55.X 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 55.X.. 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 compatible at the MDI.

55.X.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.X.

Editors Note: Liaison letters to ISO/IECISO/IEC JTC 1/SC 25 WG3 and TIA TR42 have been issued from the March 2004 Interim providing information on the additional transmission requirements specified in 55.x,

55.X.2 Link 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 and a Class F link segment of at least 100 meters will provide a reliable medium. The transmission parameters of the link segment include insertion loss, delay parameters, characteristic impedance, NEXT loss, ELFEXT loss, and return loss.

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

Editors Note: The use of Class E extrapolated to an upper frequency of 625 MHz has been identified as a starting point for the link segment specifications. IEEE 802.3 has requested feedback and guidance on the parameters that have been selected form both ISO/IECISO/IEC JTC 1/SC 25 WG3 and TIA TR42.
The Class F channel limits exceed the performance requirements of Class E therefore Class F specifications are referenced only when applicable to requirements specific to Class F such as Class F power sum alien NEXT (PS ANEXT) (55.X.3.2.1.3) and Class F Insertion Loss (55.X.3.2.1.3.1).

The link segment transmission parameters of insertion loss, NEXT loss, ELFEXT loss, and return loss specified in 55.X are ISO/IEC 11801 Class E specifications extended by extrapolating the formulas to a frequency up to (TBD ≤ 625) MHz In addition, link segment requirements are specified in subclause 55.x.4 for alien crosstalk.

55.X.2.1 Insertion loss

The insertion loss of each duplex channel shall be less than

$$1.05\left(1.82\times\sqrt{f}+0.0169\times f+\frac{0.25}{\sqrt{f}}\right)+4\times 0.02\times\sqrt{f} \quad \text{(dB)}$$

at all frequencies from 1 MHz to (TBD ≤ 625) 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.X.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 (TBD ≤ 625) MHz.

Editors Note: The 1000BASE-T specification for Differential characteristic impedance (provided above) is not a requirement (i.e., it is not tied to a shall). ISO/IEC 11801 © ISO/IEC: 2002(E) includes reference to the nominal impedance of a channel in 6.4.1 General …..The nominal impedance of channels is 100 Ω. This is achieved by suitable design and appropriate choice of cabling components (irrespective of their nominal impedance).

55.X.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 (TBD ≤ 625) MHz. The reference impedance shall be 100 Ω.

$$\text{Return\_Loss}(f) \begin{cases} 19.0 & 1 \le f < 10 \\ 24 - 5\log10(f) & 10 \le f < 40 \\ 32 - 10\log10(f) & 40 \le f \le (TBD \le 625) \end{cases}$$

where

f is the frequency in MHz.

55.X.3 Coupling parameters

55.X.3.1 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 NEXT (MDNEXT) and multiple disturber ELFEXT (MDELFEXT) loss is specified.

Editors Note: Separate requirements for MDNEXT were not specified for 1000BASE-T because the worst case channel-to-channel NEXT disturber model was utilized for all three channel-to-channel disturbers in the MatLab simulations. 1000BASE-T MDELFEXT requirements were specified because three channel-to-channel disturbers—one with a ELFEXT loss of at least 17 – 20log10(f/100) dB, one with a ELFEXT loss of at least 19.5 – 20log10(f/100) dB, and one with a ELFEXT loss of at least 23 – 20log10(f/100) were utilized in the Matlab simulations. To ensure the total FEXT coupled into a duplex channel is limited, multiple disturber ELFEXT loss was specified consistent with the power sum of the individual ELFEXT losses.

55.X.3.1.1 Near-End Crosstalk (NEXT)

55.X.3.1.1.1 Differential Near-End Crosstalk

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

$$-20 \times \log10\left(10^{\frac{74.3-15\log10(f)}{-20}} + 2 \times 10^{\frac{94-20\log10(f)}{-20}}\right) \text{ (dB)}$$

where f is the frequency over the range of 1 MHz to (TBD ≤ 625) MHz.

55.X.3.1.1.2 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.

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

$$-20 \times \log10\left(10^{\frac{72.3-15\log10(f)}{-20}} + 2 \times 10^{\frac{90-20\log10(f)}{-20}}\right) \text{ (dB)}$$

where f is the frequency over the range of 1 MHz to (TBD ≤ 625) MHz.

55.X.3.1.1.3 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 (TBD ≤ 625) MHz. as follows:

$$-10 \times \log10 \sum_{i=1}^{n} 10^{\frac{-NL(f)\,i}{10}} \text{ (dB)}$$

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.X.3.1.2 Far-End Crosstalk (FEXT)

55.X.3.1.2.1 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. 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.

Editors 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.X.

FEXT loss is defined as

$$\mathrm{FEXT\_Loss}(f) = 20 \times \log 10 \times \left(\frac{\mathrm{Vpds}(f)}{\mathrm{Vpcn}(f)} \right) \quad \text{(dB)}$$

and ELFEXT_Loss is defined as

$$\mathrm{ELFEXT\_Loss}(f) = 20 \times \log 10 \times \left(\frac{\mathrm{Vpds}(f)}{\mathrm{Vpcn}(f)} \right) - \mathrm{SLS\_Loss}(f) \quad \text{(dB)}$$

where

Vpds is the peak voltage of disturbing signal (near-end transmitter)

Vpcn is the peak crosstalk noise at far end of disturbed channel

SLS_Loss is the insertion loss of disturbed channel in dB

Editors Note: Peak voltage reference is carried forward from 1000BASE-T. Need to consider applicability for 10GBASE-T.

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

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

where f is the frequency over the range of 1 MHz to (TBD ≤ 625) MHz.

55.X.3.1.2.2 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

$$-20\times\log10\left(10^{\frac{64.8-20\log10(f)}{-20}}+4\times10^{\frac{80.1-20\log10(f)}{-20}}\right)\ \text{(dB)}$$

where f is the frequency over the range of 1 MHz to (TBD ≤ 625) MHz.

55.X.3.1.2.3 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 (TBD ≤ 625) MHz. as follows:

$$-10\times\log10\sum_{i=1}^{n}10^{\frac{-EL(f)\,i}{10}}\ \text{(dB)}$$

where

EL(f)i is the magnitude in dB of the 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

55.X.3.2 Coupling parameters between adjacent cables

Noise from signals in adjacent cables is referred to as alien crosstalk noise and can be present when cables are bound together or placed in conduit.

Editors Note: Text needs to be added to clearly identify the alien crosstalk dependencies.

55.X.3.2.1 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 and the disturbing duplex channels in adjacent cables 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.X.3.2.1.1 Multiple-Disturber Power Sum Near-End Crosstalk (PS ANEXT) loss

PS 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 (TBD ≤ 625) MHz. as follows:

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

where

AN(f)i is the magnitude in dB of PS 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 adjacent cables

The Power Sum ANEXT loss between a disturbed duplex channel and the disturbing duplex channels in adjacent cables is defined by the equations:

$$\text{PS ANEXT} > \begin{cases} X1 - 10 \cdot \log 10(f_{MHz}/100) & 1 \text{ MHz} \le f \le 100 \text{ MHz} \\ X1 - 15 \cdot \log 10(f_{MHz}/100) & 100 \text{ MHz} < f \le (\text{TBD} \le 625) \text{ MHz} \end{cases}$$

where

X1 = the intercept at f=100MHz. The intercept is referred to as the PS ANEXT constant

55.X.3.2.1.2 PS ANEXT for a Class E Channel

For a 100 meter Class E channel with the maximum insertion loss of 55.X.2.1 the PS ANEXT loss between the disturbed duplex channel and the disturbing duplex channels in adjacent cables shall be greater than

$$\text{PS ANEXT} > \begin{cases} 62 - 10 \cdot \log 10(f_{MHz}/100) & 1 \text{ MHz} \le f \le 100 \text{ MHz} \\ 62 - 15 \cdot \log 10(f_{MHz}/100) & 100 \text{ MHz} < f \le (\text{TBD} \le 625) \text{ MHz} \end{cases}$$

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

55.X.3.2.1.3 PS ANEXT for a Class F Channel

For a 100 meter Class F channel the PS ANEXT loss between the disturbed duplex channel and the disturbing duplex channels in adjacent cables shall be greater than

$$\text{PS ANEXT} > \begin{cases} 60 - 10\log_{10}(f_{MHz}/100) & 1\ \text{MHz} \le f \le 100\ \text{MHz} \\ 60 - 15\log_{10}(f_{MHz}/100) & 100\ \text{MHz} < f \le (\text{TBD} \le 625)\ \text{MHz} \end{cases}$$

The PS ANEXT for a Class F channel specified in 55.X.3.1.3 assumes the maximum insertion loss of a Class F channel in 55.X.3.2.1.3.1.

Editors Note: Alien crosstalk is not adequately specified in the ISO/IEC 11801 or TIA cabling standards. The PS ANEXT limits for both Class F and 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). TIA TR42 has initiated Project SP-3-4426-AD10 to develop augmented Category 6 cabling. The resulting requirements will be presented in a new revision or addendum to the TIA-568-B standard.

55.X.3.2.1.3.1 Insertion Loss for a Class F Channel

The PS ANEXT for a Class F Channel assumes the maximum insertion loss of a Class F channel.

The insertion loss of a Class F duplex channel shall be less than

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

at all frequencies from 1 MHz to (TBD ≤ 625) 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.

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.X.3.2.2 Multiple Disturber Alien Far-End Crosstalk (MDAFEXT) loss (ffs)

55.X.3.2.2.1 Multiple-Disturber Power Sum Far-End Crosstalk (PS AFEXT) loss (ffs)

55.X.3.3 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 100 meters of Class E or 100 meters of Class F by meeting the requirements of 55.X.1 through 55.X.3.1.2.3.

The PS ANEXT loss requirement of 55.X.4.2 can be relaxed based on a reduction in the maximum insertion loss specified in 55.X.2.1. The insertion loss reduction can be achieved by scaling the length of the Class E link segment or using Class F cabling for the link segment as specified in 55.X.3.2.1.3.

55.X.3.3.1 Insertion Loss Scaling

For the purpose of adjusting the PS ANEXT the insertion loss is assumed to scale linearly with length.

The Scaled Class E IL is defined by the following equation:

$$\text{Scaled Class E IL} = \frac{\text{Length\_m}}{100\text{m}} \times 1.05\left(1.82 \times \sqrt{f} + 0.0169 \times f + \frac{0.25}{\sqrt{f}}\right) + 4 \times 0.02 \times \sqrt{f} \quad \text{(dB)}$$

55.X.3.3.2 Insertion Loss of a Category 6 channel of 55 meters

ISO/IEC 11801 classes for balanced cabling refer to cabling channel distances of 100 meters. For cabling channels less than 100 meters the Category of the components comprising the channel applies (e.g., Category 6 components provide Class E balanced cabling performance).

The insertion loss of a Category 6 channel of 55 meters is defined by the following equation:

$$\text{Scaled Class E IL(55 m)} = \frac{55}{100} \times 1.05\left(1.82 \times \sqrt{f} + 0.0169 \times f + \frac{0.25}{\sqrt{f}}\right) + 4 \times 0.02 \times \sqrt{f} \quad \text{(dB)}$$

55.X.3.4 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:

$$PSANEXT\_Constant = 62 - (CE\_IL\_250MHz - SCE\_IL\_250MHz) \times \frac{15}{15.6} \quad \text{(dB)}$$

where

CE_IL_250MHz is the Class E insertion Loss at 250 MHz
SCE_IL_250MHz is the scaled Class E insertion at 250 MHz

55. X.3.4.1 PS ANEXT for a Category 6 channel of 55 meters

For a Category 6 channel of 55 meters with worst case insertion loss of 55.X.4.5.1.1. the PS ANEXT loss between the duplex channel and duplex channels in adjacent cables shall be greater than

PS ANEXT > { 47 - 10*log10(fMHz/100) 1 MHz ≤ f ≤ 100 MHz }
{ 47 - 15*log10(fMHz/100) 100 MHz < f ≤ (TBD ≤ 625) MHz }

55.X.4 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 2500 Mbps data that is divided across four channels can be properly reassembled at the far-end receiver.

Editors Note: The 1000BASE-T specifications for delay extended to 625 MHz are specified in 55.X.4.1 and 55.X.4.2.

Editors Note: Need to revisit link segment delay as CSMA/CD is not required.

55.X.4.1 Maximum link delay

The propagation delay of a link segment shall not exceed 570 ns at all frequencies between 2 MHz and (TBD ≤ 625) MHz

55.X.4.2 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 (TBD ≤ 625) 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.X.5 Noise environment

Editors Note: The noise environment (55.X.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 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 n 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 may 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 from signals in adjacent cables. This noise is referred to as alien crosstalk noise and is generally present when cables are bound together or placed in conduit. 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.X.X.X.

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.