ASK THE EXPERTS

Basic Transmission Line Concepts

Editor,

I've been designing digital circuits for more than 20 years. When I started, we considered 8 MHz a high clock frequency. Now my projects include systems with clock frequencies up to 1 GHz on the p.c. boards and nearly 3 GHz inside the MPUs.

Until now, our board designers have been the magicians that make the interconnections function properly, but our management is trying to move toward a more "integrated" design//simulation/layout workflow. Now I need to know more about the physical effects of layout, mainly how the traces act like transmission lines at the frequencies we use. I'd like to start at the beginning and really understand the subject. What's your recommendation for my re-education?
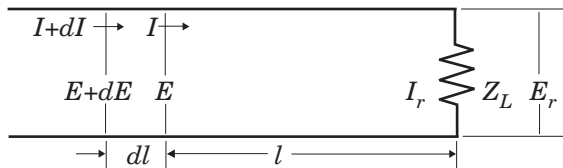
Tom Williams
"At a big Silicon Valley digital company"

Let's Go "Back to the Future"

As one outstanding engineer always said, "for every new project, start at the beginning"—which to him meant a review of Terman [1]. There are many excellent discussions of transmission lines in new and classic texts on RF/microwave design. Each one has a bit different perspective, however, and you should read several of them to find an author who approaches the topic in the manner you like best. Most professional references (non-textbook) emphasize how transmission lines are used, while most college textbooks emphasize the equations that extend AC circuit theory to transmission line theory. How much of each is needed for your personal understanding depends on how much you already know.

After reviewing a copy of Terman (Fourth Edition, 1955), we can see why an experienced engineer would rely on this text so heavily. On the subject of transmission lines, it has a significant dose of both theory and practice. The chapter begins with the voltage and current relationships on a transmission line:

$dE = I \times$ (impedance of length dl)
$\quad = I(R + j\omega L)dl$
$dI = E \times$ (admittance of length dl)
$\quad = E(G + j\omega C)dl$

These relationships show the change of voltage and current per unit length, the key concept in understanding transmission line behavior. These equations can be rearranged and expanded to get the standard differential equations that describe wave propagation on transmission lines (traveling waves).

Within just a few pages, Terman gets to the fundamental definitions of a transmission line:

Z_0 (characteristic impedance)
α (attenuation constant)
β (phase constant)

These terms include the necessary variables for frequency, wavelength, dielectric constant, etc. that cover all aspects of transmission line behavior.

Once the theory is established, he quickly gets to the practical side of things. The figure below reveals the voltage/current patterns on transmission lines with open, short, matched and mismatched terminations.

This kind of visual information can change the "dry" equations into a real-world scenario of what is happening in the circuit.

Classic texts like this are valuable for current technology because they provide excellent coverage of the fundamentals. We hope you will find the best reference (modern or classic) to meet your needs.
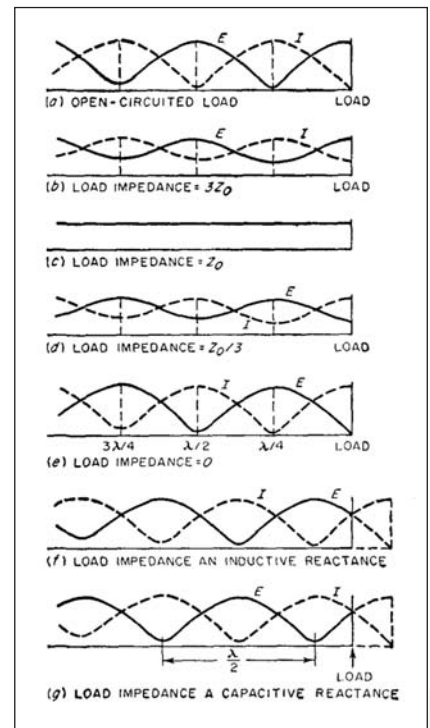

Figure 4-4 from the Fourth Edition of Terman (1).

References

1. Frederick E. Terman, *Electronic and Radio Engineering*, McGraw-Hill, Fourth Edition, 1955 (all editions are considered "essential classics").

2. Attending a short courses is another excellent way to learn this type of information. See the "Meetings & Events" column on pages 8-12.