# Requirements for Field Test Instruments and Measurements for Balanced Single Twisted-Pair Cabling

## TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

## FOREWORD

(This foreword is not part of the Standard)

ANSI/TIA-1152, Requirements for Field Test Instruments and Measurements for Balanced Twisted-Pair Cabling, was published. ANSI/TIA-1152 addresses 4-pair cabling systems. This standard will address field testing of single-pair cabling systems.

**Approval of this Standard**

TIA standards documents are developed within the Technical Committees of the TIA and the standards coordinating committees of the TIA standards board. Members of the committees serve voluntarily and without commission. The companies that they represent are not necessarily members of the TIA. The standards developed within the TIA represent a consensus of the broad expertise on the subject. This expertise comes from within the TIA as well as those outside of the TIA that have an expressed interest. The viewpoint expressed at the time that this standard was approved was from the contributors' experience and the state of the art at that time. Users are encouraged to verify that they have the latest revision of the Standard.

This standard has been prepared by the TR-42.7 Subcommittee and approved by the TIA Engineering Committee TR-42 and the American National Standards Institute (ANSI).

ANSI/TIA reviews standards every 5 years. At that time, standards are reaffirmed, rescinded, or revised according to the submitted updates. Updates to be included in the next revision should be sent to the committee chair or to ANSI/TIA.

**Relationship to other TIA standards and documents**

The following are related standards regarding various aspects of structured cabling that were developed and are maintained by Engineering Committee TIA TR-42. An illustrative diagram of the relationship to other relevant TIA standards is given in Figure 1.

- ANSI/TIA-568.0, *Generic Telecommunications Cabling for Customer Premises*
- ANSI/TIA-568.1, *Commercial Building Telecommunications Infrastructure Standard*
- ANSI/TIA-568.2, *Balanced Twisted-Pair Telecommunications Cabling and Components Standard*
- ANSI/TIA-568.3, *Optical Fiber Cabling and Components Standard*
- ANSI/TIA-568.4, *Broadband Coaxial Cabling and Components Standard*
- ANSI/TIA-568.5, Balanced Single Twisted-Pair Telecommunications Cabling and Components Standard
- ANSI/TIA-569, *Telecommunications Pathways and Spaces*
- ANSI/TIA-570, *Residential Telecommunications Infrastructure Standard*
- ANSI/TIA-606, *Administration Standard for Telecommunications Infrastructure*
- ANSI/TIA-607, *Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises*
- ANSI/TIA-758, *Customer-Owned Outside Plant Telecommunications Infrastructure Standard*
- ANSI/TIA-862, *Structured Cabling Infrastructure Standard for Intelligent Building Systems*
- ANSI/TIA-942, *Telecommunications Infrastructure Standard for Data Centers*
- ANSI/TIA-1005, *Telecommunications Infrastructure Standard for Industrial Premises*
- ANSI/TIA-1179, *Healthcare Facility Telecommunications Infrastructure Standard*
- ANSI/TIA-4966, *Telecommunications Infrastructure Standard for Educational Facilities*
- ANSI/TIA-4994, *Standard for Sustainable Information Communications Technology*
- ANSI/TIA-5017, *Telecommunications Physical Network Security Standard*

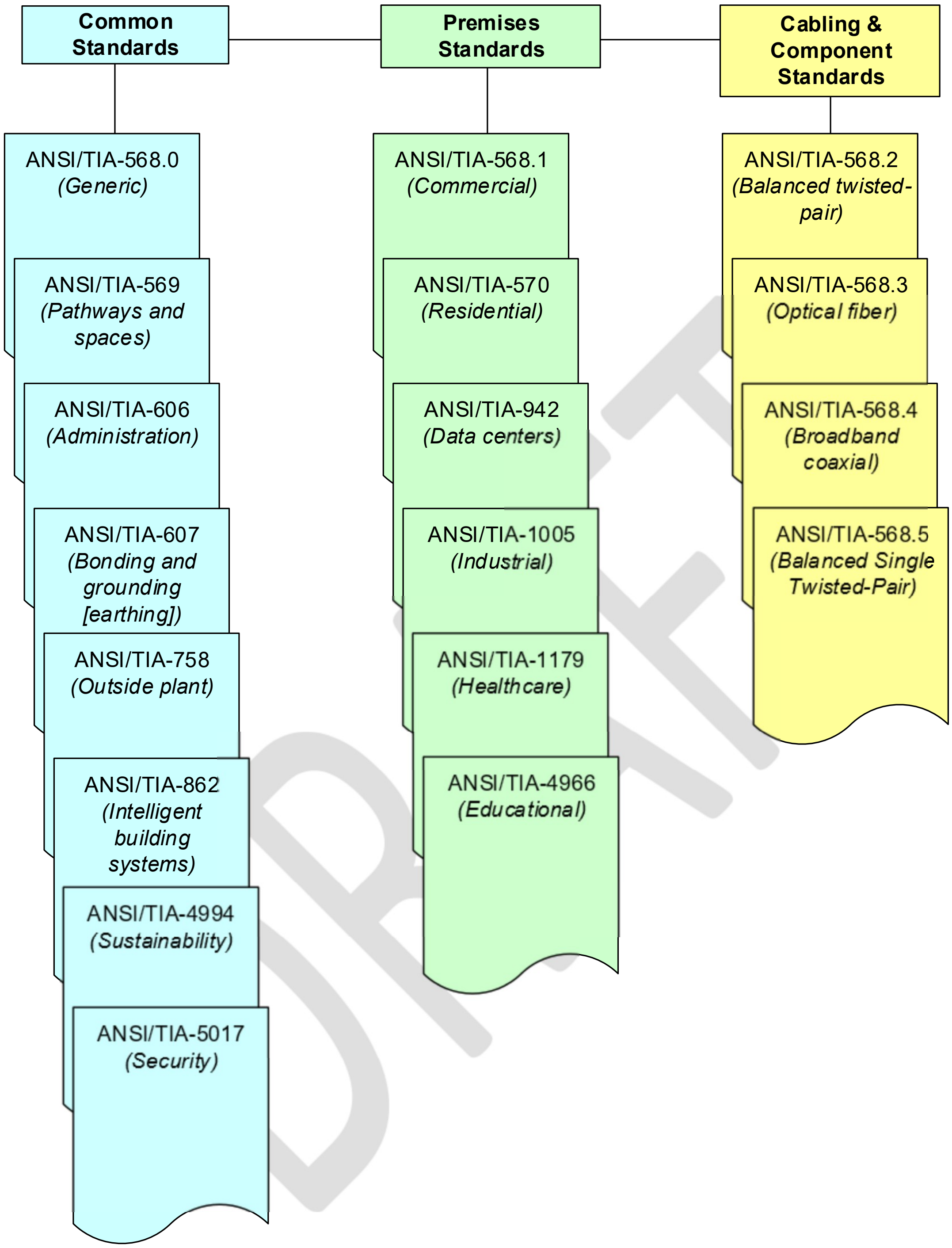




**Figure 1 - Relationship between relevant TIA Standards**

In addition, the following documents may be useful to the reader:

- *National Electrical Safety Code® (NESC®)* (IEEE C 2);
- *National Electrical Code® (NEC®)* (NFPA 70)

Useful supplements to this Standard include the BICSI *Telecommunications Distribution Methods Manual,* the *Outside Plant Design Reference Manual,* and the *Information Transport Systems Installation Methods Manual*. These manuals provide practices and methods by which many of the requirements of this standard are implemented.

**Annexes**

Annexes A, B and C are informative and are not considered requirements of this Standard.

# 1 SCOPE

This Standard specifies requirements for field test instruments and includes procedures for testing balanced single twisted-pair cabling to meet the specifications in the ANSI/TIA-568.5 and ANSI/TIA-568.7 standards. This Standard specifies the reporting and measurement accuracy requirements of field test instruments. This Standard contains methods to verify field test instrument accuracy by comparing the field test instrument measurements against laboratory equipment measurements specified in ANSI/TIA-568.5.

# 2 NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI/TIA-568.2 Balanced Twisted-Pair Telecommunications Cabling and Components Standard

ANSI/TIA-606 Administration Standard for Commercial Telecommunications Infrastructure

ANSI/TIA-568.5 Balanced Single Twisted-Pair Telecommunications Cabling and Components Standard

# 3 DEFINITIONS, ABBREVIATIONS AND ACRONYMS, UNITS OF MEASURE

## 3.1 General

For the purpose of this Standard, the following definitions, acronyms and abbreviations and units of measure apply.

## 3.2 Definitions

**administration:** The method for labeling, identification, documentation, and usage needed for installation, moves, additions and changes of the telecommunications infrastructure.

**cabling:** A combination of all cables, jumpers, cords, and connecting hardware.

**common mode rejection:** The ratio of the measured differential voltage to a common mode voltage applied to the load port.

**insertion loss:** The power loss resulting from the insertion of a component, link or channel (often referred to as attenuation).

**link:** A transmission path between two points, not including equipment and cords.

**nominal velocity of propagation:** The percentage of the speed of light at which signal travels in a cable.

**output signal balance:** The ratio of the output common mode voltage to the output differential voltage generated by a source port.

**patch cord:** A cord used to establish connections on a patch panel.

**patch panel:** A connecting hardware system that facilitates cable termination and cabling administration using patch cords.

**power sum alien near-end crosstalk:** A computation of the unwanted signal coupling from multiple uncorrelated transmitters at the near-end into a pair measured at the near-end.

**power sum attenuation to alien crosstalk ratio, far-end:** A computation of the unwanted signal coupling from multiple uncorrelated transmitters at the near-end into a pair measured at the far-end.

**return loss:** A ratio expressed in dB of the power of the outgoing signal to the power of the reflected signal.

**screen:** An element of a cable formed by a shield.

**shield:** A metallic layer placed around a conductor or group of conductors.

**telecommunications:** The transmission and reception of information by cable, radio, optical or other electromagnetic systems.

## 3.3 Acronyms and abbreviations

| | |
|---|---|
| ANSI | American National Standards Institute |
| CMR | Common mode rejection |
| DMCM | Differential mode plus common mode |
| OSB | Output signal balance |
| NVP | Nominal velocity of propagation |
| PSAACRF | Power sum attenuation to alien crosstalk ratio, far-end |
| PSANEXT | Power sum alien near-end crosstalk |
| RF | Radio frequency |
| TIA | Telecommunications Industry Association |

## 3.4 Units of measure

| | |
|---|---|
| dB | decibel |
| m | meter |
| MHz | megahertz |
| ns | nanosecond |
| µs | microsecond |

## 3.5 Variables

| | |
|---|---|
| $f$ | frequency, in MHz |

# 4 TEST INSTRUMENTS

## 4.1 General

This Standard specifies the reporting and accuracy performance requirements of field testers and provides additional guidelines for field testing procedures. Two levels of field testers based on frequency ranges are defined:

- SP-I (TBD) : 0.1 MHz to 20 MHz
- SP-II (TBD) : 1 MHz to 600 MHz

Note that the use of Level SP in the document applies to both Level SP-I and Level SP-II. Special requirements apply when testing alien crosstalk. Refer to 4.7 for more information. 4.8 contains methods to compare the results of field testers against those obtained using laboratory equipment.

## 4.2 Data reporting requirements

### 4.2.1 Parameters to be reported

The field test instrument shall be able to measure and report the following link parameters for the permanent link and channel test configurations as defined in ANSI/TIA-568.5.

Wire map, including shield connection if present
Insertion loss
Length
Return loss, measured from near-end
Return loss, measured from far-end
Transverse Conversion Loss, measured from near-end
Transverse Convertsion Loss, measured from far-end
Transverse Conversion Transfer Loss, measured from near-end
Transverse Convertsion Transfer Loss, measured from far-end
Propagation delay
DC loop resistance
DC resistance unbalance if shield is present

### 4.2.2 Wire Map

The wire map test is intended to verify pin-to-pin termination at each end and check for installation connectivity errors. For each of the 2 conductors and shield if present in the cabling, the wire map indicates:

a) continuity to the remote end
b) short between the two conductors and shield if present
c) reversed pair
d) continuity of the screen along the path of the cabling to remote end (if required)

A reversed pair occurs when the polarity of one pair is reversed at one end of the link (also called a tip/ring reversal). Refer to Figure 2 for an illustration of a reversed pair.


**Figure 2 - Reverse Pair**

### 4.2.3 Length

This clause contains specific guidelines for determination of length during field tests.

#### 4.2.3.1 Physical length vs. electrical length

The physical length of the permanent link or channel is the sum of the physical length of the cabling components between the two end points. Physical length of the permanent link or channel may be determined by physically measuring the length(s) of the cable segment(s), calculated from the length markings on the cable segments when present, or estimated from the electrical length measurement. The electrical length is derived from the propagation delay of the signals and depends on the construction and material properties of the cable (see ANSI/TIA-568.2).

When physical length is determined from electrical length, the physical length of the link calculated using electrical delay shall be reported and used for making the pass or fail decision. The pass or fail criteria is based on the maximum length allowed for the channel or permanent link as specified in ANSI/TIA-568.5 plus the nominal velocity of propagation (NVP) uncertainty of 10 %.

> NOTE – Calibration of NVP is critical to the accuracy of length measurements and can improve the accuracy. See 4.2.3.2.

#### 4.2.3.2 NVP calibration

NVP calibration is performed by measuring the length of a cable segment that is longer than 30 m using a tape measure or observing the length markings on the cable and comparing the physical length to the measured shortest of all pairs electrical length reported by the field test instruments. Field test instruments shall contain provisions for setting the measured electrical length based on the shortest delay so that this NVP will be used to compute length from propagation delay measurements during subsequent measurements.

A convenient electrical length measurement is made by terminating the cable segment with jacks and testing the length using permanent link adapters. See Figure 3.

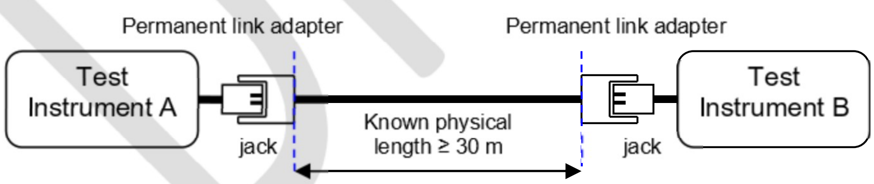


**Figure 3 - Example of NVP Calibration**

### 4.2.4 Pass/fail results

A pass or fail result for each parameter shall be determined by the specified limits for that parameter. Refer to 4.4 for detailed information on measurement accuracy requirements. An overall pass or fail condition shall be determined by the results of the required individual tests. Any fail shall result in an overall fail. In order to achieve an overall pass condition, all individual results shall be pass. Measurements reported by the field tester shall have a specified accuracy. Accuracy is the difference between the measured value reported by the field tester from the actual value. The field test instrument shall be capable of reporting the data at all measured points as defined in 4.2.5

and uploading the data to a PC or an external system and provide summary results as defined in 4.2.6.

NOTE – The field tester accuracy equations do not contain an allowance for the plug variability of different adapters connected to a permanent link under test.

### 4.2.5 Detailed results

The field tester shall be capable of reporting all connectivity information, as well as the measured values of every parameter at every frequency data point.
The detailed results shall include a pass/fail result for each of the parameters, as applicable. In addition the field tester shall save the measured data for all tested parameters.

### 4.2.6 Summary results

Detailed information may be required or desired in certain circumstances. In general, summary performance information is sufficient. The field tester shall be capable of reporting the summary information in Table 1 as a minimum.

**Table 1 - Field tester summary reporting requirements**

| Function | Measured from either end (if measurement from both directions is not required) | Measured from opposite end (if measurement from both ends is required) |
|---|---|---|
| **Wire Map** | All connectivity, including shields (if present)<br>pass/fail | Not Required |
| **Insertion Loss** | Worst case insertion loss<br>Test limit at worst case<br>Frequency at worst case<br>pass/fail | Not Required |
| **Length** | Length<br>Test limit<br>pass/fail | Not Required |
| **Return loss** | Worst case margin<br>Return loss at worst case margin.<br>Test limit at worst case margin.<br>Frequency at worst case margin<br>pass/fail<br>AND<br>Worst case return loss<br>Test limit at worst case<br>Return loss at worst case<br>Frequency at worst case | Worst case margin<br>Return loss at worst case margin.<br>Test limit at worst case margin.<br>Frequency at worst case margin<br>pass/fail<br>AND<br>Worst case return loss<br>Test limit at worst case<br>Return loss at worst case<br>Frequency at worst case |
| **TCL** | Worst case margin<br>TCL at worst case margin.<br>Test limit at worst case margin.<br>Frequency at worst case margin<br>pass/fail<br>AND<br>Worst case TCL<br>Test limit at worst case<br>TCL at worst case<br>Frequency at worst case | Worst case margin<br>TCL at worst case margin.<br>Test limit at worst case margin.<br>Frequency at worst case margin<br>pass/fail<br>AND<br>Worst case TCL<br>Test limit at worst case<br>TCL at worst case<br>Frequency at worst case |
| **TCTL** | Worst case margin<br>TCTL at worst case margin.<br>Test limit at worst case margin.<br>Frequency at worst case margin<br>pass/fail<br>AND<br>Worst case TCTL<br>Test limit at worst case<br>TCTL at worst case<br>Frequency at worst case | Worst case margin<br>TCTL at worst case margin.<br>Test limit at worst case margin.<br>Frequency at worst case margin<br>pass/fail<br>AND<br>Worst case TCTL<br>Test limit at worst case<br>TCTL at worst case<br>Frequency at worst case |
| **Propagation Delay** | Worst case propagation delay<br>Test limit at worst case<br>pass/fail | Not Required |
| **DC loop resistance** | Worst case dc loop Resistance<br>Test limit at worst case<br>pass/fail | Not Required |

Due to accuracy considerations, when the measured insertion loss is less than 3 dB, the measured return loss shall not be used in determining a fail. Return loss values greater than 25 dB may be reported as “>25 dB”.

## 4.3 Field measurement procedures

### 4.3.1 Consistency checks for field testers

The field tester manufacturer shall make available to the user a simple procedure for verifying, reporting, and recording the consistency of the field tester in the field. The following procedures are recommended.

1 Repeatability of tests on a reference link

The owner of the field tester should construct a reference link. Repeated measurements on this link should result in the same results within the magnitude of the accuracy specifications. The accuracy specification for the field tester is referenced at the limit line. Comparisons should be made at the worst case results across the frequency band.

2 Consistency of tests by testing the same link in opposite directions

Any link can be measured at first by connecting the local field tester unit to one end of the cabling and the remote field tester unit to the other end of the cabling. After performing a test, the locations of local field tester unit and remote field tester unit are exchanged. Additionally the units shall be changed whilst the adapters remain at the same end of test as the reference measurement, and following manufacturer recommendations for connection of adapters to field testers.

3 Reproducibility of tests on a reference link

Repeat measurements including new connection of the DUT to the field tester (e.g. plug in and out of the PL adapter). At least 3 people should repeat the test at least 10 times.

All worst case magnitudes should remain the same within 1.4 times the accuracy specification of the test function, except for return loss and TCL measurements. For return loss and TCL, the local return loss and TCL results obtained during the first test should be compared to the remote return loss and TCL results obtained during the second test. Similarly, the remote return loss and TCL results obtained during the first test should be compared to the local return loss and TCL results during the second test. These results should not differ by more than 1.4 times the relevant accuracy specifications.

### 4.3.2 Administration

In addition to pass/fail indications, worst case measured values of test parameters should be recorded per ANSI/TIA-606.

### 4.3.3 Test equipment connectors and cords

To maintain measurement accuracy, only test cords and adapters that are qualified by the test equipment manufacturer for the channel or link test configuration shall be used.

Connecting hardware and test cords have a limited life-cycle and should be periodically inspected for wear resulting from multiple mating cycles and bending during normal use. Consult with test equipment manufacturers for the life cycle of the connectors and cords.

Any reconfiguration of cabling components after testing may change the performance and thus invalidate previous test results. If confirmation of performance is desired the cabling shall be re-tested.

## 4.4 Field tester measurement accuracy requirements

### 4.4.1 General

Minimum performance levels have been identified for Single Pair field testers applicable to the baseline, permanent link and channel configuration. The performance requirements for Single Pair field testers are as further described in this clause. Accuracy is a function of the characteristics of the field tester and the transmission characteristics of the cabling. Each accuracy level has its own set of performance requirements as further described in this clause. Error models for each of the measurements provide estimates for the measurement accuracy for each parameter to be measured. The error models use the most important performance parameters that are expected to influence measurement accuracy. However, there may be additional sources of measurement error, which are not reflected in this error model, depending on the implementation of the measurement circuitry in the field tester.

Therefore, in addition to performance requirements for the properties of field testers, methods to compare the results obtained by field testers with those using laboratory methods are specified. Laboratory methods are described in 4.8. The deviation of the two results shall be no more than the sum total of the estimated measurement accuracy of the field tester and estimated measurement accuracy of the laboratory measurement system.

### 4.4.2 Nominal accuracy

The worst-case accuracy of a field test instrument can be calculated by inserting the applicable channel or permanent link requirements specified in ANSI/TIA-568.5 into the error models referenced in 4.6. In practice, worst case conditions of all parameters at all frequencies are highly unlikely. A first order approximation of nominal accuracy is 0.5 of the worst case computed accuracy. The actual accuracy may be better than the nominal accuracy. For detailed accuracy information, refer to the manufacturer's specifications. The limits used to calculate accuracy of the field test instrument are specified in Table 2.

**Table 2 – Limits to be used for calculating accuracy (TBD)**

| Level of field tester | Accuracy | Limit used to calculate accuracy |
|---|---|---|
| SP-I | Baseline | Category SP1 permanent link limit |
| | Permanent Link | Category SP1 permanent link limit |
| | Channel | Category SP1 channel limit |
| SP-II | Baseline | [TBD] limit |
| | Permanent Link | [TBD] limit |
| | Channel | [TBD] limit |

Table 3 shows the measurement accuracy using a compliant field tester.

**Table 3 - Nominal measurement accuracies at pass/fail limits (TBD)**

| Level of field tester | Test parameter | Freq (MHz) | Baseline accuracy at perm. link limits (± dB) | Permanent link accuracy at perm. link limits (± dB) | Channel accuracy at channel limits (± dB) |
|---|---|---|---|---|---|
| SP-I | Insertion loss | 1 | 0.6 | 0.7 | 0.7 |
| | | 20 | 0.6 | 0.7 | 0.7 |
| | Return loss | 1 | 1.4 | 1.7 | 1.5 |
| | | 20 | 1.4 | 1.7 | 1.5 |
| | TCL | 1 | 1.4 | 1.7 | 1.5 |
| | | 20 | 1.4 | 1.7 | 1.5 |
| | TCTL | 1 | 1.4 | 1.7 | 1.5 |
| | | 20 | 1.4 | 1.7 | 1.5 |
| SP-II | Insertion loss | 100 | 0.6 | 0.7 | 0.7 |
| | | 250 | 1.0 | 1.1 | 1.3 |
| | | 600 | 1.3 | 1.4 | 1.6 |
| | Return loss | 100 | 1.4 | 1.7 | 1.5 |
| | | 250 | 1.2 | 2.1 | 1.9 |
| | | 600 | 1.1 | 2.2 | 2.0 |
| | TCL | 100 | 1.4 | 1.7 | 1.5 |
| | | 250 | 1.2 | 2.1 | 1.9 |
| | | 600 | 1.1 | 2.2 | 2.0 |
| | TCTL | 100 | 1.4 | 1.7 | 1.5 |
| | | 250 | 1.2 | 2.1 | 1.9 |
| | | 600 | 1.1 | 2.2 | 2.0 |

**Table 4 - Accuracies for resistance measurements for measurement of cabling for resistance parameters (TBD)**

| Level of field tester | Test parameter | Baseline accuracy at perm. link limits | Permanent link accuracy at perm. link limits | Channel accuracy at channel limits |
|---|---|---|---|---|
| SP-I | DC loop resistance | ±(0.5Ω+1% dc loop resistance) | | |
| | DC resistance unbalance | ±(0.025Ω +0.3% dc loop resistance) | | |
| SP-II | DC loop resistance | ±(0.5Ω+1% dc loop resistance) | | |
| | DC resistance unbalance | ±(0.025Ω +0.3% dc loop resistance) | | |

### 4.4.3 Length and propagation delay performance parameters

Field testers shall comply with length, propagation delay, and delay skew performance parameters, independent of Level as shown in table 5.

NOTE - The length accuracy does not include the uncertainty of NVP calibration.

**Table 5 - Field tester requirements including accuracy for length and propagation delay (TBD)**

| Level of field tester | Parameter | Length | Propagation Delay |
|---|---|---|---|
| SP-I | Measurement range | 0 m – 1000 m | 0 μs –9μs at 1 MHz |
| | Resolution | 0.1 m | 1 ns |
| | Constant error term | 1 m up to 1000 m | 5 ns |
| | Proportional error term | 4 % **(TBD)** up to 1000 m | 4 % |
| | Error at 100 m length | 5 m | 27.7 ns |
| | Error at 1000 m length | 41 m **(TBD)** | 227.5 ns |
| SP-II | Measurement range | 0 m – 100 m | 0 μs – 1 μs at 10 MHz |
| | Resolution | 0.1 m | 1 ns |
| | Constant error term | 1 m up to 100 m | 5 ns |
| | Proportional error term | 4 % up to 100 m | 4 % |
| | Error at 30 m length | 2.2 m | 12 ns |
| | Error at 100 m length | 5 m | 27 ns |

### 4.4.4 Performance parameters for Level SP-I and SP-II field testers

Level SP-I and SP-II field testers shall conform to the requirements in Table 6 and Table 7 for the baseline, permanent link, and/or channel test configurations. Methods to verify compliance of field tester requirements are specified in 4.5.

**Table 6 - Level SP-I field tester accuracy performance (TBD)**

| Parameter | Baseline field tester | Field tester with Level SP-I permanent link adapter | Field tester with Level SP-I channel adapter | |
|---|---|---|---|---|
| Dynamic range | 3 dB over test limit | | | *dB* |
| Amplitude resolution | 0.1 | | | *dB* |
| Frequency range and resolution | 0.1 - 20 MHz : 20 kHz | | | *MHz* |
| Dynamic Accuracy IL | ± 0.75 | | | *dB* |
| Source/load return loss | 0.1-20 MHz: 20 dB | 0.1-20 MHz: 20 dB | | *dB* |
| Random Noise Floor | 0.1-20 MHz: 95 dB | 0.1-20 MHz: 90 dB | | *dB* |
| Output Signal Balance | 0.1-20 MHz: 50 dB | 0.1-20 MHz: 50 dB | | *dB* |
| Common Mode Rejection | 0.1-20 MHz: 50 dB | 0.1-20 MHz: 50 dB | | *dB* |
| Reflection Tracking | ± 0.5 | | | *dB* |
| Directivity | 0.1-20 MHz: 30 dB | 0.1-20 MHz: 30 dB | | *dB* |
| Source Match | 0.1-20 MHz: 30 dB | 0.1-20 MHz: 30 dB | | *dB* |
| Return loss of Termination | 0.1-20 MHz: 25 dB | 0.1-20 MHz: 25 dB | | *dB* |

**Table 7 - Level SP-II field tester accuracy performance (TBD)**

| Parameter | Baseline field tester | Field tester with Level SP-II permanent link adapter | Field tester with Level SP-II channel adapter | |
|---|---|---|---|---|
| Dynamic range | 3 dB over test limit | | | *dB* |
| Amplitude resolution | 0.1 | | | *dB* |
| Frequency range and resolution | 1 - 31.25 MHz : 150 kHz<br>31.25 - 100 MHz : 250 kHz<br>100 - 250 MHz : 500 kHz<br>250 - 600 MHz :1 MHz | | | *MHz* |
| Dynamic Accuracy IL | ± 0.75 | | | *dB* |
| Source/load return loss | 1-600 MHz:<br>21- 9log(f/100) dB<br>20 dB max | 1-600 MHz:<br>19- 9log(f/100) dB<br>20 dB max | | *dB* |
| Random Noise Floor | 1-600 MHz:<br>95 dB | 1-600 MHz:<br>90dB | | *dB* |
| Output Signal Balance | 1-600 MHz:<br>40-20 log (f/100) dB<br>40dB max | 1-600 MHz:<br>37-20 log (f/100) dB<br>40dB max | | *dB* |
| Common Mode Rejection | 1-600 MHz:<br>40-20 log (f/100) dB<br>40dB max | 1-600 MHz:<br>37-20 log (f/100) dB<br>40dB max | | *dB* |
| Reflection Tracking | ± 0.5 | | | *dB* |
| Directivity | 1-600 MHz:<br>30,7- 9log(f/100) dB<br>30dB max | 1-600 MHz:<br>28,7- 9log(f/100)<br>30dB max | | *dB* |
| Source Match | 1-600MHz:<br>20 dB | 1-600MHz:<br>20 dB | | *dB* |
| Return loss of Termination | 1-600MHz:<br>21- 9log(f/100) dB<br>25 dB max | 1-600MHz:<br>19- 9log(f/100) dB<br>25 dB max | | *dB* |

### 4.4.5 Performance parameters for measurement of cabling for resistance parameters

Field testers capable of measuring resistance parameters shall comply with Table 8.

**Table 8 - Performance parameters for measurement of cabling for resistance parameters (TBD)**

| | | | |
|---|---|---|---|
| SP-I | DC loop resistance Resolution | 0.1 | Ω |
| | Constant error term of DC loop resistance $E_{c,dc\_r}$ | 1 | Ω |
| | Error term proportional to the DC loop resistance $E_{d,dc\_r}$ | x% **(TBD)** | % |
| SP-II | DC loop resistance Resolution | 0.01 | Ω |
| | Constant error term of DC loop resistance $E_{c,dc\_r}$ | 0.5 | Ω |
| | Error term proportional to the DC loop resistance $E_{d,dc\_r}$ | 1% | % |

## 4.5 Procedures for determining field tester parameters

### 4.5.1 General

Field testers are designed with two units that are attached to opposite ends of the cabling to be tested. Internal to these units are source and load ports that are used for measurements. The following measurements shall be used to determine compliance with the applicable requirements, and shall apply to the entire frequency range specified in these tables. The field testers shall include functionality to make independent verification of field tester parameters.

### 4.5.2 Output signal balance (OSB)

This performance requirement is applicable to:

- TCL measurement and TCTL calculations

Output Signal Balance (OSB) is defined as the ratio of the output common mode voltage to the output differential voltage generated by a source port. ($V_d$ / $V_c$ is used instead to make the value positive per convention) as shown in Figure 4. The field test instrument shall be connected to ground for the measurement as near as possible to the port to be measured. This shall provide a low impedance path to instrument ground of the field test instrument over the specified frequency range. The OSB compliance test shall be conducted without and with a polarity reversal.

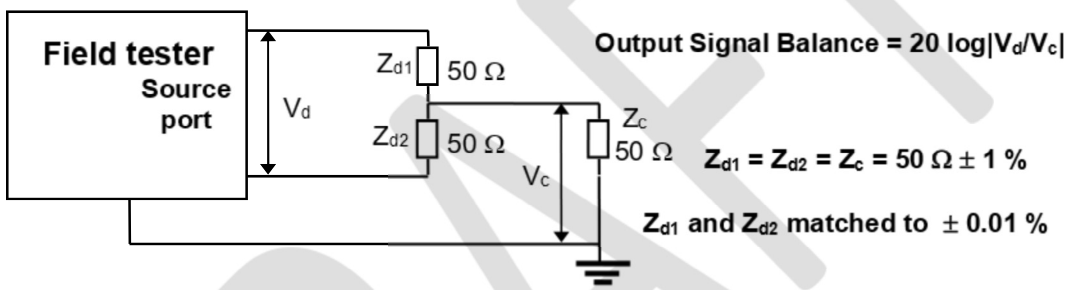


**Figure 4 - Block diagram to measuring output signal balance**

Note: This test configuration differs from the test arrangements for measuring the OSB of baluns used in laboratory measurements. This effectively causes $Z_c$ to become 25 Ω.

### 4.5.3 Common mode rejection (CMR)

This performance requirement is applicable to:

- TCL measurement and TCTL calculations

Common Mode Rejection is defined as the ratio of the measured differential voltage to a common mode voltage applied to the load port ($V_c$ / $V_m$ is used to make the value positive per convention) as shown in Figure 5. The field test instrument shall be connected to measurement ground as near as possible to the port to be measured. This connection shall provide a low impedance path to the signal ground of the field tester over the specified frequency range. The CMR compliance test shall be conducted without and with a polarity reversal.

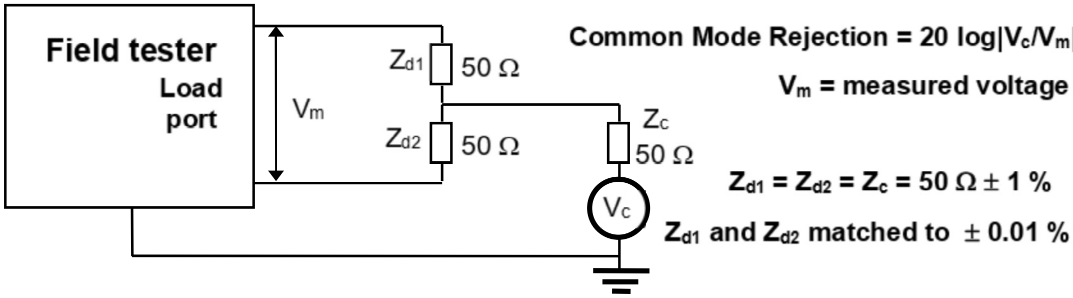


**Figure 5 - Block diagram to measuring common mode rejection**

Note: This test configuration differs from the test arrangements for measuring the CMR of baluns used in laboratory measurements. This effectively causes $Z_c$ to become 25 Ω.

#### 4.5.4 Dynamic accuracy

This performance requirement is applicable to:

- Insertion loss measurements

Dynamic accuracy is the accuracy of the measured value to an external voltage input as shown in Figure 6. The external voltage shall provide a minimum output source balance (OSB) signal of 40 dB with a minimum return loss of 20 dB.

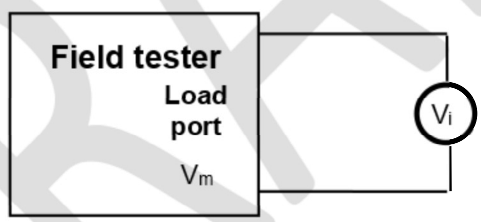


**Figure 6 - Block diagram for measuring dynamic accuracy**

Vi could be sourced by the field instrument under test and injected into the receiver through a resistive attenuator when the residual crosstalk is 30 dB below the injected signal level.

#### 4.5.5 Source/load return loss

This performance requirement is applicable to:

- Insertion loss measurements
- TCL measurement and TCTL calculations

The source and load return loss of the insertion loss measurement functions shall be measured with a network analyzer calibrated relative to a reference DMCM resistor network with return loss of better than 40 dB over the frequency range of interest. The calibration shall include an impedance matching transformer/balun with better than 40 dB longitudinal conversion loss as specified in clause B.2 of ANSI/TIA-568.2.

$$\textbf{Return loss} \geq -20\log\left(\frac{V_{reflected}}{V_{incident}}\right) \qquad (1)$$

### 4.5.6 Random noise floor

This performance requirement is applicable to:

- Alien crosstalk parameter measurements

The random noise floor is the ratio of the measured voltage $V_m$ when the source port voltage is zero, to the source port voltage $V_o$ under normal measurement conditions.

$$\textbf{Random Noise Floor} \geq -20\log\left(\frac{V_m}{V_o}\right) \qquad (2)$$

A procedure measuring voltage with an external voltmeter at the output of the detector is acceptable if it demonstrates equivalency.

### 4.5.7 Directivity

This performance requirement is applicable to:

- Return loss measurements
- TCL measurements and TCTL calculations

Directivity is the signal that couples into the measurement channel and adds to the reflected signal that is measured. It is measured by performing a return loss measurement when terminating the test interface with a DMCM resistor network according to Figure 7 that have return loss better than 40 dB relative to a reference calibration resistor from 0.1 MHz to the upper frequency limit of the category.

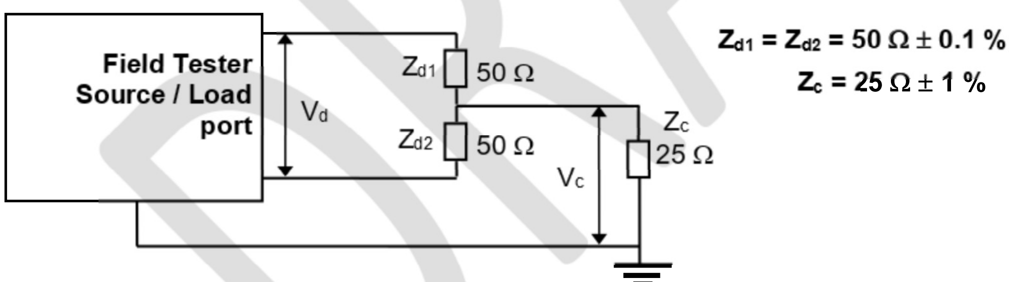


**Figure 7 - Block diagram for measuring directivity**

### 4.5.8 Reflection Tracking

This performance requirement is applicable to:

- Return loss measurements
- TCL measurements and TCTL calculations

Reflection Tracking is the response of the transducer used to determine the reflected signal. It is determined from two measurements:

- Measurement of return loss with the pair shorted (the actual reflection coefficient is -1), as a function of frequency, and
- Measurement of return loss with the pair open (the actual reflection coefficient is +1), as a function of frequency.

Reflection Tracking error is given by equation ( **3** ) for Level SP field testers.

$$Tracking_{dB} \geq -20 \cdot \log\left(\left|\frac{2(\Gamma_{load} - \Gamma_{short})(\Gamma_{open} - \Gamma_{load})}{(\Gamma_{open} - \Gamma_{short})}\right|\right) \quad (3)$$

It should be noted that in equation ( **3** ) the reflection coefficients are linear vector quantities and not dB values.

### 4.5.9 Source match

This performance requirement is applicable to:

- Return loss measurements
- TCL measurements and TCTL calculations

Source match is a measurement of the reflected signal that is not absorbed by the return loss measurement circuitry. The field tester should be first calibrated with traceable SOLT standards, then Source Match is determined from the measurements of directivity, return loss with shorted pair and return loss with open pair. With results of all measurements expressed in linear vector quantities, the source match error is given by equation ( **4** ) for Level SP field testers. Any fixturing required to interface the calibration load artifact shall not be included in the measurement.

$$Source\_Match_{dB} = -20 \cdot log\left(\left|\frac{(\Gamma_{open} + \Gamma_{short}) - 2\Gamma_{load}}{(\Gamma_{open} - \Gamma_{short})}\right|\right) \quad (4)$$

### 4.5.10 Return loss of remote termination

This performance requirement is applicable to:

- Return loss measurements
- TCL measurements and TCTL calculations

The requirements for return loss of the remote termination exceed those for the source/load return loss of the insertion loss measurement functions. In order to perform this measurement a network analyzer with S-parameter test set, capable of providing one-port calibration, shall be used as described for the source/load return loss measurement of the insertion loss function. The return loss of the termination of each pair shall be separately determined. DMCM terminations shall be applied.

### 4.5.11 Constant error term of the length measurement function

The constant error term of the length measurement function is determined by connecting the local unit to the remote unit through a short test cable and observing the reported length. The reported length shall be less than the constant error term of the length measurement function.

### 4.5.12 Error term proportional to length of the length measurement function

The length of cabling with a total length of 100 m +/- 1% shall be measured using a tape measure.

The NVP calibration shall be performed. Then cabling with a known length of approximately 50 m shall be measured. The reported length shall deviate from the actual value by less than 1/2 the amount of the error constant proportional to length.

#### 4.5.13 Constant error term of the propagation delay measurement function

The parameters that affect propagation delay accuracy include a constant error term $E_c$ and a term $E_d$ that is proportional to length of the link. The constant error term of the propagation delay measurement function is determined by connecting the local unit to the remote unit through a short test cable and measuring the propagation delay. The reported propagation delay shall be less than the constant error term of the propagation delay.

#### 4.5.14 Error term proportional to the propagation delay of the propagation delay measurement function

The propagation delay of cabling with a total length of 100 m +/- 1% shall be measured using the reference measurement procedure. The propagation delay at 10 MHz is the reference value. Then the same cabling shall be connected to the field tester and the propagation delay measured. The reported value by the field tester minus the reported value measured when a very short connection was made to the same field tester shall deviate less from the error constant that is proportional to the propagation delay of the propagation delay measurement function.

#### 4.5.15 Constant error term of dc loop resistance for measurement of cabling for resistance parameters

The procedure for determining the constant error term of dc loop resistance, $E_{c,dc\_r}$ , is to connect a connector to the field tester with shorts across each pair. The reported dc resistance in each case shall be less than the $E_{c,dc\_r}$.

#### 4.5.16 Error term proportional to the dc loop resistance for measurement of cabling for resistance parameters

The dc resistance of cabling with a total length of approximately 100 m shall be measured using a four-terminal ohmmeter with a specified accuracy of at least 0.1%. The dc resistance of the same cabling, measured with the field tester, less the observed resistance value with the pair shorted (constant error term of dc loop resistance) shall be less than the error constant term proportional to the dc resistance.

$$E_{d,DC\_r} = \frac{\Omega_{FieldTester} - E_{c,DC\_r}}{\Omega_{FourWire}} \qquad (5)$$

| | |
|---|---|
| $E_{d,DC\_r}$ | Error term proportional to dc loop resistance |
| $E_{c,DC\_r}$ | Constant error term of dc loop resistance |
| $\Omega_{FieldTester}$ | The value of the dc loop resistance as measured on the field tester |
| $\Omega_{FourWire}$ | The value of the dc loop resistance as measured on the four-terminal ohmmeter |

### 4.6 Measurement error models

#### 4.6.1 General

The measurement accuracy for the permanent link and channel is computed using the parameters in Table 6 and Table 7. The error models used to estimate the baseline measurement accuracy of the field tester are based upon the 12-parameter error model defined for network analyzer measurements with modifications and simplifications. There is no assurance that these simplifications and modifications are appropriate in every circumstance or that the error model is complete. Nevertheless, the computed estimated measurement accuracies from the error models shown in this clause are a reasonable indication of the measurement performance that may be expected from a compliant field tester. The computed estimated mesurement accuracy shall be in harmony with the results from network analyzer comparisons.

### 4.6.2 Error model for the insertion loss measurement function

The error model for the insertion loss measurement function for Level SP field testers is expressed in equation ( **6** ).

$$\boldsymbol{Accuracy_{IL}}(\mathbf{dB}) = \boldsymbol{E_{d,IL}} + 20\log_{10}\left[\frac{1+10^{\frac{-E_{RL,tester}}{10}}}{1-2*10^{\frac{-E_{RL,link}-E_{RL,tester}}{20}}-10^{\frac{-E_{RL,tester}-E_{RL,link}}{10}}-10^{\frac{-E_{RL,tester}-E_{IL,link}}{10}}}\right] \quad (6)$$

where:

| | |
|---|---|
| $Accuracy_{IL}$ | is the estimated accuracy of the insertion loss measurement function in dB |
| $E_{d,IL}$ | is the dynamic accuracy of the field tester for insertion loss in dB |
| $E_{RL,tester}$ | is the return loss of the field tester in dB |
| $E_{RL,link}$ | is the return loss of the link in dB |
| $E_{IL,link}$ | is the insertion loss of the link in dB |

Assumptions:

- Dynamic accuracy adds directly to all other error terms.
- The error from source/load return loss of the field tester plus the impact of the source/load interaction with the return loss of the link is added.

Impact from the test cable for the measurement of the connector used for the channel interface are expected to have a significant impact on the source/load return loss of the field tester.

### 4.6.3 Error model for the return loss measurement function

The error model for the return loss measurement relates to contributions to inaccuracy at the input, related to measurement of the reflected signal and contributions that are the result of reflections at the remote termination of the cabling. The estimated return loss measurement error is given by equation ( **7** ) for Level SP Pair field testers.

$$\boldsymbol{Error_{RL}} = TR + 20\cdot\log_{10}\left[\begin{array}{c} 1+10^{\left[\frac{A_{RL}-E_{DIR}}{20}\right]}+10^{-\left[\frac{A_{RL}+E_{SM}}{20}\right]}+ \\ 10^{\left[\frac{A_{RL}-E_{\mathrm{TERM}}(\mathrm{dB})-\sqrt{f}}{20}\right]}+10^{\left[\frac{A_{RL}-E_{DIR}-E_{\mathrm{OSB}}(\mathrm{dB})-E_{\mathrm{CMR}}(\mathrm{dB})}{20}\right]}\end{array}\right] \quad (7)$$

where:

$Error_{RL}$ is the estimated accuracy of the return loss measurement function in dB

| | |
|---|---|
| $A_{RL}$ | is the return loss amplitude in dB at which the error is computed |
| $TR$ | is Reflection Tracking error in dB |
| $E_{DIR}$ | is the directivity in dB |
| $E_{SM}$ | is the source match in dB |
| $E_{\mathrm{TERM}}$ | is the return loss of the remote termination in dB in return loss mode |
| $f$ | is the frequency in MHz |
| $E_{\mathrm{OSB}}$ | is the output signal balance of the field tester in dB |
| $E_{\mathrm{CMR}}$ | is the common mode rejection of the field tester in dB |

Assumptions:

- The Reflection Tracking error (like dynamic accuracy) is added directly to the remaining error terms.

- The error from directivity and source match are added worst case, since the phase of one component changes slowly while the other changes much faster. Therefore an “envelope” worst case condition is assumed. The impact from the source match error is practically minor.
- The error caused by the reflection at the remote termination is added in a power sum manner to the remainder of the error terms. It is attenuated by the assumed minimum round trip insertion loss of the link under test.

### 4.6.4 Error model for the TCL measurement function

The error model for the TCL measurement function is expressed in equation ( 8 ).

$$Accy_{TCL} = E_{d,TCL} + 20 * \log_{10}\left[1 + 10^{\frac{-(E_{DMRL,tester}+E_{CMRL,tester})}{20}} + 10^{\frac{-(E_{DMRL,tester}+E_{DMRL,link})}{20}} + 10^{\frac{-(E_{CMRL,tester}+E_{CMRL,link})}{20}} + \{(10^{\frac{(A_{TCL}-E_{RTCL})}{10}}) + (10^{\frac{(A_{TCL}-E_{TCLNF})}{10}})\}^{\frac{1}{2}}\right] \qquad (8)$$

where:

| | |
|---|---|
| $Accy_{TCL}$ is | the estimated accuracy of the TCL measurement function in dB |
| $E_{d,TCL}$ | is the dynamic accuracy of the tester for TCL in dB |
| $E_{DMRL,tester}$ | is the differential mode return loss of tester in dB |
| $E_{CMRL,tester}$ | is the common mode return loss of tester in dB |
| $E_{DMRL,link}$ | is the differential mode return loss of link in dB |
| $E_{CMRL,link}$ | is the common mode return loss of link in dB |
| $A_{TCL}$ | is the TCL signal amplitude for accuracy in dB |
| $E_{TCLNF}$ | is the TCL random noise floor of tester in dB |
| $E_{RTCL}$ | is the residual TCL of tester in dB |

### 4.6.5 Error model for the TCTL measurement function

The error model for the TCTL measurement function is expressed in equation ( 9 ).

$$Accy_{TCTL} = E_{d,TCTL} + 20 * \log_{10}\left[\left(\frac{1 + 10^{\frac{-(E_{DMRL,tester}+E_{CMRL,tester})}{20}}}{\left(1 - 10^{\frac{-(E_{DMRL,tester}+E_{DMRL,link})}{20}}\right)\left(1 - 10^{\frac{-(E_{CMRL,tester}+E_{CMRL,link})}{20}}\right)}\right) + \sqrt{(10^{\frac{(A_{TCTL}-E_{NFTCTL})}{10}}) + (10^{\frac{(A_{TCTL}-E_{RTCTL})}{10}})}\right] \qquad (9)$$

where:

| | |
|---|---|
| $Accy_{TCLT}$ | is the estimated accuracy of the TCTL measurement function in dB |
| $E_{d,TCLT}$ | is the dynamic accuracy of the tester for TCTL in dB |
| $E_{DMRL,tester}$ | is the differential mode return loss of tester in dB |

$E_{CMRL,tester}$ is the common mode return loss of tester in dB
$E_{DMRL,link}$ is the differential mode return loss of link in dB
$E_{CMRL,link}$ is the common mode return loss of link in dB
$A_{TCTL}$ is the TCTL signal amplitude for accuracy in dB
$E_{NFTCTL}$ is the TCTL random noise floor of tester in dB
$E_{RTCTL}$ is the residual TCTL of tester in dB

#### 4.6.6 Error model for the propagation delay measurement function

The error of the propagation delay contains a constant error term and an error that is proportional to propagation delay of the measured cabling. For a 100 meter limited distance, this error is approximately proportional to length; see equation ( **10** ).

$$\boldsymbol{Error_{propagation\_delay} = E_c + E_d \cdot propagation\_delay} \qquad (10)$$

where:
$E_c$ is the constant error term and
$E_d$ is the error term proportional to the propagation delay of the cabling.

#### 4.6.7 Error model for the length measurement function

The error model for length is identical to the error model for propagation delay since the length is a constant times the NVP.

#### 4.6.8 Error model for dc loop resistance

The error model for dc loop resistance is provided by the addition of the constant error term of dc loop resistances ($E_{c,dc\_r}$ ) and the error term proportional to dc loop resistance ($E_{d,dc\_r}$).

### 4.7 Alien crosstalk measurement requirements and procedures

#### 4.7.1 General

The methods in this section can be used to measure alien crosstalk properties of installed single-pair cabling.

#### 4.7.2 Test parameters

In addition to the parameters listed in 4.2.1, the field tester shall be able to measure the following parameters for the permanent link and channel test configurations as defined in this document:

ANEXT loss
AFEXT loss

The field tester shall be able to report the following parameters for the permanent link and channel test configurations as defined in this document:

PSANEXT loss
PSAACRF

The field tester shall report results and their associated test orientation (i.e. from the local end or remote end).

### 4.7.3 Test configurations

Alien crosstalk testing in the field is conducted on the installed permanent link and channel configurations. The illustrations in this annex show only one disturbing channel for simplicity.

NOTE - Alien cross-talk requirements for Single Pair channels and permanent links are specified for bundled configurations containing only Single Pair cabling components.

### 4.7.4 Test equipment for measuring alien crosstalk in installed cabling

Figure 8 through Figure 11 illustrate a physical control channel between field testers. A physical control channel is not a required implementation of this Standard. Other implementations are possible if equivalence is demonstrated.

### 4.7.5 Channel alien crosstalk testing

The test interface to the test instrument consists of two jacks that exhibit an insignificant amount of power sum alien crosstalk between them. One jack is connected to test instrument A, and the other jack is connected to test instrument B. Provisions should be made for measurement control purposes between the two test instruments. Refer to the recommendations of the manufacturer of the test equipment used for the appropriate test implementation.

The reference plane of measurement is at the location that is defined for the channel as shown in ANSI/TIA-568.5. Channels shall be tested with cords used in the channel and shall be kept as much as possible in their normal use position during the tests.

### 4.7.6 Permanent link testing

The test interface consists of two test cords terminated with plugs. One test cord is connected to test instrument A, and the other test cord is connected to test instrument B. Provision should be made for measurement control purposes between test instrument A and test instrument B. Refer to the recommendations by the manufacturer of the test equipment used for the appropriate test implementation.

The reference plane of measurement shall be at the location that is defined for the permanent link.

### 4.7.7 Alien crosstalk measurement floor

The measurement floor of the test instrument shall meet or exceed the values in equation ( **11** ) to a maximum requirement of 95 dB.

$$\boldsymbol{Measuremnt\_Floor_{Test\_Instrument}} \geq \mathbf{95 - 20}\boldsymbol{log}\left(\frac{\boldsymbol{f}}{\mathbf{100}}\right) \qquad (11)$$

The measurement floor of the test instrument shall be determined using an alien crosstalk measurement with the configuration specified in 4.7.8 or 4.7.9.

### 4.7.8 Measurement floor of the test instrument for the channel test configuration

The measurement floor of the test instrument can be established in the channel test configuration by terminating the channel with plugs that have DMCM terminations as shown in Figure 8. The common mode point shall be connected to the shield if present.

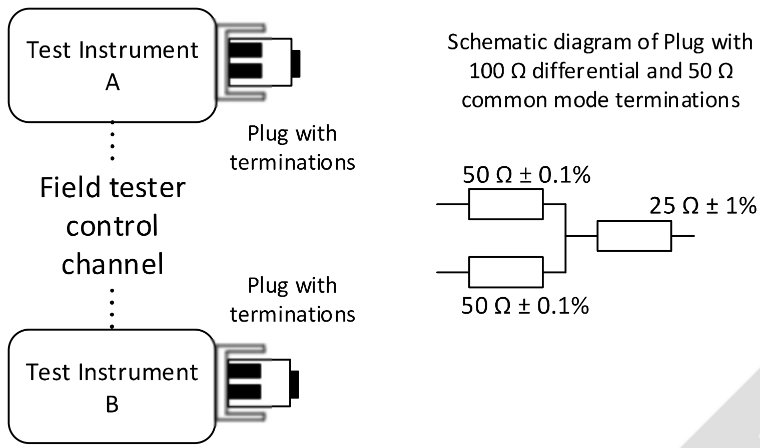


**Figure 8 - Schematic diagram for testing the measurement floor of the channel test configuration**

The power sum alien crosstalk measurement floor as a function of the expected maximum number of disturbing channels shall meet the requirement in equation ( **12** ).

$$\boldsymbol{Measurement\_Floor_{PSAXT,Nps} \geq Measurement\_Floor_{Test_{Instrument}} - 10\,log(N_{PS})\ dB} \quad (12)$$

where:

$Measurement\_Floor_{PSAXT,Nps}$ is the PSANEXT loss or PSAFEXT loss measurement floor in dB.

$N_{PS}$ is the maximum expected number of disturbing channels.

The result of equation ( **12** ) shall exceed the appropriate pass/fail limit by 6 dB.

### 4.7.9 Measurement floor of the test instrument with permanent link adapter test cords

Alien crosstalk measurements are made by terminating the test cords with jacks that have DMCM terminations as shown in Figure 9. The common mode point shall be connected to the shield if present. The same requirements as specified in 4.7.8 apply.

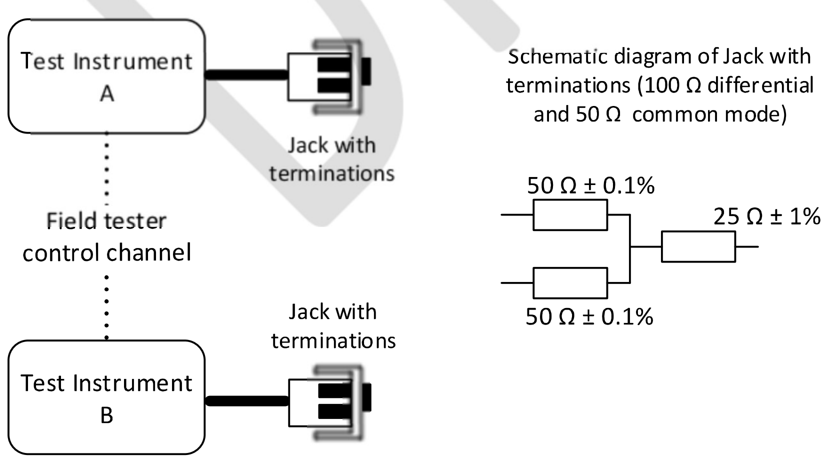


**Figure 9 - Schematic diagram for testing the measurement floor of the permanent link test configuration**

### 4.7.10 Alien crosstalk measurements

#### 4.7.10.1 Measuring ANEXT loss in the channel configuration

The schematic diagram for the ANEXT loss test from one end is shown in Figure 10.

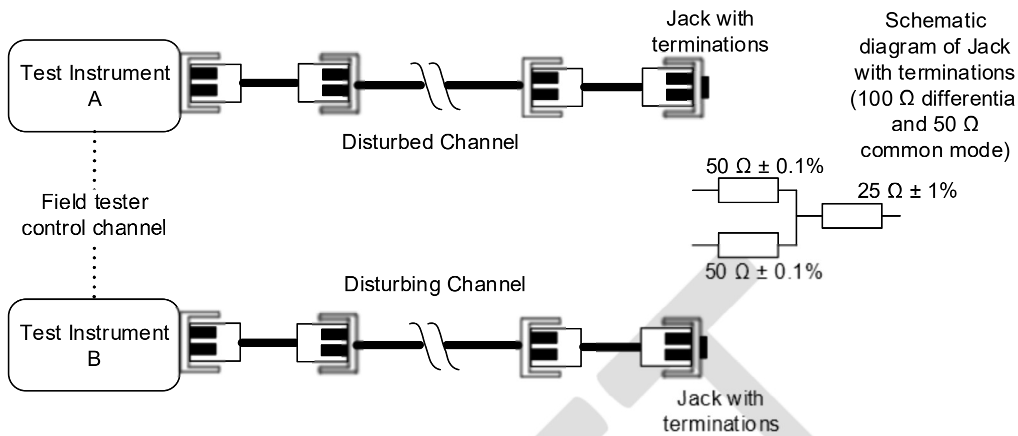


**Figure 10 - Schematic diagram to measure channel ANEXT loss**

The test instrument A is connected to the disturbed channel, and the test instrument B is connected to a disturbing channel. ANEXT loss tests from the other end can be made by swapping the test instrument with the terminations at the opposite end.

#### 4.7.10.2 Measuring AFEXT loss in the channel configuration

Measuring AFEXT loss from one end requires that the test instrument A is connected to the disturbed channel and the test instrument B is connected to a disturbing channel.

Assuming that test instrument A and test instrument B have a separate measurement control communication path connection or field tester communication channel, the schematic diagram is as shown in Figure 11. AFEXT loss tests from the other end can be made by swapping the test instrument with the terminations at the opposite end.

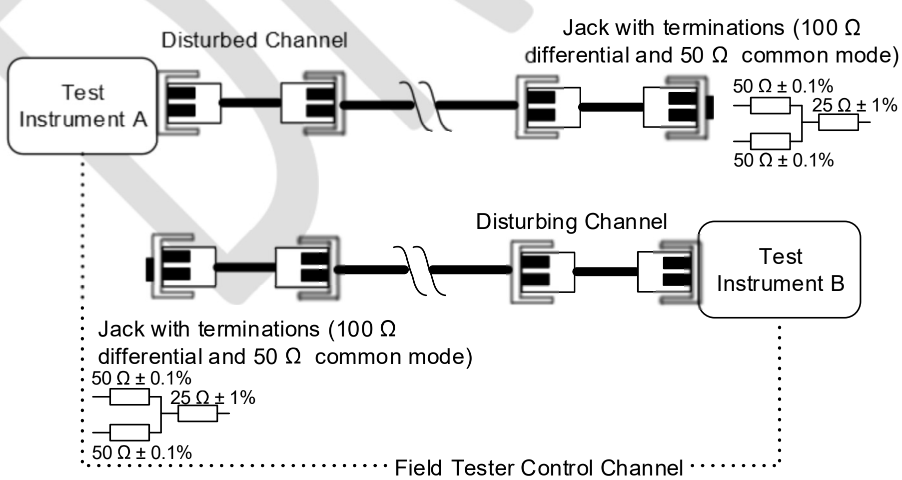


**Figure 11 - - Schematic diagram to measure channel AFEXT loss**

#### 4.7.10.3 Measurement of permanent link alien crosstalk

The measurement of ANEXT loss and AFEXT loss in the permanent link configuration is accomplished in the same manner as for the channel configuration described in 4.7.10.1 and 4.7.10.2 except that permanent link adapters replace the channel adapters and terminating plugs are used as described in 4.7.8 to terminate the disturbed and disturbing permanent links under test.

### 4.7.11 Processing measurement data

The processing of the measured ANEXT loss or AFEXT loss is specified in this clause.

#### 4.7.11.1 Computing PSANEXT loss and PSAACRF

##### 4.7.11.1.1 Computing PSANEXT loss and PSAACRF

The PSANEXT loss shall be calculated in accordance with ANSI/TIA-568.5 requirements. Only those ANEXT loss results that satisfy the significance condition per 4.7.11.2 shall be included.

The PSAACRF loss shall be calculated in accordance with ANSI/TIA-568.5 requirements. Only those AFEXT loss results that satisfy the significance condition per 4.7.11.2 shall be included.

> NOTE – Accumulated PSANEXT loss and PSAFEXT loss is computed sequentially by the addition of disturbers to previously measured results.

#### 4.7.11.2 Significance condition testing

This frequency range for Significance condition testing is only applicable to SP-II field test instruments. For SP-I, the frequency range for checking significance is 0.1 MHz to 20 MHz **(TBD)**.

Measurements in the 100 to 250 MHz frequency range shall be used to determine the significance condition. The significance condition is determined from the average frequency response expressed in dB between 100 MHz and 250 MHz. If the average measured ANEXT loss or AFEXT loss between 100 MHz and 250 MHz exceeds 90 dB, then the entire ANEXT loss or AFEXT loss response is excluded in the power sum computation. If the average measured ANEXT loss or AFEXT loss between 100 MHz and 250 MHz does not exceed the significance condition, 90dB, then the entire ANEXT loss or AFEXT loss response is included in the power sum computation.

#### 4.7.11.3 Applying measurement floor correction to alien crosstalk

The frequency response for a large number of power sum alien crosstalk floor results may be used to correct the calculated PSANEXT loss and PSAFEXT loss results. If the number of alien crosstalk measurements in a power sum alien crosstalk result is greater than 6 disturbers (from 6 disturbing channels), then the estimated measurement floor contribution to the overall power sum alien crosstalk is calculated using equation ( **13** ) The measurement floor is defined in 4.7.7.

$$\boldsymbol{PSAXT_{Estimated\_floor,Npp} = PSAXT_{Measurement\_floor,Nps} + 10\,log\left(\frac{Nps}{Npp}\right)\,dB} \qquad (13)$$

where:

$PSAXT_{Measurement\_floor,Nps}$ is the PSANEXT or PSAFEXT measurement floor in dB determined by equation ( **13** ).

$Npp$ is the number of alien crosstalk measurements included in the power sum calculations that satisfy the significance condition.

$Nps$ is the maximum expected number of disturbing channels.

The corrected PSANEXT loss result for a pair *i* is determined using equation ( **14** ):

$$PSANEXTcorrected_i = -10\,log\left(10^{-0.1 \cdot PSANEXT_i} - 10^{-0.1 \cdot PSAXT_{Estimated_{floor},Npp}}\right)\,dB \qquad (14)$$

The corrected PSAFEXT loss result for a pair *i* is determined using equation ( **15** ):

$$PSAFEXTcorrected_i = -10\,log\left(10^{-0.1 \cdot PSAFEXT_i} - 10^{-0.1 \cdot PSAXT_{Estimated\_floor,Npp}}\right)\,dB \qquad (15)$$

## 4.8 Comparison measurement procedures

### 4.8.1 General

This clause describes procedures used to compare the results obtained using laboratory equipment with those obtained with a field tester. The accuracy of this comparison is limited by the uncertainty in the reference or laboratory measurement and the return loss, differential-to-common mode and common mode-to-differential mode conversion properties of the link under test.

Field test requirements include the following parameters for which a measurement accuracy is specified:

- Insertion loss (attenuation)
- Return loss
- TCL
- TCTL
- Propagation delay
- DC loop Resistance
- Alien NEXT (ANEXT)
- Alien FEXT (AFEXT)

### 4.8.2 General requirements

The reference test setup, calibration and measurement procedures are as described in this clause.

#### 4.8.2.1 Test adapters

##### 4.8.2.1.1 General

The following clauses describe a method for measuring link parameters in such a way that measurements from the reference test setup can be compared directly with the results obtained from a field tester.

The interface to laboratory test equipment is designed to accept copper cable ends of the balanced single twisted-pair cabling to be tested or a mating connector. The interface to a field tester, however, depends upon whether a permanent link, channel or the baseline configuration is to be tested.

Special patch cords may be needed to compare the test results from a field tester and reference test setup and are described in 4.8.2.1.2.

#### 4.8.2.1.2 Special patch cords

A set of special patch cords may be used in order to be able to compare the results obtained with laboratory equipment and field testers. The special patch cords have a high quality connection inserted into the patch cord cable. This high quality connection consists of a test interface connector and a mating connector. This connection is a low insertion loss (< 0.1 dB) connection.

For the channel and baseline test configurations, the length of the cable between the mating type connector and the plug mating with the field tester should be 45 mm (1.77 in) maximum. The instrument connector should be a modular connector when the channel configuration is tested. The instrument connector should be a type that mates directly with the high quality measurement port of the field tester as shown in Figure 12
.

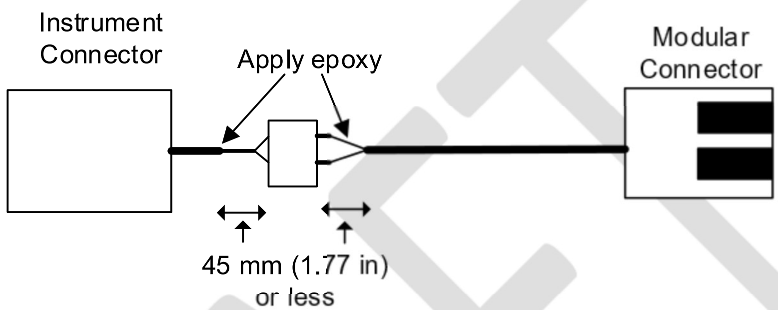


**Figure 12 - Special patch cord for the baseline and channel test comparison**

For the permanent link test configurations, the length of the cable between the modular connector and the plug mating with the link under test should be 45 mm (1.77 in) maximum. The instrument connector should be a type that mates directly with the high quality measurement port of the field tester as shown in Figure 13. Some methods used by field testers for permanent link measurements rely on special calibration factors that are associated to a manufacturer's link adapter (patch cord). The permanent link compensation can be rendered invalid if the link adapter is physically modified or a test is run without valid calibration factors. Contact the field tester manufacturer for any special precautions.

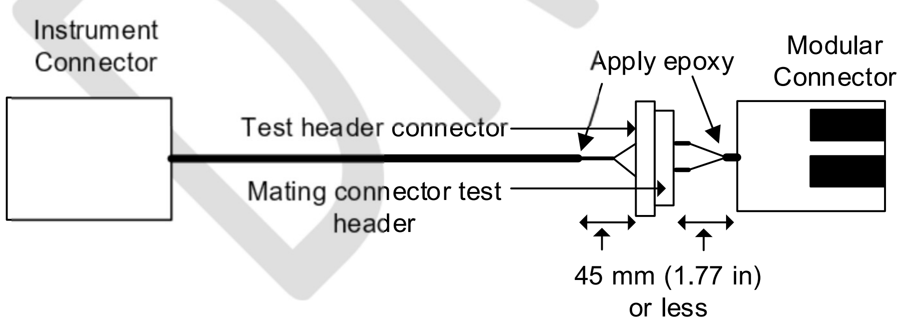


**Figure 13 - Special patch cord for permanent link test comparison**

When measuring a reference channel or permanent link with the field tester, the two sections of the special patch cord should be mated with the test connector and mating connector. When measuring the same link with the network analyzer, the two segments should be separated and the mating connector directly inserted into the test interface as defined for the channel.

#### 4.8.2.2 Comparison methods

Field tester and network analyzer results can be compared using ANSI/TIA-568.5 compliant links whose transmission test performance falls within the dynamic range of the field tester. It is desirable that a number of links be used. A set of special patch cords that is appropriate for the type of comparison as described in ANSI/TIA-568.5 may be used. The results from the network analyzer and the field tester shall be compared using methods described in 4.8.2.2. The results shall agree within the sum of the measurement accuracy of the network analyzer measurement (See Annex A) and the measurement accuracy of the field tester, (See 4.4).

The requirements of insertion loss and return loss are specified as a function of frequency. The comparison may be applied to all frequency data points as described in 4.8.2.2.2. The performance of length, propagation delay, and dc loop resistance is expressed as a single number and comparison of measurement performance is described in 4.8.2.2.1.

#### 4.8.2.2.1 Comparison method using worst case performance margin

The results obtained from the network analyzer and field tester over the specified frequency range are compared only at the worst case performance condition relative to the test limit for the link. It has been shown that small differences in the setup can cause shifts in the nulls in the frequency spectrum and slight variations in the maximum values between the nulls. The worst case performance margins shall agree within the sum of the measurement accuracies of the network analyzer and the field tester at the signal level of the worst case condition.

#### 4.8.2.2.2 Comparison method using full frequency responses

For insertion loss a comparison of the difference of highest insertion loss values reported by the field tester and network analyzer against the sum of field tester and network analyzer measurement accuracies at or near the maximum frequency of the reporting range of the field tester is sufficient.

The full frequency response evaluation method is applicable to return loss. This method uses all data from the frequency response of the network analyzer and field tester that are within the minimum reporting range of the field tester.

The observed accuracy $\mathrm{Acc}_{\mathrm{obs}}$ at every frequency data point, is computed by equation ( **16** ).

$$\boldsymbol{Acc_{obs} = Limit + 20\ \ log\left(10^{\frac{-Limit}{20}} + \left|10^{\frac{-R_{ft}}{20}} - 10^{\frac{-R_{nwa}}{20}}\right|\right)} \qquad (16)$$

where:

$Acc_{obs}$ is the observed measurement accuracy in dB.
$Limit$ is the pass/fail limit for the test configuration (permanent link or channel) in dB.

$R_{ft}$ is the reading by the field tester at the frequency of the data point in dB.

$R_{nwa}$ is the reading by the network analyzer at the frequency of the data point in dB.

NOTE - Equation ( **16** ) computes the V/V equivalent noise floor from the difference of field tester and network analyzer readings; adds it to the V/V corresponding to the pass/fail limit; converts the total of a limit signal and equivalent noise signal back into a value in dB, and subtracts this value from the pass/fail limit itself to provide the observed accuracy at the pass/fail limit of the link under test.

An example of an observed accuracy plot is in Figure 14.

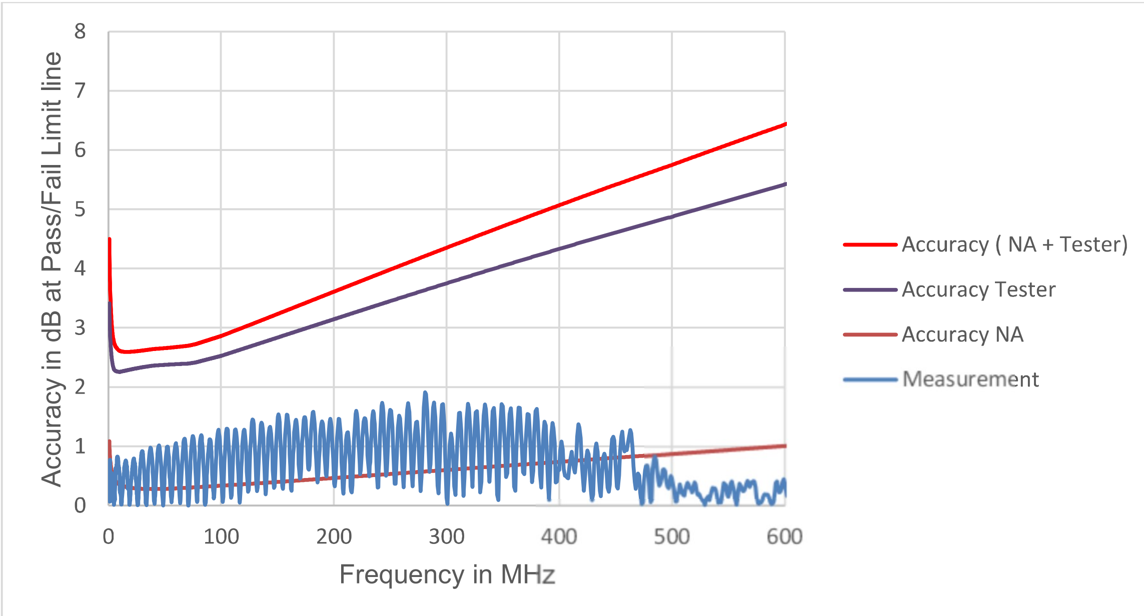


**Figure 14 - Example of observed Level SP-II accuracy**

In Figure 14, the estimated measurement accuracy of a nominally compliant Level SP-II field tester, the estimated measurement accuracy of a network analyzer based measurement system, as well as the sum of network analyzer and nominally compliant field tester accuracies have been added to the observed measurement accuracies computed from the test data. The nominal measurement accuracy of the field tester is no worse than half the value in dB of what is predicted from computations that use performance parameters that are assumed worst case at all frequencies.

# Annex A (informative) - Typical measurement accuracy of reference laboratory measurement systems

It is necessary to establish the accuracy of measurements using laboratory equipment when comparing measurements from field testers with those obtained using laboratory equipment. This includes test fixture and test interface connections. Measurement accuracy is based upon the assumptions for key performance parameters as shown in Table A.1. These are assumed to be valid after two-port calibration of the test fixture and test interface connections. The performance at key frequencies is shown in Table A.2. The properties for laboratory equipment can be measured as described in 4.5.

**Table A.1 - Typical laboratory equipment accuracy performance parameters**

| Test parameter | Parameter | Performance (dB) |
|---|---|---|
| **Insertion loss** | Dynamic accuracy | 0.2 |
| | Source/load Return Loss | 39 – 15 log(*f*/100),<br>43 dB max.<br>20 dB min |
| **ANEXT loss** | Dynamic accuracy | 0.2 |
| | Source/load RL | 39 – 15 log(*f*/100),<br>43 dB max. |
| | Random Noise Floor | 100 |
| | Residual NEXT | 90 – 20 log(*f*/100)<br>94 dB max[1)]<br>70 dB min[1)] |
| | Output Signal Balance | 50 – 20 log(*f*/100) |
| | Common Mode Rejection | 50 – 20 log(*f*/100) |
| **AFEXT** | Dynamic accuracy | 0.3 |
| | Source/load RL | 39 – 15 log(*f*/100),<br>43 dB max. |
| | Random Noise Floor | 100 |
| | Residual FEXT | 90 – 20 log(*f*/100)<br>94 dB max[1)]<br>70 dB min[1)] |
| | Output Signal Balance | 50 – 20 log(*f*/100) |
| | Common Mode Rej. | 50 – 20 log(*f*/100) |
| **Return loss** | Reflection Tracking | 0.1 |
| | Directivity | 39 – 15 log(*f*/100),<br>43 dB max.<br>20 dB min |
| | Source Match | 50 |
| | RL of termination | 45 – 15 log(*f*/100),<br>49 dB max.<br>20 dB min |
| [1)] Given in TIA 1183 | | |

**Table A.2 - Measurement performance parameters at key frequencies (TBD)**

| Test parameter | Parameter | Performance at 0.1 MHz (dB) | Performance at 20 MHz (dB) | Performance at 600 MHz (dB) |
|---|---|---|---|---|
| **Insertion loss** | Dynamic accuracy | 0.2 | 0.2 | 0.2 |
| | Source/load RL | 43.0 | 43.0 | 27.3 |
| | Random Noise Floor | 100.0 | 100.0 | 100.0 |
| | Residual NEXT | 94.0 | 94.0 | 74.4 |
| | Output Signal Balance | 50.0 | 50.0 | 34.4 |
| | Common Mode Rej. | 50.0 | 50.0 | 34.4 |
| **Return loss** | Reflection Tracking | 0.1 | 0.1 | 0.1 |
| | Directivity | 43.0 | 43.0 | 27.3 |
| | Source Match | 50.0 | 50.0 | 50.0 |
| | RL of termination | 49.0 | 49.0 | 33.3 |

The absolute accuracy of the reference load depends largely upon the properties of the termination resistor, connection to the resistor, and the calibration standard. At low frequencies, the absolute performance is limited by the RF calibration standards. At high frequencies, the absolute performance is limited by the frequency response of the chip resistors and quality of termination. With appropriate care, 2 mm (.1 in) maximum untwist, an absolute return loss measurement floor as shown in Table A.3 can be expected.

**Table A.3 - Absolute reference load return loss (TBD)**

| Frequency (MHz) | Load absolute worst case return loss (dB) |
|---|---|
| 1 | 43.0 |
| 4 | 43.0 |
| 8 | 43.0 |
| 10 | 43.0 |
| 16 | 43.0 |
| 20 | 43.0 |
| 25 | 43.0 |
| 31.25 | 43.0 |
| 62.5 | 42.0 |
| 100 | 39.0 |
| 150 | 36.4 |
| 200 | 34.5 |
| 250 | 33.0 |
| 500 | 28.5 |
| 600 | 27.3 |

This performance is used as the value of directivity and return loss of the remote termination in the determination of return loss measurement accuracy, and the source/load impedance for the determination of measurement accuracy for all other measurements.

The predicted measurement accuracy will depend on the pass/fail limit of the link or component that is tested. An example of the measurement accuracy at key frequencies is shown in **Table A.4**, based on channel limits.

**Table A.4 - Predicted measurement worst case accuracy using laboratory equipment at channel limits (TBD)**

| Limits | Frequency (MHz) | Insertion loss (dB) | Return loss (dB) | TCL (dB) | TCTL (dB) |
|---|---|---|---|---|---|
| Level SP-I Channel | 0.1 | 0.2 | 0.8 | 0.8 | 0.8 |
| | 1.0 | 0.2 | 0.7 | 0.7 | 0.7 |
| | 4.0 | 0.2 | 0.7 | 0.7 | 0.7 |
| | 8.0 | 0.2 | 0.7 | 0.7 | 0.7 |
| | 10.0 | 0.2 | 0.7 | 0.7 | 0.7 |
| | 16.0 | 0.2 | 0.7 | 0.7 | 0.7 |
| | 20.0 | 0.2 | 0.7 | 0.7 | 0.7 |
| Level SP-II | 1.0 | | | | |
| | 4.0 | | | | |
| | 8.0 | | | | |
| | 10.0 | | | | |
| | 16.0 | | | | |
| | 20.0 | | | | |
| | 25.0 | | | | |
| | 31.25 | | | | |
| | 62.5 | | | | |
| | 100.0 | | | | |
| | 125.0 | | | | |
| | 150.0 | | | | |
| | 200.0 | | | | |
| | 250.0 | | | | |
| | 300.0 | | | | |
| | 400.0 | | | | |
| | 500.0 | | | | |
| | 600.0 | | | | |

The appropriate pass/fail limit assumptions should be used to assess measurement accuracy when testing permanent links or components.

# Annex B (informative) - Derivation of Level SP-I and SP-II Source Match and Reflection Tracking terms

This annex provides the derivation for the source match and tracking terms used for Level SP-I and SP-II field tester accuracy calculations.

Figure B-1 presents a signal flow graph/error model for one-port VNA measurement. The model contains three error terms.

1) D (directivity),
2) $M_s$ (source mismatch),
3) $T_r$ (frequency response reflection tracking).

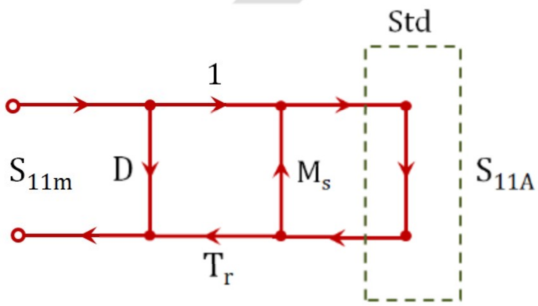


Figure B-1 - Error model for one-port VNA measurement

Using Kuhn's rules for the signal flow graph analyses [1], the mathematical relationship in Figure B-1 can be obtained as the following,

$$\mathbf{S_{11m}} = \mathbf{D} + \frac{\mathbf{T_r S_{11A}}}{\mathbf{1 - M_s S_{11A}}} \qquad \text{(B.1)}$$

Here, $S_{11m}$ is the measured reflection coefficient, and $S_{11A}$ is the true/actual reflection coefficient of a standard. Then (B.1) can be transformed to,

$$(\mathbf{1 - M_s S_{11A}})\mathbf{S_{11m}} = (\mathbf{1 - M_s S_{11A}})\mathbf{D} + \mathbf{T_r S_{11A}} \qquad \text{(B.2)}$$

Rearranging (B.2) ,

$$\mathbf{S_{11A}} = (\mathbf{S_{11m} - D})/[\mathbf{T_r} + \mathbf{M_s}(\mathbf{S_{11m} - D})] \qquad \text{(B.3)}$$

When calibration standards, open, short, and load are used, $\Gamma_{OA}$, $\Gamma_{SA}$, and $\Gamma_{LA}$ are their actual reflection coefficient, and $\Gamma_{Om}$ , $\Gamma_{Sm}$ , and $\Gamma_{Lm}$ are the measured ones.

Therefore, we can form three equations through open, short and load measurements.

$$\mathbf{(1 - M_s\Gamma_{OA})\Gamma_{Om} = (1 - M_s\Gamma_{OA})D + T_r\Gamma_{OA}} \tag{B.4}$$

$$\mathbf{(1 - M_s\Gamma_{SA})\Gamma_{Sm} = (1 - M_s\Gamma_{SA})D + T_r\Gamma_{SA}} \tag{B.5}$$

$$\mathbf{(1 - M_s\Gamma_{LA})\Gamma_{Lm} = (1 - M_s\Gamma_{LA})D + T_r\Gamma_{LA}} \tag{B.6}$$

[ (B.4)× $\Gamma_{SA}$]-[(B.5) × $\Gamma_{OA}$],

$$\mathbf{(1 - M_s\Gamma_{OA})\Gamma_{Om}\Gamma_{SA} = (1 - M_s\Gamma_{OA})D\Gamma_{SA} + T_r\Gamma_{OA}\Gamma_{SA}} \tag{B.7}$$

$$\mathbf{(1 - M_s\Gamma_{SA})\Gamma_{Sm}\Gamma_{OA} = (1 - M_s\Gamma_{SA})D\Gamma_{OA} + T_r\Gamma_{SA}\Gamma_{OA}} \tag{B.8}$$

$$\mathbf{\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\Gamma_{OA} + M_s(\Gamma_{SA}\Gamma_{Sm}\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA}) = D(\Gamma_{SA} - \Gamma_{OA})} \tag{B.9}$$

[(B.5) × $\Gamma_{LA}$]-[(B.6) × $\Gamma_{SA}$],

$$(1 - M_s\Gamma_{SA})\Gamma_{Sm}\Gamma_{LA} = (1 - M_s\Gamma_{SA})D\Gamma_{LA} + T_r\Gamma_{SA}\Gamma_{LA} \tag{B.10}$$

$$\mathbf{(1 - M_s\Gamma_{LA})\Gamma_{Lm}\Gamma_{SA} = (1 - M_s\Gamma_{LA})D\Gamma_{SA} + T_r\Gamma_{LA}\Gamma_{SA}} \tag{B.11}$$

$$\mathbf{\Gamma_{Sm}\Gamma_{LA} - \Gamma_{Lm}\Gamma_{SA} + M_s(\Gamma_{LA}\Gamma_{Lm}\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\Gamma_{LA}) = D(\Gamma_{LA} - \Gamma_{SA})} \tag{B.12}$$

$[(\mathbf{B.9}) \times (\Gamma_{LA} - \Gamma_{SA})] - [(\mathbf{B.12}) \times (\Gamma_{SA} - \Gamma_{OA})]$,

$$\mathbf{(\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\Gamma_{OA})(\Gamma_{LA} - \Gamma_{SA}) + M_s(\Gamma_{SA}\Gamma_{Sm}\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})(\Gamma_{LA} - \Gamma_{SA}) = D(\Gamma_{SA} - \Gamma_{OA})(\Gamma_{LA} - \Gamma_{SA})} \tag{B.13}$$

$$\mathbf{(\Gamma_{Sm}\Gamma_{LA} - \Gamma_{Lm}\Gamma_{SA})(\Gamma_{SA} - \Gamma_{OA}) + M_s(\Gamma_{LA}\Gamma_{Lm}\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\Gamma_{LA})(\Gamma_{SA} - \Gamma_{OA}) = D(\Gamma_{LA} - \Gamma_{SA})(\Gamma_{SA} - \Gamma_{OA})} \tag{B.14}$$

$$M_s = \frac{(\Gamma_{Sm}\Gamma_{LA} - \Gamma_{Lm}\Gamma_{SA})(\Gamma_{SA} - \Gamma_{OA}) - (\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\Gamma_{OA})(\Gamma_{LA} - \Gamma_{SA})}{(\Gamma_{SA}\Gamma_{Sm}\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})(\Gamma_{LA} - \Gamma_{SA}) - (\Gamma_{LA}\Gamma_{Lm}\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\Gamma_{LA})(\Gamma_{SA} - \Gamma_{OA})} \tag{B.15}$$

$[(\mathbf{B.9}) \times (\Gamma_{LA}\Gamma_{Lm}\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\Gamma_{LA})] - [(\mathbf{B.12}) \times (\Gamma_{SA}\Gamma_{Sm}\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})]$,

$$\mathbf{(\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\Gamma_{OA})(\Gamma_{LA}\Gamma_{Lm}\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\Gamma_{LA}) + M_s(\Gamma_{SA}\Gamma_{Sm}\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})(\Gamma_{LA}\Gamma_{Lm}\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\Gamma_{LA}) = D(\Gamma_{SA} - \Gamma_{OA})(\Gamma_{LA}\Gamma_{Lm}\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\Gamma_{LA})} \tag{B.16}$$

$$\mathbf{(\Gamma_{Sm}\Gamma_{LA} - \Gamma_{Lm}\Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA}) + M_s(\Gamma_{LA}\Gamma_{Lm}\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\Gamma_{LA})(\Gamma_{SA}\Gamma_{Sm}\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA}) = D(\Gamma_{LA} - \Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})} \tag{B.17}$$

$$\mathbf{D} = \frac{(\boldsymbol{\Gamma}_{\mathbf{Om}}\boldsymbol{\Gamma}_{\mathbf{SA}} - \boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{OA}})(\boldsymbol{\Gamma}_{\mathbf{LA}}\boldsymbol{\Gamma}_{\mathbf{Lm}}\,\boldsymbol{\Gamma}_{\mathbf{SA}} - \boldsymbol{\Gamma}_{\mathbf{SA}}\boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{LA}}) - (\boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{LA}} - \boldsymbol{\Gamma}_{\mathbf{Lm}}\,\boldsymbol{\Gamma}_{\mathbf{SA}})(\boldsymbol{\Gamma}_{\mathbf{SA}}\boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{OA}} - \boldsymbol{\Gamma}_{\mathbf{OA}}\boldsymbol{\Gamma}_{\mathbf{Om}}\boldsymbol{\Gamma}_{\mathbf{SA}})}{(\boldsymbol{\Gamma}_{\mathbf{SA}} - \boldsymbol{\Gamma}_{\mathbf{OA}})\,(\boldsymbol{\Gamma}_{\mathbf{LA}}\boldsymbol{\Gamma}_{\mathbf{Lm}}\,\boldsymbol{\Gamma}_{\mathbf{SA}} - \boldsymbol{\Gamma}_{\mathbf{SA}}\boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{LA}}) - (\boldsymbol{\Gamma}_{\mathbf{LA}} - \boldsymbol{\Gamma}_{\mathbf{SA}})(\boldsymbol{\Gamma}_{\mathbf{SA}}\boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{OA}} - \boldsymbol{\Gamma}_{\mathbf{OA}}\boldsymbol{\Gamma}_{\mathbf{Om}}\boldsymbol{\Gamma}_{\mathbf{SA}})} \quad (B.18)$$

Rearranging (B.1) & replacing with actual and measured reflection coefficient for OPEN standard,

$$\left(\frac{\mathbf{1}}{\boldsymbol{\Gamma}_{\mathbf{OA}}} - \mathbf{M_s}\right)(\boldsymbol{\Gamma}_{\mathbf{Om}} - \mathbf{D}) = \mathbf{T_r} \quad (B.19)$$

$$\mathrm{T_r} = \left(\frac{1}{\Gamma_{OA}} - \frac{(\Gamma_{Sm}\,\Gamma_{LA} - \Gamma_{Lm}\,\Gamma_{SA})(\Gamma_{SA} - \Gamma_{OA}) - (\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\,\Gamma_{OA})(\Gamma_{LA} - \Gamma_{SA})}{(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})(\Gamma_{LA} - \Gamma_{SA}) - (\Gamma_{LA}\Gamma_{Lm}\,\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\,\Gamma_{LA})(\Gamma_{SA} - \Gamma_{OA})}\right) \times$$

$$\left(\Gamma_{Om} - \frac{(\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\,\Gamma_{OA})(\Gamma_{LA}\Gamma_{Lm}\,\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\,\Gamma_{LA}) - (\Gamma_{Sm}\,\Gamma_{LA} - \Gamma_{Lm}\,\Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})}{(\Gamma_{SA} - \Gamma_{OA})\,(\Gamma_{LA}\Gamma_{Lm}\,\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\,\Gamma_{LA}) - (\Gamma_{LA} - \Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})}\right) \quad (B.20)$$

Simplifications

1) Tracking

$$\mathrm{T_r} = \left(\frac{1}{\Gamma_{OA}} - \frac{(\Gamma_{Sm}\,\Gamma_{LA} - \Gamma_{Lm}\,\Gamma_{SA})(\Gamma_{SA} - \Gamma_{OA}) - (\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\,\Gamma_{OA})(\Gamma_{LA} - \Gamma_{SA})}{(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})(\Gamma_{LA} - \Gamma_{SA}) - (\Gamma_{LA}\Gamma_{Lm}\,\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\,\Gamma_{LA})(\Gamma_{SA} - \Gamma_{OA})}\right) \times$$

$$\left(\Gamma_{Om} - \frac{(\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\,\Gamma_{OA})(\Gamma_{LA}\Gamma_{Lm}\,\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\,\Gamma_{LA}) - (\Gamma_{Sm}\,\Gamma_{LA} - \Gamma_{Lm}\,\Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})}{(\Gamma_{SA} - \Gamma_{OA})\,(\Gamma_{LA}\Gamma_{Lm}\,\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\,\Gamma_{LA}) - (\Gamma_{LA} - \Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})}\right) \quad (B.21)$$

For ideal open, short and load we have $\Gamma_A = 1, -1, 0$

$$\mathrm{T_r} = \left(1 - \frac{-2\Gamma_{Lm} - (-\Gamma_{Om} - \Gamma_{Sm})}{\Gamma_{Om} - \Gamma_{Sm}}\right) \times \left(\Gamma_{Om} - \frac{-(-\Gamma_{Lm}\,\Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})}{-(\Gamma_{LA} - \Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})}\right) \quad (B.22)$$

That is,

$$\mathrm{T_r} = \left(\frac{2\Gamma_{Lm} - 2\Gamma_{Sm}}{\Gamma_{Om} - \Gamma_{Sm}}\right) \times (\Gamma_{Om} - \Gamma_{Lm}) \quad (B.23)$$

Final form is,

$$\mathrm{T_r} = 2\left(\frac{\Gamma_{Lm} - \Gamma_{Sm}}{\Gamma_{Om} - \Gamma_{Sm}}\right) \times (\Gamma_{Om} - \Gamma_{Lm}) \quad (B.24)$$

2) Source Match

$$\mathbf{M_s} = \frac{(\boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{LA}} - \boldsymbol{\Gamma}_{\mathbf{Lm}}\,\boldsymbol{\Gamma}_{\mathbf{SA}})(\boldsymbol{\Gamma}_{\mathbf{SA}} - \boldsymbol{\Gamma}_{\mathbf{OA}}) - (\boldsymbol{\Gamma}_{\mathbf{Om}}\boldsymbol{\Gamma}_{\mathbf{SA}} - \boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{OA}})(\boldsymbol{\Gamma}_{\mathbf{LA}} - \boldsymbol{\Gamma}_{\mathbf{SA}})}{(\boldsymbol{\Gamma}_{\mathbf{SA}}\boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{OA}} - \boldsymbol{\Gamma}_{\mathbf{OA}}\boldsymbol{\Gamma}_{\mathbf{Om}}\boldsymbol{\Gamma}_{\mathbf{SA}})(\boldsymbol{\Gamma}_{\mathbf{LA}} - \boldsymbol{\Gamma}_{\mathbf{SA}}) - (\boldsymbol{\Gamma}_{\mathbf{LA}}\boldsymbol{\Gamma}_{\mathbf{Lm}}\,\boldsymbol{\Gamma}_{\mathbf{SA}} - \boldsymbol{\Gamma}_{\mathbf{SA}}\boldsymbol{\Gamma}_{\mathbf{Sm}}\,\boldsymbol{\Gamma}_{\mathbf{LA}})(\boldsymbol{\Gamma}_{\mathbf{SA}} - \boldsymbol{\Gamma}_{\mathbf{OA}})} \quad (B.25)$$

For ideal open, short and load we have $\Gamma_{A} = 1, -1, 0$

Due to $\Gamma_{LA} = 0$,

$$M_{s} = \frac{\Gamma_{Lm}\,(\Gamma_{SA} - \Gamma_{OA}) - (\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\,\Gamma_{OA})}{(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})} \tag{B.26}$$

Then,

$$M_{s} = \frac{\Gamma_{Om} + \Gamma_{Sm} - 2\Gamma_{Lm}}{\Gamma_{Om} - \Gamma_{Sm}} \tag{B.27}$$

3) Directivity

$$D = \frac{(\Gamma_{Om}\Gamma_{SA} - \Gamma_{Sm}\,\Gamma_{OA})(\Gamma_{LA}\Gamma_{Lm}\,\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\,\Gamma_{LA}) - (\Gamma_{Sm}\,\Gamma_{LA} - \Gamma_{Lm}\,\Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})}{(\Gamma_{SA} - \Gamma_{OA})\,(\Gamma_{LA}\Gamma_{Lm}\,\Gamma_{SA} - \Gamma_{SA}\Gamma_{Sm}\,\Gamma_{LA}) - (\Gamma_{LA} - \Gamma_{SA})(\Gamma_{SA}\Gamma_{Sm}\,\Gamma_{OA} - \Gamma_{OA}\Gamma_{Om}\Gamma_{SA})} \tag{B.28}$$

For ideal open, short and load we have $\Gamma_{A} = 1, -1, 0$

Due to $\Gamma_{LA} = 0$

$$D = \Gamma_{Lm} \tag{B.29}$$

# Annex C (informative) - Bibliography

The organizations listed below can be contacted to obtain reference information.

ANSI
www.ansi.org

BICSI
www.bicsi.org

TIA
www.tiaonline.org

The following reference may provide additional useful information:

[1]. P. Young, "Scattering coefficients and circuit analysis," in *14th IEE Microwave Measurements Training Course*, pp.2 -2/11, May 2005.

[2]. ANSI/TIA-1183-1 Measurement methods and test fixtures for balun-less measurements of balanced components and systems extending frequency capabilities to 2GHz.