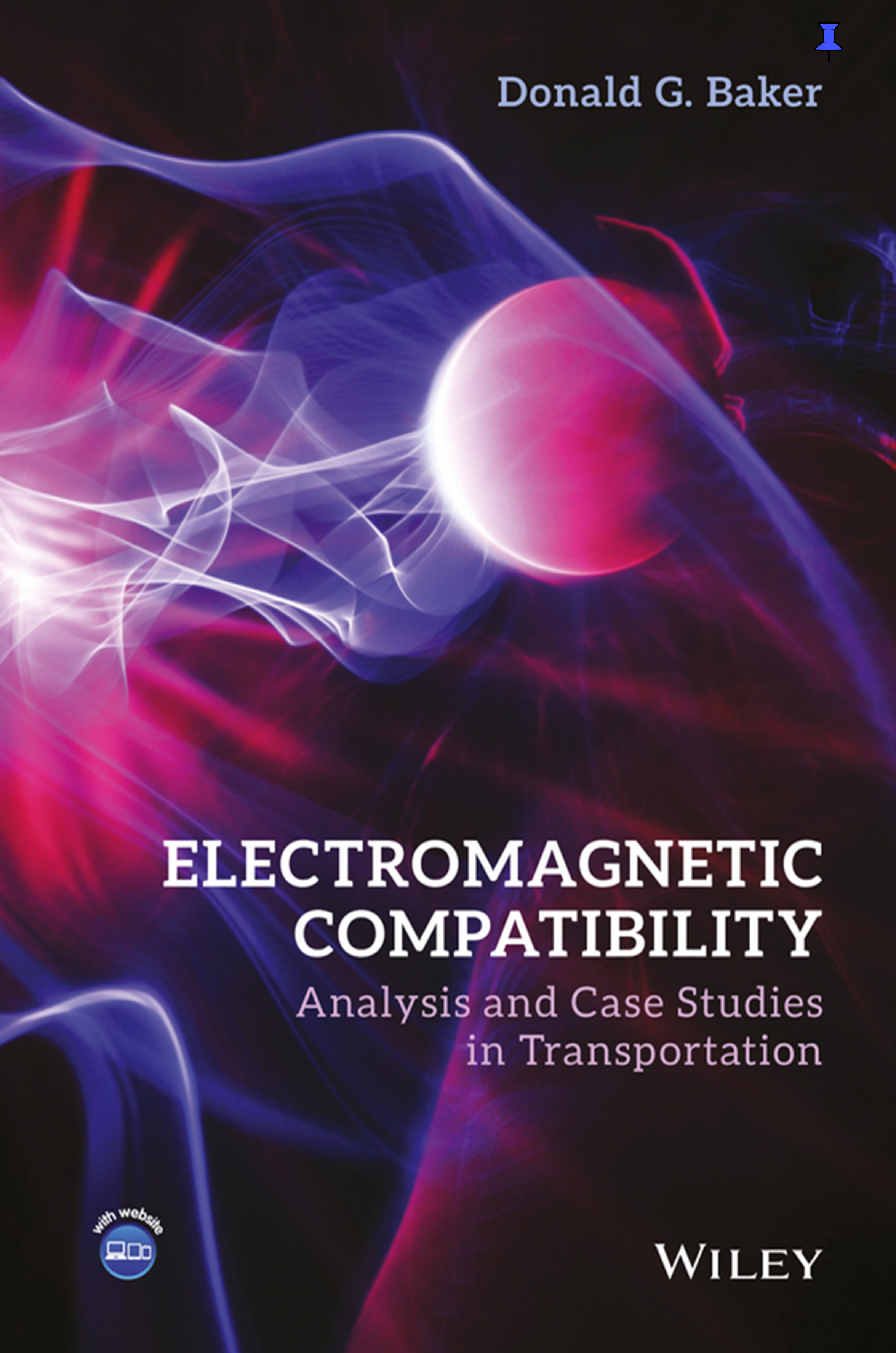

Donald G. Baker

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

CONTENTS

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

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

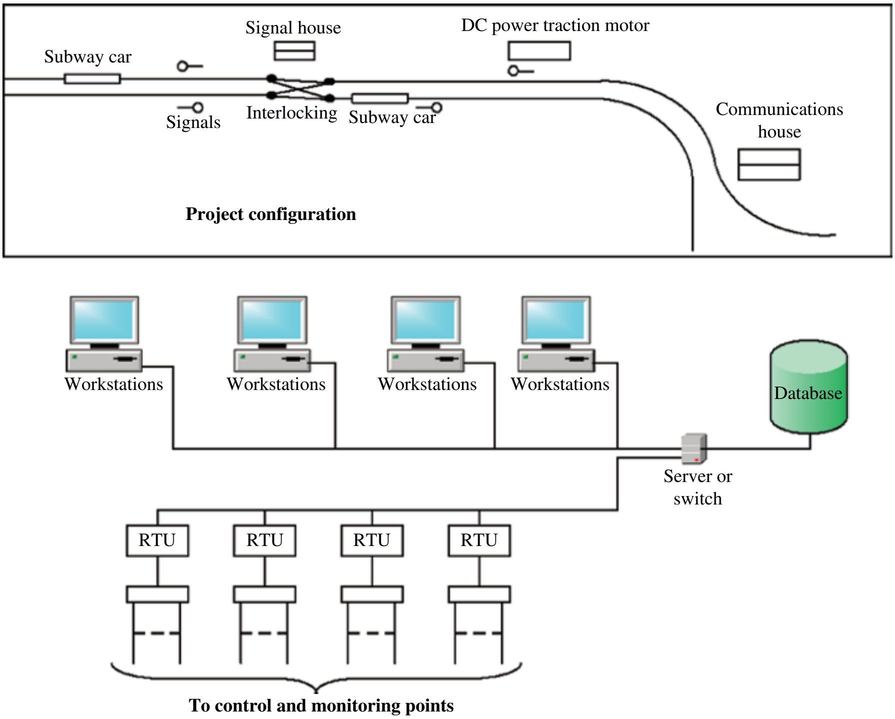

FIGURE 1.1 Operation control center simplified wall project display and workstation layout

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.

Synchronous Optical Networking (SONET) The SONET network is composed of two counter-rotating rings, as shown in Figure 1.2. The rings carry data in both directions simultaneously. This particular network has a total of 25 nodes. The head end nodes are connected to the primary OCC and backup OCC or as shown in the diagram. If a break should occur in the cable or if a node is damaged it may be removed from service and a single ring will exist that supports the other 24 nodes. Automatic switching occurs within SONET nodes that allows self-healing of the ring. If two nodes are damaged and taken out of service the ring will form two islands, that is two separate single ring nodes. Most of the newer installations have high-speed rings, for example OC-768 or the equivalent STM-256 have a transmission rate of 38.5 Gbits/s. The base rates of OC-1 and STM-1 are 51.84 and 155.52 Mbits/s respectively. All of the others are integer numbers of these base rates. All of the data from the various houses and cabinets are transported by the SONET nodes to the OCC and backup OCC. The nodes arrange all data in a digital form and arrange it in frames to perform a seamless transmission network. The bandwidth used by most authorities is much greater than necessary in most cases; they plan for large expansions that occasionally never come. Occasionally another ring is added in a gateway or a switch is used to produce a much larger ring topology.

The RTU connections are all bidirectional. They may either have fiber optic modems or be wired with copper cabling. A listing of the network functions is shown in Table 1.1.

As can be observed in Table 1.1, the communications system is not only for voice and data. It is used for command and control of the entire subway system. As a

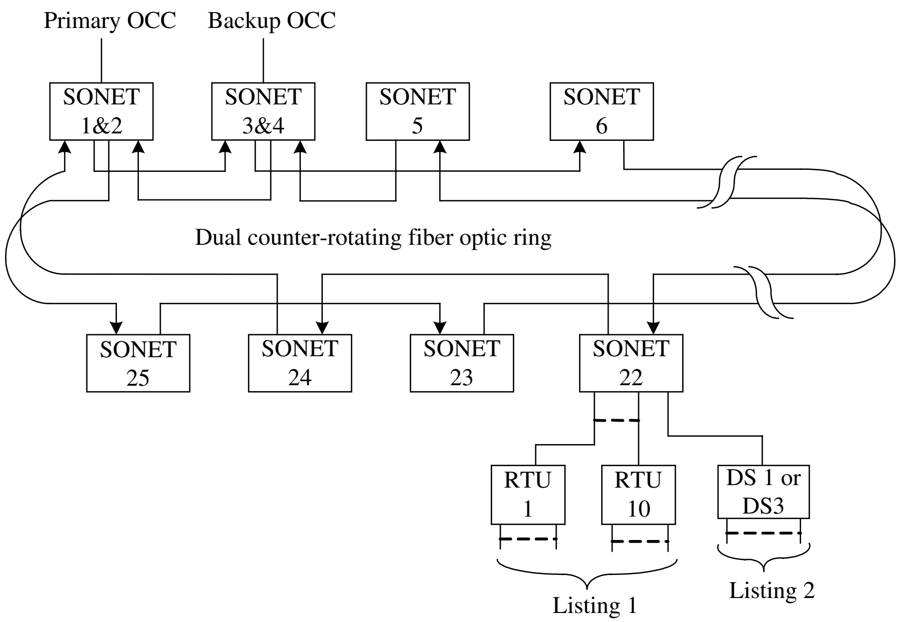

FIGURE 1.2 Network to connect all RTUs to the OCC

TABLE 1.1 Functions of Equipment in Houses, Bungalows, Cabinets and Stations Along the Right of Way

Equipment	List 1	List 2
Station platform RTUs	PLC and SCADA equipment	Telephone services
	Station communications	Emergency telephone
	Security alarms	Police Department emergency line
	Fire alarms	Fire Department direct line
	PA system control	Fare collection
	Camera monitoring	
	Parking lots camera monitoring	
	Camera control	
	Communication outage	
Communication house RTUs	AC power to the house	Telephone and extension service
	Fire alarm and suppression such as Halon gas	Fire Department direct line
	Security alarm	
	Communication outage	
	Battery monitor for Uninterrupted Power Supply (UPS)	
	UPS monitor and control	
	Emergency panel switch over	
	Smoke alarms	
	Heat alarms	
	Backup portable generator for longtime outage	
	Ventilator fan control	
Data from signal houses	Data is from vital and non-vital logic	Signal house telephone and extension
Tunnel data	Monitor and control of several vent fans in tunnels	
	Damper monitor and control in tunnels	
	Sump pump and water levels and controls in tunnels	
	Carbon monoxide level monitors in tunnels	
	Fire and smoke alarms in tunnels	

(Continued)

TABLE 1.1 (Continued)

Equipment	List 1	List 2
	Stations in tunnels of monitor and control similar to his above ground stations	
	More attention is communications houses built into tunnels i.e. extra security measures	
Data from traction power houses	Data points for control and monitoring are regulated by the DC power contractor.	Traction power house telephone and extension
Cabinets on the right of way	Signals equipment monitoring and control	Telephone service
	Audio equipment monitor and control	
	Parking lot displays control	
	SCADA equipment to monitor and control all cabinet equipment may/may not have a local RTU in the cabinet	

backup for the dispatcher, all of the subsystems have a backup by some means so that failure is always circumvented by a backup of some means. Most AC power is provided by multiple substations in the event of AC power failure. EMC is a very important aspect of the communication systems because all data is stored at the OCC and backup OCC. This is required to analyze failures using all this data to determine cause, affect and the necessary maintenance to prevent future failures. Since most of the internal wiring of a station's electronic enclosures are wired in copper, EMI emissions are always present but at a very low level if precautions are taken during the design and installation of the various pieces of equipment.

The SCADA system is similar to the nervous system of a human body. It monitors the health of a particular subsystem such as the PA system and it makes corrections or circumvents a failure. The data is all sent to the OCC that functions similar to the brain of the system. The SCADA system has analog inputs that monitor such items as radio signal strength with a set-point that will result in an alarm if the signal strength drops below a certain level or the noise level is excessive. It also monitors temperature but is also an analog function with set-points that will send an alarm to the OCC if the temperature cannot be controlled, such as air conditioning or heating system failure.

RTUs, vital logic and non-vital logic for signals all have the latter logic embedded when programmed. They use relay contacts similar to the old-style relay logic used in older installations. This relay logic is not physical; it is all done in the software and the design engineer uses the logic as it would be employed for physical relays. The software in this equipment pre-processes the data points and a series of digital coded words are sent to the OCC indicating the health of the particular area being monitored, such as station platforms, communication cabinets along the right of way, signal house data, traction power supply and mechanical maintenance data from tunnels.

The OCC and backup OCC each has two SONET terminals. This allows them each to monitor the network in both directions. A complete failure of either of these SONET nodes will allow control by the surviving node. The RTUs implement a host of other monitor and control functions, such as grounds maintenance around the buildings and in shop areas where maintenance is being performed on subway cars. Building functions such as such as fire alarms, security systems, card swipe units, interlocking doors, cameras and camera controls are all monitored and controlled in the central control room.

Security is very strict in these OCC areas. Everyone must wear a swipe edge badge with a picture. For obvious reasons it is an ideal place for vandals or terrorists to do damage and bring down the subway system. Even some office space is highly restricted, such as where the database computers or the telephone system are kept. In some office spaces some canned messages are produced to send out both with audio and video information to PA systems and display units and stations. These of course cannot be compromised to show unauthorized messages that may even cause panic at stations; this is especially true in tunnels.

Elevators at the OCC are monitored by cameras and the data is sent back to a security workstation which is equipped with several displays, including those for stations. The operator at any time can control the camera to look at a particular event and report his findings, for example vandalism on the platform or assaults. The same holds true in tunnels where accidents may be observed and recorded and saved in the event of litigation. In this section the author has provided the reader with a good overview of how the communication system functions. This allows the reader to understand where all the EMC issues may occur.

1.3 BOOK SECTIONS AND CONTENT OVERVIEW

This book is divided into five sections. The first is introduction and standards; this includes FCC, CSA and European Union standards. Some of the testing techniques are also presented to introduce the reader to facilities that will be necessary to conduct the testing. The techniques for testing are not cast in stone. Standards are living documents that must be checked before designing systems, equipment or devices. Usually the changes are minor but these subtle differences may result in costly fixes later.

The second section is devoted to the coupling between victim and culprit circuits or equipment in general. These fundamentals are used throughout the book. It may be a refresher to some readers; however, the presentation makes the book easer to read.

The third section of the book is a discussion of Maxwell's equations and the wave equations and solutions that will be used throughout the case studies. The derivation of the solutions will not be shown in detail. References are provided to assist the reader who desires to observe how the solutions were derived. In some of the case studies a derivation will be provided, but this will be on a case by case basis.

The fourth section of the book is the largest. It involves past experiences of the author; there about 20 case studies in all. These have all been in the transportation industry. They generally deal with communications in a harsh environment. The case studies are rather diverse and can be applied in other industries as well. One such case is: shielding of a communication house due to the rebar embedded in the concrete. This same technique can be used to shield a building. Some structures that may require security can use these techniques for shielding with a little modification required for the windows and vent. The tunnel case study has applications where confined spaces have RF devices used such as cell phones and Bluetooth devices, such as the automotive industry. Radio engineers analyzing antenna farms on buildings can use some of the case studies as a guide. Subway car case studies have wideband transient analysis that can be applied to the steel industry with its overhead cranes, rolling mills, electric furnaces, shears, arc welders and other equipment where arcing may be present.

The aircraft industry engineers may use some of the information provided in this book. Present-day aluminum skin aircraft provide a good ground plane for most electronics. The newer composite aircraft may require more shielding and filtering of electronic equipment. Radiation coupling between suites of equipment can result in a degradation in performance. The transportation, rail and bus systems have similar grounding problems.

Medical facilities with electronic instrumentation engineers can use some of the case studies, such as tunnel applications. Tunnels have leaky coaxial cable to extend communications underground. The same leaky cable can be used in hospitals with microcellular phones.

The fifth section is radiation exposure safety issues for maintenance and public exposure. This will be discussed briefly and tables with exposure limits provided. A particular case is provided in the case studies. This is a case study in a tunnel.

Table 1.2 is a short list of emission sources that can lead to device, equipment and system failure or performance degradation. The first five are radiation sources due to radio transmissions; several are analyzed in the case studies. The primary part is how these sources affect the performance of various equipment and systems. Most of the devices used in transportation will have a fairly good immunity, but equipment and systems have a means of implementing either cabling or wireless communication.

The sixth and 15th sources are due to computer emissions. These are in some cases very difficult to analyze, due to a combination of radiated and conducted emissions. In a particular situation, there were two open racks (one with fiber optic communication equipment, the other with a VHF police radio). The clock for the communication equipment happened to be near the VHF radio band and, when the radio was keyed, the communication link began to drop bits. As computer device clock speeds get higher they also increase their emissions for radio and other wireless communications.

TABLE 1.2 Conduction and Radiation Emission Sources

Item	Description of source	Remarks
1	Radio transmitter broadcasts	AM and FM band radios
2	Communication narrow band radio	Two-way handheld and base station
3	Cell phones	Phones and towers
4	Wireless devices	Low level radiation, mW region
5	Radars	Weather, military and handheld
6	Receiver local oscillators from computers	High frequencies, 1–10 GHz
7	Motors	Brushes and commutation
8	Switches	Arcing
9	Fluorescent lights	Harmonics
10	Light dimmers	Track switches, phase control
11	Diathermy	Track switches, phase control
12	Dielectric heaters	Track switches, phase control
13	Welders	Arcs
14	Subway centenary and hot rail	Arcing
15	Engine ignition	Radiation from spark plug wires
16	Computer peripherals	1–10 GHz switching
17	Lightning	High rise time pulse and energy
18	Galactic noise electrostatic discharge	Space communications
19	Electromagnetic pulse (EMP; nuclear blast)	Not discussed

Sources 8–14 are due to transients. These of course are in some cases very difficult to analyze due to intermittent behavior. A transient will generally need to be analyzed with a storage device unless it is cyclic. However, the random case is usually the type that most often occurs. The case studies have some transient analysis included as part of the analysis.

1.4 REGULATIONS

Regulations are living documents, that is they are continually changing. The designer that is working on a system, equipment or device must look up the regulations to ensure compliance at the time of the design. If there are regulation changes after the design is completed, there is generally a time span before the change takes effect.

1.4.1 United States FCC Regulations

FCC Part 15 radiation regulations are represented in Tables 1.3–1.5. These are radiated emission limits for systems, equipment and devices. These limits are in terms of electric fields (E). The full range of the radiation measurement is from 9 kHz to 3 GHz.

The tables can be found or generated using CFR 47 Regulations Part 15, which has a wealth of information for EMC design. The regulations provide guidance in several areas for obtaining FCC certification.

Some of the tables in this section of the book may not appear to be very useful. However, the various emission tables will provide the EMC practitioner with a lead on where to look for possible culprit sources. For example wireless devices are now very widespread and Table 1.8 provides the frequency range for these devices. When investigating a particular problem that appears to be related to radio, FCC subparts C, D, F and H can be examined if the problem appears to be related to radio communications. Tables are not provided in these sections to prevent the book from being outdated at the time of printing. The frequency spectrum allocation is continually modified by various users.

The remarks column FM 88–108 MHz radio can cause interference for very sensitivity devices. The station power is under very strict licensing; shielding or filtering in most cases will be required.

CB radios have limits but they are sometimes violated when the culprit transmitter has higher gain ("linear amplifiers called foot warmers") than allowed by FCC rules, or very high gain antennas. Generally the FCC will impose fines for these types of installations.

TABLE 1.3 FCC Emission Limit Regulations Measured at 3 m

Frequency (MHz)	Class B magnitude	Class A magnitude	Remarks
30–88	(28.9 μV/m) 29.5 dBμV/m	(100 μV/m) 40 dBμV/m	FM, CB band
88–216	(44.7 μV/m) 33.0 dBμV/m	(150 μV/m) 43.5 dBμV/m	FM, two way radio
216–960	(59.6 μV/m) 35.5 dBμV/m	(200 μV/m) 46.0 dBμV/m	Two way radio, CellP
>960	(298 μV/m) 49.5 dBμV/m	(500 μV/m) 54.0 dBμV/m	Wireless dev

TABLE 1.4 FCC Emission Limit Regulations 9 KHz To 30 MHz

Frequency	Electric field	Measurement distance (m)	Remarks
9–490 KHz	2400/f μV/m	300	AM L band
490–1705 KHz	2400/f μV/m	30	AM U band
1705 KHz to 30 MHz	30 μV/m	3	Multiple bands

TABLE 1.5 FCC Emission Limit Regulations Measured at 10 m

Frequency (MHz)	Class B magnitude	Class A magnitude	Remarks
30–88	(28.2 μV/m) 29 dBμV/m	(90 μV/m) 39 dBμV/m	FM, CB band
88–216	(47.3 μV/m) 33.5 dBμV/m	(150 μV/m) 43.5 dBμV/m	FM, two way radio
216–960	(59.6 μV/m) 35.5 dBμV/m	(210 μV/m) 46.5 dBμV/m	Two way radio, CellP
>960	(149.6 μV/m) 43.5 dBμV/m	(300 μV/m) 49.5 dBμV/m	Wireless dev

Two-way radios can cause interference due to their mobility. VHF and UHF radios and cell phones are always a source of noise. They are all licensed radiators and must be used prudently to prevent interference problems. As an example, a measurement was taken in a Paris subway station at rush hour. The noise produced by cell phone transmissions produced sufficient noise to disrupt train communications.

The emission limits apply to unintentional radiators the remarks column in Table 1.3 is to remind the audience that intentional radiators can be present. These must be measured, if present, and not be part of the measured emissions. Open air test systems (OATS) are discussed in Section 1.6 *EMC Testing Methods*. All radio signals can enter though grounds, power supplies, radiation (when a product has an extraneous projection acting as an antenna) and induction (where magnetic fields can couple into circuits). Coupling techniques are discussed in Chapter 2 with examples.

Two different distances are provided in the tables, for tests to making comparisons between Classes A and B. The distance of 3 m can easily be extrapolated to 10 m using Equation 1.1. The reason this is possible is the 3 m dipole used to measure 30 MHz is outside the near field limit $2*(\lambda/2)^2/\lambda$ or 2.5 m.

$$\Delta_{10} = 20 * (1 - \log 3) = 10.46\,\text{dB} \qquad (1.1)$$

FCC part 15 is divided into subparts as follows:

1. A General information
2. B Unintentional radiators
3. C Intentional radiators
4. D Unlicensed personal communication devices
5. E Unlicensed national information infrastructure devices
6. F Ultra wideband operation
7. G Access broadband over power line wideband operation
8. H TV band devices.

Equation 1.1 is the result of the electric field reduction as a function of 1/r where r is in meters. Class B for digital or analog and digital devices are more stringent than Class A. This classification of limits is for residential environments where emissions