IEEE 100BASE-T1 Physical Media Attachment Test Suite

Version 1.0

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This suite of tests has been developed to help implementers evaluate the functionality of their IEEE 802.3bw 100BASE-T1 Physical Media Attachment (PMA) based products.

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Version Control of Document

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1.0	Curtis Donahue	• Initial draft	11/09/2016
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Curtis Donahue	University of New Hampshire
Stephen Johnson	University of New Hampshire

2 INTRODUCTION

This particular suite of tests has been developed to help implementers evaluate the functionality of the PMA sublayer of their 100BASE-T1 products.

These tests are designed to determine if a product conforms to specifications defined in IEEE 802.3bw Physical Layer Specifications and Management Parameters for 100 Mb/s Operation over a Single Balanced Twisted Pair Cable (100BASE-T1). Successful completion of all tests contained in this suite does not guarantee that the tested device will operate with other devices. However, combined with satisfactory operation in the OPEN Alliance interoperability test bed, these tests provide a reasonable level of confidence that the Device Under Test (DUT) will function properly in many 100BASE-T1 automotive environments.

The tests contained in this document are organized in such a manner as to simplify the identification of information related to a test, and to facilitate in the actual testing process. Tests are organized into groups, primarily in order to reduce setup time in the lab environment, however the different groups typically also tend to focus on specific aspects of device functionality. A three-part numbering system is used to organize the tests, where the first number indicates the section of Clause 96 of the IEEE 802.3bw Standard on which the test suite is based. The second and third numbers indicate the test's group number and test number within that group, respectively. This format allows for the addition of future tests to the appropriate groups without requiring the renumbering of the subsequent tests.

The test definitions themselves are intended to provide a high-level description of the motivation, resources, procedures, and methodologies pertinent to each test. Specifically, each test description consists of the following sections:

Purpose

The purpose is a brief statement outlining what the test attempts to achieve. The test is written at the functional level.

References

This section specifies source material *external* to the test suite, including specific subsections pertinent to the test definition, or any other references that might be helpful in understanding the test methodology and/or test results. External sources are always referenced by number when mentioned in the test description. Any other references not specified by number are stated with respect to the test suite document itself.

Resource Requirements

The requirements section specifies the test hardware and/or software needed to perform the test. This is generally expressed in terms of minimum requirements, however in some cases specific equipment manufacturer/model information may be provided. This document does not attempt to describe every test setup and its necessary hardware or software, merely a general description of one or two implementations.

Last Modification

This specifies the date of the last modification to this test.

Discussion

The discussion covers the assumptions made in the design or implementation of the test, as well as known limitations. Other items specific to the test are covered here.

Test Setup

The setup section describes the initial configuration of the test environment. Small changes in the configuration should not be included here, and are generally covered in the test procedure section, below.

Test Procedure

The procedure section of the test description contains the systematic instructions for carrying out the test. It provides a cookbook approach to testing, and may be interspersed with observable results.

Observable Results

This section lists the specific observables that can be examined by the tester in order to verify that the DUT is operating properly. When multiple values for an observable are possible, this section provides a short discussion on how to interpret them. The determination of a pass or fail outcome for a particular test is generally based on the successful (or unsuccessful) detection of a specific observable.

Possible Problems

This section contains a description of known issues with the test procedure, which may affect test results in certain situations. It may also refer the reader to test suite appendices and/or whitepapers that may provide more detail regarding these issues.

3 List of Abbreviations and Definitions

AFEXTDC	Alien Far End Cross Conversion Loss Common to Differential
ADC	Analog to Digital Converter
ANEXTDC	Alien Near End Cross Conversion Loss Common to Differential
Automotive Cable	Balance 100 Ω one pair cable having characteristics defined in Subclause 96.7 of the IEEE 802.3bw Physical Layer Specifications and Management Parameters for 100 Mb/s Operation over a Single Balanced Twisted Pair Cable (100BASE-T1).
BI_DA	Bi-directional Data Signal Pair A
BER	Bit Error Rate
DUT	Device Under Test
DSO	Real-time Digital Storage Oscilloscope
DSP	Digital Signal Processing
ECU	Electronic Control Unit
LCL	Longitudinal Conversion Loss
LCTL	Longitudinal Conversion Transmission Loss
LP	Link Partner
MDI	Medium Dependent Interface
PCB	Printed Circuit Board
PHY	Physical Layer
PLL	Phase Locked Loop
PPM	Parts Per Million
PSAACRF	Power Sum Attenuations to Alien Crosstalk Ratio Far End
PSANEXT	Power Sum Alien Near End Crosstalk Loss
PSD	Power Spectral Density
RBW	Resolution Bandwidth
SA	RF Spectral Analyzer
Short Automotive Cable	Cabling representative of the 'Automotive Cable' definition used during transmitter testing to mate the DUT to the necessary fixtures of each test setup. This cable should be limited in length to reduce the amount of loss between the DUT transmitter and oscilloscope frontend.
TDR	Time Domain Reflectometer
TIE	Time Interval Error
UI	Unit Interval
VBW	Video Bandwidth
VNA	RF Network Analyzer

4 DUT Required Capabilities and 802.3bw Reference Table

Test Name		Test Number	Required Capabilities	IEEE 802.3bw References
Group 1: Electrical Measurements				
Maximum Transmitter Output Droop		Test 5.1.1	Test Mode 1	• Subclause 96.5.4.1 – Transmitter output droop • Subclause 96.5.2 – Test modes • Subclause 96.5.3 – Test fixtures
Transmitter Distortion		Test 5.1.2	Test Mode 4	• Subclause 96.5.4.2 – Transmitter distortion • Subclause 96.5.2 – Test modes • Subclause 96.5.3 – Test fixtures
Transmitter Timing Jitter	Case 1: MASTER	Test 5.1.3	Test Mode 2	• Subclause 96.5.4.3 – Transmitter timing jitter • Subclause 96.5.2 – Test modes • Subclause 96.5.3 – Test fixtures
	Case 2: SLAVE		TX_TCLK access	
Transmitter Power Spectral Density		Test 5.1.4	Test Mode 5	• Subclause 96.5.4.4 – Transmitter power spectral density • Subclause 96.5.2 – Test modes • Subclause 96.5.3 – Test fixtures
Transmit Clock Frequency		Test 5.1.5	Test Mode 2	• Subclause 96.5.4.5 – Transmitter clock frequency • Subclause 96.5.2 – Test modes • Subclause 96.5.3 – Test fixtures
MDI Return Loss		Test 5.1.6	Active Transmitter	• Subclause 96.8.2.1 – MDI return Loss
MDI Mode Conversion Loss		Test 5.1.7	Active Transmitter	• Subclause 96.8.2.2 – MDI mode conversion loss
Transmitter Peak Differential Output		Test 5.1.8	Active Transmitter	• Subclause 96.5.6 – Transmitter peak differential output
Group 2: PMA Receive Tests				
Bit Error Rate Verification		Test 5.2.1	The ability to send and receive frames[1]	• Subclause 96.5.5.1 – Receiver differential input signals • Section 7 – Link segment characteristics
Receiver Frequency Tolerance		Test 5.2.2	The ability to send and receive frames[1]	• Subclause 96.5.5.2 – Receiver frequency tolerance • Subclause 96.7 – Link Segment Characteristics
Alien Crosstalk Noise Rejection		Test 5.2.3	The ability to send and receive frames[1]	• Subclause 96.5.5.3 – Alien crosstalk noise rejection • Subclause 96.7 – Link segment characteristics

[1] This can be accomplished through a loopback, responding to ICMP requests, or by forwarding traffic through two ports

All tests are designed for the IEEE 802.3bw Physical Layer Specifications and Management Parameters for 100 Mb/s Operation over a Single Balanced Twisted Pair Cable (100BASE-T1)

For the purposes of this test suite, the DUT is one port of a 100BASE-T1 capable device that includes a 100BASE-T1 PHY mounted on a PCB with an MDI connector and any necessary circuitry such as a low pass filter or common mode choke. All tests will be performed at the MDI connector of the DUT.

5 GROUP 1: Electrical Measurements

Overview:

The tests defined in this section verify the voltage parameters defined for 100BASE-T1 capable PHY's in section 5 of the IEEE 802.3bw Physical Layer Specifications and Management Parameters for 100 Mb/s Operation over a Single Balanced Twisted Pair Cable (100BASE-T1).

5.1 Test 5.1.1 – Maximum Transmitter Output Droop

Purpose: To verify that the transmitter output level does not droop more than the maximum specified amount.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.2 - Test modes
[2] Ibid., subclause 96.5.3 - Test fixtures
[3] Ibid., subclause 96.5.4.1 - Transmitter output droop

Resource Requirements:

- DSO
- Differential probe, or 2-pin to SMA Adapter with matched length 50 Ω coaxial cables
- Short Automotive Cable

Discussion:

Reference [1] states that a 100BASE-T1 device shall implement 4 test modes. These test modes are provided to measure electrical characteristics and verify compliance. Reference [2] defines the test fixture to be used to perform the test. Reference [1] defines the operation of a device while in test mode 1, and reference [3] provides a specification for the maximum allowable droop for the transmitter.

This test requires the DUT to operate in transmitter test mode 1. While in test mode 1, the DUT shall generate a sequence of at least 34 +1 symbols followed by at least 34 -1 symbols continually transmitted.

Droop is calculated after measuring the peak voltage (V_{pk}) and the voltage 500 ns after the peak (V_{delay}). The difference $V_d = V_{pk} - V_{delay}$. Droop = V_d/V_{pk} * 100%. This is performed on both the positive and negative peaks of the waveform transmitted by test mode 1. The magnitude of the droop should be less than 45.0%.

Test Setup: Refer to test suite appendix 5.A.3

Procedure:

1. Configure the DUT so that it is operating in transmitter test mode 1.
2. Connect BI_DA from the MDI to Test Fixture 1.
3. Find the rising-edge initial peak voltage (V_{pk}) in the waveform.
4. Measure the amplitude of the waveform at 500 ns after the initial peak (V_{delay}) to find the droop voltage (V_d).
5. Compute the droop between V_{pk} and V_d.
6. For enhanced accuracy, repeat steps 3-5 multiple times.
7. Repeat using a falling edge reference.

Observable Results:

a. The maximum magnitude of both the positive and negative droop shall be less than 45.0%.

Possible Problems: None.

5.2 Test 5.1.2 – Transmitter Distortion

Purpose: To verify that the distortion of the transmitter is within the conformance limits.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.2 - Test modes
[2] Ibid., subclause 96.5.3 - Test fixtures
[3] Ibid., subclause 96.5.4.2 - Transmitter distortion

Resource Requirements:

- DSO
- High Impedance Differential Probe
- Short Automotive Cable
- Transmitter Distortion Adapter

Discussion:

Reference [1] states that a 100BASE-T1 device shall implement 4 test modes. These test modes are provided to measure electrical characteristics and verify compliance. Reference [2] defines the test fixture to be used to perform the test, as well as the disturbing signal characteristics (see to appendix 5.A.4 for more details). Reference [1] defines the operation of a device while in test mode 4, and reference [3] provides a specification for the maximum allowable distortion for the transmitter.

In this test, the peak distortion is measured by capturing the test mode 4 waveform and finding the least mean squared error. The peak error between the ideal reference and the observed symbols is the peak transmitter distortion. Reference [3] provides Matlab code for determining the peak distortion, note this code assumes the disturber signal and the data acquisition clock of the oscilloscope are frequency locked to the DUT TX_TCLK.

Test Setup: Refer to appendix 5.A.4

Procedure:

1. Configure the DUT so that it is sourcing the transmitter test mode 4 waveform.
2. Configure the disturber source as described in [2].
3. Connect BI_DA from the MDI to Test Fixture 2.
4. Capture 2 ms of consecutive symbols in the test mode 4 waveform.
5. Using the code provided in [3], process the 2ms capture in Matlab to calculate the peak distortion at 10 or more uniformly spaced phase offsets over 1 UI.

Observable Results:

a. The peak transmitter distortion should be less than 15mV for all of the sampled phase offsets over 1 UI.

Possible Problems:

a. If the vertical resolution of the oscilloscope is less than 10 bits, then a low pass filter must be used during post-processing. The Matlab code provided in [3] includes such a LPF.

b. If the TX_TCLK of the DUT is not accessible or the DUT does not have an external clock input, the test equipment will not be able to synchronize internal sampling clocks. Because of this, phase offsets will occur in test equipment and measured distortion values will most likely be worse than if the DUT's TX_TCLK was available.

5.3 Test 5.1.3 – Transmitter Timing Jitter

Purpose: To verify that the transmitter timing jitter of the PMA is within the conformance limits.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.2 - Test modes
[2] Ibid., subclause 96.5.3 - Test fixtures
[3] Ibid., subclause 96.5.4.3 - Transmitter timing jitter

Resource Requirements:

- DSO
- Differential probe, or 2-pin to SMA Adapter with matched length 50Ω coaxial cables
- Short Automotive Cable

Discussion:

Reference [1] states that a 100BASE-T1 device shall implement 4 test modes. These test modes are provided to measure electrical characteristics and verify compliance. Reference [2] defines the test fixture to be used to perform the test. Reference [3] provides a specification for the maximum allowable timing jitter for the transmitter.

Case 1 – MASTER transmitter timing jitter

When in test mode 2, the PHY transmits +1 symbols followed by -1 symbols continuously. In this mode, the transmitter output should be a $33\frac{1}{3}$ MHz signal and the RMS TIE jitter measured at the PHY MDI output shall be less than 50 ps. The RMS TIE jitter is measured over an integration time interval of at least 1 ms.

Case 2 – SLAVE transmitter timing jitter

SLAVE transmitter timing jitter can only be performed when the DUTs TX_TCLK is exposed and accessible. For normal operation as the SLAVE, the DUTs reference clock is recovered from a compliant LP PHY operating as MASTER. The RMS TIE jitter of the SLAVE TX_TCLK shall not exceed 0.01 UI (150 ps).

Test Setup: Refer to test suite appendix 5.A.3

Procedure:

Case 1 – MASTER transmitter timing jitter

1. Configure the DUT so that it is operating in transmitter test mode 2.
2. Connect BI_DA from the MDI to Test Fixture 1.
3. Capture at least 1 ms and process the capture to determine the RMS TIE jitter.

4. For enhanced accuracy, repeat step 3 multiple times.

Case 2 – SLAVE transmitter timing jitter

1. Configure the DUT so that it is operating in normal mode, forced to SLAVE.
2. Configure the LP so that it is operating in normal mode, forced to MASTER.
3. Connect the DUT TX_TCLK to the DSO.
4. Achieve a link between DUT and LP using a short automotive cable.
5. Capture at least 1 ms and process the capture of TX_TCLK to determine the RMS TIE jitter.
6. For enhanced accuracy, repeat step 4 multiple times.

Observable Results:

Case 1 – MASTER transmitter timing jitter

a. The RMS TIE jitter measured at the MDI output should not exceed 50 ps.

Case 2 – SLAVE transmitter timing

b. The RMS TIE jitter of the SLAVE TX_TCLK should not exceed 0.01 UI (150 ps).

Possible Problems: If the DUT does not provide access to the TX_TCLK, SLAVE jitter (case 2) testing cannot be performed as described in [3].

5.4 Test 5.1.4 – Transmitter Power Spectral Density (PSD)

Purpose: To verify the transmitter power spectral density are within the conformance limits.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.2 - Test modes
[2] Ibid., subclause 96.5.3 - Test fixtures
[3] Ibid., section 96.5.4.4 - Transmitter power spectral density

Resource Requirements:

- SA, or DSO with spectral measurement capabilities
- Balun (if necessary)
- Differential probe, or 2-pin to SMA Adapter with matched length 50 Ω coaxial cables
- Short Automotive Cable

Discussion:

Reference [1] states that a 100BASE-T1 device shall implement 4 test modes. These test modes are provided to measure electrical characteristics and verify compliance. Reference [2] defines the test fixture to be used to perform the test. Reference [1] defines the operation of a device while in test mode 5, and reference [3] provides the transmitter PSD mask.

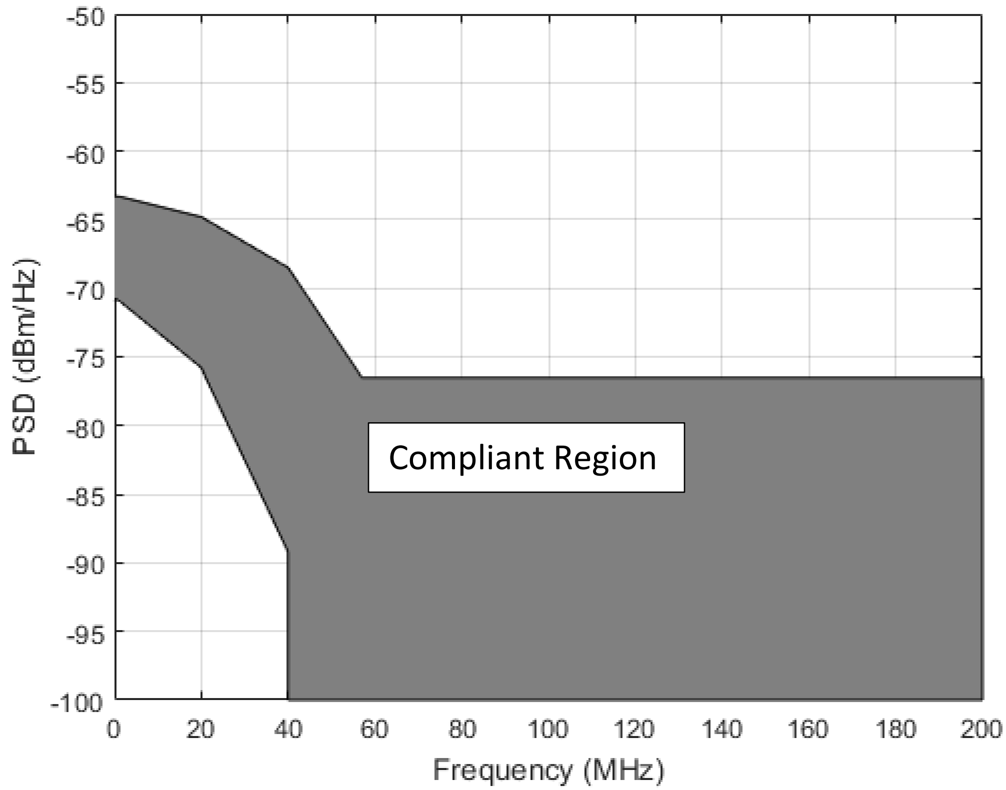
Test Setup: Refer to test suite appendix 5.A.5

Procedure:

1. Configure the DUT so that it is operating in transmitter test mode 5.
2. Connect BI_DA from the MDI to Test Fixture 3.
3. Configure the SA settings as follows: RBW = 10 KHz, VBW = 30 KHz, Sweep time > 60 seconds, Detector = RMS. If using a DSO perform equivalent setup.
4. Capture the spectrum of the transmitted test mode waveform using a SA (or DSO).
5. Compute the transmitter PSD.

Observable Results:

a. The PSD of the transmitter output while operating in test mode 5 shall fit within the transmitter PSD mask defined in [3], and shown below.



Possible Problems: None.

5.5 Test 5.1.5 – Transmit Clock Frequency

Purpose: To verify that the frequency of the Transmit Clock is within the conformance limits.

References:

[1] IEEE Std. 802.3bw, section 96.5.4.5 - Transmit clock frequency

Resource Requirements:

- DSO
- Differential probe, or 2-pin to SMA Adapter with matched length 50 Ω coaxial cables
- Short Automotive Cable

Discussion:

Reference [1] states that all 100BASE-T1 devices must have a symbol transmission rate of $66\frac{2}{3}$ MHz ± 100ppm while operating in MASTER timing mode. This corresponds to a transmit clock of 66.6603 MHz to 66.6736 MHz.

The reference clock used in this test is the one obtained in test 5.1.3, Transmitter Timing Jitter - Case 1. The frequency of this clock, extracted from the transmitted test mode 2 waveform, shall have a base frequency of $66\frac{2}{3}$ MHz ± 100ppm.

Test Setup: Refer to test suite appendix 5.A.3

Procedure:

1. Configure the DUT so that it is operating in transmitter test mode 2.
2. Connect BI_DA from the MDI to Test Fixture 1.
3. Using a narrow-bandwidth PLL, extract the clock frequency from the transmitted symbols.
4. For enhanced accuracy, repeat step 3 multiple times.
5. Measure the frequency of the transmit clock.

Observable Results:

a. The transmit clock generated by the DUT shall have a frequency between 66.6603 MHz and 66.6736 MHz.

Possible Problems: None.

5.6 Test 5.1.6 – MDI Return Loss

Purpose: To measure the return loss at the MDI.

References:

[1] IEEE Std. 802.3bw, subclause 96.8.2.1 – MDI return loss

Resource Requirements:

- VNA, TDR with frequency domain capabilities, or DSO with frequency domain capabilities
- Balun (if necessary)
- Differential probe, or 2-pin to SMA Adapter with matched length 50 Ω coaxial cables
- Short Automotive Cable

Discussion:

A compliant 100BASE-T1 device shall ideally have a differential characteristic impedance of 100Ω. This is necessary to match the characteristic impedance of the automotive cabling. Any difference between these impedances will result in a partial reflection of the transmitted signals. Return loss is a measure of the signal power that is reflected due to the impedance mismatch. Reference [1] specifies the conformance limits for the reflected power measured at the MDI. The specification states that the return loss must be maintained transmitting data or control symbols.

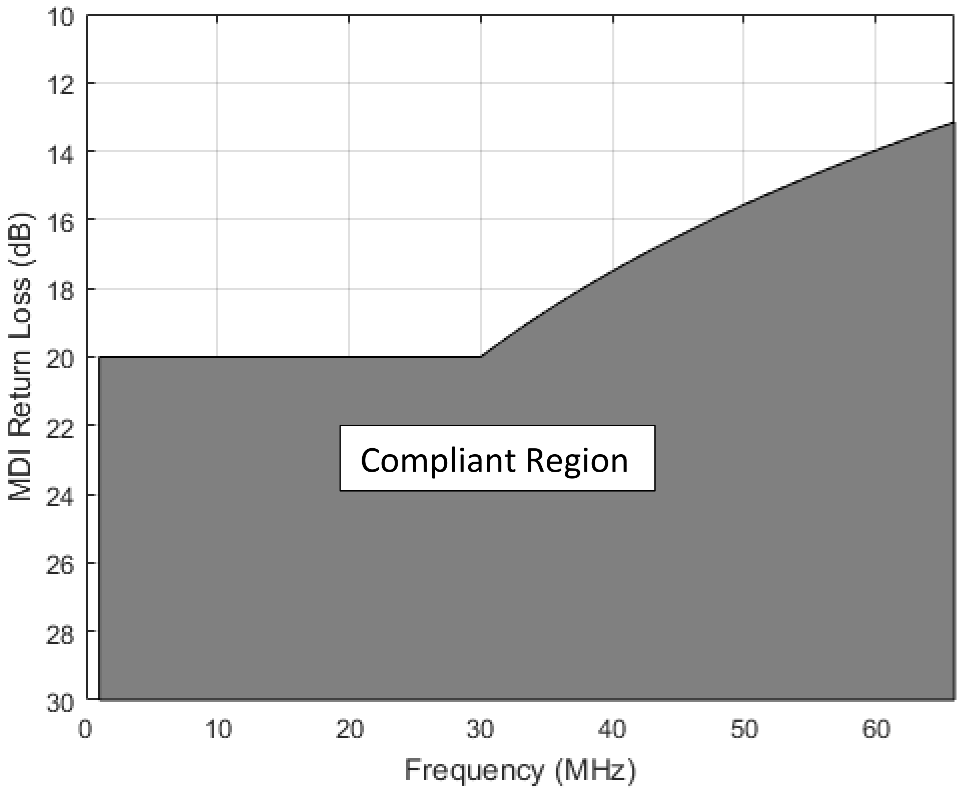
Test Setup: Refer to test suite appendix 5.A.6

Procedure:

1. Configure the DUT for SLAVE mode operation.
2. Calibrate the VNA (or TDR, or DSO) to remove the effects of the test jig and connecting cable.
3. Connect the BI_DA from the MDI to the test equipment.
4. Measure the reflections at the MDI referenced to a 100Ω characteristic impedance.

Observable Results:

a. The return loss measured at the MDI shall be at least 20 dB from 1 to 30M Hz, and at least 20-20*log10(f/30) dB from 30 to 66 MHz when referenced to a characteristic impedance of 100 Ω, as shown below.



Possible Problems: None.

5.7 Test 5.1.7 – MDI Mode Conversion Loss

Purpose: To measure the mode conversion loss at the MDI.

References:

[1] IEEE Std. 802.3bw, subclause 96.8.2.2 – MDI mode conversion loss

[2] OPEN Alliance TC8 Automotive Ethernet ECU Test Specification

Resource Requirements:

- VNA, or TDR with frequency domain capabilities, or DSO with frequency domain capabilities
- Differential probe, or 2-pin to SMA Adapter with matched length 50 Ω coaxial cables
- Short Automotive Cable

Discussion:

A compliant 100BASE-T1 device shall ideally have a differential characteristic impedance of 100Ω, however mismatches in the positive and negative polarities of the MDI output will introduce mode conversion. Reference [1] specifies the conformance limits for the mode conversion measured at the MDI.

Test Setup: Refer to test suite appendix 5.A.6

Procedure:

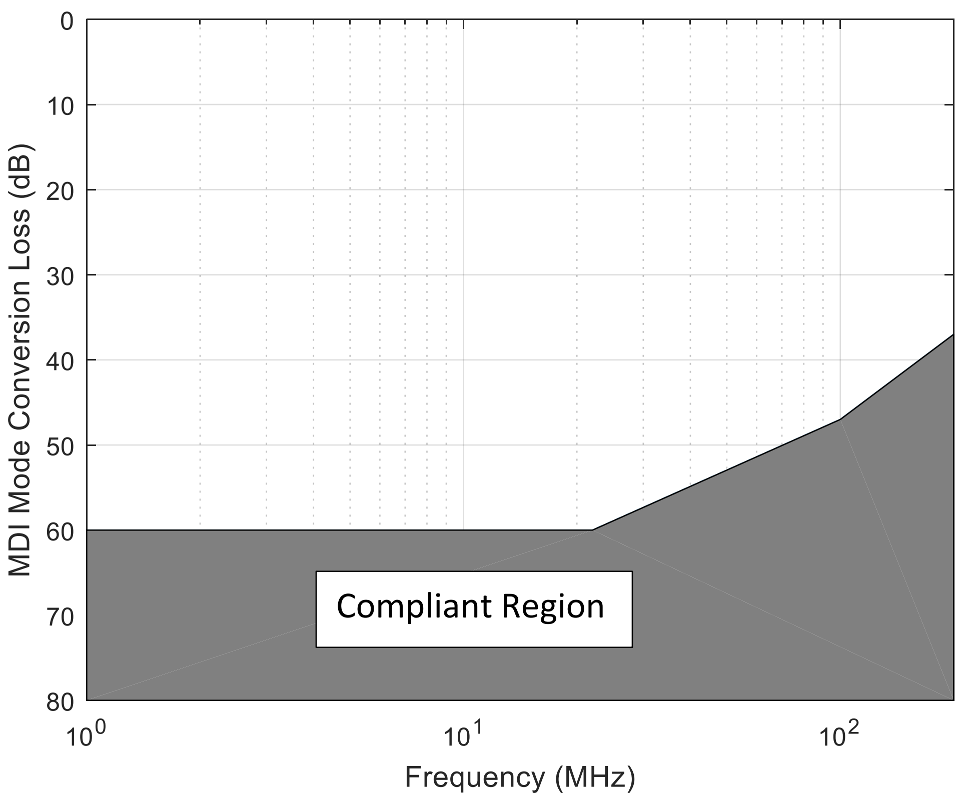
1. Configure the DUT for SLAVE mode operation.
2. Calibrate the VNA (or TDR, or DSO) to remove the effects of the test jig and connecting cable.
3. Connect the BI_DA from the MDI to the test equipment.
4. Measure the mode conversion at the MDI referenced to a 100 Ω characteristic impedance.

Observable Results:

a. The mode conversion loss measured at the MDI shall meet the mask defined in [2] when referenced to a characteristic impedance differential mode of 100 Ω and characteristic impedance common mode of 25 Ω, as shown below.[2]

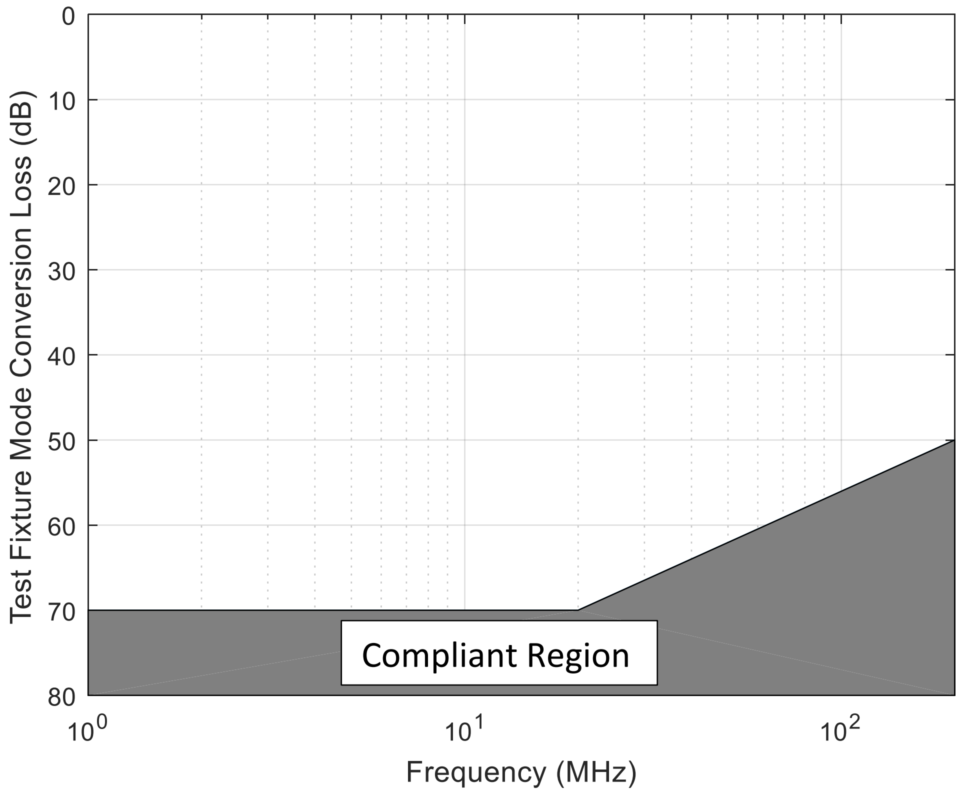
[2] The limit described in observable result a. is derived in [2] and modified from the IEEE definition provided in [1]. Reference [2] provides a table of frequency and loss values to define the MDI mode conversion loss limit, but for convenience an equivalent equation is provided below, as well as a diagram.

$$TCL(f) = \begin{cases} 60 & dB \quad for\ 1\ MHz \le f < 22\ MHz \\ 60 - \left(\dfrac{13}{\log_{10}(100/22)}\right) \times \log_{10}(f/22) & dB \quad for\ 22\ MHz \le f < 100\ MHz \\ 47 - \left(\dfrac{10}{\log_{10}(200/100)}\right) \times \log_{10}(f/100) & dB \quad for\ 100\ MHz \le f < 200\ MHz \end{cases}$$



Possible Problems: When measuring mode conversion loss, the impedance balance of the cabling and test fixtures in the test setup is critical. Any fixtures used to connect the MDI of the DUT to the test equipment should have sufficient mode conversion loss margin compared to the MDI requirement. To achieve a high degree of reliability of measurement results it is recommended in [2] that the test fixture mode conversion loss meet a specified mask when referenced to a characteristic impedance differential mode of 100 Ω and characteristic impedance common mode of 25 Ω. Reference [2] provides a table of frequency and loss values to define the MDI mode conversion loss limit, but for convenience an equivalent equation is provided below, as well as a diagram.

$$TCL(f) = \begin{cases} 70 & dB \quad for\ 1\ MHz \leq f < 20\ MHz \\ 70 - 20\times \log_{10}(f/200) & dB \quad for\ 20\ MHz \leq f < 200\ MHz \end{cases}$$


Test Fixture Mode Conversion Loss (dB)
0
10
20
30
40
50
60
70
80
Compliant Region
10^0
10^1
10^2
Frequency (MHz)

5.8 Test 5.1.8 – Transmitter Peak Differential Output

Purpose: To verify that the peak-to-peak differential amplitude does not exceed the specified amount.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.6 – Transmitter peak differential output
[2] Ibid., subclause 96.5.2 - Test modes
[3] Ibid., subclause 96.5.3 - Test fixtures

Resource Requirements:

- DSO
- Differential probe, or 2-pin to SMA Adapter with matched length 50 Ω coaxial cables
- Short Automotive Cable

Discussion:

Reference [1] states that any 100BASE-T1 transmitter peak-to-peak differential amplitude shall be less than 2.2 V_{PP} when measured with a 100 Ω termination. It also states that this is to be true for all transmit modes including SEND_I and SEND_N modes. This test could be performed when the DUT is configured as MASTER and in the TRAINING state of the PHY Control state diagram; however, Test Mode 5, as described in [2], is labeled as "Normal operation at full power" and is generated by transmitting random data through the same scrambling process as SEND_I. Either operating mode should be sufficient for this test and yield comparable results. Test Fixture 1, defined in [3], should be used to measure transmitter peak differential output.

Test Setup: Refer to test suite appendix 5.A.3

Procedure:

1. Configure the DUT so that it is operating as MASTER or operating in transmitter test mode 5.
2. Connect BI_DA from the MDI to Test Fixture 1.
3. Measure the peak-to-peak amplitude of the waveform.
4. For enhanced accuracy, repeat step 3 multiple times.

Observable Results:

a. The maximum differential peak-to-peak amplitude of the waveform shall be less than 2.2 V_{PP}.

Possible Problems: None.

6 GROUP 2: PMA Receive Tests

Overview:

This section verifies the integrity of the 100BASE-T1 PMA Receiver through frame reception tests.

6.1 Test 5.2.1 – Bit Error Rate Verification

Purpose: To verify that the DUT can maintain a BER of less than 10^{-10}.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.5.1 - Receiver differential input signals
[2] Ibid., subclause 96.7 – Link segment characteristics
[3] IOL TP-PMD Test Suite Appendix 25.D
[4] Appendix 5.B – 100BASE-T1 Cabling for Receiver Testing

Resource Requirements:

- Packet transmit/monitoring station
- Automotive cables of varying lengths

Discussion:

Reference [1] states that a 100BASE-T1 capable PHY shall not exceed a BER of less than 10^{-10}. The cables used for receiver BER testing are automotive cables, conformant to the characteristics described in [2] but representative of a worst case channel. Channel characteristics of the worst case channel are further discussed in [4]. Packet transmit and monitoring stations are used to verify the BER of the DUT.

Based on the analysis given in reference [3], if more than 7 errors are observed in $3x10^{10}$ bits (about 2,470,000 1,518-byte packets), it can be concluded that the error rate is greater than 10^{-10} with less than a 5% chance of error. Note that if no errors are observed, it can be concluded that the BER is no more than 10^{-10} with less than a 5% chance of error.

Test Setup: Refer to test suite appendix 5.A.7

Procedure:

1. Configure the DUT as MASTER.
2. Connect the packet monitoring station to the automotive cable.
3. Connect the DUT to the automotive cable.
4. Send 2,470,000 1,518-byte packets (for a 10^{-10} BER) and the monitor will count the number of packet errors.
5. Repeat step 4 for the remaining automotive cables.
6. Repeat steps 4-5 with the DUT configured as SLAVE.

Observable Results:

a. The DUT shall maintain a BER of less than 10^{-10} for all automotive cable lengths.

Possible Problems: None.

6.2 Test 5.2.2 – Receiver Frequency Tolerance

Purpose: To verify that the DUT can properly accept incoming data with the symbol rate of $66\frac{2}{3}$ MHz +/- 100 ppm.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.5.2 - Receiver frequency tolerance
[2] Ibid., subclause 96.7 – Link segment characteristics
[3] Appendix 5.B – 100BASE-T1 Cabling for Receiver Testing

Resource Requirements:

- Packet transmit/monitoring station capable of a configurable transmit clock
- Automotive cable representative of worst case channel

Discussion:

Reference [1] states that a 100BASE-T1 capable PHY shall properly accept incoming data with the symbol rate of $66\frac{2}{3}$ MHz +/- 100 ppm. This corresponds to a transmit clock of 66.6603 MHz to 66.6736 MHz. Please refer to Test 5.2.1 – Bit Error Rate Verification, of this document, for further details regarding the worst case channel and packet analysis. The cables used for receiver frequency tolerance testing are automotive cables, conformant to the characteristics described in [2] but representative of a worst case channel. Channel characteristics of the worst case channel are further described in [3].

Test Setup: Refer to test suite appendix 5.A.7

Procedure:

1. Configure the DUT as SLAVE.
2. Connect the packet transmit/monitoring station to the automotive cable.
3. Connect the DUT to the automotive cable.
4. Configure the packet transmit/monitoring station to transmit data with a clock of 66.6603 MHz.
5. Send 2,470,000 1,518-byte packets (for a 10^{-10} BER) and monitor the number of packet errors.
6. Repeat step 3-5 using a transmit clock of 66.6736 MHz.

Observable Results:

a. The DUT shall maintain a BER of less than 10^{-10} when recovering a transmit clock of 66.6603 MHz or 66.6736 MHz for all automotive cable lengths.

Possible Problems: None.

6.3 Test 5.2.3 – Alien Crosstalk Noise Rejection

Purpose: To verify that the DUT can maintain a bit error rate of less than 10^{-10} in the presence of a crosstalk noise source.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.5.3 – Alien crosstalk noise rejection
[2] Ibid., subclause 96.7 – Links characteristics
[3] Appendix 5.B – 100BASE-T1 Cabling for Receiver Testing

Resource Requirements:

- Packet transmit/monitoring station
- Worst case automotive crosstalk noise injection cable
- IEEE 100BASE-T1 100 Mbps idle symbol noise source

Discussion:

Reference [1] defines a test cable which uses a resistive network to inject crosstalk noise into the receive path of the DUT. Reference [1] goes on to state that a 100BASE-T1 capable PHY shall not exceed a BER of less than 10^{-10}, even with alien crosstalk noise present. The cables used for receiver frequency tolerance testing are automotive cables, conformant to the characteristics described in [2] but representative of a worst case channel. Channel characteristics of the worst case channel are further discussed in [3].

Test Setup: Refer to test suite appendix 5.A.8

Procedure:

1. Configure the DUT as MASTER.
2. Connect the packet transmit/monitoring station to the worst case automotive crosstalk noise injection cable.
3. Connect the DUT to the worst case automotive crosstalk noise injection cable.
4. Send 2,470,000 1,518-byte packets (for a 10^{-10} BER) and the monitor will count the number of packet errors.
5. Repeat step 4 with the DUT configured as SLAVE.
6. Repeat steps 1 through 5 using a Gaussian signal generator as the noise source.

Observable Results:

a. The DUT shall maintain a BER of less than 10^{-10} when using the worst case automotive crosstalk noise injection cable with a compliant 100BASE-T1 transmitter as the noise source.
b. The DUT shall maintain a BER of less than 10^{-10} when using the worst case automotive crosstalk noise injection cable with a Gaussian signal generator as the noise source.

Possible Problems: None.

7 Test Suite Appendix

Overview:

The appendices contained in this section are intended to provide additional low-level technical details pertinent to specific tests defined in this test suite. Test suite appendices often cover topics that are beyond the scope of the standard, but are specific to the methodologies used for performing the measurements covered in this test suite. This may also include details regarding a specific interpretation of the standard (for the purposes of this test suite), in cases where a specification may appear unclear or otherwise open to multiple interpretations.

Scope:

Test suite appendices are considered informative, and pertain only to tests contained in this test suite.

7.1 Appendix 5.A – 100BASE-T1 Transmitter Test Fixtures

Purpose: To provide a reference implementation of Test Fixtures 1 through 3 as well as other transmit and receive test setups.

References:

[1] IEEE Std. 802.3bw, subclause 96.5.3 - Test fixtures
[2] Ibid., subclause 96.7 – Link segment characteristics
[3] Ibid., subclause 96.8 – MDI specification
[4] Ibid., subclause 96.5.5.3 – Alien crosstalk noise rejection
[5] Ibid., subclause 96.5.4.3 - Transmitter timing jitter
[6] Appendix 5.B – 100BASE-T1 Cabling for Receiver Testing
[7] OPEN Alliance TC8 Automotive Ethernet ECU Test Specification

Resource Requirements:

- DSO: Capable of 1 GHz bandwidth and a sampling rate of 2 GS/s or higher.
- SA: Capable of operating up to 200 MHz with a dynamic range of 50 dBm or higher, or equivalent Digital oscilloscope with spectral measurement capabilities.
- VNA: Capable of measuring up to 200 MHz, or equivalent TDR with frequency domain capabilities
- Packet transmit/monitoring system
- Differential probe, or 2-pin to SMA Adapter with matched length 50 Ω coaxial cables
- Transmitter distortion adapter
- High Impedance Differential Probe: Capable of operating up to 1 GHz or higher.
- Balun: Capable of operating up to 200 MHz or higher.
- Disturbing signal generator: Capable of producing a sinusoid with differential amplitude of 5.4 Vpp and a frequency of $11.11\overline{1}$ MHz
- Automotive cabling: Various lengths
- Worst case automotive crosstalk noise injection cable
- IEEE 100BASE-T1 100Mbps Idle Symbol Noise Source

Discussion:

5.A.1- Introduction

Reference [1] defines three test fixtures to be used in the verification of 100BASE-T1 transmitter specifications. The purpose of this appendix is to present a reference implementation of these test fixtures, however the implementations described here are not the only acceptable method of performing the test cases defined in this document. This appendix describes test setups that can be used as Test Fixtures 1 through 3, a setup for MDI Return Loss, a setup for MDI Mode Conversion Loss, and Group 2: PMA Receive Test measurements.

5.A.2 – Cabling and Adapters

Reference [2] states that 100BASE-T1 is designed to operate over 100 Ω one pair cable (automotive cable), and [3] defines the MDI connector can be any connector currently used in the automotive industry that does not degrade a signal worse than a 15 meter 100 Ω one pair cable. Leaving the choice of cabling and MDI connector up to the DUT manufacturer; because of this, flexibility is required in the development of the test setups. An SMA adapter board accompanied by a short automotive cable will be used to connect the DUT to test equipment. Figure A.1 illustrates the SMA adapter.

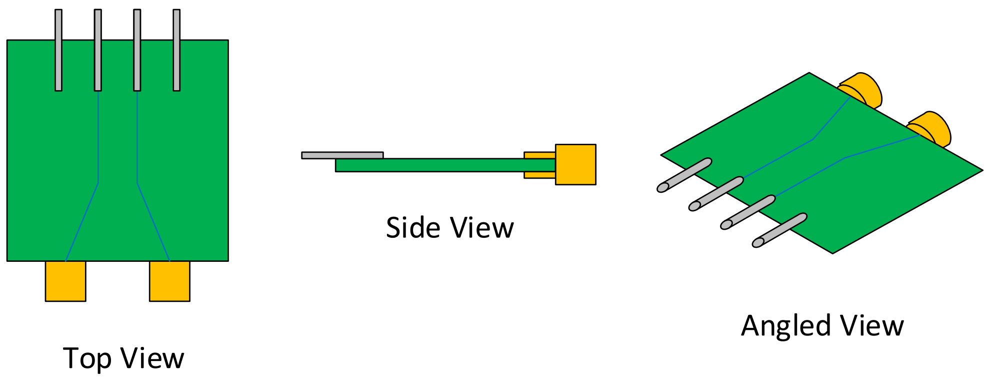


Figure A.1: 2-pin to SMA Adapter

Due to the wide variety of connectors that could be tested, a single cable cannot be used to connect every DUT to the SMA adapter. A Short automotive cable with a connector that can mate with the DUT MDI on one end and can connect to the two pins on the SMA adapter, described above, on the other end will be used. By doing this a different cable can be used for each DUT and allow calibrating out the loss of the cable and adapter so that the test point will be at the devices MDI.

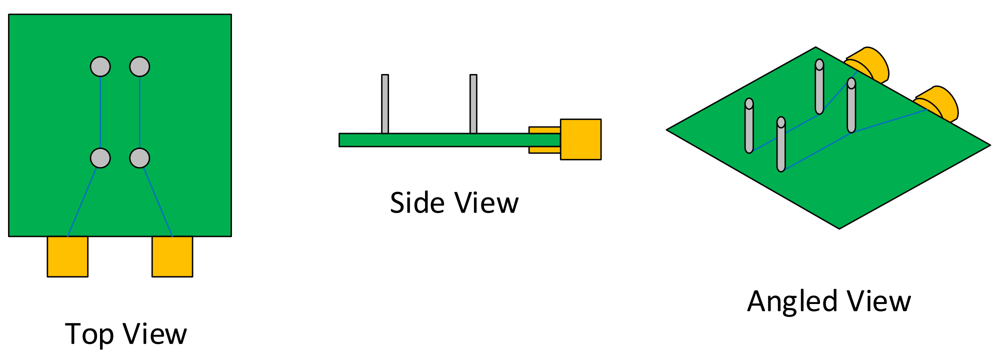


Figure A.2: Transmitter Distortion Adapter

A second adapter was developed for measuring transmitter distortion, illustrated in Figure A.2. To measure distortion an additional probing point is needed so that the disturbing sine wave can be delivered to the DUT, as well as measure the sum of the test mode 4 pattern and the disturbed voltage with a high impedance differential probe. This adapter is incorporated into the Test Fixture 3 test setup described in Figure A.5.

5.A.3 – Test Fixture 1

Test Fixture 1 described in [1] will be used for maximum transmitter output droop and transmitter timing jitter (Case 1: MASTER transmitter timing jitter). Figure A.3 shows a diagram of the Test Fixture 1 setup.

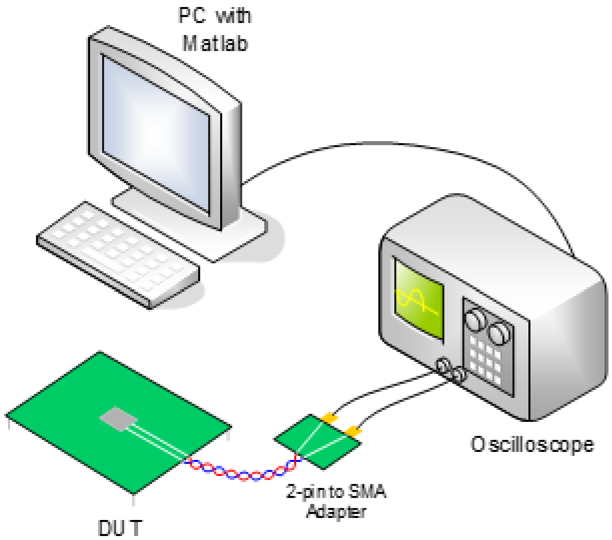


Figure A.3: Droop, Jitter (Master) Test Setup (Test Fixture 1)

The DUT is connected to the short automotive cable and 2-pin to SMA adapter described in 5.A.2, then connected to the DSO using matched length SMA cables. The test mode waveforms are downloaded to a pc where Matlab scripts post-process the data. Alternatively, a differential probe and 100 Ω termination may be used instead of the 2-pin to SMA fixture and 50 Ω cables.

When testing SLAVE jitter Test Fixture 1 must be modified to include the use of a 100BASE-T1 link partner. The DUT is forced to link in SLAVE mode and the MDI is connected to the MDI of the LP (which is forced to link in MASTER mode) using a short automotive cable. The TX_TCLK of the DUT is then connected to the DSO. See Figure A.4 for this setup. If the TX_TCLK of the DUT is not accessible SLAVE jitter cannot be performed as described in [5].

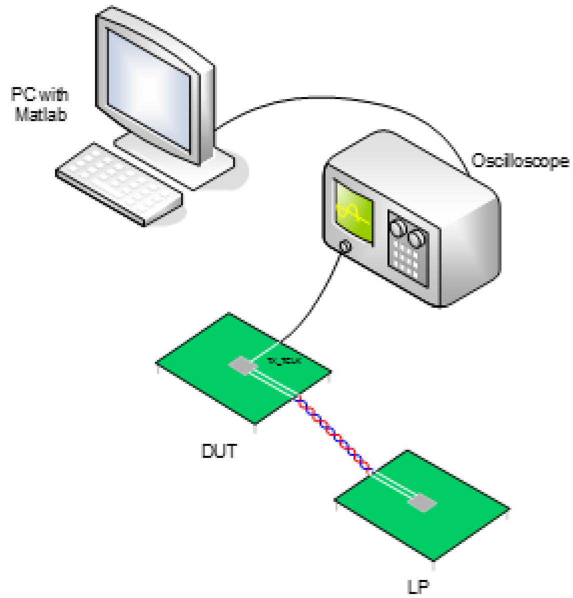


Figure A.4: Jitter (SLAVE) Test Setup

5.A.4 – Test Fixture 2

In Test Fixture 2, the DUT is directly connected to a 100 Ω differential voltage generator. The voltage generator transmits a sine wave of specific frequency and amplitude; which is referred to as the disturbing signal, V_d. An oscilloscope monitors the output of the DUT through a high impedance differential probe. The disturbing sine wave characteristics are given in Table A-1.

Table A-1: Characteristics of disturber waveform

V_d Amplitude	V_d Frequency
5.4 V peak-to-peak	$11.11\overline{1}$ MHz

The purpose of V_d is to simulate the presence of a remote transmitter. If the DUT is not sufficiently linear, the disturbing signal will cause significant distortion products to appear in the DUT output. Note that while the oscilloscope sees the sum of the V_d and the DUT output, only the DUT output is of interest. Therefore post-processing, or hardware filtering, is required to remove the disturbing signal from the measured waveform. If a hardware filter is employed to remove V_d from the measured waveform it must be positioned such that the DUT MDI receives V_d while being removed from the differential probe path.

Upon looking at the Test Fixture 3 definition shown in [1], it is important to note that V_d is defined as the voltage before the 50Ω resistors. Thus, the amount of voltage seen at the transmitter under test is 50% of the original amplitude of V_d.

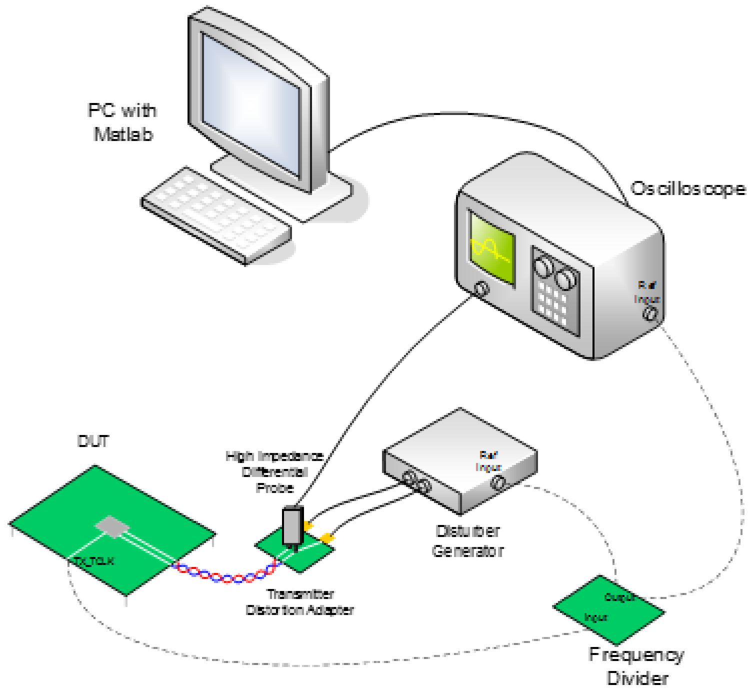


Figure A.5: Distortion Test Setup (Test Fixture 2)

The IEEE 802.3bw specification requires the test equipment used for transmit distortion measurements be synchronized with the DUT's TX_TCLK, this guarantees that the internal sampling clock of each piece of equipment shares a common clock source and is phase locked. How to generate a reference clock from the TX_TCLK is not defined but can be achieved in several ways. Using a frequency divider to generate a 10 MHz clock from the $66\frac{2}{3}$ MHz TX_CLK is one such technique. This is depicted in Figure A.4 with a dashed line. However, depending on the DUT's design and form factor the TX_TCLK may not be exposed or brought out to a probe-able pin. When the TX_TCLK is not accessible distortion testing will need to be tested without test equipment synchronization. Because of this phase offsets will occur between the clock sources of each test equipment, and measured distortion values will most likely be worse than if the DUT's TX_TCLK was available.

A Matlab script is provided in the IEEE 802.3bw specification to calculate transmitter distortion. Embedded within the script are hardware requirements for the oscilloscope used to capture the test mode 4 pattern. The requirements include a sample rate of 2GS/s and an ADC vertical resolution of 8 bits or more. It also goes on to state that if the ADC resolution is less than 10 bits then the data is to be processed through an optional section of code that includes a $33\frac{1}{3}$ MHz low pass filter. However since the oscilloscope sample rate and ADC resolution are not discussed outside the Matlab code it makes the implementation of the optional code subjective and left to the interpretation of the tester. Additionally, ADC vertical resolution settings available to the user will differ from equipment vendor to equipment vendor. There are DSOs in the market that offer >8 bit native ADC vertical resolution but most DSOs have a native ADC vertical resolution of 8 bits. Depending on the DSO the ADC resolution may be increased above the native settings, this is achieved by applying DSP techniques. The exact details of the

DSP used to increase the ADC resolution is proprietary and is up to the equipment vendor to divulge. Since the DSP techniques used to increase the ADC resolution are not fully available to the user it is possible that the unspecified filtering can artificially lower distortion values. Measured distortion values will vary significantly based on the ADC settings, care should be taken when choosing ADC settings. When testing transmitter distortion the sample rate should be exactly 2GS/s and the Matlab low pass filter will only be used if the native ADC resolution is less than 10 bits.

5.A.5 – Test Fixture 3

Test Fixture 3 described in [1] will be used for transmitter PSD measurements. The PSD profile is downloaded from the SA and post-processed in Matlab. Figure A.6 shows a diagram of the Test Fixture 3 setup. A balun is necessary to convert the differential transmission of the DUT to a single-ended input for the SA. Alternatively a DSO may be used for measuring PSD, such a setup is demonstrated in Test Fixture 1 (5.A.3).

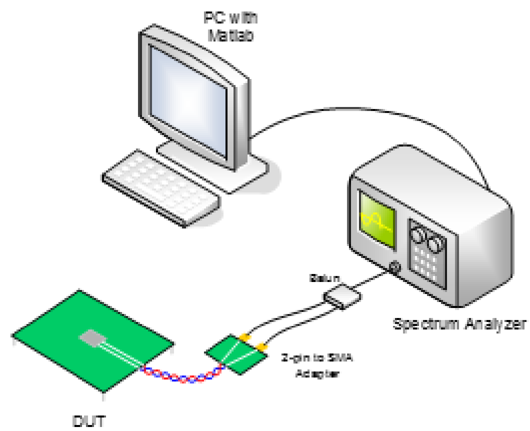


Figure A.6: PSD Test Setup (Test Fixture 3)

5.A.6 – MDI Return Loss and MDI Mode Conversion Loss Setup

The MDI return loss and mode conversion loss measurements are typically performed with a VNA. Depending on the design of the VNA there may only be a single input port, if this is the case a balun will need to be used to convert the differential transmission of the DUT to a single-ended input for the VNA. See figure A.7. However, if the VNA has two or more input ports a balun is not necessary, see Figure A.8.

When using a VNA, the MDI Mode Conversion Loss measurement must be performed on a multi-port network analyzer. When measuring mode conversion loss the impedance balance of the cabling and test fixtures in the test setup is critical. In addition to the test fixtures used it is highly recommended that a reference ground plane is placed under the test setup, and securely connected to the test fixture for sufficient grounding. Any fixtures used to connect the MDI of the DUT to the test equipment should have sufficient mode conversion loss margin compared to the MDI requirement. To achieve a high degree of reliability of measurement results OPEN Alliance TC8 recommends in [7] a test fixture mode conversion loss requirement.

Alternatively, a DSO may be used for performing the MDI measurements, such a setup is not shown in this document. For accurate results, the DSO should have sufficient dynamic range to verify compliance.

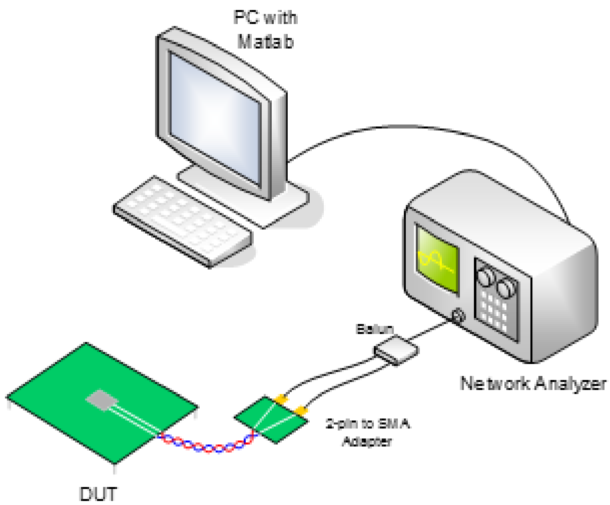


Figure A.7: MDI Return Loss with Single Input VNA

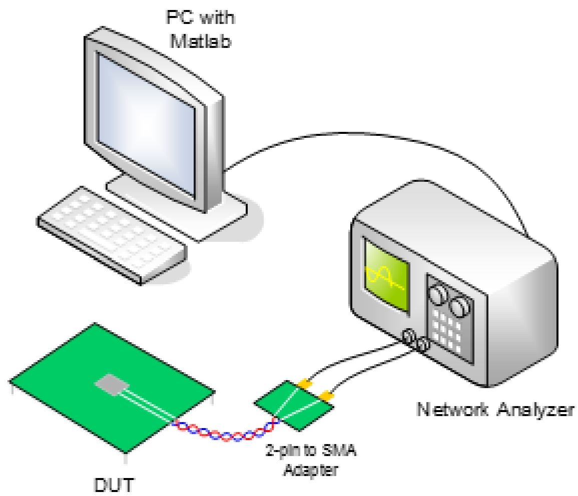


Figure A.8: MDI Return Loss and MDI Mode Conversion Loss with Two Input VNA

5.A.7 – PMA Receiver Testing Setup

Figure A.9 describes the setup for Test 5.2.1 and 5.2.2, the only difference between the setups is the frequency of the link partner transmit clock. A packet generation and monitoring station will be used to measure the amount of dropped packets. This test is performed over various automotive cable lengths, representative of the worst case channel defined in [2], to simulate real world environments. The channel characteristics regarding the worst case channel is discussed in [6].

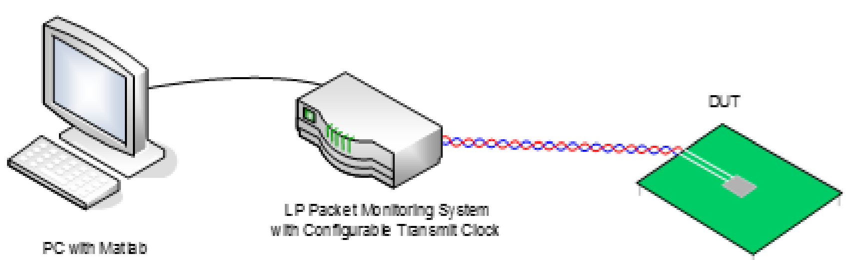


Figure A.9: BER & Receiver Frequency Tolerance Test Setup

5.A.8 – Alien Crosstalk Noise Rejection Setup

Figure A.9 describes the test cable used to introduce the crosstalk source defined in [4]. A small adapter populated with the necessary resistors is soldered to the end of an automotive cable, closest to the receiver under test. Since the MDI mechanical specification can vary between vendors an additional, very short, automotive cable is necessary to connect the DUT to the adapter. The insertion loss of the test cable, including the very short patch cable, is conformant to the worst case characteristics described in [2]. The channel characteristics regarding the worst case channel is discussed in [6].

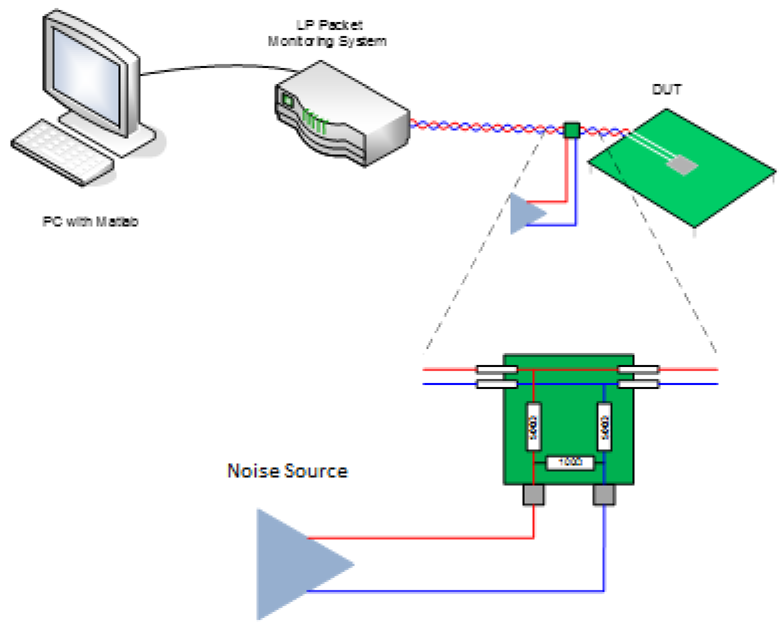


Figure A.10: Alien Crosstalk Noise Rejection Setup

7.2 Appendix 5.B – 100BASE-T1 Cabling for Receiver Testing

Purpose: To describe the characteristics of various automotive cables used to verify BER, Receiver Frequency Tolerance, and Alien Crosstalk Noise Rejection.

References:

[1] IEEE 802.3bw, subclause 96.7 – Link segment characteristics

[2] OPEN Alliance TC2 100BASE-T1 EMC Definitions for Communication Channel

Discussion:

Reference [1] specifies the 100BASE-T1 cabling system by defining it as a differential 100 Ω one pair cabling system up to 15 meters in length with inline connectors, and goes on to give specification limits for insertion loss, return loss, and alien crosstalk. [2] further defines the cabling system with several more parameters including LCL, LCTL, ANEXT, AFEXT, PSANEXT, PSAACRF, AFEXTDC, and AFEXTDC. Reference [2] also specifies the whole communications channel as “the complete electrical wired connection between two ECUs with Ethernet interface” (Ethernet interface in this case is equivalent to MDI) and continues to specify the channel with a maximum of 4 inline connectors. While [1] does specify a maximum whole communication channel (WCC) segment length of 15 meters, component and cable quality used in the WCC will dictate the overall performance, meaning a WCC may be greater than 15 meters in length but still be conformant to the previously listed parameter limits. That being said, a “worst case” channel is ideally defined as a WCC with 4 inline connectors and channel characteristics that are as close to the parameter limit values as possible while still being in the conformant range.

While a “worst case” WCC (WC-WCC) is ideally a channel that is close to violating the parameter limits but still conformant, it is nearly impossible to meet this criteria for all channel parameters. Instead, the WC-WCC is more specifically defined as a channel with 4 inline connectors that is tuned to nearly violate the insertion loss specifications while being conformant to the return loss limit. Figure 5.B-1 shows the insertion loss limit defined in [1] and [2] in red, while all other curves represent channels that have losses equivalent to 10, 20, 30, 40, 50, 60, 70, 80, and 90 % of the WC-WCC.

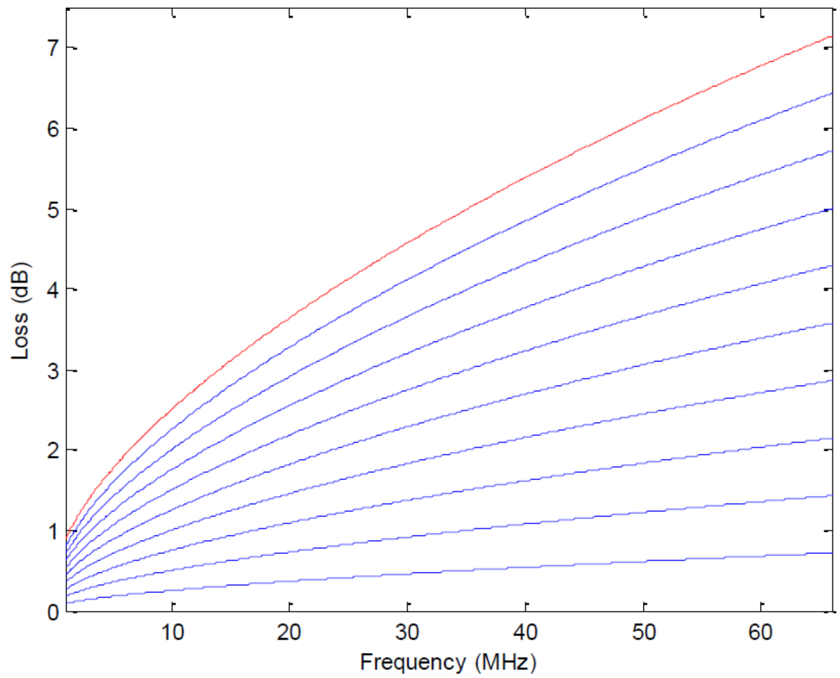


Figure 5.B-1: Worst Case Whole Communication Channels

Testing over more than one WCC ensures that the DUT can not only communicate with a LP over channels with significant loss but also can communicate over shorter WCCs which are less lossy but usually have worse return loss characteristics.