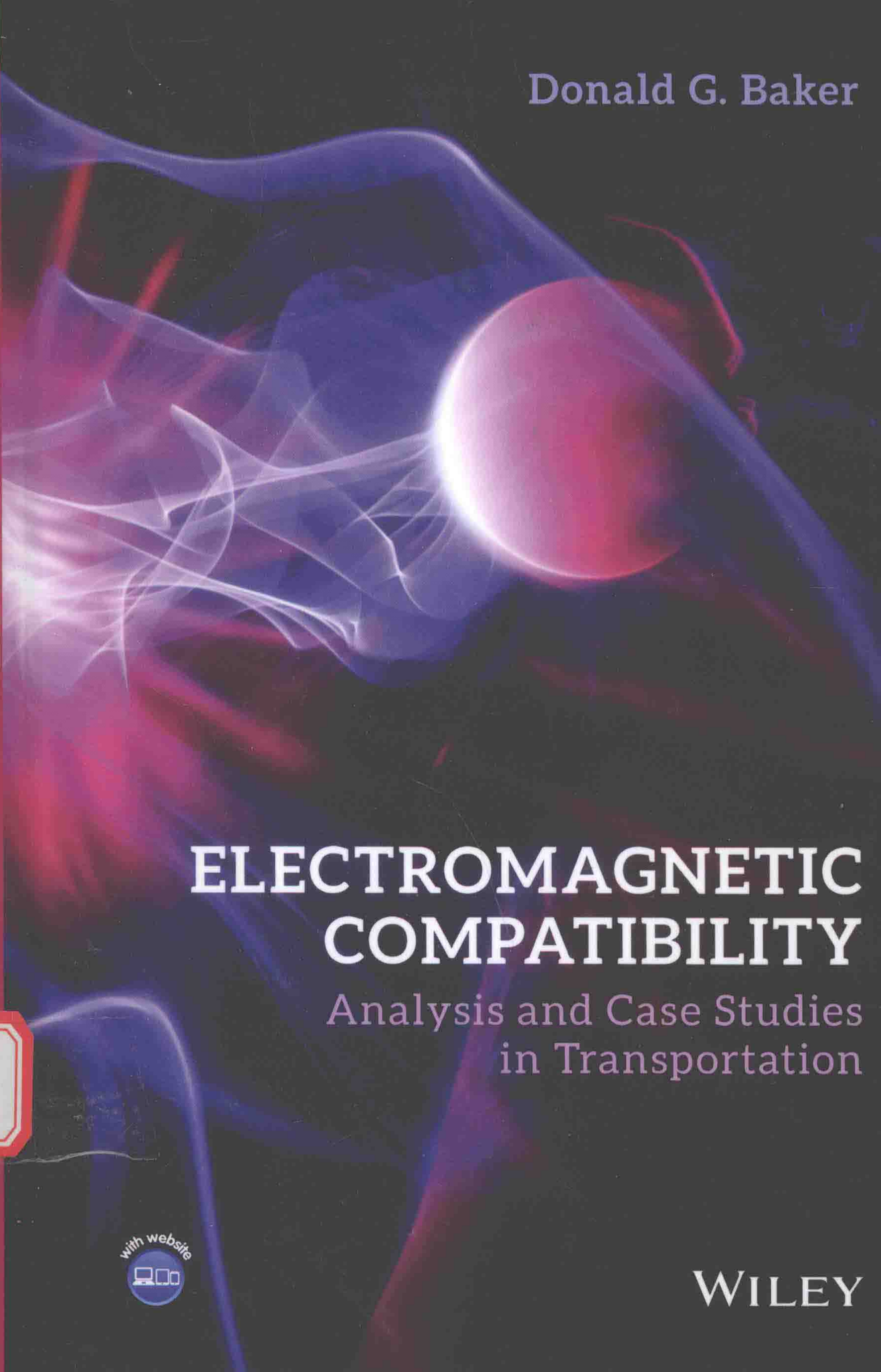

Donald G. Baker

ELECTROMAGNETIC COMPATIBILITY

Analysis and Case Studies in Transportation

with website

WILEY

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Analysis and Case Studies in Transportation

DONALD G. BAKER

WILEY

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Dedicated to:
My wife Barbara
Daughters Tricia and Stephanie
Grandchildren Aidan, Addie, Evan and Marlaina

PREFACE

A contributor to this book both directly and indirectly is my friend and colleague Dr. Kent Chamberlin of the University of New Hampshire (UNH). He was my professor while taking graduate school courses toward a PhD degree (did not finish because of health problems). He was instrumental in teaching me the finer points in vector analysis applied to EMC issues. Previously I was working and analyzing EMC problems that could be reduced to a Cartesian form of equations. These were much easier to work with than the cylindrical and spherical differential equations. Many times the wave equation was unnecessary to do an analysis. Under his tutelage I could read and study more complex books on the subject, such as the ones written by Dr. Balanis (located in the References).

This book is written in several chapters, the first being the regulations for electromagnetic emissions for electric and magnetic fields. The second chapter is an introduction to electromagnetic compatibility (EMC). This has some simple examples, as shown by illustration in equations that are necessary for a PE without previous training or a person wishing to delve into this field. The third chapter of this book catalogues the solutions to the wave equation and Maxwell's equations in Cartesian, cylindrical and spherical coordinate systems and also has several examples for the use of these systems.

The next three chapters are devoted to communication issues in transportation requiring EMC analysis. These include analysis of communication houses, signals bungalows/houses and the effects of magnetic and electric fields on the equipment inside, external radiation from licensed radios, cell phones, spread-spectrum devices, power lines, power supplies and other types of emissions that are induced on communication lines and PC boards. These chapters have many examples that can be used as a guide for the engineer in deciding how to analyze a particular anomaly caused by electric and magnetic fields. As emphasized previously, never try to overextend an analysis of frequency airspace without knowing the limitations of the equations. One must always keep vigilant when understanding that the equations are only a tool and would be equivalent to a mechanic using a hammer to remove his spark plugs.

The seventh chapter of this book is related to health and safety issues and catalogs many of the safety issues that must be observed due to electromagnetic emissions, with examples. In each of the chapters of this book, problems are provided at the end of the chapter to reinforce the knowledge gained by studying the chapter. Answers are provided at the end and in many cases the answers are provided with equations with the numbers shown so as to guide the engineer reading the chapter to a result and in some cases the engineer can use the equations by just changing the numbers slightly.

The eighth chapter of this book has miscellaneous documents and functions that may be useful in generating or answering a requirements document in transportation with a report, as is often required. More often than not, test results are required for the EMC analysis until the integration phase is complete. Then, only if an EMC issue occurs after commissioning, all test results are released and generally can be found in DOT documents. During the 1980s when working in research and not in systems, test results were usually required for EMC analysis for military-type projects. But most commercial and consumer products require test results that must be provided to the FCC, usually through test laboratories, such as Underwriter Laboratories, if the company producing a product does not have facilities for testing. Since all the products installed in the system must be FCC approved, with care no emissions will be present due to the system. Often the analysis is only a guide used by the system engineer to prevent anomalies from occurring.

The ninth chapter deals with signals and tracks and the effects of electromagnetic emission signals, both from track and signals. For each of these entities examples of signals equipment functions and how these affect communications is the object of this study. Signals equipment operates using both copper and fiber optic networking and rails function similar to transmission lines and these are low-frequency communications on the rails themselves. However many new spread-spectrum devices are used in signals for conveying information from the rails to the operational control center (OCC). Examples of signals are provided at the end of the chapter, as mentioned previously, to reinforce the knowledge of the person studying EMC effects.

The last chapter of this book provides useful examples that may be used in EMC analysis. These consist of both equations and situations where these anomalies may be examined. These not only apply to communications and transportation but can be generally used for other analyses as required. The audience will find that some of the information in this book is used for other EMC analyses outside the realm of transportation, such as emissions within the home that may be causing EMC issues, the design of cabinets and enclosures that require strict EMC shielding from emissions both internal and external, the automotive industry where harsh environments with radiation emission is present from electric car drives, ignition systems, GPS, emissions from cell phones, wireless games, shielded buildings with security issues, navigational aids emissions, airports and many others that are outside the realm of how this book may be used. There is a course that was originally a one-week seminar in PowerPoint for PEs that is now available at www.wiley.com/go/electromagneticcompatibility. This PowerPoint presentation is meant for the layman and is not heavily involved with vector analysis.

Donald G. Baker PE

ABOUT THE AUTHOR

Donald G. Baker began his experience in 1965 at the Motorola Corporation after graduation from the Illinois Institute of Technology with a BSEE in electronics. Motorola required that each engineer with less than one year's experience attend their plant school. The first design project was a 70 MHz phase lock loop for a Tract 92 Tropo-Scatter Radio System. At this time a transistor design at 70 MHz was an advanced project. The next design with some patents was a military grade audio signal generator for Holt Instrument with the patent for the feedback circuit in 1968.

The next series of designs was for the Magnaflux Corporation from 1968 until 1972: during which time the following equipment test equipment was designed: (i) a conductivity meter requiring a patent for the bridge circuit (one of these meters is used as a federal standard for calibration of conductivity meters), (ii) an ultrasonic crack detector with a oscilloscope type readout designed for detecting cracks at one-10 000th inch below the material surface, (iii) a meter type and (iv) an ultrasonic crack detection unit for large cracks below the surface that did not require the accuracy of the initial crack detector.

The next series of designs were for the Sundstrand Corporation (machine tool division). The author obtained a MSEE from IIT night school in 1972 and worked from 1972 to 1978 on the following design projects:

1. The control system for the Clinch River Nuclear Breeder Reactor for refueling. This design required using an analog computer design of differential equations that were sampled and converted to digital format for the government of the refueling system as a safety precaution. The plug drives for alignment to the fueling grapple were all controlled by a digital computer composed by the Digital Equipment Corporation (DEC).
2. The design of a six phase motor to be used for a spindle drive at 75 000 rpm to be used on milling machines.

3. Transistorized H drives to be used for the digital control of milling machine positioning.
4. An ultrasonic method for correcting spring-back in milling machines to increase accuracy.

The author was employed by EXTEL Corporation designing audio modems from 1978 to 1979. While employed by Microtek, 1980 to 1982, he designed a telephone caller ID system for analog phones using spread-spectrum technology. During employment by MIT Research (MITRE) from 1982 to 1990, he worked on several projects that are classified as secret and cannot be divulged at this time. Even their titles are secret; however most of the designs were used for fiber-optic networking. Employment from 1990 to 1991 with the Deleuw Cather involved EMC analysis and reliability work.

Employment from 1991 to 2013 was for the SESCO, Harmon and GE Corporations. This was all at the same workplace as the various companies changed hands but the work remain the same. The author's tasks were as follows: (i) analysis of all EMC issues for transportation communications and sensor systems, (ii) reliability studies, (iii) maintainability studies and (iv) communication computer timing issues. The last work while retired is writing this book from March 2013 to March 2015 for the first iteration of the manuscript. Miscellaneous work from 1966 to 1968 was teaching elementary courses in electronics and instrumentation at high schools and from 1972 to 1990 teaching as an adjunct professor at several junior colleges and graduate schools.

Several of the corporations where the author was employed were involved in mergers or went out of business completely; but some of the information about the author's work can be found in the author's books on fiber optics written in 1985, 1986 and 1987.

ABOUT THE COMPANION WEBSITE

This book is accompanied by a companion website:

www.wiley.com/go/electromagneticcompatibility

The website includes:

- PowerPoint slides for PEs based on an Electromagnetic Compatibility EMC Seminar
- Appendix A

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1

INTRODUCTION

1.1 INTRODUCTION

This book presents a vast number of areas of industry beside transportation. Transportation is one of the harshest environments for communications. Electromagnetic compatibility (EMC) is in most of the industrialized world today. As computer and other electronic components get smaller, the need for EMC analysis and testing becomes more acute. Systems are generally designed and built with components that meet or exceed requirements for emissions. However, a piece of equipment may pick up extraneous noise from emissions through a host of poor practices in grounding and wiring.

The engineer designing system components must be vigilant during the design phase to check for emissions during prototyping, production and final design phases. The closer to final product the component gets, the more expensive becomes the correction in design. As an example, a circuit board design with a poor layout can be very costly in the final stage of design. While doing consulting work, the author was asked to help a particular manufacturer get a production board into production. The board had so many defects that the FCC sent a notice the equipment could not be connected to telephone lines. The solution was not very simple. The designer did not have the correct isolation transformer and the output and input lines were not separated sufficiently to maintain the isolation. There were many other problems with the design but the point is the printed circuit (PC) board had to be redesigned and several optical isolators added to complete the design.

The case studies are the result of several analyses required to satisfy the various State Authority Requirements. More often, the testing is part of the overhaul testing of the final systems during commissioning of a transportation system. The analysis brings to light some of the EMC issues that may arise. Often the specification sheets

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Donald G. Baker.

Companion website: www.wiley.com/go/electromagneticcompatibility

for system components such as amplifiers, radios signals equipment and so on will have certain minimum Immunity Requirements that the system component must operate under with no effect in performance.

1.2 DEFINITIONS OF COMMONLY USED TERMS

Electromagnetic Compatibility (EMC) This is the ability of equipment, systems or devices to operate without deficiencies in performance in an electromagnetic environment. The system, equipment or device must also be non-polluting to the electromagnetic environment, that is it must not have emissions (both radiated and conducted) that affect other systems, equipment or devices. The electromagnetic environment is composed of both radiated and conducted emissions.

Susceptibility This is the ability of a system, equipment or device to respond to electromagnetic emissions interference. The emissions may be either radiated, conducted or both. Susceptibility is noise that affects the performance of system, equipment or device.

Immunity The ability of equipment to operate with the required performance in the presence of electromagnetic interference noise.

Electromagnetic Interference (EMI) Electromagnetic Interference (EMI) is noise due to electromagnetic energy through emissions, either radiated, conducted or both. This does not include distortion due to non-linearities in the system, equipment or device.

Radio Frequency Interference (RFI) This is radiation due to intentional and unintentional radiators. The limits are shown in the tables presented in the sections on standards.

Culprit This is the source of the emissions that result in a reduction in performance of the victim equipment, device, circuit or system. The culprit can be manmade or extraneous signals from galactic noise.

Victim This is the device, equipment, circuit or system that is affected by the culprit. It depends on the coupling from the culprit. Coupling can be due to electric fields, magnetic fields, poor grounds, lack of proper supply filtering or combinations of these.

Supervisory Control and Data Acquisition (SCADA) System This system monitors and controls complex equipment. It automates the complex system with control and monitor functions at an operation central control (OCC) room. A simplified version of the control room is shown in Figure 1.1. The project configuration is a large display the size of a wall in the OCC, that is 9 × 14 feet. The display shown in

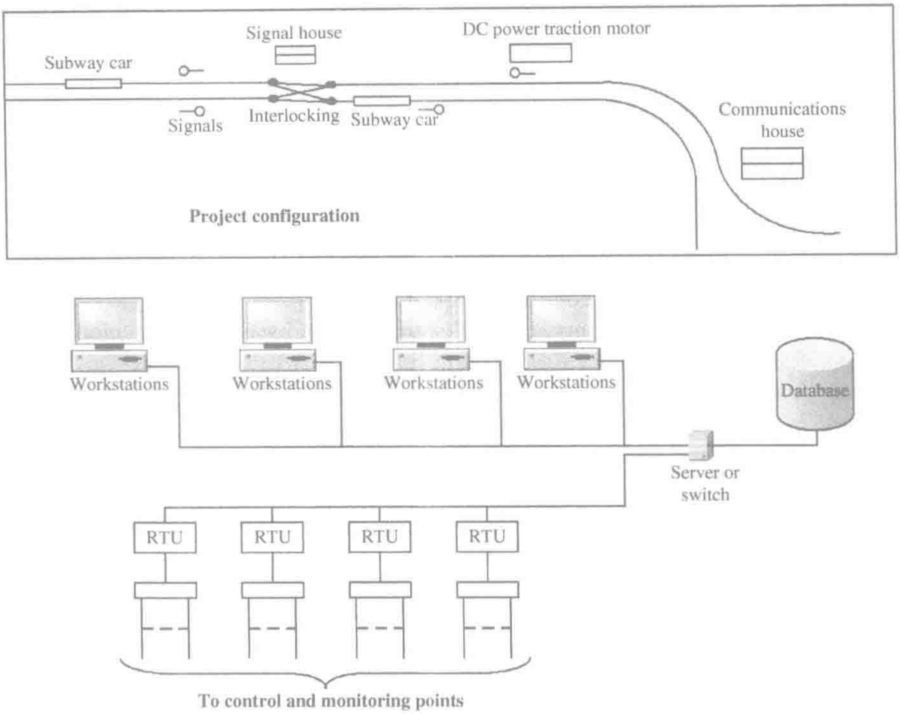

FIGURE 1.1 Operation control center simplified wall project display and workstation layout

the figure is only an example of what might be shown on the actual display. It may have as many as 15 or 20 interlockingss and signal houses and 10–12 communication houses in many miles of track, all displayed on this one board in symbolic form. It is the whole subway or bus system that is displayed. It may also have highway crossings shown with crossing gates and warning lights. The signals shown are positioned along the rails showing the direction of the traffic flow. The DC power supply houses for traction motors are shown. There may be many of these also depending on the project size. In the actual display the subway cars are shown moving in various directions and the display may indicate flow against the signals traffic. This is controlled from the OCC.

The workstations are arranged connected to a central server. Generally two servers are connected in tandem (one is a backup for the other). The primary runs the functions and the secondary shadows the primary. In the event of a failure an automatic switch over to the secondary occurs so that the service is restored; this provides a failsafe operation. Each of the workstations generally has the same software but some are dedicated to maintenance personnel, others are traffic control and one is dedicated for managerial functions. They all have logon passwords and the managerial station may have a lock to prevent tampering, with further identification functions so that only personnel with the correct credentials can use the workstation.

A large database holds information in the archives that are used later for statistical purposes and record the maintenance functions that have been performed on the equipment in the field. The network connects the workstations to the server and this is all done with fiber optics. The connections between the server and/or switch and the remote terminal units (RTUs) have a fiber optic self-healing ring with a SONET unit that connects several RTUs to a single node on the network. As can be observed, Figure 1.1 is a very simplified version of the communications between the control and monitor of devices. More details on the communications network are shown in Chapter 2 under the heading communications.

All OCCs have a backup control room, not in the same building. In the event of a catastrophe these control rooms are smaller and will not have all the functionality of the major control room. They have enough functionality to keep the subway or bus system functional if the main control room is damaged or destroyed. The backup control room will have a limited number of workstations, usually about half the number of the main control room. It will have an alternate site server/switch with the backup function of the main control room. As can be observed, signals carry the signal house data via RS 232 or RS 422 fiber optic connections to the communication house to be transported to the OCC for updating the project configuration screen. Occasionally in large systems a heartbeat is required from each RTU to determine if data is there and needs to be transported to the OCC. The heartbeat is a polling method for the RTUs. Some systems have interrupts instead of the heartbeat; this is all embedded in the software at the server/switch. The reason for designating a server/switch is some systems are small and only require servers; others are very large and require a switch and server.

Remote Terminal Unit (RTU) These units interface to objects and equipment that either monitor or control pieces of equipment such as radio systems, PA systems on platforms, visual displays on platforms, ticket collection, pumps, ventilating fans in tunnels, fire and intrusion alarm systems, power for communications and traction power supplies. This unit is also equipped with a programmable logic controller (PLC).

Programmable Logic Controller (PLC) These controllers are used for signals. They monitor and control interlockings and signage along the right of way, monitor headway between subway trains switch and control block information and other functions that are necessary for signaling.

The Communications Network The simplified workstations shown in Figure 1.1 have more than one display, usually from three to four depending on the size of the project. The reason being that dispatchers can magnify a part of the network shown on the display board for use on his/her part of the rail system. The dispatcher also has a two-way radio to be used to communicate directly with the motorman and conductor on the subway. In the event of a complete failure of the network, the dispatcher can keep in touch with the motorman and conductor via the radio system. Sometimes both radio and network are used simultaneously, depending on the traffic on the system, that is during rush hours or emergencies.