Impedance Discontinuities of Right Angle Bends…

90 degree, chamfered, and radial

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Introduction

The results presented below are a portion of a larger study on the propagation of signals through "90 degree", chamfered, and radius bends. Not all of the data has been gathered. A subset of the data is shown below. Eventually a full set of data will be compiled in a full report. In the mean time, think of this as a set of working notes that are pertinent to the recent discussions that we wish to share a little bit early.

Some Conclusions for the given transmission line structures…

- It is possible (and rather easy) to propagate a signal to a transmission line bend with sufficient risetime to see the bend.
- It is very important to KNOW the risetime AT the right angle bend in order to quantify if a right angle bend is having an effect on a signal.
- A 90 degree bend is a discontinuity.
- A "90 degree" bend shows a 1 ohm discontinuity relative to a 50 ohm transmission line at a 45 pS risetime.
- A "90 degree" bend shows a ~0.65 ohm discontinuity relative to a 50 ohm transmission line at a ~65 pS risetime.
- A radius bend does not show any appreciable discontinuities relative to a 50 ohm transmission line at risetimes as fast as 45 pS.
- It is easy to see these effects with equipment that has been around for over 10 years.

Some Recommendations for the given transmission line structures…

- A radial bend is preferred when working with 65 pS risetimes and faster. Depending on system impedance tolerances and PCB manufacturing tolerance, a radial bend may be required at slower risetimes.
- If a 90 degree bend is required, to mimimize the effect of a 90 degree bend, DO NOT put a 90 degree bend right outside the chip package. This is a sure way to immediately provide the most degradation to the signal. It is better to allow the natural tendencies of a lossy transmission line to help you slow down your risetime BEFORE the bend. Thus reducing the impact of the bend.
- If the system is 50 ohms, at 45 pS, 1 ohm is 20 percent of a typical +/- 5 ohm transmission line impedance target.
- If the system is 50 ohms, at 65 pS, 1 ohm is 13 percent of a typical +/- 5 ohm transmission line impedance target.

Some further research

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These are some of the tasks either to be done or already in progress.

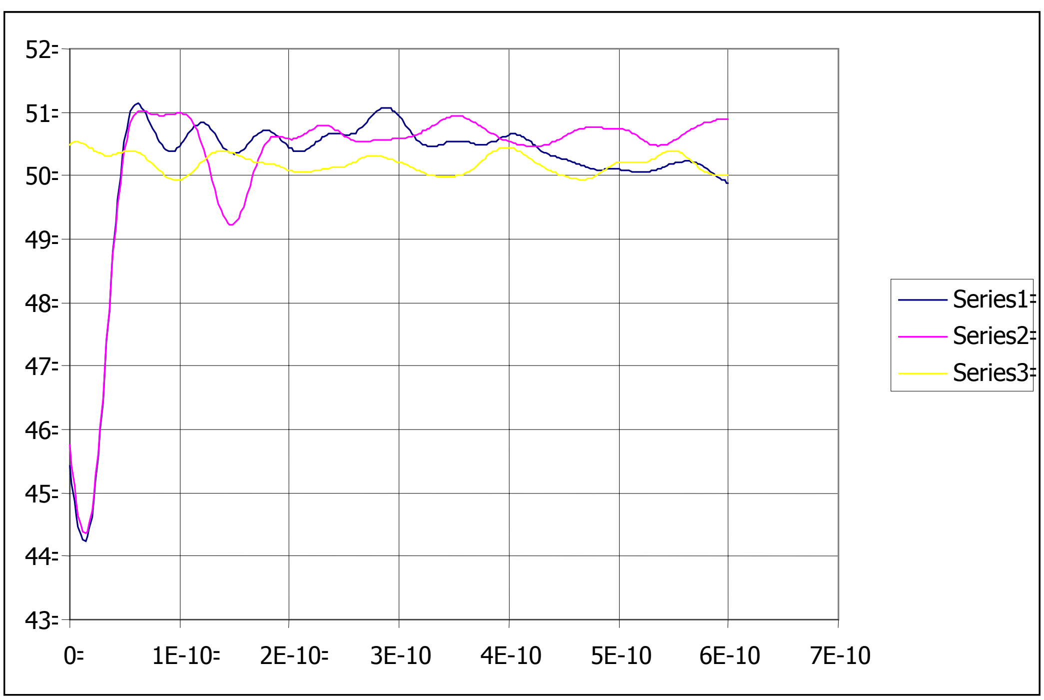
- Add data for chamfered bends (PCBs are constructed… data has not been gathered).
- Create models to further research the limits of performance of right angle bends.
- Confirm models to today's geometry and material. Use the models to explore different materials.
- Define, by TDR measurement, where the right angle discontinuity can no longer be seen (i.e. How slow must the signal be before you can start to neglect the bend?)
- Review the performance of right angle bends in the frequency domain.
- Review other literature with regards to bends in transmission line design.
- Create models to correlate to data provided. Use the same modeling method to explore typical cases that are seen in today's PCB designs. Further expand the analysis to cover next generation transmission line requirements.

Right Angle Bends…

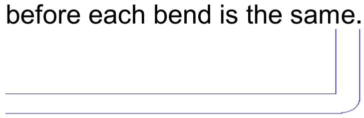
Food (data) for thought….

See the geometries and the TDR traces included in this document. The TDR data is somewhat worthless without knowing the test conditions, transmission line geometries, PCB materials, etc. Eventually, a full set of details is planned to be published / presented. At this point, I will report that this is actual data from a circa 1989 HP 54120 series TDR and the traces were constructed using a typical signal line trace width in a stripline configuration.
The first discontinuity is the cable to PCB interface (including an SMA launch, via and via stub into the PCB). There is room for improvement with the PCB to cable. The impedance at the second discontinuity on "Series" 2 is at a risetime of 45 pS. The impedance difference at the discontinuity is about 1 ohm.

Which TDR trace shows the radius bend? Series, Series2, or Series3
Which TDR trace shows the Right Angle bend? Series, Series2, or Series3
Which TDR trace shows a 50-ohm termination? Series, Series2, or Series3



Another example… In this case, there is about 6.5” before the bend. Yes, the length of trace before each bend is the same.

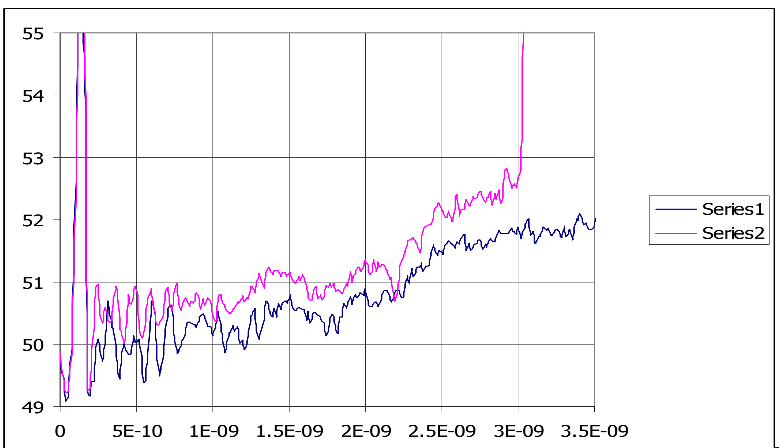


(not to scale)

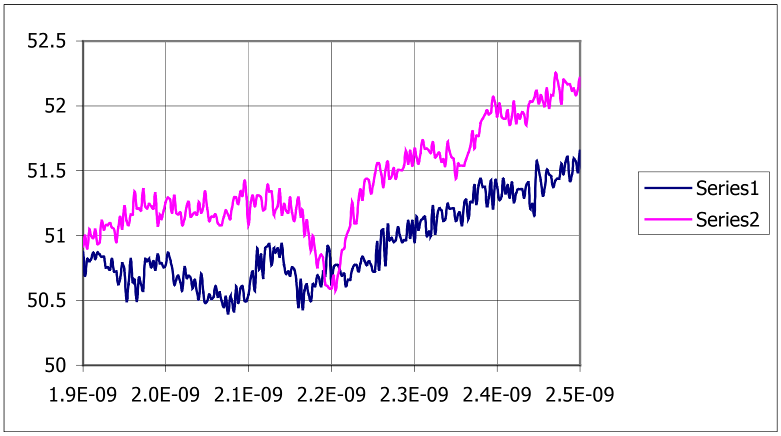
The signal was launched with a microprobe. As can be seen in the TDR data, there is a need to work on the probe pad design in order to improve the launch. Because these two traces are on the same board, the *general* 0.5ohm difference between the two traces is most likely related to signal trace etch differences. The “rising” of the TDR trace is a well-documented effect that relates to the electrical losses of the materials used in PCB construction.

There is a discontinuity at about 2.25 nS? At this point, there is further PCB related signal degradation as compare to the 45 pS in the previous example, so the risetime of the signal that is seen at the bend is slower. The data is not complete yet, but preliminary calculations indicate a risetime of about 60 pS to 70 pS

Which TDR trace shows the radius bend? Series or Series2
Which TDR trace shows the Right Angle bend? Series or Series2



Here is a closer look at that discontinuity such that we can get a better idea of the magnitude of the discontinuity. There is about a 0.6 to 0.7 ohm difference at the discontinuity.



Lets add some data from “Microstrip Lines and Slotlines”; K.C. Gupta, Artech House, 1996 to show the correlation with predictions in microwave literature.

Here is a table put together from the diagram in Gupta:

edge rate	bandwidth	square corner loss	45 degree corner loss	reflection coeffieient square corner	reflection coefficient 45 degree corner
45 ps	7.7 GHz	-35 dB	-40 dB	1.78%	1%
65 ps	5.38 Ghz	-39 dB	-44 dB	1.12%	0.60%
100 ps	3.5 GHz	-43 dB	-49 dB	0.70%	0.35%
150 ps	2.3 GHz	-48 dB	-53 dB	0.40%	0.20%

From the TDR measurements, which were made, we would expect the following:

At 45 ps edge rate we expected to see a Z0 reduction down to 49.11 ohms, or 0.9 ohms loss.

At 65 ps edge rate we expected to see a Z0 reduction down to 49.44 ohms, or 0.56 ohms loss.

The numbers measured show good correlation with the VNA data which Gupta provides. (Funny how that works!)

For those who are skeptical, a 5 ohm impedance mismatch to 50 ohms is equivalent to a loss of 25.6 dB or 5.2% reflection coefficient. A 10 ohms impedance mismatch relates to a 19 dB loss or 11.1% reflection coefficient.

Does this mean the transmission line is bad? Maybe… but it does shows that a right angle bend can eat up a significant amount of your impedance budget. If a system requires 50 ohms and a 10% impedance tolerance, a right angle bend will demand 20% of that budget at 45 pS and 10% of the budget at 65 pS.

Other questions that come to mind…

- If there is a contract with the PCB manufacturer is to supply PCBs with a 50 ohm +/- 10% impedance and the traces are nominally 45 ohms… except at the right angle bend…. Who is responsible for the cost of manufacturing the PCBs?
- Do radial bends help with impedance control when considering manufacturing manufacturing tolerances?