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TC1/TC2 Return Loss Spec

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Supporters

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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 are de-correlated by delay
  - In-phase reflections add as a fixed voltage (20 log10(N_nodes) dB), whereas nodes separated by enough delay add as uncorrelated noise power – due to interacting random transmitted bits.
  - Delay of even 1/10 baud tends to decorrelate the reflections
    - This means ~4 nsec one-way or 20% of a DME transition interval round trip
  - Zimmerman_3da_01_03122024 slide 19 bounded the combination as decorrelating all except nearest pairs of nodes, giving a bound on combination of:
6 dB + 10log10(N_nodes/2 -1) dB with minimal delay across the TCI itself…
- The only possible generic (non-location or non-loss sensitive) improvement is to have all nodes decorrelated, not even pairs (this depends on the delay across a TCI)

Simulations show compensated T's decorrelate nodes

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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)

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

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

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What about Frequency Content?

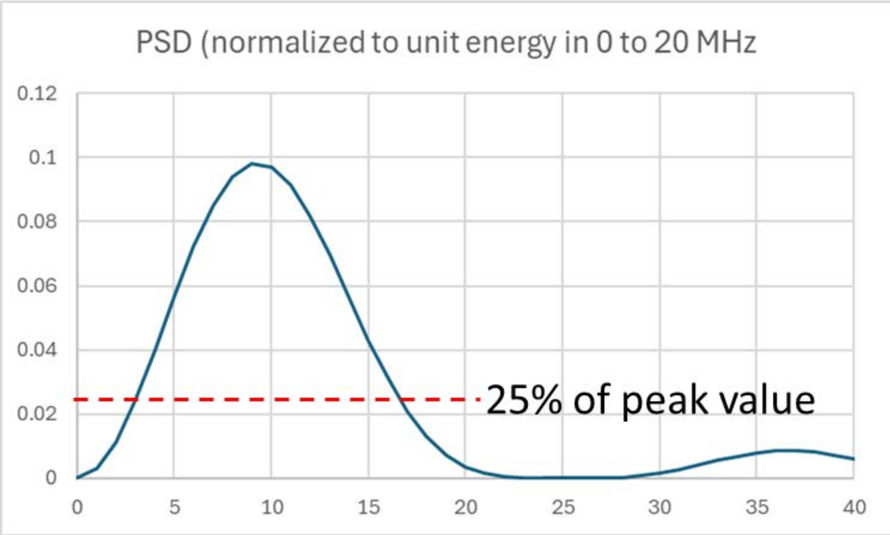
Not only are the reflections (noise) weighted, but the detection SNR is also shaped as the PSD of the transmitted signal

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

PSD for Manchester Coded Signal:

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

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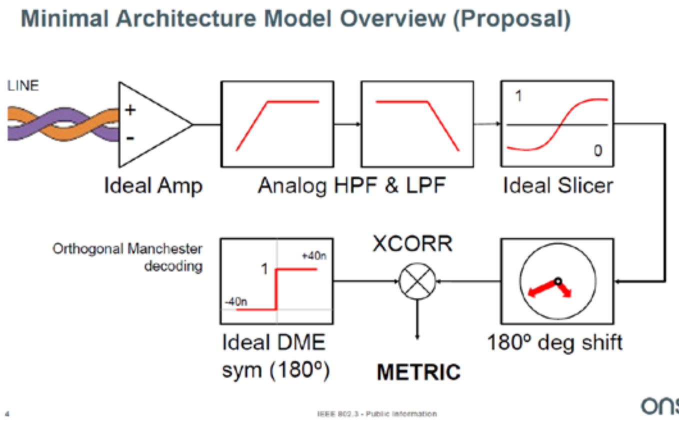
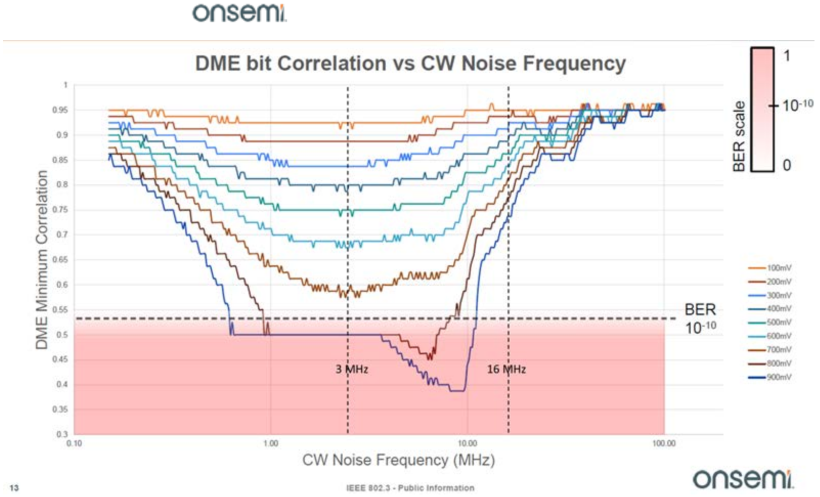
Impact of noise sources falls off below 3 MHz, above 16 MHz

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





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

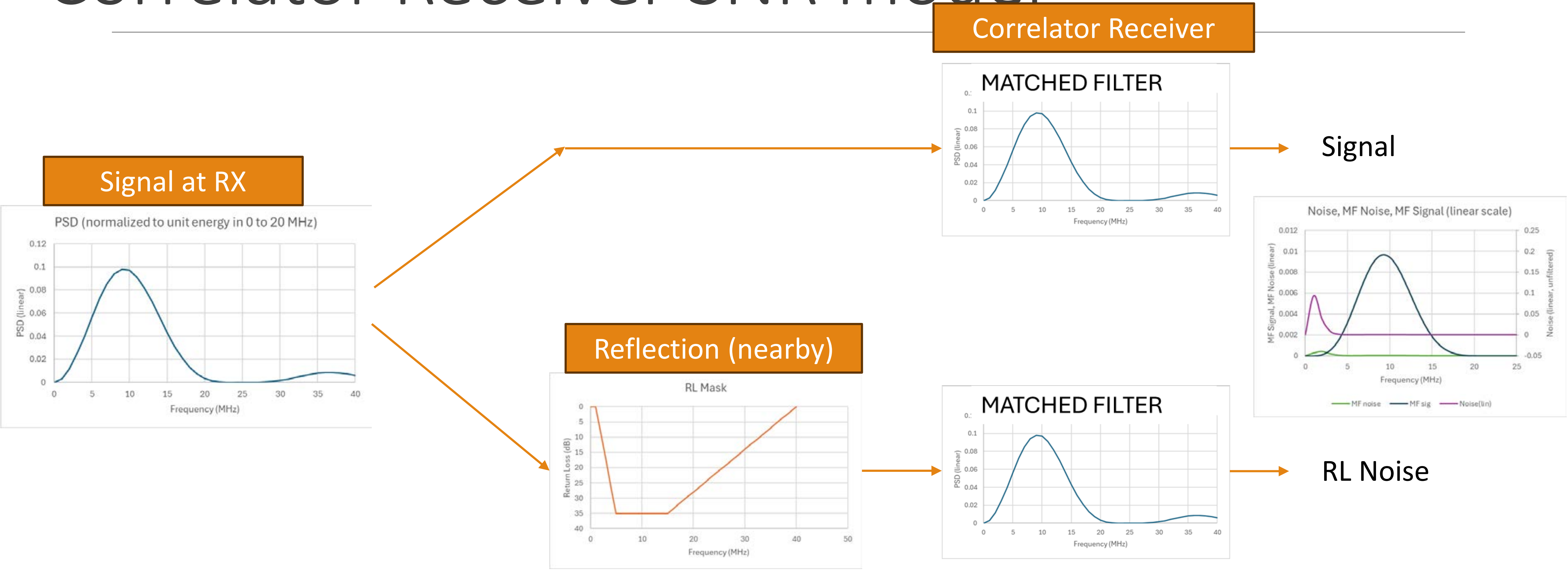
Decorrelated reflections will act as noise source with the transmit PSD x Mask PSD into the receiver

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 result

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

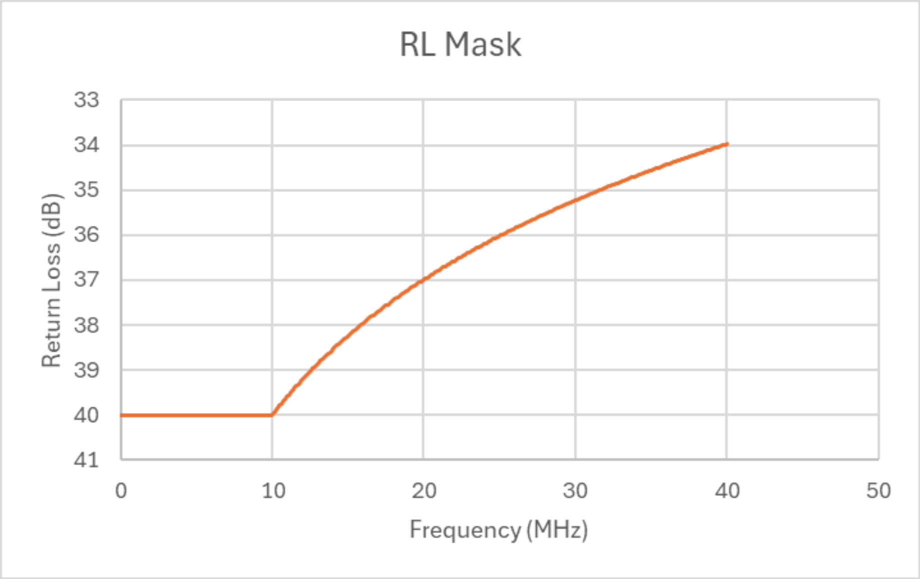
Reference case: ODVA Mask for 40 nodes

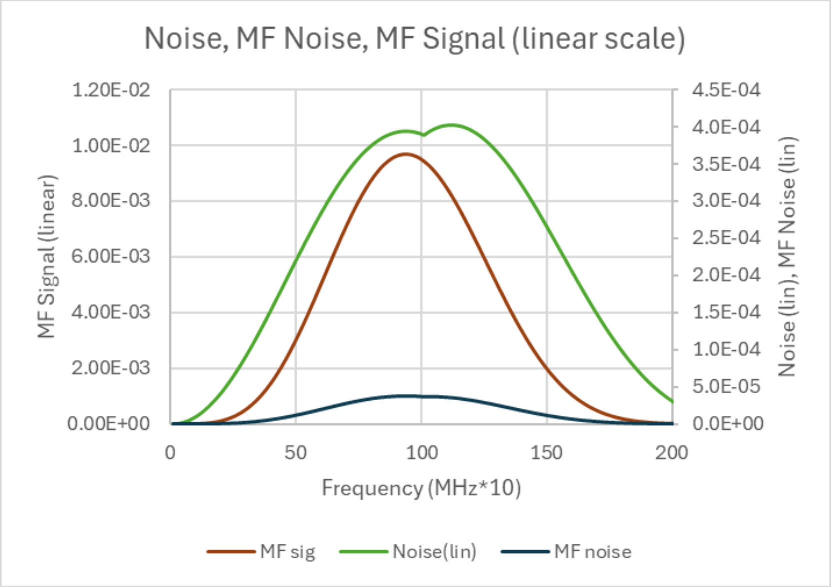
Ref: mask in brandt_3da_01_0324.pdf - gives 23.6 dB MF SNR at 40 nodes

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

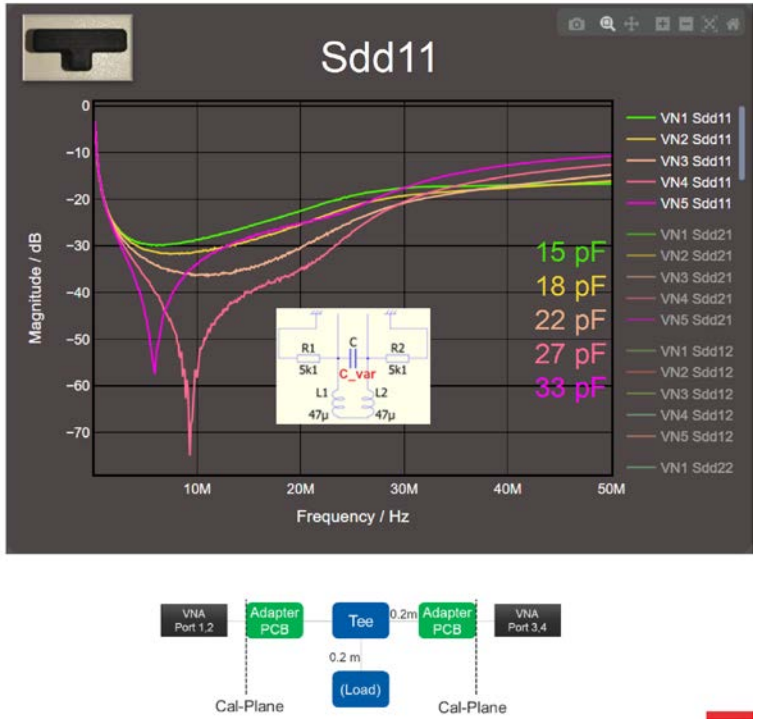




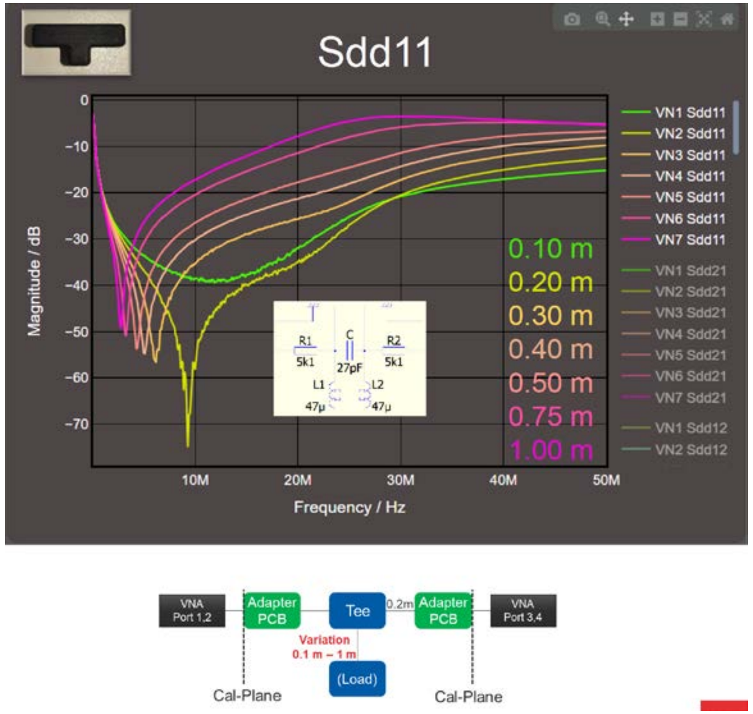
Compare with Existing Models / variation

Schreiner_3da_March_24.pdf – notches move & disappear, shape remains

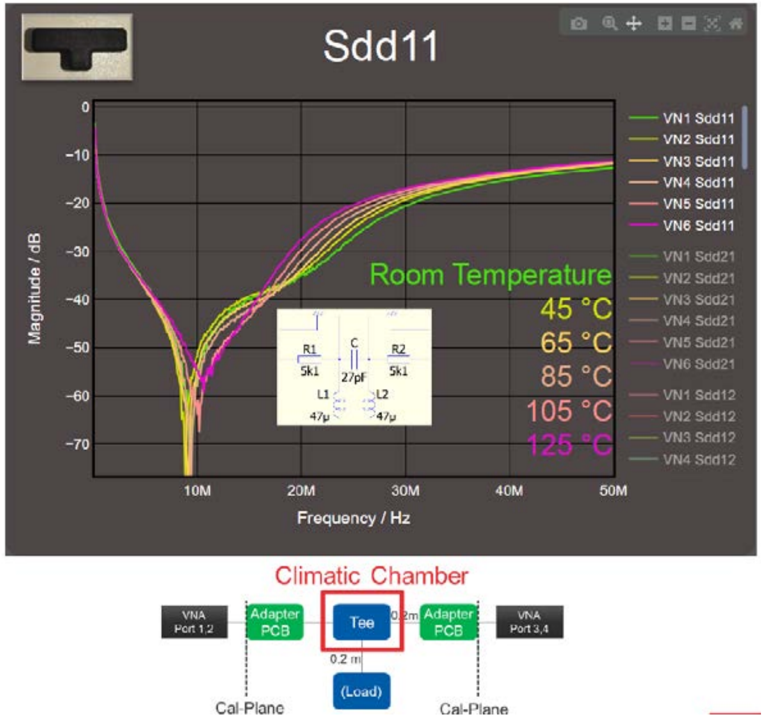
Capacity Variation (slide 9)



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

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

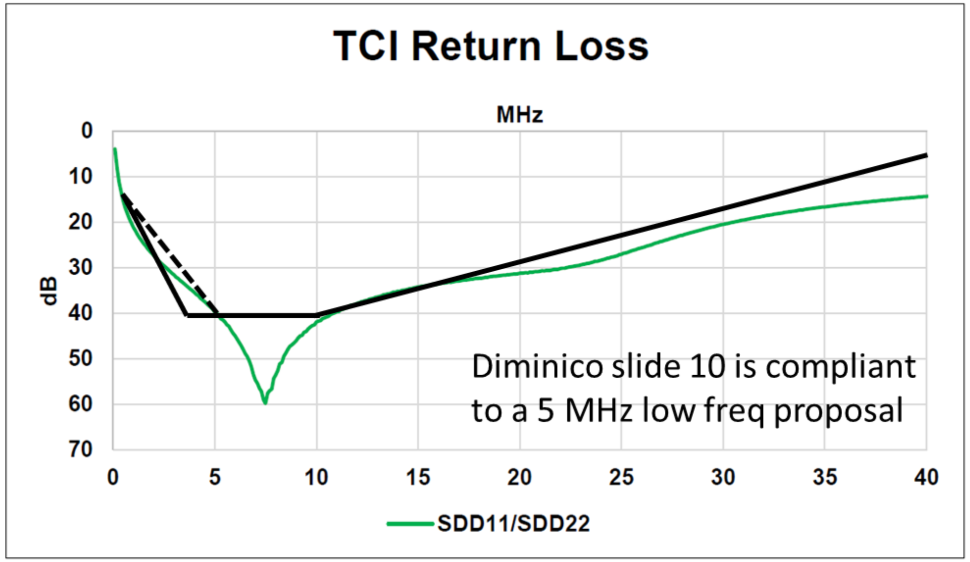
- Increasing lower frequency 40 dB floor start to 5 MHz results in ~0.9 dB SNR loss at 32 nodes relative to reference case (40 node ODVA)
  - 1.8 dB loss at 40 nodes, still > 8 dB margin
  - 3 MHz floor corner reduces loss to ~0.3 dB at 32 nodes, 1.3 dB at 40 nodes
- Fits Schreiner measurements, and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

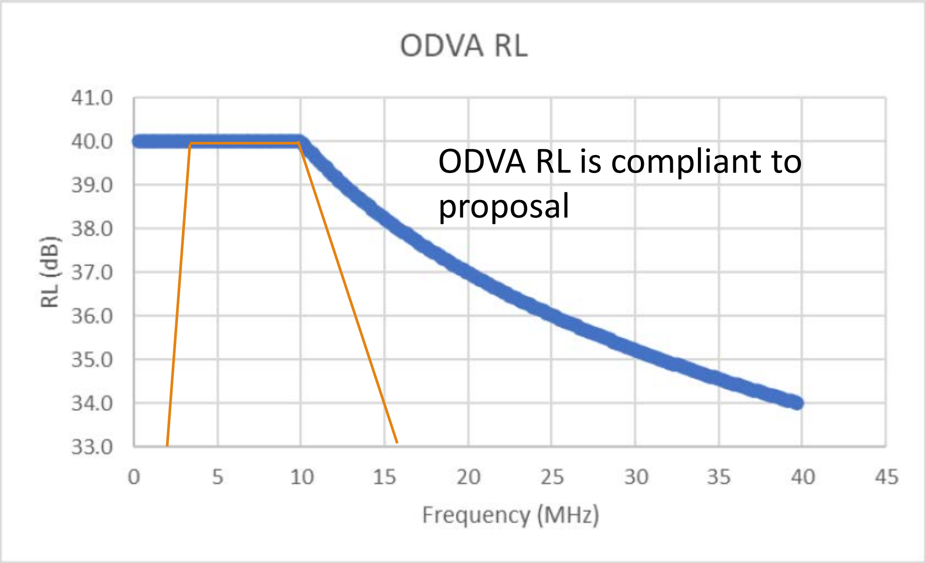
RL Floor	40	dB				Geom SNR	20.2	dB
Mask corners	Low (MHz)	High(MHz)				Linear SNR	21.7	dB
	3	10				MF SNR	23.3	dB
Nodeallow	32	nodes				Nodefactor	15.05	dB
Cutoffs	low (MHz)	high(dB to 40MHz)		lowval	40M RL			
	0.301	6		15	6.00			

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



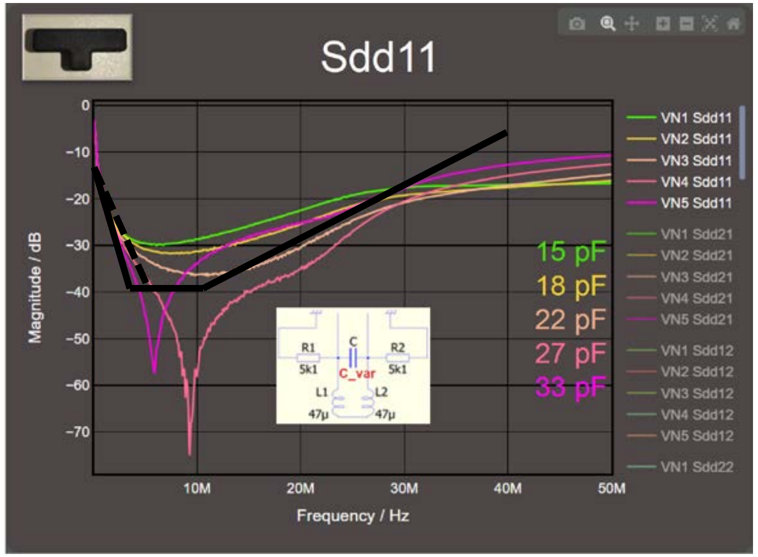
See, e.g., brandt_3da_01_0324.pdf slide 5
(emphasizes lower frequencies)
No allowance for power coupling



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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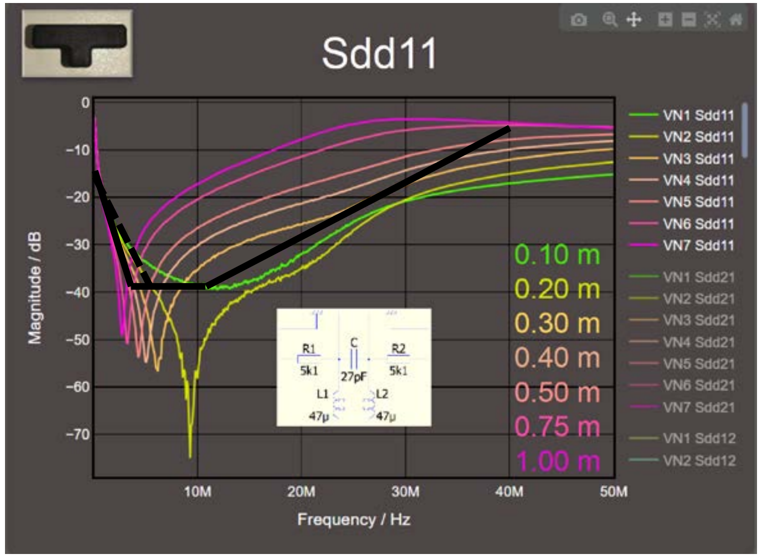

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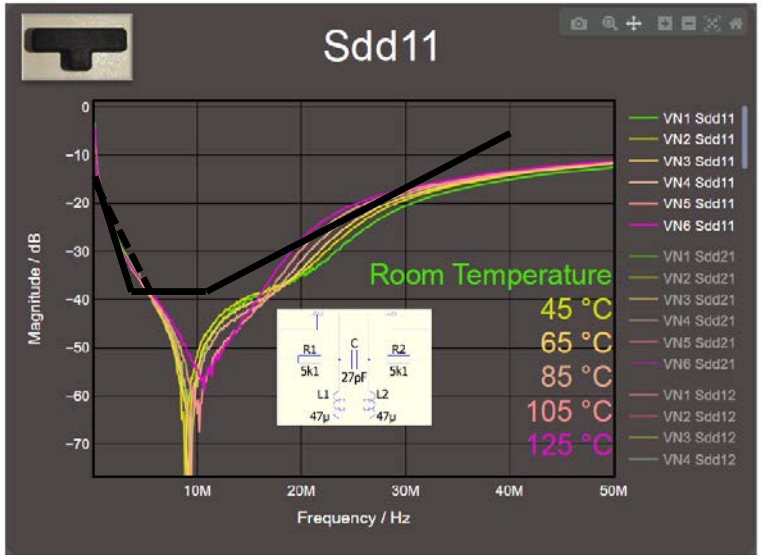
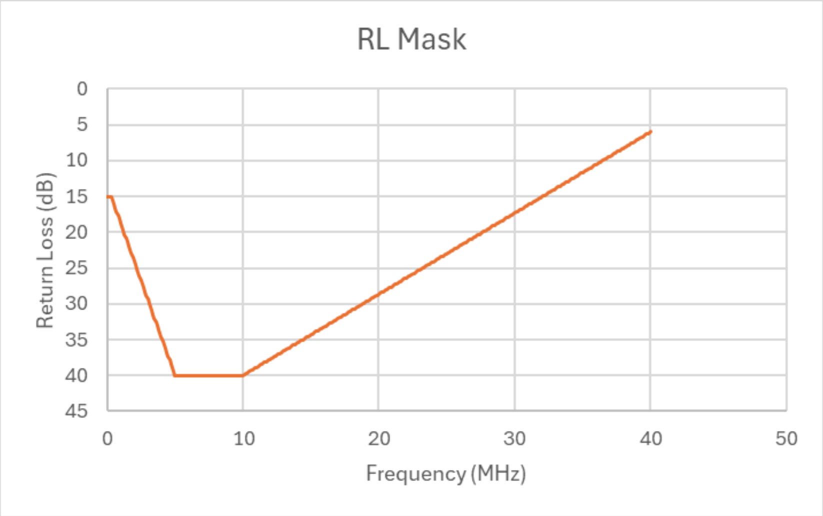


Proposal

Replace TCI return loss (equation 168-5):

RL (f) ≥ 15 + (f-.3)*(25/4.7) dB for 0.3 MHz ≤ f < 5 MHz
40 dB for 5 MHz ≤ f < 10 MHz
40 - (f-10)*(34/30) dB for 10 MHz ≤ f < 40 MHz



Discussion of Performance Loss

We are operating with a budget for ISI that is -10dB relative to detection
- This degrades performance in the dominant noise (e.g., CW or EMC) by 0.4 dB
- For example, 1Vpp uncorrelated noise tolerance becomes 955mVpp

More usual would be to budget ISI -6dB relative to detection
- This would degrade performance in the dominant noise by 1.0 dB
- 1Vpp noise tolerance becomes 891mVpp for uncorrelated noise…

For the uncorrelated case, the difference of a 1dB loss vs. an 0.4 dB loss (0.6dB) can come out of the insertion loss budget (because it is driven by external noise)

However, we may be sensitive to noise such as a 12.5 MHz CW, which would produce a correlated offset at the receiver
- Then, the -6dB point would reduce noise amplitude tolerance by 6 dB (1 Vpp becomes 500 mVpp)
- In this case, -10dB operation may be preferable

Designing to a -6dB point enables greater mismatch, more implementation flexibility, and enables other masks

Designing to the -10dB point enables greater surety in external EMC environments

Mask Comparison

Mask:	ODVA RL	40dB Template	Diminico	1dB Template	Alt 1dB Template
MF SNR(dB)	23.58	22.74	18.10	18.96	19.03
Perf Loss(dB)	0.4	0.4	1.2	1.0	1.0

40dB template (slide 17):

RL (f) ≥	15 + (f-.3)*(25/4.7) dB	for 0.3 MHz ≤ f < 5 MHz
	40 dB	for 5 MHz ≤ f < 10 MHz
	40 - (f-10)*(34/30) dB	for 10 MHz ≤ f < 40 MHz

Diminico:

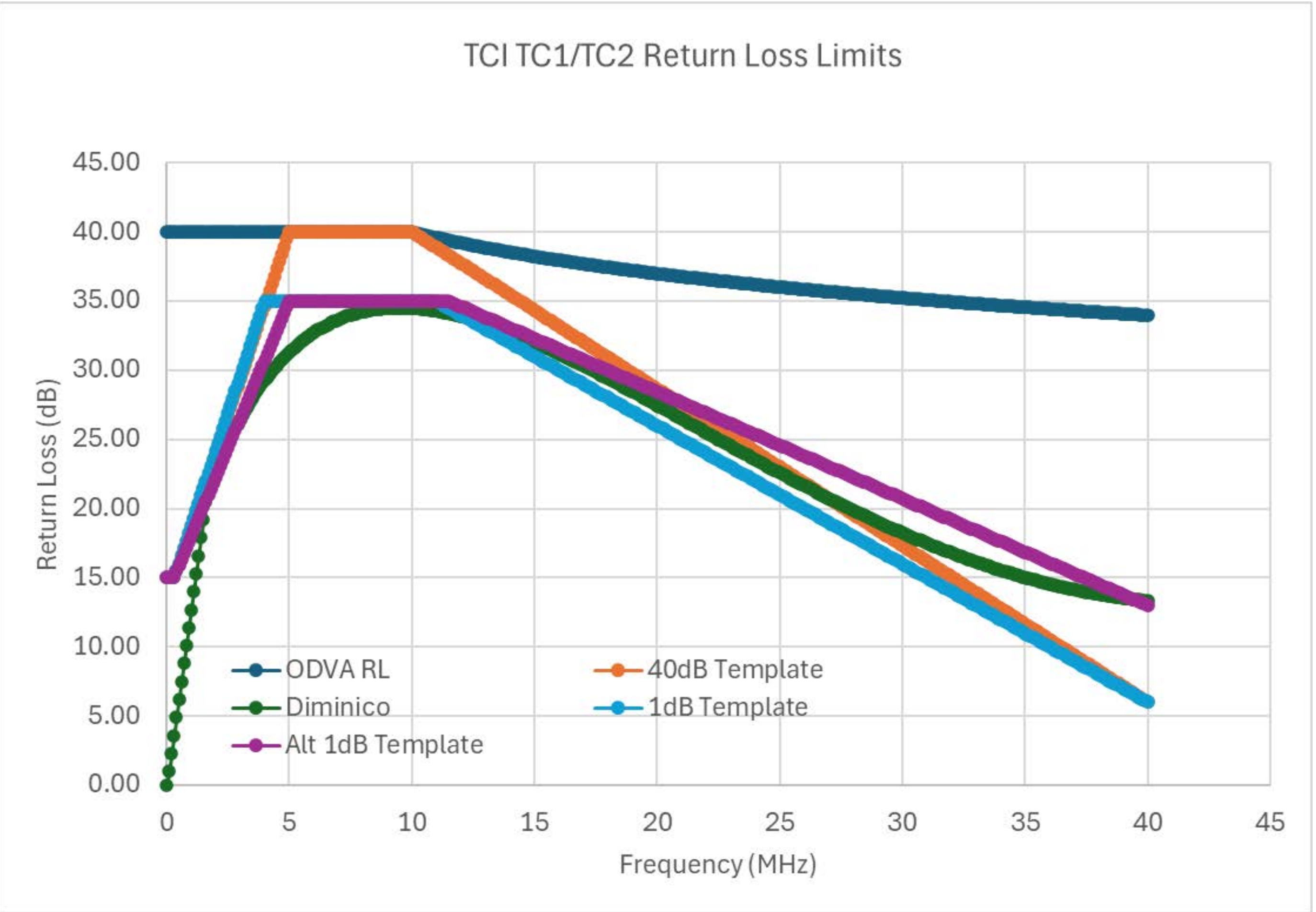
RL (f) ≥	13*(f) - 0.3 dB	for 0.3 MHz ≤ f < 1.7 MHz
	- 38.55- 50.28*LOG(f) - 3.16/f + (69.31*SQRT(f) – 10.19*f + 0.0636*f^2 dB	for 1.7 MHz ≤ f < 40 MHz

1dB template:

RL (f) ≥	15 + (f-.3)*(20/3.7) dB	for 0.3 MHz ≤ f < 4 MHz
	35 dB	for 4 MHz ≤ f < 11 MHz
	35 - (f-11)*(29/29) dB	for 11 MHz ≤ f < 40 MHz

Alt 1dB template:

RL (f) ≥	15 + (f-.3)*(20/4.7) dB	for 0.3 MHz ≤ f < 5 MHz
	35 dB	for 5 MHz ≤ f < 11.5 MHz
	35 - (f-11.5)*(22/28.5) dB	for 11.5 MHz ≤ f < 40 MHz



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Recommendations

Adopt TCI RL Mask proposal on slide 17

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)

Consider whether to specify the minimum delay across a TCI

Thank You