Supplemental Measurements of System Background Noise in 10GBASE-T Systems

IEEE P802.3bq 40GBASE-T Task Force

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Supplemental Noise Measurements Purpose & Goals

- Purpose – Characterize background noise in representative systems that are candidates for 40GBASE-T PHYs
  - Support the P802.3bq PHY Baseline Proposal ad hoc's request for "…measurement results of background noise in systems, including broadband, stationary, and nonstationary narrowband sources."
  - Why? System background noise power may be a significant factor in optimizing 40GBASE-T PHY designs

- Goals - This is a follow-on assessment intended to
  - Better establish absolute system background noise levels
  - Provide examples of background noise observed on other 10GBASE-T systems (server LAN-On-Motherboard, or LOM; switch)

Methodology Overview

- Establish the measurement noise floor
  - PSD of noise from 500kHz to 3GHz at reference plane
    - Common-mode termination on short S/FTP RJ45 patch cord
  - Use instrument-specific capability* to extend the measurement noise floor
- Characterize system background noise
  - PHY active but with all transmitters disabled
  - Measure system noise at MDI
    - RJ45 connection
  - Subtract measurement noise floor to highlight system-specific background noise

*Specifically, Noise Floor Extension

Noise Floor Extension (NFE)

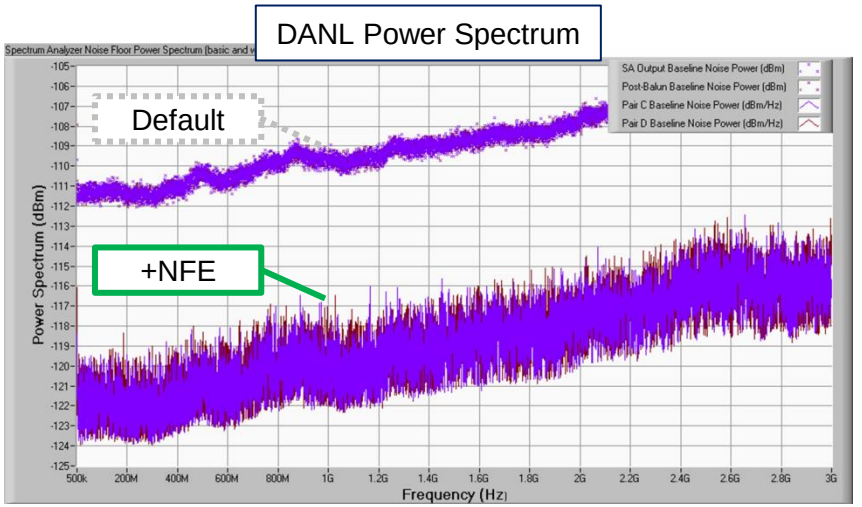
- Measurements made within ~20dB of an analyzer's displayed noise level will be affected by noise
  - Analyzer noise adds to the apparent power of the measured signal
  - The result that is somewhat higher than the true/actual figure
- Typical solutions
  - Reduce analyzer RBW
  - Add a low-noise amplifier/pre-amp
  - Reduce/eliminate instrument attenuation
  - Enable averaging (reduce VBW, average traces, use an average detector) to reduce variability
- Alternative
  - Model noise power and subtract from measurement results to reduce the effective noise level = Noise Floor Extension (NFE)

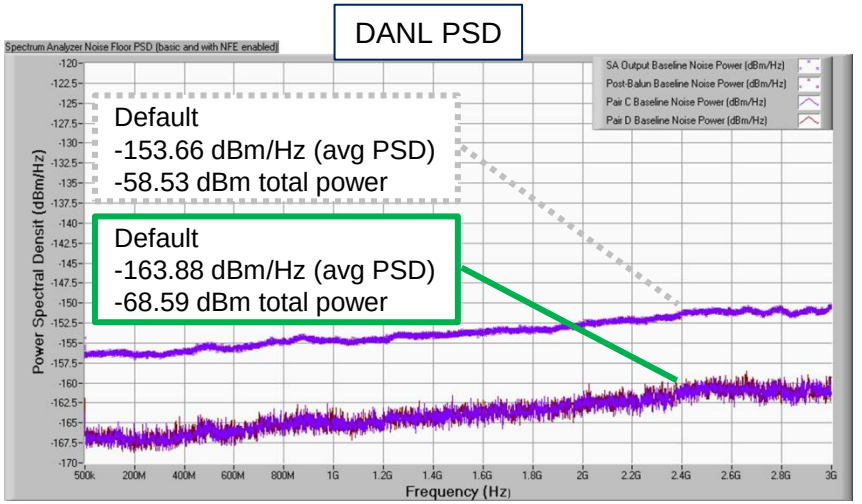
NFE Effectiveness

- Average DANL is usually reduced by 10 to12 dB below 3GHz
  - Apparent noise level is reduced, but only analyzer noise power is subtracted
  - Apparent displayed signal power will be reduced only if the analyzer noise power is a significant part of their power
- Both discrete signals and the signal noise floor are more accurately measured with NFE enabled.

Spectrum Analyzer DANL Comparison

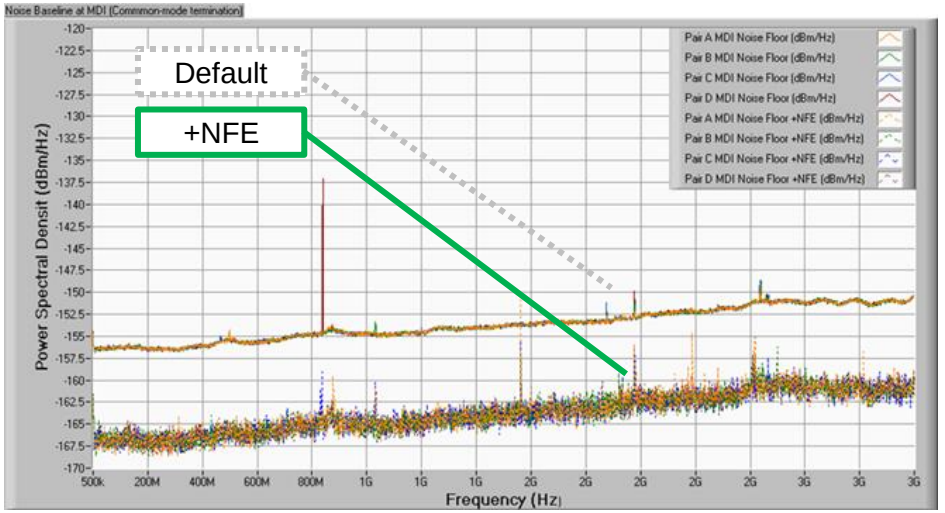
- Displayed Average Noise Level, or DANL, is noise generated within the spectrum analyzer (SA) itself
  - Plots show the SA DANL (top) and noise PSD (bottom) with settings used for background noise measurements
  - The top pair of traces (purple & crimson “x”) in each plot is the DANL measured at the SA input and balun (50 ohm terminations) without NFE
  - The bottom pair of traces in each plot is the same measurement with NFE enabled





Measurement Noise Floor With & Without NFE

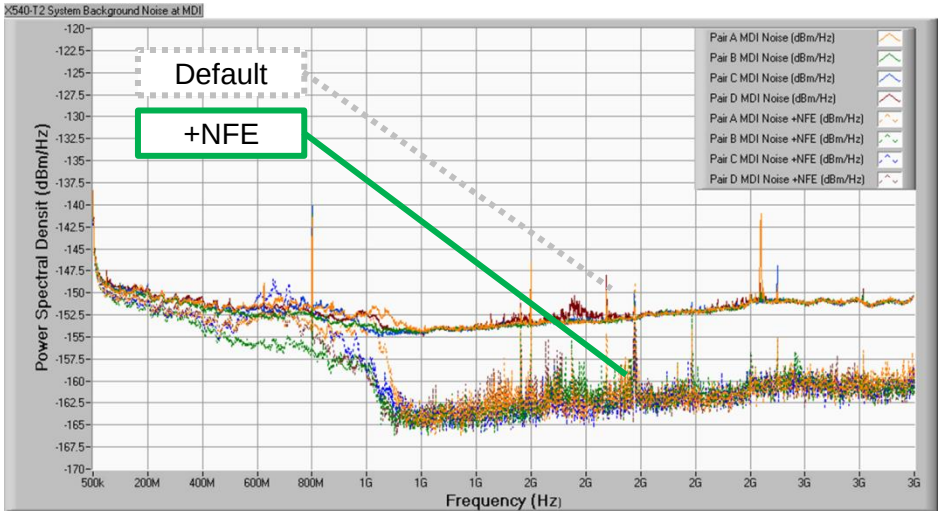
- Noise floor as measured at the MDI interface (RJ45 plug) is consistent across all 4 pairs and ~10dBm/Hz better than previous results
  - Average noise is improved from approximately -153.7 dBm/Hz to -**163.7 dBm/Hz**
  - Noise power (PSD integrated from 500kHz – 3GHz) is improved from approximately -58.5 dBm to **-68.4 dBm/Hz**
- The 10dBm/Hz improvement is reflected in subsequent measurements



Pair (Pins)	Average noise (dBm/Hz)	Average noise (dBm/Hz) with NFE	Noise Power (dBm)	Noise Power (dBm) with NFE
A (1,2)	-153.67	**-163.71**	-58.52	**-68.31**
B (3,6)	-153.67	**-163.76**	-58.52	**-68.40**
C (4,5)	-153.67	**-163.75**	-58.52	**-68.41**
D (7,8)	-153.66	**-163.72**	-58.52	**-68.37**

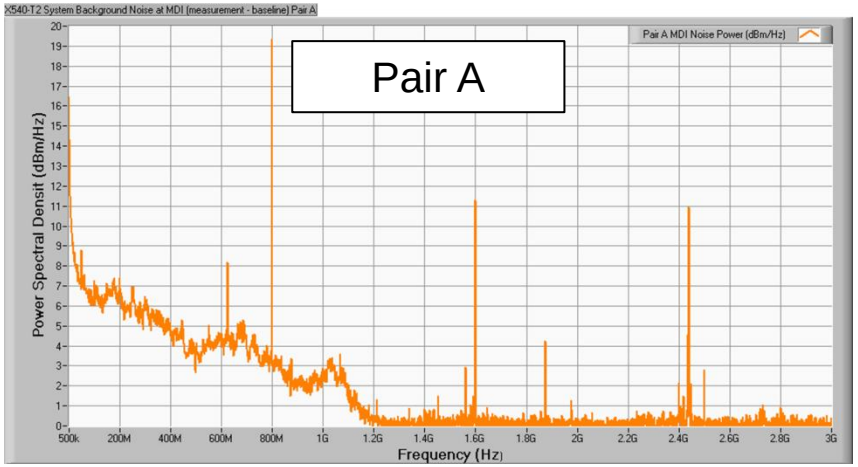
DUT #1 MDI Noise With & Without NFE

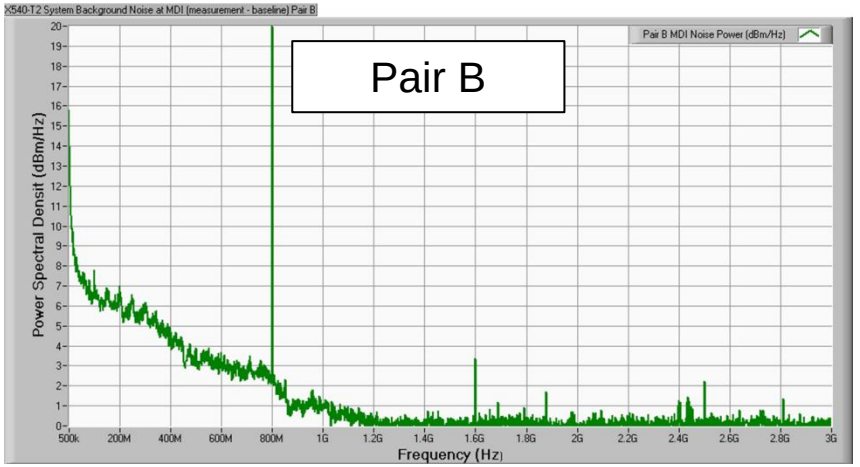
- System background noise for DUT #1 as measured at the MDI interface (RJ45 jack) displays the following characteristics:
  - Broadband source(s) from 500kHz to ~1.2GHz
  - Narrowband source (800MHz, 1.6GHz)
  - Narrowband source (625MHz, 1.875GHz, 2.5GHz)
- Average noise (all pairs) is ~ **-158.8 dBm/Hz**
- Noise power (PSD integrated from 500kHz – 3GHz, all pairs) is ~ **-61.3 dBm**

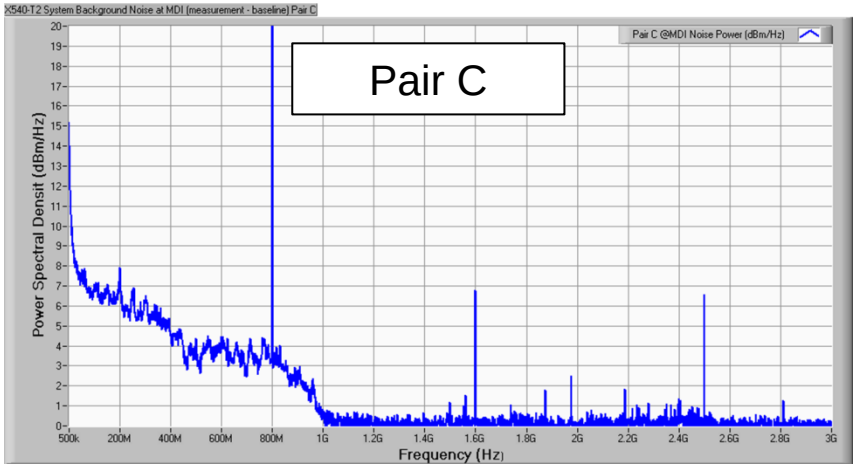


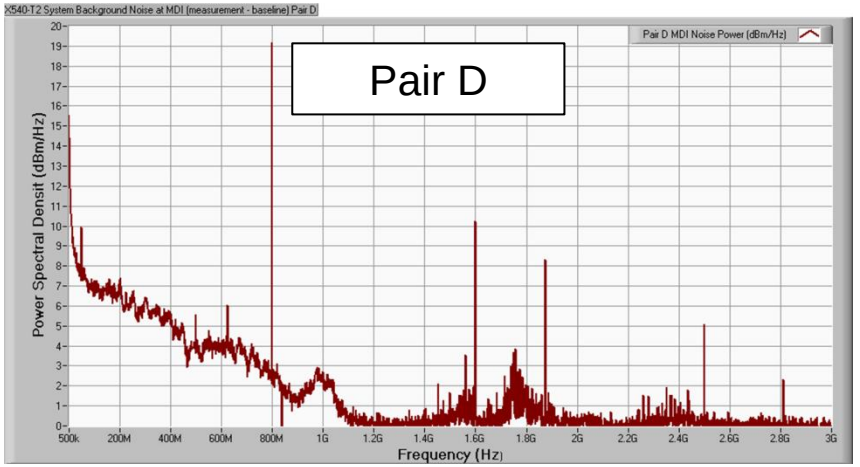
Pair (Pins)	Average noise (dBm/Hz)	Average noise (dBm/Hz) with NFE	Noise Power (dBm)	Noise Power (dBm) with NFE
A (1,2)	-151.91	**-158.46**	-56.78	**-61.05**
B (3,6)	-152.24	**-159.33**	-57.10	**-62.24**
C (4,5)	-152.08	**-158.75**	-56.92	**-60.90**
D (7,8)	-151.92	**-158.79**	-56.80	**-61.18**

MDI Noise Measurements, DUT#1
Per-pair noise above noise floor (-NFE)



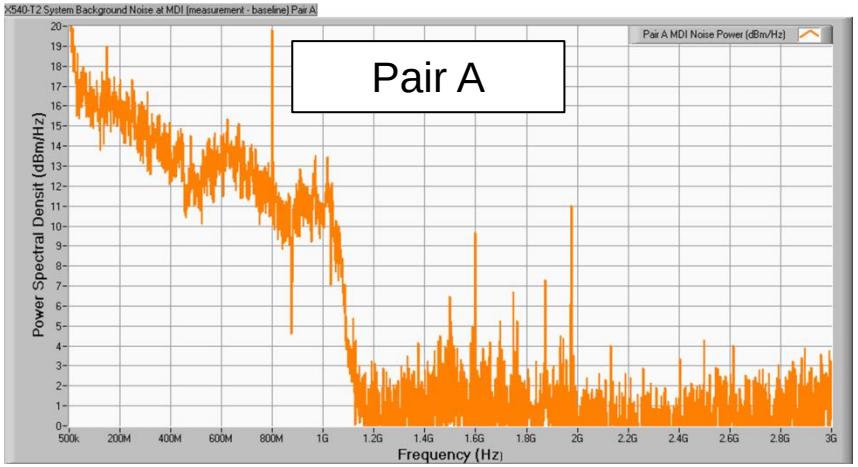


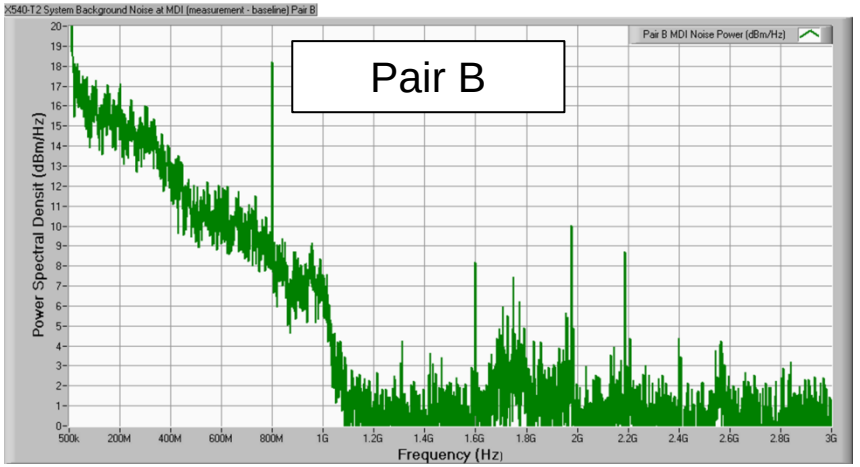


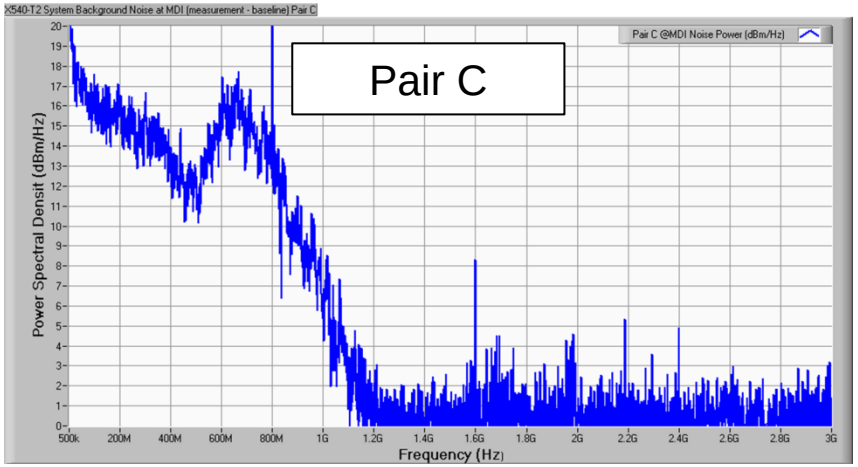


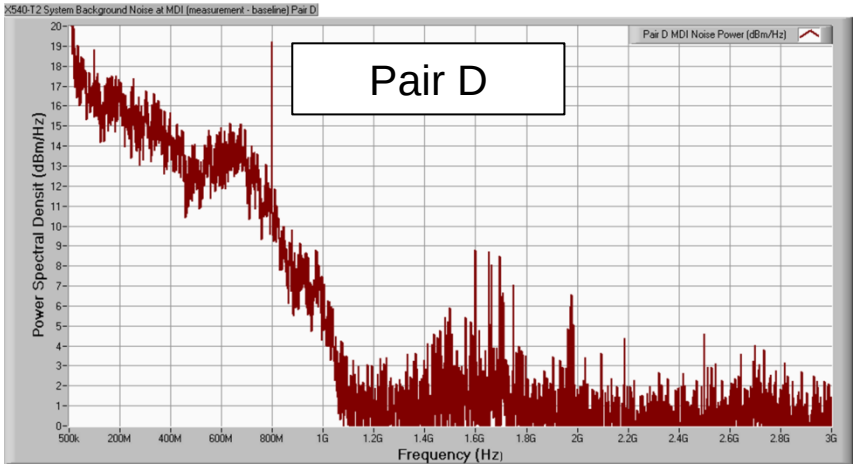
Some pairs appear to have unique sources (Pair A 600MHz; Pair D 1.6GHz - 2GHz)

MDI Noise Measurements, DUT#1
Per-pair noise above noise floor (+NFE)









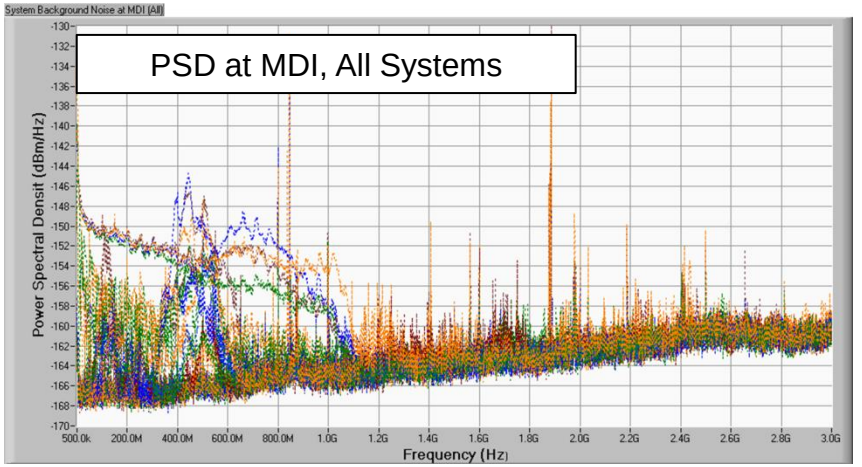
Some pairs appear to have unique sources (Pair A 600MHz; Pair D 1.6GHz - 2GHz)

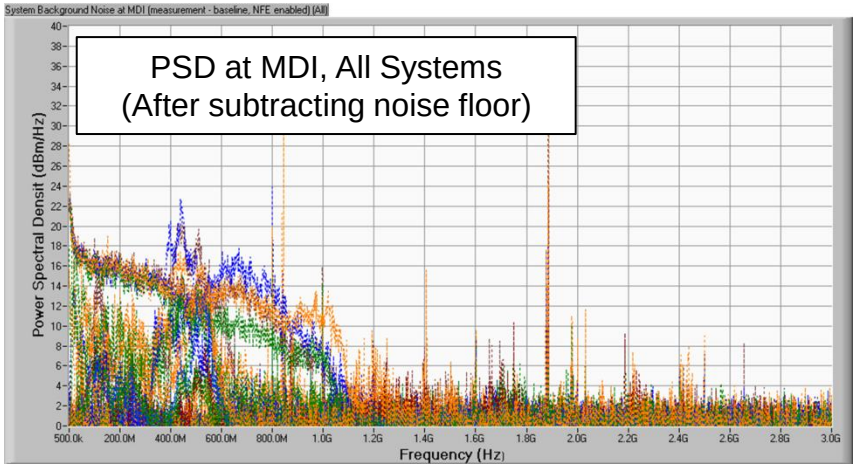
Other System Background Noise Measurements

- Similar system background noise measurements are included for other 10GBASE-T systems
  - A 2nd 10GBASE-T adapter (“DUT #2” in cibula_3bq_02a_0314.pdf)
  - A 10GBASE-T server design with the controller implemented as a LOM
  - A 10GBASE-T switch
    - One set of measurements includes an active adjacent port to compare crosstalk coupling and system background noise
- Measurement plots and per-port results are included in supplementary backup material
- Overall results are presented in the following slide

MDI Measurements With NFE (All)

Condition	PHY	4-Pair Average noise (dBm/Hz)	4-Pair Average Noise Power (dBm)
Measurement Noise Floor	n/a	-163.74	-68.37
NIC #1	A	-158.83	-61.34
NIC #2	B	-162.72	-67.20
LOM P0	A	-161.37	-65.48
LOM P0	A	-161.99	-64.52
Switch P1	C	-163.65	-68.15
Switch P2	C	-163.68	-67.50
Switch P2 + xtalk	C	-163.74	-68.39





Results & Observations

- Average measured background noise for all systems (10GBASE-T network adapters, server LOM, and switch) is between **-164 dBm/Hz and -159 dBm/Hz**
- Average measured noise power for all systems is between **-68 dBm and -61 dBm/Hz**
- For the systems evaluated in this investigation, most background noise power is observed below about 1.4GHz
  - Measured system noise in this range is worst-case about 24 dBm/Hz above the measurement noise floor
- A variety of system clock/RF sources are the primary contributors between 1.4GHz and 3GHz
- Specific background noise (assumed both broadband and stationary) varies across both MDI trace pairs and design implementations

Conclusions

- Improved measurements of several 10GBASE-T implementations indicate an average system background noise level of approximately -162 dBm/Hz

- While average system background noise levels are comparable…
  - Specific background noise levels vary with implementation
  - Background noise levels also vary across MDI pairs

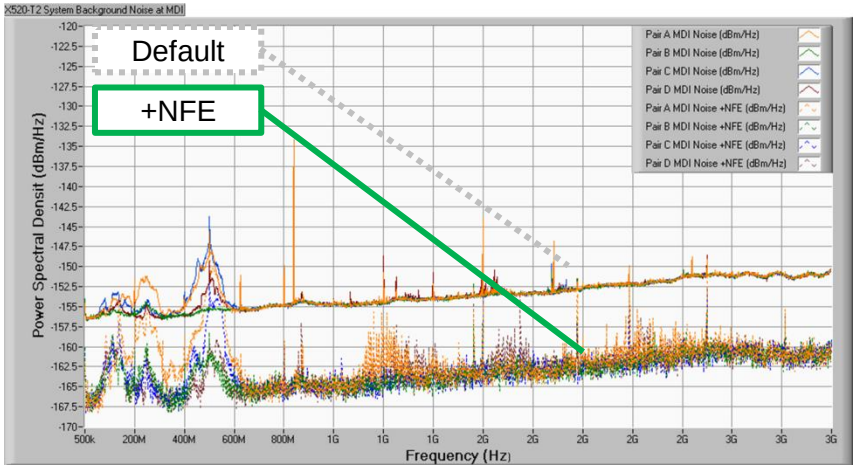
Next Steps/Further Investigation

- Post-Beijing request from the PHY Baseline Proposal ad hoc
  - √ Provide MDI-based measurements in other systems
    - 10GBASE-T server LAN-on-motherboard? Switches?
    - Included in this contribution!
  - – Measure the observed peak-to-peak noise voltage levels, integrated from 10MHz (or thereabouts) to at least 1.6GHz
    - Provide more information related to PBO and uncoded bits

Thank You!

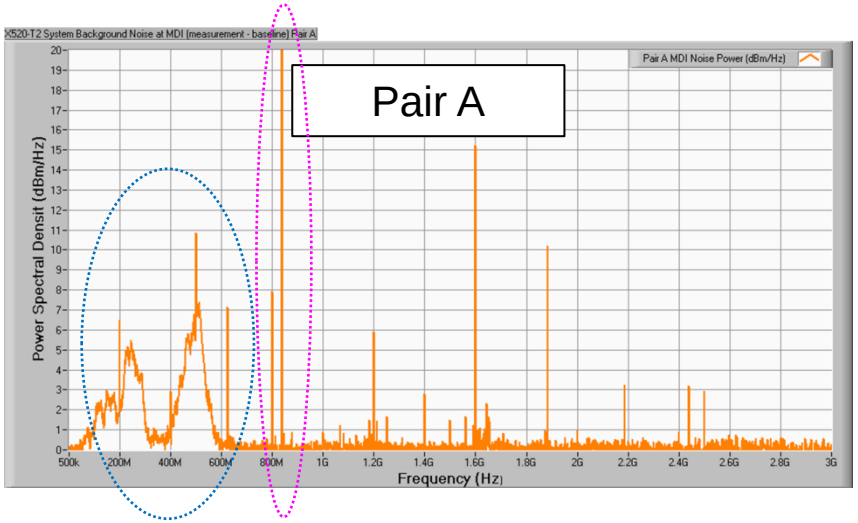
DUT #2 MDI Noise With & Without NFE

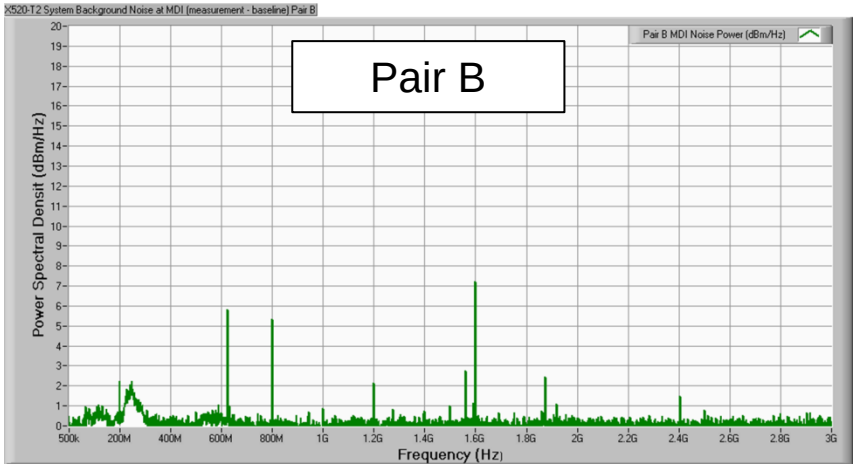
- System background noise for DUT #2 as measured at the MDI interface (RJ45 jack) displays the following characteristics:
  - Multiple source(s) from 500kHz to ~300MHz and between 400MHz and 600MHz
  - Unrelated (?) narrowband source at 500MHz
  - Narrowband source (800MHz, 1.6GHz)
  - Narrowband source (625MHz, 1.875GHz, 2.5GHz
- Average noise (all pairs) is ~ **-162.7 dBm/Hz**
- Noise power (PSD integrated from 500kHz – 3GHz, all pairs) is ~ **-67.2 dBm**

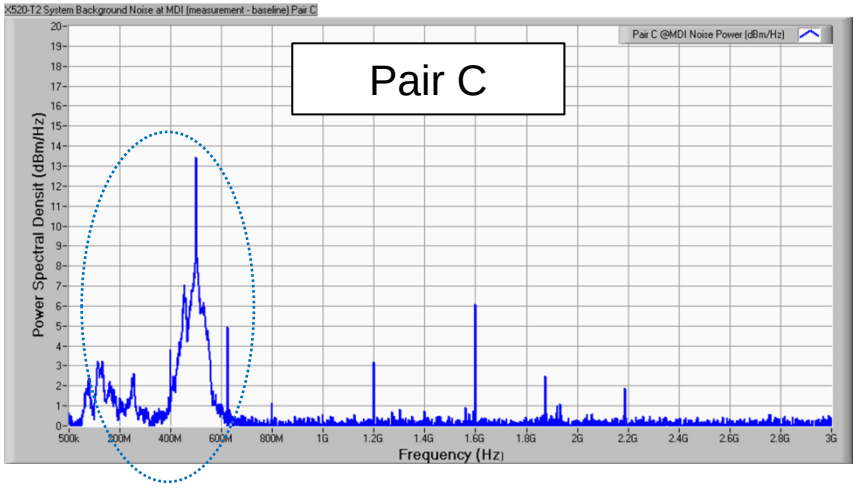


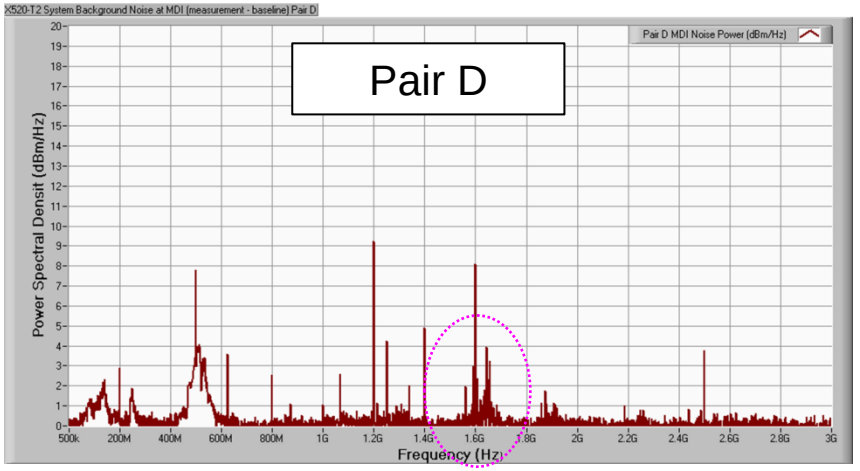
Pair (Pins)	Average noise (dBm/Hz)	Average noise (dBm/Hz) with NFE	Noise Power (dBm)	Noise Power (dBm) with NFE
A (1,2)	-153.12	**-161.91**	-57.34	**-65.85**
B (3,6)	-153.57	**-163.17**	-58.45	**-67.96**
C (4,5)	-153.22	**-162.91**	-58.07	**-67.41**
D (7,8)	-153.44	**-162.90**	-58.33	**-67.56**

MDI Noise Measurements, DUT#2
Per-pair noise above noise floor (-NFE)



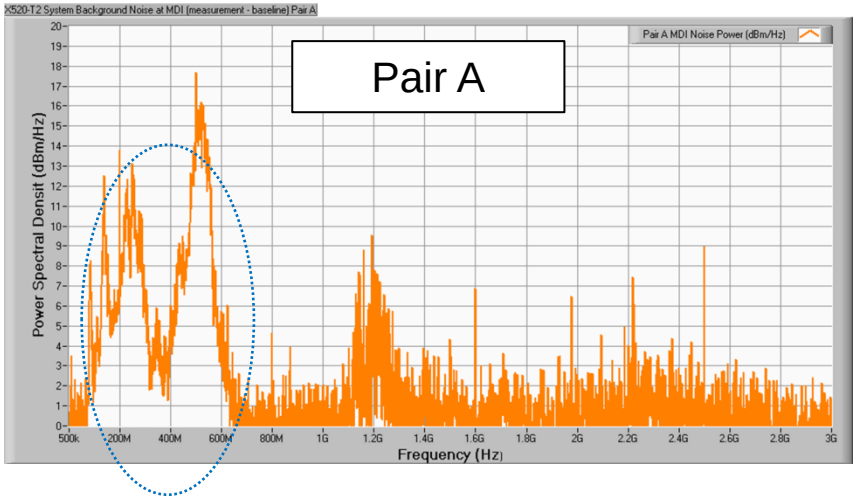


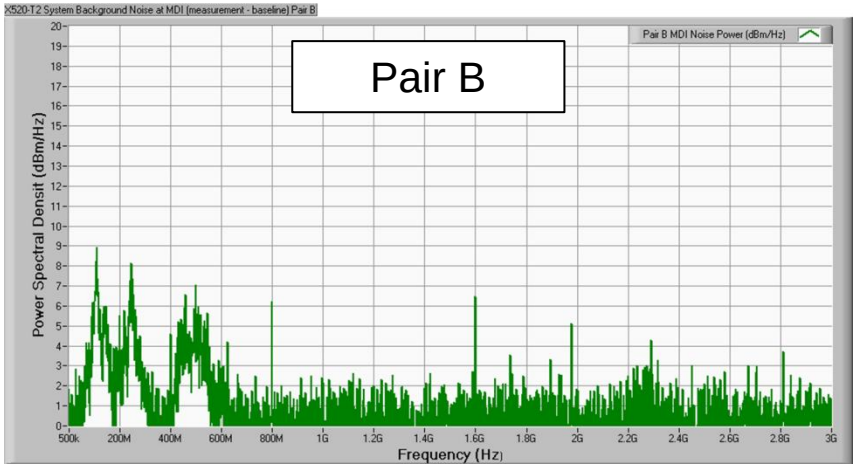


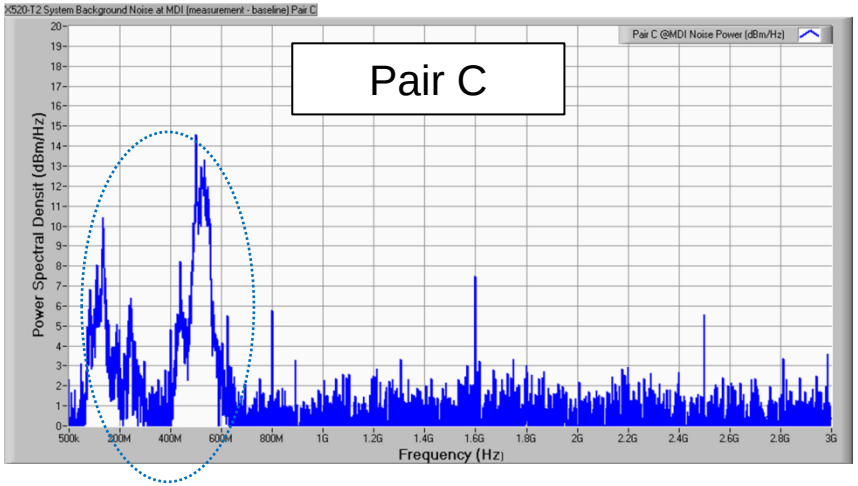


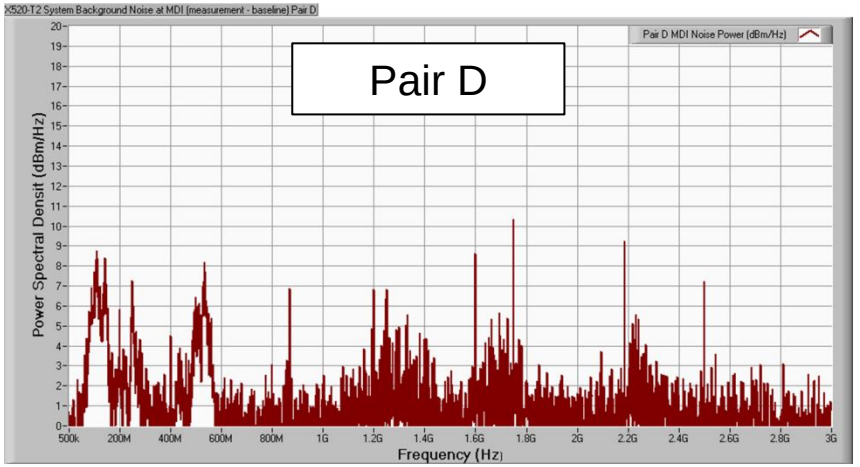
Unique sources (Pair A 839MHz; Pair D 1.5GHz – 1.7GHz); note more low frequency noise on A & C

MDI Noise Measurements, DUT#2
Per-pair noise above noise floor (+NFE)







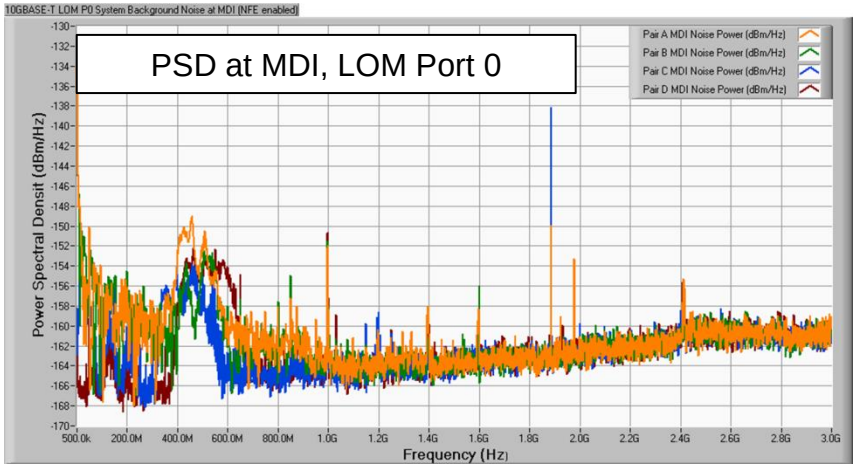


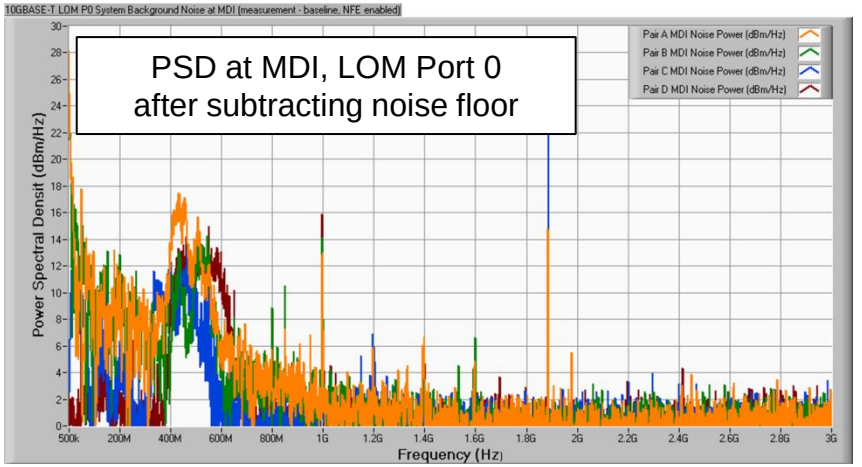
Note more low frequency noise on A & C

MDI Measurements, Server LOM P0

Pair (Pins)	Average noise (dBm/Hz)	Noise Power (dBm)
A (1,2)	-161.09	-63.88
B (3,6)	-161.47	-65.13
C (4,5)	-161.44	-66.55
D (7,8)	-161.46	-66.34

- System background noise for DUT #1 as measured at the MDI interface (RJ45 jack) displays the following characteristics:
  - Broadband source(s) from 500kHz to ~1.2GHz
  - Narrowband source (800MHz, 1.6GHz)
  - Narrowband source (625MHz, 1.875GHz, 2.5GHz)
- Average noise (all pairs) is ~ **-161.4 dBm/Hz**
- Noise power (PSD integrated from 500kHz – 3GHz, all pairs) is ~ **-65.5 dBm**

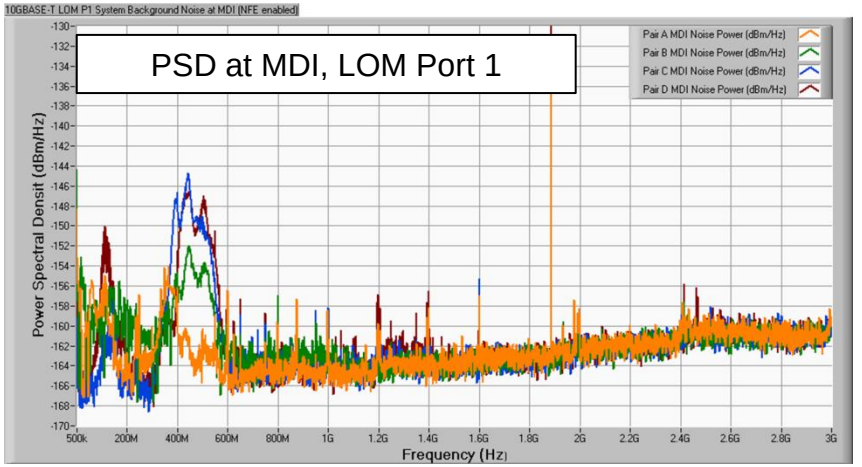


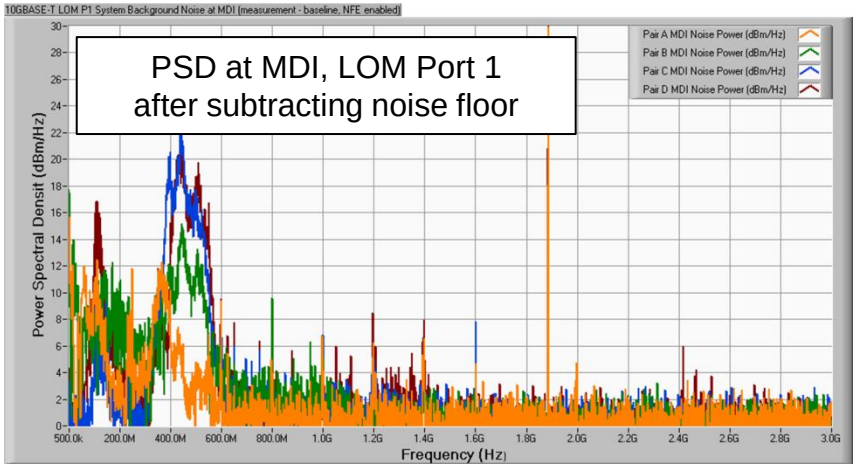


MDI Measurements, Server LOM P1

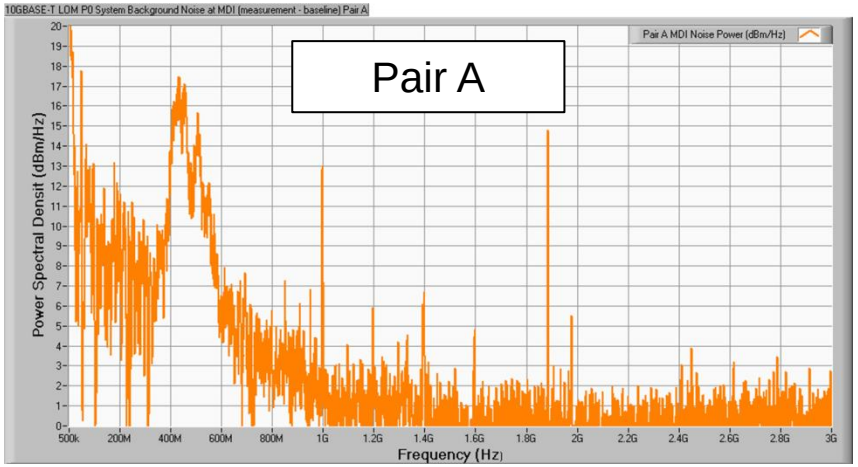
Pair (Pins)	Average noise (dBm/Hz)	Noise Power (dBm)
A (1,2)	-162.42	-66.19
B (3,6)	-161.79	-66.07
C (4,5)	-162.08	-64.13
D (7,8)	-161.67	-61.67

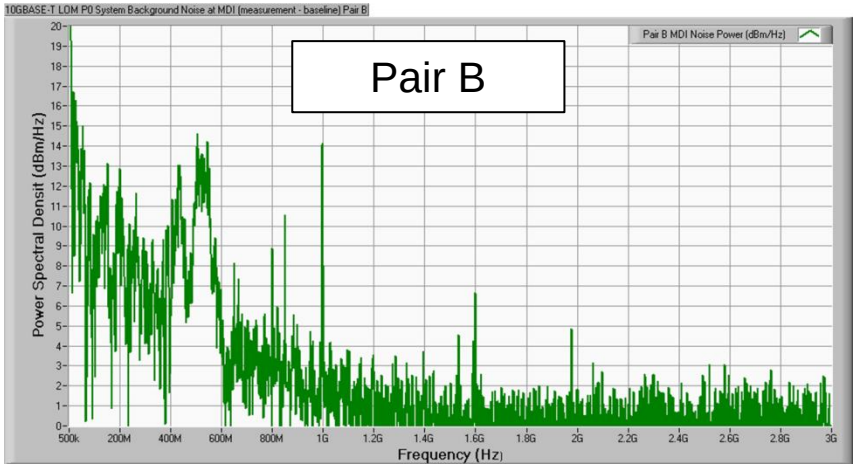
- System background noise for DUT #1 as measured at the MDI interface (RJ45 jack) displays the following characteristics:
  - Broadband source(s) from 500kHz to ~1.2GHz
  - Narrowband source (800MHz, 1.6GHz)
  - Narrowband source (625MHz, 1.875GHz, 2.5GHz)
- Average noise (all pairs) is ~ **-162.0 dBm/Hz**
- Noise power (PSD integrated from 500kHz – 3GHz, all pairs) is ~ **-64.5 dBm**

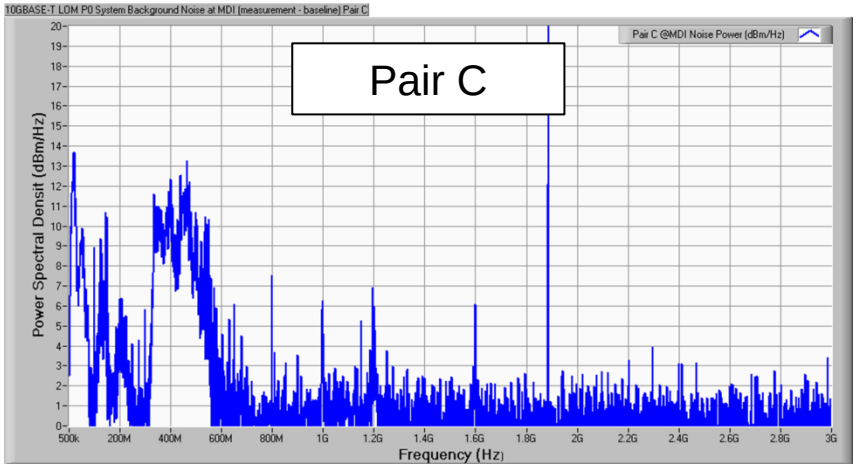


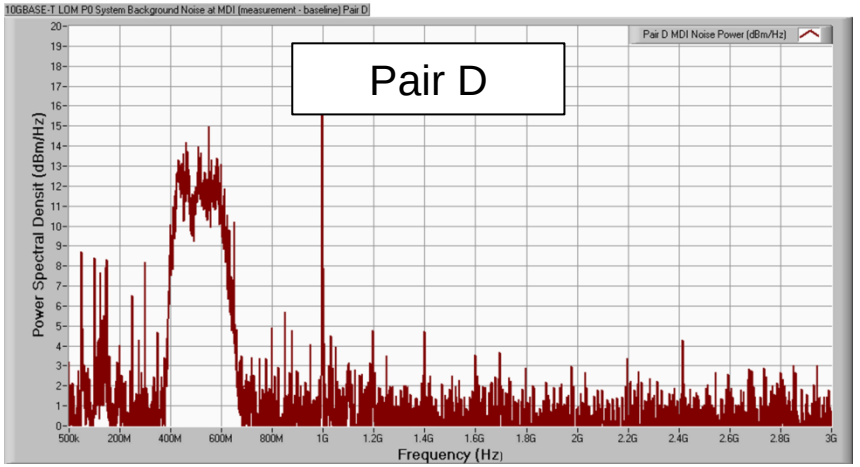


MDI Noise Measurements, LOM P0
Per-pair noise above noise floor

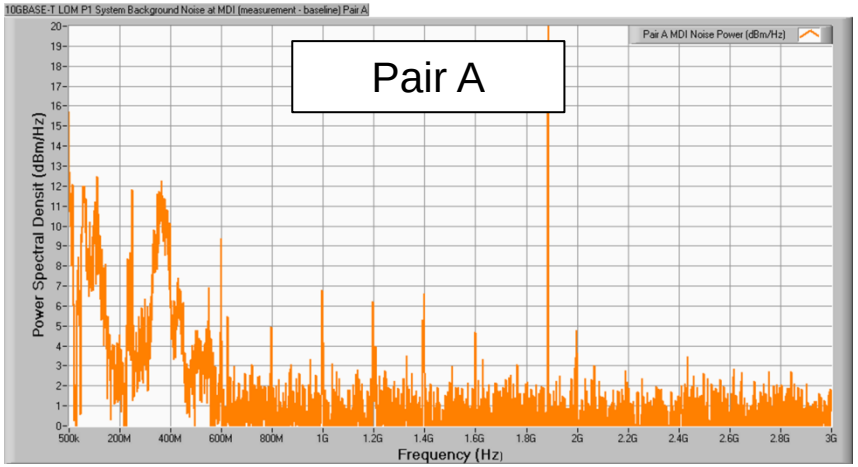


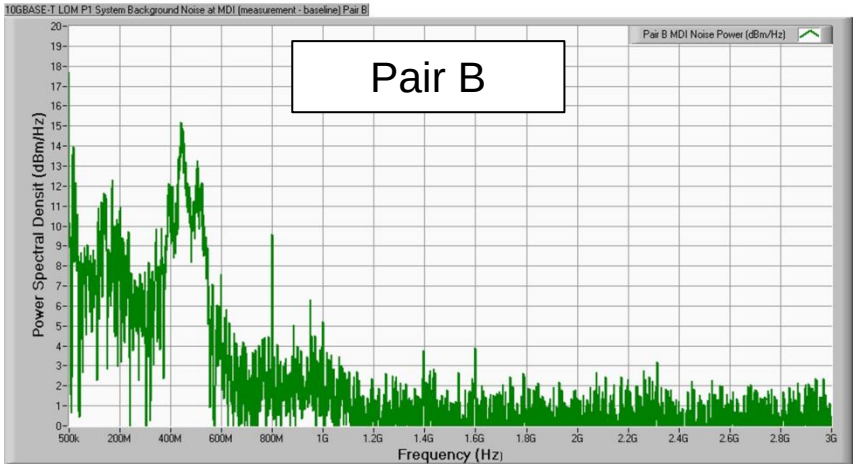


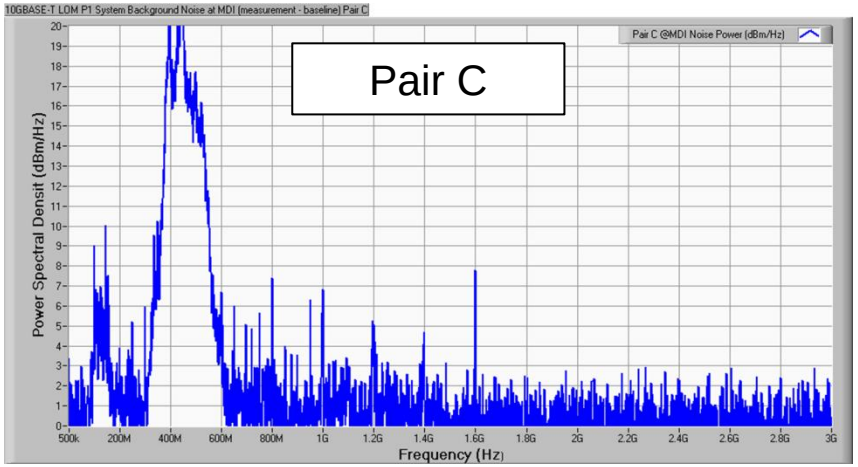


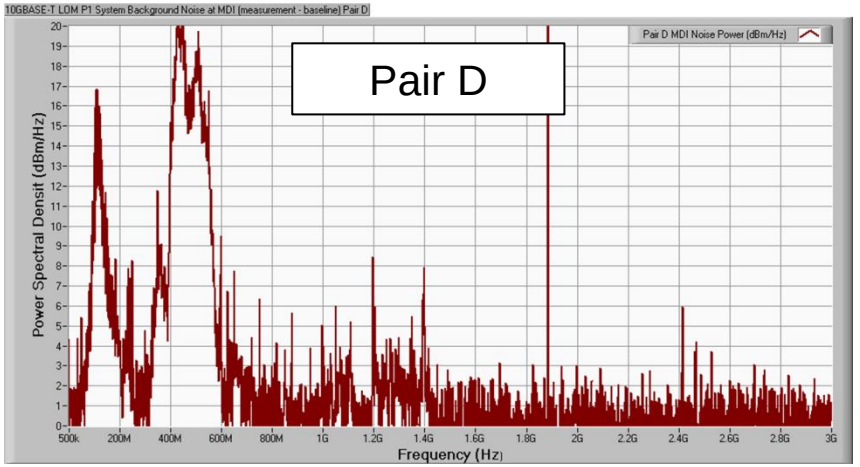


MDI Noise Measurements, LOM P1
Per-pair noise above noise floor









MDI Measurements, Switch P1

Pair (Pins)	Average noise (dBm/Hz)	Noise Power (dBm)
A (1,2)	-163.50	-67.47
B (3,6)	-163.71	-68.39
C (4,5)	-163.76	-68.45
D (7,8)	-163.64	-68.29

- System background noise for DUT #1 as measured at the MDI interface (RJ45 jack) displays the following characteristics:
  - Broadband source(s) from 500kHz to ~1.2GHz
  - Narrowband source (800MHz, 1.6GHz)
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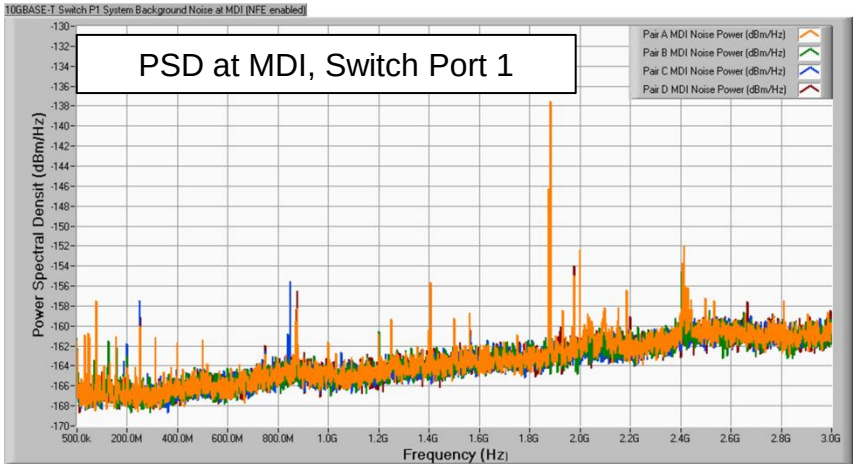
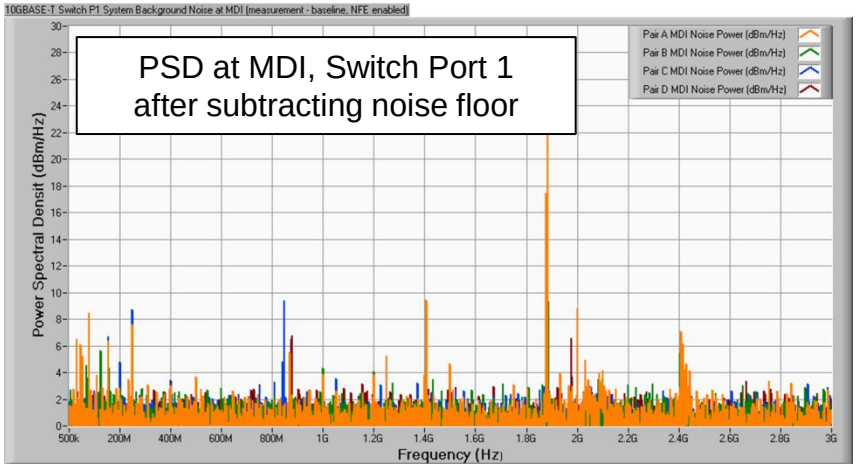
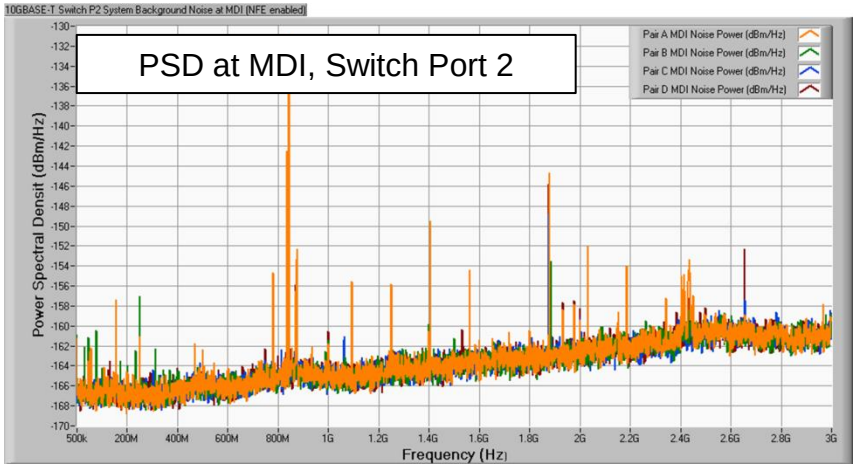


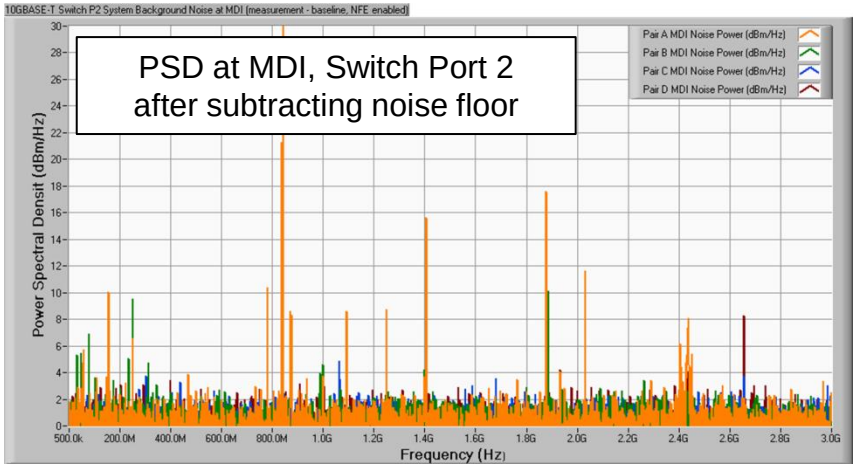


MDI Measurements, Switch P2

Pair (Pins)	Average noise (dBm/Hz)	Noise Power (dBm)
A (1,2)	-163.58	-65.71
B (3,6)	-163.73	-68.40
C (4,5)	-163.74	-67.64
D (7,8)	-163.67	-68.24

- System background noise for DUT #1 as measured at the MDI interface (RJ45 jack) displays the following characteristics:
  - Broadband source(s) from 500kHz to ~1.2GHz
  - Narrowband source (800MHz, 1.6GHz)
  - Narrowband source (625MHz, 1.875GHz, 2.5GHz)
- Average noise (all pairs) is ~ **-163.7 dBm/Hz**
- Noise power (PSD integrated from 500kHz – 3GHz, all pairs) is ~ **-67.5 dBm**

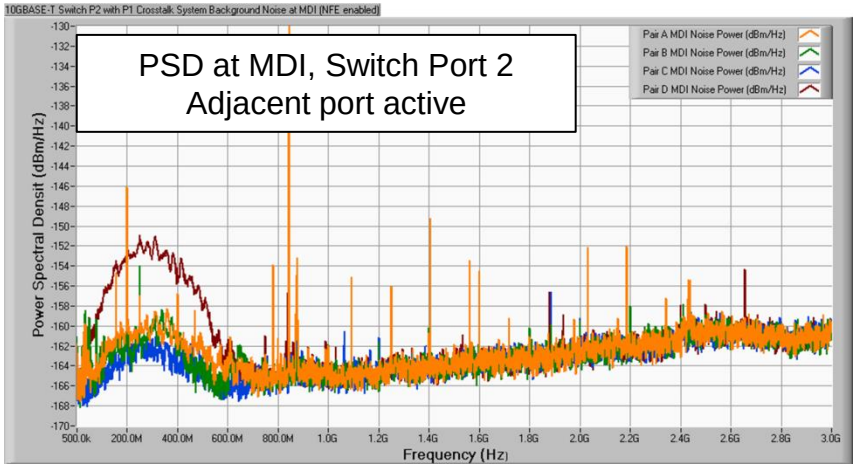


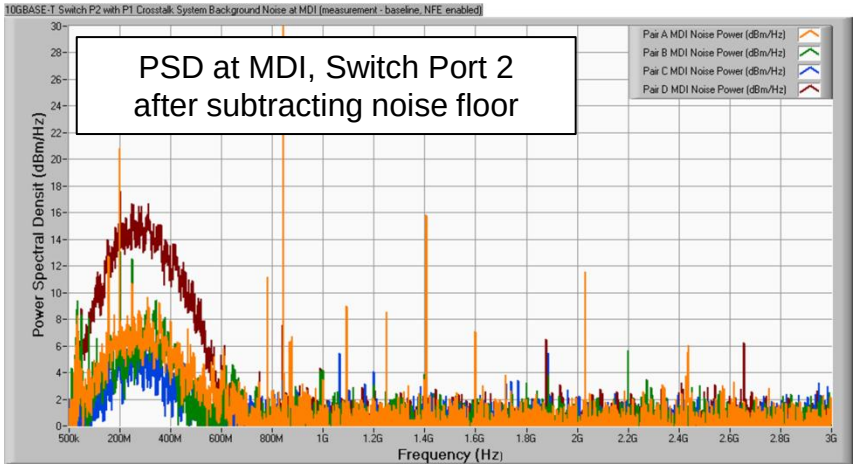


MDI Measurements, Switch P2 xtalk

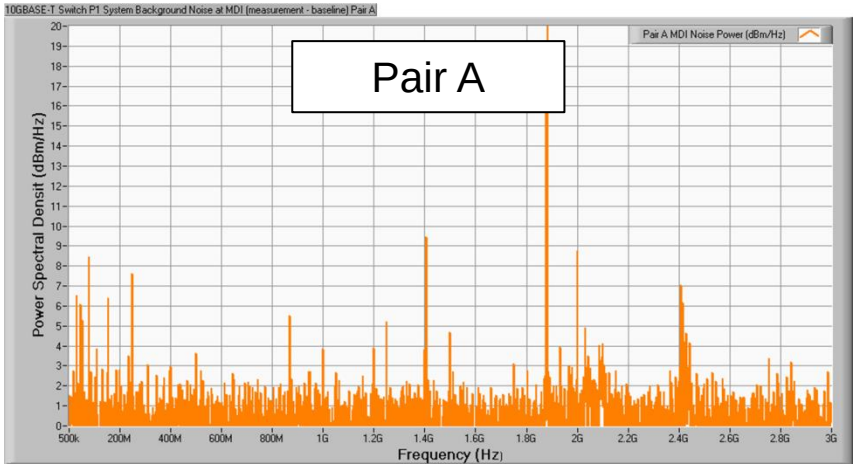
Pair (Pins)	Average noise (dBm/Hz)	Noise Power (dBm)
A (1,2)	-163.71	-68.33
B (3,6)	-163.76	-68.42
C (4,5)	-163.75	-68.42
D (7,8)	-163.72	-68.39

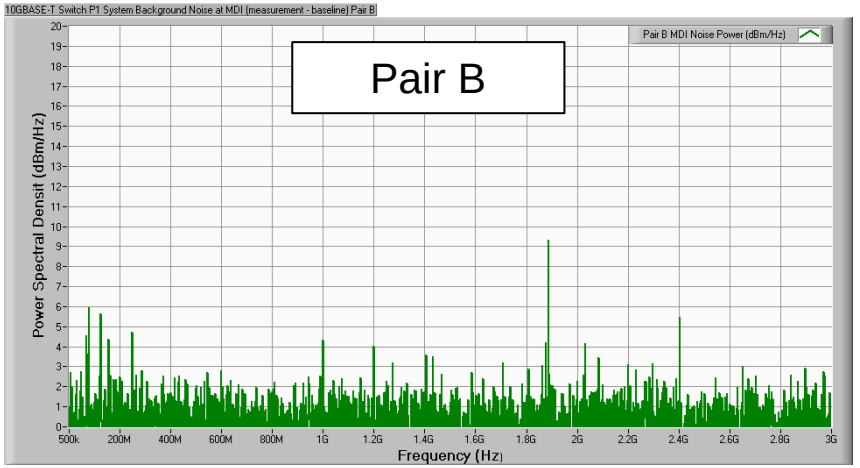
- System background noise for DUT #1 as measured at the MDI interface (RJ45 jack) displays the following characteristics:
  - Broadband source(s) from 500kHz to ~1.2GHz
  - Narrowband source (800MHz, 1.6GHz)
  - Narrowband source (625MHz, 1.875GHz, 2.5GHz)
- Average noise (all pairs) is ~ **-163.7 dBm/Hz**
- Noise power (PSD integrated from 500kHz – 3GHz, all pairs) is ~ **-68.4 dBm**

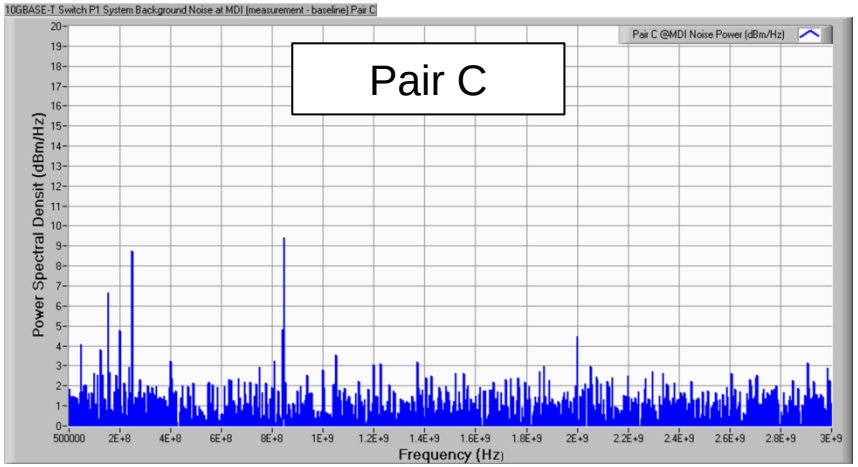


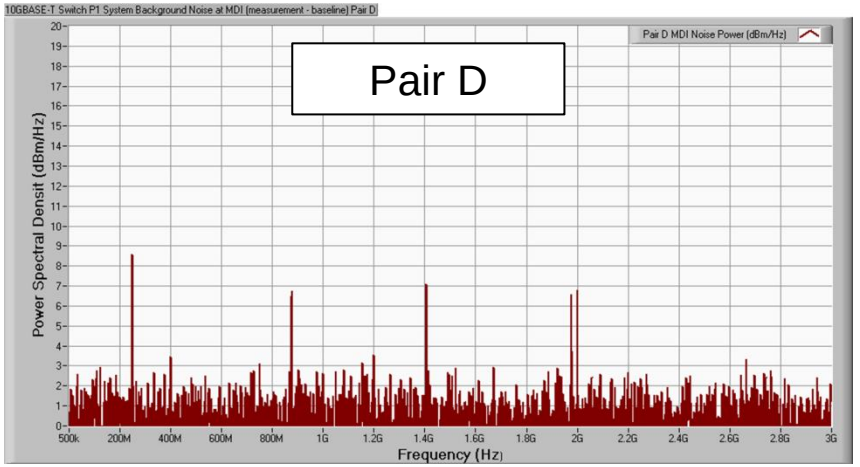


MDI Noise Measurements, Switch P1
Per-pair noise above noise floor

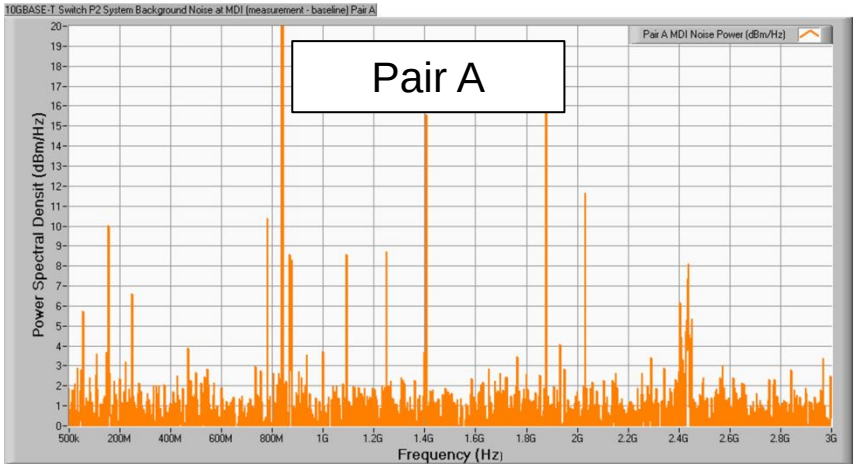


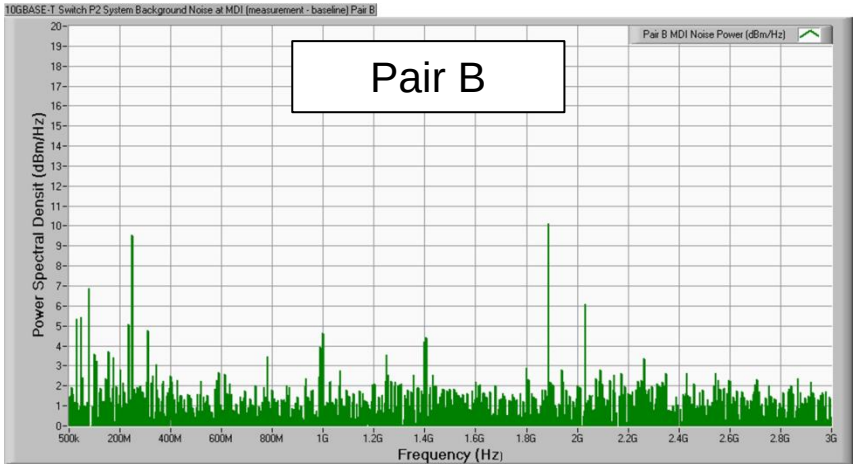


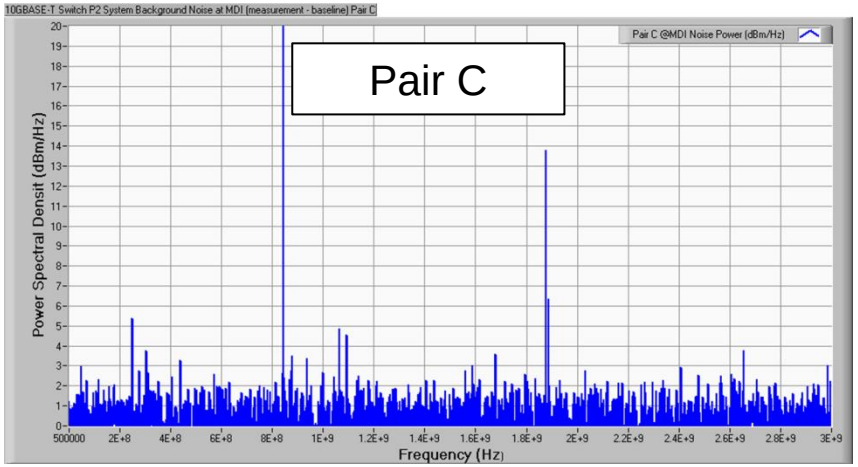


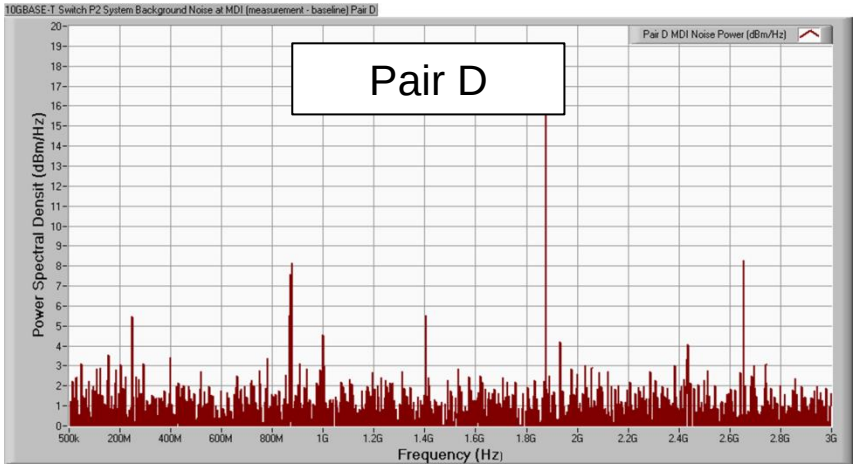


MDI Noise Measurements, Switch P2
Per-pair noise above noise floor

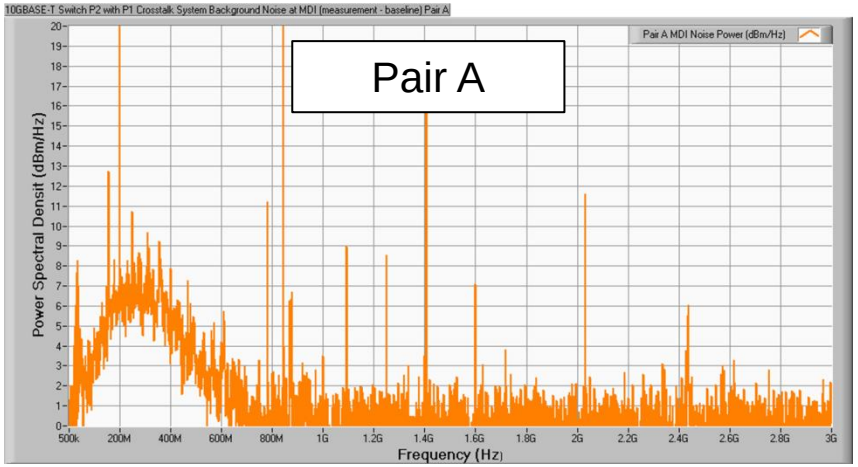


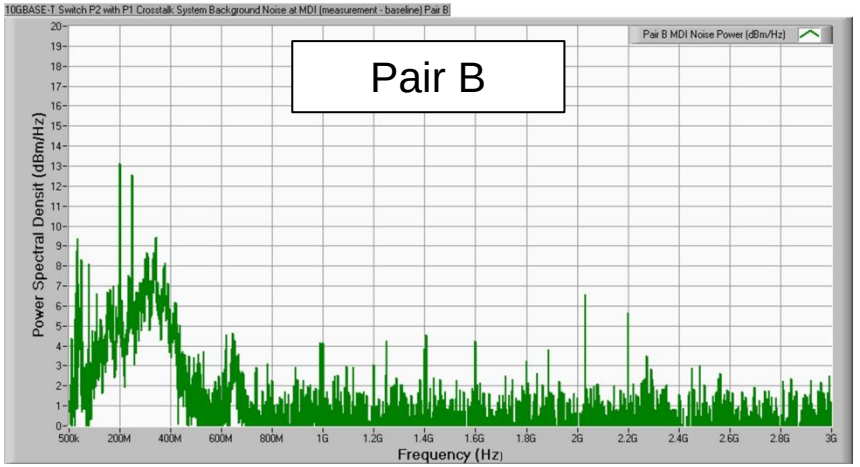


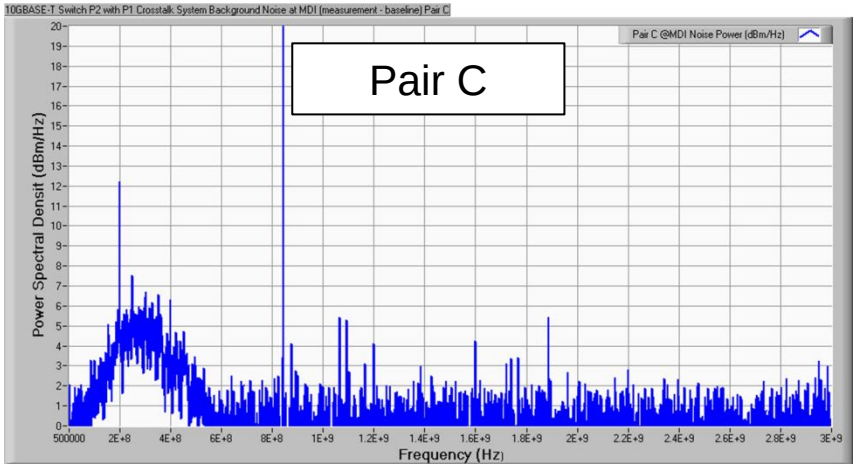


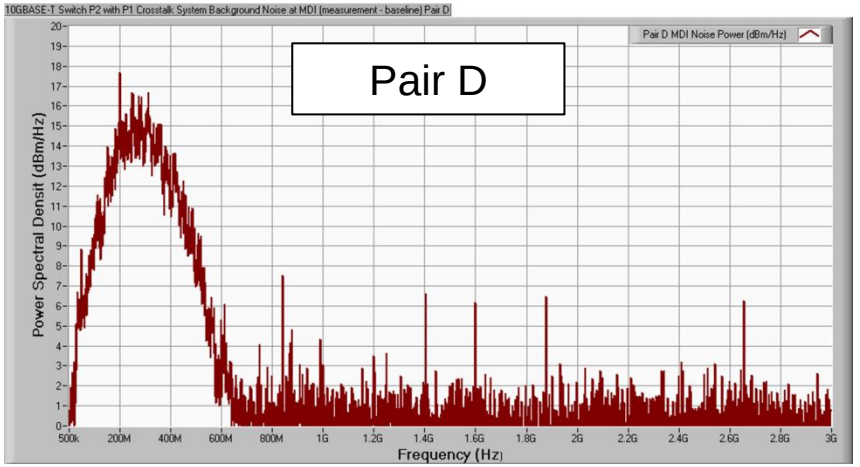


MDI Noise Measurements, Switch P2 xtalk
Per-pair noise above noise floor

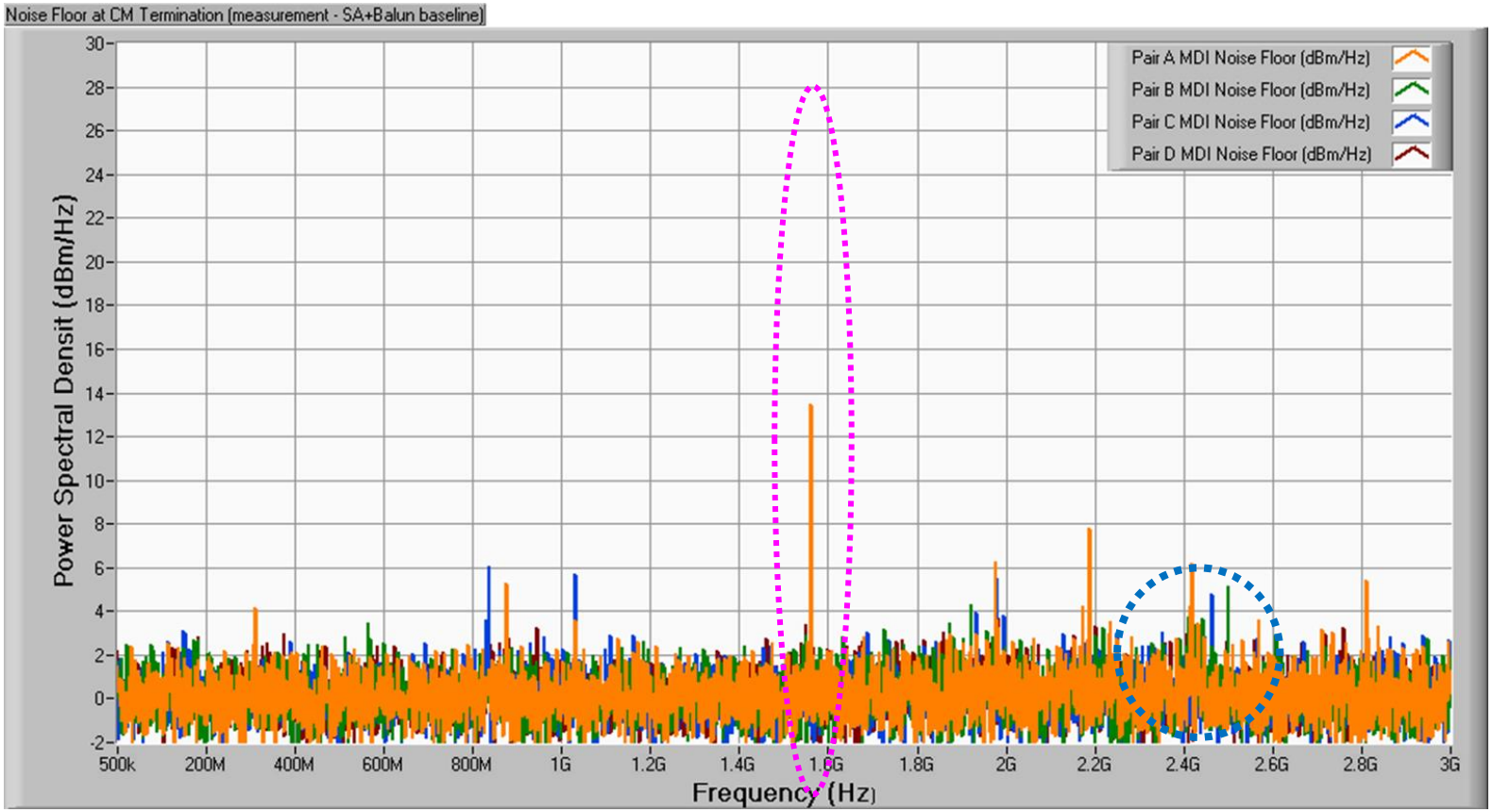








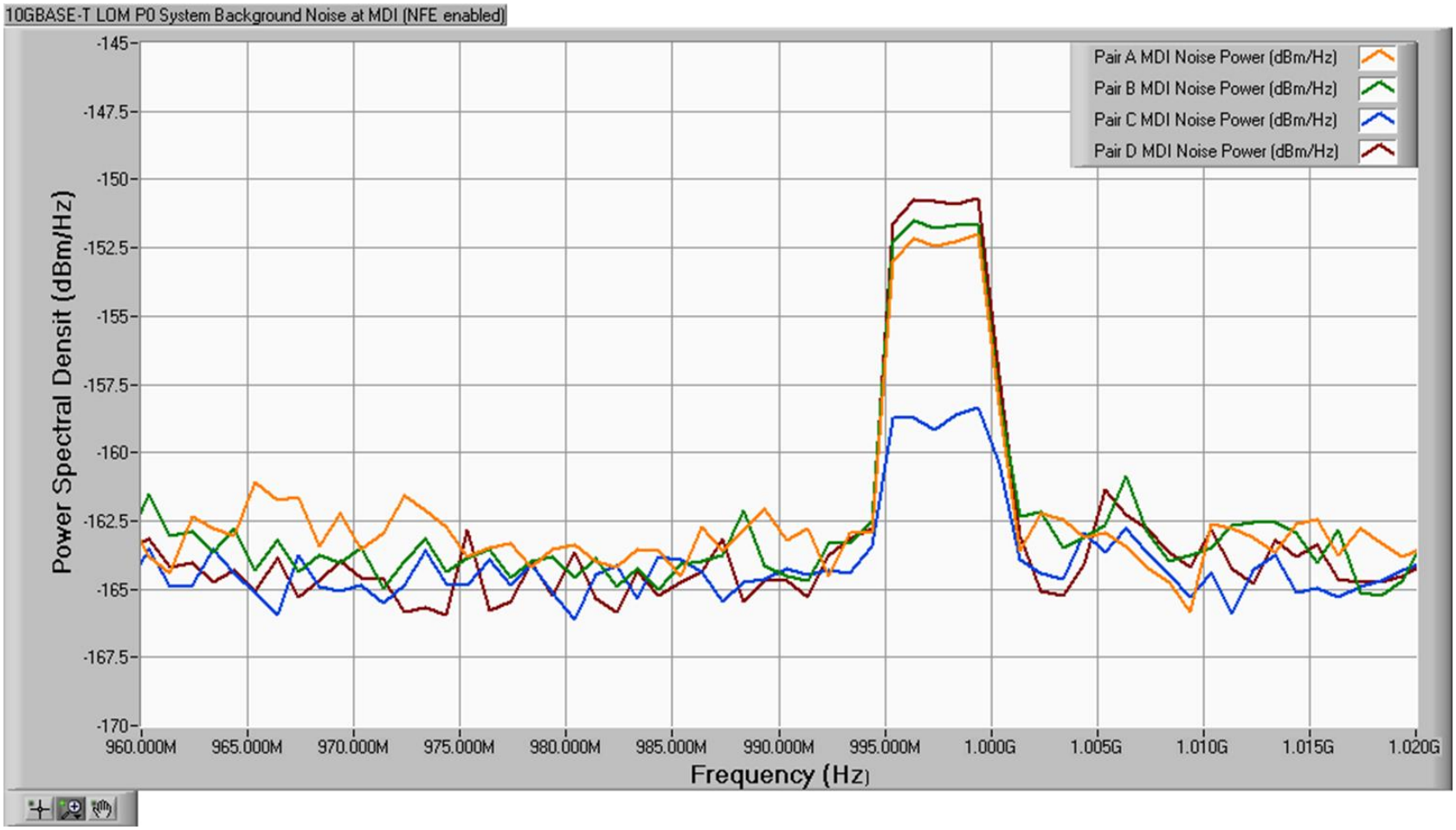
Test Fixture Noise Above DANL (+NFE)



Noise floor measurement on Slide 6 with the spectrum analyzer DANL removed

- Pair D single-frequency source above 800MHz is unknown (May be an artifact?)
- Signals on all pairs between 2.4GHz-2.5GHz assumed to be 802.11 channels

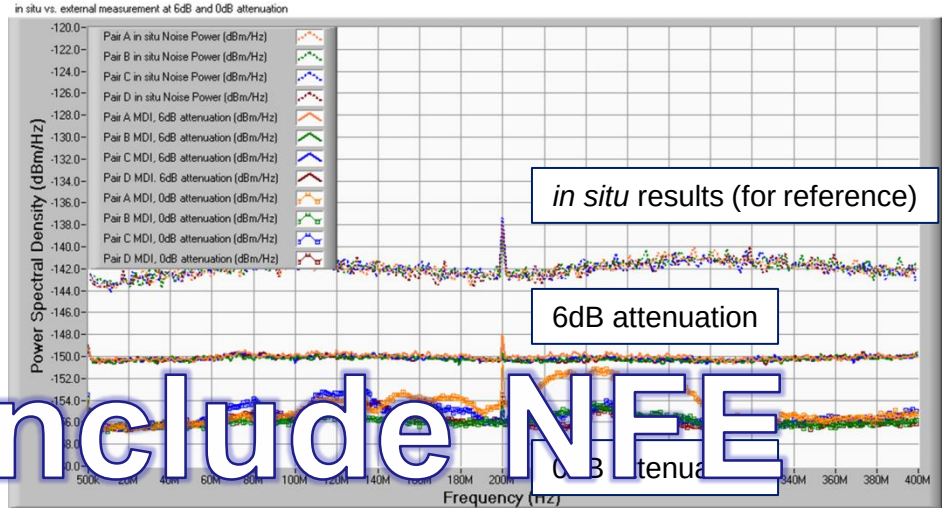
Server LOM Noise Example
“1GHz” Clock Source



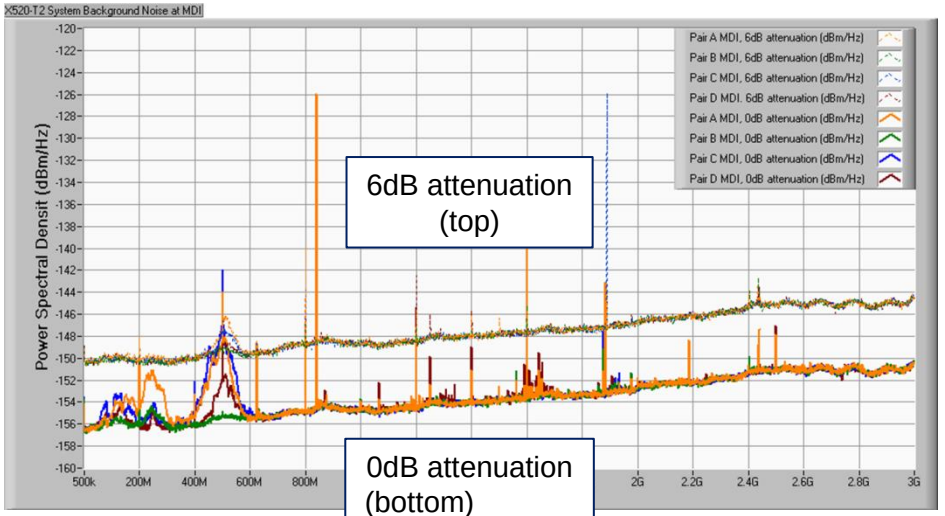
Possible spread-spectrum source?

Analyzer RF Attenuation

- Spectrum analyzer may default to a specific default attenuation setting based on the reference level
- System background noise measurements at default (6dB) attenuation may mask low-level noise
- 0dB attenuation used to obtain maximum sensitivity



Does not include NFE



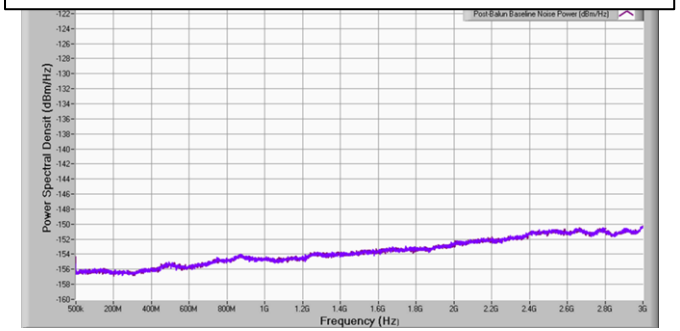
Clarification on Fixture Noise Above Spectrum Analyzer Noise Floor

Test fixture/interconnect noise floor measured at the patch cable RJ45 plug

A

Spectrum analyzer noise floor measured at the instrument input

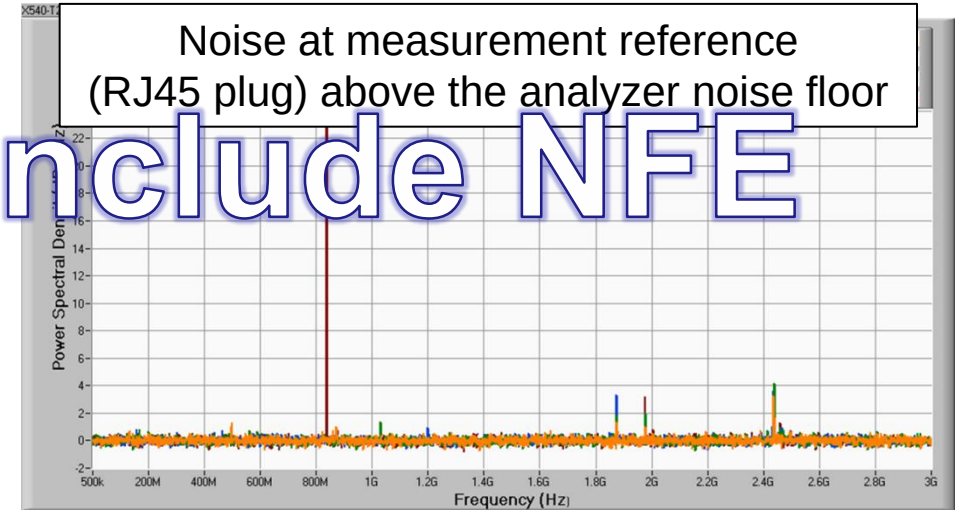
B



Does not include NFE

C

Noise at measurement reference (RJ45 plug) above the analyzer noise floor



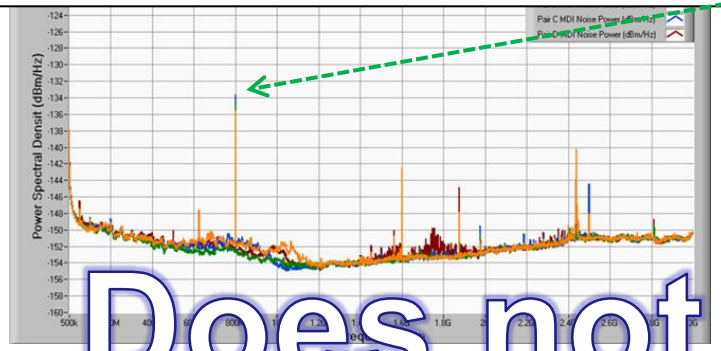
C = A – B

Subtracting the spectrum analyzer noise highlights interconnect/fixture noise above the instrument noise floor

Clarification on System Background Noise Above CM Measurement Noise Floor

System background noise measured at the MDI (or PHY) interface

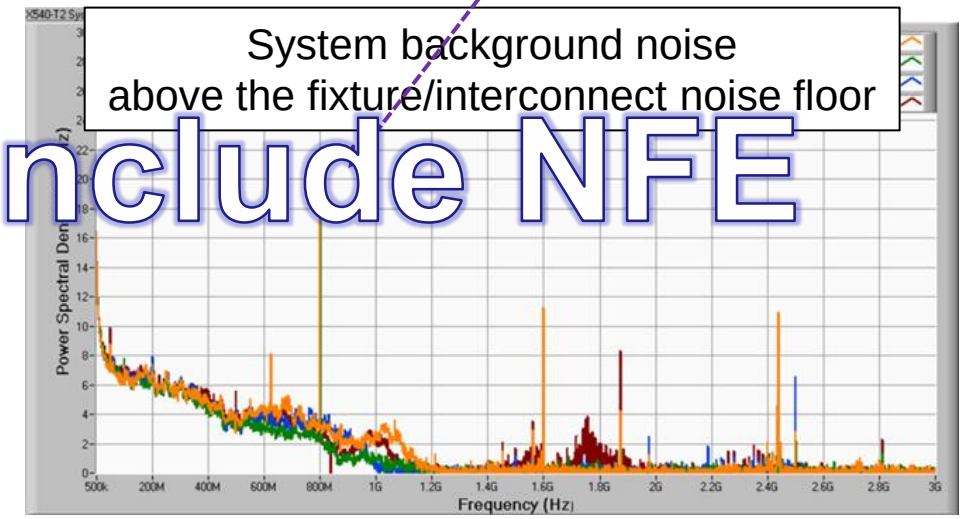
A



Pair	Measured Noise (dBm/Hz)	Noise Above Fixture Noise Floor (dBm/Hz)
A (1,2)	-135.5	19.4
B (3,6)	-134.7	20.0
C (4,5)	-133.6	21.1
D (7,8)	-135.9	19.2

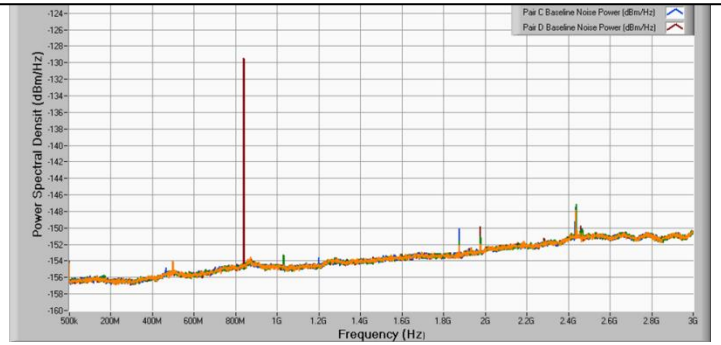
System background noise above the fixture/interconnect noise floor

C



Test fixture/interconnect noise floor measured at the patch cable RJ45 plug

B



Does not include NFE

C = A – B

Subtracting fixture noise highlights system background noise above the test fixture noise floor