Reflections on Return Loss

Reflections on Return Loss

What it is

Why it’s important

It’s Impact on high density, high performance switch matric designs

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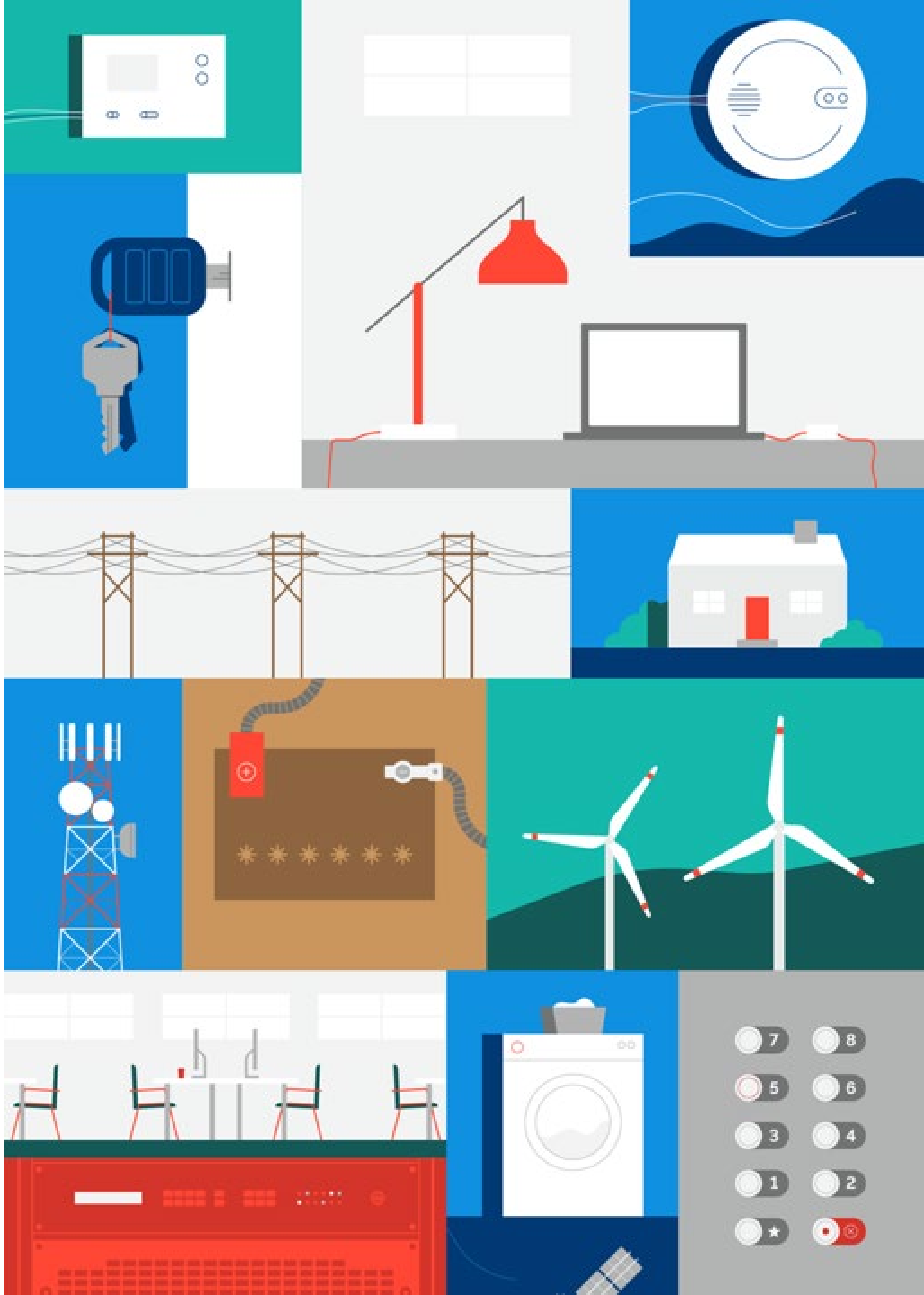
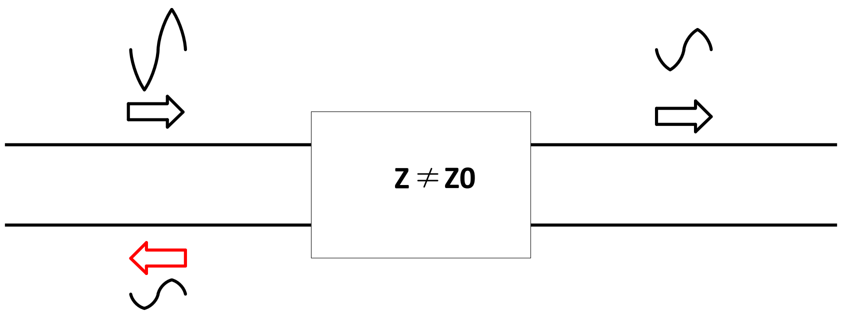


What is Return Loss?

- Return Loss (dB): a measure of how much power is reflected at a connection point in a transmission line



  - Higher return loss -> less signal is reflected, and more power goes through
  - RL = $-10\log_{10}(|P_R/P_I|)$ = $-20\log_{10}(|V_R/V_I|)$ = $-20\log_{10}(|\Gamma|)$

    Where P is power, V is voltage, R is reflected, and I is incident and Γ is reflection coefficient
  - Also, RL = -$|S_{11}|$ and is always positive
- But why do many datasheets show return loss as negative
  - Modern Vector Network Analyzers display S_{11}
  - Previous Scalar Analyzers displayed P_R/P_I
  - Many people are accustomed to seeing RL as negative

Menlo Micro MM5130 Datasheet

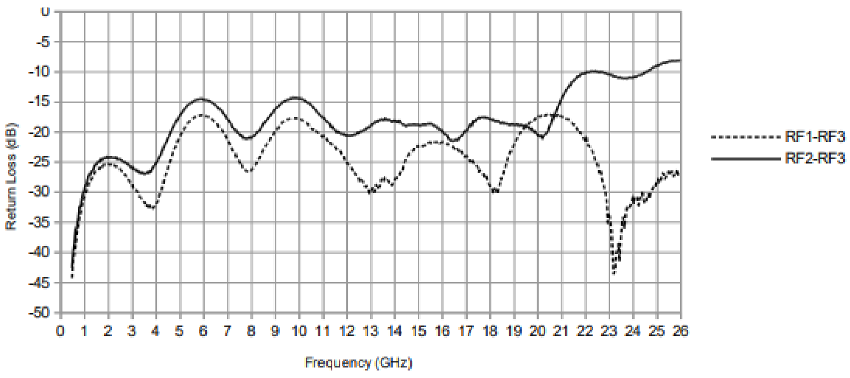


Figure 18. Super-Port Configuration Return Loss / S11

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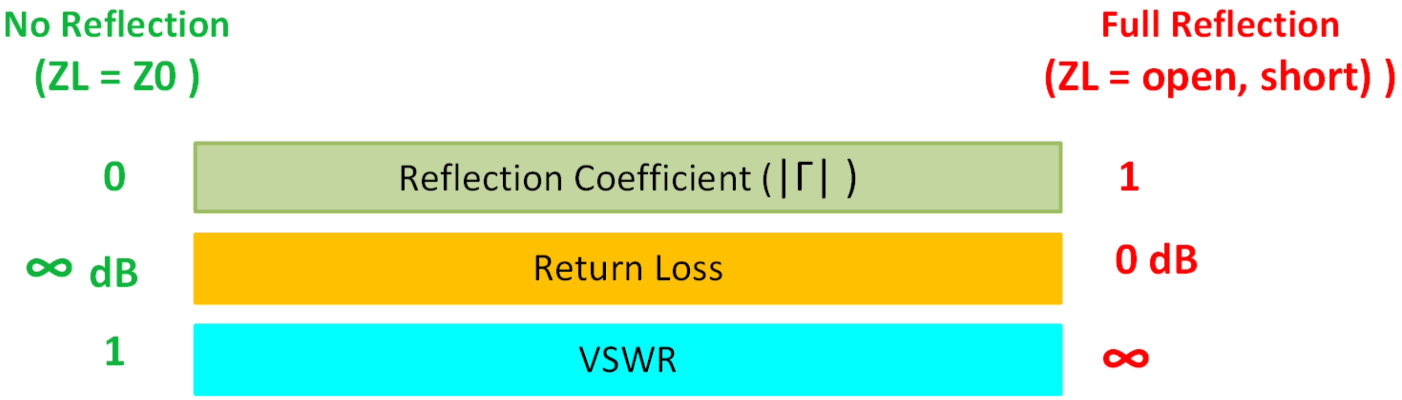
What is Return Loss?

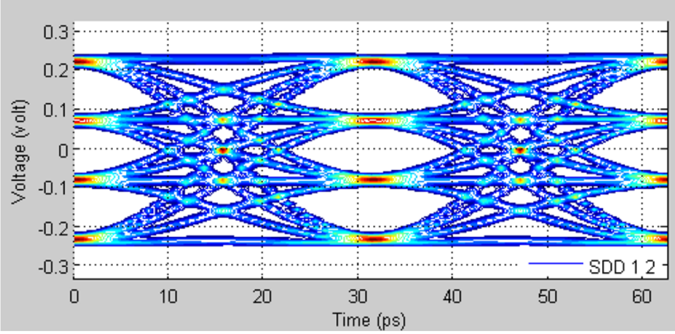
- Reflection Coefficient (Γ): The ratio of reflected to incident voltage
  - $|\Gamma| = |V_R/V_I| = |Z_L - Z_0| / |Z_L + Z_0|$
  - Range between 0 to 1, where 0 means no reflection and 1 mean total reflection
- VSWR (Voltage Standing Wave Radio): measures the efficiency of power transfer
  - VSWR = (1+|Γ|) / (1-|Γ|)
  - Lower VSWR -> better match (no reflection)



Why is Return Loss Important?

- RL directly affects how efficiently a system transmits signals

  - Wireless Communication (e.g., Wi-Fi, cellular, satellite)
    - In antenna design, high RL -> most of the transmitted signal is radiated by the antenna
    - Poor RL -> reduces the range and effectiveness of the communication system
  - RF Circuit Design (e.g., filters, amplifiers, couplers)
    - Good RL ensures components pass signals efficiently without unwanted reflections
    - Identifies distorted signals and reduction in system performance
  - Test and Measurement
    - Poor RL may cause signal integrity issues
    - Results in closing of Eye diagram and increased BER



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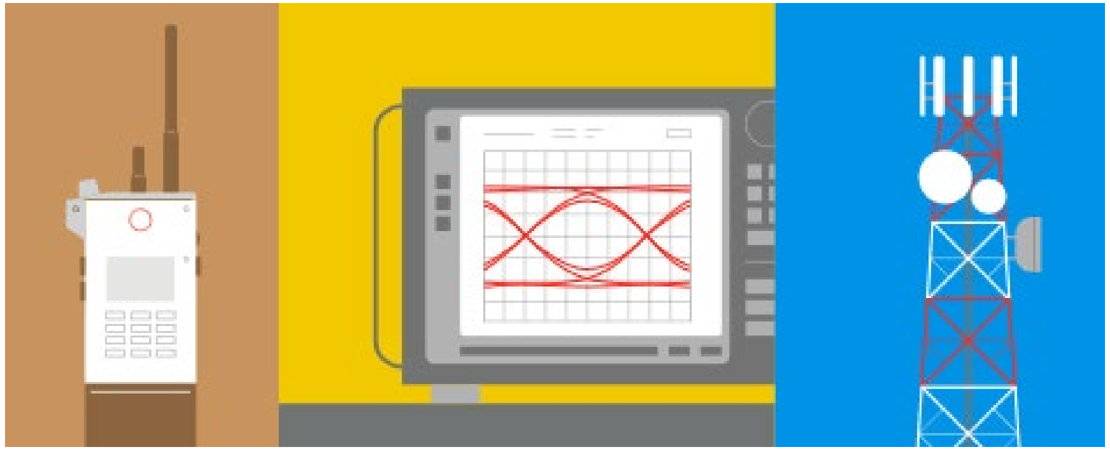
Some common causes of poor Return Loss

- System Design
  - Impedance mismatch between components (ex. amplifier output does not match the impedance of connected transmission line)
  - Poor PCB layouts (ex. Trace width, substrate material, spacing from ground plane)
  - Any discontinuity can introduce mismatch/RL issues

- Test and Measurements
  - Damaged/ poor quality connectors and cables
  - Improper calibration of the VNA
  - Temperature variations in the environment



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Misconceptions on Return Loss

- Performance can be improved by adding loss (padding) in front of the discontinuity
  - The objective of improving return loss is usually to improve power transfer
  - Adding loss simply reduces the power incident on the discontinuity
  - While the overall return loss is improved, system performance and efficiency is degraded

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Cascaded Return Loss

- Why does return loss degrade when parts are cascaded?

  - Each system component has its own Return loss (RL) and is a measure of its reflected power
  - In effect these are voltage waves that combine to form a standing wave
  - To determine possible worst-case return loss we assume all voltages add in phase – for a wide bandwidth part this is highly likely.
  - Calculated from reflection coefficient of each component $\Gamma = 10^{-(RL/20)}$
  - Cascaded Return Loss for an N number of cascaded sections
    - $RL_{CAS} = -20 * \log_{10}(\sqrt{}(\Gamma_1^2 + \Gamma_2^2 + \Gamma_3^2 + \Gamma_4^2 + \Gamma_5^2 + \ldots \Gamma_N^2))$

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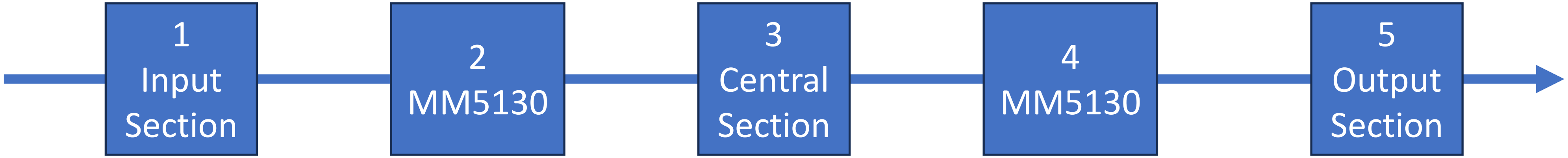
Cascaded Return Loss

- Cascade definition for two MM5130 switches



- Input section contains pads and lines from system input to the MM5130 die
- Center section contains lines between parts
- Output section contains pads and lines from the MM5130 die to the output
- Sections 3 & 4 may be repeated for multiple cascade devices

Cascaded Return Loss

- For example, at 12 GHz the SP4T path MM5130 Return Loss is typically 13 dB
- Assuming 20 dB Return Loss for interconnecting sections then resultant Return Loss could go to ~8.85 dB

Section	1. Input	2. MM5130	3. Central	4. MM5130	5. Output
Return Loss	20	13	20	13	20
Reflection Coeff	0.1	0.223872	0.1	0.223872	0.1
Combined RC		0.245191	0.264799	0.346753	0.360884
Combined Return Loss		-12.2099	-11.5417	-9.1996	-8.85264

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Cascaded Return Loss

- For example, at 12 GHz the Superport adjacent path MM5130 Return Loss is typically 17 dB
- Assuming 20 dB Return Loss for interconnecting sections then resultant Return Loss could go to ~11.55 dB

Section	1. Input	2. MM5130	3. Central	4. MM5130	5. Output
Return Loss	20	17	20	17	20
Reflection Coeff	0.1	0.141254	0.1	0.141254	0.1
Combined RC		0.173068	0.199882	0.244755	0.264396
Combined Return Loss		-15.2357	-13.9845	-12.2254	-11.5549

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Cascaded Return Loss

- The previous examples give an idea of how the worst-case cascaded return loss can have an impact on overall system performance
- Q: How likely is this to happen in our systems?
- A: It depends
  - A narrowband system (<3 GHz) can usually avoid this with careful design
  - A wideband system is almost certainly going to see degradation
- Q: What is the best way to verify in my system?
- A: Download S-parameter files for the switch configuration you wish to use and import into your circuit simulation software
  - **Always, always, always** perform a circuit simulation with the design transmission lines and component S-parameters prior to finalizing layout
  - Optimizing line lengths/impedances can help improve performance in return loss
- It is recommended to perform 3D EM simulation of the final circuit layout prior to tape-out
  - Component S-parameters can be used

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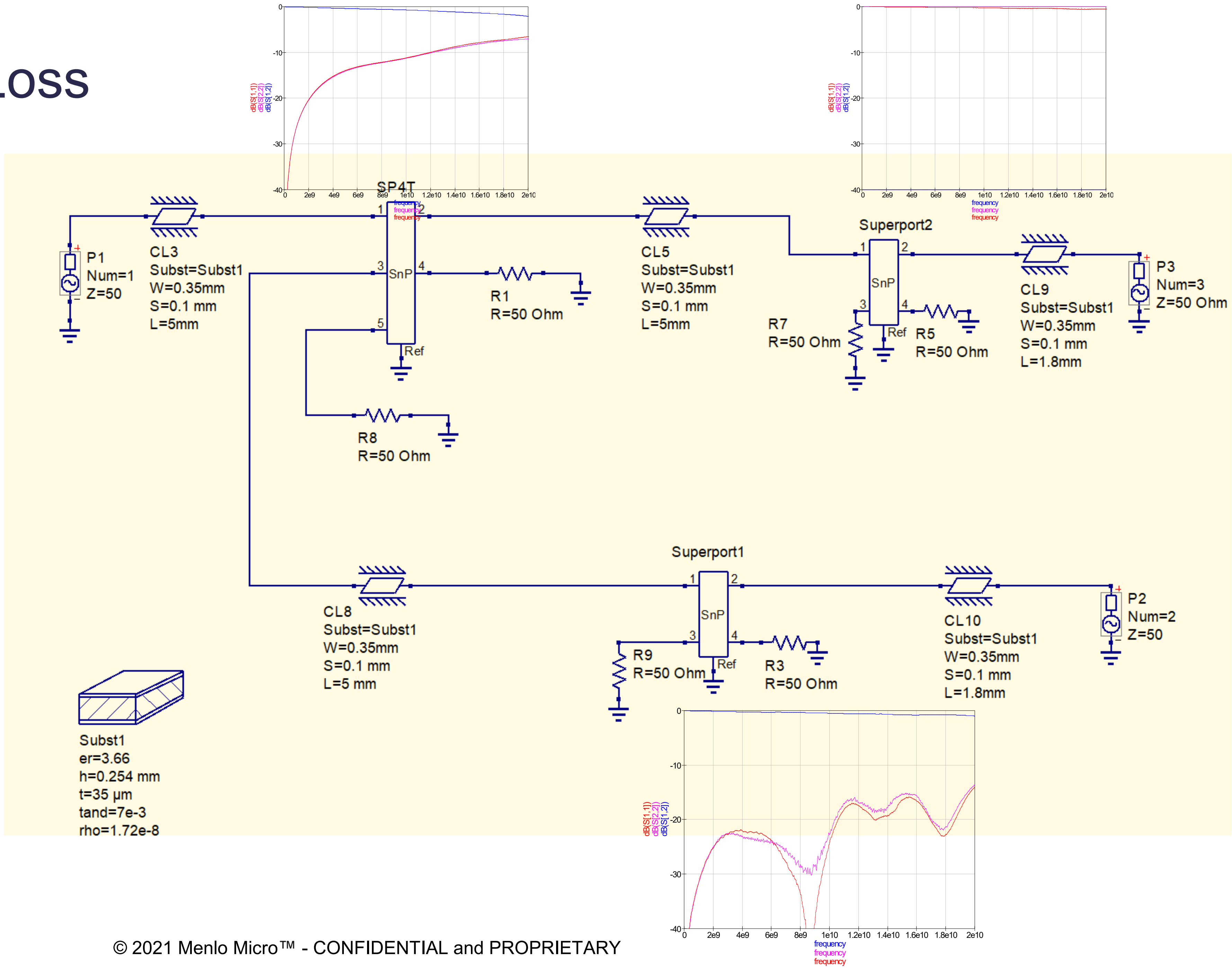
Cascaded Return Loss

- Switch Matrix example

SP4T closed 1-3

Superport1 closed 1-2

Superpport2 all open



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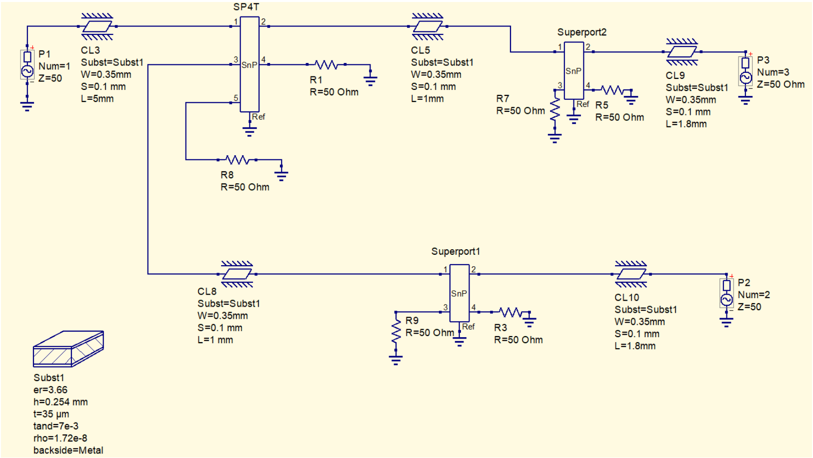
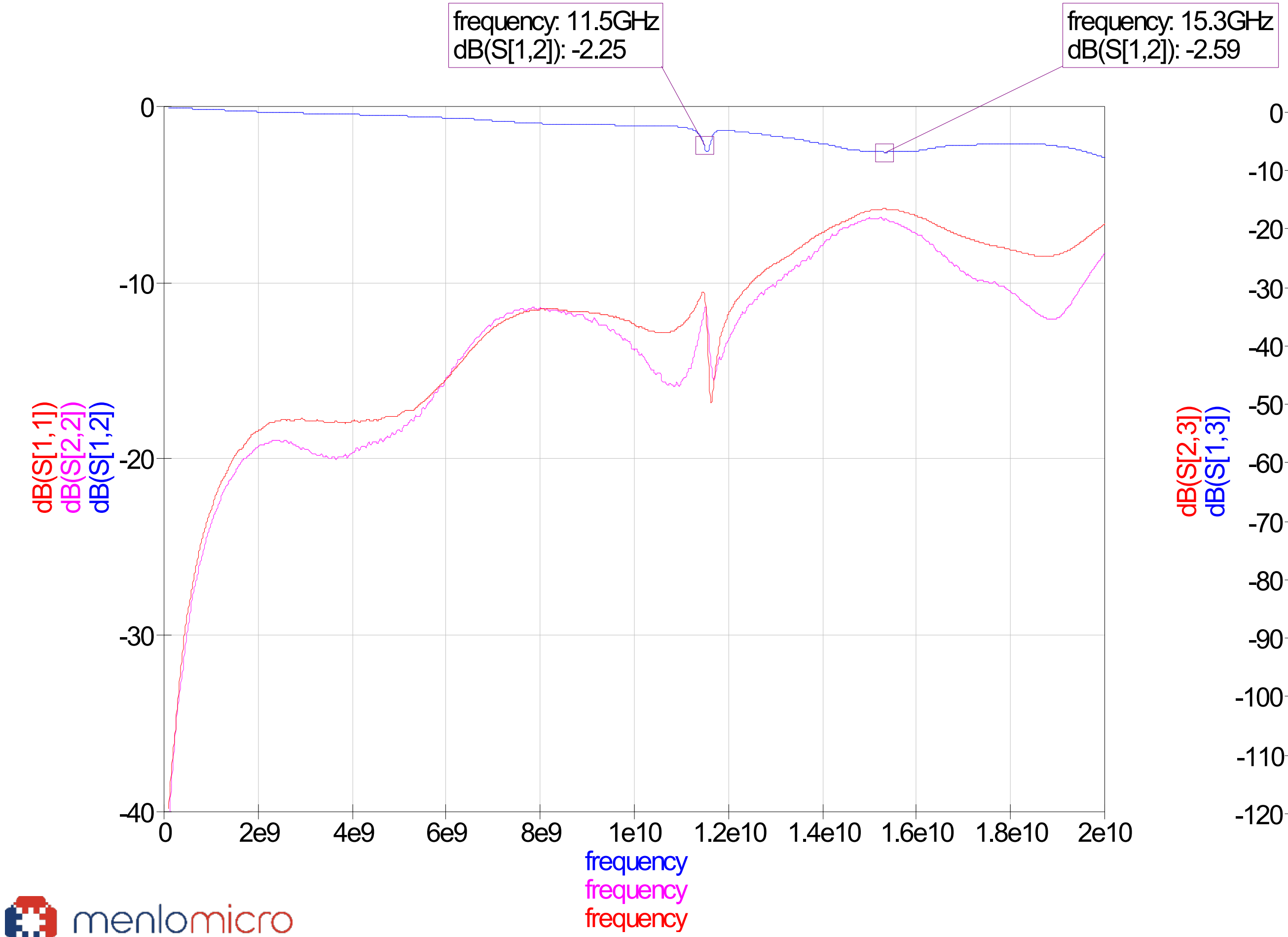
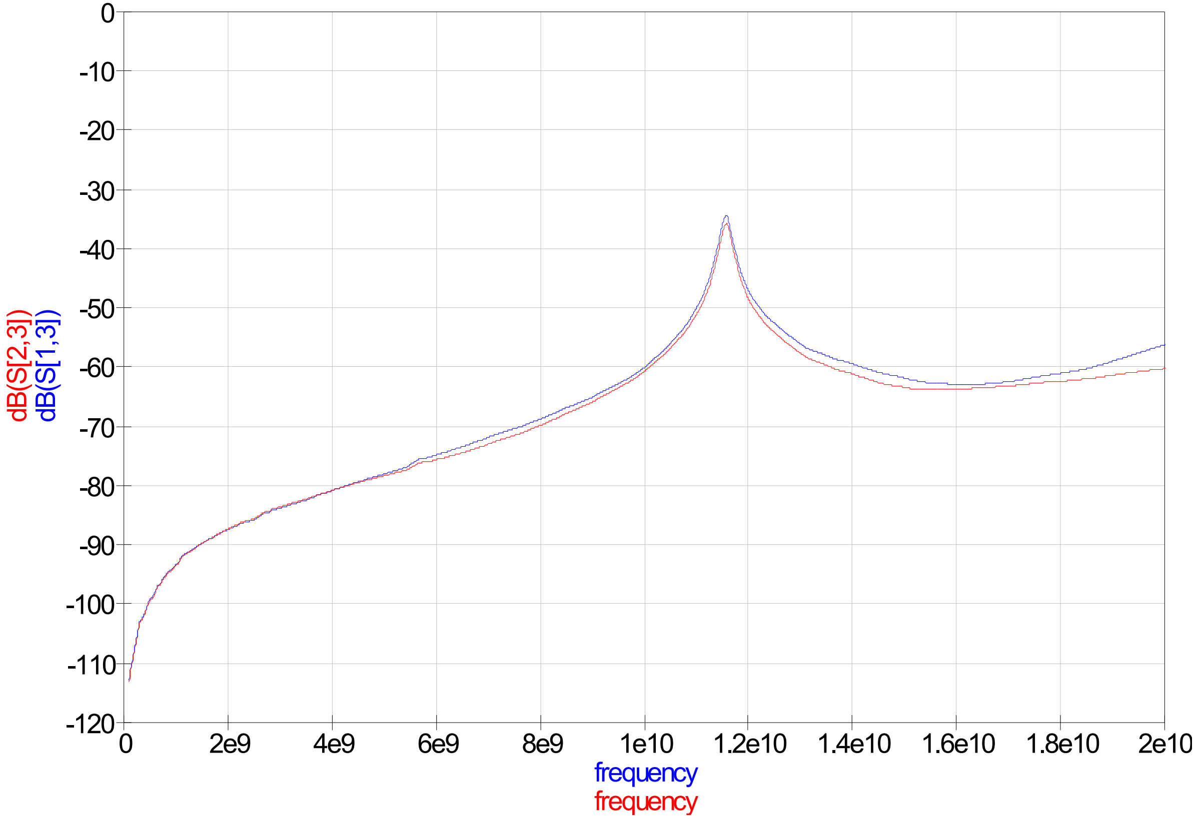
Cascaded Return Loss

- Where did the notch at 11.5 GHz come from?
- Why is the RL so bad between 14-17 GHz?







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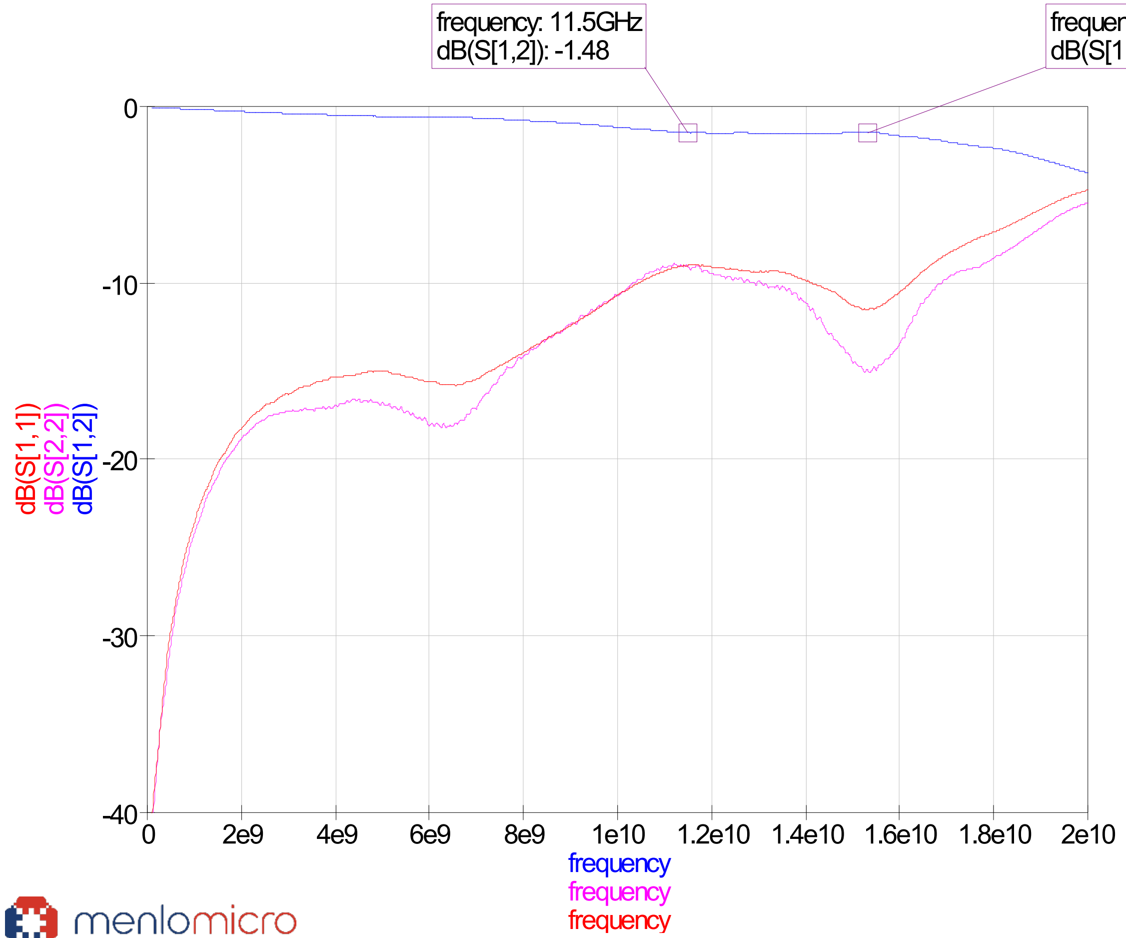
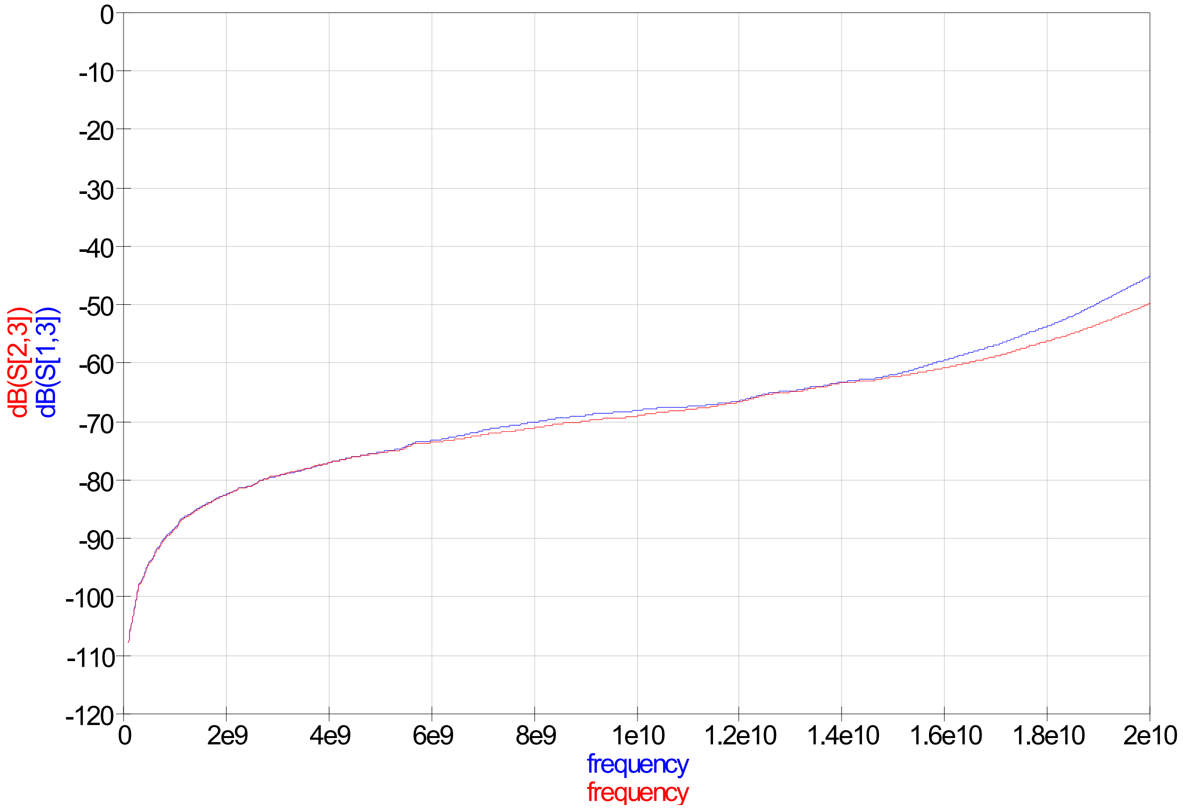
Cascaded Return Loss

- Reduce length of line between SP4T and SP2 (CL5) moves the notch
- Reduce length of line between SP4T and SP1 (CL8) improves RL





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Designing for optimized Return Loss

•Minimize discontinuities

- Discontinuities can be any change within the signal path
  - Bends in traces
  - Trace dimension changes
  - Trace running near changes in dielectric constant
  - Vias
  - Ground plane gaps
  - Substrate changes
  - Device return loss (match)

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Reflections on Return Loss

Q & A

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Thank You