When this book was originally published in 1969, an understanding of transmission lines was required mainly by a select group of professionals. Computers and integrated circuits have changed this quite significantly. The chemist, physicist, and metallurgist, designing integrated circuit packages and materials, the computer scientist, providing Computer Aided Design software tools for package, circuit, system, and layout design, as well as the circuit designer and system architect are some of the professionals who now must have such knowledge to be effective in their work. Most of these professionals have little or no background in this subject. Such people have found this book quite valuable both as a fundamental introduction, and as a reference on subjects relevant to modern day integrated circuits.

In the 1960s, I was pursuing research on advanced, high speed magnetic thin film memories with pulse rise times of \( \frac{1}{2} \) to 4 ns. The typical word and bit-line lengths were such that the electrical delay was roughly comparable to the rise time, resulting in behavior which fell in the transition region between that of lumped circuits and ordinary transmission lines. At that time, mainstream computers and other electronic systems were still built from discrete components, and magnetic cores dominated the memory market. To a large extent, these components could be designed using discrete, lumped circuit analysis with little knowledge of discontinuities, reflections, or wave propagation. Thus I was forced, by necessity, to acquire the knowledge which resulted in this book.

At this time, the entire field of electronics was on the threshold of entering a new domain which would ultimately require a wide range of engineering and science professionals to have at least some basic understanding of transmission lines. This was gradually brought on by the advent and evolution of the integrated circuit chip, which allowed an ever increasing speed and density of electronic systems, especially computers. This need came about in the following manner.

Fundamentally, in any electrical circuit for which the rise time is much longer
than the total electrical line delay, lumped circuit analysis is often adequate (see Section 5.7-5.9). This was typical for most of the electronic systems in the mid 1960s, e.g., pulse rise-times of 30 to hundreds of ns were common. Using a typical line delay of 2 ns per foot, a “fast” rise-time of 30 ns corresponded to an electrical length of 15 feet. Thus, lines much less than 15 feet could be considered lumped lines, which was generally the case. Electronic board lengths as well as local interconnection lengths were a few feet or less. The interconnections between cabinets were longer and typically behaved as transmission lines, so standard coaxial cables such as RG 58 A/U were commonly used.

If the pulse rise times and electrical line delays all scaled (decreased) at the same rate, nothing would change, neglecting skin effect and other second order effects. However, what happened was that the increasing speed of the circuits caused the rise-times to decrease substantially, while the longest lines did not decrease proportionally. This results from the fact that the number of components in the systems did not remain fixed. Rather, large scale integration allowed much more complex systems to be built with thousands of times more components. Hence, in order to package all these, we still have modules, card, boards, and small cabinets. Since the 1960s, rise-times have decreased by a factor of between 100 to 1000. Lines which earlier could be considered lumped circuits and achieved with simple wire connections have to now be uniform transmission lines. Since hundreds or even thousands of such lines are needed between relatively small modules, they obviously cannot be large coaxial cables. Rather, they must be fabricated and compatible with integrated circuit technology.

In the 1960s, lumped circuit analysis could be applied to a typical circuit card, about 3 by 5 inches, as well as to the interconnections at higher levels, between adjacent or nearby cards. Only some of the longer interconnections between boards and cabinets needed transmission line analysis. Today, the design of the interconnections at nearly all levels, such as between chip modules, cards, boards, whatever, requires transmission line analysis. Even within a single integrated circuit chip, the longer circuit and/or interconnection paths can require transmission line analysis, or an understanding of the fundamental concepts to achieve proper behavior.

In order to make continued progress in integrated circuits, it is necessary to provide much more than just simple scaling to smaller dimensions. Additional problems are encountered at ever smaller dimensions which are not present or not significant at larger dimensions. In addition to the usual fabrication problems of small, thin, uniform pairs of lines, increasingly serious difficulties are encountered due to pure line resistance, interconnection discontinuities, non-uniform conductors due to via holes, skin effect, anomalous skin effect, dielectric constant, dis-
persion, and radiation to name some. Solutions to these problems require many disciplines—chemist, metallurgist, physicist, programmer—all of whom need some understanding of transmission lines. Many such professionals have little or no background in transmission lines or circuit theory and have found this book invaluable both as a learning text and reference.

The fundamental nature of this book has maintained its relevance over a relatively long period and is still in demand today. Unfortunately, it has been out of print for over ten years, thus leaving a significant void for many professionals. I have a long range goal of updating and expanding this book, but this task will require several years. In the mean time, the IEEE Press, by re-issuing the original text, with corrections, and at an affordable price, is filling a significant need. I am very grateful and indebted to those people in industry and universities who suggested this undertaking, and to IEEE Press, especially Russ Hall, for listening and following through.

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