6 TRANSMISSION REQUIREMENTS

6.1 General

This clause contains the transmission performance specifications for 100 Ω balanced twisted-pair cabling and components.

To serve a multi-disturber environment, this Standard specifies transmission parameters as both worst-case pair-to-pair measurements and power sum calculations that approximate multi-disturber effects.

Transmission parameters are applicable to channels, direct attach channels, permanent links, cables, cords, and connecting hardware. This clause describes the transmission parameters and develops the applicable generic equations for each parameter. All requirements apply at both ends or in both directions.

The test methods in Annex C, for balun based measurements, or in Annex D, for balun-less measurements, may be used.

6.1.1 Return loss

Return loss shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category.

6.1.2 Insertion loss

Insertion loss shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category.

6.1.3 NEXT loss

NEXT loss shall be measured for all pair combinations of the DUT from 1 MHz up to the maximum specified frequency for the category.

6.1.4 PSNEXT loss

PSNEXT loss takes into account the combined crosstalk (statistical) on a receive pair from all near-end disturbers operating simultaneously. PSNEXT loss is calculated in accordance with ASTM D 4566 as a power sum on a selected pair from all other pairs as shown in equation (2) for the case of an n-pair DUT.

$$PSNEXT_k = -10\log\left(\sum_{i=1, i\neq k}^{n} 10^{-\frac{NEXT_{k,i}}{10}}\right) dB \tag{2}$$

where:

n is the total number of pairs under test (DUT).

$NEXT_{k,i}$ is the measured NEXT loss, in dB, to pair k from pair i.

k is the number of the disturbed pair.

i is the number of a disturbing pair.

PSNEXT loss shall be calculated for all pairs of the DUT.

6.1.5 FEXT loss

FEXT loss shall be measured for all pair combinations of the DUT from 1 MHz up to the maximum specified frequency for the category.

6.1.6 ACRF

ACRF shall be calculated for all DUT pair combinations by subtracting the insertion loss of the disturbed pair of the DUT from the FEXT loss as shown in equation (3).

$$ACRF_{k,i} = FEXT_{k.i} - IL_k \text{ dB} \quad (3)$$

where:

IL_k is the insertion loss of the disturbed pair.

k is the number of the disturbed pair in a disturbed DUT.

i is the number of a disturbing pair in a disturbing DUT.

$i \neq k$.

NOTE - ACRF has been referred to as ELFEXT in previous editions of this Standard.

6.1.7 PSACRF

PSACRF takes into account the combined crosstalk (statistical) on a receive pair from all far-end disturbers operating simultaneously. PSACRF is calculated as a power sum on a selected pair k from all other pairs as shown in equation (4) for the case of an n-pair DUT.

$$PSACRF_k = -10\log\left(\sum_{i=1,i\neq k}^{n} 10^{-\frac{FEXT_{k,i}}{10}}\right) - IL_k \text{ dB} \quad (4)$$

where:

n is the total number of pairs under test (DUT).

IL_k is the insertion loss of the disturbed pair.

k is the number of the disturbed pair in a disturbed DUT.

i is the number of a disturbing pair in a disturbing DUT.

NOTE - PSACRF has been referred to as PSELFEXT in previous editions of this Standard.

6.1.8 TCL

Where specified, TCL shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category.

Category 6 channel TCL is provided for information only.

NOTES,
1 TCL and LCL parameters have reciprocity. LCL can be determined using a TCL measurement.
2 When achievable, a 50 dB measurement plateau is recommended.

6.1.9 ELTCTL

Where specified, TCTL shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category.

ELTCTL shall be calculated for all DUT pairs as shown in equation (5). ELTCTL is specified for the opposite ends of the same pair. ELTCTL between pairs is not specified.

$$ELTCTL_{DUT} = TCTL_{DUT} - IL_{DUT\_DM} \tag{5}$$

where:

IL_{DUT_DM} is the differential mode DUT insertion loss.

6.1.10 Coupling attenuation

Coupling attenuation is measured in accordance with IEC 62153-4-5 or IEC 62153-4-9 for all screened pairs of horizontal cable from 30 MHz up to the maximum specified frequency for the specified category.

> NOTE - Measurements are made from 30 MHz to 2000 MHz depending on the Category of cable under test for all devices under test, but the measurements above the upper frequency of the specified category are for information only.

6.1.11 Propagation delay

Propagation delay shall be measured for all pairs of the DUT from 1 MHz up to the maximum specified frequency for the category.

6.1.12 Propagation delay skew

Propagation delay skew shall be calculated for all pair combinations of the DUT from 1 MHz up to the maximum specified frequency for the category.

6.1.13 PSANEXT loss

PSANEXT loss takes into account the combined alien crosstalk (statistical) on a receive pair from all external near-end disturbers operating simultaneously. PSANEXT loss is calculated as a power sum on a selected pair k from all other pairs as shown in equation (6) for the case of a 4-pair DUT.

$$PSANEXT_k = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{4}10^{-\frac{ANEXT_{k,i,j}}{10}}\right) dB \tag{6}$$

where:

N is the total number of disturbing devices under test (DUT).

$ANEXT_{k,i,j}$ is the measured ANEXT loss, in dB, to pair k of the disturbed DUT from pair i in disturbing DUT j.

k is the number of the disturbed pair in a disturbed DUT.

i is the number of a disturbing pair in a disturbing DUT.

j is the number of a disturbing DUT.

ANEXT loss shall be measured for all DUT pair combinations and PSANEXT loss shall be calculated for all DUT pairs.

6.1.14 Average PSANEXT loss

Average PSANEXT loss is calculated by averaging the individual PSANEXT loss values, in dB, for all four pairs in the disturbed DUT at each frequency point as shown in equation (7).

$$AVERAGE\_PSANEXT = \frac{\sum_{k=1}^{4} PSANEXT_k}{4} \text{ dB} \quad (7)$$

where:

$PSANEXT_k$ is the magnitude, in *dB*, of PSANEXT loss as determined by equation (6).

6.1.15 PSAFEXT loss (connecting hardware only)

PSAFEXT loss takes into account the combined alien crosstalk (statistical) on a receive pair from all external far-end disturbers operating simultaneously. PSAFEXT loss is calculated as a power sum on a selected pair from all other pairs as shown in equation (8) for connecting hardware.

$$PSAFEXT_k = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{4} 10^{-\frac{AFEXT_{k,i,j}}{10}}\right) \text{ dB} \quad (8)$$

where:

N is the total number of disturbing devices under test (DUT).

$AFEXT_{k,i,j}$ is the measured AFEXT loss, in dB, to pair k of the disturbed DUT from pair i in disturbing DUT j.

k is the number of the disturbed pair in a disturbed DUT.

i is the number of a disturbing pair in a disturbing DUT.

j is the number of a disturbing DUT.

AFEXT loss shall be measured for all connecting hardware pairs and PSAFEXT loss shall be calculated for all connecting hardware pairs. Category 6A and category 8 connecting hardware AFEXT loss shall be measured in accordance with Annex C or D.

6.1.16 PSAACRF

AFEXT loss is the coupling of crosstalk at the far-end from external DUT pairs into a disturbed pair of the 4-pair DUT under test. PSAACRF is the calculated power sum from all external pairs into the disturbed pair. Annex N provides additional information on PSAACRF and AFEXT loss normalization. PSAACRF for a DUT is determined using equation (9) for the case of a 4-pair DUT.

$$PSAACRF_k = PSAFEXT_k - IL_k \text{ dB} \quad (9)$$

For channels and permanent links, the calculations in equations (10) through (12) shall be used to determine PSAFEXT loss when the disturbed pair has greater insertion loss than the disturbing pair.

If $IL_k > IL_{ij,}$ then:

$$AFEXTnorm_{k,i,j} = AFEXT_{k,i,j} + (IL_k - IL_{i,j}) - 10\log\left(\frac{IL_k}{IL_{i,j}}\right) \text{ dB} \tag{10}$$

If $IL_k \leq IL_{ij,}$ then:

$$AFEXTnorm_{k,i,j} = AFEXT_{k,i,j} \text{ dB} \tag{11}$$

where:

$$PSAFEXT_k = -10\log\left(\sum_{j=1}^{N}\sum_{i=1}^{n} 10^{-\frac{AFEXTnorm_{k,i,j}}{10}}\right) \text{ dB} \tag{12}$$

$PSAACRF_k$ is the PSAACRF of disturbed pair *k*.

$AFEXTnorm$ is AFEXT loss, in dB, normalized to the coupled length (the minimum length of the disturbed and disturbing pair) relative to the length of the disturbed pair.

IL_k is the insertion loss of disturbed pair *k*.

$IL_{i,j}$ is the insertion loss of pair i of disturbing DUT *j*.

N is the total number of disturbing devices under test (DUT).

n is the number of pairs in disturbing devices under test *j* (usually 4).

$AFEXT_{k,i,j}$ is the measured AFEXT loss, in dB, to pair *k* of the disturbed DUT from pair *i* in disturbing DUT *j*.

k is the number of the disturbed pair in a disturbed DUT.

i is the number of a disturbing pair in a disturbing DUT.

j is the number of a disturbing DUT.

ACRF shall be measured for all DUT pair combinations and PSAACRF shall be calculated for all DUT pairs.

6.1.17 Average PSAACRF

Average PSAACRF is calculated by averaging the individual PSAACRF values, in dB, for all four pairs in the disturbed DUT at each frequency point as shown in equation (13).

$$AVERAGE\_PSAACRF = \frac{\sum_{k=1}^{4} PSAACRF_k}{4} \text{ dB} \tag{13}$$

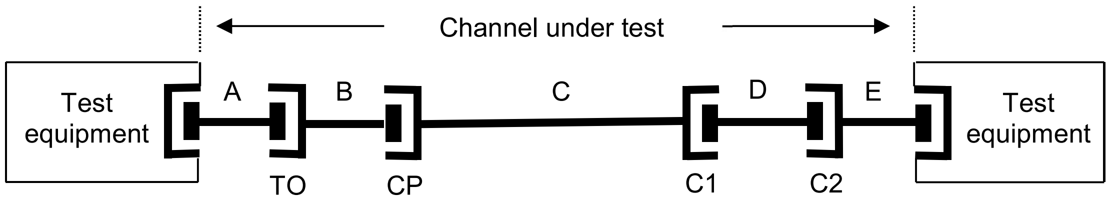
where:

$PSAACRF_k$ is the magnitude, in *dB*, of PSAACRF as determined by equation (9)

6.2 Channel configurations

6.2.1 Category 3 through category 6A channel configuration

This clause contains the transmission performance specifications for balanced twisted-pair channels. The channel test configuration is illustrated in figure 3. See Annex L for worst case modeling configurations.



Legend

Cables and cords
Work area cord .... A
Optional consolidation point cabling . B
Horizontal cabling C
Patch cord or jumper cable............... D
Telecommunications room equipment cord.......................... E

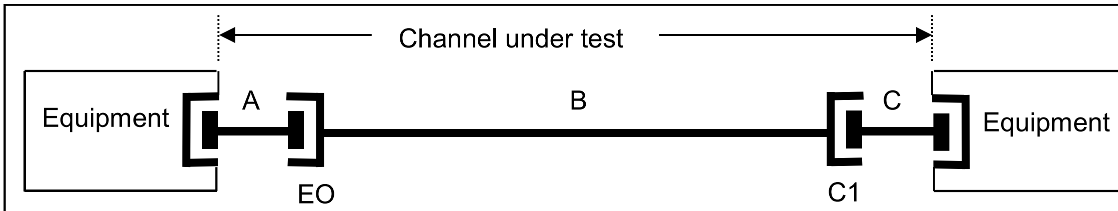
Connecting hardware
Telecommunications outlet/connector ....TO
Optional consolidation point connector ....CP
Horizontal cross-connect or interconnect C1, C2

Maximum length
B + C.................................. 90 m (295 ft)
A + D + E .... 10 m (32.8 ft)

Figure 3 - Supplemental schematic representation of a channel test configuration

6.2.2 Category 8 channel configuration

The channel test configuration is defined by this clause.



Legend

Cables and cords
Equipment cord............................A, C
Horizontal cabling ....B

Connecting hardware
Equipment Outlet...........................EO
Interconnect C1

Maximum length

A + C .... see table 4
B .... 24 m (79 ft)

Figure 4 - Supplemental schematic representation of a category 8 channel configuration

Horizontal Channel topology shall consist of a maximum of two connectors, horizontal cable and two equipment cords as shown in Figure 4.

For the maximum (24 m) permanent link length, the maximum total patch cord length is based upon the insertion loss de-rating of the modular cord cable when compared to the horizontal cable insertion loss. This de-rating factor is generally based upon the wire gauge (AWG) of the conductors used in the modular cord cable. Typically 22/23 AWG conductors have a 0% de-rating factor, 24 AWG conductors have a 20% de-rating factor, and 26 AWG conductors have a 50% de-rating factor. The maximum total length of equipment cords for a channel built from a 24 m permanent link are shown in Table 4.

Table 4 - Equipment cord de-rating and allowed length for 24 m permanent Link

Equipment cord de-rating factor (%)	length of cordage allowed (m)
0	7.2
20	6
50	4.8

6.3 Channel transmission performance

6.3.1 Category 3 through category 6A dc loop resistance

DC loop resistance for category 3, 5e, 6, and 6A channels shall not exceed 25 Ω at any temperature from 20 °C to 60 °C. Refer to TIA TSB-184-A for additional information on channel resistance related to guidance on delivering power.

6.3.2 Category 8 channel dc loop resistance

DC loop resistance for category 8 channels shall not exceed 6.4 Ω when measured at 20 °C or corrected to a temperature of 20 °C using the correction factors specified in ASTM-D4566. Using a temperature coefficient of resistance of 0.00393 for copper, the resistance at 60 °C is 7.22 Ω. Refer to TIA TSB-184-A for additional information on channel resistance related to guidance on delivering power.

6.3.3 Channel dc resistance unbalance

DC resistance unbalance shall be calculated for each pair of the channel in accordance with equation (14). This requirement is satisfied if the result of equation 14 is less than 3 % or if the difference between R1 and R2 is less than 200 mΩ. DC resistance unbalance is not specified for category 3 channels.

$$Resistance\_Unbalance_{pair} = \left(\frac{|R_1 - R_2|}{R_1 + R_2}\right)100\% \qquad (14)$$

where:

R_1 is the dc resistance of conductor 1.

R_2 is the dc resistance of conductor 2.

6.3.4 Channel dc resistance unbalance between pairs

For categories 3 through 6A, dc resistance unbalance between pairs is not specified. Guidelines are provided in TIA TSB-184-A.

For Category 8, dc resistance unbalance between pairs shall be calculated for the channel in accordance with equation (15) This requirement is satisfied if the result of equation (15) is less than 7 % or if the difference between R_{P1} and R_{P2} is less than 50 mΩ. This applies to all 6 combinations of any 2 of the 4 pairs.

For the purposes of field testing, whenever the difference between R_{P1} and R_{P2} is less than 200 mΩ, the DC resistance unbalance requirement between pairs is met.

$$Resistance\_Unbalance_{Between\_pairs} = \left(\frac{|R_{P1} - R_{P2}|}{R_{P1} + R_{P2}}\right)100\% \qquad (15)$$

Where:

R_{P1} is the dc parallel resistance of the conductors of a pair.
R_{P2} is the dc parallel resistance of the conductors of another pair.

The resistance for any pair PX may be calculated from individual conductor resistance values using equation (16).

$$R_{PX} = \frac{(R_{C1}R_{C2})}{(R_{C1} + R_{C2})} \qquad (16)$$

6.3.5 Channel mutual capacitance

Mutual capacitance is not specified for channels.

6.3.6 Channel capacitance unbalance: pair-to-ground

Capacitance unbalance is not specified for channels.

6.3.7 Channel characteristic impedance and structural return loss (SRL)

Characteristic impedance and structural return loss (SRL) are not applicable for channels.

6.3.8 Channel return loss

Channel return loss shall meet or exceed the values determined using the equations shown in Table 5 for all specified frequencies.

Table 5 - Channel return loss

	Frequency (MHz)	**Return loss (dB)**
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f < 20$ $20 \le f \le 100$	17 $17 - 10\log(f/20)$
Category 6	$1 \le f < 10$ $10 \le f < 40$ $40 \le f \le 250$	19 $24-5\log(f)$ $32-10\log(f)$
Category 6A	$1 \le f < 10$ $10 \le f < 40$ $40 \le f < 398.1$ $398.1 \le f \le 500$	19 $24-5\log(f)$ $32-10\log(f)$ 6
Category 8	$1 \le f < 10$ $10 \le f < 40$ $40 \le f < 130$ $130 \le f < 1000$ $1000 \le f \le 2000$	19.0 $24-5\log(f)$ 16.0 $35-9\log(f)$ 8 dB

The channel return loss values in Table 6 are provided for information only.

Table 6 - Minimum channel return loss

Frequency (MHz)	Category 5e (dB)	Category 6 (dB)	Category 6A (dB)	Category 8 (dB)
1.00	17.0	19.0	19.0	19.0
4.00	17.0	19.0	19.0	19.0
8.00	17.0	19.0	19.0	19.0
10.00	17.0	19.0	19.0	19.0
16.00	17.0	18.0	18.0	18.0
20.00	17.0	17.5	17.5	17.5
25.00	16.0	17.0	17.0	17.0
31.25	15.1	16.5	16.5	16.5
62.50	12.1	14.0	14.0	16.0
100.00	10.0	12.0	12.0	16.0
200.00	-	9.0	9.0	14.3
250.00	-	8.0	8.0	13.4
300.00	-	-	7.2	12.7
400.00	-	-	6.0	11.6
500.00	-	-	6.0	10.7
600.00	-	-	-	10.0
1000.00	-	-	-	8.0
1500.00	-	-	-	8.0
2000.00	-	-	-	8.0

6.3.9 Channel insertion loss

Channel insertion loss limits are derived from equation (17).

$$InsertionLoss_{channel} = 4(InsertionLoss_{conn}) + (InsertionLoss_{cable}) + ILD_{channel} \text{ dB} \quad (17)$$

where:

$$InsertionLoss_{cable} = 1.02 \cdot InsertionLoss_{cable,100m} \text{ dB}, \quad (18)$$

$InsertionLoss_{cable,100m}$ is the insertion loss of 100m of the appropriate category of cable, see clause 6.6.8,

$InsertionLoss_{conn}$ is the insertion loss of the appropriate category of connecting hardware, see clause 6.10.8, and

$ILD_{channel} = 0$ *dB* for category 3 and 5e channels (19)

$ILD_{channel} = 0.0003 f^{1.5}$ *dB* for category 6 channels (20)

$$ILD_{channel} = 0.03(1.82\sqrt{f} + 0.091f + \frac{0.25}{\sqrt{f}})\ dB \text{ for category 6A channels} \qquad (21)$$

where,

$ILD_{channel}$ is the insertion loss deviation allowance for a channel.

NOTES,
1 The Insertion loss of the channel allows for a 20% increase of insertion loss for cord cable.
2 The insertion loss of the channel does not take into consideration the 0.1 dB measurement floor of the connecting hardware insertion loss requirement.
3 The channel insertion loss requirement is derived using the insertion loss contribution of 4 connections.
4 For the purposes of field measurements, calculated channel limits that result in insertion loss values less than 3 dB revert to a requirement of 3 dB maximum (see ANSI/TIA-1152-A).

Category 8 Channel insertion loss limits are derived from the modeling equation (22).

$$InsertionLoss_{channel} = 2(InsertionLoss_{conn}) + B(InsertionLoss_{cable\_30m}) + ILD_{channel}\ dB \qquad (22)$$

Where:

B is the insertion loss scaling factor for horizontal cable including a 20% equipment cord de-rating for 6 m of cord cable and including 24 m of horizontal cable as shown in equation (23).

$$B = 1.2 \times 6/100 + 24/100 = 0.312 \qquad (23)$$

And:
$InsertionLoss_{cable\_30m}$ is the insertion loss of the horizontal cable, see clause 6.6.8.
And:
$InsertionLoss_{conn}$ is the insertion loss of the connecting hardware, see clause 6.10.8.
$ILD_{channel}$ is the insertion loss deviation allowance for a channel, see equation (24).

$$ILD_{channel} = 0.0324\sqrt{f}\ dB \text{ for category 8 channels} \qquad (24)$$

NOTES:
1 Table 7 allows a 20% de-rating of insertion loss for cord cable.
2 The insertion loss of the channel does not take into consideration the 0.1 dB measurement floor of the connecting hardware insertion loss requirement.