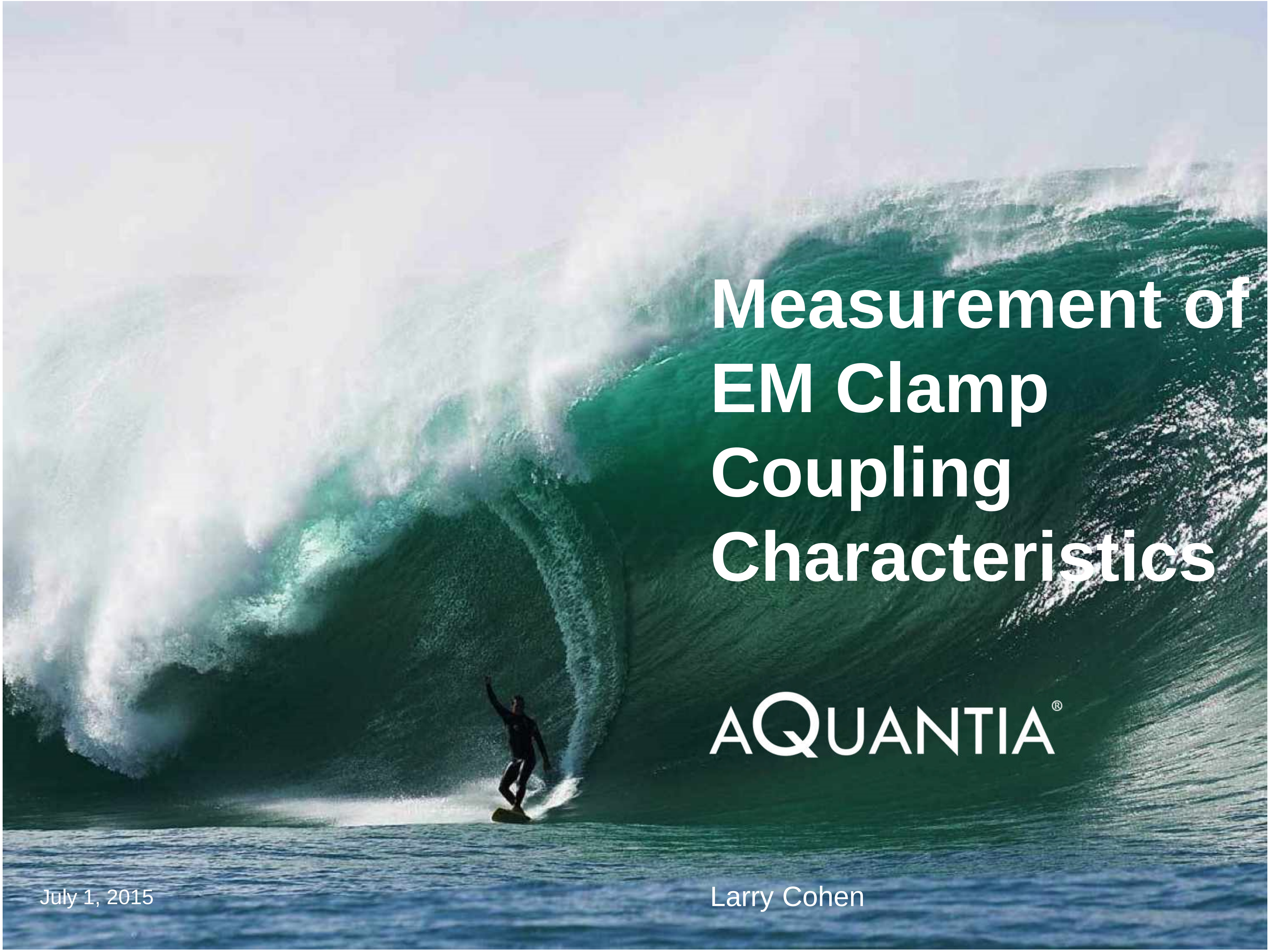


Measurement of EM Clamp Coupling Characteristics

AQUANTIA®

July 1, 2015

Larry Cohen

Overview

- **Purpose:** Measure coupling characteristics of the EM (Campbell) clamp to determine variation of common-mode coupling and differential coupling over all four pairs with different cable types
  - **Identify stable and reproducible test setup configurations for impulse noise testing in the standard**
- Goals of this measurement set
- EM clamp measurement test setup
- Measurement results and observations for different cable types
- Summary of main results
- Next steps
- Additional measurement results

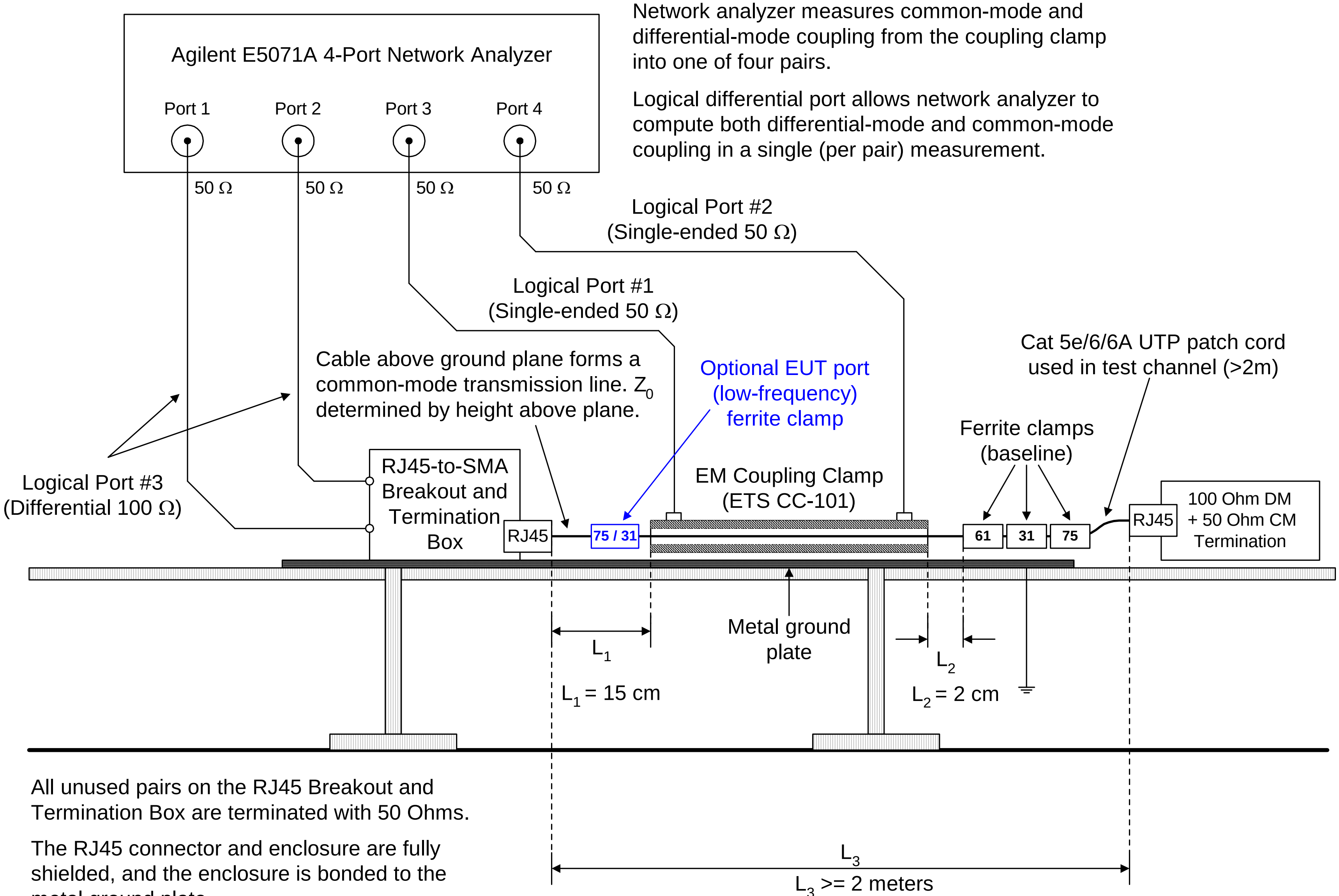
Goals of this Measurement Set

- Determine usage limitations of the EM clamp for impulse noise and radiated immunity pre-compliance testing
  - Impulse noise test bandwidth depends upon data rate (below 400 MHz for 1G, 2.5G and 5G), radiated immunity testing requires useful bandwidth up to 1 GHz
- Determine variation of injected common-mode and differential signals across all four pairs
  - Common-mode coupling variation should be minimal across all four pairs
  - Differential coupling variations across all four pairs should not be too extreme
  - Ratio of differential to common-mode coupling should not change much with different test setup configurations
  - Above criteria will determine the useful frequency range of the EM coupling clamp
- Is the ratio of common-mode to differential coupling consistent with external field coupling results ?
  - Evaluation will require examination of EMC lab test data
- **Main goal:** Identify stable and reproducible test setup configurations for impulse noise testing in the standard

EM Clamp Measurement Test Setup

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.

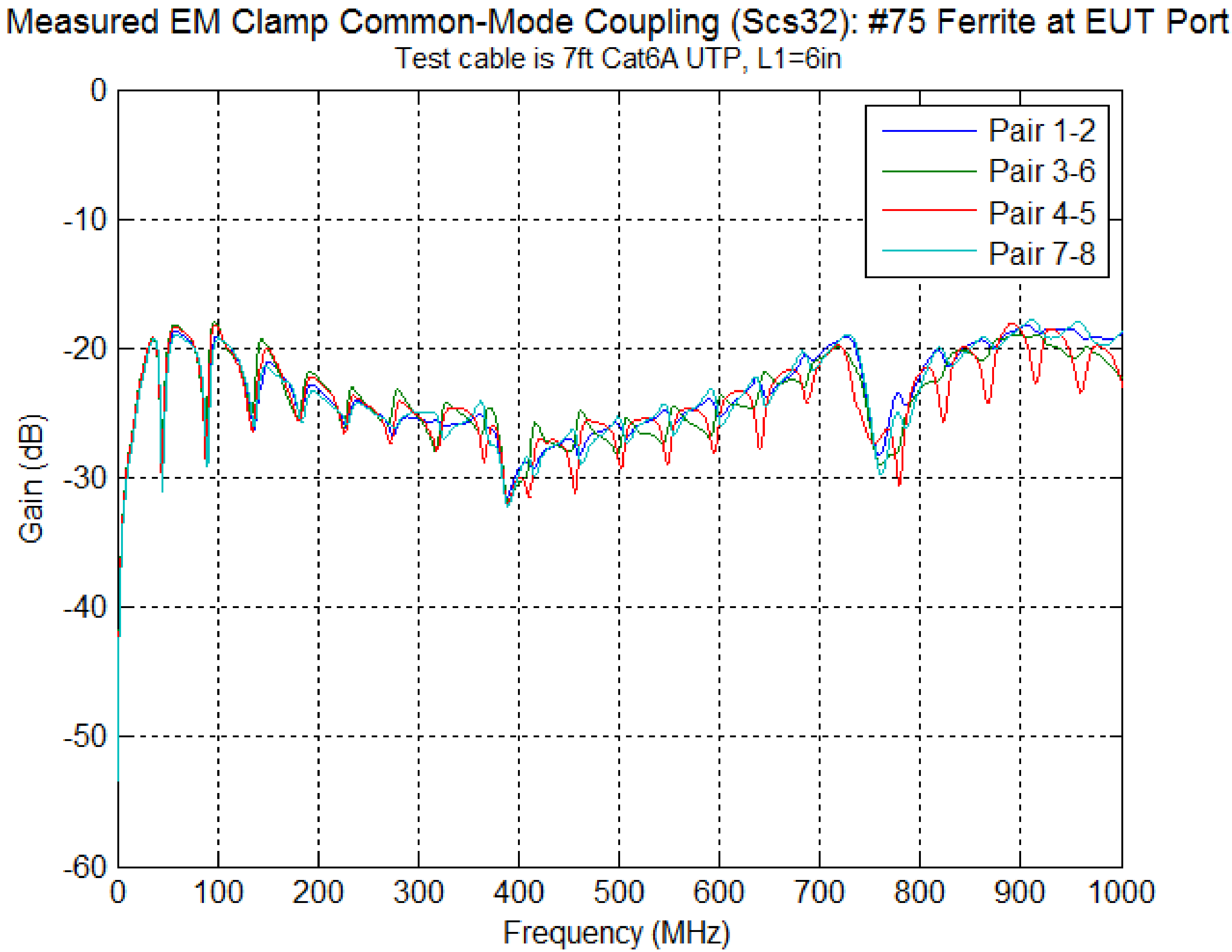


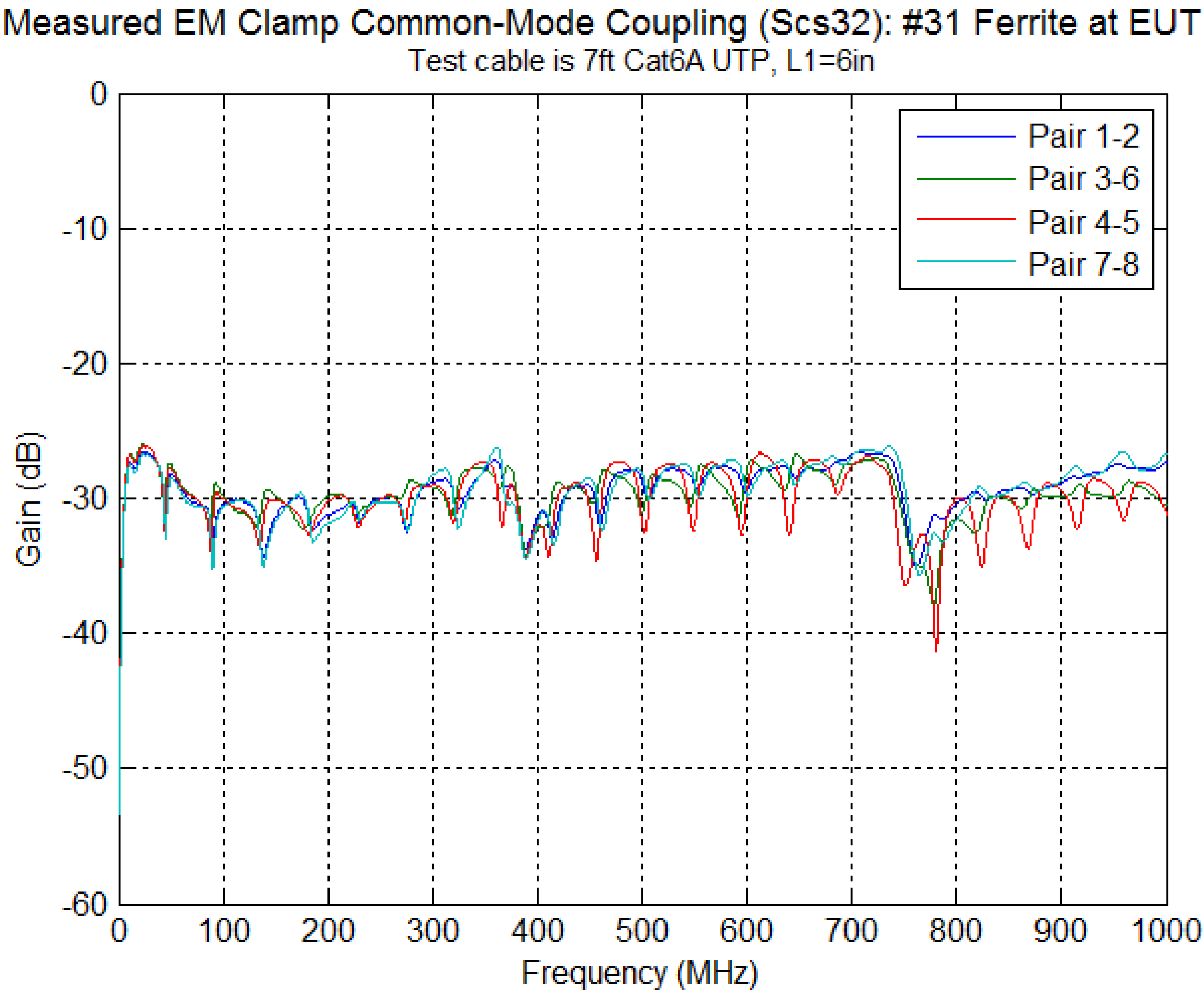
All unused pairs on the RJ45 Breakout and Termination Box are terminated with 50 Ohms.

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

Summary of Measurement Results

- Test cables
  - 7ft Cat 6A UTP patch cord
  - 7ft Cat 5e UTP patch cord (stabilized in clamp with tape)
- Measured parameters (frequency response plots for each parameter)
  - Measured common-mode coupling all four cable pairs (Scs32)
  - Measured differential coupling into all four cable pairs (Sds32)
  - Measured clamp injection port reflection over all four cable pairs (Sss22)
  - Computed differential to common-mode coupling ratio
- Test setup configurations
  - Added #75 ferrite clamp at EUT port of clamp
  - Added #31 ferrite clamp at EUT port of clamp
- A full measurement data set for Cat 6 UTP was not completed, but the partial results were similar to Cat 5e UTP


Measured EM Clamp Common-Mode Coupling (Scs32): #75 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=6in
Gain (dB)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
0
100
200
300
400
500
600
700
800
900
1000
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8


Measured EM Clamp Common-Mode Coupling (Scs32): #31 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=6in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
0
-10
-20
-30
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-60
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300
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700
800
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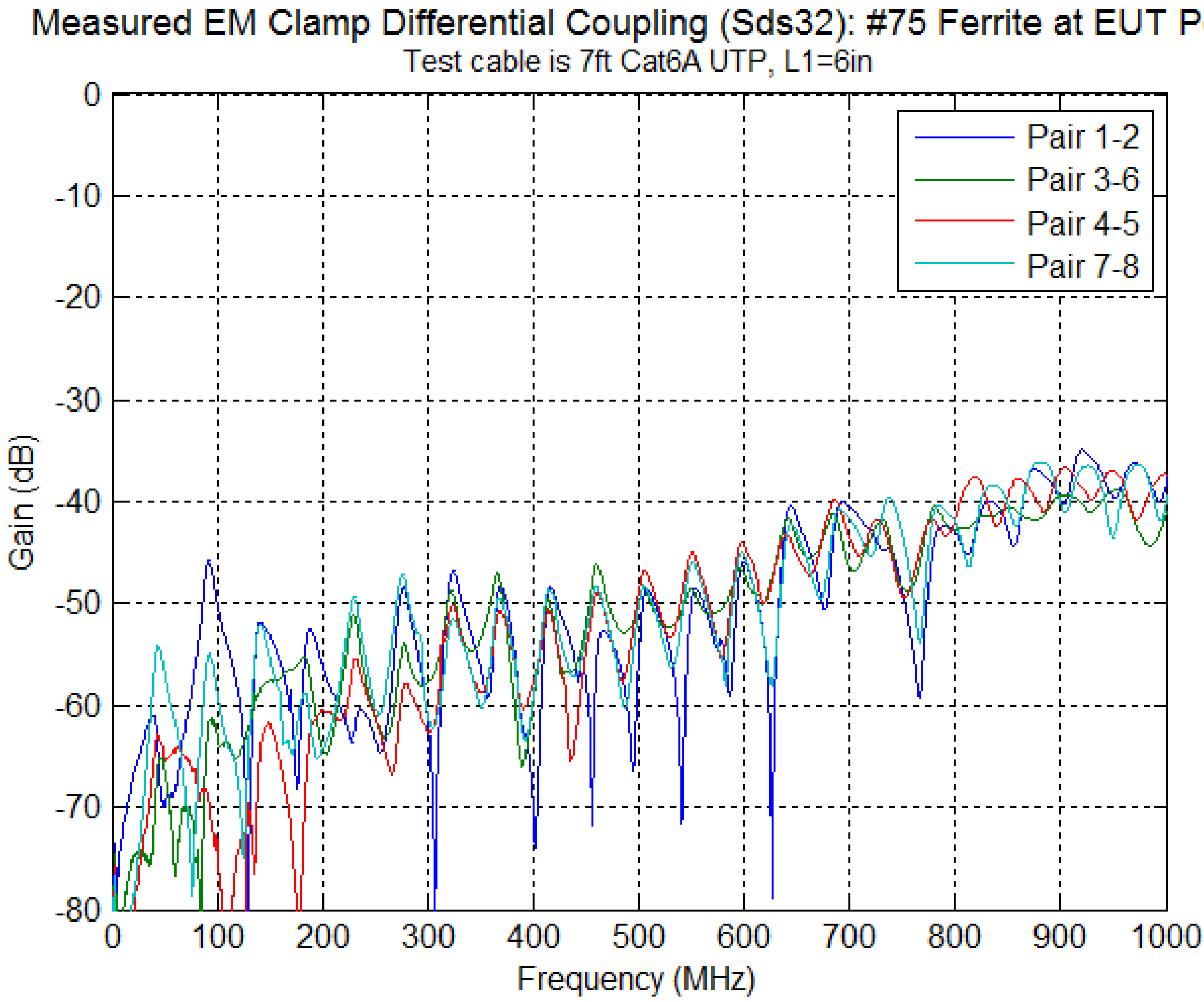
Measured EM Clamp Differential Coupling (Sds32): #75 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=6in
Gain (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
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100
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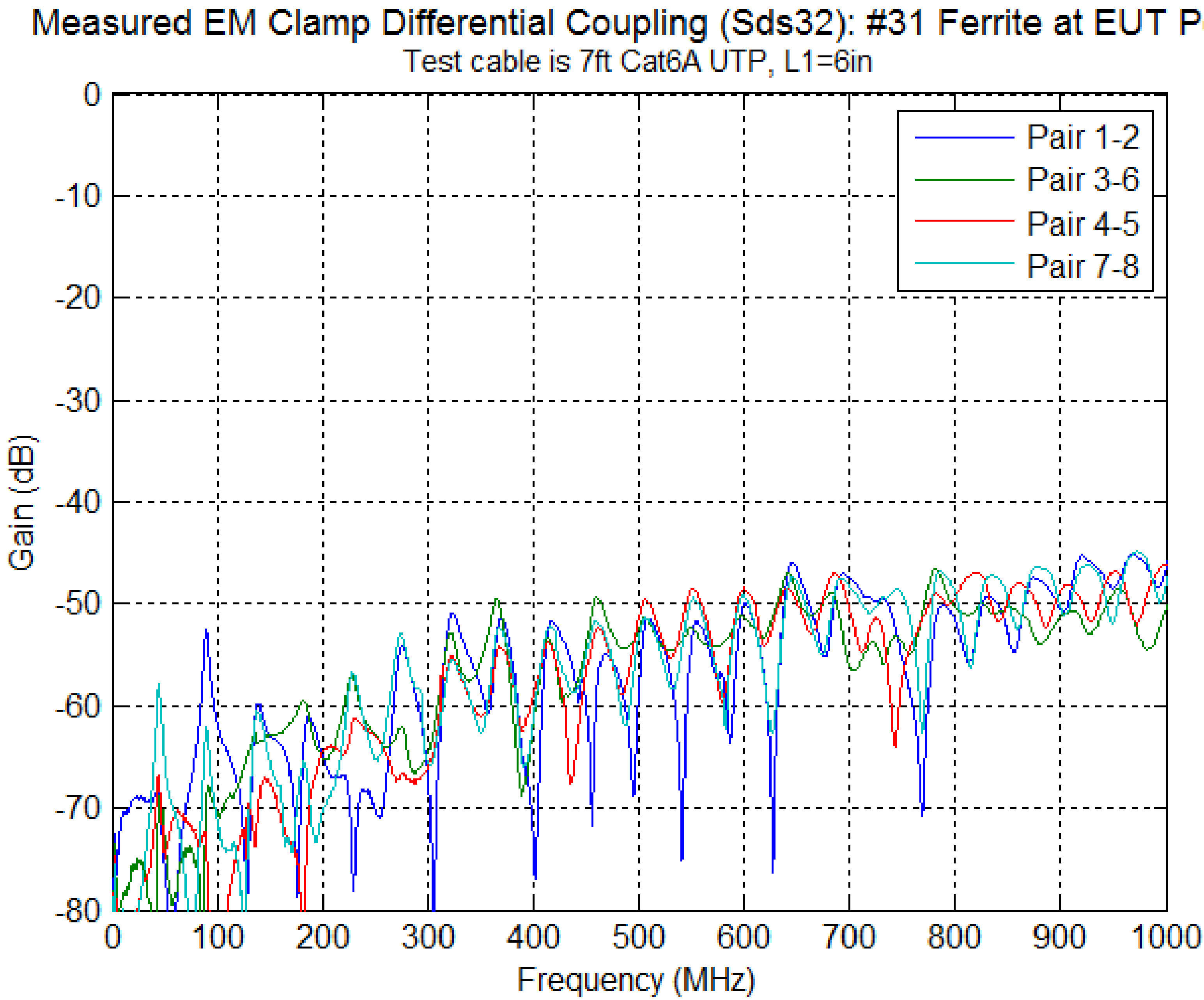
400
500
600
700
800
900
1000
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8


Measured EM Clamp Differential Coupling (Sds32): #31 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=6in
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
Gain (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
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100
200
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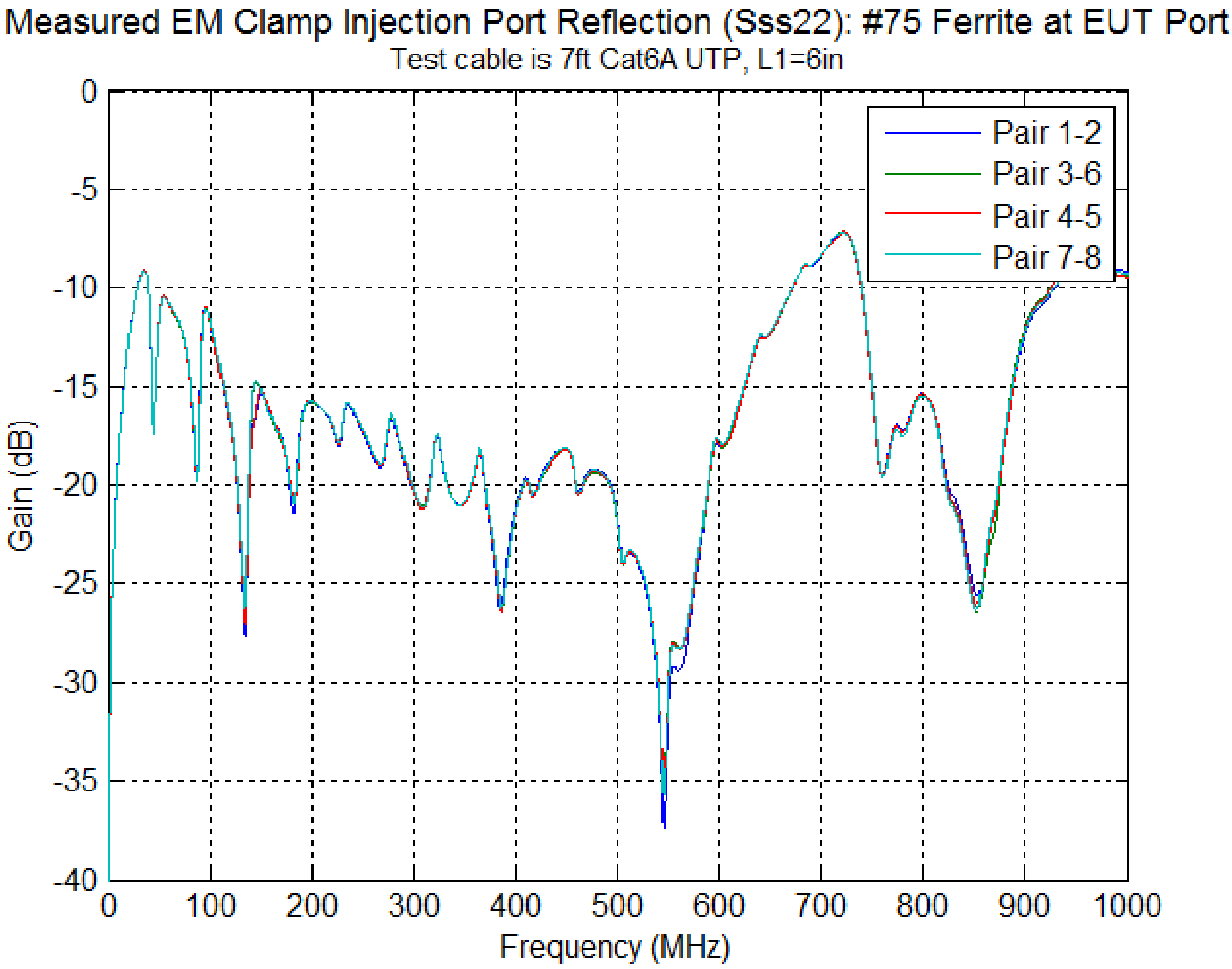
700
800
900
1000
Frequency (MHz)


Measured EM Clamp Injection Port Reflection (Sss22): #75 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=6in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
0
-5
-10
-15
-20
-25
-30
-35
-40
0
100
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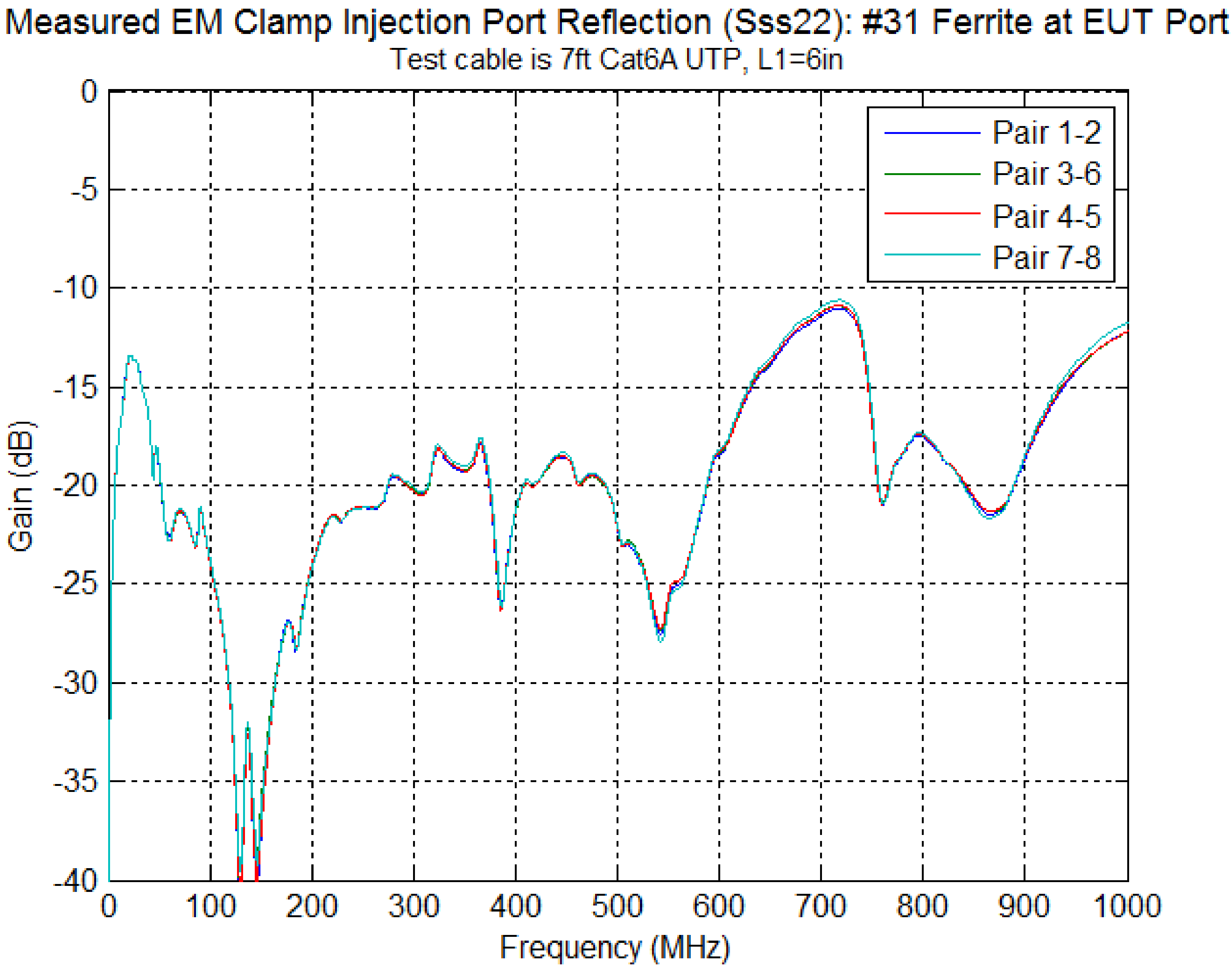
800
900
1000


Measured EM Clamp Injection Port Reflection (Sss22): #31 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=6in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
0
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-10
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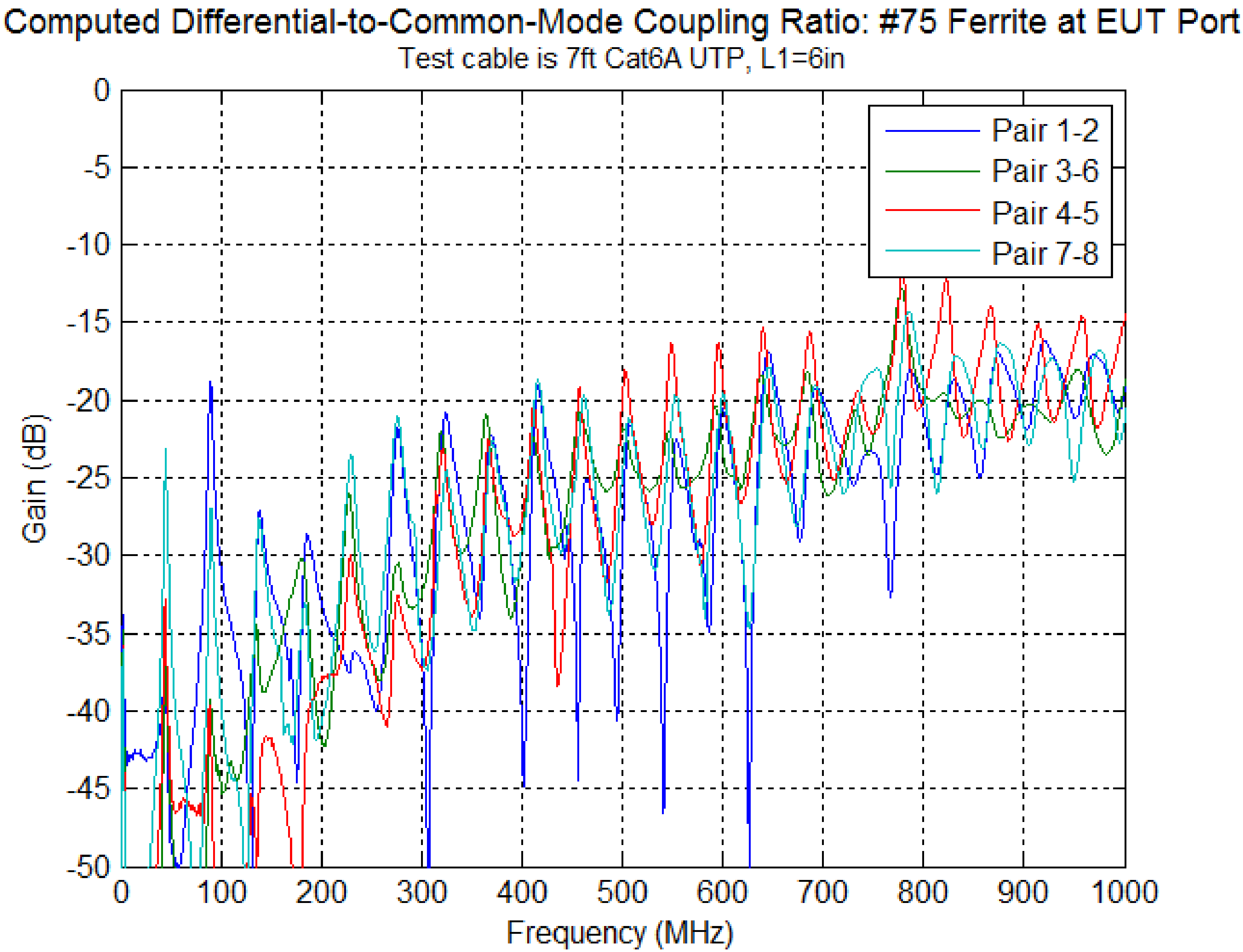

Computed Differential-to-Common-Mode Coupling Ratio: #75 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=6in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
0
-5
-10
-15
-20
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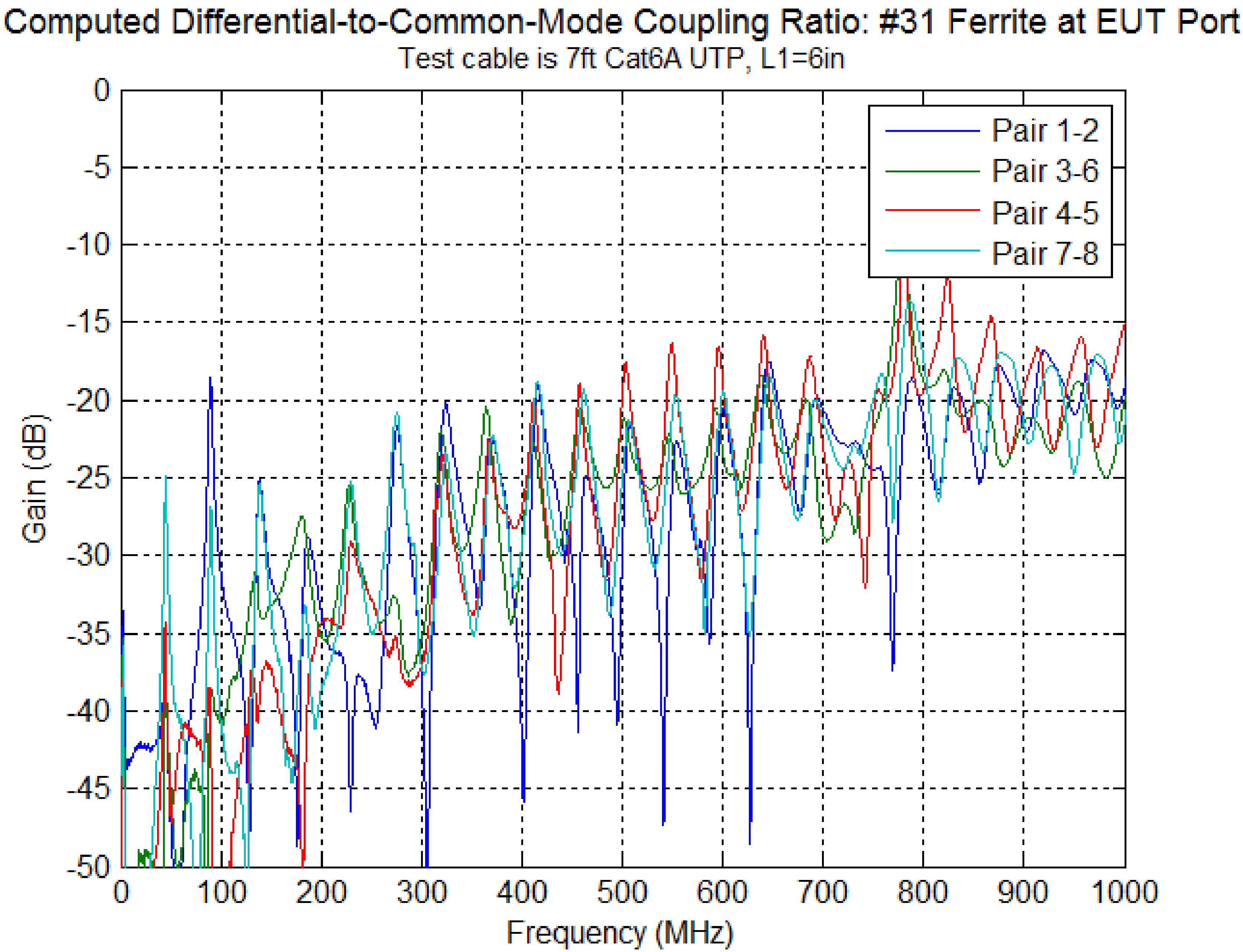

Computed Differential-to-Common-Mode Coupling Ratio: #31 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=6in
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
Gain (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
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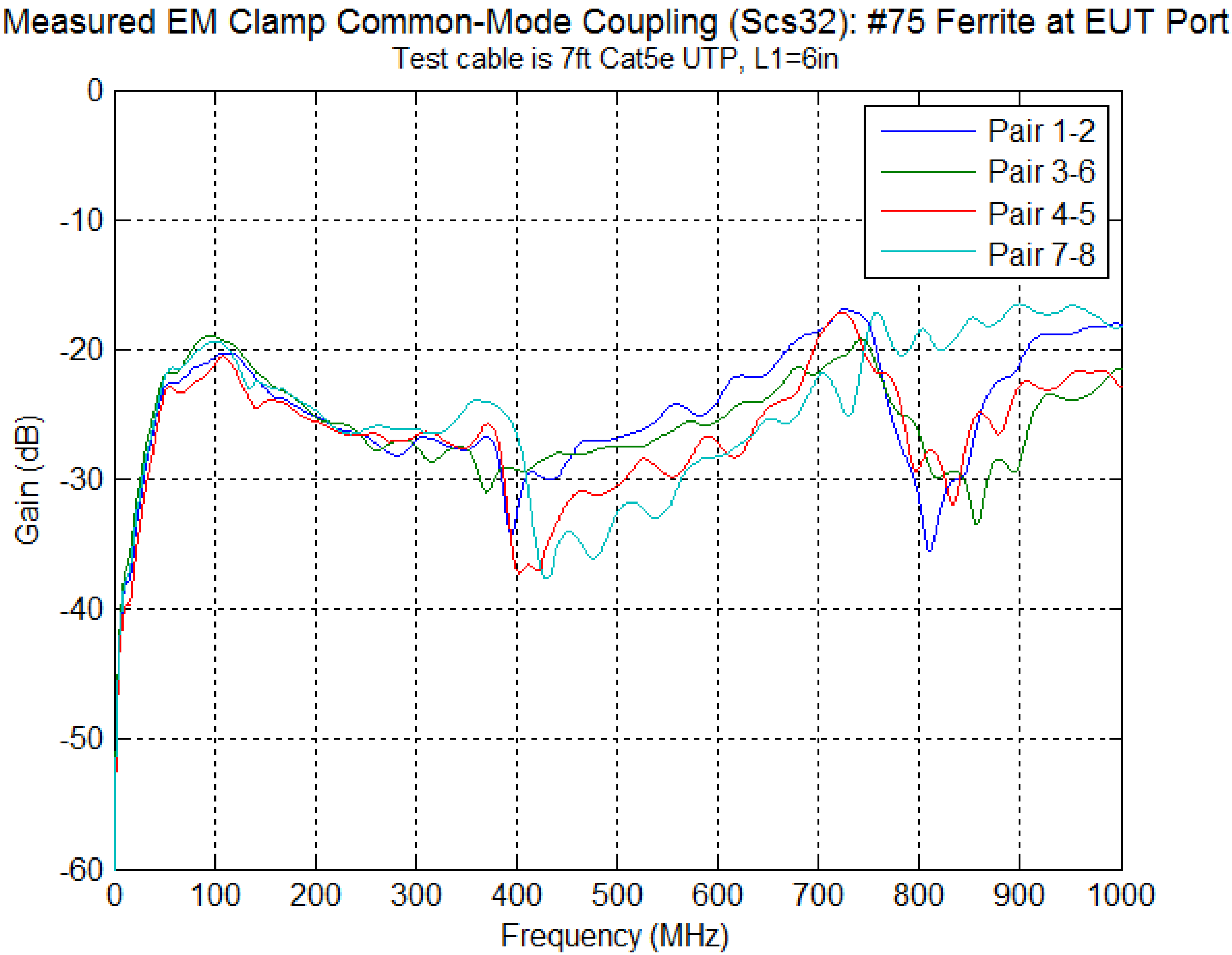
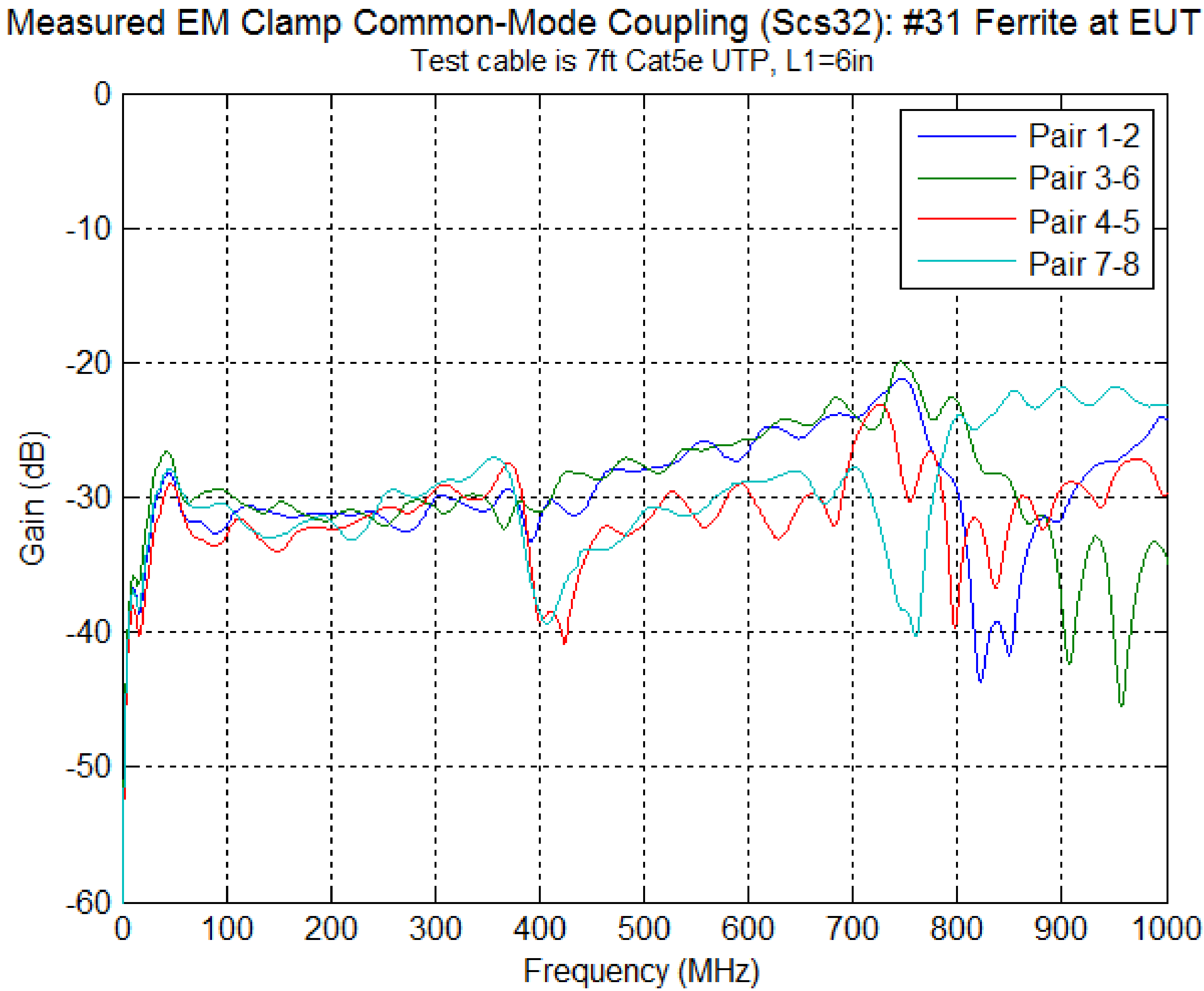
800
900
1000

Observations for Cat 6A UTP Measurements

- Cat 6A UTP provides consistent common-mode coupling across all four pairs to at least 800 MHz
  - Cat 6A UTP common-mode coupling has nulls from far-end reflection of the test cable
  - Depth of far-end reflection nulls reduced with when a #31 ferrite clamp is placed at the EUT port of the clamp; also flattens frequency response
  - Common-mode coupling null near 400 MHz is not as excessively deep
  - Cat 6A UTP setup stable over L1 distance variation (see Additional Measurement Data)
- Injection port reflection improves with the addition of EUT ferrite clamps, especially with the #31 ferrite clamp
- Because of the larger cable diameter, Cat 6A UTP is “frozen” inside clamp (barely fits inside the CC-101 clamp) which actually improves reproducibility
- Differential to common-mode coupling ratio remains does not change much with different test setup configurations



Measured EM Clamp Common-Mode Coupling (Scs32): #75 Ferrite at EUT Port
Test cable is 7ft Cat5e UTP, L1=6in
Gain (dB)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
0
100
200
300
400
500
600
700
800
900
1000
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8


Measured EM Clamp Common-Mode Coupling (Scs32): #31 Ferrite at EUT Port
Test cable is 7ft Cat5e UTP, L1=6in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
0
-10
-20
-30
-40
-50
-60
0
100
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300
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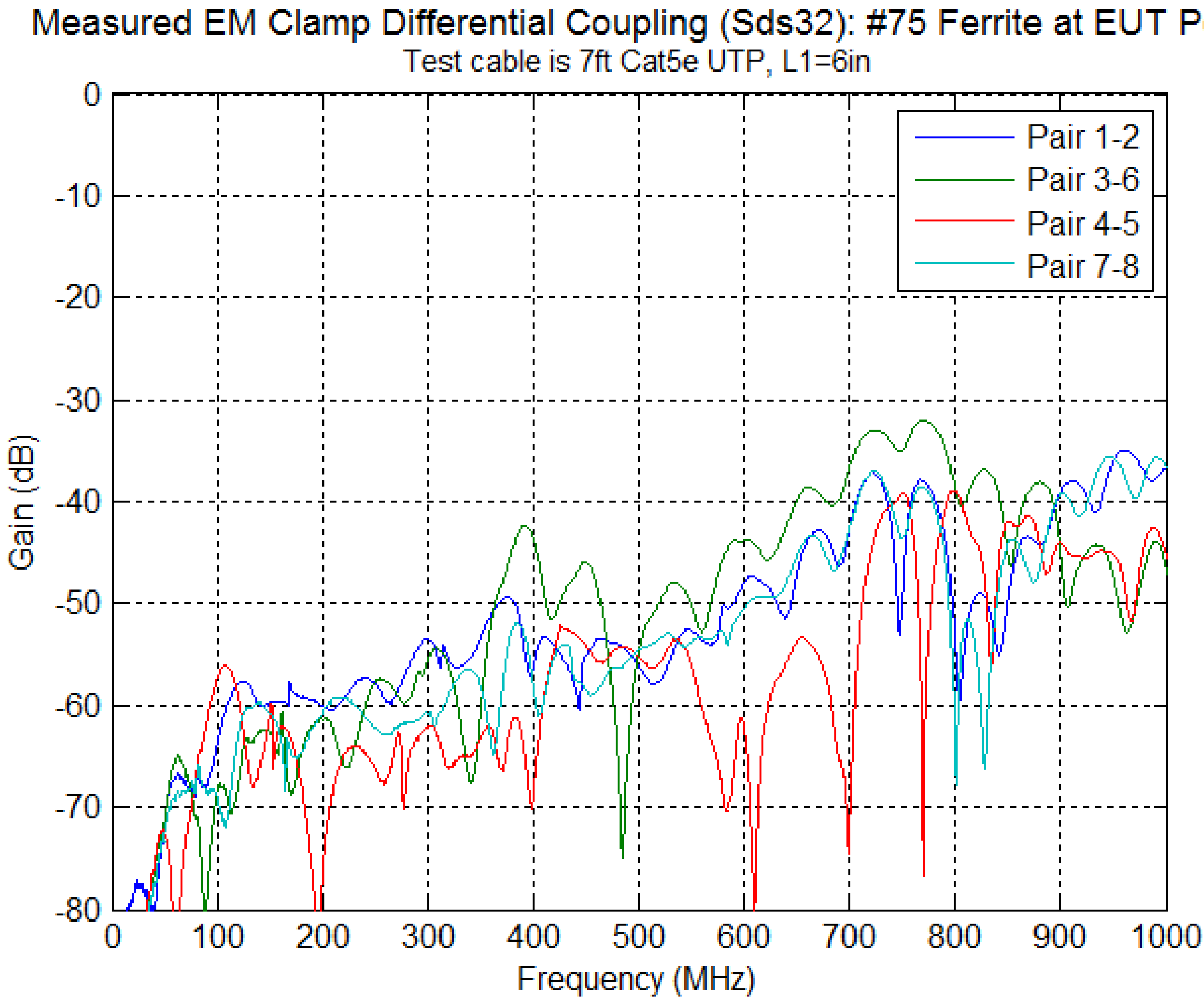
500
600
700
800
900
1000


Measured EM Clamp Differential Coupling (Sds32): #75 Ferrite at EUT Port
Test cable is 7ft Cat5e UTP, L1=6in
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
Gain (dB)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
0
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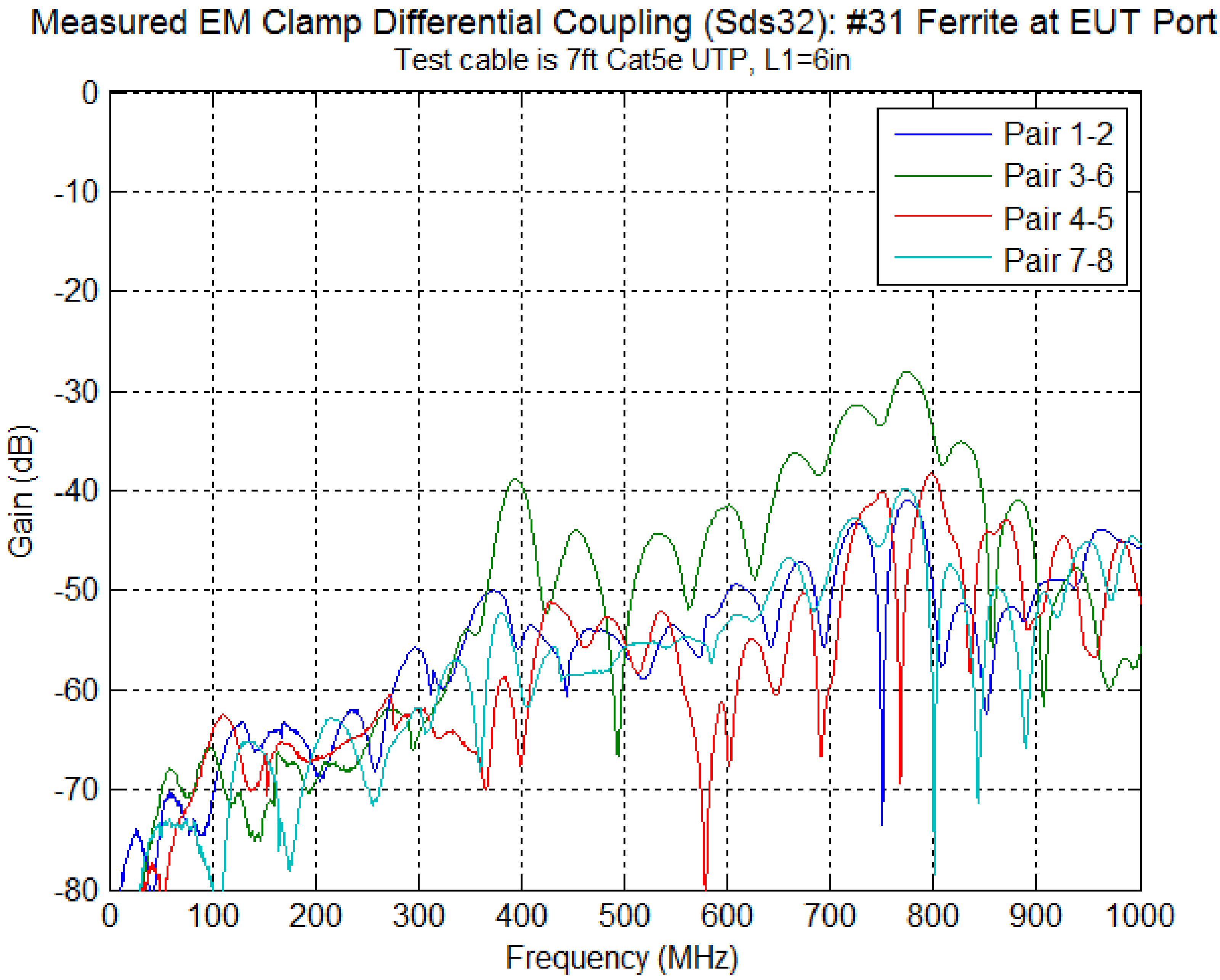

Measured EM Clamp Differential Coupling (Sds32): #31 Ferrite at EUT Port
Test cable is 7ft Cat5e UTP, L1=6in
Gain (dB)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
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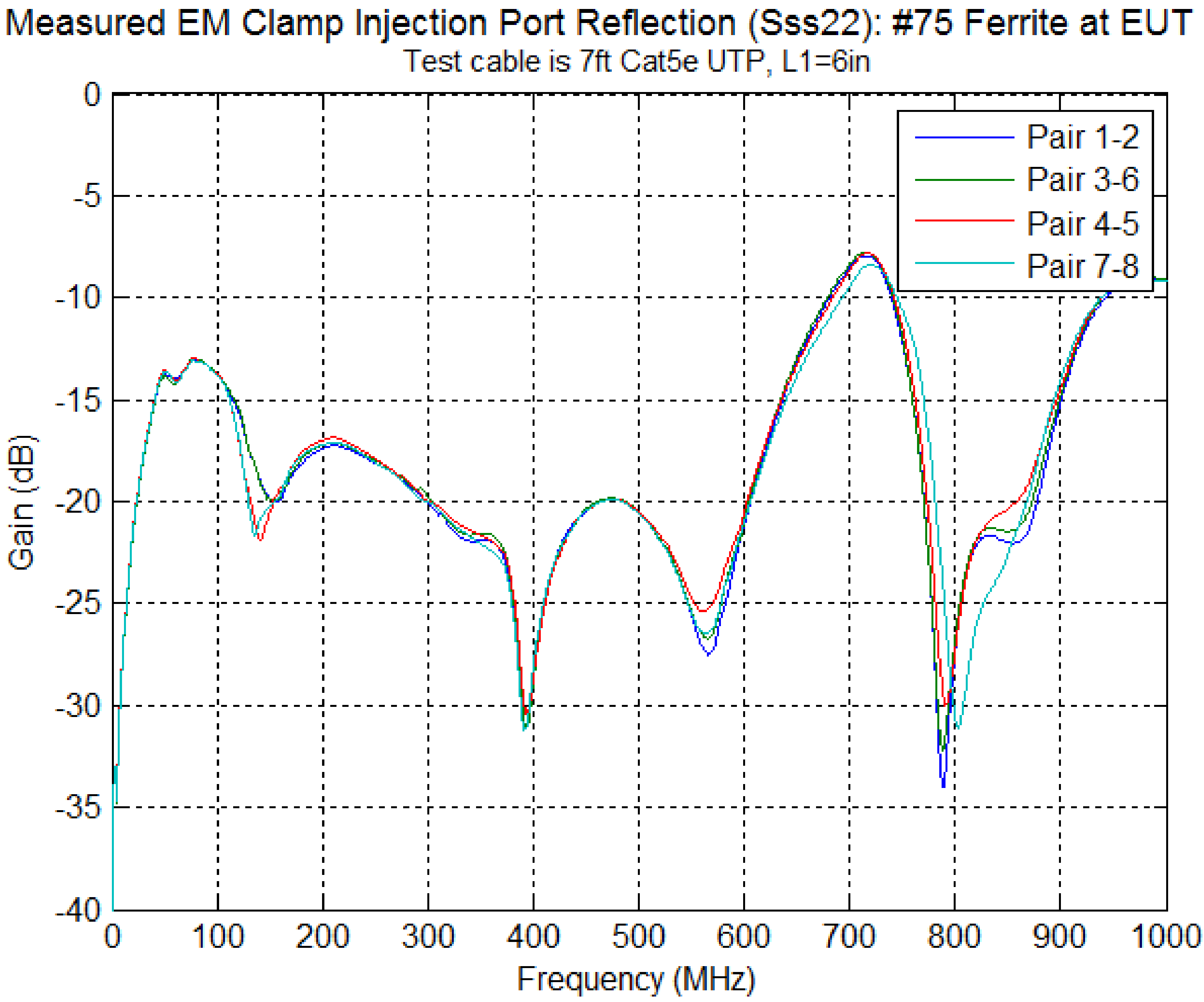
900
1000
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8



Measured EM Clamp Injection Port Reflection (Sss22): #75 Ferrite at EUT Port
Test cable is 7ft Cat5e UTP, L1=6in
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
Gain (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
0
100
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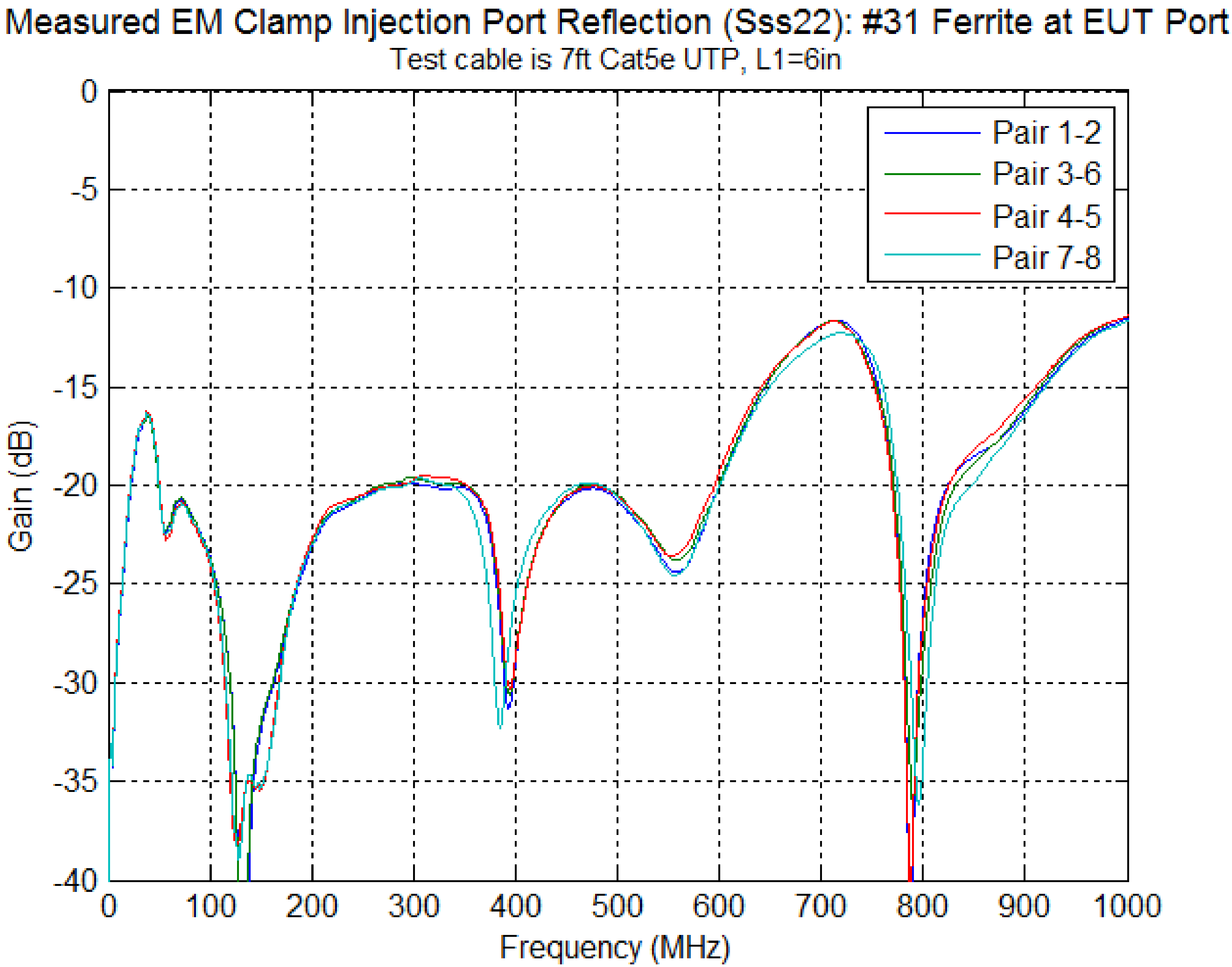
Measured EM Clamp Injection Port Reflection (Sss22): #31 Ferrite at EUT Port
Test cable is 7ft Cat5e UTP, L1=6in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
0
-5
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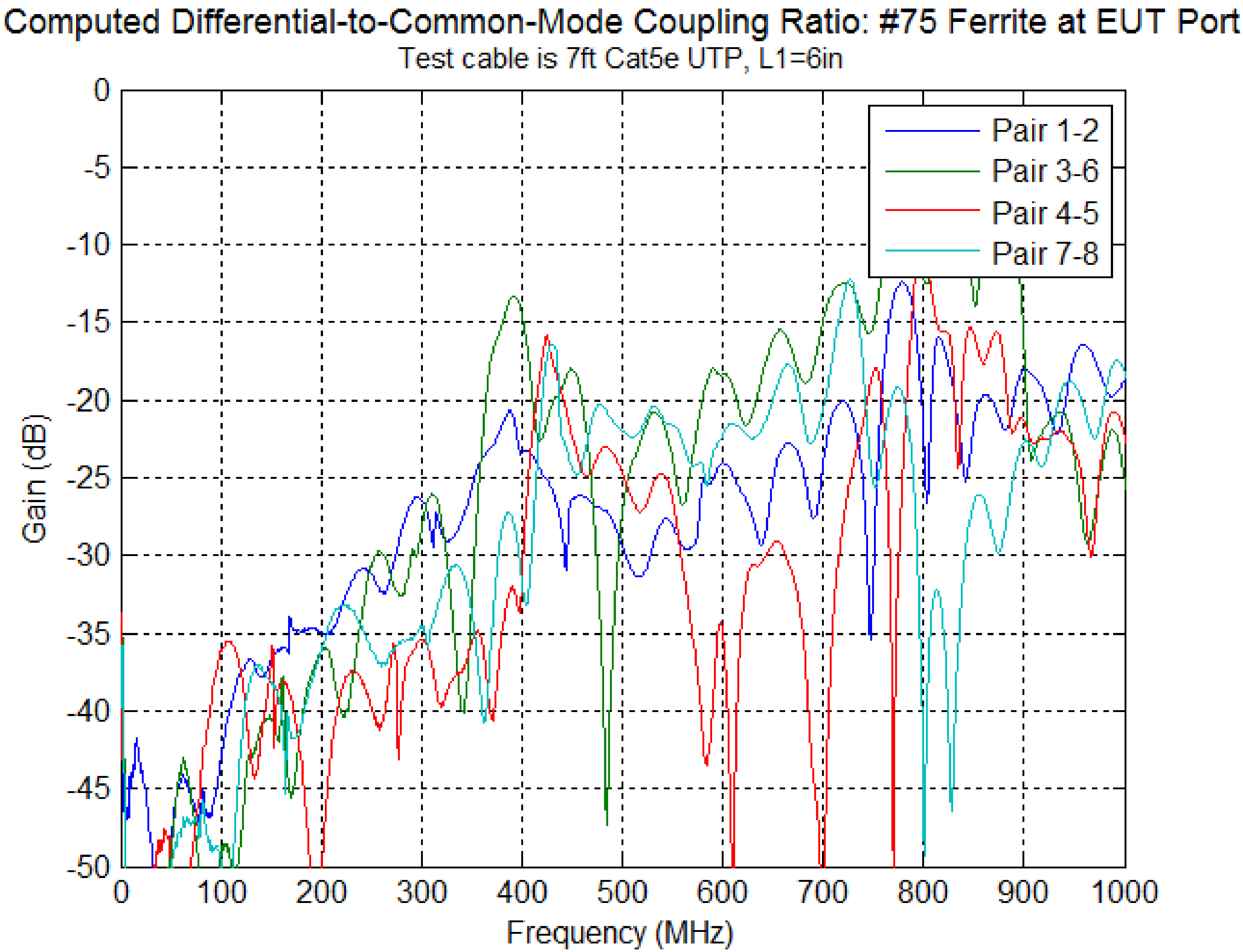
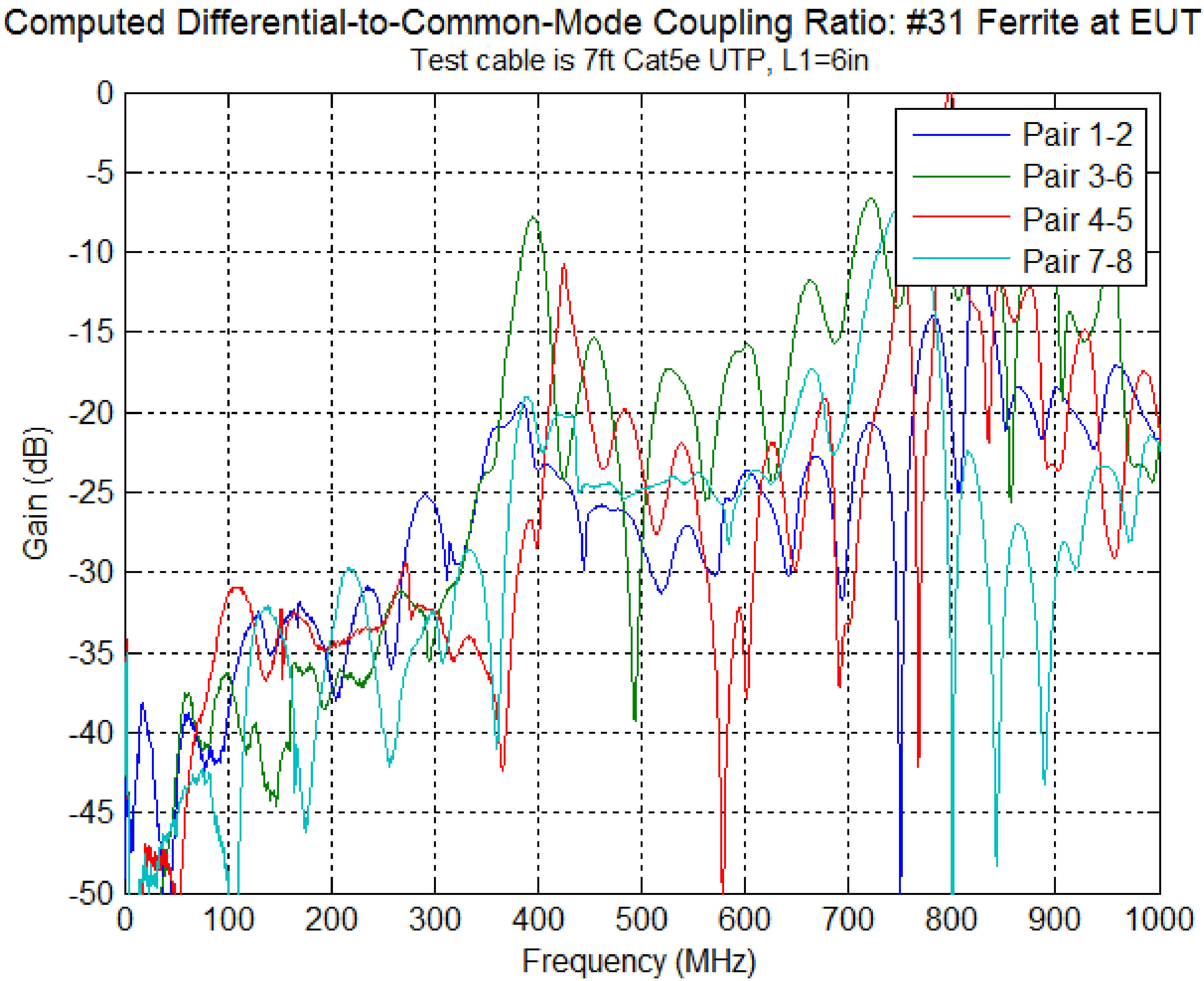


Computed Differential-to-Common-Mode Coupling Ratio: #75 Ferrite at EUT Port
Test cable is 7ft Cat5e UTP, L1=6in
Gain (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0
100
200
300
400
500
600
700
800
900
1000
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8


Computed Differential-to-Common-Mode Coupling Ratio: #31 Ferrite at EUT Port
Test cable is 7ft Cat5e UTP, L1=6in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0
100
200
300
400
500
600
700
800
900
1000

Observations for Cat 5e UTP Measurements

- Cat 5e UTP provides consistent common-mode coupling across all four pairs to at least 350 MHz
  - Cat 5e UTP common-mode coupling does not have nulls from far-end reflection of the test cable
  - Difficult to eliminate deep null near 400 MHz without “tuning” the setup using a network analyzer (“tuning” is adjusting cable position, baseline ferrite position, and L1 distance)
  - Restrictions on L1 distance not sufficient to eliminate deep nulls
- Injection port reflection improves with the addition of EUT ferrite clamps, especially with the #31 ferrite clamp
- Cat 5e UTP and Cat 6 UTP can slide inside of clamp and cause possible reproducibility issues
  - Problem may be mitigated by wrapping tape around cable to increase its diameter inside the clamp and freeze its position (don’t use a tape with a high dielectric constant
- Differential to common-mode coupling ratio remains does not change much with different test setup configurations

Main Observations and Results

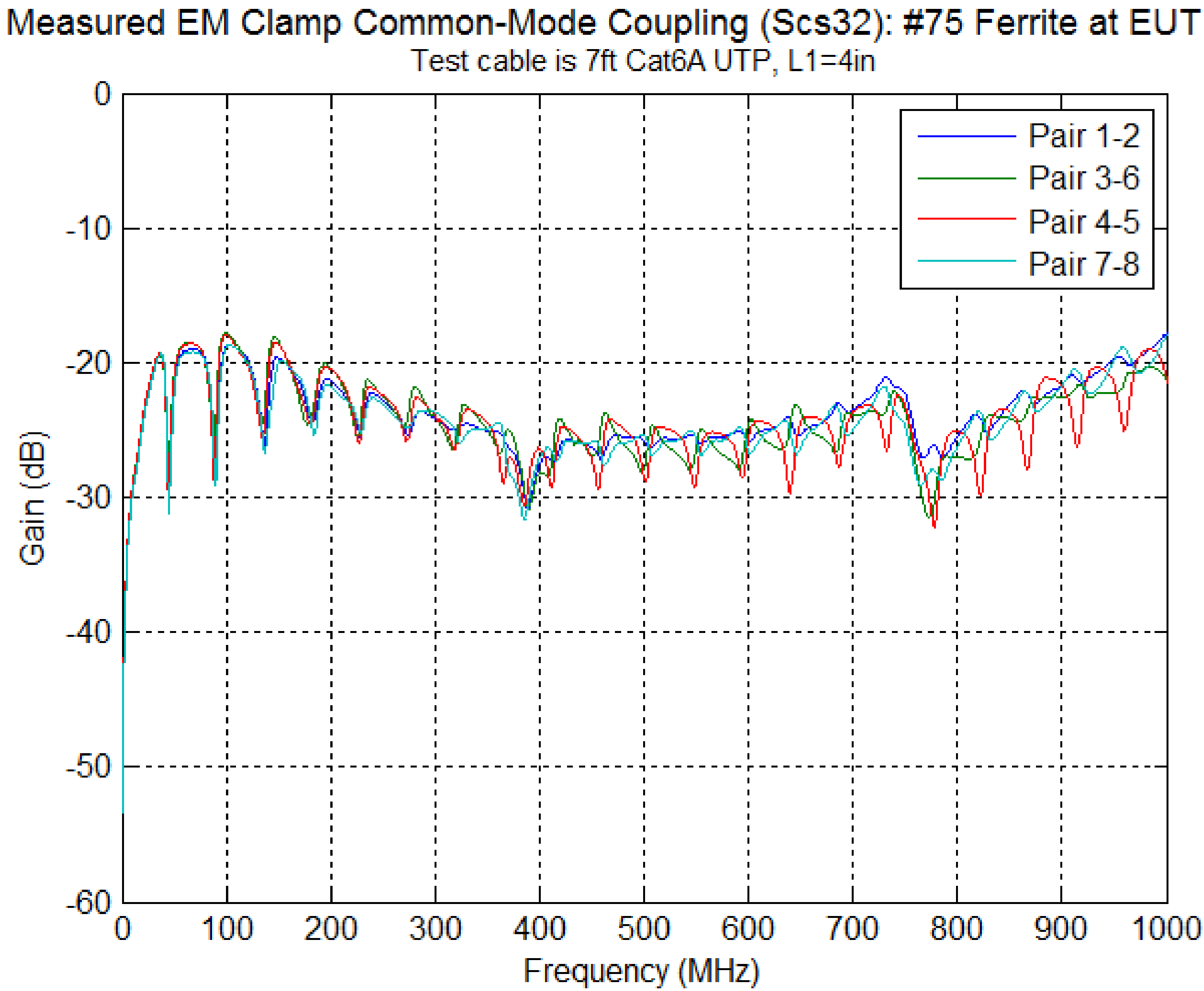
- There is a significant variation in the EM coupling characteristics between Cat 5e / Cat 6 UTP and Cat 6A UTP
- The useful frequency limit of the EM coupling clamp is limited to about 350 MHz for Cat 5e/ Cat 6 UTP, but may extend to 1 GHz for Cat 6A UTP.
  - CM coupling variation increases above coupling null near 400 MHz
  - Can't eliminate deep CM coupling null near 400 MHz without "tuning" the test setup; problem is slightly worse for Cat 6 UTP than Cat 5e UTP
  - The EM clamp is useful for impulse noise testing for 1G/2.5G/5G data rates with Cat 5e UTP and Cat 6 UTP, but not for the 10G data rate unless Cat 6A UTP is used
  - Use of the EM clamp for pre-compliance radiated immunity testing to 1 GHz with Cat 5e / Cat 6 UTP is limited; may need a significant power amplifier to overcome coupling nulls near 400 MHz and 800 MHz
- Use of Cat 6A UTP in the EM clamp provides more stable injection characteristics, but it is unknown if the differential-to-common-mode coupling ratio is similar to to results observed in an EMC test lab
- Adding a #75 ferrite clamp at the EUT port is may be best for radiated immunity test applications; adding a #31 ferrite at the EUT port may be best for (wideband) impulse injection applications

Next Steps

- Need to verify Cat 6A UTP coupling stability over various Cat 6A cable samples (in progress)
- Measure impedance of ferrite clamp network(s) to provide a proper standard specification (in progress)
- Determine if the ratio of common-mode to differential coupling for the shown cable configuration is consistent with external field coupling results
  - Evaluation will require examination of EMC lab test data
- Test clamp coupling with screened and shielded cable
- Define an impulse waveform generation method for impulse noise testing with the EM clamp (in progress)

Additional Measurement Data

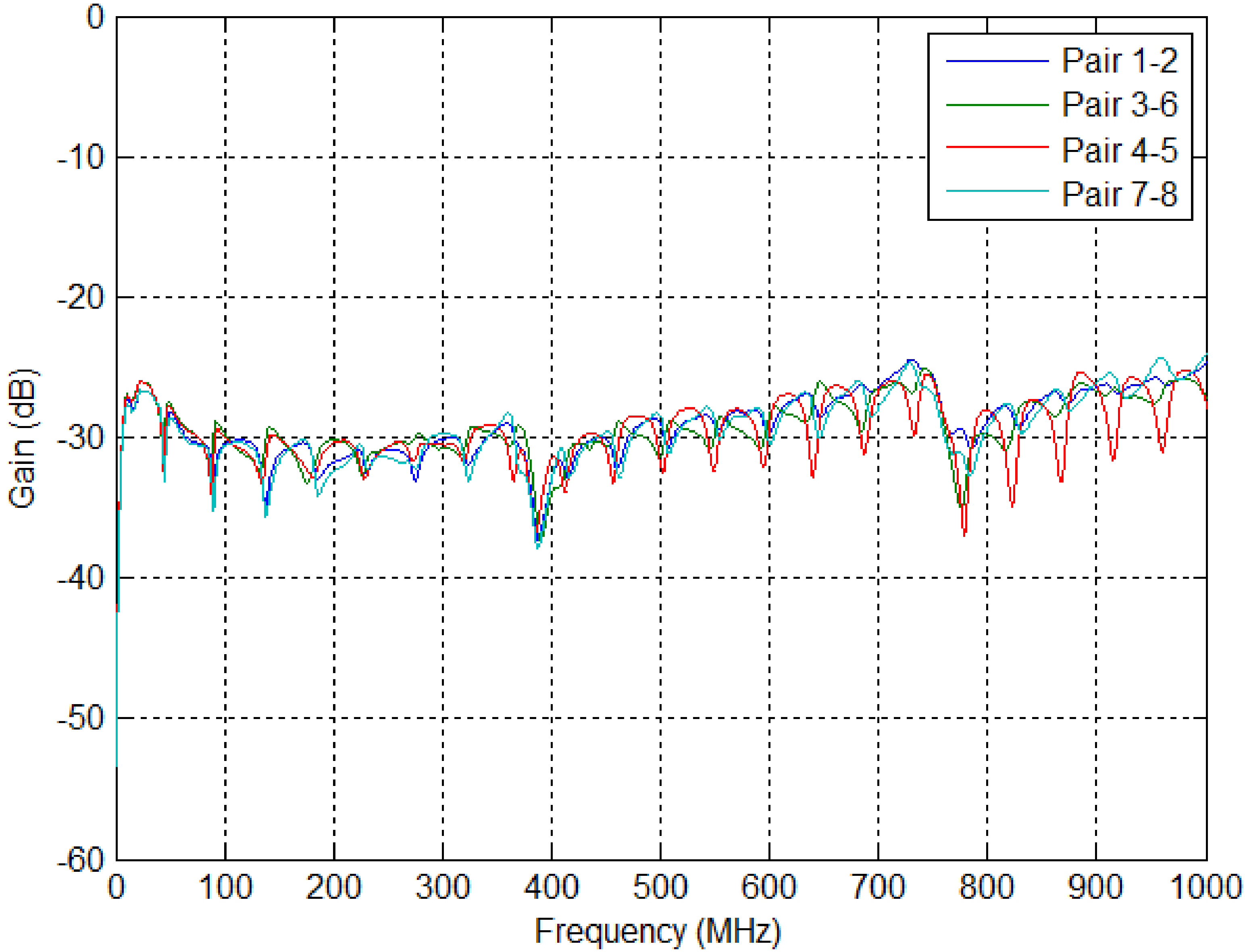
- Determine stability of Cat 6A UTP setup over variation of L1 distance
- Test cable is 7ft Cat 6A UTP patch cord
- Measured parameters (frequency response plots for each parameter)
  - Measured common-mode coupling all four cable pairs (Scs32)
  - Measured differential coupling into all four cable pairs (Sds32)
- Test setup configurations
  - Added #75 ferrite clamp at EUT port of clamp, L1 = 4 inches
  - Added #31 ferrite clamp at EUT port of clamp, L1 = 4 inches
  - Added #75 ferrite clamp at EUT port of clamp, L1 = 8 inches
  - Added #31 ferrite clamp at EUT port of clamp, L1 = 8 inches

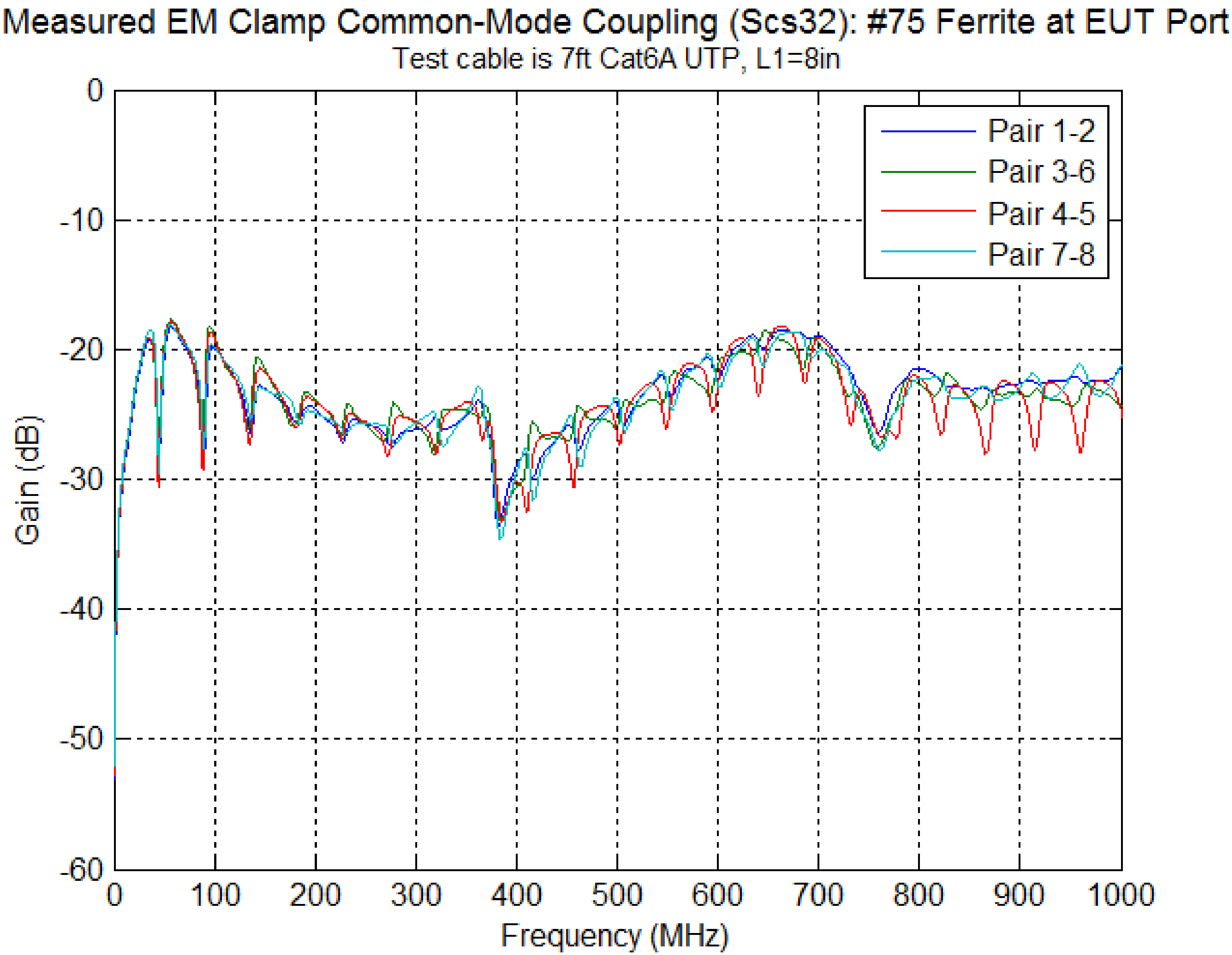


Measured EM Clamp Common-Mode Coupling (Scs32): #75 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=4in
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
Gain (dB)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
0
100
200
300
400
500
600
700
800
900
1000

Measured EM Clamp Common-Mode Coupling (Scs32): #31 Ferrite at EUT Port

Test cable is 7ft Cat6A UTP, L1=4in





Measured EM Clamp Common-Mode Coupling (Scs32): #75 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=8in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
0
-10
-20
-30
-40
-50
-60
0
100
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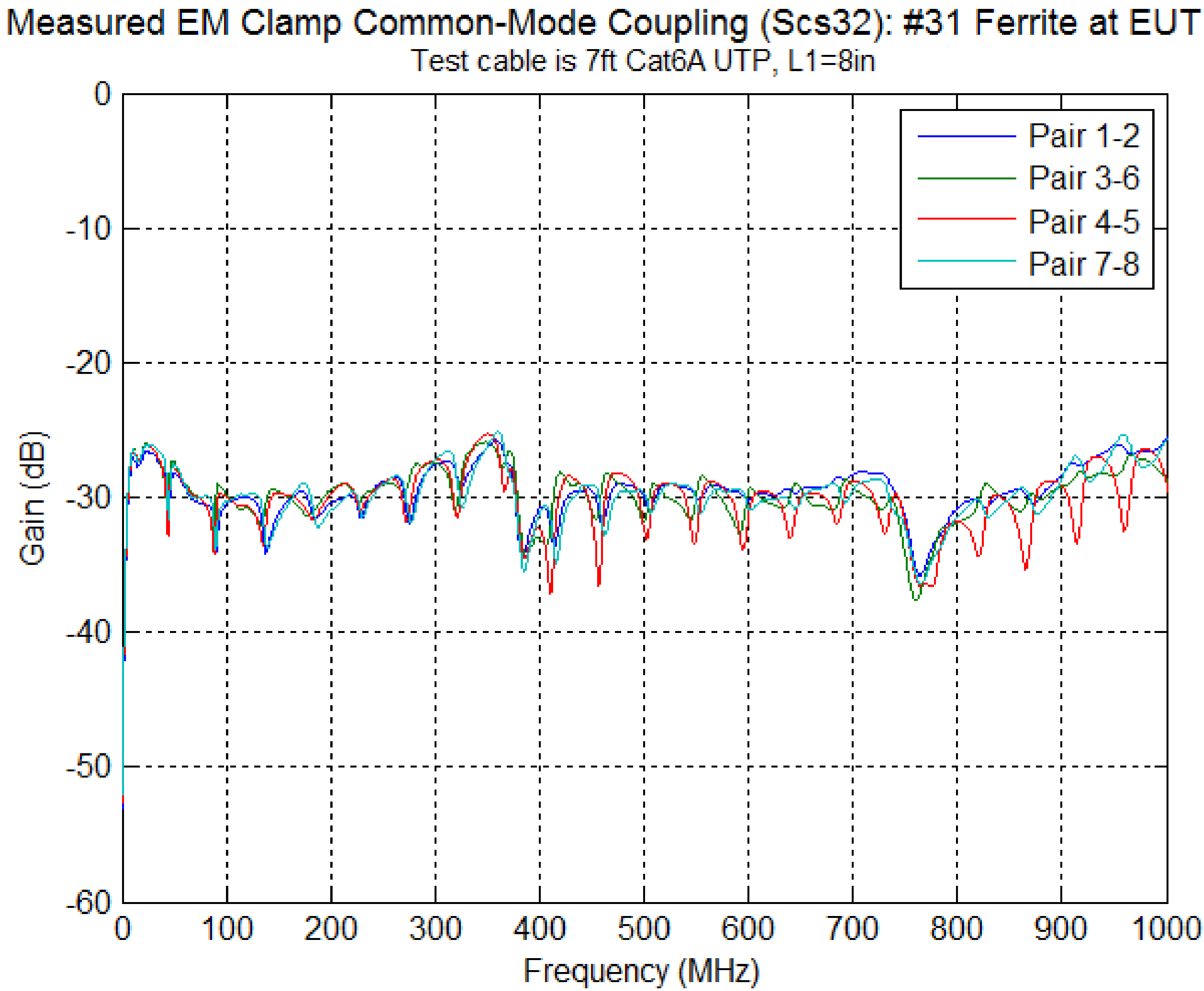
300
400
500
600
700
800
900
1000


Measured EM Clamp Common-Mode Coupling (Scs32): #31 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=8in
Gain (dB)
Frequency (MHz)
0
-10
-20
-30
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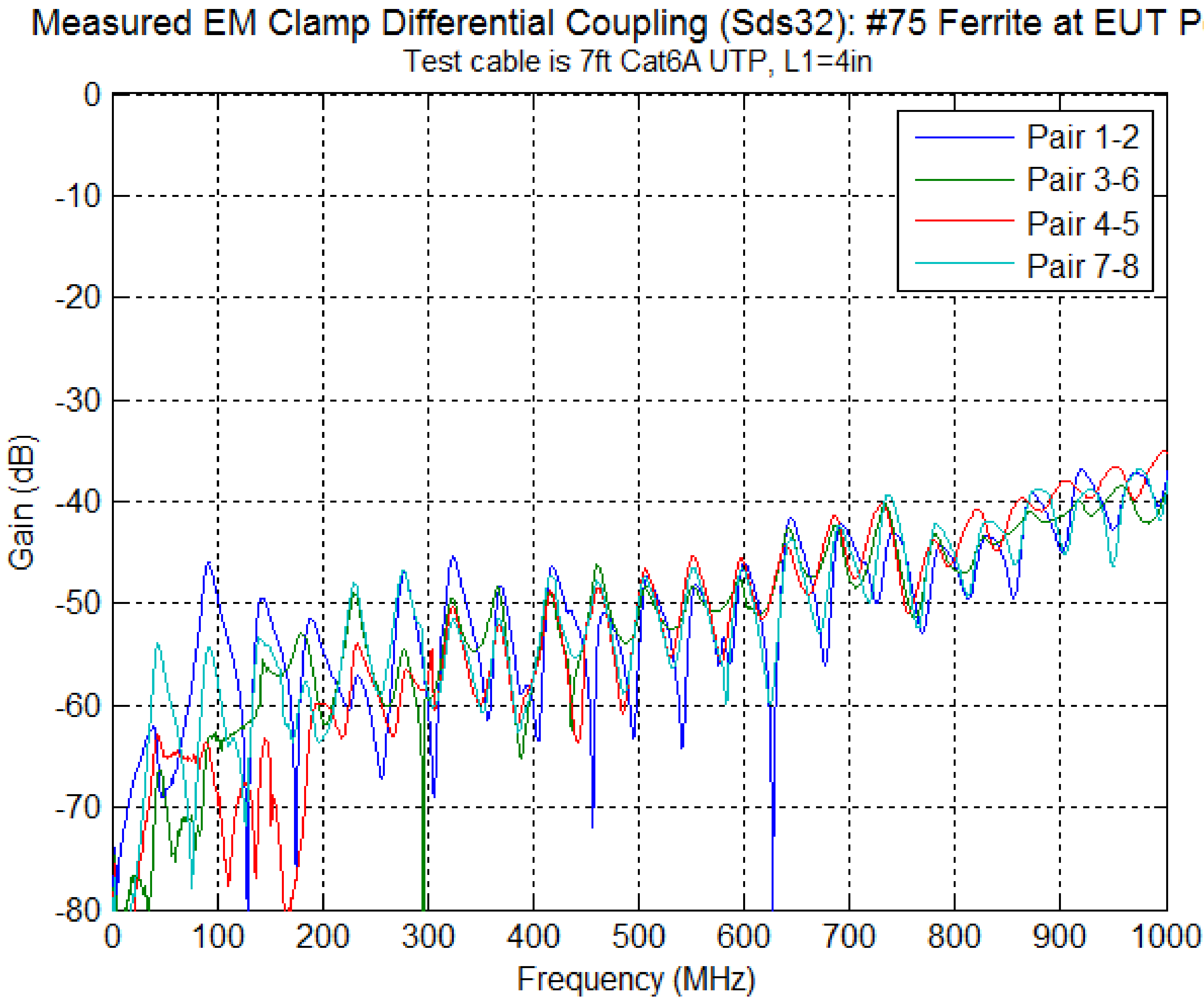
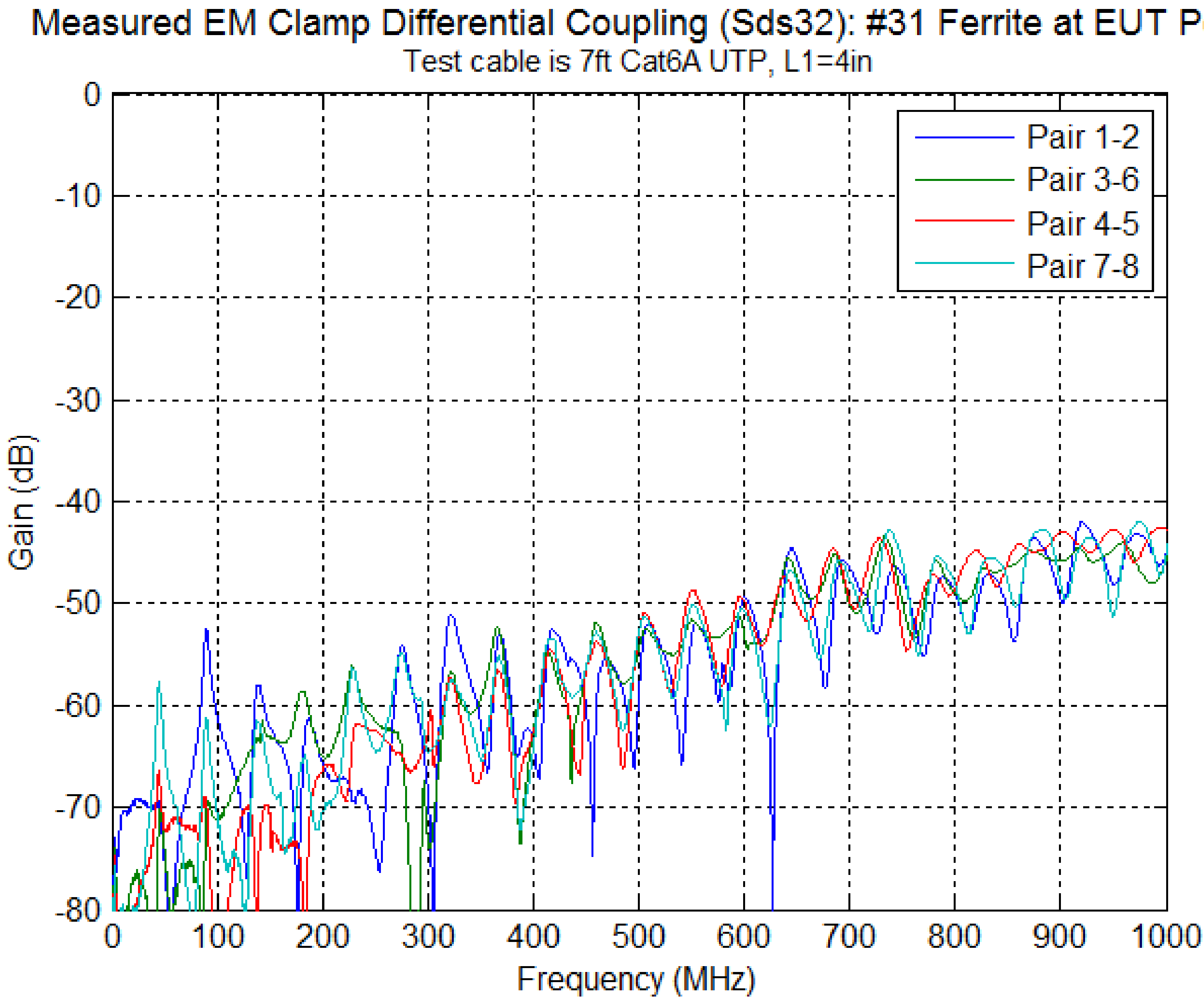
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8



Measured EM Clamp Differential Coupling (Sds32): #75 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=4in
Gain (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8


Measured EM Clamp Differential Coupling (Sds32): #31 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=4in
Gain (dB)
Frequency (MHz)
0
-10
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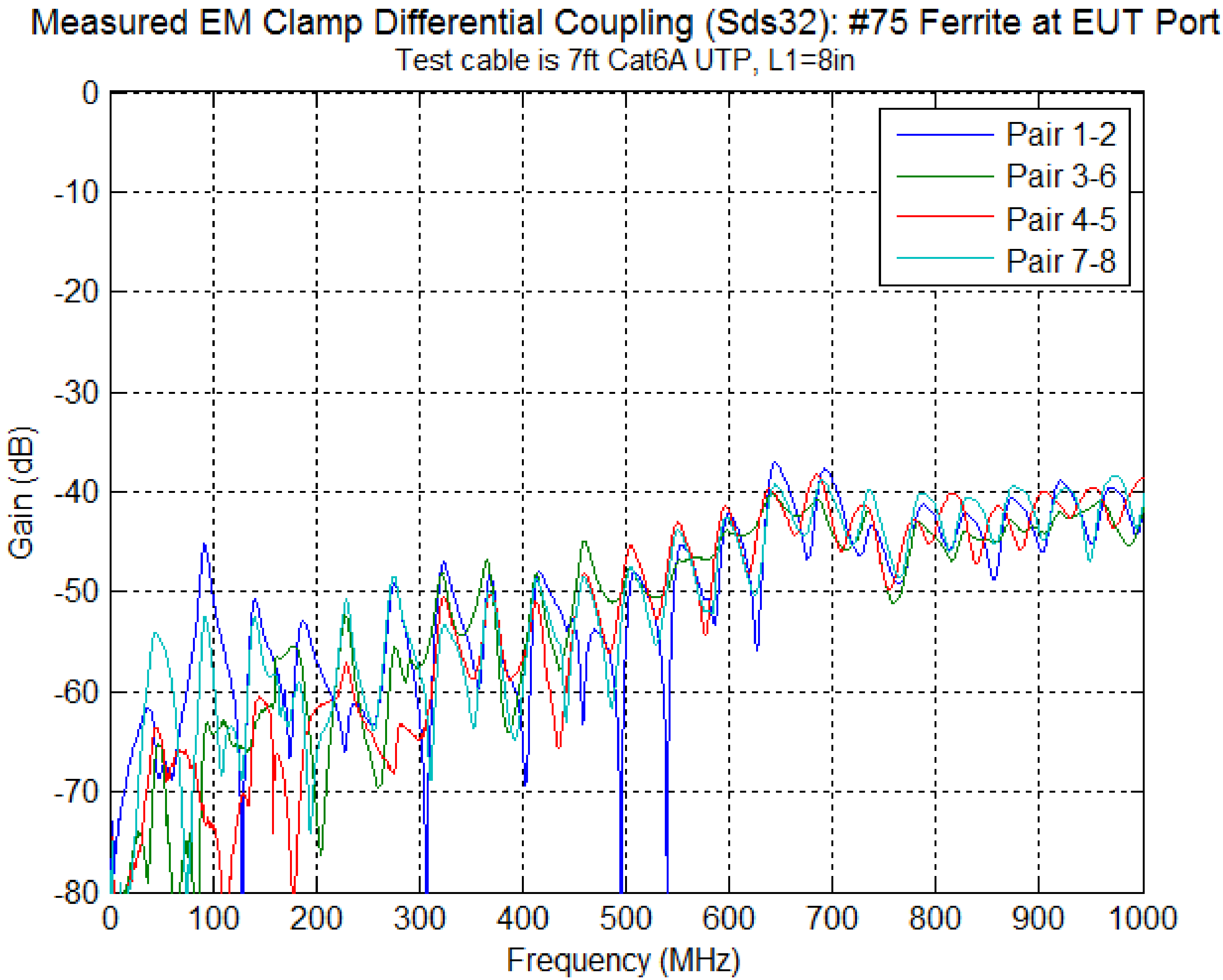
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8


Measured EM Clamp Differential Coupling (Sds32): #75 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=8in
Gain (dB)
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8
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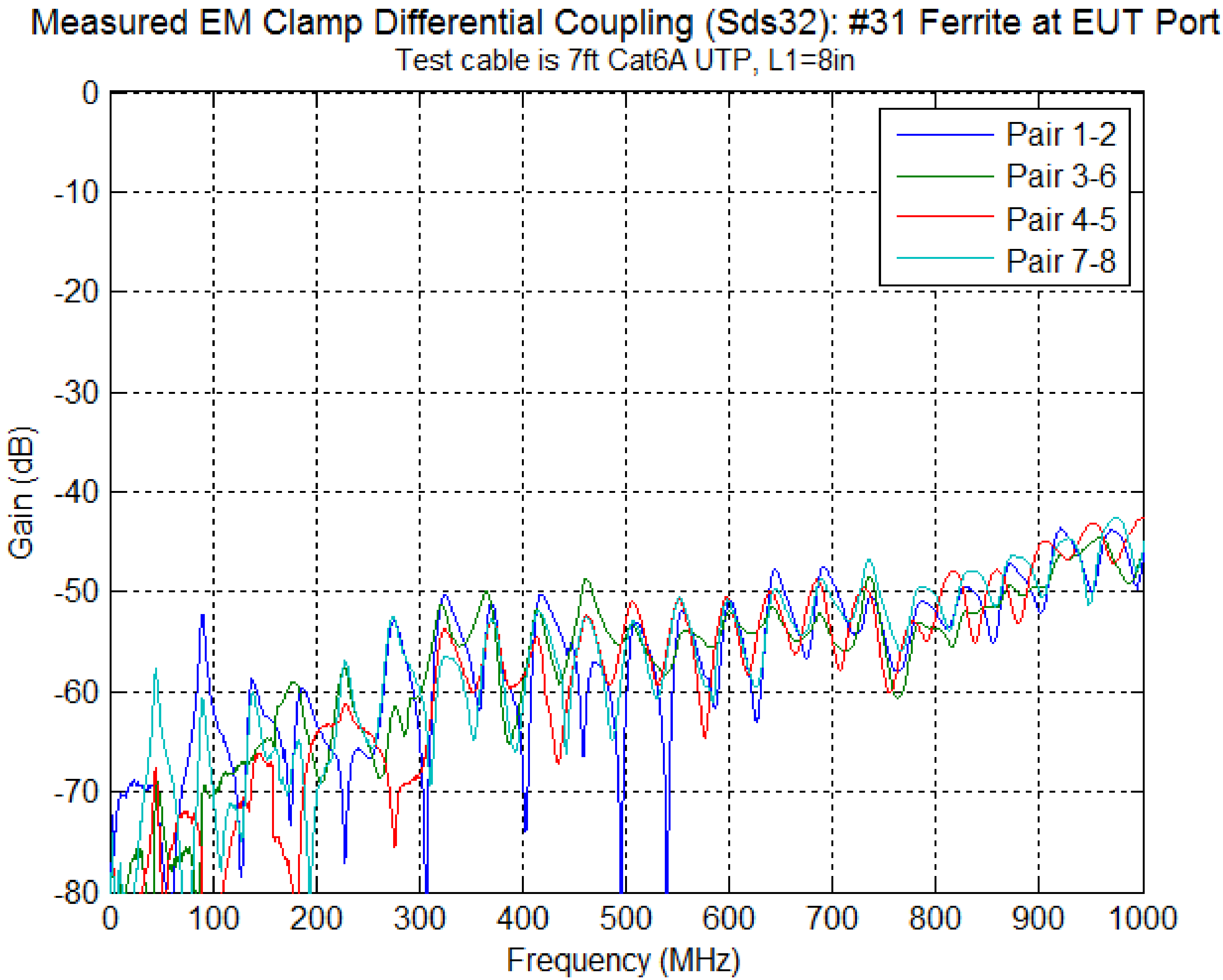

Measured EM Clamp Differential Coupling (Sds32): #31 Ferrite at EUT Port
Test cable is 7ft Cat6A UTP, L1=8in
Gain (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)
Pair 1-2
Pair 3-6
Pair 4-5
Pair 7-8