TC1/TC2 Return Loss Spec

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Comment 53: Need to determine the Return Loss Mask

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Many templates can be simulated, but that doesn't make a requirement

- Fitting an implementation leads to fixed complexity and relative cost for all time
- Can be difficult to match with component variation
- PHY's inherent response to reflections ultimately governs the requirement

Requirement needs to be consistent with simulations, and implementable

Example implementations exist that we can draw on, hopefully improve on (ODVA specification, compensated T's)

- A PHY-driven specification should allow these, AND
- Adds more possibilities for reducing cost/complexity

Basic Principles

See zimmerman_3da_01_03122024.pdf

TC1/TC2 return loss produce reflections, combined reflection must be within the noise budget

- Relation to node count depends on whether nodes add in-phase or uncorrelated
  - Delay of even 1/10 baud decorrelates the reflections (4 nsec one-way)
  - Previous presentation (slide 19) bounded with pairs of nodes reflecting in-phase, to:
    6 dB + 10log10(N_nodes/2 -1) dB
  - Only generic improvement is if all nodes decorrelated, about 3 dB better where all nodes reflect uncorrelated

This is on average, we will address frequency dependence next…

Simulations appears that compensated T's decorrelate nodes more than

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Simulation results on compensated T's show receive delay is enough to decorrelate reflections

- Consensus model tracks eye centers per bit
  - Nodes 1 & 18 are dummies
- 60ns/15 node-spans = 4 nsec/span (one-way)

node	receive_delay
0001	47759.875ns
0002	1.875ns
0003	5.625ns
0004	9.375ns
0005	13.375ns
0006	17.375ns
0007	21.125ns
0008	25.375ns
0009	29.125ns
0010	33.125ns
0011	36.875ns
0012	40.875ns
0013	44.875ns
0014	48.875ns
0015	52.875ns
0016	56.625ns
0017	60.875ns
0018	62.625ns

This means we don't need pair-wise correlation, and we can regain 3 dB, using RL spec based on all nodes power-sum (10log10(N_nodes-1) dB)

- Decorrelated reflections is the best we can do
- Anything better is a special case of spacing interacting with baud timing, and requires precise installation practice

What about Frequency Content?

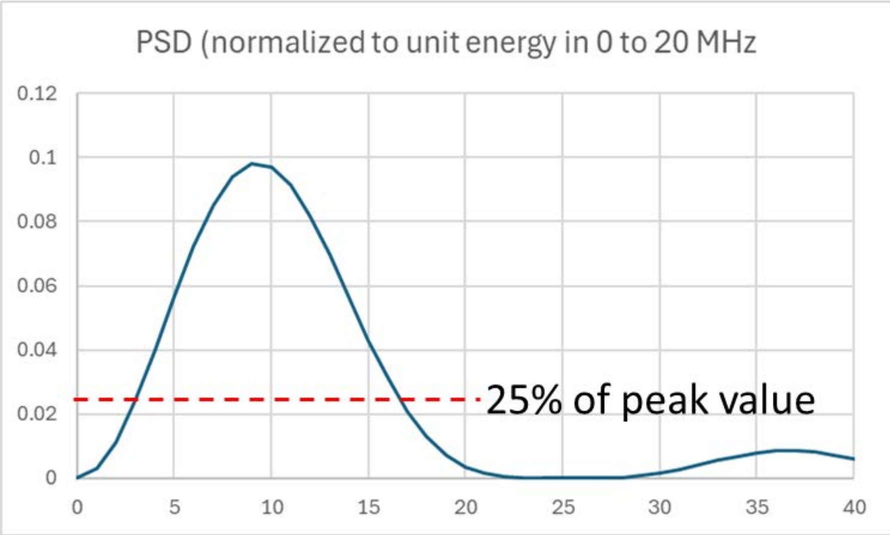
Not only are the reflections (noise) weighted, but the detection SNR is also shaped as the PSD of the transmitted signal

- Correlative receiver in model is an approximation of a Matched filter

PSD for Manchester Coded Signal:

$$S(f) = A^2 T \, \mathrm{sinc}^2\left(\frac{fT}{2}\right) \sin^2\left(\frac{\pi f T}{2}\right)$$

>25% of peak value between 3.0 and 16.6 MHz



Frequencies outside interval (3 MHz, 16.6 MHz) matter little

- *Impact on SNR is attenuated by > 10 dB due to transmit PSD distribution…(only 8% of power)*

Consistent with Consensus Model Receiver (beruto_3da_20220711_rx_model.pdf)

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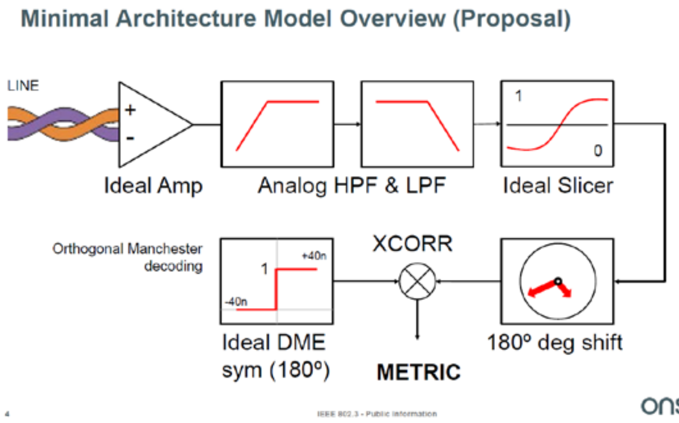
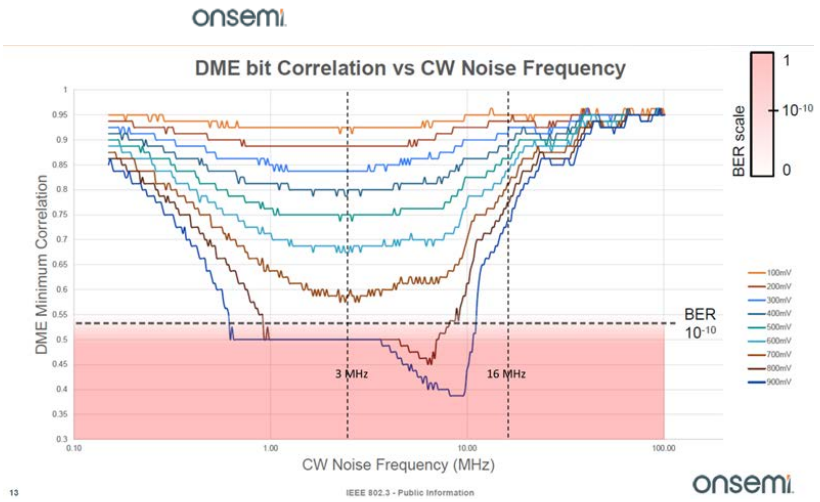
Impact of noise sources falls off below 3 MHz, above 16 MHz

- Correlator governs performance if analog filter passes signal & noise
- HPF has insignificant effect
- LPF at 15 MHz slightly reduces high frequency effect





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Considerations for RL specification

Receiver is impacted by a single, integrated matched filter output

- Will be forgiving in low-frequency structure of the mask, enabling power
- BUT – will require new education & proof of technique
  - For example – how accurate must the filter be? What resolution? Over what frequency range?

Industry is used to derived frequency masks

- Measurements and simulations of designs have been presented (Paul, Diminico, Schreiner)
  - Consensus model has shown curves that work
- BUT - workable curves derived from various simulated designs will lock in complexity, make compliance difficult or specific to a design
  - For example – at what level of RL do we stop following a design's RL to an increasing RL specification? Can we trade excess RL at one frequency for an exceedance at another?

And, most importantly, how good is "good enough"?

Compromise approach: Mask tested as noise

Consider a traditional template return loss mask
- RL floor mid-band, decreasing at low frequencies and high frequencies
- Floor and corner frequencies can be easily adjusted

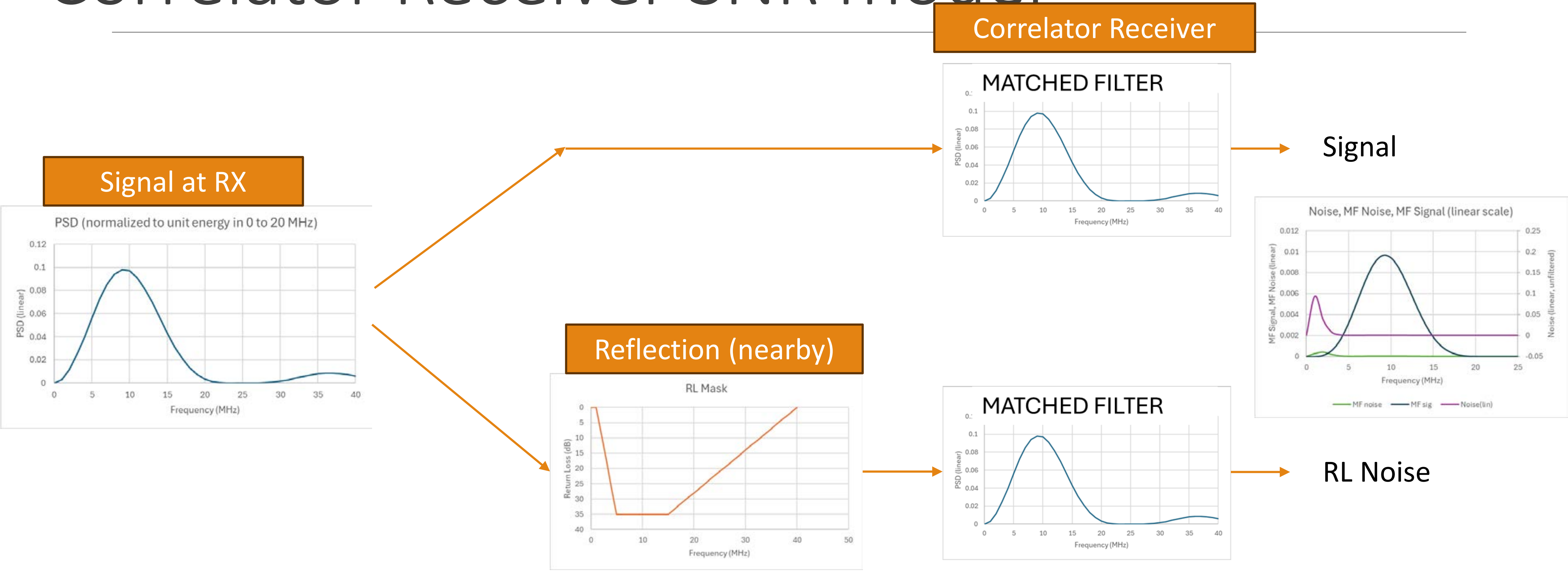
Decorrelated reflections will act as noise source with the transmit PSD x Mask PSD into the receiver

Evaluate the receiver SNR in the presence of that noise
- Independent of insertion loss (IL) since signal and reflection both see the IL
- Weighted by correlator receiver filtering (mask modeling)

Adjust the template mask to determine tolerable SNR
- Adjust the RL floor level based on the

Don’t build in excess margin (experience with model shows combined RL does NOT hug the mask)

Correlator Receiver SNR model



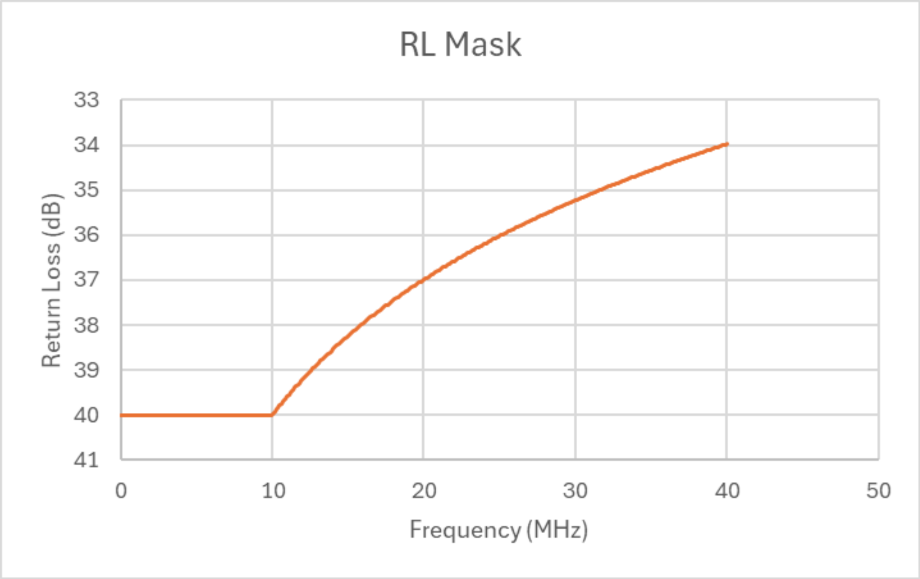
Detection SNR is the integral of the signal energy over the integral of the noise energy

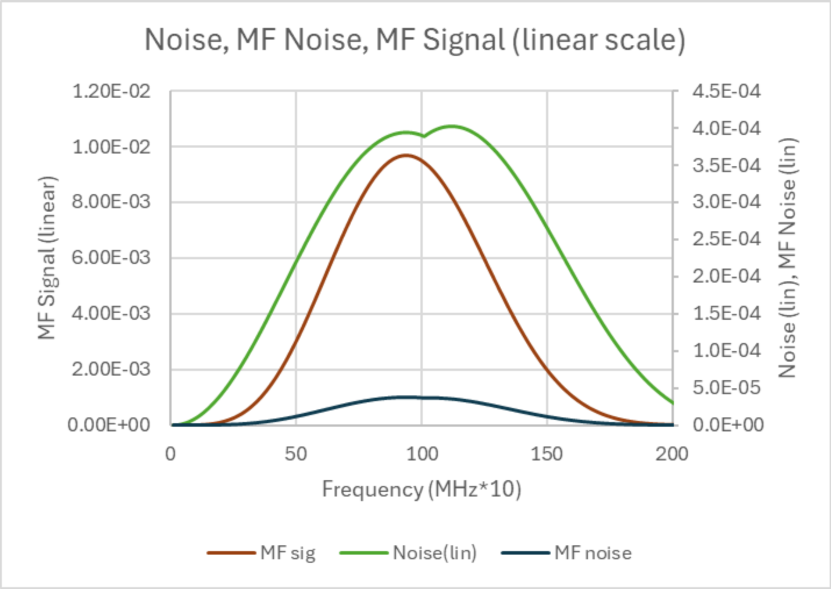
Reference case: ODVA Mask for 40 nodes

Ref: mask in brandt_3da_01_0324.pdf - gives 23.6 dB MF SNR at 40 nodes
40 node count from https://www.odva.org/library_proceedings/enhancements-to-single-pair-ethernet-for-constrained-devices/

ODVA Mask						Geom SNR	23.2	dB
nodes	40					Linear SNR	23.4	dB
						MF SNR	23.6	dB
						Nodefactor	16.02	dB

~10 dB margin





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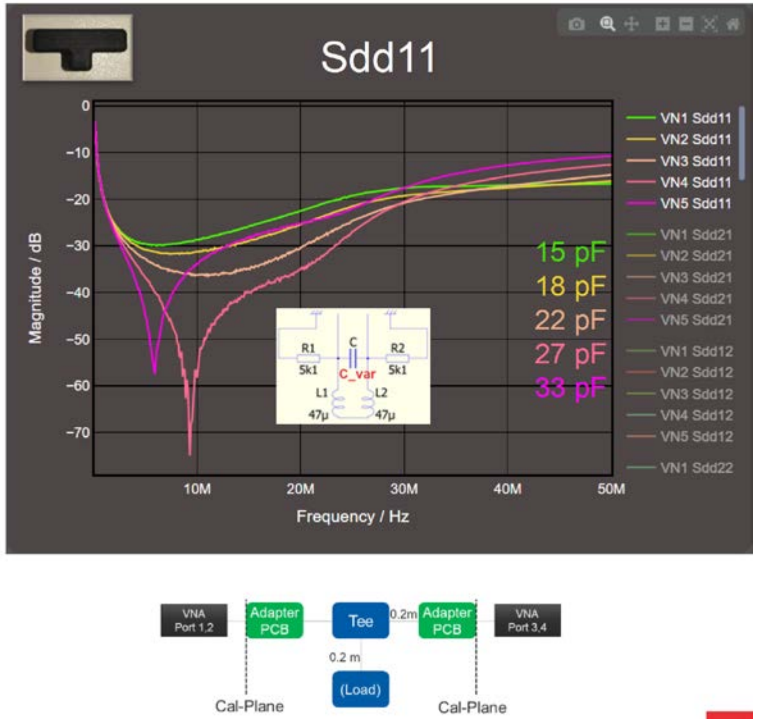
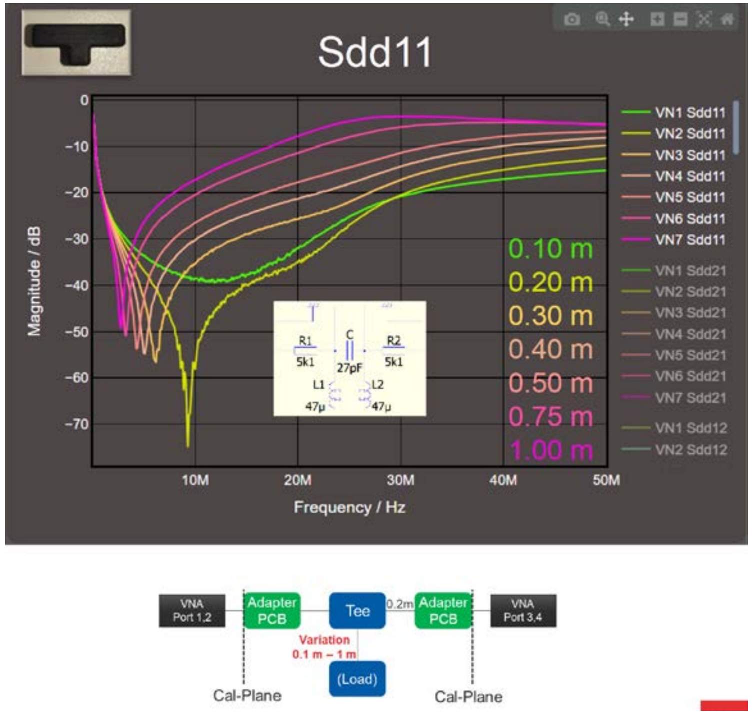
Compare with Existing Models / variation

Schreiner_3da_March_24.pdf – notches move & disappear, shape remains

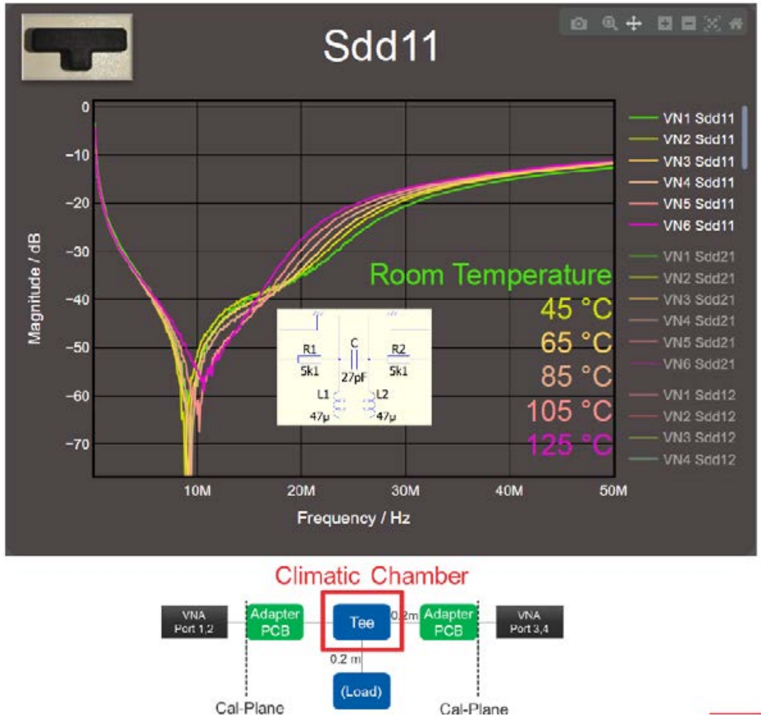
Capacity Variation (slide 9)



Stub Length (slide 10)



Temperature(slide 11)



Suggested Mask Construction

Construct a traditional mask based on an RL floor that increases on either end.

Simulations and existing specifications rarely go below 15 dB RL at low frequencies

Set 40 dB RL at 6 dB

- Schreiner measurements indicate RL plateaus ~ 10 dB at high frequencies, but at higher slope, 6 dB allows for this
- Other RL masks pin at < 10 dB at high frequencies
  - Investigations show no advantage of limiting the mask at frequencies over 15 MHz…

Set 40 dB floor – consistent with ODVA, consistent with mismatch results from Schreiner

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RL tradeoffs

High frequency behavior

- No improvements extending plateau above 10 MHz (consistent w/ODVA)
- No improvements lowering 40 dB level below 6 dB

Low frequency behavior

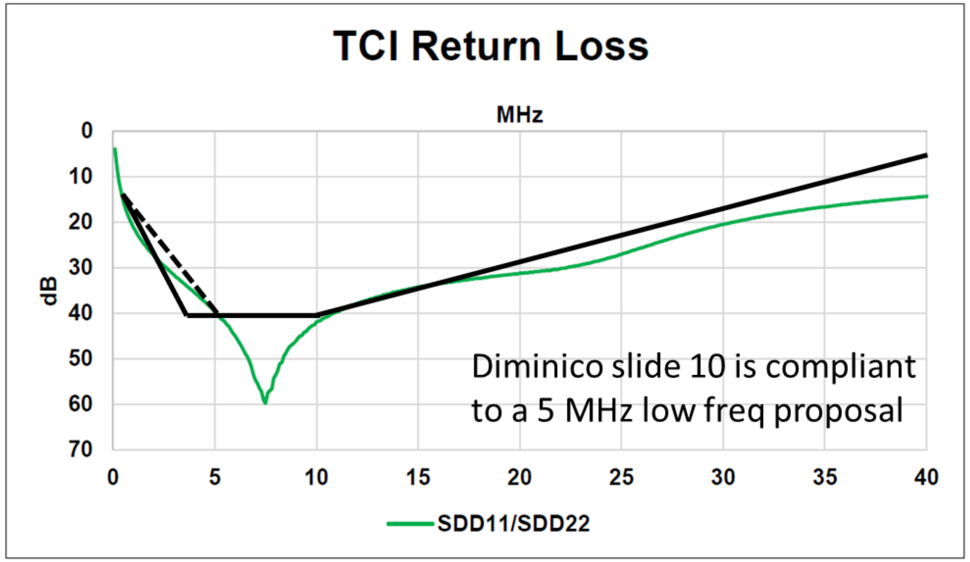
- Increasing lower frequency 40 dB floor start to 5 MHz results in ~0.9 dB SNR loss at 32 nodes relative to reference case (40 node ODVA)
  - 1.8 dB loss at 40 nodes, still > 8 dB margin
  - 3 MHz floor corner reduces loss to ~0.3 dB at 32 nodes, 1.3 dB at 40 nodes
- Fits Schreiner measurements, and allows for mismatch

RL Floor	40	dB				Geom SNR	19.0	dB
Mask corners	Low (MHz)	High(MHz)				Linear SNR	20.2	dB
	5	10				MF SNR	22.7	dB
Nodeallow	32	nodes				Nodefactor	15.05	dB
Cutoffs	low (MHz)	high(dB to 40MHz)		lowval	40M RL			
	0.301	6		15	6.00			

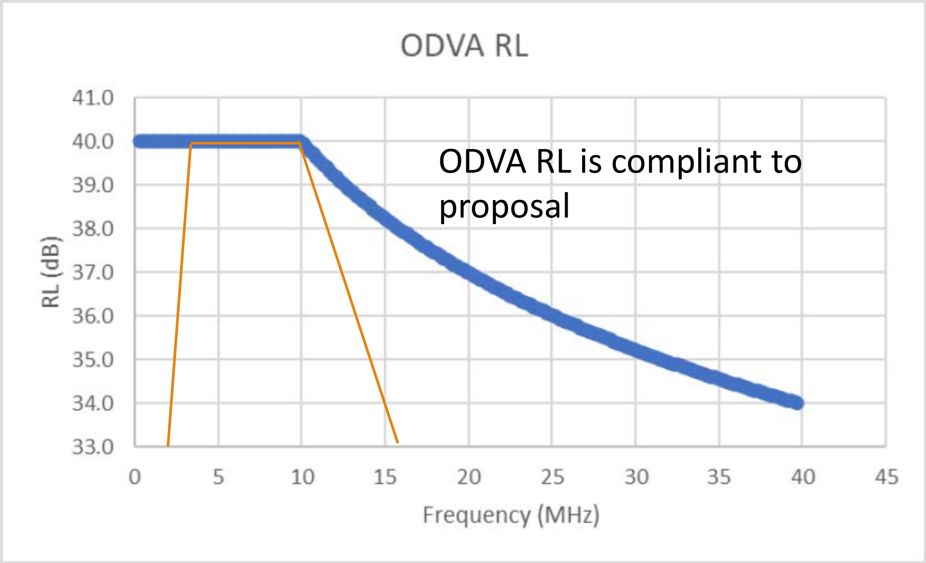
RL Floor	40	dB				Geom SNR	20.2	dB
Mask corners	Low (MHz)	High(MHz)				Linear SNR	21.7	dB
	3	10				MF SNR	23.3	dB
Nodeallow	32	nodes				Nodefactor	15.05	dB
Cutoffs	low (MHz)	high(dB to 40MHz)		lowval	40M RL			
	0.301	6		15	6.00			

Compare with Existing Models

See, e.g., diminico_3da_01_031224.pdf slide 10
Emphasizes deeper notch, takes bigger SNR loss at low freqs, offset by deeper notch



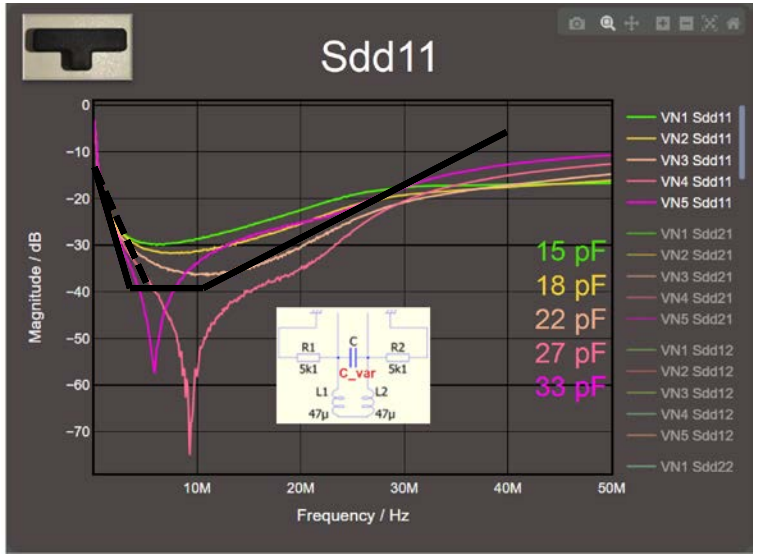
See, e.g., brandt_3da_01_0324.pdf slide 5
(emphasizes lower frequencies)
No allowance for power coupling



Compare with Schreiner measurements & variation

Schreiner_3da_March_24.pdf – 5 MHz mask fits with most variations

Capacity Variation (slide 9)



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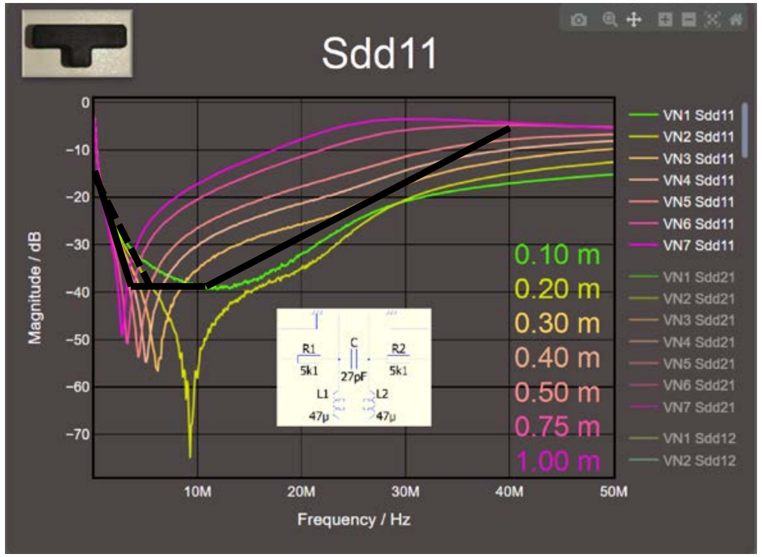

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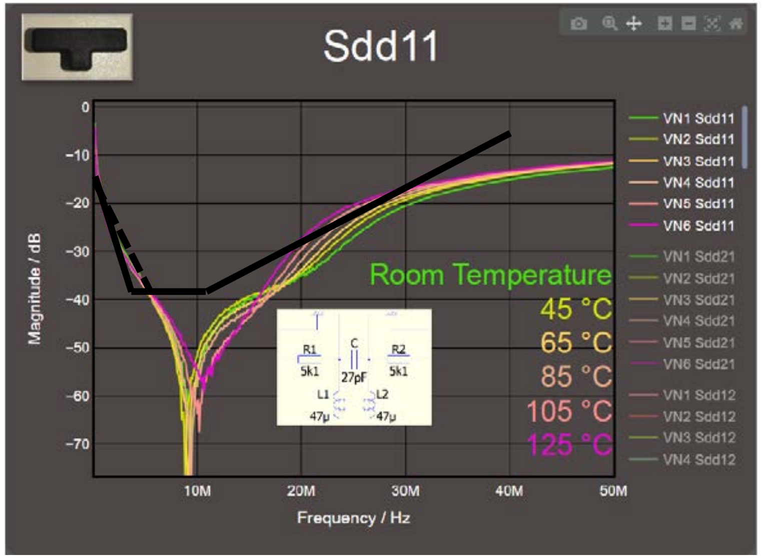
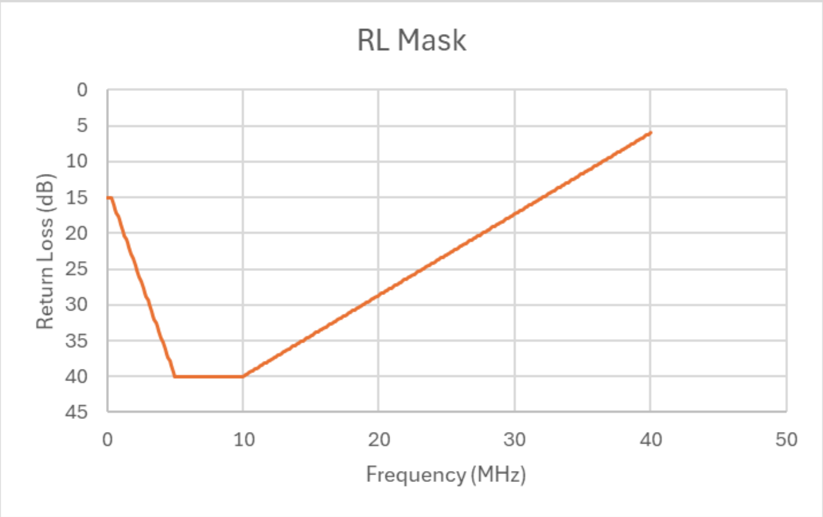


Proposal

Replace TCI return loss (equation 168-5):

$$RL(f) \geq \begin{cases} 15 + (f-.3)*(25/4.7)\ \text{dB} & \text{for } 0.3\ \text{MHz} \leq f < 5\ \text{MHz} \\ 40\ \text{dB} & \text{for } 5\ \text{MHz} \leq f < 10\ \text{MHz} \\ 40 - (f-10)*(34/30)\ \text{dB} & \text{for } 10\ \text{MHz} \leq f < 40\ \text{MHz} \end{cases}$$



Recommendations

Adopt TCI RL Mask proposal on slide 16

Validate receiver performance on hardware

- Shaped (AWGN) noise source with proposed RL mask levels and shapes
- Investigate BER degradation

Can later tweak high frequency shape or floor based on broad measurement inputs of devices & hardware sensitivity results

- (can do this in WG and even SA ballot)

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Thank You