Book On Power Integrity Explores Measurement Issues, Practically and In Depth

"*Power Integrity: Measuring, Optimizing, and Troubleshooting Power Related Parameters in Electronics Systems*," by Steven M. Sandler, copyright 2014 by McGraw-Hill Education, 319+ pages.

Reviewed by David G. Morrison, Editor, How2Power.com

If you opened a copy of Steve Sandler's new book and you started flipping through its pages, one thing would quickly become apparent. There are a lot of pictures of test setups and measurements and more measurements. That would be a valid impression because at heart, this is a book about electronics test and measurement. It's not a book that aims to cover all electronics measurements, but rather those that relate mainly to assessing power integrity in electronics systems.

If that description sounds a bit narrow in scope to your ears, it probably encompasses a lot more measurements than you realize and the measurements described here will be relevant to many engineers for whom "power integrity" is not part of their job description. The author gives us an indication that these measurement techniques cast a wide net across many areas of electronic design when he notes, in the opening chapter, that the book addresses "all aspects of making high fidelity measurements, including power, high-speed, and low-power analog and instrumentation circuits."

There's a great deal in this book concerning the measurement of noise in distributed systems. "Distributed systems," or "distributed power systems" is not a reference to distributed power architectures like those encountered in modern telecom, datacom and computing applications. But rather, in the context of "power integrity" discussions, distributed systems is almost synonymous with the term "power distribution networks" or PDNs, which take power all the way from the board-level power converters to the loads.

Noise, of course, is of paramount importance to discussions of power integrity. And as systems evolve toward higher performance with high-speed logic devices like FPGAs, CPUs and ASICs switching faster and faster, noise issues become more challenging. Often, these noise issues concern the components used for power conversion. Consequently, many of the discussions and measurements featured in this book involve voltage references, linear regulators, and switching regulators, not to mention other familiar building blocks like op amps and ADCs.

PI And Relevancy To Power Electronics

While those discussions of building block power components should be enough to suggest this book is relevant to engineers involved with power conversion, the author does make the point in the introduction that "new technologies, such as eGaN, GaN, SiC and GaAs will present new measurement challenges due to the combination of high voltage and ultra high-speed switching." And the author certainly addresses these challenges in a number of places in the book. Some power electronics engineers may be particularly interested in the chapter on measuring edge rates since that provides designers with tools for measuring the new crop of power switches as they push rise times below the 1 nanosecond barrier said to be in place today for fast-switching POL converters.

There are also chapters here on how to measure familiar power supply specs like PSRR, ripple and noise, step load response, and stability. If you're a power electronics engineer, you may feel these measurements are old hat. However, the author's treatment of these and other familiar parameters is anything but. He attacks these measurements from many different angles using different measurement domains, different instruments, and many different techniques. More on these points in a bit. But for now, suffice it to say, you will most likely encounter some fresh ideas in this book when it comes to measuring even the most familiar power-related parameters.

The Mission

Before going into further detail, I think it's worth digressing here to discuss why the author wrote this book—something that is spelled out thoroughly in chapter one. The author explains at the start "I chose to write this book because it has become increasingly clear to me that much of the data that we need to do our jobs as electrical engineers is lacking. Either the data we need is missing entirely or when we do have data—that we have created or received from others—it is frequently lacking in completeness, fidelity, and/or accuracy."

These observations lead to a central tenant of the book, that data sheets and other sources of data are almost invariably incomplete for the designer's purposes and so, it is imperative for the engineer to make his or her own measurements. However, as the author also explains in the introduction, he hopes that component suppliers will realize that there is a real need for them to supply more comprehensive and accurate data.

"One goal for this book is to show component and device manufacturers the breadth and fidelity of the data end-users really do need to do their jobs as well as to help them improve their datasheets accordingly."

The author also spells out some other important goals in the intro like teaching design and test engineers how to make high-fidelity measurements more easily by using the "appropriate techniques and equipment." He also hopes that "test instrument manufacturers will gain insight into the issues engineers are facing as well as how they can improve their equipment capabilities, operating systems, software and documentation." Finally and possibly of greatest significance, the book aims to show "the impact that power supply performance has on the systems they power."

The Book's Structure

There are 15 chapters in this book spread out across 300+ pages. As the author notes in the Chapter 1 introduction, many of the early chapters (chapters 2-6) lay a foundation by discussing measurement principles and different approaches to measurement as reflected in the chapter titles—"Measurement Philosophy" and "Measurement Fundamentals." And then there are the chapters that discuss the various categories of test equipment—"Test Instruments" and "Probes, Injectors and Interconnects." Finally a chapter on "Distributed Systems" (chapter 6) sets down basics relating to power integrity, identifying the noise paths that exist in a distributed system.

As the author notes at the end of chapter 6, the discussion on distributed systems nicely sets up all that follows: "The remaining chapters [7-15] are dedicated to the equipment and measurement techniques required to perform measurements of each of these noise paths, as well as some helpful troubleshooting techniques." This division of the book into two large sections means the reader doesn't have to read it all at once. As the author suggests, you could read the first six chapters to get the essential grounding in the subject. Then, when you need to make one of the measurements explained in a later chapter, you could refer to the relevant chapter.

While all of the early chapters will be especially enlightening for new engineers who probably receive scant instruction in the finer points of test and measurement, I think these chapters should still appeal to experienced engineers because of the author's insights when discussing even simple matters such as what needs to be documented. Moreover, in these sections and elsewhere in the book, there are lots of clues about sources of measurement errors and how to avoid them. The chapters on test instruments provide both general discussions about various classes of instruments and all assorted adapters, probes and interconnects; followed by very detailed discussions of specific instrument models and their capabilities.

Up to this point, my descriptions of the book have focused heavily on the measurements. But the book also provides extensive discussion of the parameters being measured. Before explaining how to measure them, the author defines them and then explains the essential relationships which must be understood in order to measure them. Important equations are derived as needed. In some cases, simulations are performed to validate the derivations and actual measurements attest further to their validity.

In some ways, this book is as much about non-obvious relationships between different aspects of circuit performance as it is about measurement. But you might not gain an understanding of these relationships without making the measurements described.

Noise Measurement Is A Central Theme

Having discussed the general structure of the book, I might be tempted to give a blow by blow summary of the chapters, particularly with so many chapters describing very specific types of measurement. (If you'd like to get an overview of all the measurement topics, I recommend a quick skimming of the table of contents found at Amazon.)

So rather than summarize all the chapters, I'll look at some of the major themes that stood out in reading this book. I'll also share more of my impressions and observations and maybe even identify some potential sources of controversy.

One of the major themes of this book is the importance of noise and the imperatives to measure it. Some of the related issues addressed at length are:

- Where does noise go in a distributed power system?
- What are all the ways I can measure it?
- And then how can I perform additional measurements to identify the source of the noise?

Then there are the related issues that the author addresses:

- What instruments, probes, adapters, and cables can I use to make all these measurements? Not just equipment types, but the actual models.
- What does the actual setup look like and how do I calibrate it?
- What tips and tricks will help me to make accurate measurements?

If all of these issues sound familiar, then maybe it's because you watched Steve Sandler's video series on "Troubleshooting Distributed Power Systems." Naturally, the book goes into more detail on everything discussed in the videos, so if you had questions after watching those videos, you may find your answers in this book. As in the video series, the importance of the impedance measurements is stressed and at 41 pages, the chapter on measuring impedance is one of the longest.

Many Ways To Measure

Another theme that pervades the book is the existence of many different ways to measure a particular parameter. These ways are explained in the early chapters, but then reiterated in the later chapters on specific measurements.

First, there are the different measurement domains (time, spectral, frequency, and impedance), which are closely tied to specific types of instruments. Then, there are the different methods (direct versus indirect, in-circuit versus out-of-circuit); plus all the different ways to probe, inject signals and make other connections.

The discussions of how to make specific measurements are broken down into many parts. General concepts are explained first, followed by details on making each part of the setup, calibrating and verifying the setups and verifying the results.

Specific instruments, probes, adapters, and interconnects are described generally, but then there are also details about specific instruments and how to use them. Almost always, the author describes and demonstrates multiple methods for making measurements using different types of instruments and other hardware and the different domains mentioned above. These measurements often illustrate the advantages or disadvantages of certain domains or methods such as differences in instrument sensitivity, dynamic range, and bandwidth as these characteristics relate to specific types of measurement.

The author also performs similar types of measurements on different components and circuits to make points about the measurements, certain relationships among parameters, or the sensitivities of the components. Furthermore, we see similar setups and measurements using different *models* of instruments so that we see differences in various aspects of their performance or features. The author weighs in on these differences in instrument capabilities, sometimes overtly and sometimes subtly.

In all the discussions of how to make measurements, the author provides many recommendations, guidelines and warnings. Often this advice is provided (or reiterated) in the special tips and tricks sections within each chapter.

Many Instruments (And Vendors) Are Featured Here

As mentioned above, actual test instruments, probes, adapters, preamps, interconnects and other accessories are featured prominently throughout the book. Chapters 4 and 5 discuss the characteristics and capabilities of specific test equipment at length. Then, those same models appear in the relevant chapters on making specific measurements.

The author leans heavily in some cases on what I would describe as his "go to" instruments like the Bode 100 VNA from Omicron Lab and Agilent's E5061B VNA. He also uses Picotest adapters throughout the book. It should be noted that Picotest is the author's company and his company also sells the Bode 100. But his esteem for the Agilent E5061B is very clear. And outside the VNA and adapters area, the author also devotes plenty of space to oscilloscopes, and spectrum analyzers from the likes of Tektronix, Teledyne LeCroy, Agilent and Rohde and Schwarz. So it's clear he doesn't mind touting the capabilities of others vendors' instruments.

However, you might wonder why other VNAs aren't featured here and in many cases that is a reflection of their low-frequency limitations since most VNAs target RF applications. And what about all the frequency response analyzers (FRAs) offered by some of the well-known niche companies in the power supply test world? These are only briefly mentioned in the book, and the only example of one used in the book is the Bode 100, which is both an FRA and VNA. But according to the author, he was heavily discouraged by other FRA vendors from writing about their instruments!

Sources Of Controversy

The author has written many articles and done videos on the subject of Bode plots and their shortcomings as a means of assessing control loop stability in power supplies and other functions. Here too, he takes on this somewhat controversial issue, explaining how Bode plots may fail to predict control loop instabilities, how Bode measurements are not an option when the feedback loop is not accessible, why Nyquist charts with their inclusion of stability margin are more helpful in some cases, and other points. These issues are discussed extensively in Chapter 8.

Perhaps less controversial, but still provocative is the book's central theme , which I would summarize as "you better measure everything, because you can't trust data you get off a datasheet or from other sources." There are certainly examples to support this philosophy in the book. For instance, the author cites the case where the datasheet recommends that a certain capacitor be used with its voltage regulator or op amp and as the author's measurements demonstrate, that cap actually degrades circuit performance.

Another message that's tacitly implied: There are no free lunches when it comes to test equipment, at least not if you are working on modern high-speed systems with advanced FPGAs, CPUs, and high-speed logic. Or if you are trying to measure fast-switching power devices. You'll need more measurement bandwidth in many cases than you thought. And the author's message, mostly implied, is that old or low-cost instrumentation is very often inadequate.

Careful Measurement Yields Surprises

As the author demonstrates, the making of high-fidelity measurements with sensitive instruments often reveals the unexpected. For example in Chapter 12, when the author measures the output noise of an LM317 voltage regulator, he discovers spurious responses spaced 1 kHz apart, which are note readily explained. And certainly, throughout the book, there are many examples of measurement details that could easily be missed if certain tests or details of the test setup were neglected.

I suspect that for engineers reading this book, there may be many surprises, as they discover the breadth of methods described by the author, the lesser-known relationships among important parameters, and the many, many potential sources of error, some of which become increasingly important when designing advanced electronic systems.