10BASE-T1L Droop / Return Loss vs Power Coupling Magnetics

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ANALOG DEVICES

AHEAD OF WHAT'S POSSIBLE™

Droop vs Magnetics

Droop	Footprint	Volume	Cost	Photo
10%	18.3mm x 18.3mm **3.3cm²**	**4cm³**	100%	
12.6%	12.3mm x 12.3mm **1.5cm²**	**1.2cm³**	49%	
23%	12.3mm x 12.3mm **1.5cm²**	**0.9cm³**	42%	

- Arbitrarily selected magnetics vendor
- Compares droop performance at sustained 2A operation
- 2 inductor packages per power coupling network
- Measured droop values are from a sample size of 1, standard droop values will need to be margined

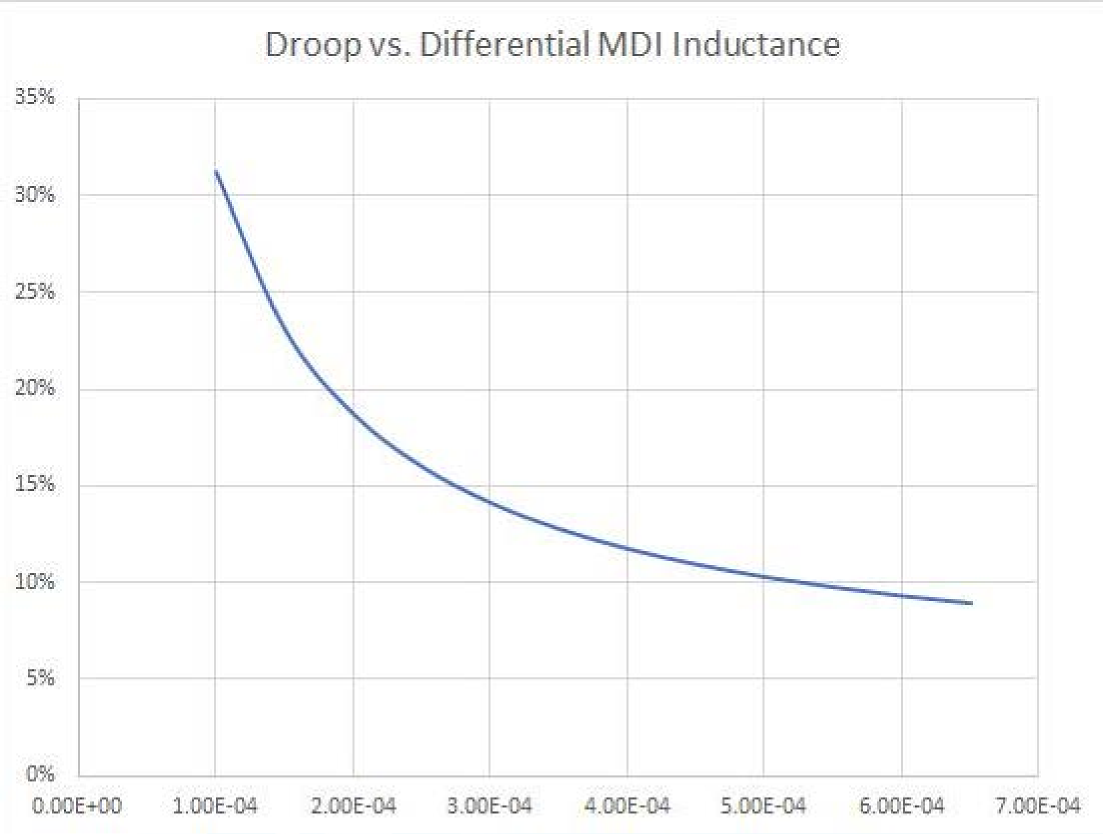
Power Coupling Network Over-specification

- Presently, Class 15 PoDL power coupling network designs have the following attributes
  - Large inductors
  - Heavy inductors
  - 33% to 50% of BOM cost per port
- State of the standard
  - Clause 146 droop requirements driven by intrinsic safety requirements not applicable to the bulk of the market

- Power coupling networks can be economized by rationalizing clause 146 requirements when paired with a Clause 104 PSE or PD
  - Droop
  - Return Loss

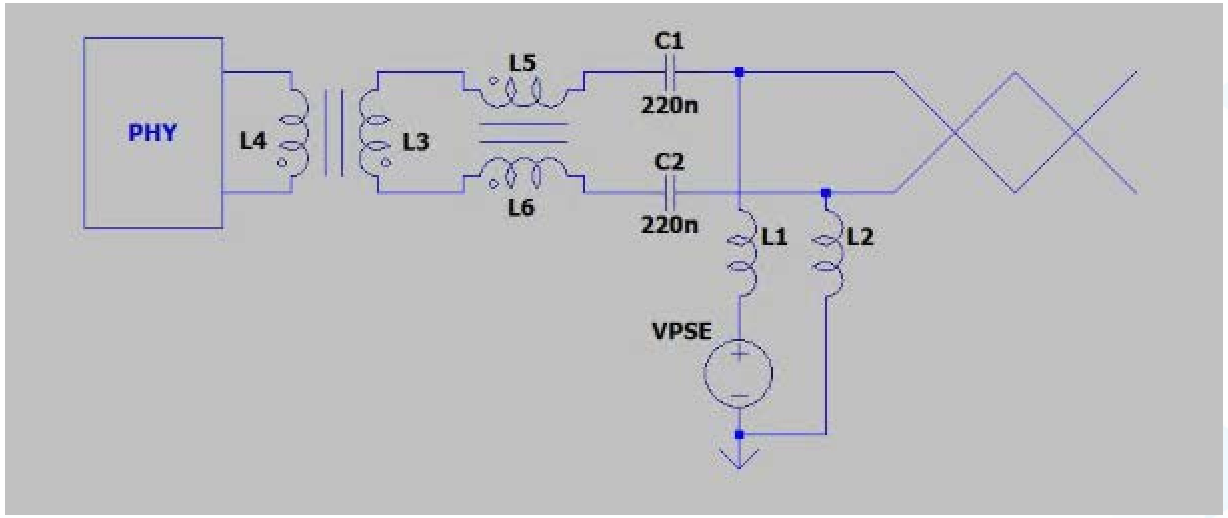
Droop vs Differential MDI Inductance

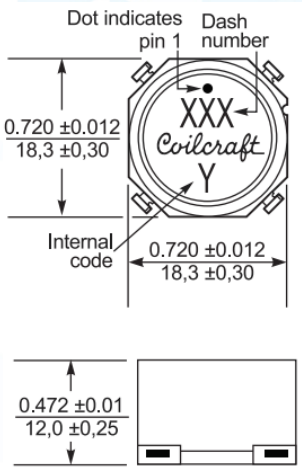
- Assumes
  - 220nF DC blocking caps
  - 10% drop for tolerance
  - 30% drop for voltage coefficient



Existing 10% Droop

- Relative cost: **100%**

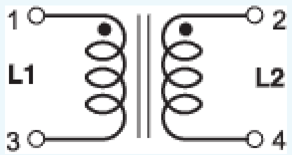


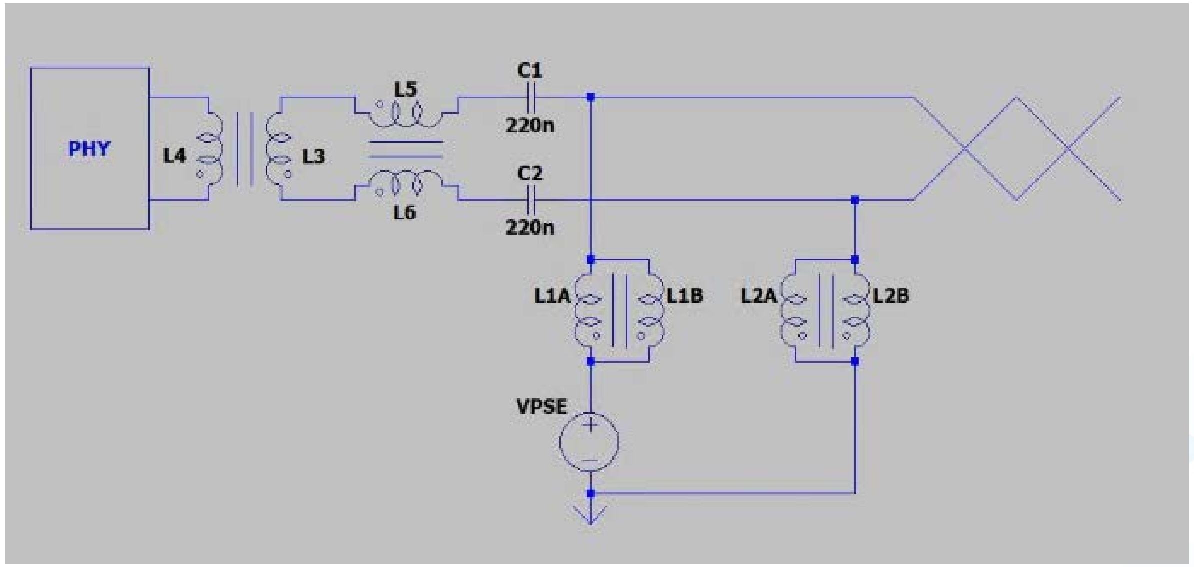


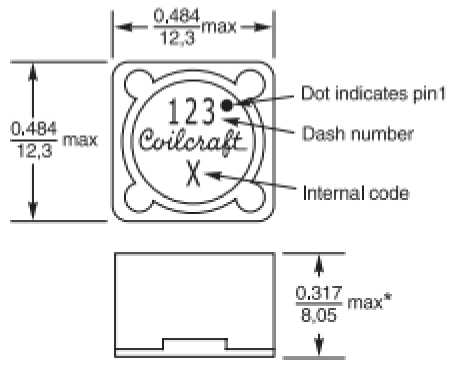
Part number 1	Inductance (µH) 2 *(Tolerance: ±10%)*	DCR (Ω) 3		SRF typ (kHz) 4	Isat (A) 5			Irms (A) 6	
		typ	max		10% drop	20% drop	30% drop	20°C rise	40°C rise
MSS1812T-474KED	470	0.200	0.230	1350.0	2.4	2.7	2.8	1.39	2.10

12.6% Droop

- Relative cost: **49%**



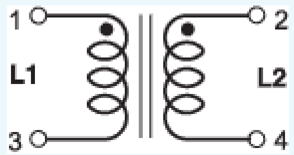


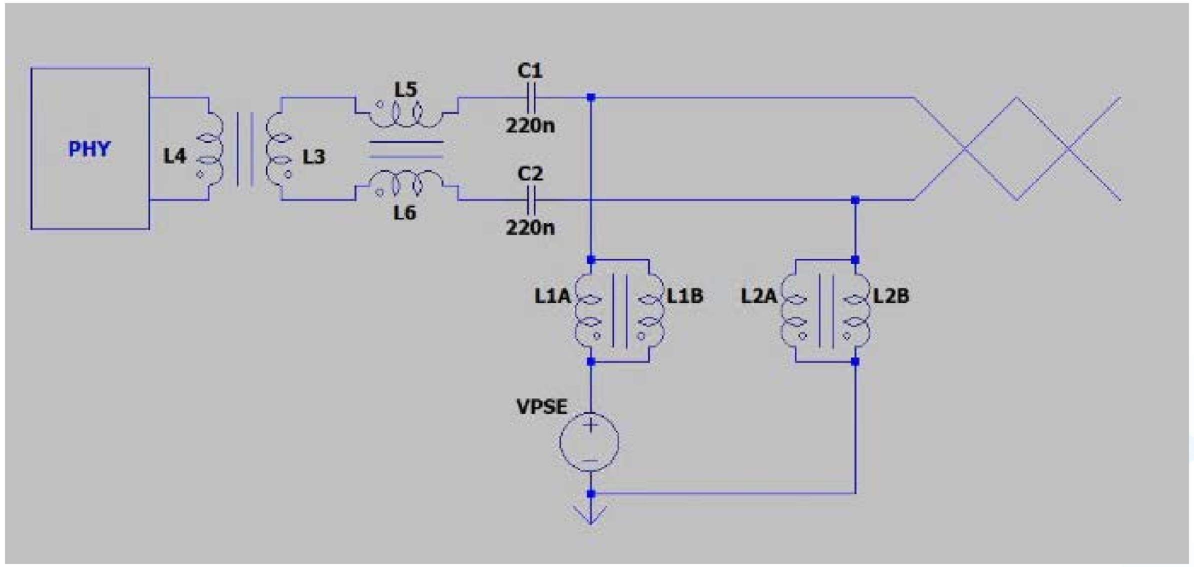


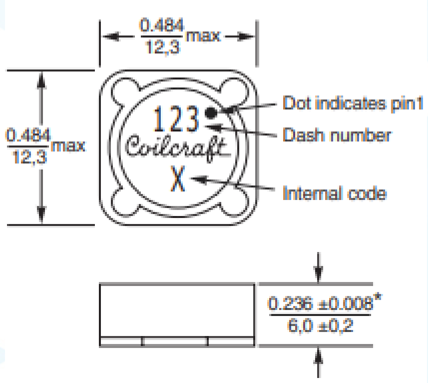
Part number 1 (Hover for schematics)	Inductance (µH) 2 *(Tolerance: ±10%)*	DCR max (Ω) 3	SRF typ (MHz) 4	Coupling coefficient	Leakage Inductance (µH) 5	Isat (A) 6			Irms (A)	
						10% drop	20% drop	30% drop	both windings 7	one winding 8
MSD1278H-184KED	180	0.47	4.2	>0.99	2.5	1.8	2.0	2.2	1.07	1.54

23% Droop

- Relative cost: **42%**







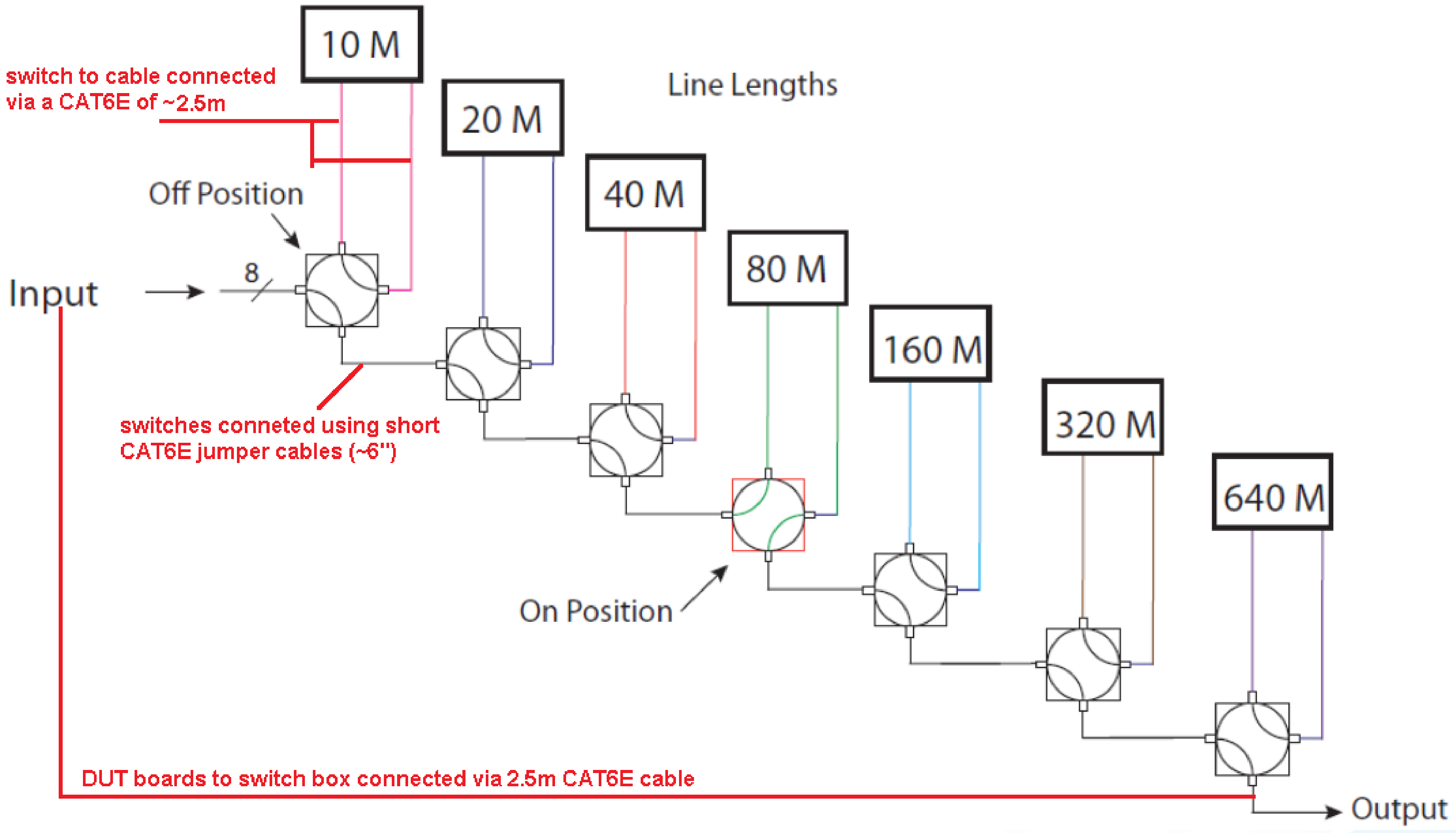
Part number 1 (Hover for schematics)	Inductance (µH) 2 *(Tolerance: ±20%)*	DCR max (Ω) 3	SRF typ (MHz) 4	Coupling coefficient	Leakage Inductance (µH) 5	Isat (A) 6	Irms (A)	
							both windings 7	one winding 8
MSD1260-104ML_	100	0.32	5.0	0.99	1.4	2.2	1.1	1.5

PHY Performance / Conformance with Low Inductance Power Coupling

- A like for like comparison is shown for the PHY performance / conformance with a standard power coupling network that meets the Clause 146 droop requirements versus a low inductance power coupling network
  - Identical setup in both case – only difference is the power coupling inductor
  - Worst case channel beyond IEEE limits
    - Target a worst case channel with large number of connectors / cable segments, sweeping from 0m to 1000m
    - Add noise greater than the IEEE limit to stress the PHYs
    - Push the channel to the limit where the PHYs cannot bring up links at both 1.0V and 2.4V peak-peak transmit levels at longer cable lengths around 1000m
  - Aim is to compare the standard power coupling with low inductance under conditions where the PHY is already severely stressed
- Typically a 10BASE-T1L PHY can operate over a single cable with no noise at well over 1500m at both 1.0V and 2.4V peak-peak transmit levels
  - However, once worst case channels are used and significant amounts of noise are added the reach deteriorates significantly
  - The benefit of 2.4V peak-peak transmit level is tolerance to a greater amount of noise

PHY Cable Sweep Setup

- The following is the lab setup for 10BASE-T1L cable sweep testing
  - By switching in different cable lengths we can cover increments of 10m out to >1000m
  - Use a mix of cables to create worst case channels



5 segment, 24 pair G-fast DSL switch.

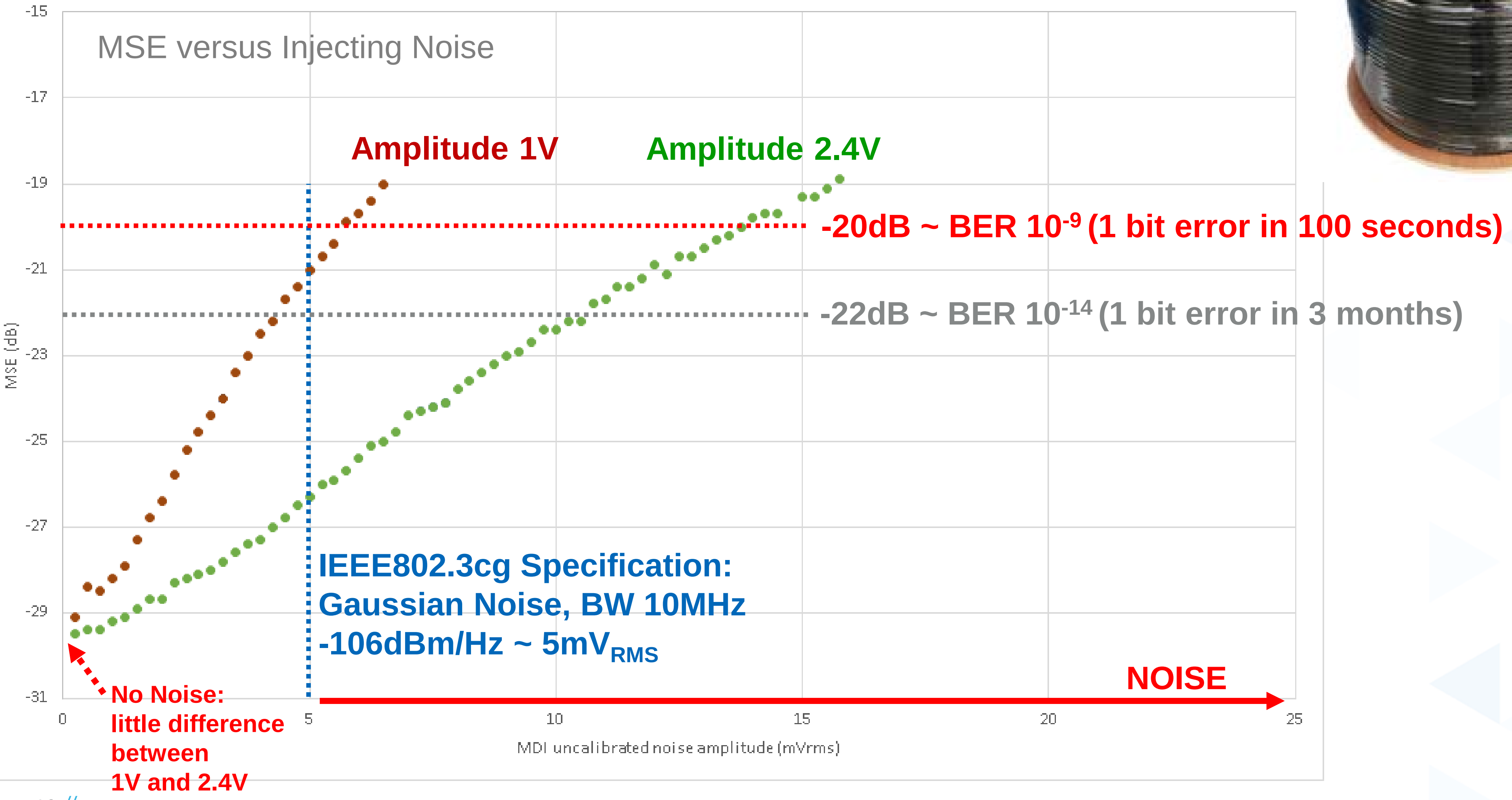
All the 4 connectors for switch node are accessible via RJ45 headers on the backplane of the switch box.

MDI connector on DUT board:
Phoenix 1803280
MC 1,5/ 3-G-3,81

MDI connector on cables:
Phoenix 1803581
MC 1,5/ 3-ST-3,81

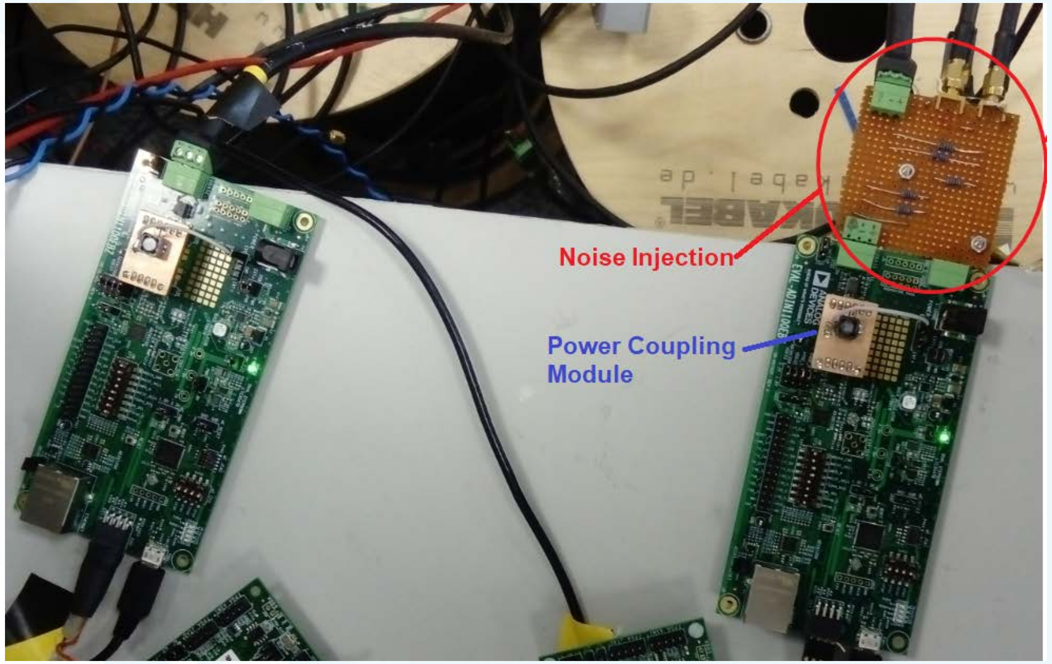
Baseline PHY Performance with Noise

> 1000m cables combined to be close to specification limit (IEEE802.3cg 146.7.1.1.1 Link Segment Insertion Loss)



PHY Performance 0 to 1000m with Link Statistics

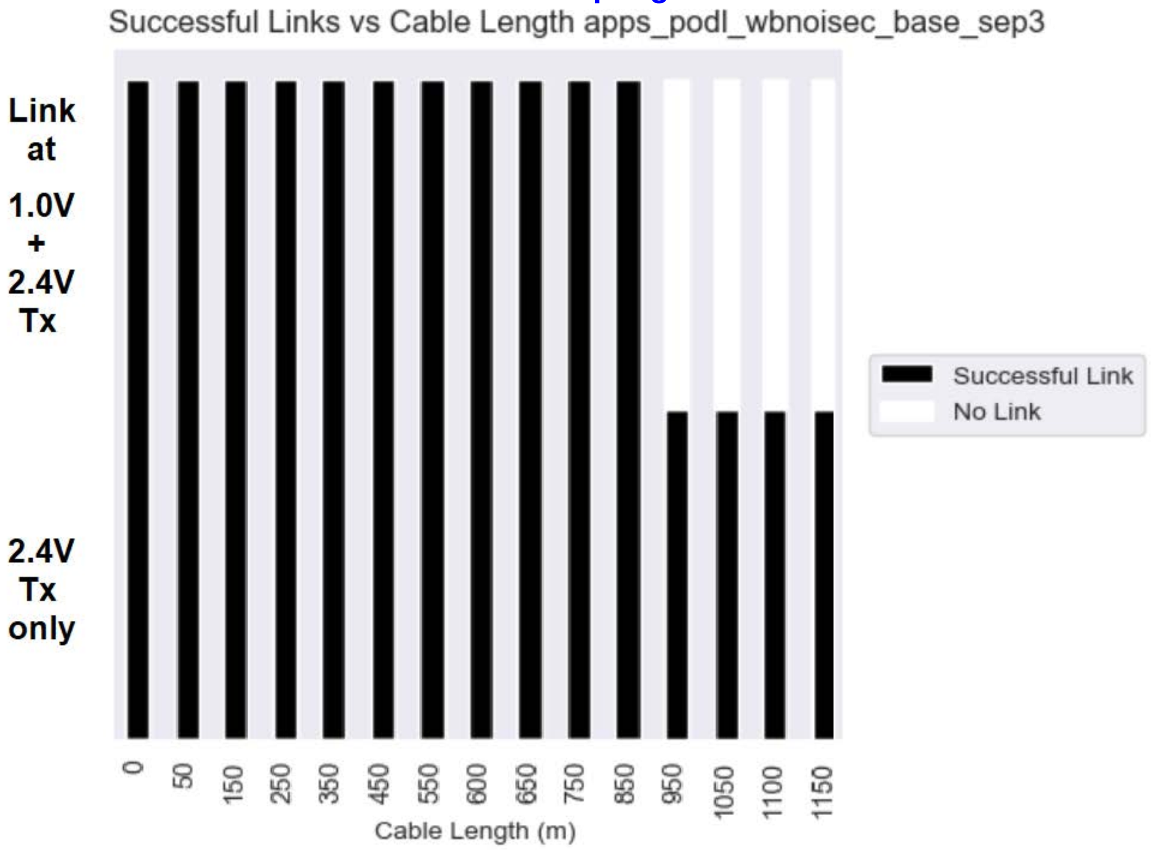
- Worst case channel, wideband noise greater than IEEE limits
  - Side by side results with standard power coupling network at 10% droop using 470 μH inductors vs. 25% droop using coupled 39 μH inductors
    - For component tolerance, tested beyond the 23% droop / 100 μH inductor
    - Essentially slide 5 vs. slide 7
- Ran a number of different tests to verify that there is very little impact on PHY performance
  - Cable sweeps 0 to 1000m with a link up at 1.0V and 2.4V peak-peak transmit amplitude
    - Transmit data, capture link statistics, MSE, link up times, etc.
  - Cable sweeps 0 to 1000m with 100 link-up attempts at 1.0V and 2.4V peak-peak transmit amplitude
    - Verify successful link-up
  - IEEE conformance data for droop and return loss
  - Tested a range of inductors: 120μH, 82μH & 39μH



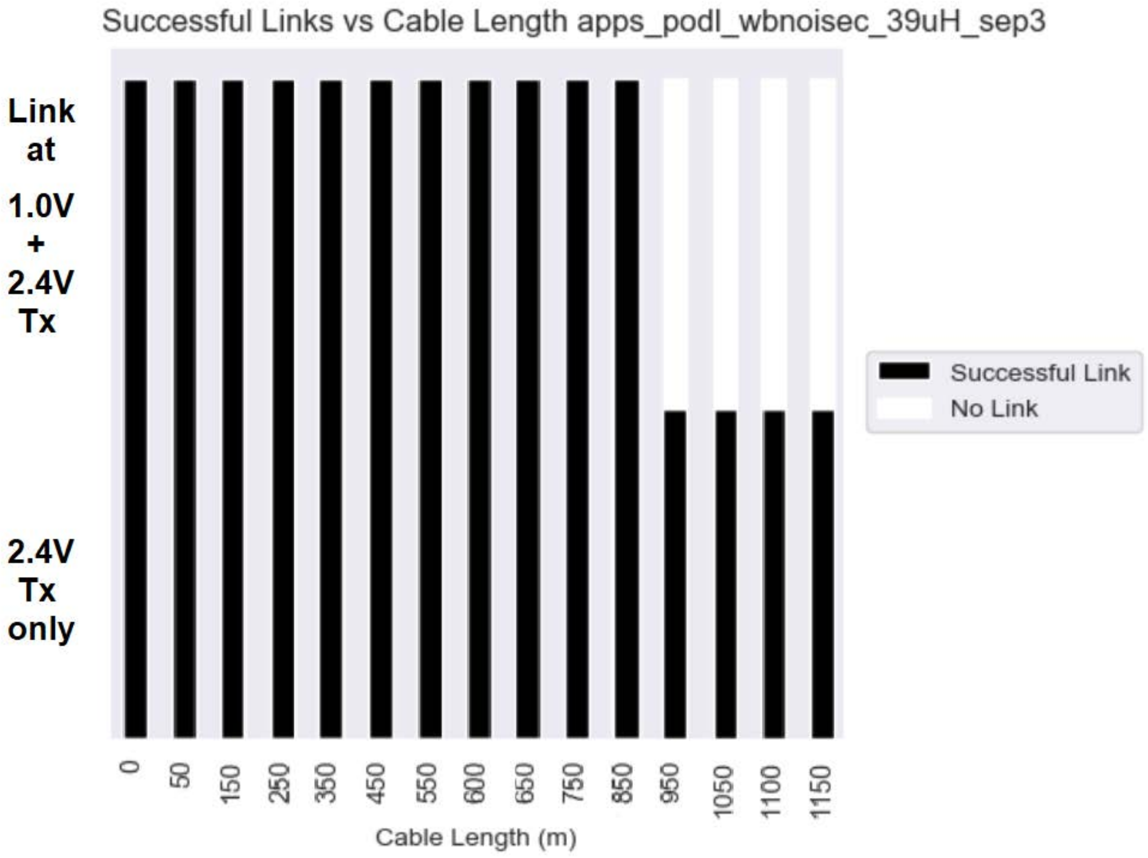
PHY Performance 0 to 1000m Cable Sweeps

- Side by side comparison of standard power coupling network with low inductance power coupling
  - One link-up attempt at 1.0V and one link-up attempt at 2.4V transmit amplitude
  - Under these worst case channel condition the PHY does not link-up at 1.0V peak-peak Tx amplitude at longer lengths – but no difference in performance

Standard Power Coupling



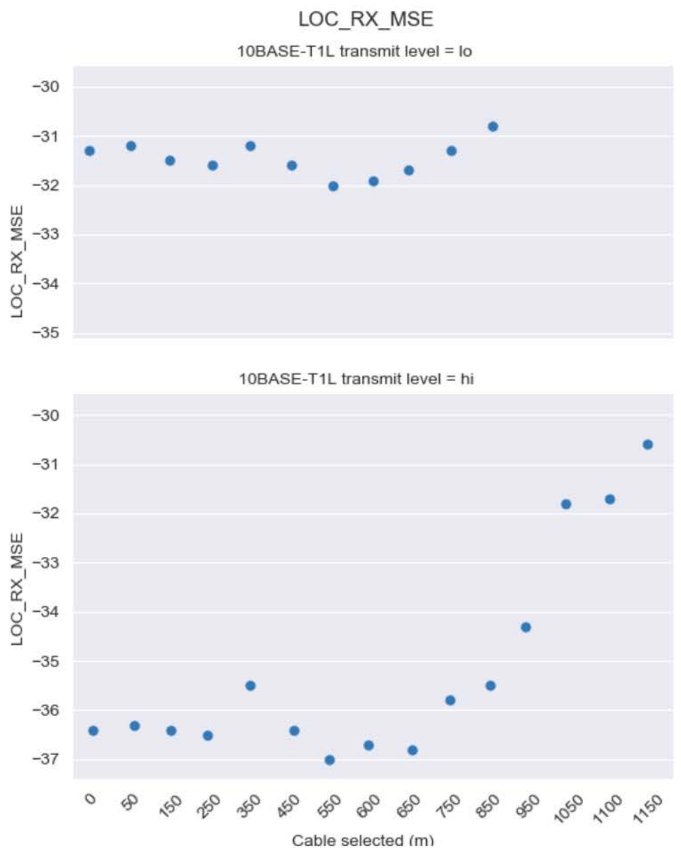
Low Inductance Power Coupling - 78µH



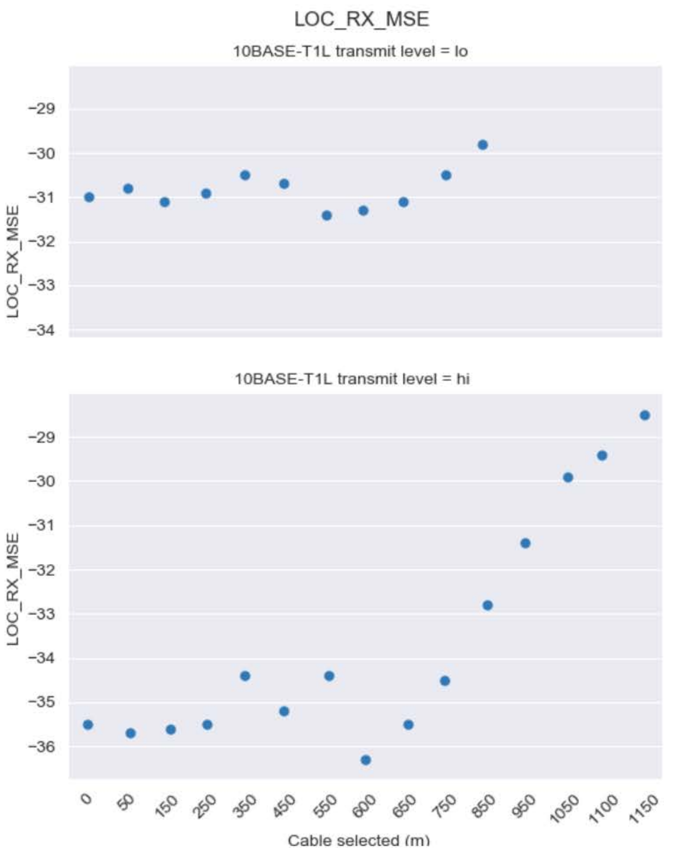
PHY Performance 0 to 1000m - MSE

- Side by side comparison of standard power coupling network with low inductance power coupling
  - MSE for 1.0V and 2.4V transmit amplitude shown – little difference in performance
    - Looks like about 1dB reduction in MSE between the two cases – but still lots of margin

Standard Power Coupling



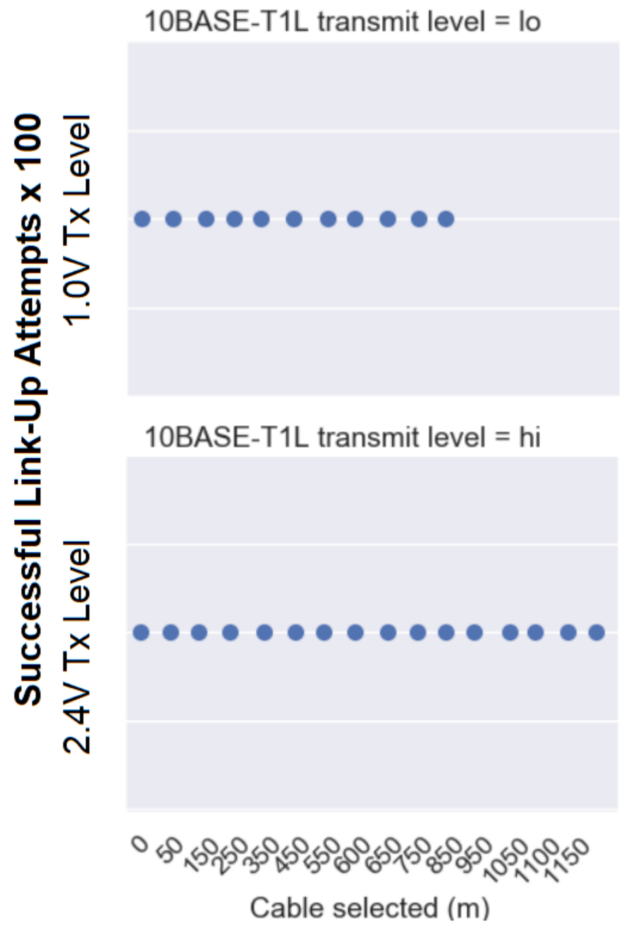
Low Inductance Power Coupling - 78µH



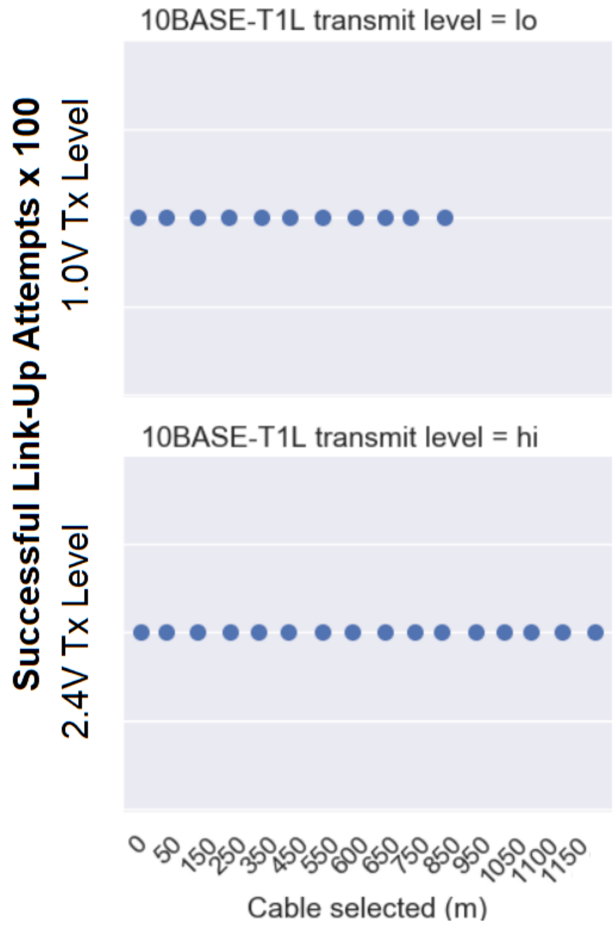
PHY Performance 0 to 1000m – Multiple Link-up's

- Side by side comparison of standard power coupling network with low inductance power coupling
  - Successful link up for 100 attempts at 1.0V and 2.4V transmit level – no difference in performance

Standard Power Coupling



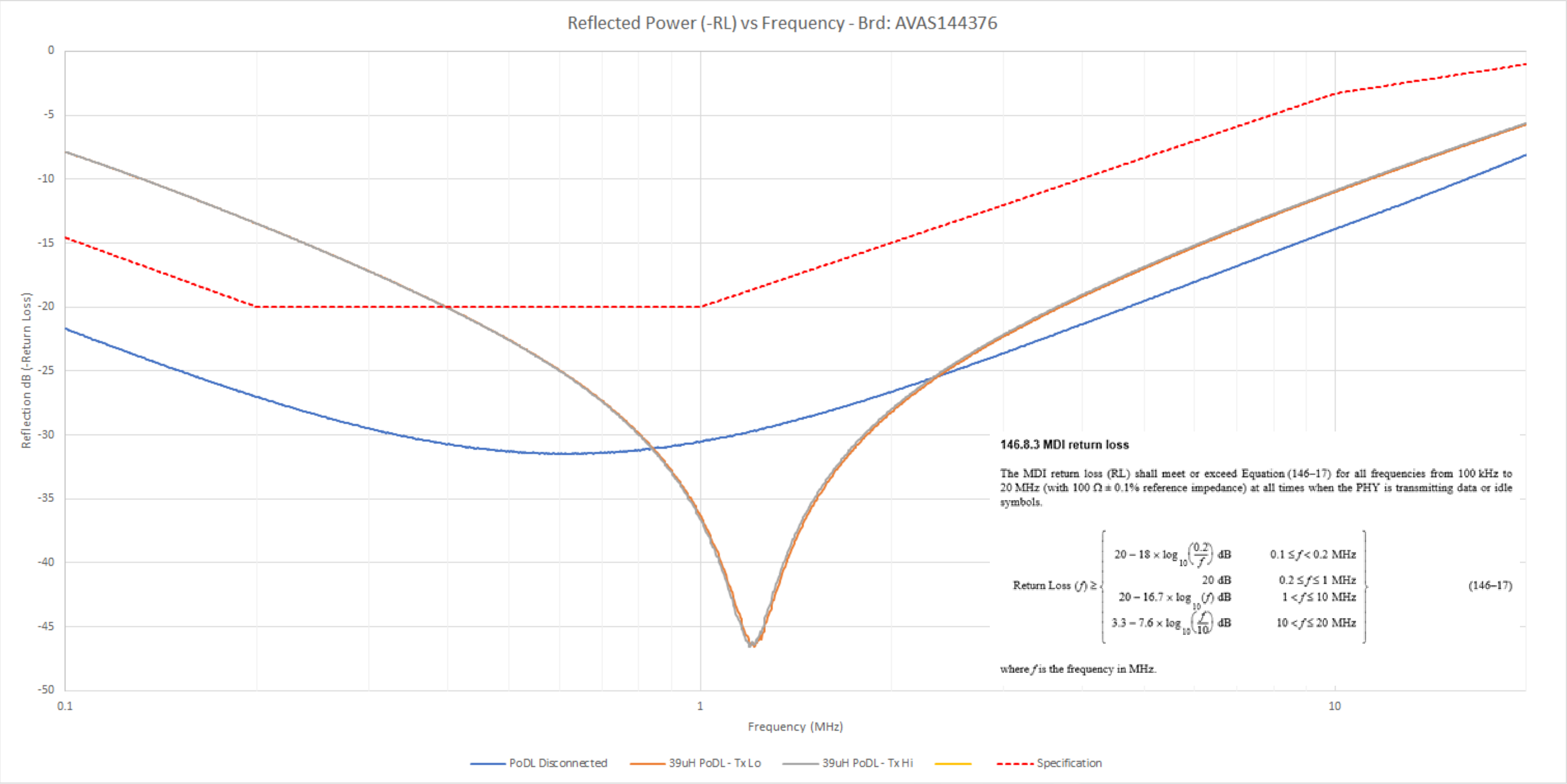
Low Inductance Power Coupling - 78µH



PHY Conformance – Return Loss

- Return Loss is impacted at lower frequencies by low inductance power coupling network

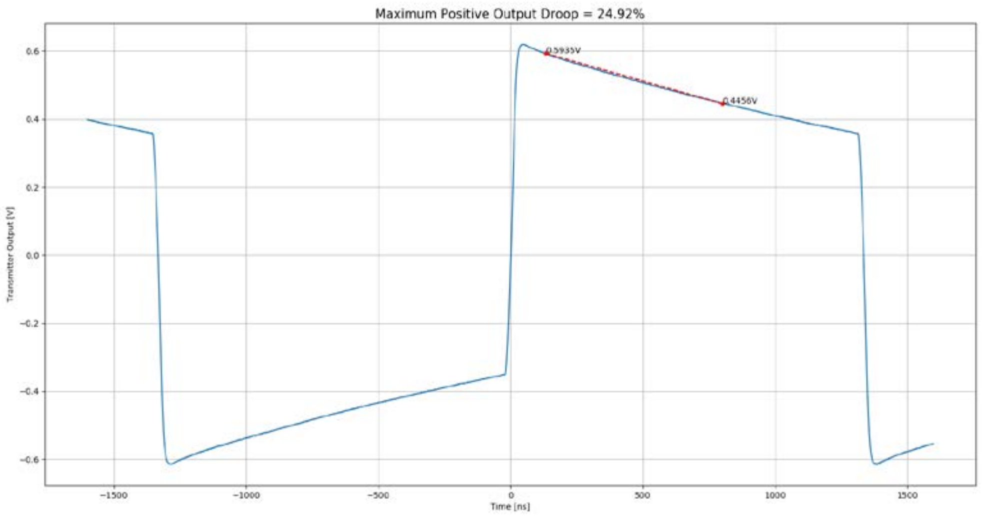
Low Inductance Power Coupling - 78µH



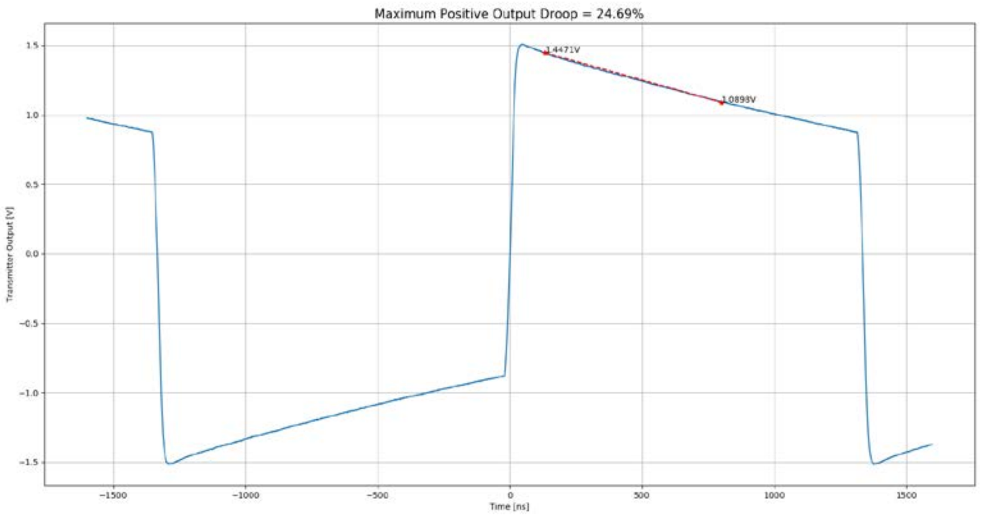
PHY Conformance - Droop

- Droop is increased to ~25% by the low inductance power coupling network
  - Shown for the 1.0V and 2.4V peak-peak transmit signals

1V Low Inductance Power Coupling - 78µH

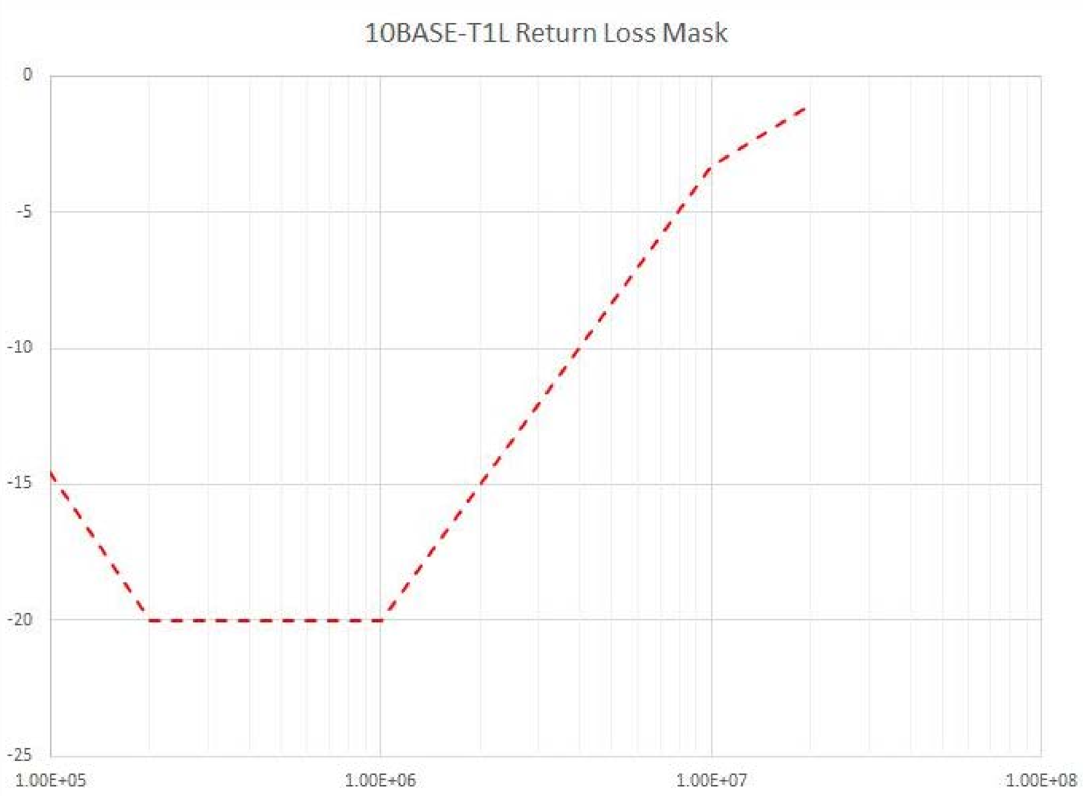


2.4V Low Inductance Power Coupling - 78µH



Thank You

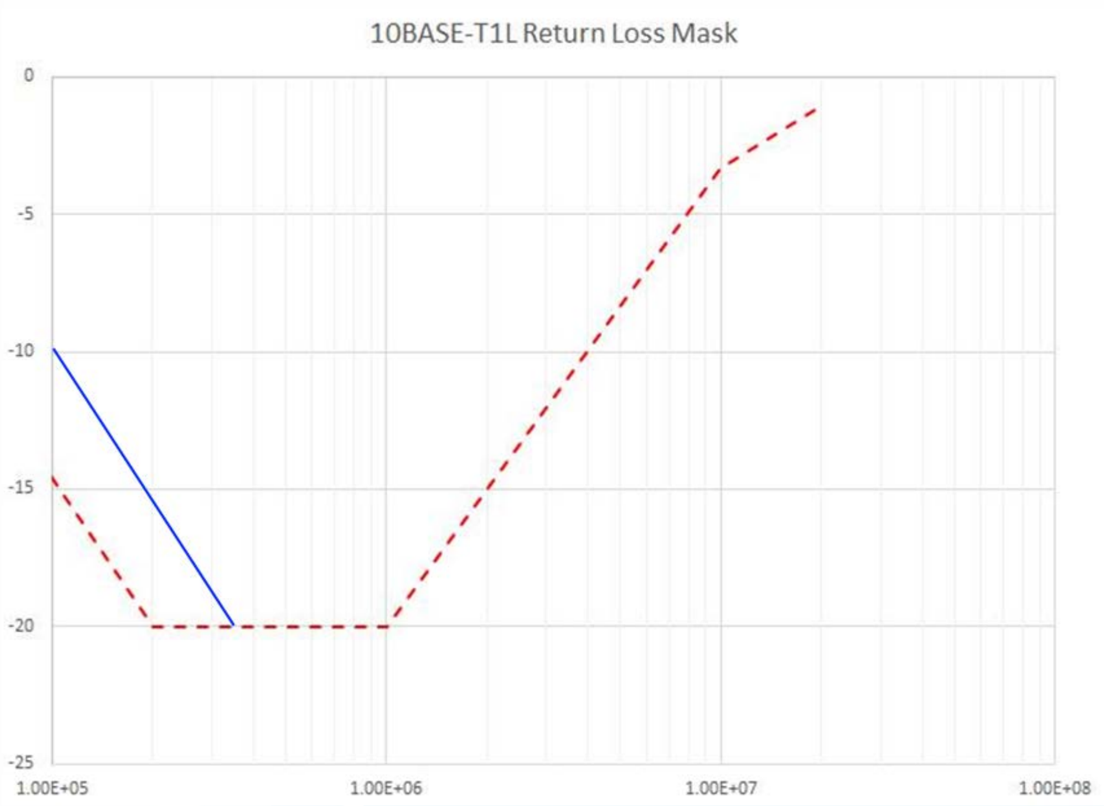
Existing Clause 146 Return Loss Requirement

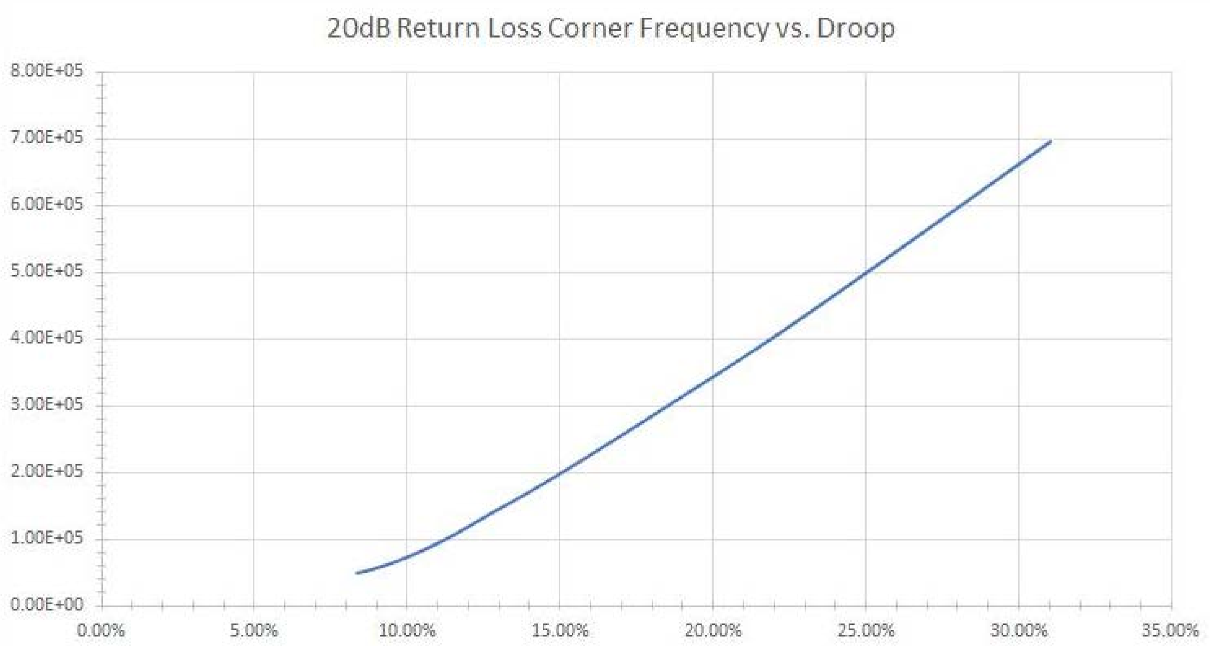


- **Right:** Illustration of Return Loss
- **Bottom:** Actual Clause 146 requirement

$$\text{Return Loss}(f) \geq \begin{cases} 20 - 18 \times \log_{10}\left(\frac{0.2}{f}\right) \text{ dB} & 0.1 \leq f < 0.2 \text{ MHz} \\ 20 \text{ dB} & 0.2 \leq f \leq 1 \text{ MHz} \\ 20 - 16.7 \times \log_{10}(f) \text{ dB} & 1 < f \leq 10 \text{ MHz} \\ 3.3 - 7.6 \times \log_{10}\left(\frac{f}{10}\right) \text{ dB} & 10 < f \leq 20 \text{ MHz} \end{cases} \quad (146\text{–}17)$$

Return Loss for Exemplar 20% Droop





Insertion Loss vs Droop