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# Modeling of High Speed PCB-Interconnects, Vias and Connectors for the Estimation of SI-Losses

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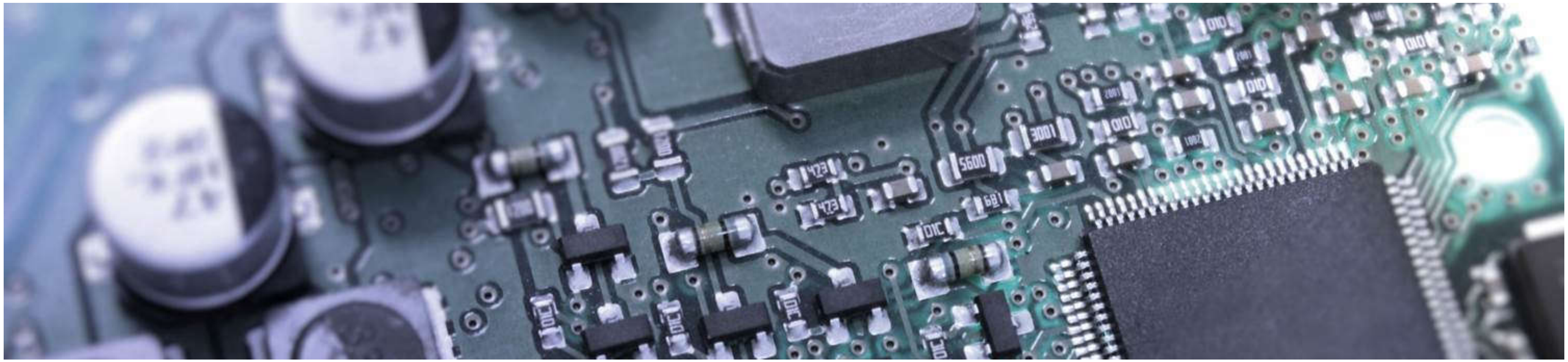


# Outline of the Talk

- Problem Definition & Basics of SI-Losses
- Modeling of PCB-Traces/Vias/Connectors (Xtors)
- Physics Interface for FEM Simulation of PCB-Traces/Vias
- B-Field Simulation of Vias/Connectors using Comsol
- Computation of Characteristics Impedance
- Conclusions

# Problem Definition & Basics of SI-Losses

At low-frequency a small segment of PCB-trace/interconnect behaves like a resistive element, whereas at HF it behaves like a transmission line with RLGC parasitic elements.

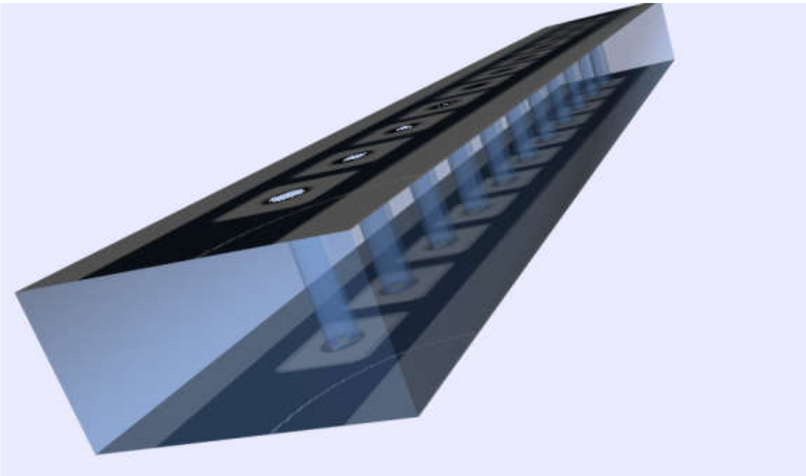
HF-Signal transmission from the driver to receiver through PCB-Interconnects/Vias & Connectors can be of either

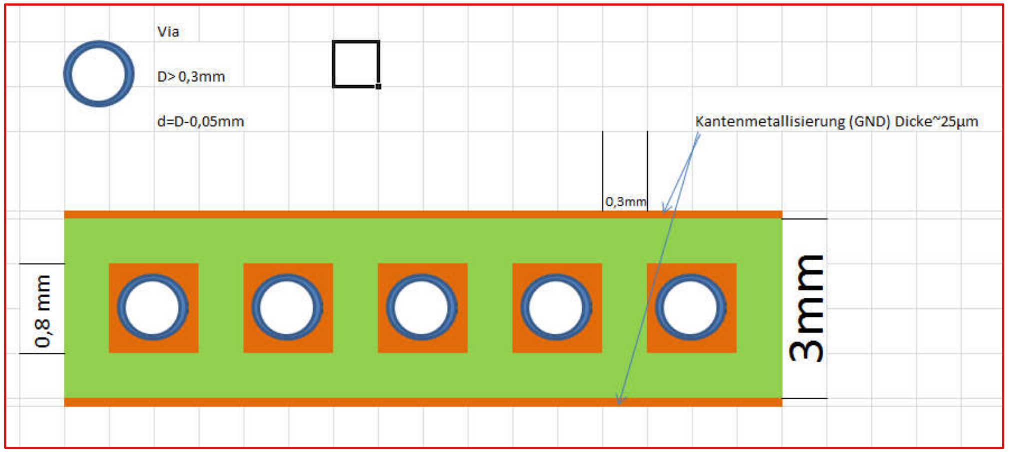
- Single-Ended type: i.e., one signal line & a signal return path (a ground plane)
- Differential-Pair type: i.e. two lines with opposite signals and a ground plane.

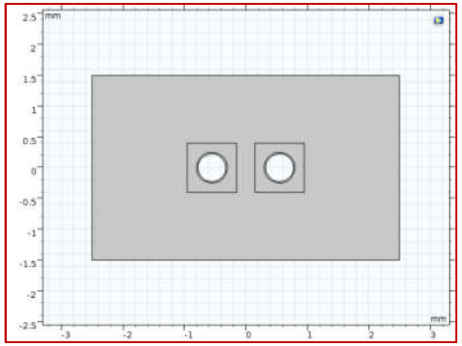
In both cases matching of impedances between Driver output, PCB-traces/Vias & Receiver input impedance are necessary.

- Uncontrolled Impedance leads to Signal reflection/attenuation or distorted signal at the Receiver side – which is also called Loss of Signal Integrity (SI)!!

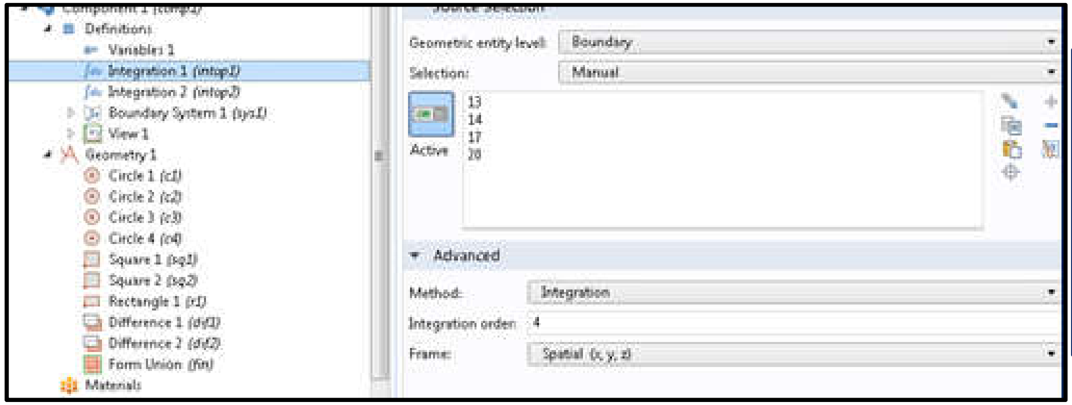
# 3D and 2D views of Connectors/Vias





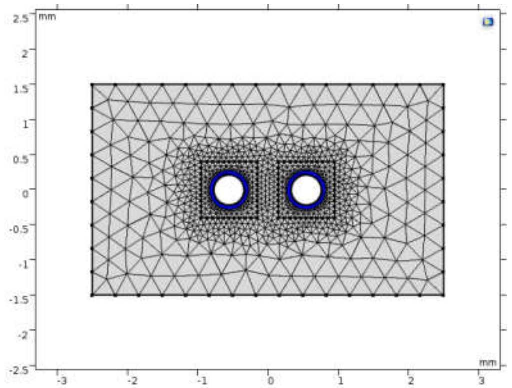



# Modeling of PCB-Traces/Vias/Connectors




Variables

| Name | Expression | Unit | Description |
|---|---|---|---|
| Rch | real(1[V/m]/intop2(mf.Jz)) | Ω/m | Distributed resistance |
| Lch | imag(1[V/m]/intop2(mf.Jz))/omegaw | H/m | Distributed inductance |
| Cch | imag(intop1(reacf(V)*1[A/m])/1[V])/omegaw | F | Capacitance |
| Gch | real(intop1(reacf(V)*1[A/m])/1[V]) | S | Shunt conductance |
| Zch | sqrt((Rch+j*omegaw*Lch)/(Gch+j*omegaw*Cch)) | | Characteristic impedance |
| gamma | sqrt((Rch+j*omegaw*Lch)*(Gch+j*omegaw*Cch)) | | Propagation constant |



# Physics Interface:FEM Simulation of PCB-Traces/Vias

- Electric Currents *(ec)*
  - Current Conservation 1
  - Electric Insulation 1
  - Initial Values 1
  - Electric Potential 1
  - Electric Potential 2
  - Ground 1
  - Equation View
- Magnetic Fields *(mf)*
  - Ampère's Law 1
  - Magnetic Insulation 1
  - Initial Values 1
  - Ampère's Law 2
  - External Current Density 1
  - External Current Density 2
  - Perfect Magnetic Conductor 1
  - Equation View

Variables

| Name | Expression | Unit | Description |
|---|---|---|---|
| Rch | real(1[V/m]/intop2(mf.Jz)) | Ω/m | Distributed resistance |
| Lch | imag(1[V/m]/intop2(mf.Jz))/omegaw | H/m | Distributed inductance |
| Cch | imag(intop1(reacf(V)*1[A/m])/1[V])/omegaw | F | Capacitance |
| Gch | real(intop1(reacf(V)*1[A/m])/1[V]) | S | Shunt conductance |
| Zch | sqrt((Rch+j*omegaw*Lch)/(Gch+j*omegaw*Cch)) | | Characteristic impedance |
| gamma | sqrt((Rch+j*omegaw*Lch)*(Gch+j*omegaw*Cch)) | | Propagation constant |
| | | | |

Equation form:

Study controlled

Show equation assuming:

Study 1 (single-ended), Stationary

$$\nabla\cdot\mathbf{J} = Q_{j,v}$$

$$\mathbf{J} = \sigma\mathbf{E} + \mathbf{J}_e$$

$$\mathbf{E} = -\nabla V$$

Equation form:

Frequency domain

Frequency:

User defined

$f$ frq Hz

$$\nabla\times\mathbf{H} = \mathbf{J}$$

$$\mathbf{B} = \nabla\times\mathbf{A}$$

$$\mathbf{J} = \sigma\mathbf{E} + j\omega\mathbf{D} + \sigma\mathbf{v}\times\mathbf{B} + \mathbf{J}_e$$

$$\mathbf{E} = -j\omega\mathbf{A}$$

# Frequency Domain Simulation of High Speed Vias

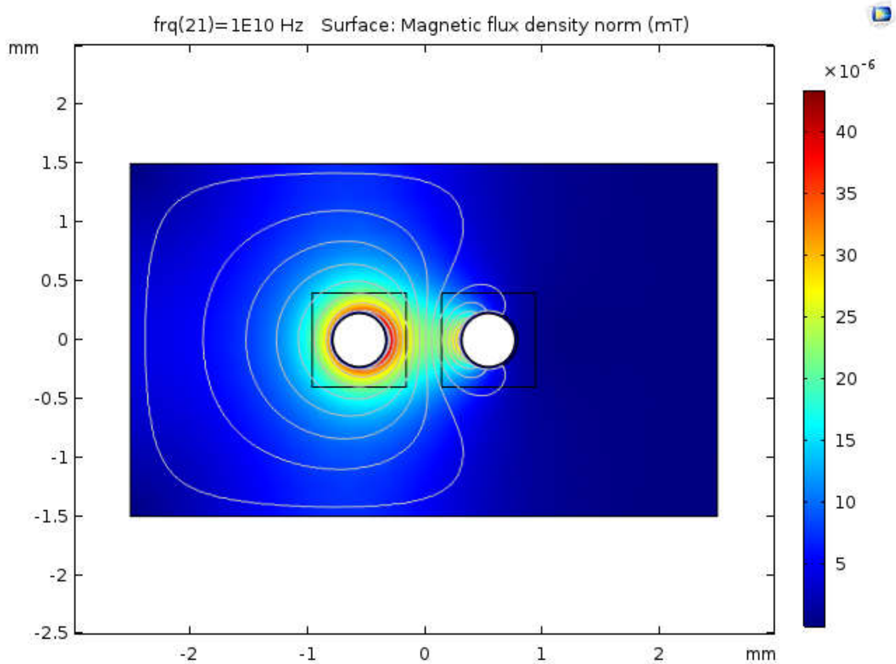



Figure-1: Frequency domain simulation (frequency sweep 1MHz to 0.8 GHz) of high-speed vias for the estimation single-ended impedance ($Z_0$) of the connector-wire.

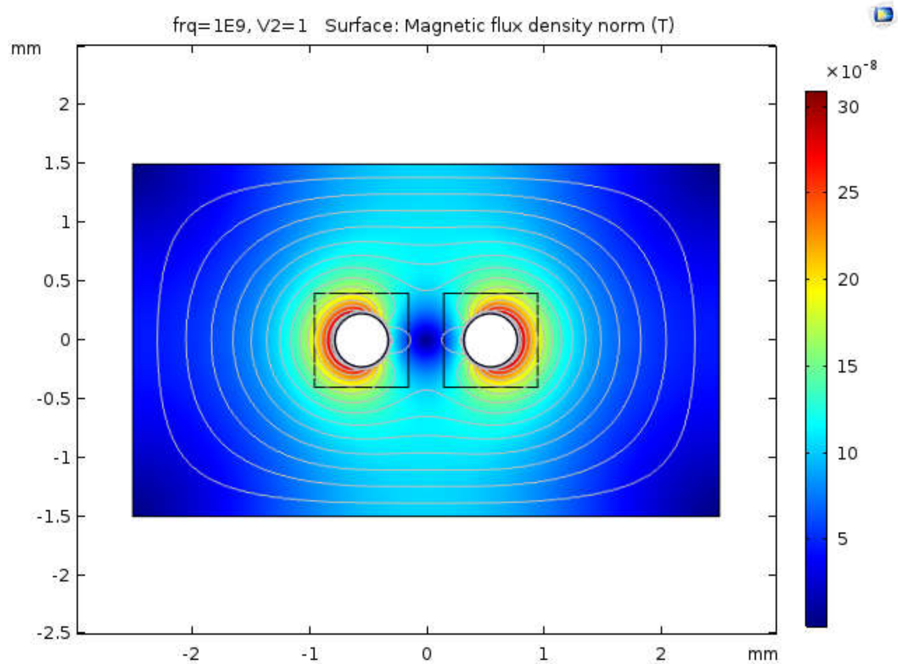



Figure-2: Frequency domain simulation (1 GHz) of high-speed vias for the estimation differential-pair impedance (Zdiff) of two neighboring connector-wires.

# Frequency Domain Simulation of High Speed Vias

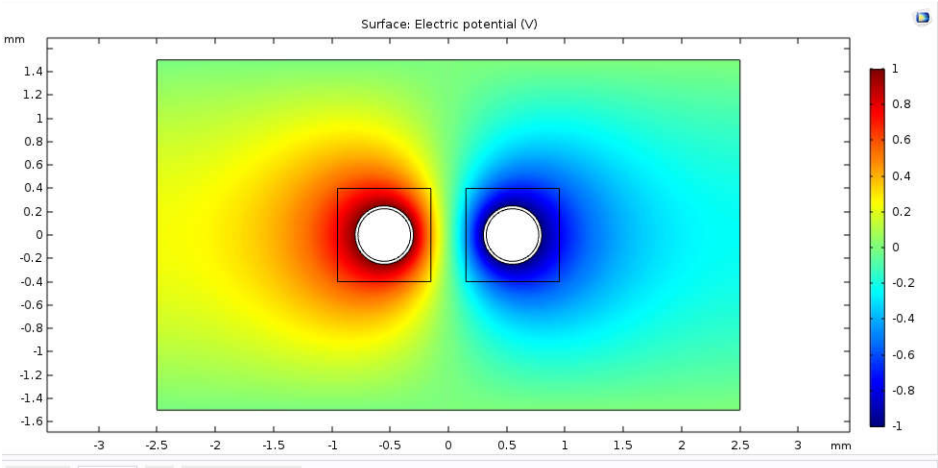



Figure-3: Frequency domain simulation (frequency sweep 1.0 GHz to 10 GHz) of high-speed vias for the estimation Differential impedance ($Z_{diff}$) of the Vias/connectors.

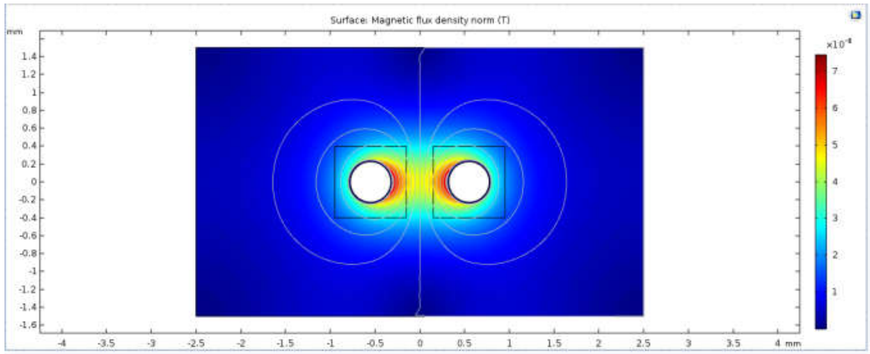



Figure-4: MF-field simulation (1GHz to 10 GHz) of high-speed vias/connectors for the estimation differential-pair impedance ($Z_{diff}$) of two neighboring Vias/connectors.

# $Z_0$ Computation for High Speed –Vias/Xtors

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Table-1: Frequency Domain(@1 MHz to 0.8 GHz) Simulation of High Speed-Vias/Connectors for the computation of $Z_0$. Notice that $Z_0$ tends to be constant for the freq above 0.6 GHz

Messages | Progress | Log | Table 2 (single-ended, frequency sweep)

| frq (Hz) | Distributed resistance (Ω/m) | Distributed inductance (H/m) | Capacitance (F) | Shunt conductance (S) | Characteristic impedance | Propagation constant | sqrt(Lch/Cch) |
|---|---|---|---|---|---|---|---|
| 1.0000E6 | 0.52131 | 3.6262E-7 | 2.9834E-15 | 3.3695E-19 | 11096-1253.2i | 2.3491E-5+2.0799E-4i | 11025 |
| 1.0000E7 | 0.61721 | 3.5886E-7 | 2.9834E-15 | 3.3695E-19 | 10969-150.09i | 2.8135E-5+0.0020561i | 10968 |
| 1.0000E8 | 1.9676 | 3.5438E-7 | 2.9834E-15 | 3.3695E-19 | 10899-48.153i | 9.0264E-5+0.020430i | 10899 |
| 2.0000E8 | 2.7738 | 3.5348E-7 | 2.9834E-15 | 3.3695E-19 | 10885-33.986i | 1.2741E-4+0.040808i | 10885 |
| 3.0000E8 | 3.3968 | 3.5308E-7 | 2.9834E-15 | 3.3695E-19 | 10879-27.762i | 1.5612E-4+0.061178i | 10879 |
| 4.0000E8 | 3.9233 | 3.5284E-7 | 2.9834E-15 | 3.3695E-19 | 10875-24.057i | 1.8038E-4+0.081542i | 10875 |
| 5.0000E8 | 4.3935 | 3.5268E-7 | 2.9834E-15 | 3.3695E-19 | 10873-21.557i | 2.0204E-4+0.10190i | 10873 |
| 6.0000E8 | 4.8123 | 3.5256E-7 | 2.9834E-15 | 3.3695E-19 | 10871-19.680i | 2.2134E-4+0.12226i | 10871 |
| 7.0000E8 | 5.1977 | 3.5246E-7 | 2.9834E-15 | 3.3695E-19 | 10869-18.222i | 2.3910E-4+0.14262i | 10869 |
| 8.0000E8 | 5.5566 | 3.5239E-7 | 2.9834E-15 | 3.3695E-19 | 10868-17.047i | 2.5564E-4+0.16298i | 10868 |

# $Z_{diff}$ Computation for High Speed –Vias/Xtors

Table-2: Frequency Domain (@ 1 GHz to 10 GHz) Simulation of High Speed-Vias/Connectors for the computation of $Z_{diff}$. Notice that $Z_{diff}$ is roughly constant for the freq above 8 GHz.

| frq (GHz) | V2 (V) | Distributed resistance (Ω/m) | Distributed inductance (H/m) | Capacitance (F) | Shunt conductance (S) | Characteristic impedance | Propagation constant | sqrt(Lch/Cch) |
|---|---|---|---|---|---|---|---|---|
| 1.0000 | -1.0000 | 5.6349 | 2.6651E-7 | 3.9812E-15 | 4.4964E-19 | 8181.8-13.766i | 3.4436E-4+0.20466i | 8181.8 |
| 2.0000 | -1.0000 | 7.9776 | 2.6625E-7 | 3.9812E-15 | 4.4964E-19 | 8177.8-9.7495i | 4.8776E-4+0.40913i | 8177.8 |
| 3.0000 | -1.0000 | 9.7848 | 2.6613E-7 | 3.9812E-15 | 4.4964E-19 | 8176.0-7.9738i | 5.9838E-4+0.61356i | 8176.0 |
| 4.0000 | -1.0000 | 11.316 | 2.6606E-7 | 3.9812E-15 | 4.4964E-19 | 8174.9-6.9171i | 6.9211E-4+0.81797i | 8174.9 |
| 5.0000 | -1.0000 | 12.671 | 2.6601E-7 | 3.9812E-15 | 4.4964E-19 | 8174.2-6.1971i | 7.7509E-4+1.0224i | 8174.2 |
| 6.0000 | -1.0000 | 13.903 | 2.6598E-7 | 3.9812E-15 | 4.4964E-19 | 8173.7-5.6665i | 8.5047E-4+1.2268i | 8173.7 |
| 7.0000 | -1.0000 | 15.041 | 2.6595E-7 | 3.9812E-15 | 4.4964E-19 | 8173.3-5.2547i | 9.2011E-4+1.4312i | 8173.3 |
| 8.0000 | -1.0000 | 16.104 | 2.6593E-7 | 3.9812E-15 | 4.4964E-19 | 8172.9-4.9232i | 9.8523E-4+1.6355i | 8172.9 |
| 9.0000 | -1.0000 | 17.108 | 2.6591E-7 | 3.9812E-15 | 4.4964E-19 | 8172.6-4.6491i | 0.0010467+1.8399i | 8172.6 |
| 10.000 | -1.0000 | 18.062 | 2.6590E-7 | 3.9812E-15 | 4.4964E-19 | 8172.4-4.4175i | 0.0011050+2.0443i | 8172.4 |

# Conclusion:

- ✓ 2D-Model of High Speed PCB-Vias were built and simulated using Comsol frequency domain tool. PCB-Traces & Connectors are also modeled/simulated in the same manner.
- ✓ Both Single-Ended & Differential-Pair of Vias were simulated at 0.5 GHz or 1 GHz and above. Parasitic RLGC-elements were extracted from High speed Vias/Connector @ GHz-frequencies.
- ✓ At high frequencies (>8 GHz) the Diff. Char. Impedances $Z_{diff}$ tend to be constant and close to the Sqrt($L_{ch}/C_{ch}$).
- ✓ As $Z_0$ & $Z_{diff}$ = sqrt(($R+jwL$)/($G+jwC$)) and at GHz freq. R & G should be negligible, the results approx. match with the reality.

# Thank you very much for your attention!