Production, measurement and simulation of a low mass flex cable for multi gigabit/s readout for the LHCb VELO upgrade

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Abstract

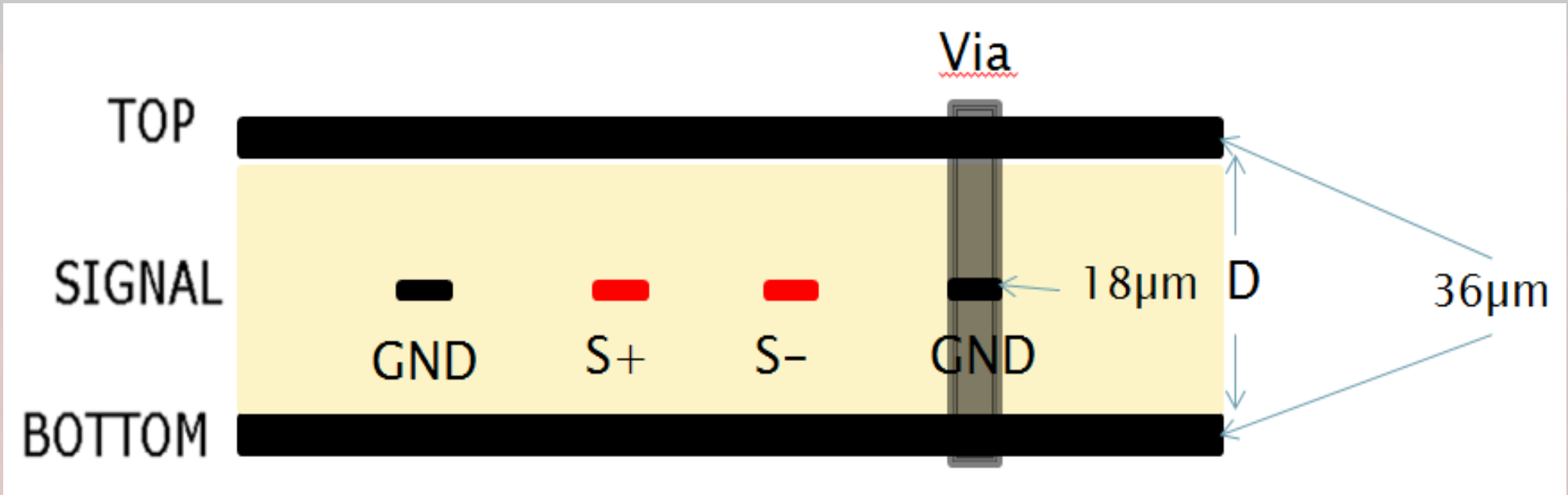
The goal of this project is to examine the feasibility of data transmission up to ~5 Gbit/s on a short (~60 cm) low mass flex cable, for the readout of the upgraded vertex detector (VELO) of the LHCb experiment. They will be in a vacuum and very high radiation environment and also partly in the particle acceptance. For the full system 1600 readout links will be required. A set of single-ended and differential (edge-coupled) striplines, with a variety of line parameters have been prototyped using a material specifically tailored for this type of application (Dupont Pyralux AP-plus polyimide). To reduce mass, the total thickness of the cable is kept to 0.7 mm. We will present measurements of the characteristic impedance, insertion and return loss, obtained both from time and frequency domain, as well as a comparison with simulations and expectations. Also the effectiveness of grounded guard traces and the use of ground via holes to reduce crosstalk will be reported. From the measurements we were also able to extract the material properties such as the dielectric constant and loss factor up to several GHz. The measurements were done with a Vector Network Analyzer (VNA), TDR/TDT Digital Sampling Oscilloscope, serial PRBS generator and analyzer for eye diagram and CAD tools such as Agilent ADS and ANSYS HFSS simulators.

Cable description:

Differential coplanar-stripline with isolating guard traces between pairs.

Made with Dupont Pyralux AP-plus polyimide with dielectric constant 3.4 and dissipation factor (Loss tangent) of 0.002 at 5 GHz.

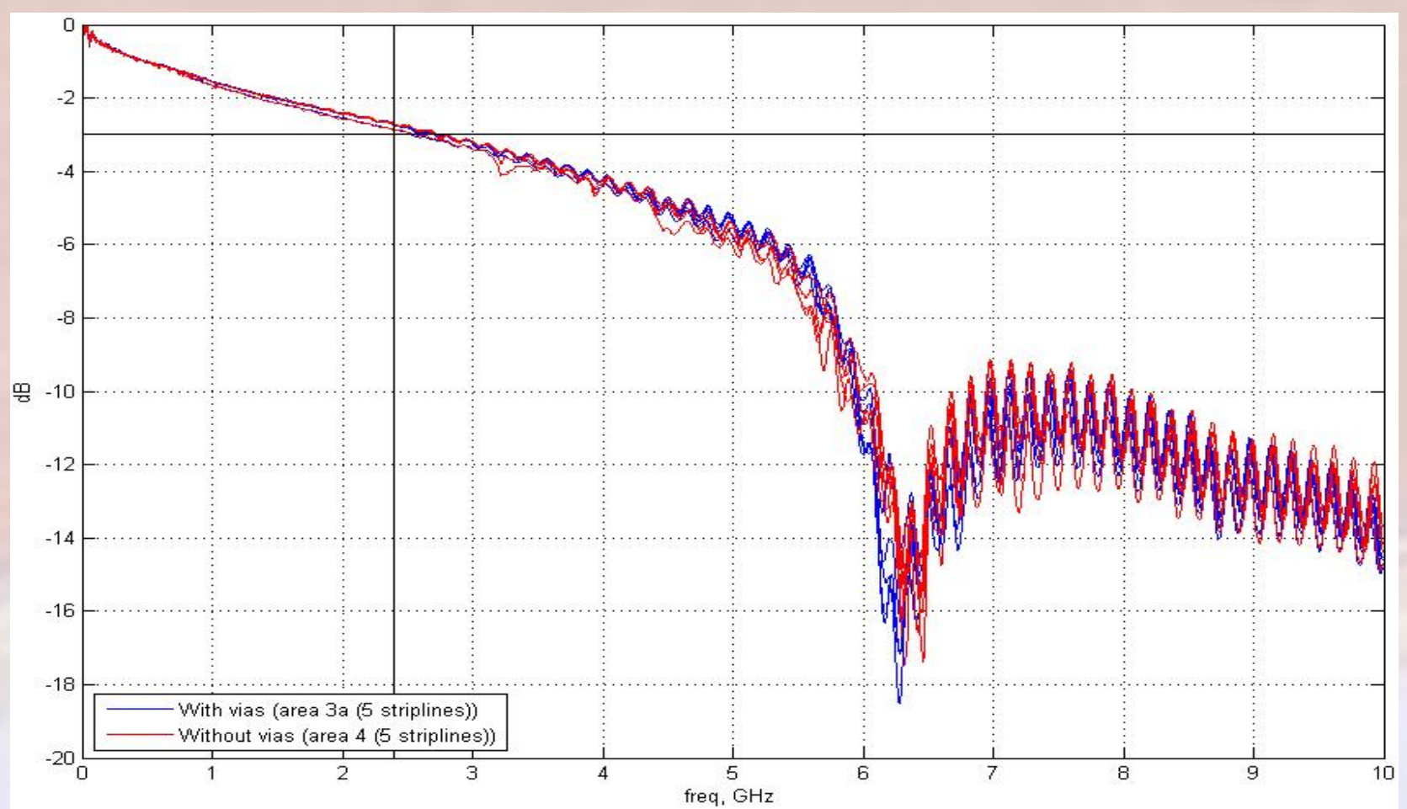
- First prototype: dielectric thickness (D) ~500 µm; total thickness ~700 µm (about 2x65 µm of cover lay on top and bottom).
- Second Prototype: dielectric thickness (D) ~350 µm; total thickness ~550 µm (also with 2x65 µm cover lay).



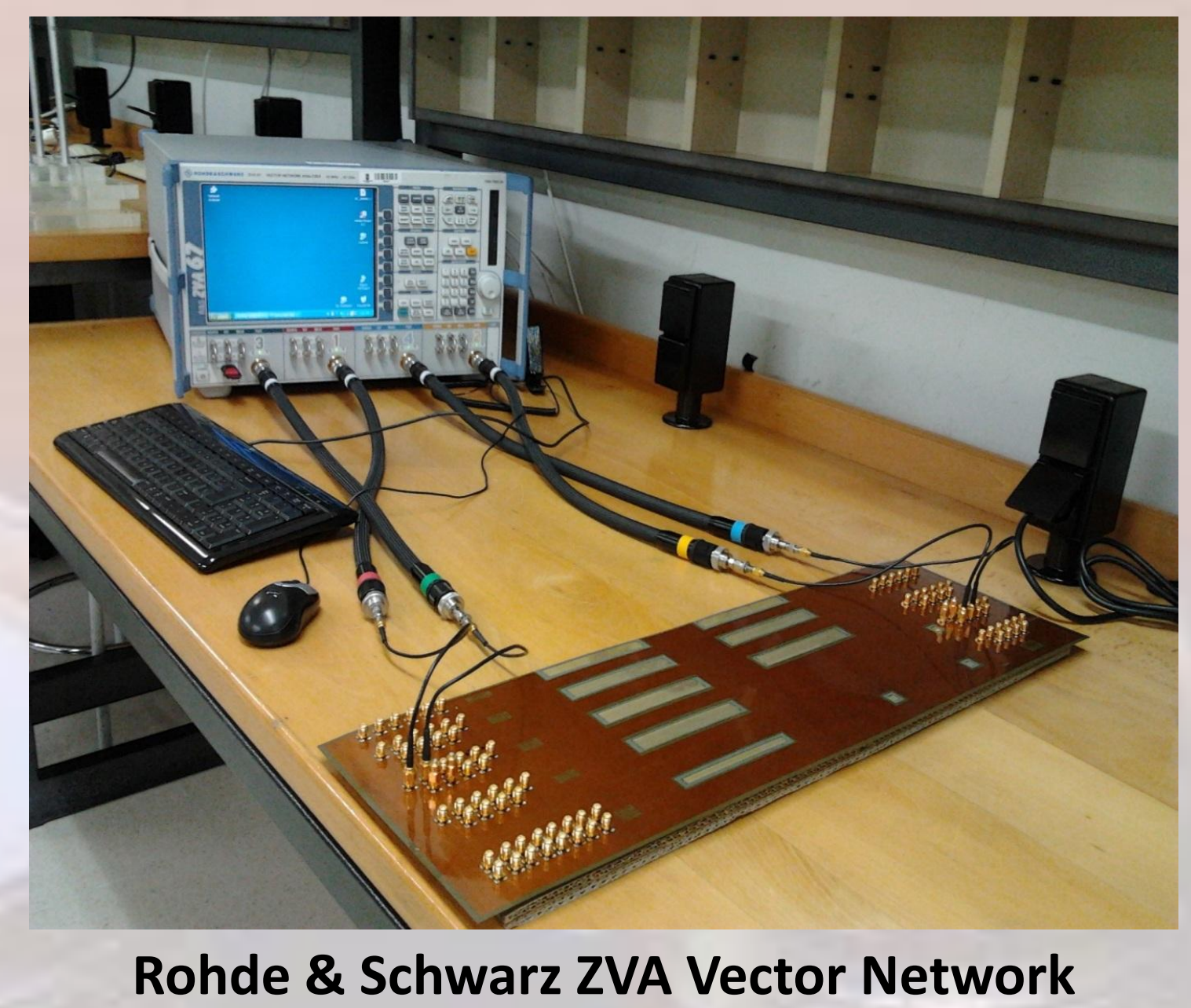
Cable section

Several effects were studied in the frequency domain (first prototype):

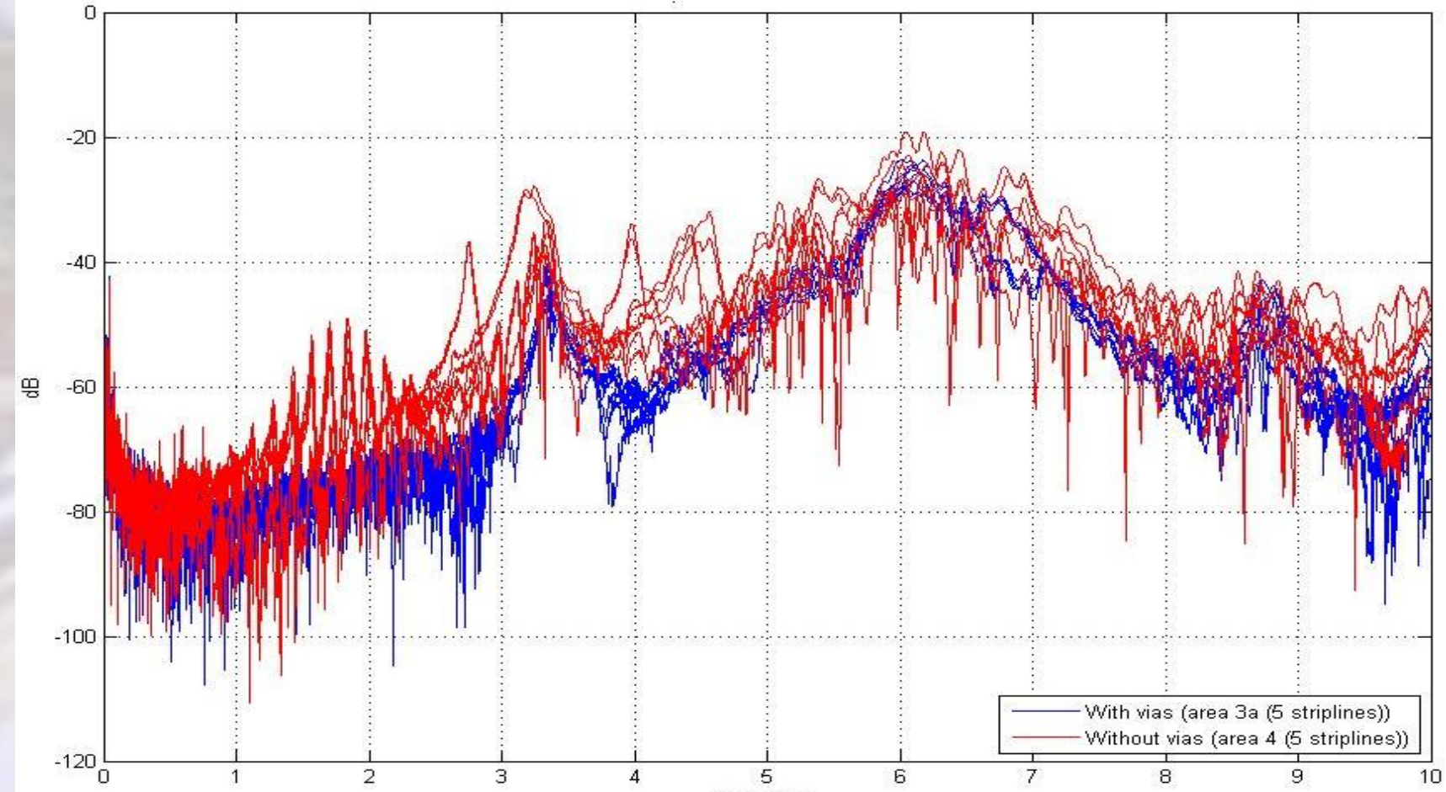
- Guard traces are very effective for suppressing crosstalk.
- Via holes on ground traces: they do not contribute significantly to further suppress crosstalk.
- Surface mount right angle SMA Connectors were used to connect all the lines. Using a special layout we could avoid the use of routing via's on the signal path. Nevertheless a sharp insertion loss appeared around 6 GHz. By using a 3D EM-field simulation we could explain it as a resonance in a parasitic cavity and eliminate it by an improved layout.
- Physical line parameters: variation of trace width, inter-trace gap and length in addition to single and differential line approaches were studied to see the effect on transmission line parameters. The trace width was varied from 250 to 310 µm, the inter-trace gap from 150 to 750 µm and the length from 50 to 100cm. Only the length contribution is significant.
- Micro miniature connectors (MOLEX SlimStack 0.4 mm): these very low mass connectors turn out to have very low insertion losses at high frequencies.



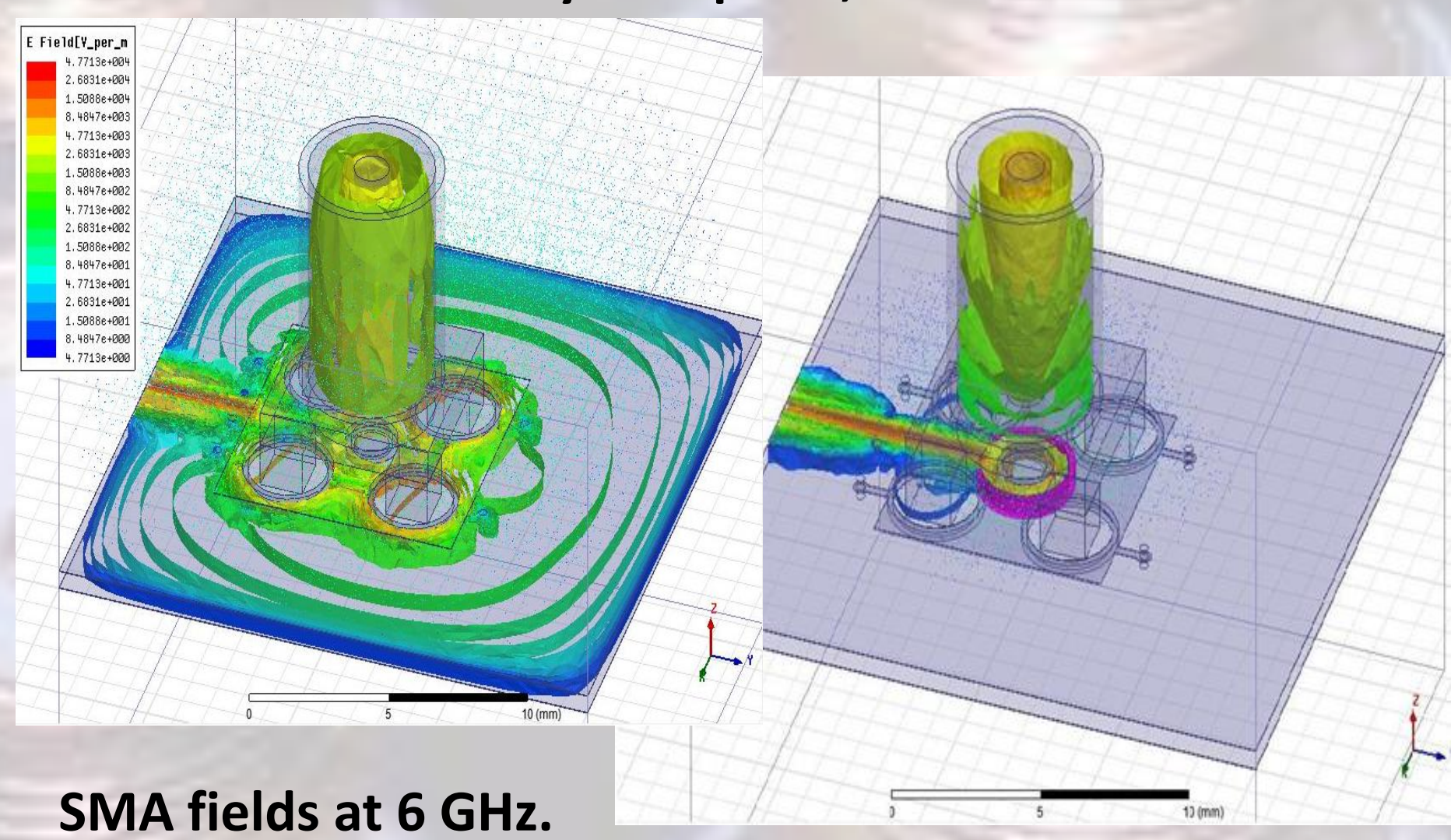
Parameter S21 differential



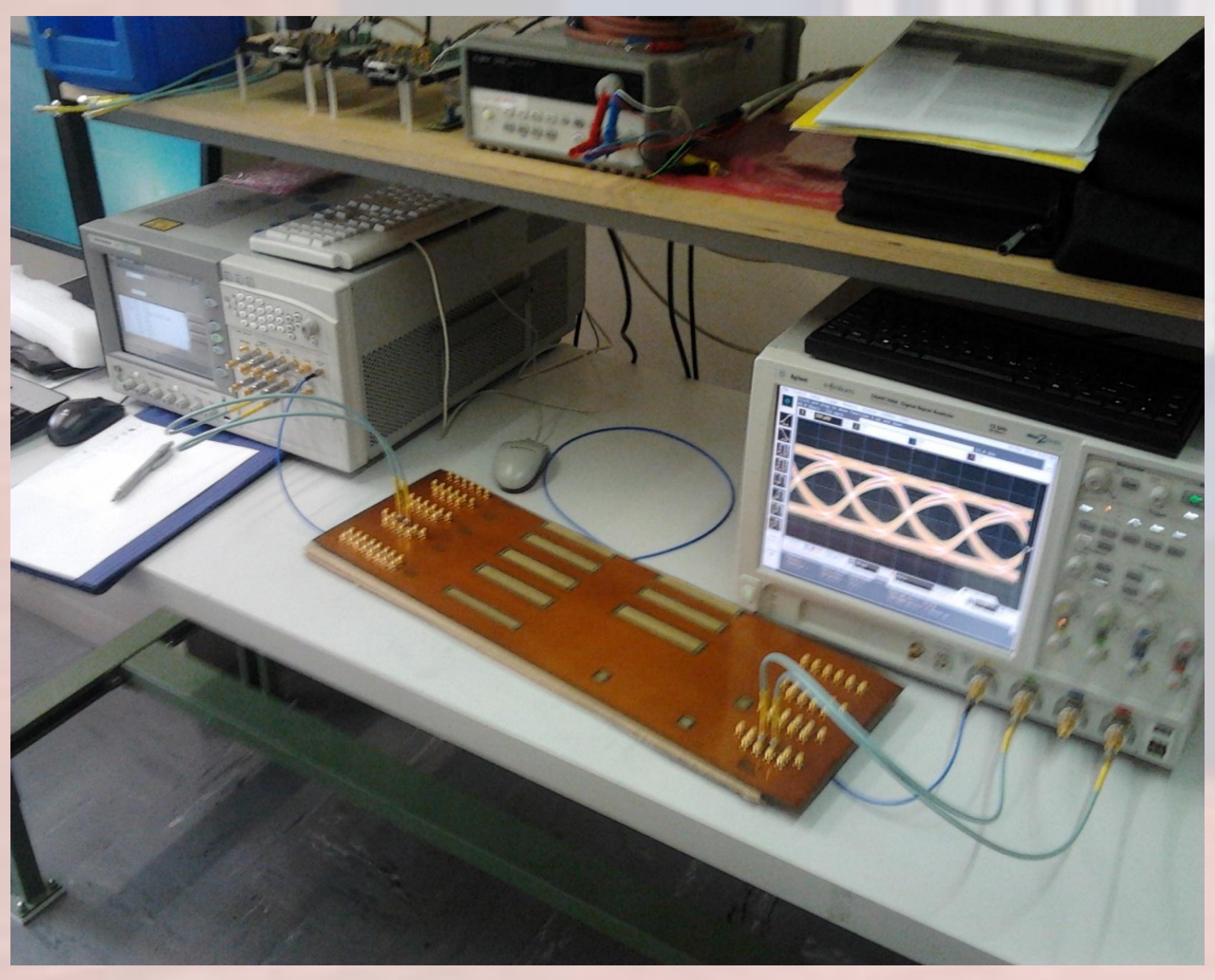
Rohde & Schwarz ZVA Vector Network Analyzer 4 ports, 67 GHz.

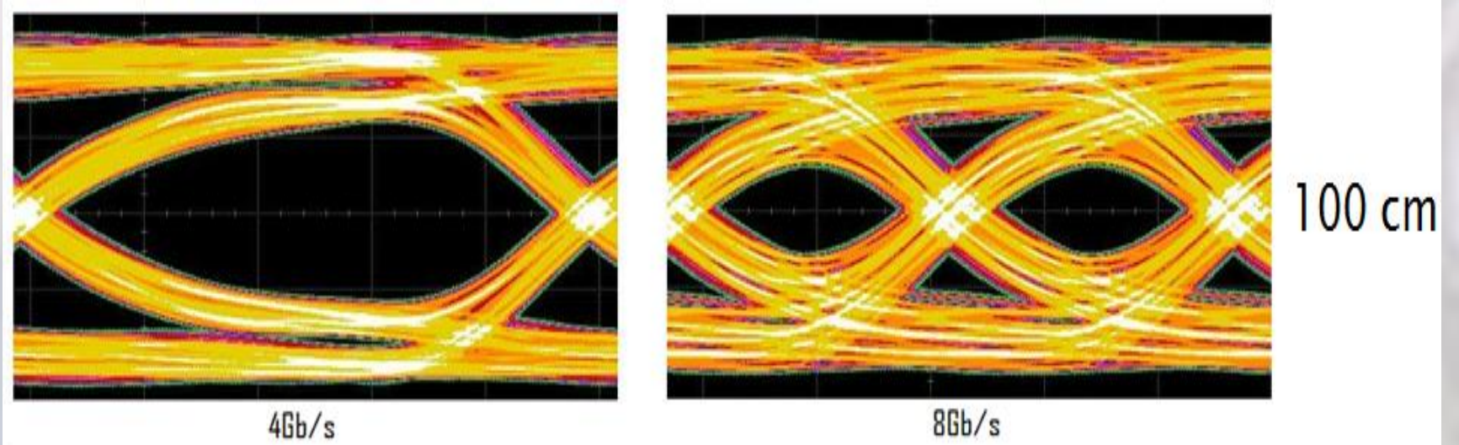


Crosstalk between adjacent differential striplines



SMA fields at 6 GHz.
With insertion loss (left). Improved layout (right).

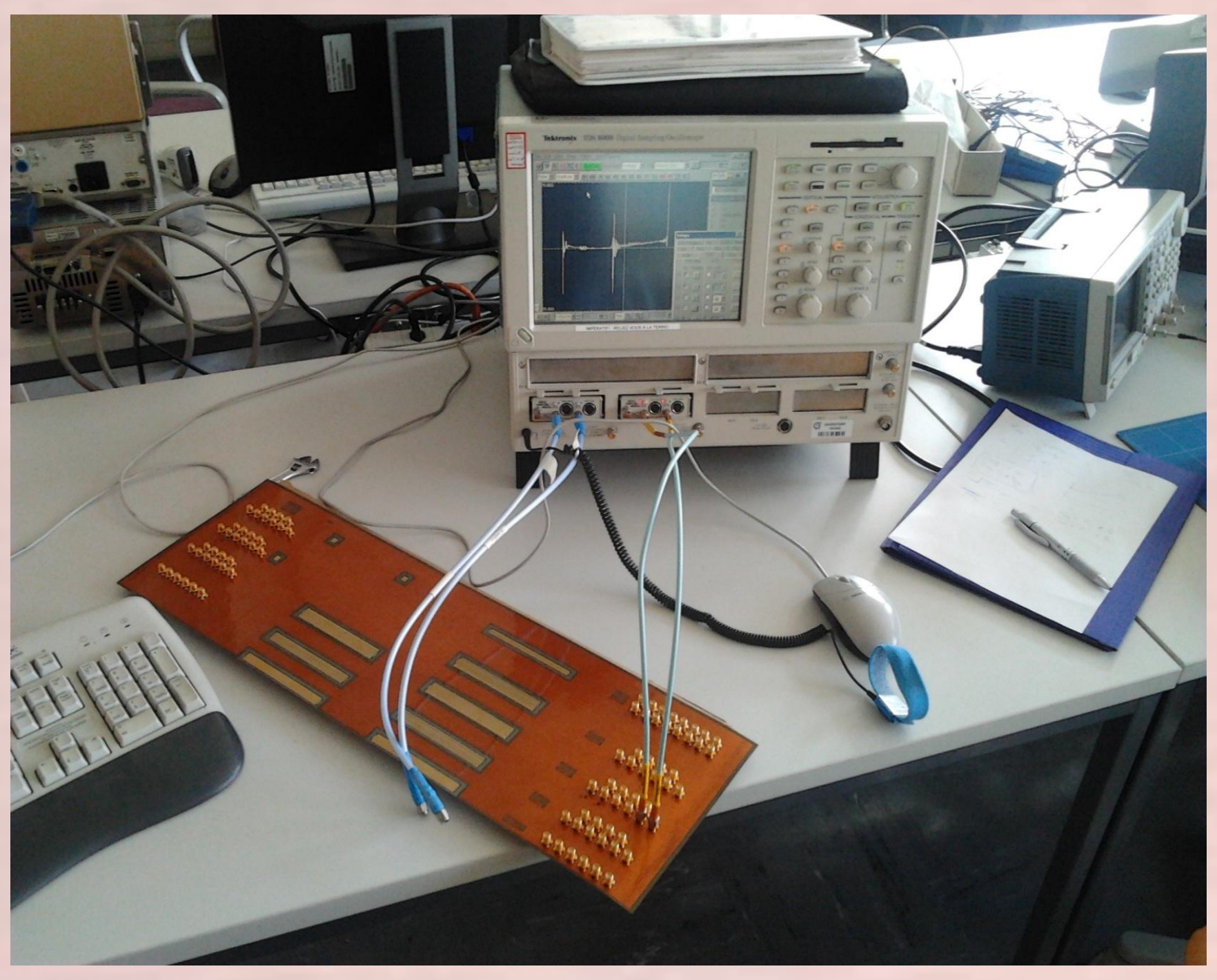




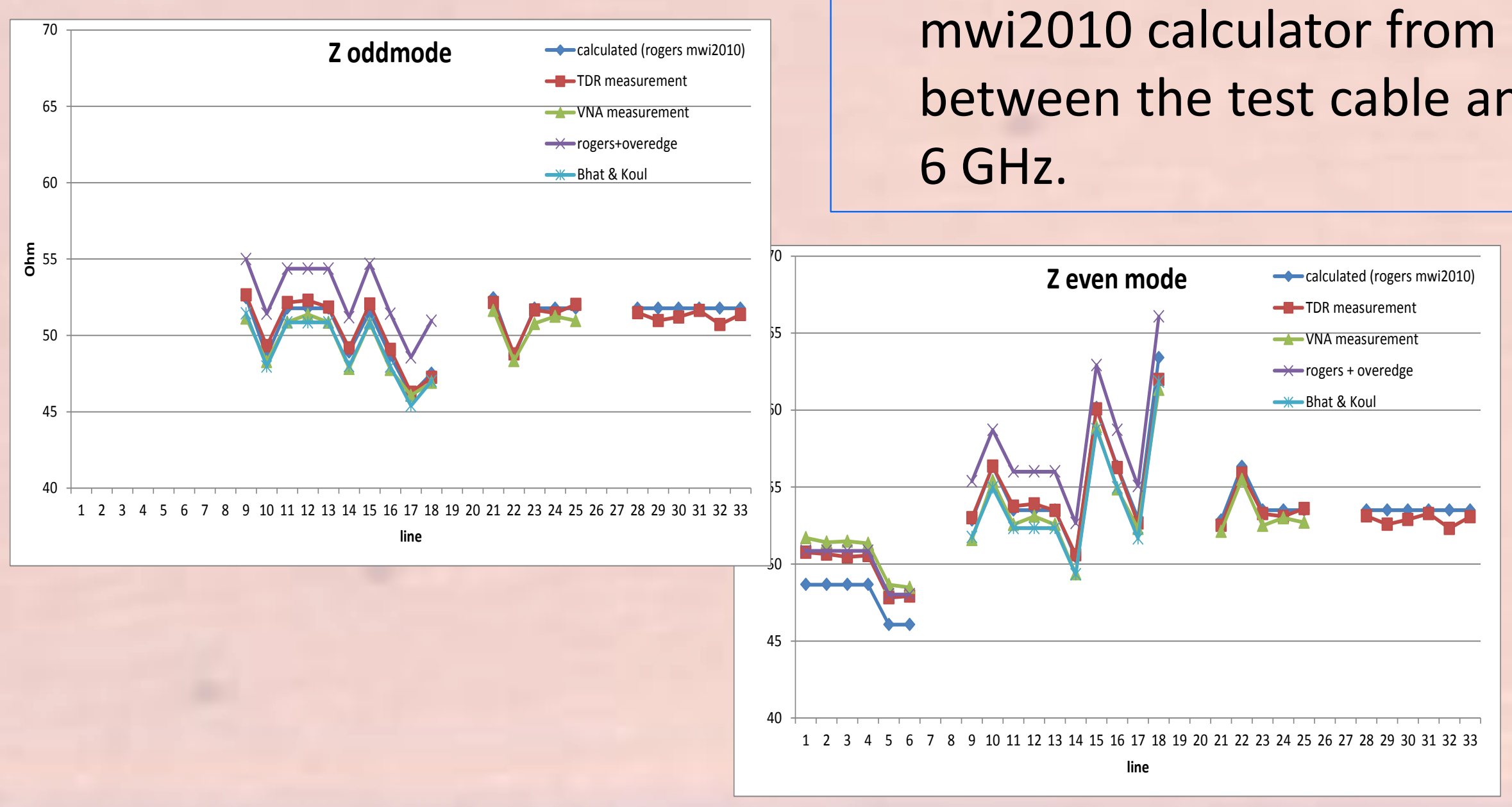
Agilent J-Bert N4903B High-Performance Serial Bert and Agilent Infiniium DSA91204A Digital Signal Analyzer for eye diagram measurement (left). Eye diagram for 100 cm length. (left 4GHz, right 8GHz).

Several effects were studied in the time domain (first prototype):

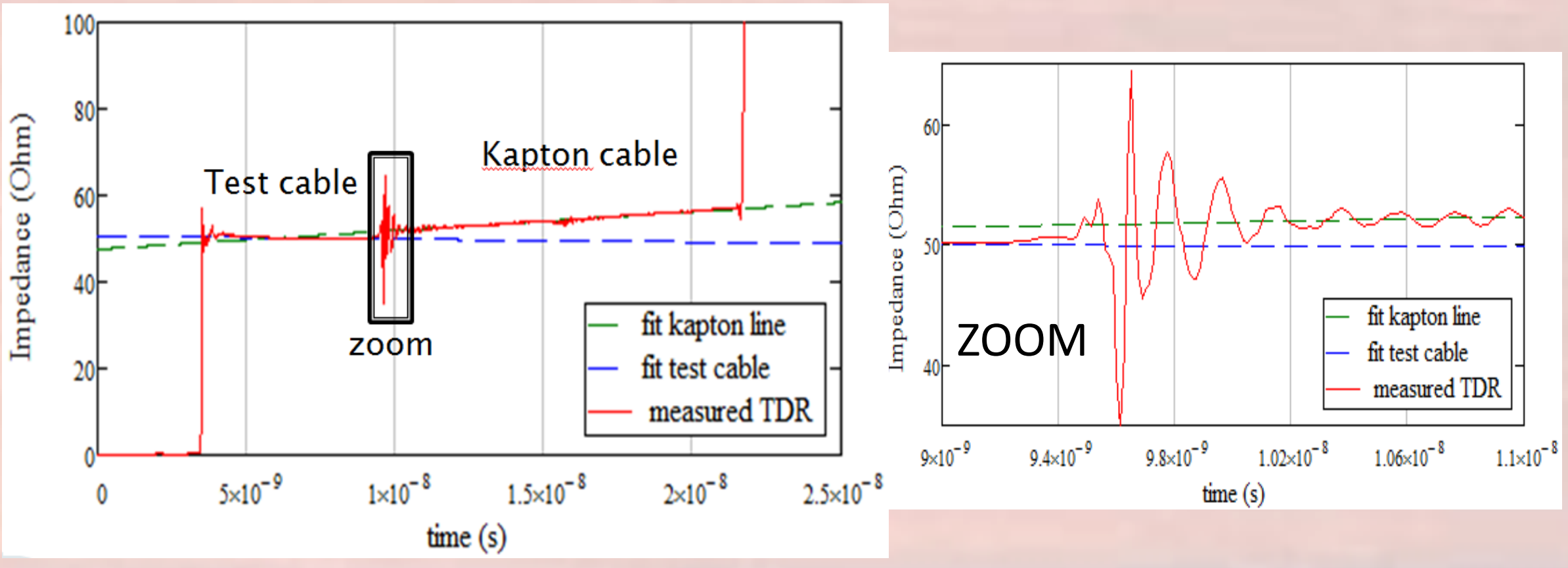
- Eye diagrams were measured at 4 and 8 GHz. We compare them with simulated eye diagrams obtained with the Lecroy SI-studio software. The measurements prove that transmission is very well possible up to at least 5 GHz.
- The characteristic impedance profile along the line. The values correspond very well with the mwi2010 calculator from Rogers corp. Also, the observed ringing (period ~170 ps) at the transition between the test cable and the measurement cable corresponds to the absorption peak in S21 at 6 GHz.



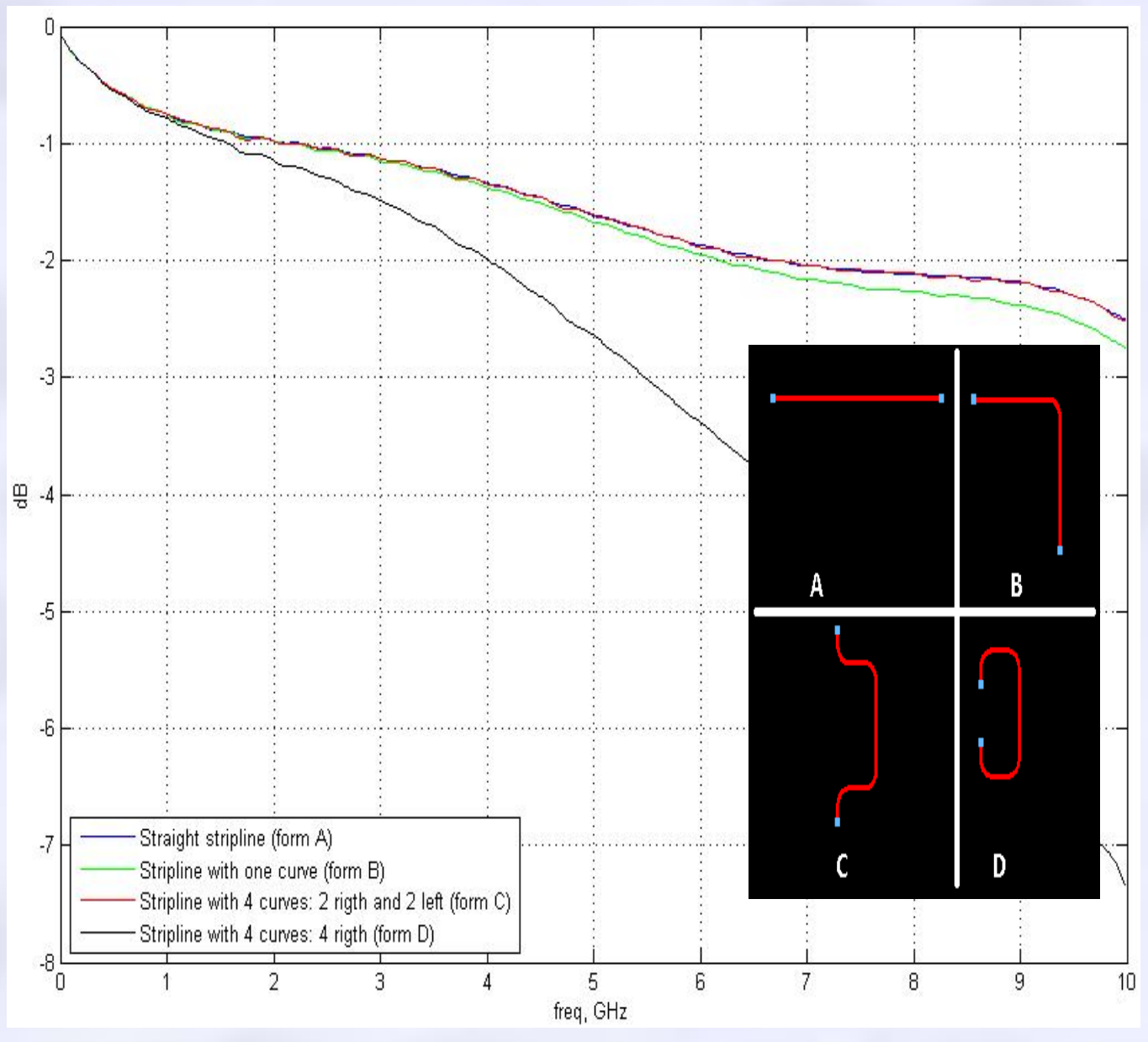
Tektronix TDS 8000 Digital Sampling Oscilloscope for impedance measurements.



Comparison between impedance at measurement and calculation. (Odd and Even mode)



Impedance measurement along the test and measurement (Kapton) cables.

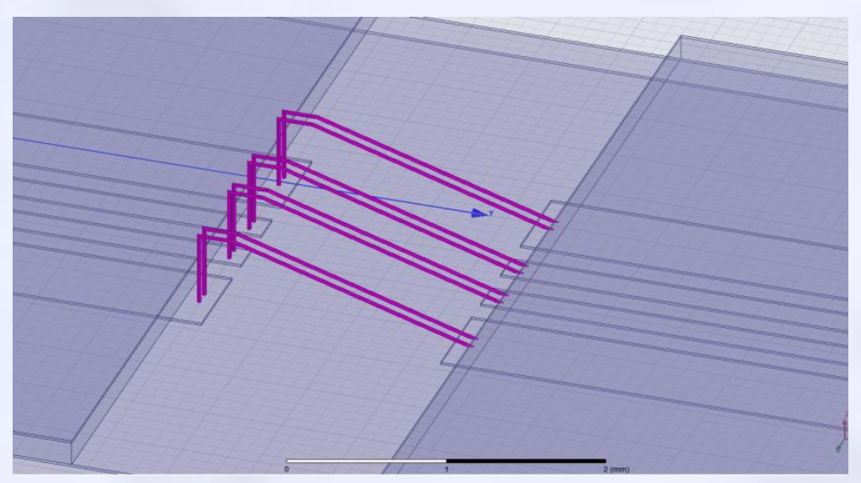


S21 differential of lines with or without turns.

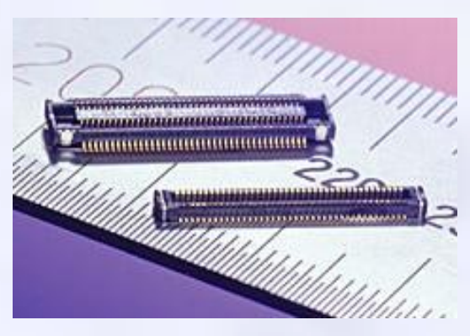
Future work:

Design, manufacturing and testing the second prototype with the results of the first version:

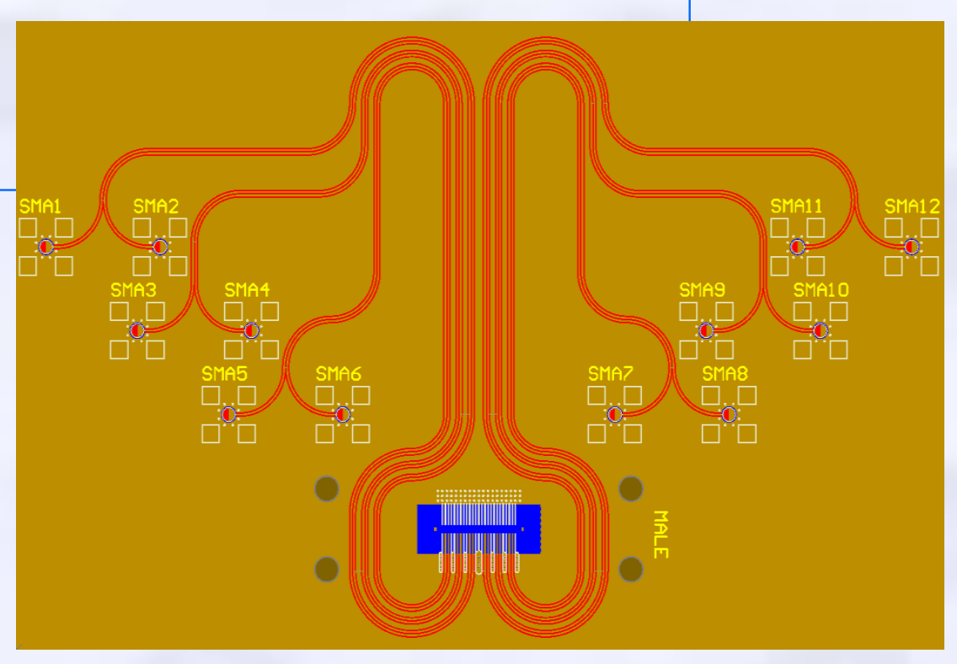
- Thinner laminates (350 um of dielectric (D)).
- Improve SMA pad layout.
- Improved testing: Layout for 'THRU' calibration technique.
- Equalize left and right turns in signal traces to minimize inter-pair skew.
- Closer to final cable layout.
- Use SMA-Molex adapter and bonding.



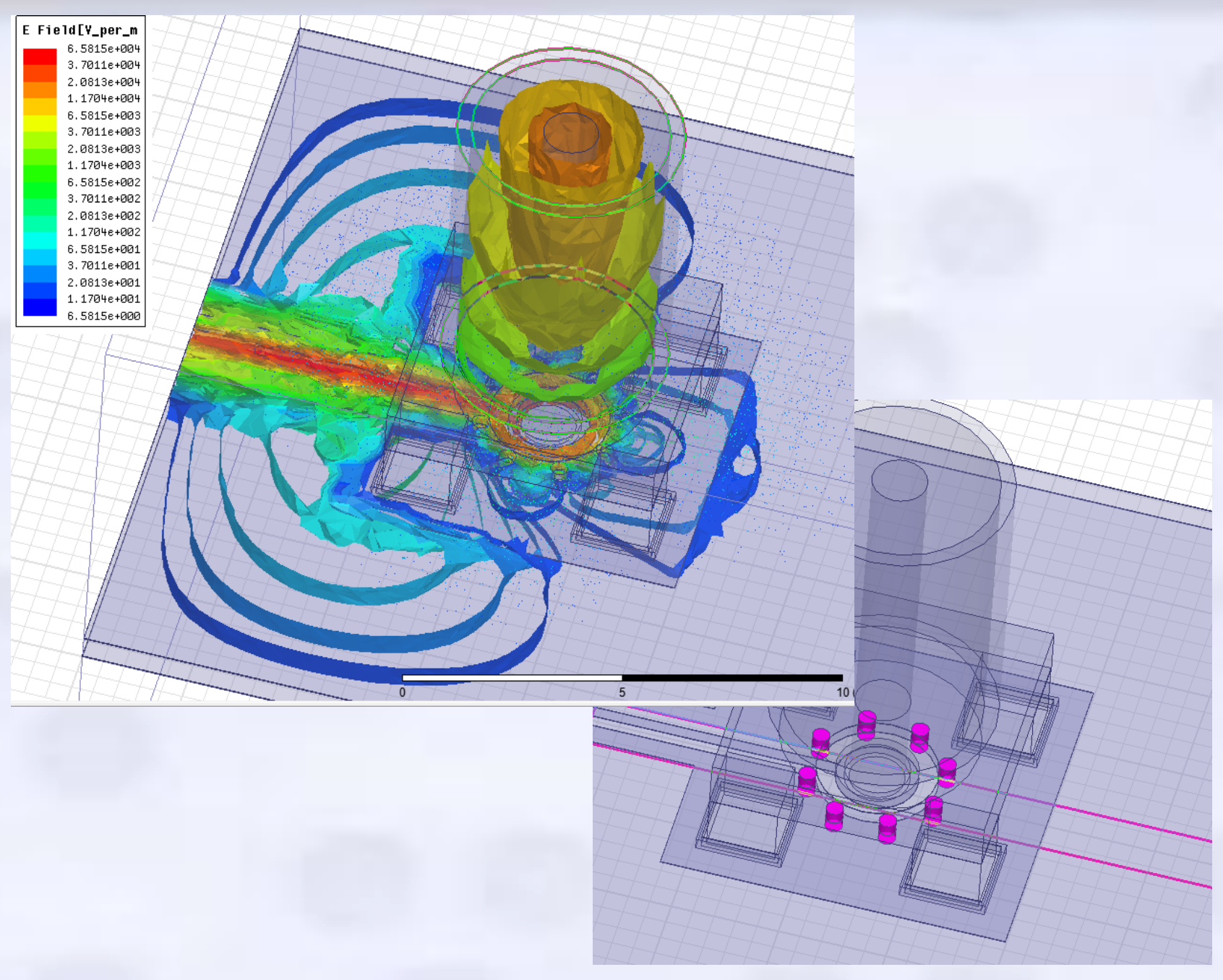
Bonding



Molex SlimStack 0.4mm connector. (male and female)



Altium design of SMA-Molex adapter



Use via´s to avoid the insertion loss in SMA.

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