Application Note AP8259

Impedance not correlating with models at sub 75 micron line widths?

Using test coupons at reduced dimensions

Summary

Recently customers have questioned divergence from field solver predictions when building sub 75 micron line widths. Below this width the distance between modeled and measurement appears significant. This study illustrates that you should first look at the measurement to pinpoint the source of divergence which progressively increases as line width / copper thickness is reduced still further. This example follows a single coupon from design at 129 Ohms differential pair and shows the steps taken to align the initial impedance measurement at an average of 148 Ohms through to a very tight correlation between measured and modeled. Coupons used in this study were built with subtractive process at the lower limits of achievable line widths with traditional technology

Report

This is the report of a project to design some coupons for testing extremely small structures with controlled impedance. And the process of seeking to reduce the discrepancy between modelled and measured in stages.

For this coupon the trace thickness is of the order of 11 microns and the requested trace width 45 microns with spacing between traces 100 microns (25 microns = (1 thousandth of an inch = 1 mil))

The stack-up and the achievable dimensions were obtained from the PCB manufacturer and entered into Speedstack then the differential structures were adjusted to achieve the desired impedances.

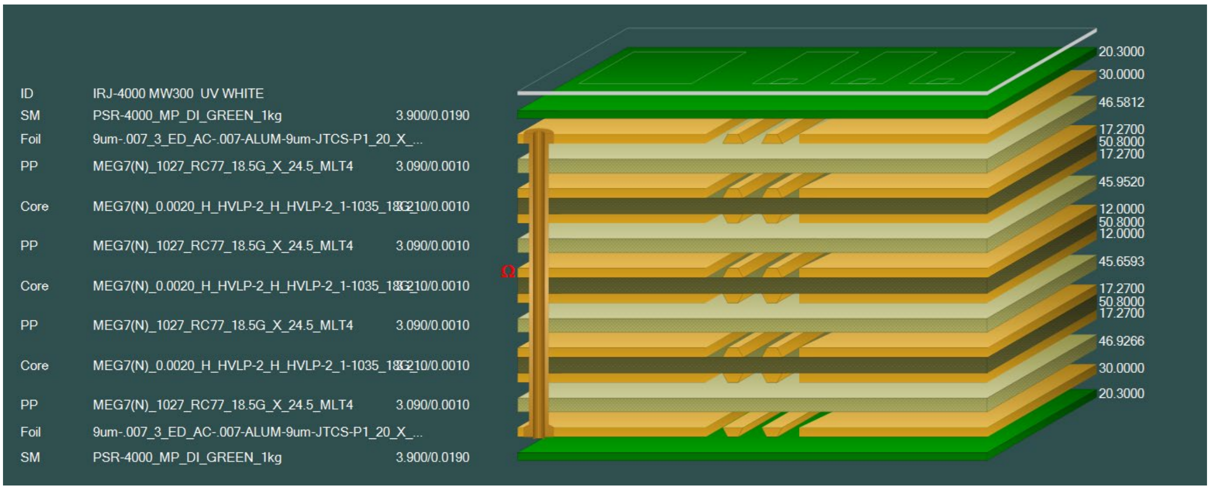

Fig 1: The design data for Trace 1 in Speedstack is shown below.

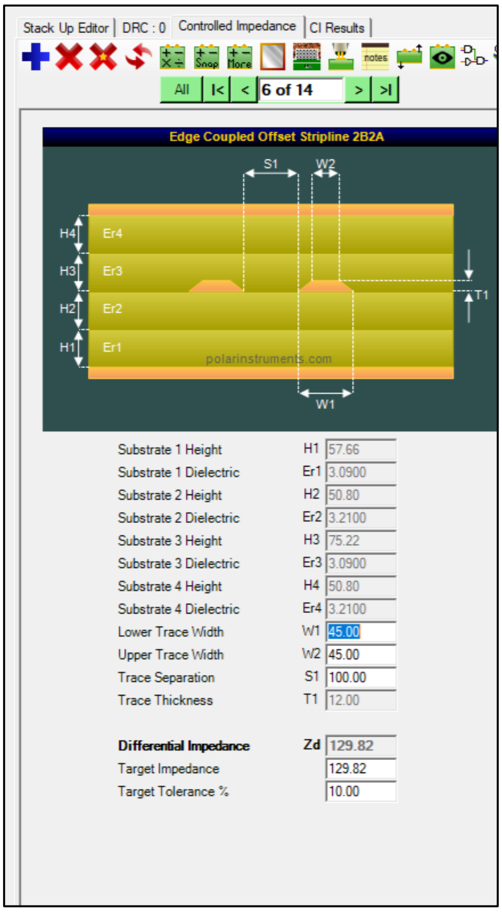

Fig 2: The design intention in this stack solves at 129.8 Ohms for the purpose of the experiment. This is one selected of a range of impedances built for the study.

Before looking at the characteristic impedance measurement of a 45 micron line – here is an example of a typical 100 micron (or wider) transmission line impedance test:

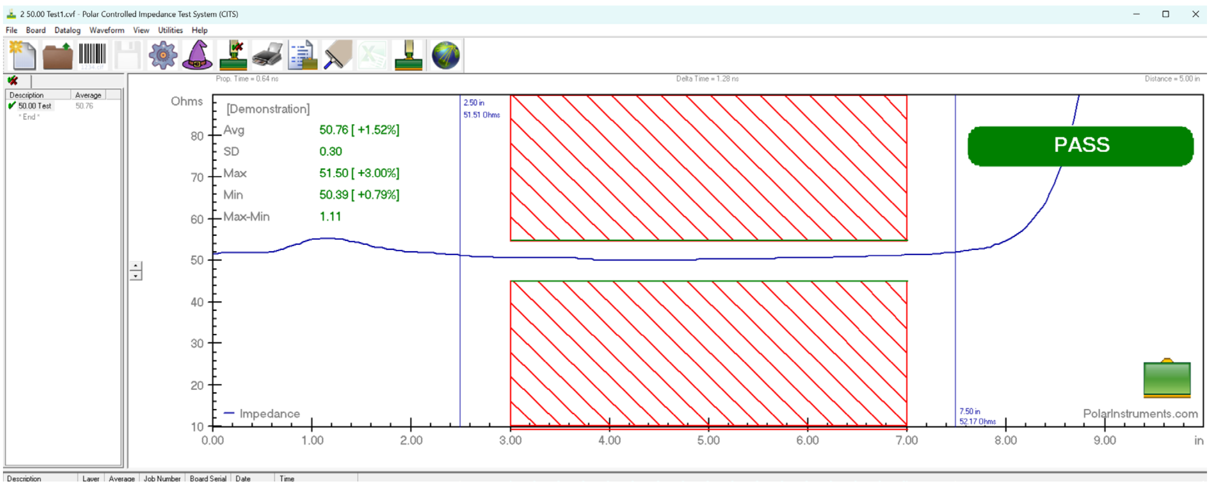

Fig 3: A typical 100 micron line width impedance test

Take note that the measured area is relatively flat over the tested length and the average or any spot reading will be a reasonable indication of the characteristic impedance.

Coupons were then manufactured and tested using Polar CITS880s, first with a conventional Absolute measurement and then employing Launch Point Extrapolation to obtain impedance measurements from a situation where the traces are sloping due to their high DC resistance, which is an inevitable result of very small dimensions. For instance, one conductor of trace 1 measures 7.5 Ohms end to end.

Initial results:

Speedstack is predicting an impedance of 129 Ohms for the structure under test.

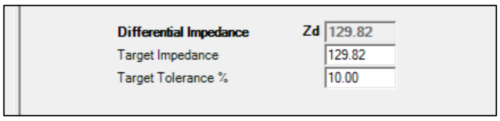

Fig 4: Speedstack calculation of the structure's impedance

CITS880s is measuring an average Zdiff of 145 Ohms with standard settings

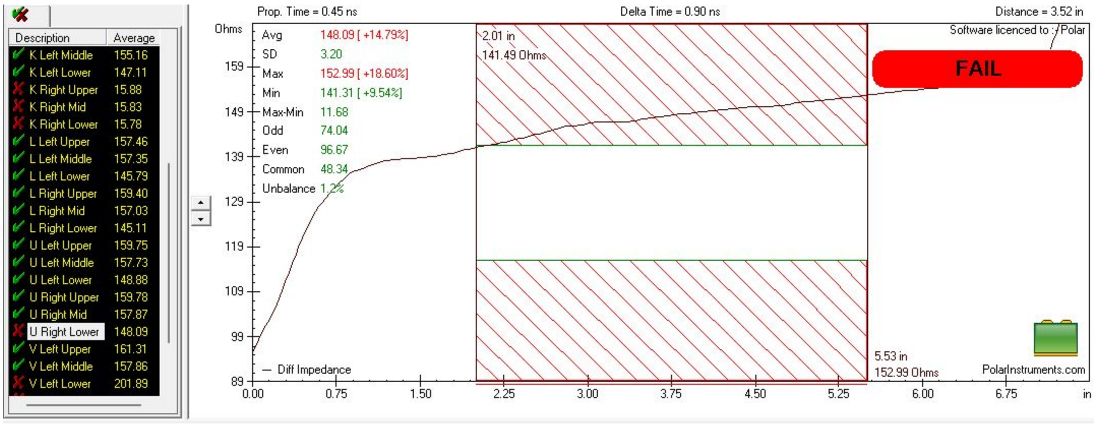

Fig 5: Conventional impedance test method – Absolute: an average of 148 Ohms on the specific trace under test – with a design impedance of 130 Ohms.

Contrast the test region on the measured 45 micron coupon on Fig 3 and the trace above in Fig 5 shows a steady upward trend along the coupon and a FAIL of the impedance test.

This trend is not an indication of the characteristic impedance – rather it is indicative of the DC resistance of the fine line superimposing itself on the reflected TDR trace.

Characteristic impedance is an inherent property of a transmission line and it is independent of length so the operator needs to remove the DC resistance element if an accurate measure of characteristic impedance is to be made.

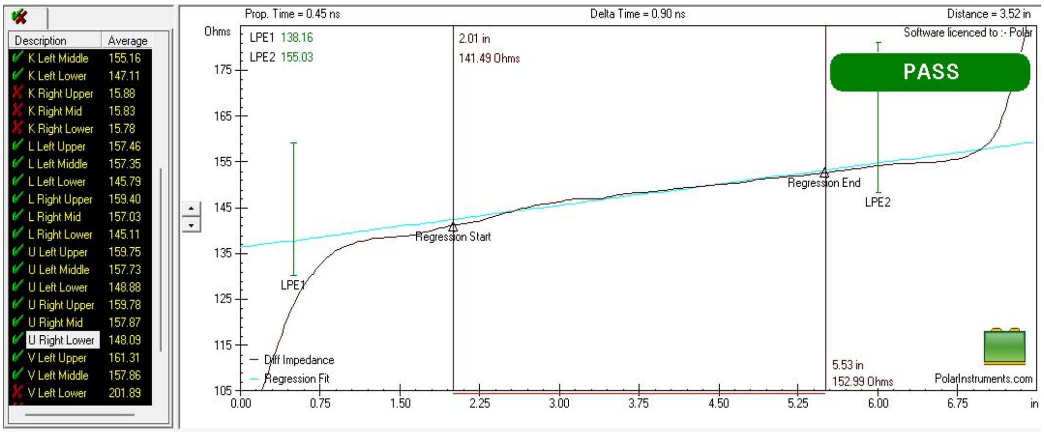

Fig 6: Polar CITS880s employing Launch Point Extrapolation

Recognising the upward trend of the reflection and measuring the coupon with a multimeter to confirm significant DC resistance in the trace – we can adjust the test method to LPE (Note 1) and this brings the measurement down to 138 Ohms at the LPE 1 point. Still 5 or so ohms to go but closer than the initial numbers were indicating.

Further:

The design data giving the intended dimensions and the measured results are listed in the tables below (at three separate locations and on 3 different Polar and Tektronix measurement instruments.)

Trace	Design Z	Measured Z (Test system 1)	Measured Z (Test system 2)	Measured Z (Test system 2)
1	129.8	138.8	138.0	139.6
2	138.4	148.4	146.3	148.4
3	140.1	151.8	147.6	150.2

Table 1: The coupon trace under analysis measured with 3 different test systems.

In order to determine why there is still a difference between measured and modeled, the coupon was sectioned in three places (at the centre and near to each end) and the dimensions of the copper obtained. This data was then used to calculate the impedance of the traces so this could be compared to the above data. Variations of dimensions at the three sections along the trace could also be seen.

Coupon	Average measured Z	Section 1 Start	Section 2 Center	Section 3 End
1	138.6	140.9	141.2	140.3
2	147.7	151.1	153.0	152.0
3	149.9	150.3	151	152

Table 2: The mechanical cross section data is fed back into the field solver and new predictions calculated with actual rather than intended dimensions.

This raises the question of where the design did not match the reality of the coupon.

The graphic below shows the data and it is clear that the design has been over etched as the traces are narrower than expected and the spacing between traces is greater.
Traces are also thinner than expected, which is a different process as the copper is reduced to this thickness by etching before traces are laid out. Variations between the three measurement sites indicate variation along the trace and this may result in the impedance varying along the trace resulting in bumps or unevenness in the displayed impedance waveform.

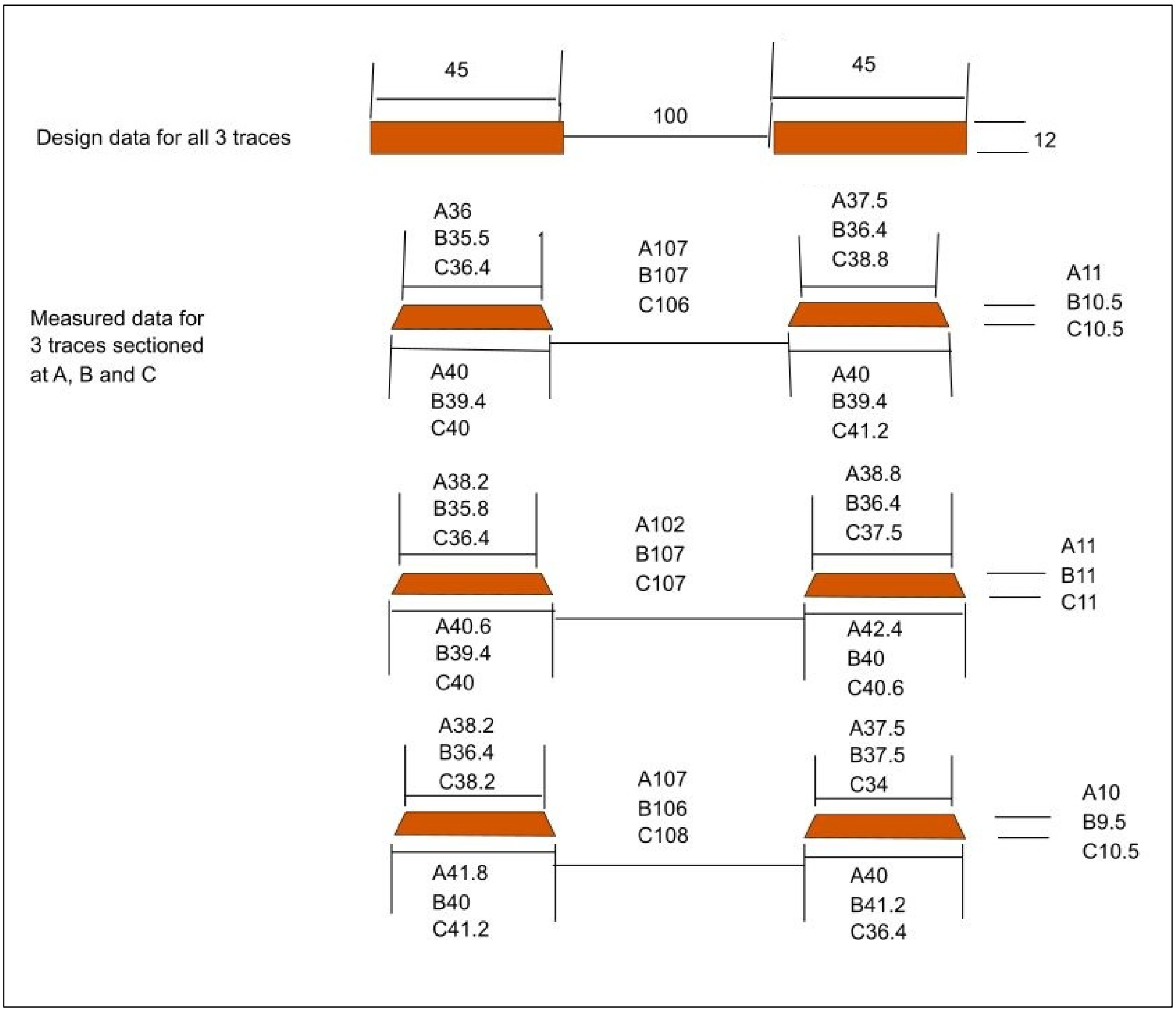

Figure 7: – Design vs actual section data for 3 examples sectioned at 3 points.

In the specific section for this analysis:

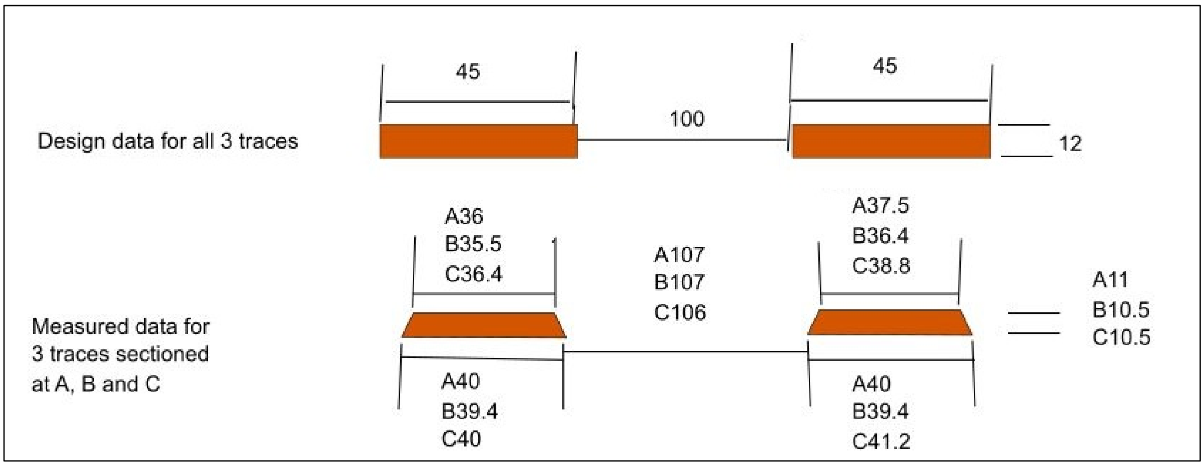

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Figure 8: – Mechanical design dimension vs precision microsection
– actual traces 9 to 10 microns narrower than requested.

In Table 2 above we are now within 1 or 2 ohms or less variation between predicted and measured which is an extremely favourable outcome.

So, to recap:

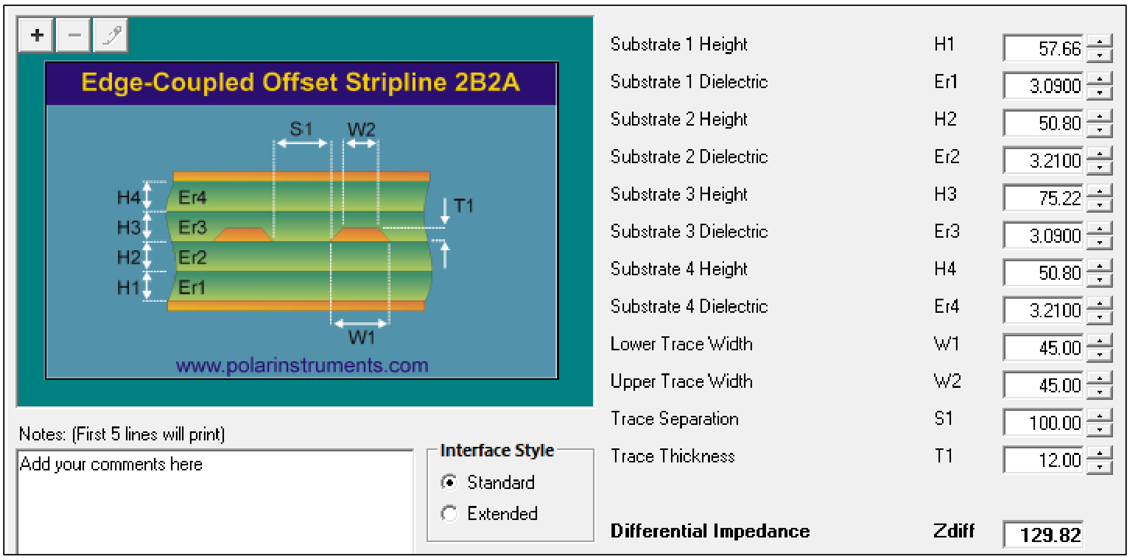


Fig 9: As designed W1 nom 45 microns S =100

Z_{diff} requested 129.8 ohms

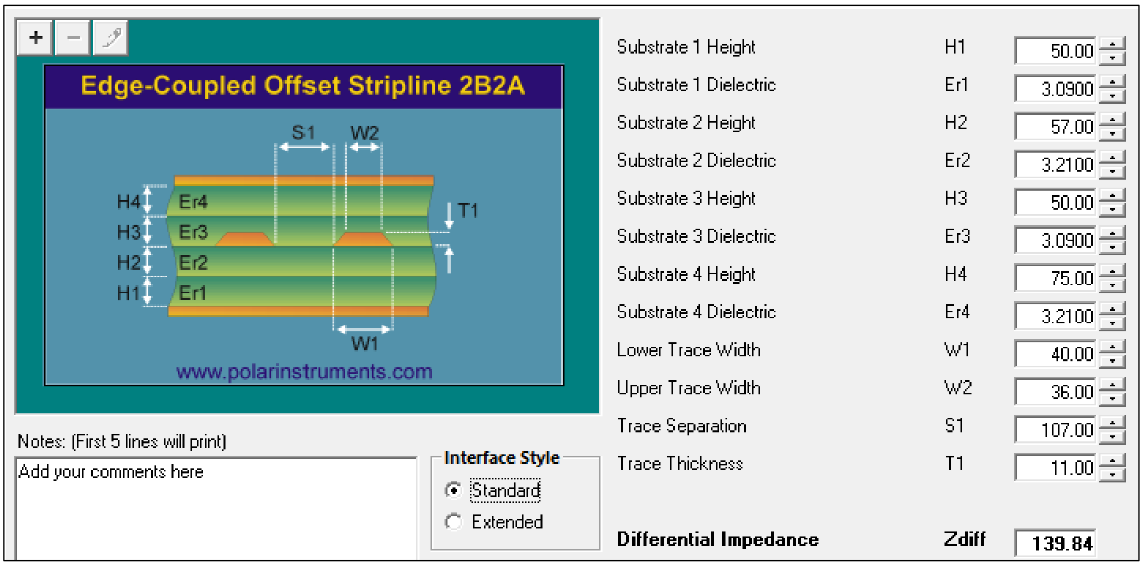


Fig 10: As sectioned – actual values: W1 40 microns: W2 36 microns: S = 107 microns

Z_{diff} predicted 139.84 Ohms (one section only shown for clarity)

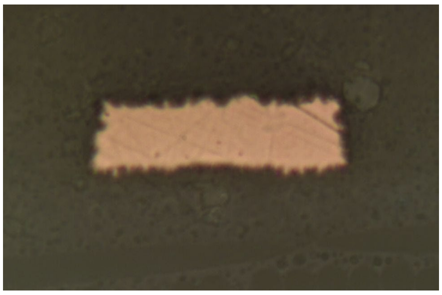
The 139.84 Ohms predicted from section data is well within normal expected tolerance – from the LPE measured of 138 to 139.6 ohms measured on 3 separate test systems.

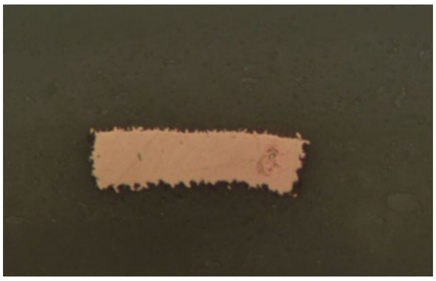
Conclusion:

The long held assumption that the resistance component of a PCB transmission line is small enough to ignore when compared with the characteristic impedance falls down when geometries fall below 50 microns. At these dimensions the DC resistance becomes significant and will impose an upward trend on a TDR trace or VNA measuring in time domain mode. This needs to be removed using an appropriate method. IPC propose either Launch Point Extrapolation – detailed in this note or DC resistance compensation. After taking this into account, should there still be significant deviation between measured and modeled it is recommended that further analysis through precision microsection should be pursued.

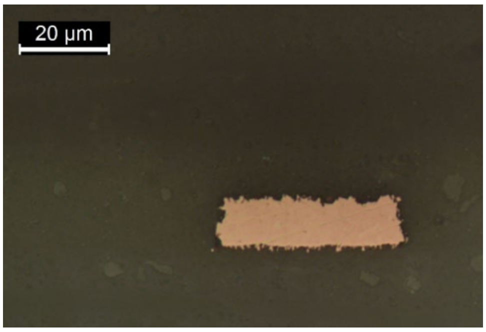
Further information from sections of the coupon under test and other coupons in the same study group

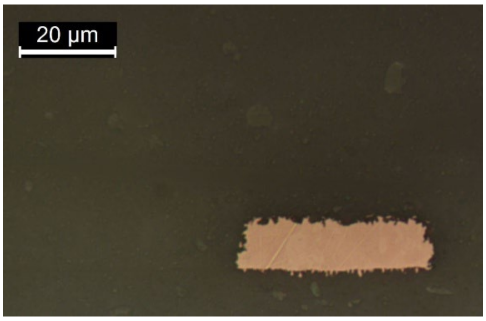
Looking closely at the sections reveals much variation in roughness and distortion of the copper due to glass bundles in the laminate.

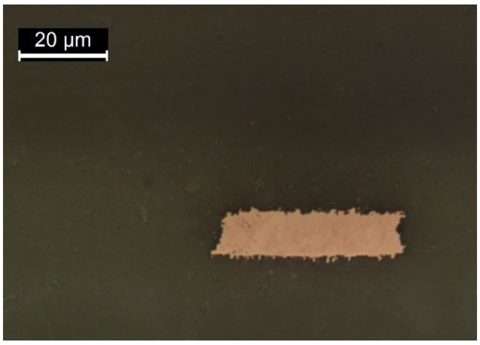




Below is a set of three sections of the same trace at different points along its length.

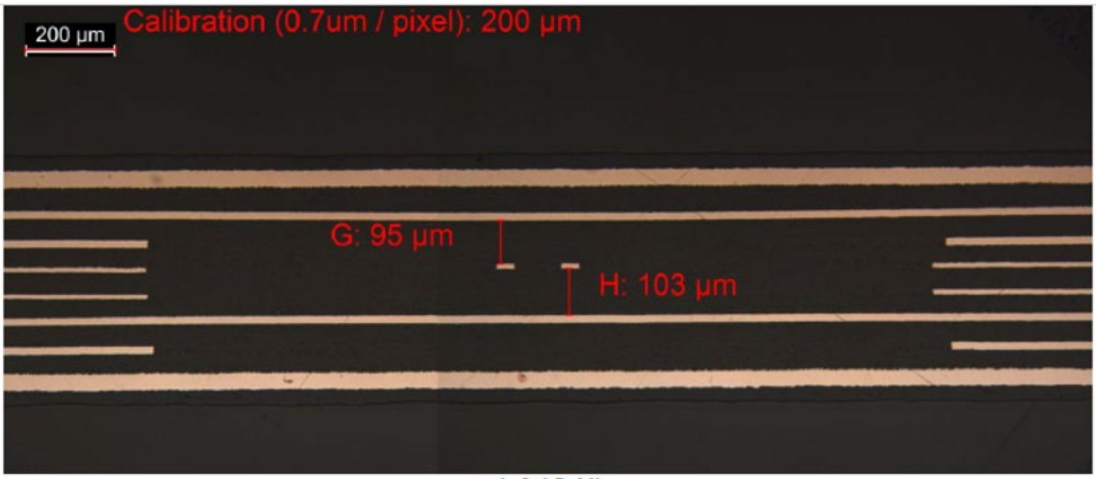






When obtaining measurements to enter into a calculator it necessary to estimate the width and thickness of the copper. This requires careful and skilled assessment of the images.

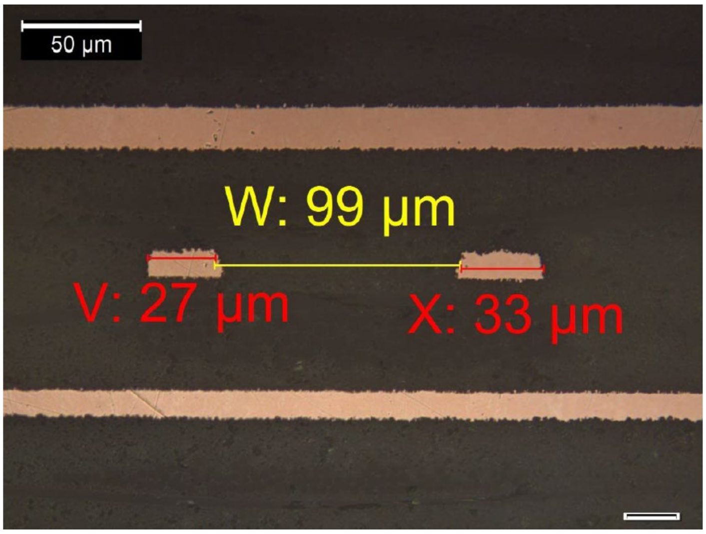
Below is a typical picture of the trace at a section point showing ground planes above and below and the etched back copper in unused layers.



1-6 (G,H)

Example of imbalance:

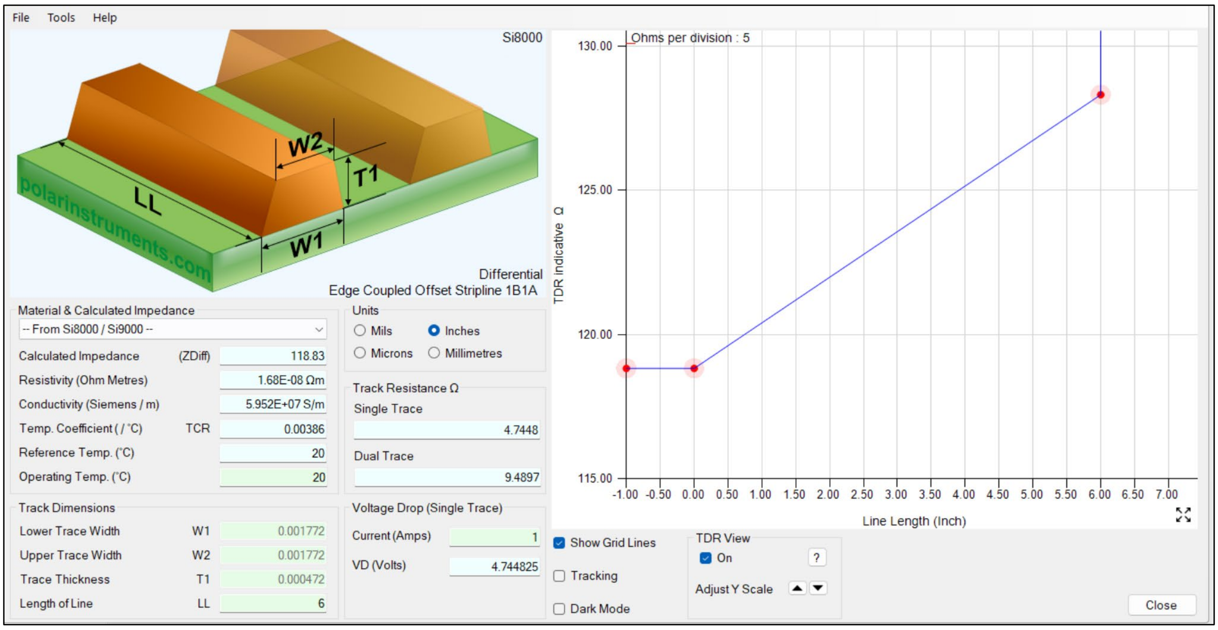
During the study, differential pairs with mechanical imbalance between the left and right conductor were also witnessed as illustrated below. These were confirmed by measuring the individual lines with single ended measurement.



Example of differential trace imbalance

It is recommended that when measuring with TDR that at these geometries the TDR test has "Unbalance Warning" selected to flag these conditions. (Note 3) The trace studied in detail had some but not significant imbalance between the sides of the differential pair – others showed more with one outlier shown above.

Adding confidence with tools:



Simulating the effect of trace resistance with TDR View in TRC Plus

On fine geometries you can use tools such as TRC Plus to obtain get an indication of the impact of DC resistance by entering the geometries and coupon line length and selecting TDR view.

Glossary / appendix:**

Note 1: *Launch point extrapolation (LPE)*. Regression fit line on the measured interval of an impedance coupon where the line is projected back to the "launch point" i.e., the start of the impedance trace on the coupon for the purpose of de-embedding the DC resistance component of the measurement – leaving purely the characteristic impedance value which is independent of line length.

Note 2: Distributed resistance in a transmission line explained:

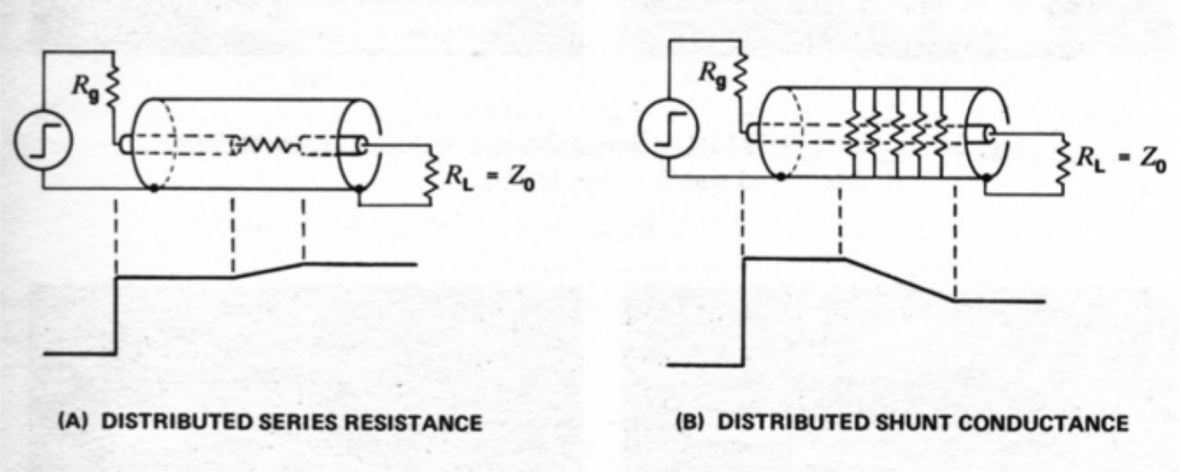


Fig. 3-7. Distributed-resistance discontinuities and their reflections.

Source: Time-Domain Reflectometry Measurements – Strickand. Tektronix Measurement series. 1970

Strickand's extensive measurement booklet explains in detail the nature of how different circuit elements in a transmission line impact the TDR reflection. The above figure shows the effect of Distributed series resistance and for completeness here distributed shunt conductance.

Note 3: Imbalance test – This study was taken using coupons produced with conventional subtractive methods – at the limits of present production capabilities. This does mean a greater chance of line to line variation on differential pairs as well as variation along the whole trace. This is less likely with additive or semi additive processes (SAP or MSAP) however these are much more costly and production intensive methods required when moving line widths below 25 microns. When working at these line widths checking for imbalance on differential pairs adds a further confidence level in the measurement.