IEEE CX4
Quantitative Analysis of Return-Loss

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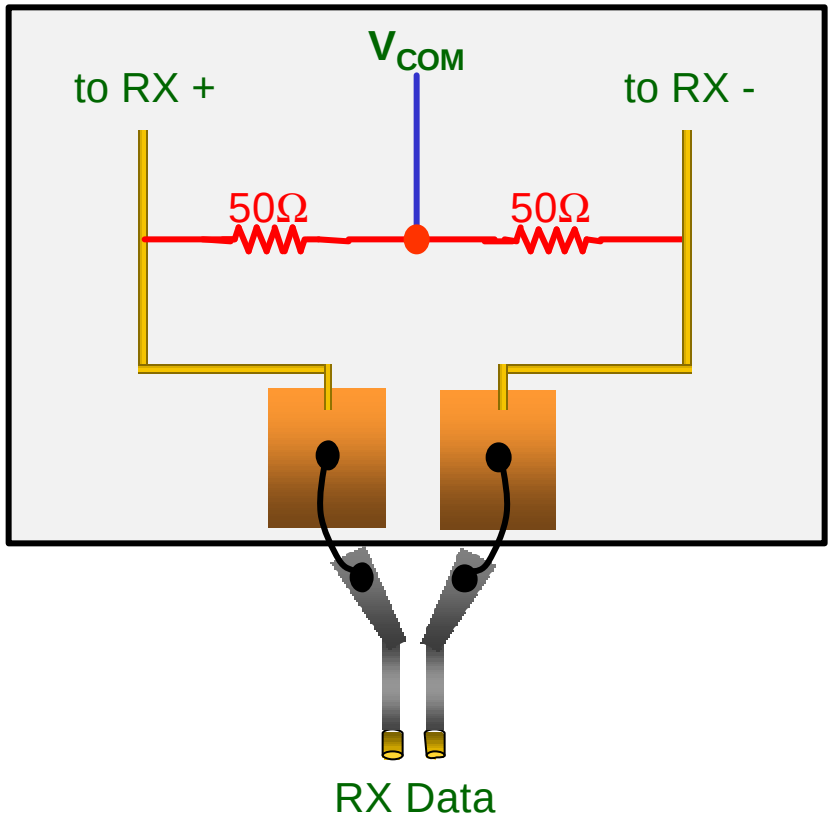
Return Loss Issues for IEEE 10G-Base-CX4

- Realizable
  - Is the spec realizable with standard packages and I/O structures
  - Define guideline for package requirements to meet specifications
  - Consider bondwire and trace inductance

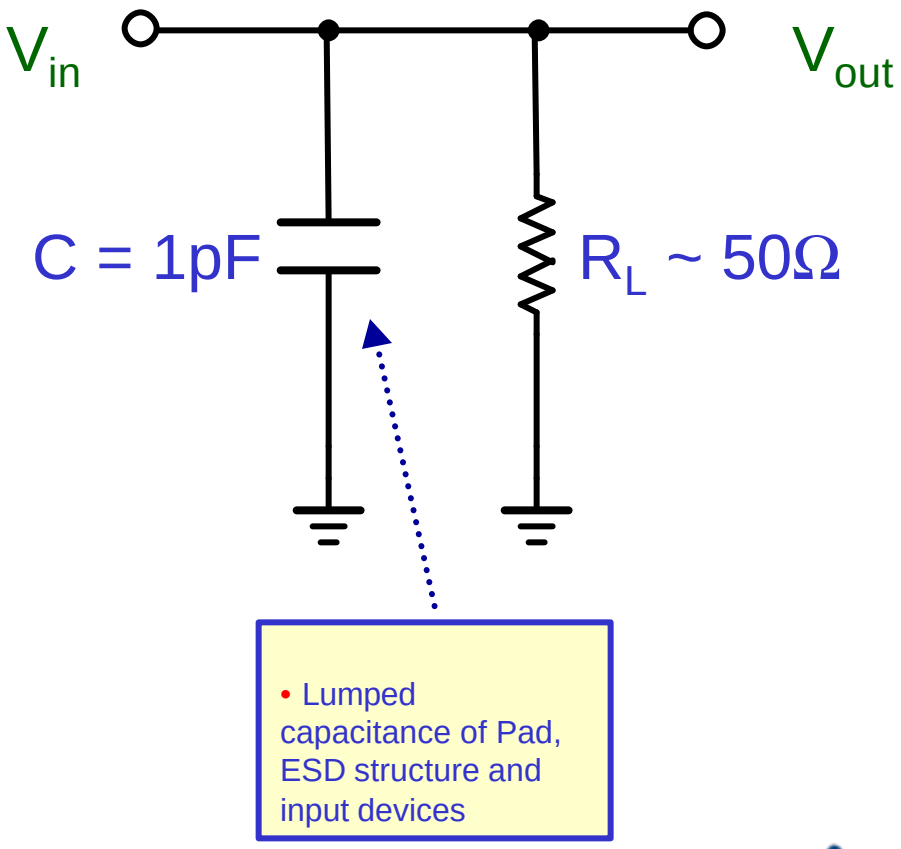
- Impact on Performance
  - How does return loss effect margin
  - What is minimum short-channel

Example Differential RX Termination

IC Implementation



Single-Ended Lumped Model



S-Parameters for Capacitive Termination

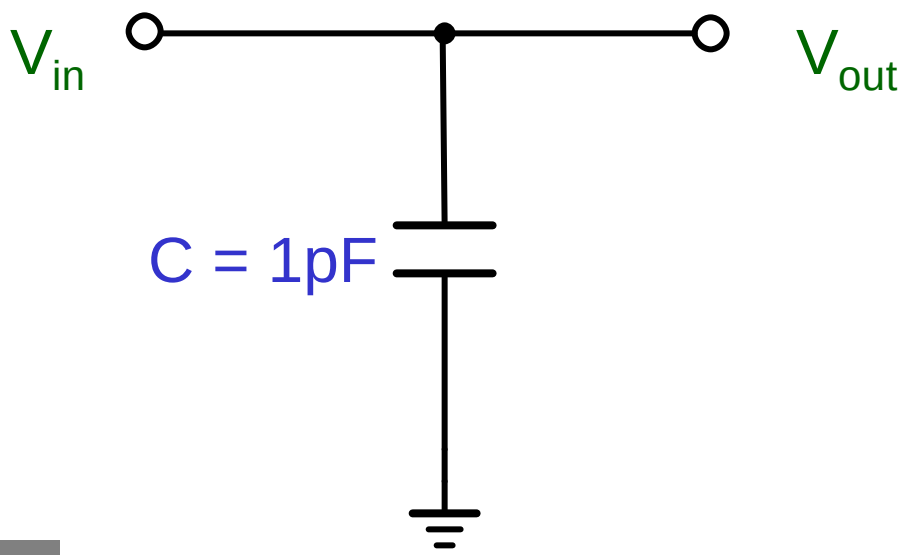
S-parameters

$$\mathbf{S} = \frac{1}{1+st}\begin{bmatrix} -st & 1 \\ 1 & -st \end{bmatrix}$$

Where, $t = \frac{RC}{2}$

$$\mathbf{S}_{RX\,11}(s) = \mathbf{S}_{TX\,11}(s) = \frac{-st}{1+st}$$

Single-Ended Lumped Model



- Reflection Coefficient / Return-Loss is high-pass function with unity-gain at high frequencies

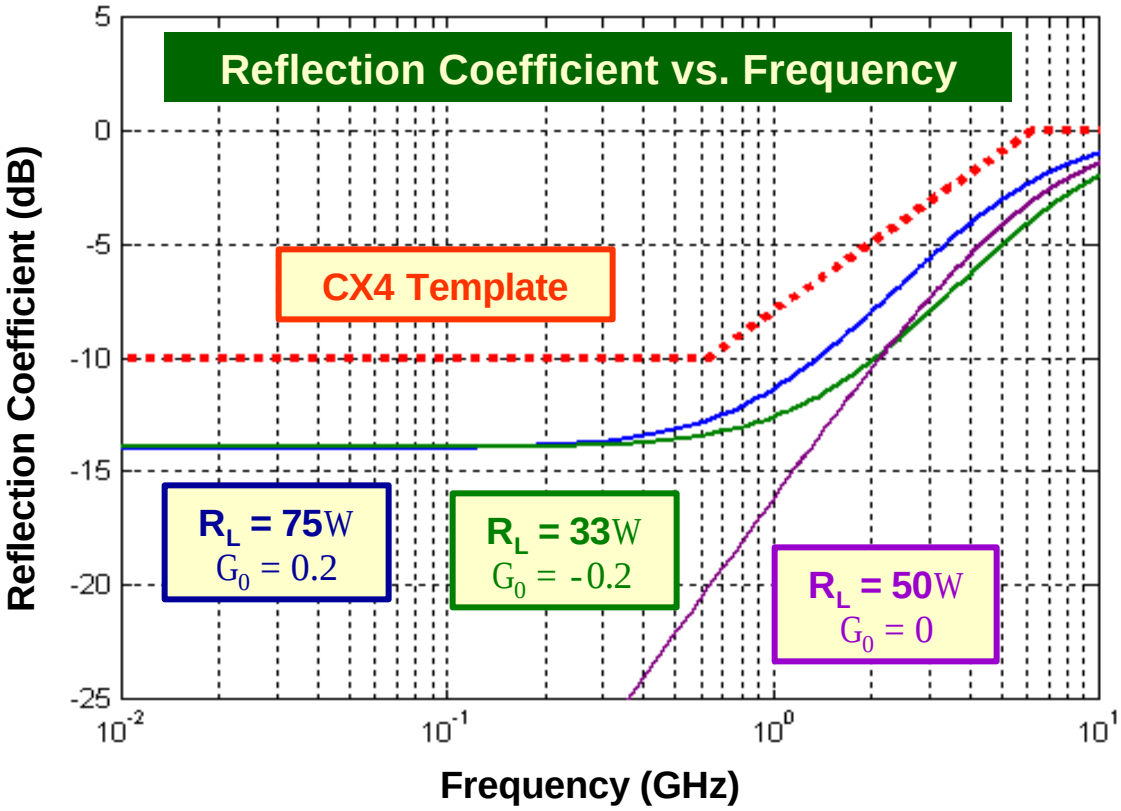
Reflection Coefficient for DC Mismatch

Reflection Coefficient

$$\Gamma = \frac{\Gamma_0 - st}{1 + st}$$

where, $t = (R_L \parallel R)C$

$$\Gamma_0 = \frac{R_L - R}{R_L + R}$$



- Reflection Coefficient (Return-Loss) is a high-pass function with unity-gain at high frequencies and DC gain determined by mismatch in R_L

Reflections in Time Domain

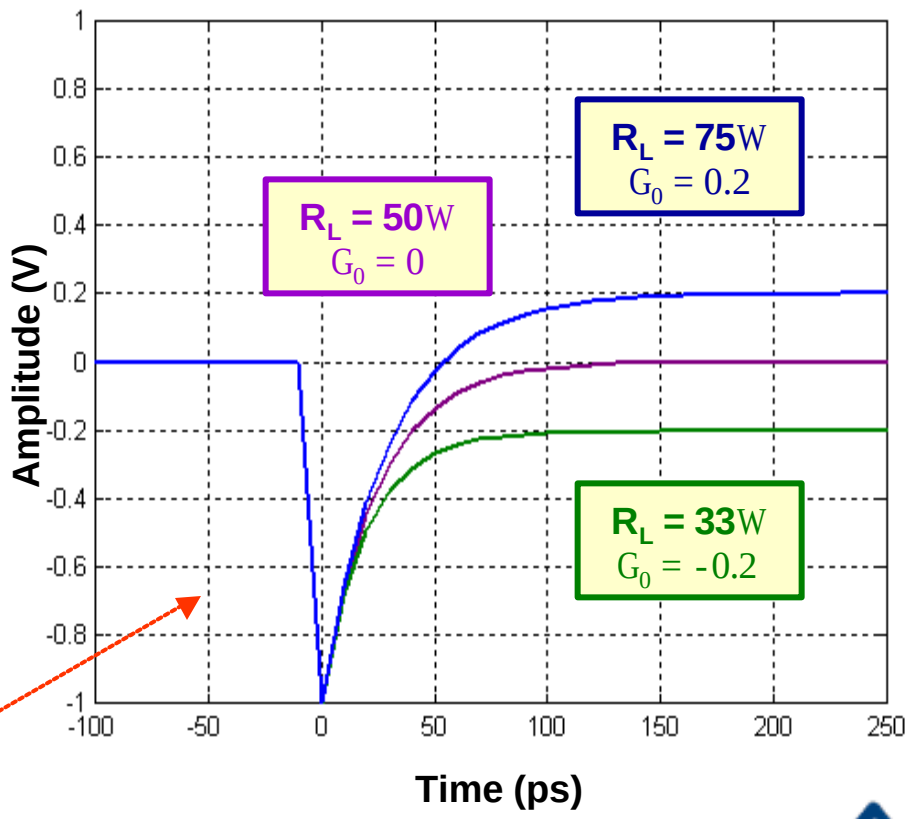
Impulse Response

$$h_{11}(t) = \left[-d(t) + \frac{[1+\Gamma_0]}{t} e^{-\frac{t}{t}} \right] u(t)$$

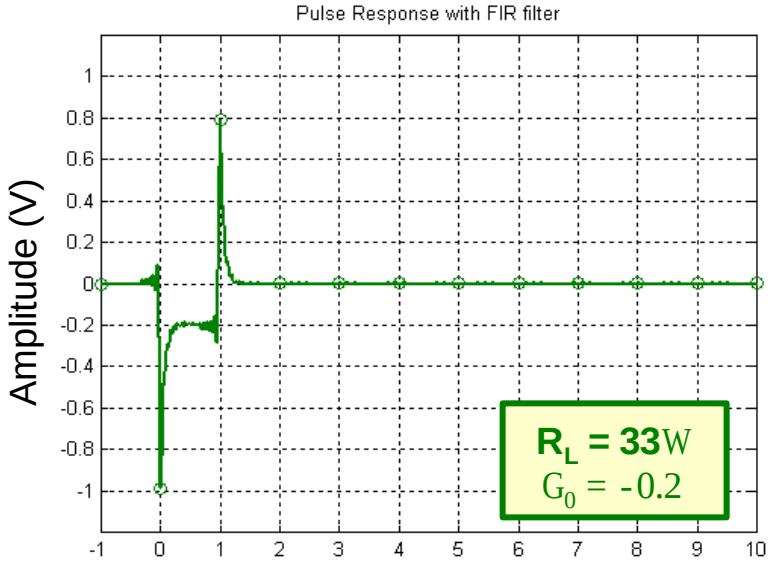
Step Response

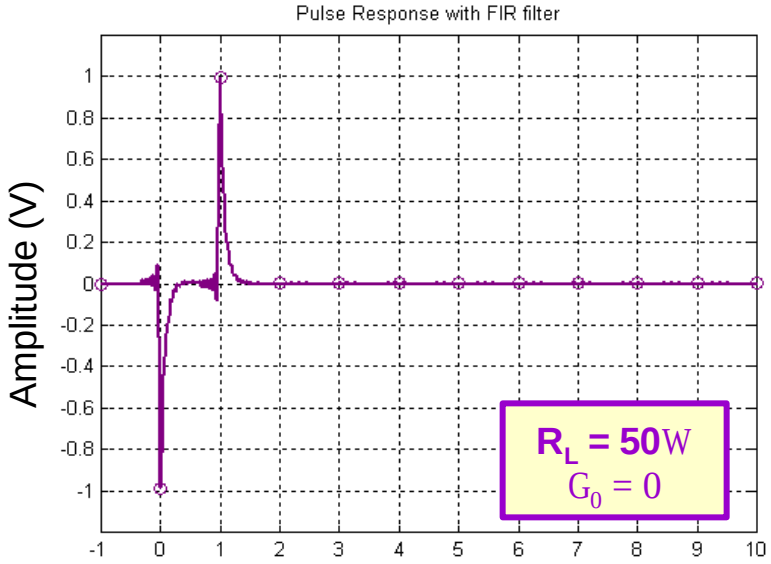
$$\text{step}_{11}(t) = \left[\Gamma_0 - [1+\Gamma_0] e^{-\frac{t}{t}} \right] u(t)$$

Step Response (TDR)

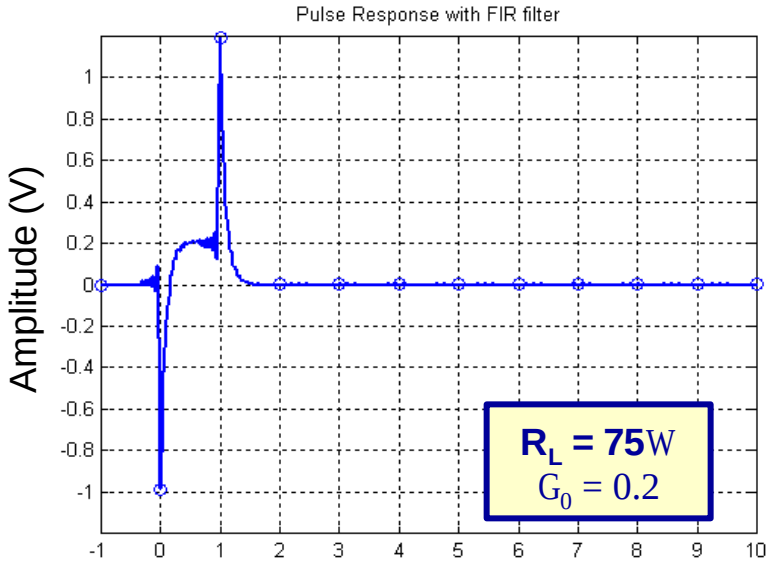


Reflections in Time Domain: Pulse Response





Unit Interval (320ps)



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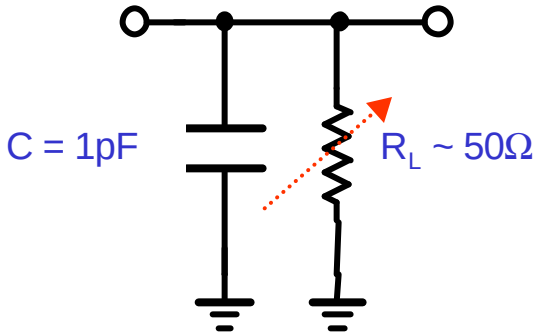


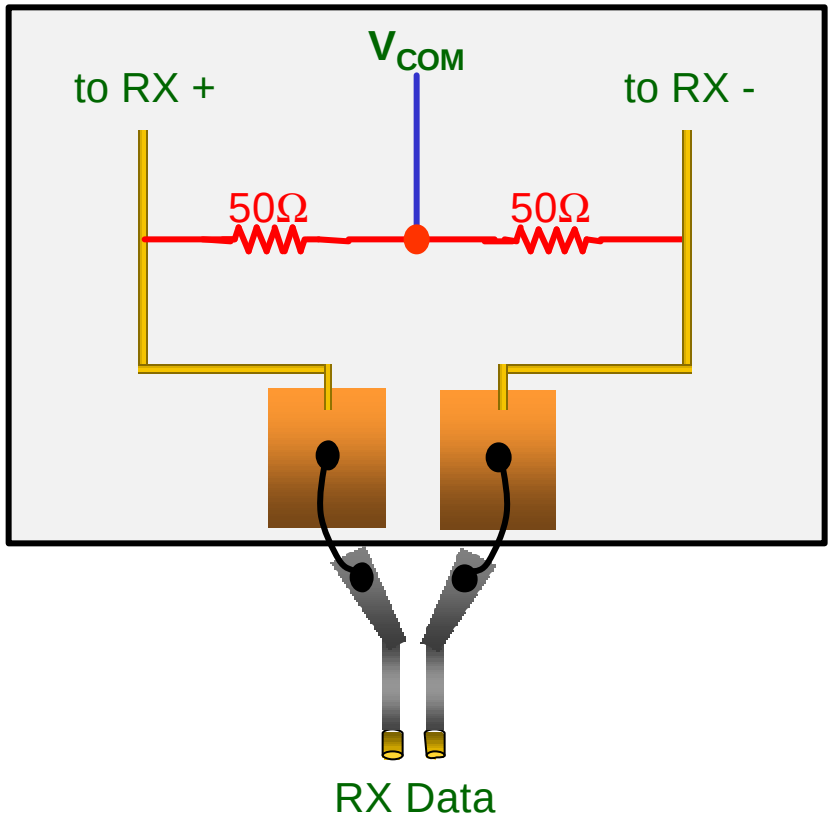
Return Loss Issues for IEEE 10G-Base-CX4

- Realizable
  - Is the spec realizable with standard packages and I/O structures
  - Define guideline for package requirements to meet specifications
  - Consider bondwires and trace inductance

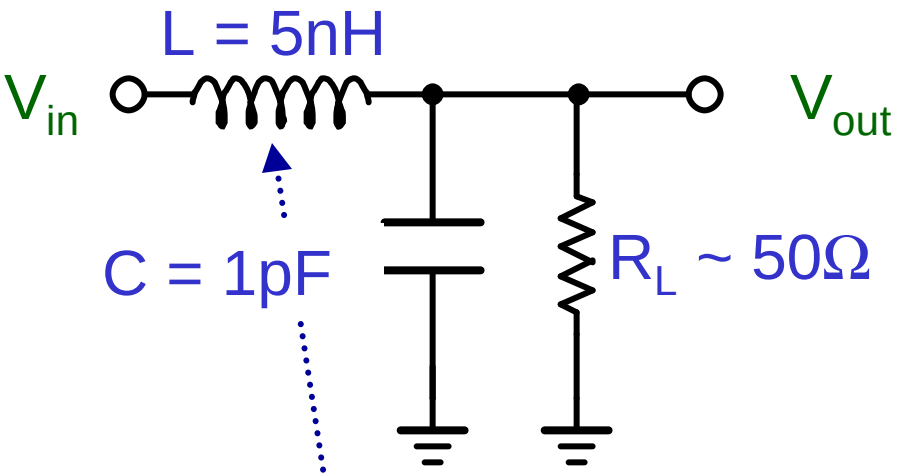
- Impact on Performance
  - How does return loss effect margin
  - What is minimum short-channel

RX with Bondwire & Trace Inductance

IC Implementation



Single-Ended Lumped Model

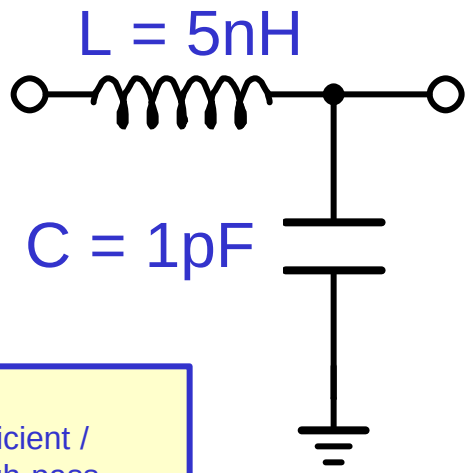


- Lumped inductance of package trace and bondwire

S-Parameters: Bondwire & Trace Inductance

$$\mathbf{S} = \frac{1}{1 + s\left[\frac{RC}{2} + \frac{L}{2R}\right] + s^2\left[\frac{LC}{2}\right]} \begin{bmatrix} s\left[-\frac{RC}{2} + \frac{L}{2R}\right] + s^2\left[\frac{LC}{2}\right] & 1 \\ 1 & s\left[-\frac{RC}{2} + \frac{L}{2R}\right] - s^2\left[\frac{LC}{2}\right] \end{bmatrix}$$

$$\mathbf{S}_{RX11}(s) = \frac{s[t_1 - t_2] + 2s^2 t_1 t_2}{1 + s[t_1 + t_2] + 2s^2 t_1 t_2}$$



Where, $t_1 = \frac{L}{2R}$ $t_2 = \frac{RC}{2}$

- Reflection Coefficient / Return-Loss is high-pass function with unity-gain at high frequencies

Reflection Coefficient with DC Mismatch

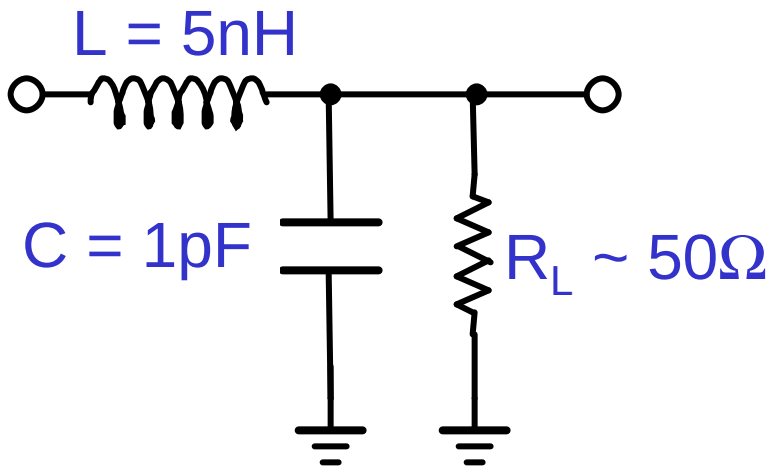
$$\Gamma_{RX11}(s) = \frac{\Gamma_0 + s\left[t_1(1-\Gamma_0) - t_2(1+\Gamma_0)\right] + 2s^2 t_1 t_2 (1+\Gamma_0)}{1 + s\left[t_1(1-\Gamma_0) + t_2(1+\Gamma_0)\right] + 2s^2 t_1 t_2 (1+\Gamma_0)}$$

where,

$$\Gamma_0 = \frac{R_L - R}{R_L + R}$$

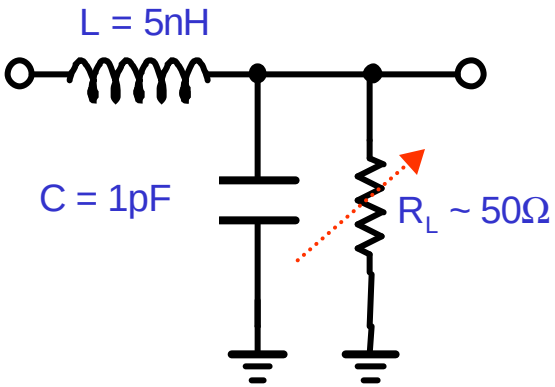
$$t_1 = \frac{L}{2R}$$

$$t_2 = \frac{RC}{2}$$

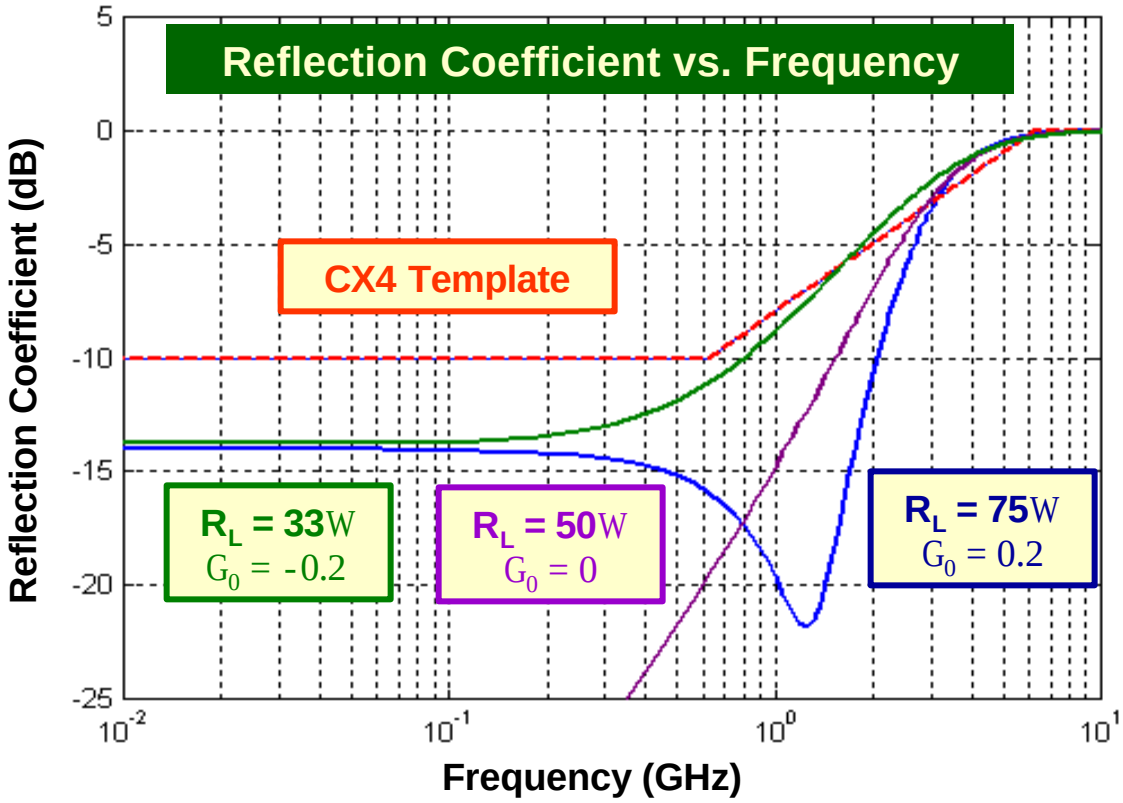


Reflection Coefficient for 1pF & 5nH

Termination Network



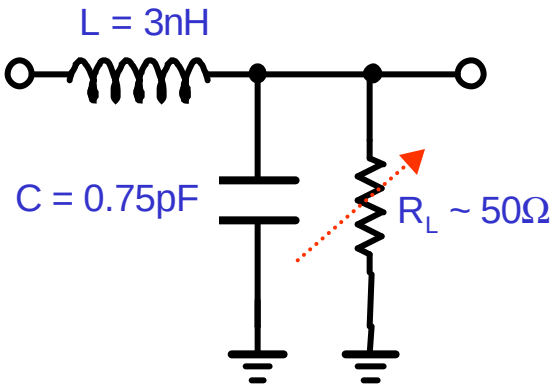
Reflection Coefficient vs. Frequency

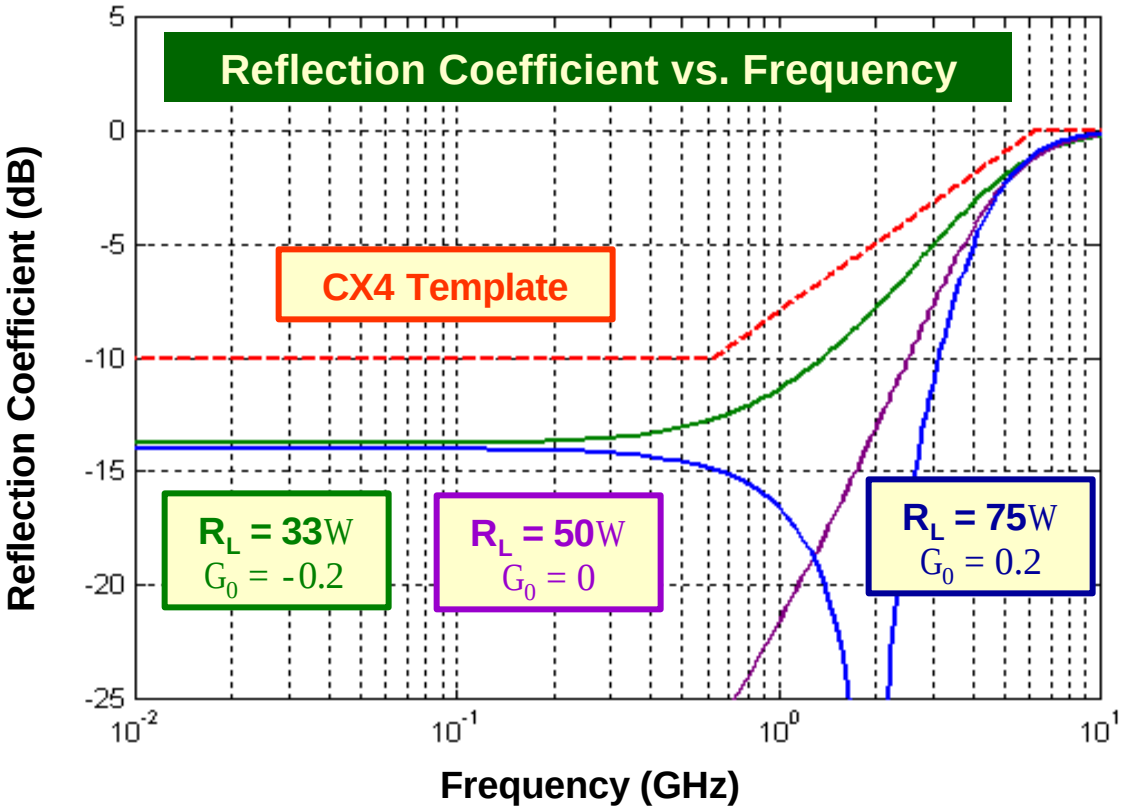


- Return-Loss violates template for 1pF and 5nH for wide range of values for RL

Reflection Coefficient for 0.75pF & 3nH

Termination Network

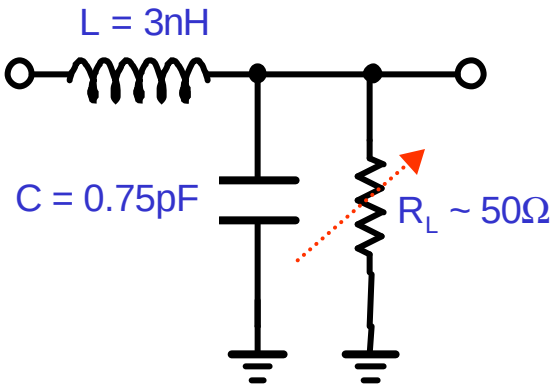




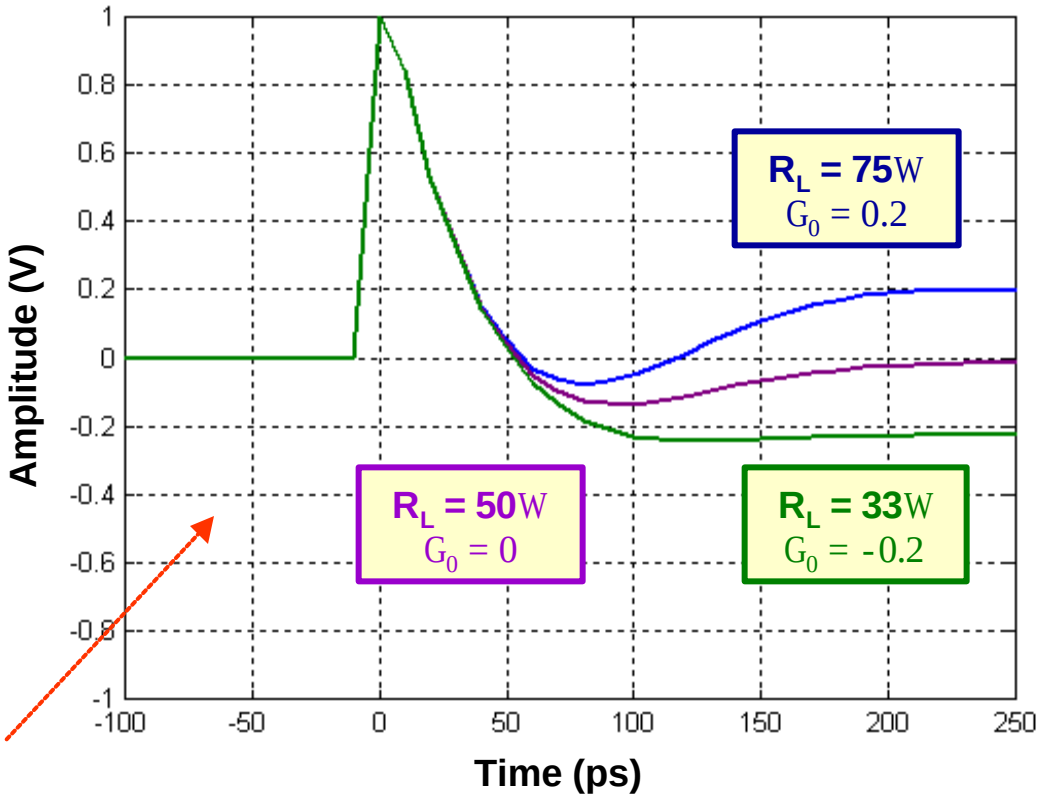
- Return-Loss meets template for 0.75pF and 3nH for wide range of values for RL. Notice resonant null for 75Ω load.
- Spec is achievable, but care must be taken in package

Reflections in Time Domain

Termination Network

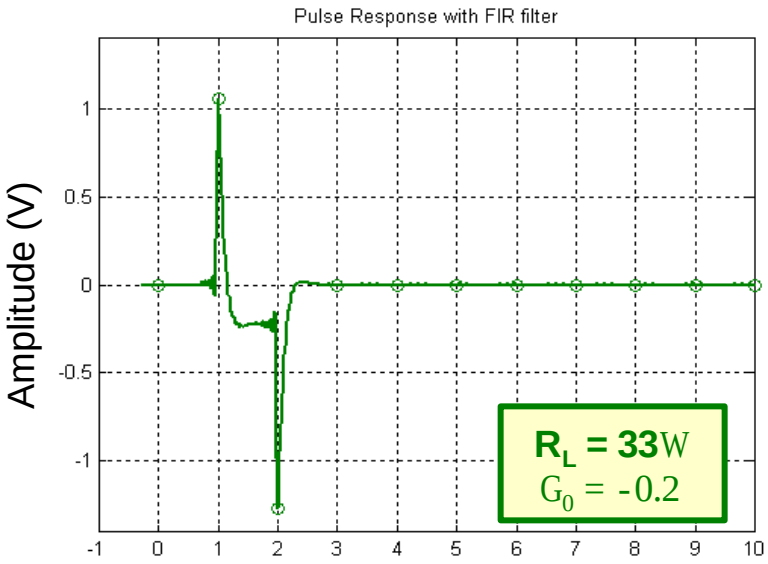


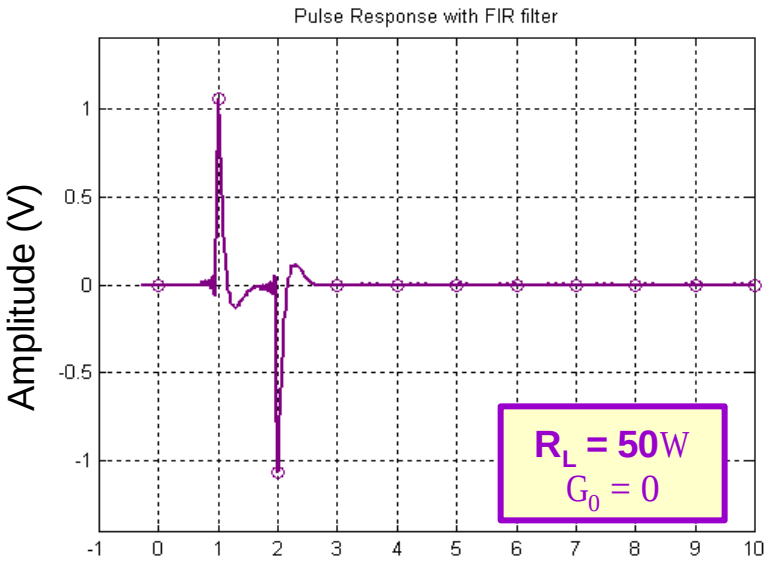
Step Response (TDR)



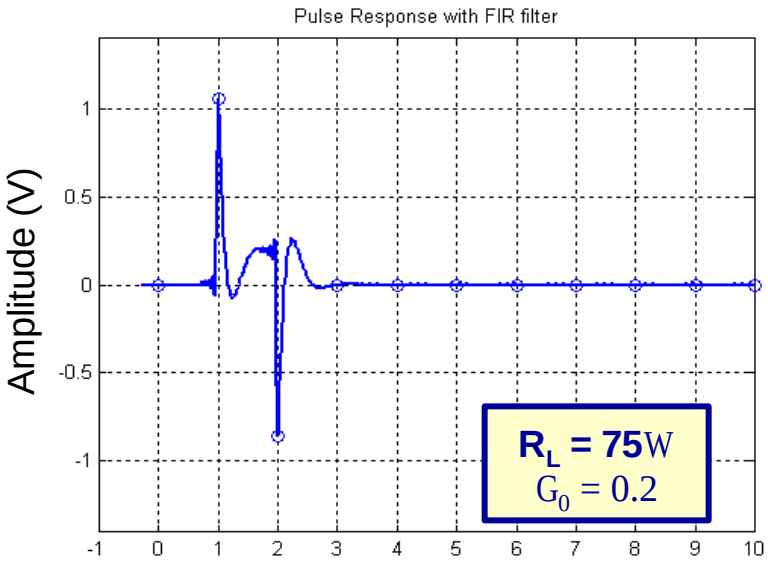
- Step response shows open circuit at high-frequency due to inductor and some ringing due to 2nd-order dynamics

Reflections in Time Domain: Pulse Response





Unit Interval (320ps)



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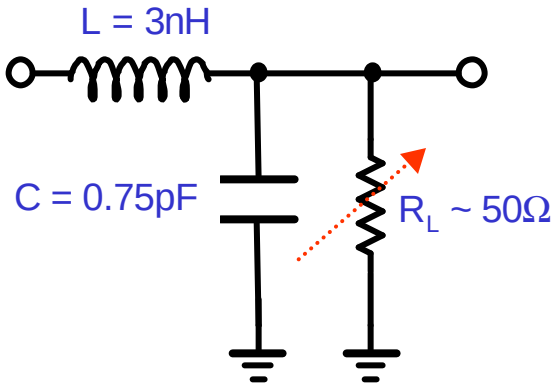

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Definition of Terms: Frequency Domain

$S_{CH11}(s)$

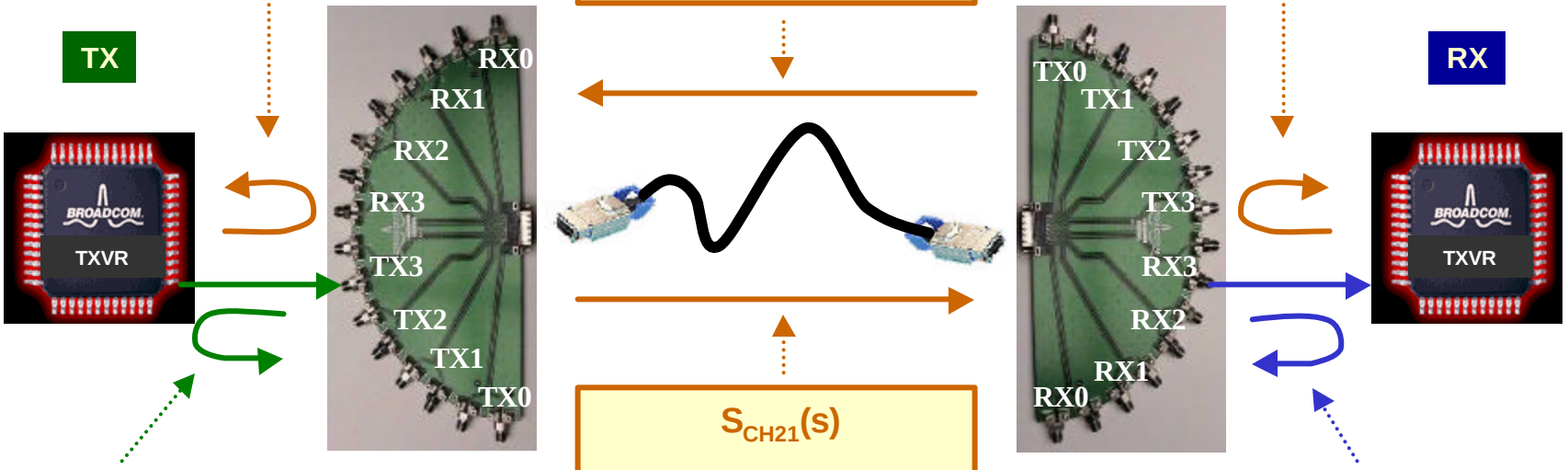
- Reflection at TX-end of Channel with 50-Ohm line

$S_{CH12}(s)$

- Reverse transmission on channel with 50-ohm source and load

$S_{CH22}(s)$

- Reflection at TX-end of Channel with 50-Ohm line



$S_{CH21}(s)$

- Forward transmission on channel with 50-ohm source and load

$S_{TX11}(s)$

- Reflection at TX with 50-Ohm line

$S_{RX11}(s)$

- Reflection at RX with 50-Ohm line

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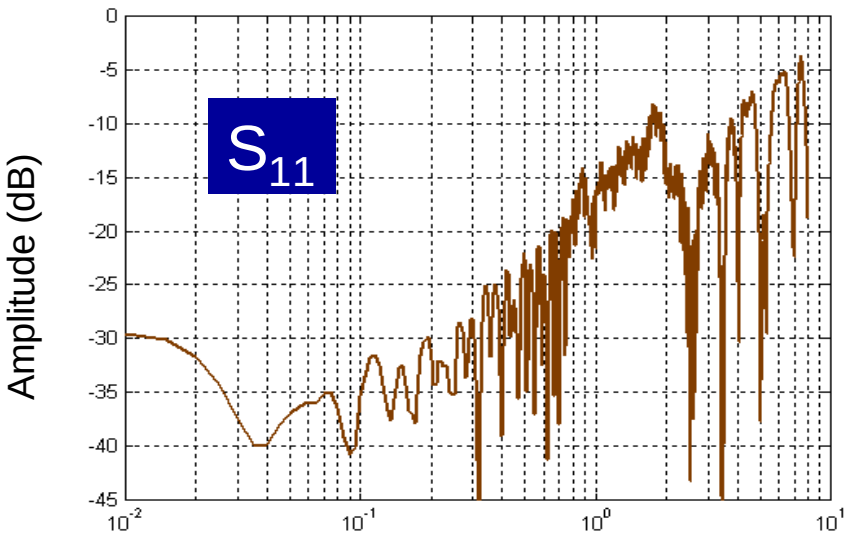
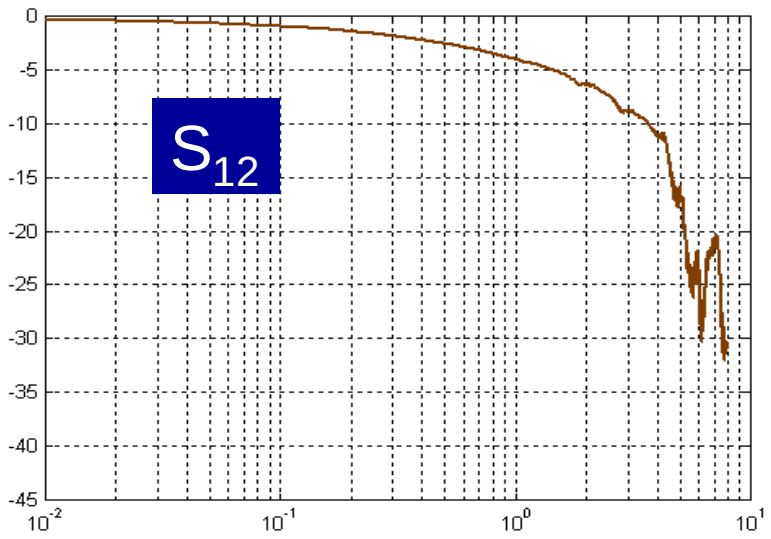
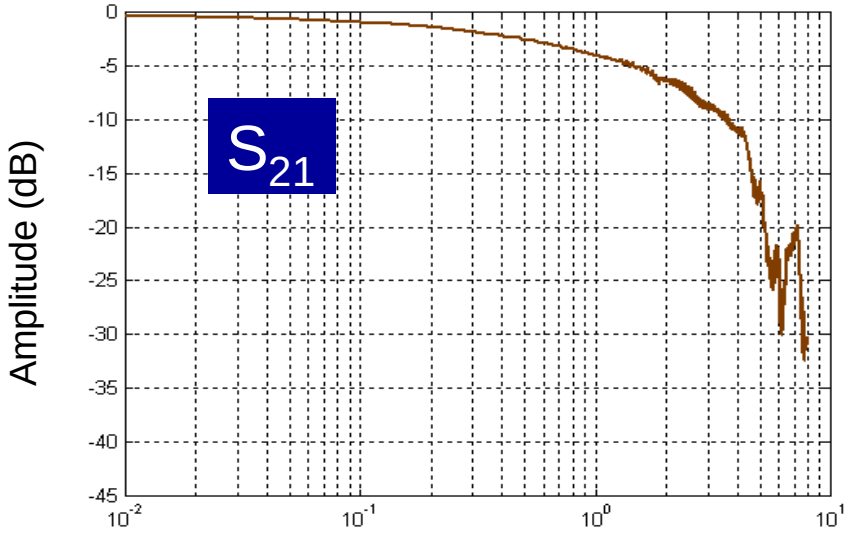
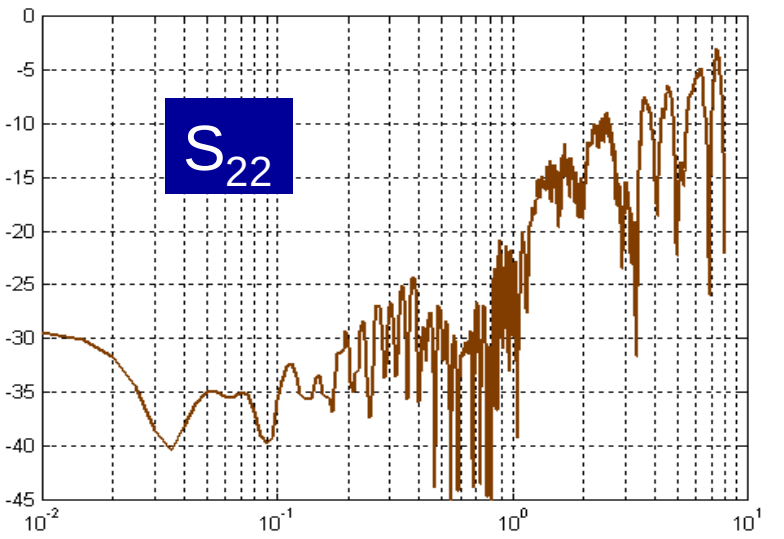
Channel S-Parameters: 3m InfiniBand Cable

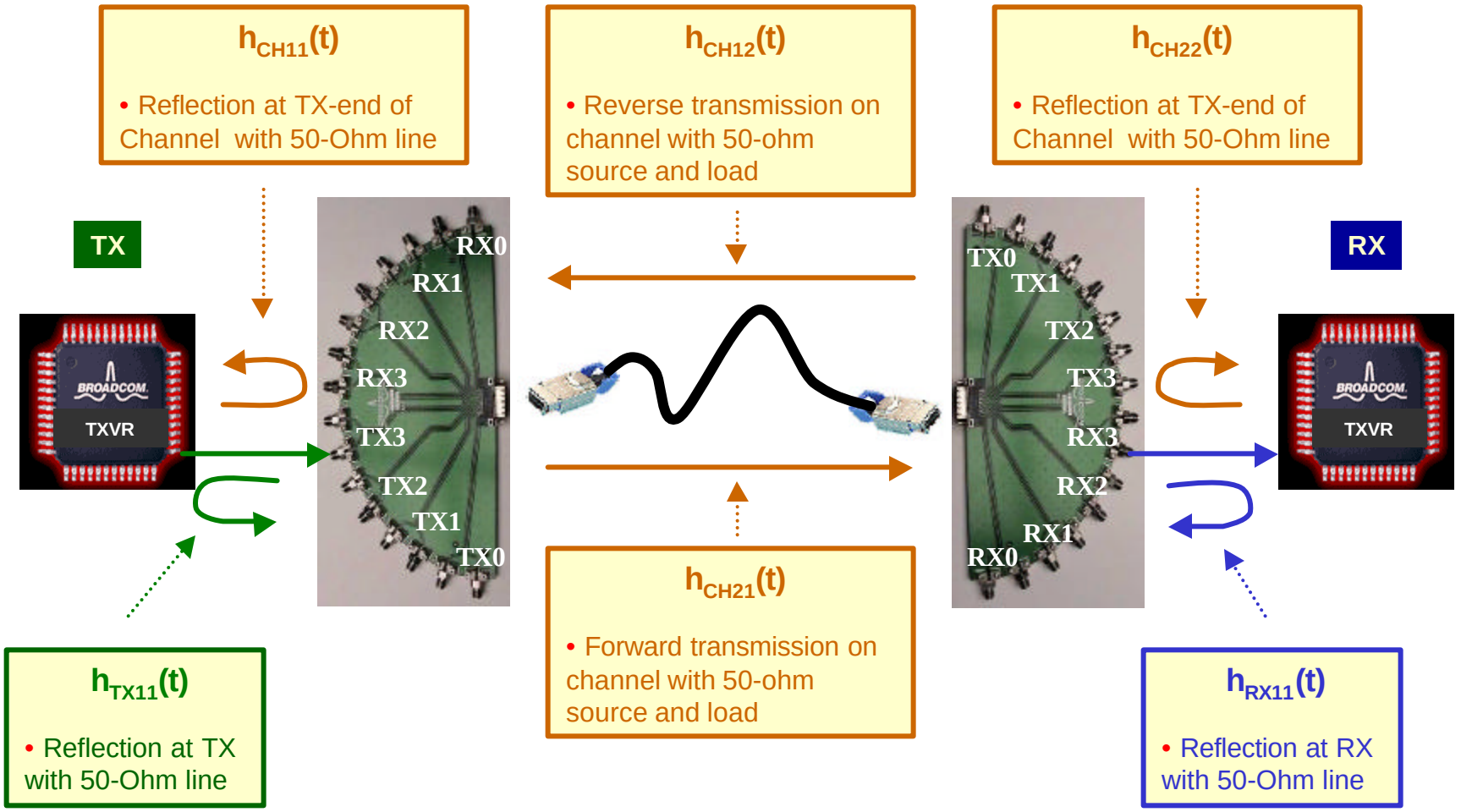




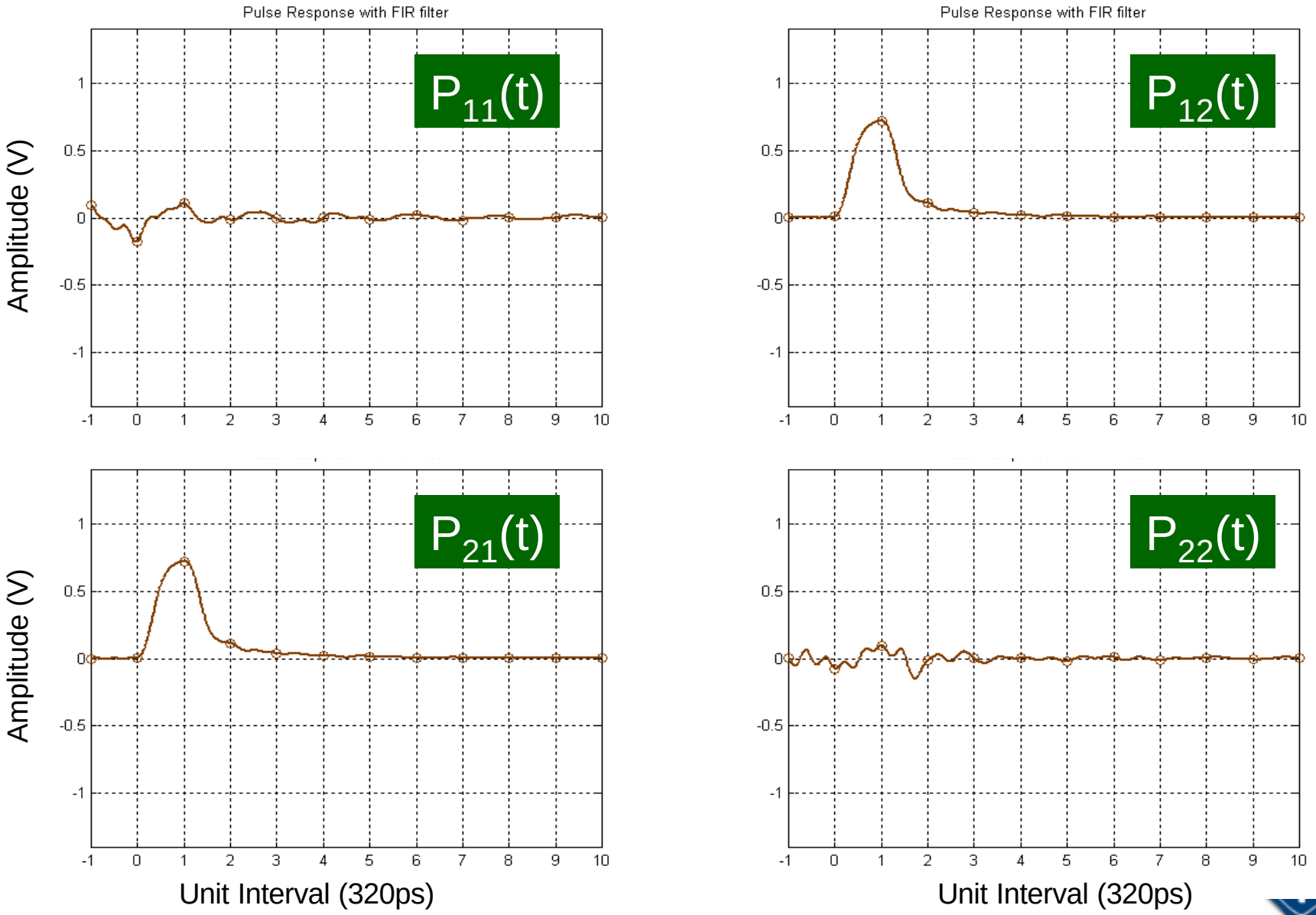




Definition of Terms: Time Domain



Reflections in Time Domain: Pulse Response



First-Order Reflection Analysis: Path 1

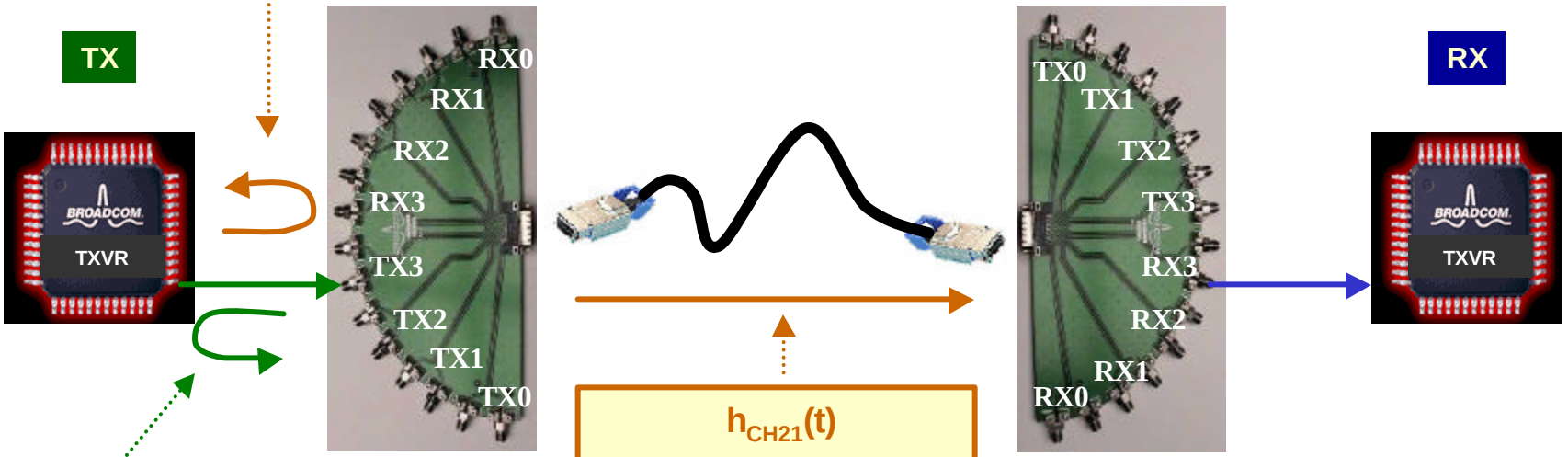
$h_{CH11}(t)$

- Reflection at TX-end of Channel with 50-Ohm line

Path 1: $h_{CH11}(t)*h_{TX11}(t)*h_{CH21}(t)$

TX

RX



$h_{CH21}(t)$

- Forward transmission on channel with 50-ohm source and load

$h_{TX11}(t)$

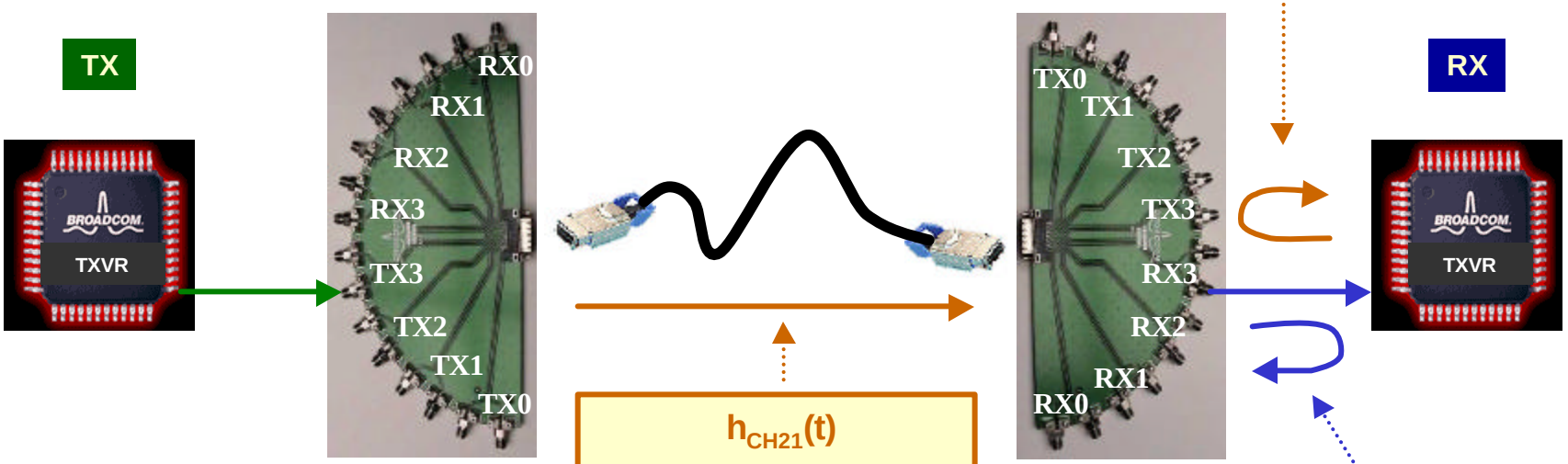
- Reflection at TX with 50-Ohm line

First-Order Reflection Analysis: Path 2

Path 2: $h_{CH21}(t)*h_{RX11}(t)*h_{CH22}(t)$

$h_{CH22}(t)$

- Reflection at TX-end of Channel with 50-Ohm line



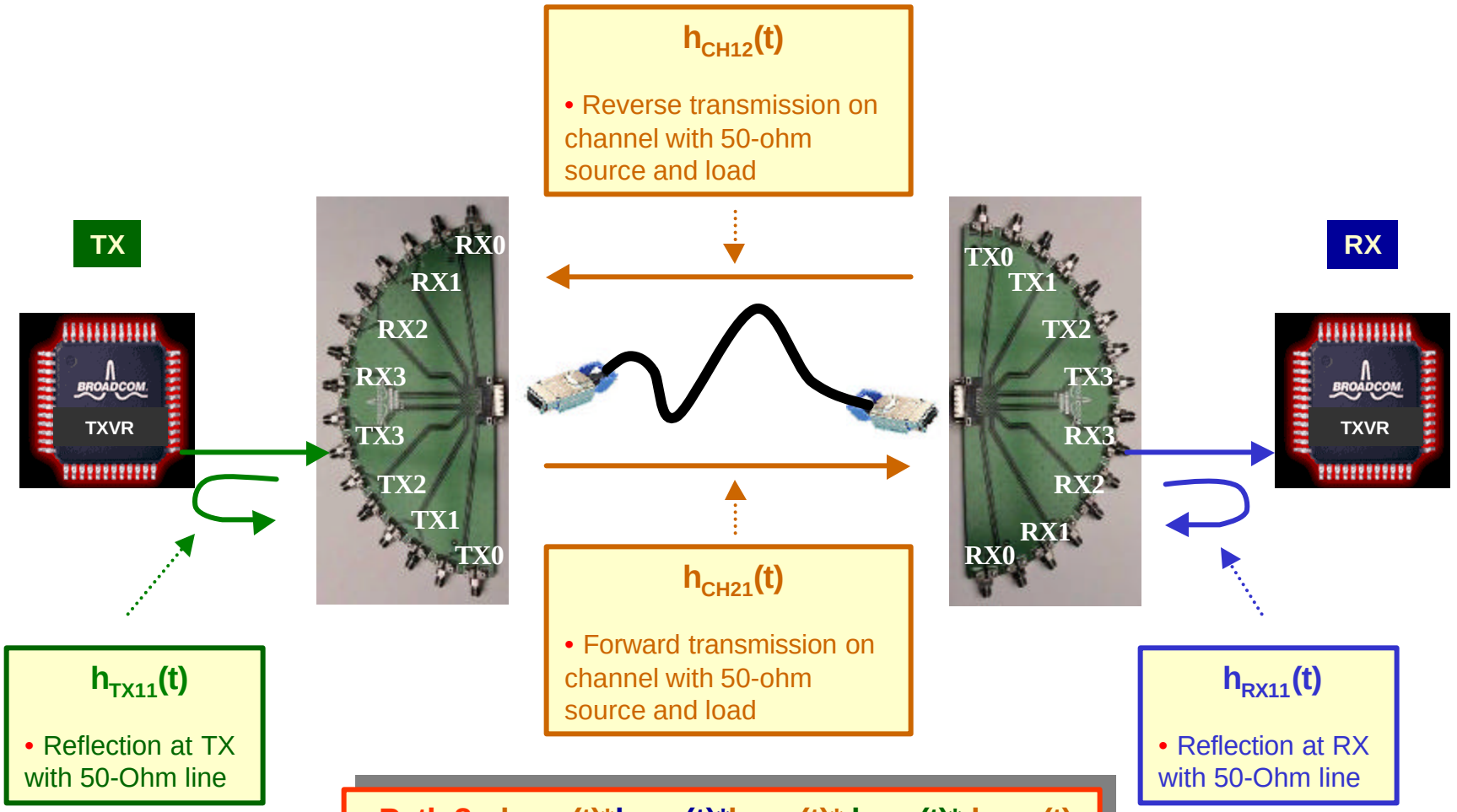
$h_{CH21}(t)$

- Forward transmission on channel with 50-ohm source and load

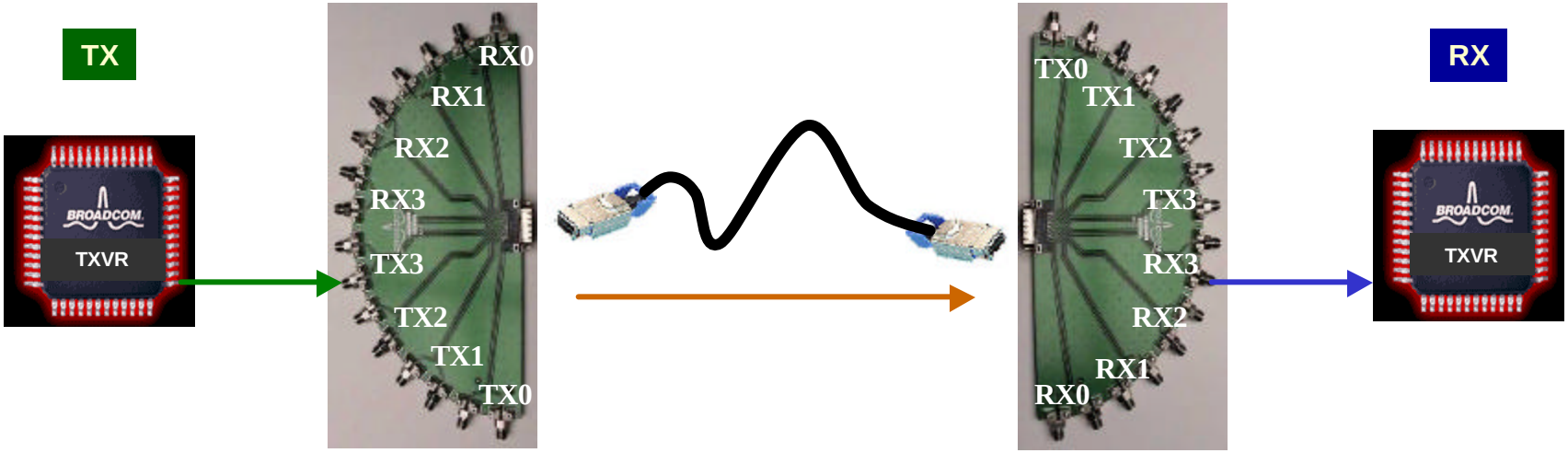
$h_{RX11}(t)$

- Reflection at RX with 50-Ohm line

First-Order Reflection Analysis: Path 3

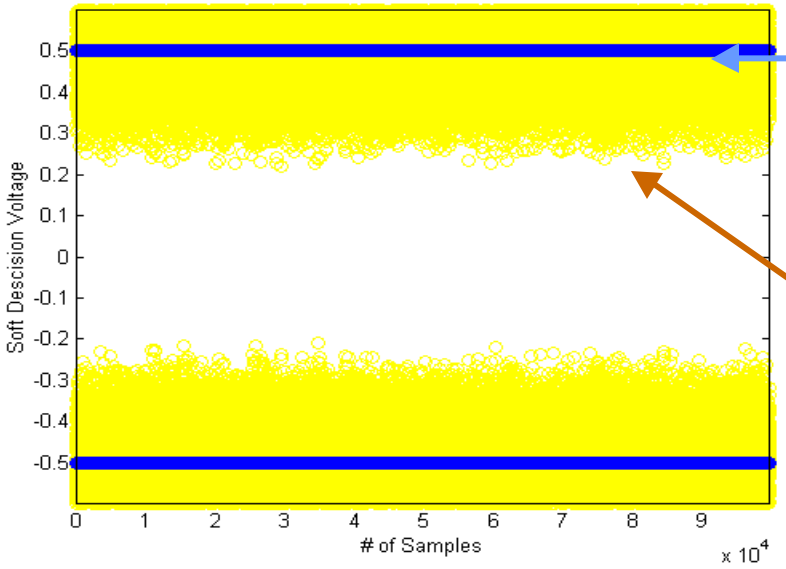


First-Order Reflection Performance: 0m



Margin @ BER 10^{-17}

Perfect Termination:	1000.0-mV
RL = 33Ω:	148.0-mV
RL = 50Ω	325.7-mV
RL = 75Ω	392.0-mV



Blue: Signal, & Jitter

Yellow: Reflections

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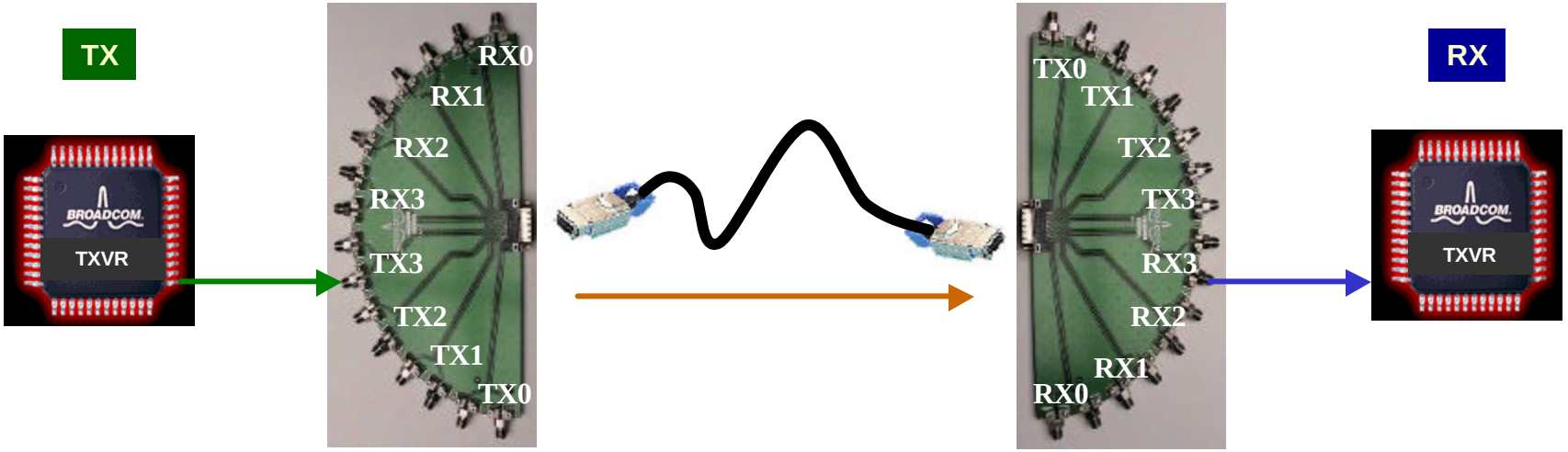
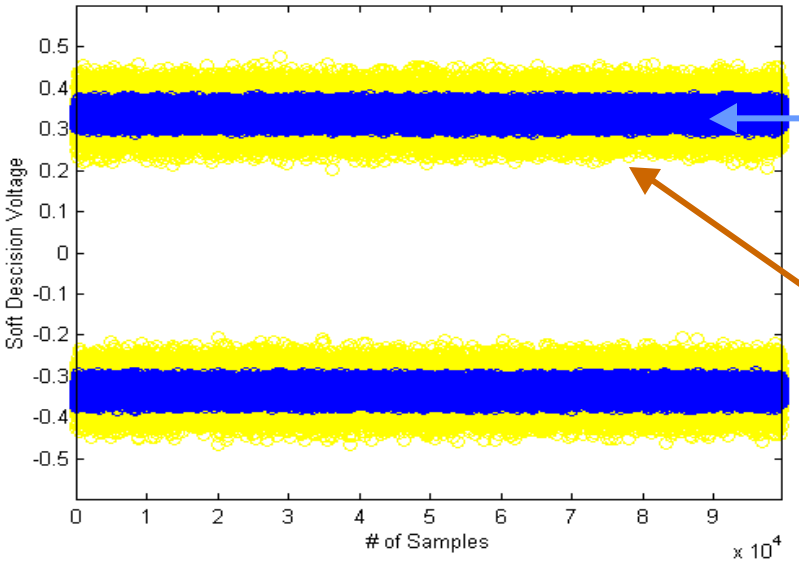
First-Order Reflection Performance: 1m



Margin @ BER 10^{-17}

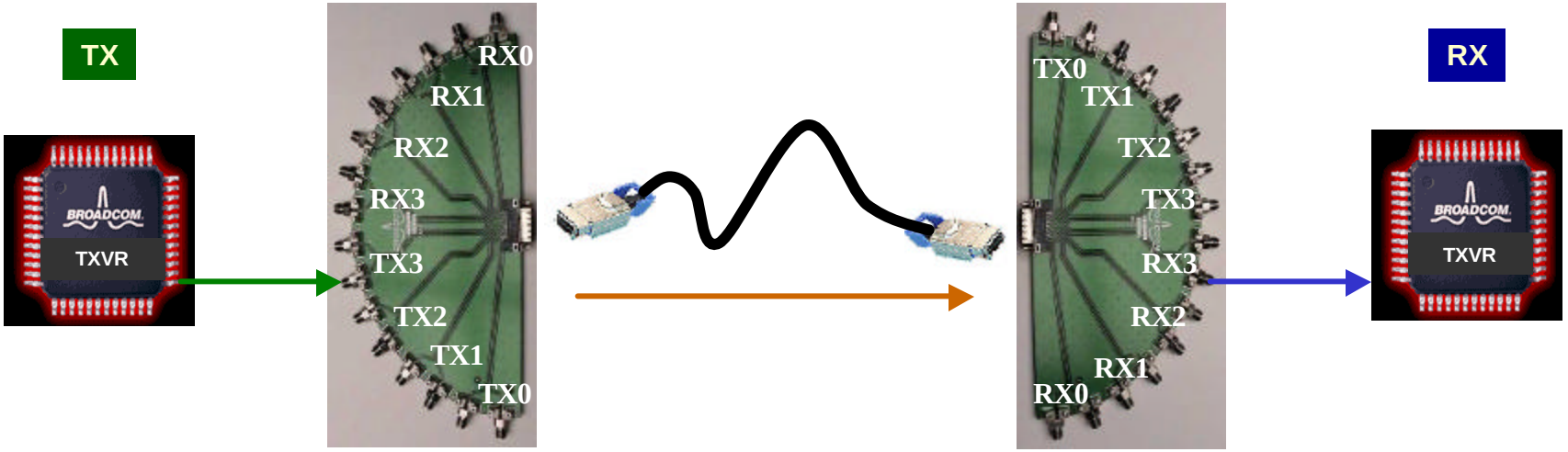
Perfect Termination:	545.0-mV
RL = 33Ω:	322.0-mV
RL = 50Ω	413.9-mV
RL = 75Ω	468.0-mV



Blue: Signal, & Jitter

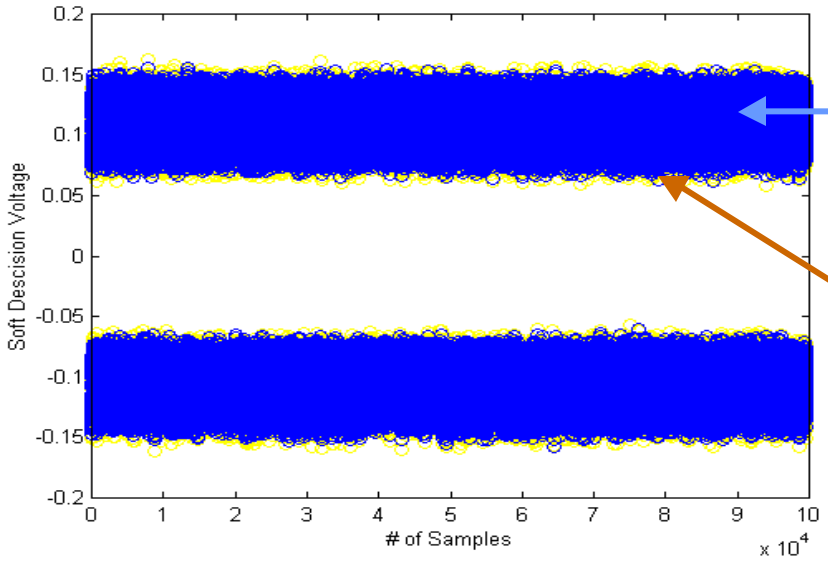
Yellow: Reflections

First-Order Reflection Performance: 15m



Margin @ BER 10^{-17}

Perfect Termination:	87.0-mV
RL = 33Ω:	44.7-mV
RL = 50Ω	68.1-mV
RL = 75Ω	79.6-mV



Blue: Signal, & Jitter

Yellow: Reflections

Return Loss Conclusions

- Return-Loss specs can be achieved with standard packages and ESD structures
- DC matching is not critical
  - Signal has no DC content
  - 14-dB or 50% DC deviation can be easily tolerated
- Resonant nulls could improve return-loss but can not be controlled accurately in production
- Long channel margin degrades approximately 30-mV due to reflections
- Short channel margins are acceptable with 0m channel
  - In practice the package and board trace will provide filtering for 0m channel and reflections will be much less severe (similar to 1m channel case)

END