PCB Design 007 ***QuietPower*** **column**

Be careful with Tlines in plane models

Istvan Novak, Oracle, November 2011

In the past column "Simulating planes with SPICE" you saw how we can determine the grid equivalent circuit parameters for a plane pair. We determined the parameters based on loss-less transmission-line equations. You may wonder: is it better to use LC lumped components in the SPICE netlist, or is it better to make use of SPICE's built-in transmission-line models. In short we can use either of them, but we need to set up our models and expectations correctly.

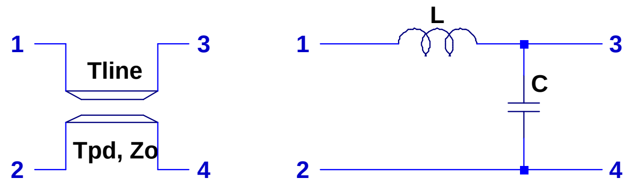

Figure 1: *Schematics symbol of a loss-less transmission line on the left, and an L-C representation of an electrically short transmission line on the right.*

Figure 1 shows a loss-less transmission line schematics element, a Tline, where the Tpd propagation delay and Zo characteristic impedance are all we need to describe the circuit. If the transmission line represents a trace, we assume that between nodes 2 and 4 we have a DC connectivity through the reference path, usually a plane. This assumption is also captured in the L-C equivalent circuit, where the reference sides of the input and output, nodes 2 and 4, are tied together. If we use this L-C equivalent circuit for each plane cell in the grid model, we will provide DC continuity both on the high and low sides, exactly as we expect it from a power and ground plane pair. We also have to remember that for a single-lump L-C equivalent circuit to be valid to describe a transmission line, the sqrt(L*C) propagation delay has to be much smaller than the period of the highest frequency of interest.

However, when we use a SPICE Tline element in the SPICE grid circuit, inside SPICE the Tpd and Zo parameters will be converted to a behavioral model, shown in *Figure 2*. Note that the circuit is completely symmetrical, but more importantly it has no DC connection between the input and output sides, neither on the high side nor on the low side. Why is this important for us to know? Because the Tline behavioral model provides only differential description of the circuit, we DO NOT have any direct connectivity laterally, between the high-side and low-side input and output terminals. This means that with a Tline grid we can not simulate the voltage drop horizontally along the planes, neither DC nor AC.

Using loss-less models like shown in *Figure 1*, we would expect zero DC drop both in the upper and lower planes. Instead, when we use a Tline grid, we will get the response of an open circuit. In the L-C equivalent circuit shown on the right of *Figure 1*, we get the proper DC connectivity in both the upper and lower paths. The ideal resistance-less L inductor in the upper path connects nodes 1 and 3.

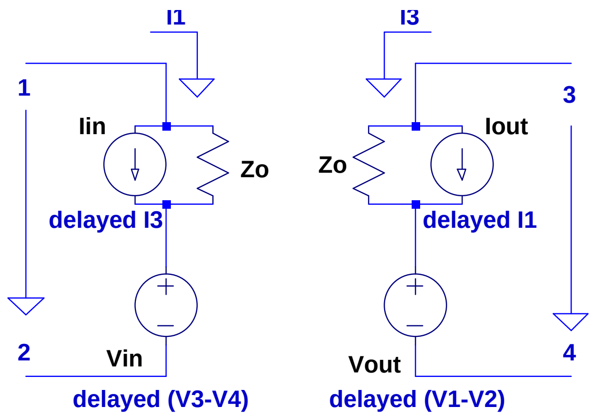

***Figure 2**: Equivalent SPICE circuit of a loss-less transmission line.*

The connectivity in the lower path is simply retained by an ideal connection between nodes 2 and 4. On the other hand, getting the proper connectivity at DC really does not really matter for a loss-less model, because we expect zero voltage drop anyway. It matters, however, for lossy models and also at AC. If we place a resistor in series to the Tline model or in series to the inductor, as shown in *Figure 3*, we can model the horizontal voltage drop due to plane resistance.

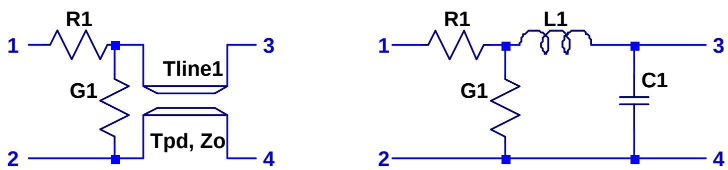

***Figure 3:** Schematics of a lossy transmission line on the left, and an L-C representation of an electrically short lossy transmission line on the right.*

To ensure causality, in *Figure 3* the circuit elements should be frequency dependent. The G1 parallel conductance represents the dielectric losses, R1 accounts for the sum of the resistive losses in the upper and lower planes. If we want to simulate the voltage drop separately in the upper and lower planes, we can split R1 and place a resistor representing the lower plane's loss in the lower path. This way we can simulate both the differential plane behavior and the horizontal voltage drop with the same circuit. We have to keep in mind that if we add R1 and G1 to an ideal Tline element, the result is non-causal, but for many power distribution applications it is acceptable, since usually we do not need to simulate the precise noise wave-shape.

Unfortunately the equivalent circuit shown on the left of *Figure 3*, using the Tline element, still will not provide horizontal connectivity. One workaround is that instead of using a single R1 in series of the Tline, we can place a series resistor between terminals 1 and 3, which will represent the resistance in the upper plane, and a resistor between terminals 2 and 4 to represent the resistance of the lower plane.