EMC

Electromagnetic Compatibility

Made Simple

Printed Circuit Board and System Design

Mark I. Montrose

Calculus ——> Algebra

$$\frac{d(\text{Maxwell})}{d(\text{EMC})} = \text{Ohms Law}$$

Montrose Compliance Services, Inc.

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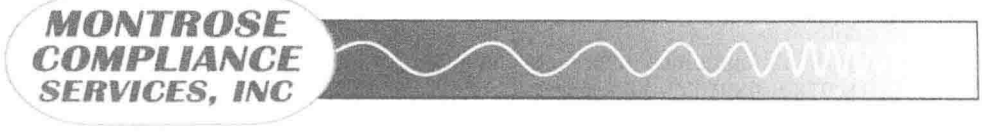

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Printed Circuit Board and System Design

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Preface

- *EMC Made Simple* ®
- *Electromagnetic Compatibility Made Simple* ® and
- *Maxwell Made Simple* ®

These three phrases are a registered trademark of Montrose Compliance Services as well as my tagline and approach to designing products based on simplifying the most complex aspect of electrical engineering and design. Understanding electromagnetics is critical for designing products using electrical power to provide an intrinsic function of use. Although devices may use a DC power source, once it enters a product and arrives at circuitry, conversion to analog occurs. Analog typically is a motional wave function described with units of Hertz. The popular and non-specific definition of RF is anything greater than DC to daylight again, with units of Hertz. Once we convert to the analog world we enter the field of electromagnetic functions. Using digital technology, electrical interference from radiated emissions becomes a concern as well as immunity to perturbations and performance requirements.

There is no system I am aware of that does not convert DC energy or signals to the AC mode either through an onboard power supply providing both voltage and current to active components. We thus live in an analog world since it takes a finite amount of time for a digital signal to transition from low-to-high and high-to-low. For those who consider themselves only a digital designer, remember the real [technical] definition of digital is "infinitely fast AC slew rate signal." With this definition, there is therefore no such thing as digital components. This is because between binary "1" and "0" is the realm of analogue radio frequency! Digital components in reality contain gain function devices, similar to op-amps driven to saturation for all inputs and outputs. This means they function using fast AC slew rates of operation, producing an AC spectral profile across a broad frequency range.

The focus of this book is to take a complex field of engineering and simplify it for those who never took courses in electromagnetics, or had difficulty in understanding calculus as it relates to applied engineering applications. Engineers and designers in this category must develop products to be functional and compliant to a multitude of standards that include regulatory compliance. In many companies, product designs are performed not only by [experienced] engineers, but also by a wide variety of talent all with various areas of expertise. A person who spent years working in a manufacturing facility can be transferred to engineering working as a technician to help on time critical tasks. They may also be assigned to work in regulatory compliance that includes electromagnetic compatibility (EMC), product safety, telecommunication approvals, medical applications, documentation related to various directives (RoHS, WEEE, REACH and numerous other acronyms) plus other requirements. Technicians and recent graduates are generally not trained in product design yet they take on more and more responsibility that may include printed circuit board layout and integration to meet regulatory standards without being educated in the field of compliance: thus, they must learn everything in real-time often without having a mentor.

When employed at several major companies in Silicon Valley, California, technicians who worked with me did time consuming tasks with vigor and excellence, but usually not design, analysis or troubleshooting. My time was spent solving problems created by engineers that were easy to identify and fix, but which could have been performed by someone else only if this person had knowledge of *EMC Made Simple*®. When everyone in a team understands what needs to be done using common sense, along with a basic understanding of electromagnetics, our work would have been more efficient.

As a consultant, I find that most of my clients have limited expertise in solving complex problems or they delegate the job to someone else to get a product "certified." Even with junior engineers and technicians, the senior compliance engineer may be overworked trying to optimize a system for both functionality as well as compliance. In addition, they must spend time with those in product design by helping them understand where problem areas are and explaining electromagnetics using simple definitions and examples. If they had an easy to read book that could be given to team members, educating them would be an easier task.

Most of the time with these observations, EMC engineers must fix a poor design after printed circuit boards (printed circuit board) are assembled and ready for customer shipment, hoping they pass EMC tests. If designers and engineers understood electrical engineering in a "simplified manner," and consider all aspects of system development and not just a specific area such as printed circuit board or mechanical design, things could turn out differently. Engineers must now know about multiple aspects of engineering that includes how to design a printed circuit board using schematic capture and layout tools, material science, mechanical design, thermal issues, low-cost manufacturing requirements, along with testing, troubleshooting and support.

In years of working as an EMC consultant with hundreds of small to medium size companies, I find that many do not have resources, both in terms of senior or experienced engineers or money to purchase simulation programs to perform computational analysis. I have observed on a consistent basis that designers constantly experiment with trial and error fixes without understanding the problem, or means of finding a simple solution using Ohms law instead of Maxwell Equations. The incentive for writing this book comes from numerous students whom I teach professionally in the United States, Europe and Asia as well as clients that call me in under emergency conditions usually after a product fails EMC testing. Everyone wants to know "*How and why does EMI get developed within a printed circuit board*" in a simplified manner without use of math or computational analysis. Recognizing a need to fill a gap that currently does not exist within the published literature (at time of writing), I want to enlighten readers to a field of engineering that is considered to be a science of *Black Magic*.

My goal is to help companies and engineers worldwide that cannot afford to hire a consultant or experienced senior compliance engineers with design knowledge that includes circuit analysis at the schematic level, using *Maxwell Made Simple®*.

Given the observations above, we can simplify design engineering to achieve success quickly and at low cost. ***The target audience*** of this book is:

1. Those who never studied applied EMC engineering but now work in the field as a technician or engineer due to a shift in job assignment, or the need for a compliance engineer.
2. Managers of regulatory compliance staff who provide resources such as technical expertise or mentoring.
3. Those who have "never" done a simulation or performed computational analysis at a high level, or probably ever will. [I estimate that close to 95% of my clients have never simulated anything for numerous reasons that include cost, time to market, lack of expertise to use any type software package in the time or frequency domain, etc.]. These are all generally smaller size companies.
4. Printed circuit board designers who must create a design only from a schematic and bill-of-material, and then told to make it will pass EMC without the aid of a senior or experienced EMC engineer reviewing their layout. This includes third-party resources or staff that has minimal interaction with designers and EMC experts.
5. Application and technical support engineers from component manufacturers that must solve customer problems.

6. University professors who want to learn new techniques on how to simplify the process of teaching applied electromagnetics and design engineering in a manner that helps students visualize this complex field, while providing a solid foundation based on theory and applications.

This book is ***unsuited*** for:

1. Those who use computational analysis to analyze designs, both pre- and post-layout.
2. Senior engineers with many years of experienced and understand the field of EMC at a high level.
3. Those who work in a company dealing with high-technology design having access to sophisticated instrumentation, software tools and staff with considerable experience in design engineering.
4. Those who would rather hire a consultant or third party resource to do their regulatory compliance and design because the field of EMC is too difficult to understand.

About the book structure

During my career as a consultant, I estimate that somewhere between 80-90% of problems encountered deal with having a poor power distribution network on a printed circuit board or improper implementation and use of decoupling capacitors in addition to having poor RF return paths. Referencing and I/O interconnects take up the remainder of product design failures. Therefore, these three primary topics are covered extensively in this book.

For one wanting to learn about other aspects of printed circuit board design such as layer stackup, impedance control, signal integrity, terminations, I/O and interconnects, ESD protection, backplane and daughter card interfacing, plus other unique aspects of printed circuit board development, please refer to the Reference section for a list of outstanding sources of books and technical publications. This book "*is not written to be a complete publication on all aspects of printed circuit board design, but a simplified handbook to get a product to near perfect completion using solid theory and known design and layout techniques that work based on years of experience.*"

Having authored previous printed circuit board design related books for signal integrity and EMC, a different approach is taken with this book. Why compete with other publications that attempt to be all-inclusive covering every possible aspect of engineering design, or to those that just want to get the job done and do not care about electromagnetic theory and related mathematics. Therefore, this book covers critical aspects one needs to know for success. It is also important to emphasize that using this book will not guarantee success, it should however help make success easier to achieve.

Regardless of advances in technology, the topics identified above have not conceptually changed over the years except for unique aspects of device logic applications and implementations. Where technological advancements have occurred in semiconductor manufacturing, these usually are associated with having a stable power distribution network or ensuring sufficient power is available to minimize plane bounce. Losses in board material also contribute to poor signal integrity and development of common-mode RF energy, examined in Chapter 2, "*Transmission Line Theory Made Simple.*"

Regardless of specialty that an engineer or designer works within such as design, testing and manufacturing, a design team must produce a product that can be built quickly and at low cost. Frequently, more emphasis is placed on system level functionality to meet a marketing specification rather than the need to meet legally mandated EMC and product safety requirements. Redesigning anything significantly

increases costs that includes, but is not limited to engineering manpower along with administrative overhead.

My focus as a consultant is to assist and advise in the design of high technology products at minimal cost by helping educate clients in *EMC Made Simple*®. Implementing suppression techniques into the printed circuit board saves money, enhances performance, increases reliability, helps achieves first time compliance with emissions and immunity requirements, in addition to having the product function as desired.

EMC engineers know various tricks of the trade on how to apply rework or a quick fix on a printed circuit board to pass a particular test. When a problem develops, there is little one can do except to re-spin the board. By understanding *EMC Made Simple*®, our work as design engineers will become fun again along with accolades from management for getting the job done correctly on the first prototype of the system.

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Acknowledgment

It has been nearly eight years since I published my last book on EMC and expected it to be my last. This book is a comprehensive presentation that includes system level design in addition to printed circuit board layout to achieve EMC, unique in style and content. I want to acknowledge the following that played a part in the development of this book.

Ed Nakauchi, my co-author of our book *Testing for EMC Compliance-Approaches and Techniques*, who assisted in editing and clarifying content.

Elya Joffe, a long-time friend and colleague, who like all of my previous books, provided outstanding scrutiny during the review process. Comments were associated with very high-speed design issues in addition to the section of correlating Maxwell's Equations to Ohms Law.

To W. Michael King, PhD, who gave tremendous guidance and feedback. Michael is not only my mentor but also life-long friend. Without Michael, I would not have been able to achieve the knowledge that has allowed me to become not only a consultant and educator, but also an engineer with the ability to view things differently than others in this rapidly changing field. A new viewpoint within electrical engineering is now required with today's technology and his ability to teach me how to think in three dimensions and not conform to standard means of presenting EMC design is greatly appreciated.

My most special acknowledgment is to Monica Maxwell who encouraged me to write this book. We originally discussed the content to be a brief summary of important areas of EMC engineering, a collection of Cliff Notes based on university seminars that I teach internationally. What started as a short manuscript culminated in a comprehensive book on multiple aspects related to the field of EMC. This book is a well thought-out perspective on design engineering never before published appealing to engineers globally.

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Table of Contents

Table of Contents v
Preface xvii
Acknowledgment xxi

1 EMC or Maxwell Made Simple 1
1.1 Time Domain vs. Frequency Domain 2
1.2 History of Electromagnetics (Made Simple) 2
1.3 Theory of Electromagnetics (Maxwell Made Simple) 9
1.4 Antenna Definitions Related to Field Propagation from Source 12
1.4.1 Reactive Near-Field Region 12
1.4.2 Radiating Near-Field (Fresnel) Region 13
1.4.3 Far-Field (Fraunhofer) Region 13
1.5 Relationship Between Electric and Magnetic Sources 13
1.6 Electromagnetic Fields Represented as Antenna Elements 17
1.6.1 Conductive pathways 19
1.7 Maxwell Simplified-Further Still (Conversion Frequency to Time Domain) 19
1.8 Concept of Flux Cancellation (Flux Minimization) 24
1.9 Skin Effect and Lead Inductance 24
1.10 What are Common-Mode and Differential-Mode Currents? (Made Simple) 27
1.10.1 Differential-Mode Current Description 29
1.10.2 Differential-Mode Radiated Emission Equations 30
1.10.3 Common-Mode Current Description 32
1.10.4 Common-Mode Radiated Emission Equations 36
1.10.5 How Common-Mode Current Drives I/O Cables 36
1.10.6 Conversion between Differential-Mode and Common-Mode Currents 38
1.11 Antenna Efficiency 39
1.12 Fundamental Principals and Concepts for Suppressing RF Energy 40
1.12.1 Fundamental Principles of EMI Suppression 40
1.12.2 Fundamental Concepts of EMI Suppression 40
1.13 Hidden Schematic or Parasitics of Passive Components 41
1.13.1 Wires, Printed Circuit Board Traces and Transmission Lines 43
1.13.2 Resistors 45
1.13.3 Capacitors 46
1.13.4 Inductors 47
1.13.5 Transformers 48

2 Inductance Made Simple 51
2.1 Types of Inductance 51
2.1.1 Self-Inductance 51
2.1.2 Mutual Inductance 53
2.1.3 Partial Inductance 56
2.1.4 Mutual Partial Inductance 56
2.2 Impedance and Transmission Line Behavior Related to RF Return Current 59
2.2.1 Typical transmission line configuration 59
2.2.2 Path of Least Impedance 59
2.2.3 RF Return Current Travel in a Transmission Line 60
2.3 Inductance Concerns Related to Printed Circuit Board Layout 62
2.3.1 Loop Inductance 62

2.3.2 Loop Mutual Inductance 63
2.3.3 Decoupling Capacitor Mounting Related to Lead Inductance 63
2.3.4 Via Configuration and its Effect on Lead Inductance 65

3 Transmission Line Theory Made Simple 67
3.1 Definition of Signal Integrity with Regard to Transmission Line Theory 67
3.2 Primary Concerns Related to High-Speed Signal Integrity Problems 69
3.3 Defining Transmission Line Structures 71
3.4 Types of Transmission Lines 72
3.4.1 Coaxial cable 72
3.4.2 Microstrip 72
3.4.3 Embedded Microstrip 72
3.4.4 Stripline (Single and Dual) 73
3.4.5 Balanced lines 73
3.4.6 Lecher lines 75
3.4.7 Single-wire 75
3.4.8 Waveguide 75
3.4.9 Optical fiber 76
3.5 Description of a Typical Transmission Line System 76
3.6 Transmission Line Structures in a Printed Circuit Board 77
3.6.1 Lossless Transmission Line 77
3.6.2 Lossy Transmission Line 79
3.7 Transmission Line Effects on Signal Propagation 80
3.7.1 Conditions That Create Ringing 84
3.8 Transmission Line Termination Overview 86
3.9 RF Current Distribution 87
3.10 Analysis of RF Return Paths 89
3.11 Creating an Optimal RF Return Path 91
3.12 How RF Return (Image) Planes Work 92
3.12.1 Image Plane Implementation and Concept 93
3.13 Image or RF Return Path Violations 96
3.14 Layer Jumping–Use of Vias 98
3.14.1 Layer Jumping Concerns 99
3.15 Split Planes and Their Effect on RF Return Path Discontinuity 101
3.15.1 Digital-to-Analog Partitioning (Split Return Plane) 103
3.15.2 Using a Ferrite Bead versus Inductor in Split Plane Configurations 105
3.16 Flux Cancellation Concepts (Optimizing RF Current Return) 106

4 Power Distribution Made Simple 109
4.1 The Need for Optimal Power Distribution 109
4.2 Power Distribution Network as Transmission Lines 110
4.3 Primary Requirements for Enhanced Power Distribution 110
4.4 Defining Capacitor Usage on Printed Circuit Boards 111
4.4.1 Bulk Capacitor Description 112
4.4.2 Bypass Capacitor Description 113
4.4.3 Decoupling Capacitor Description 113
4.5 Review of Resonance (Basic Circuit Analysis) 114
4.5.1 Series Resonance 114
4.5.2 Parallel Resonance 115
4.5.3 Parallel *C*–Series *RL* Resonance (Anti-resonant Circuit) 115
4.6 Physical Characteristic of Capacitors 116
4.6.1 Capacitor Types 116

4.6.2 Commonly Used Dielectrics 117
4.6.3 Impedance Plots Based on Dielectric Composition 120
4.6.4 Effective Range of Decoupling Capacitor Familiese 121
4.6.5 Energy Storage Capabilities of Capacitors 122
4.6.6 Impedance (Actual Self-Resonant Frequency) 123
4.6.7 Resonance of a Capacitor When Installed on a Printed Circuit Board 126
4.7 Capacitors Placed in Parallel (Anti-Resonant Effect) 129
4.8 Power and Return Planes Providing Internal Decoupling Capacitance 132
4.8.1 Calculating Power and Return Plane Capacitance 133
4.9 Vias and Their Effects in Solid Planes 134
4.9. 1 Combined Effects of Plane Capacitance with Discrete Capacitors 135
4.10 Effects of ESR and ESL in Decoupling Applications 137
4.10.1 Effects on Performance-Changes in *ESL* Values 137
4.10.2 Effects on Performance-Changes in *ESR* Values 138
4.11 Planes as RF Return Path for Transmission Lines 138
4.12 Multi-Pole Decoupling Methodology 139
4.13 Effects of Proper Decoupling Implementation 142
4.14 Simplified Description of the Capacitor Brigade 143
4.15 Radius of Operation-Effectiveness of Maintaining Voltage Levels 144
4.16 Equivalent Circuit Model of a Printed Circuit Board 145
4.16.1 Transmission line (trace) inductance 147
4.17 Conflicting Rules for Printed Circuit Board Decoupling 149
4.17.1 Where do we locate a decoupling capacitor 150
4.17.2 Should we install decoupling capacitors with no components 151
4.17.3 Should we use a capacitor with high ESR or low ESR? 153
4.17.4 Relationship between capacitance value and packaging dimensions? 154
4.17.5 Should we use one capacitor per power/return pair 154
4.18 Inductance of Mounting Pads for Components and Capacitors 156
4.19 Bypass and Decoupling Value Calculation 159
4.20 Capacitive Effects on Signal Traces (Wave Shaping) 162
4.21 Bulk Capacitor Application 165
4.22 Buried Capacitance 167
4.23 Summary-Guidelines for Power Distribution Networks 171

5 Referencing Made Simple 175
5.1 An Overview on Referencing (a.k.a. Grounding) 175
5.2 Definitions 176
5.3 Defining Various Types of Grounding Systems 177
5.4 Common Grounding Symbols 178
5.5 Different Types of 0V-Referencing 179
5.6 Fundamental Grounding Concepts 179
5.6.1 Grounding Misconceptions 179
5.7 Primary Concerns Related to the Issue of Grounding and Referencing 180
5.7.1 Grounding for Product Safety 180
5.7.2 Signal Referencing for Components (AC Signals or RF Return Current) .. 184
5.8 Grounding Methodologies 188
5.8.1 Single-Point Grounding Methodology 189
5.8.2 Multiple Connections to Single-Point Reference 194
5.8.3 Hybrid Grounding 197
5.9 Controlling Common Impedance Coupling Between Transmission Lines 199
5.9.1 Lowering the Common Impedance Path Inductance 200
5.9.2 Avoiding a Common Impedance Path in the First Place 201

5.9.3 Minimizing Ground Inductance 203
5.10 Controlling Common-Impedance Coupling in Power and Return Planes 204
5.11 Breaking Ground Loops 207
5.11.1 Transformer isolation 208
5.11.2 Optical isolation 209
5.11.3 Common-mode choke isolation 210
5.11.4 Balanced circuitry 210
5.12 Resonances When Using Multi-Point Grounding 213
5.13 Signal and Ground Loops (Not Eddy Current Loops) 216

6 Shielding, Gasketing and Filtering Made Simple 219
6.1 The Need to Shield 219
6.2 Basic Shielding Equations 220
6.3 Theory of Shielding Effectiveness – Made Simple 221
6.3.1 Technical Explanation-Shielding Theory 222
6.3.2 Shielding Effects 223
6.3.3 Near-Field Conditions 225
6.4 Losses Achieved with Shielding Material 225
6.4.1 Reflection Loss 225
6.4.2 Absorption Loss 227
6.4.3 Skin Effect and Skin Depth 229
6.4.4 Reflections Internal in Thin Shields 231
6.4.5 Composite Absorption and Reflection Loss 232
6.5 Apertures in Shield Barriers 234
6.5.1 Single Apertures 235
6.5.2 Multiple Apertures 239
6.5.3 Slot Antenna Polarization 241
6.5.4 Waveguide Below Cutoff 242
6.5.5 Waveguides or Transmission Lines Between Enclosures and Systems 243
6.6 Penetrating a Shield Barriers 244
6.6.1 Proper and Improper Shield Penetrations 244
6.7 Cable Shield Grounding and Termination 247
6.7.1 Types and Applications of Cable Shields 248
6.7.2 Grounding the Cable Shields–One End or Both 251
6.7.3 Cable Shield Termination Overview–System Level 255
6.7.4 Implementing a Cable Shield into an Assembly 257
6.7.5 Terminating a Cable Shield Properly 258
6.7.6 Aspects to Consider When Specifying a Shielded Cable 259
6.8 Shielded Compartments 259
6.8.1 Board Level Component Shields 261
6.9 Gaskets-Application and Implementation 261
6.9.1 Material composition and performance 263
6.9.2 Common Gasket Material 264
6.9.3 Environmental Aspects of Gasket Use 268
6.9.4 Mechanical Problems When Using Gaskets 268
6.10 Conductive Coatings 276
6.10.1 Concerns When Using Coatings 277
6.11 Filters 280
6.11.1 What is an EMI Filter? 280
6.11.2 Insertion loss 280
6.11.3 Basic passive filter elements 281
6.11.4 Parasitics related to filter components 284

6.11.5 Basic filter configurations 285
6.11.6 Common-mode and differential-mode filters 287
6.11.7 Signal line filter configurations 289
6.11.8 Criteria in selecting an EMI filter for AC mains applications 293
6.11.9 Using ferrite material for filtering 295
6.11.10 Use of ferrite material on cables 297
6.11.11 How to select a ferrite device for use on printed circuit board traces 299
6.11.12 Feedthrough capacitor filter 302
6.11.13 Three terminal capacitor filter 303
6.11.14 Installation Guidelines for Filters 304

Appendix A – Maxwell Made Simple 307
Appendix B – The Decibel 313
Appendix C - Fourier Analysis 317
Appendix D - Conversion Tables 321
Appendix E – Glossary 325
References 339
Index 343
About the Author 343