Common-Mode Noise Rejection Specifications and Initial Considerations for 40GBASE-T

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Supporters

- Supporters welcome!

Abstract

The IEEE 802.3 10GBASE-T standard as defined in Clause 55 includes an informative specification for receiver common-mode noise rejection (CMNR). The corresponding cable clamp test, based on a similar normative 1000BASE-T requirement defined in Subclause 40.6.1.3.3, may be performed on systems integrating 10GBASE-T PHYs.

This presentation reviews the existing 10GBASE-T receiver common-mode noise rejection specification and test, presents a set of measurements from the current test fixture, and identifies some initial considerations relevant to the 40GBASE-T standard.

Goals

- Review existing BASE-T CMNR specifications
- Share some characteristics of an implementation of the test referenced in Subclause 55.5.4.3
- Present initial considerations towards a corresponding specification in Clause 98

Some Background

- Why define CMNR requirements and tests for receivers using twisted-pair cabling?
  - Characterize and/or limit the sensitivity of the PMA receiver to common-mode noise from the cabling system that generally results when the cabling system is subjected to electromagnetic fields.
- CMNR specifications are defined and test methods described for existing 802.3 BASE-T PHYs.

Relevant “Historical Documents”*

- 10BASE-T & 100BASE-TX
  - “Surely, you don't think 10Mb and 100Mb are… [insert despaired Thermian moan] …Those poor people.”
- 1000BASE-T
  - At least one referenced contribution (“An Improved Common Mode Noise Tolerance Test for 1000BASET”, L. Adriaenssens) and records of active discussion during comment resolution.
- 10GBASE-T
  - At least two contributions (“Common-mode noise, Impedance Balance, Common-mode output voltage,” cobb_1_0505.pdf; “PHY PMA electrical specs baseline proposal for 803.an,” gupta_1_0704.pdf and some discussion during comment resolution.
  - Some observations in comments received for 802.3an were similar to those recently noted in the P802.3bq PHY Baseline Proposal ad hoc (see “40GBASE-T Suggestions,” German Feyh, Broadcom).

*With apologies to “Galaxy Quest” fans…

BASE-T CMNR 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 Subclause 9.2.3	1.0V 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	Informative (“may perform,” not in PICS)	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

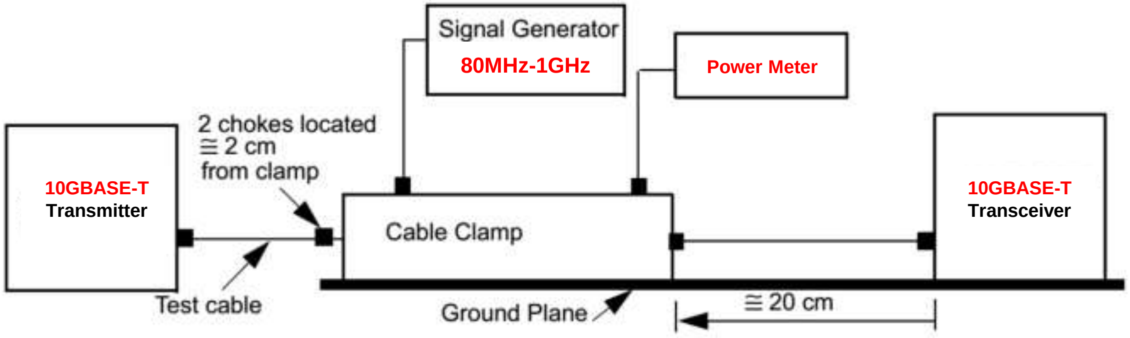
* Relevant requirements for each standard listed in the table are included for reference at the end of the presentation
** Measured at the receiver end of injection fixture

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.

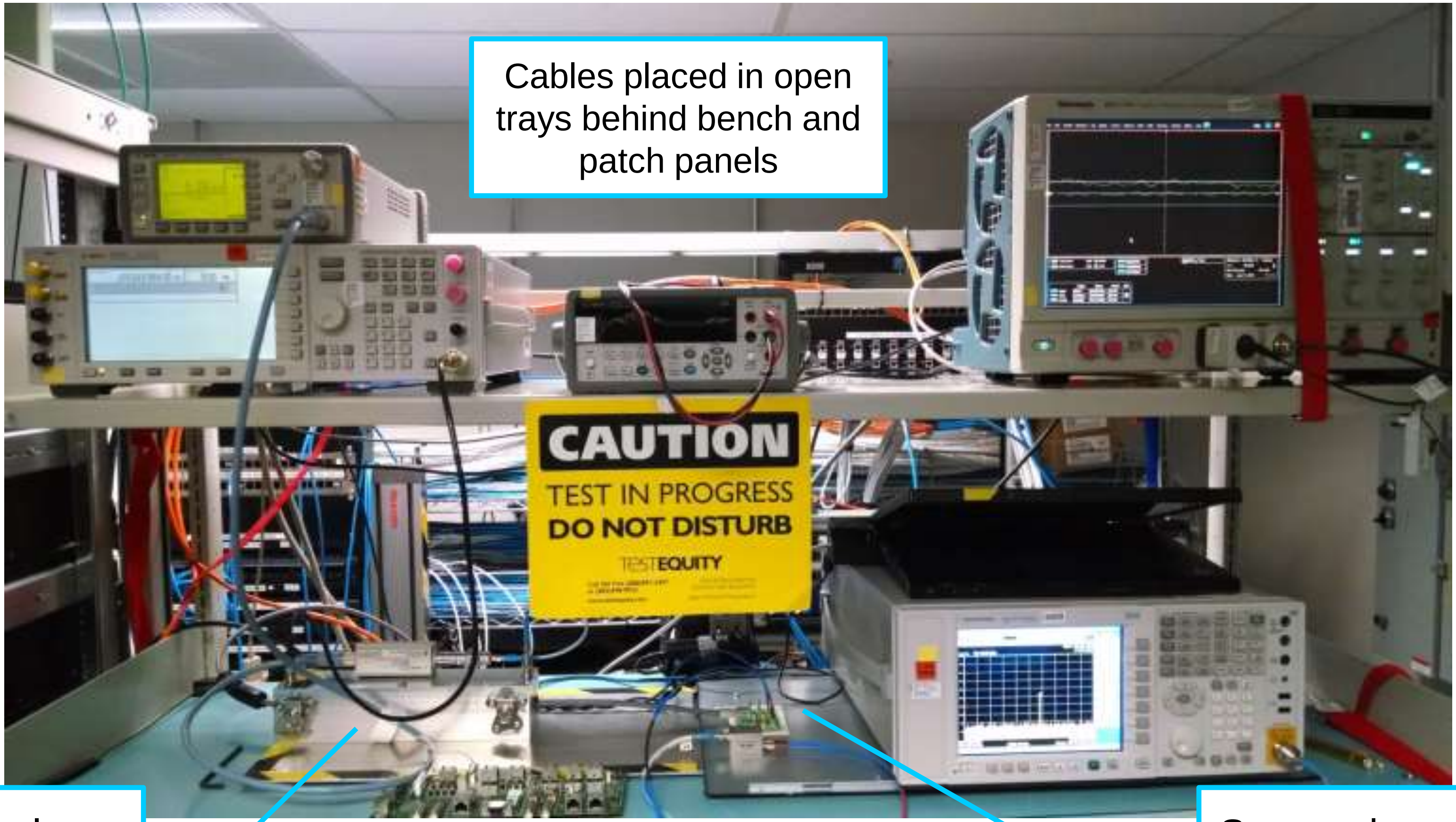
- The common-mode noise can be simulated using the cable clamp test defined in 40.6.1.3.3. A 6dBm sine wave signal from 80 MHz to 1000 MHz can be used to simulate an external electromagnetic field. Operational requirements of the transceiver during the test are determined by the manufacturer. A system integrating a 10GBASE-T PHY may perform this test.



A representative 10GBASE-T Receiver Common-mode rejection test

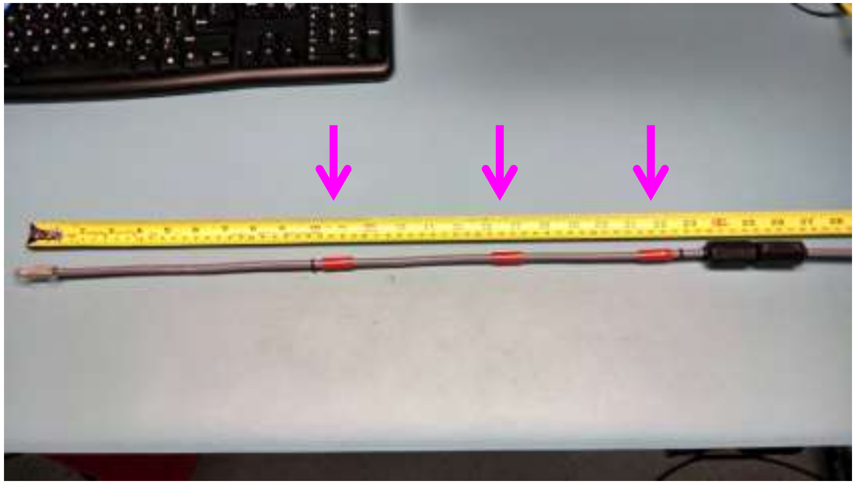
- No requirement in the Clause 55 PICS, 55.12.6 PMA Electrical Specifications for Subclause 55.5.4.3, therefore assume informative

A Clause 55.5.4.3 CMNR Setup (Characterization configuration)



Test Fixture Considerations

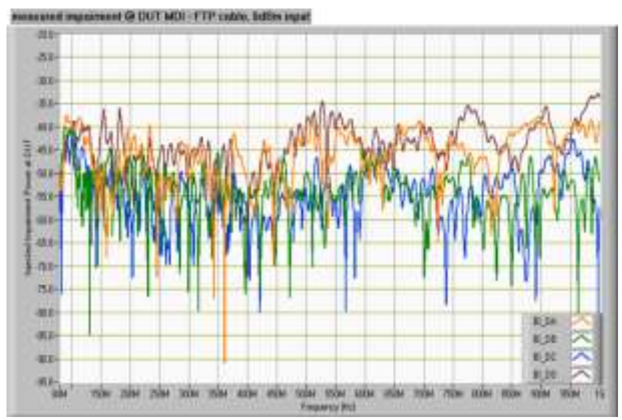
- Experience with real cables in the recommended test fixture suggests that some method of aligning, centering and supporting the cable in the cable clamp helps with test repeatability
  - Tie wraps (not pinching) to indicate required spacing
  - Non-conductive supports (foam tape) to center the cable in the clamp

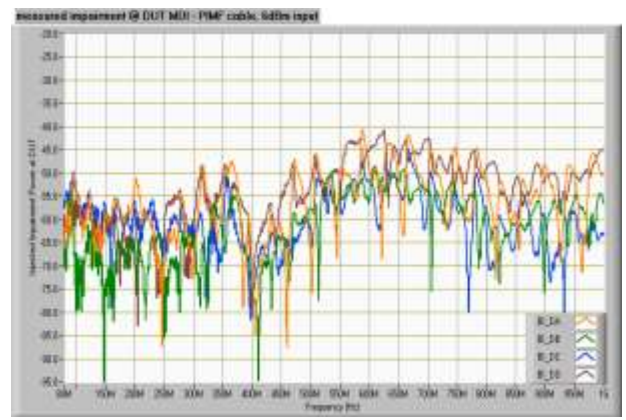


Cable Clamp Characteristics UTP/FTP/PIMF Comparison

Injected noise power measured at cable clamp output with constant 6dBm input

Differential noise power measured at DUT MDI





UTP FTP PIMF

One* Rx CMNR Test Design

- One test pass includes 7 BER test segments, ~15min/segment
  - 1x baseline segment (no noise injection)
  - 6x impairment segments (noise injection over 1 of 6 frequency bands)
- Sweep step tables use 401 points for each band
  - 382 kHz resolution on injected sine impairments; 1s dwell at each frequency step
  - Injected power is corrected for cable clamp response
- Pass/Fail Criteria
  - Link within expected link times, no link drops, meets BER

**One other known implementation uses different dwell times, # points, and Pass/Fail criteria*

80-233MHz
233-386MHz
387-539MHz
540-692MHz
693-846MHz
.847-1GHz

Frequency	Injected Power (dBm)	Step (kHz)
80.0000000 MHz	11.92	
80.3823775 MHz	11.99	382.3775
80.7647550 MHz	11.85	382.3775
81.1471325 MHz	11.55	382.3775
81.5295100 MHz	11.20	382.3775
81.9118875 MHz	10.70	382.3775
82.2942650 MHz	10.45	382.3775
82.6766425 MHz	10.25	382.3775
83.0590200 MHz	10.17	382.3775
83.4413975 MHz	10.09	382.3775
83.8237750 MHz	10.03	382.3775
84.2061525 MHz	10.00	382.3775
84.5885300 MHz	9.93	382.3775
84.9709075 MHz	8.99	382.3775
85.3532850 MHz	8.87	382.3775
85.7356625 MHz	8.77	382.3775
86.1180400 MHz	8.67	382.3775
86.5004175 MHz	8.59	382.3775
86.8827950 MHz	8.47	382.3775

…continues to 233MHz

Sample Results (FTP) 2-connector channels

Length	Frequency	Before RF Immunity Fix: Good Rx	Lost Frames	Rx Errors	BER	Status	After RF Immunity Fix: Good Rx	Lost Frames	Rx Errors	BER	Status
16m	Baseline	516,772,821	0	0	0.00E+00	PASS	520,454,815	0	0	0.00E+00	PASS
	80-233MHz	519,828,059	327795	211865	3.37E-08	FAIL	524,155,257	0	0	0.00E+00	PASS
	233-386MHz	525,550,395	77424	43673	6.86E-09	FAIL	513,314,061	0	0	0.00E+00	PASS
	387-539MHz	515,249,853	0	0	0.00E+00	PASS	521,700,147	0	0	0.00E+00	PASS
	540-692MHz	525,496,035	0	0	0.00E+00	PASS	524,106,401	0	0	0.00E+00	PASS
	693-846MHz	514,297,787	0	0	0.00E+00	PASS	518,712,801	0	0	0.00E+00	PASS
	.847-1GHz	525,375,541	0	0	0.00E+00	PASS	525,374,112	0	0	0.00E+00	PASS
26m	Baseline	524,109,228	0	0	0.00E+00	PASS	518,239,806	0	0	0.00E+00	PASS
	80-233MHz	523,433,580	205803	107121	1.69E-08	FAIL	524,818,964	0	0	0.00E+00	PASS
	233-386MHz	517,003,402	0	0	0.00E+00	PASS	521,057,920	0	0	0.00E+00	PASS
	387-539MHz	517,417,311	0	0	0.00E+00	PASS	518,852,676	0	0	0.00E+00	PASS
	540-692MHz	522,165,987	0	0	0.00E+00	PASS	513,156,584	0	0	0.00E+00	PASS
	693-846MHz	518,095,842	0	0	0.00E+00	PASS	515,158,961	0	0	0.00E+00	PASS
	.847-1GHz	514,844,187	0	0	0.00E+00	PASS	519,156,507	0	0	0.00E+00	PASS
36m	Baseline	523,432,086	0	0	0.00E+00	PASS	524,288,275	0	0	0.00E+00	PASS
	80-233MHz	519,027,478	255568	121835	1.94E-08	FAIL	517,007,441	0	0	0.00E+00	PASS
	233-386MHz	523,188,336	27308	21560	3.40E-09	FAIL	524,147,011	0	0	0.00E+00	PASS
	387-539MHz	514,518,256	0	0	0.00E+00	PASS	520,631,670	0	0	0.00E+00	PASS
	540-692MHz	520,943,127	0	0	0.00E+00	PASS	520,017,870	0	0	0.00E+00	PASS
	693-846MHz	518,933,896	0	0	0.00E+00	PASS	516,376,424	0	0	0.00E+00	PASS
	.847-1GHz	517,760,698	0	0	0.00E+00	PASS	525,269,146	0	0	0.00E+00	PASS

- PHY performance before PHY-specific RF immunity improvement varies with external EMI frequency.
- Errors are be observed at specific frequencies in the 80MHz to 386MHz region

Some Considerations for Clause 98

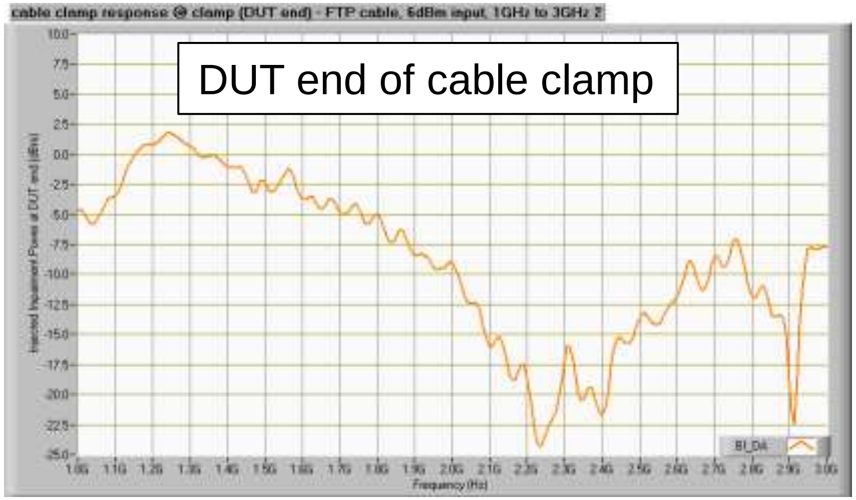
- Four existing and widely adopted BASE-T standards include a receiver CMNR specification
  - A normative requirement in 3 of 4 standards
- Common-mode noise coupling has been observed on multiple cable lengths and types
  - It is not just a concern for 0db IL margin channels
  - Lower (but comparable) noise power is observed on PIMF-type cable
- CMNR testing has been useful in improving 10GBASE-T PHY receiver common-mode noise performance
  - “Cell phone” panic no is no longer an issue; do we want to repeat this experience with 40GBASE-T?

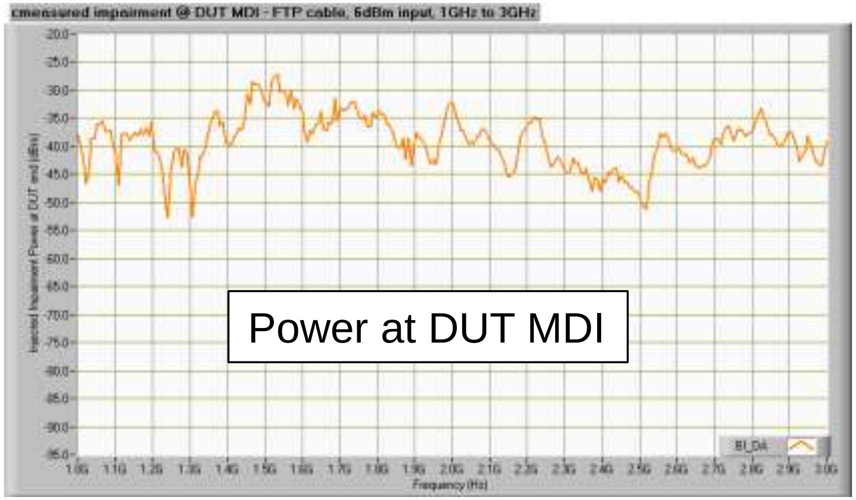
Extending the Cable Clamp Beyond 1GHz?

Plots show measurements of noise power measured at the DUT end of the cable clamp and at the DUT MDI connection

- Injected power = 6dBm from 1GHz to 3GHz
- Power at DUT end varies from +1.7dBm to -24.3dBm

Will be difficult to calibrate to a constant +6dBm level over this range…





Conclusion and Ideas for Further Discussion/Study

- Should a receiver common-mode noise rejection specification should be retained in Clause 98?
  – Would maintain consistency with existing standards
  – Would provide PHY developers and system implementers with a design/performance target for a known receiver impairment
- If so, the 10GBASE-T specification, Clause 55.5.4.3, should be reviewed and updated to be relevant for 40GBASE-T operating requirements
  – Evaluate alternate test fixtures and impairment injection techniques?
  – Better define (or define…) performance criteria?
  – Normative vs. Informative?
- Note that it's not just a "PHY problem" - channel elements are contributors, too.
  – Can we improve shielding effectiveness of cables and interconnects?
  – What's the role of grounding/bonding?
  – Other?

Thank You!

Questions?

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-)

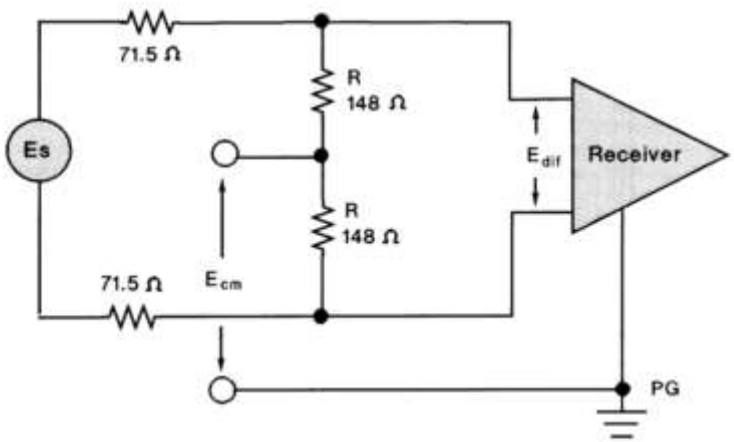


Figure 14–19—Receiver common-mode rejection test circuit

- 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

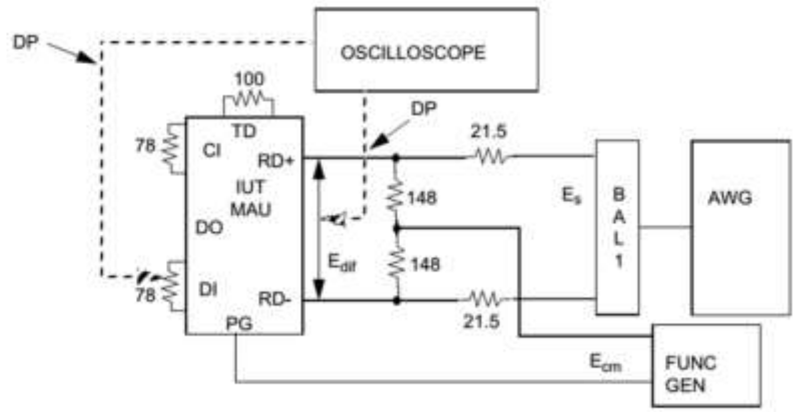


Figure 6-17 — Test setup J

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.

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

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)

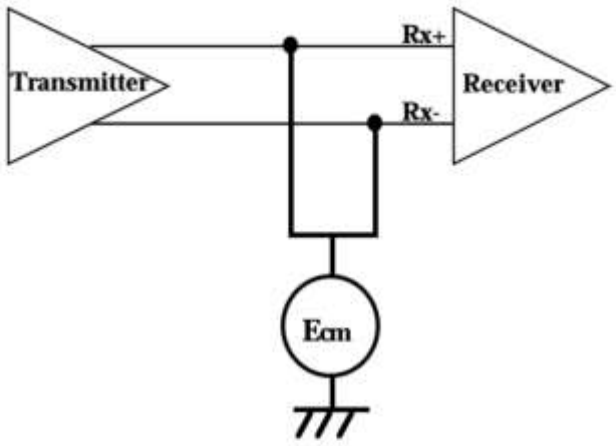


Figure 16 – Common mode rejection

- 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.

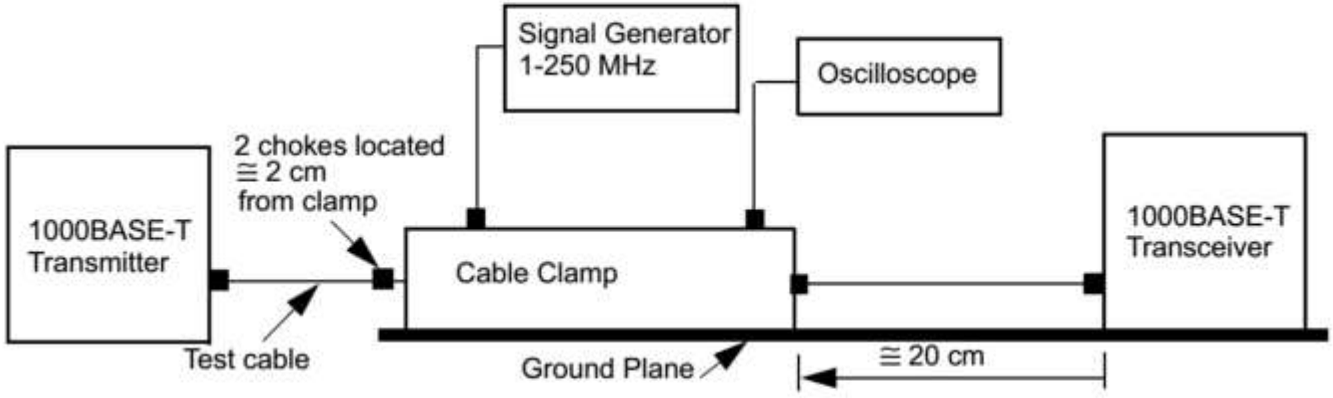


Figure 40–28—Receiver common-mode noise rejection test

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

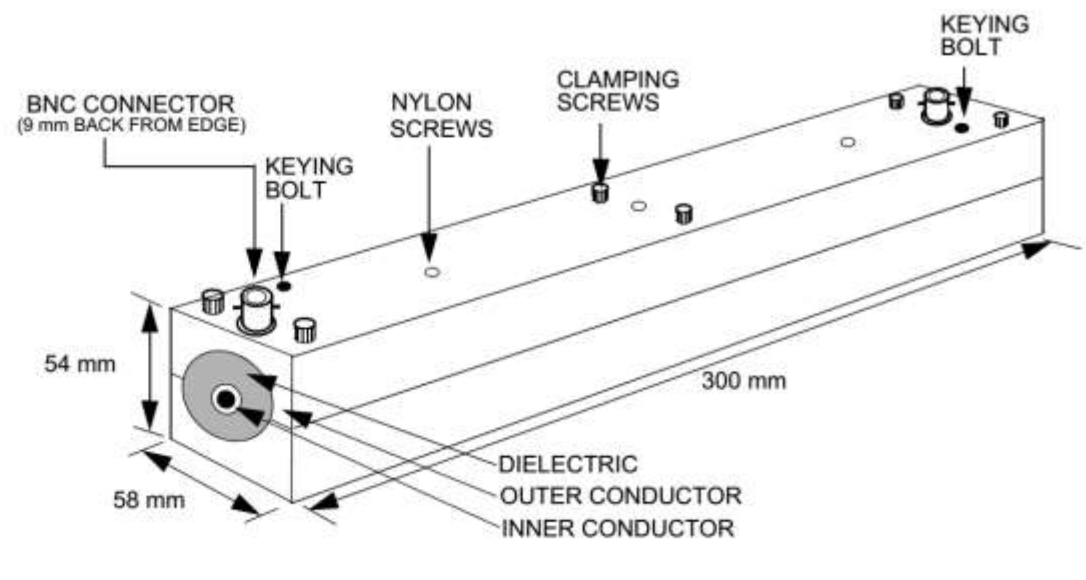
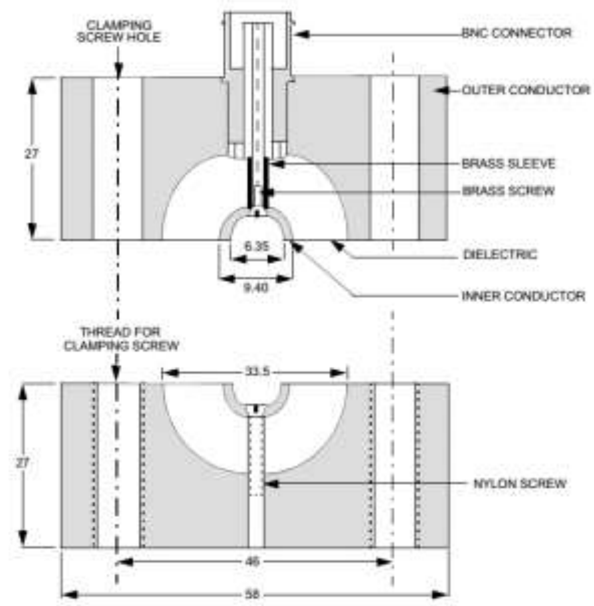


Figure 40B–1—Cable clamp



ALL DIMENSIONS IN MM

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)

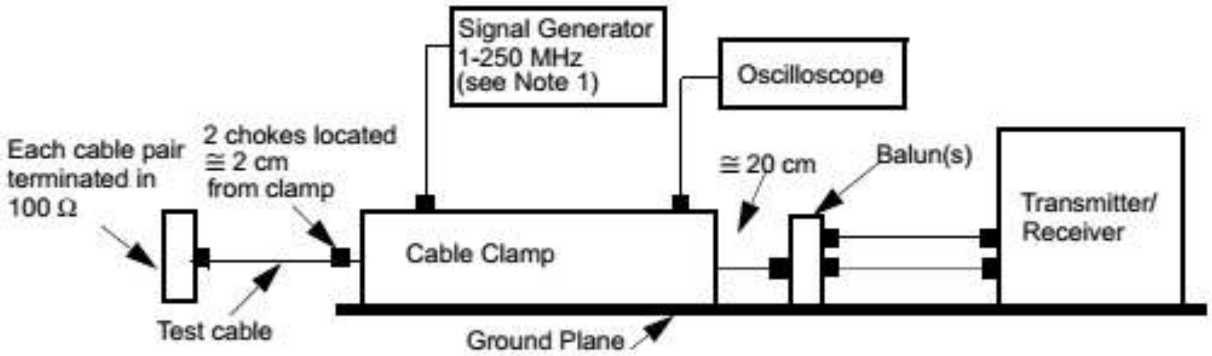


Figure 40B–3—Cable clamp validation test configuration

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.

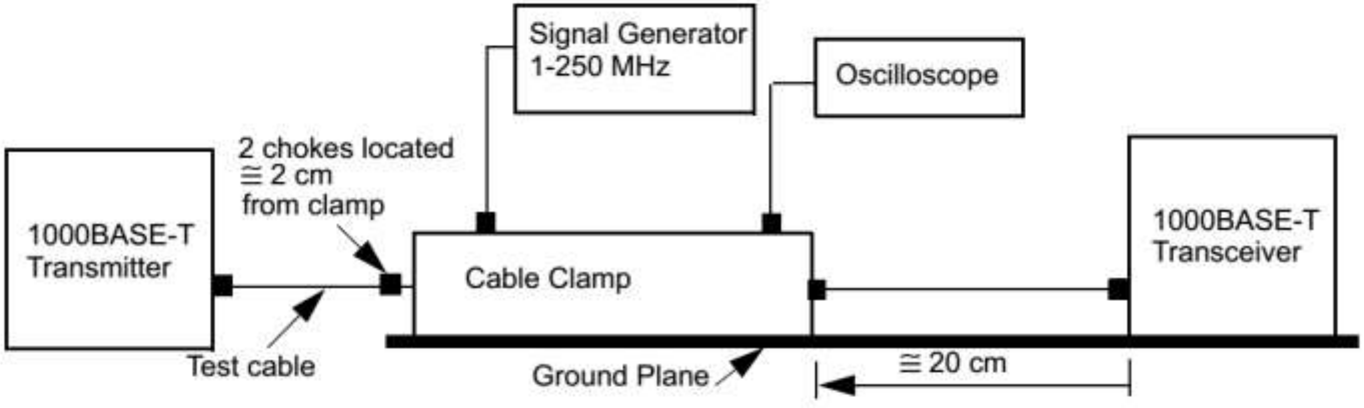


Figure 40–28—Receiver common-mode noise rejection test