Testing Impulse Noise Tolerance

AQUANTIA®

May 19, 2015

Larry Cohen

Overview

- Purpose: Describe some potential methods for testing impulse noise tolerance
  - Test methods described also useful for in-house RF immunity testing
  - Emphasis of presentation is on test signal injection methods
- Discuss need for impulse noise immunity test in standard
- Proposed test methods and example test setups
  - EM coupling (Campbell) clamp as shown in 1000Base-T
  - Absorbing clamp coupling (standard EMC device)
  - Direct injection (custom test fixture circuit)
- Measurement of EM coupling clamps
  - EM coupling (Campbell) clamp (ETS CC-101)
  - EM absorbing clamp (Fischer F-2031-23mm)
- Initial observations of different test methods
- Next steps and discussion points

Why Do We Need Impulse Noise Testing?

- Standard EMC regulations cover compliance requirements for very large impulse noise events caused by high-voltage ESD events and large switch contact arc transients (EFT)
  - Typical ESD test levels are 4 kV contact discharge and 8 kV air discharge
  - Main intent is to insure that terminal equipment does not get damaged or destroyed by strong ESD and EFT events during normal operation
- EMC standards are not designed to verify operational integrity (BER) of data links under normal operating conditions
  - EMC standards do not test the operational effects (BER degradation) of more frequent low-level ESD (or EFT) events below potentially damaging energy levels
  - ESD test waveforms are not fully representative of the impulse noise interference that may be encountered in the enterprise environment under normal operating conditions
- Existing EMC test standards do not specify consistent test conditions
  - EMC standards allow a large amount of latitude and manufacturer's discretion in the selection of a test configuration
  - Cannot guarantee repeatable test conditions and test results across products from different manufacturers
  - Considerable variability of test conditions, even when following EMC test standard to the letter
- New data standards must provide necessary test guidance for impulse noise interference from low-level ESD and EFT sources to ensure proper operational integrity (BER) across products from different manufacturers

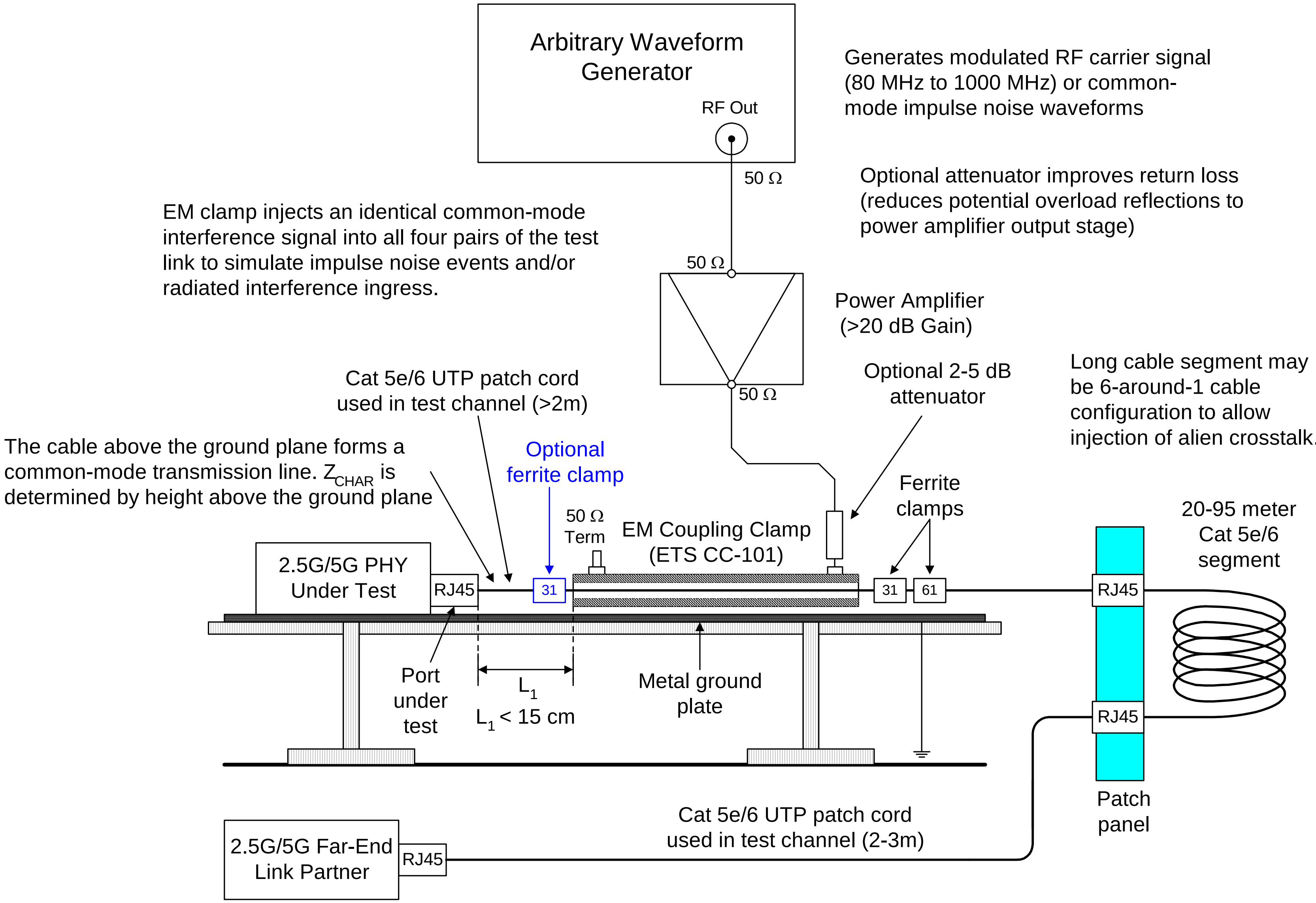
Potential Methods for Injecting Test Disturbance

- Direct differential injection
  - Can inject precise common-mode or differential signals into each pair; disturbers may be different or identical for each pair
  - Adds an additional connector junction(s) to channel; injection circuits will degrade channel insertion loss and return loss
- EM coupling (Campbell) clamp defined in 1000Base-T
  - Injects identical common-mode signal on all four pairs; differential disturber signal created by channel imbalance
  - Non-intrusive, does not degrade channel insertion loss and return loss
  - Works as a coaxial transformer; slightly directional coupling
  - External ferrite clamps are required at far-end port for isolation of link partner
  - Produced by only one supplier (ETS)
- EM absorbing clamp
  - Current probe transformer (inductive) injection of common-mode signal at port under test; differential disturber signal created by channel imbalance
  - Non-intrusive, does not degrade channel insertion loss and return loss
  - Far-end port is isolated by internal ferrite clamps; provides some directional coupling
  - Common EMC test instrument; units available from several different suppliers

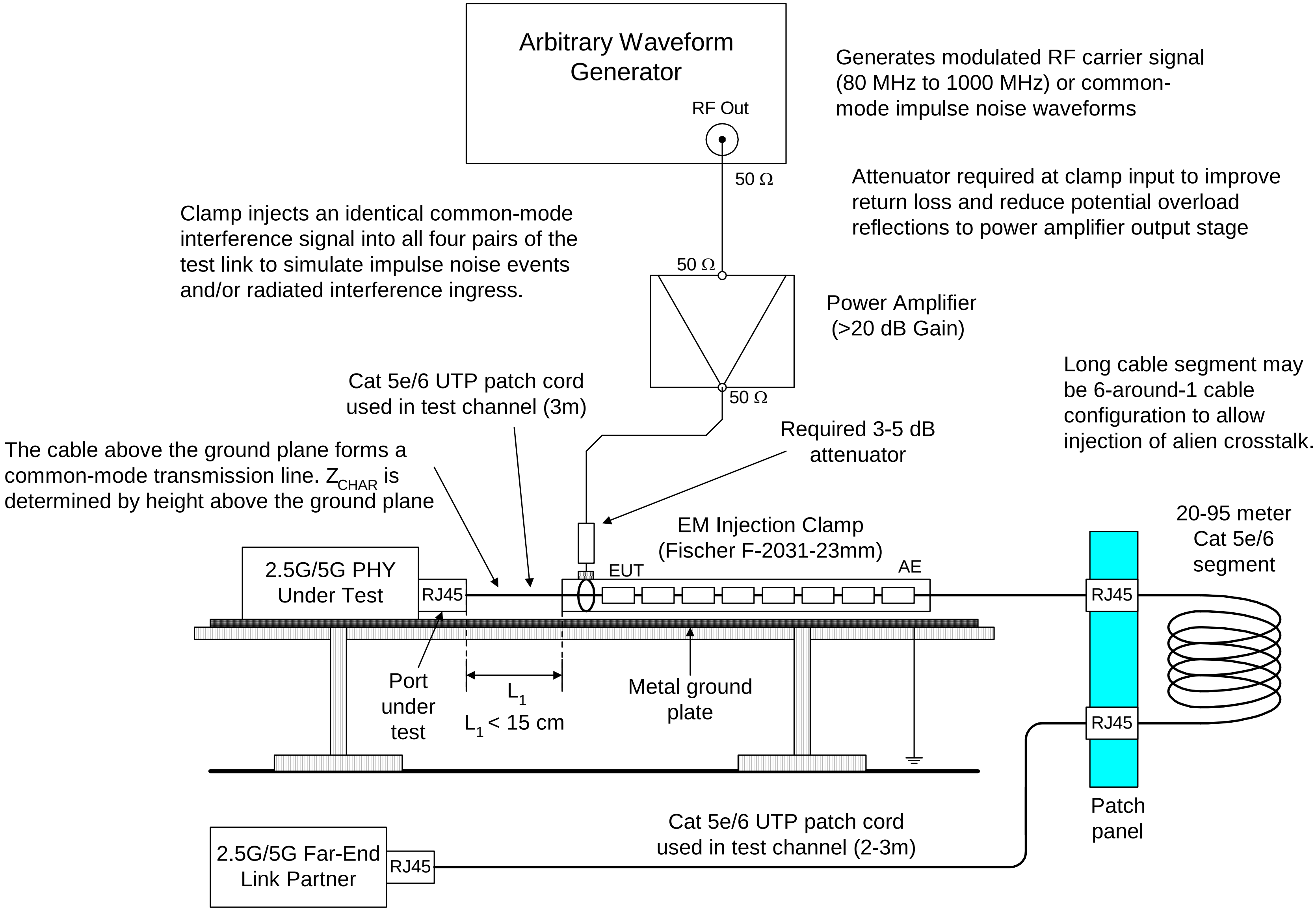
Basic Description Test Procedure

- For all test setups, the test procedure is a two step process
  - Different from clamp noise impairment test in 1000Base-T where the signal injection source is simply fixed at a specified level
- Calibration phase
  - Set up desired test channel; do not turn on other impairment sources (e.g. alien crosstalk in clamp setup)
  - Substitute a 4-pair RJ45-to-SMA breakout test fixture for the MDI port of the PHY under test; substitute a CM/DM termination block at the far end of the test channel
  - Use a 4-port vector network analyzer (or fixed-level swept sine wave signal source) to measure common-mode and differential coupling of the injection apparatus to the each of 4 pairs at the MDI port (under test) breakout test fixture
  - Use measured coupling transfer function to “pre-distort” the test signal source so to provide the desired target signal at the port under test
- Test phase
  - Replace the port under test breakout fixture with the actual PHY under test; replace the far-end termination with the actual link partner
  - Apply “pre-distorted” signal sources to the injection apparatus; add additional impairments (e.g. 6-around-1 alien crosstalk) as necessary
  - Initialize data link between the PHY under test and the far-end link partner and perform all required impairment tolerance tests

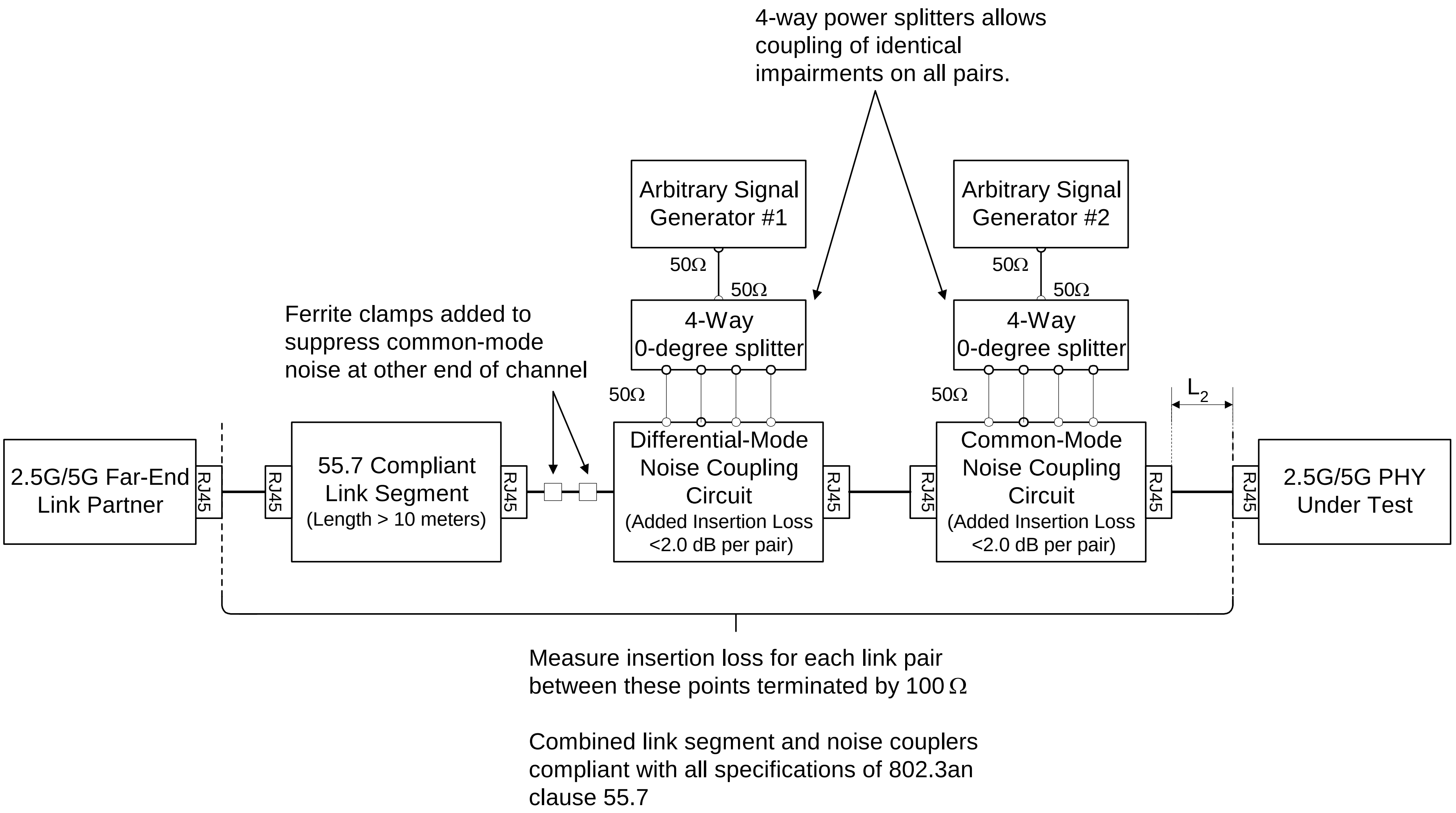
Example EM Coupling Clamp Setup for Impulse Noise (Radiated Immunity) Testing



Example EM Absorbing Clamp Setup for Impulse Noise (Radiated Immunity) Testing



Example Direct Injection Setup for Impulse Noise (Radiated Immunity) Testing



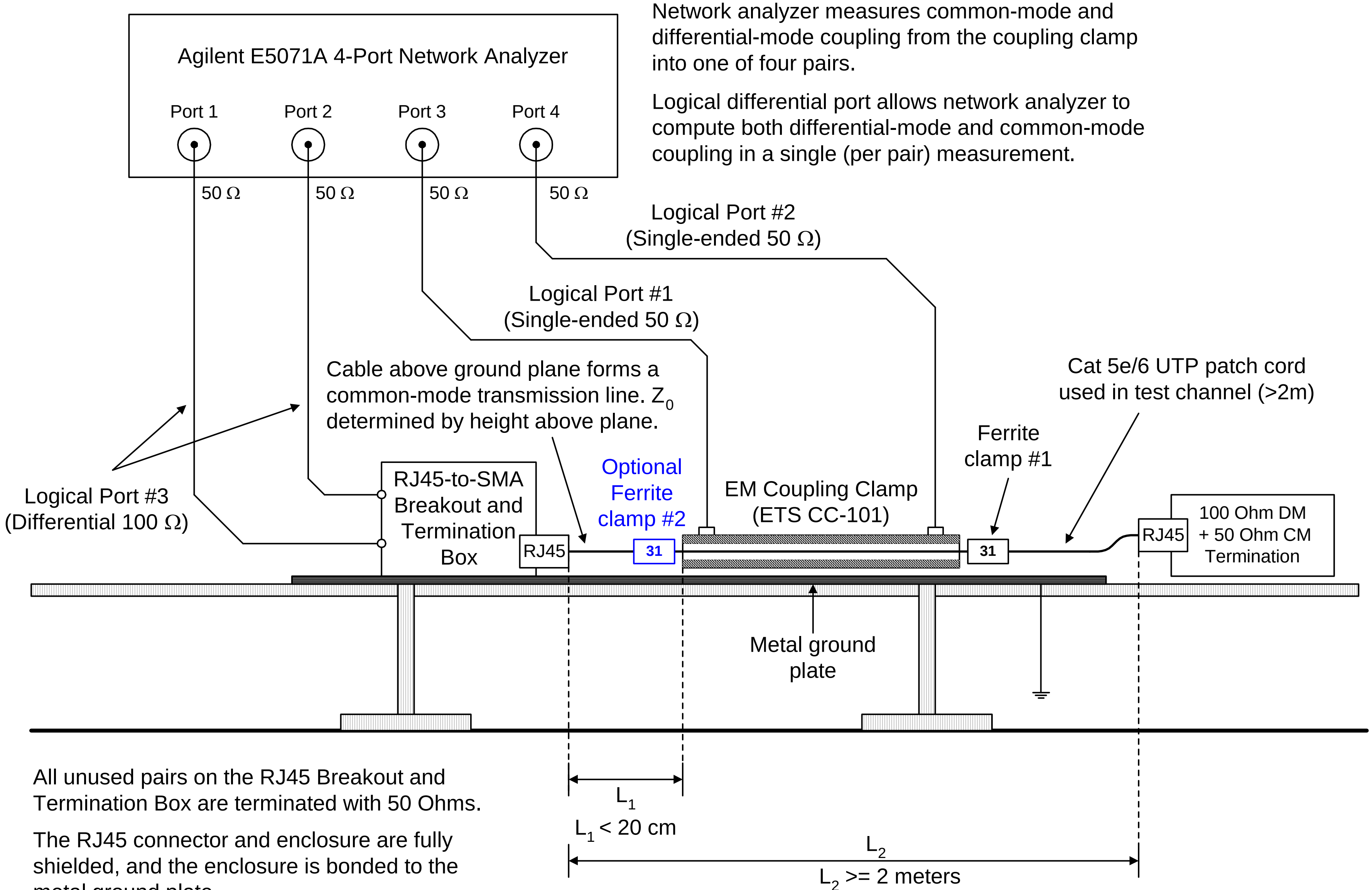
Measurement of Noise Injection Test Equipment

- Standard EMC radiated immunity testing uses a narrowband modulated sine wave interference source
  - Easy to provide source amplitude adjustments for coupling loss variations (correction table)
- Impulse noise tolerance testing uses a wideband short-duration pulse signal source
  - Need relatively flat coupling loss across a wide bandwidth to preserve test signal fidelity
- For both types of EM coupling clamps we need to determine the following:
  - Common-mode coupling loss (transfer function); potential usable bandwidth
  - Signal injection port return loss; poor return loss can degrade driver amplifier performance
  - Sensitivity to test setup variations; effect of distance between clamp and MDI port under test, effect of cable height above ground plane, effect of placement position of ferrite clamps
  - Compute time-domain pulse response
  - Can the coupling transfer function be modified to improve pulse coupling fidelity?
- For a direct injection test fixture we need to determine the following:
  - Coupling loss and return loss of signal injection port
  - Added insertion loss to channel under test
  - Return loss degradation; creation of “false” echo signals
- A direct injection test fixture was unavailable for characterization at this time

Test Setup to Measure EM Coupling (Campbell) Clamp

Network analyzer measures common-mode and differential-mode coupling from the coupling clamp into one of four pairs.

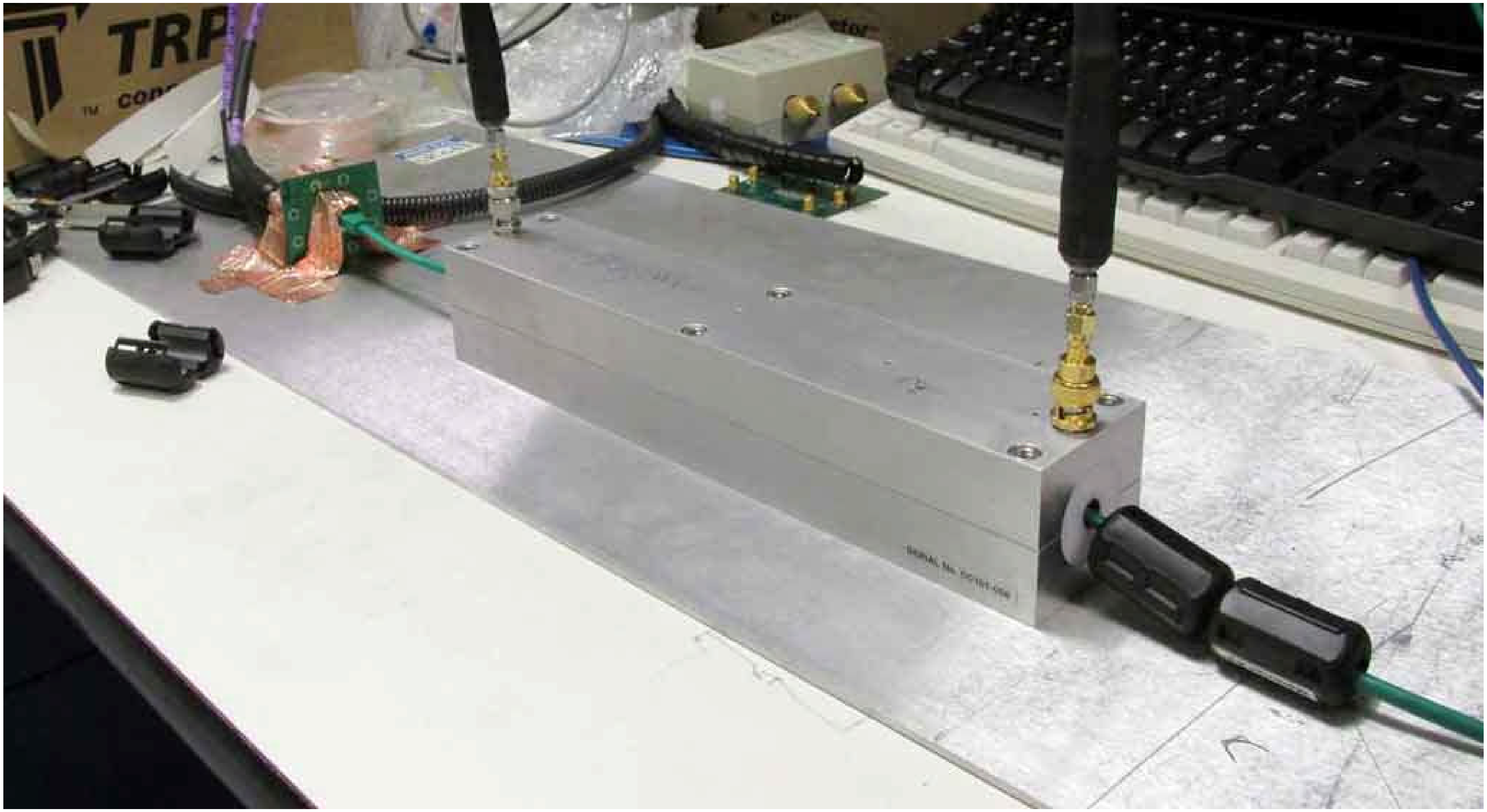
Logical differential port allows network analyzer to compute both differential-mode and common-mode coupling in a single (per pair) measurement.

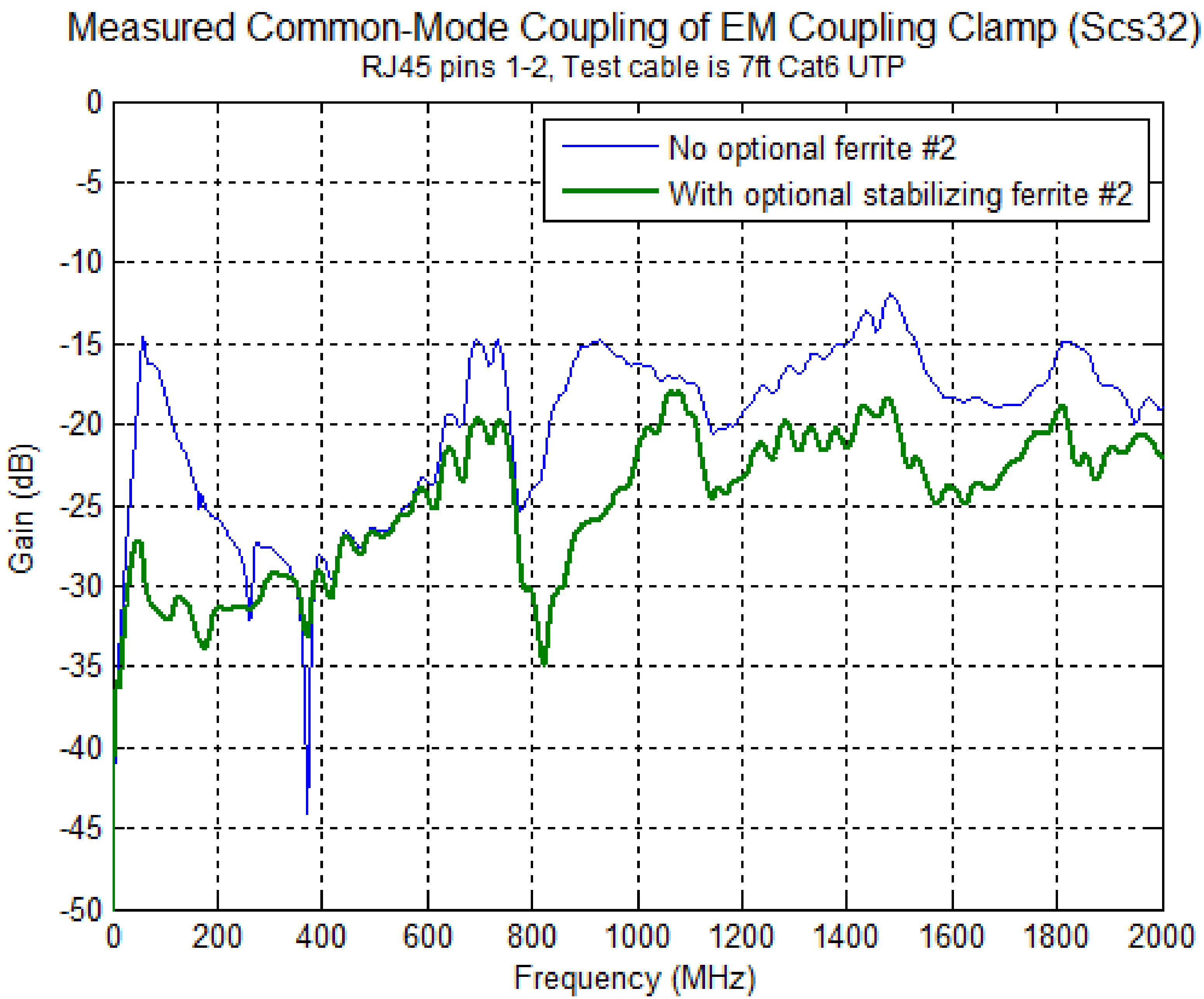


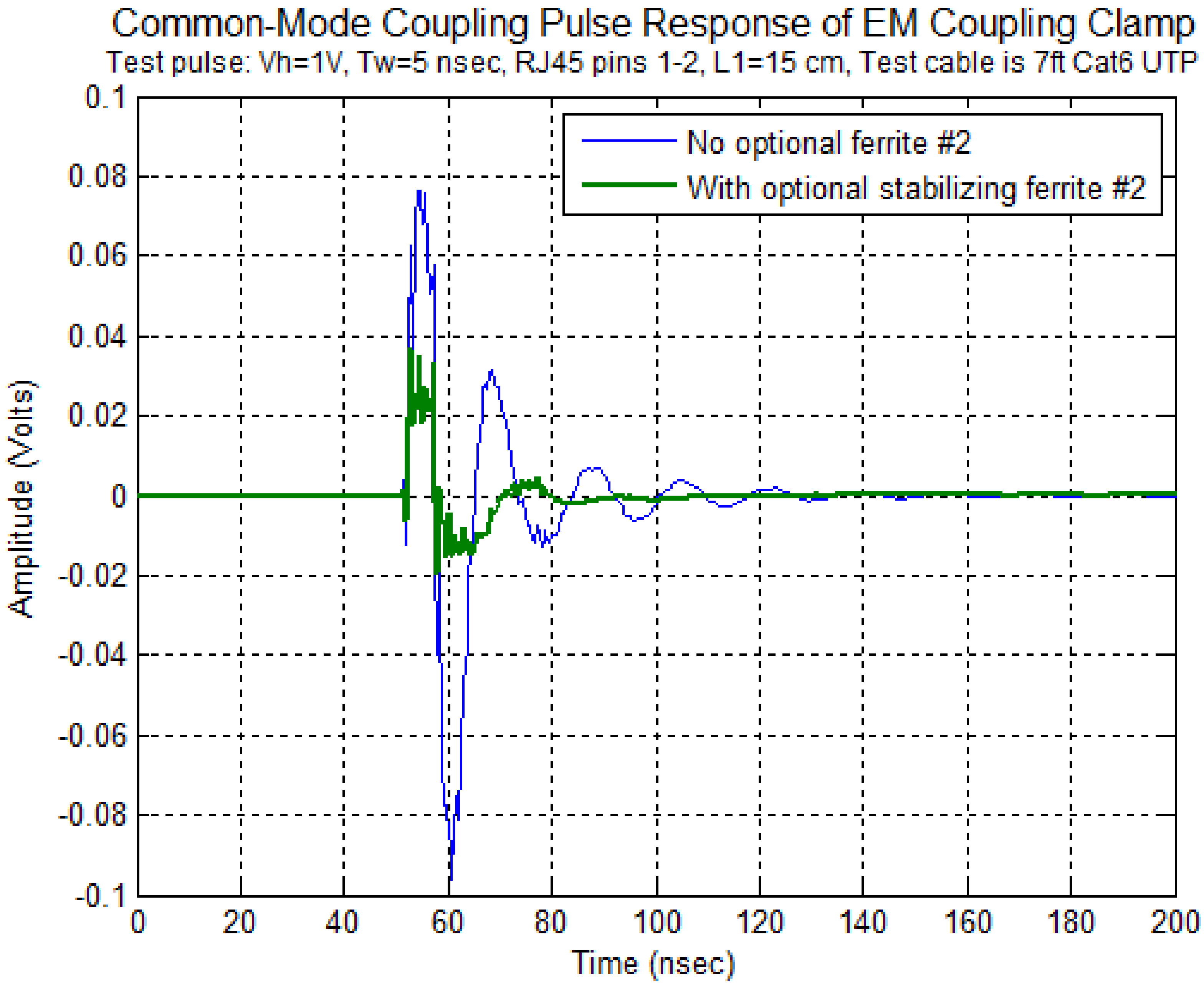
All unused pairs on the RJ45 Breakout and Termination Box are terminated with 50 Ohms.

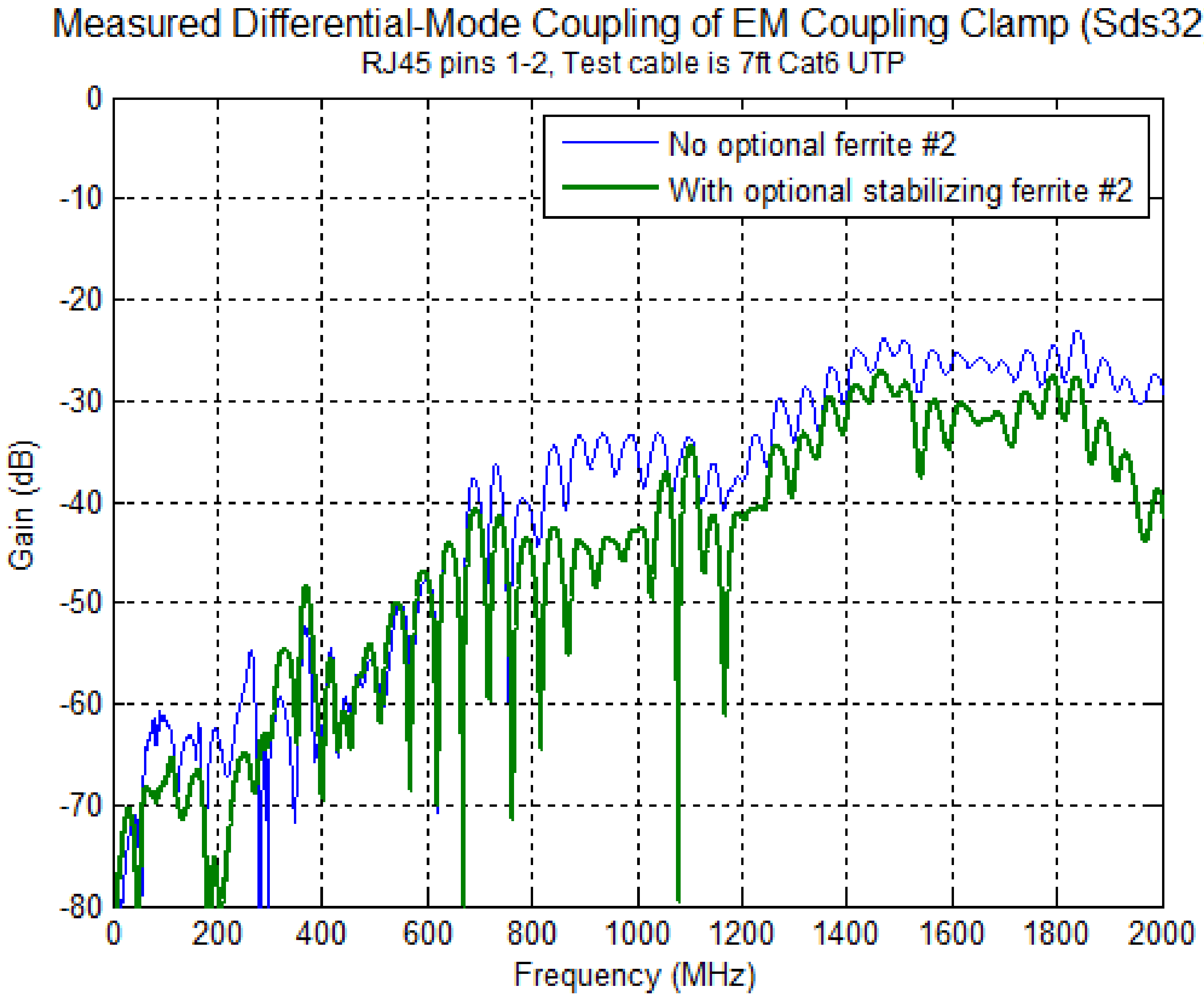
The RJ45 connector and enclosure are fully shielded, and the enclosure is bonded to the metal ground plate.

Test Setup to Measure EM Coupling (Campbell) Clamp

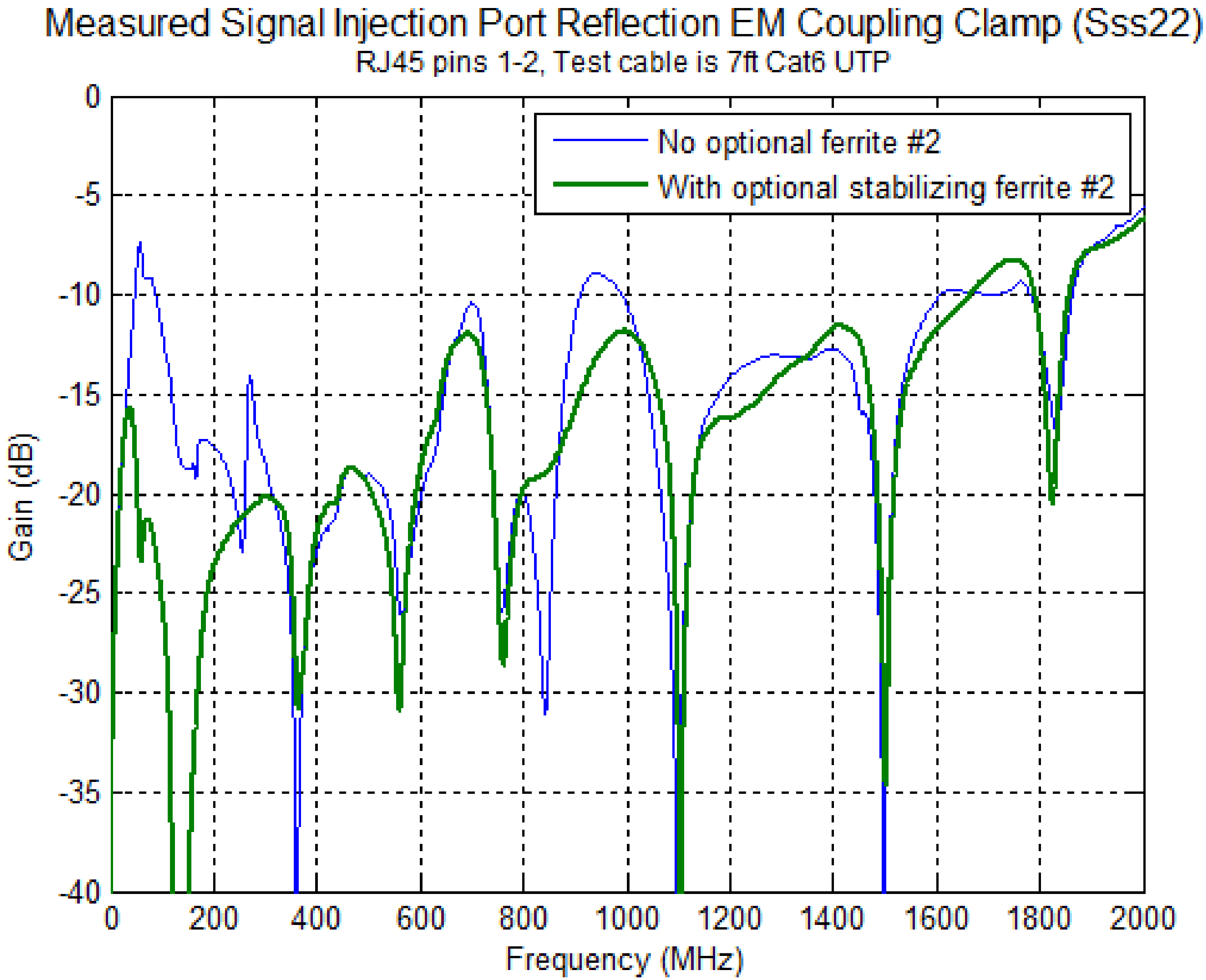



Measured Common-Mode Coupling of EM Coupling Clamp (Scs32)
RJ45 pins 1-2, Test cable is 7ft Cat6 UTP
No optional ferrite #2
With optional stabilizing ferrite #2
Gain (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0
200
400
600
800
1000
1200
1400
1600
1800
2000

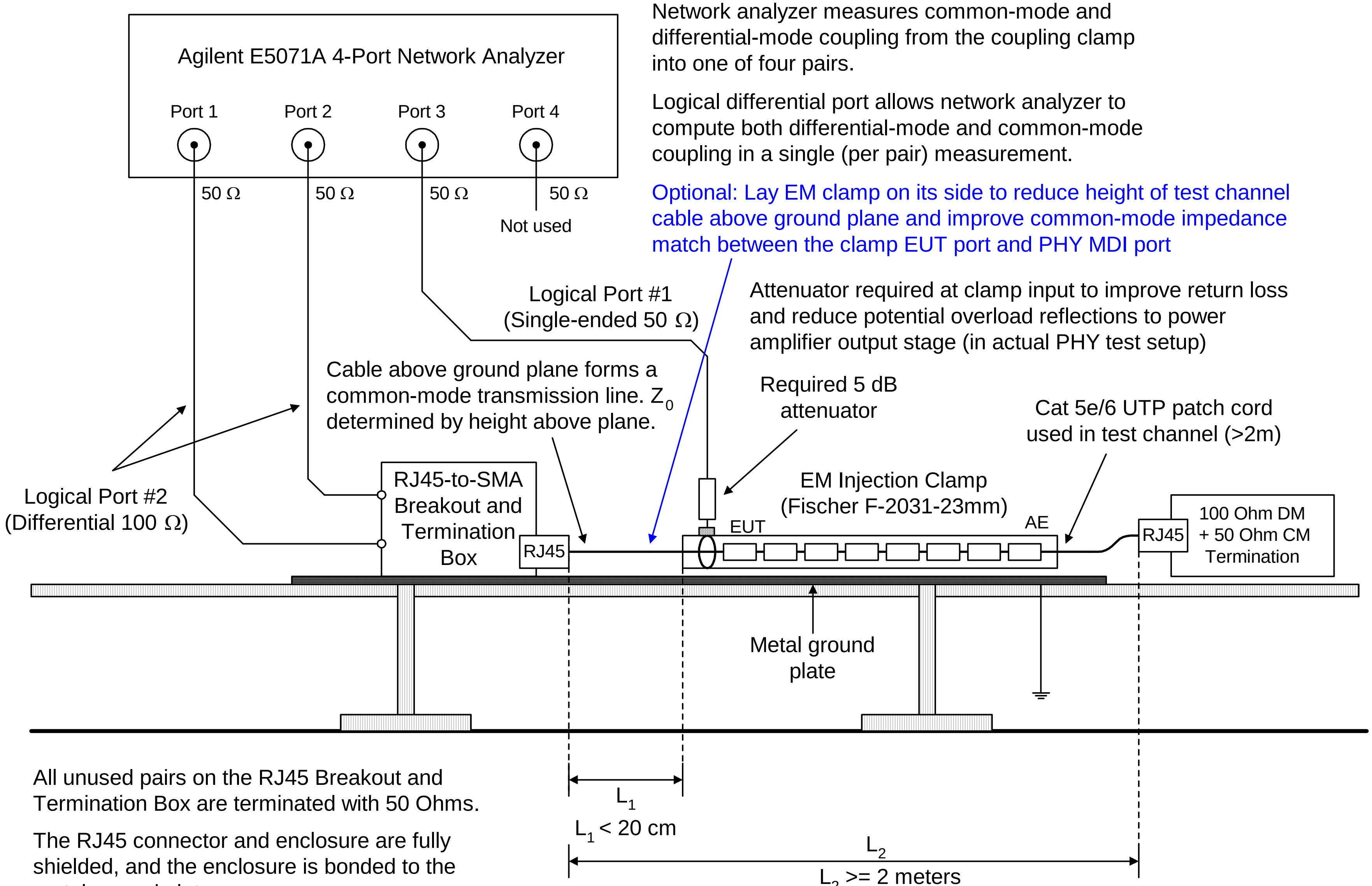

Common-Mode Coupling Pulse Response of EM Coupling Clamp
Test pulse: Vh=1V, Tw=5 nsec, RJ45 pins 1-2, L1=15 cm, Test cable is 7ft Cat6 UTP
No optional ferrite #2
With optional stabilizing ferrite #2
Amplitude (Volts)
Time (nsec)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
0
20
40
60
80
100
120
140
160
180
200



Measured Differential-Mode Coupling of EM Coupling Clamp (Sds32)
RJ45 pins 1-2, Test cable is 7ft Cat6 UTP
No optional ferrite #2
With optional stabilizing ferrite #2
Gain (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
Frequency (MHz)
0
200
400
600
800
1000
1200
1400
1600
1800
2000


Measured Signal Injection Port Reflection EM Coupling Clamp (Sss22)
RJ45 pins 1-2, Test cable is 7ft Cat6 UTP
No optional ferrite #2
With optional stabilizing ferrite #2
Gain (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Test Setup to Measure EM Absorbing Clamp Coupling



Network analyzer measures common-mode and differential-mode coupling from the coupling clamp into one of four pairs.

Logical differential port allows network analyzer to compute both differential-mode and common-mode coupling in a single (per pair) measurement.

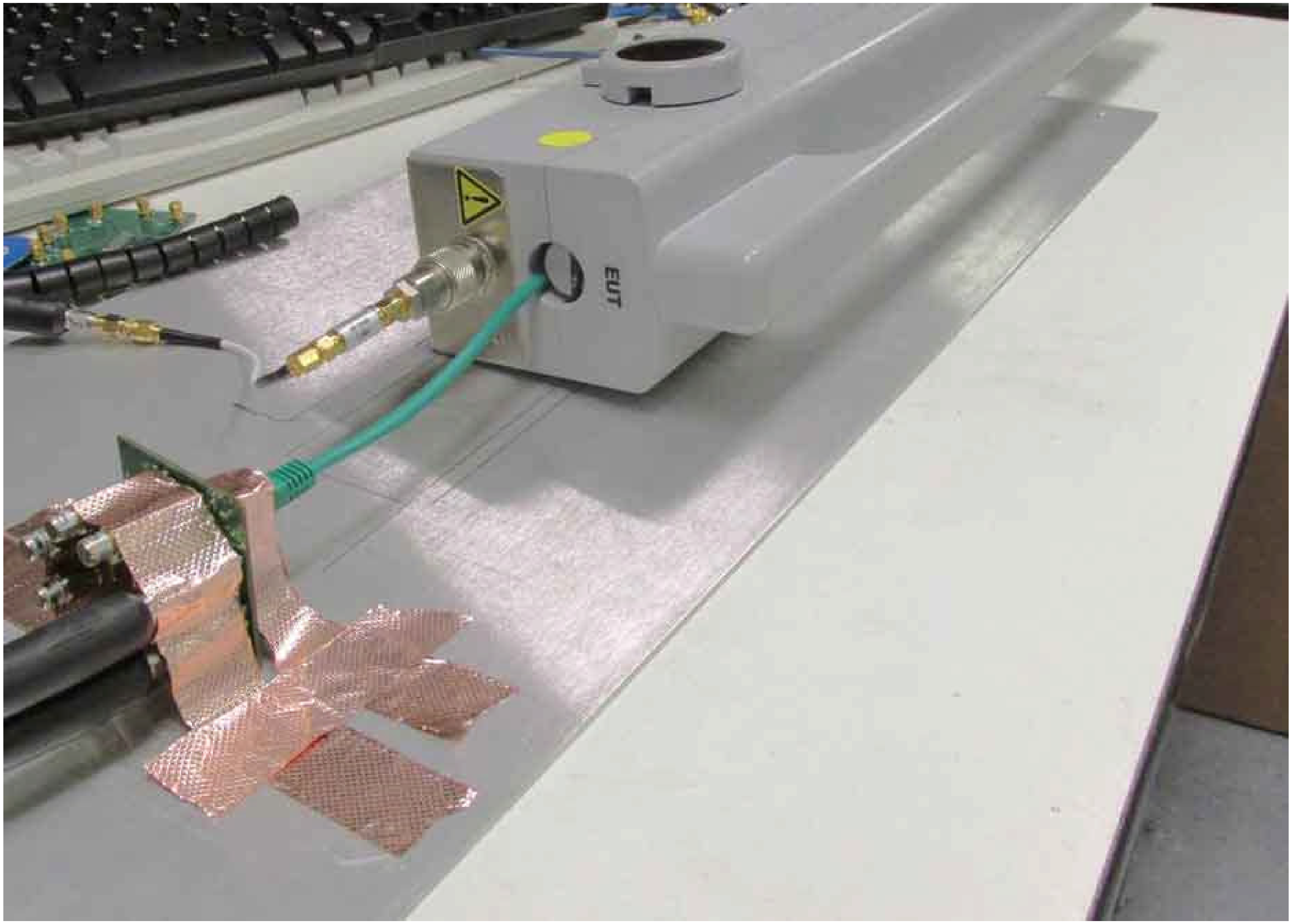
Optional: Lay EM clamp on its side to reduce height of test channel cable above ground plane and improve common-mode impedance match between the clamp EUT port and PHY MDI port

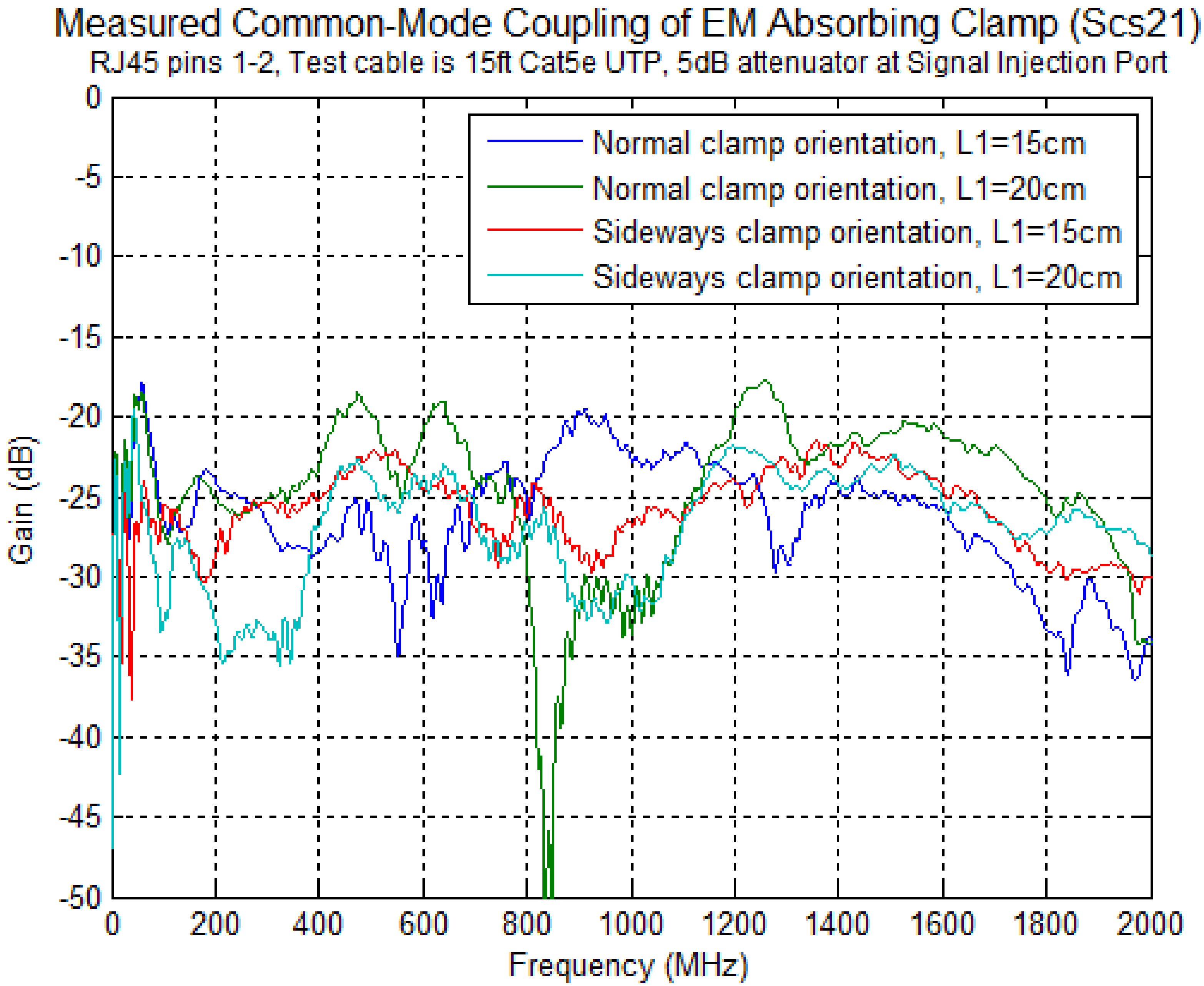
Attenuator required at clamp input to improve return loss and reduce potential overload reflections to power amplifier output stage (in actual PHY test setup)

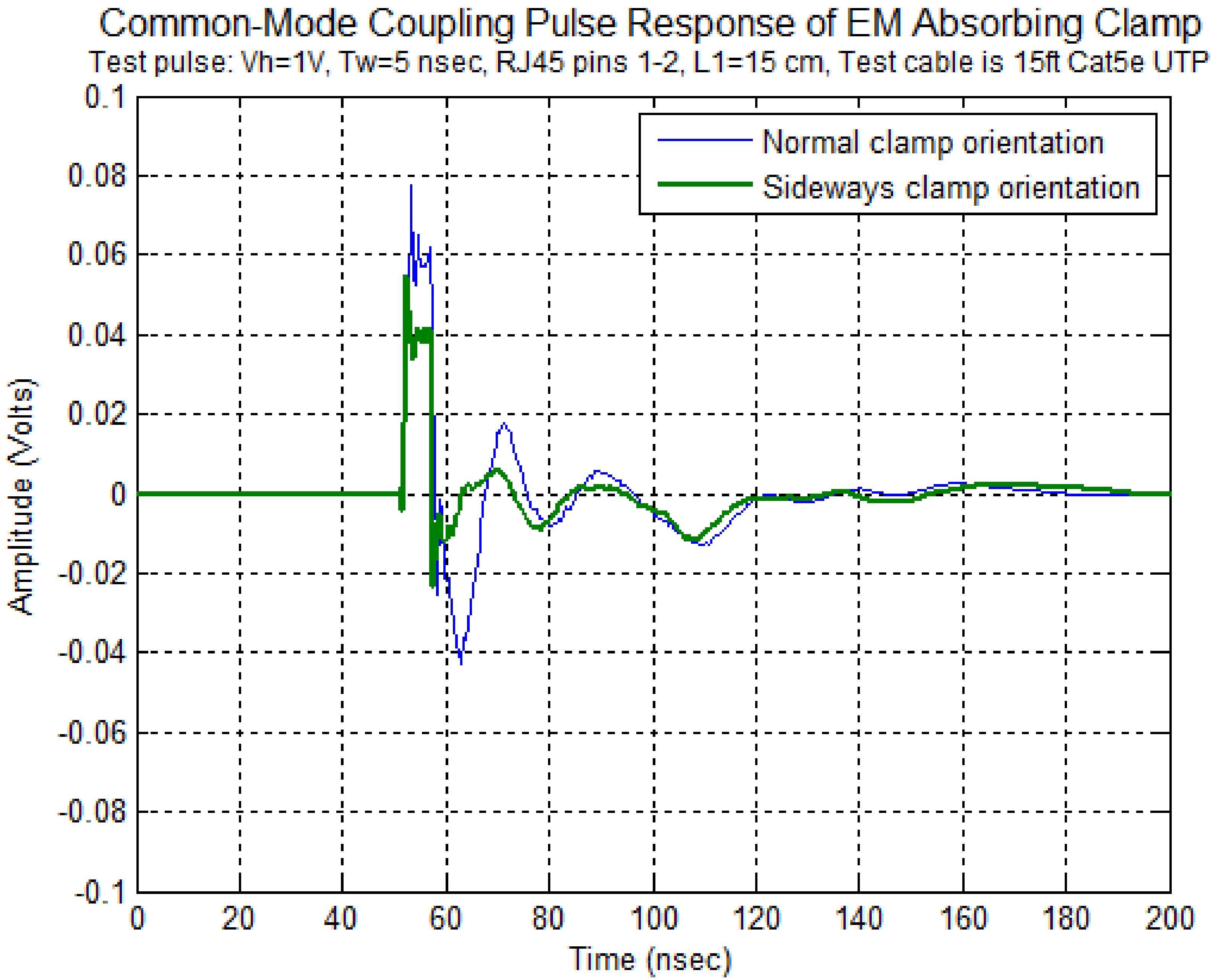
All unused pairs on the RJ45 Breakout and Termination Box are terminated with 50 Ohms.

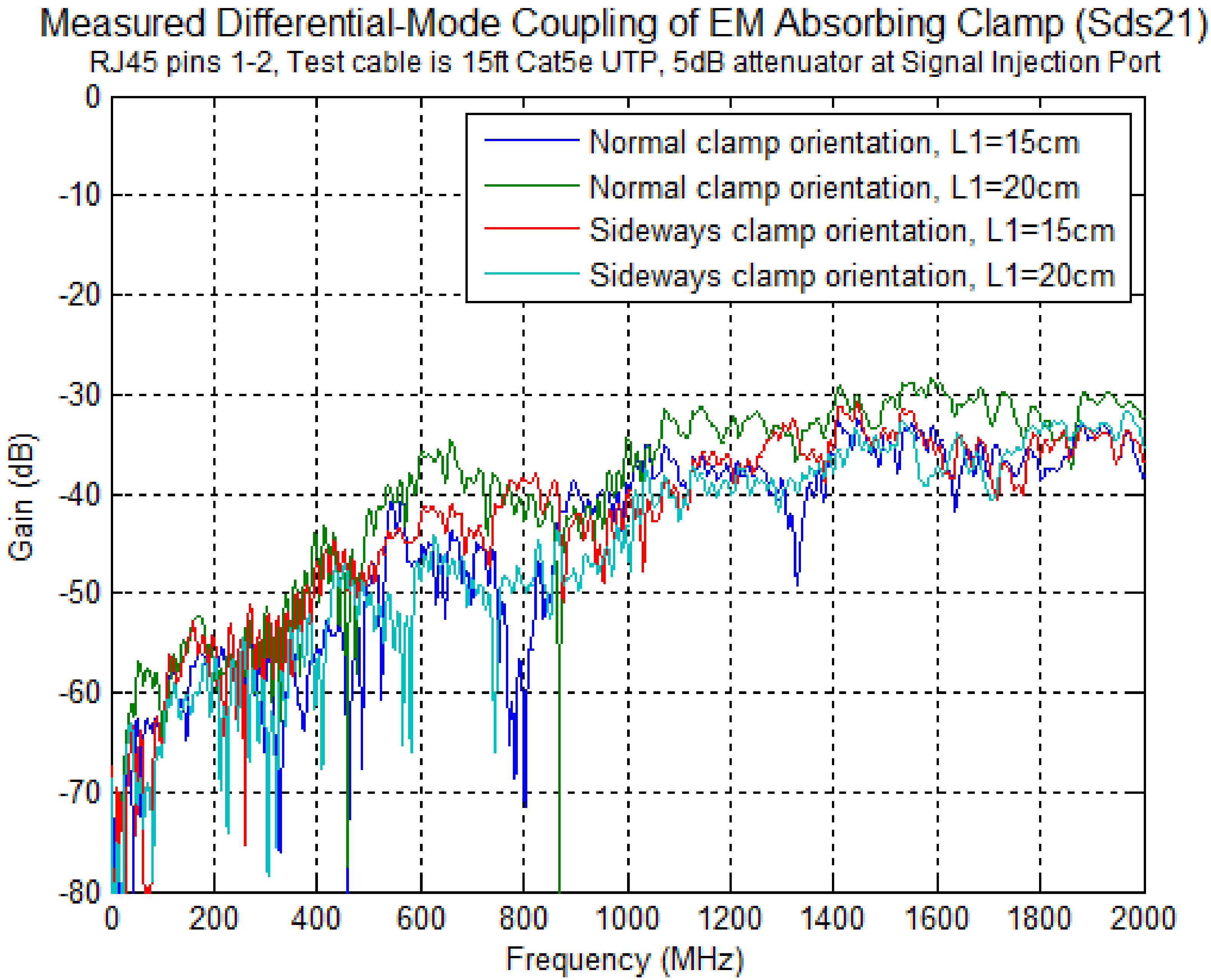
The RJ45 connector and enclosure are fully shielded, and the enclosure is bonded to the metal ground plate.

Test Setup to Measure EM Absorbing Clamp Coupling

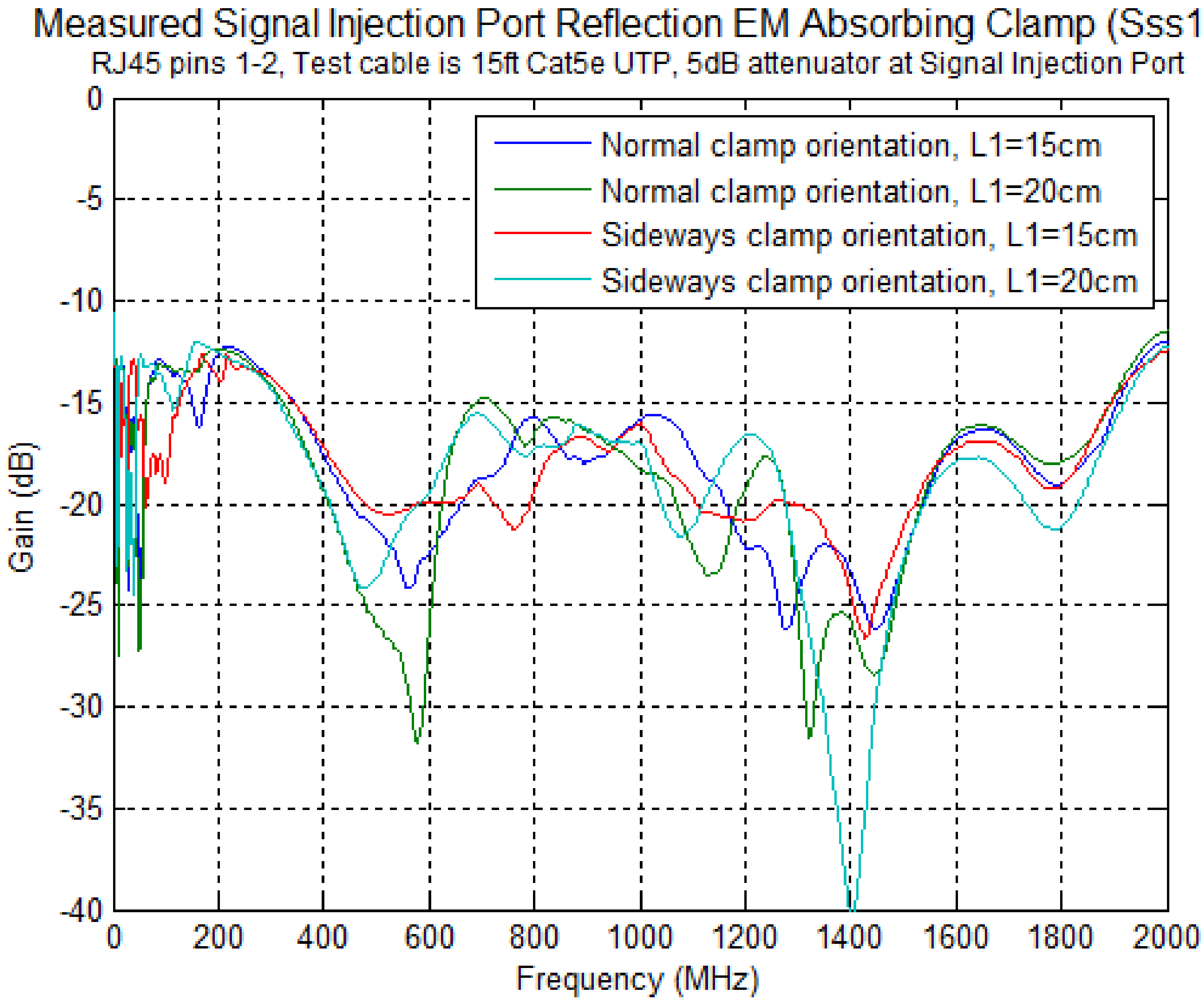



Measured Common-Mode Coupling of EM Absorbing Clamp (Scs21)
RJ45 pins 1-2, Test cable is 15ft Cat5e UTP, 5dB attenuator at Signal Injection Port
Normal clamp orientation, L1=15cm
Normal clamp orientation, L1=20cm
Sideways clamp orientation, L1=15cm
Sideways clamp orientation, L1=20cm
Gain (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (MHz)


Common-Mode Coupling Pulse Response of EM Absorbing Clamp
Test pulse: Vh=1V, Tw=5 nsec, RJ45 pins 1-2, L1=15 cm, Test cable is 15ft Cat5e UTP
Normal clamp orientation
Sideways clamp orientation
Amplitude (Volts)
Time (nsec)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
0
20
40
60
80
100
120
140
160
180
200



Measured Differential-Mode Coupling of EM Absorbing Clamp (Sds21)
RJ45 pins 1-2, Test cable is 15ft Cat5e UTP, 5dB attenuator at Signal Injection Port
Normal clamp orientation, L1=15cm
Normal clamp orientation, L1=20cm
Sideways clamp orientation, L1=15cm
Sideways clamp orientation, L1=20cm
Gain (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (MHz)



Measured Signal Injection Port Reflection EM Absorbing Clamp (Sss11)
RJ45 pins 1-2, Test cable is 15ft Cat5e UTP, 5dB attenuator at Signal Injection Port
Normal clamp orientation, L1=15cm
Normal clamp orientation, L1=20cm
Sideways clamp orientation, L1=15cm
Sideways clamp orientation, L1=20cm
Gain (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (MHz)

Observations for EM Coupling (Campbell) Clamp Injection Method

- Usable bandwidth to beyond 1GHz, but there may be coupling loss problems below 20 MHz; could affect tolerance testing of switch contact arc impulse noise
- Adding loss (ferrite) at the near end port of the EM coupling clamp equalizes the gain of the common-mode coupling transfer function (and signal port return loss)
  - Greatly improves quality of pulse injection and reduces deep coupling nulls which could saturate the driver amplifier output
  - Added coupling loss requires greater output power from driver amplifier across operating bandwidth; this is a potential problem
  - Improves signal injection port return loss
  - Reduces coupling variability from changes in L_1; reduces sensitivity to physical movement
- Injects common-mode disturber signal on all four pairs simultaneously as would occur in the real world
  - Can inject a target common-mode ingress signal across all four pairs over a significant bandwidth
  - Difficult to inject a specified target differential disturber signal into even a single pair
- Each individual setup must be calibrated before performing the actual test; test setup still sensitive to physical movement, even with added stabilizing ferrite clamp
- Useful for standard narrowband sine wave radiated immunity testing

Observations for EM Absorbing Clamp Injection Method

- Usable bandwidth to beyond 1GHz, but there may be coupling loss problems below 20 MHz; could affect tolerance testing of switch contact arc impulse noise
- Requires less driving power than the EM coupling (Campbell) clamp
- Placing EM absorbing clamp sideways (reduces cable height above ground plane) and keeping L_1 less than 15 cm improves the common-mode impedance matching between the clamp EUT port and the PHY MDI port
  - Removes deep nulls which can cause problems for driver amplifiers
- Signal injection port return loss is from the internal current transformer and is very poor without an added attenuator
- Injects common-mode disturber signal on all four pairs simultaneously as would occur in the real world (for impulse noise and other EMI disturbances)
  - Can inject a target common-mode ingress signal across all four pairs over a significant bandwidth
  - Difficult to inject a specified target differential disturber signal into even a single pair
- Each individual setup must be calibrated before performing the actual test; test setup is sensitive to physical movement
- Also very useful for standard narrowband sine wave radiated immunity testing to at least 10V/meter equivalent field strength

Observations for Direct Injection Method

- Physically modifies the test channel; degrades channel insertion loss and return loss; may cause significant errors for wide bandwidth data links
  - Design of injector circuit is conceptually simple, but may be difficult in practice because required precision and the need to follow high-frequency layout methods
  - Can generate customized signals for each individual pair or identical common-mode and/or differential signals across all four pairs
  - May not require full calibration before each test; injection coupling not as sensitive to physical movement as clamp setups
- Using a Cat 7 connectors on the test fixture should reduce channel return loss degradation
- In the real world, most external EMI disturbers have very strong common-mode signal components which interact with the PHY line transformer and AFE
  - Need both common-mode and differential signal components for a proper noise tolerance test; complicates test setup

Next Steps and Discussion Points

- Perform time-domain coupling measurements with an arbitrary waveform generator and determine actual feasibility of test waveform pre-distortion
- Find methods to make clamp test setups less sensitive to physical movement
- What test signal should be used for impulse noise tolerance testing?
- Are there problems with clamp injection of switch contact arc impulse noise which contain significant energy below 10 MHz?
- What mix of common-mode and differential mode disturber injection is required to properly test the impulse noise tolerance of a PHY?
  - The common-mode rejection/conversion characteristics of the line transformer and AFE affect the characteristics of the final differential disturber seen at the receiver
- Should an impairment injection method be specified at all?
  - Is it better to simply define the injection apparatus as a black box with specific electrical characteristics?