Newnes

INCLUDES

FREE
NEWNES ONLINE
MEMBERSHIP

PLATFORM INTERFERENCE IN WIRELESS SYSTEMS

Models, Measurement, and Mitigation

- Addresses a growing problem in RF/wireless devices–interference created inside the devices, which impair their operation
- Covers devices, ranging from laptop PCs to mobile phones to Bluetooth headsets
- Explains the sources of such intra-system interference, how to detect and measure such interference, design techniques for mitigating the interference, and proven techniques for eliminating the interference

Kevin Slattery / Harry Skinner

Platform Interference in Wireless Systems

This page intentionally left blank

Platform Interference in Wireless Systems

Models, Measurement, and Mitigation

Kevin Slattery & Harry Skinner

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Newnes is an imprint of Elsevier

Newnes

Newnes is an imprint of Elsevier
30 Corporate Drive, Suite 400, Burlington, MA 01803, USA
Linacre House, Jordan Hill, Oxford OX2 8DP, UK

Library of Congress Cataloging-in-Publication Data
Application Submitted

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

ISBN: 978-0-7506-8757-7

For information on all Newnes publications
visit our web site at *www.books.elsevier.com*

07 08 09 10 10 9 8 7 6 5 4 3 2 1

Printed in the United States of America

Contents

Preface

This book has been written with the practicing EMI engineer in mind. To that end, we have eschewed much of the usual mathematical development, providing only the aspects of theory that we think will help to advance the story and provide a means for readers to develop their own intuitions and perspectives. Where necessary, we have laid out the mathematics we used to develop our ideas and approaches. We have included in the appendices all code that we used toward model building and analysis. We have primarily relied upon Mathematica (Wolfram Research) and SystemView (Agilent). We assume that some readers will use the code to write their own routines in other systems.

For a long time, this work has been in piecemeal gestation for both authors. The entire work came together rather quickly in the end, and we wish to make it clear that any errors in text are purely our own.

This page intentionally left blank

CHAPTER 1

Introduction

1.1 Setting The Scene

With the advent of mobile computing, wireless communication has become an integral part of the computer platform. Who would now consider buying a laptop without wireless? At the same time, the once simple communications devices such as cell phones now have functions that require subsystems ordinarily associated with computer devices. So what's the big deal? The problem is that these devices were never intended to coexist. Communications devices were not designed with high-speed digital logic in mind. High-speed digital logic never included communications as a design vector. The end result is that these devices don't work well together, so much shoehorning is currently undertaken to make them cohabit in the same device. This shoehorning generally incurs costs in terms of product delays and additional mitigation solutions. It is a sobering thought that 3 dB of noise can reduce the performance of your communications system by 50%. It is even more sobering that 20 or even 30 dB of noise is common on some devices. This book has two main intentions:

1. To provide an education about the principles of radio frequency interference (RFI).
2. To provide a reference source for identifying noise-related issues and mitigating them in your current or future system design explanation.

When considering what we should name this book, many titles came to mind. We wanted to capture the uniqueness of the topic while communicating the essence of the book. Interference as a topic is overly broad. In the EMI/EMC world, interference is a system-to-system or environment-to-system phenomenon. Similarly, in the wireless world, interference can be one wireless system to another or a consequence of environment. Electromagnetic interference, or EMI, is measured in field strength (dBμV/m, or decibel ratio referenced to 1 microvolt per meter). In wireless, receive signal strength is a measure of power and is calculated using dBm (or decibel ratio of watts to 1 milliwatt). It is interesting to note that these two seemingly distinct and separate disciplines are so similar yet so different. This book is an attempt to bring these worlds together. You may ask why this is necessary and why now. The answer is quite simple.

In the mid 1990s, computer systems (classified as *unintentional radiators* by the Federal Communications Commission [FCC]) operated in the hundreds of MHz, and wireless functionality as part of a computer wasn't even a glimmer in someone's eye. Laptops were a fairly new device—an evolutionary development of the "luggables" of the early 1990s. Wireless communication (as a mobile feature/device) was essentially limited to cell phones, which were similar in many ways to these luggables. However, this has changed in the last few years. With the launch of Intel's Centrino® brand, wireless functionality became a fundamental part of mobile computing—a must-have. Today, many devices have wireless functionality integrated with computer functions. They range from GPS receivers on our vehicles that we can program for directions to handheld devices that combine a phone, a music player, and an instant and e-mail messaging system. It is clear that this trend will continue and is likely to accelerate. Designing these devices has become increasingly more complex. Although many industry experts talk about the convergence of computers and communications, it is clear that these are still two distinct worlds, and that the devices requiring both functions continue to challenge designers around the world. Why is this so difficult? Today's multiusage mobile devices incorporate one or more radios operating from 800 MHz to the single-digit GHz. They also incorporate digital circuitry with processing, memory, and storage operating from the high hundreds of MHz to several GHz. This overlap in frequency is the crux of the issue. Today's radios were not designed with this in mind. RF engineers typically design and simulate the operation of their radios in white or Gaussian noise environments. Today's digital systems were conceived without any comprehension of wireless communications, and they tend to generate noise that is inherently non-Gaussian. When these two components meet, we have an undefined environment that typically leads to less than stellar operation and below par performance. In some cases, wireless will simply cease to function. What we truly have is a collision between communications and computing. Special attention to this issue will ensure that devices requiring computer and wireless functionality make it to market in the desired timeframe at the required price points.

1.2 Wireless vs. EMI

One may ask why EMI regulations do not protect against this type of issue. To answer this question, we must first look at the intent as well as the context of the regulations. When such regulations first appeared, the FCC was concerned primarily with protecting terrestrial broadcasts such as TV and radio. Their major concern was that other devices in close proximity would interfere and disturb the reception of such services. The EMI limits introduced were therefore based on a system-to-system interference model. Hence, they were measured at a distance of 3 m, which, among other reasons, was to equate to device (aggressor-to-victim) separation. The limits were indeed intended to provide some level of protection from devices separated by approximately 10 feet, which at a stretch were located in the same room, but likely in an adjacent room or, in fact, next door. So, although perhaps a good starting point, it is clear that these regulations are wholly insufficient in themselves and in some ways completely inapplicable to protection of wireless devices collocated in the same system. In fact, the FCC doesn't care if you interfere with yourself! To illustrate this point, we'll look at the existing EMI limits (FCC Part 15 ITE) at 2.5 GHz and compare this to 802.11 b/g wireless sensitivity requirements. For the purpose of this illustration, we will assume that the radio receiver is 3 cm away from the EMI source.

EMI Limits:

2.5 GHz @1 MHz BW = 54 dBμV/m (@3 m)

Translating for distance = 94 dBμV/m (@3 cm) [20 log (300/3)]

Converting to dBm = −13 dBm [dBm = dBμV − 107]

Wireless Sensitivity Requirements:

802.11 b/g (11 Mbps) = −86 dBm (@20 MHz)

Converting for BW = −73 dBm (@1 MHz) [10 log (20/1)]

As we can see, there is a 60 dB difference between the EMI limit and the required level to ensure wireless functionality as indicated in the 802.11 specification. In the EMI world, 60 dB is a big number. In the wireless world, it is huge, where 1 and 2 dB performance gains can be the subject and result of a life's work. In real-world terms, this means that the wireless voltage requirements are 1,000 times more stringent than current EMI regulations. It is also clear that, as stated earlier, meeting EMI requirements is a good starting point at best. This may be a relatively simple model, but it nevertheless enforces the message that EMI/EMC compliance guarantees nothing with respect to wireless functionality when the radio is integrated into the same device as the digital electronics.

To further hit the point home, Figure 1.1 shows a plot of noise measured using 802.11 embedded antennas on a production notebook running between 2.3 and 2.6 GHz.

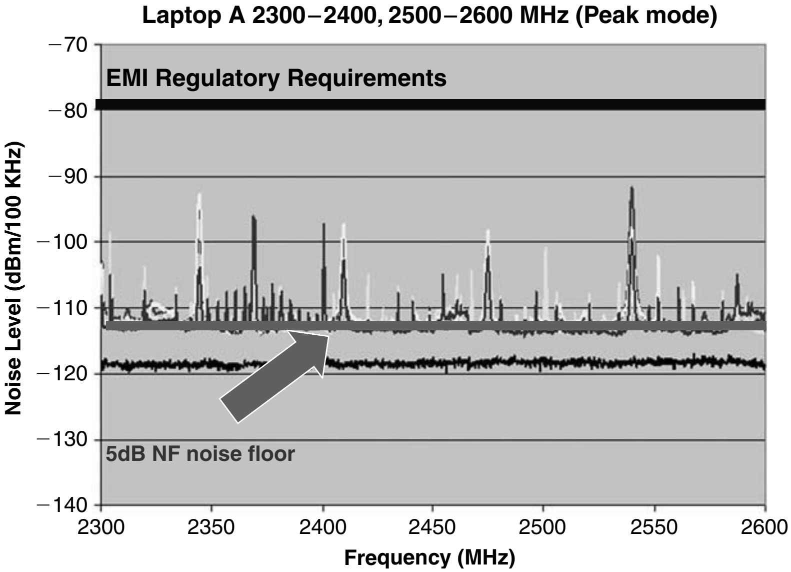

Figure 1.1: Noise measurements on a production notebook.

Two lines are plotted: the wireless sensitivity requirements (assuming a 5 dB noise figure for the radio and incorporating the gain for the antenna used) and the EMI limit for the device in question (FCC Class B). The system in question easily meets EMI requirements, but has considerable noise up to 20 dB above the level required by the integrated 802.11 radio. It is clear that this system may have difficulty operating to specified parameters, depending on what radio channel is used.

1.3 Addressing the Fundamentals

In discussing RFI and EMI in this book, our approach is to look for underlying physical phenomena in order to develop design techniques that can be applied consistently across multiple designs in a cost-effective manner. It is not our intention to help the reader identify point solutions that typically work for a single design instantiation and result in "new" approaches time and time again. In the same way, throwing parts at problems can work when the budget is unlimited, but doing this will cause problems when cost is a consideration. Besides, in most cases, this method treats the symptoms rather than the cause. It is the inherent intention of this book to address RFI fundamentals, solving the problem at the source where possible, or at least building the paddock as close to the barn as possible.

Correcting EMI and RFI problems *after* systems are designed and ready to go into production is usually expensive and can result in program delays that adversely affect the acceptance of a new product. It is preferable to follow good engineering practice during the design and development phases. The goal should be to produce designs capable of functioning without adverse effects in the predicted or specified electromagnetic environment. In addition, these devices must not interfere with other circuits. The electromagnetic theory, signal analysis, measurement techniques, compliance standards, and design guidelines described in this book should all aid in meeting the goal of intended wireless functionality and maximum system performance when applied early enough in the design cycle.

In a well-controlled RFI/EMC management scheme, the appropriate engineer reviews and approves all design drawings, takes part in design reviews, is a member of design change committees, and is notified of any proposed changes in a design. Keep in mind that any shortcut in EMC design or control can cause a lengthening in testing, fixing, and retesting time, as well as an additional cost.

The designer must realize that EMC is an iterative process composed of design, analysis, fabrication, and measurement. A first-pass solution is not always achieved. During project schedule development, the engineer should build into the process a sufficient amount of time to cover several iterations of EMC reduction.

In order to understand the best approach to an RFI/EMI solution, we must first define radiating structures and signal sources. Throughout the text, we will describe experiments and methods of measurement as they are applicable and in relation to the particular problems being addressed. The measurement techniques that we use will be discussed in detail. We will emphasize good measurement and experimental practices and not rely only on “clean” simulations. While measurement can be tricky, messy, and fraught with the possibility of error, it is still the very foundation of science.

In the first chapter, we will describe the problem of platform interference in wireless systems. We will show system spectrums of various types—the nature of the emissions of several dominant system components such as processors, chipsets, LAN, and so on. We will discuss the impact of even low-level emissions on wireless system performance. In Chapters 2 and 3, we will describe the analysis of signals in platforms such as high-speed data streams, system clocks, and display streams. In Chapters 2 and 3, we will cover measurement and modeling techniques. We will describe methods used to characterize the impact of different platform signal types on wireless performance. We will also discuss methods used to visualize the electric and magnetic fields in the near fields of radiators.

We will develop analytical approaches with the use of simulation tools, simple closed form analytical models, and the statistics of interferers. We will then show models of notebook display lids, desktop enclosures, packages, and heat sinks. In Chapter 4, we will outline and sketch approaches to mitigation of platform interference.

We will also discuss a number of commercially available analytical tools. We have leaned heavily on Mathematica from Wolfram Research, HFSS from Ansoft, and Flo-EMC from Flomerics. Each of these packages has strengths and complements the others.

1.3.1 Platform Interference: Describing the Problem

In order to address the challenges of RFI, one must take an approach to break the problem into manageable pieces. We will attempt to look at the problem from the perspective of both the digital electronics (the aggressor/source) as well as the radio (the victim). Figure 1.2 shows the problem in simple interference and electromagnetic compatibility terms.

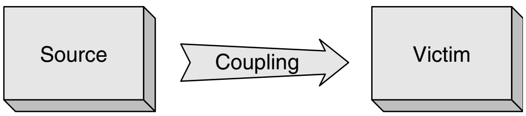

Figure 1.2: The aggressor/victim model.

The source above is the digital electronics and its subsystems. Examples are clocks, high-speed I/O (Input/Output) traces, cables, power delivery networks, LCD panels, memory subsystems, or processing components. The victim is the wireless radio itself and constitutes both the antenna subsystem and any associated RF components. The coupling depiction indicated above covers both radiated (through the air) and conducted (shared power, Vcc, and/or ground, Vss, connections). Typically, the coupling path represents a loss path that reduces the amount of energy the victim radio will see. Locating the antenna away from noisy electronics or shielding the noisy electronics increases this loss path, reducing the level of noise seen by the radio. The following example illustrates the power of this simple model in breaking down the problem.

Source X creates a noise equivalent to 10 μW (–20 dBm); 10% of this noise ends up being radiated into the surrounding environment (1 μW = –30 dBm). We will assume that there is some shielding between the noise source X and the radio antenna that gives us 40 dB attenuation. We can then calculate that the radio will see –70 dBm noise (–30 dBm—40 dB). This may seem okay, but given that the majority of radios have sensitivity in the –90 dBm range, this noise is already 20 dB above the sensitivity threshold of the radio, and the noise would reduce its performance by 75%. This may seem surprising. Even with 40 dB of isolation or attenuation between a 1 μW radiated noise source and a representative radio receiver, 75% of the wireless performance will be lost. It is even more surprising that only 10 pW of noise seen by the radio antenna can reduce the wireless performance by as much as 50% (range/throughput).

A very similar model, which looks at the problem from an RF perspective, is shown in Figure 1.3. The figure shows a rather simplified view of the radio world: the transmitter, the transmission channel, and the receiver. For now, we will simply look at the portion of the radio that resides on the platform and the part of the radio transmission channel associated with the platform. Platform noise is added into the channel at a number of possible locations and can be considered as the summation of individual sources resulting in a complex signal.

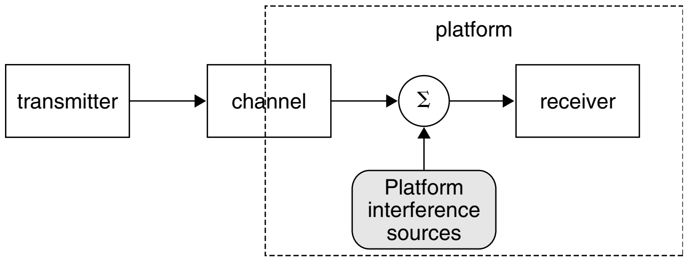

Figure 1.3: Signal channel and receiver.

A good representation of how platform noise adds to the transmitted radio signal such that the receiver sees a summation of the intended signal and the local generated platform noise. Unfortunately, this is not the model used by RF designers today; they use a very similar model, but they use a white Gaussian noise source instead of "Platform Interference Sources." The issue here is that platform-generated noise is typically non-Gaussian, and, as such, the present radio design does not comprehend the impact of such sources. Figure 1.4 illustrates this fact.

A theoretical representation of white Gaussian noise using normalized frequency is shown (*right*). The response is flat across the entire spectrum. Conversely, the figure on the left shows the noise from a 5 Gb/s Serial I/O bus, where the spectrum is far from flat with a