mode of propagation where the electric and magnetic fields surrounding the conductors lie solely in the transverse plane orthogonal to the line axis. This structure is capable of guiding waves whose frequencies range from dc to where the line cross-sectional dimensions become a significant fraction of a wavelength. At higher frequencies, higher-order modes coexist with the TEM mode and other guiding structures such as waveguides and antennas are more practical structures for transmitting the signal between a source and a load. There are many applications for this wave-guiding structure. High-voltage power transmission lines are intended to transmit 60 Hz sinusoidal waveforms and the resulting power. In addition to this low-frequency power frequency, there may exist other, higher-frequency components of the transmitted signal such as when a fault occurs on the line or a circuit breaker opens and recloses. The waveforms on the line associated with these events have high-frequency spectral content. Cables in modem electronic systems such as aircraft, ships and vehicles serve to transmit power as well as signals throughout the system. These cables consist of large numbers of individual wires that are packed into bundles for neatness and space conservation. The electromagnetic fields surrounding the individual wires interact with each other and induce signals in all the other adjacent circuits. This is unintended and is referred to as *crosstalk*. This crosstalk can cause functional degradation of the circuits at the ends of the cable. The prediction of crosstalk will be one of our major objectives in this text. There are numerous other similar structures. A printed circuit board (PCB) consists of a planar dielectric board on which rectangular cross section conductors (lands) serve to interconnect digital devices as well as analog devices. Crosstalk can be a significant functional problem with these PCB's as can the degradation of the intended signal transmission through attenuation, time delay, and other effects. Signal degradation, time delay and crosstalk can create significant functional problems in today's high-speed digital circuits so that it is important to understand and predict this effect. It has been said that optical fibers will eliminate many of these problems associated with metallic conductors such as crosstalk. Although this is true to a large degree, full implementation of fiber optic transmision paths will occur well into the future because of the present low cost and significant use of metallic-conductor lines.

The analysis of a *two-conductor* line ($n = 1$) is a standard and well-understood subject in all Electrical Engineering curricula. However, the analysis of MTL's consisting of three or more coupled conductors is not as well known. The purpose of this text is to provide a compact and complete description of the existing mathematical techniques for analyzing MTL's. The assumption of the TEM mode of propagation on the line results in a set of coupled partial differential equations. These are referred to as the *transmission-line equations.* The sole purpose of this text is to investigate ways of solving these transmission-line equations for MTL's and incorporating the constraints imposed by the terminations into that general solution. If one looks at the research literature, one finds a seemingly unbounded number of methods for analyzing MTL's. However, there actually exist a small number of standard techniques which we will elucidate in this text. Understanding the primary, fundamental analysis techniques given in this text will allow the reader to understand and categorize the myriad of seemingly new analysis techniques that appear in the literature. Our focus will be on two important *interference* mechanisms in MTL's—crosstalk and the effects of incident electromagnetic fields on MTL's. In the case of crosstalk, the driving signals are in the termination networks and produce the electromagnetic fields of the line which result in intended as well as unintended reception in the terminations. In the case of incident field illumination of the MTL, the driving signals are produced by distant sources and can also create interference effects in the MTL. These driving signals can be characterized in the *frequency* domain (single frequency sinusoidal signals) and the *time domain* (general time variations). It is convenient to break our analyses into these two classes. If the terminations are linear, the time domain results can be obtained from the frequency domain results by superposition. For nonlinear terminations, the general time-domain results must be obtained directly.

The text is divided into eight chapters. Considerable thought has gone into the organization of the text. The author is of the strong opinion that organization of subject material into a logical and well thought out form is perhaps the most important pedagogical technique in a reader's learning process. This logical organization is one of the important attributes of the text. Chapter 1 discusses the background and rationale for the use of MTL's. The general properties of the TEM mode of propagation are discussed, and the transmission-line equations are derived several ways for two-conductor lines. The various classifications of MTL's (uniform, lossless, homogeneous medium) are discussed along with the restrictions on the use of the TEM model. Chapter 2 provides a derivation of the MTL equations along with the general properties of the per-unit-length parameter matrices in those equations. A key ingredient in all MTL characterizations is the per-unit-length parameter matrices in the MTL equations. All structural dimensions of MTL's are contained in these per-unit-length parameter matrices and nowhere else. If one intends to obtain predictions of the response of a MTL without actually constructing it, one must not only solve the MTL equations but also determine the per-unit-length parameters. Solving the MTL equations without determining the per-unit-length parameters is of no use. Chapter 3 details the general techniques for determining these per-unit-length parameters for a MTL. Analytical as well as numerical methods will be discussed. The general solution of the MTL equations begins with the frequency-domain analysis in Chapter 4. Chapter 5 examines the direct, time-domain solution of the MTL equations. The solution techniques in the previous chapters for a MTL require matrix methods and numerical solution. Chapter 6 gives closed-form solutions in terms of the line parameters for the case of a three-conductor line. This serves to elucidate the general behavior that is common to all MTL's and gives useful design formulae. Chapter 7 examines the effects of an electromagnetic field incident on the MTL. The effect of this incident field is to yield sources distributed along the line rather than existing solely in the termination networks. The general solution of the MTL equations for this case is examined. Chapter 8 provides the application of these techniques to interconnections of transmission lines: Transmission- Line Networks.

There are a number of important learning aids included in this text. A limited but representative set of end-of-chapter problems are provided. Computed data are obtained in each chapter to illustrate the methods, and experimental results are provided to illustrate their accuracy or limitations. These are provided for two practical applications: a ribbon cable and a PCB. It is important for the reader to obtain a feel for the prediction accuracy and limitations of the MTL model. These computed and experimental results provide that insight. And finally, several FORTRAN codes were written to implement the methods of this book. Each of these codes implements one of the important analysis techniques described in the text. They are written in ANSI Fortran 77 language and may be compiled with any standard FORTRAN compiler. They are suitable for use on personal computers. Thus the reader can immediately begin testing each technique for practical structures of his/her choosing. These computer codes can be downloaded from the Wiley ftp site at

ftp://ftp.wiley.com/public/sci_tech_med/multiconductor_transmission/

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