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Frequency-Dependent Per-Port Renormalization

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Agenda

- Problem statement
- Study summary
- Introduction to the FDPP method
- Case study of applying FDPP
- Comparison of the results obtained by the conventional method and the FDPP method

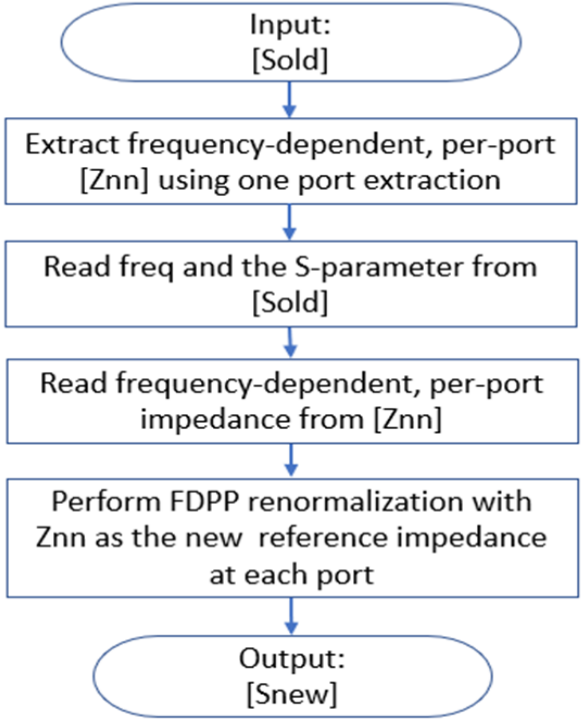
Problem statement

- Conventionally, the industry uses fixed impedance values as the TX/RX terminations
- In reality the TX/RX termination impedances vary with frequency (frequency-dependent) rather than be a constant value throughout the frequency range
- In addition, the TX and RX terminations have different characteristics from each other
- Should we use FDPP (Frequencydependent Per-port Renormalization) impedance instead of constant impedance? Is it worthwhile to make such change?

Study summary

- Compared to the conventional method, the S-param obtained by the FDPP method show remarkably worse return loss, and less worse insertion loss
- The eye/COM obtained by the FDPP method also show worse results compared to the conventional method. The degradation can be as large as ~10%
- **Recommend to use FDPP for end2end channel S-param extraction**
- In addition, one proposal to Touchstone spec:
  - Add support to frequency-dependent impedance

Computation flow of FDPP



Sold: The original S-param extracted using fixed impedance.
Snew: The renormalized S-param using FDPP method

$$[S'] = [A]^{-1} \bullet ([S] - [R]) \bullet ([I] - [R] \bullet [S])^{-1} \bullet [A] \quad (3)$$

Where,
R is the reflection matrix,

$$[R] = \begin{bmatrix} r(Z_1) & 0 & \cdots & 0 \\ 0 & r(Z_2) & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & r(Z_n) \end{bmatrix},$$

$r(Z_n)$ is the reflection coefficient of each port,

$$r(Z_n) = \frac{Z_n - Z_n, before}{Z_n + Z_n, before},$$

$[A]$ is the conversion matrix,

$$[A] = \begin{bmatrix} A_1 & 0 & \cdots & 0 \\ 0 & A_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & A_n \end{bmatrix},$$

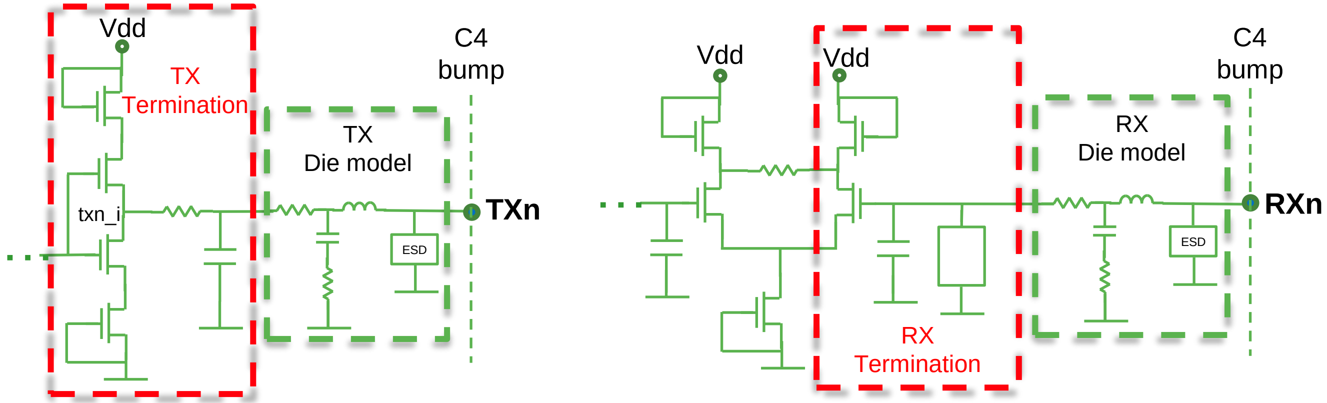
$[A_n]$ is the conversion coefficient for each port,

$$A_n = \sqrt{\frac{Z_n}{Z_n, before}} \bullet \frac{1}{Z_n + Z_n, before}$$

I is identity matrix.

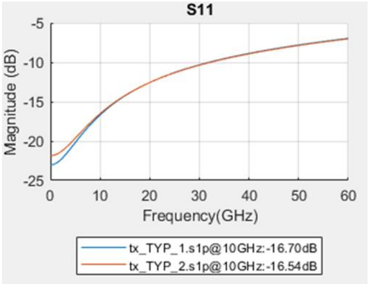
TX/RX Termination + die model

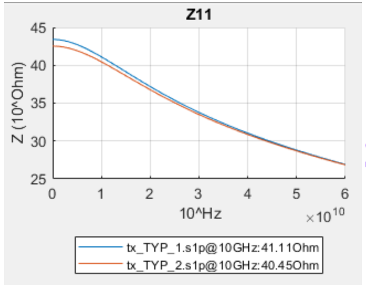
- TX Termination: series termination targeted at 42.5Ohm
- RX Termination: shunt termination targeted at 42.5Ohm
- With calibration circuit the termination of TX/RX can be tuned pretty close to 42.5Ohm, but only around the Nyquist rather than across the full frequency range

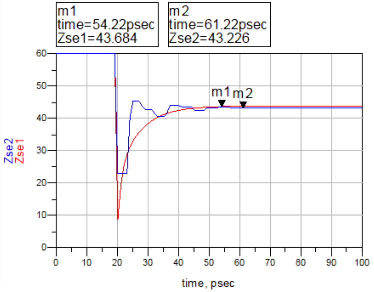


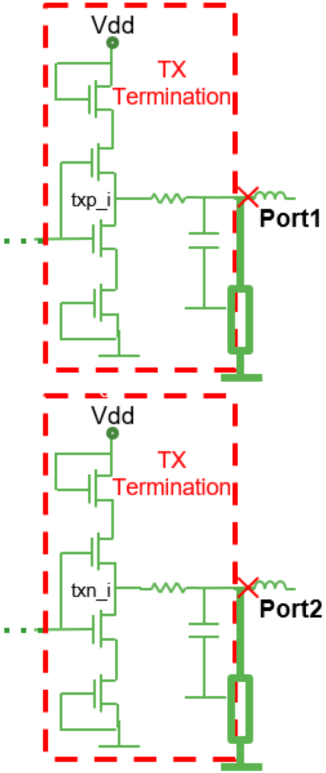
One-port termination extraction

- The TX/RX Termination should be extracted using One-port termination extraction technique
- Quite often, designers don't really do this extraction – they simply use the calibration target impedance (42.5 Ohm, 50 Ohm, etc.) in channel simulation
- Due to the existence of parasitics, it is impossible to have a constant impedance across the frequency range which is evidenced by the plots below – neither S11 nor Z11 is constant over the frequency range
- **Frequency-dependent termination impedance should be used rather than constant impedance!**



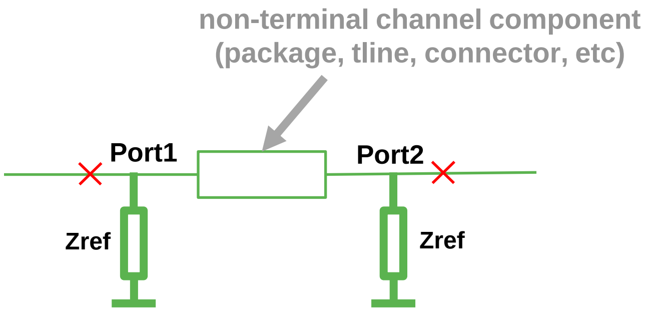






Case#1: Extracting the snp of non-terminal channel components

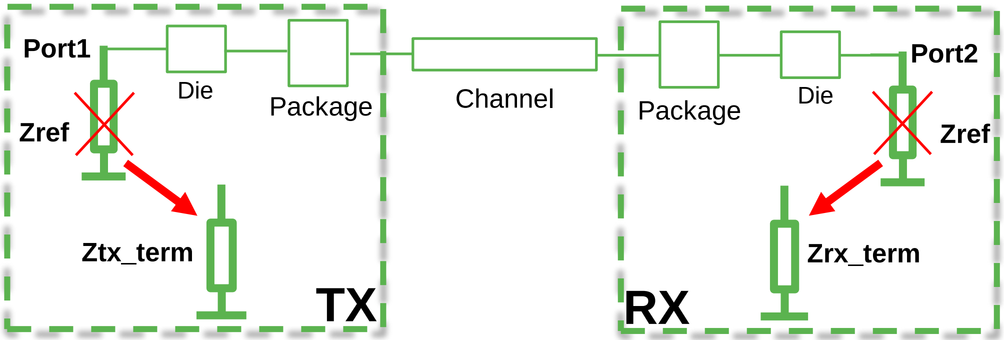
- The **Non-terminal** channel components
  - All channel components that are not the TX/RX terminations, e.g., die, package, channel, connector, etc.
- Proposed extraction method for Non-terminal channel components
  - Using fixed Zref, eg, 42.5Ohm, 50Ohm, or else value, for the extraction of the S-params of each non-terminal component. The impedances used can be different from each other
- The reasons for not using FDPP impedance to extract non-terminal channel components:
  - There is no need to use FDPP in cascading. Fixed impedance gives the identical result as FDPP (if ever feasible)
  - So far the Touchstone 2.0 can only support per-port impedance, but not frequency-dependent impedance. This limitation makes it impossible to implement FDPP S-params in TS format. To that goal proprietary S-param format has to be used



Non-terminal channel component model extraction

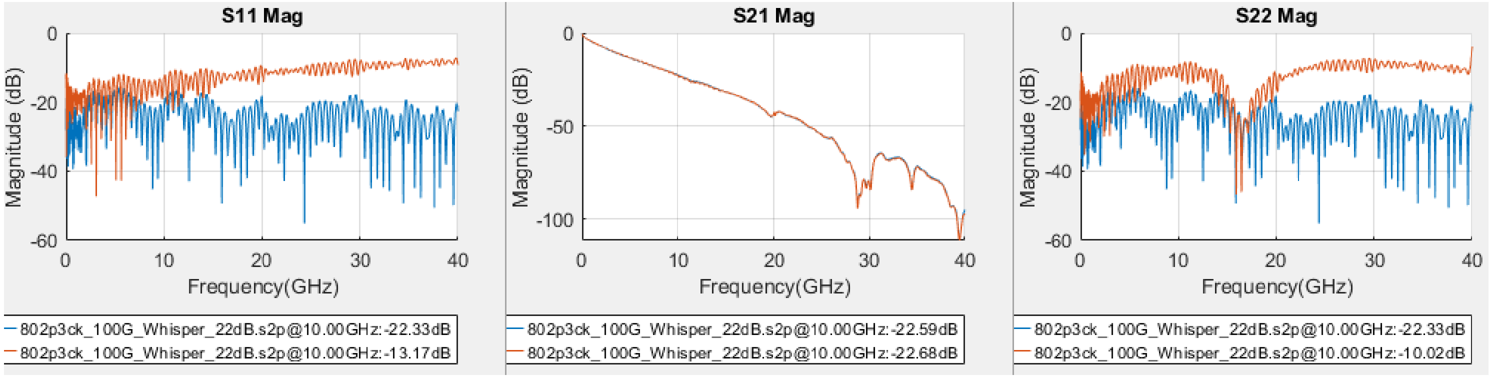
Case#2: Extracting end2end channel model

- For **end2end** channel model extraction, recommend to replace the fixed Zref by frequency-dependent Ztx_term and Zrx_term for better accuracy
  - Renormalize all non-terminal channel components' models to one uniform impedance and cascade them into one S-param
  - Apply FDPP TX/RX terminations to the cascaded S-param to obtain a full channel S-param which better reflects the characteristics of the channel than using fixed impedance
  - Apply the FDPP-extracted/renormalized end2end channel S-param in eye/COM simulation to obtain accurate channel performance evaluation



Channel example#1: S-param

- Large deviations are shown on the return loss items (S11, S22) extracted using fixed Zref vs using FDPP Zref
- The S11, S22 extracted by FDPP method is remarkably worse than that extracted using fixed Zref
- S21 does not deviate too much between using the two methods (-22.59dB vs -22.68dB, at 10GHz)

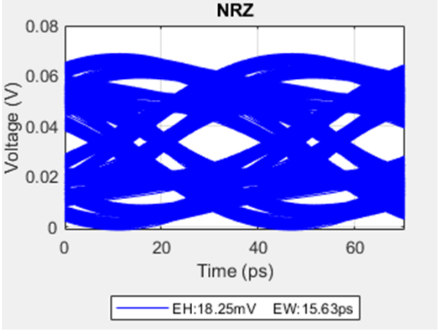


Blue: Zref = 42.5Ohm;
Red: Zref = frequency-dependent Ztx_term, Zrx_term

Channel example#1: eye, COM

- Both the eye results and the COM FOM obtained by FDPP method are worse than that obtained using fixed impedance 42.5Ohm (which is the target impedance for this serdes TX/RX designs)
- The COM performance deviation is -9.77% which is quite beyond the negligible range. For better accuracy, the fixed Zref should be replaced by frequency-dependent Ztx_term and Zrx_term, in a per-port manner

Zref = 42.5 Ohm



FDPP

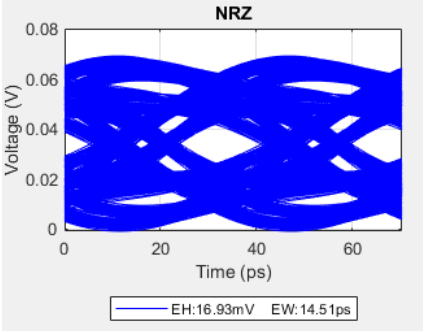
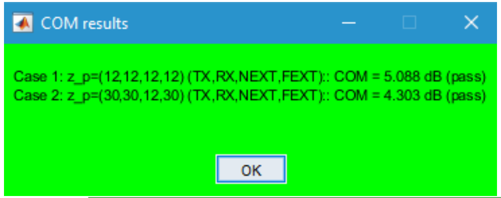
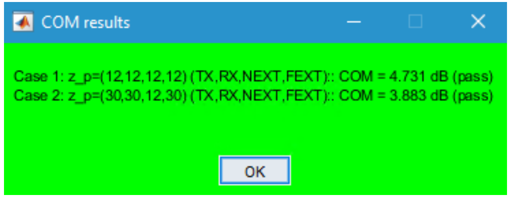


Table I: EH/EW & COM values

Termination	EH (mV)	EW (ps)	COM (dB)
Constant	18.25	16.93	4.30
FDPP	15.69	14.51	3.88
Delta	-7.23%	-7.2%	-9.77%





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