Replacing Common-Mode Frequency Masks with Modal ERL Specifications via Signal Flow Graph Analysis

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IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet ad-hoc

August 28, 2025

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Abstract

Current common-mode frequency domain masks do not accurately reflect their true impact on link performance. This work introduces a modal signal flow graph framework that directly relates common-mode behavior to system-level metrics.

By using Modal Effective Return Loss (ERL) as the specification, this method provides a simple, measurable, and performance-driven replacement for frequency-domain masks

Introduction

- ❑ Utilizing the principles of signal flow in COM, this presentation explores a comprehensive understanding of modal channel signal flow.
- ❑ Topics covered include basic flow diagrams, load node reduction, and the application of signal flow loops within the modal signal flow graph.

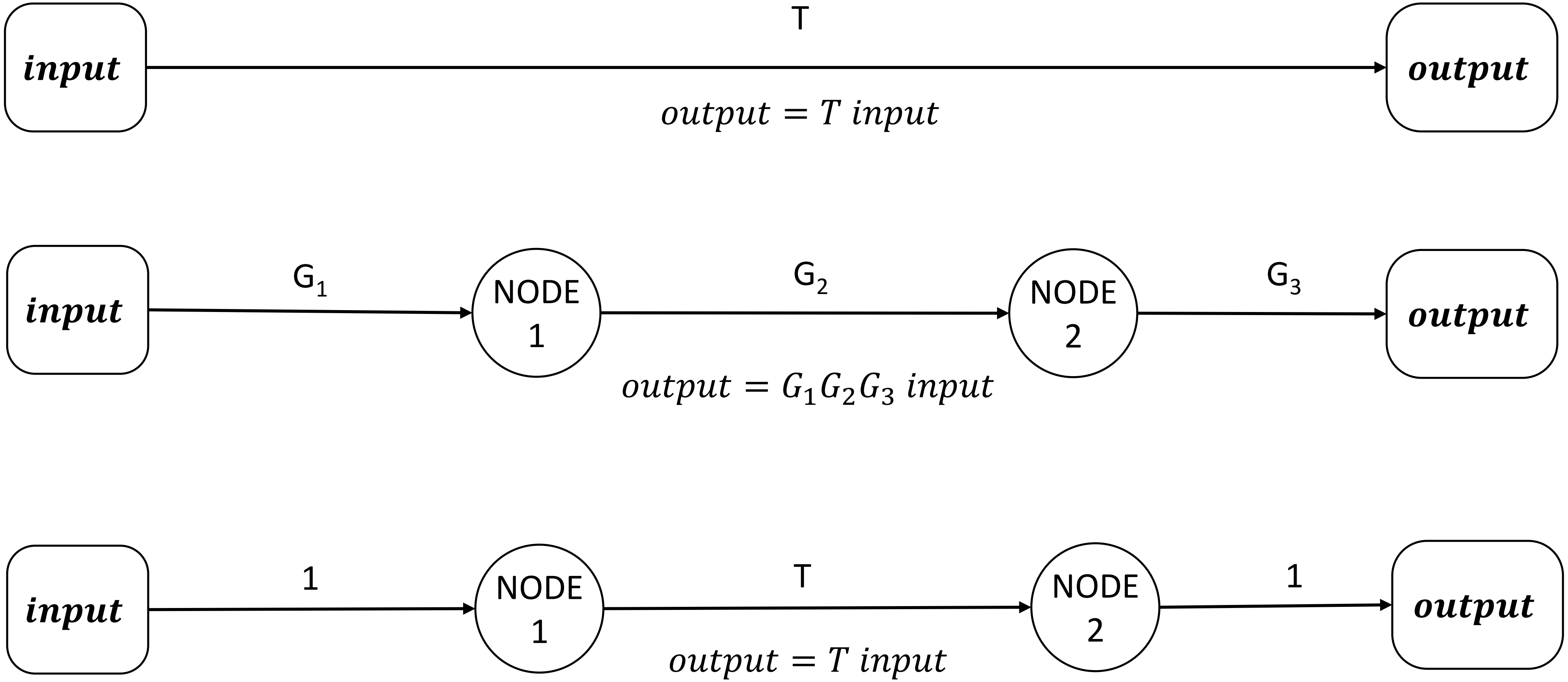
Mason's Rule[1][2] for Transfer function

- $T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$
  - G_k: Gain of the k^th forward path of N paths.
  - Δ: Determinant of the graph
  - Δ_k: Determinant with loops touching the k^th path removed.
- $\Delta = 1 - \sum L_i + \sum L_i L_j - \sum L_i L_j L_k + \cdots$
  - L_i : Loop gain of each individual loop.
  - $L_i L_j$, $L_i L_j$, … $L_i L_j L_k$: Product of gains of non-touching loops.
  - Higher-order terms include products of three or more non-touching loops
- **Step by Step Application of Mason's Rule**
  - Identify all N **forward paths** and compute their gains G_k.
  - Identify all **loops** and compute their gains (L_i)
  - Find all combinations of **non-touching loops in (Δ_i)**
  - Compute $\mathbf{\Delta_k}$ for each forward path the compute for k loops not on path k
  - Plug into the formula to get the **overall transfer function**.

[1] S. J. Mason, "Power gain in feedback amplifiers," *IRE Transactions on Circuit Theory*, vol. CT-1, no. 2, pp. 20–25, Jun. 1954
[2] S. J. Mason, "Feedback theory—Further properties of signal flow graphs," Proc. IRE, vol. 44, no. 7, pp. 920–926, Jul. 1956. doi: 10.1109/JRPROC.1956.275147

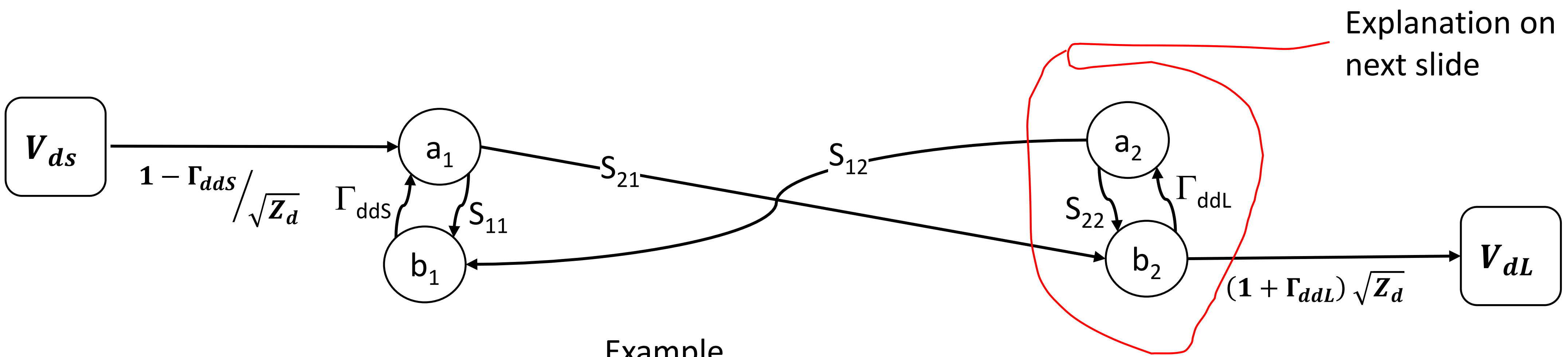
Simple flow graphs

A few simple concepts



Basic flow diagram for differential-to-differential voltage transmission

2 port s-parameter



<u>Example</u>

b1 = s11 *a1

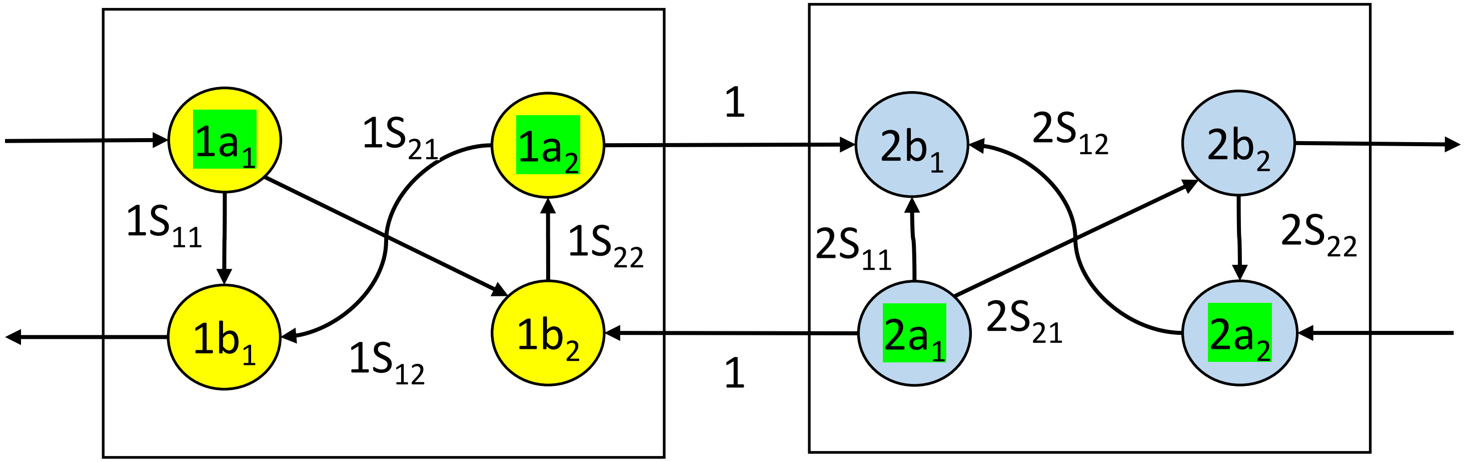
s11= b1/a1 | a2 = 0

a’s are forward waves

b’s are reverse waves

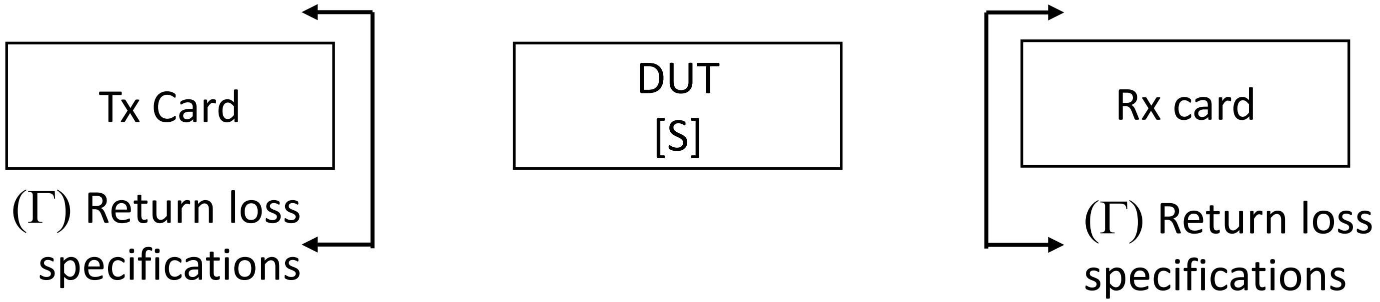
Cascade of 2 port s-parameters using signal flow graph

Cascade by alternating the flipping of the s-parameter diagram



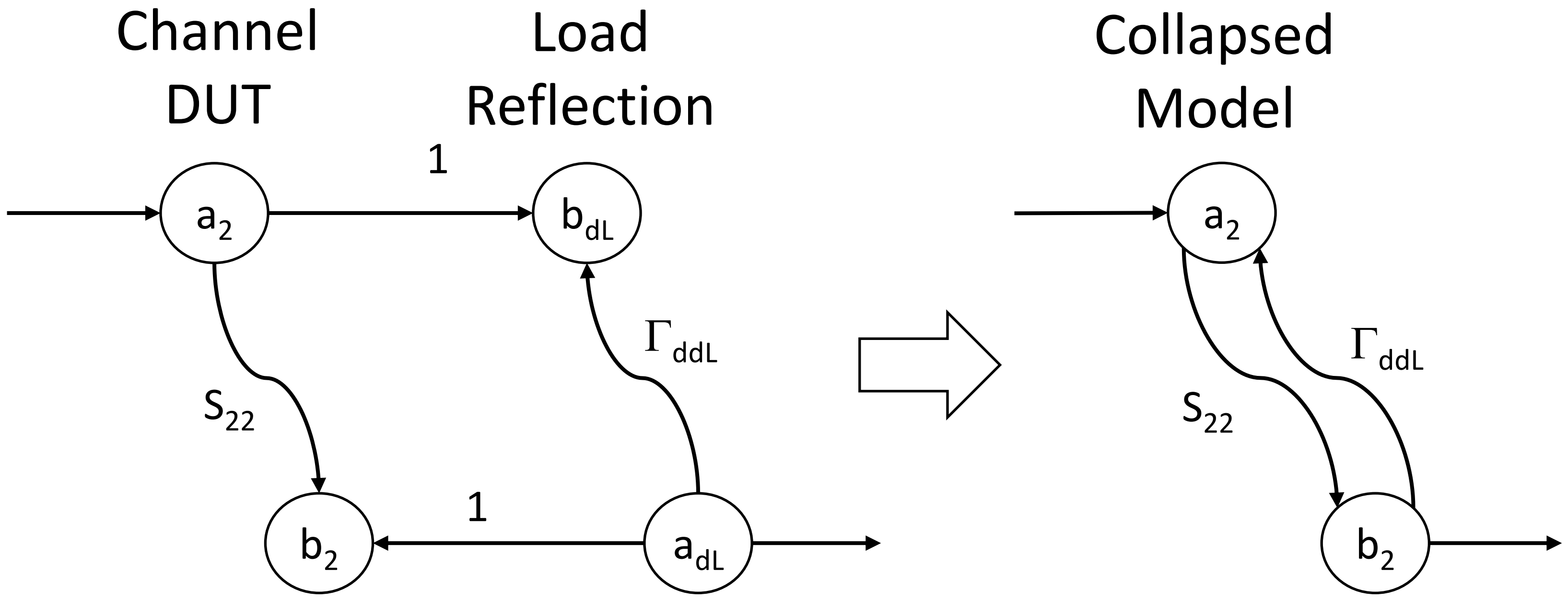
Consider Numerical Assessment using Assignment of Values for the Gammas (Γ)

From specified Tx and Rx return loss



- It is useful to use a number (ERL) for an estimation of modal Γs
- $\Gamma_{mode} = 10^{\frac{-ERL_{mode}}{20}}$

Termination Node Reduction

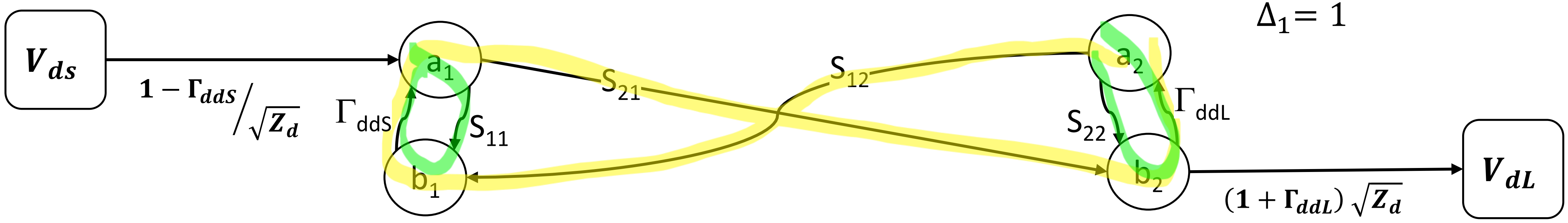


2 Port example for T or Voltage Transfer Function (VTF)

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

$$T = \frac{G_1}{1 - L_1 - L_1 - L_3 + L_1 L_2}$$

$$\Delta_1 = 1$$



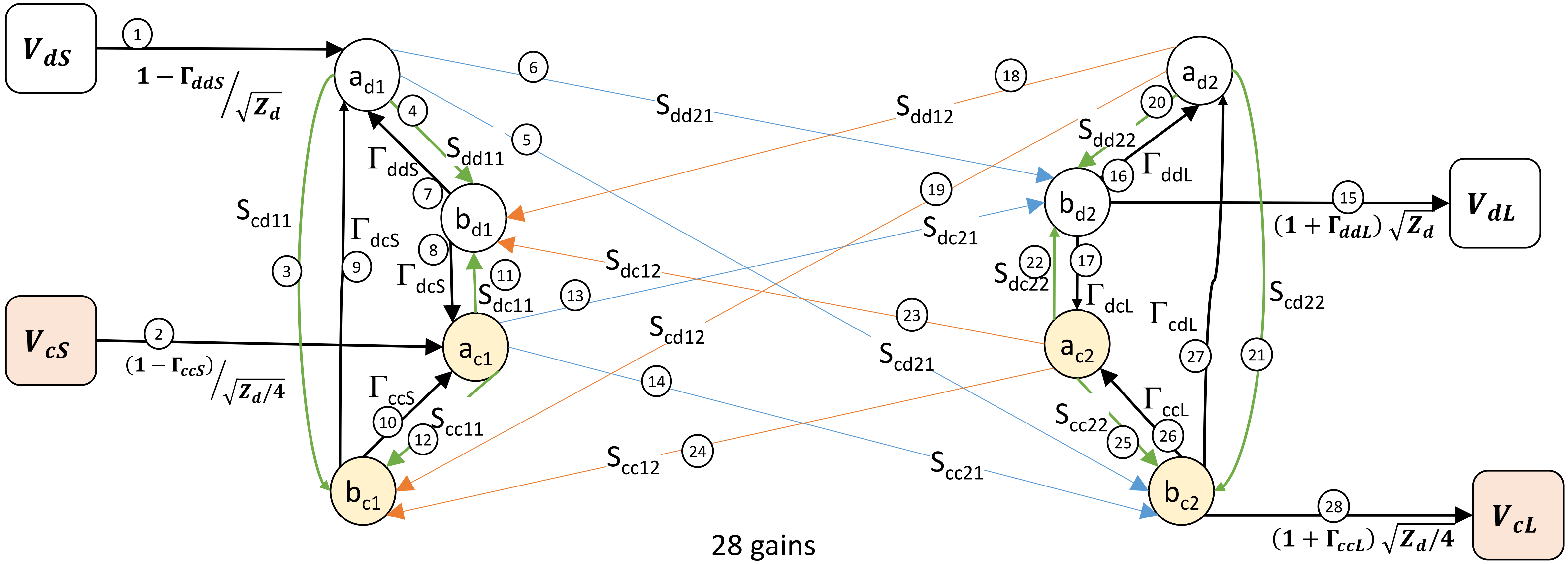
- **Loop Gains L_i:**
  - $L_1 = \Gamma_{ddS} \cdot sdd_{11}$
  - $L_2 = \Gamma_{ddL} \cdot sdd_{22}$
  - $L_3 = \Gamma_{ddL}\Gamma_{ddS} \cdot sdd_{12} sdd_{21}$
- **Non-Touching Loop Combinations L_l:**
  - $L_1 L_2 = \Gamma_{ddL}\Gamma_{ddS} \cdot sdd_{11} sdd_{22}$
- **Forward Path Gain**
  - $G_1 = sdd_{21} \cdot (\Gamma_{ddL}+1) \cdot (1-\Gamma_{ddS})$

This is what is used in COM and differential to differential simulations

$$\mathrm{VTF} = \mathrm{T} = \frac{sdd21 * (1 - \Gamma_{ddS}) * (\Gamma_{ddL} + 1)}{1 - \Gamma_{ddS} * sdd11 - \Gamma_{ddL} * sdd22 - \Gamma_{ddL} * \Gamma_{ddS} * sdd12 * sdd21 + \Gamma_{ddL} * \Gamma_{ddS} * sdd11 * sdd22}$$

Complete Modal Flow Graph for a 4-port S-parameter

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$



28 gains
Details follow

Nodes and Gains

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

From	To	#	Gain	From	To	#	Gain
ad1	V_dS	1	$(1 - \Gamma_{\mathrm{ddS}})/\sqrt{Z_d}$	V_dL	bd2	15	$(1 + \Gamma_{ddL})\sqrt{Z_d}$
ac1	V_cS	2	$(1 - \Gamma_{\mathrm{ccS}})/\sqrt{Z_c}$	ad2	bd2	16	Γ_{ddL}
bc1	ad1	3	Scd11	ac2	bd2	17	Γ_{cdL}
bd1	ad1	4	Sdd11	bd1	ad2	18	Sdd12
bc2	ad1	5	Scd21	bc1	ad2	19	Scd12
bd2	ad1	6	Sdd21	bd2	ad2	20	Sdd22
ad1	bd1	7	Γ_{ddS}	bc2	ad2	21	Scd22
ac1	bd1	8	$\Gamma\mathrm{cdS}$	bd2	ac2	22	Sdc22
ad1	bc1	9	Γ_{dcS}	bd1	ac2	23	Sdc21
ac1	bc1	10	Γ_{ccS}	bc1	ac2	24	Scc12
bd1	ac1	11	Sdc11	bc2	ac2	25	Scc22
bc1	ac1	12	Scc11	ac2	bc2	26	Γ_{ccL}
bd2	ac1	13	Sdc21	ad2	bc2	27	Γ_{dcL}
bc2	ac1	14	Scc21	V_cL	bc2	28	$(1 + \Gamma_{ccL})\sqrt{Z_c}$

Forward Path Gains
G_{13} is in the VTF in COM

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

#	Forward Path Gain
1	$\Gamma_{ccS} * scd11 * sdc21 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
2	$\Gamma_{ccL} * \Gamma cS * scc21 * scd11 * sdc22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
3	$\Gamma_{dcL} * \Gamma_{ccS} * scc21 * scd11 * sdd22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
4	$\Gamma_{cdS} * sdc21 * sdd11 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
5	$\Gamma_{ccL} * \Gamma_{cdS} * scc21 * sdc22 * sdd11 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
6	$\Gamma_{dcL} * \Gamma_{cdS} * scc21 * sdd11 * sdd22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
7	$\Gamma_{ccL} * scd21 * sdc22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
8	$\Gamma_{ccL} * \Gamma_{cdS} * scd21 * sdc21^2 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
9	$\Gamma_{ccL} * \Gamma_{ccS} * scc12 * scd21 * sdc21 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
10	$\Gamma\_dcL * \Gamma\_cdS * scd21 * sdc21 * sdd12 * (\Gamma_{ddL} + 1) * (1 - \Gamma\_ddS)$
11	$\Gamma_{dcL} * \Gamma_{ccS} * scd12 * scd21 * sdc21 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
12	$\Gamma_{dcL} * scd21 * sdd22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
13	$sdd21 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$

Forward Path Gains, G_k, and Δ_k

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

#	Forward Path Gain
1	$\Gamma_{ccS} * scd11 * sdc21 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
2	$\Gamma_{ccL} * \Gamma cS * scc21 * scd11 * sdc22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
3	$\Gamma_{dcL} * \Gamma_{ccS} * scc21 * scd11 * sdd22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
4	$\Gamma_{cdS} * sdc21 * sdd11 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
5	$\Gamma_{ccL} * \Gamma_{cdS} * scc21 * sdc22 * sdd11 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
6	$\Gamma_{dcL} * \Gamma_{cdS} * scc21 * sdd11 * sdd22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
7	$\Gamma_{ccL} * scd21 * sdc22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
8	$\Gamma_{ccL} * \Gamma_{cdS} * scd21 * sdc21^2 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
9	$\Gamma_{ccL} * \Gamma_{ccS} * scc12 * scd21 * sdc21 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
10	$\Gamma\_dcL * \Gamma\_cdS * scd21 * sdc21 * sdd12 * (\Gamma_{ddL} + 1) * (1 - \Gamma\_ddS)$
11	$\Gamma_{dcL} * \Gamma_{ccS} * scd12 * scd21 * sdc21 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
12	$\Gamma_{dcL} * scd21 * sdd22 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$
13	$sdd21 * (\Gamma_{ddL} + 1) * (1 - \Gamma_{ddS})$

$$\Delta_2, \Delta_3, \Delta_4, \Delta_6, \Delta_8, \Delta_9, \Delta_{10}, \Delta_{11} = 1$$

$$\Delta_1 = \Delta_5 = 1 - \Gamma_{dcL}\, scd22 - \Gamma_{ccL}\, scc22$$

$$\Delta_7 = \Delta_{12} = 1 - \Gamma_{cdS}\, sdc11 - \Gamma_{ccS}\, scc11$$

$$\begin{aligned}\Delta_{13} &= \Gamma_{ccL}\Gamma_{ccS}\, scc11\, scc22 \\ &- \Gamma_{ccL}\, scc22 - \Gamma_{dcL}\, scd22 \\ &- \Gamma_{cdS}\, sdc11 - \Gamma_{ccS}\, scc11 \\ &- \Gamma_{ccL}\, scc12\, scc21 \\ &+ \Gamma_{dcL}\Gamma_{ccS}\, scc11\, scd22 \\ &- \Gamma_{dcL}\Gamma_{ccS} scc21\, scd12 \\ &+ \Gamma_{ccL}\Gamma_{cdS}\, scc22\, sdc11 \\ &- \Gamma_{ccL}\Gamma_{cdS}\, scc21\, sdc21 \\ &- \Gamma_{dcL}\Gamma_{cdS}\, scc21\, sdd12 \\ &+ \Gamma_{dcL}\Gamma_{cdS}S\, scd22\, sdc11 + 1\end{aligned}$$

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

Delta (Δ), 84 loops

- ❑ Δ=1-negative terms + positive terms
- ❑ Many terms are greater than 4^{th} order.
- ❑ Many terms may be considered insignificant

Negative terms 4^{th} order or less

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

Δ=1-negative terms + positive terms

Γ_ccL scc22
Γ_dcS scd11
Γ_dcL scd22
Γ_cdS sdc11
Γ_cdL sdc22
Γ_ddS sdd11
Γ_ddL sdd22
Γ_ccS scc11
Γ_cdL Γ_cdS sdc21
Γ_ccL Γ_ccS scc11 scc22
Γ_ccL Γ_ccS scc12 scc21
Γ_ccL Γ_dcS scc12 scd21
Γ_dcL Γ_ccS scc21 scd12
Γ_dcL Γ_dcS scd12 scd21
Γ_cdL Γ_ccS scc12 sdc21
Γ_ccL Γ_cdS scc21 sdc21
Γ_ccS Γ_ddS scd11 sdc11
Γ_cdS Γ_dcS scc11 sdd11
Γ_cdL Γ_dcS scc12 sdd21
Γ_dcL Γ_cdS scc21 sdd12
Γ_ddL Γ_ccS scd12 sdc21
Γ_ccL Γ_ddL scd22 sdc22
Γ_cdL Γ_dcL scc22 sdd22
Γ_ccL Γ_ddS scd21 sdc21
Γ_dcL Γ_ddS scd21 sdd12
Γ_ddL Γ_dcS scd12 sdd21
Γ_ddL Γ_cdS sdc21 sdd12
Γ_cdL Γ_ddS sdc21 sdd21
Γ_ddL Γ_ddS sdd12 sdd21

Negative terms 5^{th} to 6^{th} order

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

Δ=1-negative terms + positive terms

Γ_cdL Γ_ccS Γ_ddS scd11 sdc21
Γ_ccL Γ_ddL Γ_cdS scd22 sdc21
Γ_ccL Γ_ccS Γ_ddS scc11 scc22 sdd11
Γ_ccL Γ_ccS Γ_ddS scc12 scd21 sdc11
Γ_ccL Γ_cdS Γ_dcS scc12 scc21 sdd11
Γ_ccL Γ_cdS Γ_dcS scc22 scd11 sdc11
Γ_ccL Γ_ddL Γ_ccS scc11 scc22 sdd22
Γ_ccL Γ_ddL Γ_ccS scc12 scd22 sdc21
Γ_ccL Γ_ddL Γ_ccS scc21 scd12 sdc22
Γ_cdL Γ_dcL Γ_ccS scc11 scd22 sdc22
Γ_cdL Γ_dcL Γ_ccS scc12 scc21 sdd22
Γ_cdL Γ_dcL Γ_ccS scc22 scd12 sdc21
Γ_ccL Γ_ccS Γ_ddS scc21 scd11 sdc21
Γ_ccL Γ_cdS Γ_dcS scc11 scd21 sdc21
Γ_dcL Γ_ccS Γ_ddS scc11 scd22 sdd11
Γ_dcL Γ_ccS Γ_ddS scc21 scd11 sdd12
Γ_dcL Γ_ccS Γ_ddS scd12 scd21 sdc11
Γ_dcL Γ_cdS Γ_dcS scc11 scd21 sdd12
Γ_dcL Γ_cdS Γ_dcS scc21 scd12 sdd11
Γ_dcL Γ_cdS Γ_dcS scd11 scd22 sdc11

Γ_ccL Γ_ddL Γ_dcS scc12 scd22 sdd21
Γ_ccL Γ_ddL Γ_dcS scc22 scd11 sdd22
Γ_ccL Γ_ddL Γ_dcS scd12 scd21 sdc22
Γ_cdL Γ_dcL Γ_dcS scc12 scd21 sdd22
Γ_cdL Γ_dcL Γ_dcS scc22 scd12 sdd21
Γ_cdL Γ_dcL Γ_dcS scd11 scd22 sdc22
Γ_cdL Γ_ccS Γ_ddS scc11 sdc22 sdd11
Γ_cdL Γ_ccS Γ_ddS scc12 sdc11 sdd21
Γ_cdL Γ_cdS Γ_dcS scc12 sdc21 sdd11
Γ_cdL Γ_cdS Γ_dcS scd11 sdc11 sdc22
Γ_ccL Γ_ddL Γ_cdS scc21 sdc22 sdd12
Γ_ccL Γ_ddL Γ_cdS scc22 sdc11 sdd22
Γ_cdL Γ_dcL Γ_cdS scc22 sdc21 sdd12
Γ_cdL Γ_dcL Γ_cdS scd22 sdc11 sdc22
Γ_cdL Γ_cdS Γ_dcS scc11 sdc21 sdd21
Γ_cdL Γ_dcL Γ_cdS scc21 sdc21 sdd22
Γ_ddL Γ_ccS Γ_ddS scc11 sdd11 sdd22
Γ_ddL Γ_ccS Γ_ddS scd11 sdc21 sdd12
Γ_ddL Γ_ccS Γ_ddS scd12 sdc11 sdd21
Γ_ddL Γ_cdS Γ_dcS scc11 sdd12 sdd21

Γ_ddL Γ_cdS Γ_dcS scd11 sdc11 sdd22
Γ_ddL Γ_cdS Γ_dcS scd12 sdc21 sdd11
Γ_ccL Γ_ddL Γ_ddS scc22 sdd11 sdd22
Γ_ccL Γ_ddL Γ_ddS scd21 sdc22 sdd12
Γ_cdL Γ_dcL Γ_ddS scc22 sdd12 sdd21
Γ_cdL Γ_dcL Γ_ddS scd22 sdc22 sdd11
Γ_ccL Γ_ddL Γ_ddS scd22 sdc21 sdd21
Γ_cdL Γ_dcL Γ_ddS scd21 sdc21 sdd22

Negative terms 7th order or more

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scd11 scd22 sdc21

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scd12 scd21 sdc21

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scd12 scd21 sdc21

Γ_cdL Γ_dcL Γ_cdS Γ_dcS scd11 scd22 sdc21

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc11 scc22 sdd12 sdd21

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc11 scd22 sdc22 sdd11

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc12 scc21 sdd11 sdd22

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc12 scd21 sdc21 sdd12

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc12 scd22 sdc11 sdd21

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc21 scd11 sdc22 sdd12

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc22 scd11 sdc11 sdd22

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc22 scd12 sdc21 sdd11

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scd12 scd21 sdc11 sdc22

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc11 scc22 sdd11 sdd22

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc11 scd21 sdc22 sdd12

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc12 scc21 sdd12 sdd21

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc12 scd21 sdc11 sdd22

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc12 scd22 sdc21 sdd11

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc21 scd12 sdc22 sdd11

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc22 scd11 sdc21 sdd12

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc22 scd12 sdc11 sdd21

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scd11 scd22 sdc11 sdc22

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc11 scc22 sdd11 sdd22

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc11 scd21 sdc22 sdd12

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc12 scc21 sdd12 sdd21

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc12 scd21 sdc11 sdd22

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc12 scd22 sdc21 sdd11

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc21 scd12 sdc22 sdd11

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc22 scd11 sdc21 sdd12

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc22 scd12 sdc11 sdd21

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scd11 scd22 sdc11 sdc22

Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc11 scc22 sdd12 sdd21

Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc11 scd22 sdc22 sdd11

Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc12 scc21 sdd11 sdd22

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Γ_cdL Γ_dcL Γ_cdS Γ_dcS scd12 scd21 sdc11 sdc22

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc11 scd21 sdc21 sdd22

Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc21 scd12 sdc21 sdd21

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc11 scd22 sdc21 sdd21

Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc21 scd11 sdc21 sdd22

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc11 scd22 sdc21 sdd21

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc21 scd11 sdc21 sdd22

Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc11 scd21 sdc21 sdd22

Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc21 scd12 sdc21 sdd21

Δ=1-negative terms + positive terms

Positive terms 4th order

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

Δ=1-negative terms + positive terms

Γ_ccL Γ_dcS scc22 scd11

Γ_dcL Γ_dcS scd11 scd22

Γ_ccL Γ_cdS scc22 sdc11

Γ_ccS Γ_ddS scc11 sdd11

Γ_cdS Γ_dcS scd11 sdc11

Γ_cdL Γ_dcS scd11 sdc22

Γ_dcL Γ_cdS scd22 sdc11

Γ_ccL Γ_ddL scc22 sdd22

Γ_cdL Γ_dcL scd22 sdc22

Γ_dcL Γ_ddS scd22 sdd11

Γ_cdL Γ_cdS sdc11 sdc22

Γ_ddL Γ_ddS sdd11 sdd22

Positive terms 6th order or more

$$T = \frac{output}{input} = \frac{\sum_{k=1}^{N} \Delta_k G_k}{\Delta}$$

Γ_ccL Γ_ccS Γ_ddS scc12 scc21 sdd11
Γ_ccL Γ_ccS Γ_ddS scc22 scd11 sdc11
Γ_ccL Γ_cdS Γ_dcS scc12 scd21 sdc11
Γ_ccL Γ_ddL Γ_ccS scc11 scd22 sdc22
Γ_ccL Γ_ddL Γ_ccS scc22 scd12 sdc21
Γ_cdL Γ_dcL Γ_ccS scc12 scd22 sdc21
Γ_ccL Γ_ccS Γ_ddS scc11 scd21 sdc21
Γ_ccL Γ_cdS Γ_dcS scc21 scd11 sdc21
Γ_dcL Γ_ccS Γ_ddS scc21 scd12 sdd11
Γ_dcL Γ_cdS Γ_dcS scc11 scd22 sdd11
Γ_dcL Γ_cdS Γ_dcS scd12 scd21 sdc11
Γ_ccL Γ_ddL Γ_dcS scc22 scd12 sdd21
Γ_cdL Γ_dcL Γ_dcS scc12 scd22 sdd21
Γ_cdL Γ_dcL Γ_dcS scd12 scd21 sdc22
Γ_cdL Γ_ccS Γ_ddS scc12 sdc21 sdd11
Γ_ccL Γ_ddL Γ_cdS scc22 sdc21 sdd12
Γ_cdL Γ_ccS Γ_ddS scc11 sdc21 sdd21
Γ_ccL Γ_ddL Γ_cdS scc21 sdc21 sdd22
Γ_ddL Γ_ccS Γ_ddS scc11 sdd12 sdd21
Γ_ddL Γ_ccS Γ_ddS scd12 sdc21 sdd11
Γ_ddL Γ_cdS Γ_dcS scd11 sdc21 sdd12

Γ_ccL Γ_ddL Γ_ddS scc22 sdd12 sdd21
Γ_ccL Γ_ddL Γ_ddS scd22 sdc22 sdd11
Γ_cdL Γ_dcL Γ_ddS scd21 sdc22 sdd12
Γ_ccL Γ_ddL Γ_ddS scd21 sdc21 sdd22
Γ_cdL Γ_dcL Γ_ddS scd22 sdc21 sdd21
Γ_ccL Γ_ddL Γ_ccS Γ_ddS scd12 scd21 sdc21
Γ_cdL Γ_dcL Γ_ccS Γ_ddS scd11 scd22 sdc21
Γ_cdL Γ_dcL Γ_cdS Γ_dcS scd12 scd21 sdc21
Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc11 scd21 sdc22 sdd12
Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc12 scc21 sdd12 sdd21
Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc12 scd22 sdc21 sdd11
Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc21 scd12 sdc22 sdd11
Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc22 scd11 sdc21 sdd12
Γ_ccL Γ_ddL Γ_ccS Γ_ddS scd11 scd22 sdc11 sdc22
Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc11 scc22 sdd12 sdd21
Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc11 scd22 sdc22 sdd11
Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc12 scd21 sdc21 sdd12
Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc21 scd11 sdc22 sdd12
Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc22 scd12 sdc21 sdd11
Γ_ccL Γ_ddL Γ_cdS Γ_dcS scd12 scd21 sdc11 sdc22
Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc11 scc22 sdd12 sdd21

Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc12 scc21 sdd11 sdd22
Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc12 scd21 sdc21 sdd12
Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc21 scd11 sdc22 sdd12
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Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc22 scd12 sdc21 sdd11
Γ_cdL Γ_dcL Γ_ccS Γ_ddS scd12 scd21 sdc11 sdc22
Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc11 scd21 sdc22 sdd12
Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc12 scc21 sdd12 sdd21
Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc12 scd22 sdc21 sdd11
Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc21 scd12 sdc22 sdd11
Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc22 scd11 sdc21 sdd12
Γ_ccL Γ_ddL Γ_ccS Γ_ddS scc11 scd22 sdc21 sdd21
Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc11 scd21 sdc21 sdd22
Γ_ccL Γ_ddL Γ_cdS Γ_dcS scc21 scd12 sdc21 sdd21
Γ_cdL Γ_dcL Γ_ccS Γ_ddS scc21 scd12 sdc21 sdd21
Γ_cdL Γ_dcL Γ_cdS Γ_dcS scc11 scd22 sdc21 sdd21

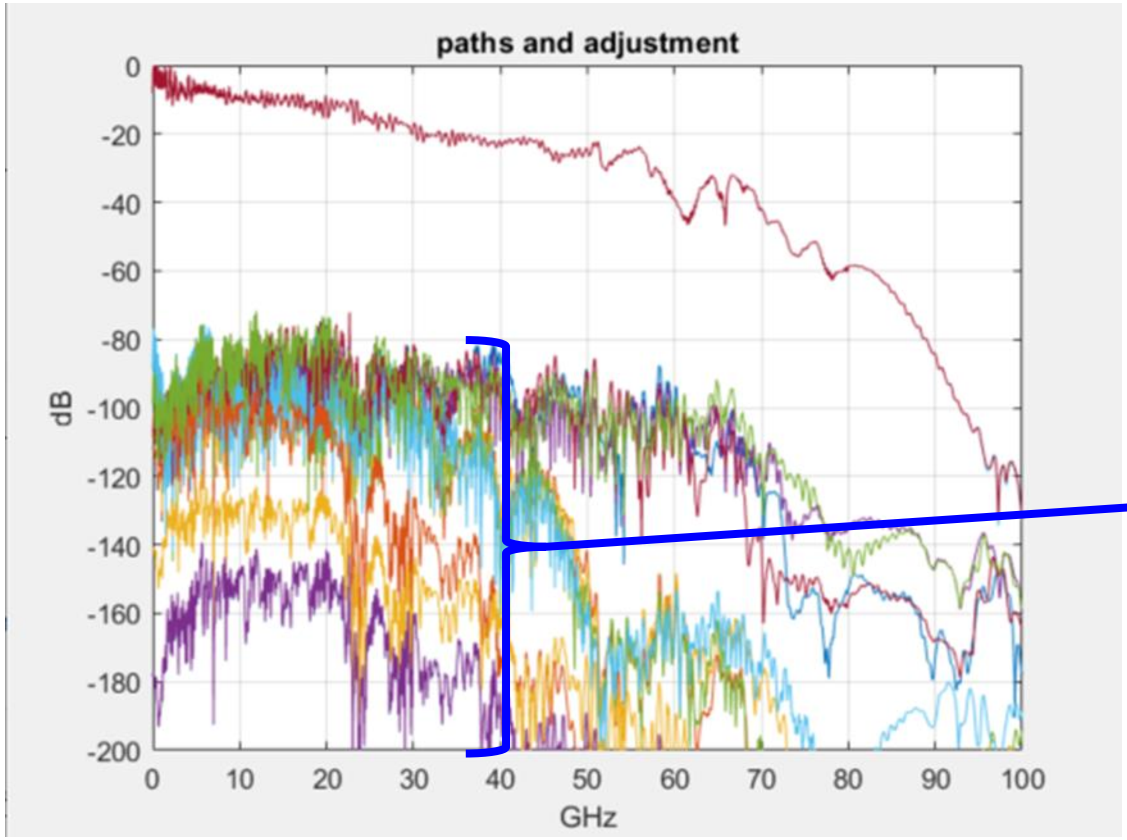
Δ=1-negative terms + positive terms

Quick Evaluations

- ❑ Just a simple example for now.
- ❑ Recall a previous slide
  - $\Gamma_{mode} = 10^{\frac{-ERL_{mode}}{20}}$
- ❑ In this example we use lowest Γ results for a mated test fixture
- ❑ 2 cases… start at forming budget
  - ERL_{dd} =10 ;ERL_{cc}=3; ERL_{dc}=17.5; ERL_{cd}=17.7;
    - Computed from: https://www.ieee802.org/3/dj/public/tools/MTF/sekel_3dj_02_2503.zip
  - ERL_{dd} =10 ;ERL_{cc}=5; ERL_{dc}=20; ERL_{cd}=20;
- ❑ Channel
  - HH_5in_DAC_X_0p5m_HN_3in_thru_TP0_Tx7_to_TP5_Rx7 https://www.ieee802.org/3/dj/public/tools/CR/weaver_3dj_02_2311.zip
- ❑ Determine SNR_{ISI} from pulse response with and without modal effect
- ❑ COM computed from pulse responses(PR). (no MLSD)
  - Just a quick check here

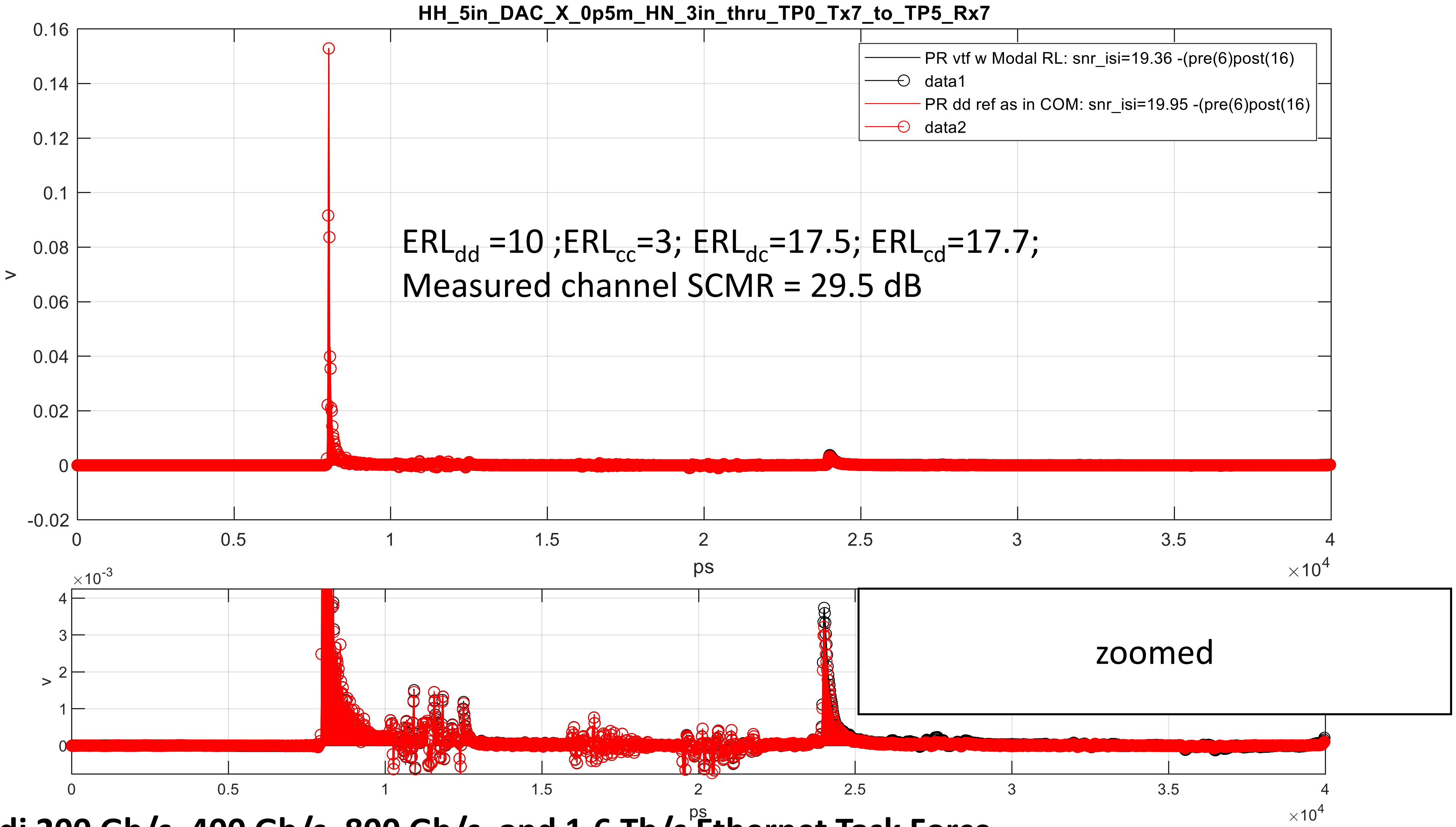
Many paths can have low impact

IL of this channel is 25.3 db at 53.125 GHz

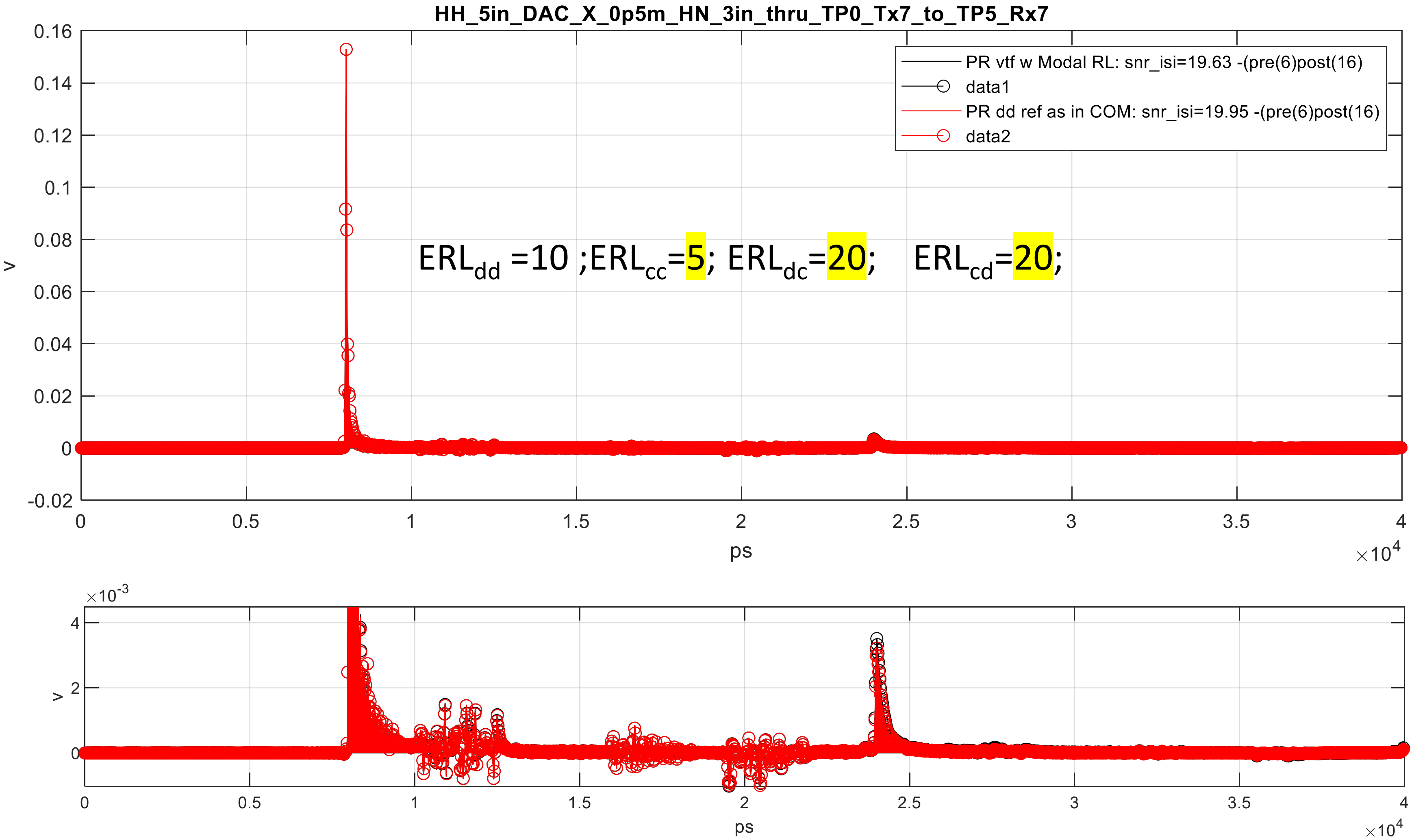


These represent the loss of other gain paths.
They seem pretty small but let's take a closer look

PR of the VTF(dd) with and without modal contributions: delta COM = 0.238 dB



Improving modal ERL: PR w/wout modal contributions delta: COM = 0.130 dB



Summary

- Modal Voltage Transfer Function (VTF) can be extended to evaluate modal parameters.
- The VTF approach is well-defined but involves complex calculations.
- Evaluating modal gains with interactions uses Mason's Rule transfer function formula.
- An initial example shows a small delta COM when modal reflections are considered
- Symbolic Octave and Matlab scripts are available for computing modal VTFs.
  - Can be used in the Matlab symbolic live script environment
  - Produces a VTF function handle in Octave and Matlab
    - Signal_flow_graph_masons_rule_solver.m (main program)
    - compute_denominator_delta.m
    - compute_path_deltas.m
    - find_forward_paths.m
    - find_unique_loops.m
    - https://opensource.ieee.org/802-com/com_code/-/tree/main/Exploratory/Signal_flow_graphs?ref_type=heads

Future Directions

- Modal Effective Return Loss (ERL) offers a practical metric to replace modal masks
- The modal VTF is a framework for CM budgeting
- Modal ERL specs can be used to enhance SCMR_CH
- It's likely that a channel with high SCMR_CH are less impacted modal termination impairments.
- Using modal ERL supports forming a closed budget

Thank You!