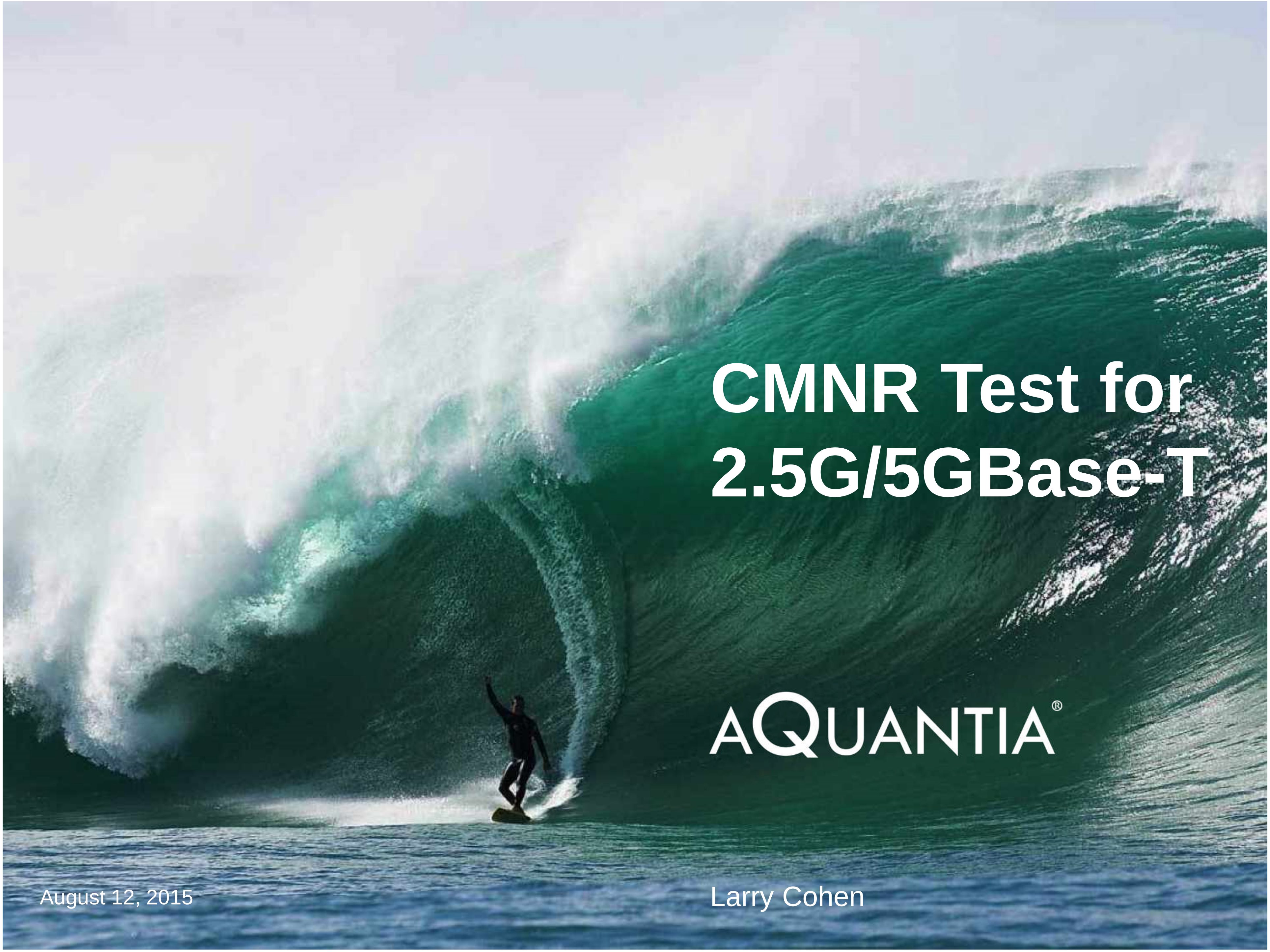

CMNR Test for 2.5G/5GBase-T

AQUANTIA®

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Overview

- **Purpose:** Define a test setup, procedure, and some test parameters for a common-mode noise rejection (CMNR) test for 2.5G/5GBase-T
  - Goal is a PHY test that reproduces the observed RF ingress from a 3 (10) Volt/meter incident electric field on exposed UTP cabling and verifies proper operation of a data link under this condition
  - Eliminate highly variable test conditions in EMC standard immunity tests
- Discussion of the need for a CMNR test in the standard and potential test methods
- Some CMNR test specifications for 2.5G/5GBase-T with some initial proposals
- Basic description of CMNR test procedure
- Description of CMNR test using a coaxial cable (CC) clamp test setup
  - CC clamp CMNR sweep test setup
  - CC clamp CMNR frequency sweep calibration measurement test setup
  - CC clamp RF envelope rise time measurement test setup
- Some CC clamp coupling measurement results
- Some RF envelope rise time measurement results
- Observations from CC clamp measurement results
- Next steps and discussion points

The Need for a Common-Mode Noise Rejection (CMNR) Test

- Existing EMC radiated immunity standards are designed to test the radiated interference tolerance of end terminal equipment, not the data links attached to the equipment
  - Conducted immunity testing (IEC 61000-4-6) provides some form common-mode noise rejection (CMNR) testing for the attached data links but only up to 80 MHz (150 kHz to 80 MHz)
  - CMNR is indirectly tested during standard EMC radiated immunity testing from 80 MHz to 1000 MHz (IEC 61000-4-3)
- Existing EMC radiated and conducted immunity standards tests do not specify consistent test conditions for the data links connected to the equipment under test
  - EMC standards allow a large amount of latitude and manufacturer's discretion in the selection of the test configuration for connected data links in both radiated and conducted immunity tests
  - Considerable variability of test conditions from differences in test equipment, even when following EMC test standard to the letter (e.g. signal generator harmonics)
  - Considerable variability of external field intensity outside of calibrated 1.5 meter square box region defined per IEC 61000-4-3 (radiated immunity testing from 80 MHz to 1000 MHz)
- The addition of a dedicated CMNR to the data standard provides the equivalent channel impairment of a consistent reproducible conducted and/or radiated immunity test where the “device” under test is now the connected data link channel
  - The CMNR test can address the problems from variable test conditions observed with EMC radiated immunity product testing on 10GBase-T systems
  - Test parameters (e.g. frequency points and dwell time) can be optimized for BER test protocols

Possible Methods for Injecting a Common-Mode Test Signal

- Direct injection (good for differential signals, not so good for common-mode signals)
  - Can inject precise differential signals into each pair independently, or a common-mode signal into one pair
  - With same common-mode (CM) signal injected on all four pairs at the same time, test channel becomes a cable over ground plane where the impedance and coupling are no longer well behaved
  - Unbalance (component mismatch) in coupling network can cause excessive CM-to-differential conversion
  - High coupling loss because need for high-impedance “bridging” across the test channel
  - Needs external ferrite clamps on AE (auxiliary equipment) side to isolate far-end transceiver link partner
  - Adds additional connector junction(s) to channel; will degrade channel insertion loss and return loss
  - Customized test fixture; not available commercially
- EM clamp from IEC 61000-4-6 (not all units work from 80 MHz to 1000 MHz)
  - Injects same common-mode signal on all four pairs; differential disturber from channel imbalance
  - Designed to work from 150 kHz to 80 MHz, but some units work up to 1000 MHz
  - Provides directional coupling above 10 MHz which eliminates need for external ferrite clamps at AE side to isolate far-end link partner; but needs external ferrite clamps (#75 material) for operation below 10 MHz
  - Non-intrusive, does not disturb channel or degrade channel insertion loss and return loss
  - Common EMC test instrument; units available from several different suppliers
- Coaxial cable clamp (originally defined in Annex 40B, enhancements in Annex 113A)
  - Injects same common-mode signal on all four pairs; differential disturber from channel imbalance
  - Non-intrusive, does not disturb channel or degrade channel insertion loss and return loss
  - Needs external ferrite clamps on AE side to isolate far-end transceiver link partner
  - Some narrowband nulls in the common-mode coupling that must be addressed by the test procedure
  - Produced by only one supplier (ETS); different versions with slightly different characteristics

Defining a CMNR Test Specification for 2.5G/5GBase-T

- Use the existing text, diagrams, and tables in Annex 113A and Annex 40B as much as possible
  - Some new items below can be added with simple notes to the existing text or diagrams in Annex 113A
  - Text or data values specific to the 802.3bz standard can be defined in Clause 126.5.4.3 and substituted in the designated section(s) of Annex 113A
- Test methodology (proposed text)
  - The CMNR test should use the coaxial cable (CC) clamp (Annex 40B / Annex 113A) or conducted immunity EM clamp (IEC 61000-4-6); these methods provide best reproduction of the actual RF ingress
- Some CMNR test specifications for 802.3bz (substitution into existing Annex 113A text or added notes to existing text and/or diagrams); new items in blue
  - Test frequency range (slide #6)
  - Set of test frequency points and dwell time (slide #7)
  - Signal generator output level (slides #8, #24)
  - Add 1kHz 80% amplitude modulation to the RF test signal during the test phase to correspond with the EMC standard product radiated and conducted immunity test procedures (slide #8)
  - Signal generator harmonic distortion (slides #9, #25, #26)
  - Test signal generator envelope rise/fall time min/max limits (slides #10, #27, #28)
  - Common-mode termination impedance for measurement balun (not the same as output port impedance!!); see slide #11
  - Common-mode validation output level at EUT port (Table 113A-2); new proposal in future contribution (see slide #11)

Choice of CMNR Test Frequency Range

- EMC standard (IEC 61000-4-3) general purpose radiated immunity test uses the frequency range from 80 MHz to 1000 MHz
  - Depending upon product requirements (e.g. operating bandwidth), products may be tested up to 6 GHz
  - The lower 80 MHz limit was selected mainly because of the test equipment limitations for achieving the necessary uniform field area; need a large test chamber and strong power amplifier below 80 MHz
  - CMNR test equipment does not begin to have limitations until below 10 MHz (CC clamp coupling, test baluns)
- Possible test frequency range options for the CMNR test
  1. Keep 80 MHz to 1000 MHz test range: Corresponds to general purpose radiated immunity test but misses some frequency bands (e.g. 30 MHz to 80 MHz) with significant potential interference
  2. Set frequency range from 30 MHz to 1000 MHz: 30 MHz is generally considered the demarcation point (at least by the FCC) where dominant interference sources change from conducted to radiated, but the CMNR test should consider ingress from conducted interference
  3. Set test frequency range from 10 MHz to 1000 MHz: Covers the most of the region of observed ingress impairments, but the main reason for the 10 MHz lower limit is to address possible test equipment bandwidth limitations (CC clamp coupling, EM clamp directionality, test baluns, power amplifiers)
  4. Set test frequency range from 1 MHz to 1000 MHz: Covers almost every conceivable ingress impairment, but may be difficult to implement because of test equipment bandwidth limitations
  5. For any of the above lower limits, increase the upper test limit to 2 GHz: More interferers in 1.8 GHz to 2.0 GHz now than when 10GBase-T was standardized
- **Initial proposal for 802.3bz: Set test frequency range from 10 MHz to 1000 MHz**

CMNR Frequency Test Points and Dwell Time

- EMC standard radiated and conducted immunity tests specify a minimum dwell time limit (0.5 second per frequency point) and a maximum frequency step size (1% of the preceding frequency value), but no specific values for each parameter
  - Actual values are determined by the product manufacturer
- Example test point sets
  - For 10 MHz to 1000 MHz with step = 1% of preceding frequency point → 464 points
  - For 10 MHz to 1000 MHz with step = 1 MHz → 991 points
  - For 10 MHz to 1000 MHz with step = 2 MHz → 446 points
- **Initial proposal for 802.3bz: CMNR test should follow the EMC standard maximum 1% frequency step size limit, but set the dwell time to provide optimal accuracy of data link performance (BER) monitoring equipment**
  - Total test time (number of points • dwell time) depends upon data rate and number of test data packets used in BER test
  - Dwell time can vary for different data rates
  - For now, dwell time is TBD (need to talk to people who perform actual BER tests)

CMNR Test Signal Generator Output Level

- Test signal generator output level: Must have enough output power to overcome the CM injection device coupling losses and provide the target CM ingress level to the test channel with and without modulation.
  - For the CC and EM clamps, simulating CM ingress at 10 Volts/meter requires more than +6 dBm clamp input power
  - Need to specify a minimum signal generator output level and add a note to Annex 113A stating that the signal generator “block” may include an added external power amplifier
  - **Initial proposal for 802.3bz: Set minimum signal generator output level to +35 dBm**
  - Proposal based on target CM value in Table 113A-2 using CC clamp with added margin (+5 dB) for 1 kHz 80% amplitude modulation (see slide #24)
- Potential problem from CM coupling nulls near 400 MHz in CC clamp (slide #19)
  - With the proposed output level it will not be possible to properly compensate for the CM coupling nulls
  - Depth of null may vary greatly between pairs; full correction may introduce an even greater error component in some pairs
  - Possible solution: Place a cap on the output level and provide a best effort correction
- **Additional item: Add 1kHz 80% amplitude modulation to the RF test signal during the CMNR test phase to correspond with the EMC standard product RF immunity test procedures (both radiated and conducted).**

CMNR Test Signal Generator Harmonic Distortion

- A harmonic distortion specification is required for the signal at the injection device input to eliminate the presence of multiple interferer tones when only one specific interferer tone should be present
  - Inconsistencies in the harmonic distortion (HD) levels of EMC lab signal generators have caused ambiguous results in 10GBase-T radiated immunity testing
- The signal generator block (including any external power amplifier) needs an output harmonic distortion specification to keep harmonic spurs at least 10 dB (?) below the main carrier
- For 802.3bz the main concern is in the 10 MHz to 200 MHz frequency band
- **Initial proposal for 802.3bz: Set maximum level for all for all harmonic spurs at the CM injection device input to –35 dBc**
  - Based upon CC clamp coupling measurements in slides #25, #26
- Standard EMC test signal generator harmonic distortion values for reference (typical values seen in EMC lab equipment)
  - Radiated immunity test: HD is typically –15 dBc at the antenna input and –6 dBc for the measured field strength
  - Goal in radiated immunity test is to keep harmonic content low enough to limit uncertainty error for the measured field strength
  - Conducted immunity: HD of test signal is specified as better than –15 dBc

CMNR Test Signal Envelope Rise/Fall Time Limits

- Problem: For standard EMC immunity tests, some signal generators generate a wideband transient event when they change frequencies
  - Characteristic is equipment dependent and not specified in any EMC test standards
  - These transient events have been observed to cause inconsistent immunity test results between different EMC labs for 10GBase-T systems
- Proposed solution: Ramp down signal envelope before each test signal frequency change, and ramp up signal envelope after each test signal frequency change
  - Envelope control can be achieved by an external variable attenuator (see slides #13, #15)
  - Eliminates signal generator frequency step transient artifacts which may cause false error results; more accurate model for real signals
- **Initial proposal for 802.3bz: Set test signal envelope rise/fall time from 50 to 100 usec**
  - Proposed values match observed envelope rise/fall time of common radio transmitters (see slides #27, #28)

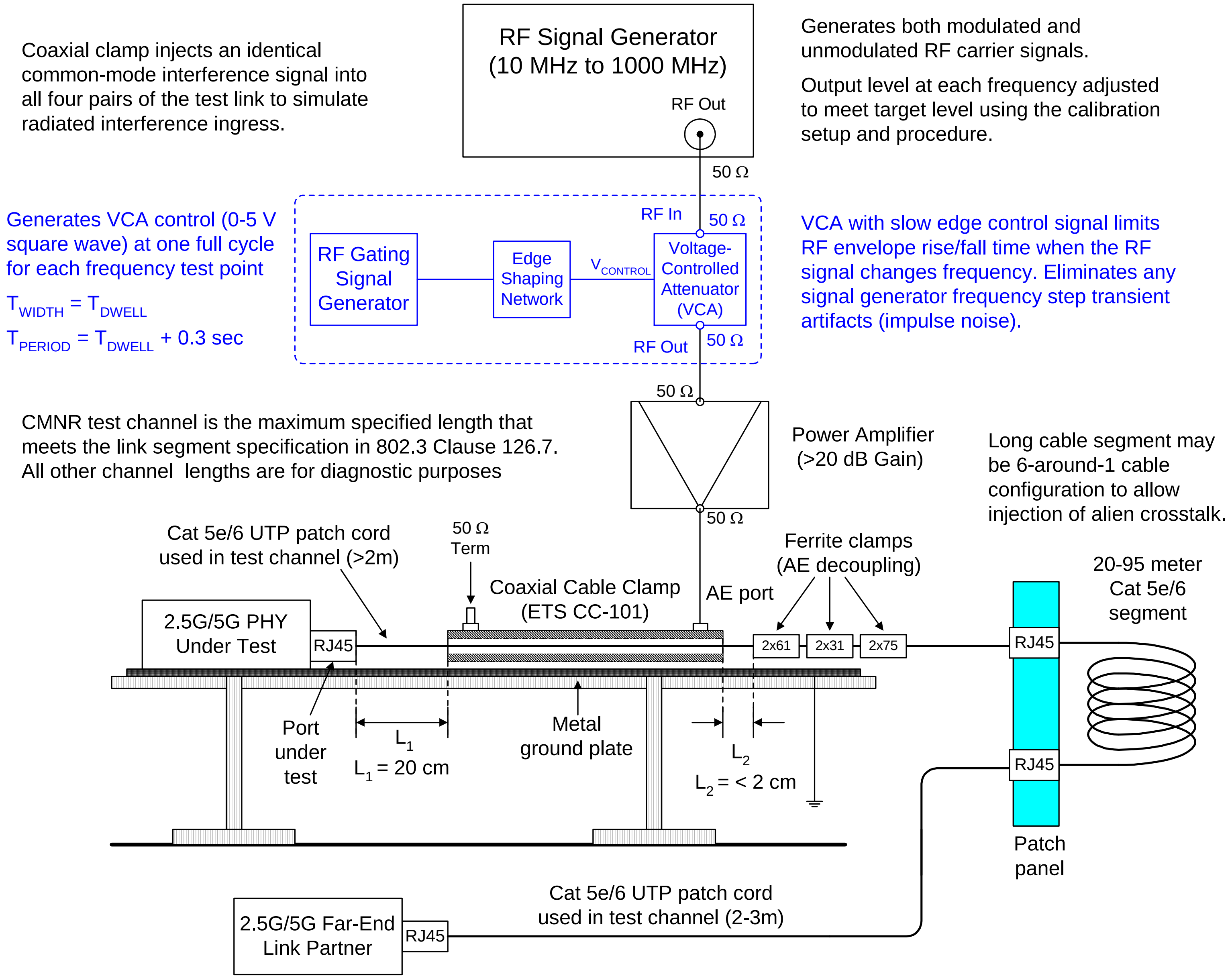
Other CMNR Test Specifications

- Common-mode termination impedance for measurement balun
  - Not the same as the balun common-mode output port impedance
- Problem: In Annex 113A, the CM impedance for each unused pair at during calibration (validation) is 25 Ohms (both sides terminated with 50 Ohms)
  - This is a good for shielded cable (in 802.3bq), but not for UTP in 802.3bz
  - **Initial 802.3bz proposal: Add a common-mode termination specification for the measurement balun; specify a CM termination of 50 or 75 Ohms (better value for UTP used in 802.3bz).**
  - Unused measurement pairs can be properly terminated by “Y” network (see pair termination circuit in slides #14, #15)
- Common-mode validation output level at EUT port (Table 113A-2)
  - New proposal in future (companion) contribution
  - Main difference in new proposal is a rolloff of the CM target level above 250 MHz; this rolloff is constant from 80 MHz to 1000 MHz
  - CM rolloff characteristic matches observed anechoic chamber measurements (at least to 1000 MHz)
  - **Initial proposal for 802.3bz: Use Table 113A-2**

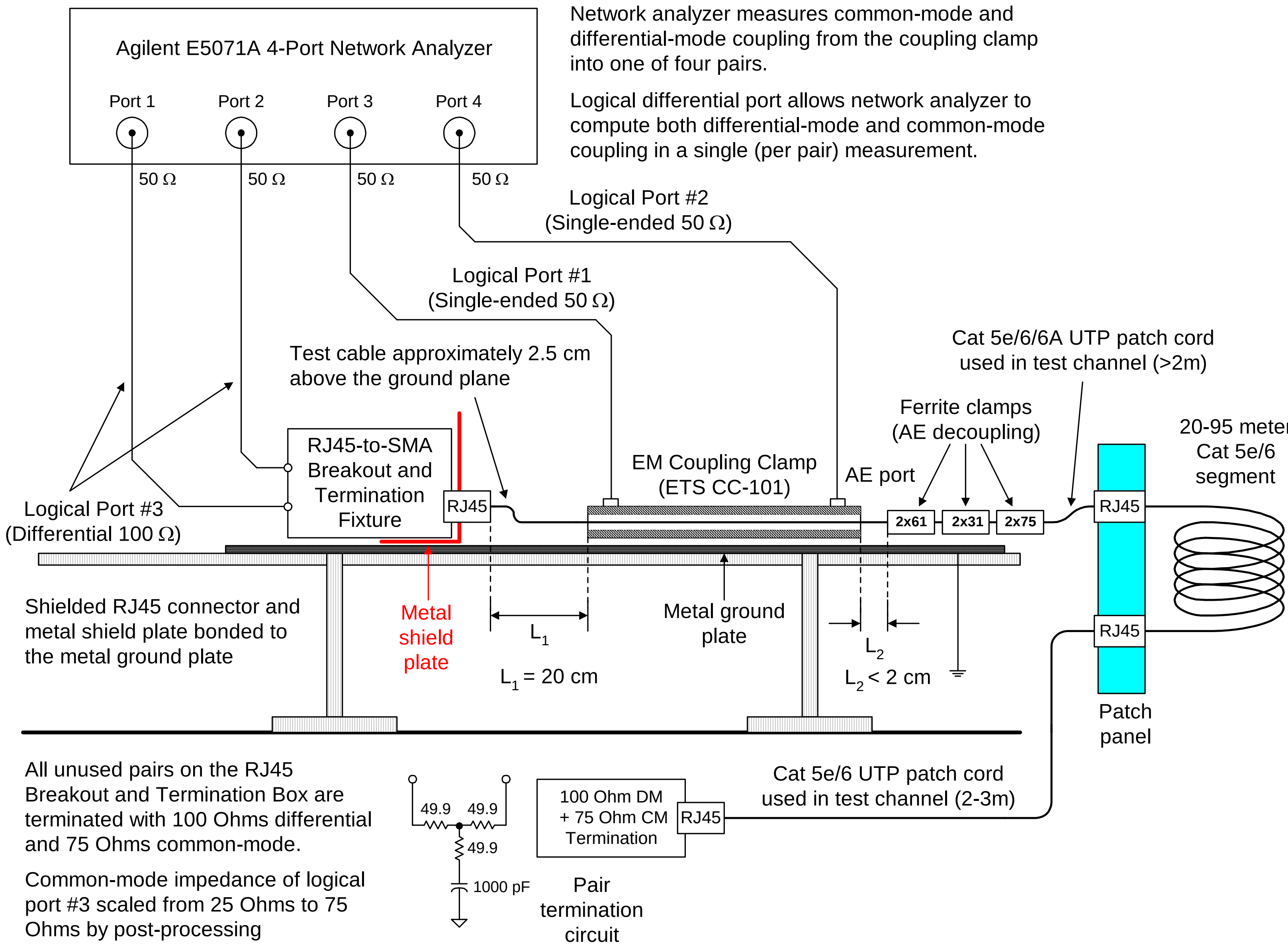
Basic Description of CMNR Test Procedure

- For all test setups, the test procedure is a three step process
  - Different from clamp noise impairment test in 1000Base-T where the signal injection source is simply fixed at a specified level
- Validation of injection device electrical parameters (insertion loss and return loss of signal injection ports as per Annex 113A.2)
- Calibration phase (measure coupling of injection device to test channel, Annex 113A.3)
  - Set up test desired test channel; do not turn on other impairment sources (e.g. alien crosstalk)
  - Substitute a 4-pair RJ45-to-SMA breakout/balun test fixture for the MDI port of the EUT
  - Use a 4-port vector network analyzer (or fixed-level swept sine wave signal source and power meter) to measure CM and differential coupling of the injection apparatus to the each of 4 pairs at the MDI port breakout test fixture; note test signal is <u>not</u> modulated
  - Compute difference between measured calibration CM ingress (coupling loss) and target CM ingress to create a correction table to adjust the RF output level vs. frequency and provide target CM ingress level at each frequency
- Test phase (inject test signal into test cable channel and monitor performance)
  - Replace the port under test breakout fixture with the actual PHY port under test
  - Initialize data link between the PHY under test and the far-end link partner
  - Perform test; sweep the "corrected" signal source and monitor data link performance metrics; add additional impairments (e.g. 6-around-1 alien crosstalk) as necessary

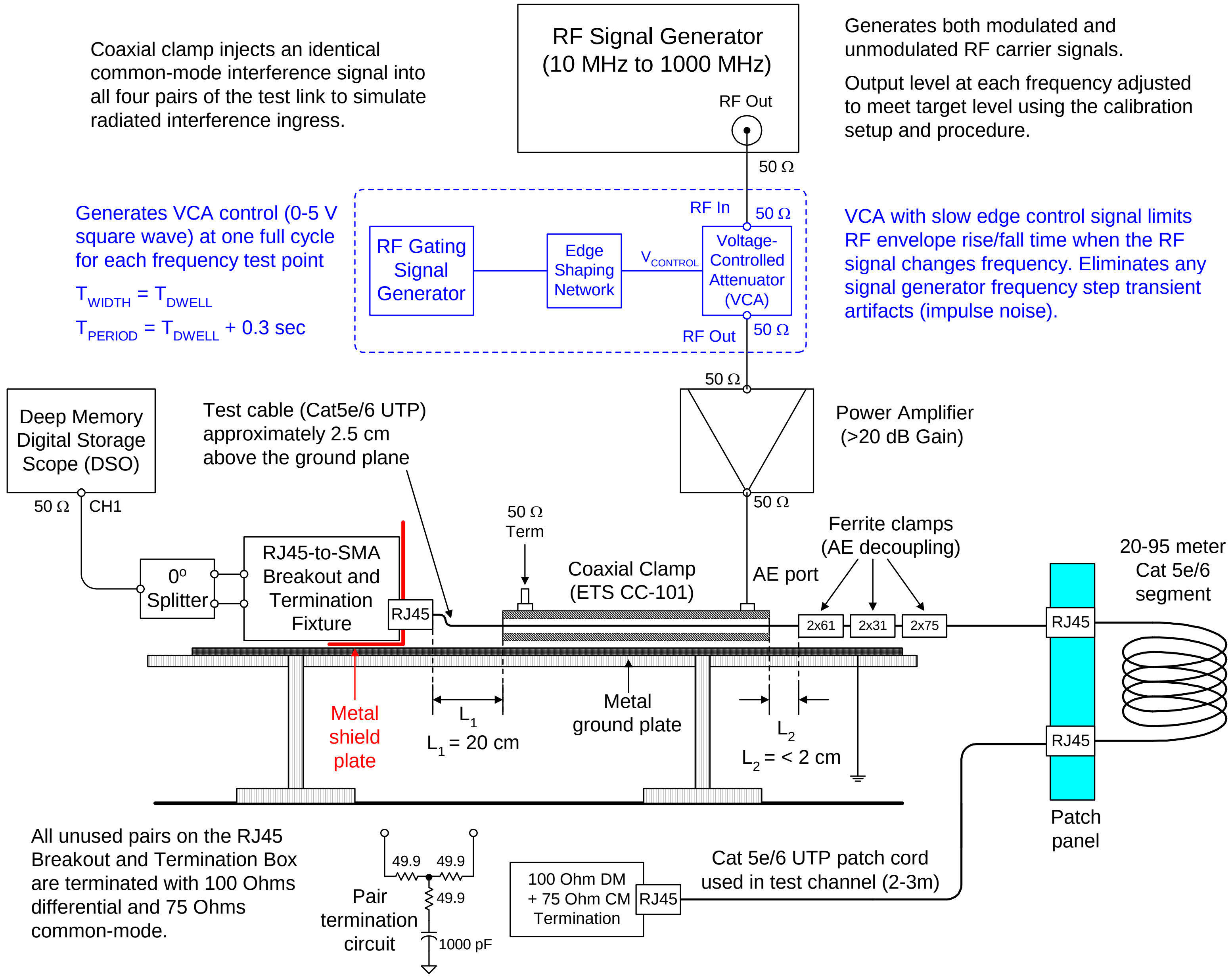
Coaxial Cable Clamp CMNR Sweep Test Setup

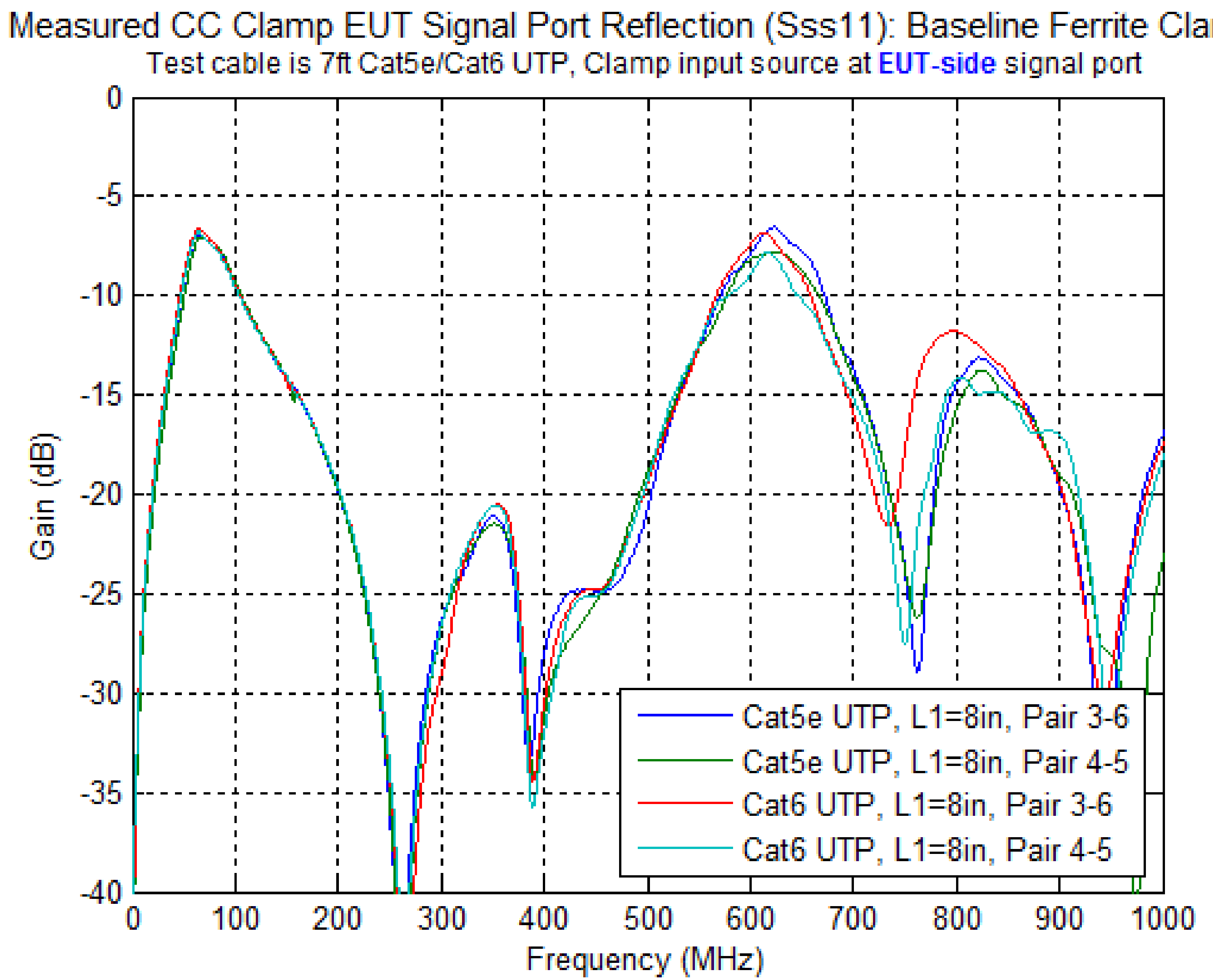


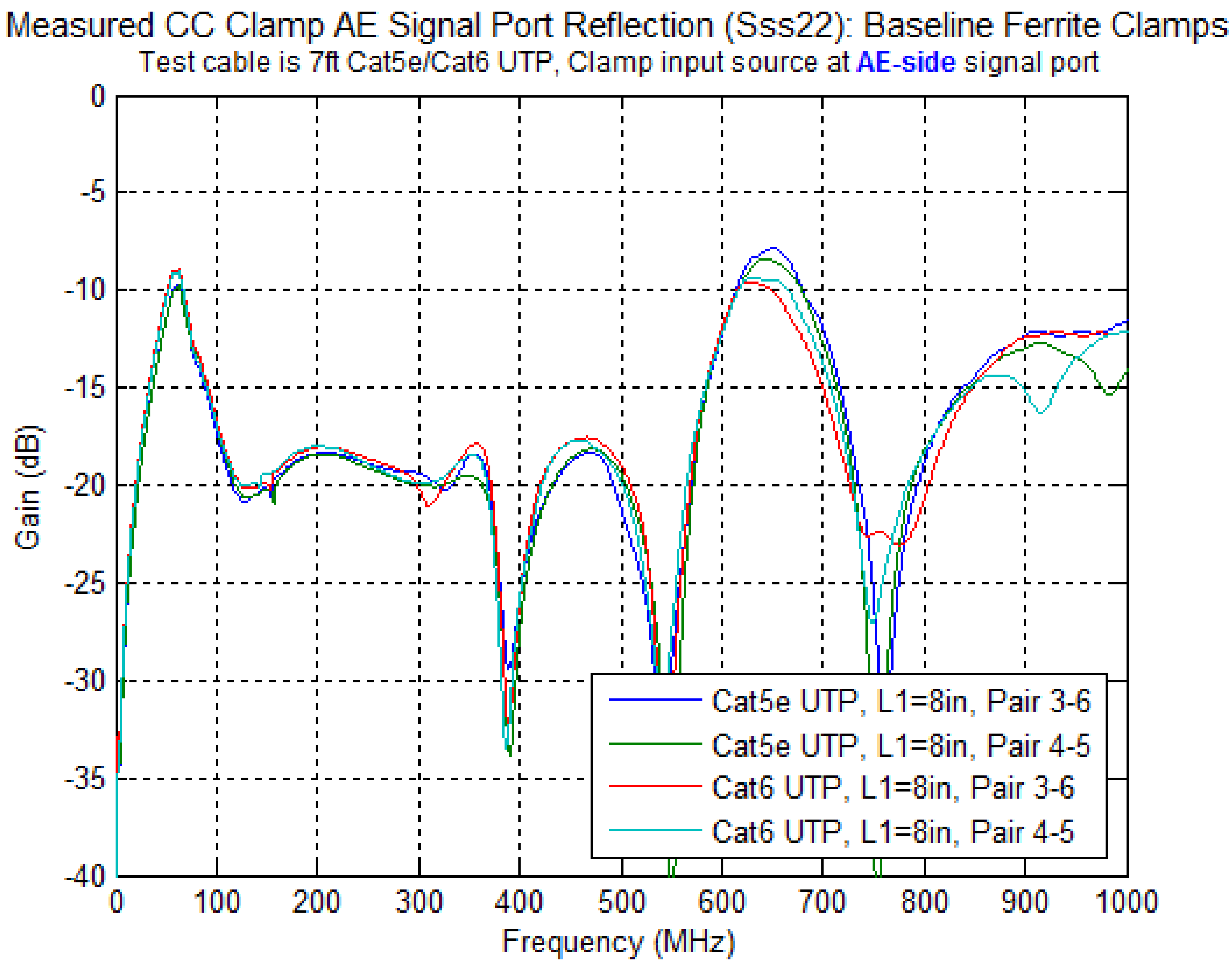
Coaxial Cable Clamp CMNR Calibration Measurement Test Setup

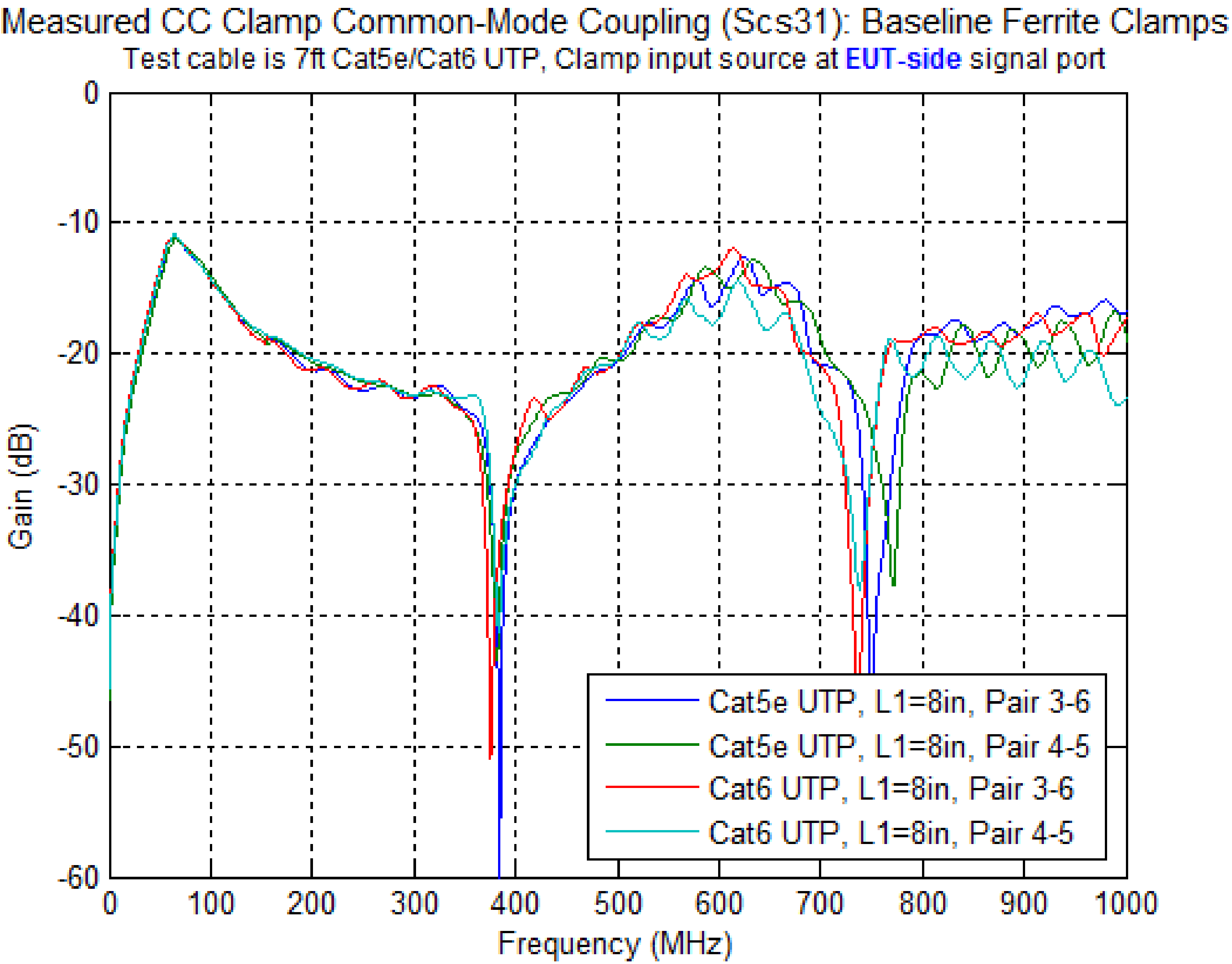


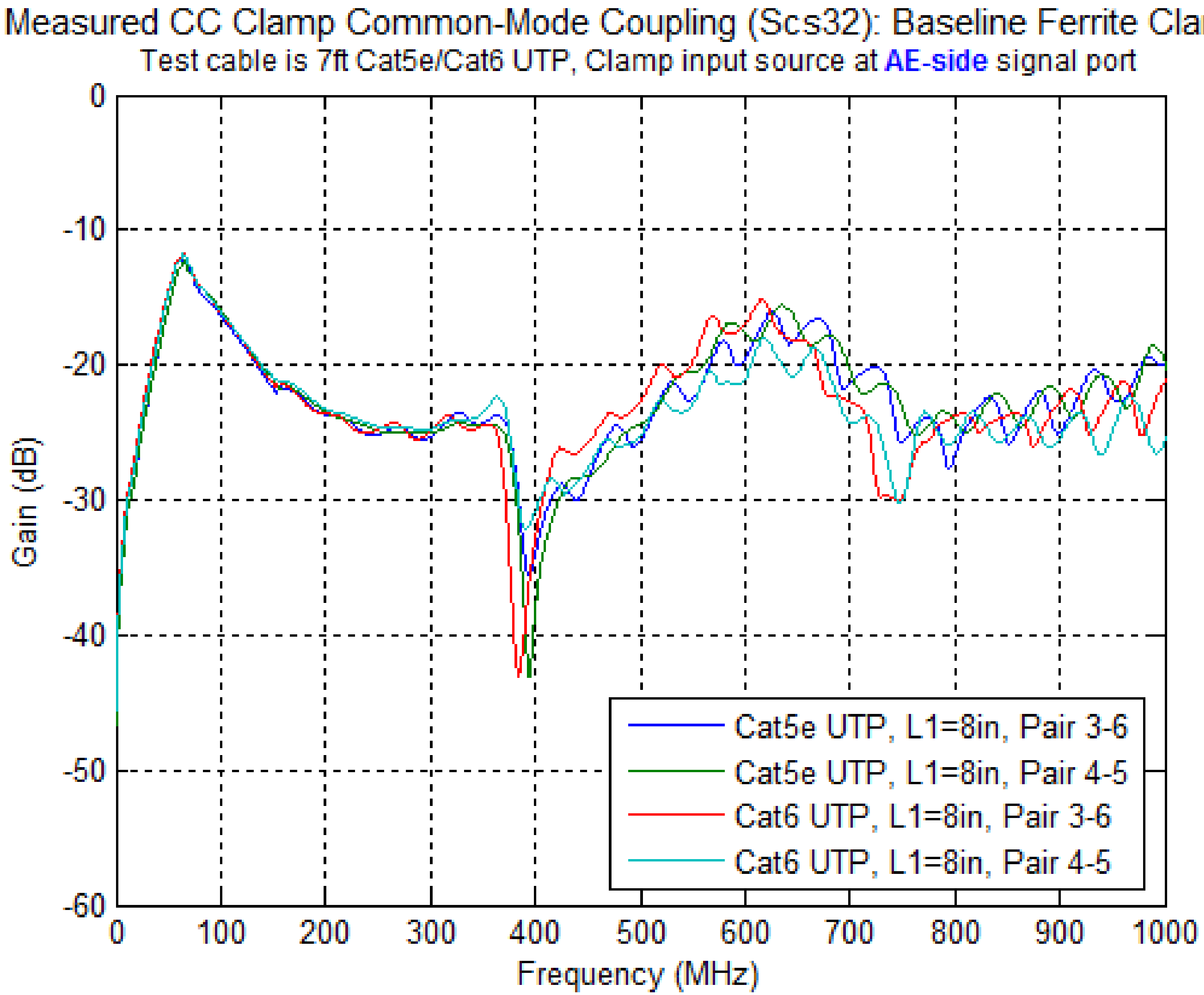
CMNR Test (CC Clamp) RF Envelope Rise Time Measurement Test Setup



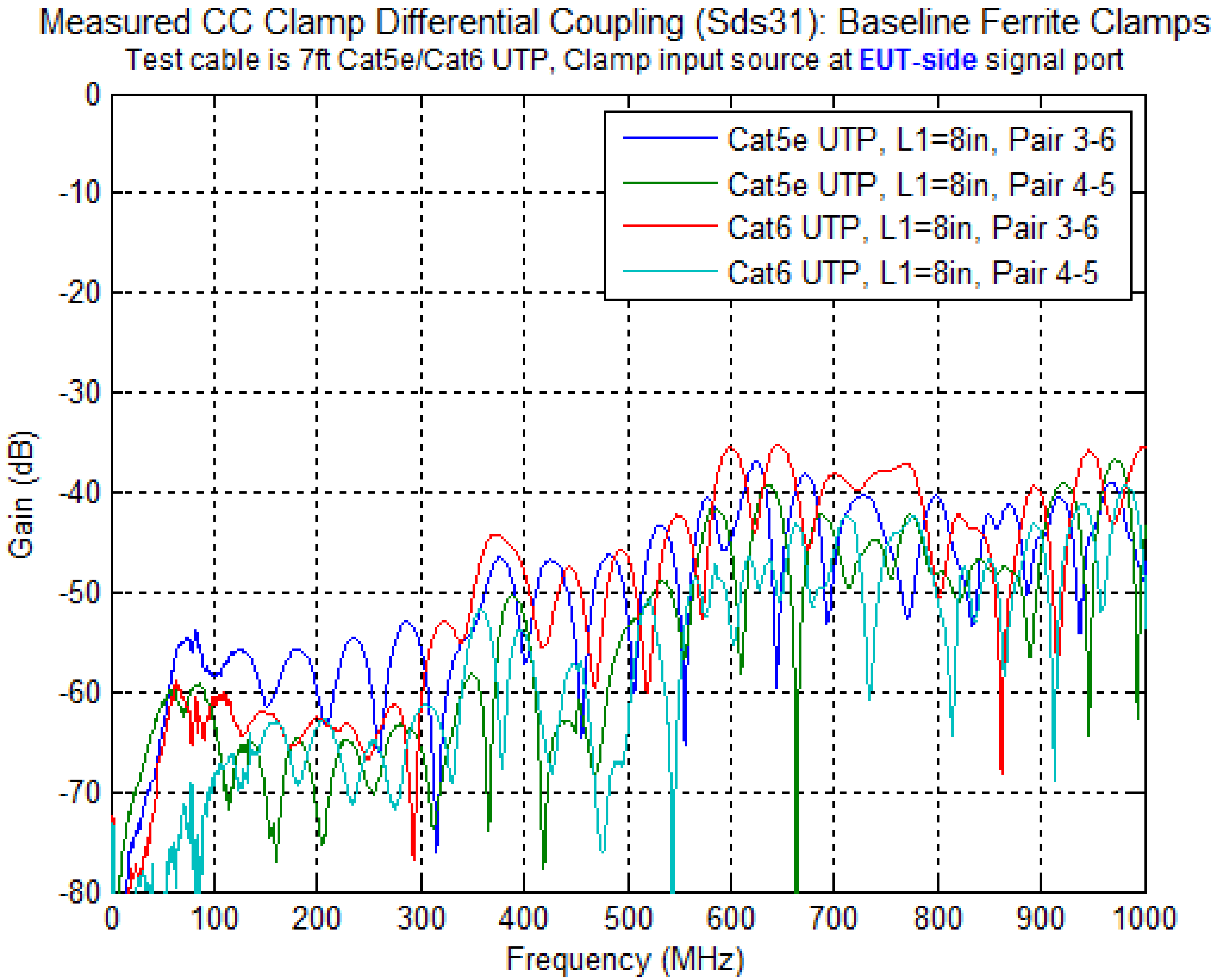

Measured CC Clamp EUT Signal Port Reflection (Sss11): Baseline Ferrite Clamps
Test cable is 7ft Cat5e/Cat6 UTP, Clamp input source at EUT-side signal port
Gain (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
0
100
200
300
400
500
600
700
800
900
1000
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Cat6 UTP, L1=8in, Pair 3-6
Cat6 UTP, L1=8in, Pair 4-5

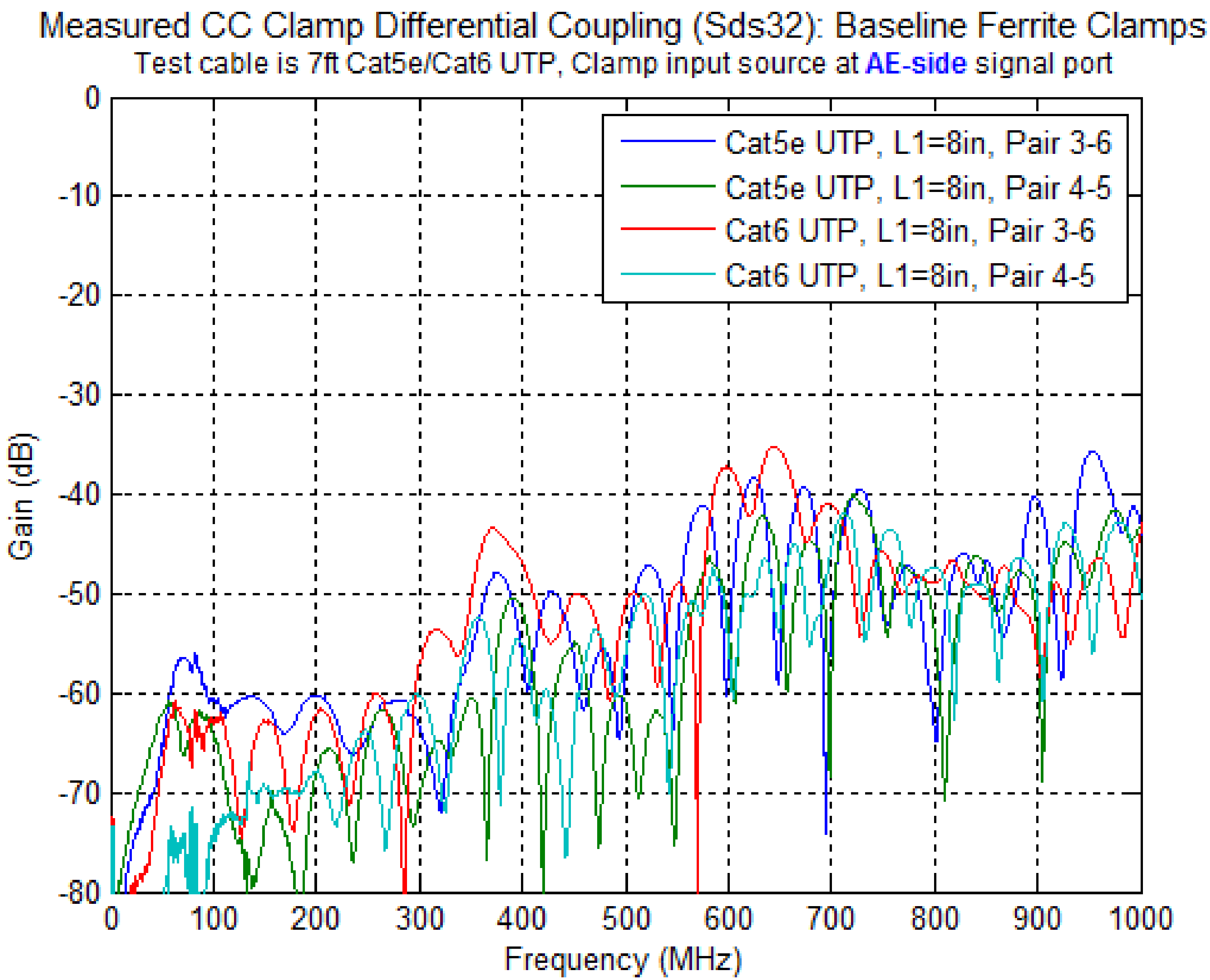

Measured CC Clamp AE Signal Port Reflection (Sss22): Baseline Ferrite Clamps
Test cable is 7ft Cat5e/Cat6 UTP, Clamp input source at AE-side signal port
Gain (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
0
100
200
300
400
500
600
700
800
900
1000
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Cat6 UTP, L1=8in, Pair 3-6
Cat6 UTP, L1=8in, Pair 4-5


Measured CC Clamp Common-Mode Coupling (Scs31): Baseline Ferrite Clamps
Test cable is 7ft Cat5e/Cat6 UTP, Clamp input source at EUT-side signal port
Gain (dB)
0
-10
-20
-30
-40
-50
-60
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Cat6 UTP, L1=8in, Pair 3-6
Cat6 UTP, L1=8in, Pair 4-5

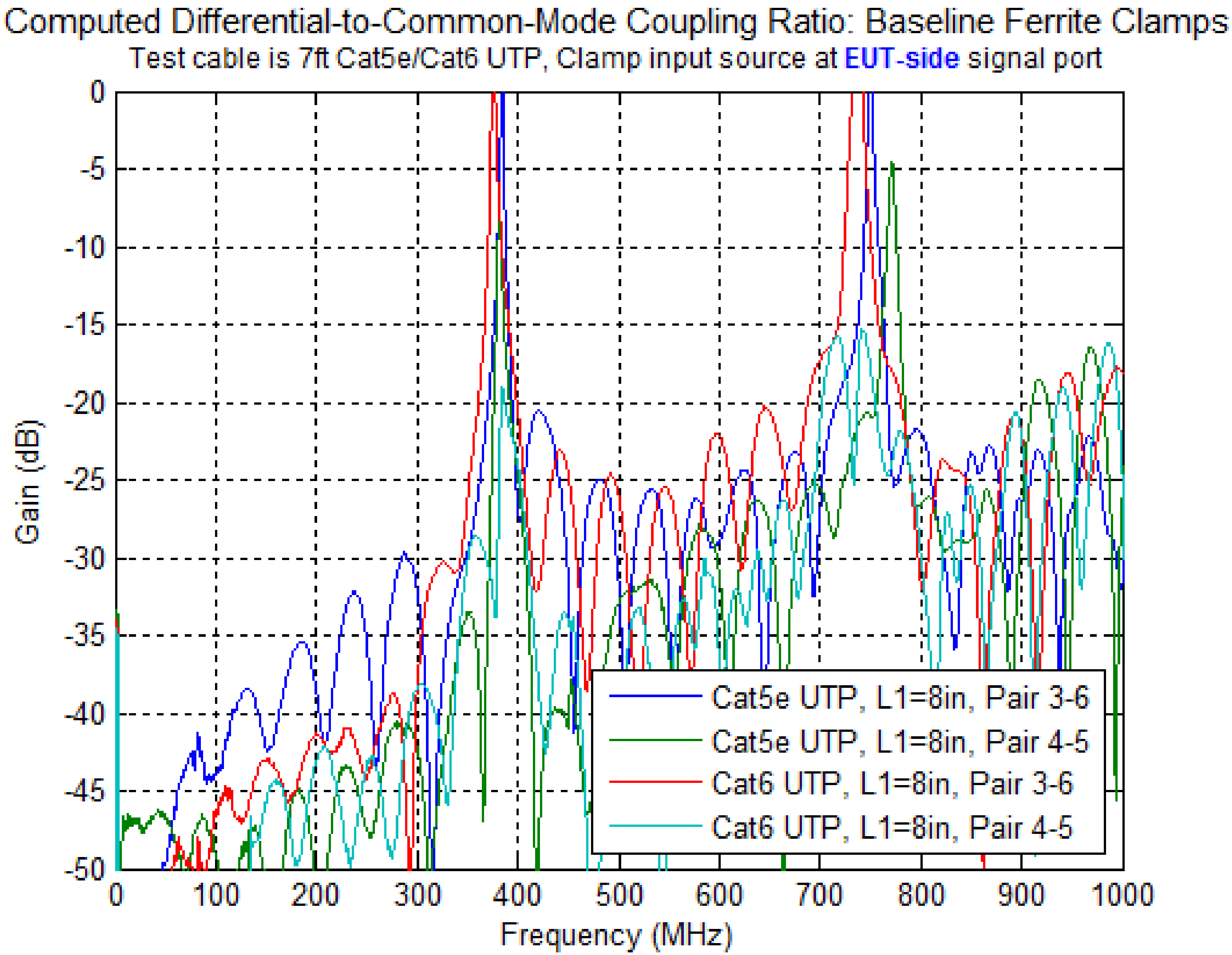


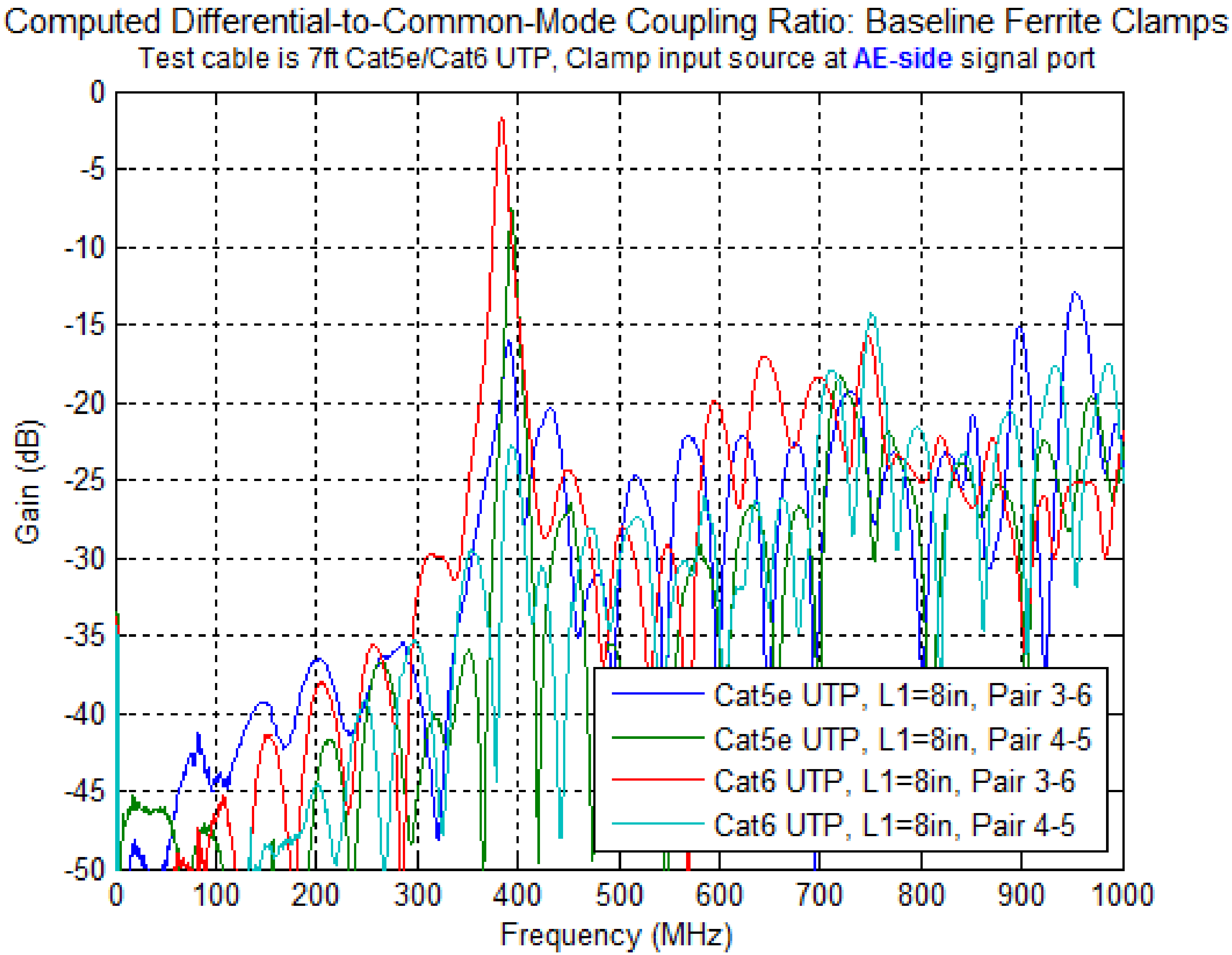
Measured CC Clamp Common-Mode Coupling (Scs32): Baseline Ferrite Clamps
Test cable is 7ft Cat5e/Cat6 UTP, Clamp input source at AE-side signal port
Gain (dB)
0
-10
-20
-30
-40
-50
-60
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Cat6 UTP, L1=8in, Pair 3-6
Cat6 UTP, L1=8in, Pair 4-5


Measured CC Clamp Differential Coupling (Sds31): Baseline Ferrite Clamps
Test cable is 7ft Cat5e/Cat6 UTP, Clamp input source at EUT-side signal port
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Cat6 UTP, L1=8in, Pair 3-6
Cat6 UTP, L1=8in, Pair 4-5
Gain (dB)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
0
100
200
300
400
500
600
700
800
900
1000

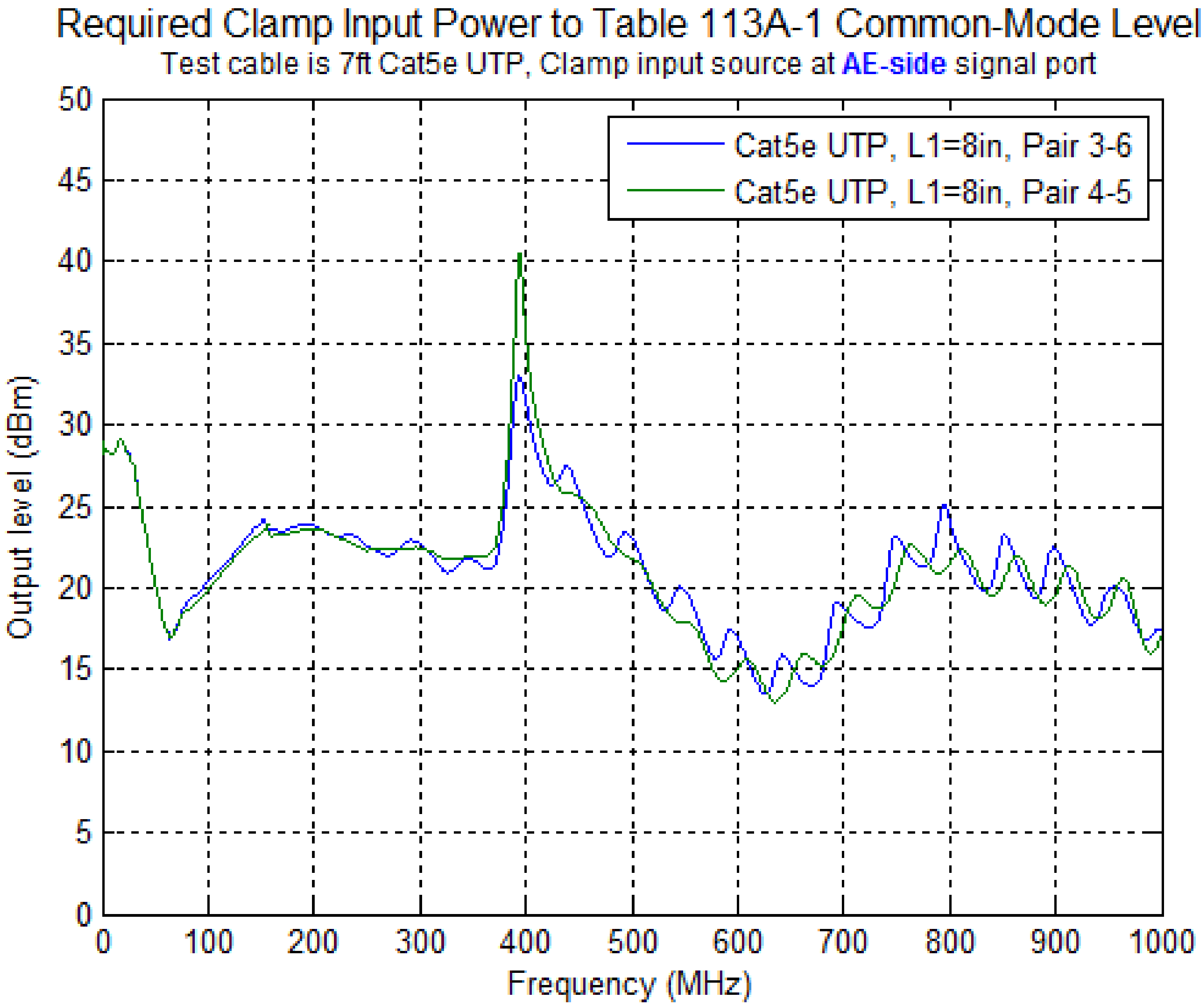


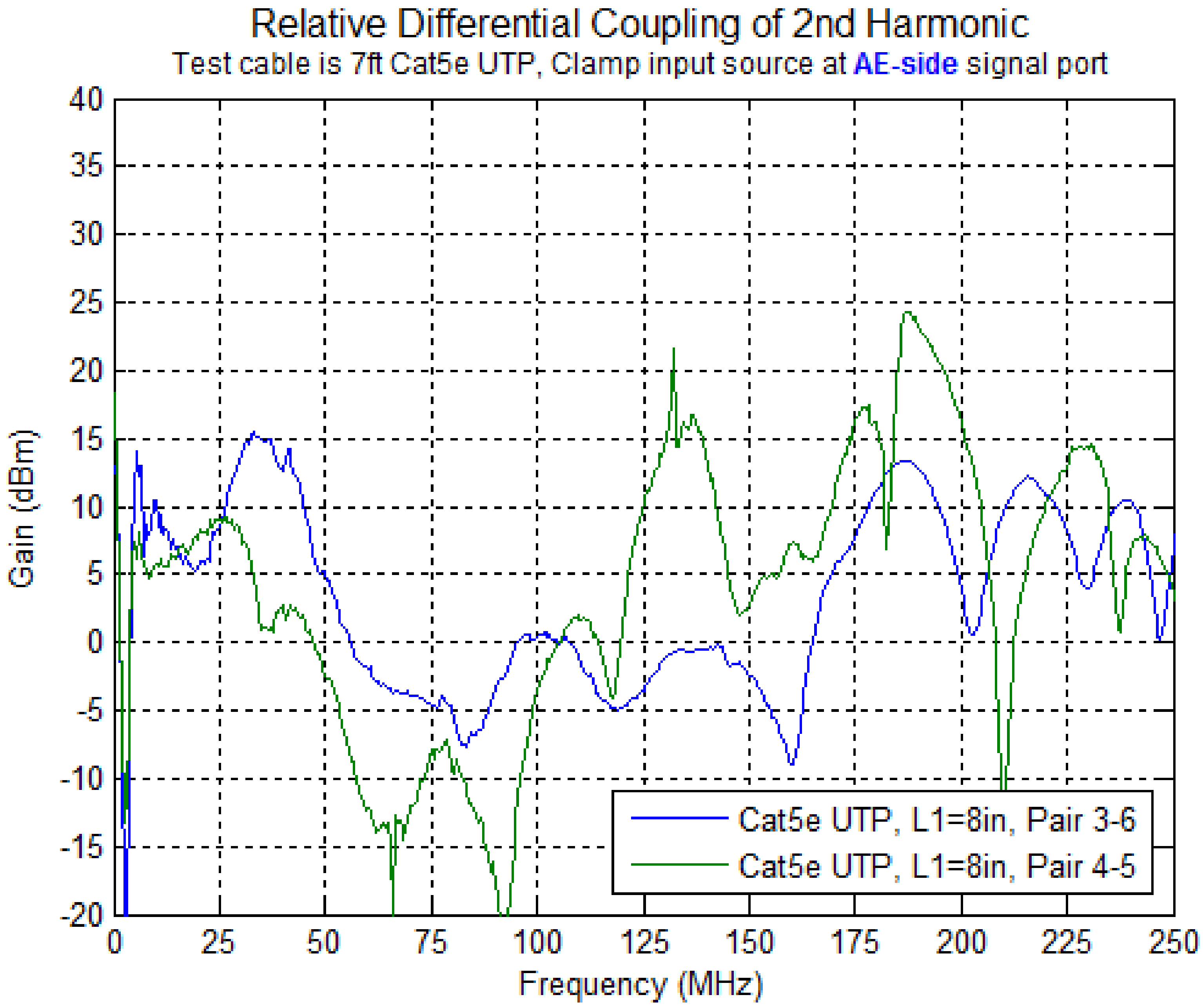
Measured CC Clamp Differential Coupling (Sds32): Baseline Ferrite Clamps
Test cable is 7ft Cat5e/Cat6 UTP, Clamp input source at AE-side signal port
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Cat6 UTP, L1=8in, Pair 3-6
Cat6 UTP, L1=8in, Pair 4-5
Gain (dB)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
0
100
200
300
400
500
600
700
800
900
1000


Computed Differential-to-Common-Mode Coupling Ratio: Baseline Ferrite Clamps
Test cable is 7ft Cat5e/Cat6 UTP, Clamp input source at EUT-side signal port
Gain (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0
100
200
300
400
500
600
700
800
900
1000
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Cat6 UTP, L1=8in, Pair 3-6
Cat6 UTP, L1=8in, Pair 4-5

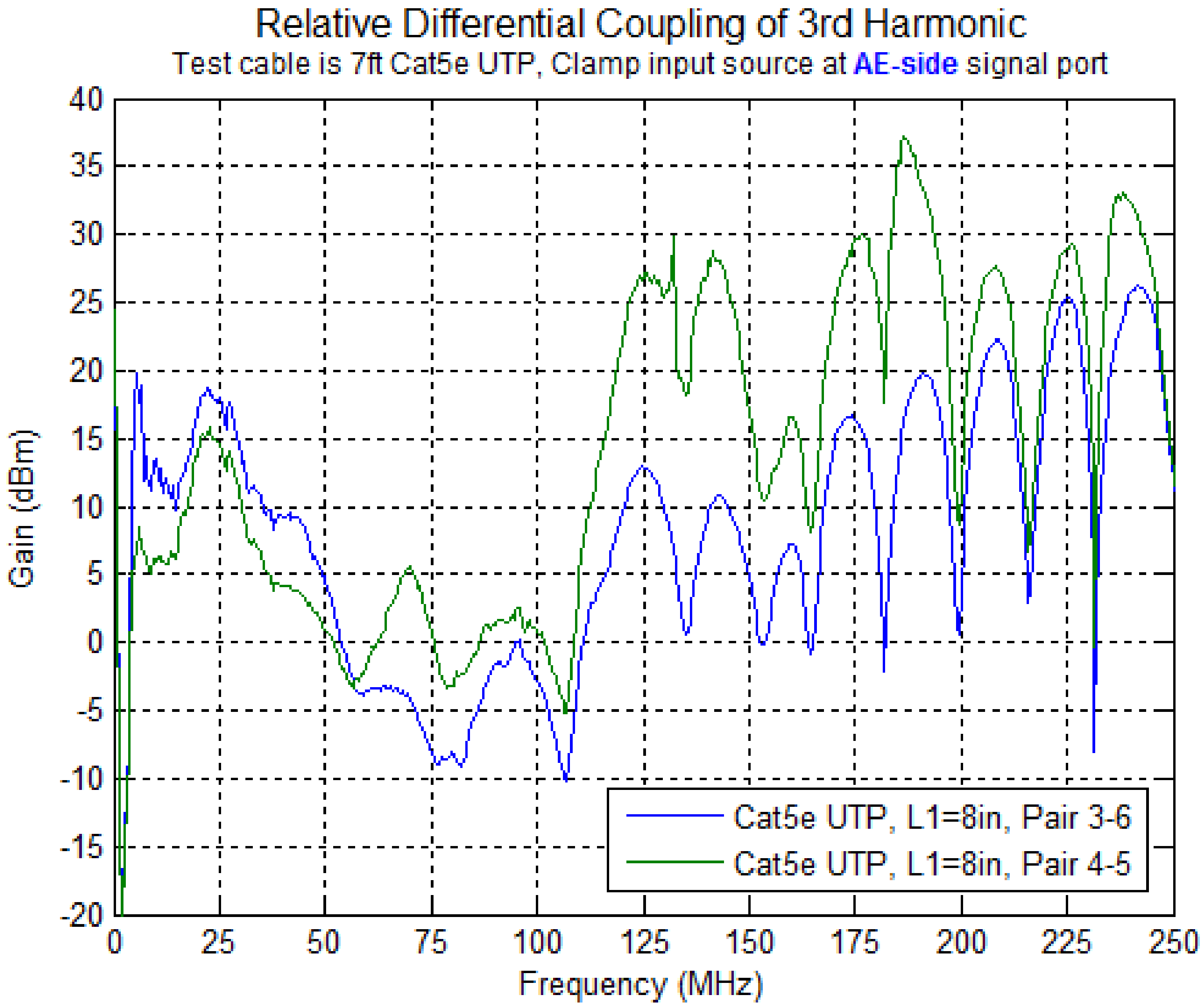


Computed Differential-to-Common-Mode Coupling Ratio: Baseline Ferrite Clamps
Test cable is 7ft Cat5e/Cat6 UTP, Clamp input source at AE-side signal port
Gain (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Cat6 UTP, L1=8in, Pair 3-6
Cat6 UTP, L1=8in, Pair 4-5


Required Clamp Input Power to Table 113A-1 Common-Mode Level
Test cable is 7ft Cat5e UTP, Clamp input source at AE-side signal port
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5
Output level (dBm)
Frequency (MHz)
0
5
10
15
20
25
30
35
40
45
50
0
100
200
300
400
500
600
700
800
900
1000

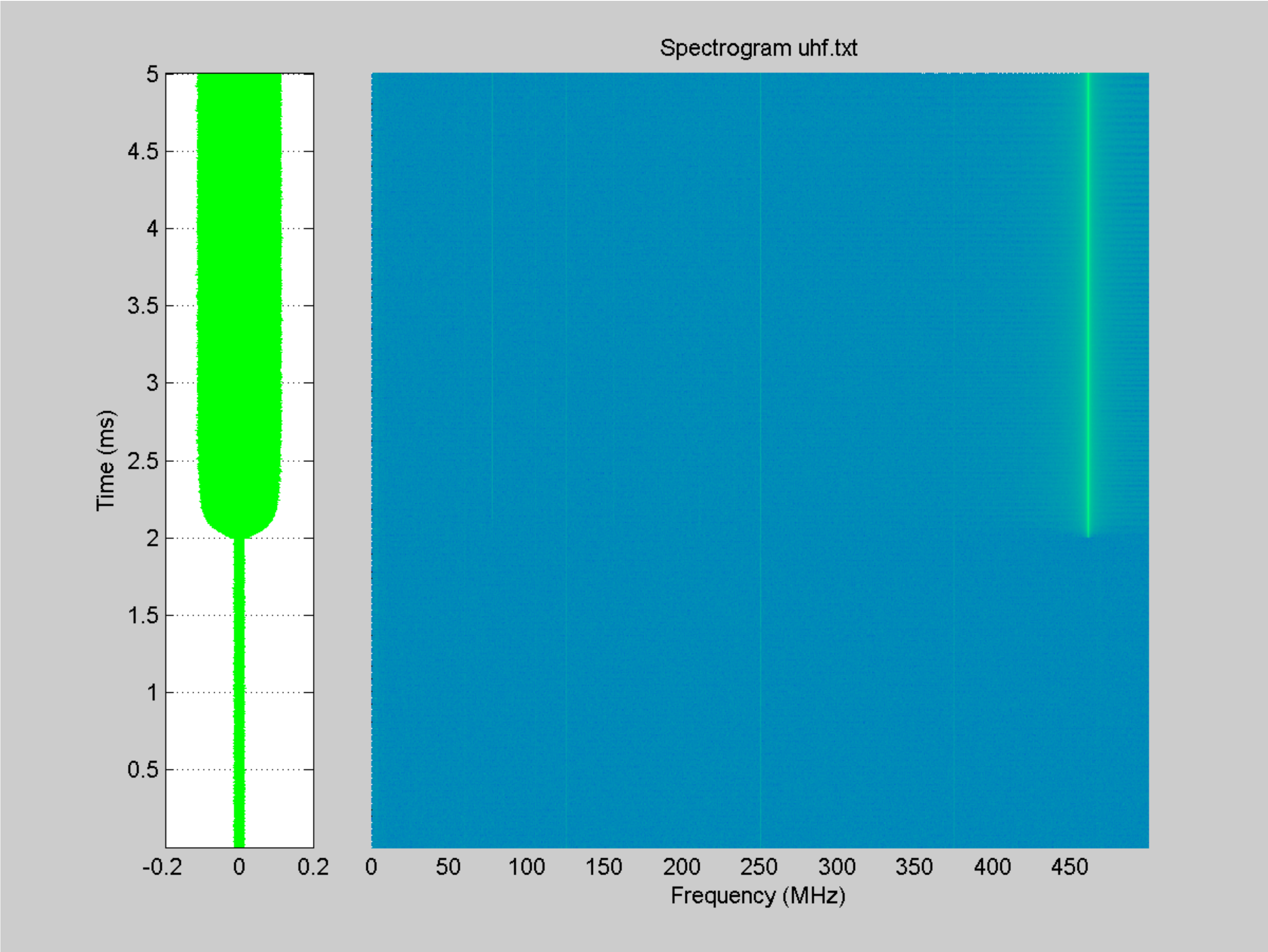


Relative Differential Coupling of 2nd Harmonic
Test cable is 7ft Cat5e UTP, Clamp input source at AE-side signal port
Gain (dBm)
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
0
25
50
75
100
125
150
175
200
225
250
Frequency (MHz)
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5

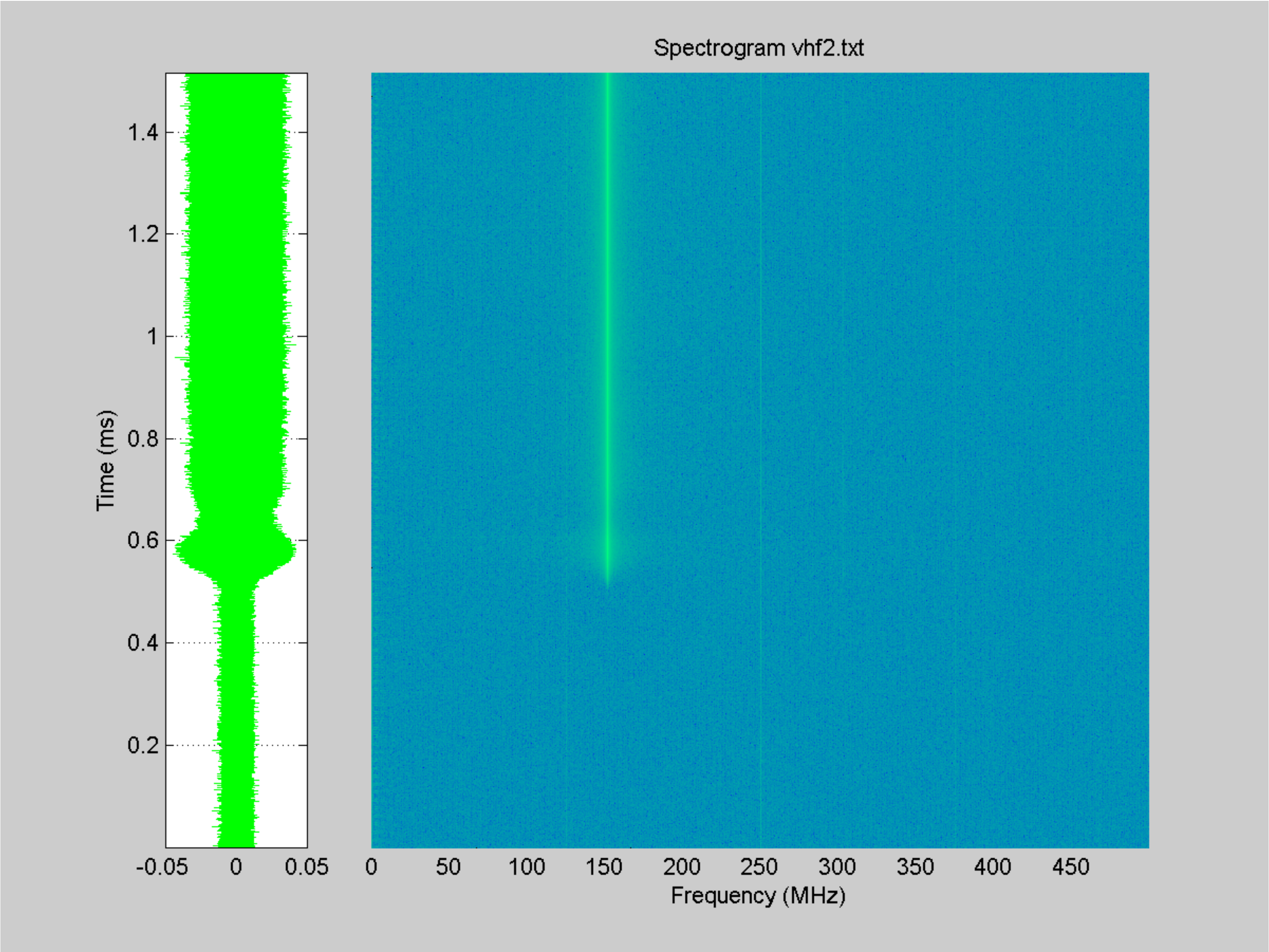


Relative Differential Coupling of 3rd Harmonic
Test cable is 7ft Cat5e UTP, Clamp input source at AE-side signal port
Gain (dBm)
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
0
25
50
75
100
125
150
175
200
225
250
Frequency (MHz)
Cat5e UTP, L1=8in, Pair 3-6
Cat5e UTP, L1=8in, Pair 4-5

RF Envelope Transient from FRS Radio Transmitter



RF Envelope Transient from VHF Radio Transmitter



Observations from CC Clamp Measurements

- The CC clamp used for these measurements (ETS CC-101) is nearly identical to the clamp described in Annex 40B, but the copper tube inside diameter is slightly larger (0.313” vs. 0.250”); this clamp is different from the device described in Annex 113A
- CM coupling from clamp relatively independent of UTP cabling type (e.g. Cat5e, Cat6) and is more suitable as a baseline RF ingress reference
  - Differential mode ingress depends upon cabling type; not useful for calibration purposes
- Injecting test signal at AE-side port reduces depth of coupling nulls and improves test signal input port return loss; but creates slightly increased coupling loss
- The common-mode coupling in each of four pairs is nearly identical up to 350 MHz; this is the optimal range for the CC clamp test setup
- There is a narrow CM coupling null near 400 MHz which cannot be properly corrected; this null is likely due to the CC clamp physical structure
  - Dip appears in this region for both CC-101 and CC-102 clamps
  - Need to address this in the test procedure
  - Work pending on reducing this effect by modifying the clamp construction
- The CC clamp coupling is sensitive to the following parameters:
  - The cable length between the clamp (EUT-side) and the RJ45 break-out board (or EUT)
  - The height of the test cable above the metal plate ground plane
  - Proper ground plane contact of the RJ45 break-out board ground (or EUT)
  - Common-mode termination impedance per pair

Next Steps and Discussion Points

- Should we add a CMNR test to the standard?
  - Verify operation in the presence of this impairment
  - Eliminate inconsistencies that occur with EMC standard radiated and conducted immunity testing
- What frequency test range should we use?
- What set of frequency points and dwell time should we use?
- Proposed required levels for signal generator output level and harmonic distortion
- Common-mode coupling null in CC clamp: Should we simply correct as best possible (limit max clamp input level) and ignore the residual error?
  - The error region would be very narrow and likely would not affect the outcome
  - Depth of null may vary greatly between pair; full correction may introduce an even greater error component in some pairs
  - Some work pending on reducing this effect by modifying the CC clamp construction
- Should we add envelope rise/fall time control?
  - This is actually a better model of real-world signals
- CMNR CM target level: Should we use the current levels in Table 113A?
  - Alternative proposal in a separate contribution
  - Given the test channel is maximum length compliant link segment, should the test levels correspond to a 3 V/meter field or a 10 V/meter external field?
- Build and test a working system; determine construction details
- **Goal is to have working text by September interim meeting!**