SI 101 S-parameters

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Z and Y Matrices (1)

$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

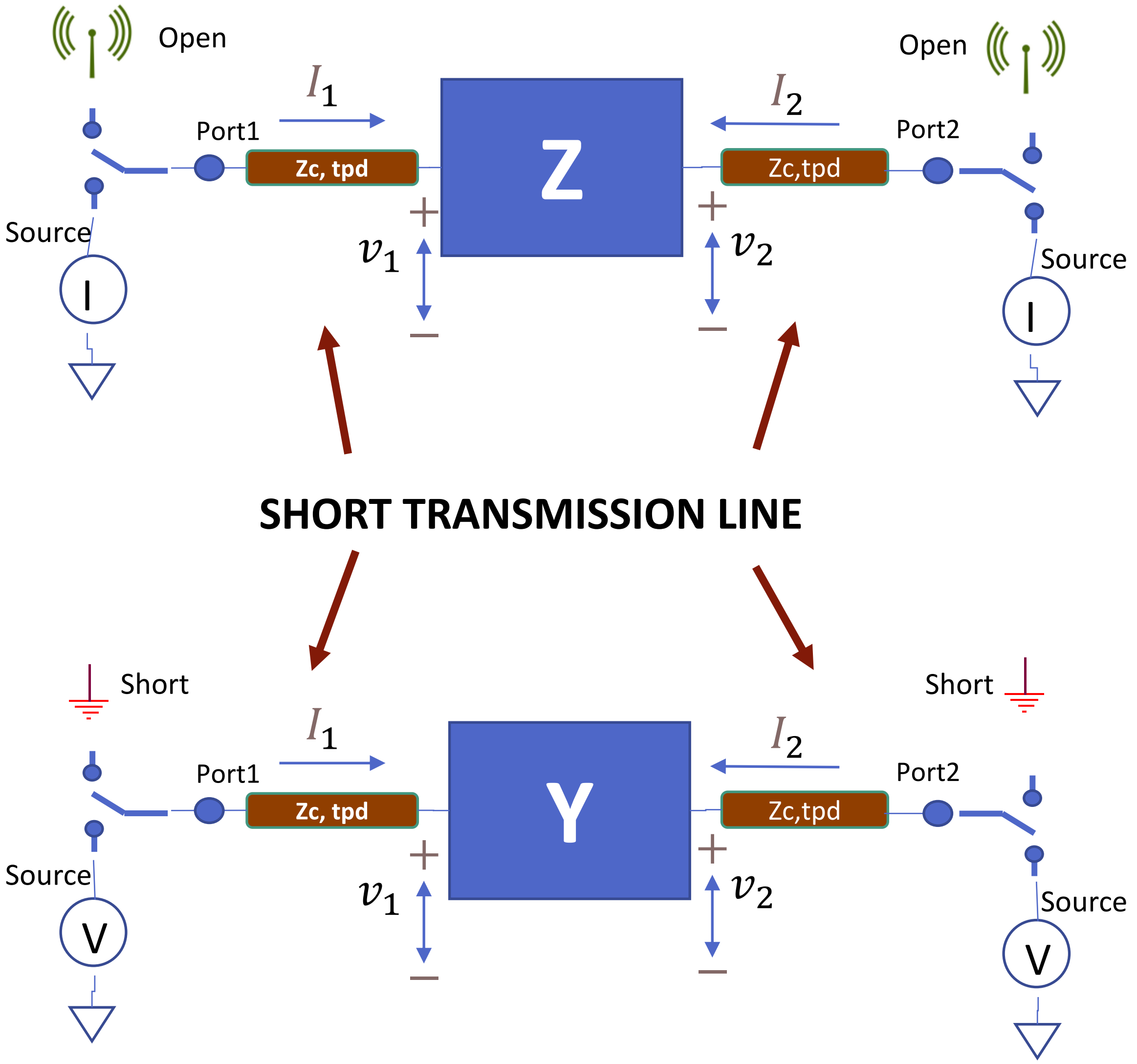
$$z_{11} = \left.\frac{v_1}{I_1}\right|_{I_2=0} \qquad z_{12} = \left.\frac{v_1}{I_2}\right|_{I_1=0}$$

$$z_{21} = \left.\frac{v_2}{I_1}\right|_{I_2=0} \qquad z_{22} = \left.\frac{v_2}{I_2}\right|_{I_1=0}$$

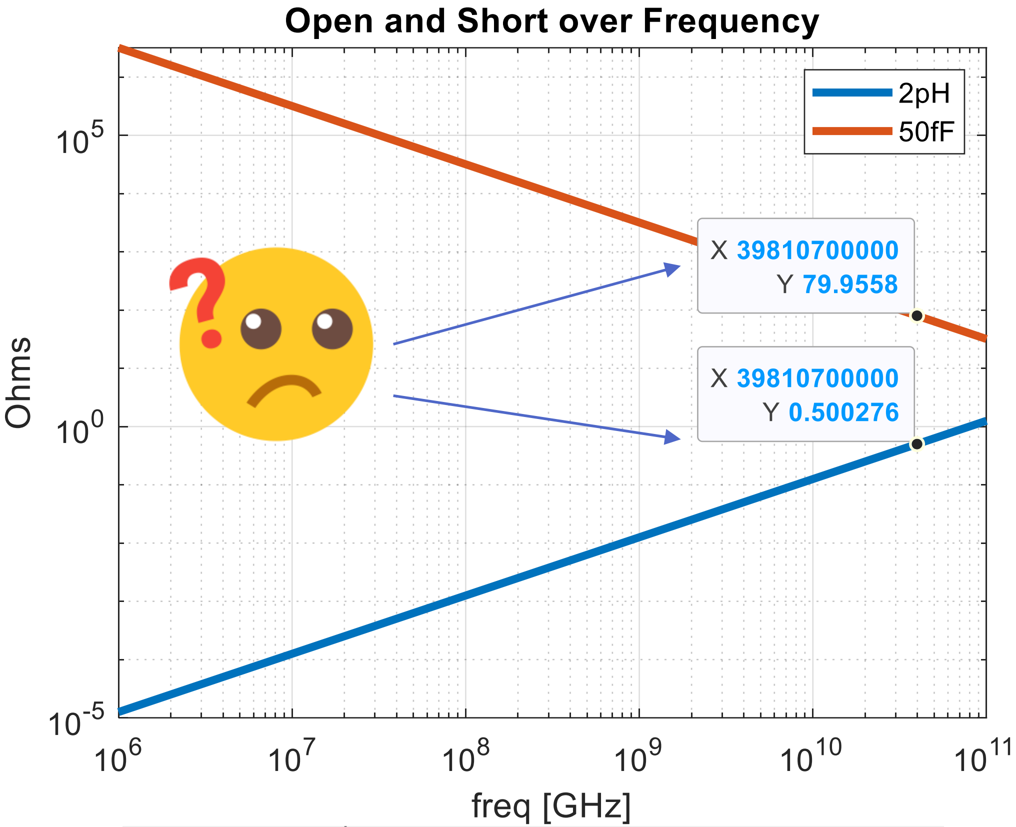
$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$

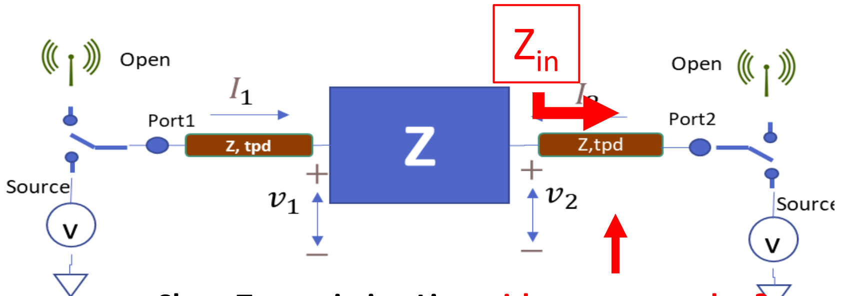
$$Y_{11} = \left.\frac{I_1}{v_1}\right|_{v_2=0} \qquad Y_{12} = \left.\frac{I_1}{v_2}\right|_{v_1=0}$$

$$Y_{21} = \left.\frac{I_2}{v_1}\right|_{v_2=0} \qquad Y_{22} = \left.\frac{i_2}{v_2}\right|_{v_1=0}$$



Z and Y Matrices (2)

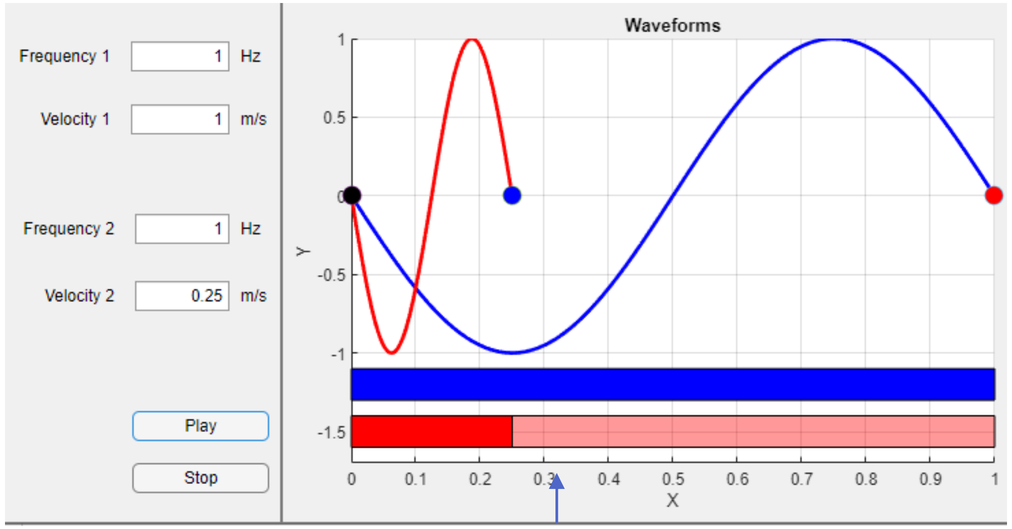




Short Transmission Line with respect to what?

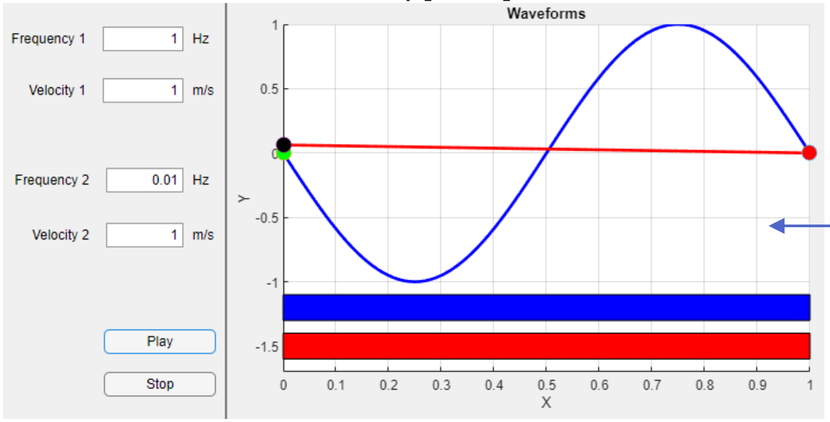
$$\lambda = \frac{v}{f}$$ **The Wave-Length**

$$z_{in} = z_0 \cdot \frac{z_L + j z_0 \tan \beta d}{z_{0} + j z_L \tan \beta d}$$



Same frequency, different propagation speed

Speed= Speed/4, electrically L_{ength}=L_{ength}



For the same length, different frequency, the red is considered lumped, since **L** = $\lambda/100$

λ *is our measurement stick*

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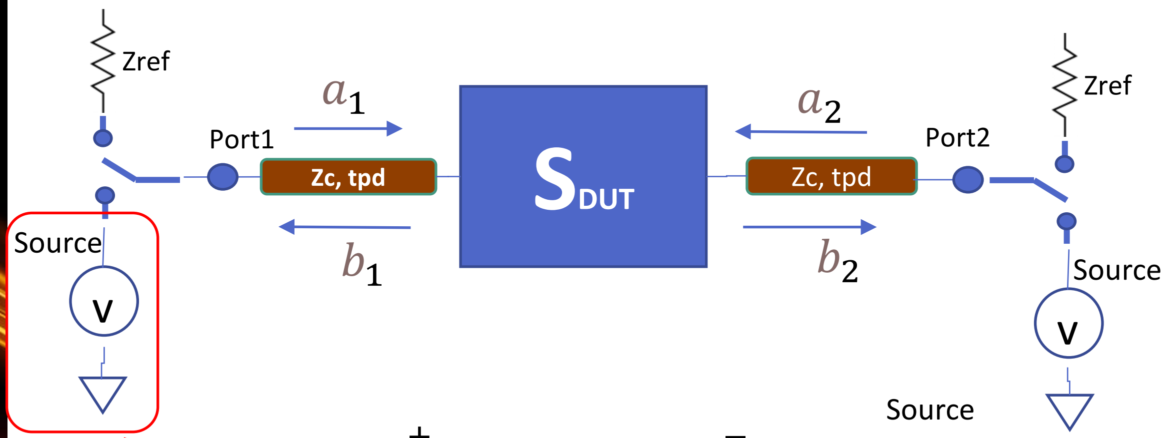
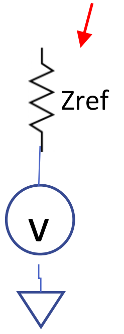
S-Parameters





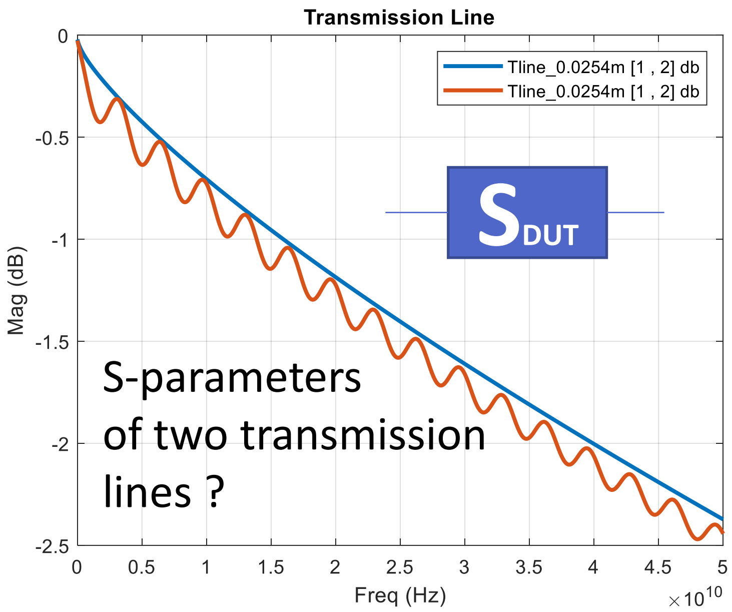
$$a_x = \frac{v_x^+}{\sqrt{Zref}} \qquad b_x = \frac{v_x^-}{\sqrt{Zref}}$$

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} \qquad S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0}$$

$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} \qquad S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0}$$

Means, no reflections at the port (where the instrument is)



NO!!!, Z_{REF}= 50 Ohms, Z_{REF}= 40 Ohms

https://www.signalintegrityjournal.com/articles/270-s-parameter-renormalization-the-art-of-cheating

- Independent of transmission line length (mostly is just a delay)
- Easier to terminate to an impedance not an open/load)
- All the small variations can be calibrated out

$$\Gamma = \frac{z_{REF} - z_c}{z_{REF} + z_c} = 0 \Rightarrow z_{REF} = z_c$$

S PARAMETERS ARE INCOMPLETE WIHTOUT ZREF

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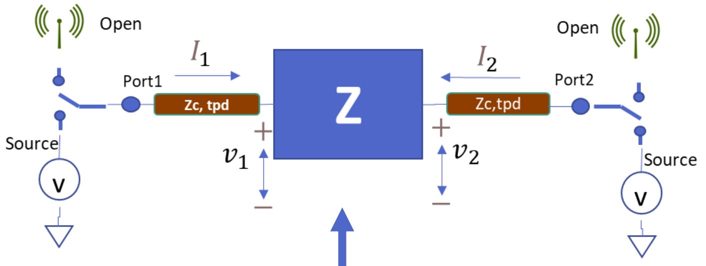
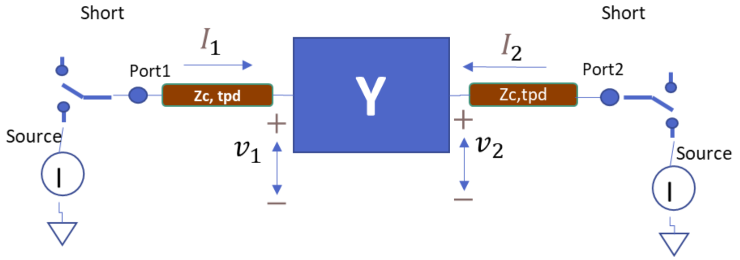
Timeline



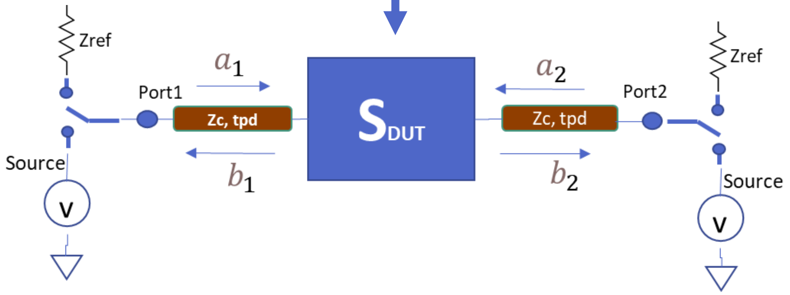
Very low frequency

Then, in simulation world mathematically, we could compute any N-port parameters from any other.



Easier to get a short than an open, extended its use to higher frequencies

With advanced Calibration methods, 100+ GHz and beyond



Generic Timeline

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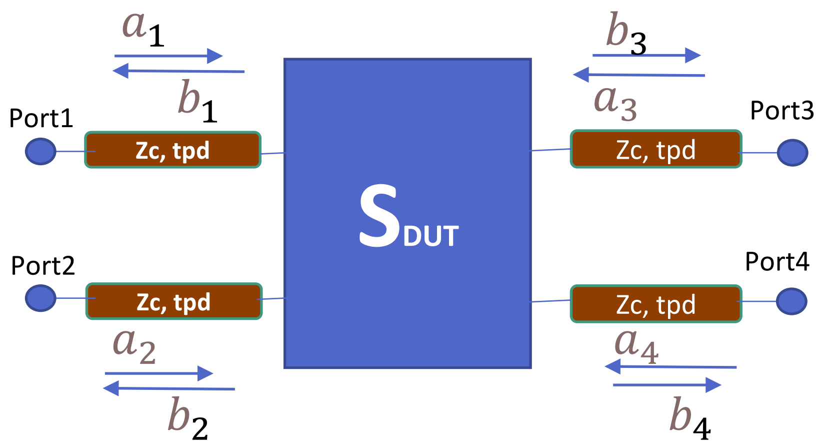
N-Ports & Mixed Mode S-Parameters



$$b_1 = s_{11}a_1 + s_{12}a_2 + s_{13}a_3 + s_{14}a_4$$
$$b_2 = s_{21}a_1 + s_{22}a_2 + s_{23}a_3 + s_{24}a_4$$
$$b_3 = s_{31}a_1 + s_{32}a_2 + s_{33}a_3 + s_{34}a_4$$
$$b_4 = s_{41}a_1 + s_{42}a_2 + s_{43}a_3 + s_{44}a_4$$

$$\frac{b_4 - b_3}{a_2 - a_1} = \frac{b_{d2}}{a_{d_1}} \qquad a_1 = -a_2 \Rightarrow a_{d1} = 2a_2$$

Boundary condition

It's all about boundary condition setup

	$a_{1,3}=-a_{2,4}$ $a_d=a_{1,3}-a_{2,4}$	$a_{1,3}=a_{2,4}$ $a_d=a_{1,3}+a_{2,4}$
$b_{1,3}=-b_{2,4}$ $b_d=b_{1,3}-b_{2,4}$	S_{DD}	S_{DC}
$b_{1,3}=b_{2,4}$ $b_d=b_{1,3}+b_{2,4}$	S_{CD}	S_{CC}

$$b_3 = -s_{31}a_2 + s_{32}a_2$$
$$b_4 = -s_{41}a_2 + s_{42}a_2$$

$$b_4 - b_3 = b_{d2} = 0.5\, a_{d1}(-s_{41} + s_{42} - s_{31} + s_{32})$$

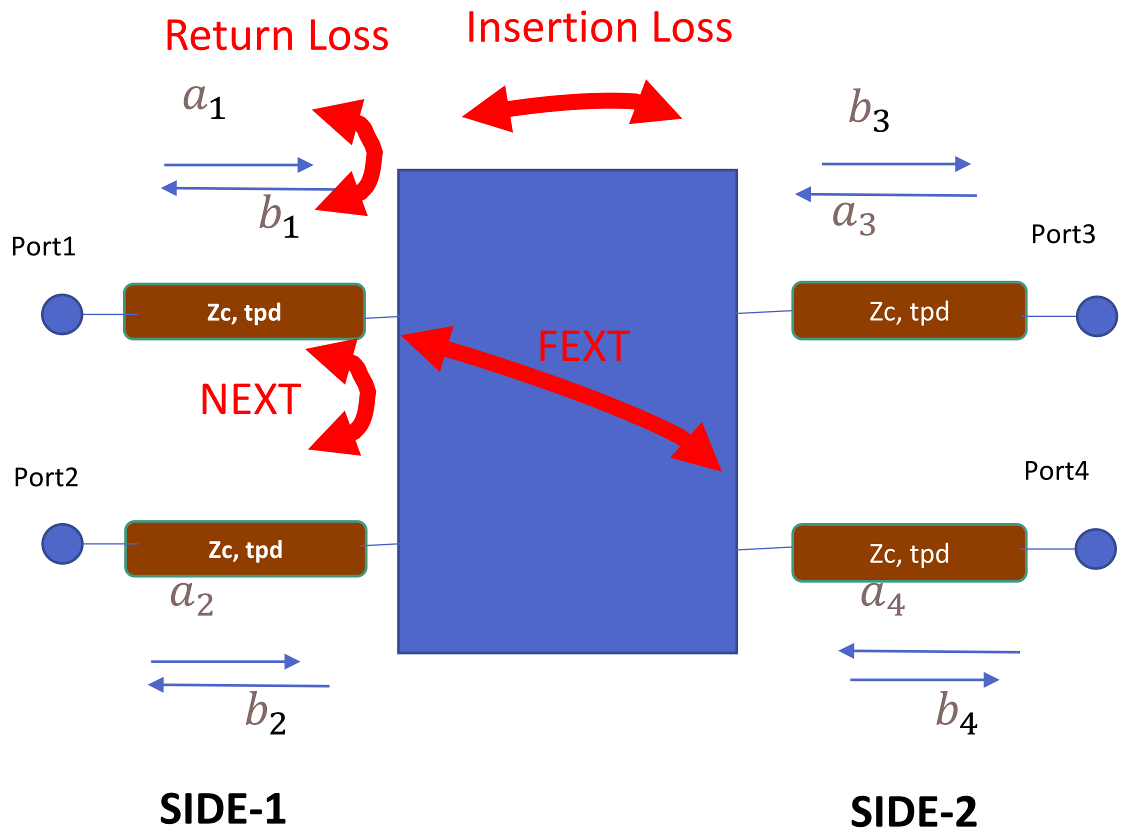
$$S_{dd21} = \frac{b_{d2}}{a_{d_1}} = 0.5\,(-s_{41} + s_{42} - s_{31} + s_{32})$$

Differential Insertion Loss

Common Nomenclature

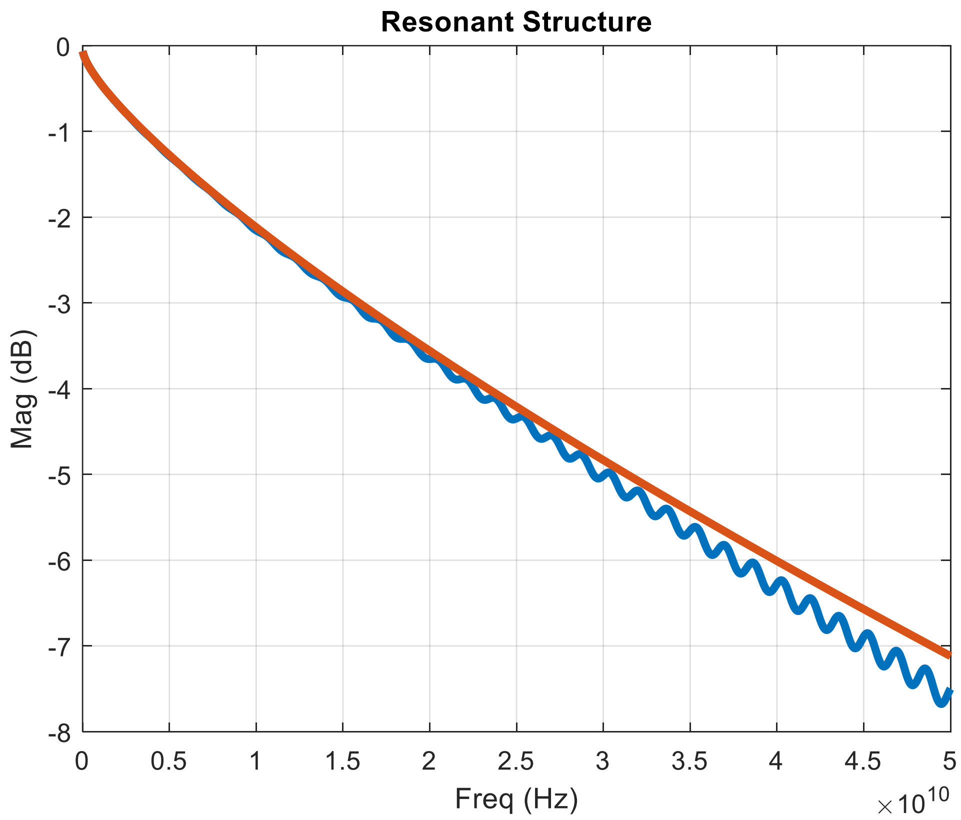
- **Return Loss:** Like reflection in SI, means all that return is lost since it does not get to the other side

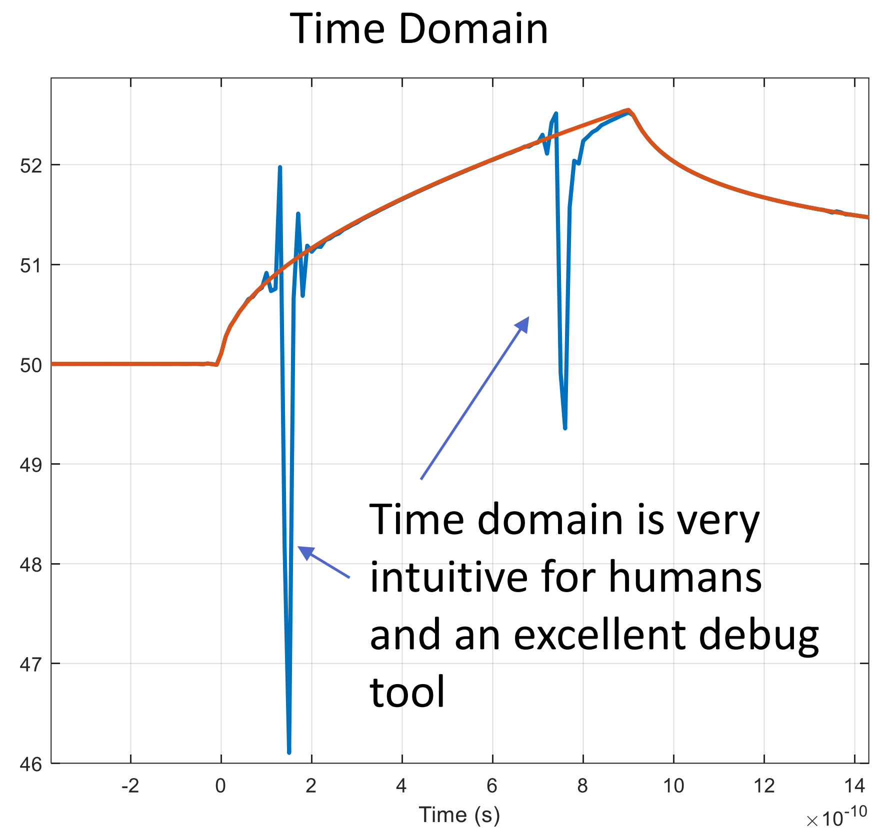
- **Insertion Loss:** When we insert something (for passives), on a perfect channel we incur losses. When we have actives, in general this is called Gain (G), but it's the same thing

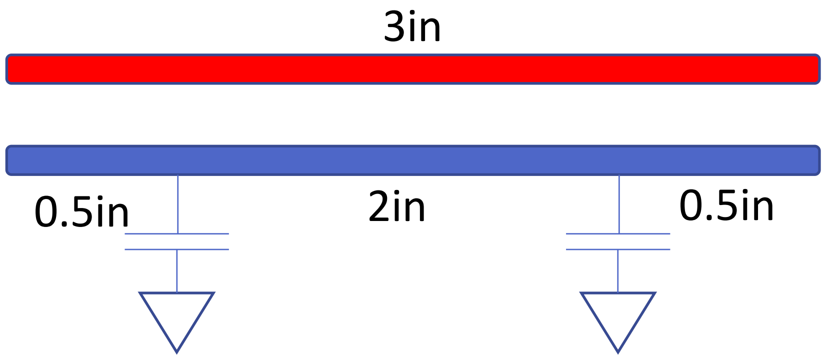


- **Crosstalk:** Energy diverted to a non intended port (receiver)
  - **Far end crosstalk or FEXT:** When the "victim" port is on the far side of the "aggressor" port
  - **Near end crosstalk or NEXT:** When the "victim" port is on the same side as the "aggressor" port

Resonances in S-parameters

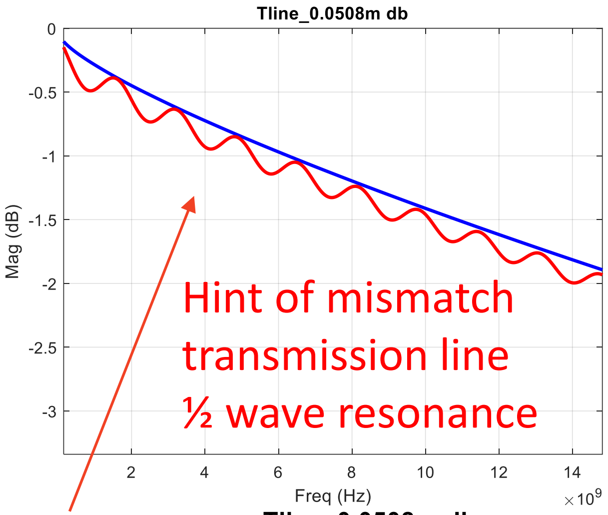


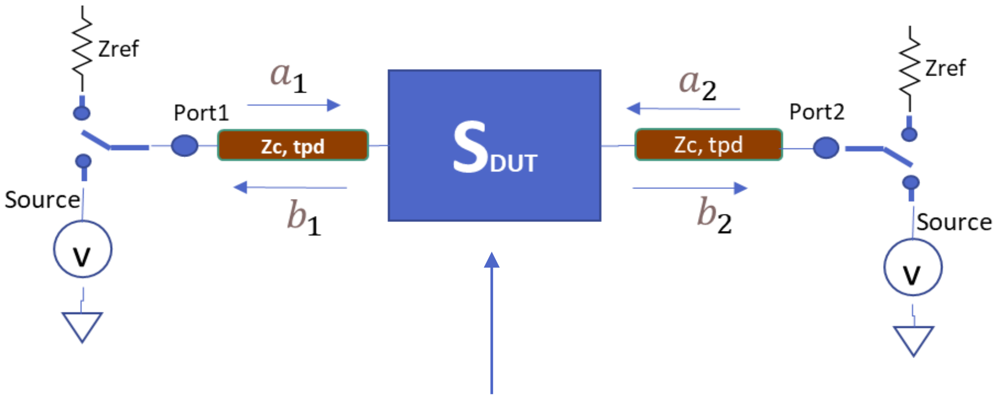


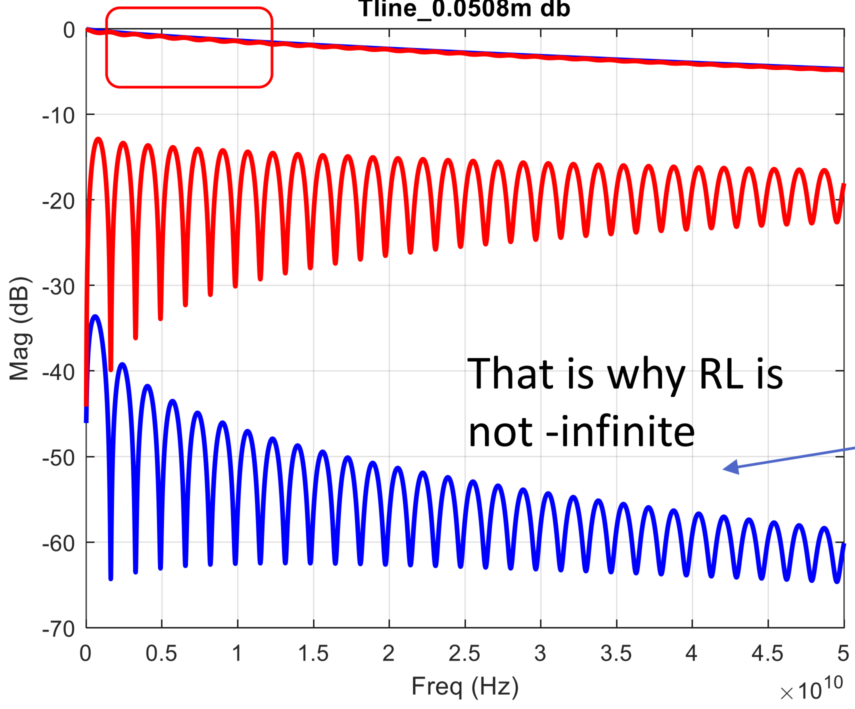


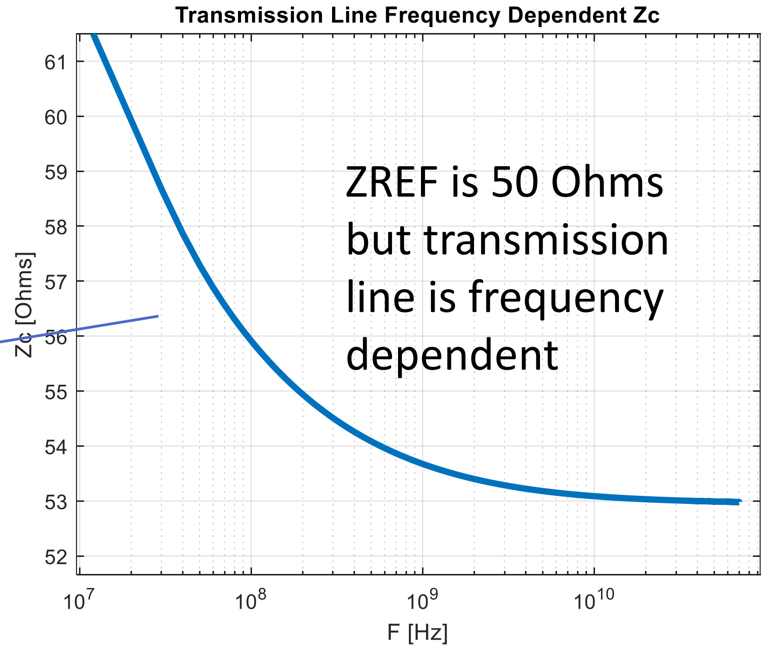
- In time domain every point, represent a time and location (easy to understand)
- In frequency domain, every frequency point represents all locations at all times.

Transmission Line IL and RL

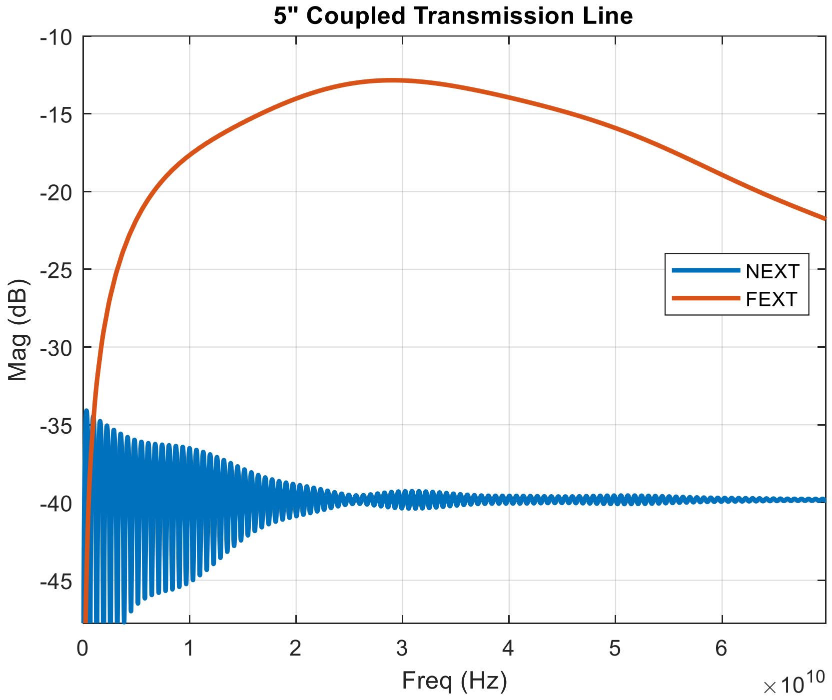


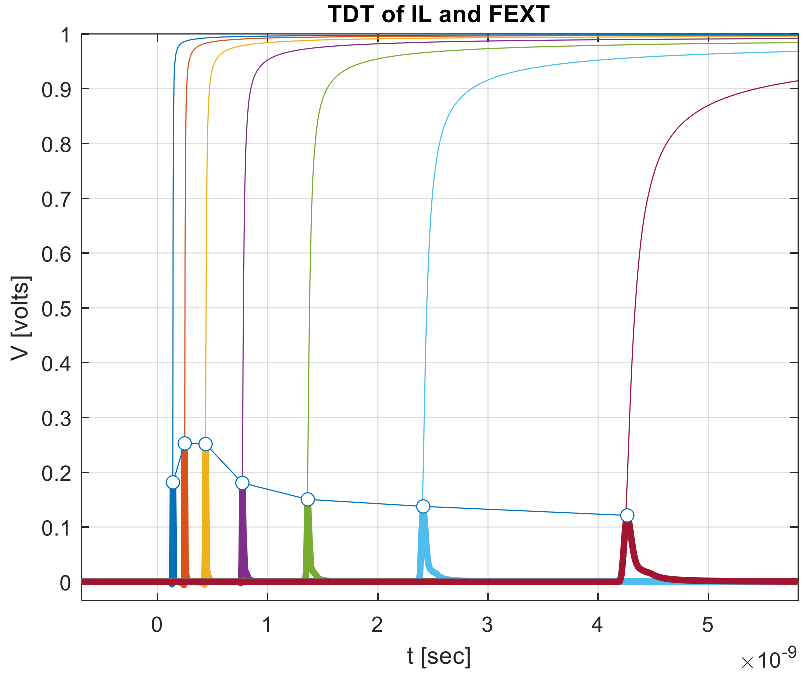


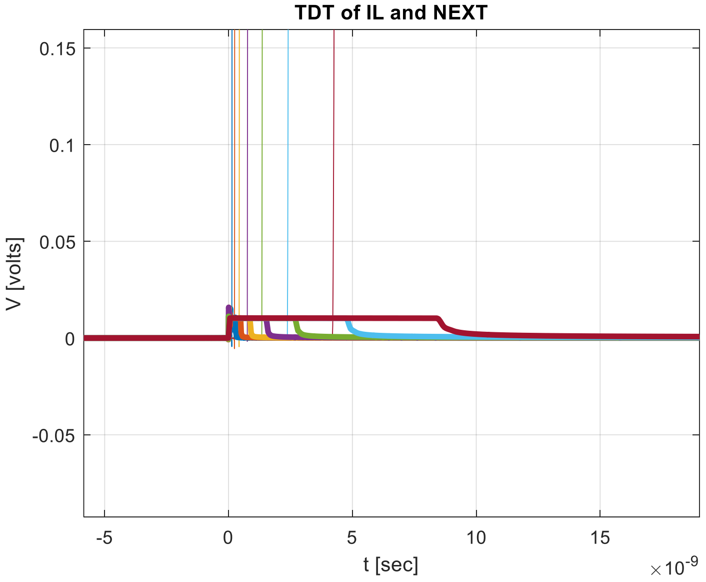


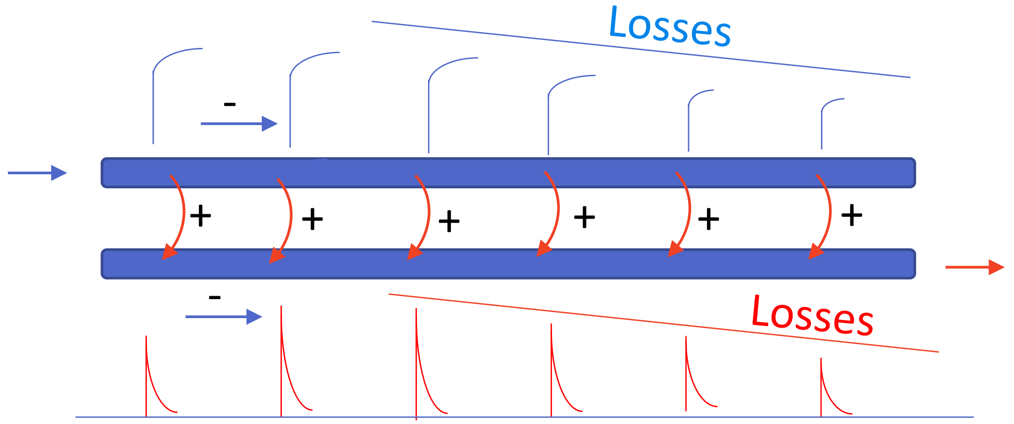


FEXT and NEXT Crosstalk



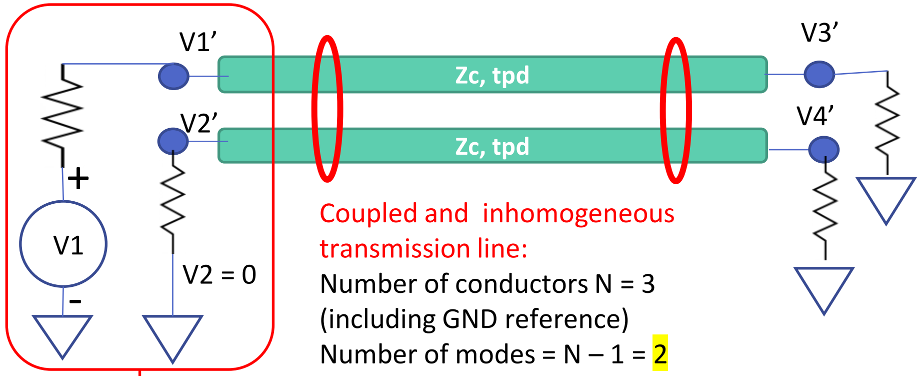




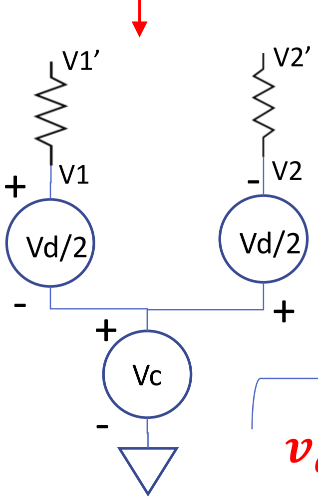


Example, Single Ended In Differential Interconnect (Problem Introduction)

http://www.electrical-integrity.com/Paper_download_files/DC07_SUN_difflosses_v14.pdf



Coupled and inhomogeneous transmission line:
Number of conductors N = 3 (including GND reference)
Number of modes = N – 1 = 2



Two orthogonal propagation modes "odd" (differential) & "even" (common mode)

Represent the sources based on the modes

$$v_d = v_1 - v_2 \qquad v_c = \frac{v_1 + v_2}{2}$$

$$v_1 = v_c + \frac{v_d}{2} \qquad v_2 = v_c - \frac{v_d}{2}$$

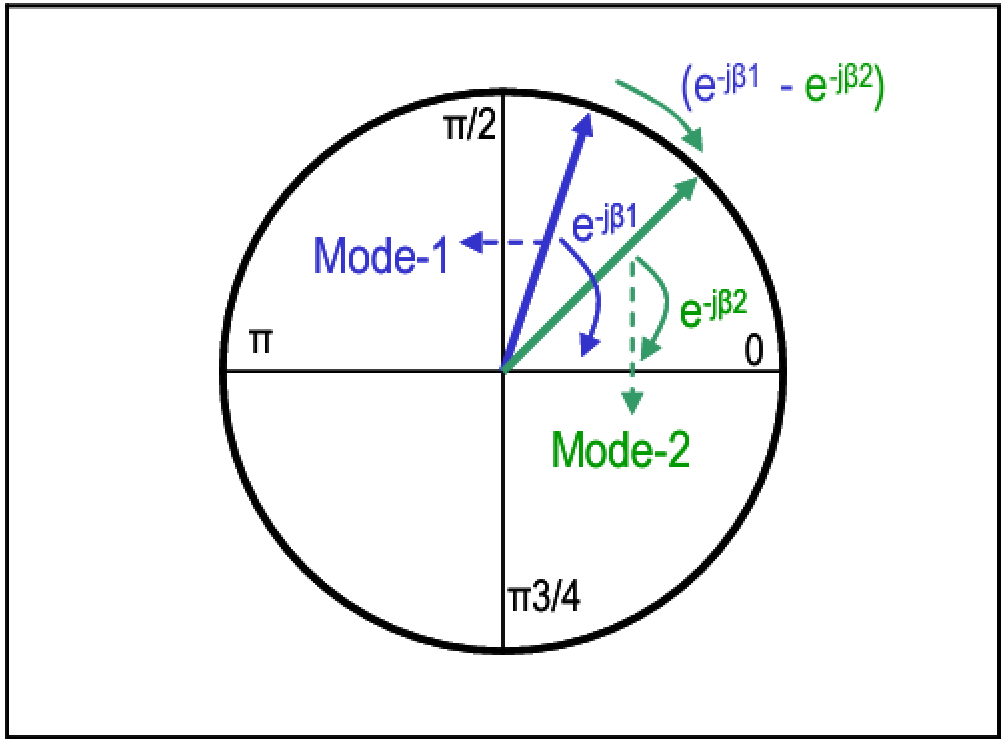
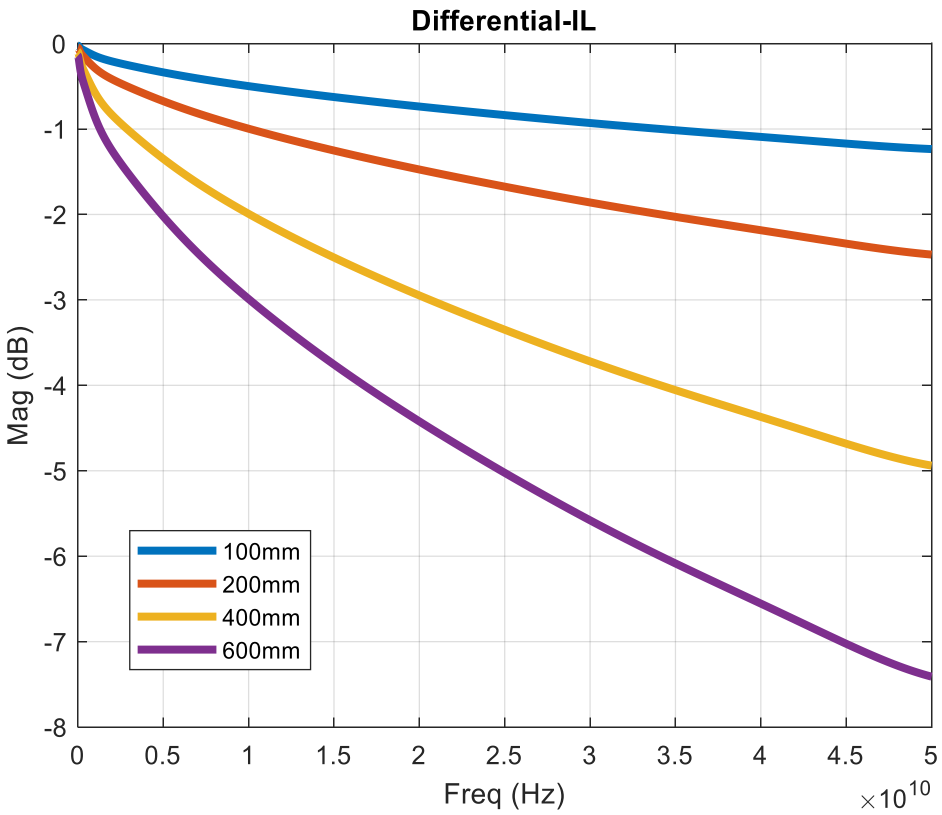


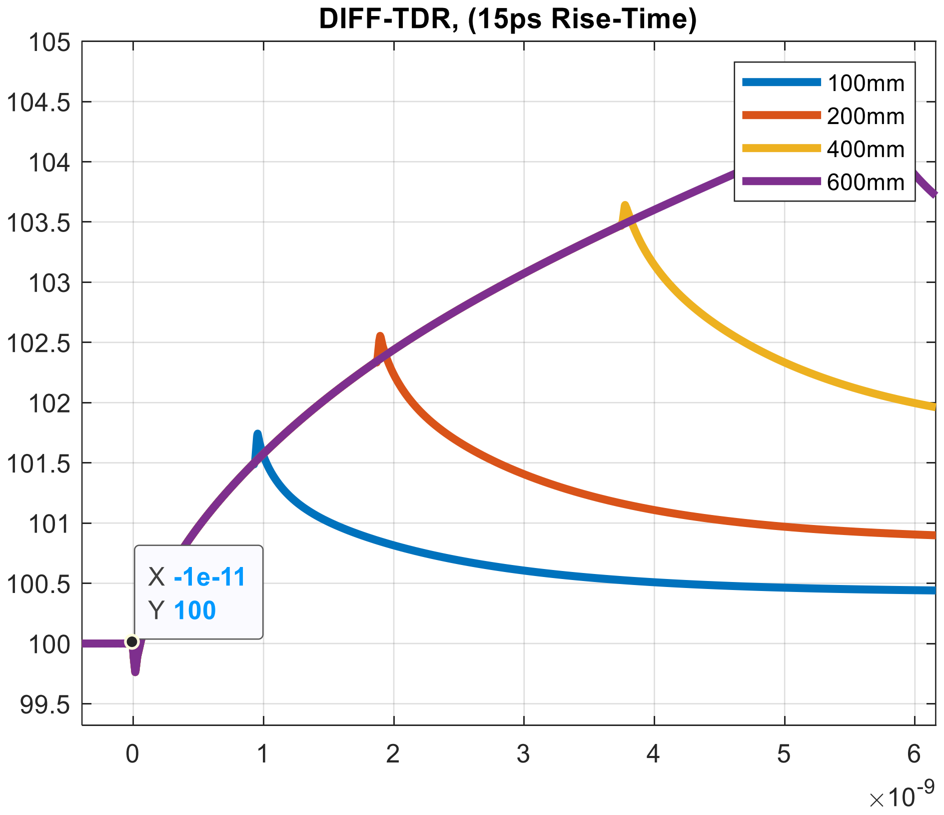
Figure 10: Phasor representation of the modal velocities.

If the modes propagation delay are different, as we move through the line the vectors will constructively add or subtract. For a long enough line will see increased IL

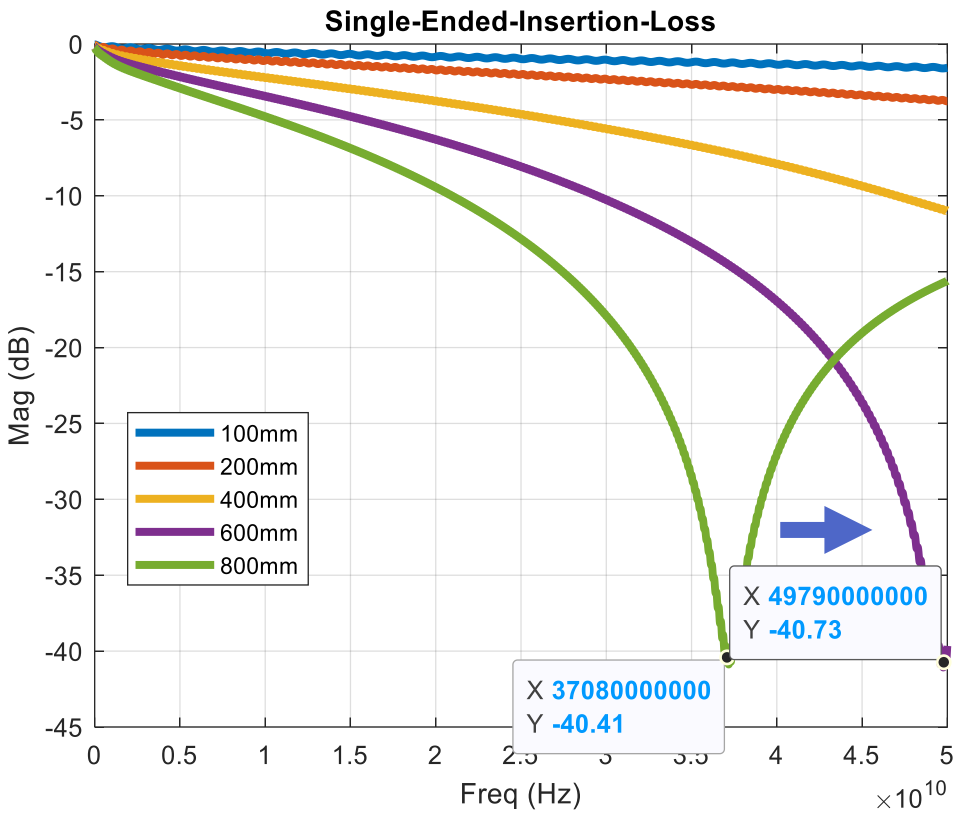
Differential IL and TDR

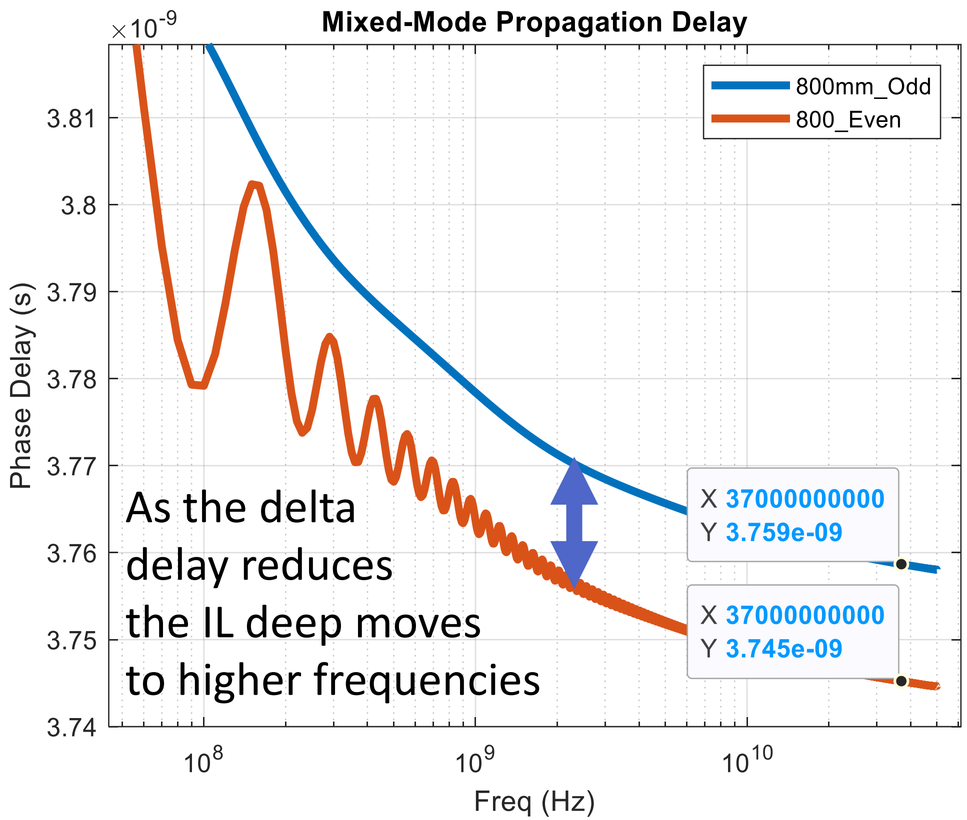
- Very clean and uniform differential transmission.





Single Ended Results in Differential System



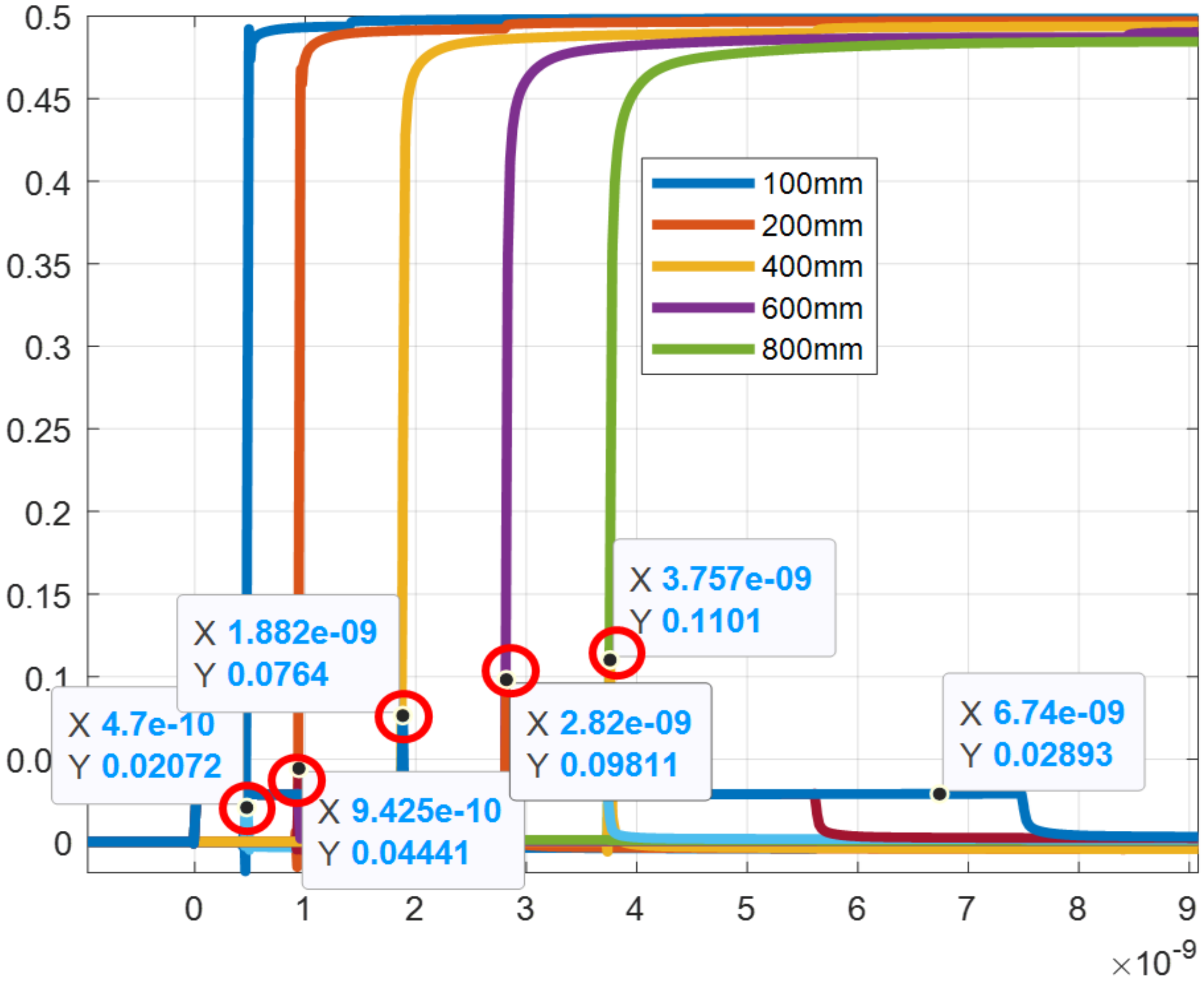


These are assuming one pair is terminated to 50 Ohms

- Resonances will be length dependent and related to 2/(delta-modal delay)
- Difference in odd and even propagation delay

Far End and Near End Crosstalk

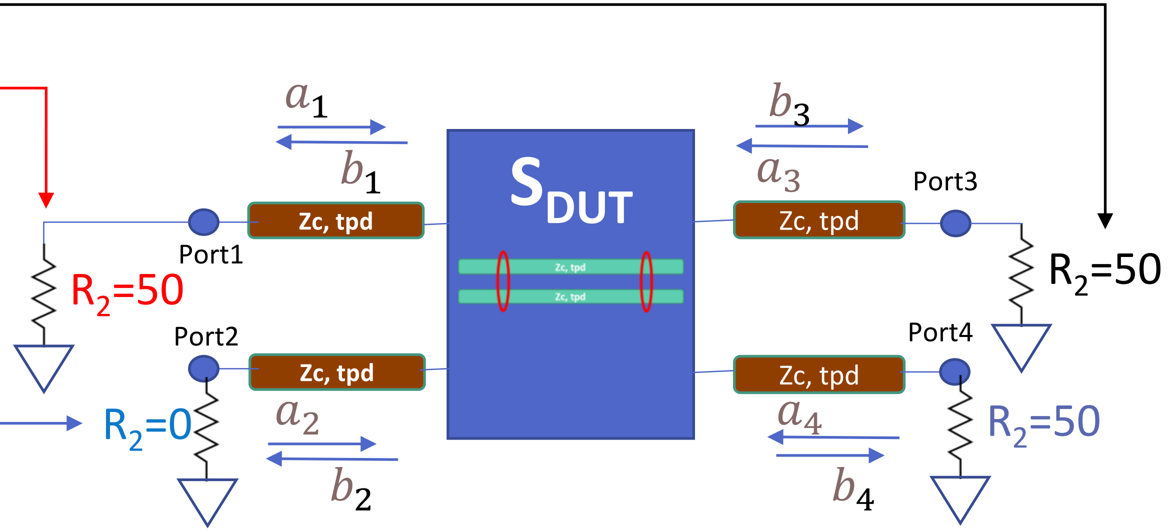
- Far end crosstalk indicating inhomogeneous medium.
- The longer the length the higher the FEXT accumulation, until due to losses will start to level and decay

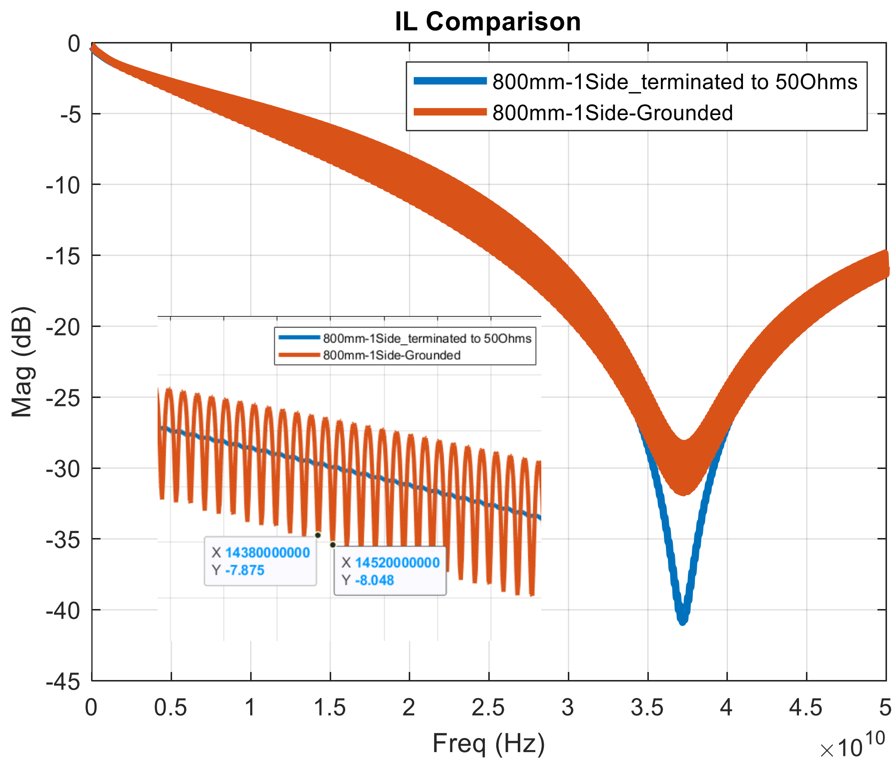


Grounding One Side of a Diff-Pair

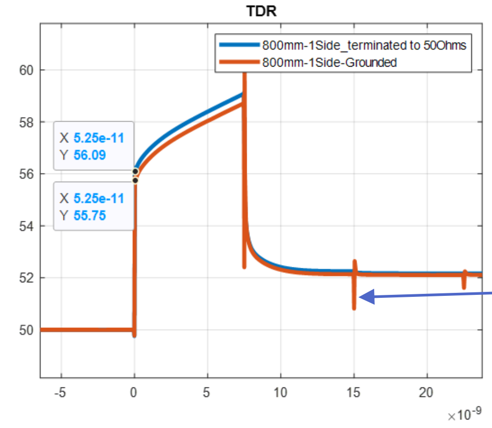
Simply renormalizing S-parameters (no need of anything else)

S_{DUT_R} = Renorm(S_{DUT} , [50, 0, 50,50])





- Grounding one side of a diff-pair produces resonances related to the length of the cable



Resonances in the Time domain

Summary

- S-parameters introductions and evolution from Z and Y
- Mixed Mode S-parameters and generation for other cases
- Nomenclature
- S-parameter features normally found
  - Resonances
  - Crosstalk
  - Reference
- Single Ended in Differential Pair example

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