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

IEEE P802.3bq 40GBASE-T Task Force

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System Background Noise Measurement
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 preliminary assessment intended to…
  – Describe a measurement methodology
  – Present initial measurement results based on that methodology
  – Stimulate further discussion of system noise measurement methodologies and ideas for further work in this area
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

• Characterize system background noise
  – PHY active but with all transmitters disabled
  – Measure system noise at MDI
    • RJ45 connection
  – Measure system noise at PHY
    • As close to PHY pins as practically possible
  – Subtract measurement noise floor to highlight system-specific background noise

• Compare measurements to identify system noise sources and evaluate MDI-based vs. PHY-based results
Instrument Configuration

• Spectrum analyzer measurement of system background differential noise
  – Instrument configuration – raw power spectrum
    • Span: 0Hz to 3GHz
    • Attenuation: 0dB
    • Detector: Average
    • RBW & VBW: 30kHz, 30kHz
    • Averaging type: Log Power
    • No. averages: 2x
  – Instrument configuration – noise marker spectrum (non-user-configurable differences only)
    • RBW & VBW: 30kHz, 3kHz
    • Averaging type: RMS

• Raw power spectrum may mask low-level stationary sources
  – Noise marker power spectrum used for all system noise measurements

Power spectrum of common-mode termination on patch cable

Power spectrum with noise marker function enabled
Measurement Setup (Noise Floor)

Spectrum Analyzer

Single-ended to differential balun 300kHz – 3GHz

1x RJ45 to 8x 50ohm SMP breakout

Common-Mode Load Test Fixture

Coax SMA cables

Twisted pair patch cable

300kHz-3GHz Balun

2x SMA

RJ45/SMA Breakout

4 pairs 15cm CAT7

Load at each pair

50 ohms

50 ohms

(+)

(-)
# Noise Floor Measurement

- Noise floor as measured at the MDI interface (RJ45 plug) is consistent across all 4 pairs
  - Average noise is approximately **-153.7 dBm/Hz**
  - Noise power (PSD integrated from 500kHz – 3GHz) is approximately **-58.5 dBm**

<table>
<thead>
<tr>
<th>Pair (Pins)</th>
<th>Average noise (dBm/Hz)</th>
<th>Noise Power (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (1,2)</td>
<td>-153.67</td>
<td>-58.52</td>
</tr>
<tr>
<td>B (3,6)</td>
<td>-153.67</td>
<td>-58.52</td>
</tr>
<tr>
<td>C (4,5)</td>
<td>-153.67</td>
<td>-58.52</td>
</tr>
<tr>
<td>D (7,8)</td>
<td>-153.66</td>
<td>-58.52</td>
</tr>
</tbody>
</table>
Measurement Setup (MDI)

- **Spectrum Analyzer**
- **Single-ended to differential balun 300kHz – 3GHz**
- **1x RJ45 to 8x 50ohm SMP breakout**
- **DUTs in server All Tx disabled (MMD1.9, 0x0001)**

**DUTs**:
- DUT#1
- DUT#2
MDI Measurements, DUT#1

<table>
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<th>Pair (Pins)</th>
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<tbody>
<tr>
<td>A (1,2)</td>
<td>-151.91</td>
<td>-56.78</td>
</tr>
<tr>
<td>B (3,6)</td>
<td>-152.24</td>
<td>-57.10</td>
</tr>
<tr>
<td>C (4,5)</td>
<td>-152.08</td>
<td>-56.92</td>
</tr>
<tr>
<td>D (7,8)</td>
<td>-151.92</td>
<td>-56.80</td>
</tr>
</tbody>
</table>

• 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 ~ **-152.0 dBm/Hz**
• Noise power (PSD integrated from 500kHz – 3GHz, all pairs) is ~ **-56.9 dBm**
• Note that subtracting the noise floor gives a better picture of system background noise characteristics above the noise floor
MDI Noise Measurements, DUT#1

Per-pair noise above noise floor

Some pairs appear to have unique sources (Pair A 600MHz; Pair D 1.6GHz - 2GHz)
### MDI Measurements, DUT#2

<table>
<thead>
<tr>
<th>Pair (Pins)</th>
<th>Average noise (dBm/Hz)</th>
<th>Noise Power (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (1,2)</td>
<td>-153.12</td>
<td>-57.34</td>
</tr>
<tr>
<td>B (3,6)</td>
<td>-153.57</td>
<td>-58.45</td>
</tr>
<tr>
<td>C (4,5)</td>
<td>-153.22</td>
<td>-58.07</td>
</tr>
<tr>
<td>D (7,8)</td>
<td>-153.44</td>
<td>-58.33</td>
</tr>
</tbody>
</table>

- 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 ~ **-153.4 dBm/Hz**
- Noise power (PSD integrated from 500kHz – 3GHz, all pairs) is ~ **-58.0 dBm**
MDI Noise Measurements, DUT#2
Per-pair noise above noise floor

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

DUT with all Tx disabled
Connections are post “cell phone” filter
## Noise Measurements, PHY vs MDI

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<th>Average noise (dBm/Hz)</th>
<th>Noise Power (dBm)</th>
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<tbody>
<tr>
<td>C (4,5) @ MDI</td>
<td>-153.22</td>
<td>-58.07</td>
</tr>
<tr>
<td>C (4,5) @ PHY</td>
<td>-153.19</td>
<td>-57.95</td>
</tr>
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</table>

- Plots compare system background noise measured at the MDI with another measurement as close as practically possible to the PHY pins
  - It is difficult to instrument MDI trace pairs in real systems
  - Most PCB designs include few to no MDI trace debug features in order to preserve signal integrity
  - Disclaimer: “Adapter ports were harmed in the measuring of this data”

- More high-frequency signals are present before the MDI filter (an expected result)
- However, average noise and total noise power are comparable

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![PSD at MDI & PHY](image1)

**PSD at MDI & PHY after subtracting noise floor**
MDI & PHY power above noise floor

There is some obvious and expected overlap between measured noise. The PHY measurement includes more signals/sources above 1GHz.
Results & Observations

• Average measured background noise for these two systems (10GBASE-T network adapters) is between -152dBm/Hz and -153dBm/Hz

• Average power for “easy” (at MDI) and “hard” (at PHY) measurements is about the same for the limited case presented.
  – Observed an expected “richer” spectrum – more peaks – before the on-board AFE “cell phone” filter.

• Specific background noise (assumed both broadband and stationary) varies across both MDI trace pairs and design implementations

<table>
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<th>Measurement</th>
<th>Average noise (dBm/Hz)</th>
<th>Noise Power (dBm)</th>
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<tbody>
<tr>
<td>DUT#1</td>
<td>-152.0</td>
<td>-56.9</td>
</tr>
<tr>
<td>DUT#2</td>
<td>-153.4</td>
<td>-58.0</td>
</tr>
<tr>
<td>Pair at MDI</td>
<td>-153.2</td>
<td>-58.1</td>
</tr>
<tr>
<td>Pair at PHY</td>
<td>-153.2</td>
<td>-58.0</td>
</tr>
</tbody>
</table>
Conclusions

• Measurements of two 10GBASE-T implementations indicate an average system background noise level of approximately -152 dBm/Hz to -153 dBm/Hz
  – This is in line with the -150 dBm/Hz level discussed in the January 14, 2014 P8023bq PHY Baseline Proposal ad hoc meeting minutes

• While average system background noise levels are comparable…
  – Specific background noise levels vary with implementation
  – Background noise levels may also vary across MDI pairs
Next Steps/Further Investigation

• Seeking feedback from the PHY Baseline Proposal ad hoc regarding these results
  – Implications for PHY design (power, complexity)
  – Relative importance of the additional information observed in PHY-vs. MDI-based measurements of system background noise power
    • If larger data sets are requested, MDI-based measurement is easier

• Improvements in measurement techniques?
  – Example: Use noise floor extension features (may be manufacturer-specific)
  – Time-domain, FFT based measurements to get non-stationary sources (power-on or other power delivery transients, noise from memory/storage transactions)

• Measurements in other systems?
  – 10GBASE-T server LAN-on-motherboard? Switches?
Thank You!
External vs. in-situ Method

- Recalling that the *in situ* tool is designed for basic system debug/manufacturing test, we can conclude that it gives an interesting starting point.

- Comparing earlier *in situ* results to results obtained with bench equipment, an external spectrum analyzer (or other test & measurement tool) is better suited for background noise characterization, especially for 40GBASE-T frequencies of interest.

*in situ results from internal tool PHY state unknown*

*Spectrum analyzer at MDI PHY in Tx disabled state*

*in situ test results were presented in the Channel Modeling ad hoc meeting held January 23, 2014. See cibula_3bq_channel_modeling_ad_hoc_initial_assessment_PCB_noise.pdf*