10GBASE-T Receiver Performance in Cable Clamp and EMI Chamber Testing

IEEE P802.3bq 40GBASE-T Task Force

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Motivation – Continuing work in support of the Rx CMNR ad hoc, including…

Rx CMNR ad hoc charter and scope/deliverables

- Investigate the receiver common mode noise rejection (Rx CMNR) test, also known as the cable clamp test, and define an appropriate specification for 40GBASE-T

Areas for Discussion & Investigation

- Identify improvements/augmentations to the existing test and associated configuration/calibration procedures
- Evaluate noise coupling over supported cabling systems

"Things Needed"

- Relationship/correlation between the Rx CMNR test and system immunity requirements (standards-based and ad-hoc/those not comprehended by standards) – ***focus of this contribution***

Overview of this Correlation Effort

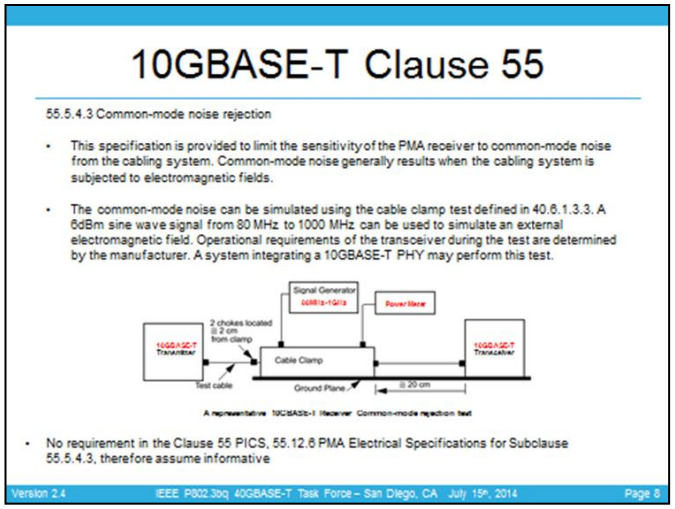
- Perform a representative receiver external EM interference rejection test using the 10GBASE-T cable clamp, two representative channels (Cat6a UTP and Cat8 S/FTP), and a pair of 10GBASE-T devices.

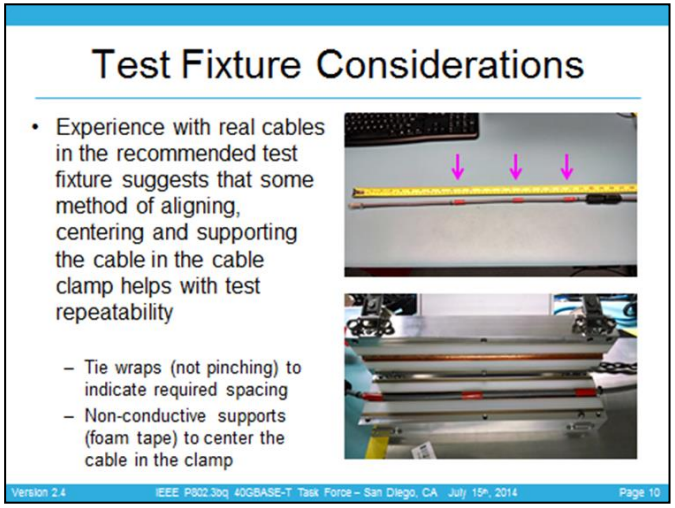
- Repeat this test, using the *same* impairment frequencies, channels, devices, and systems, in an EMC radiated immunity test environment. Two physical layouts of the test channel are used in an initial check on EM interference coupling in this environment.

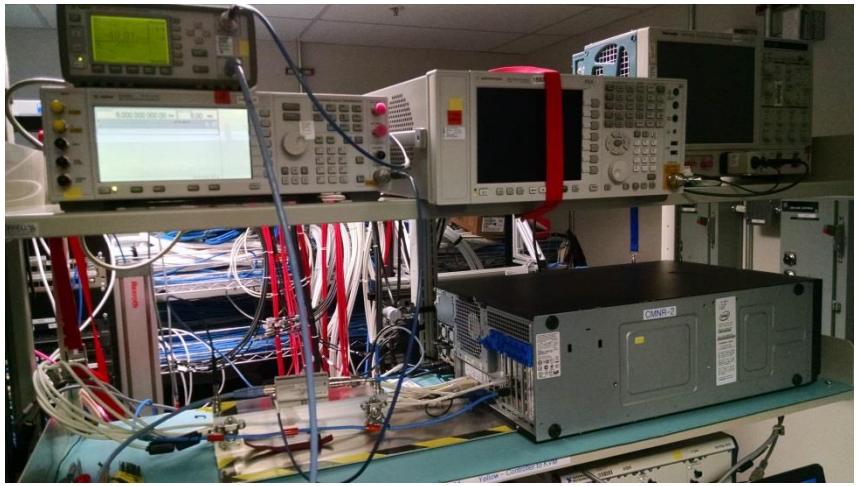
- Compare results from the two environments.

EM Rejection Test Setup

- Excerpts from previous P802.3bq task force contributions (available from the P802.3bq public area)
- Follows Clause 40.6.1.3.3, Annex 40B and 55.5.4.3 with slight modifications
- Similar setup used in the chamber correlation lab site







Clamp Rx CMNR Test Design (1/2)
Test and Test Segments

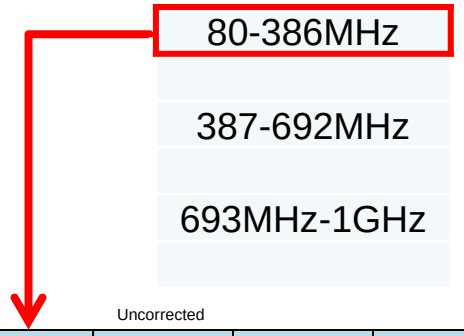
Test Segment	Operating Mode	Link Configuration	Packet Size	Minimum # Packets	Start Frequency (Hz)	Stop Frequency (Hz)	Source signal power
1	Normal (set up DUT and LP, check TTL, run BER test)	Autonegotiate link mode, speed and loop timing (M/S)	1514 bytes	500,000,000	none	none	0.0 dBm
2	Normal (set up DUT and LP, check TTL, run BER test)	Autonegotiate link mode, speed and loop timing (M/S)	1514 bytes	500,000,000	80,000,000	385,901,900 (401 steps)	6.0 dBm
3	Normal (set up DUT and LP, check TTL, run BER test)	Autonegotiate link mode, speed and loop timing (M/S)	1514 bytes	500,000,000	386,666,700	692,568,600 (401 steps)	6.0 dBm
4	Normal (set up DUT and LP, check TTL, run BER test)	Autonegotiate link mode, speed and loop timing (M/S)	1514 bytes	500,000,000	693,333,300	1,000,000,000 (401 steps)	6.0 dBm

This illustrates the test table for a single 80MHz to 1GHz Rx CMNR test pass used in the clamp portion of this investigation

- Each impairment segment is ~307MHz wide with 401 points in each segment (765 kHz resolution) and a total of 1,203 discrete frequencies
- Dwell time is 500ms/point, resulting in a single sweep time of ~3.33 minutes
- A 307MHz wide sweep is repeated ~5 times during a nominal 15 minute BER test pass

Clamp Rx CMNR Test Design (2/2)
List Sweep Table Example

- One test pass includes 4 BER test segments, ~15min/segment
  - 1x baseline segment (no noise injection)
  - 3x impairment segments (noise injection over 1 of 3 frequency bands)
- 80MHz-1GHz sweep step tables use 401 points for each band
  - 765 kHz resolution on injected sine impairments; 500ms dwell at each frequency step
  - Injected power is corrected for cable clamp response
- Pass/Fail Criteria
  - Link within expected link times, no link drops, meets BER



Uncorrected

Frequency	Response to 6dBm (dBm)	Source Power for 6dBm (dBm)	Corrected Response (dBm)	Step (kHz)
80.000000MHz	5.90	6.10	6.03	n/a
80.764750MHz	5.90	6.10	6.03	764.750
81.529510MHz	5.90	6.10	6.03	764.760
82.294260MHz	5.90	6.10	6.03	764.750
83.059020MHz	5.90	6.10	6.03	764.760
83.823770MHz	5.90	6.10	6.03	764.750
84.588530MHz	5.90	6.10	6.03	764.760
85.353280MHz	5.90	6.10	6.03	764.750
86.118040MHz	5.90	6.10	6.05	764.760
86.882790MHz	5.92	6.08	6.03	764.750
87.647550MHz	5.92	6.08	6.03	764.760
88.412300MHz	5.92	6.08	6.03	764.750
89.177060MHz	5.92	6.08	6.03	764.760
89.941810MHz	5.92	6.08	6.03	764.750
90.706570MHz	5.91	6.09	6.02	764.760
91.471320MHz	5.91	6.09	6.02	764.750
92.236080MHz	5.91	6.09	6.02	764.760
93.000830MHz	5.90	6.10	6.03	764.750
93.765590MHz	5.90	6.10	6.03	764.760

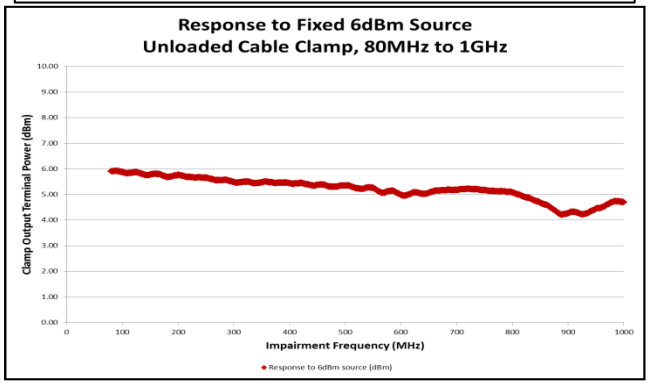
…continues to 386MHz

Typical EM Interference Rejection Test Flow

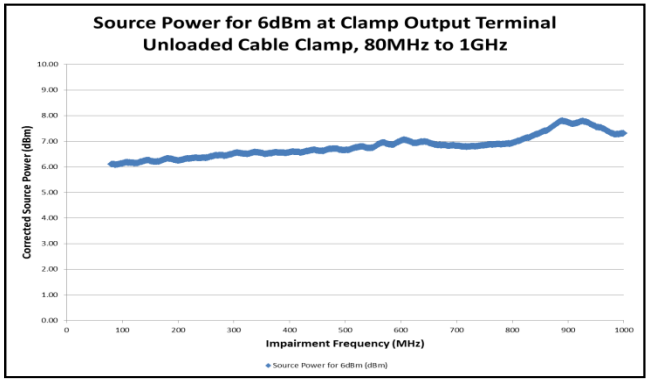
1. Perform cable clamp calibration, and calculate any required correction factors
   - The cable clamp is “unloaded” during calibration for these correlation tests
2. Configure DUT and LP systems
3. Run 1st segment (no noise) for baseline
4. Run 2nd through 4th segments
   1. Begin impairment sweep and cycle continuously throughout each test segment frequency list
   2. Initiate link event (AN restart, reset, etc).
   3. Collect Tx/Rx statistics and relevant PHY health indicators for both the DUT and LP
5. Compile data and analyze results

Confirming “signal power measured at the output of the clamp does not exceed 6dBm”

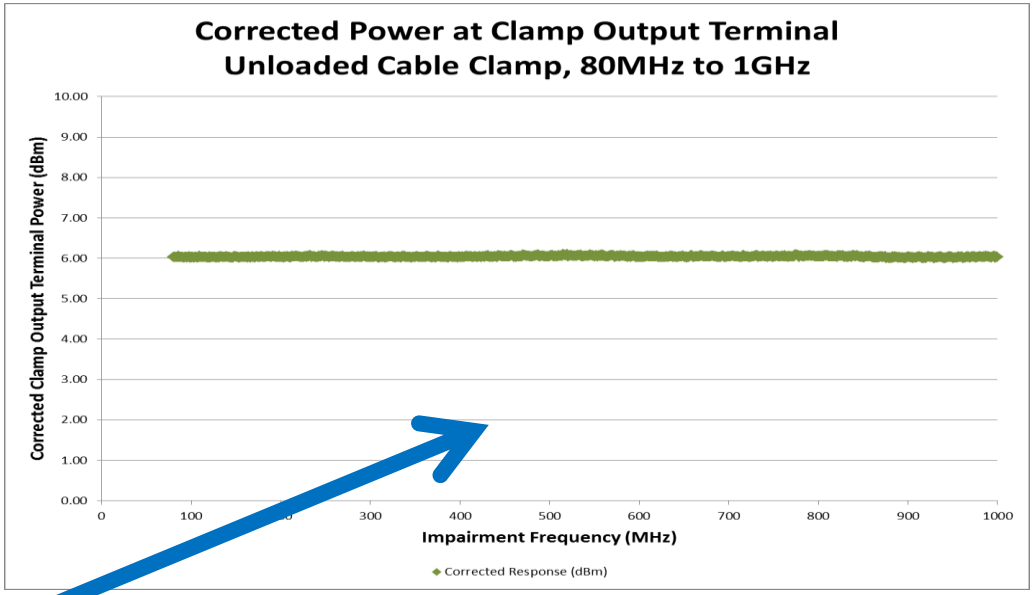
1. Measure clamp response to fixed +6dBm source



2. Calculate required source power for +6dBm at “DUT end”

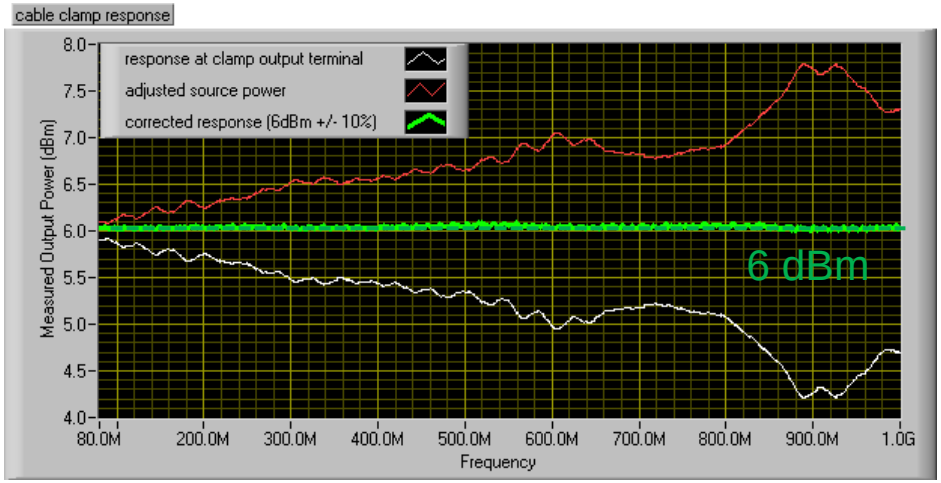


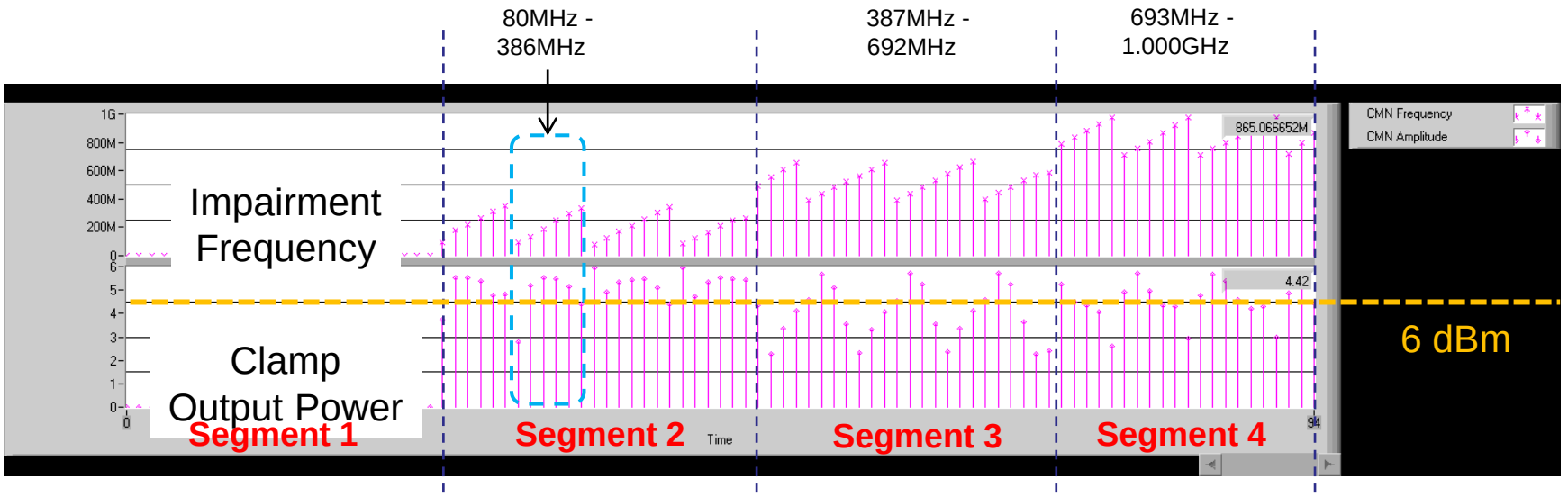
3. Confirm corrected power to DUT (ideally 6dBm +/- 10%)



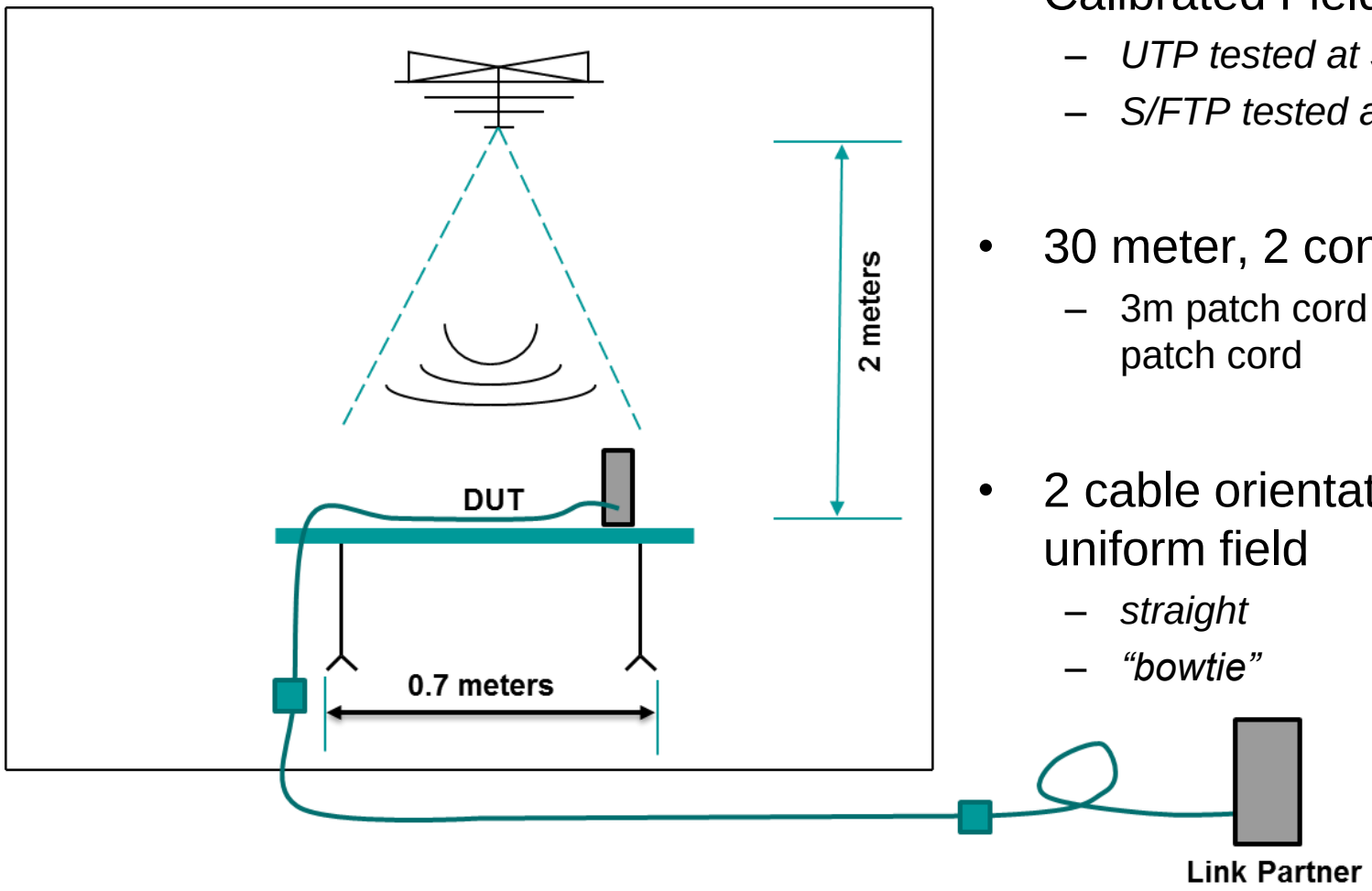
Measured Impairment Power With Unloaded Clamp Calibrated to 6dBm

- Uncorrected response at right varies from 5.92 dBm to 4.20 dBm and is adjusted to a constant 6dBm before the test
- Measured response (below) during Rx CMNR testing shows cable loading effect





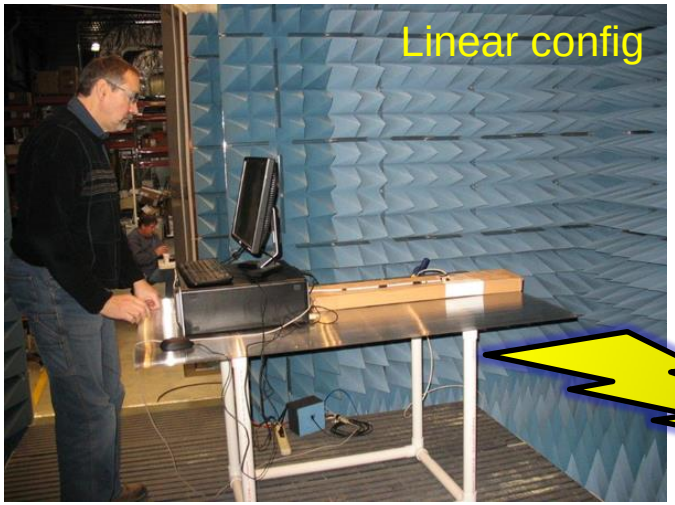
EMI Chamber Setup Diagram

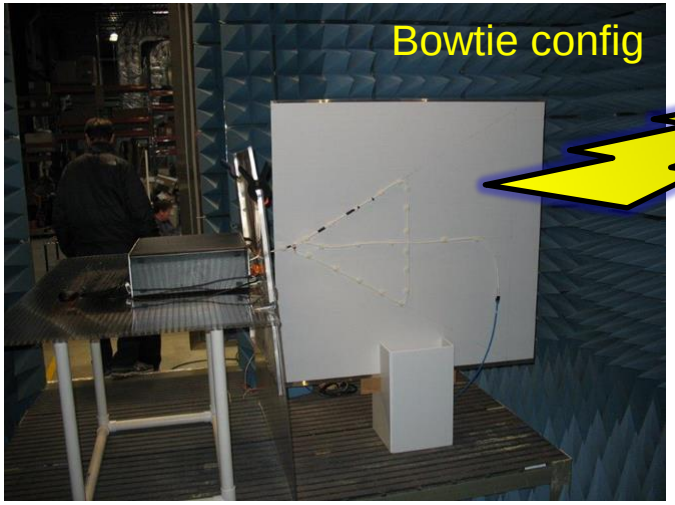


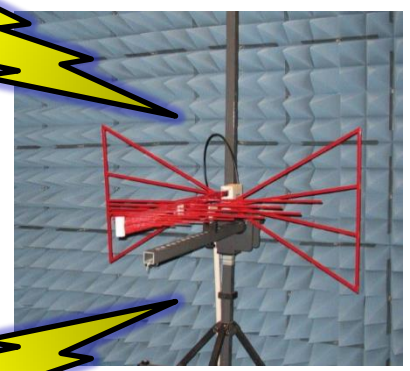
- Calibrated Field over 1 meter^2
  - *UTP tested at 3 V/m*
  - *S/FTP tested at 10 V/m*
- 30 meter, 2 connector channel
  - 3m patch cord + 23m cable + 4m patch cord
- 2 cable orientations within uniform field
  - *straight*
  - *"bowtie"*

EMI Chamber Setup

- System with DUT is located 2m from source antenna on a non-conductive table
- The two cable orientations are illustrated in the photographs
  - Linear, with the 3m patch cord element positioned as in a typical radiated immunity test; ~1m of cable illuminated
  - Bowtie, with the 3m patch cord, one connector, and 23m link segment elements configured in as a receiving antenna; ~25m cable illuminated







Chamber Rx CMNR Test Design

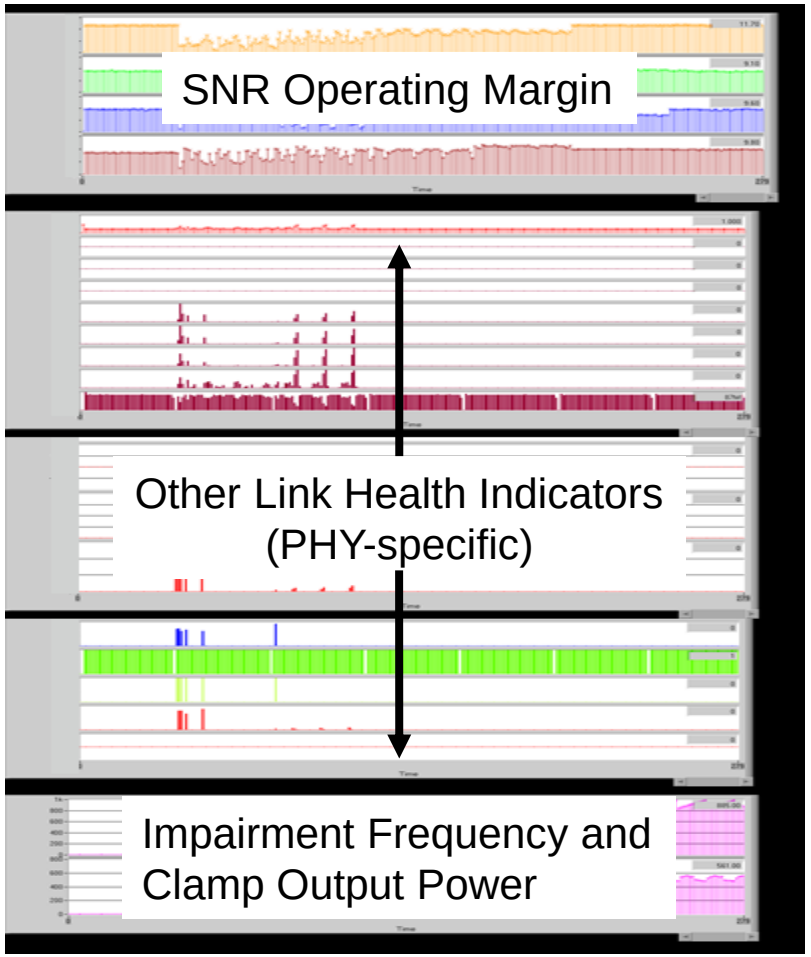
Test Segment	Operating Mode	Link Configuration	Packet Size	Minimum # Packets	Start Frequency (Hz)	Stop Frequency (Hz)	Source signal power
1	Normal (set up DUT and LP, check TTL, run BER test)	Autonegotiate link mode, speed and loop timing (M/S)	1514 bytes	500,000,000	none	none	0.0 dBm
2	Normal (set up DUT and LP, check TTL, run BER test)	Autonegotiate link mode, speed and loop timing (M/S)	1514 bytes	500,000,000	200,066,500	385,901,900 (244 steps)	6.0 dBm
3	Normal (set up DUT and LP, check TTL, run BER test)	Autonegotiate link mode, speed and loop timing (M/S)	1514 bytes	500,000,000	386,666,700	692,568,600 (401 steps)	6.0 dBm
4	Normal (set up DUT and LP, check TTL, run BER test)	Autonegotiate link mode, speed and loop timing (M/S)	1514 bytes	500,000,000	693,333,300	1,000,000,000 (401 steps)	6.0 dBm

This illustrates the test table for a single 200MHz to 1GHz Rx CMNR test pass used in the chamber portion of this investigation (limited to 200MHz start frequency by source antenna)

- Each impairment segment is ~307MHz wide with 244 points in the 1st segment, and 401 points in the other segments (765 kHz resolution) and a total of 1,046 discrete frequencies
- Dwell time is 500ms/point, resulting in a single sweep time of ~3.33 minutes
- A 307MHz wide sweep is repeated ~5 times during a nominal 15 minute BER test pass

Representing Test Data & Results

- Many PHY link health indicators and other debug information can be monitored & recorded during each test segment
- A minimum data set could include counts of link drops (if any), packet errors, and the noise frequencies associated with those events/errors
- Parameters of interest are recorded at ~10s intervals during each test segment; impairment frequencies and measured clamp power are logged throughout the test.



Example of low-level PHY health indicators from an EM rejection test

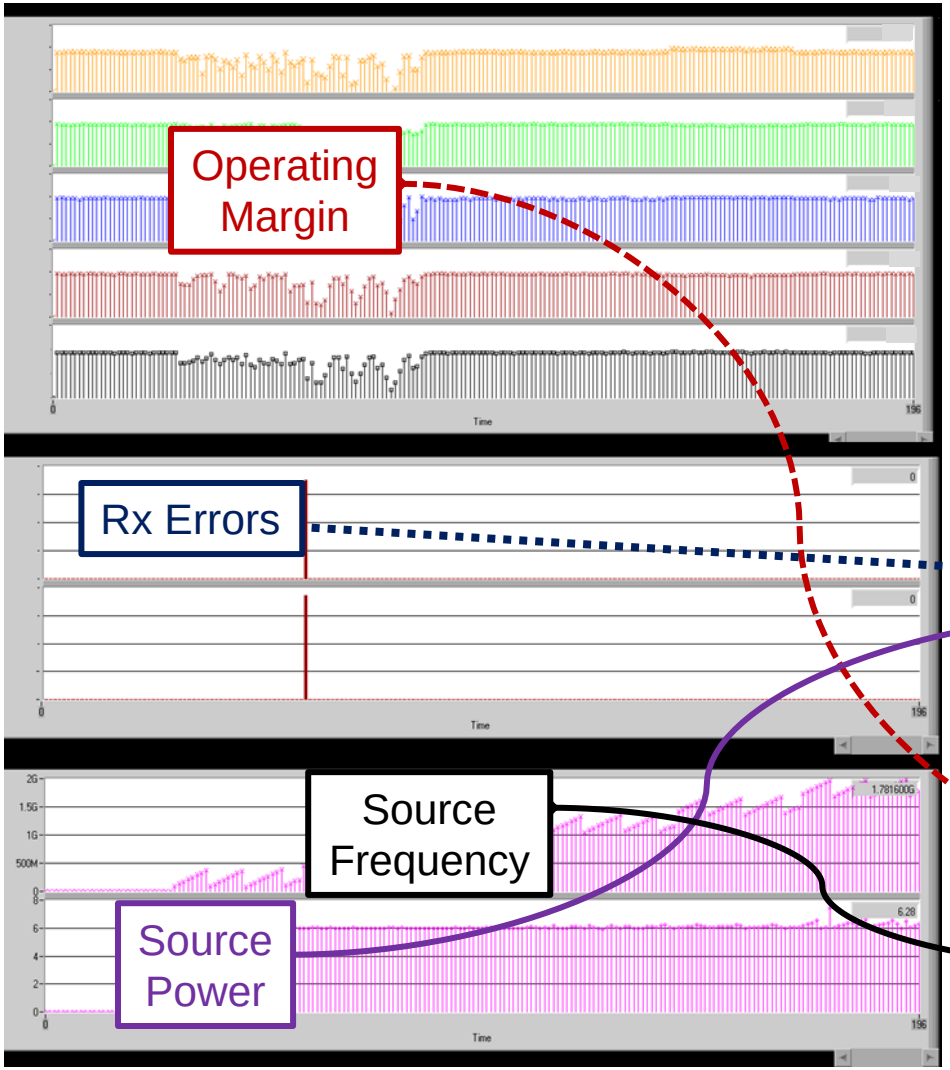
Final Results Summary (Example)

- Test results include basic operational requirements as determined by the manufacturer
  - In this implementation, we evaluate, time-to-link, link speed, # of link attempts, link drops, # packets Tx/Rx, Rx errors, and BER/FER

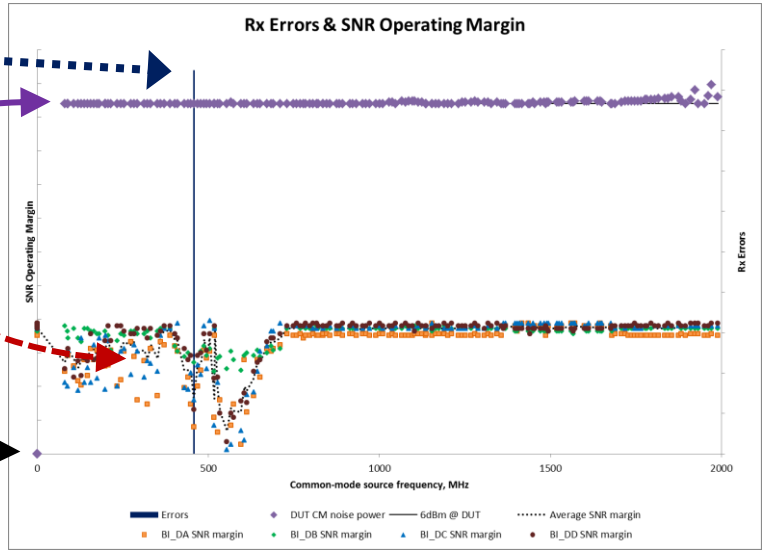
Test ID:	Link # attempts:	Link # drops:	Link time (ms):	DUT Link speed	DUT Good Tx:	DUT Good Rx:	DUT Lost Frames:	DUT Rx Errors:	DUT Rx-based BER:	DUT Status:
Baseline	1	0	6098	10000 Mb/s	516284137	516284137	0	0	0.00E+00	PASS
80-300MHz	1	0	5905	10000 Mb/s	516413035	516413035	0	0	0.00E+00	PASS
400-719MHz	1	0	6097	10000 Mb/s	516643396	516643396	0	0	0.00E+00	PASS
720-1039MHz	1	0	5723	10000 Mb/s	515848959	515848959	0	0	0.00E+00	PASS
1040-1359MHz	1	0	5913	10000 Mb/s	515816192	515816192	0	0	0.00E+00	PASS
1360-1679MHz	1	0	5911	10000 Mb/s	516531269	516531269	0	0	0.00E+00	PASS
1.680-2.000GHz	1	0	6091	10000 Mb/s	515824748	515824748	0	0	0.00E+00	PASS
Totals	**7**	**0**	**0/7, avg. = 5963**	10000 Mb/s	**3,613,361,736**	**3,613,361,736**	**0**	**0**	**0**	**0/7**

Test ID:					LP Good Tx:	LP Good Rx:	LP Lost Frames:	LP Rx Errors:	LP Rx-based BER:	LP Status:
Baseline					747948965	747948965	0	0	0.00E+00	PASS
80-300MHz					744601074	744601074	0	0	0.00E+00	PASS
400-719MHz					747828993	747828993	0	0	0.00E+00	PASS
720-1039MHz					746998329	746998329	0	0	0.00E+00	PASS
1040-1359MHz					746110184	746110184	0	0	0.00E+00	PASS
1360-1679MHz					746061199	746061199	0	0	0.00E+00	PASS
1.680-2.000GHz					743404262	743404262	0	0	0.00E+00	PASS
Totals					**5,222,953,006**	**5,222,953,006**	**0**	**0**	**0**	**0/7**

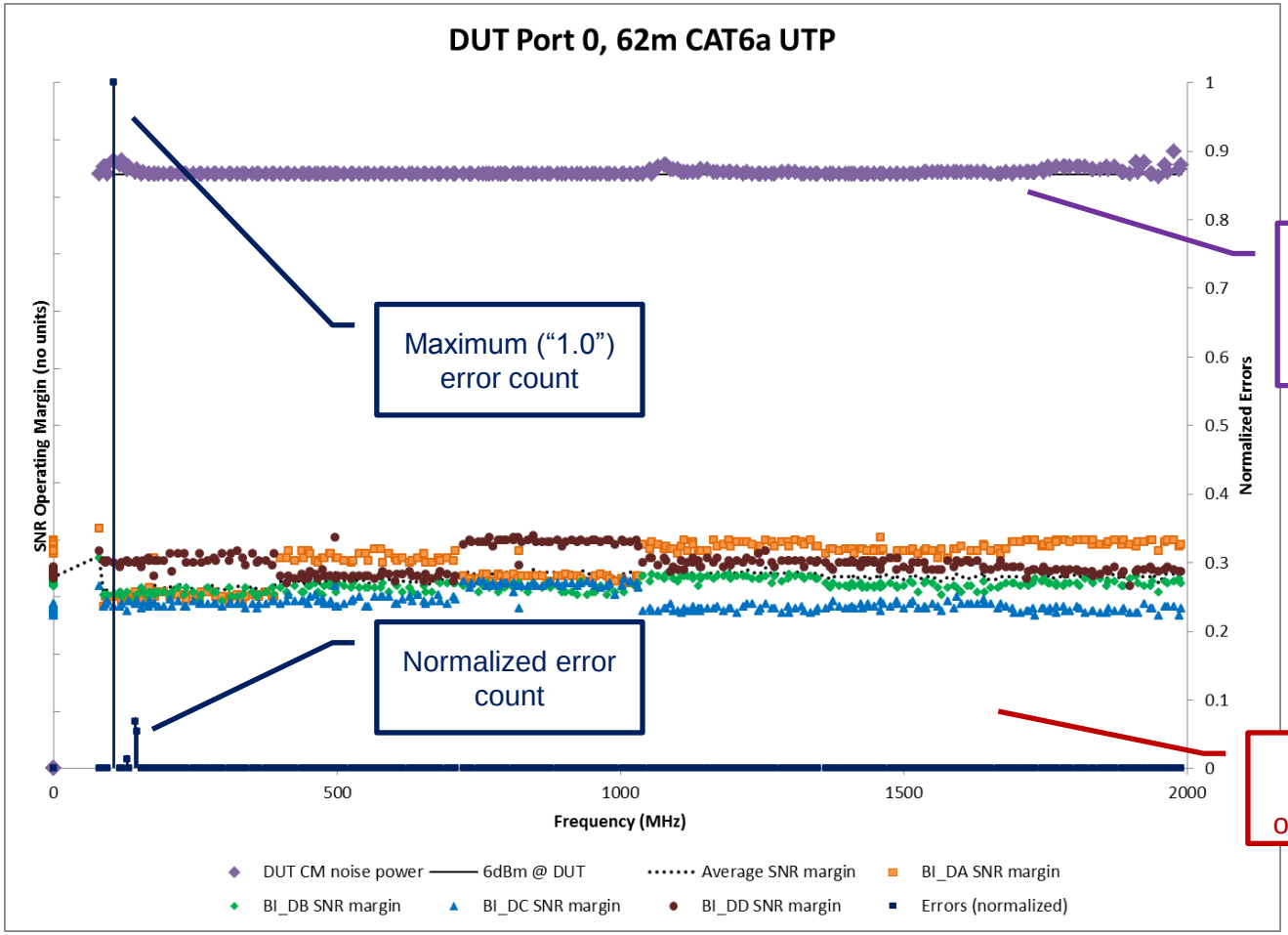
Alternate Data Representation for this Investigation



- Test data and link health indicators are collected for each segment and normally plotted as a function of time
- Sorting and re-formatting results as a function of frequency allows a quick comparison of port performance vs. frequency to facilitate debug or, in this case, “observe” the coupled EM field impairment



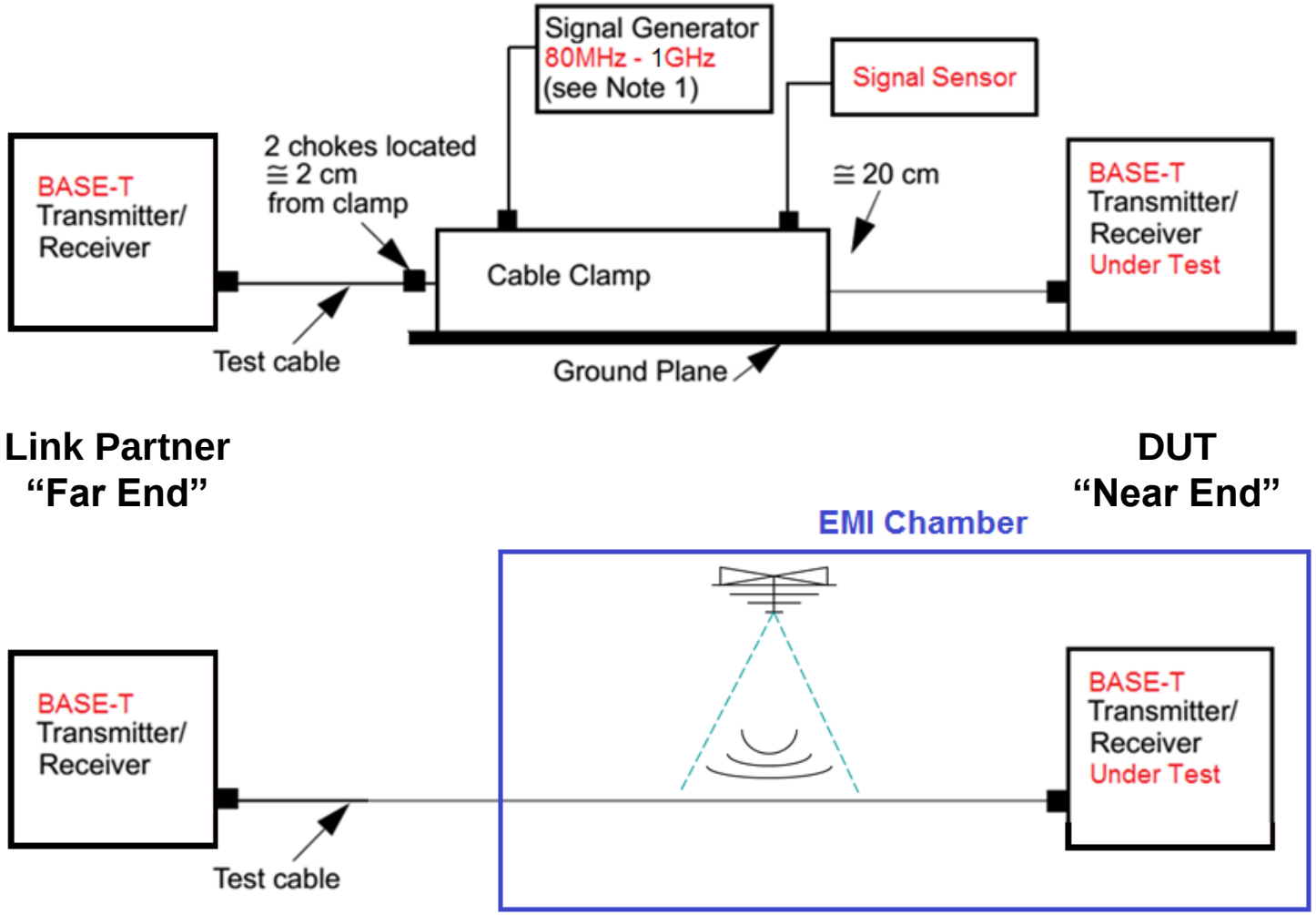
EMI Rejection Frequency Plot Decoder



Measured power at clamp output

Per-pair and average SNR operating margin

Configurations & Terminology



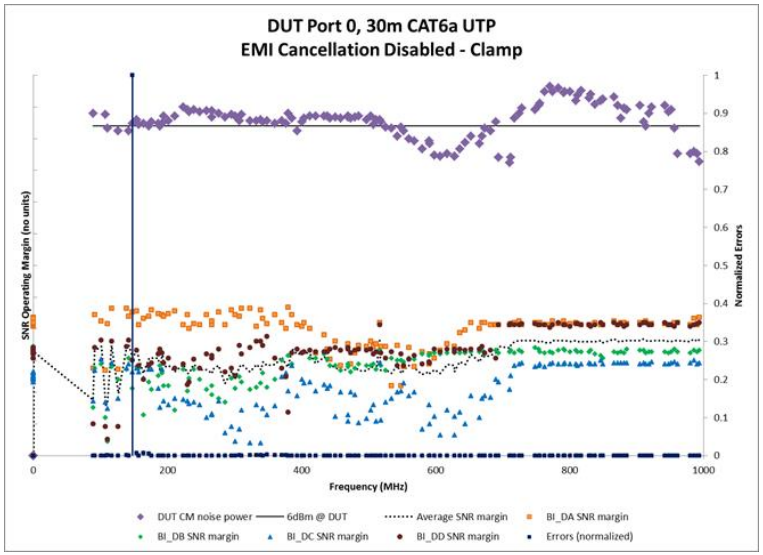
Results Set #1

- Frequency plots for production dual-port device (baseline operation with EMI features disabled)
  - Cat6a UTP
  - 30m, 2-connector channel (3m+23m+4m)
  - Impairment (clamp or antenna signal) coupled onto the 3m patch cord
  - Cable clamp source power is adjusted for 6dBm at cable clamp output with no cable in the clamp
  - Field strength is calibrated for 3V/m over $1m^2$ area

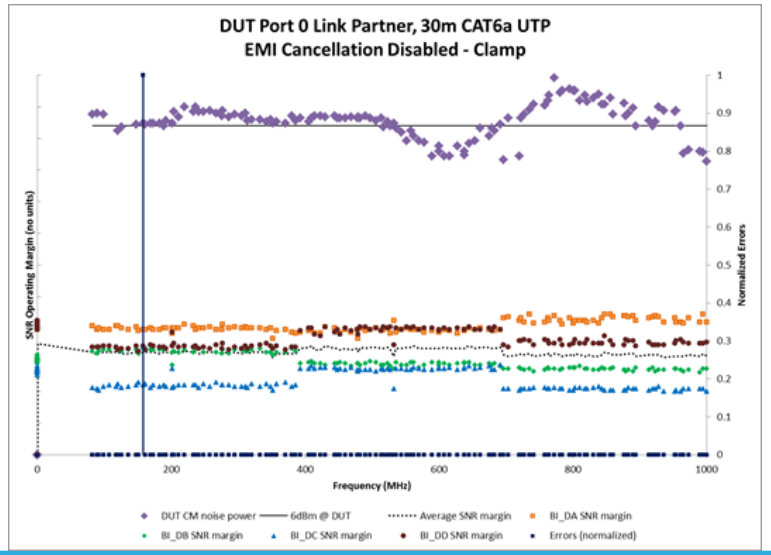
EM Rejection Clamp, UTP

- Results for clamp and Cat6a UTP
  - Clamp-induced impairment is detected between 80MHz and ~750MHz
  - Far-end errors are detected; doesn't necessarily align with far-end margin – suggests a need to either better suppress far-end coupling, or identify and d/dx errors from "bad Tx"

Note – for these and following results, the upper plot is DUT/ near-end and the lower is Link Partner/far-end



"Near end"

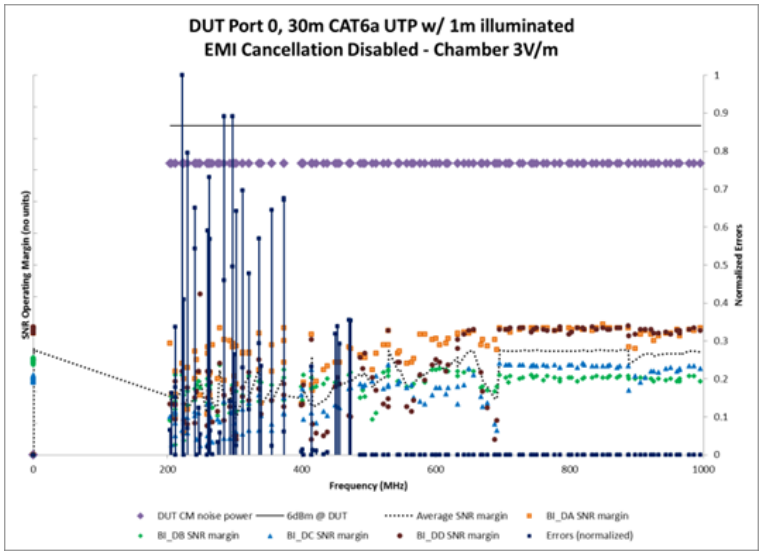


"Far end"

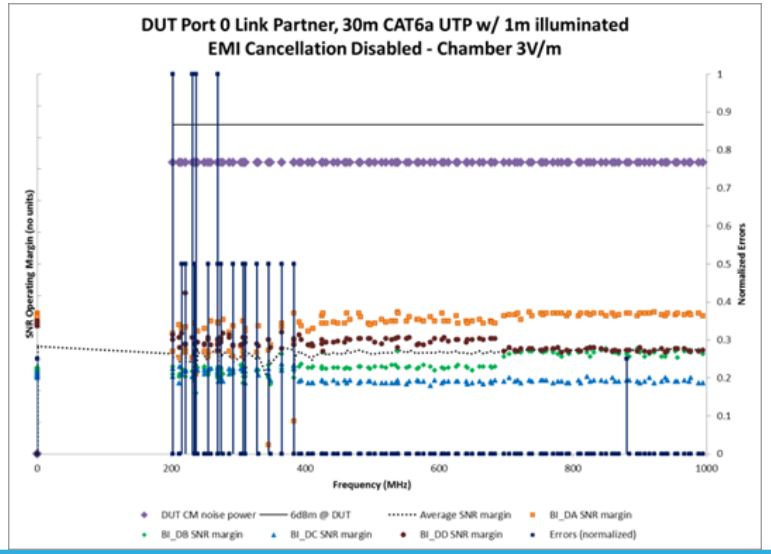
EM Chamber, Linear (1m), UTP

- Results for 3V/m field and 1m straight Cat6a UTP
  - Chamber-induced impairment is detected between 200MHz and ~725MHz
  - Error counts for both near- and far- end are higher than with the clamp; far-end shows some reduced margin at lower frequencies

Note – Due to source antenna characteristics, all chamber tests use a 200MHz–1GHz bandwidth for this initial evaluation



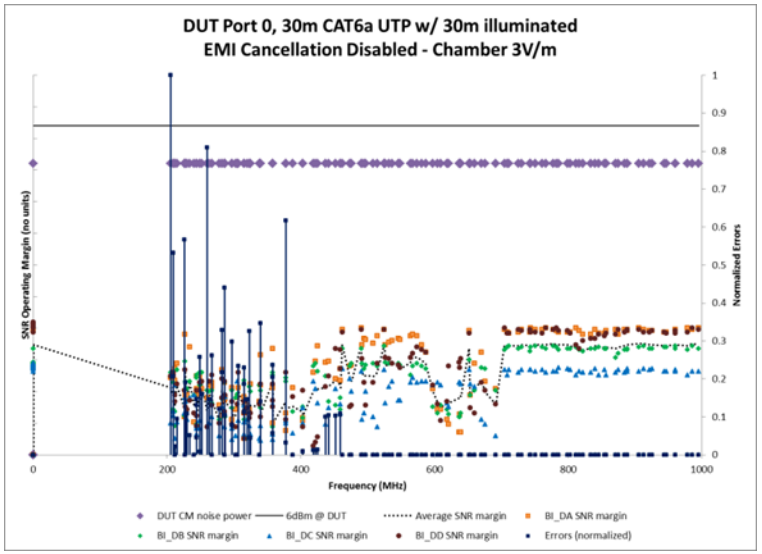
"Near end"



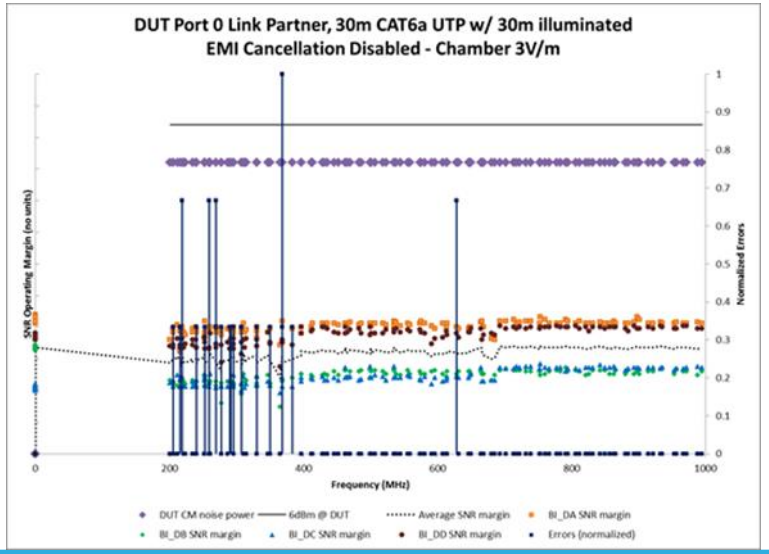
"Far end"

EM Chamber, Bowtie (30m), UTP

- Results for 3V/m field and 30m bowtie Cat6a UTP
  - Chamber-induced impairment is again detected between 200MHz and ~725MHz
  - *Suggestion* of more near-end coupling between 600MHz and 700MHz



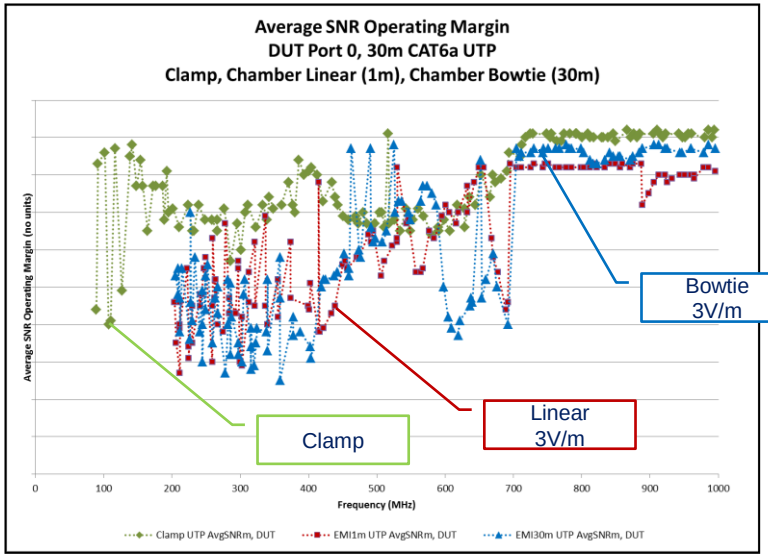
"Near end"



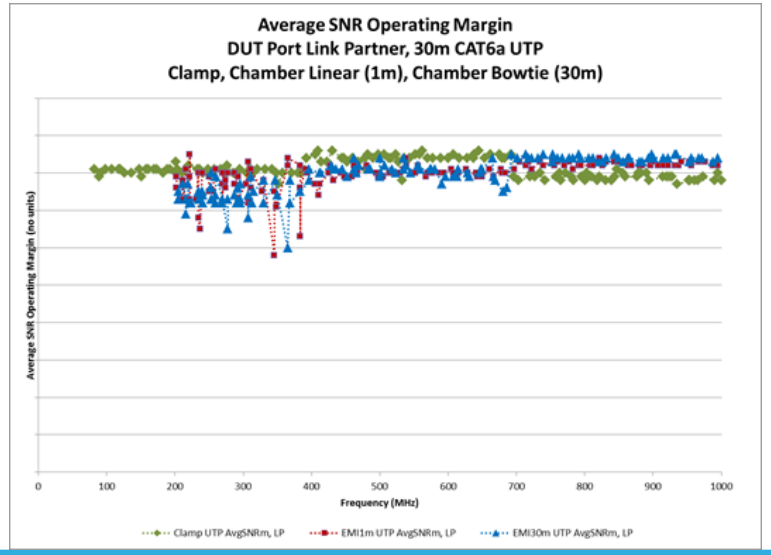
"Far end"

CAT6a UTP Results Comparison

- Simplified views of DUT and Link Partner results using average SNR operating margin and relative normalized total errors to compare the three stress conditions
  - Lower avg. SNR operating margins, and higher error counts, are observed in the chamber tests
  - Both setups can benefit from some better far-end noise suppression



"Near end"



"Far end"

Cable Type	Impairment Source	Normalized Total DUT Errors	Normalized Total LP Errors
Cat6A UTP	Clamp	0.02	0.03
Cat6A UTP	Linear (1m)	1.00	0.88
Cat6A UTP	Bowtie (30m)	0.64	1.00

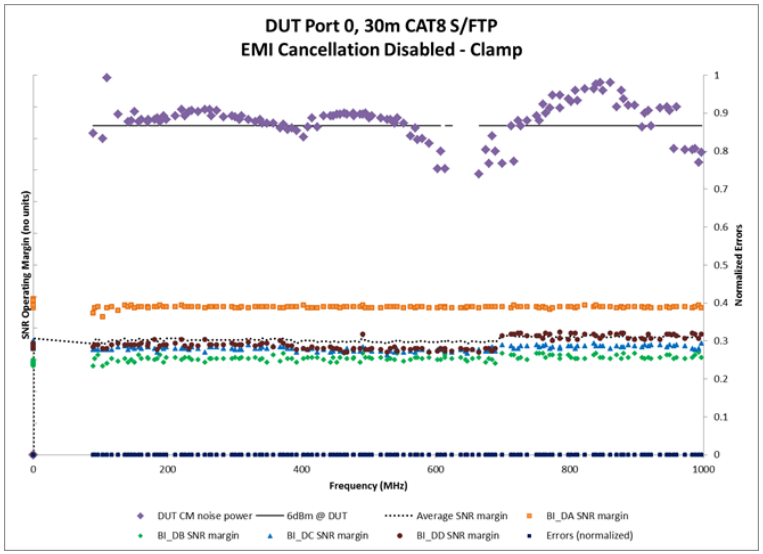
Total LP errors = 0.004% of Total DUT errors

Results Set #2

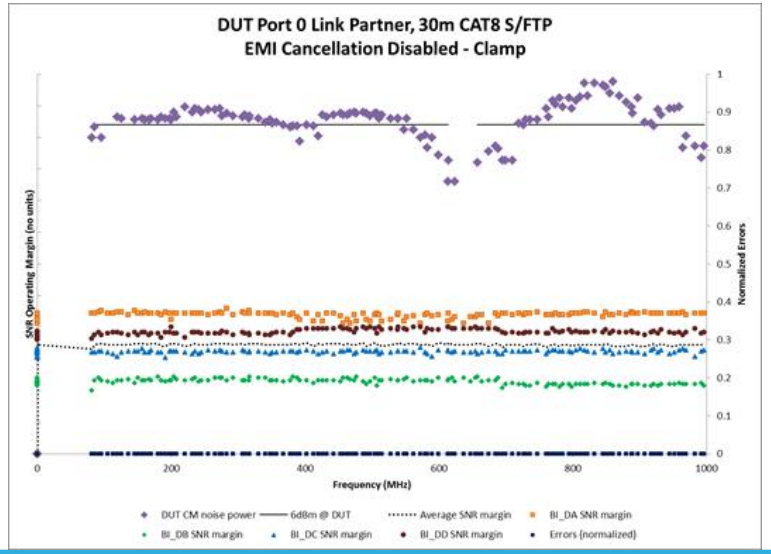
- Frequency plots for production dual-port device (baseline operation; EMI features disabled)
  - Cat8 S/FTP
  - 30m, 2-connector channel (3m+23m+4m)
  - Impairment (clamp or antenna signal) coupled onto the 3m patch cord
  - Cable clamp source power is adjusted for 6dBm at cable clamp output with no cable in the clamp
  - Field strength is calibrated for 10V/m over $1m^2$ area

EM Rejection Clamp, S/FTP

- Results for clamp and Cat8 S/FTP
  - Little/no evidence of induced impairment using average SNR operating margin & errors as the figure-of-merit
  - Other low-level PHY system performance indicators (not shown) show that the external field is being coupled into the system
  - Resulting noise power is not significant for the 10GBASE-T PHY



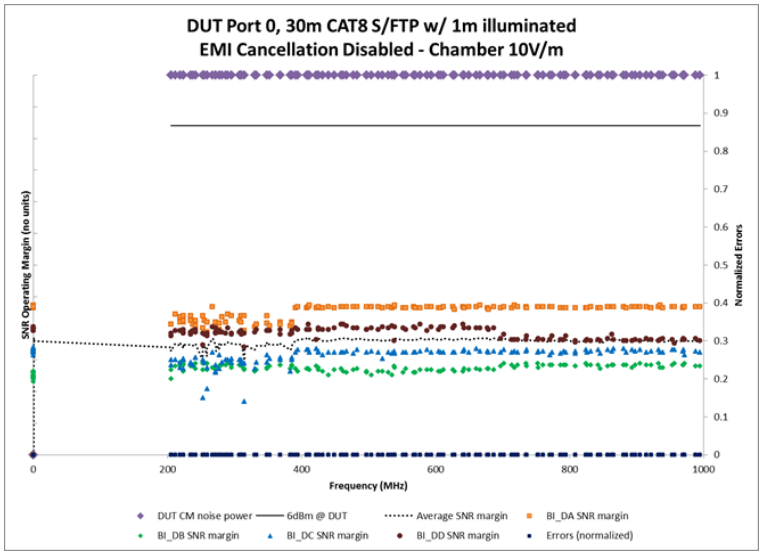
"Near end"



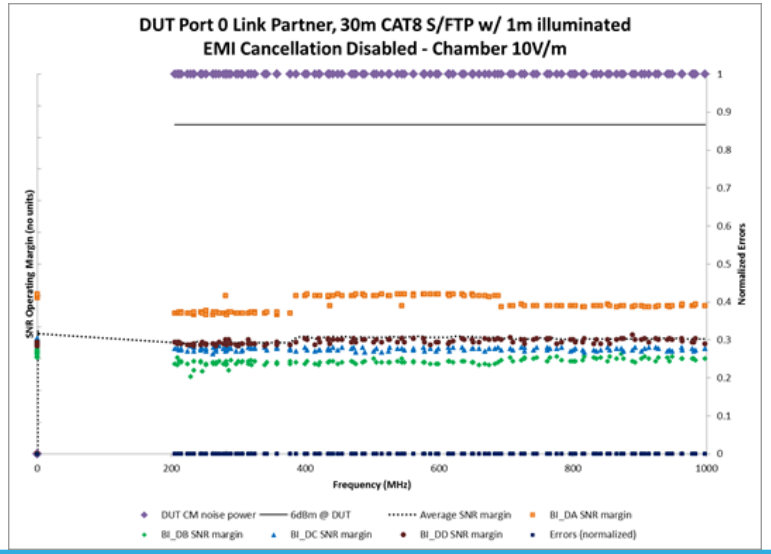
"Far end"

EM Chamber, Linear (1m), S/FTP

- Results for 10V/m field and 1m straight Cat8 S/FTP
  - More variation in average SNR operating margin at the DUT/near-end
  - Suggests more impairment power is coupled to the channel and MDI in this environment



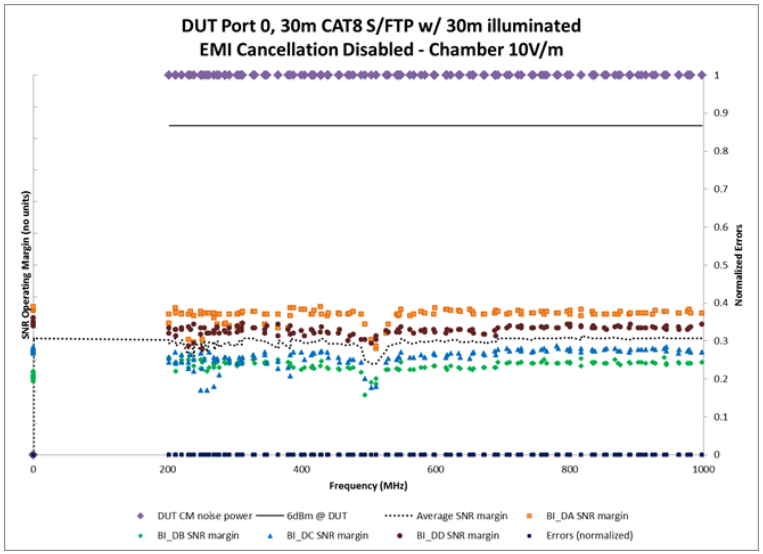
"Near end"



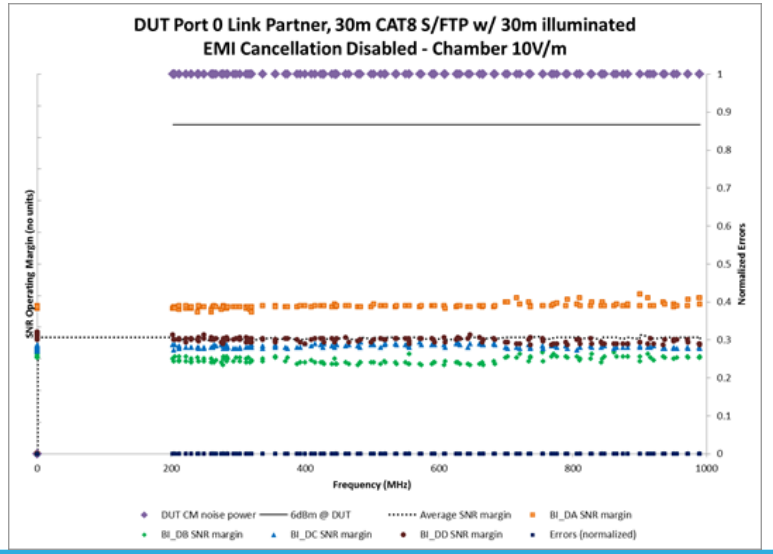
"Far end"

EM Chamber, Bowtie (30m), S/FTP

- Results for 10V/m field and 30m bowtie Cat8 S/FTP
  - Comparable to 1m linear configuration
  - Reported operating margins suggest higher external EM field pickup
  - Some interesting behavior at the DUT/near-end between 200MHz-300MHz and around 500MHz



"Near end"

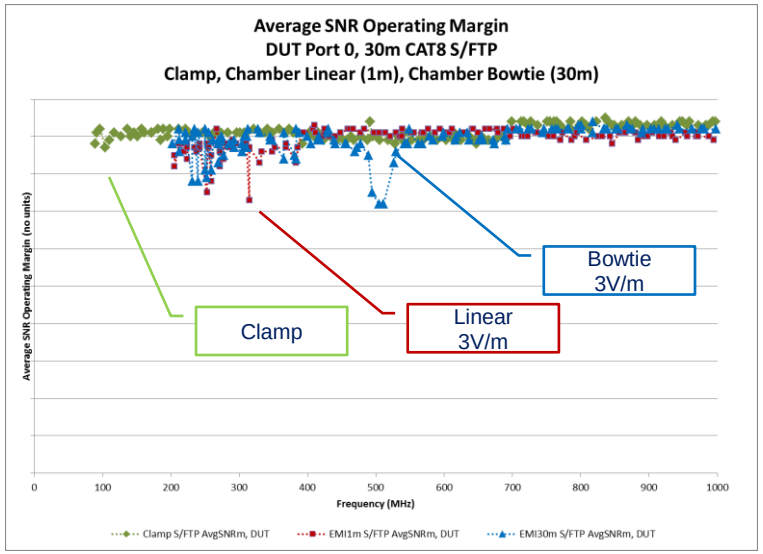


"Far end"

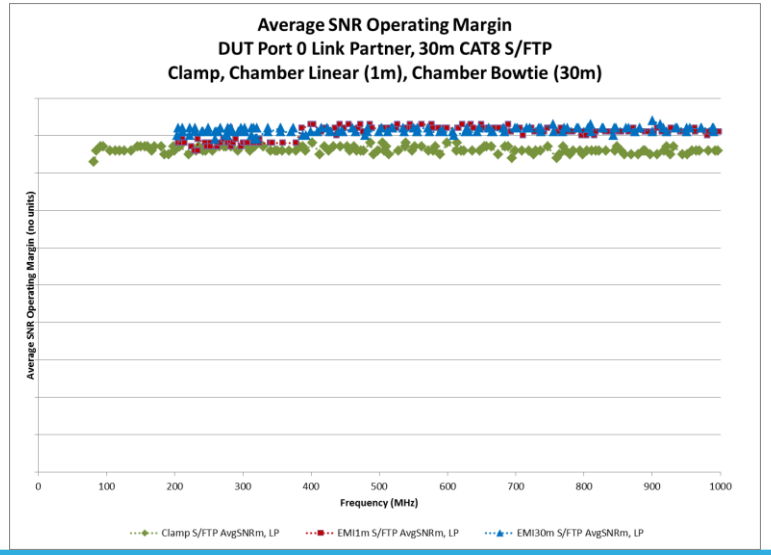
CAT8 S/FTP Results Comparison

- Simplified views of DUT and Link Partner results using average SNR operating margin and relative normalized total errors to compare the three stress conditions
  - Lower avg. SNR operating margins are observed in the chamber tests
  - There are some observable differences between the two EM chamber configurations
  - No noticeable far-end effects in any of the three setups

No error table – no errors reported!



"Near end"



"Far end"

Recommended Text for 113.5.4.3 (From March 4th, 2015 Rx CMNR ad hoc)

113.5.4.3 Rejection of External EM Fields

- When the cabling system is subjected to electromagnetic fields, currents are generated in the shield which may be converted to interference. This specification is provided to limit the sensitivity of the PMA receiver to external EM fields picked up by the cabling and interconnect system. It provides an assessment method of the electromagnetic performance of the link segment and the PHY, including the MDI.

- An 80 MHz to 2000 MHz test can be made based on the cable clamp test defined in 40.6.1.3.3, a 30 meter plug-terminated Category 8 channel that meets the requirements of 113.7, and suitable broadband ferrites. All components in the test remain over the ground reference plane. A sine wave with the amplitude held constant over the whole frequency range from 80MHz to 2000MHz, with the amplitude calibrated so that the signal power measured at the output of the clamp does not exceed 6dBm, is used to generate the external electromagnetic field and corresponding shield current.

- A system integrating a 40GBASE-T PHY may perform this test to evaluate anticipated performance in regulatory test environments. Operational requirements of the transceiver during the test are determined by the manufacturer.

- *Editor's note (to be removed prior to publication): Commenters are encouraged to confirm the source-adjustment criteria, measurement points, and levels used with the clamp methodology in this subclause.*

Rx CMNR ad hoc
Potential Paths Forward Re-visited

- Measure channel coupling characteristics **(ONGOING EFFORTS WITH GOOD PROGRESS)**
  - How much differential-mode noise results when a channel is exposed to common-mode noise?
    - In a chamber environment (see pischl_3bq_01b_1014.pdf)
    - In the cable clamp environment (see cibula_3bq_02a_1114.pdf,Moffitt_ClampAssessmentUpdate_Feb18'15.pdf)

- Evaluate system/PHY response/performance **(ONGOING EFFORTS WITH GOOD PROGRESS)**
  - What are the effects of the resultant noise on system and PHY operating parameters (error ratio/rate, operating margin?
    - In the cable clamp environment (**THIS CONTRIBUTION AND UPCOMING AD HOCs)**
    - In a chamber environment (**THIS CONTRIBUTION AND FOLLOW-UP WORK**)

- Establish correlation between regulatory requirements and lab conformance tests **(WORK IN PROCESS)**
  - Modeling? – xV/m source coupled into cable assuming certain coupling characteristics, then confirm with chamber measurements
    - Test configurations, including anomalous configurations as a point of reference/investigation
    - Coupling technologies – how to effectively inject noise beyond 900MHz (or the limit of the cable clamp method)? Or is the existing clamp sufficient as suggested by early efforts?

- Guidance for test implementers **(WORK IN PROCESS IN THE AD HOC)**
  - Clamp verification & calibration with needed enhancements for 25Gbps/40Gbs operation
  - Test definition – source-adjustment criteria, measurement points, and levels
  - Corresponding informative text (Annex) for Clause 113

Summary

- Initial correlation testing between cable clamp and EMC chamber environments over a 200MHz to 1GHz range, has been completed, using two cable types and a representative 2-connector channel
  - Observed 10GBASE-T PHY receive performance, while not absolutely correlated, is comparable in the two environments
  - Using a basic set of operational metrics, this investigation suggests that the present clamp test source power provides less external impairment coupling than representative EMC test environments
- Further correlation testing will be performed as the details of implementation for Subclause 113.5.4.3, Rejection of External EM Fields, are refined
- Additional contributions and collaborations are encouraged

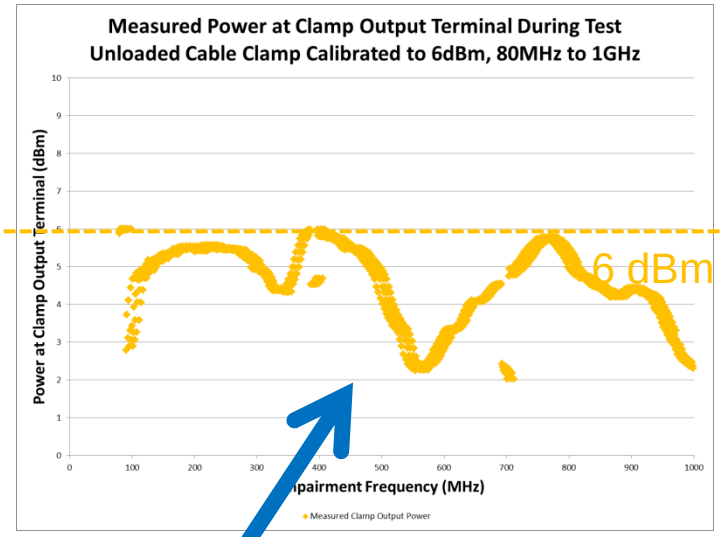
Thank You!

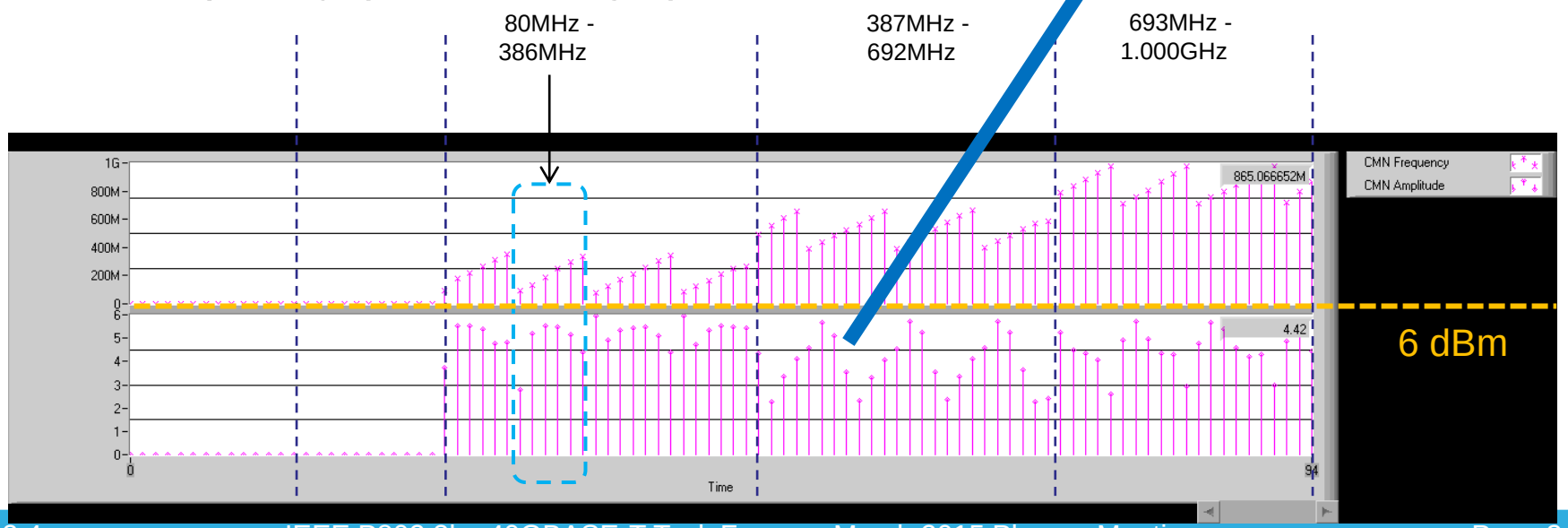
Rx CMNR Equipment List

Intel ND X-Lab Twisted-Pair Receiver Common-Mode Noise Rejection Equipment List			
Function	**Model/Description**	**Additional information**	**Comment**
Signal source	Agilent E4438C Vector Signal Generator 250 kHz to 6 GHz	http://www.keysight.com/en/pd-1000004297:epsg:pro-pn-E4438C/esg-vector-signal-generator	Relatively high-power output (20dBm max)
Signal monitoring (test)	Agilent E4416A EPM-P Series Single Channel Power Meter	http://www.keysight.com/en/pd-1000003554:epsg:pro-pn-E4416A/epm-p-series-single-channel-power-meter	
	Agilent E9323A E-Series Peak and Average Power Sensor, 50 MHz to 6 GHz	http://www.keysight.com/en/pd-1000003561%3Aepsg%3Apro-pn-E9323A/e-series-peak-and-average-power-sensor-50-mhz-to-6-ghz?cc=US&lc=eng	
Signal monitoring (calibration)	Agilent N9030A PXA Signal Analyzer, 3 Hz to 50 GHz	http://www.keysight.com/en/pd-1721037-pn-N9030A/pxa-signal-analyzer-3-hz-to-50-ghz?cc=US&lc=eng	Used to measure differential noise power at the MDI. Better sensitivity and dynamic range than time-domain (scope) instruments.
	ETS PI102 Precision instrumentation balun, Female-SMA connector to (2) Female-SMA connectors	http://www.etslan.com/products.cgi?cat=6	
Test fixture	ETS CC103 Ground Plane - Aluminum 0.125" thick 12" x 30"	http://www.etslan.com/products.cgi?cat=4	Cable clamp and DUT server chassis are bolted to the ground plane
	ETS CC109 Cable Clamp - 3/8" cable aperture with 4 spring latches	http://www.etslan.com/products.cgi?cat=4	Large diameter clamp for CAT6a cables
Other	2x servers		
	10GBASE-T adapters or eval boards		
	Various 10GBASE-T channels		
	SMA/coax cables		

Measured Impairment Power With Unloaded Clamp Calibrated to 6dBm

- Clamp output power presented to DUT during test with CAT6A UTP cable varies from 6.01 dBm to 2.03 dBm
- Time-stamped measured response (below) logged during Rx CMNR testing shows cable loading effect over frequency (shown at right)





Measured Impairment Power With Loaded Clamp Calibrated to 6dBm

- Uncorrected response at right varies from -10.4 dBm to +4.79 dBm from 80MHz to 2GHz
- Corrected response (below) as measured during Rx CMNR testing – significant improvement!