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EFFECT OF SHIELDING ON CABLE RF INGRESS MEASUREMENTS

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OVERVIEW

- **Purpose:** Examine the common-mode and differential RF ingress levels of 4-pair UTP, F/UTP, and F/FTP cables at an (RJ45) MDI port termination under identical test conditions (layout geometry) from a controlled external RF field in an anechoic chamber
  - Test data gathered from an earlier RF immunity study for 10GBase-T PHY equipment
  - Measurements are coupled signal levels into various cable types and independent of any PHY design
  - **Use comparison of data from UTP sample and shielded cable samples to quantify benefit of cable shielding on reducing RF ingress**
- Background for performing test
- Description of measurement procedure and test cases
- Plots of measured RF ingress for various cable samples and comparison of RF ingress levels between UTP and best shielded cable (F/FTP)
- **Main results:**
  - **Good shielded twisted pair cabling (F/FTP) can reduce common-mode ingress levels by about 30 dB and can reduce differential ingress from 15 to 30 dB vs UTP cabling**
  - **Use of shielded twisted pair cables can significantly improve RF immunity of data links allowing PHY implementations with lower transmit power and wider bandwidth than unshielded twisted pair (UTP) in the automotive environment**

BACKGROUND FOR PERFORMING TEST

- Background issues
  - We were using F/UTP and F/FTP shielded cable to prevent RF ingress from the attached test channel cabling while performing radiated immunity testing on 10GBase-T products
  - Intent was to isolate the external field ingress effects solely to the PHY EUT (equipment under test)
  - **We observed some F/UTP patch cords allowed RF ingress levels comparable to UTP patch cords which created errors and reproducibility issues in our EUT test results**
- Purpose of the original RF ingress measurement procedure
  - Measure RF ingress level differences between UTP, F/UTP, and F/FTP from different vendor’s cable samples **under identical test conditions** to determine relative shielding effectiveness
  - Use a known calibrated external field strength (10 V/meter) near the MDI port interface to determine approximate ingress levels during an actual RF immunity test
  - Measure RF ingress from 80 MHz to 1000 MHz
- **For determining shield effectiveness, our main interest is the RF ingress level difference between the UTP cable and the best F/UTP or F/FTP cable**

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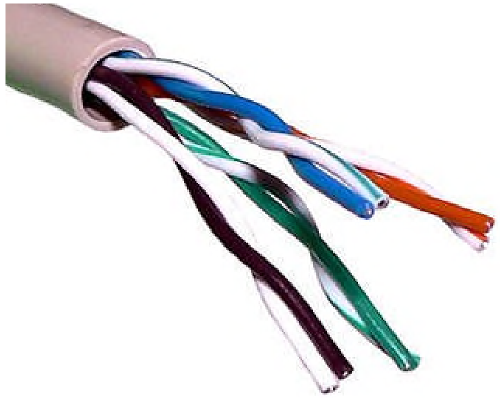
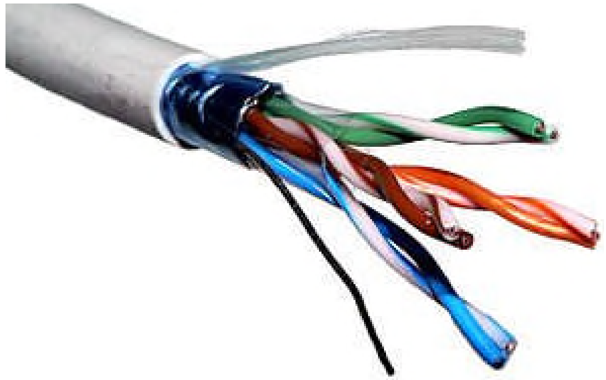
DESCRIPTION OF EVALUATED TWISTED PAIR CABLE TYPES



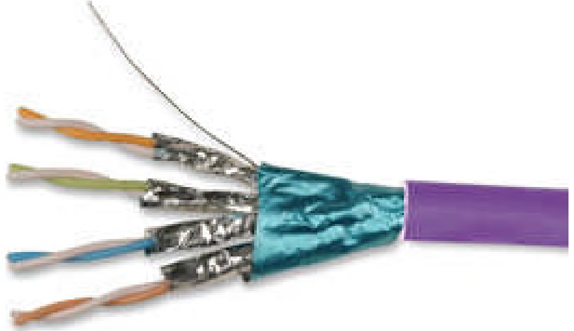
UTP

Unshielded twisted pair without any additional shielding



F/UTP

Single foil shield around all four pairs



F/FTP

Foil shield around each pair plus an additional single foil shield around all four pairs

All cable types have four pairs with 100 Ω characteristic impedance for each pair

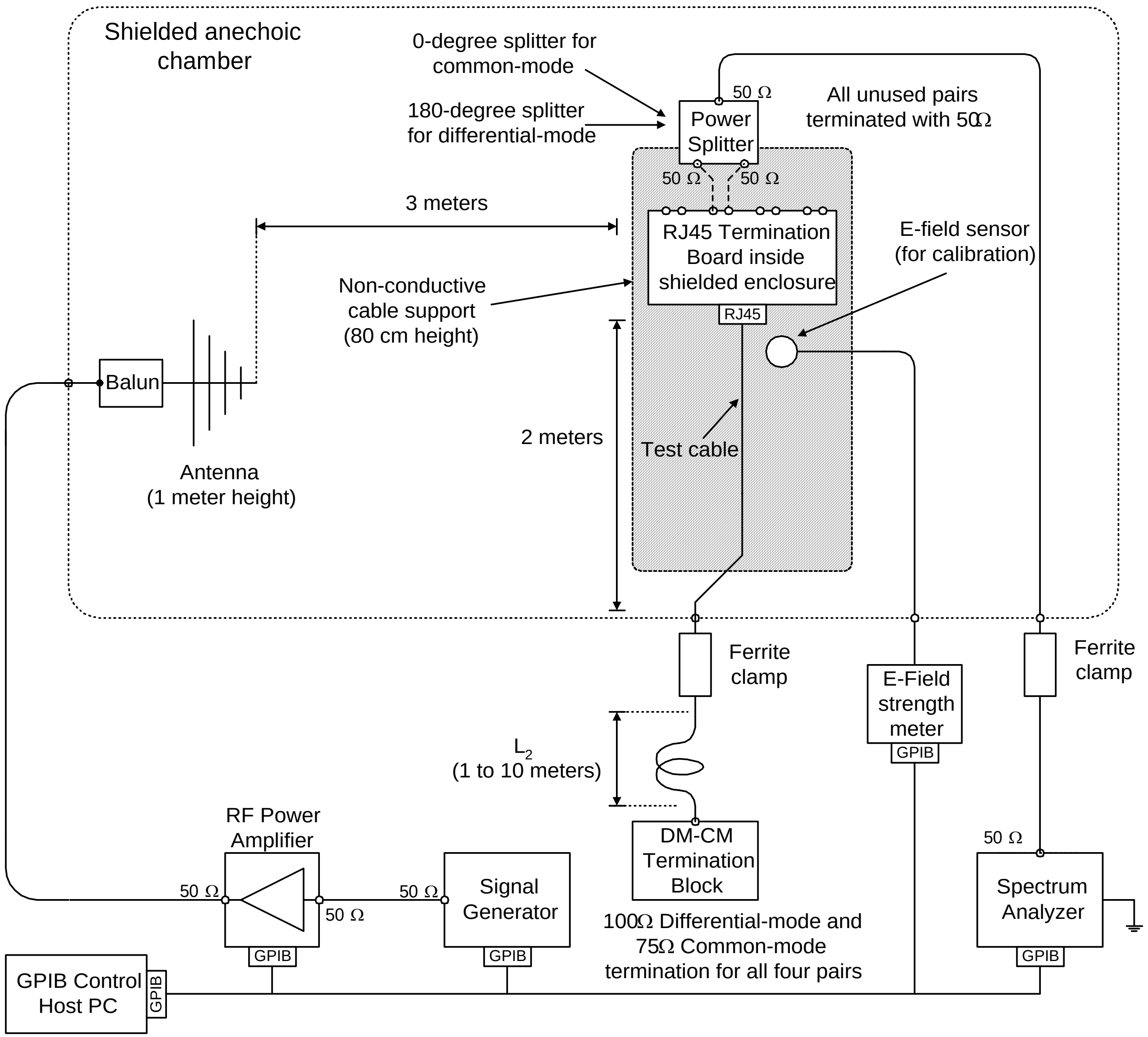
BASIC DESCRIPTION OF TEST SETUP TO MEASURE RF INGRESS

- Test was performed in a 3m anechoic chamber
- Very simple linear cable layout; did not use any complex layout geometry
  - Total exposed cable length of 2 meters; 1.3 meters in fixed horizontal configuration
- E-field was locally monitored (and calibrated) near the MDI termination test fixture RJ45 port; calibration target was 10 V/meter
- Measured both common-mode and differential mode RF ingress levels for all cable samples
- Measured pair 1-2 on all cable samples to reduce impedance mismatch effect of RJ45 connector (did not use split pair 3-6)
- Simple shielded RJ45 termination fixture with no magnetic components, only an RJ45 connector with coaxial SMA connector breakouts
- Measured RF ingress from 100 MHz to 1000 MHz
  - 100 MHz lower limit was due to limitations in the available test equipment
- Performed initial tests with no cable attached to the termination fixture to establish a measurement noise floor

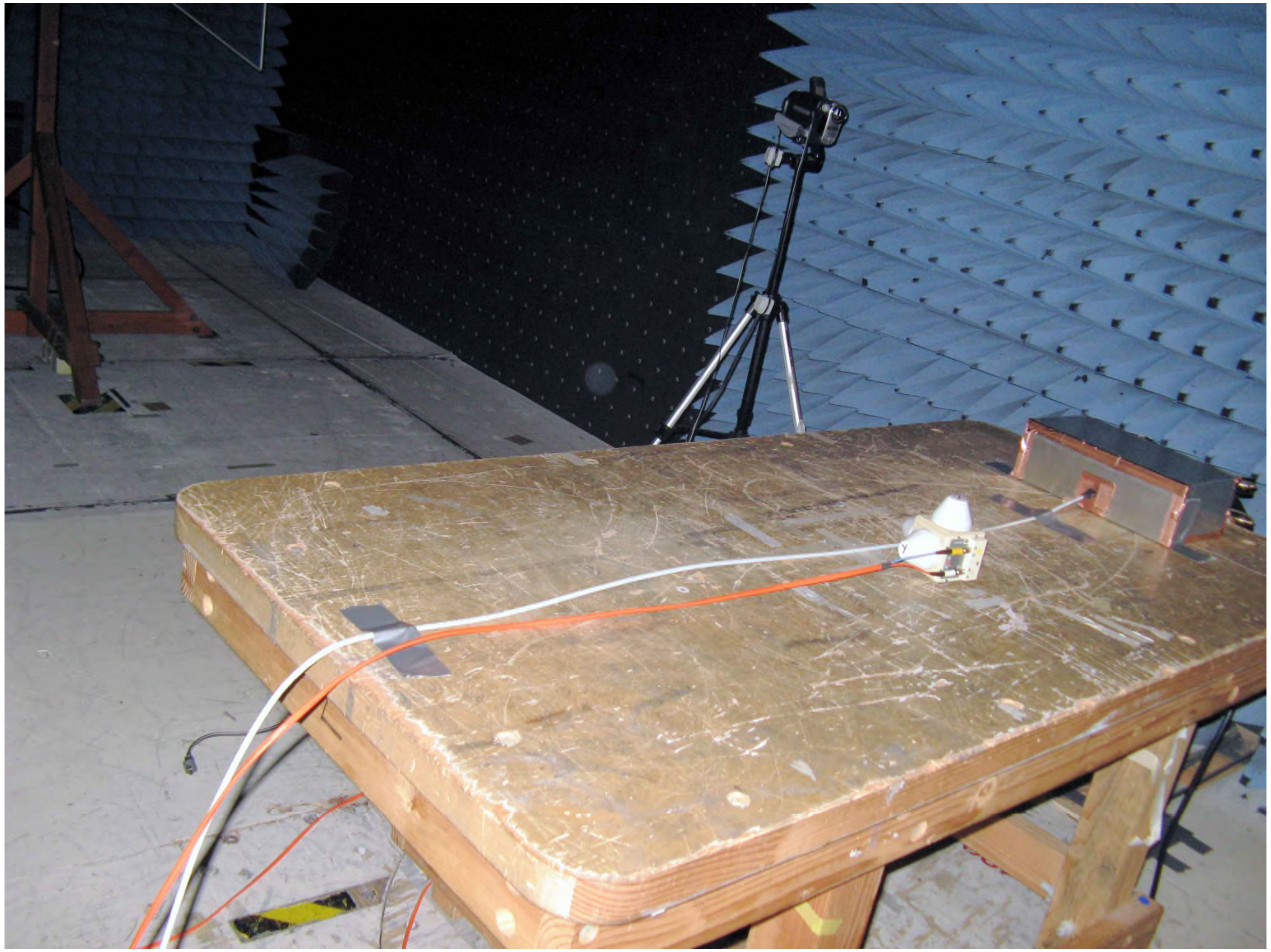
CABLING RF INGRESS MEASUREMENT PROCEDURE

- Build test setup in chamber as shown in diagram; place 180-degree splitter on Pair 1-2 to initially measure differential-mode ingress
- Adjust output level of signal generator so that the measured E-field level is 10 V/meter; use an unmodulated carrier (CW) as the test signal
  - No 80% AM carrier normally used in standard radiated immunity testing
- Measure and record ingress signal level with the spectrum analyzer at each frequency point
  - Loss of coaxial cable between the splitter and spectrum analyzer subtracted from the raw measurement data, but not the insertion loss of the splitter (about 1 dB)
- Using GPIB control, step signal generator at from 100 MHz to 1000 MHz at 10 MHz intervals; repeat previous three steps at each signal generator frequency
- Replace the 180-degree splitter with a 0-degree splitter to measure common-mode signal ingress
- Repeat above measurement sequence for common-mode ingress level on Pair 1-2
- Repeat the entire above test sequence with different cable sample
- For final result differential-mode reference impedance is 100 Ω and common-mode reference impedance is 25 Ω (-50 dBm → 1 mV @ 100 Ω, 500 μV @ 25 Ω)

SETUP TO MEASURE CABLE RF INGRESS FROM AN EXTERNAL RADIATED FIELD

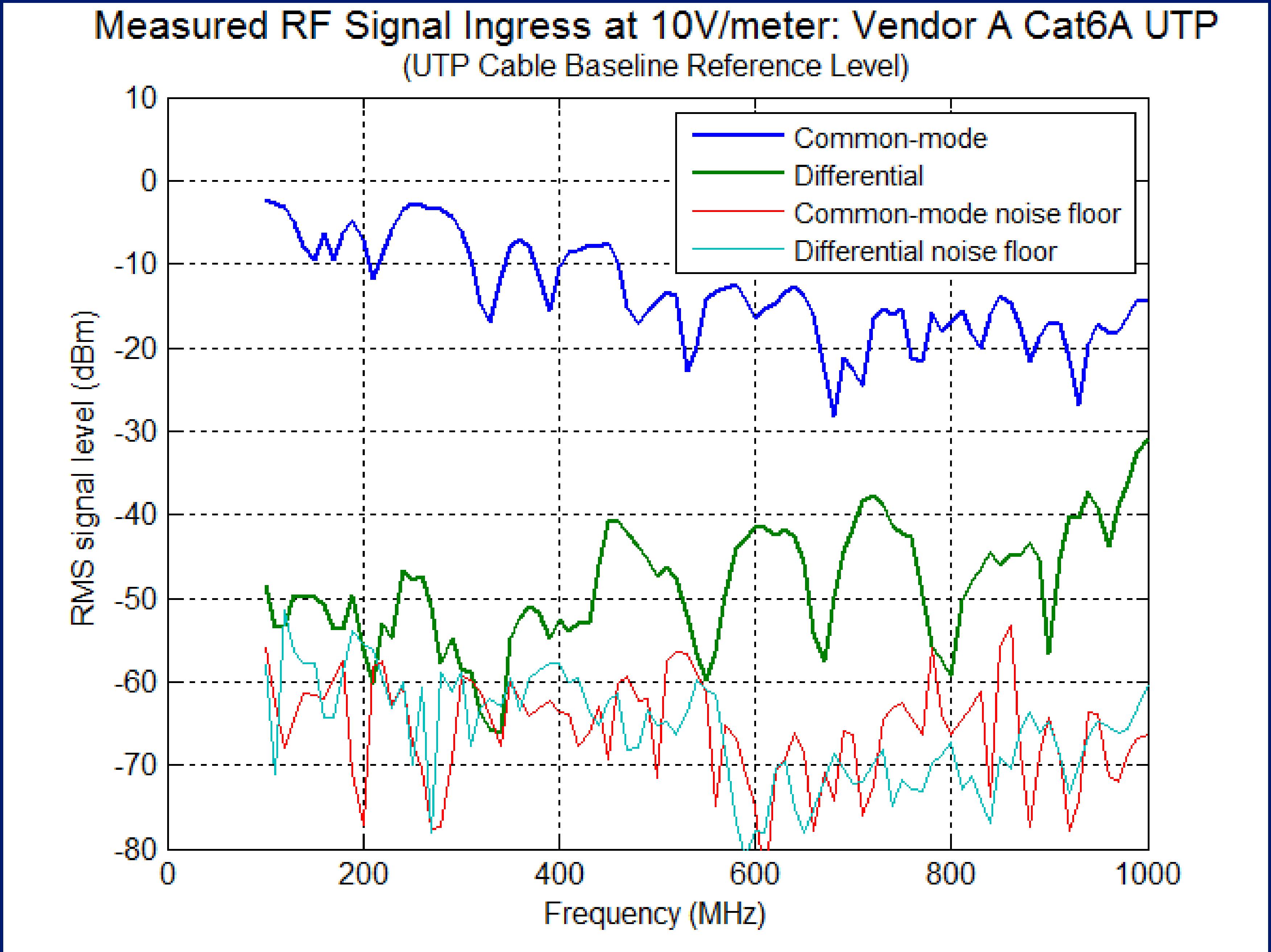


CABLING RF INGRESS MEASUREMENT TEST SETUP



MEASUREMENT TEST CASES

- Test cables
  - No cable attached to termination box (determine measurement noise floor)
  - Vendor A Cat 6A UTP (10 meters); unshielded twisted pair
  - Vendor B Cat 6 F/UTP (50 feet); foil screen around all four pairs, no shield per pair
  - Vendor C Cat 6 F/UTP (10 meters); foil screen around all four pairs, no shield per pair
  - Vendor D Cat 6 F/FTP (10 meters); foil screen around all four pairs, foil shield per pair
- Plot only horizontal antenna polarization (dominant orientation)
- Total exposed cable length of 2 meters; 1.3 meters in fixed horizontal configuration
- Measured both differential-mode and common-mode ingress voltage
- Measured only Pair 1-2 for each cable sample; sufficient for performance comparison and minimal impedance distortion through RJ45 connector
- For final ingress level result is in dBm: Differential-mode reference impedance is 100 Ω and common-mode reference impedance is 25 Ω.



Measured RF Signal Ingress at 10V/meter: Vendor A Cat6A UTP
(UTP Cable Baseline Reference Level)
Common-mode
Differential
Common-mode noise floor
Differential noise floor
RMS signal level (dBm)
Frequency (MHz)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
200
400
600
800
1000

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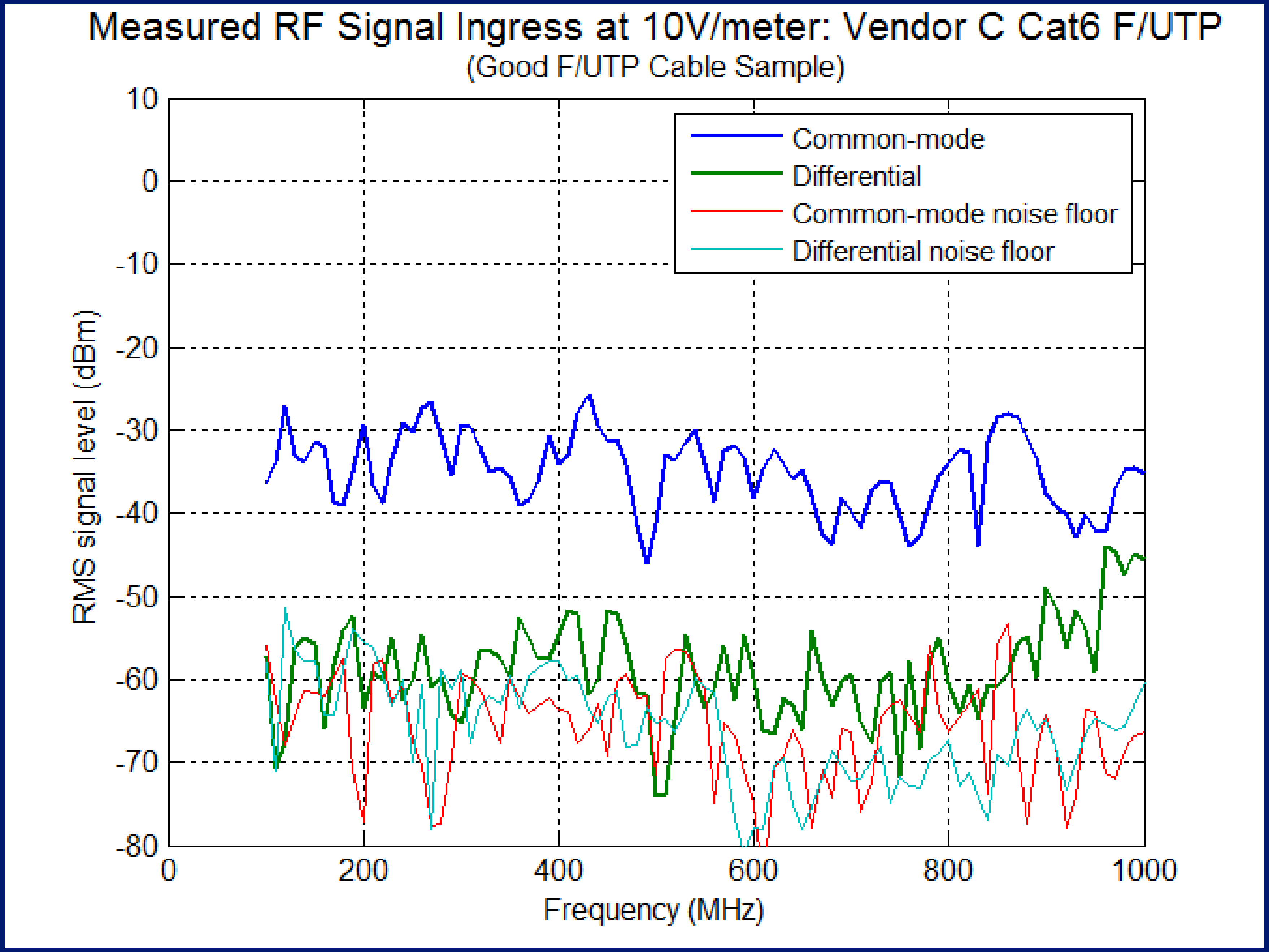
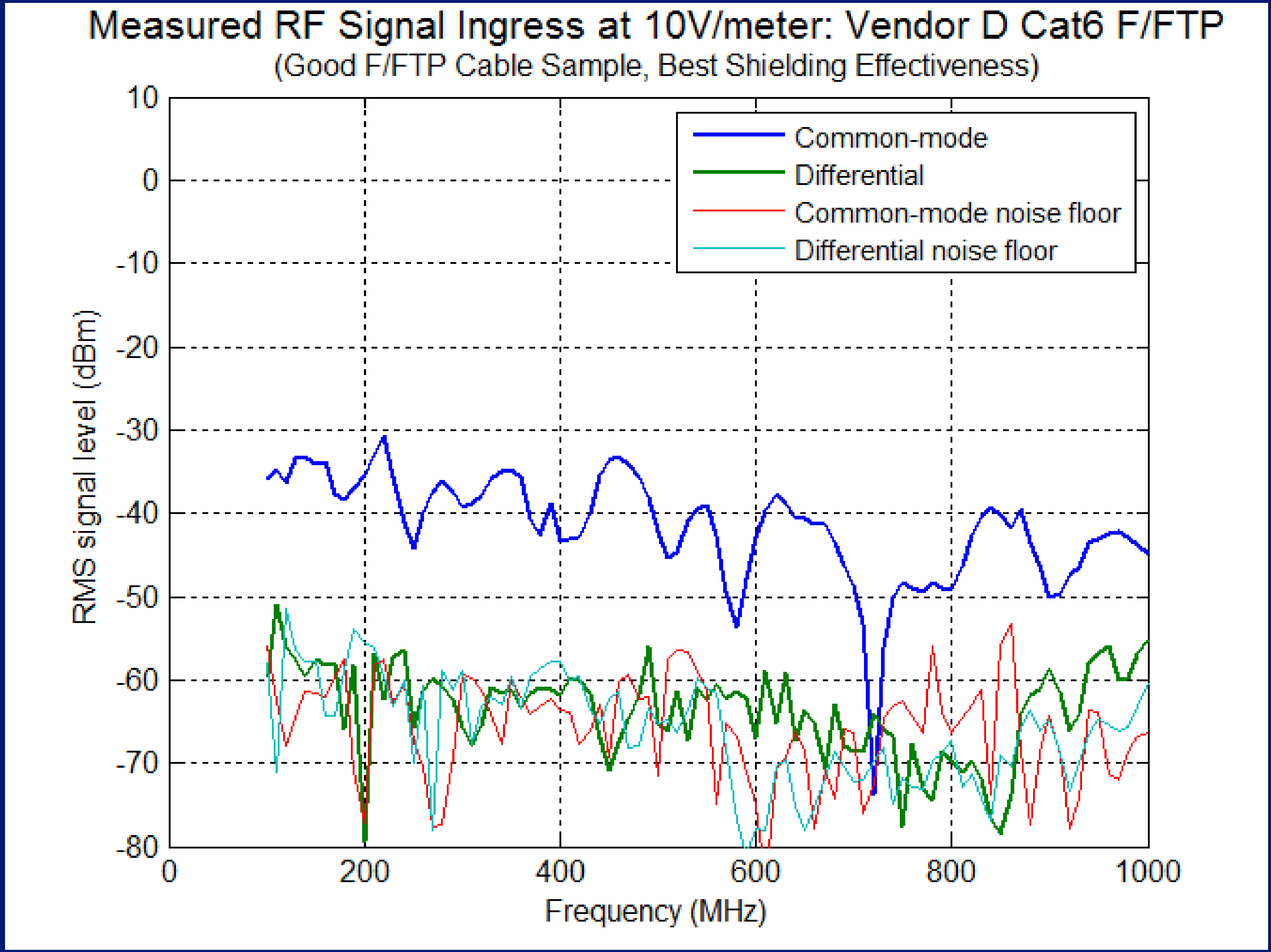
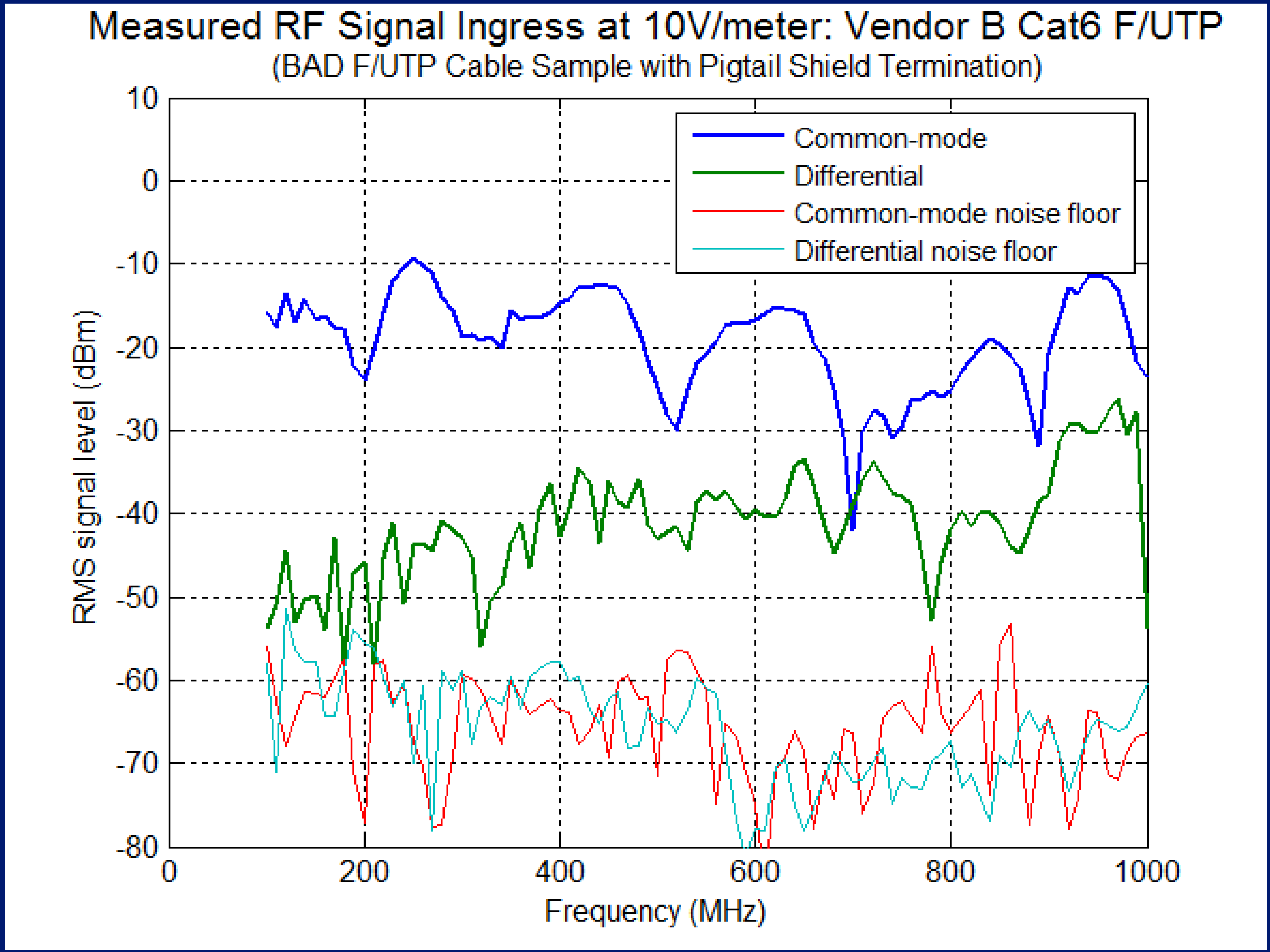
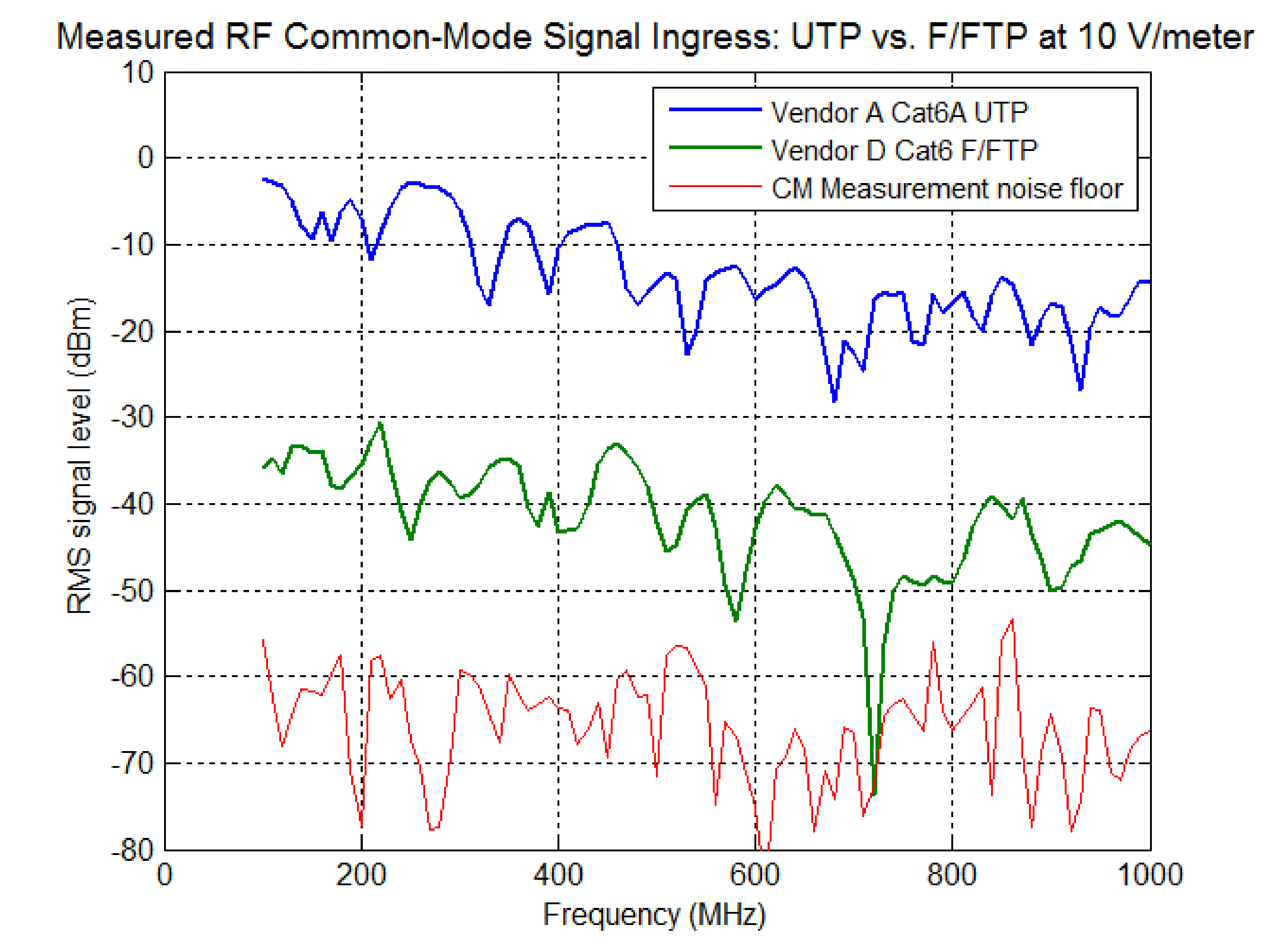
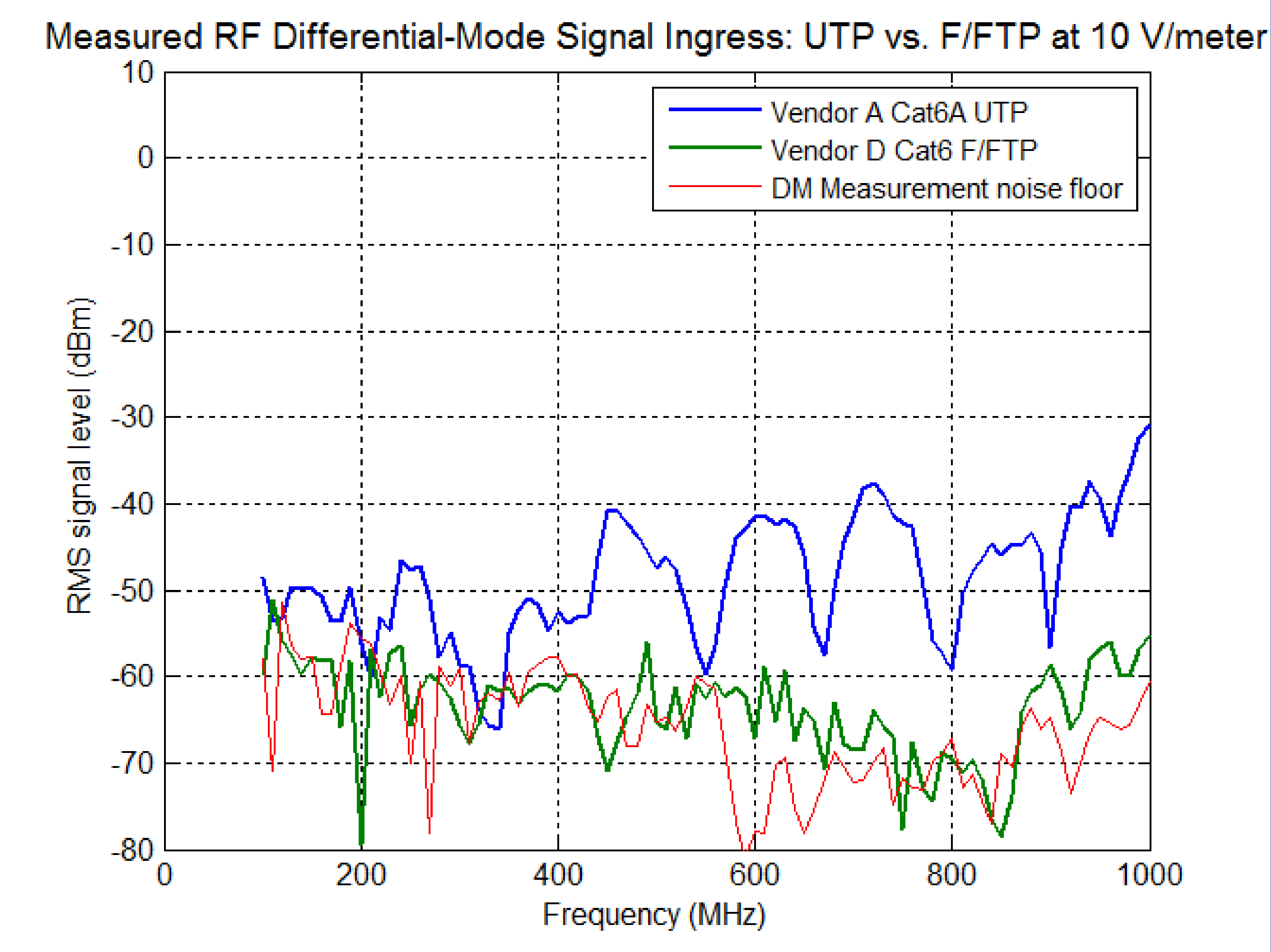

Measured RF Signal Ingress at 10V/meter: Vendor C Cat6 F/UTP
(Good F/UTP Cable Sample)
RMS signal level (dBm)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
200
400
600
800
1000
Frequency (MHz)
Common-mode
Differential
Common-mode noise floor
Differential noise floor


Measured RF Signal Ingress at 10V/meter: Vendor D Cat6 F/FTP
(Good F/FTP Cable Sample, Best Shielding Effectiveness)
Common-mode
Differential
Common-mode noise floor
Differential noise floor
RMS signal level (dBm)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
200
400
600
800
1000
Frequency (MHz)


Measured RF Signal Ingress at 10V/meter: Vendor B Cat6 F/UTP
(BAD F/UTP Cable Sample with Pigtail Shield Termination)
RMS signal level (dBm)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
200
400
600
800
1000
Frequency (MHz)
Common-mode
Differential
Common-mode noise floor
Differential noise floor

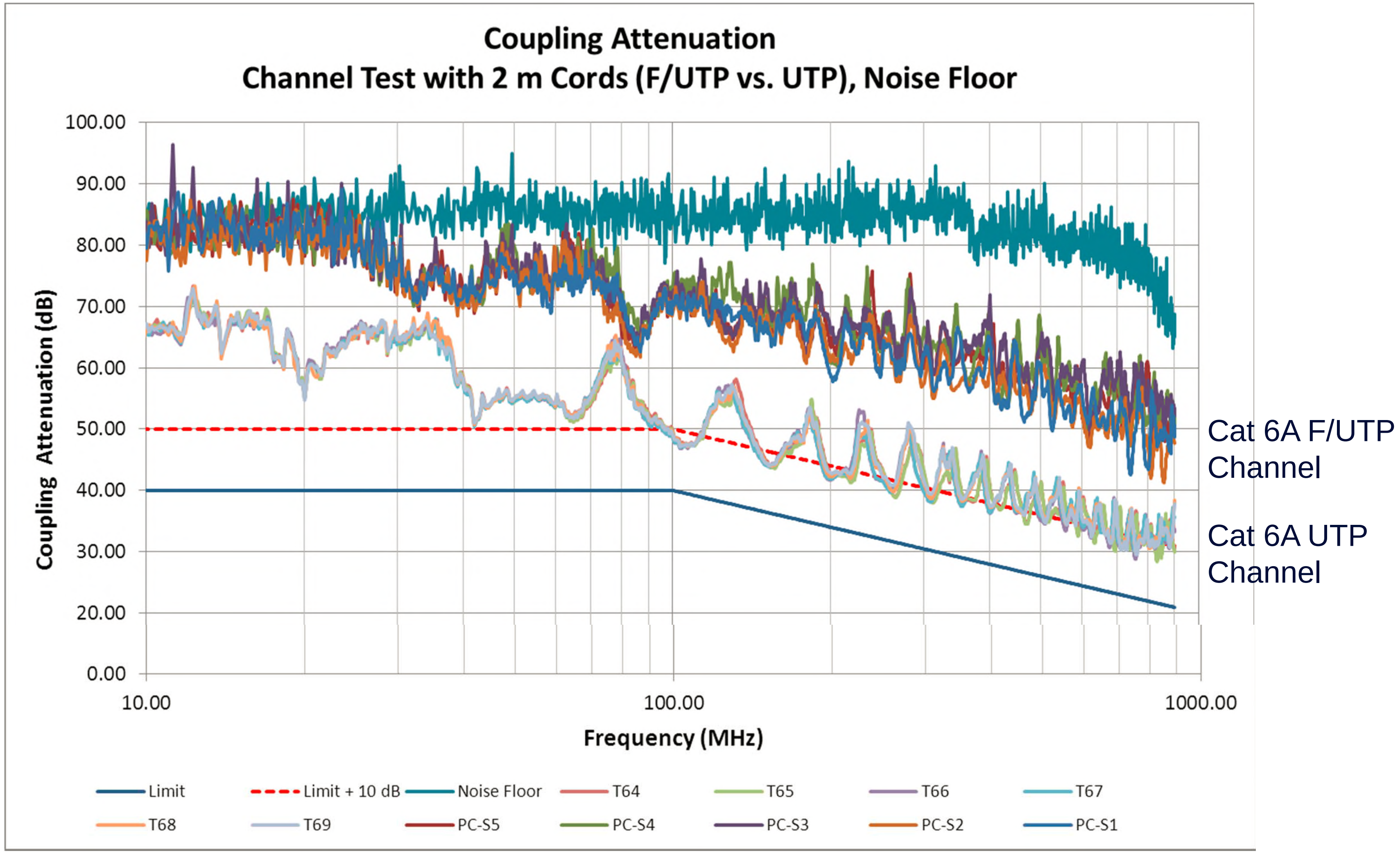

Measured RF Common-Mode Signal Ingress: UTP vs. F/FTP at 10 V/meter
Vendor A Cat6A UTP
Vendor D Cat6 F/FTP
CM Measurement noise floor
RMS signal level (dBm)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
200
400
600
800
1000
Frequency (MHz)


Measured RF Differential-Mode Signal Ingress: UTP vs. F/FTP at 10 V/meter
RMS signal level (dBm)
Frequency (MHz)
Vendor A Cat6A UTP
Vendor D Cat6 F/FTP
DM Measurement noise floor
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
200
400
600
800
1000

ESTIMATING DIFFERENTIAL-MODE RF INGRESS REDUCTION

- Chamber measurements indicate shielding reduced common-mode ingress by 30 dB, but direct measurement of the differential ingress reduction was not possible
  - Measured differential ingress levels for the F/FTP were at the measurement noise floor
- Differential-mode ingress caused by internal conversion of an externally induced common-mode signal into a differential signal within the cable (mode conversion)
  - Conversion due to unbalanced impedance and/or external coupling between each conductor of the twisted pair
  - Presence of an external shield may degrade the balance of a twisted pair due to the varying and non-uniform distance between each conductor and shield (conductor geometry cross-section); reduction may be less than for common-mode ingress
- Given the same cable balance as UTP, a differential mode ingress reduction of 30 dB is achievable
- A coupling attenuation measurement from **kish_3bp_01_0513** (slide #14) indicates 10 to 20 dB reduction of differential ingress with Cat 6A F/UTP vs Cat 6A UTP
- Slides 11 and 12 of this presentation show about 5 dB reduction in RF ingress for F/FTP vs. F/UTP → potential lower bound of about 15 dB improvement vs UTP
  - F/FTP pair/shield cross-section geometry is similar to single pair STP

COUPLING ATTENUATION MEASUREMENT FROM **KISH_3BP_01_0513**



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SUMMARY

- Measurements indicate good shielding (F/FTP) can reduce common-mode ingress levels by about 30 dB vs unshielded cable (UTP)
- Measured differential ingress levels for the F/FTP were at the measurement noise floor, but estimates based on coupling attenuation measurements indicate differential ingress can be reduced from 15 to 30 dB vs unshielded cable (UTP)
- Shielded cables are not alike in RF ingress performance and shielding effectiveness
  - Significant performance differences from shield-to-connector termination (full 360-degree for good F/UTP and F/FTP cables, pigtail for bad F/UTP cable)
  - Improper implementation can eliminate benefits
- Use of shielded twisted pair cables can significantly improve RF immunity of data links allowing PHY implementations with lower transmit power and wider bandwidth than unshielded twisted pair (UTP) in the automotive environment