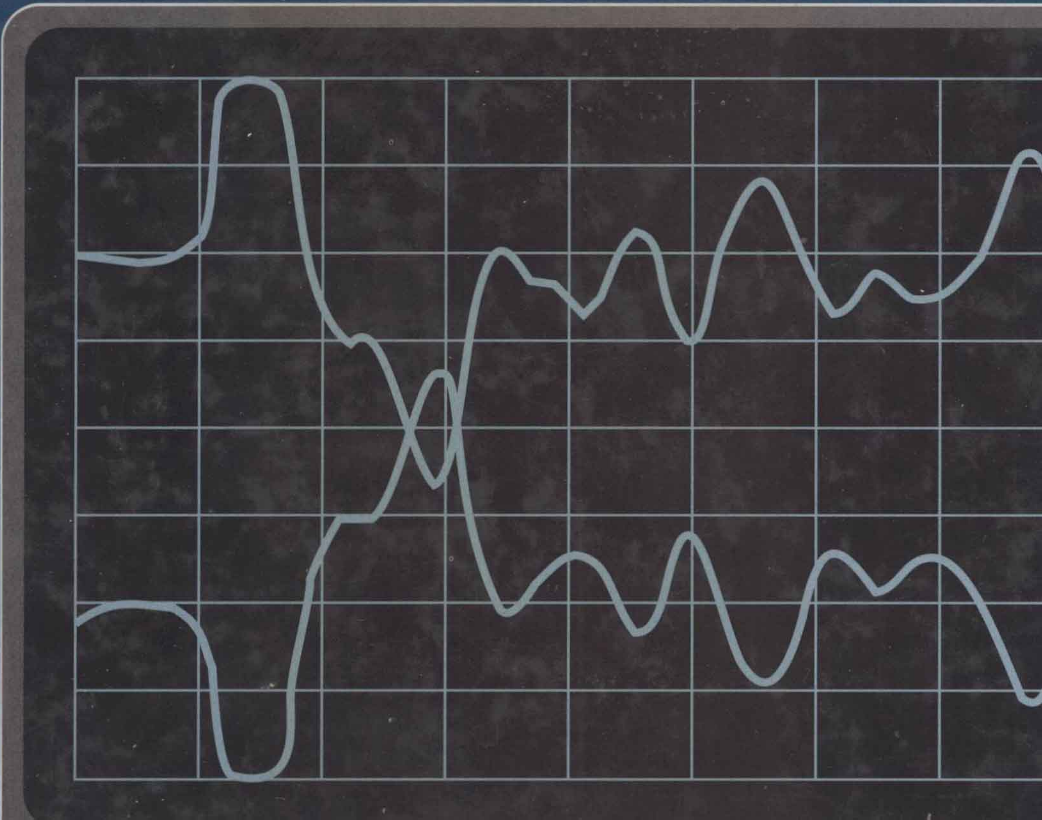
HIGH FREQUENCY MEASUREMENTS AND NOISE IN ELECTRONIC CIRCUITS

A Practical Guide of Successful Techniques for Designing, Debugging, and Reducing Noise

DOUGLAS C. SMITH



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HIGH FREQUENCY MEASUREMENTS AND NOISE IN ELECTRONIC CIRCUITS

To my loving wife Deborah and our kids,

Doug, Didi, and David,

and also my friends and associates for their help

especially George A. Florio,

Professor L. Ensign Johnson of Vanderbilt University,

W. Michael King, and Henry W. Ott

for providing inspiration and help not only

for this book but throughout my career.

Preface

Necessity is said to be the mother of invention. Over the years, I have developed a philosophy and a set of methods for the purpose of measuring high frequency signals and noise in electronic circuits and for characterizing and mitigating high frequency noise (such as that caused by digital logic or switching power supplies) in electronic circuits as well. This development was made necessary by the realization that common measurement methods, such as with the common passive high impedance scope probe and oscilloscope, could yield errors of 100 percent and more in the amplitude of a waveform. Often I noticed that the process of trying to measure a signal or noise in a circuit affected its operation, further diminishing my confidence in a measurement.

In this book, I discuss a philosophy of measurement that ensures accurate results. In addition, new measurement techniques are presented later in the book that can yield accurate measurement of signals or noise in a circuit, and permit the characterization and location of sources of noise that heretofore were difficult if not impossible to deal with.

After reading this book, the reader should be able to measure signals and noise in electronic circuits as well as locate and reduce, if necessary, noise generated by electronic circuits or external interference. Most, hopefully all, of the "magic" of dealing with topics like ground noise, ground loops, location of noise sources, and other ElectroMagnetic Interference (EMI) effects will be removed and the reader will be able to characterize and mitigate noise in circuits with confidence.

This book is intended for practicing electrical engineers and students of electrical engineering at the undergraduate level. Readers are welcome to contact me with questions or comments at P. O. Box 524, Rumson, NJ 07760-0524.

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1

Introduction

For many engineers and students, high frequency design and measurement techniques contain a liberal dose of "magic." This is unfortunate as these techniques can be explained in reasonably simple terms that allow their use in day-to-day engineering. The purpose of this book is to develop a measurement philosophy and a set of techniques that will allow the reader to measure high frequency signals and noise for the purpose of verifying design intent and to debug the design if problems are found. The techniques presented in this book are useful for measurements ranging from the noise margin in a digital circuit, to tracking down the effect of switching power supply noise on system operation, and even to evaluating system response to an **E**lectrostatic **D**ischarge (ESD) event.

In the process of investigating measurements, some discussion of noise mitigation techniques is difficult to avoid. These additional techniques will come as "icing on the cake" for the reader. After reading this book, the reader should be able to approach high frequency design, measurement, and noise mitigation techniques with confidence and realize that the subject can even be fun, not withstanding that sometimes measurements of this type are made late at night in a crisis atmosphere.

This is a good place to ask the question: What is meant by "high frequency" in the context of measurement and design? The working definition to be used in this book is the following: High frequency is that frequency above which parameters of the circuit that are normally considered parasitic and to be ignored, such as the inductance of a few inches of wire, become important enough to affect circuit operation. This can happen anywhere from a few MHz to several GHz depending on the design. The frequency range from 20 to 500 MHz is critical to a wide range of electronic equipment and is the primary frequency range that will be discussed in this book. Extension of the principles discussed to higher frequencies, in the GHz range, will be made where appropriate.

MEASUREMENT PHILOSOPHY AND TOPICS COVERED

This book is as much about measurement philosophy as any particular measurement technique. Throughout the book, a philosophy of measurement will be developed. It is hoped that by discussing several important measurement and noise mitigation techniques, the reader will be able to extend the principles and underlying philosophy to any situation requiring accurate measurements. Typical of the kind of questions the reader should find answers to are:

1. Why does connection of an oscilloscope to a malfunctioning circuit sometimes cause the circuit to work properly? This can be a frustrating experience, enough so as to tempt a design engineer to leave the scope probe in the circuit!
2. What factors can cause the result of a measurement to conflict with observed circuit observation? Occasionally, signal distortion or noise levels are measured that would seem to preclude proper circuit operation, yet the circuit operates perfectly! Conversely, the circuit does not operate, yet no reason can be uncovered.
3. How can noise be measured if it can not be seen on an oscilloscope?
4. At what frequencies do circuit parasitics, such as lead inductance, become important to measurement accuracy or circuit operation?
5. How can the effect on an electronic circuit of a measurement be minimized?

6. What techniques are available to prevent external interference from introducing error into a measurement?

In order to answer these and other questions, the following topics will be discussed at length in this book:

1. High frequency measurement techniques and philosophy
2. Review of basic theory including:
   - Inductance
   - Magnetic coupling
   - Electromagnetic interference
3. Scope probe effects:
   - Ground lead resonance
   - Ground lead impedance
   - Compensation
4. Noise measurement techniques:
   - Balanced coaxial probe
   - Square magnetic loop
5. Noise source location techniques
6. General measurement philosophy
7. Measurements on switching power supplies
8. Measurements involving ElectroStatic Discharge, and other severe forms of interference to electronic systems.

Oscilloscope Probes

Scope probes are familiar to most engineers and electrical engineering students. This familiarity will be exploited in the following chapters as a context for introducing measurement concepts. These concepts will then be extended to more advanced measurement techniques.

The scope probe ground lead, called a pigtail in EMI circles, can result in errors on the order of 100 percent in the peak amplitude of a measurement. The inductance of this lead can cause resonant effects and inject unintended signals into the measurement. Chapter 4 will be devoted to this very important subject. The reader will be able to quantitatively measure the amount of error that results from the probe ground lead or any pigtail connection of the shield of a coaxial cable.

The problems associated with scope probe measurements do have silver linings though. It is through a discussion of these problems that a general measurement philosophy which has application to all types of measurements will be developed. This philosophy, a central point of which is to be suspicious of measurement results, will be applied to more advanced measurement techniques later in the book.

New Measurement Techniques

It is easy to be intimidated by an array of expensive test equipment. Figure 1.1 shows an effect often noticed by the author. The effect is that the confidence in a measurement is monotonically related to the cost of the test equipment. As the cost of the measurement equipment approaches $40,000, most of us tend to believe the measurement.

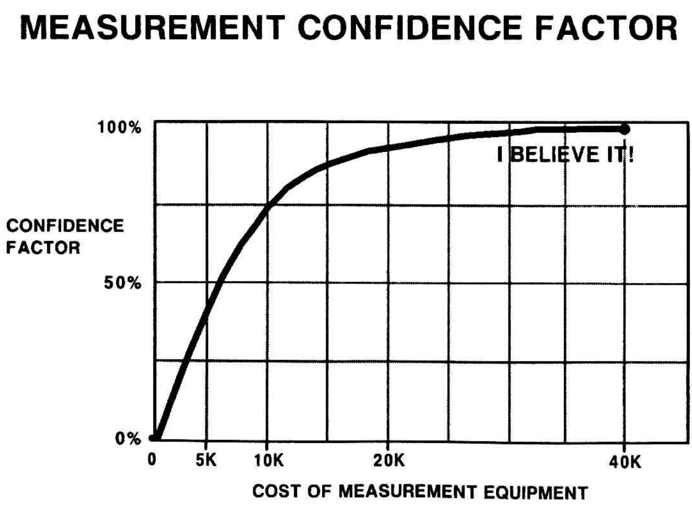

Figure 1.1 Measurement confidence factor.