## 55.7 Link segment characteristics

10GBASE-T is designed to operate over ISO/IEC 11801 Class E or Class F 4-pair balanced cabling that meets the additional requirements specified in this subclause. Each of the four pairs supports an effective data rate of 2500 Mbps in each direction simultaneously. The term “link segment” used in this clause refers to four duplex channels. The term “duplex channel” will be used to refer to a single channel with full duplex capability. Specifications for a link segment apply equally to each of the four duplex channels. All implementations of the balanced cabling link segment specification shall be compliant at the MDI.

Link segment testing shall be conducted using source and load impedances of 100 Ω.

### 55.7.1 Cabling system characteristics

The cabling system used to support 10GBASE-T requires 4 pairs of ISO/IEC 11801 Class E or Class F balanced cabling with a nominal impedance of 100 Ω.

Additionally:

a) 10GBASE-T uses a star topology with Class E or Class F balanced cabling used to connect PHY entities.
b) 10GBASE-T is an ISO/IEC 11801 Class E and Class F application with the additional transmission requirements specified in 55.7.2 and 55.7.3, respectively.

### 55.7.2 Class E link segment transmission parameters

The transmission parameters contained in this subclause are specified to ensure that a Class E link segment of at least 55 to 100 meters will provide a reliable medium. The transmission parameters of the link segment include insertion loss, delay parameters, nominal impedance, NEXT loss, ELFEXT loss, and return loss. In addition, link segment requirements are specified for alien crosstalk.

Note—The link segment transmission parameters of insertion loss and ELFEXT loss specified are ISO/IEC 11801 Class E specifications extended by extrapolating the formulas to a frequency up to 500 MHz. The link segment transmission parameters of NEXT loss, MDNEXT loss and Return Loss specified in 55.7 are ISO/IEC 11801 Class E specifications extended beyond 250 MHz by utilizing the equations referenced in TIA TR42 D1.0 TSB-155.

#### 55.7.2.1 Insertion loss

The insertion loss of each duplex channel shall be less than

$$\frac{L}{100} \times 1.05\left(1.82 \times \sqrt{f} + 0.169 \times f + \frac{0.25}{\sqrt{f}}\right) + 4 \times 0.02 \times \sqrt{f} \text{ (dB)}$$

where L is length in meters and the frequency is from 1 MHz to 500 MHz. This includes the attenuation of the balanced cabling pairs, including work area and equipment cables plus connector losses within each duplex channel. The insertion loss specification shall be met when the duplex channel is terminated in 100 Ω.

#### 55.7.2.2 Differential characteristic impedance

The nominal differential characteristic impedance of each link segment duplex channel, which includes cable cords and connecting hardware, is 100 Ω for all frequencies between 1 MHz and 500 MHz.

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#### 55.7.2.3 Return loss

Each link segment duplex channel shall meet or exceed the return loss specified in the following equation at all frequencies from 1 MHz to 500 MHz. The reference impedance shall be 100 Ω.

$$\text{Return\_Loss}(f) = \begin{cases} 19 & 1 \le f < 10 \\ 24 - 5\log 10(f) & 10 \le f < 40 \\ 32 - 10\log 10(f) & 40 \le f < 400 \\ 6 & 400 \le f \le 500 \end{cases} \quad \text{(dB)}$$

where $f$ is the frequency in MHz.

#### 55.7.2.4 Coupling parameters between duplex channels

In order to limit the noise coupled into a duplex channel from adjacent duplex channels, Near-End Crosstalk (NEXT) loss and Equal Level Far-End Crosstalk (ELFEXT) loss are specified for each link segment. In addition, each duplex channel can be disturbed by more than one duplex channel. To ensure the total NEXT loss and FEXT loss coupled into a duplex channel is limited, multiple disturber Near-End Crosstalk (MDNEXT) and multiple disturber ELFEXT (MDELFEXT) loss is specified.

##### 55.7.2.4.1 Differential Near-End Crosstalk (NEXT)

In order to limit the crosstalk at the near end of a link segment, the differential pair-to-pair Near-End Crosstalk (NEXT) loss between a duplex channel and the other three duplex channels is specified to meet the bit error rate objective specified in 55.1. The NEXT loss between any two duplex channels of a link segment shall be at least

$$-20 \times \log 10\left(10^{\frac{74.3 - 15\log 10(f)}{-20}} + 2 \times 10^{\frac{94 - 20\log 10(f)}{-20}}\right) \quad \text{(dB)}$$

where f is the frequency $(1 \le f < 330)$ in MHz.

The NEXT loss between any two duplex channels of a link segment shall be at least

$$31 - 50 \times \log 10\left(\frac{f}{330}\right) \quad \text{(dB)}$$

where f is the frequency $(330 \le f \le 500)$ in MHz.

##### 55.7.2.4.2 Multiple Disturber Near-End Crosstalk (MDNEXT) loss

Since four duplex channels are used to transfer data between PMDs, the NEXT that is coupled into a data carrying channel will be from the three adjacent disturbing duplex channels.


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To ensure the total NEXT coupled into a duplex channel is limited, multiple disturber NEXT loss is specified as the power sum of the individual NEXT losses. The Power Sum loss between a duplex channel and the three adjacent disturbers shall be greater than

$$-20 \times \log 10\left(10^{\frac{72.3 - 15\log 10(f)}{-20}} + 2 \times 10^{\frac{90 - 20\log 10(f)}{-20}}\right) \qquad \text{(dB)}$$

where f is the frequency $1 \le f < 330$ in MHz and

$$28 - 42 \times \log 10\left(\frac{f}{330}\right) \qquad \text{(dB)}$$

where f is the frequency $(330 \le f \le 500)$ in MHz.

**55.7.2.4.3 Multiple-Disturber Power Sum Near-End Crosstalk (PS NEXT) loss**

PS NEXT loss is determined by summing the power of the three individual pair-to-pair differential NEXT loss values over the frequency range 1 MHz to 500 MHz. as follows:

$$-10 \times \log 10 \sum_{i=1}^{n} 10^{\frac{-NL(f)i}{10}} \qquad \text{(dB)}$$

where

| | |
|---|---|
| NL(f)i | is the magnitude in dB of NEXT loss at frequency f of pair combination i |
| i | is the 1, 2, or 3 (pair-to-pair combination) |
| n | is the number of pair-to-pair combinations |

**55.7.2.4.4 Equal Level Far-End Crosstalk (ELFEXT) loss**

Equal Level Far-End Crosstalk (ELFEXT) loss is specified in order to limit the crosstalk at the far end of each link segment duplex channel and meet the BER objective specified in 55.1.1. Far-End Crosstalk (FEXT) is crosstalk that appears at the far end of a duplex channel (disturbed channel), which is coupled from another duplex channel (disturbing channel) with the noise source (transmitters) at the near end.

Editor's Note: For 1000BASE-T the error rate is specified as symbol error rate, frame error rate and bit error rate. For 10GBASE-T D1.0, as a starting point, the BER objective of 10^-12 specified in 55.1 will be utilized throughout subclause 55.7.

FEXT loss is defined as

$$\text{FEXT\_Loss(f)} = 20 \times \log 10\left(\frac{V_{pds(f)}}{V_{pcn(f)}}\right) \qquad \text{(dB)}$$

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and ELFEXT_Loss is defined as

$$\text{ELFEXT\_Loss(f)} = 20 \times \log 10\left(\frac{V_{pds(f)}}{V_{pcn(f)}}\right) - \text{SLS\_Loss(f)} \qquad (dB)$$

where

*V*pds is the peak voltage of disturbing signal (near-end transmitter)
*V*pcn is the peak crosstalk noise at far end of disturbed channel
SLS_Loss is the insertion loss of disturbed channel in dB

The worst pair ELFEXT loss between any two duplex channels shall be greater than

$$-20 \times \log 10\left(10^{\frac{67.8 - 20\log 10(f)}{-20}} + 4 \times 10^{\frac{83.1 - 20\log 10(f)}{-20}}\right) \qquad \text{(dB)}$$

where *f* is the frequency over the range of 1 MHz to 500 MHz.

**55.7.2.4.5 Multiple Disturber Equal Level Far-End Crosstalk (MDELFEXT) loss**

Since four duplex channels are used to transfer data between PMDs, the FEXT that is coupled into a data carrying channel will be from the three adjacent disturbing duplex channels. To ensure the total FEXT coupled into a duplex channel is limited, multiple disturber ELFEXT loss is specified as the power sum of the individual ELFEXT losses. The Power Sum loss between a duplex channel and the three adjacent disturbers shall be greater than

$$-20 \times \log 10\left(10^{\frac{64.8 - 20\log 10(f)}{-20}} + 4 \times 10^{\frac{80.1 - 20\log 10(f)}{-20}}\right) \qquad \text{(dB)}$$

where *f* is the frequency over the range of 1 MHz to 500 MHz.

**55.7.2.4.6 Multiple-Disturber Power Sum Equal Level Far-End Crosstalk (PS ELFEXT) loss**

PS ELFEXT loss is determined by summing the power of the three individual pair-to-pair differential ELFEXT loss values over the frequency range 1 MHz to 500 MHz as follows:

$$\text{PSELFEXT\_Loss(f)} = -10 \times \log 10 \sum_{i=1}^{i=n} 10^{\frac{-EL(f)i}{10}}$$

where

EL(*f*)i is the magnitude of ELFEXT loss at frequency *f* of pair combination i
i is the 1, 2, or 3 (pair-to-pair combination)
n is the number of pair-to-pair combinations


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#### 55.7.2.5 Coupling parameters between link segments

Noise coupled between the disturbed duplex channel in a link segment and the disturbing duplex channels in other link segments is referred to as alien crosstalk noise.

Editor's Note: Text needs to be added to clearly identify the alien crosstalk dependencies.

##### 55.7.2.5.1 Multiple Disturber Alien Near-End Crosstalk (MDANEXT) loss

In order to limit the alien crosstalk at the near end of a link segment, the differential pair-to-pair Near-End Crosstalk (NEXT) loss between the disturbed duplex channel in a link segment and the disturbing duplex channels in other link segments is specified to meet the bit error rate objective specified in 55.1. To ensure the total Alien NEXT coupled into a duplex channel is limited, multiple disturber Alien NEXT loss is specified as the power sum of the individual Alien NEXT disturbers.

##### 55.7.2.5.2 PS ANEXT Adjustment

The adjusted PS ANEXT loss requirement is determined by first calculating the PS ANEXT_constant and utilizing the constant in the PS ANEXT limit line model.

The PS ANEXT_constant is defined by the following equation:

$$\text{PSANEXT\_constant} = 62 - (\text{CE\_IL\_250}MHz - \text{SCE\_IL\_250}MHz) \times \frac{15}{15.6} \qquad \text{(dB)}$$

where

CE_IL_250 MHz is the Class E insertion loss at 250 MHz
SCE_IL_250 MHz is the scaled Class E insertion loss at 250 MHz.

##### 55.7.2.5.3 Multiple-Disturber Power Sum Near-End Crosstalk (PS ANEXT) loss

ANEXT loss is determined by summing the power of the individual pair-to-pair differential Alien NEXT loss values over the frequency range 1 MHz to 500 MHz. as follows:

$$-10 \times \log 10 \sum_{i=1}^{n} 10^{\frac{-AN(f)i}{10}} \qquad \text{(dB)}$$

where

| | |
|---|---|
| AN(f)i | is the magnitude in dB of ANEXT loss at frequency f of pair combination i |
| i | is the pair-to-pair combination (1 to n) |
| n | is the number of pair-to-pair combinations between link segments |

The Power Sum ANEXT loss between a disturbed duplex channel in a link segment and the disturbing duplex channels in other link segments shall be greater than:

$$PSANEXT \geq \begin{cases} PSANEXTconstant - 10\log 10(\frac{f}{100}) \ \ (dB) & 1 \leq f \leq 100 \\ PSANEXTconstant - 15\log 10(\frac{f}{100}) \ \ (dB) & 100 < f \leq 500 \end{cases}$$

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where f is the frequency in MHz.

Editors Note: Alien crosstalk is not adequately specified in the ISO/IEC 11801 or TIA cabling standards. The PS ANEXT limits for Class E are the minimum requirements for 100 meter operation and are not intended to represent the PS ANEXT performance limits of the cabling (i.e., the PS ANEXT performance of the cabling may be better than the minimum requirements specified in 10GBASE-T).

**55.7.2.5.4 Multiple Disturber Alien Far-End Crosstalk (MDAFEXT) loss (ffs)**

**55.7.2.5.5 Multiple -Disturber Power Sum Alien Far-End Crosstalk (PS AFEXT) loss (ffs)**

**55.7.3 Class F link segment transmission parameters**

The Class F link segment transmission parameters are specified in ISO/IEC 11801 with the addition of link segment transmission parameters for alien crosstalk as specified in this subclause.

**55.7.3.1 Insertion Loss for a Class F link segment (informative)**

The Class F insertion loss specified here is provided as an informative reference to assist in the calculation of the PS ANEXT loss to insertion loss ratio requirements as specified in 55.7.5.

The insertion loss of a Class F duplex channel is less than

$$1.05\left(1.8\times\sqrt{f}+0.01\times f+\frac{0.2}{\sqrt{f}}\right)+4\times 0.02\times\sqrt{f} \qquad \text{(dB)}$$

at all frequencies from 1 MHz to 500 MHz. This includes the attenuation of the balanced cabling pairs, including the cords and connecting hardware losses within each duplex channel. The insertion loss specification is met when the duplex channel is terminated in 100 Ω.

NOTE— The Class F insertion loss is an improvement of 2.1 dB at 250 MHz over the Class E insertion loss specifications resulting in a 2 dB relaxation in the Class F PS ANEXT requirement.

**55.7.3.2 Coupling parameters between link segments**

Noise coupled between the disturbed duplex channel in a link segment and the disturbing duplex channels in other link segments is referred to as alien crosstalk noise.

Editor's Note: Text needs to be added to clearly identify the alien crosstalk dependencies.

**55.7.3.2.1 PS ANEXT**

For a 100 meter Class F channel the PS ANEXT loss between a disturbed duplex channel in a link segment and the disturbing duplex channels in other link segments shall be greater than

$$PSANEXT \geq \left\{ \begin{array}{ll} 60-10\log 10(\frac{f}{100}) \quad (dB) & 1 \leq f \leq 100 \\ 60-15\log 10(\frac{f}{100}) \quad (dB) & 100 < f \leq 500 \end{array} \right\}$$

where f is the frequency in MHz.


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The PS ANEXT for a Class F channel specified in 55.7.3.2.1.3 assumes the maximum insertion loss of a Class F channel in 55.7.3.3.1

Note: The PS ANEXT values listed above are are for certification of the channel. For simulating PHY performance to estimate system margin, the PS ANEXT numbers must be increased by 2.5 dB. This represents the difference between the limit line, which is used for channel certification, and the average value of PS ANEXT which will be lower than the limit line.

Editors Note: Alien crosstalk is not adequately specified in the ISO/IEC 11801 or TIA cabling standards. The PS ANEXT limits for Class F are the minimum requirements for 100 meter operation and are not intended to represent the PS ANEXT performance limits of the cabling (i.e., the PS ANEXT performance of the cabling may be better than the minimum requirements specified in 10GBASE-T).

**55.7.3.2.2 Multiple Disturber Alien Far-End Crosstalk (MDAFEXT) loss (ffs)**

**55.7.3.2.3 Multiple -Disturber Power Sum Alien Far-End Crosstalk (PS AFEXT) loss (ffs)**

**55.7.4 Augmented link segment transmission parameters (informative)**

TIA TR42 has initiated Project SP-3-4426-AD10 to develop a augmented Category 6 cabling. The resulting requirements will be presented in a new revision or addendum to the TIA-568-B standard.

The augmented link segment transmission parameters will be specified in this subclause. The augmented link segment transmission parameters meet or exceed the Class E link segment transmission parameters specified in 55.7.2 with the following exceptions: insertion loss and PS ANEXT.

**55.7.4.1 Insertion Loss**

The insertion loss of an augmented link segment is less than

$$1.05\left(1.8\times\sqrt{f}+0.01\times f+\frac{0.2}{\sqrt{f}}\right)+4\times 0.02\times\sqrt{f} \qquad \text{(dB)}$$

at all frequencies from 1 MHz to 500 MHz. This includes the attenuation of the balanced cabling pairs, including the cords and connecting hardware losses within each duplex channel. The insertion loss specification is met when the duplex channel is terminated in 100 Ω.

**55.7.4.2 Coupling parameters between link segments**

Noise coupled between the disturbed duplex channel in a link segment and the disturbing duplex channels in other link segments is referred to as alien crosstalk noise.

Editor's Note: Text needs to be added to clearly identify the alien crosstalk dependencies.

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**55.7.4.2.1 PS ANEXT**

For a 100 meter augmented link segment, the PS ANEXT loss between a disturbed duplex channel in a link segment and the disturbing duplex channels in other link segments is greater than

$$PSANEXT \geq \begin{cases} 60 - 10\log 10(\frac{f}{100}) \quad (dB) & 1 \leq f \leq 100 \\ 60 - 15\log 10(\frac{f}{100}) \quad (dB) & 100 < f \leq 500 \end{cases}$$

The PS ANEXT for an augmented link segment assumes the maximum insertion loss as specified in 55.7.4.1.

*Editor's note: PSAFEXT limits need to be added with reference to test methods.*

**55.7.4.2.2 Multiple Disturber Alien Far-End Crosstalk (MDAFEXT) loss (ffs)**

**55.7.4.2.3 Multiple -Disturber Power Sum Alien Far-End Crosstalk (PS AFEXT) loss (ffs)**

**55.7.5 PS ANEXT loss to insertion loss ratio requirements**

To ensure reliable operation, a minimum signal to noise ratio (SNR) must be maintained. The minimum SNR is assured for Class E by meeting the requirements in 55.7.2 and for Class F by meeting the requirements of 55.7.3. The PS ANEXT loss requirement can be relaxed based on a reduction in the maximum insertion loss. The insertion loss reduction can be achieved by scaling the length of a Class E link segment or by using a Class F or augmented link segment.

**55.7.6 Delay**

In order to simultaneously send data over four duplex channels in parallel, the propagation delay of each duplex channel as well as the difference in delay between any two of the four channels are specified. This ensures the 10 Gbps data that is divided across four channels can be properly reassembled at the far-end receiver.

**55.7.6.1 Maximum link delay**

The propagation delay of a link segment shall not exceed 570 ns at all frequencies between 2 MHz and 500 MHz.

**55.7.6.2 Link delay skew**

The difference in propagation delay, or skew, between all duplex channel pair combinations of a link segment, under all conditions, shall not exceed 50 ns at all frequencies from 2 MHz to 500 MHz. It is a further functional requirement that, once installed, the skew between any two of the four duplex channels due to environmental conditions shall not vary more than 10 ns within the above requirement.

**55.7.7 Noise environment**

Editor's Note: The noise environment (55.7.5) sub clause is extracted from 1000BASE-T specification with minor changes. This text will likely evolve to reflect the 10GBASE-T noise environment assumptions.

The 10GBASE-T noise environment consists of noise from many sources. The primary noise sources that impact the objective BER are NEXT and echo interference, which are reduced to a small residual noise


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using cancellers. The remaining noise sources, which are secondary sources, are discussed in the following list. The 10GBASE-T noise environment consists of the following:

a) Echo from the local transmitter on the same duplex channel (cable pair). Echo is caused by the hybrid function used to achieve simultaneous bi-directional transmission of data and by impedance mismatches in the link segment. It is impractical to achieve the objective BER without using echo cancellation. Since the symbols transmitted by the local disturbing transmitter are available to the cancellation processor, echo interference can be reduced to a small residual noise using echo cancellation methods.

b) Near-End Crosstalk (NEXT) interference from the local transmitters on the duplex channels (cable pairs) of the link segment. Each receiver will experience NEXT interference from three adjacent transmitters. NEXT cancellers are used to reduce the interference from each of the three disturbing transmitters to a small residual noise. NEXT cancellation is possible since the symbols transmitted by the three disturbing local transmitters are available to the cancellation processor.

c) Far-End Crosstalk (FEXT) noise at a receiver is from three disturbing transmitters at the far end of the duplex channel (cable pairs) of the link segment. FEXT noise can be cancelled in the same way as echo and NEXT interference although the symbols from the remote transmitters are not immediately available.

d) Inter-Symbol Interference (ISI) noise. ISI is the extraneous energy from one signaling symbol that interferes with the reception of another symbol on the same channel.

e) Noise from non-idealities in the duplex channel, transmitters, and receivers; for example, DAC/ADC non-linearity, electrical noise (shot and thermal), and non-linear channel characteristics.

f) Noise coupled between link segments. Noise coupled between the disturbed duplex channel in a link segment and the disturbing duplex channels in other link segments is referred to as alien crosstalk noise.Since the transmitted symbols from the alien NEXT noise source are not available to the cancellation processor (they are in another cable), it is very difficult to cancel the alien NEXT noise. To ensure robust operation the alien NEXT noise must meet the specification of 55.7.5.

g) The background noise for 10GBASE-T is expected not to exceed -150 dBm/Hz.. A background noise limit of -150 dBm/Hz was assumed in the 10GBASE-T Matlab simulation models.

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