Annex 113A Technical Tutorial Working Document

IEEE P802.3bz ENUCA and P802.3bq RxCMNR ad hocs

October 21st, 2015

Working Outline

- Introduction/Background
  - What do the normative clauses address – e.g. why do we have rejection of external EM fields/common-mode noise rejection specifications?
- Relationship between the normative specifications and the informative annex(es)
  - How the normative & informative text work together
- Cable clamp methodology
  - Overview of the clamp methodology; use in IEEE and other standards
- Annex 113A review/walk-through
  - What's in the Annex
- Using the Annex
  - Best practices for calibration, validation, and testing
  - Example of a system-level test (start to finish)

Reviewed in 10/7 ENUCA ad hoc

Outline For "Introduction/Background"

- Why a technical tutorial on an informative Annex?
- Why do we have rejection of external EM fields/common-mode noise rejection specifications?
- What will we be discussing?

Introduction (1/2)

- Why a technical tutorial on an informative Annex?
  - Introduce a new Annex that outlines a re-useable methodology for injecting RF impairments to Ethernet cabling
  - Explain the relationship between normative clauses and the informative Annex.
  - Summarize technical work on the cable clamp test that has been presented in the P802.3bq Rx CMNR and P802.3bz ENUCA ad hocs.
  - Summarize best practices when using cable clamp test methodologies for practitioners

Introduction (2/2)

- Why do we have rejection of external EM fields/common-mode noise rejection specifications?

Summarize EM susceptibility/ immunity requirements?

- **ISO/IEC**
- **EN**
- **FCC**
- **Etc.**

Immunity to What?

- **Scope of Discussion: Immunity to signals from RF transmitters, including**
  - TV, AM/FM Radio
  - HAM, Walkie-Talkies
  - Wireless LAN
  - Cell phones
- **Signals from these transmitters**
  - Can be coupled onto unshielded cables (UTP)
  - Are mostly common mode, but some CM-differential conversion happens in the cable & magnetics resulting in a small differential noise
    - This type of differential alien noise cannot easily be cancelled.
- **We are not addressing other aspects of Immunity here:**
- ESD, CDE, Power, Magnetic Fields, AWGN, Alien crosstalk, etc…

Why Consider for MultiGBASE-T?

Compare 10GBASE-T and 1000BASE-T

- SNR Margin
  - 1000BASE-T had more margin in the system
    - Most CAT5e cables are much better than spec
    - Most products achieve 140-150m+ reach
  - 10GBASE-T Margin
    - Design target is close to channel capacity
    - Mature PHY and good cabling are required to exceed 100m with margin
- Frequency Range:
  - 1000BASE-T = 125M symbols/sec; most energy <= 80MHz
  - 10GBASE-T = 800M symbols/sec; most energy <= 500MHz
  - Most common offenders: Radios ~150Mhz & 450MHz; 850MHz cell phone

Noise sources that were well out of band for 1000BASE-T are in-band for 2.5/5/10/25/40GBASE-T

Industry Immunity Requirements

- Immunity environments are generally defined by electromagnetic “threats” or disturbances
- The first widespread application of RF immunity requirements was introduced with the European Union’s 1989 EMC Directive
  - Published in 1989; originally to take effect in 1992.
  - Delayed until 1996 due to a lack of suitable EMC standards and time needed for manufacturers to prepare
- The original EMC Directive 89/336/EEC was replaced by a new Directive 2004/108/EC, with a transition period 20 July 2007 – 20 July 2009.
- EMC for radio equipment in the EU is mandated by the R&TTE (Radio and Telecommunications Terminal Equipment) Directive 1999/5/EC.

Source - Why 50% of Products Fail EMC Testing the First Time
Intertek Testing Services NA, Inc.

Regulatory Immunity Tests

- **US Commercial Market -** FCC; No Immunity requirement
- **Europe -** CISPR 24; Requires a set of Immunity tests intended to simulate real world electromagnetic environments.
  - RF, ESD, Lighting surge, electrical fast transients, magnetic fields, voltage dips & drop-outs. The relevant ones for Annex 113A include
    - Radio Frequency electromagnetic fields (i.e. Radiated Immunity)
      - IEC 61000-4-3; 80MHz-1GHz, 3V/m
      - Frequency change rate of 1%, at least 1 second dwell
    - Radio Frequency Conducted
      - IEC 61000-4-6; 150kHz-80MHz, 3V
- **US Telecom market –** NEBS
  - Telcordia GR1089: 8.5V/m radiated immunity

Specify test levels and multiple, largely user-defined performance criteria

Immunity Testing

- Immunity pre-testing requires generating electromagnetic disturbances that simulate the requirements in the applicable immunity or EMC standards.
  - RF radiated immunity testing is normally performed in a shielded chamber to avoid radiating illegal RF signals across the radio spectrum.
  - Lacking a shielded chamber, certified and/or licensed radio transmitters approved for use in the test location may be used
  - Some convenient transmitter types and their operating frequency bands (for US operation) are listed below:

Off-the-Shelf RF Sources	
Source	Frequency
CB radio	27 MHz
Portable phone handset	49 MHz, 900 MHz, 2.5GHz and 5 GHz
Garage door opener	300 MHz
Walkie-talkie	460 MHz
Cell phone, analog TDMA	800 MHz
Cell phone, PCS	1900 MHz
Wireless LAN, Wi-Fi	2450 MHz

- Leaves some gaps in frequency ranges typically specified for immunity!

Outline for “Normative clauses & Annexes”

- Outline existing requirements

- Differentiate/clarify normative text (113.5.4.3, 126.5.4.3) and informative Annex (Annex 113A)

- Differentiate Clause 40.6.1.3.3/Annex 40B and Clauses 113/126 and Annex 113A

- Relationship between 113.5.4.3,126.5.4.3 and Annex 113A

BASE-T EM Immunity Requirements*

Standard	SubClause	Requirement	Test Method	Impairment	Method
10BASE-T (Clause 14)	14.3.1.3.5 Common-mode rejection	Normative ("M") in PICS	Defined in IEEE 1802.3-2001	25V peak-to-peak square wave signal, <= 500 kHz	Direct injection into receive pair
100BASE-TX (Clause 25)	25.2 (by reference to ANSI X3.263-1995, Subclause 9.2.3)	Normative ("M") in PICS	Described in ANSI X3.263-1995, Subclause 9.2.3	1[illegible]V peak-to-peak sine wave signal from "0 MHz" to 125 MHz	Direct injection into receive pair
1000BASE-T (Clause 40)	40.6.1.3.3 Common-mode noise rejection	Normative ("M") in PICS	Described in Subclause 40.6.1.3.3 and Annex 40B	1.0Vrms (1.414 Vpeak)** sine wave signal from 1 MHz to 250 MHz	Coupling to all four pairs using cable clamp described in Annex 40B
10GBASE-T (Clause 55)	55.5.4.3 Common-mode noise rejection	Normative ("may perform") Permissible within the limits of the standard No PICS (no "shall)	Refers to Subclause 40.6.1.3.3	6 dBm sine wave signal from 80 MHz to 1000 MHz	Coupling to all four pairs using cable clamp described in Annex 40B
25G/40GBASE-T (P802.3bq D2.3 Clause 113)	113.5.4.3 Common-mode noise rejection	Normative ("may perform") Permissible within the limits of the standard No PICS (no "shall)	Described in Annex 113A	6 dBm sine wave signal from 80 MHz to 2000 MHz	Coupling to all four pairs using cable clamp described in Annex 113A
2.5G/5GBASE-T (P802.3bz D1.1 Clause 126)	126.5.4.3 Common-mode noise rejection	Normative ("may perform") Permissible within the limits of the standard No PICS (no "shall)	Described in Annex 113A	13 dBm sine wave signal from 80 MHz to 1000 MHz	Coupling to all four pairs using cable clamp described in Annex 113A

* Relevant requirements for each released standard listed in the table are included for reference at the end of the presentation

** Measured at the receiver end of injection fixture

Normative or Informative?

- From the 2014 IEEE-SA Standards Style Manual
  - Normative text is information that is required to implement the standard and is therefore officially part of the standard.
  - Informative text is provided for information only and is therefore not officially part of the standard.

Normative Text & Annex 113A "Calling" clause concept

```
Sub Rejection_of_External_EM_Fields()

' From P802.3bq, D2.3, 113.5.4.3
' An 80 MHz to 2000 MHz test can be made based on the cable clamp test described in Annex 113A, a 30
' meter plug-terminated cabling that meets the requirements of 113.7, and suitable broadband ferrites. All
' components in the test remain over the ground reference plane. A sine wave with the amplitude held constant
' over the whole frequency range from 80 MHz to 2000 MHz, with the amplitude calibrated so that the
' signal power measured at the output of the clamp does not exceed 6 dBm, is used to generate the external
' electromagnetic field and corresponding shield current.

ftype = sine
fstart = 80
fstop = 2000
pdBm = 6

P802_3bq_113_5_4_3 = Annex113A(ftype, fstart, fstop, pdBm)

' From P802.3bz, D1.1, 126.5.4.3
' An 80 MHz to 1000 MHz test can be made based on the cable clamp test described in Annex 113A, a 30
' meter plug-terminated cabling that meets the requirements of 113.7, and suitable broadband ferrites. All
' components in the test remain over the ground reference plane. A sine wave with the amplitude held constant
' over the whole frequency range from 80 MHz to 1000 MHz, with the amplitude calibrated so that the
' signal power measured at the output of the clamp does not exceed 6 dBm, is used to generate the external
' electromagnetic field and corresponding shield current.

ftype = sine
fstart = 80
fstop = 1000
pdBm = 6

P802_3bz_126_5_4_3 = Annex113A(ftype, fstart, fstop, pdBm)

End Sub

Function Annex113A(ftype, fstart, fstop, fpower)

' From P802.3bq, D2.3, 113.5.4.3
' Refer to the receiver specifications of the PHY under test for specific impairments (ftype)
' impairment source power levels (fpower),
' and relevant frequency ranges (fstart, fstop).

End Function
```

Outline for “Cable Clamp Methodology”

- Clamp methodology overview
  - What it does, how it works
- Clamp methodologies in regulatory testing
  - Conducted immunity “EM clamp”
  - Radiated immunity “pre-compliance testing”
- Clamp methodology in 802.3
  - Clause 40.6.1.3.3/55.5.4.3 and Annex 40B

Outline for "Annex 113A walk-through"

- What's in the Annex/main sections/features
  - Overview
  - Description of cable clamp
  - Validation
    - Cable clamp calibration
    - Cable clamp electrical measurement
      - Insertion loss, return loss limits
    - Cable clamp validation
      - Common-mode and differential-mode limits
  - Test Setup

Outline for "Using Annex 113A"

- Best practices
  - Summary of best practices/pitfalls for each of the main sections
    - Hardware & instrument setups
    - Measurement techniques
- Example(s)
  - Start-to-finish example of a system-level test
    - Starting with pieces & parts and ending with a running test
  - Relationship/correlation to EMI chamber tests

Summary

- Introduced a new Annex that outlines a re-useable methodology for injecting RF impairments to Ethernet cabling
- Explained the relationship between normative clauses and the informative Annex.
- Summarized technical work on the cable clamp test that has been presented in the P802.3bq Rx CMNR and P802.3bz ENUCA ad hocs.
- Summarized best practices when using cable clamp test methodologies for practitioners

Thank You!

10BASE-T Clause 14

14.3.1.3.5 Common-mode rejection

- Receivers shall assume the proper state on DI for any differential input signal Es that results in a signal Edif that meets 14.3.1.3.1 even in the presence of common-mode voltages Ecm (applied as shown in Figure 14-19).
- Ecm shall be a 25 V peak-to-peak square wave, 500 kHz or lower in frequency, with edges no slower than 4 ns (20%-80%).
- Additionally, Ecm shall contribute no more than 2.5 ns of edge jitter to the signal transmitted on the DI circuit. The combination of the receiver timing jitter of 14.3.1.3.1 and the common-mode induced jitter are such that the MAU shall add no more than 4.0 ns of edge jitter to Es before sending the signal on the DI circuit.
  - DI = 10BASE-T receive path
  - 14.3.1.3.11 Receiver differential input signals - defines acceptable signal characteristics for the RD circuit (RD+, RD-)

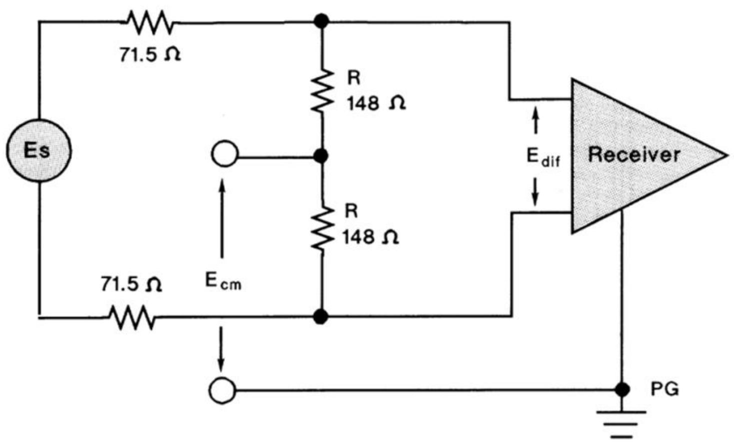

Figure 14–19—Receiver common-mode rejection test circuit

- Mandatory requirement in the Clause 14 PICS, 14.10.4.5.13 Receiver specification , Item RS10

IEEE Std 1802.3-2001*

Test Case ID: 1411.11.06, RD circuit common-mode rejection.

- Status: MANDATORY
- Standard Reference: 14.3.1.3.5; PICS Reference : 14.10.4.5.13/10
- Test Purpose: To verify the receiver common-mode rejection.
- Test Setup: Test setup J.
- Test Procedure : Apply power to the MAU. Apply test signal 15, as differential input signal Es, to the test fixture such that a 585 mV signal, Edif is present on the RD circuit of the MAU. Monitor the differential input signal, Edif, at the RD circuit of the MAU and the DI circuit. Apply test signal 17 as Ecm. Check the DI circuit for the proper state and for jitter.
- Conformance: Defined in Subclause 14.3.1.3.5 Common-mode rejection

*IEEE Conformance Test Methodology for IEEE Standards for Local and Metropolitan Area Networks

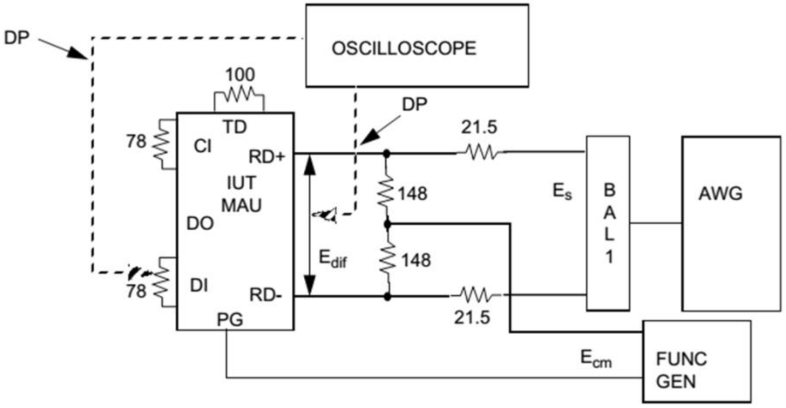

Figure 6-17 — Test setup J

Test signal 15 from the AWG is defined as A MAU–RD signal consisting of a single frame of 512 bits of pseudo-random data. Amplitude of 585 mV peak and maximum edge transition times.

100BASE-TX Clause 25

Defined in ANSI X3.263-1995*, Subclause 9.2.3
Common-mode rejection

- Receiver shall deliver the proper value for PM_UNITDATA.indication, at the specified Bit Error Rate, for any signal meeting the requirements of 10.1.
- The receiver shall deliver the correct value for Ecm applied as shown in figure 16. Ecm shall be a 1,0 V peak-to-peak sine wave from 0 MHz to 125 MHz.
- The impedance of the text *(sic)* equipment shall not disrupt the impedance of the channel.
- NOTE - Implementers are encouraged to test to the applicable country EMC standards.

*Fibre Distributed Data Interface (FDDI) - Token Ring Twisted Pair Physical Layer Medium Dependent (TP-PMD)

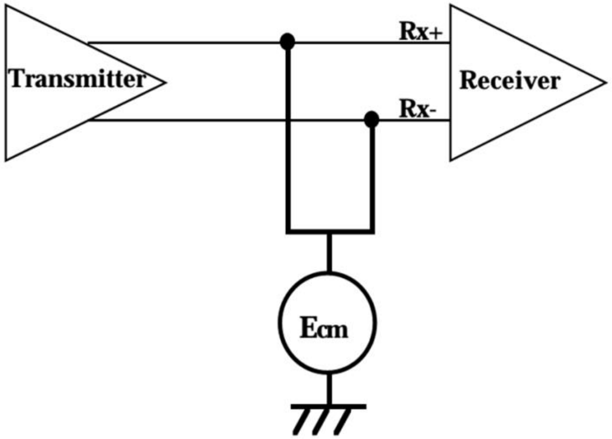

Figure 16 – Common mode rejection

- Mandatory requirement in the Clause 25 PICS, 25.6.4.2 PMD compliance, Item PD2

1000BASE-T Clause 40

40.6.1.3.3 Common-mode noise rejection

- This specification is provided to limit the sensitivity of the PMA receiver to common-mode noise from the cabling system. Common-mode noise generally results when the cabling system is subjected to electromagnetic fields. Figure 40-28 shows the test configuration, which uses a capacitive cable clamp, that injects common-mode signals into a cabling system.

- A 100-meter, 4-pair Category 5 cable that meets the specification of 40.7 is connected between two 1000BASE-T PHYs and inserted into the cable clamp. The cable should be terminated on each end with an MDI connector plug specified in 40.8.1. The clamp should be located a distance of ~20 cm from the receiver. It is recommended that the cable between the transmitter and the cable clamp be installed either in a linear run or wrapped randomly on a cable rack. The cable rack should be at least 3 m from the cable clamp. In addition, the cable clamp and 1000BASE-T receiver should be placed on a common copper ground plane and the ground of the receiver should be in contact with the ground plane. The chassis grounds of all test equipment used should be connected to the copper ground plane. No connection is required between the copper ground plane and an external reference. A description of the cable clamp, as well as the validation procedure, can be found in Annex 40B.

1000BASE-T Clause 40

40.6.1.3.3 Common-mode noise rejection (continued)

- A signal generator with a 50Ω impedance is connected to one end of the clamp and an oscilloscope with a 50Ω input is connected to the other end of the clamp. The signal generator shall be capable of providing a sine wave signal of 1 MHz to 250 MHz. The output of the signal generator is adjusted for a voltage of 1.0Vrms (1.414 Vpeak) on the oscilloscope.
- While sending data from the transmitter, the receiver shall send the proper PMA_UNITDATA.indication messages to the PCS as the signal generator frequency is varied from 1 MHz to 250 MHz. NOTE - Although the signal specification is constrained within the 1-100 MHz band, this test is performed up to 250 MHz to ensure the receiver under test can tolerate out-of-band (100-250 MHz) noise.
- Mandatory requirement in the Clause 40 PICS, 40.12.7 PMA Electrical Specifications, Items PME53 and PME54.

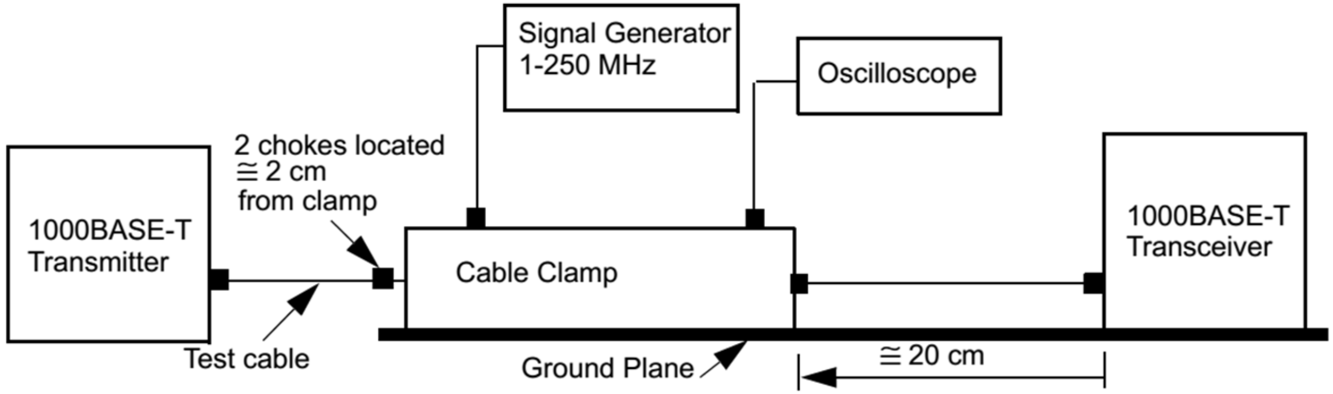

Figure 40–28—Receiver common-mode noise rejection test

Annex 40B – Description of Cable Clamp

- This annex describes the cable clamp used in the common-mode noise rejection test of 40.6.1.3.3, which is used to determine the sensitivity of the 1000BASE-T receiver to common-mode noise from the link segment. As shown in Figure 40B-1, the clamp is 300 mm long, 58 mm wide, 54 mm high with a center opening of 6.35 mm (0.25 in). The clamp consists of two halves that permit the insertion of a cable into the clamp.

- The clamp has a copper center conductor and an aluminum outer conductor with a high density polyethylene dielectric. The following is a review of the construction and materials of the clamp:
  - a) Inner conductor - Copper tubing with an inner diameter of 6.35 mm (0.25 in) and an outer diameter of 9.4 mm (0.37 in).
  - b) Outer conductor - Aluminum bar that is 300 mm long and approximately 54 mm by 58 mm. The bar is milled to accept the outer diameter of the dielectric material.
  - c) Dielectric - High Density Polyethylene (Residual, TypeF) with dielectric constant of 2.32. An outside diameter of 33.5 mm and an inner diameter that accepts the outside diameter of the copper inner conductor.
  - d) Connectors - BNC connectors are located 9 mm (0.39 in) from each end of the clamp and are recessed into the outer conductor. The center conductor of the connector is connected to the inter *(sic)* conductor as shown in Figure 40B–2.
  - e) Clamping screws - Six screws are used to connect the two halves of the clamp together after the cable has been inserted. Although clamping screws are shown in Figure 40B–1, any clamping method may be used that ensures the two halves are connected electrically and permits quick assembly and disassembly.
  - f) Nylon screws - Used to align and secure the inner conductor and dielectric to the outer conductor. The use and location of the screws is left to the manufacturer.
  - g) Keying bolts - Two studs used to align the two halves of the clamp.

- As shown in Figure 40B -2 the inner conductor on the bottom half of the clamp extends slightly (~ 0.1mm) above the dielectric to ensure there is good electrical connection with the inner conductor of the top half of the clamp along the full length of the conductor when the two halves are clamped together.

- The electrical parameters of the clamp between 1MHz and 250 MHz are as follows:
  - a) Insertion loss: < 0.2 dB
  - b) Return loss: > 20.0 dB

Cable Clamp Construction

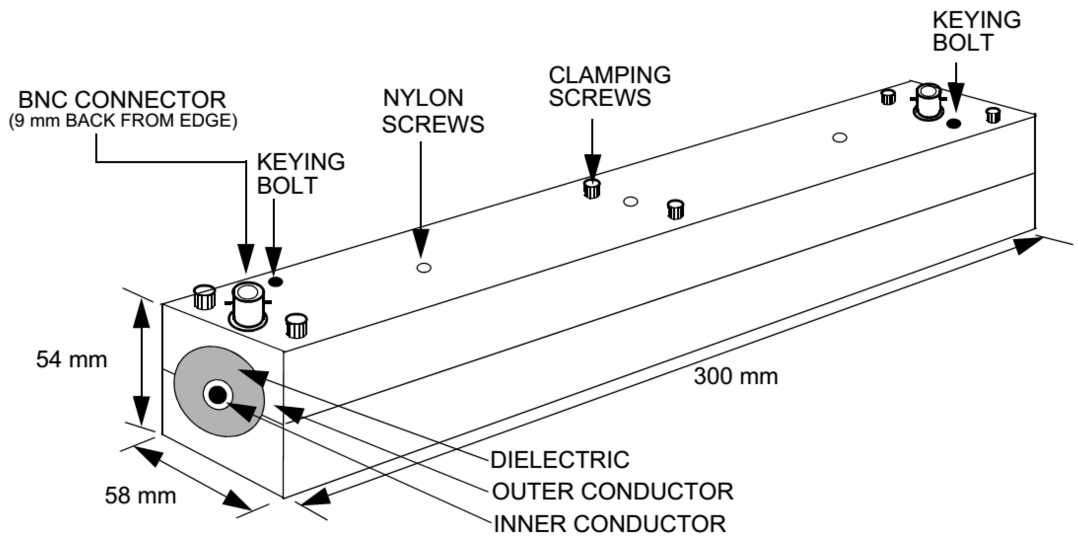

Figure 40B–1—Cable clamp

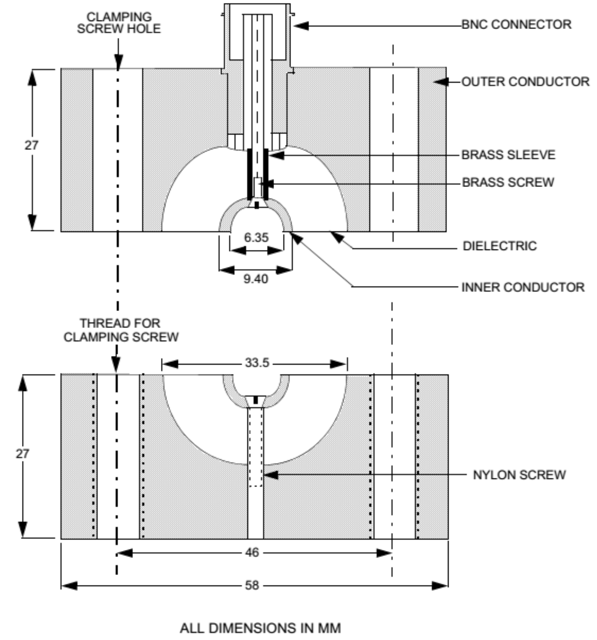

Figure 40B–2—Cross-section of cable clamp

Annex 40B.1 Cable clamp validation (1)

- In order to ensure the cable clamp described above is operating correctly, the following test procedure is provided. Prior to conducting the following test shown in Figure 40B–3, the clamp should be tested to ensure the insertion loss and return loss are as specified above. The cable clamp validation test procedure uses a well-balanced 4-pair Category5 unshielded test cable or better that meets the specifications of 40.7.

- The test hardware consists of the following:
  - a) Resistor network - Network consists of three 50 ±0.1% Ω resistors; two resistors are connected in series as a differential termination for cable pairs and the other resistor is connected between the two and the ground plane as a common-mode termination.
  - b) Balun - 3 ports, laboratory quality with a 100Ω differential input, 50Ω differential output, and a 50Ω common-mode output:
    - Insertion Loss (100Ω balanced <-> 50Ω unbalanced): <1.2 dB (1-350MHz)
    - Return Loss: >20 dB (1-350 MHz)
    - Longitudinal Balance: >50 dB (1-350 MHz)
  - c) Test cable - 4-pair 100 ΩUTP category 5 balanced cable at least 30 m long.
  - d) Chokes (2) - Wideband Ferrite Material:
    - Inter-diameter: 6.35 to 6.86 mm
    - Impedance: 250Ω @ 100 MHz
  - e) Ground plane - Copper sheet or equivalent.
  - f) Signal generator
  - g) Oscilloscope
  - h) Receiver

Annex 40B.1 Cable clamp validation (2)

- With the test cable inserted in the cable clamp, a signal generator with a 50 Ω output impedance is connected to one end of the cable clamp and an oscilloscope with a 50Ω input impedance is connected to the other end. The signal generator shall be capable of providing a sine wave signal of 1 MHz to 250 MHz. The output of the signal generator is adjusted for a voltage of 1.0 Vrms (2.83 Vpp) at 20 MHz on the oscilloscope. The remainder of the test is conducted without changing the signal generator voltage. The cable pairs not connected to the balun are terminated in a resistor network, although when possible it is recommended that each cable pair be terminated in a balun. It very important that the cable clamp, balun, receiver, and resistor networks have good contact with the ground plane. The two chokes, which are located next to each other, are located approximately 2.0 cm from the clamp. The cable between the clamp and the balun should be straight and not in contact with the ground plane.

- The differential-mode and common-mode voltage outputs of the balun should meet the limits shown in Table 40B-1 over the frequency range 1 MHz to 250 MHz for each cable pair. The differential mode voltage at the output of the balun must be increased by 3 dB to take into account the 100-to-50 impedance matching loss of the balun.

- NOTE - Prior to conducting the validation test the cable clamp should be tested without the cable inserted to determine the variation of the signal generator voltage with frequency at the output of the clamp. The signal generator voltage should be adjusted to 1 Vrms (2.83 Vpp) at 20 MHz on the oscilloscope. When the frequency is varied from 20 MHz to 250 MHz, the voltage on the oscilloscope should not vary more than ±7.5%. If the voltage varies more than ±7.5%, then a correction factor must be applied at each measurement frequency

Annex 40B.1 Cable clamp validation (3)

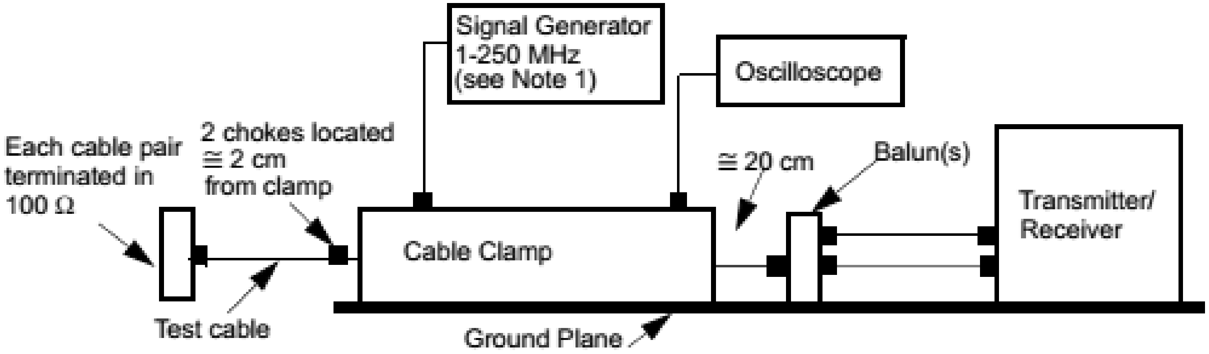

Figure 40B–3—Cable clamp validation test configuration

Table 40B–1—Common- and differential-mode output voltages

Frequency (*f*)	Common-mode voltage	Differential-mode voltage
1-30 MHz	<0.1+0.97(f/30) Vpp	<2.4 + 19.68 (f/30) mVpp
30-80 MHz	<1.07 Vpp	<22 mVpp
80-250 MHz	<1.07 – 0.6 (f-80)/170 Vpp	<22 mVpp

10GBASE-T Clause 55

55.5.4.3 Common-mode noise rejection

- This specification is provided to limit the sensitivity of the PMA receiver to common-mode noise from the cabling system. Common-mode noise generally results when the cabling system is subjected to electromagnetic fields.
- The common-mode noise can be simulated using the cable clamp test defined in 40.6.1.3.3. A 6 dBm sine wave signal from 80 MHz to 1000 MHz can be used to simulate an external electromagnetic field. Operational requirements of the transceiver during the test are determined by the manufacturer. A system integrating a 10GBASE-T PHY may perform this test.

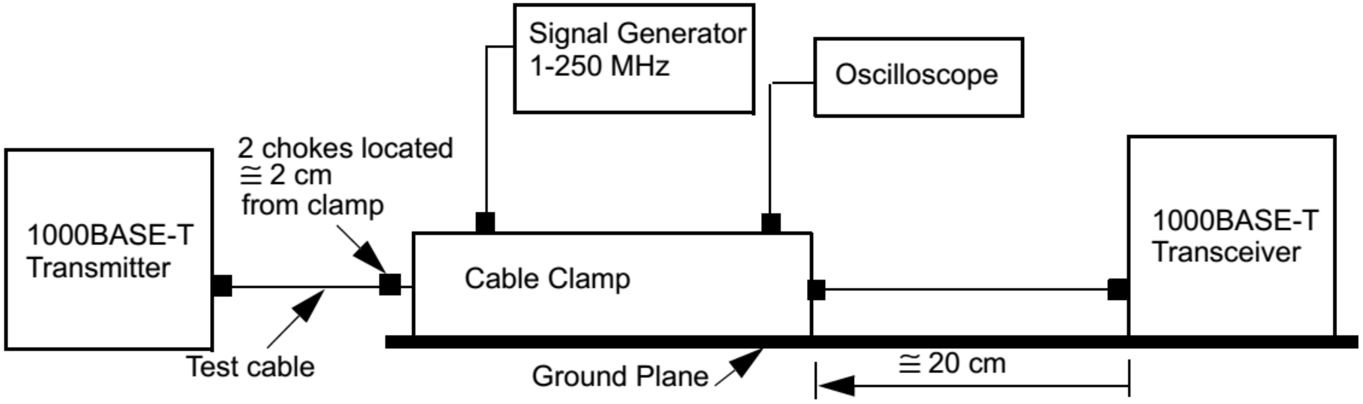

Figure 40–28—Receiver common-mode noise rejection test

References/Bibliography

- The Compliance Club, “EMC testing Part 4 – Radiated immunity”
  - http://www.compliance-club.com/archive/keitharmstrong/emc_testing4.html
- The Compliance Club, “EMC testing Part 5 – Conducted Immunity”
  - http://www.compliance-club.com/archive/old_archive/011021.htm
- Why 50% of Products Fail EMC Testing the First Time - Intertek Testing Services NA, Inc.
  - http://www.intertek.com/uploadedFiles/Intertek/Divisions/Commercial_and_Electrical/Media/PDF/EMC_Testing/Why-50-Percent-Fail-EMC-WP.pdf
- Add more here…