Rule of Thumb #5: Capacitance per length of 50 Ohm transmission lines in FR4

Eric Bogatin - January 17, 2014

C_{Len} = 3.3 pF/inch

This rule of thumb estimates the capacitance per length of all 50 Ohm lines in FR4.

Remember: before you start using rules of thumb, be sure to read the Rule of Thumb #0: Use rules of thumb wisely.

Previous Rule of Thumb #4: The skin depth of copper

At low frequency, a transmission line, open at one end, looks like a capacitor. After all, it is just two conductors, the signal path and the return path, with some insulation between them. This is illustrated in the figure below which plots the input impedance of a transmission line and the impedance of an ideal capacitor. At low frequency, they predict exactly the same impedance.

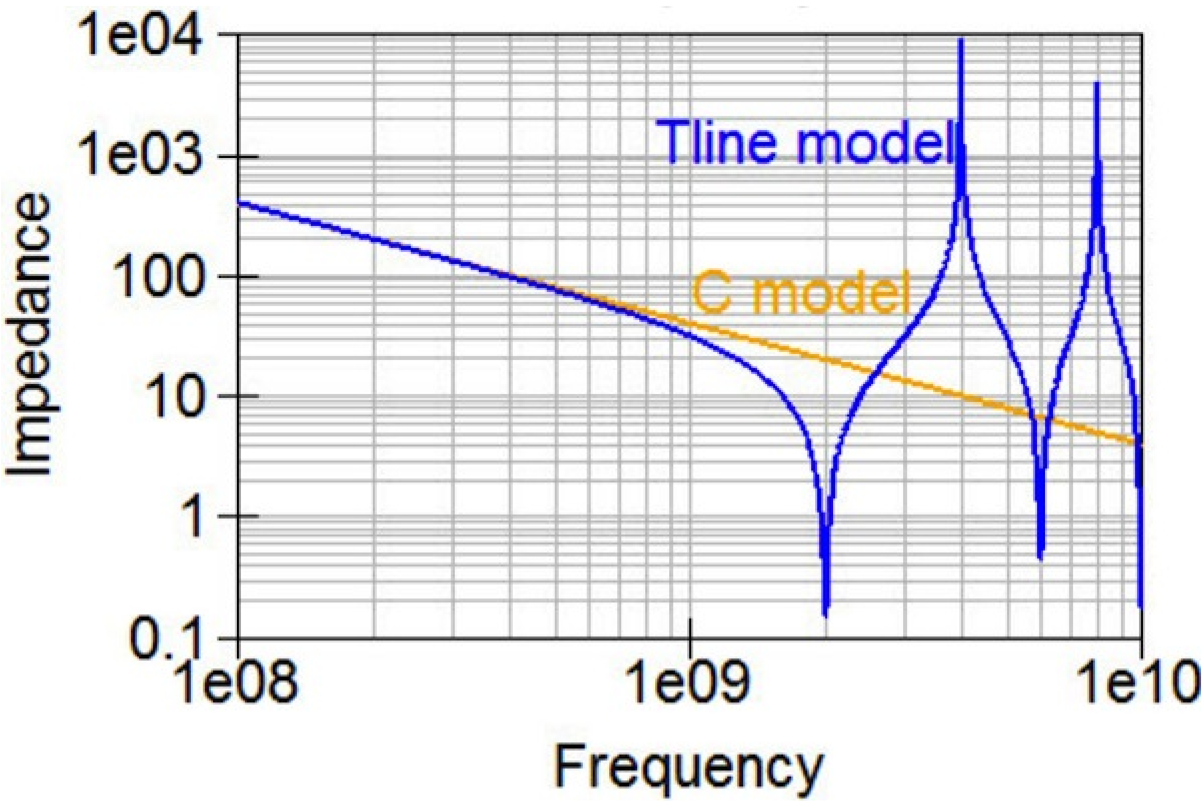

Figure 1. Input impedance of a transmission line open at the far end and an ideal capacitor.

To connect a transmission line with a total L and C value, we can approximate a real transmission line with an n-section LC model. Solving the circuit model, we get,

$$Z_0 = \sqrt{\frac{L}{C}} \quad \text{and} \quad TD = \sqrt{LC}$$

By taking the ratio, we get the total capacitance as

$$C = \frac{TD}{Z_0}$$

This very reasonable. If the length of the line increases, so should the total capacitance. If the characteristic impedance decreases, like the line width increases, the total capacitance should increase.

The time delay is related to the speed of the signal in the material and the physical length:

$TD = \frac{Len}{c}\sqrt{Dk}$ with c = speed of light in air, Dk = the dielectric constant of the materials.

This gives the total capacitance in a transmission line as

$$C = \frac{TD}{Z_0} = \frac{\frac{Len}{c}\sqrt{Dk}}{Z_0} = \frac{Len}{cZ_0}\sqrt{Dk}$$

For the special case of FR4 with Dk = 4 and the speed of light in air as 12 inch/nsec, the capacitance per length of any transmission line is

$$\frac{C}{Len} = C_{Len} = \frac{\sqrt{Dk}}{cZ_0} = \frac{\sqrt{4}}{12\ {}^{in}/_{nsec} \times 50\Omega} = 0.0033\ {}^{nF}/_{in} = 3.3\ {}^{pF}/_{in}$$

This says that ALL 50 Ohm transmission lines in FR4 have exactly the same capacitance per length. If we make the line width wider, we have to make the dielectric thicker to preserve the 50 Ohms, and this keeps the capacitance the same.

For example, a 50 Ohm line 2 inches long has a capacitance of about 6.6 pF.

Now you try it:

1. How much capacitance does a package lead have if it is 0.25 inches long?

2. What is the total capacitance in a long trace on a board, 10 inches long?

Next rule of thumb: RoT #6: The loop inductance per length of all 50 Ohm transmission lines.

Also See:

- RoT #3: Signal speed on an interconnect
- RoT #2: Signal bandwidth from clock frequency
- Counterfeit threats for electronic parts