Signal speed and propagation delay in a PCB transmission line

Amit Bahl Follow
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This article was first published on the Sierra Circuits blog.

It is the second of the PCB Transmission Line series and follows the article entitled What is a PCB transmission line? It was written with the great help of Atar Mittal, Sierra's Electrical Engineer and General Manager.

At high frequencies, transmission lines need to have a controlled impedance to predict the behavior of the signals and avoid signal reflections, crosstalk, electromagnetic noise, etc. which could damage the signal quality and cause errors.

This is the reason why you need to know at which speed signals propagate on transmission lines and the time they take to do so. I will give you a few equations to calculate the signal speed and the propagation delay for both striplines and microstrips.

Signal speed

Let's first discuss the speeds at which signals propagate on a PCB interconnect.

Electromagnetic signals travel in vacuum (or air) at the same speed as of light, which is:

$$Vc = 3 \times 10^{8}\ M/\sec = 186{,}000 \text{ miles/second} = 11.8\ inch/nanosecond \text{ (in/ns)}$$

A signal travels on a PCB transmission line at a slower speed, affected by the dielectric constant (Er) of the PCB material – the relations for calculating the signal speed on a PCB are given below:

Signal speed on striplines: $$V_{p\ (inner)} \approx \frac{Vc}{\sqrt{Er}} \approx \frac{11.8\ in/ns}{\sqrt{Er}} \quad \text{(1a)}$$

Signal speed on microstrips: $$V_{p\ (outer)} \approx \frac{Vc}{\sqrt{Er_{eff}}} \approx \frac{11.8\ in/ns}{\sqrt{Er_{eff}}} \quad \text{(1b)}$$

Where:

Vc is the velocity of light in vacuum or air

Er is the dielectric constant of the PCB material

Ereff is the effective dielectric constant for microstrips; its value lies between 1 and Er, and is approximately given by:

$$Er_{eff} \approx (0.64\ Er + 0.36) \quad \text{(1c)}$$

Thus, the speeds of signals on a PCB is less than that in air. If Er equals about 4 (like for FR4 material types), then the speed of signals on a stripline is half that in air, i.e. it is about 6 in/ns.

Henceforth, you can use Vp to denote the speed of signals on a PCB.

Propagation delay (tpd)

The propagation delay is the time taken by a signal to propagate over a unit length of the transmission line:

$$t_{pd} = \frac{1}{V} \quad \text{(2a)}$$

$$t_{pd} \approx 85 \sqrt{Er}\ ps/in \text{ in striplines} \qquad (2b)$$

$$t_{pd} \approx 85 \sqrt{Er_{eff}}\ ps/in \text{ in microstrips} \qquad (2c)$$

The signal speeds and propagation delays for a few PCB materials are given in the table below:

Material	Er	Er_{eff}	V microstrip	V stripline	t_{pd} microstrip	t_{pd} stripline
Vacuum or air	1	1	11.8 in/ns	11.8 in/ns	85 ps/in	
Isola 370HR	4.0	2.92	6.90 in/ns	5.9 in/ns	145 ps/in	170 ps/in
Isola I-SPEED	3.64	2.69	7.20 in/ns	6.18 in/ns	139 ps/in	162 ps/in
Isola I-META	3.45	2.57	7.36 in/ns	6.35 in/ns	136 ps/in	158 ps/in
Isola Astra MT77 or Tachyon 100G or Rogers 3003	3.0	2.28	7.8 in/ns	6.8 in/ns	128 ps/in	147 ps/in
Rogers 4000 series	3.55 – 3.66	2.63 – 2.7	~7.20 in/ns	~6.20 in/ns	~139 ps/in	~161 ps/in

The next article of this PCB Transmission Line series will focus on controlled impedance. It will answer the question: When is the length of an interconnection to be considered as a controlled impedance transmission line?

Published By

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This article focuses on signal speed and propagation delay in a PCB transmission line.

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2y ...

Very useful sir.with control impedance calculation iam trying for frequency loss estimate

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Vadim Zhuravliov
Senior Researcher, Head of Fundamental Electrical Engineering Department at BSUIR
2y ...

Thanks, clearly and compactly. It is better to duplicate units in universal SI.

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Edson Camilo
CAD Layout Engineer na Instituto de Pesquisas Eldorado
2y ...

Thanks a lot, Mr. Bahl this informations increase a lot our knowledge. This is the reason control length is important when you are working with GigaHertz .

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