

Contents

Preface ix

Acknowledgements ix
About the Terminology x
Overview of the Chapters x
Appendices xiii

Chapter 1 A Short History of Digital Interconnection 1

Digital Transforms to Microwave Design 3
Mathematical Approximations 4

Chapter 2 Transmission Lines 7

Electrical Characteristics 8
 Characteristic Impedance: Z_0 9
 Geometry and Impedance: Z_0 11
 Moving on to Fields 13
 Back to Characteristic Impedance 16
 Even and Odd Impedance 17
 Differential Impedance 18
Length-Related Issues 20
 Voltage and Current Envelopes 23
 Smith Chart 26
 Reflection Coefficient 31
 Insertion Loss 34

- Return Loss 37
- Crosstalk 38
- EMI 41
- Conclusion 42

Chapter 3 Mathematical Background For Microwaves 43

- Analytical Procedures 44
- Refresher: Complex Numbers and Matrices 46
 - Complex Numbers 46
 - Matrices 48
- Introducing S parameters 52
 - Frequency Domain and Time Domain 67
 - Peeling 72

Chapter 4 Peeling and Mason's Rule 73

- How Peeling Works 73
- Implementing Peeling 75
- Examples 79
 - Creating S Parameters 80
- Loss 88
- More Fourier Transform Considerations 89
- Crosstalk 92
 - Frequency factors 92
 - Directionality 94
 - The Directional Coupler 94
 - Turns Ratio 96
 - The Transformer 96
 - Differential 98
 - T Lines vs. L-C 100
- Mason's Rule 102

Chapter 5 The Mathematics of Fields 105

- Maxwell 105
 - Deconstruction 111
 - Curl and Divergence 116
 - E Field 117
 - H Field 118
- A Simple Field Solver 118
 - The Discrete Curl 120
 - The Discrete Time Derivative 120
 - The Questions of Practicality 121

The Boundaries	122
A Field-Solver Sampler	123
The Wave Equation	130
Reflection Coefficient	134
Conclusion	138

Chapter 6 Differential Signaling 139

Definitions	140
Voltage	140
The Differential Receiver	142
The Differential Transmitter	144
Differential Transmission Lines	148
Coupling	151
Image Currents	152
Balance	155
Conclusion	157

Chapter 7 Modeling Issues 159

Time Domain Analysis	160
SPICE	160
Unmodelable Features	161
Differential and Common Modes	162
Return Paths and Image Currents	166
Differential Transmission	168
Differential Receivers	169
Differential Transmission Lines	171
Corners and Bends	172
Modelable Features	176
Frequency Dependent Loss	177
Copper Loss	177
Dielectric Loss	179
Drivers and Receivers	181
Packages	182
Breakouts	184
Interconnects	185
Connectors	186
Cables	188
Modeling Philosophy	190
Monte Carlo	190
Experiment Design	191

Communications Theory	191
Spreadsheets and Mathematics Software	195
Frequency Domain Analysis	196
Conversions between Frequency and Time Domains	196
Why Frequency Domain?	197
Equalization	199
Radiation	200
Crosstalk	201
Planar Waveguide	201
Vias	203
Patch Antennae	204
Slot Antennae and Hole Size	204
Common-Mode on Cables	205
Conclusion	205

Chapter 8 Board Layout 207

Fundamentals	207
Eye Diagrams	208
Test Patterns	211
Frequency-Dependent Loss	213
Jitter	216
Planning the Stackup	218
Coupling	219
Corners	222
Vias	223
Discrete Components	226
Reference Planes and Plane Splits	227
Slot Lines	229
Plane Resonances	230
Package Breakouts	230
Connectors	230
Test Points	231
Impedance Tolerances	231
Weave Effects	232
Special Cases: Measurement Boards	233

Chapter 9 Test Equipment 237

Oscilloscope	237
Real Time	237
Sampling Scopes	239
Care	240

Time Domain Reflectometer	241
Network Analyzer	243
Care	244
Application	245
What a Network Analyzer Does	247
Spectrum Analyzer	248
Probes and Probing	248
Auxiliary Equipment	250
Cables	251
Basic Measurements	252
Transmitter	253
Traces	259
Conclusion	260

Appendix A Signal Integrity 261

Appendix B Matlab 101 267

Navigation	267
Variables	268
Ranges	269
Operations	271
Transpose	271
Matrix Operations	272
Element by Element	272
Scripts	273
Functions	273
Looping	274
Files and I/O	275
Help	277

Appendix C Further Reading 279

Electromagnetic Fields and Interactions	279
Microwave Transistor Amplifiers, Analysis and Design	280
The Transmission-Line Modeling Method TLM	280
Numerical Methods for Scientists and Engineers	281
Analysis of Multiconductor Transmission Lines	281
Transmission Line Design Handbook	282
Principles of Microwave Circuits	283
Microstrip Lines and Slotlines	283
Foundations for Microwave Engineering	284
Finite Elements for Electrical Engineers	284

viii ■ Designing High-Speed Interconnect Circuits

Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotropic Media	284
Time-Domain Methods for Microwave Structures, Analysis and Design	285
Arbitrary Pulse Shape Synthesis via Non-uniform Transmission Lines	285
Microwave Engineering	285

Glossary 287

Index 297