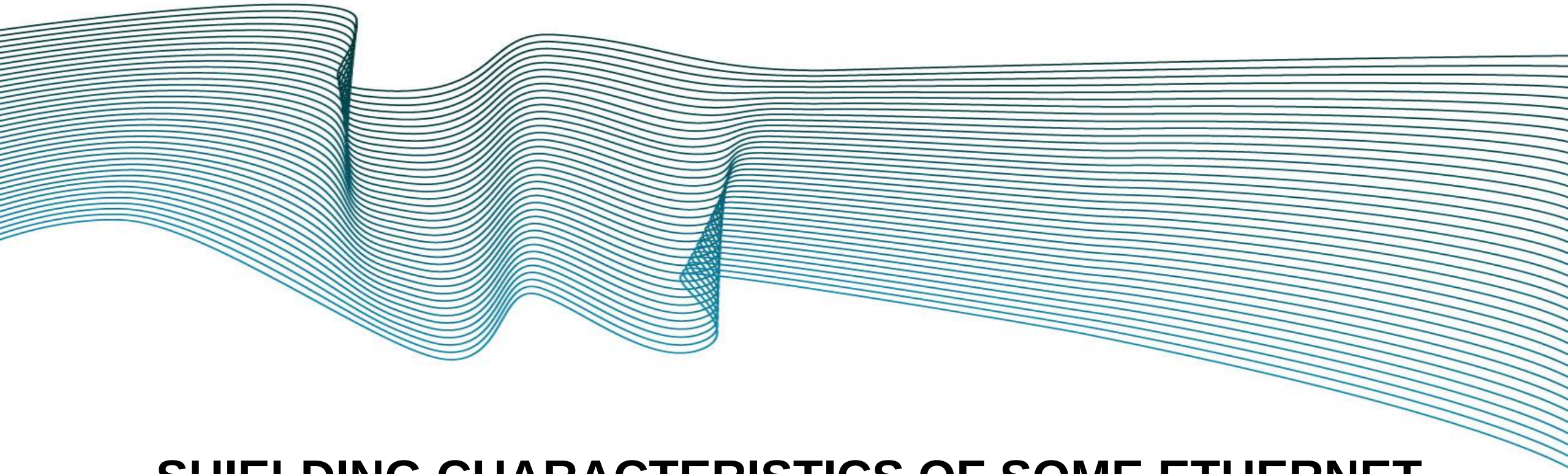

SHIELDING CHARACTERISTICS OF SOME ETHERNET CHANNELS UNDER RADIATED-IMMUNITY TEST CONDITIONS: METHOD AND INITIAL RESULTS

Version 03

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ABSTRACT - 1

The upcoming Ethernet standards for data-rates beyond 10 Gbps over copper channels propose shielded cables and connectors. The quality of the cable and connector shields is typically tested with bench-methods that measure “screening attenuation”, “shielding effectiveness”, or “transfer impedance”.

The balance and conversion of shielded cables is often not tested nor specified. When specified, the conversion is defined by bench-level methods and usually for each individual pair.

While these bench methods can be useful in characterizing the quality of the shield and balance to reject EMI, they do not reveal to what levels of common-mode and differential-mode EMI an Ethernet transceiver is exposed to in realistic test conditions using various cables and connectors.

ABSTRACT - 2

This study:

a) Describes a test method for direct assessment of EMI conditions to which a transceiver may be exposed under the radiated-immunity test conditions.

b) Provides initial test results obtained on some available cabling systems.

The described test method and results can be expanded in future, to include various EMC-test conditions, magnetics, connectors, and cabling options. By measuring under the realistic conditions of the immunity tests, the results can help further development of transceivers and the components of the channel to meet various EMC-immunity requirements.

OBJECTIVES

- Provide a test method for characterizing EMI rejection by various cables and connectors under realistic conditions of radiated-immunity tests in anechoic chamber.
- Measure induced common-mode and differential-mode voltages at the MDI during the Radiated Immunity test from 80 MHz to 1 GHz, at the nominal level of 10 V/m (rms) and with 80% AM, as a function of cable and connector types.
- Provide initial information about the required common and differential mode EMI levels and suppression that a transceiver must be able to handle.

- The method can be easily adapted and used to measure real induced voltage levels in various immunity test setups, such as conducted-immunity, ESD, other transients, as well as a function of adding various EMI-suppression devices etc.

CABLES AND CONNECTORS USED IN THE STUDY

- The following cables and connectors were received from the participants*:
  - CAT6a UTP with Unshielded RJ45
  - CAT6a F/UTP with Shielded CAT6a RJ45
  - CAT6a S/FTP with Shielded CAT6a RJ45, two vendors
  - CAT7a S/FTP with Shielded CAT6a RJ45
  - CAT7a S/FTP with TERA® connector
  - CAT8.2 S/FTP with Shielded ARJ45® connector
  - CAT8 Prototype F/FTP with Shielded CAT8 Prototype RJ-45
- Channel lengths, with three segments:
  - 10m (2.5m + 6.5m + 1m)
  - 30m (2m + 26m + 2m)
- Use of female-female inline couplers is indicated on the charts
- In addition, some cables were tested with the following lengths:
  - 2m
  - 26m

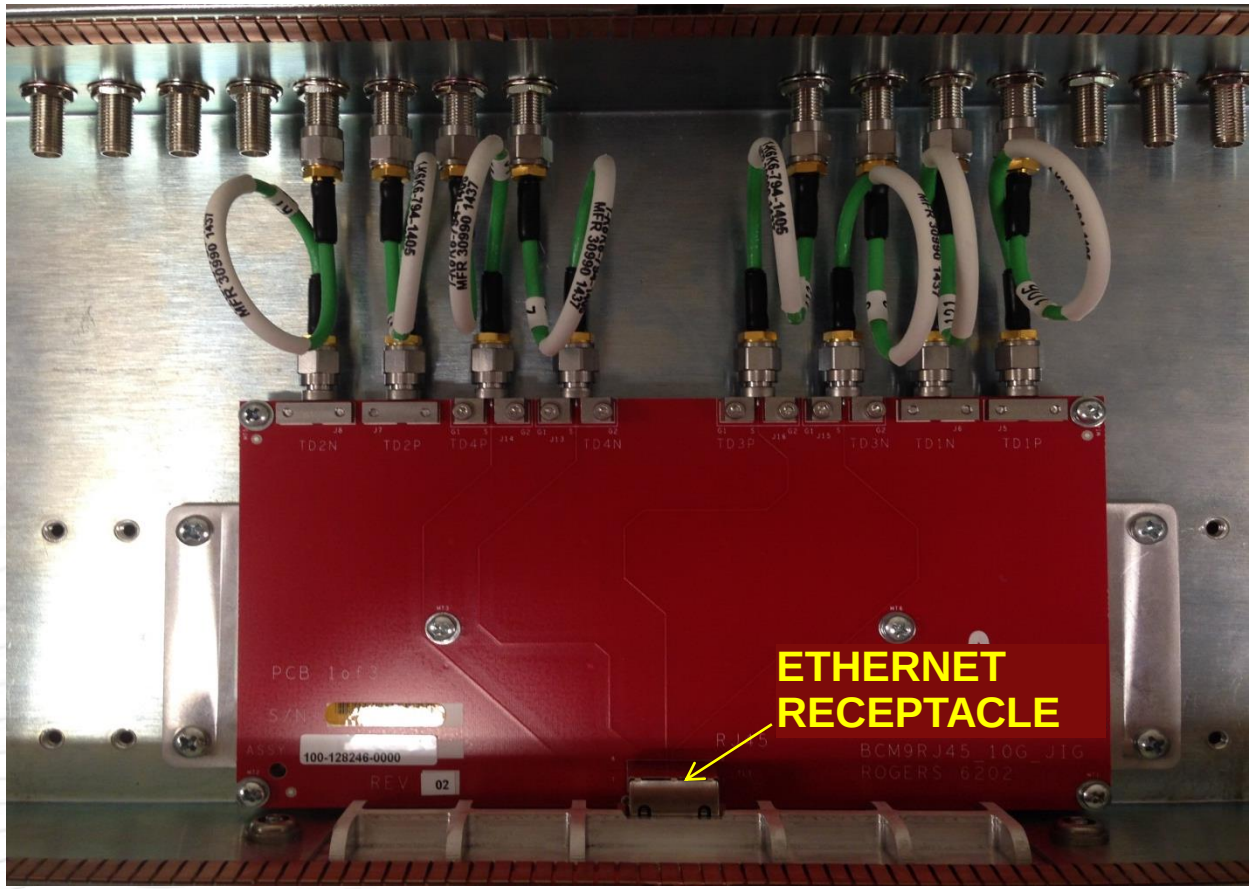
*Nomenclature and description listed as received from the participants.

PCB FIXTURE FOR MEASUREMENT

- PCBs were designed to host three types of Ethernet receptacles:
  - Shielded CAT6a RJ45 (fixture used with all types of RJ45)
  - ARJ45®
  - TERA®
- The PCBs provide transition from the receptacles to 3.5 mm coaxial connectors.
- Each PCB is mounted in metal enclosure, which simulates a typical DUT.

PCB FIXTURE MOUNTED IN A METAL ENCLOSURE

- Coaxial connections for measurements with a scope
- Receptacle mounted as in a realistic device
- Enclosure covered during tests
- Careful balanced design
  - Trace length matching
  - Specified 5% impedance tolerance
  - Homogeneous PCB dielectric material (Rogers)

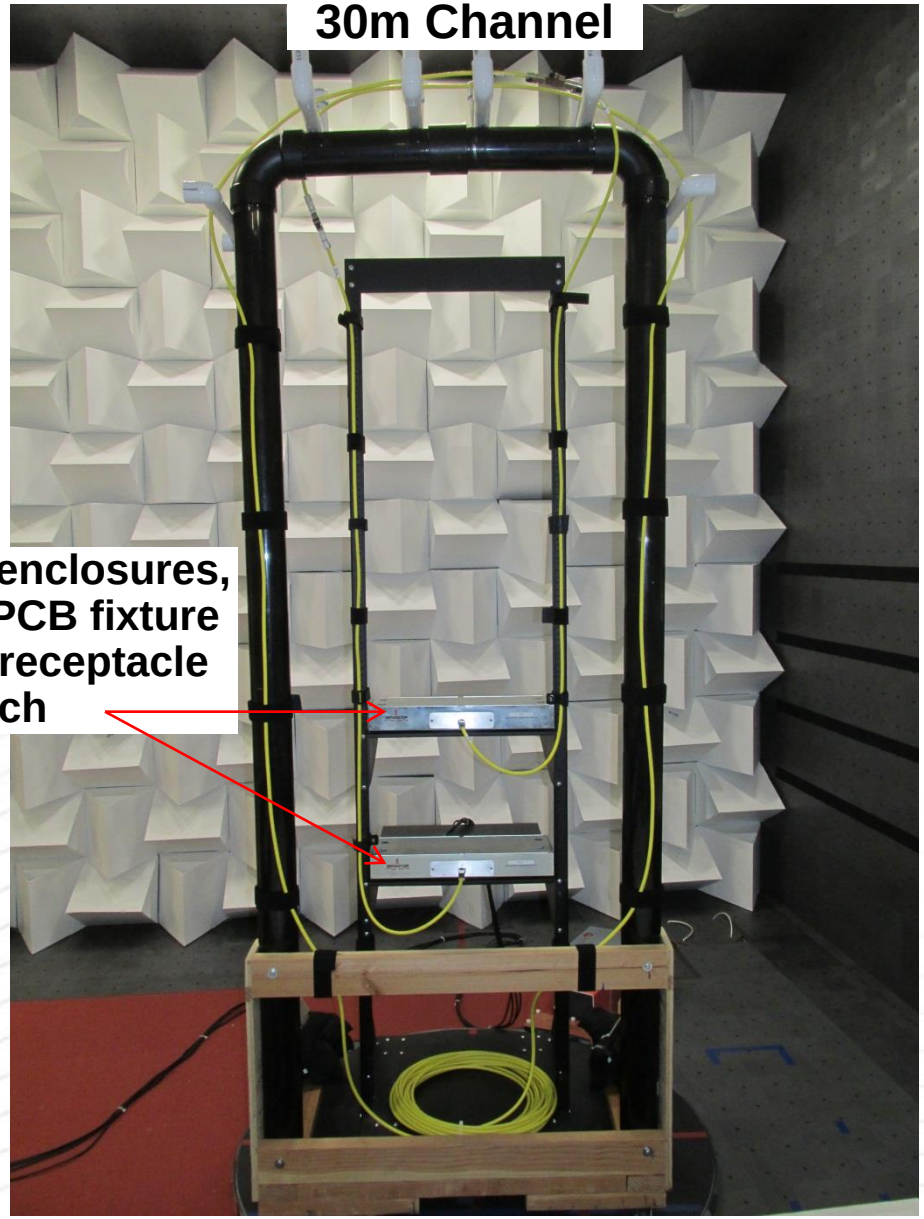


TWO ENCLOSURES WITH PCB FIXTURES IN A METAL RACK

- Two enclosures mounted in a metal rack inside an anechoic chamber.
- A channel or cable under test connected between two enclosures, simulating a test condition with e.g. two switches connected to one another.
- The channel/cable under test laid out per GR1089 setup.
- Coaxial cables from the enclosure to the chamber wall, and to a scope outside.

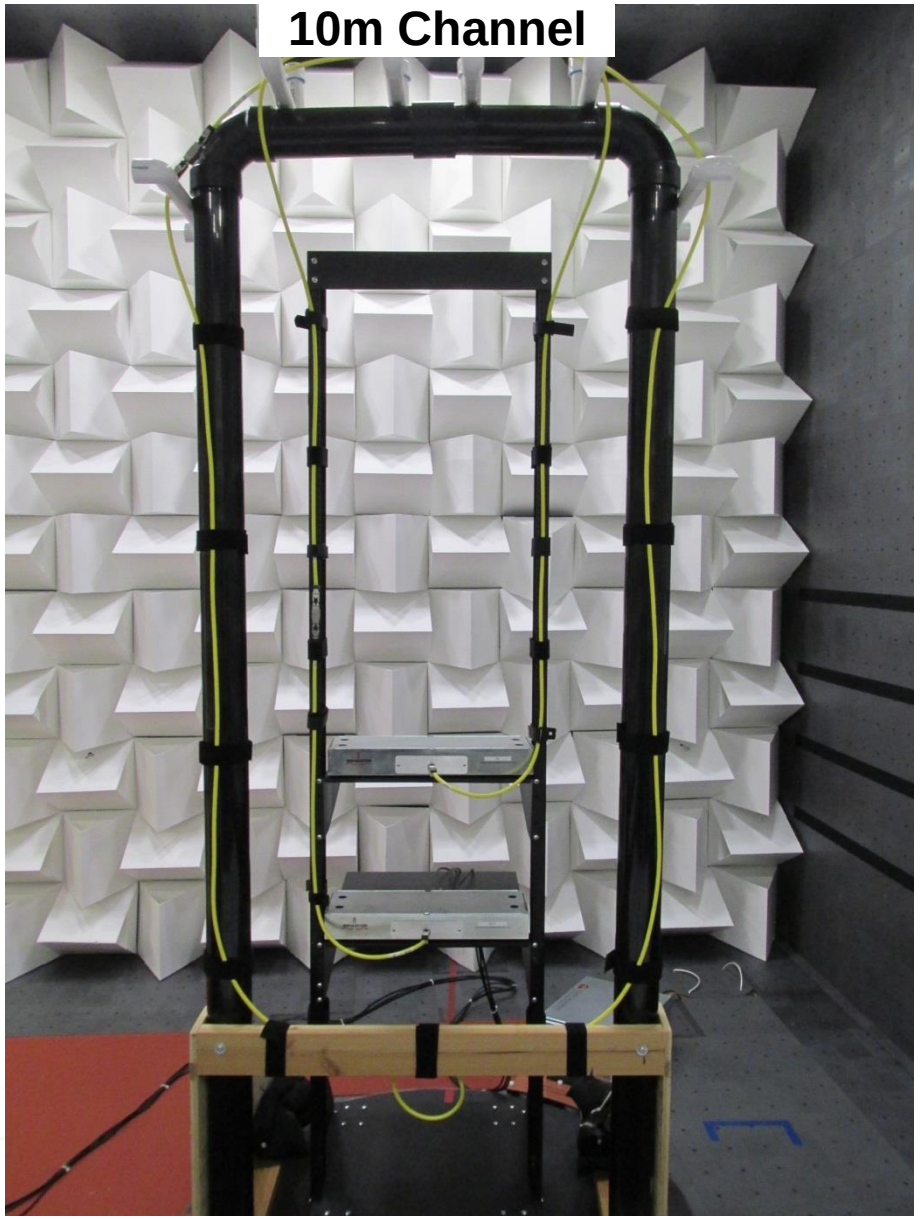
CABLE-RACK SETUP PER GR-1089

30m Channel



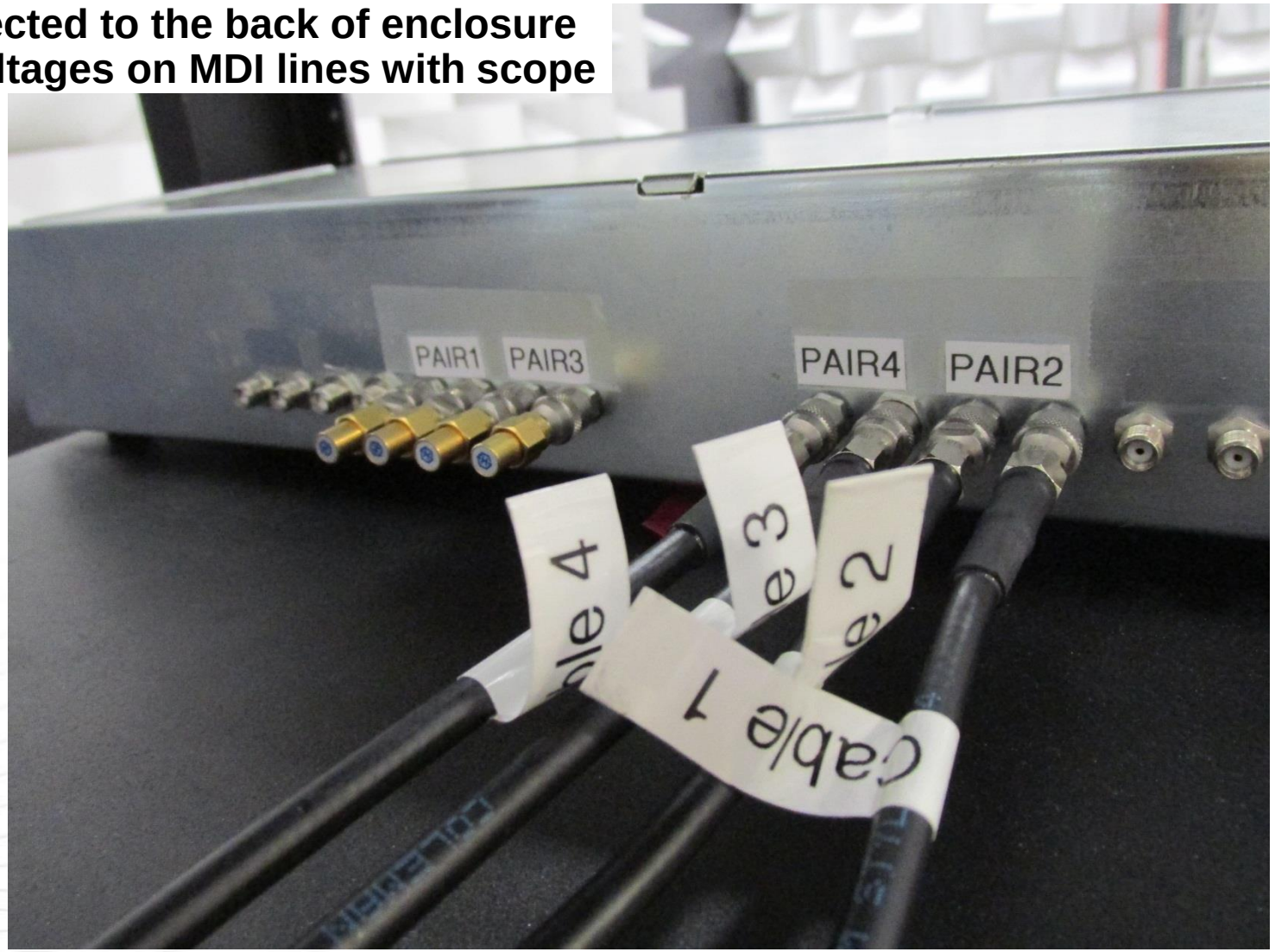
Two enclosures, one PCB fixture with receptacle in each

10m Channel



COAXIAL CABLES TO SCOPE OUTSIDE THE CHAMBER

Cables connected to the back of enclosure to measure voltages on MDI lines with scope

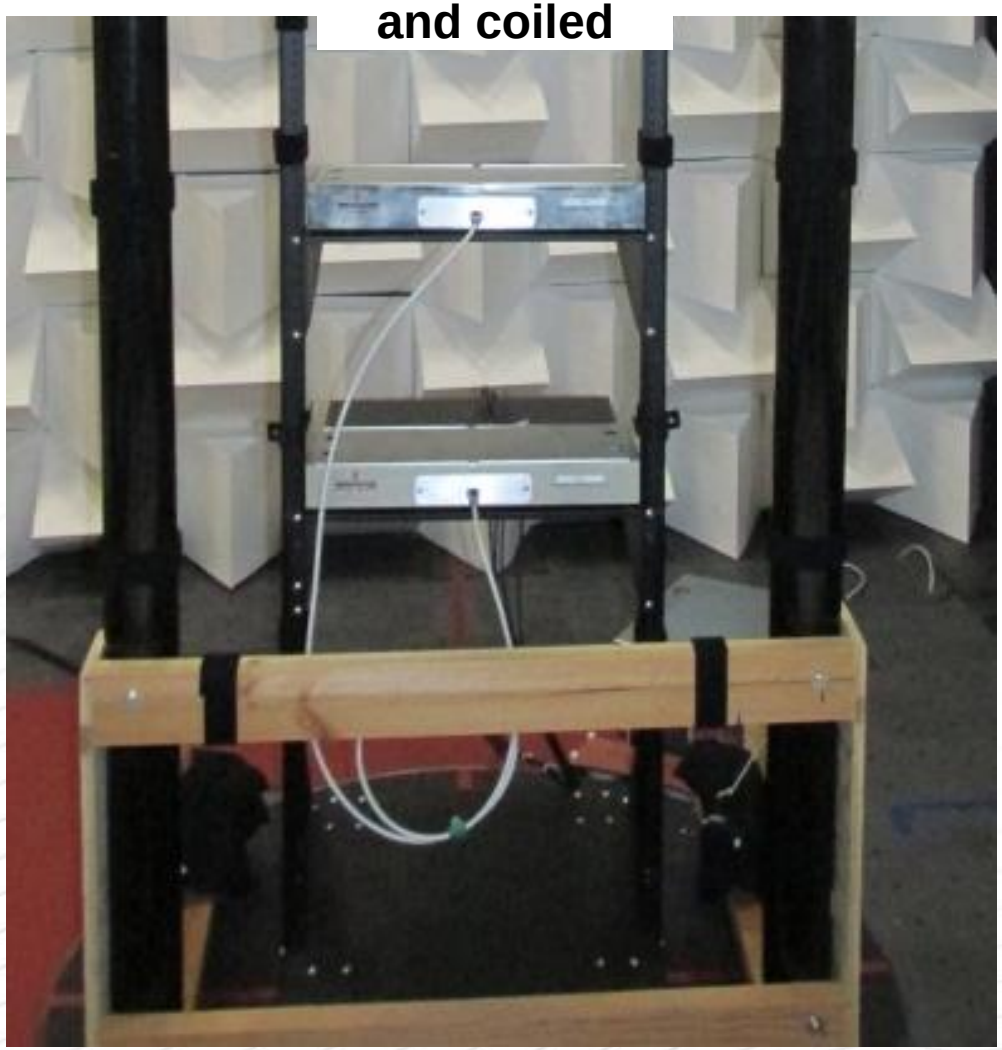


TEST SETUP CONDITIONS

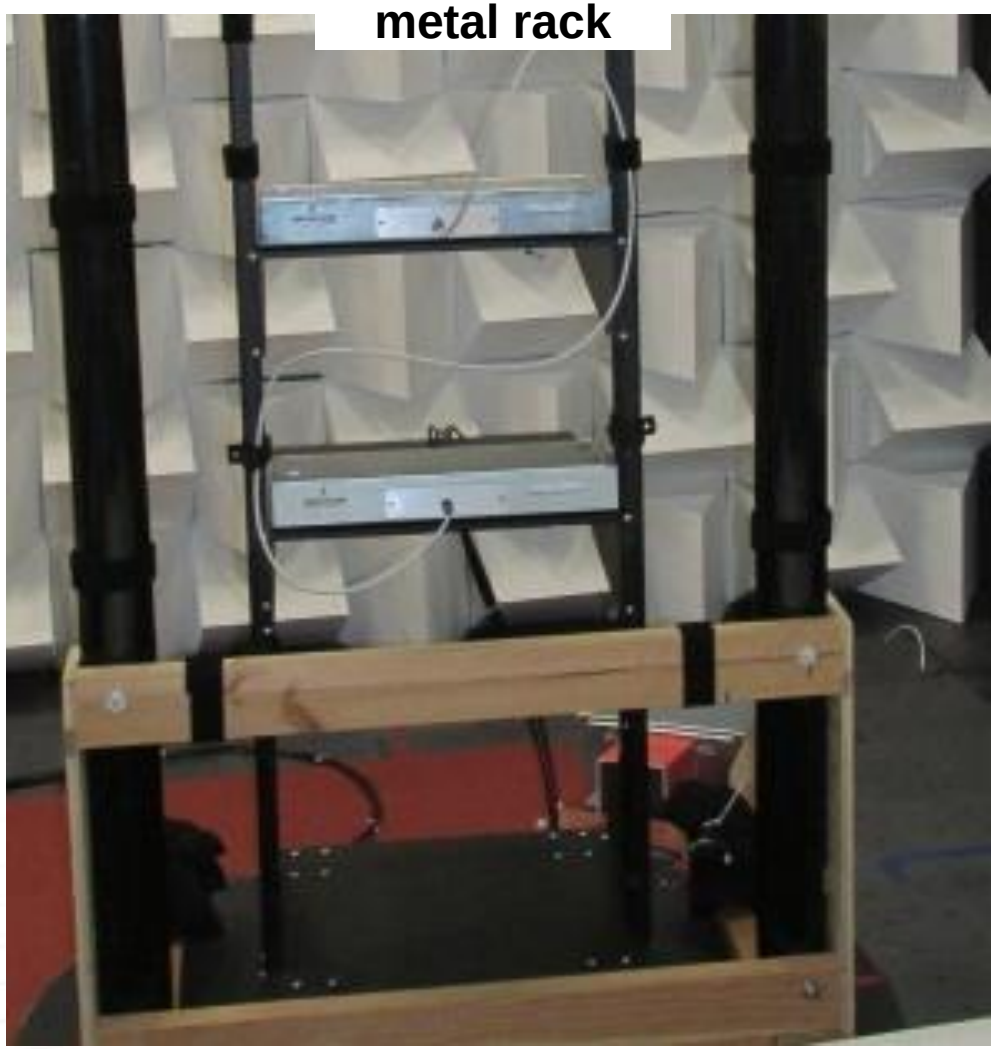
- The entire setup was exposed to radiated-immunity test as in a real test scenario.
- Frequency range of test: 80 MHz - 1 GHz.
- Nominal test level = $10V_{rms}$ with 80% AM, which results in 25.5 V/m peak.
- Sine-wave with 25.5 V/m peak was used, no modulation.
- The real exposure levels vary, and can considerably exceed the nominal level.
- Vertical and horizontal polarizations of the antenna included in the results.
- The DUT setup was NOT rotated, due to lack of time. Only “front” exposure.
- Peak Common & Differential voltages were measured.
- Maximum of all readings (envelope) is plotted in the charts.

ADDITIONAL SETUPS TO INVESTIGATE RESPONSE OF 2m CABLES

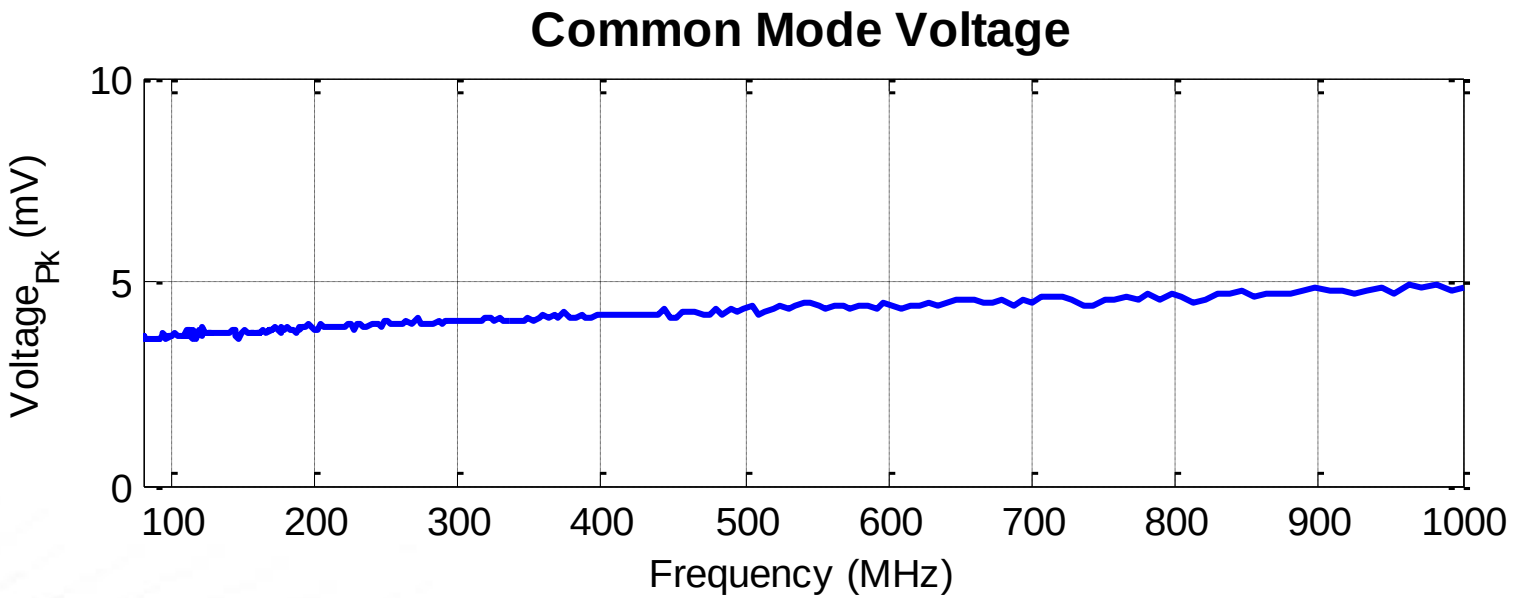
Hanging down and coiled

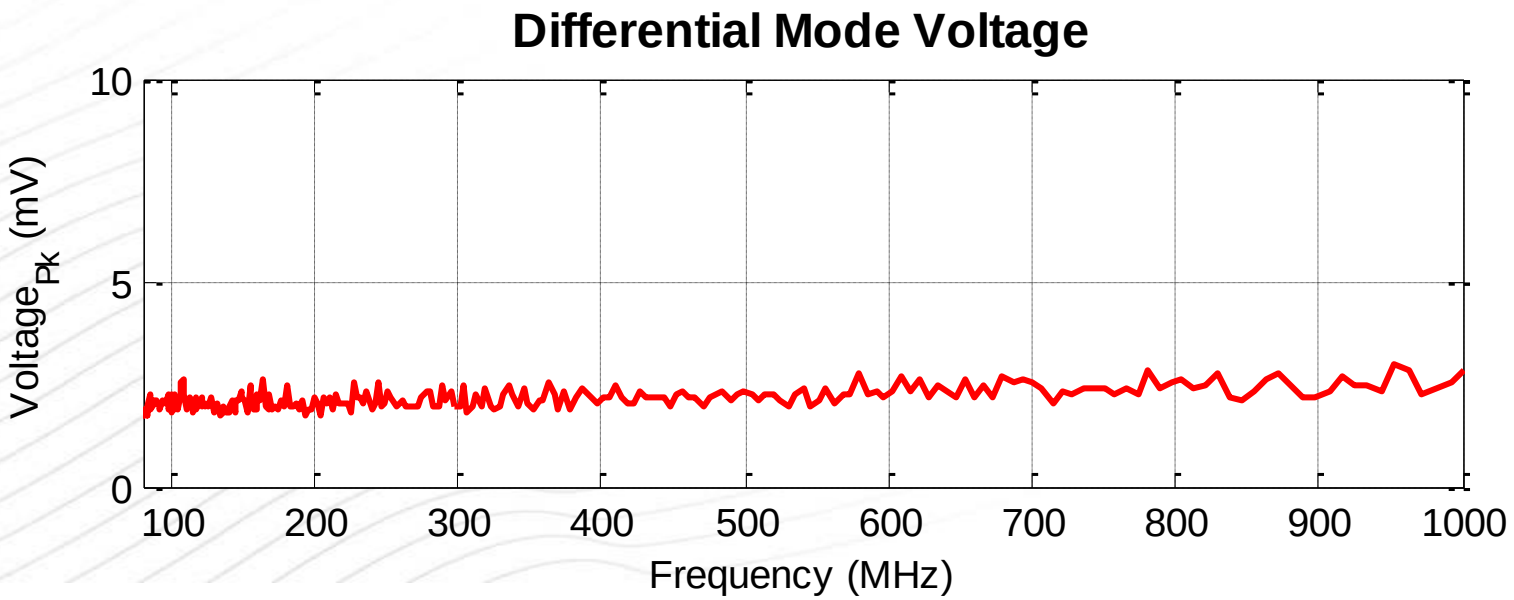


Taped to the metal rack

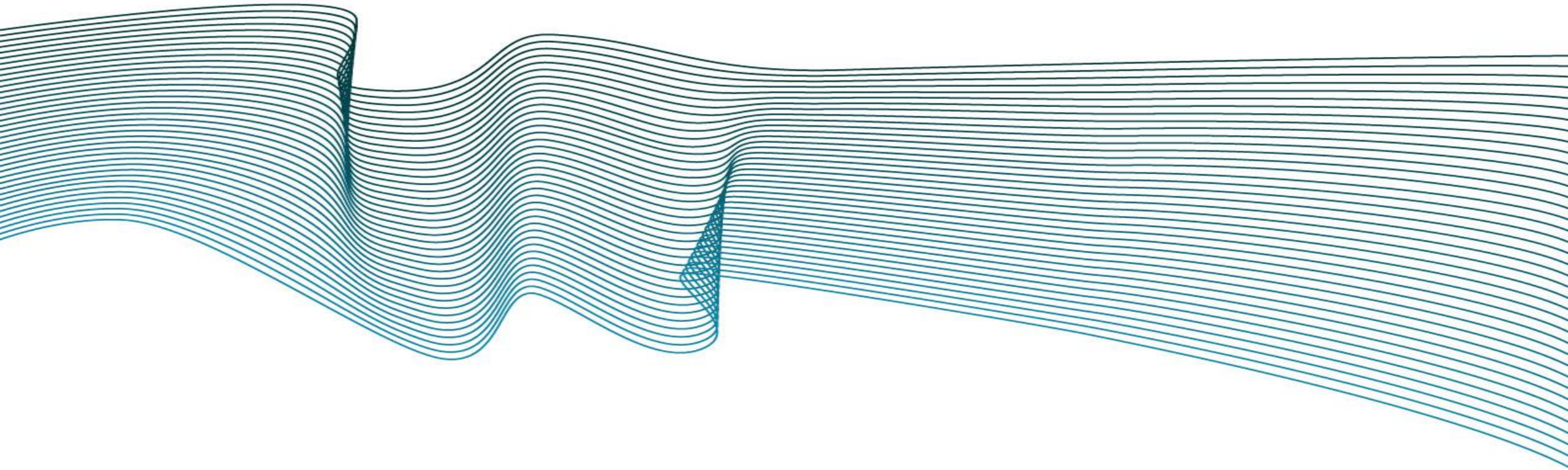


NULL MEASUREMENTS, without Ethernet cable connected





There is no considerable parasitic pickup by the test setup

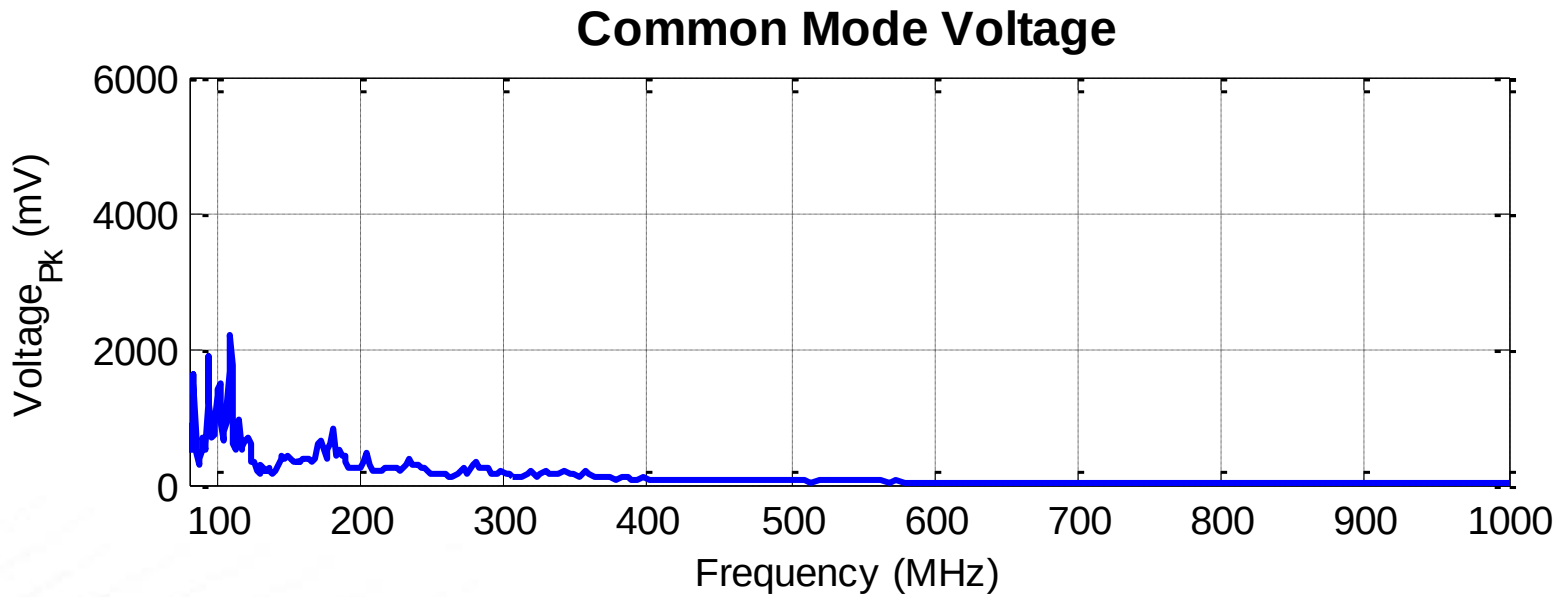


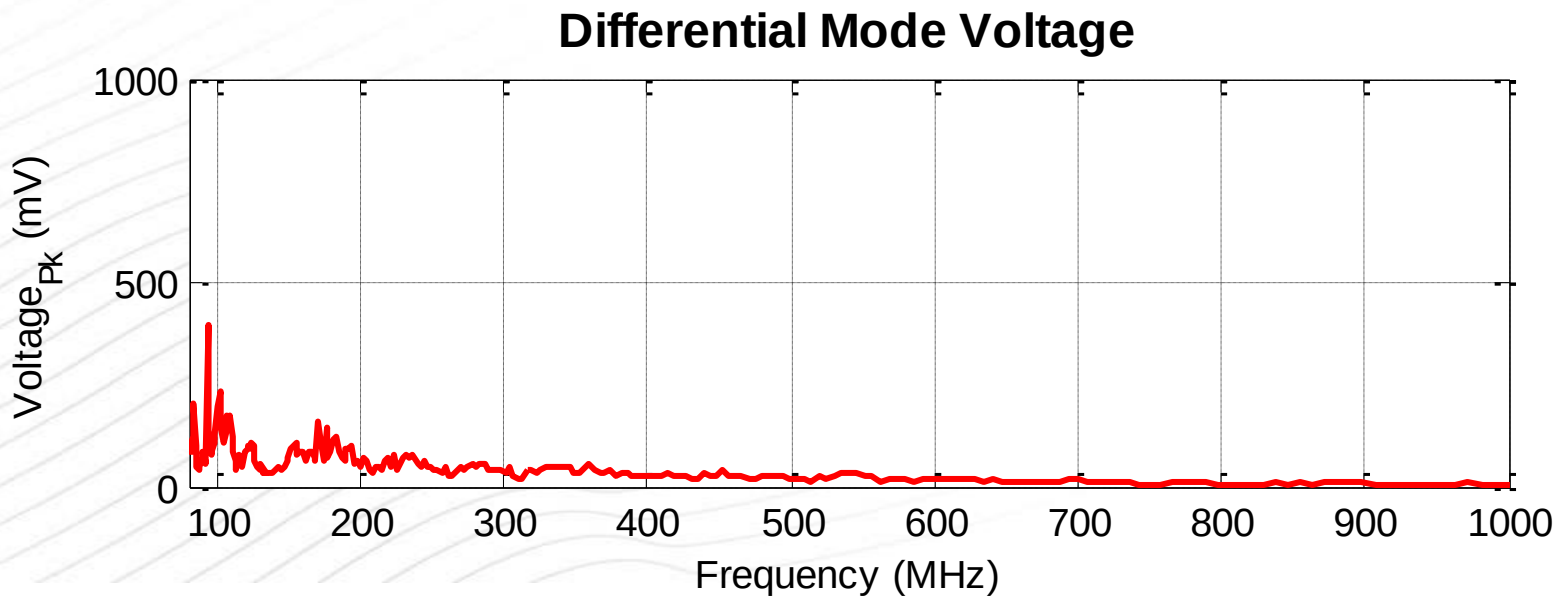
RESULTS

Grouped by cable category

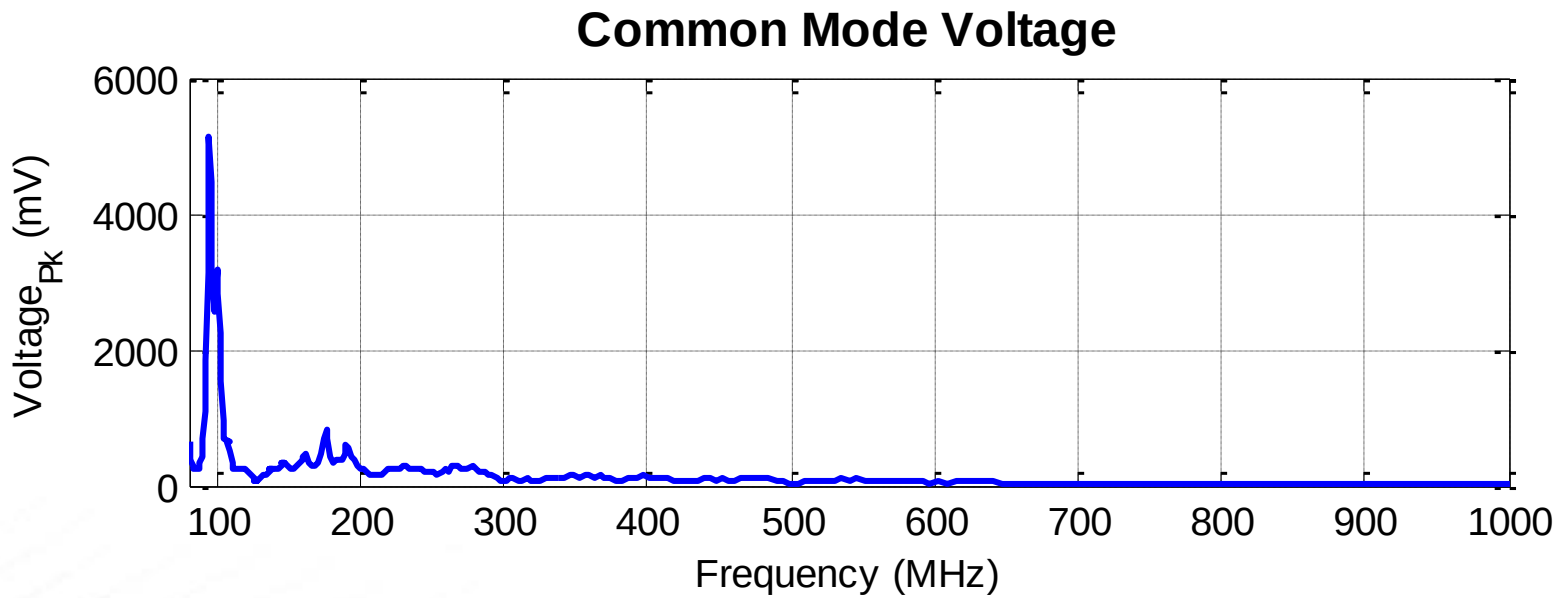
CAT6a UTP
RJ45 Connectors

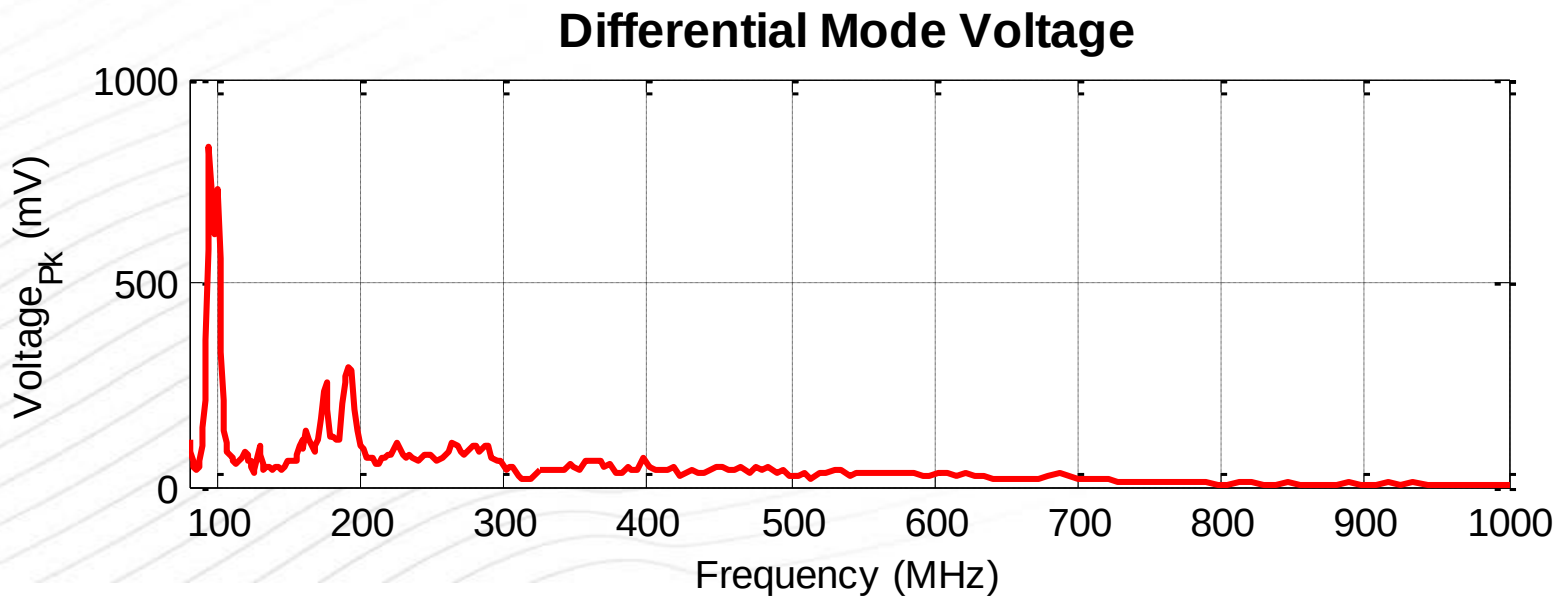
30m CHANNEL, CAT6a UTP, RJ45
2 Female-Female unshielded inline couplers





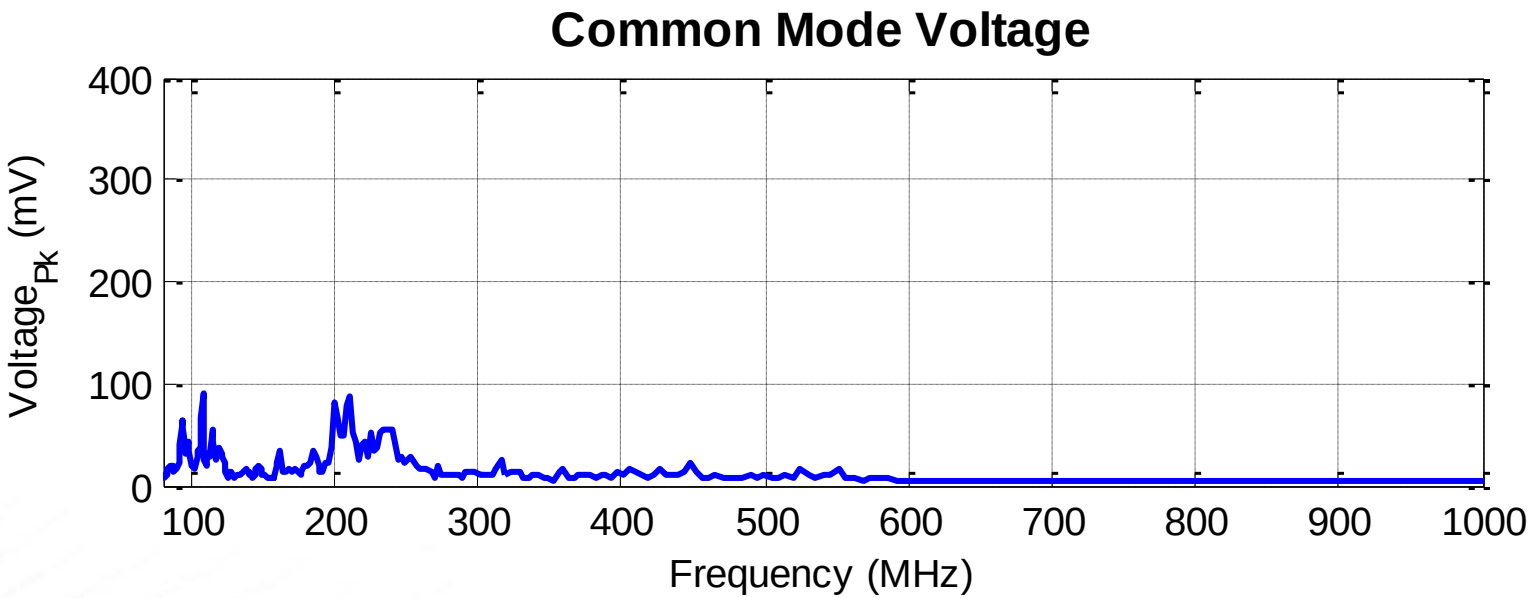
10m CHANNEL, CAT6a UTP, RJ45
2 Female-Female unshielded inline couplers

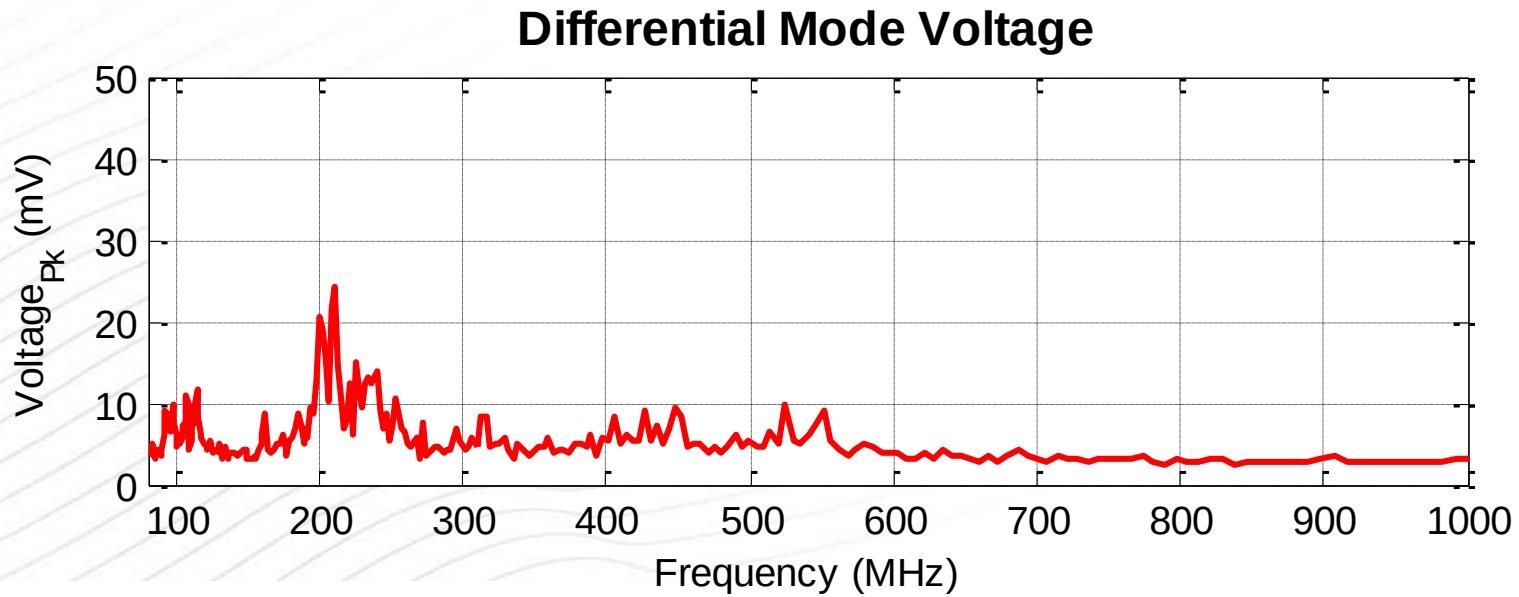




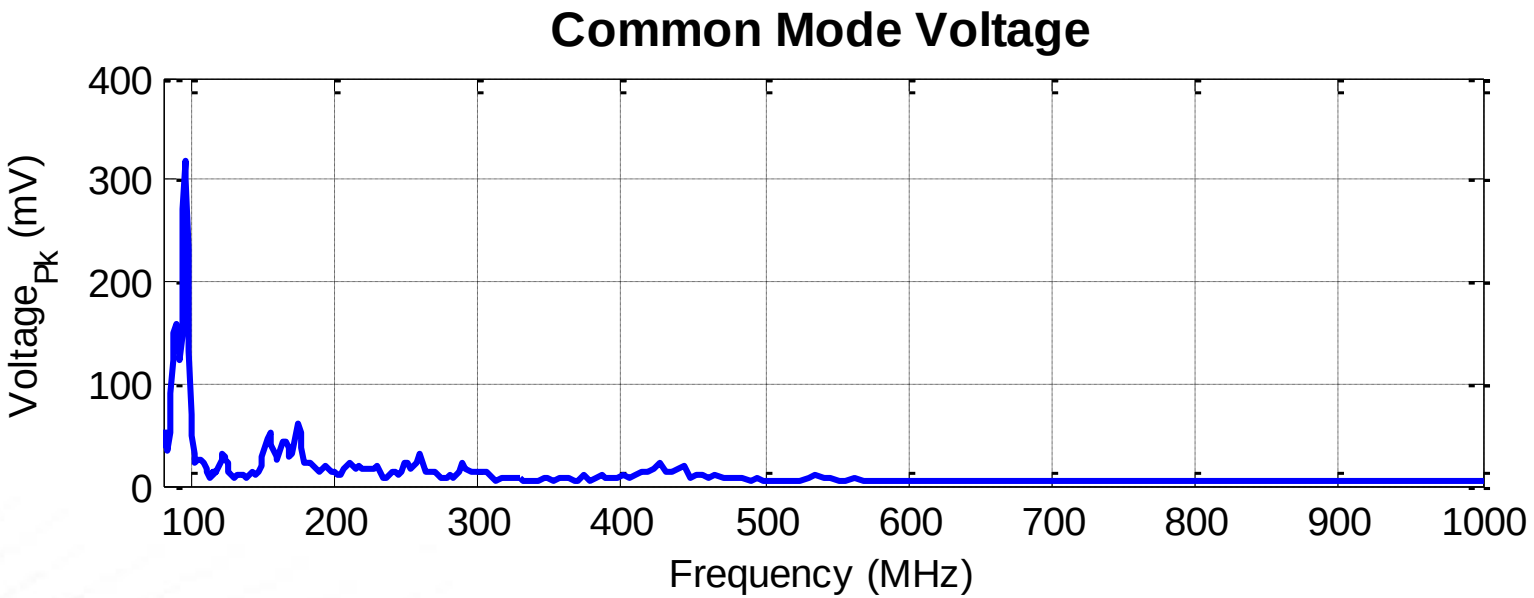
CAT6a F/UTP and S/FTP
Shielded CAT6a RJ45 Connectors

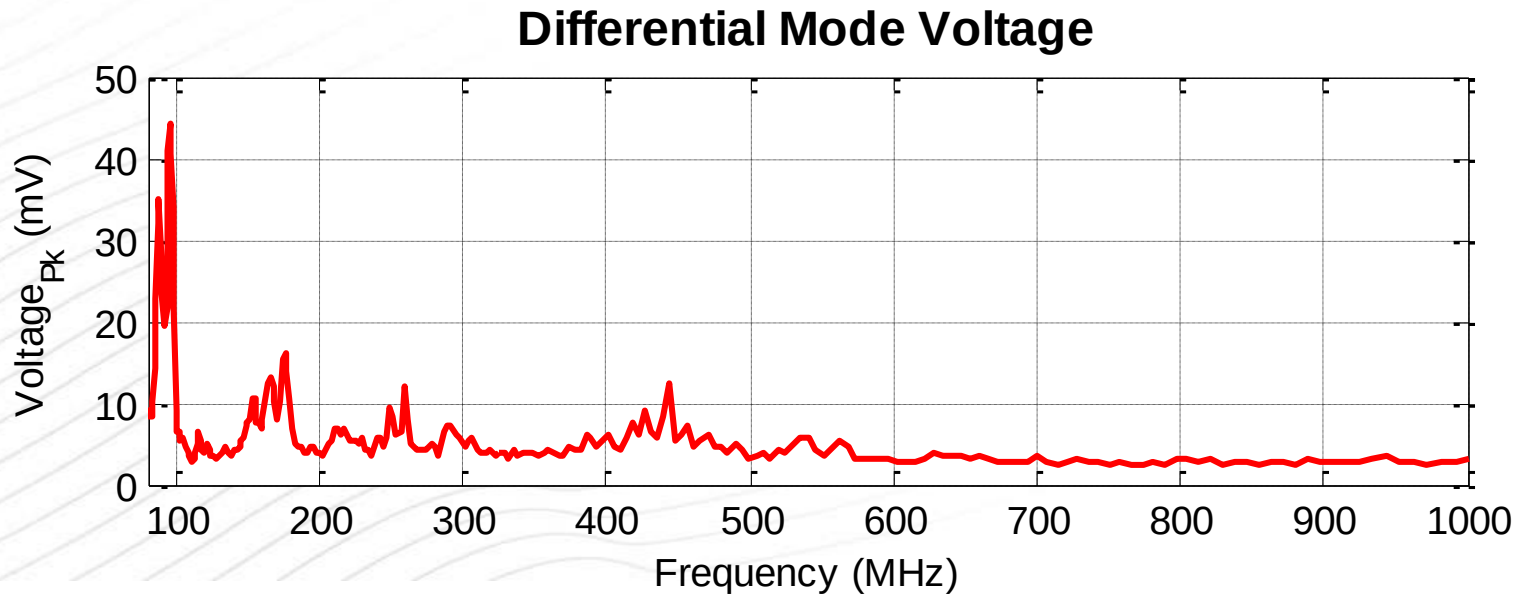
30m CHANNEL, CAT6a F/UTP, SHIELDED CAT6a RJ45
2 Female-Female shielded inline couplers



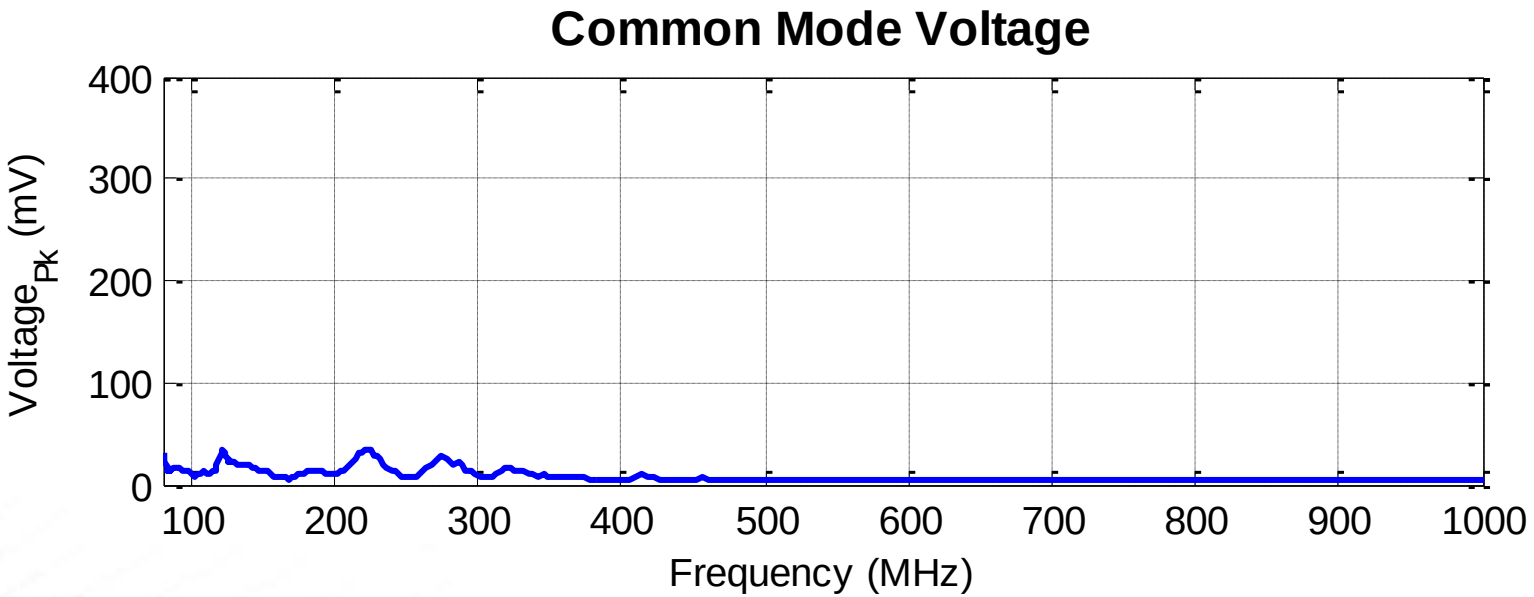


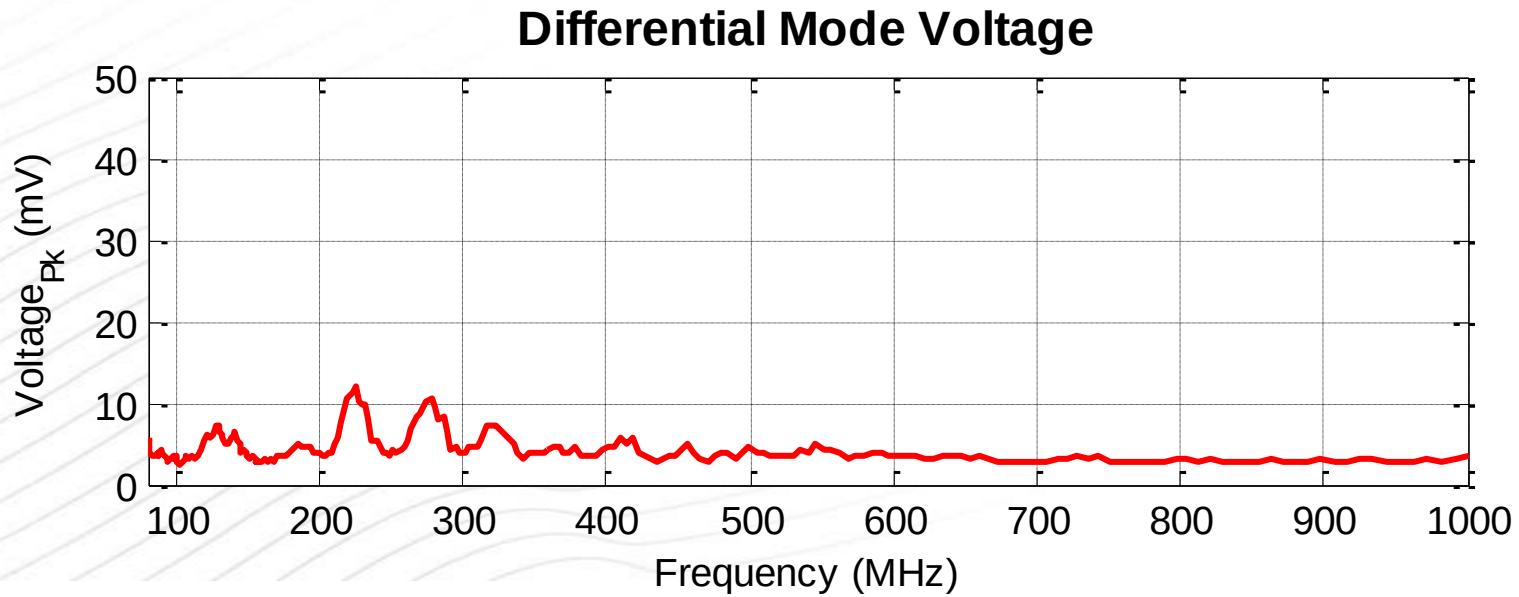
10m CHANNEL, CAT6a F/UTP, SHIELDED CAT6a RJ45
2 Female-Female shielded inline couplers



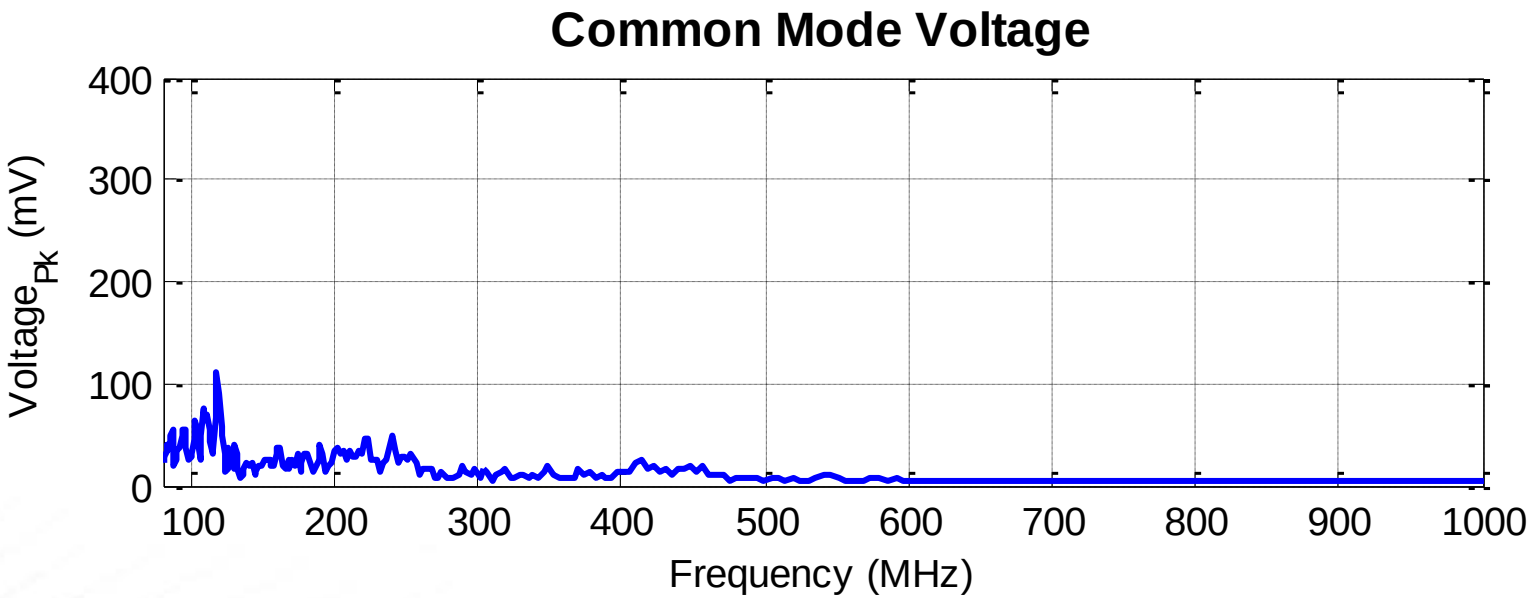


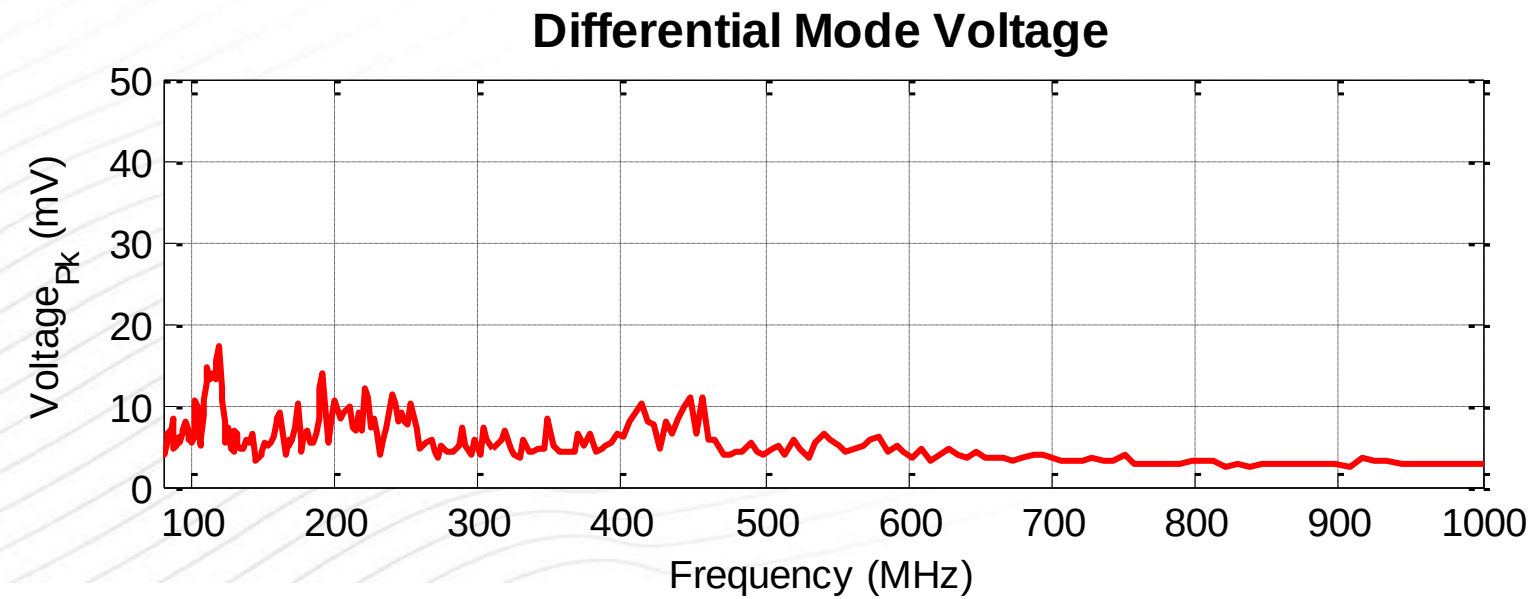
2m CABLE, CAT6a F/UTP, SHIELDED CAT6a RJ45, HANGING DOWN & COILED



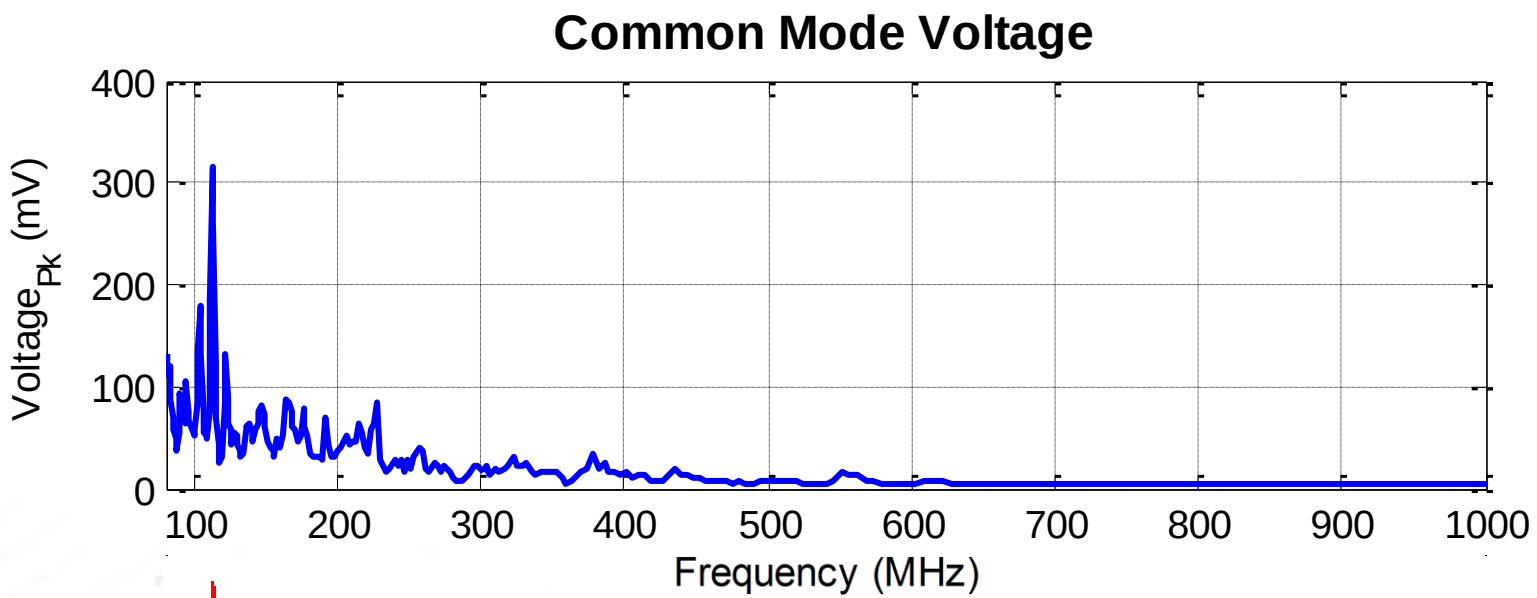


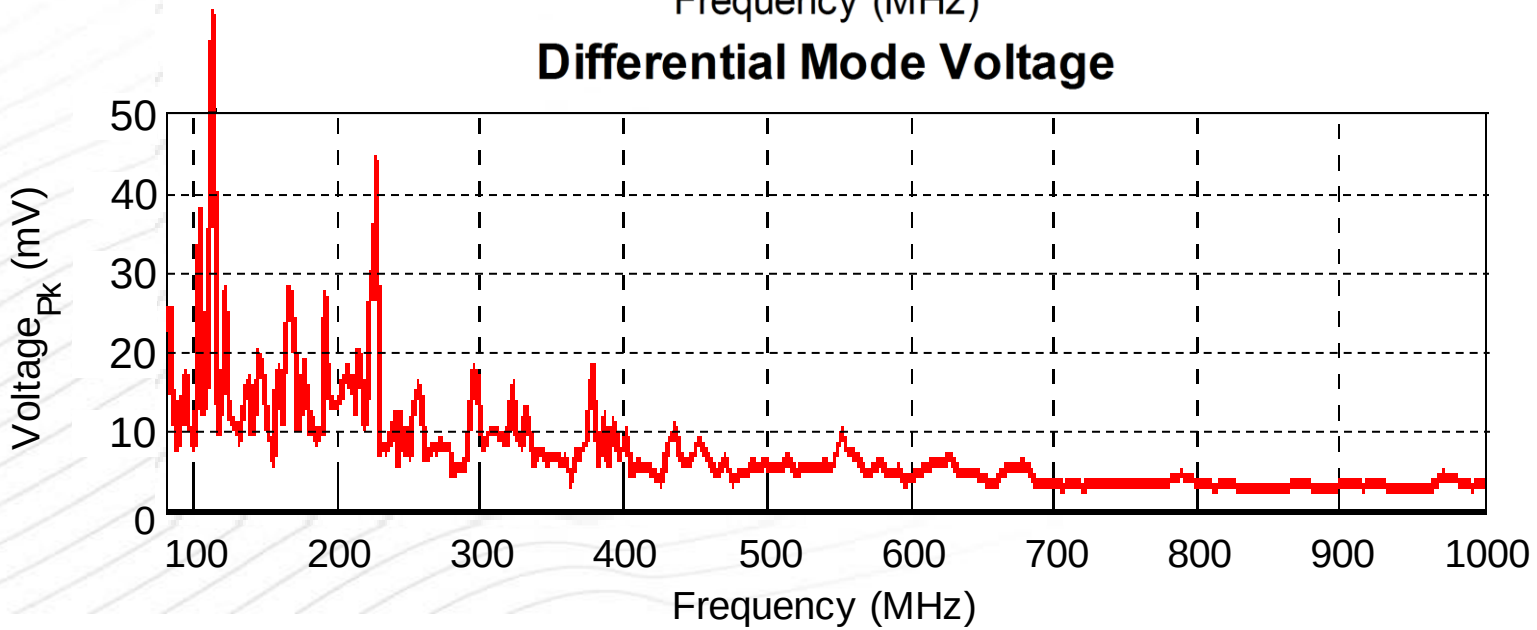
26m CABLE, CAT6a F/UTP, SHIELDED CAT6a RJ45



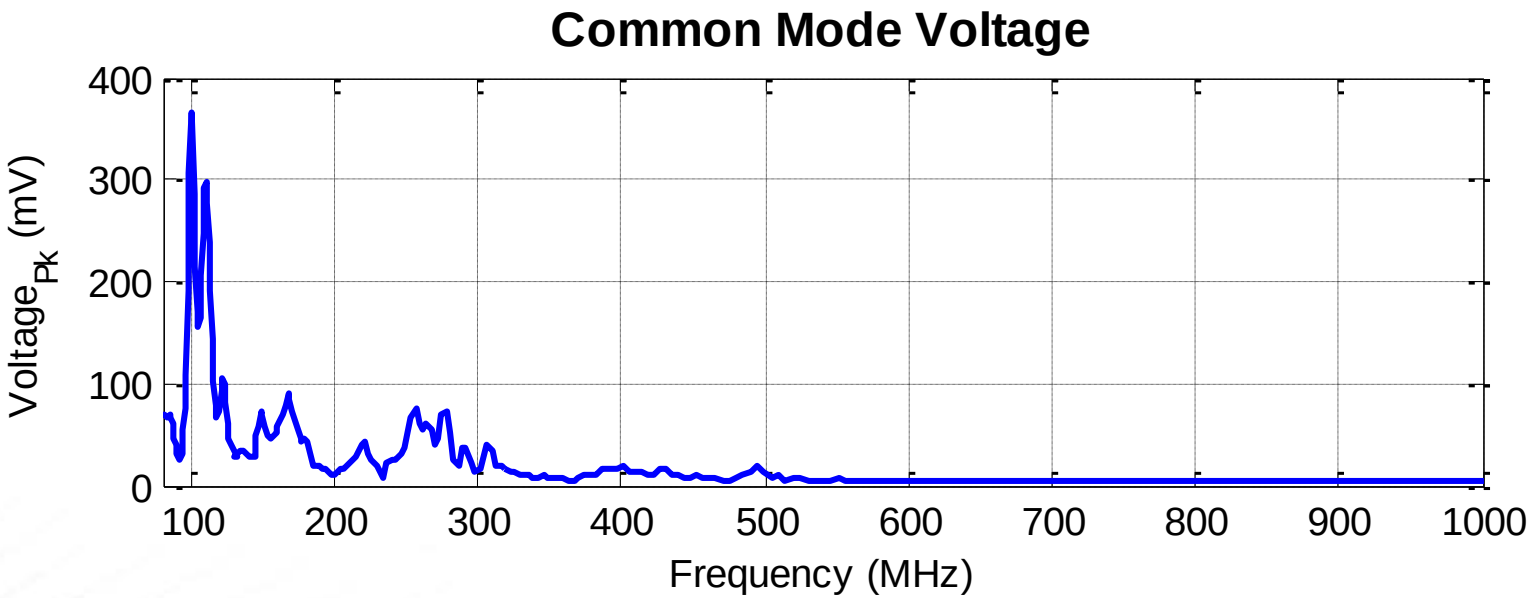


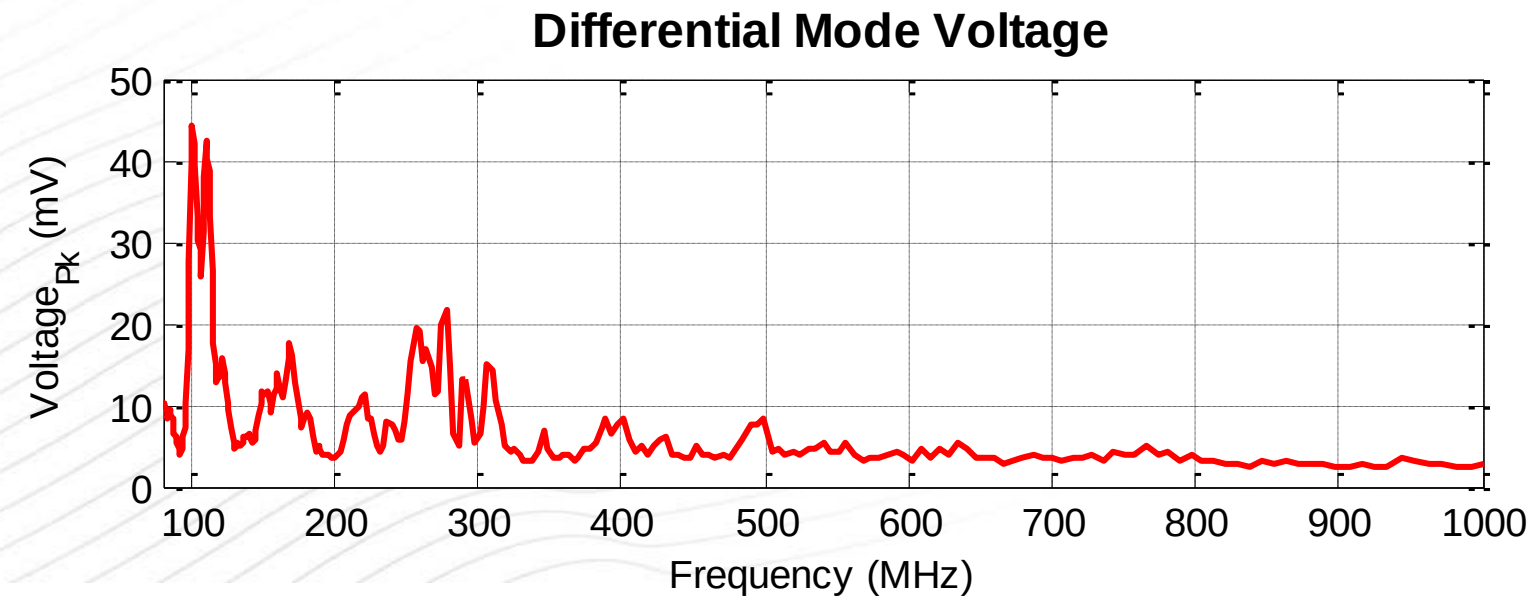
30m CHANNEL, CAT6a S/FTP, SHIELDED CAT6a RJ45 VENDOR A



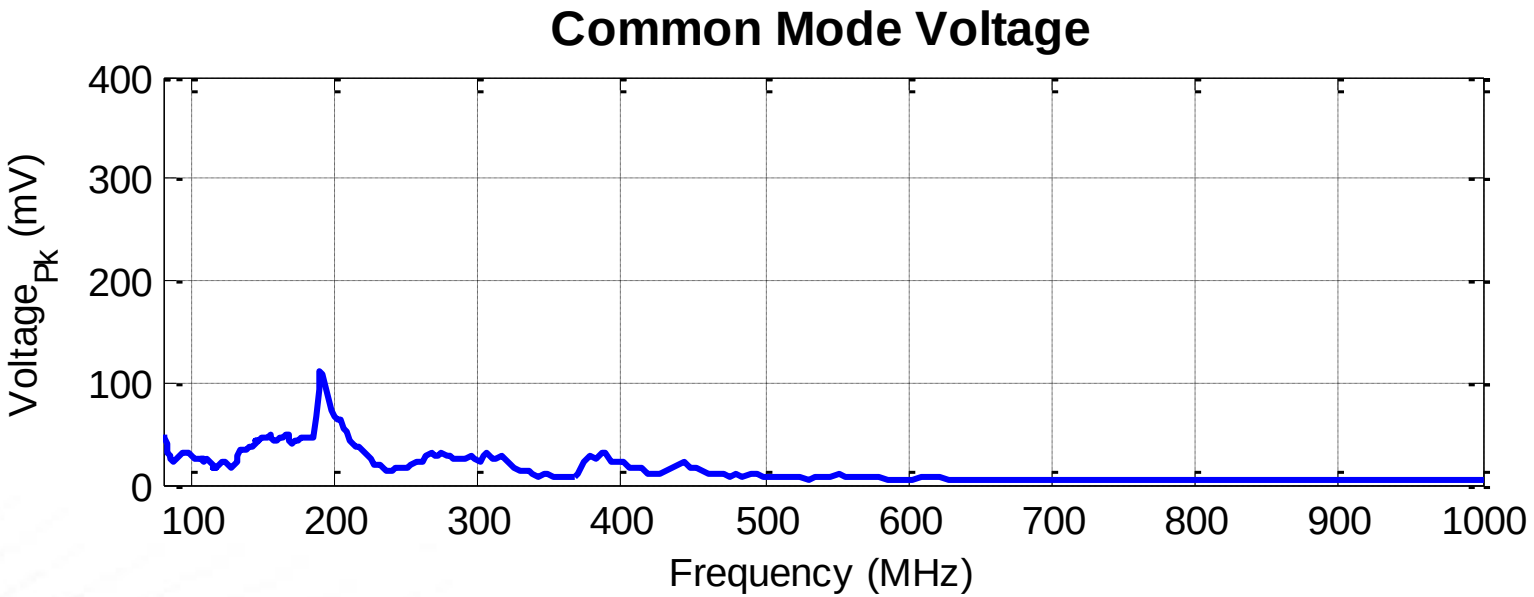


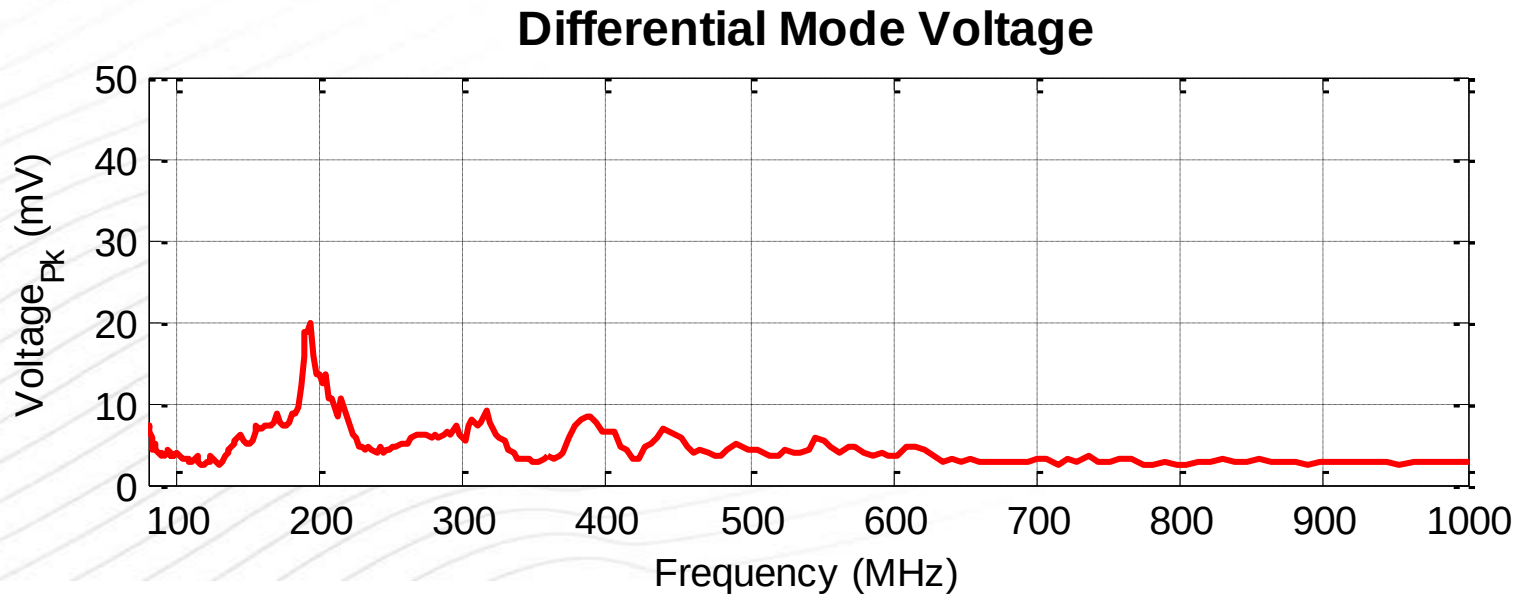
10m CHANNEL, CAT6a S/FTP, SHIELDED CAT6a RJ45 VENDOR A



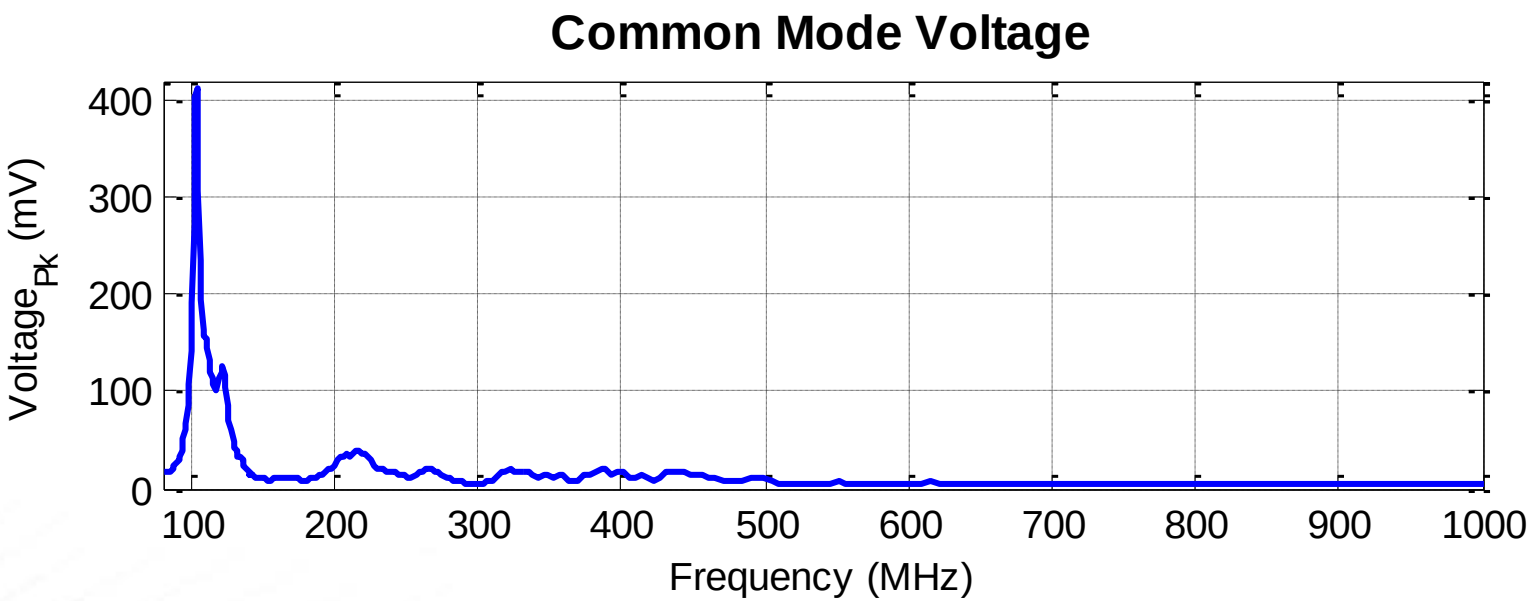


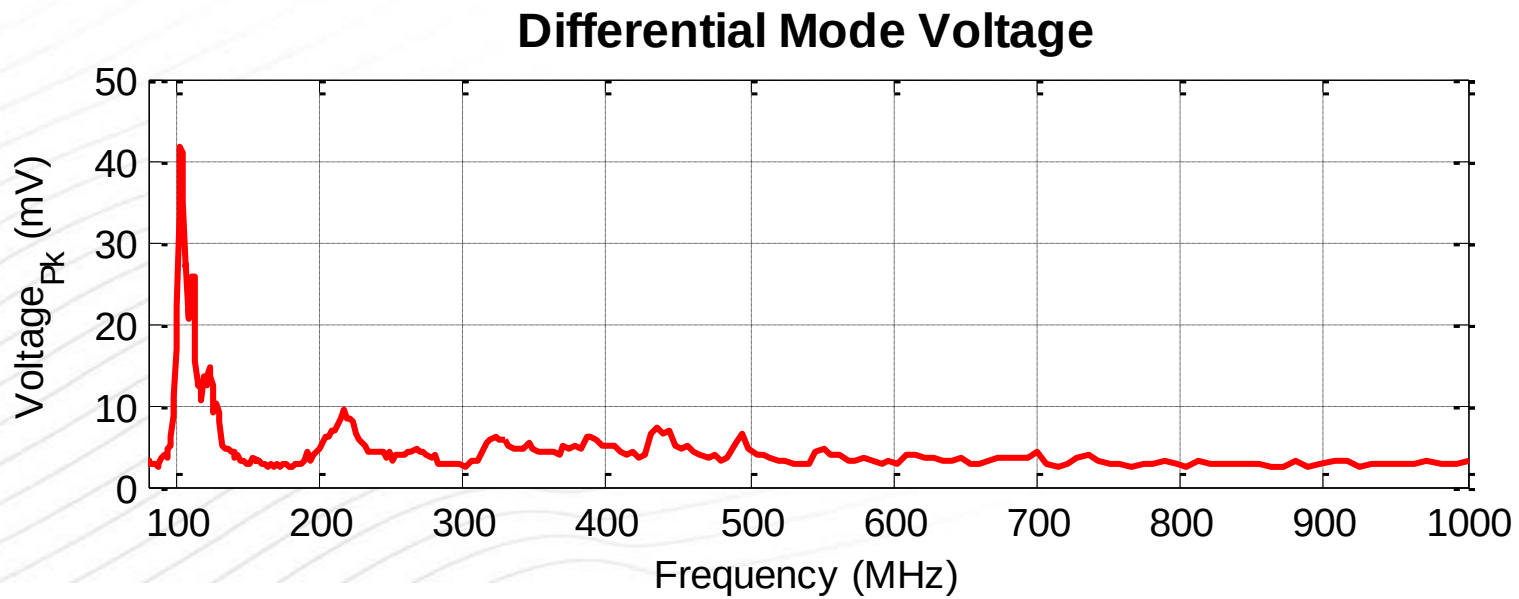
2m CABLE, CAT6a S/FTP, SHIELDED CAT6a RJ45, HANGING DOWN & COILED





2m CABLE, CAT6a S/FTP, SHIELDED CAT6a RJ45, TAPED TO METAL RACK



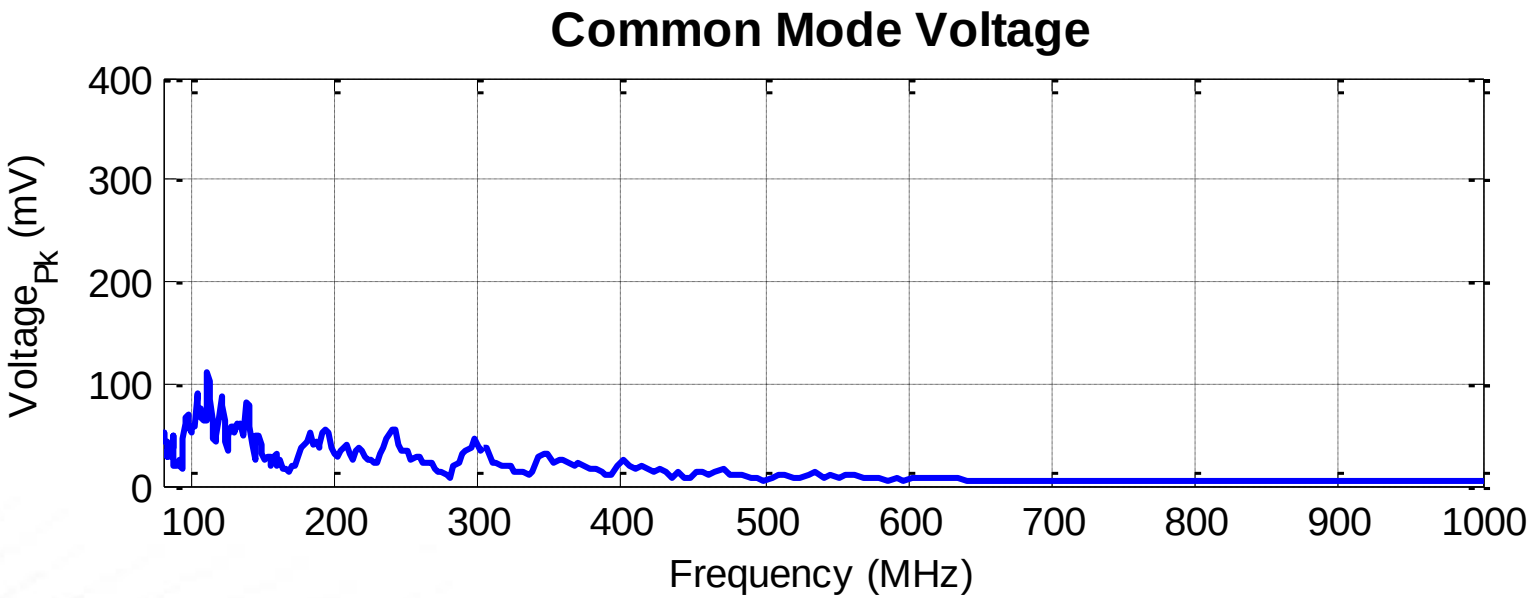


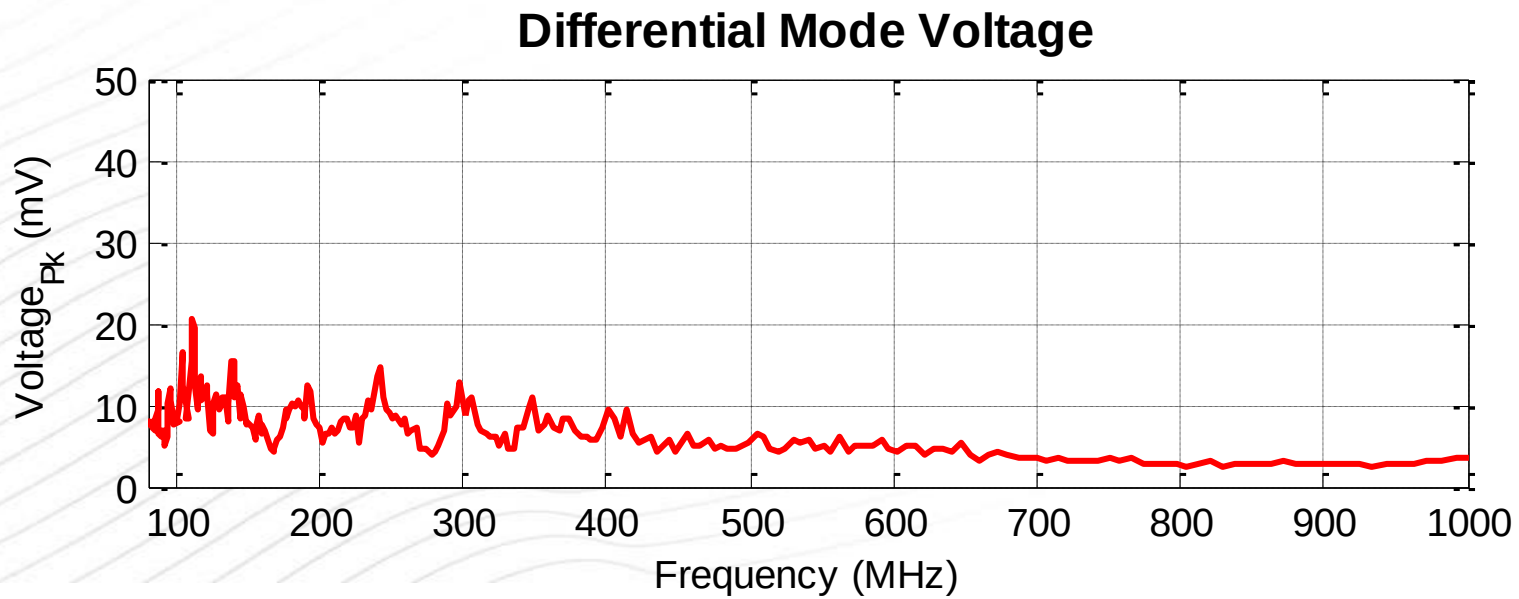
The sharp peak is caused by the cable layout.

It could happen in real tests.

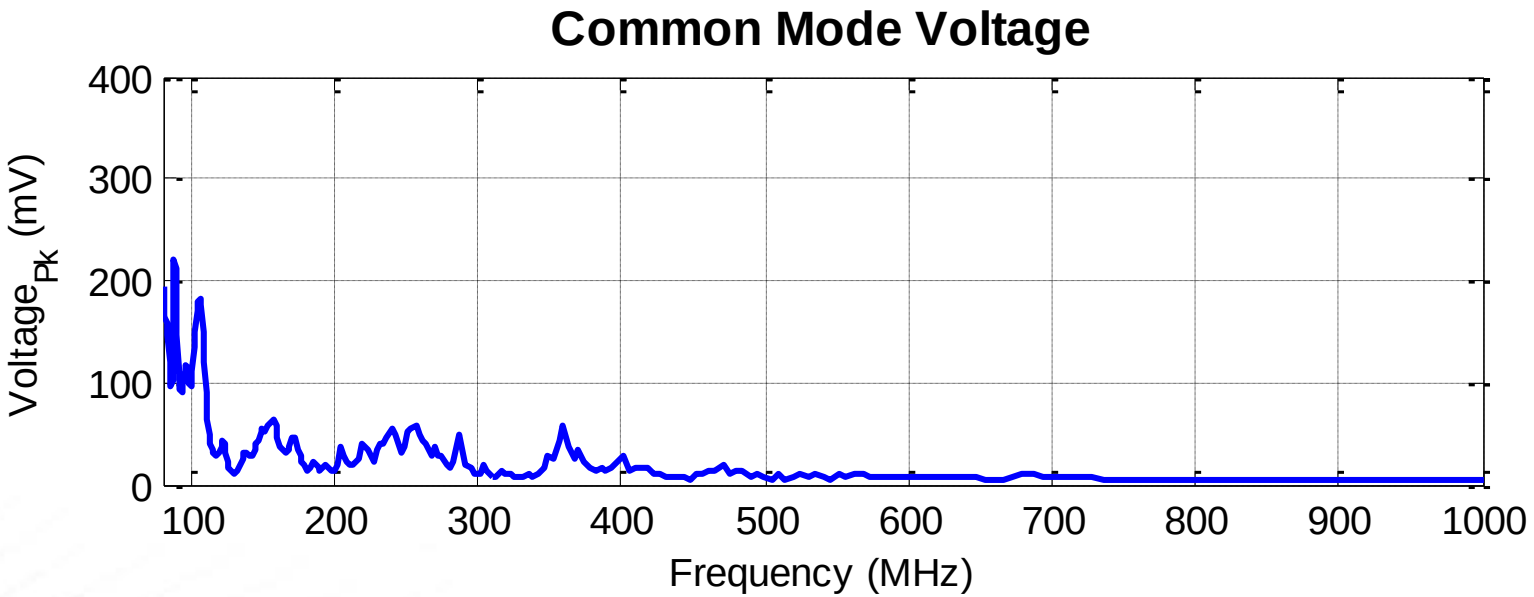
The peak level is about 2x higher than the level with CAT8.2 S/FTP and ARJ45 under the same conditions.

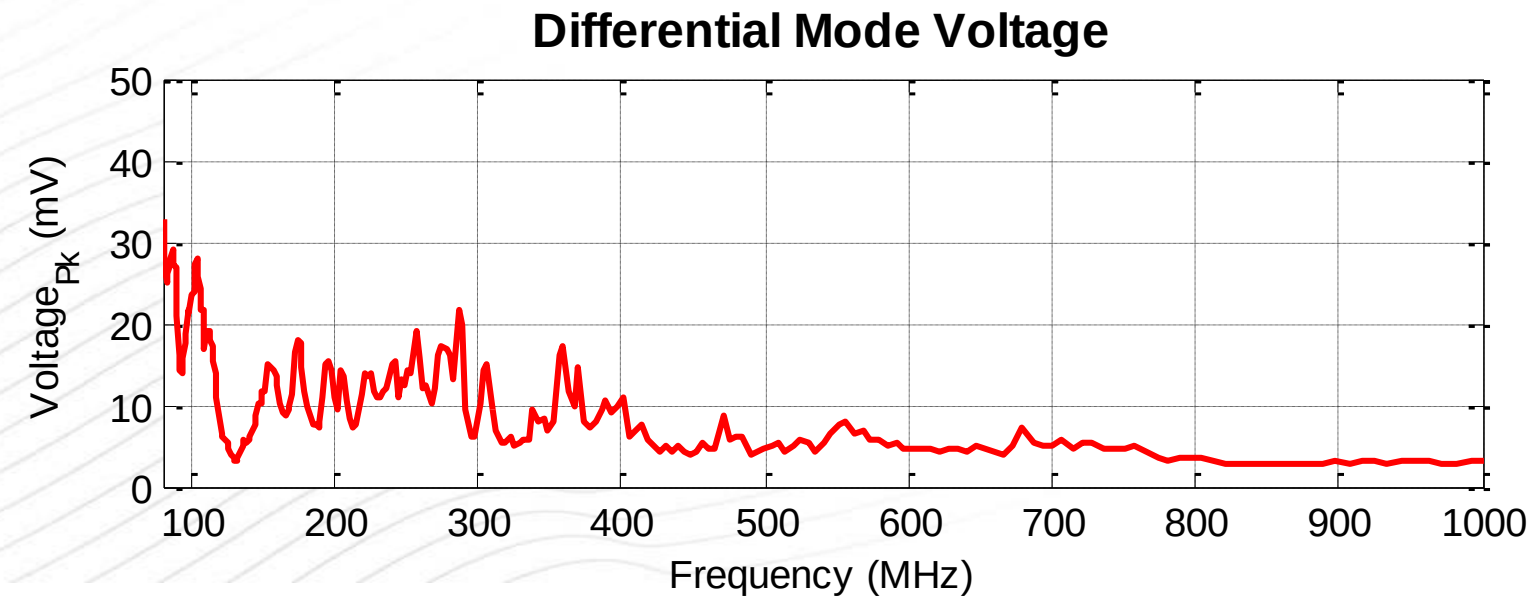
30m CHANNEL, CAT6a S/FTP, SHIELDED CAT6a RJ45 VENDOR B





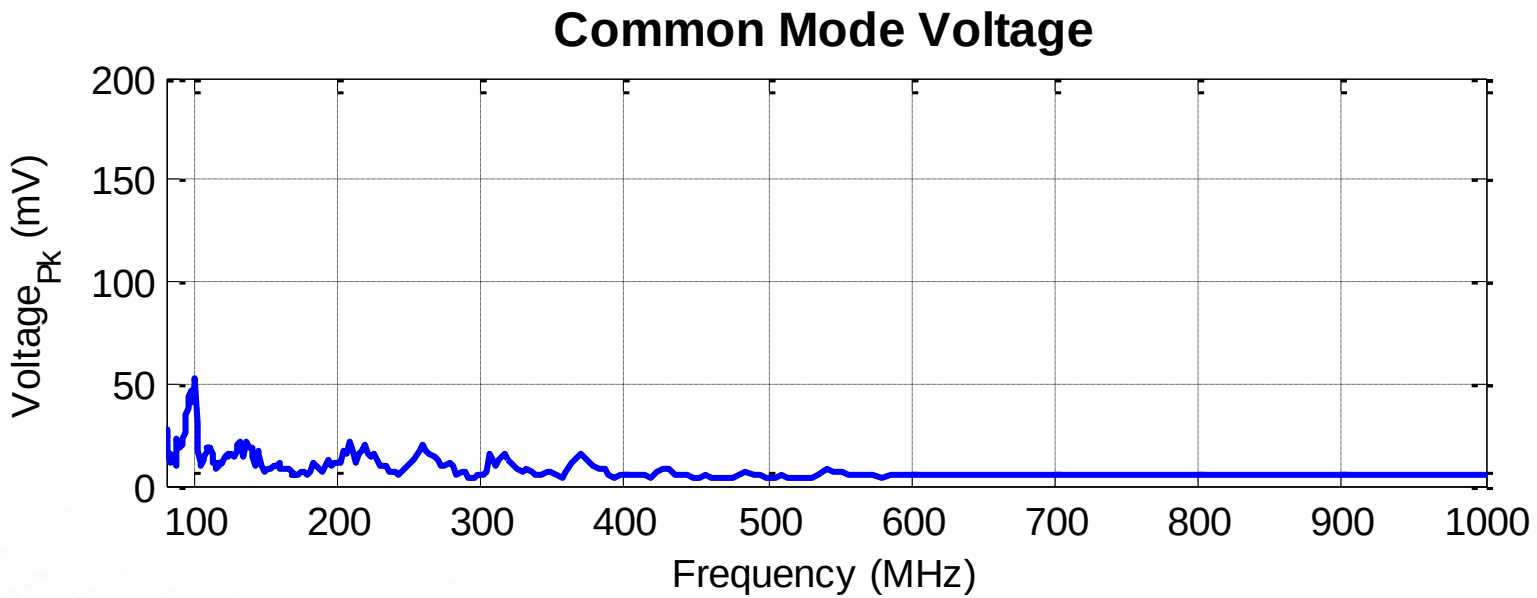
10m CHANNEL, CAT6a S/FTP, SHIELDED CAT6a RJ45 VENDOR B

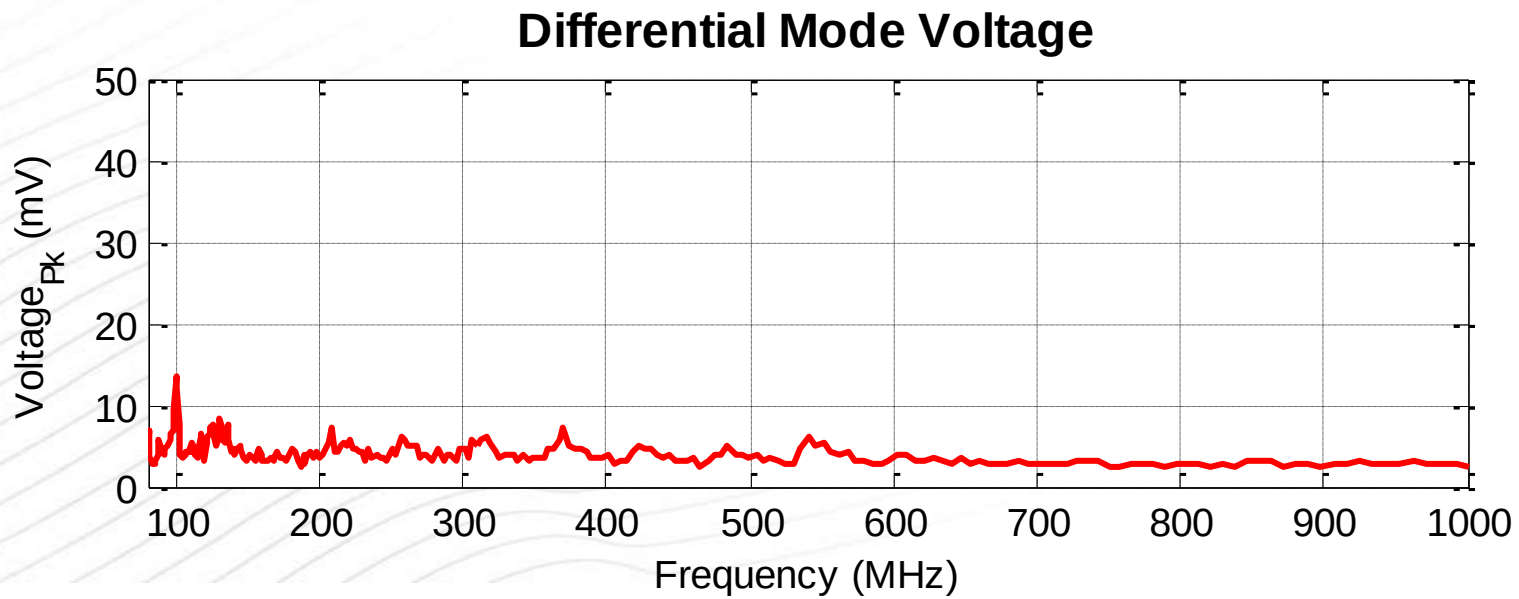




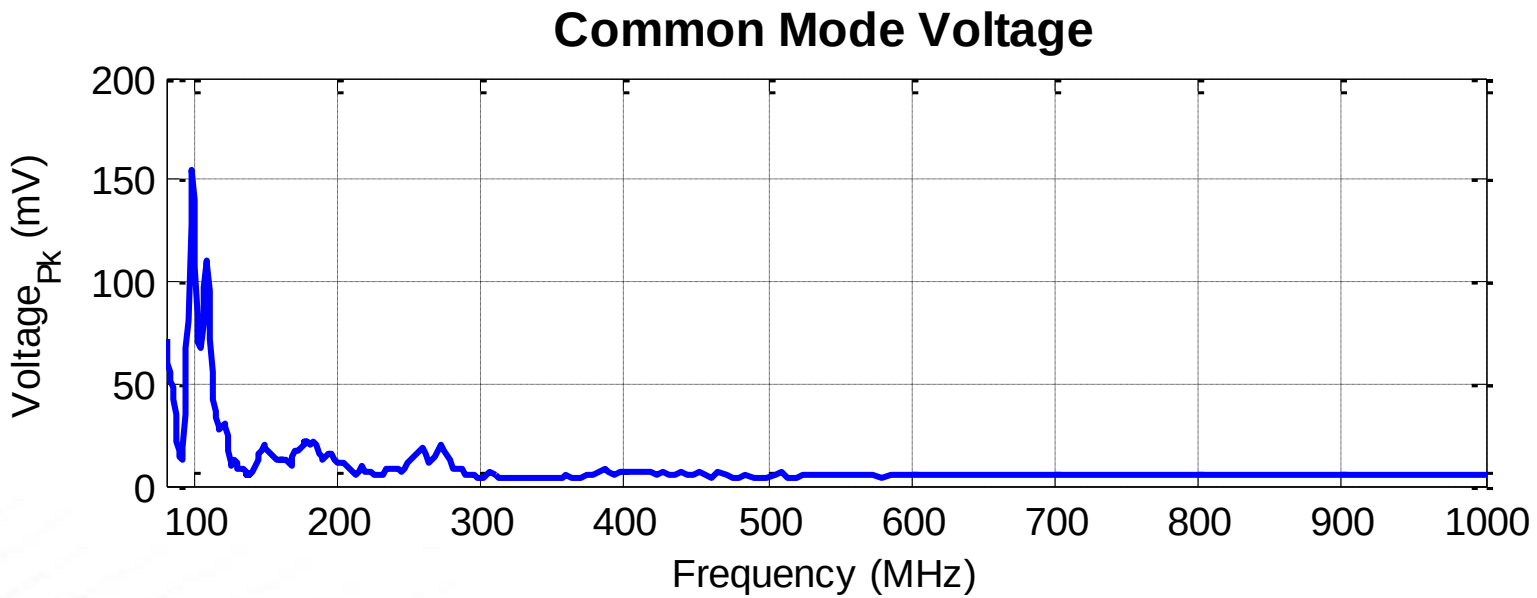
CAT7a S/FTP
Shielded CAT6a RJ45 and TERA Connectors

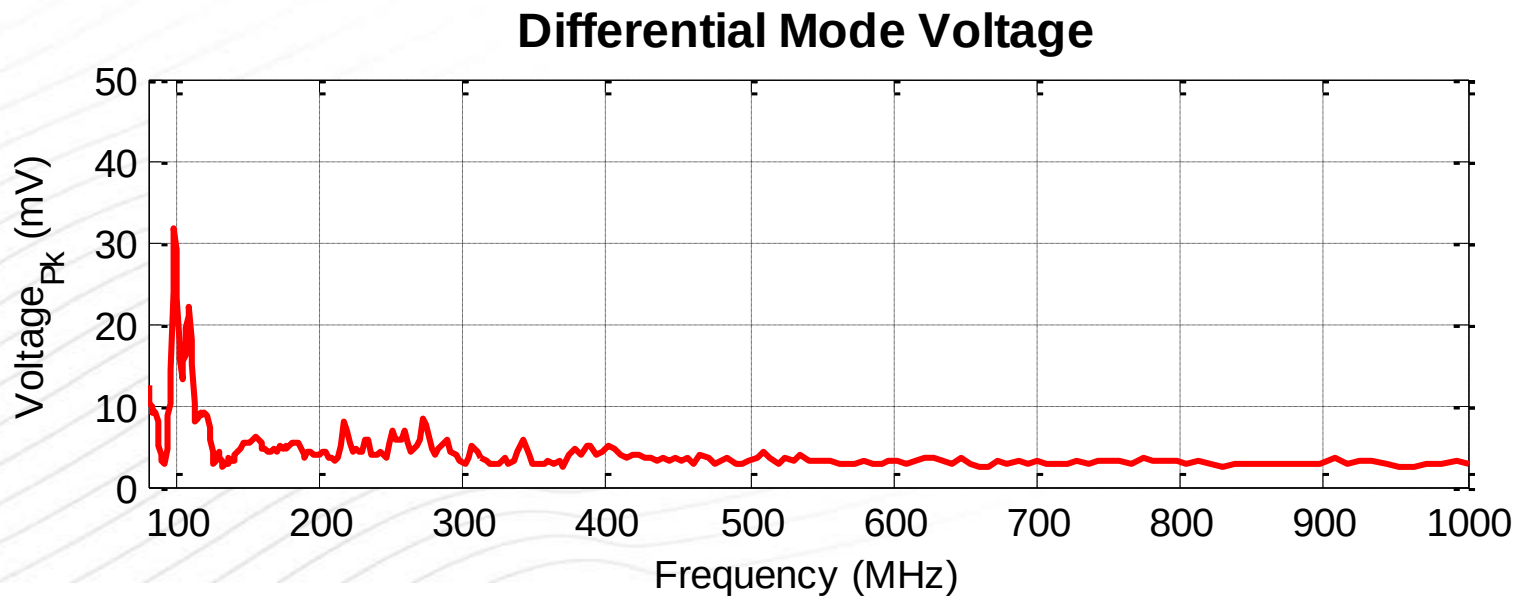
30m CHANNEL, CAT7a S/FTP, SHIELDED CAT6a RJ45
2 Female-Female shielded inline couplers



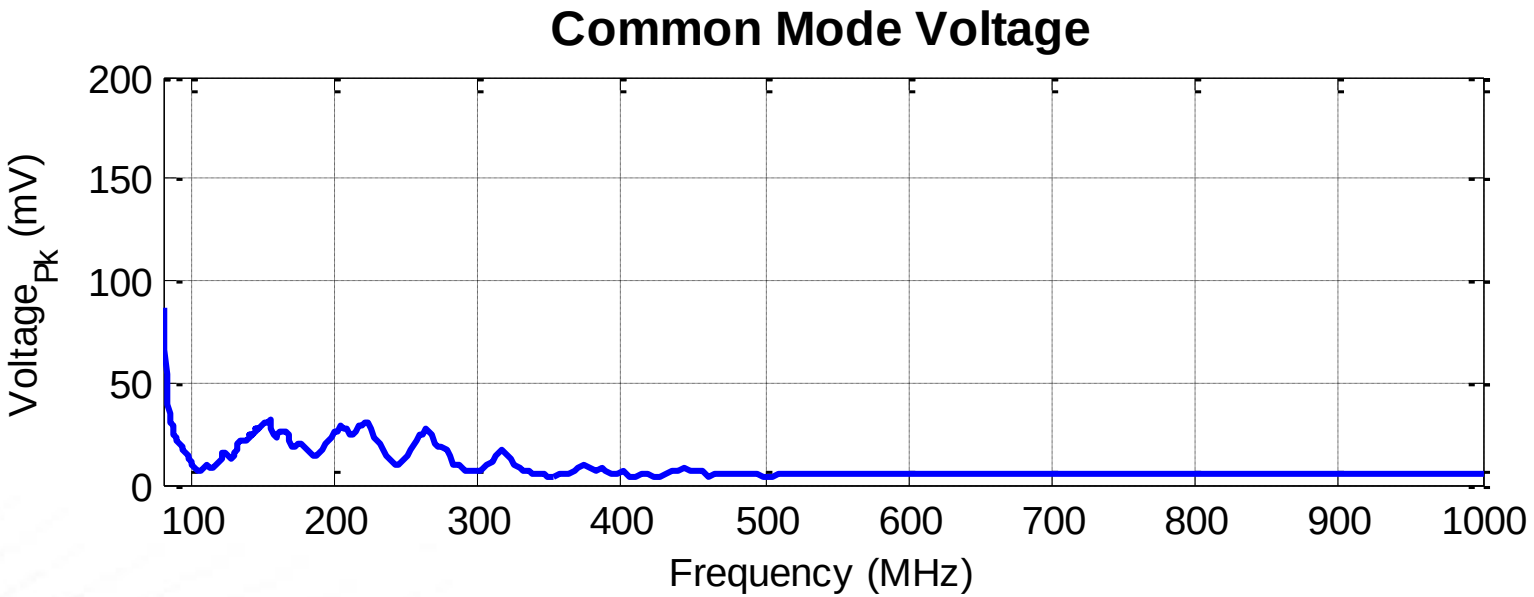


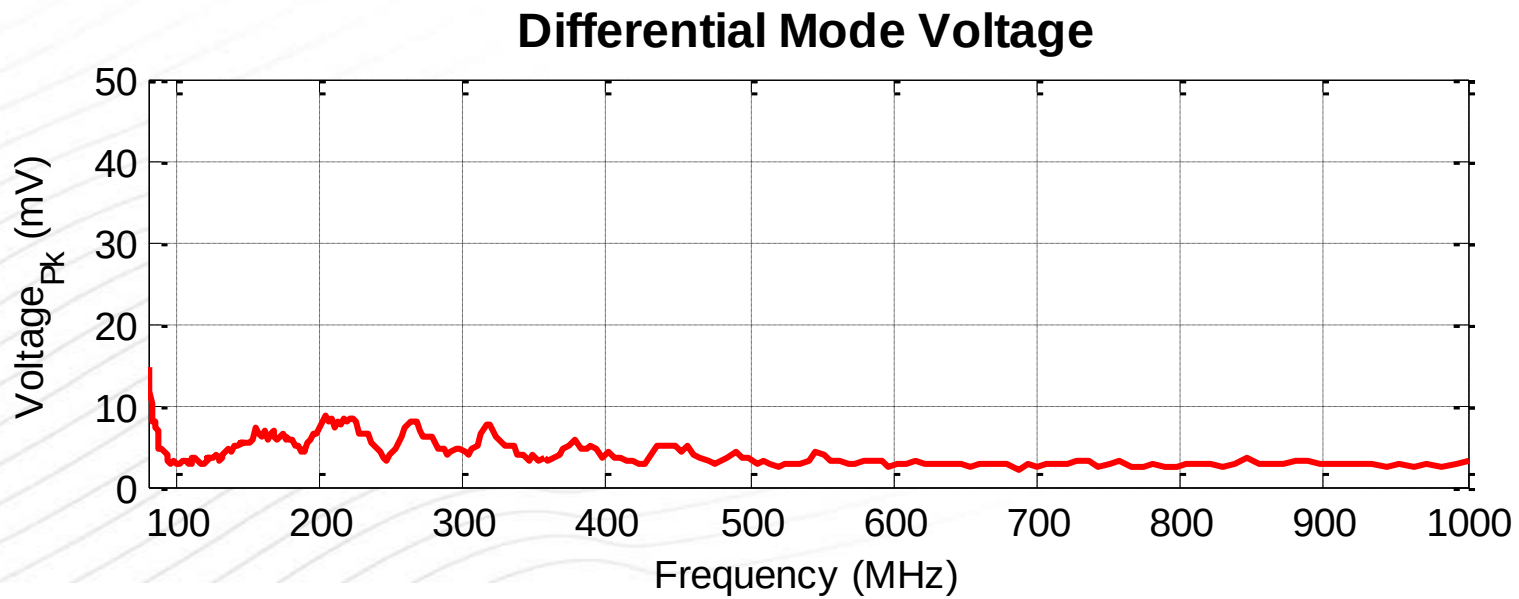
10m CHANNEL, CAT7a S/FTP, SHIELDED CAT6a RJ45
2 Female-Female shielded inline couplers



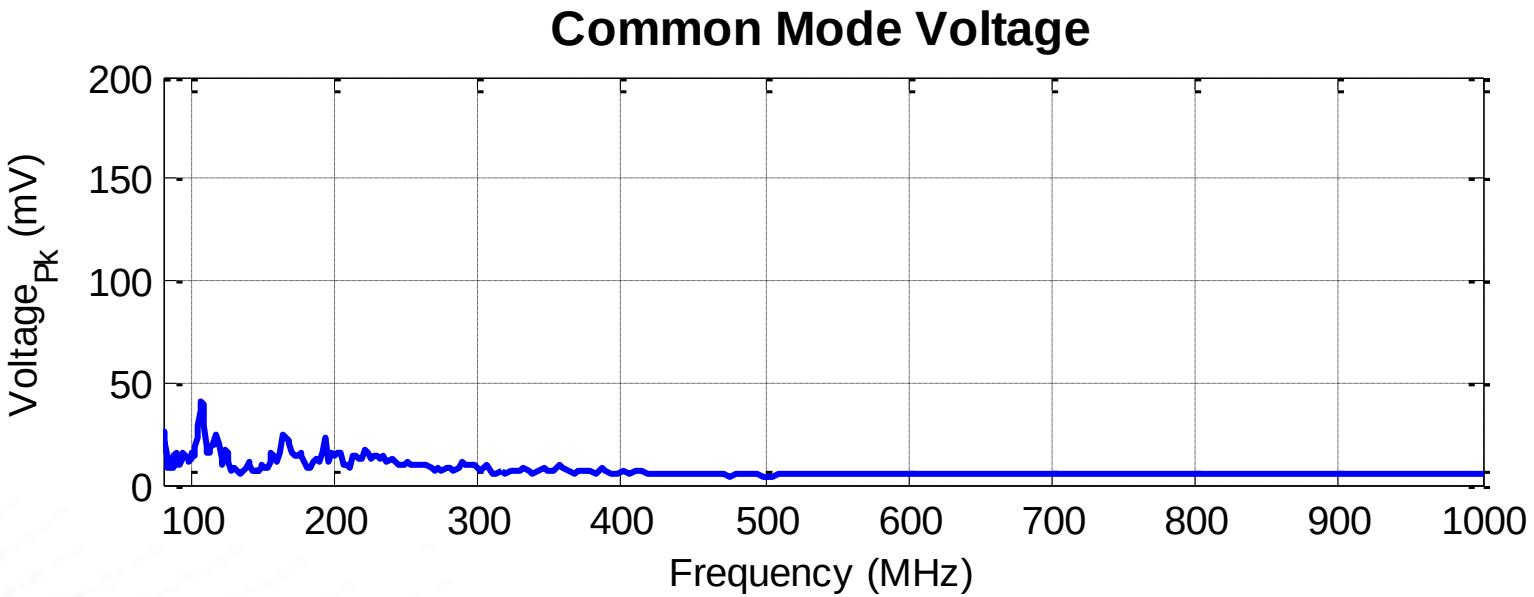


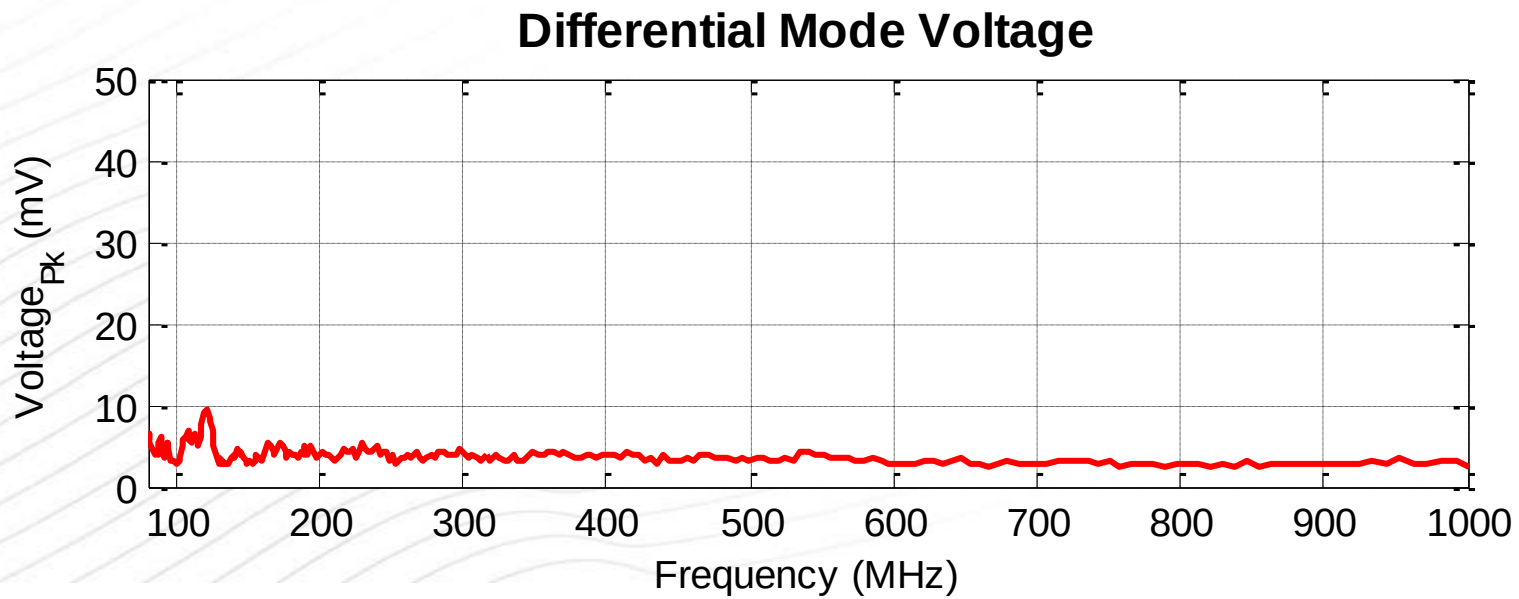
2m CABLE, CAT7a S/FTP, SHIELDED CAT6a RJ45, HANGING DOWN & COILED



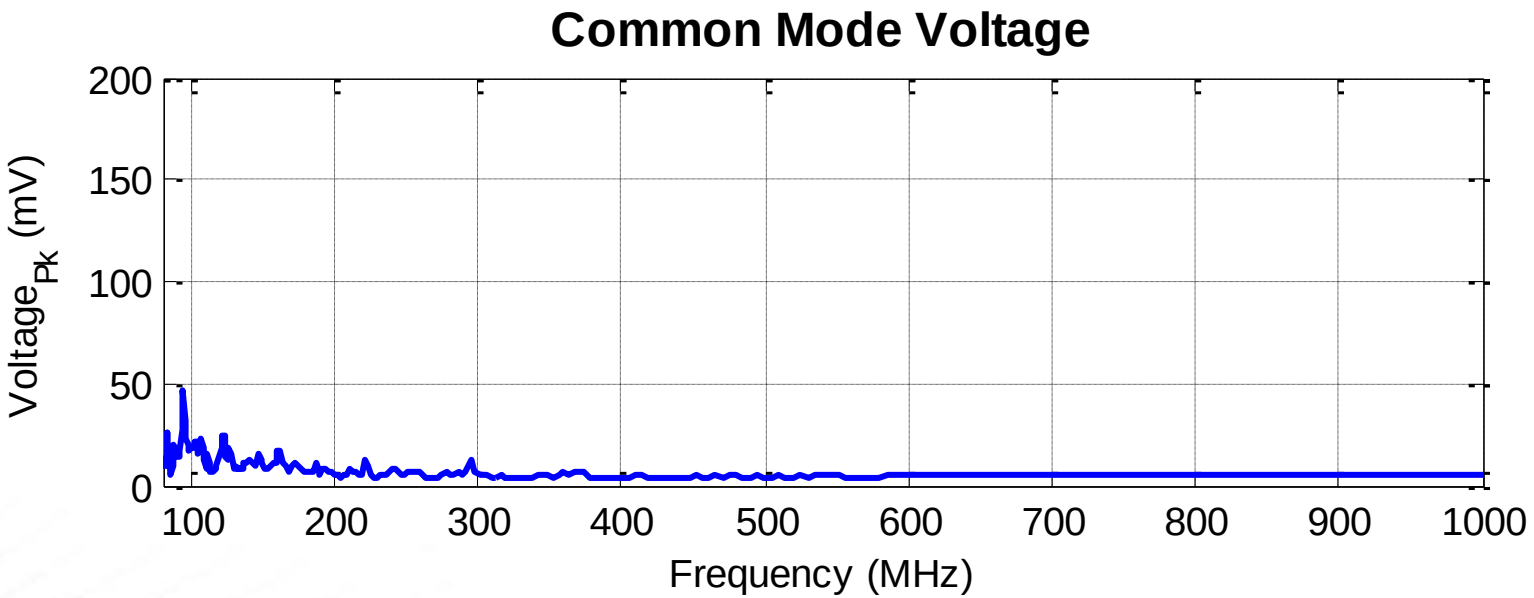


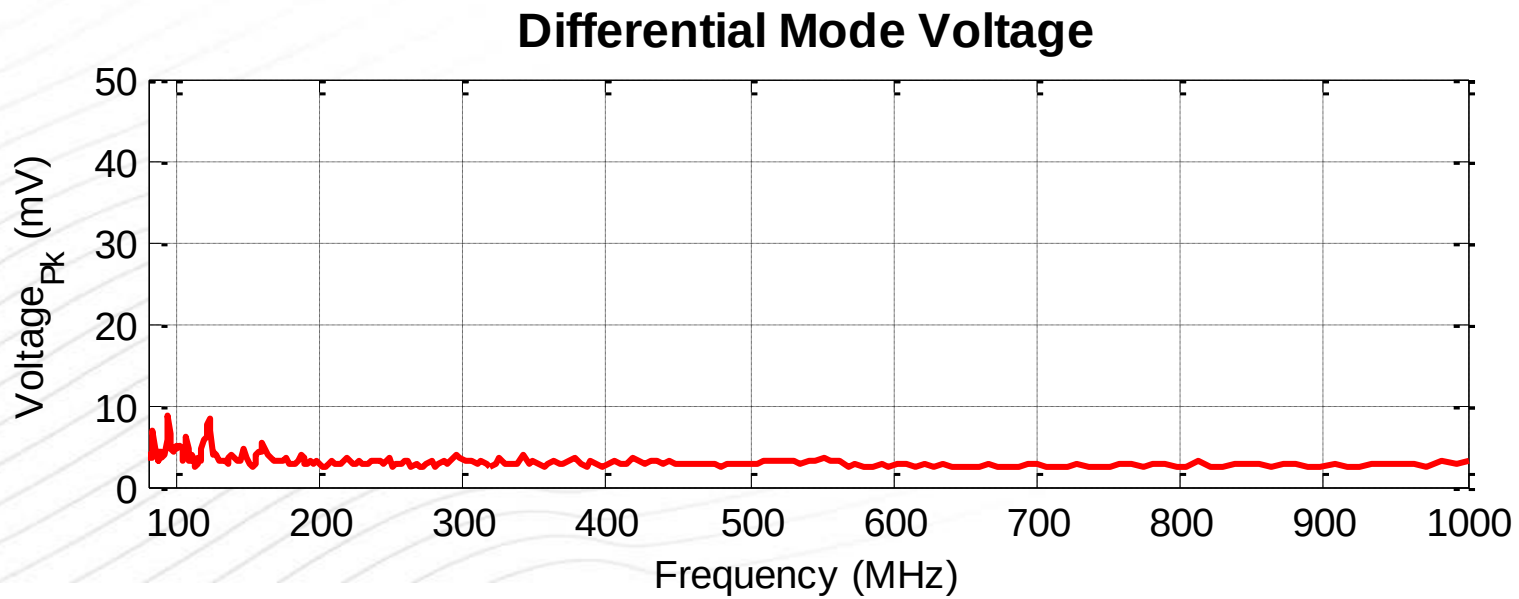
26m CABLE, CAT7a S/FTP, SHIELDED CAT6a RJ45



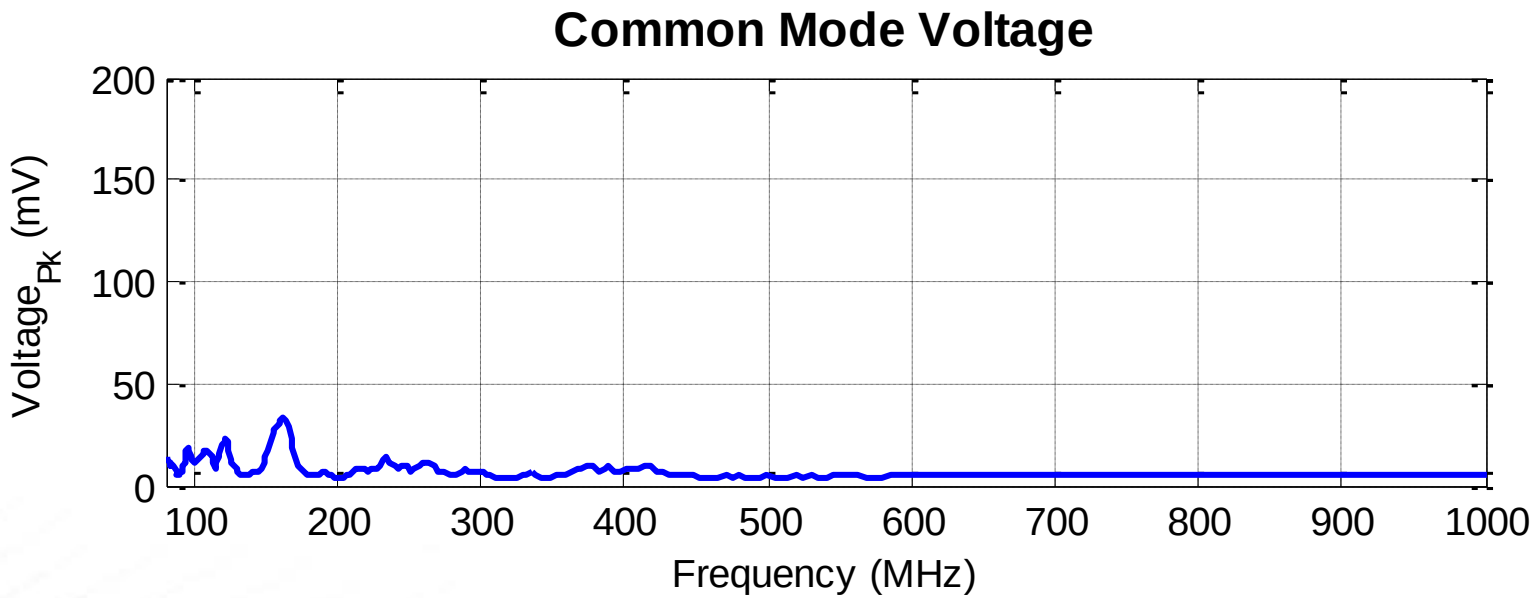


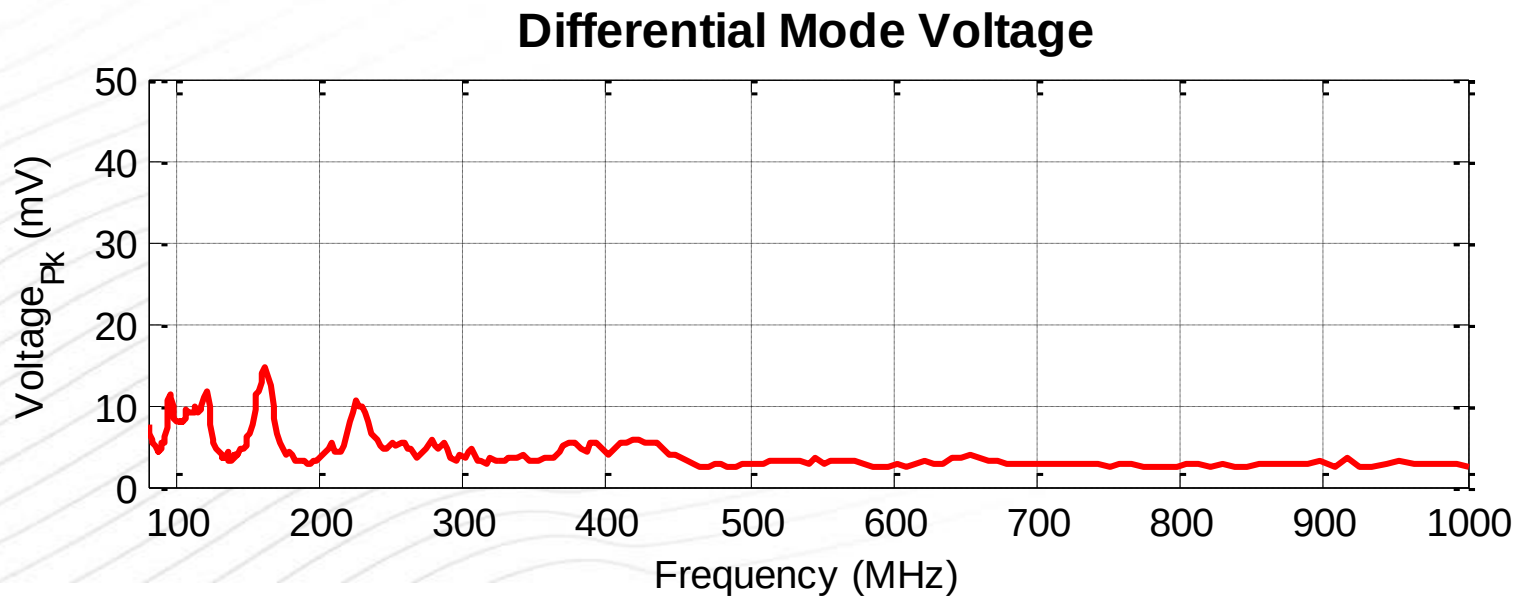
30m CHANNEL, CAT7a S/FTP, TERA CONNECTOR





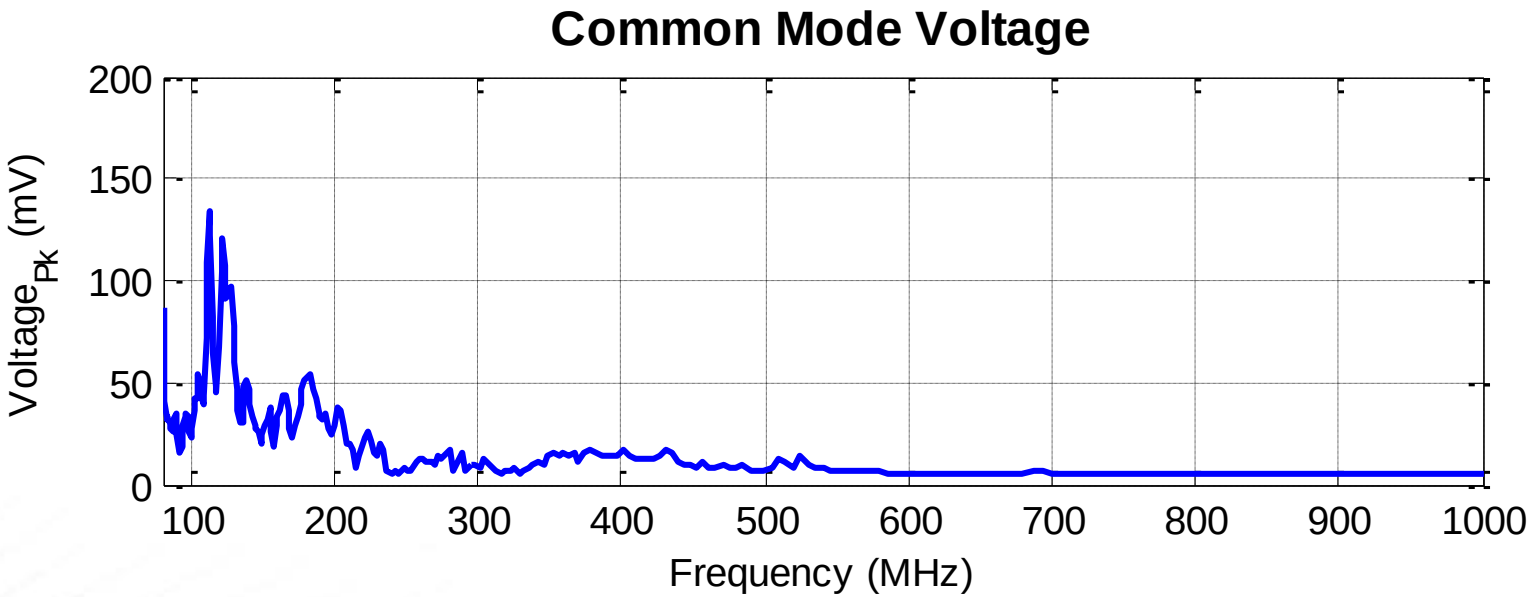
10m CHANNEL, CAT7a S/FTP, TERA CONNECTOR

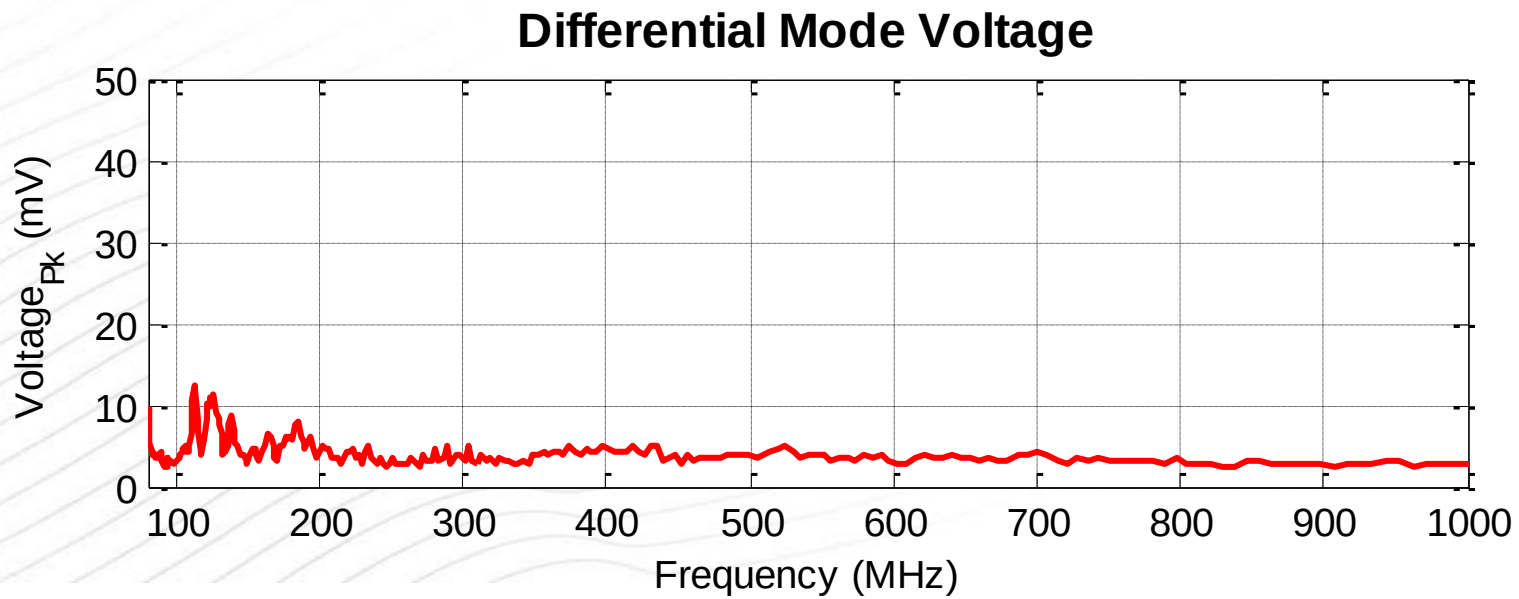




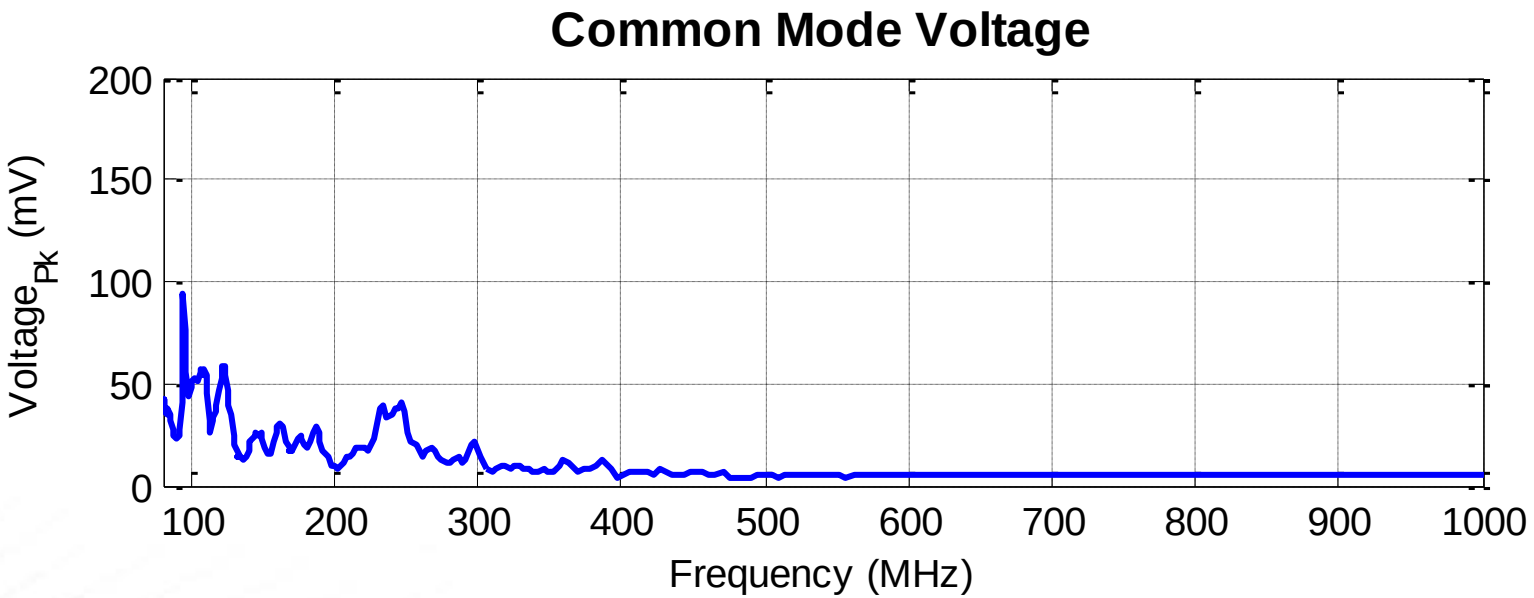
CAT8.2 S/FTP
Shielded ARJ45 Connectors

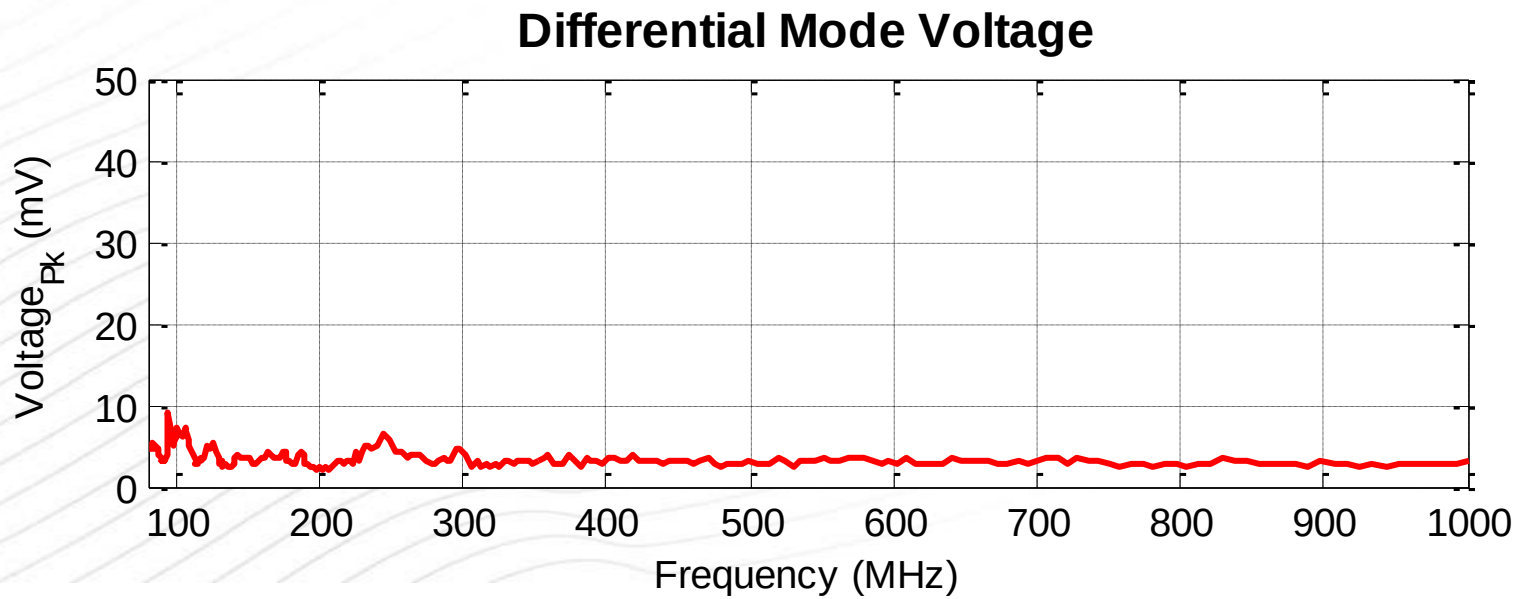
30m CHANNEL, CAT8.2 S/FTP, SHIELDED ARJ45
2 Female-Female shielded inline couplers



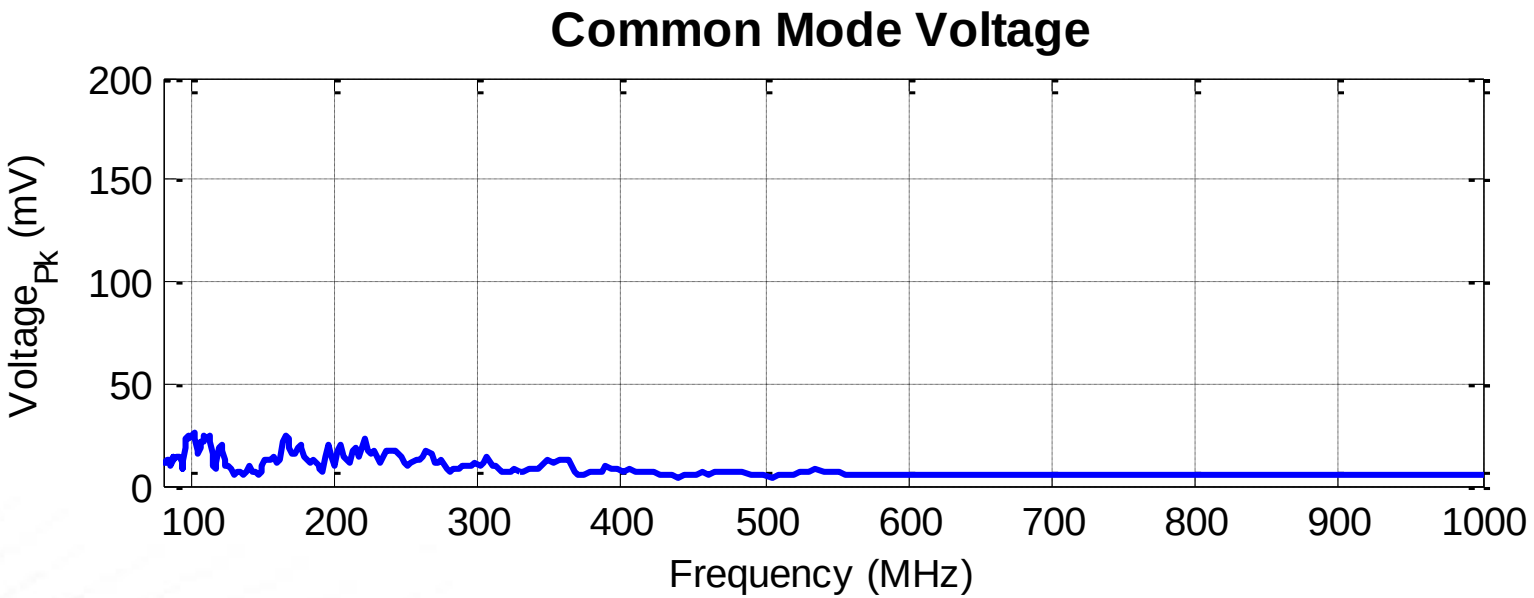


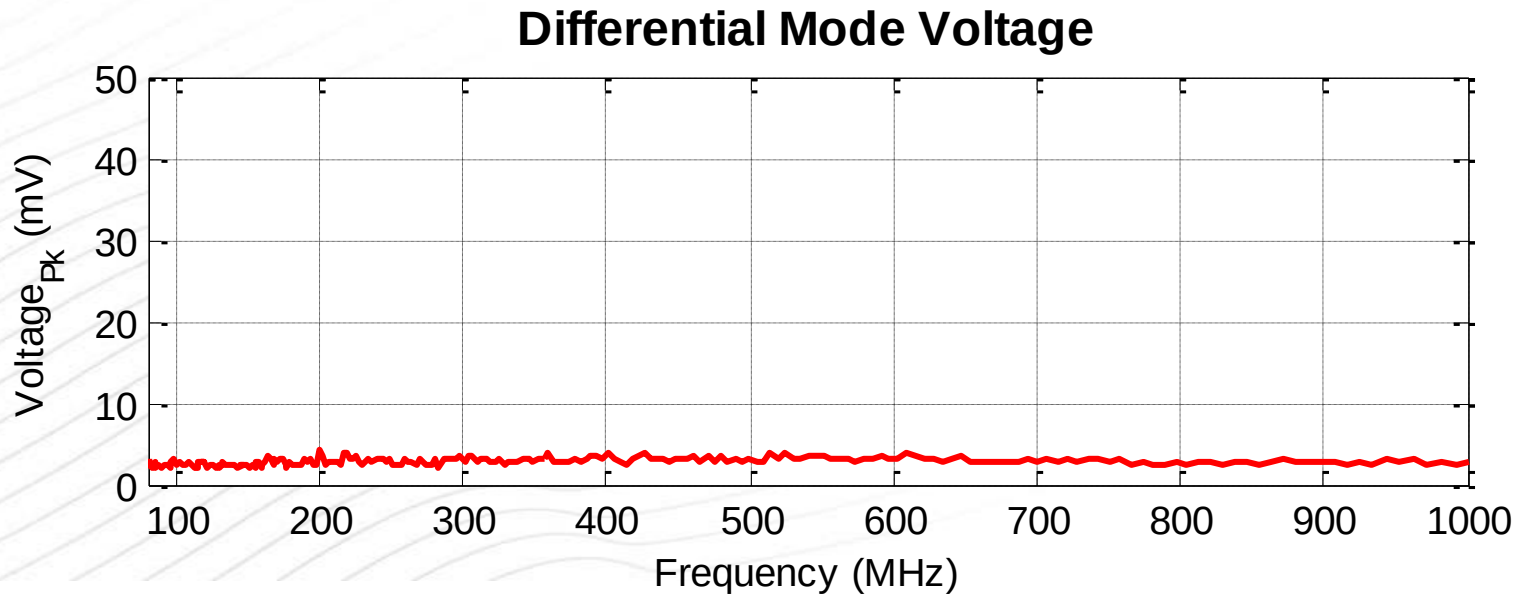
10m CHANNEL, CAT8.2 S/FTP, SHIELDED ARJ45
2 Female-Female shielded inline couplers



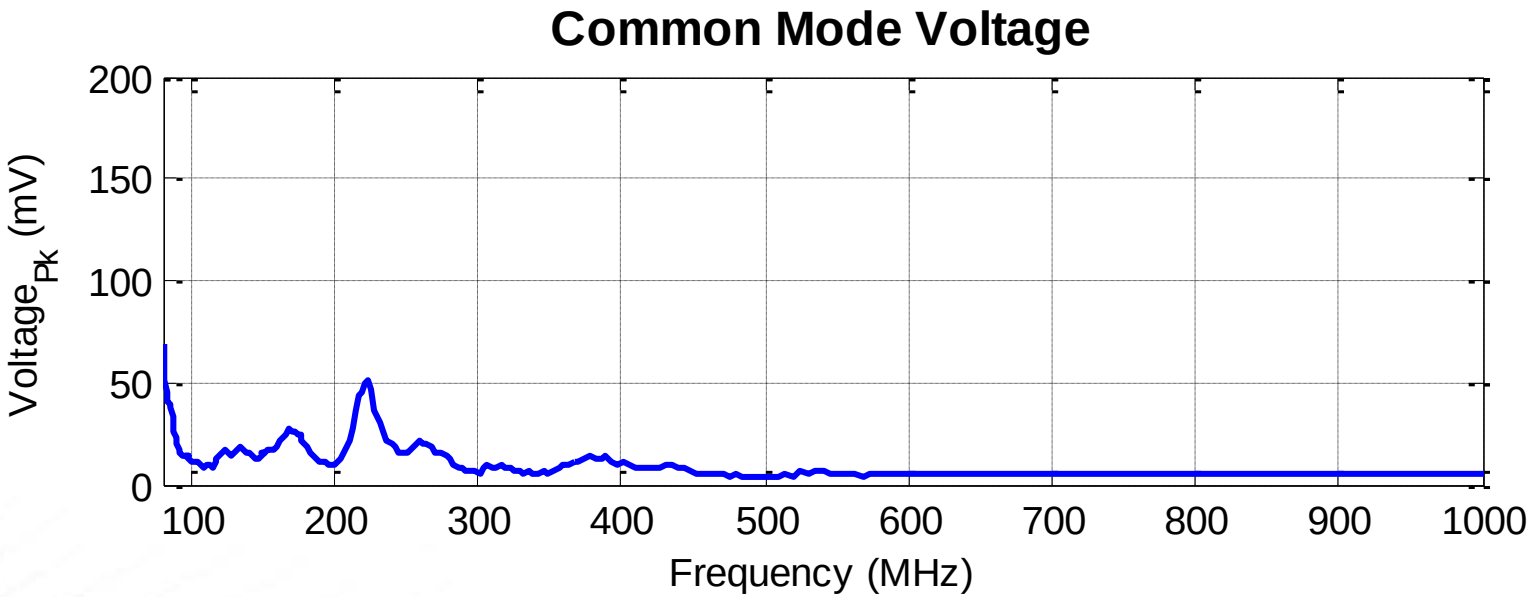


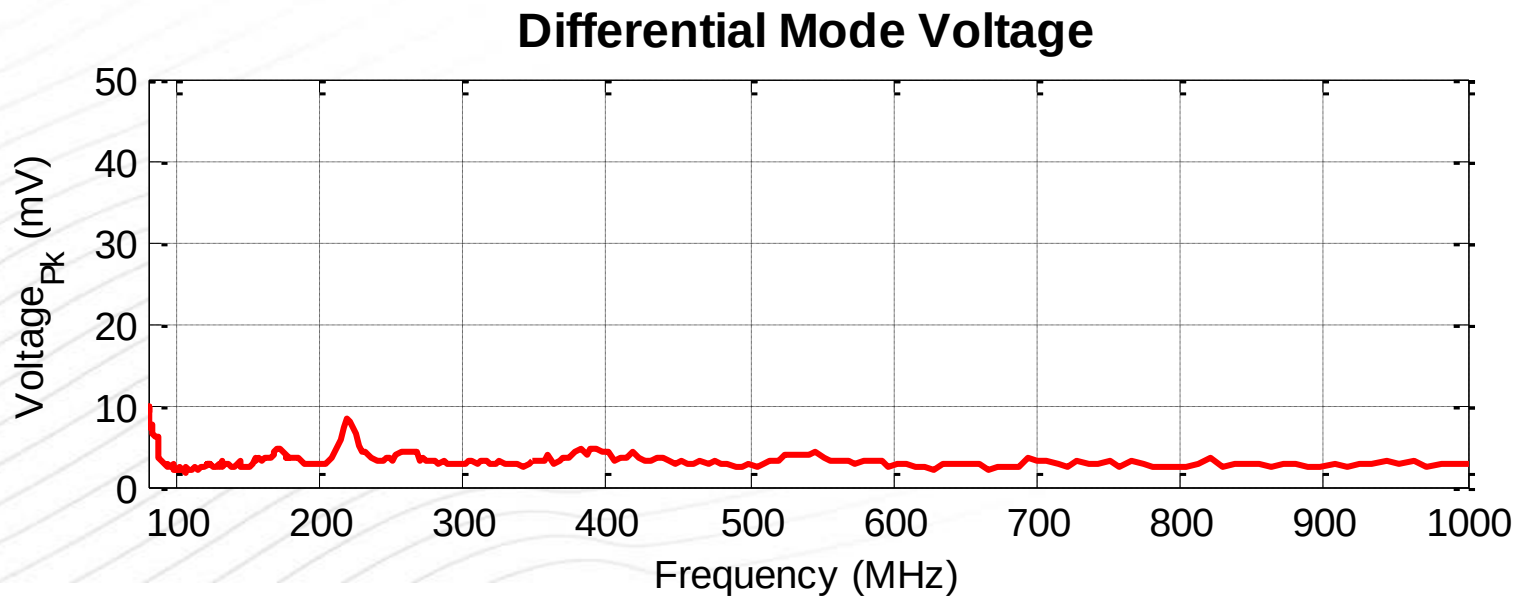
26m CABLE, CAT8.2 S/FTP, SHIELDED ARJ45



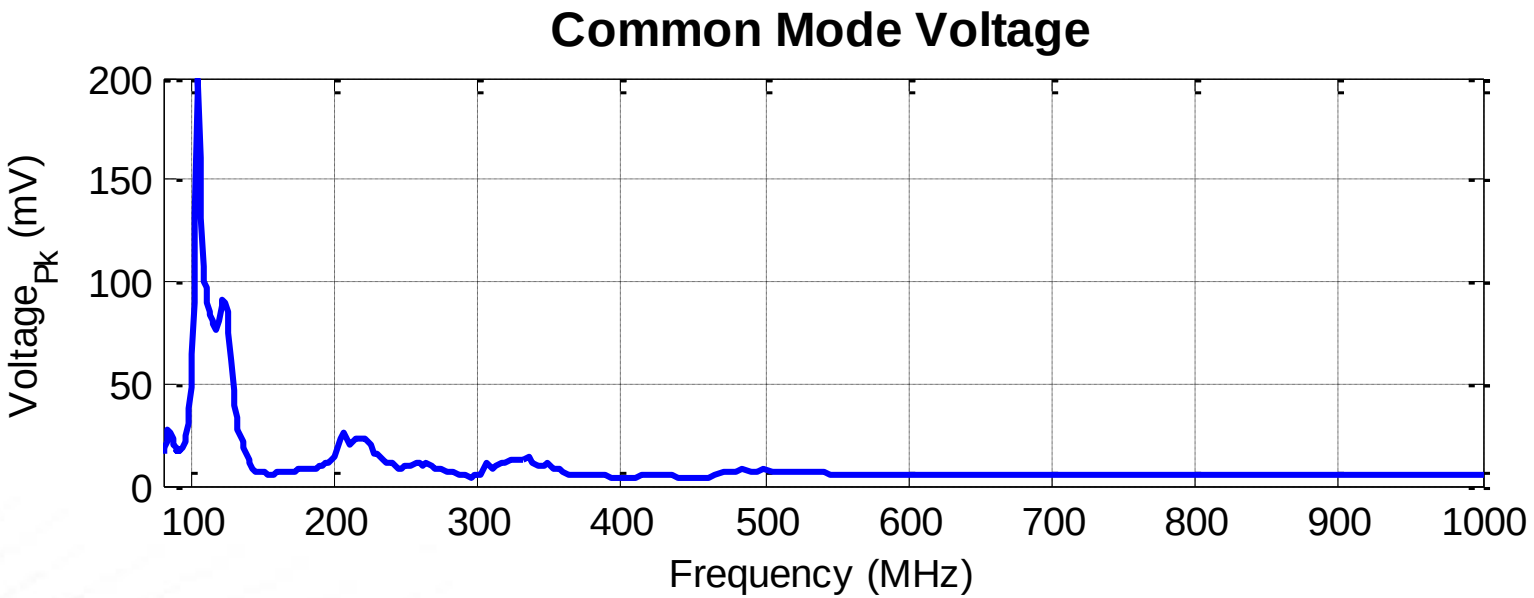


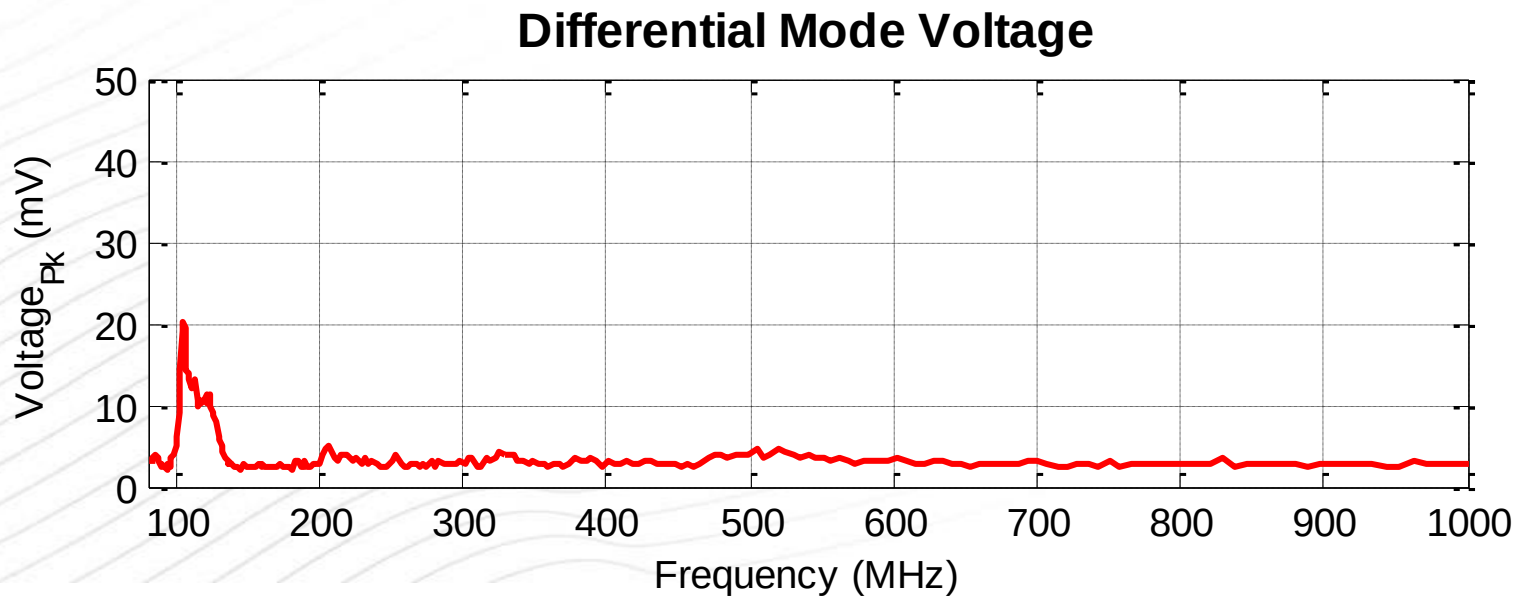
2m CABLE, CAT8.2 S/FTP, SHIELDED ARJ45, HANGING DOWN & COILED





2m CABLE, CAT8.2 S/FTP, SHIELDED ARJ45, TAPED TO METAL RACK





The sharp peak is caused by the cable layout.

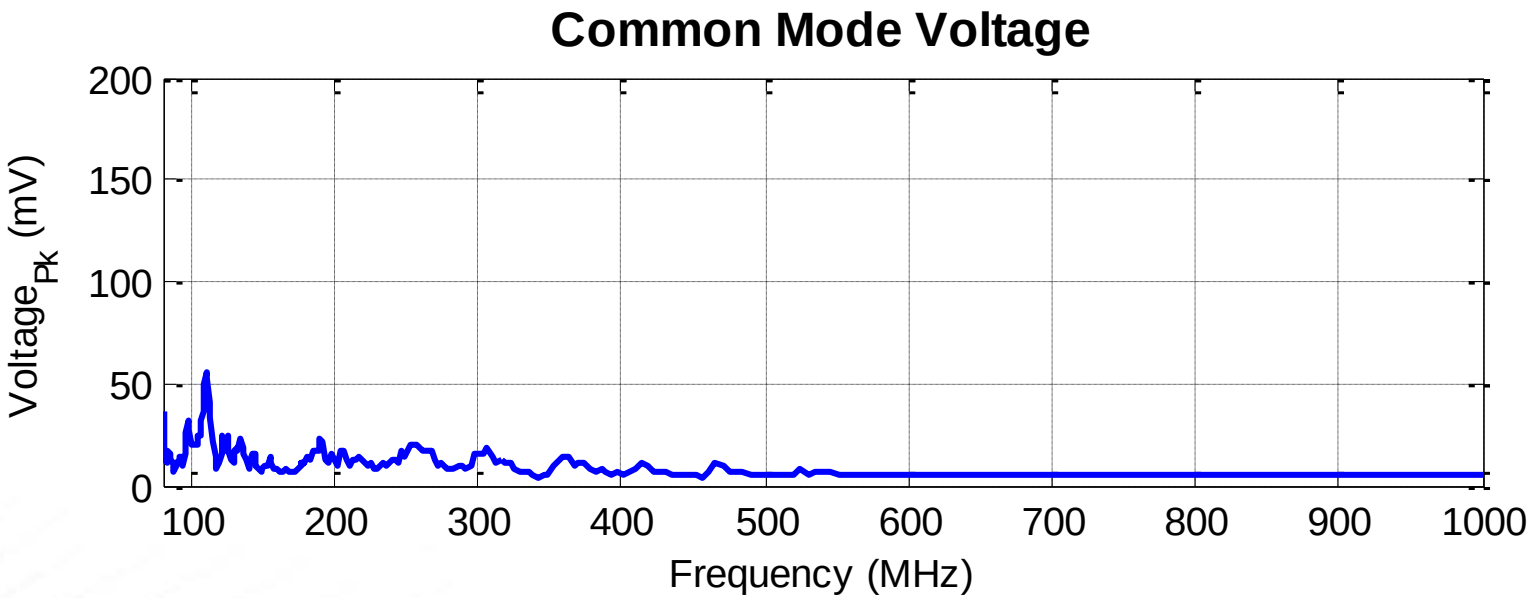
It could happen in real tests.

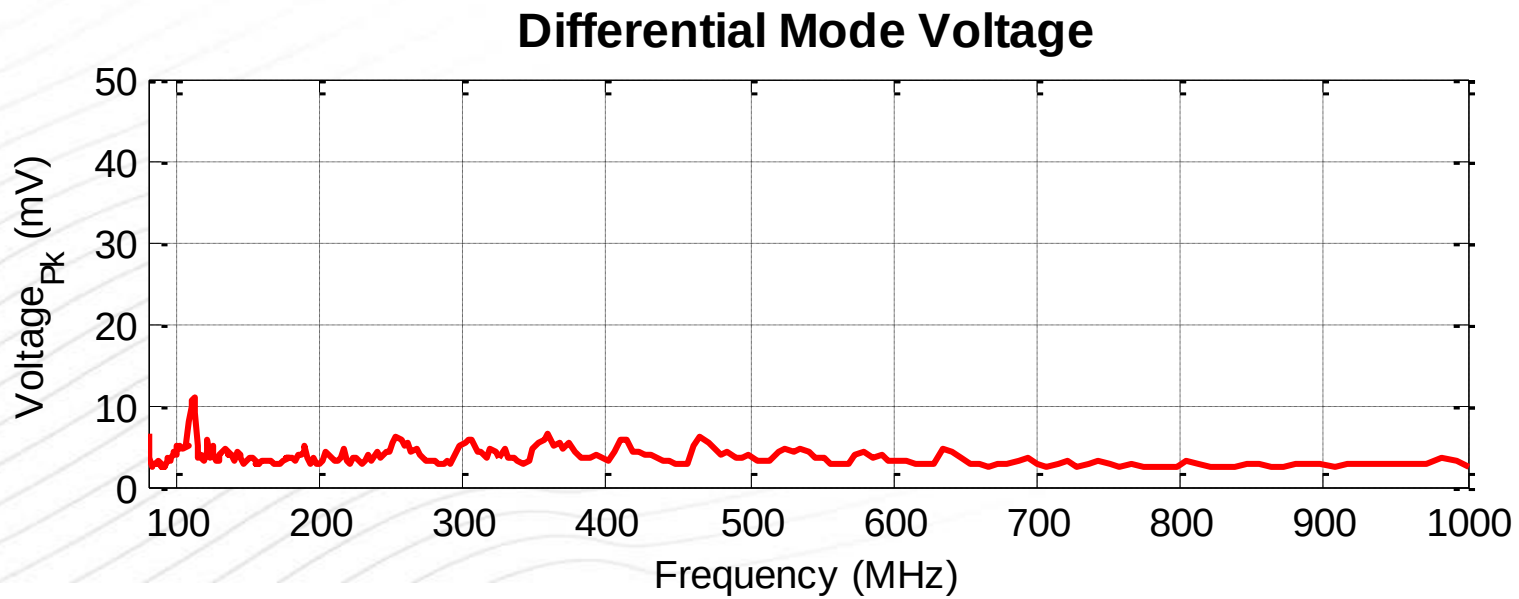
The peak level is about ½ of the level with CAT6a S/FTP and RJ45 under the same conditions.

CAT8 Prototype F/FTP

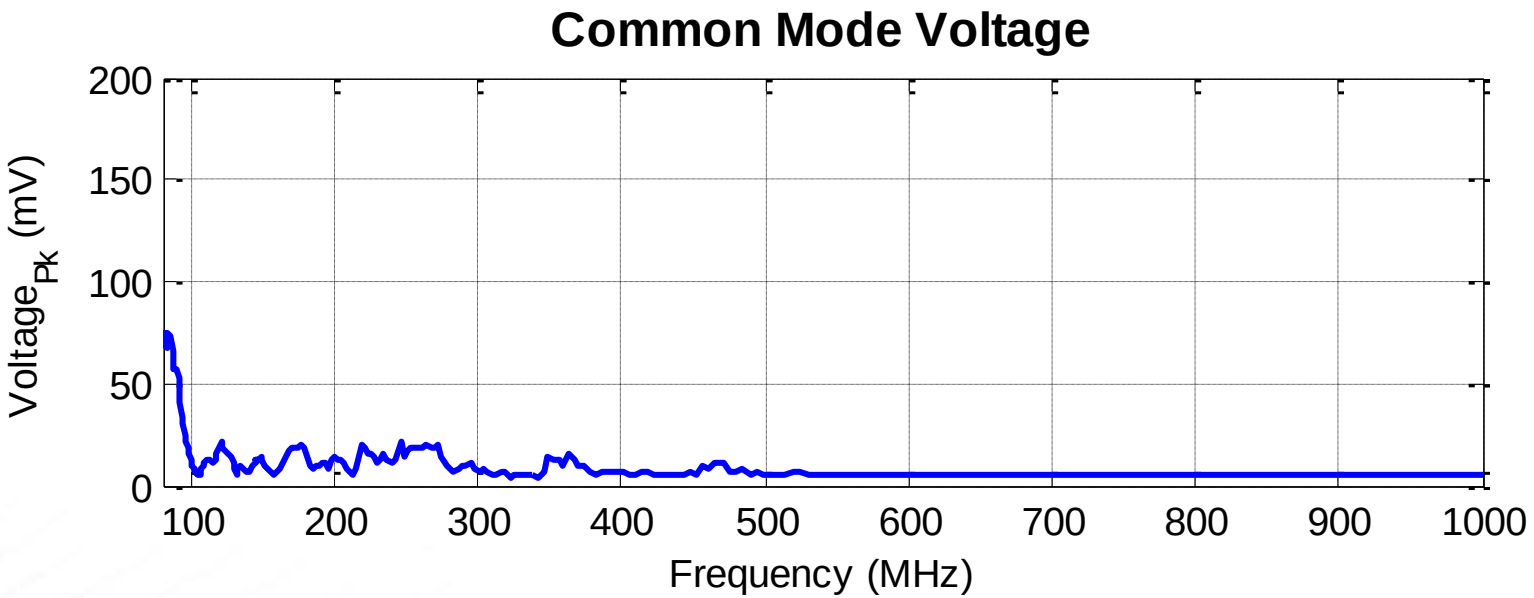
CAT8 Prototype RJ-45 Connectors

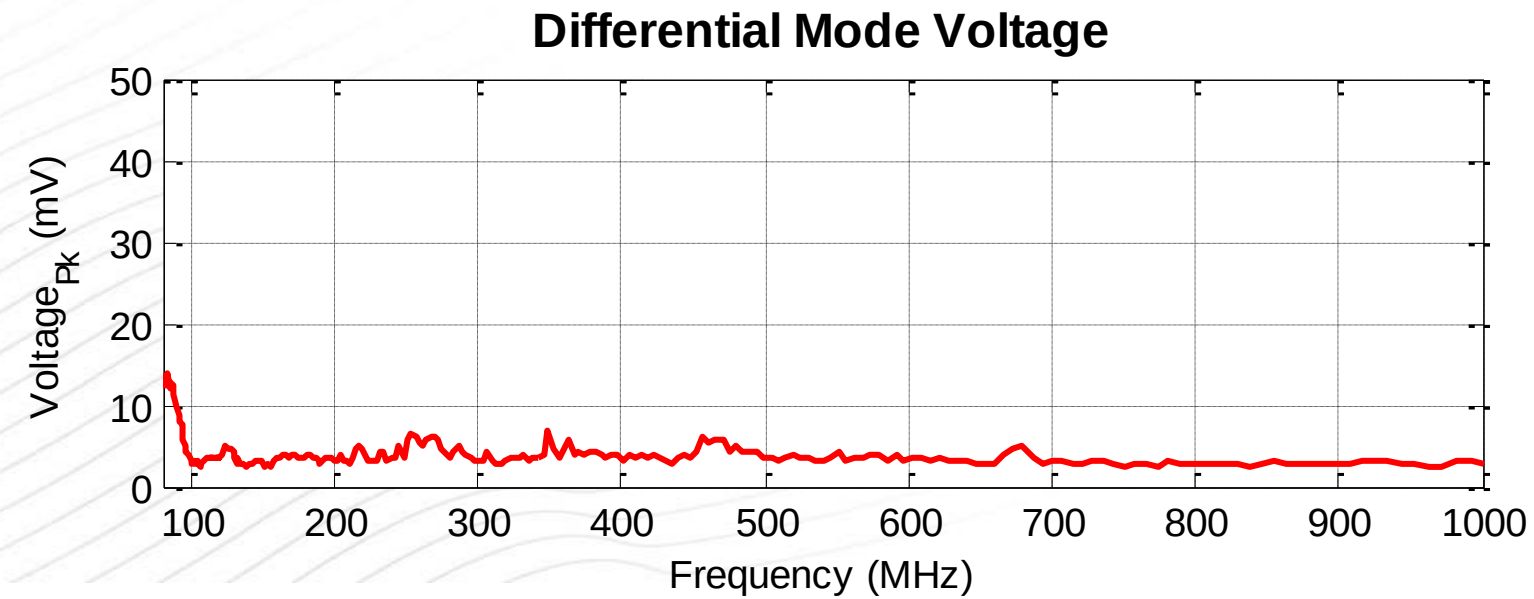
30m CHANNEL, CAT8 PROTOTYPE F/FTP, CAT8 PROTOTYPE RJ-45

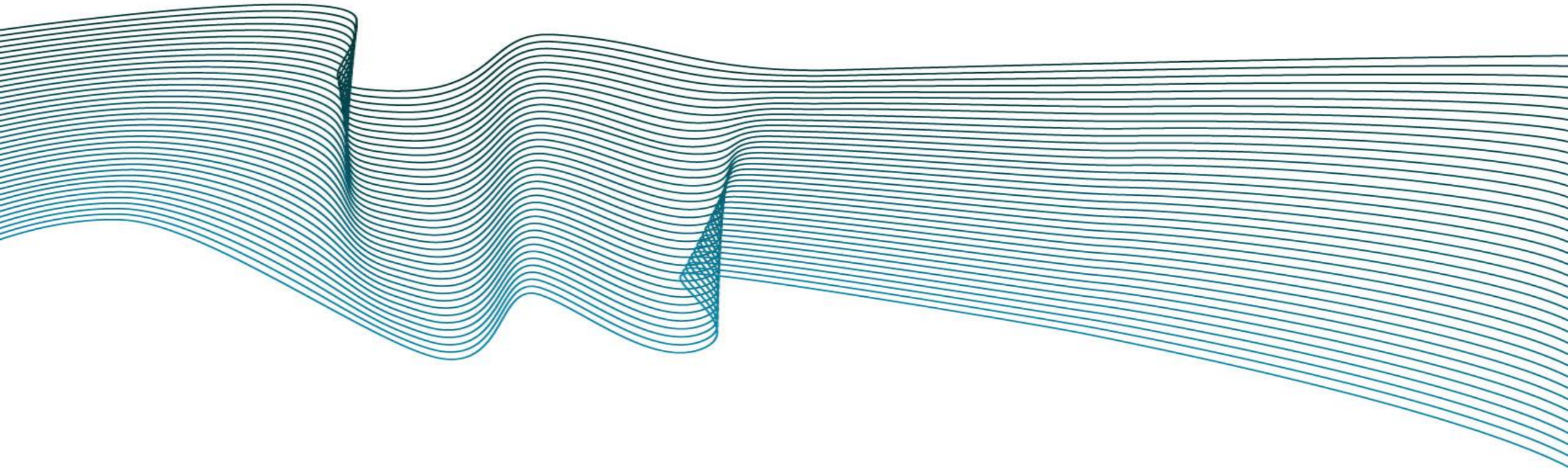




10m CHANNEL, CAT8 PROTOTYPE F/FTP, CAT8 PROTOTYPE RJ-45







SUMMARY TABLES

MAXIMUM MEASURED VOLTAGES, CAT6a UTP

Description	Common Mode (mV_{Pk})	Differential Mode (mV_{Pk})	DM/CM, dB
30m Channel RJ45	2200@120MHz 2000@ 90MHz	400@90MHz	-14
10m Channel RJ45	5000@90MHz	800@90MHz	-15.9

MAXIMUM MEASURED VOLTAGES, CAT6a F/UTP, S/FTP, CAT6a RJ45

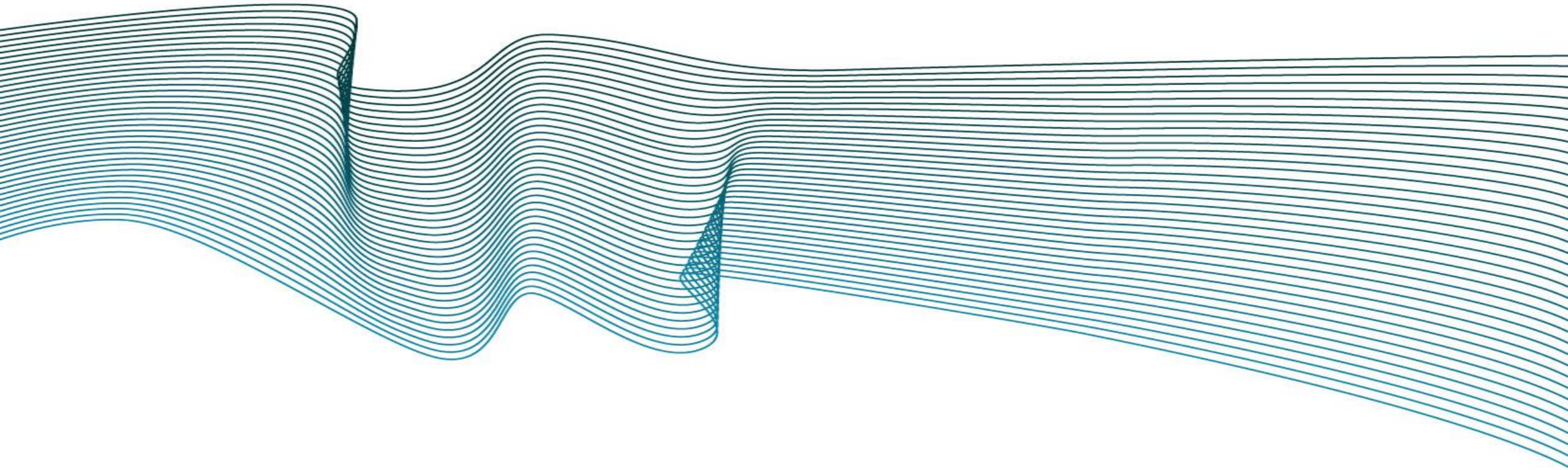
Description	Common Mode (mV_{Pk})	Differential Mode (mV_{Pk})	DM/CM, dB
30m Channel F/UTP RJ45	100@110MHz&220MHz	25@220MHz	-18.9
10m Channel F/UTP RJ45	320@90MHz	45@90MHz	-17
2m Cable F/UTP RJ45 Hanging, coiled	30@230MHz	10@230MHz	-9.5
26m Cable F/UTP RJ45	100@120MHz	15@120MHz	-16.5
30m Channel S/FTP RJ45	320@120MHz	60@120MHz	-14.5
10m Channel S/FTP RJ45	380@100MHz	45@100MHz	-18.6
2m Cable S/FTP RJ45, Taped to metal rack	400@100MHz	40@100MHz	-20
2m Cable S/FTP RJ45 Hanging, coiled	110@190MHz	20@190MHz	-14.8
30m Channel S/FTP RJ45	110@120MHz	21@120MHz	-14.4
10m Channel S/FTP RJ45	220@85MHz	30@85MHz	-17.3

MAXIMUM MEASURED VOLTAGES, CAT7a S/FTP

Description	Common Mode (mV_{Pk})	Differential Mode (mV_{Pk})	DM/CM, dB
30m Channel S/FTP RJ45	50@100MHz	15@100MHz	-10.5
10m Channel S/FTP RJ45	150@100MHz	30@100MHz	-14
2m Cable S/FTP RJ45 Hanging, coiled	60@80MHz	10@80MHz	-15.6
26m Cable S/FTP RJ45	40@110MHz	10@130MHz	x
30m Channel S/FTP TERA	48@90MHz	8@90MHz	-15.6
10m Channel S/FTP TERA	35@160MHz	15@160MHz	-7.4

SUMMARY: MAXIMUM MEASURED VOLTAGES, CAT8.x S/FTP, F/FTP

Description	Common Mode (mV_{Pk})	Differential Mode (mV_{Pk})	DM/CM, dB
30m Channel CAT8.2 S/FTP ARJ45	140@120MHz	12@120MHz	-21.3
10m Channel CAT8.2 S/FTP ARJ45	90@90MHz	9@90MHz	-20
26m Cable CAT8.2 S/FTP ARJ45	25@100MHz	5@100MHz	-14
2m Cable CAT8.2 S/FTP ARJ45 Taped to metal rack	200@100MHz	20@100MHz	-20
2m Cable CAT8.2 S/FTP With ARJ45, Hanging, coiled	50@240MHz	8@240MHz	-15.9
30m Channel CAT8 Prototype F/FTP, CAT8 Prototype RJ45	52@120MHz	11@120MHz	-13.5
10m Channel CAT8 Prototype F/FTP, CAT8 Prototype RJ45	65@80MHz	13@80MHz	-14



OBSERVATIONS AND COMMENTS

OBSERVATIONS - LEVELS

- Significant levels for CAT6a up to ~400 MHz and for higher categories up to ~300 MHz.
- 10m channel showed higher coupled levels than 30m channel.
- 2m-cable had strong peaks as a function of the cable layout. Other lengths and layouts?
- The peak induced voltages per tested category (2m taped cable excluded) are:
  - 6a (UTP): 5000 mV CM & 800 mV DM
  - 6a: 320 mV CM & 60 mV DM
  - 7a: 150 mV CM & 30mV DM
  - 8.x 140 mV CM & 13mV DM

- Note that on the fixture for RJ45 we only used a shielded CAT6a receptacle, regardless of the exact type of the RJ45 connectors terminated on the measured cables.

OBSERVATIONS - CONVERSION

- Even when the absolute induced levels are relatively low, due to the effect of the shields, the observed CM-DM conversion in all conditions is relatively very high.
- This can be seen by comparison of the induced CM and DM levels.
- The levels - only calculated at the frequencies of the measured peaks - are in the ranges:
  - 6a (UTP): -14 dB to -15.9 dB
  - 6a: -9.5 dB to -20 dB
  - 7a: -7.4 dB to -15.6 dB
  - 8.x -13.5 dB to -21.3 dB
- Any problem with the shields could create high levels of differential-mode EMI. Further study and improvement of conversion by the MDI, cables, and connectors is strongly suggested.
- Conversion measured in real conditions can be very different and much higher (may be orders of magnitude) than conversion measured on test benches and for each pair separately.

COMMENTS

- We measured induced voltages only under very limited but realistic test conditions. The presented data are only initial and show only the minimum levels to consider. Other factors, e.g. cable layout, length, resonances, can result in considerably higher levels.
- Further evaluation of all test-conditions and realistic use-conditions is necessary to establish the worst-case CM and DM EMI levels at the MDI.
- The levels at the MDI connectors are measured directly by a scope, with 50Ω input impedance at each channel. The CM impedance termination for each pair is 25Ω. MDI might likely contain EMI-suppression CM chokes with high CM impedance. The induced CM and DM voltages at the MDI pins could be at least twice as high as measured with the described fixture. CM EMI would be attenuated before it reaches the transceiver, but not the DM EMI.
- We tested at the typical nominal test level of 10 V/m (rms), without any margin included. Adding margin (at least 3-6 dB) to any measured data is strongly suggested.
- Consider real application. What happens if the shield is broken or degraded - even “slightly”?
- Evaluation of cable and connector response under the conditions of Conducted Immunity test in the frequency range 150 kHz – 80 MHz should also be considered.