Introduction

SIGNAL INTEGRITY is a field of electrical engineering involving the transfer of information from one place to another. The goal is to transfer information efficiently, free of errors, and at high speed. The accomplishment of this goal involves the analysis, measurement, and simulation of waveforms at a transmitter and receiver and the behavior of the channel through which the waveforms pass.

The channel involves interconnected devices like connectors, cables, and printed circuit board (PCB) traces, and the analysis of these devices involves primarily their electromagnetic properties. Most books on signal integrity include teaching on these electromagnetic properties and how the device geometry, materials, and construction affect these properties in order to provide the engineer with useful information such that their designs can be controlled. This book is not about that.

Two integral topics in signal integrity design are measurement and simulation, and the engineer is constantly trying to reconcile their knowledge about how to affect the system, the computer simulation of the system, and the measurements made of the system. The measurements and simulations in signal integrity involve waveforms (either transmitted or received) and the behavior of the channel. Measurements of waveforms are generally made with digital oscilloscopes, and measurements of the behavior of the channel are usually made with vector network analyzers or time-domain reflectometers. The concept of waveforms is not difficult, although their sampled nature might cause some complexity.

The electromagnetic behavior of the channel is generally abstracted using network parameters, called scattering parameters, or s-parameters. S-parameters are the primary output of simulation tools and measurement instruments that simulate and measure the behavior of the channel. The concept of the s-parameters comes from the microwave community and was originally used to describe the behavior of antennas, filters, amplifiers, and other microwave devices. S-parameters are a sampled frequency-domain construct just as waveforms from oscilloscopes are sampled time-domain constructs.

In the microwave community, most often the frequency-domain aspect of a microwave device is used in simulations with other frequency-domain measurements of the signals that interact with them, as measured by a spectrum analyzer, for example. The interactions between frequency-domain signals and microwave devices in the frequency domain are well understood by the microwave engineer, and, often, the narrow-band nature of many designs makes the analysis and measurement relatively straightforward. In signal integrity, the interaction between time-domain waveforms and frequency-domain devices characterized by their s-parameters adds an element of difficulty.

The goals of this book are as follows:

- To address comprehensively the abstract concept of s-parameters and the theory behind them, from both a mathematical and circuit theory standpoint.

- To provide methods and software tools for manipulating s-parameters in ways that are commonly required by engineers.
- To provide solutions for several broad topics encountered involving s-parameters, such as simulation and de-embedding in both the time and frequency domain.
- To provide the theory and mechanics of how time-domain waveforms interact with frequency-domain s-parameters.
- To provide the mathematical concepts of how s-parameters are measured, both by frequency-domain and time-domain instruments and how they can be viewed in both domains.

All of the theory is accompanied by software that is part of an open-source software project, called *SignalIntegrity*. The goal of the software project is to provide free software tools for solving signal integrity problems, and this book describes the construction of this software that would be useful to a project contributor, and connects the mostly mathematical theory with the software implementation that is useful for users of the software.

Organization

This book is organized in four distinct parts:

- Part I, Scattering Parameters – the mathematical and circuit theory of s-parameters and s-parameter systems.
- Part II, Applications – the theory and programmatic techniques for solving four specific classes of problems: s-parameter determination, de-embedding, virtual probing, and linear simulation.
- Part III, Signal Processing and Measurement – the theory and software for signal processing in signal integrity, notably, how waveforms and filters generated in linear simulations from s-parameters interact. This part also covers the analytical topics of measurement, model extraction, and the impedance profile, an important signal integrity tool that is the time-domain view of return loss.
- Part IV, *SignalIntegrity* – the organization and usage of the *SignalIntegrity* Python software project.

At the end of the book, the following appendices are provided:

- Appendix A, Terminology and Conventions – the mathematics nomenclature used in the book.
- Appendix B, Telegrapher's Equations – some derivations of the telegrapher's equations, used for the derivation of the transmission line in Chapter 7.
- Appendix C - Matrix Algebra – some details of the matrix algebra and nonlinear fitting methods used in this book.
- Appendix D, Symbolic Device Solutions – some details of larger symbolic device solutions for the devices derived in Chapter 6. These provide some insight into how a user might generate symbolic solutions themselves.

Readers and teachers should view Part I and Part III as the theoretical meat of this book, along with the mathematical descriptions of the solutions in Part II.

For a practitioner, perhaps Part II is the most useful for scripted solutions, with Part I forming the theoretical backdrop, especially Chapter 4, S-Parameter System Models, with the remaining chapters used as a reference to be read when required. Certainly, all of the concepts in Part II present useful concepts in the field.

And, of course, software developers are welcome to attempt to alter or even contribute to the development. In this case, Part IV would be where to start, with Part II providing software details of the solutions provided.