10 Mb/s Single Twisted Pair Ethernet

10BASE-T1L MDI Return Loss

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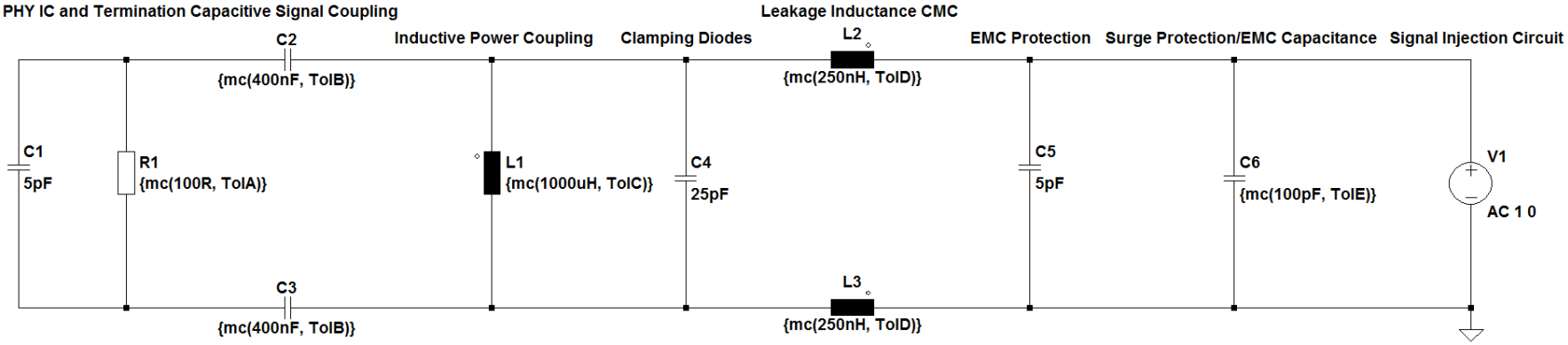
MDI Return Loss Simulation

- The MDI Return Loss of a 10BASE-T1L PHY has been simulated using a simple LTSpice model with the following parameters:
  - PHY termination resistance: 90 to 110 Ω (100 Ω ± 10 %) in parallel to 5 pF parasitic capacitance
  - Signal coupling capacitance: 200 to 600 nF (400 nF ± 50 % to allow DC biasing and have a minimum of 200 nF)
  - Power coupling inductors: 500 µH to 1500 µH (1000 µH ± 50 %)
  - Clamping diodes across the power coupling inductors: 25 pF
  - CMC leakage inductance: 0 to 1 µH (500 nH ± 100 %)
  - EMC/ESD Protection: 5 pF
  - Surge protection and other EMC capacitances: 0 to 200 pF (100 pF ± 100 %)
- With the LTSpice model a Monte Carlo simulation has been run with the above mentioned tolerances.




```
.param TolA = 0.10      Termination Resistor Value Range is 90 to 110 ohms
.param TolB = 0.50      Signal Coupling Capacitor Value Range is 200 to 600 nF
.param TolC = 0.50      Power Coupling Inductor Value Range is 500 to 1500 µH
.param TolD = 1.00      Leakage Inductance Value Range is 0 to 500 nH
.param TolE = 1.00      Surge Protection Capacitance/EMC Capacitance Range is 0 to 200 pF
.step param run 1 1000 1
.ac dec 100 10k 20e6    Plot (100+1/I(V1))/(100-1/I(V1)) for Differential Mode Return Loss
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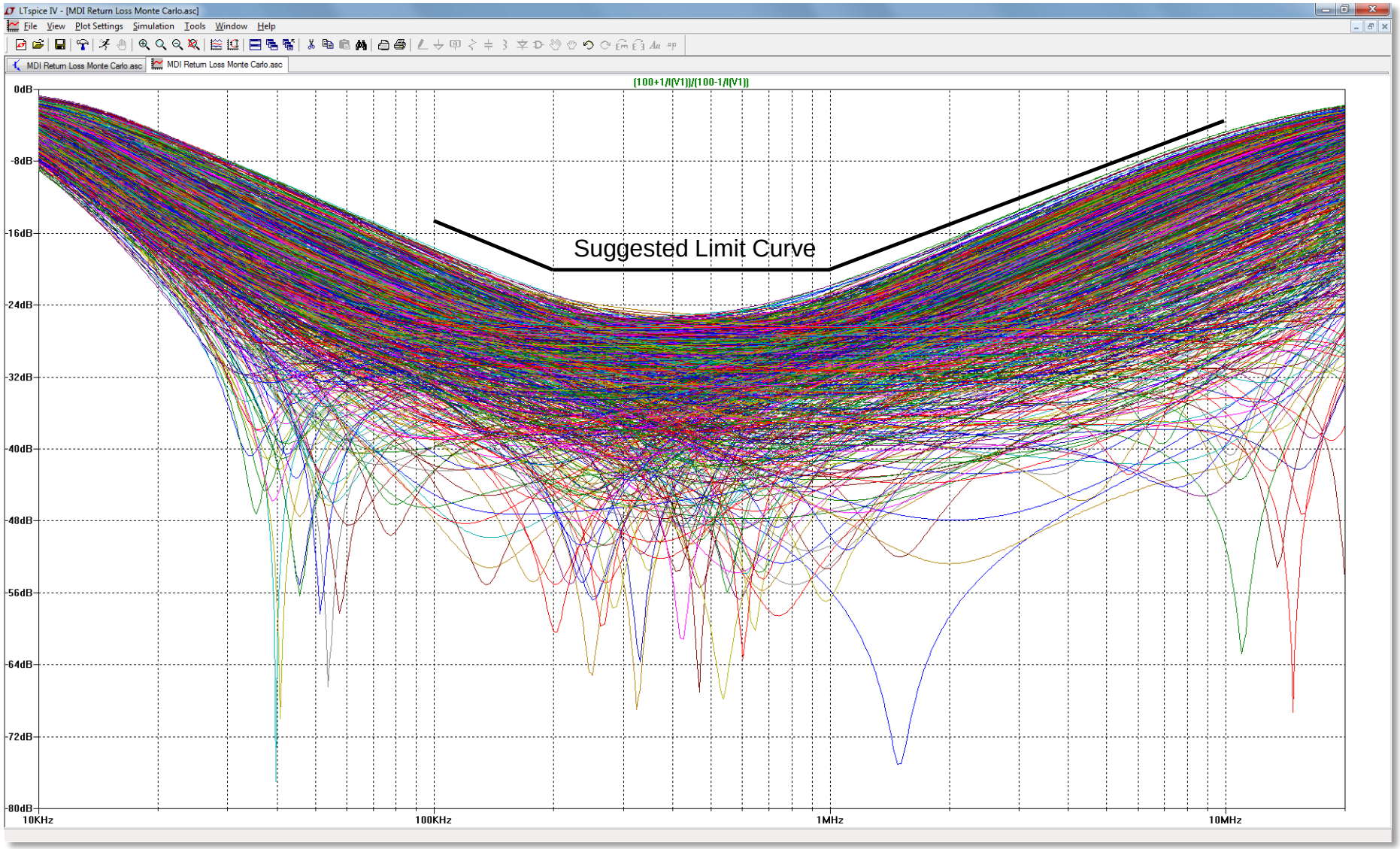
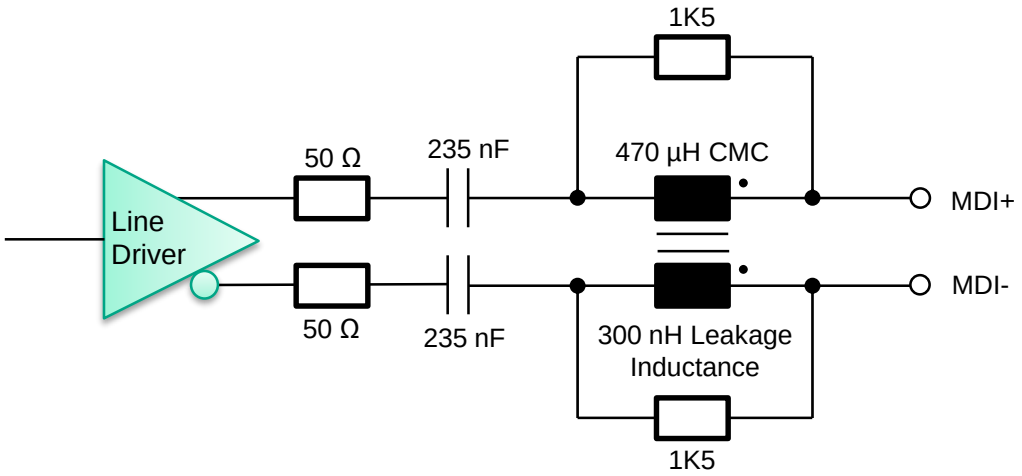
MDI Return Loss Simulation



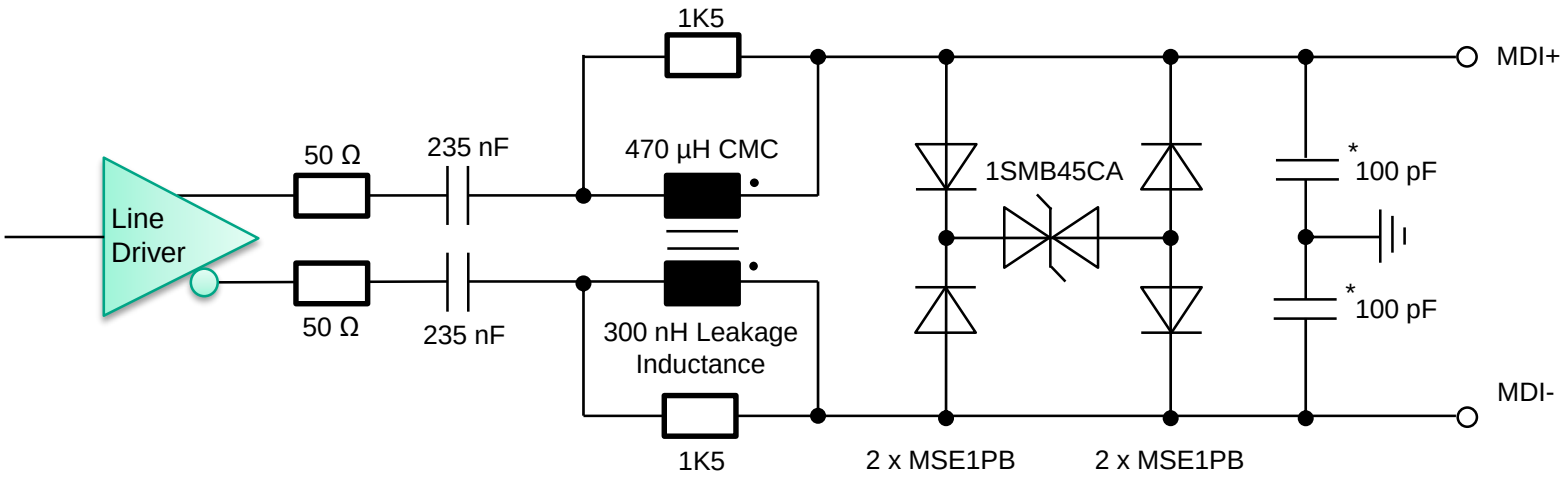
MDI Return Loss Measurements

- To verify the simulation results the MDI Return Loss has been measured with a typical FPGA based Evaluation Board.
- To perform the measurement, the signal transmission (not the driver) of the Evaluation Board has been disabled.
- The power coupling network was not powered, but had the power supply connection being shorted.
- For each of the following measurements the termination resistors were changed to 45 Ω, 50 Ω, and 55 Ω (90 Ω, 100 Ω and 110 Ω differential resistance).
- The following setups have been measured:
  - PHY including a 470 µH CMC, in parallel with two 1500 Ω resistors to prevent resonance effects, without additional EMC protection (no ESD/surge/EFT protection):



MDI Return Loss Measurements

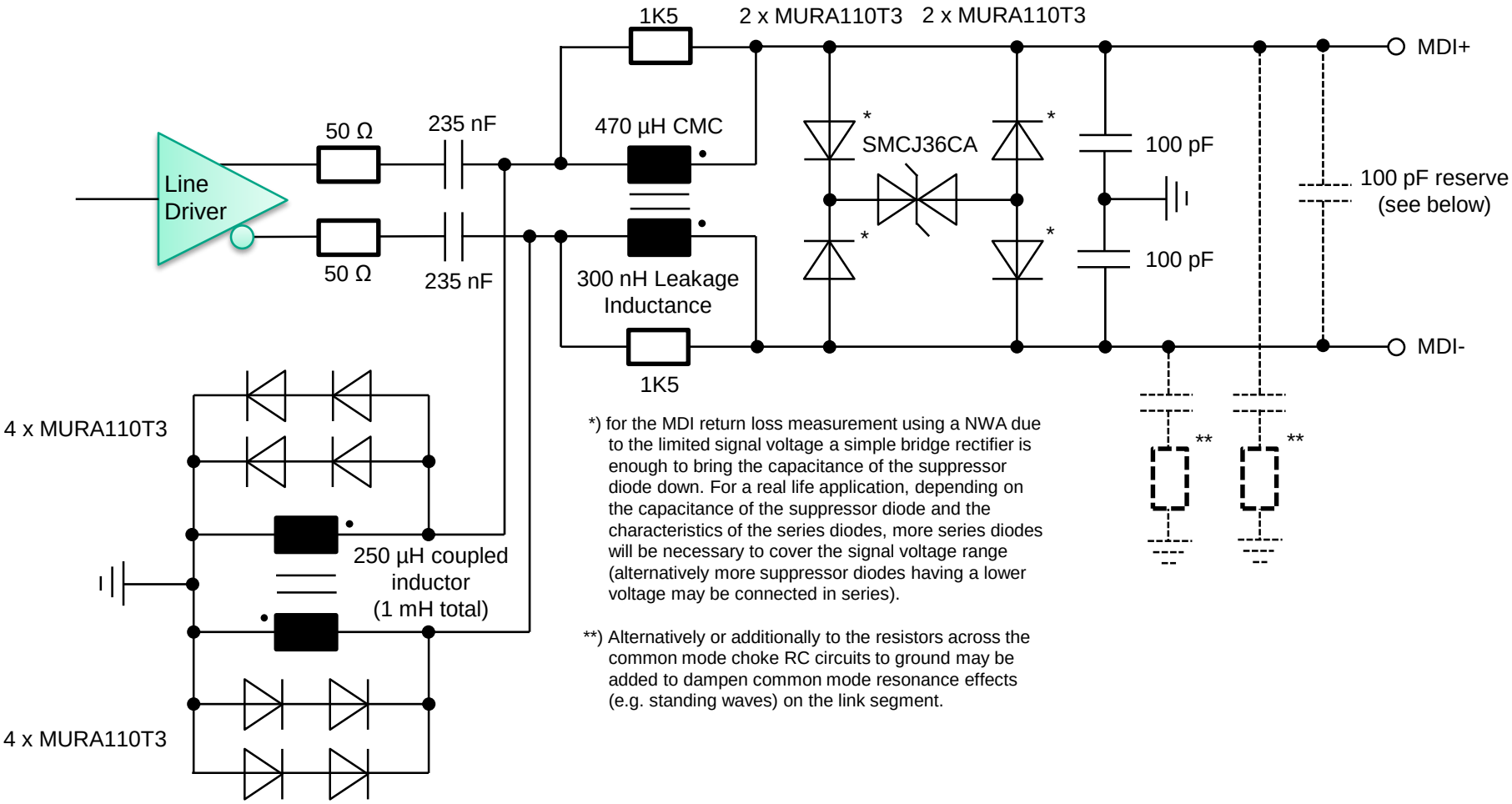
- Standard Evaluation Board EMC protection (470 µH CMC, ESD/simple surge protection (5 pF), 100 pF capacitor from each line to ground (50 pF differential capacitance)):



*) A good matching (± 1 % to ± 2 %) of the EMC capacitors to GND is important for a good EMC behavior. If there is a higher difference in capacitance; the LCL limits (see later in this presentation) likely will fail.

MDI Return Loss Measurements

- Standard Evaluation Board EMC protection + PHY side PoDL power injection circuit (1 mH and clamping diodes (25 pF)) + additional robust surge protection (additional 50 pF differential capacitance):



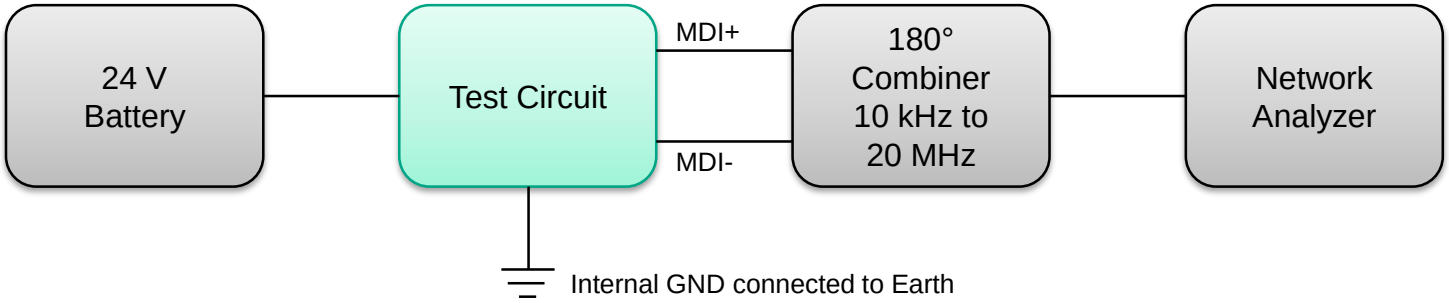
*) for the MDI return loss measurement using a NWA due to the limited signal voltage a simple bridge rectifier is enough to bring the capacitance of the suppressor diode down. For a real life application, depending on the capacitance of the suppressor diode and the characteristics of the series diodes, more series diodes will be necessary to cover the signal voltage range (alternatively more suppressor diodes having a lower voltage may be connected in series).

**) Alternatively or additionally to the resistors across the common mode choke RC circuits to ground may be added to dampen common mode resonance effects (e.g. standing waves) on the link segment.

- Circuit above + additional 100 pF capacitor directly across the MDI connector (dashed lines in the schematic diagram above).

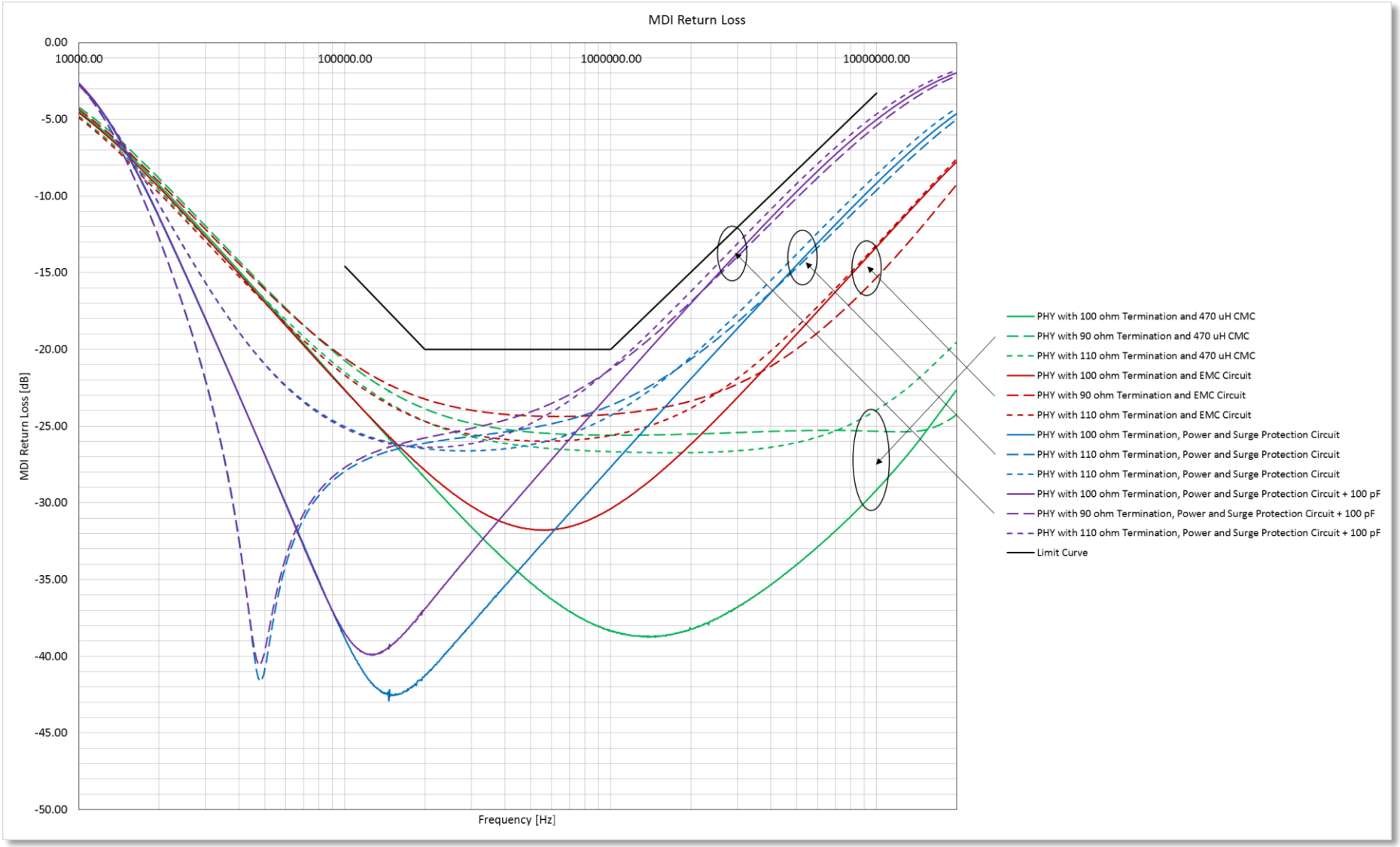
MDI Return Loss Measurements

- The following measurement setup has been used for the MDI return loss measurement:



- As test circuit the circuits described on the three previous pages have been used.
- As combiner a Mini Circuits ZFSCJ-2-2-S splitter has been used.
- The network analyzer has been calibrated to the MDI port position.

MDI Return Loss Measurements



MDI Return Loss Limit Curve

- Based on the simulation results and the measurements with the FPGA based evaluation board the following limits for the MDI return loss are suggested:

$$MDI\ Return\ Loss\ \geq \begin{cases} 20\ dB\ -18\ dB \cdot log_{10}\left(\frac{0.2\ MHz}{f_{MHz}}\right) & for\ 0.1\ MHz \leq f < 0.2\ MHz \\ 20\ dB & for\ 0.2\ MHz\ \leq f\ \leq 1\ MHz \\ 20\ dB\ -16.7\ dB \cdot log_{10}\left(\frac{f_{MHz}}{1\ MHz}\right) & for\ 1\ MHz\ < f\ \leq 10\ MHz \end{cases}$$

- The suggested MDI Return Loss limit curve is similar to the MDI Return Loss limit curve of 1000BASE-T1, scaled down in frequency by a factor of 100 (as 1000BASE-T1 transmits 750 MS/s vs. 7.5 MS/s for 10BASE-T1L).
- While 1000BASE-T1 has a base line of the MDI Return Loss limit curve of 18 dB, the base line of the suggested 10BASE-T1L Return Loss limit curve is 20 dB as it is also for 100BASE-T1.

Thank You