End to End Links

A new Ethernet channel definition to help Customers

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Abstract

As Ethernet expands so does the methods of measuring the cabling system performance. Industrial customers tend to install cables and then terminate in-place. The quality of the field termination is dependent on many factors including wire end preparation. The cables and connectors used in the channel may meet or exceed the component specifications, but if improperly terminated the link or channel may not. The cabling industry channel definitions and tests do not include the plugs (or connections) at the two ends of the channel. This means that, if the ends of the cables are improperly prepared the channel will pass but the performance may be less than satisfactory. The international standards committees for industrial have been working to define a new definition called End to End Links (E2E Links). These links not only include the connections between the two ends but also include the end connections. This paper will discuss these new links and how they will help your customers and field service personnel diagnose cable problems and verify cabling in the field.

Keywords

Physical Layers, Ethernet, IEC, ISO/IEC, TIA, E2E Links, MICE, Automation Island,

White Paper

Preface

The use of long cords is common practice in the design and deployment of industrial control networks. Long cords (greater than 10M) are outside the current “Generic Cabling” specifications. Further these cords are typically assembled and terminated in situ. Since this practice has been used for years, there is void in performance Verification and Certification testing. Currently, an owner/operator has no way to determine if the Link meets the necessary performance level to assure the cabling will support the intended applications. The E2E Link attempts to address the testing issues with Industrial Links and has been defined for the most common Link configurations.

Back Ground

Within the structured cabling systems exists 4 cabling subsystems, Campus, Building, Floor and Intermediate see Figure 1.

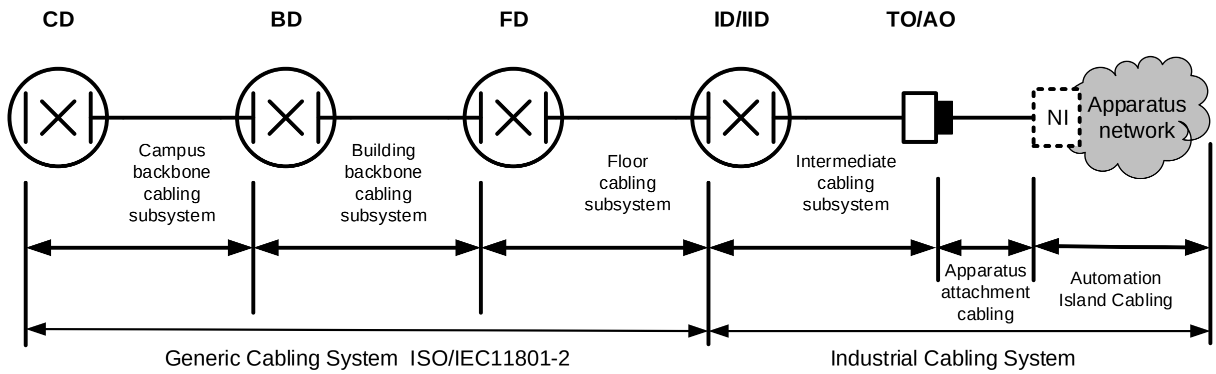


Figure 1 System and Subsystems

The subsystems are distributers (CD, BD, and FD and ID/IID) where cross connects are housed. The distributors can be located in Entrance Facilities, Equipment rooms, Telecommunications rooms/enclosures. The area of focus for this paper is the cabling extending from the Telecommunications room/enclosure where the ID/IID may be installed. This cabling consists of the last cross connect or Interconnect, horizontal cabling and the work-area components. Leading into the Apparatus network and within the Apparatus Network exists many cabling connections (Channels) between equipment interfaces see Figure 2.

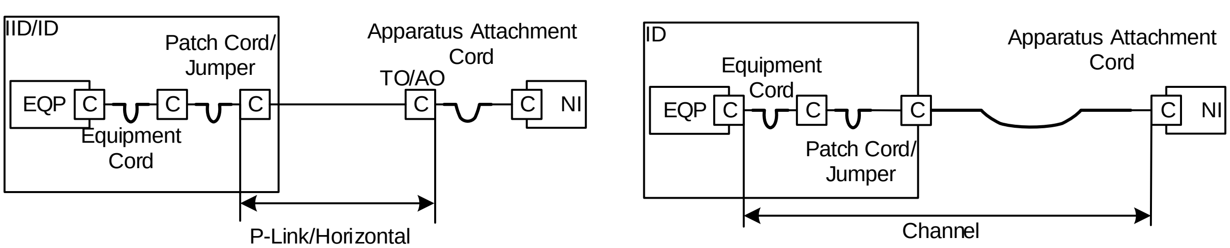


Figure 2 Example of Channel and P-Link

The horizontal cabling systems are also called Permanent links (P-Link) see Figure 2. These Permanent links include the horizontal cable between the patch panel and the work area outlet. The Permanent link and the work area cabling (work area cords) make up a Channel. Work area cords are sometimes mistermed as patch cords. Most industrial point to point links fall within the work area cord definitions. The standards limit the channel length to 100 Meters maximum. The length elements of the channel are parsed out as follows, Cords 10 Meters, Horizontal cabling 90 Meters, totaling 100 Meters. Each of the elements that make up the channel have individual test specifications that have been defined by the cabling standards bodies.

Long Cords

For Industrial installations long cords are commonly used for point to point connections without patch panels or cross connects. In this case the point to point connections are said to make up the channel from a test perspective. For example a Permanent link begins and ends with Jacks see Figure 3. A cord begins and ends in plugs, but are mostly limited to 10 meters max. The above figures show a typical Generic configuration of a connection between equipment and NI interfaces. These connections are greatly simplified using the long cords as shown in Figure 4.

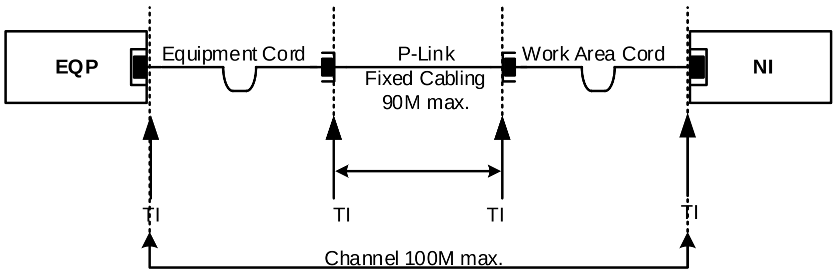


Figure 3 Test Demarcation points of a P-Link and Channel

Figure 4 Direct Link (Cord)

Testing

Testing of these sub elements of a channel are all inclusive with respect to the components that make them up. Remember that a channel is made up of all cords (equipment cords cross connect cords and work area cords) and the Permanent link. This is not true for a channel test. While physically both ends of a channel have plugs the channel test excludes the plugs at both ends, see Figure 3 above. The channel test, theoretically will not find transmission performance problems if they are presented at the end plugs. To solve this problem, E2E Links was created. The E2E Links define the Link to include the two end plugs. The process of redefining the channels to include the end plugs. The channel models had to be modified to include transmission models of the last two connections as shown in Figure 6 through Figure 13 below.

Bulkheads

It is common in Industrial installations to use Bulkhead connectors to enter and exit enclosures. The use of Bulkhead connectors present some modeling challenges in that their transmission performance is not tightly regulated by the cabling standards. The modeling has to take this into consideration. Schematically the bulkhead looks like that detailed in Figure 5 below. The three variants span from one physical connection with a cable to two physical connectors equaling 1 or two connections. As you can see, the three variants can electrically pose technical problems in the modeling of connections.

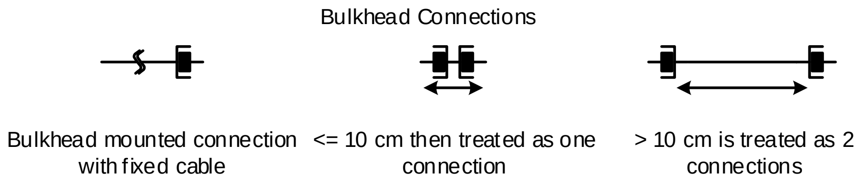


Figure 5 Examples of Bulkhead Connections

The generic standards define a channel to have a maximum of 4 connections. They do not count the end device connections since the plugs are not part of the channel definition. While the industrial standards do allow bulkheads that equal 2 connections, the channel definitions do not support exceeding the 4 connections allowed in the channel.

Since E2E links now include the two connections at the end of the link, we now speak of 6 connections (4 channel and 2 link ends). The reader will see this in the following E2E Link examples later in this paper.

Limit Lines

This paper will show the differences between the limit lines of a Channel and E2E Links. Further this paper will describe the field testing process for the E2E Links. There are 3 sets of primary measurements (Insertion Loss, Return Loss and NEXT) to describe the transmission performance of an E2E Link. In addition there are another 3 that are derivatives of the primary limits in the form of Power Sum measurements (PSACRF (Attenuation Cross Talk Ratio), PSACRF and PSNEXT. ACRF is similar to the FEXT (Far End Cross Talk) measurement.

Applications and Performance Levels

Applications supported by cabling are categorized by their bandwidth requirements requiring different performance levels. In the US the standards define cabling performance levels using "Category" designations (i.e.; Category 5, Category 5e, Category 6 …..). In the international community the cabling performance levels are defined as Classes, (i.e.; Class D, Class E, Class E_A….). Since the E2E Link is the responsibility of ISO/IEC, Classes are used to describe the performance levels for Channels, Permanent Links (P-Links) and E2E Links. As in the Channel and P-Link, the E2E Link limits are described by a set of equations as a function of frequency. The upper end of the frequency range is defined by the bandwidth requirements of the supported applications. The equations along with their graphs are provided in this paper for comparison purposes.

ODVA BW Requirements

While ODVA only supports up to 100Mb/s Ethernet, Category 5E/Class D channels supports to 1Gb/s. However the E2E Link definitions are extended to Category 6/Class E Links. There are good reasons to use Category 6/Class E links, as these class of cables have extended performance specifications to help reduce the effects of noise on the system. There are even better reasons to use cabling defined by ODVA and the industrial standards in ANSI/TIA as these are designed to support the applications while in high noise, common in Industrial environments. The modeling and limit line definitions for E2E links were modeled to support both Class D and Class E Links.

E2E Link Performance Limits

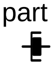
The critical cabling parameters are as listed below in Table 1.

Table 1 Critical Cabling Parameters

Parameter (Standard)		Comments
Insertion Loss	IL	Measured
Return Loss	RL	Measured
Impedance	Z	Measured
Near end Cross Talk	NEXT	Measured
Far End Cross Talk	FEXT (ACRF)	Measured
Power Sum NEXT	PS NEXT	Derived
Power Sum Far End Cross Talk	PSACRF	Derived
Delay	Delay	Measured
Delay Skew	Delay Skew	Derived
Parameter (Extended)		**Comments**
Transverse Conversion Loss	TCL	Measured
Equal Level Transverse Conversion Transfer Loss	ELTCTL	Measured
Coupling Attenuation	CA	Measured Lab only
DC Resistance	DCR	Measured important for POE
DC Resistance unbalance	DCR unbalance	Measured important for POE

Today's field testers have the ability to do all of the above tests with the exception of Coupling Attenuation.

E2E Link Examples

The following schematic diagrams detail the supported E2E Links. These links are supported by modeling cases and by new limits for testing. It should be noted that, while the generic standards only allow for 4 connections in a channel, E2E Links add the last two end connections, totaling 6 connections maximum. Physically there is no change in the allowed connections in a channel, but from a modeling and electrical definition perspective there is now 6 connections. The following schematic figures are progressively arranged in complexity. In addition the Test Interface (TI) markers now show that the connections are part of the definition, thus part of the measurements. In the schematics a connection is symbolized as: 

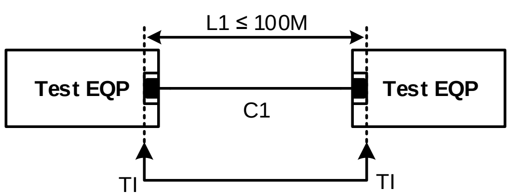


Figure 6, One Segment, 2 Connection E2E Link

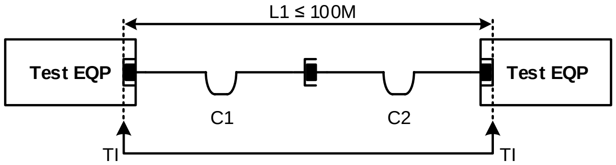


Figure 7, Two Segment, Three Connection E2E Link

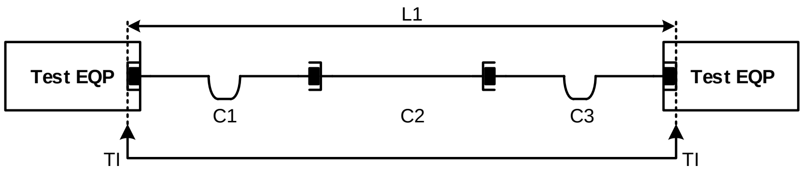


Figure 8, Three Segment, Four Connection E2E Link

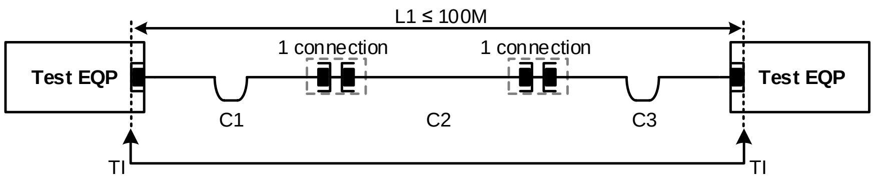


Figure 9, Three Segment, Four Connection E2E Link

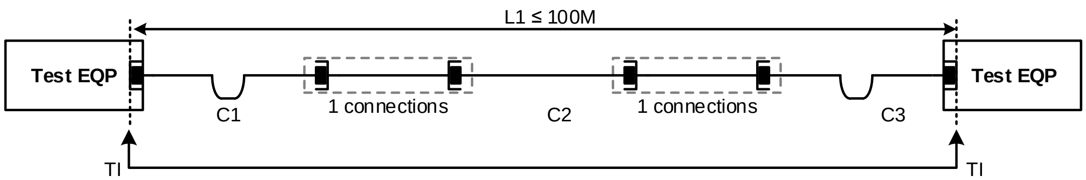


Figure 10, Three Segment, Four Connection E2E Link

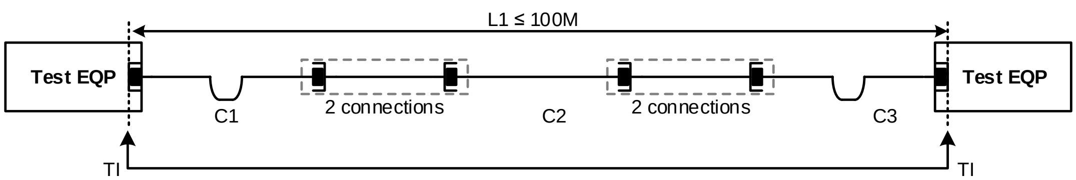


Figure 11, Three Segment, Six Connections E2E Link

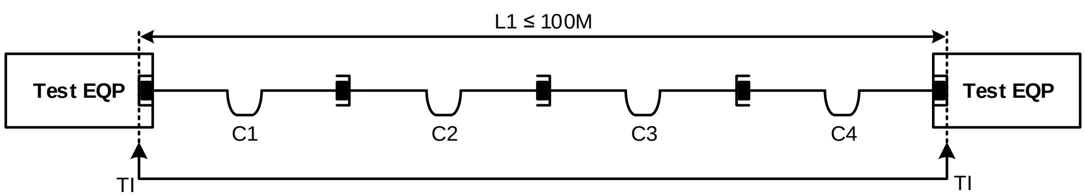


Figure 12, Four Segment, Five Connection E2E Link

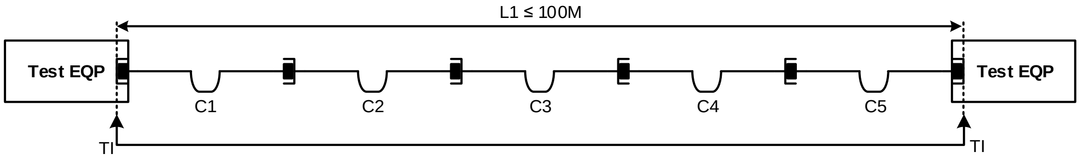


Figure 13, Five Segment, Six Connection, E2E Link

It should be noted that Figure 11 is equivalent to a full Generic cross connect channel. In addition while the schematics show cords as segments, the segments can be P-Links

E2E Link Equations and Test Limits

The addition of the two end plugs has an impact on the channel modelling that causes the limit lines to change accordingly. For each E2E link case there is a corresponding modeling case. In addition these cases are repeated for Class D and Class E E2E Links. Where possible the Channel graph limits are provided for comparison.

Insertion Loss

Equation 1 Class D E2E Link Insertion Loss

Class D E2E link insertion loss dB [n = number of connections 2-6]
$\left(\frac{L}{100}\right)\cdot\left(1{,}9108\cdot\sqrt{f}+0{,}0222\cdot f+\frac{0.2}{\sqrt{f}}\right)+\left(n\cdot 0{,}04\cdot\sqrt{f}\right)$
NOTE 1 To align with ISO/IEC 11801-1 permanent link requirements, the maximum length for 1- and 2-segment E2E links is 90 m NOTE 2 Calculated values less than 4 dB revert to 4 dB For connections numbers > 2 (L/100) is replaced with 1.05

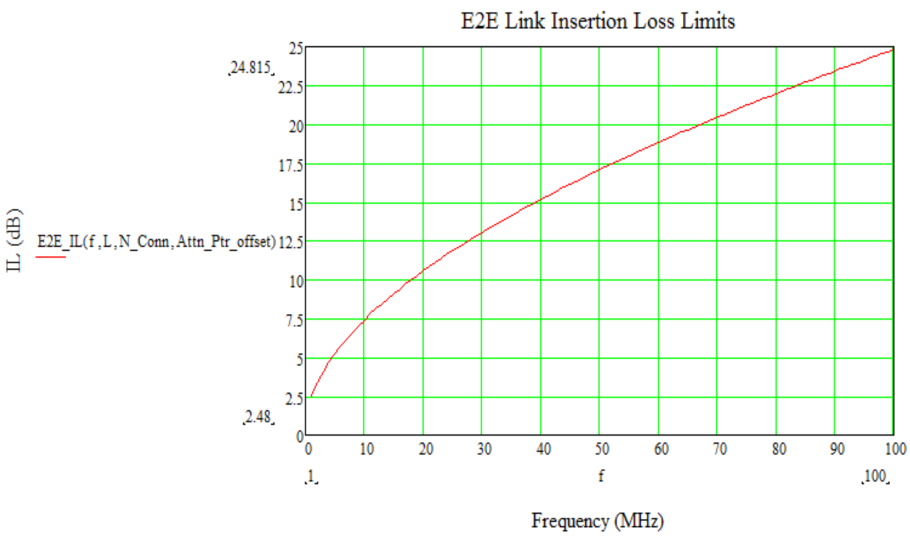


Figure 14 E2E Link Worst Case Class D Insertion Loss

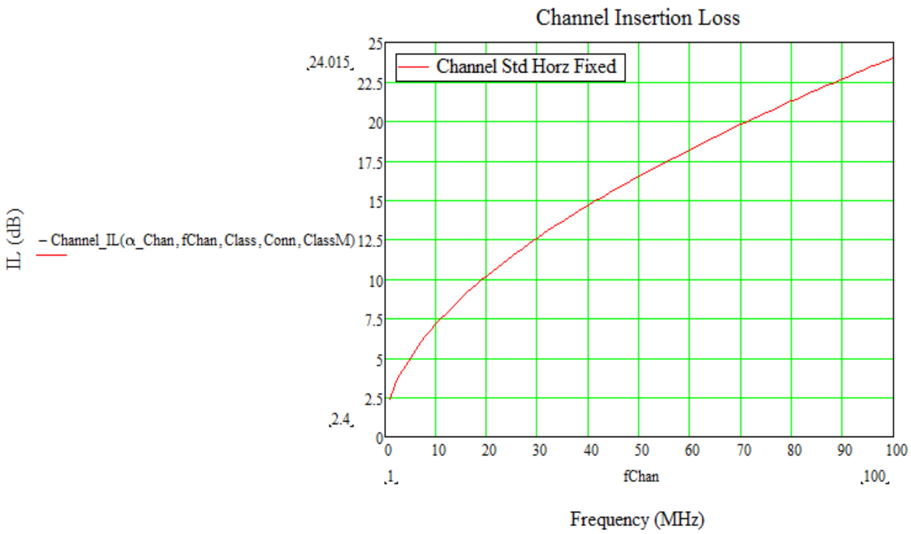


Figure 15 ISO Worst Case Class D Channel Insertion Loss

Equation 2 Class E E2E Link Insertion Loss

Class E E2E link insertion loss [n = number of connections 2-6] dB
$\left(\frac{L}{100}\right)\cdot\left(1{,}82\cdot\sqrt{f}+0{,}0169\cdot f+\frac{0.25}{\sqrt{f}}\right)+\left(2\cdot 0{,}02\cdot\sqrt{f}\right)$
NOTE 1 To align with ISO/IEC 11801-1 permanent link requirements, the maximum length for 1- and 2-segment E2E links is 90 m. NOTE 2 Calculated values less than 4 dB revert to 4 dB. For connections numbers > 2 (L/100) is replaced with 1.05

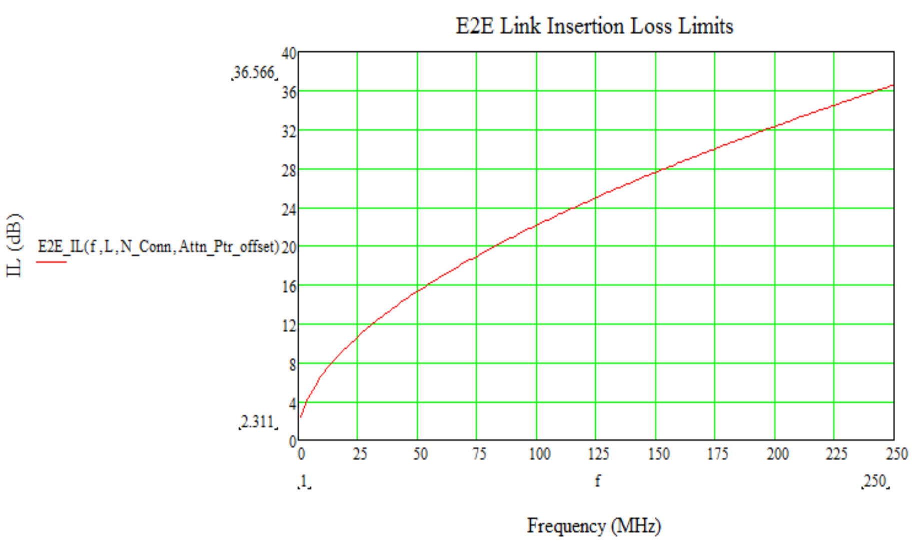


Figure 16 E2E Link Worst Case Class E Insertion Loss

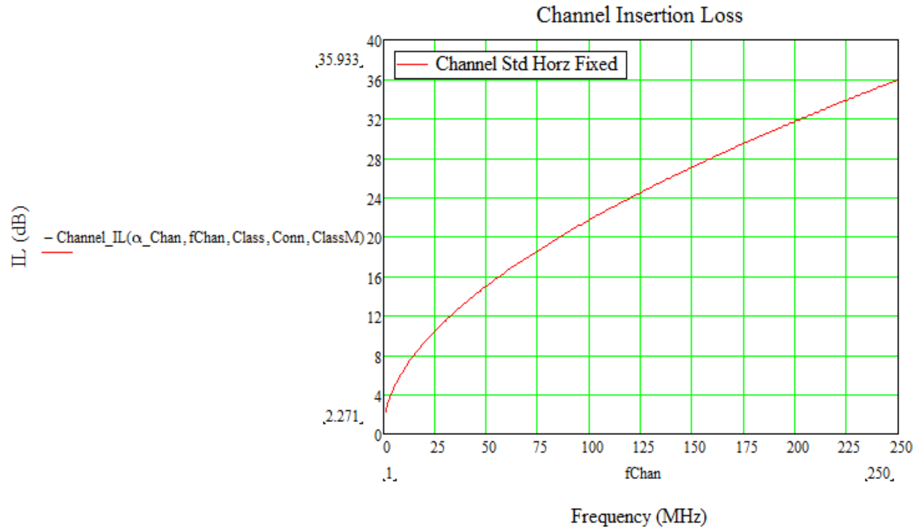


Figure 17 ISO Worst Case Class E Channel Insertion Loss

Return Loss

Equation 3 Class D Worst E2E Link Return Loss

Class D E2E link return loss 6 Connections dB	
$1 \le f \le 20$	$17 - \left(0{,}27 + \left(1{,}29 \cdot \left(\frac{f-1}{99}\right)\right)\right)$
$20 < f \le 100$	$30 - 10 \cdot \log(f) - \left(0{,}27 + \left(1{,}29 \cdot \left(\frac{f-1}{99}\right)\right)\right)$

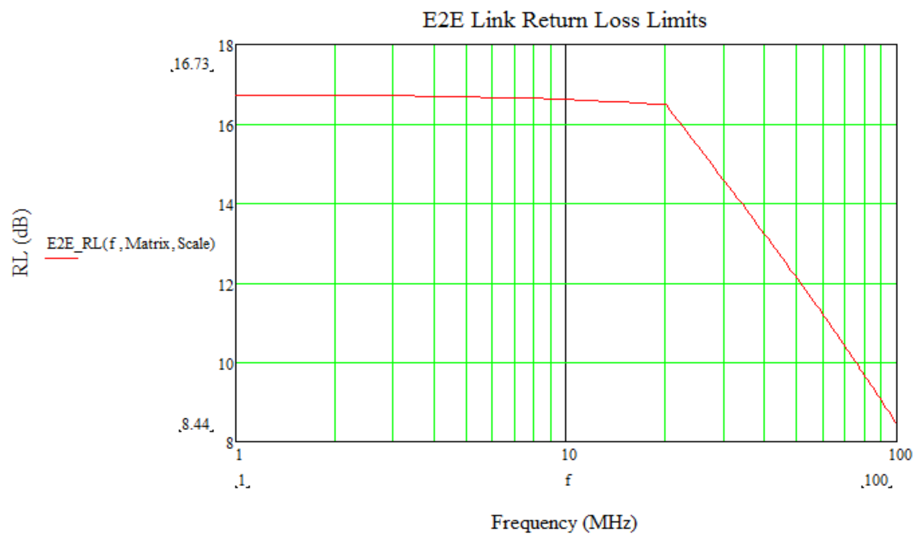


Figure 18 E2E Link Worst Case Class D Return Loss

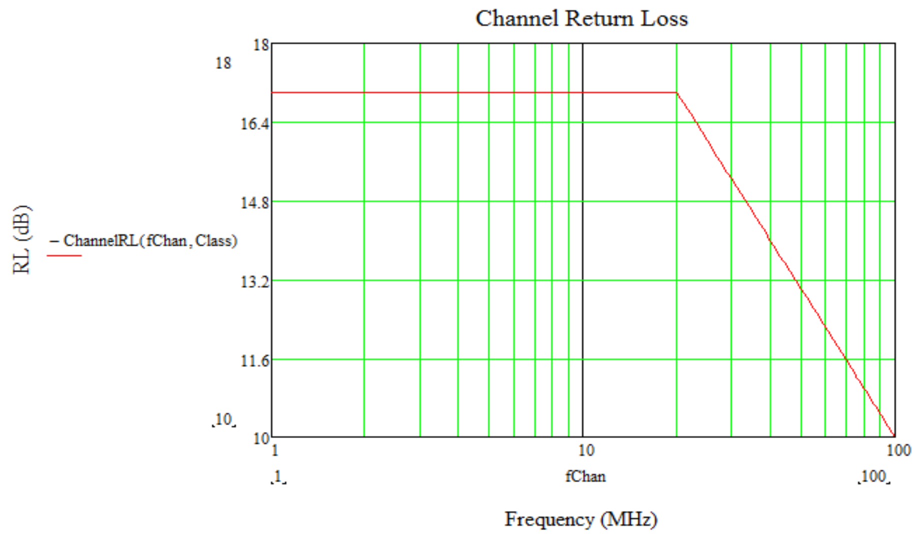


Figure 19 ISO Worst Case Class D Channel Return Loss

Equation 4 Class E Worst E2E Link Return Loss

Class E E2E link return loss 6 Connections dB	
$1 \leq f \leq 10$	$19 - \left(0{,}55 + \left(1{,}47 \cdot \left(\frac{f-1}{249}\right)\right)\right)$
$10 < f \leq 40$	$24 - 5 \cdot \log(f) - \left(0{,}55 + \left(1{,}47 \cdot \left(\frac{f-1}{249}\right)\right)\right)$
$40 < f \leq 250$	$32 - 10 \cdot \log(f) - \left(0{,}55 + \left(1{,}47 \cdot \left(\frac{f-1}{249}\right)\right)\right)$

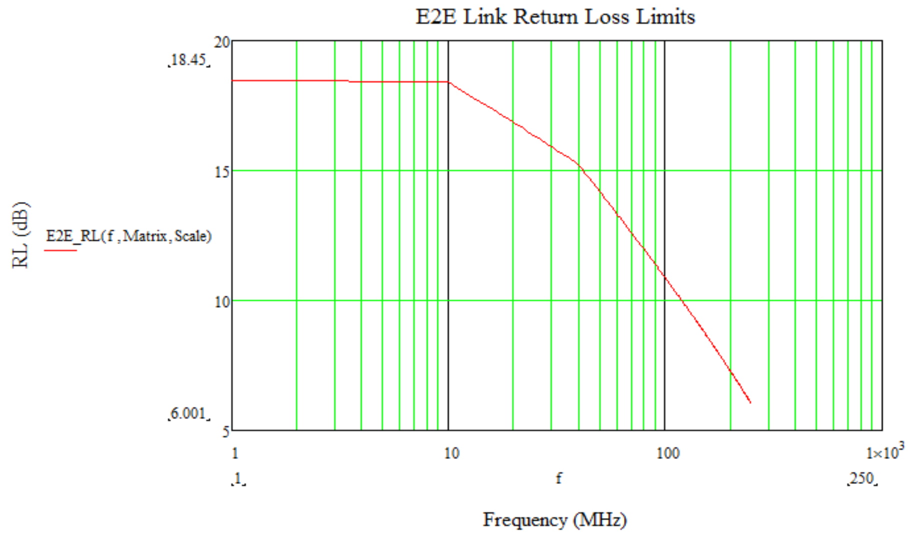


Figure 20 E2E Link Worst Case Class E Return Loss

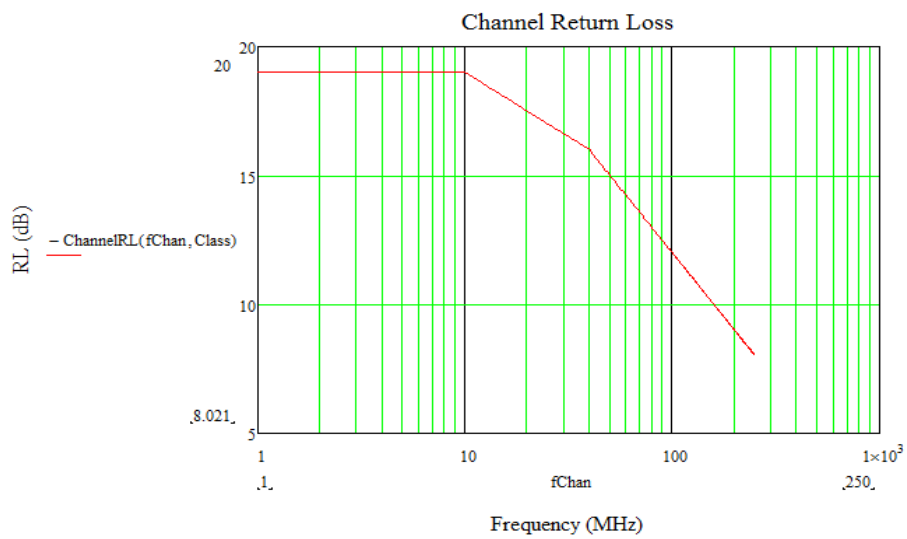


Figure 21 ISO Worst Case Class E Channel Return Loss

NEXT Limits

Equation 5 Class D Worst E2E Link Return Loss

Class D E2E link NEXT 6 Connections dB
$\left(-20 \cdot log\left(10^{\frac{65{,}3-15\cdot\log(f)}{-20}} + 2 \cdot 10^{\frac{83-20\cdot\log(f)}{-20}}\right)\right) - \left(1{,}26 \cdot \left(\frac{f-1}{99}\right)\right)$
NOTE Calculated values greater than 65 dB revert to 65 dB.

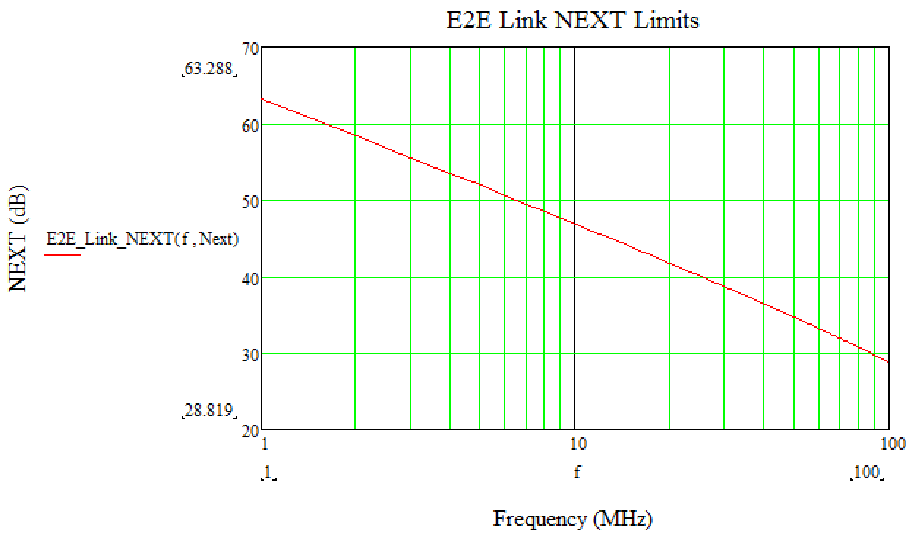


Figure 22 E2E Link Worst Case Class D NEXT Loss

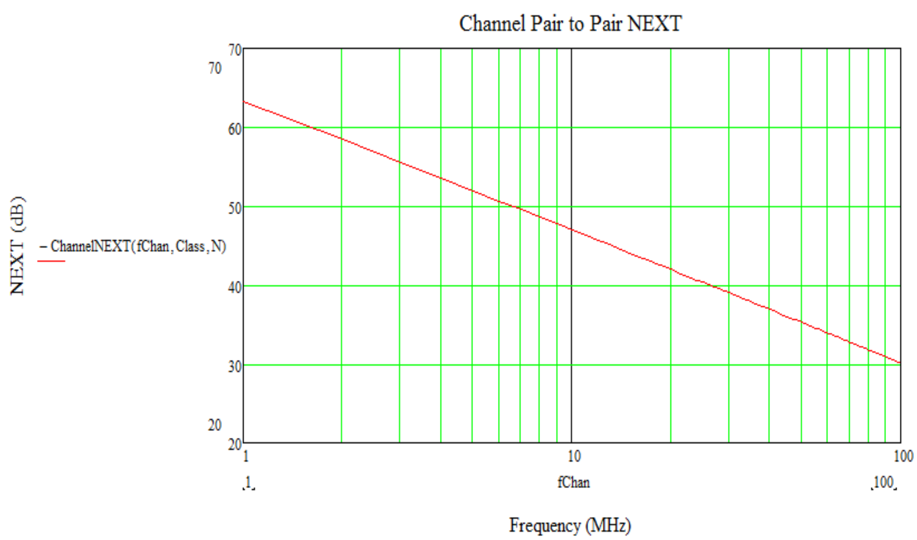


Figure 23 ISO Worst Case Class D Channel NEXT

Equation 6 Class E Worst E2E Link NEXT Loss

Class E E2E link NEXT 6 Connections dB
$$\left(-20 \cdot log\left(10^{\frac{74{,}3-15\cdot\log(f)}{-20}} + 2\cdot 10^{\frac{94-20\cdot\log(f)}{-20}}\right)\right) - \left(2{,}38\cdot\left(\frac{f-1}{249}\right)\right)$$
NOTE Calculated values greater than 65 dB revert to 65 dB.

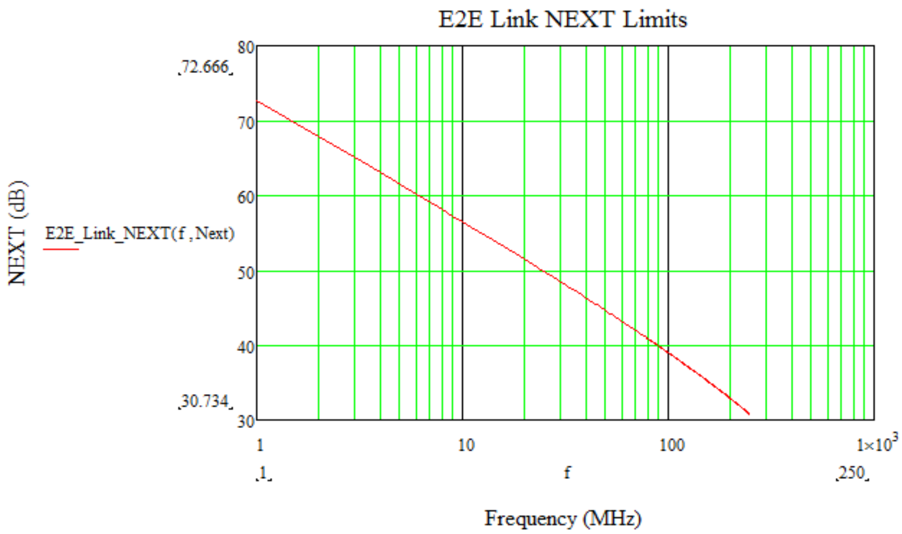


Figure 24 E2E Link Worst Case Class E NEXT Loss

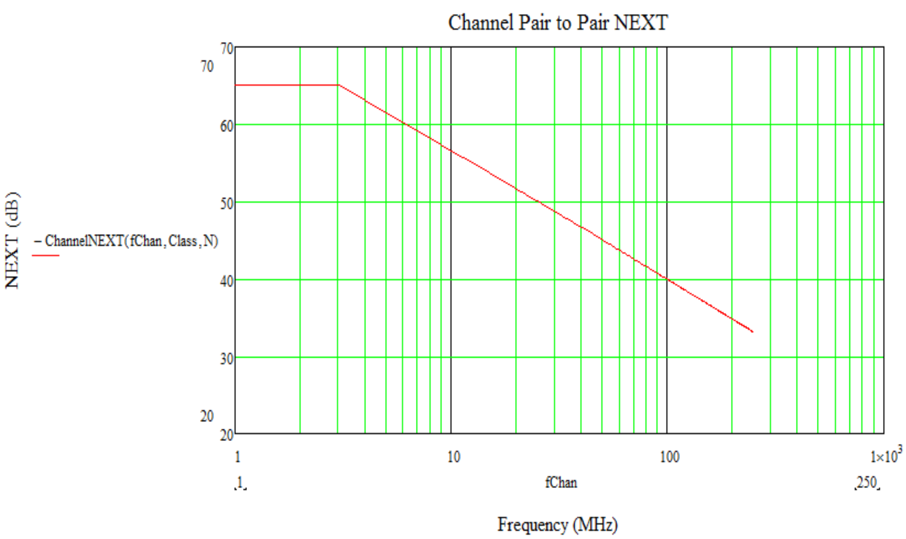


Figure 25 ISO Worst Case Class E Channel NEXT

PSNEXT

Equation 7 Class D Worst E2E Link PSNEXT Loss

Class D E2E link PSNEXT 6 Connections dB
$\left(-20 \cdot log\left(10^{\frac{62{,}3-15\cdot\log(f)}{-20}} + 2 \cdot 10^{\frac{80-20\cdot\log(f)}{-20}}\right)\right) - \left(1{,}26 \cdot \left(\frac{f-1}{99}\right)\right)$
In cases where measured insertion loss is less than 4 dB, the pass/fail limits for PSNEXT should not apply.

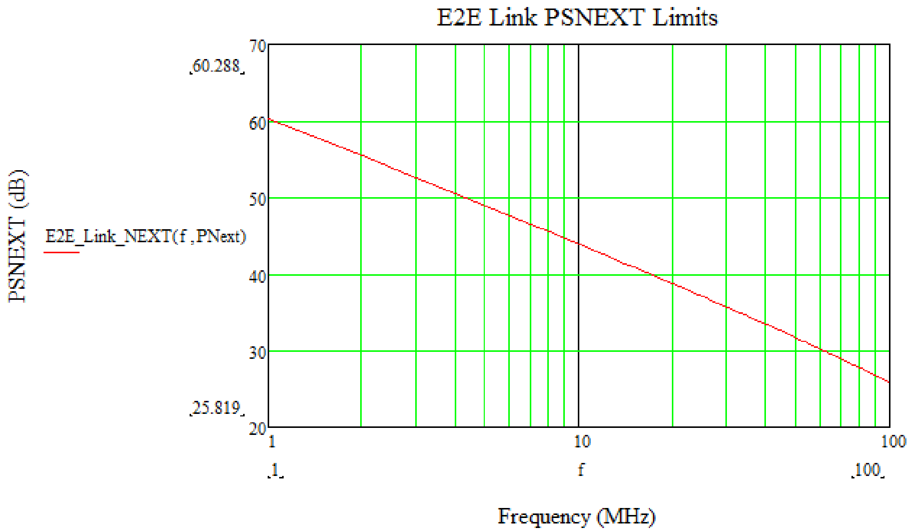


Figure 26 E2E Link Worst Case Class D PSNEXT Loss

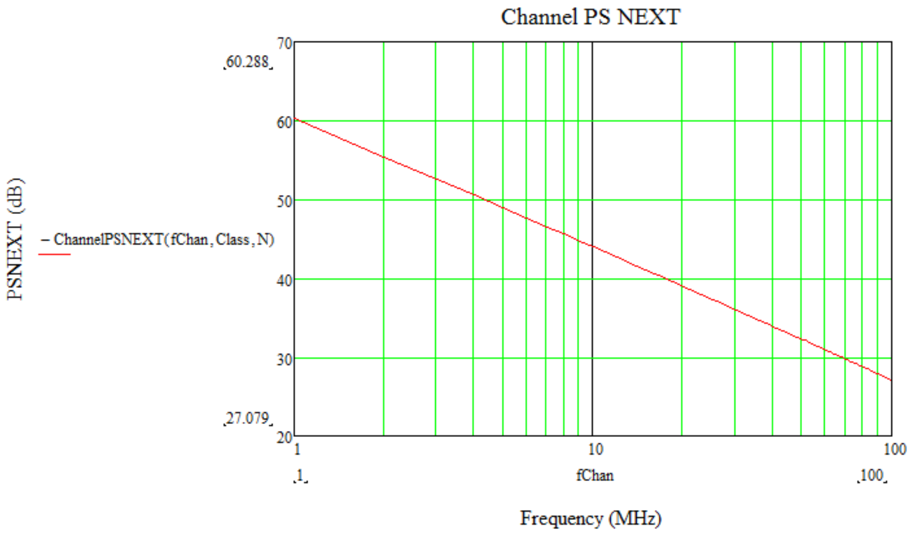


Figure 27 ISO Worst Case Class D Channel PSNEXT Loss

Equation 8 Class E Worst E2E Link PSNEXT Loss

Class E E2E link PSNEXT 6 Connections dB
$\left(-20 \cdot log\left(10^{\frac{72{,}3-15\cdot\log(f)}{-20}} + 2 \cdot 10^{\frac{90-20\cdot\log(f)}{-20}}\right)\right) - \left(2{,}38 \cdot \left(\frac{f-1}{249}\right)\right)$

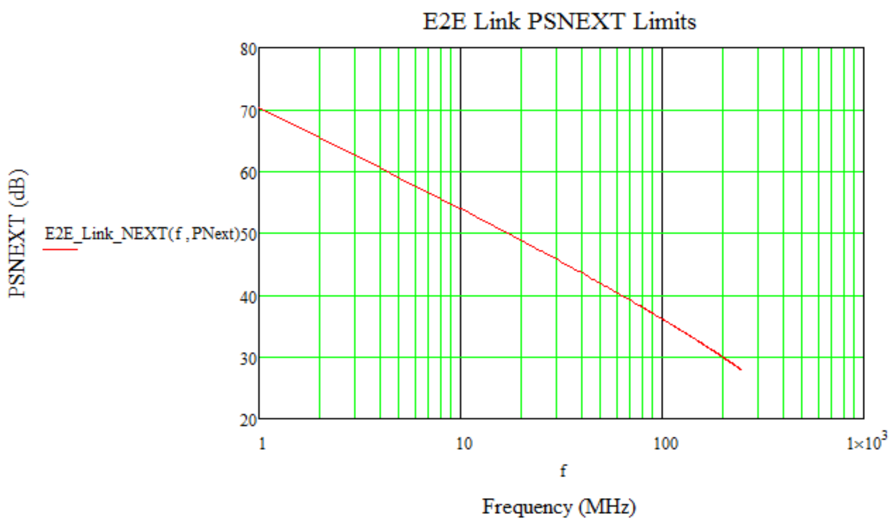


Figure 28 E2E Link Worst Case Class E PSNEXT Loss

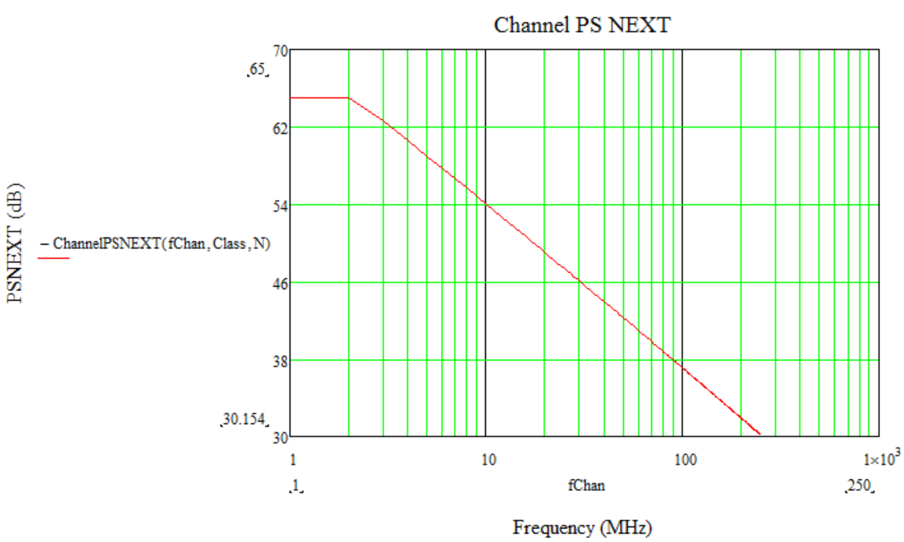


Figure 29 ISO Worst Case Class E Channel PSNEXT Loss

ACR-F Limits

Equation 9 Class D Worst E2E Link ACR-F

Class D E2E Link ACR-F 6 Connections dB
$$\left(-20 \cdot log\left(10^{\frac{63{,}8-20\cdot\log(f)}{-20}} + 4\cdot 10^{\frac{75{,}1-20\cdot\log(f)}{-20}}\right)\right) - 1{,}12$$
ACR-F at frequencies that correspond to measured FEXT values of greater than 70,0 dB are for information only.

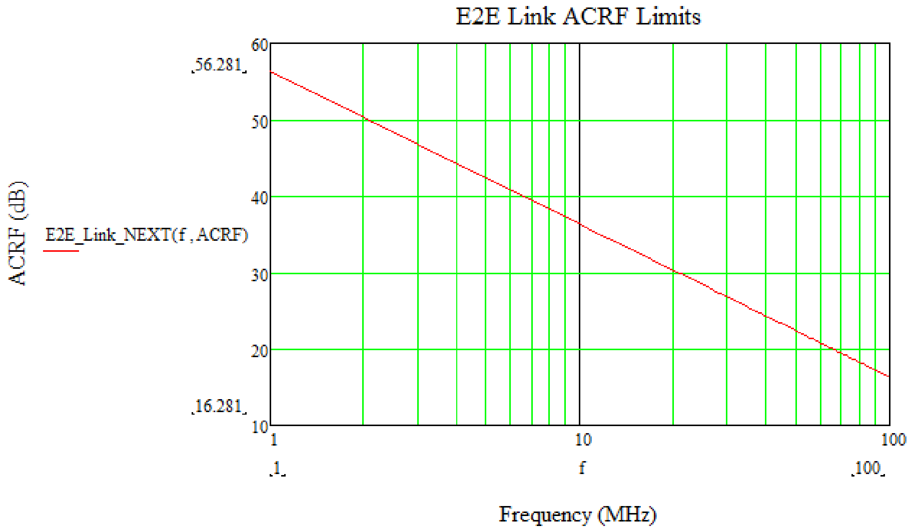


Figure 30 E2E Link Worst Case Class D ACR-F

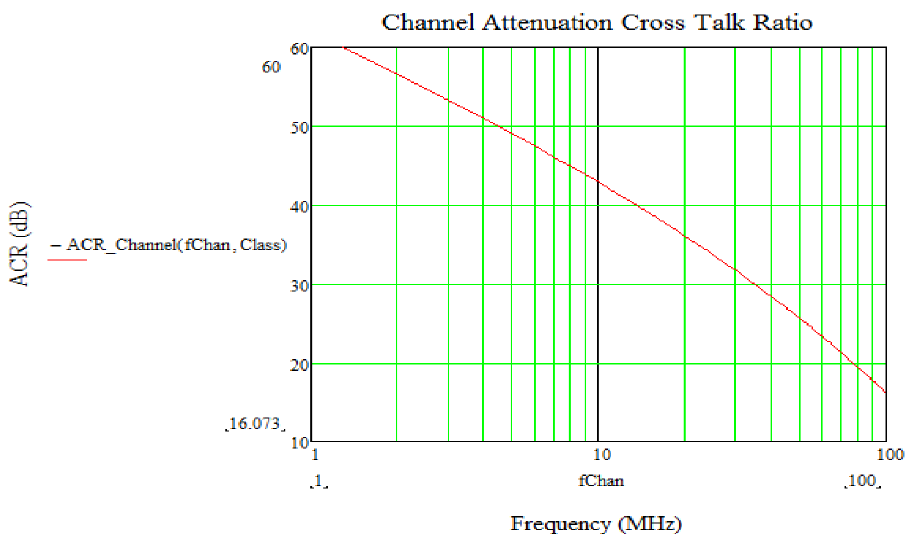


Figure 31 ISO Worst Case Class D Channel ACR-F

Equation 10 Class E Worst E2E Link ACR-F

Class E E2E Link ACR-F 6 Connections dB
$\left(-20 \cdot log\left(10^{\frac{67,8-20\cdot\log(f)}{-20}} + 4 \cdot 10^{\frac{83,1-20\cdot\log(f)}{-20}}\right)\right) - 0,46$
ACR-F at frequencies that correspond to measured FEXT values of greater than 70,0 dB are for information only.

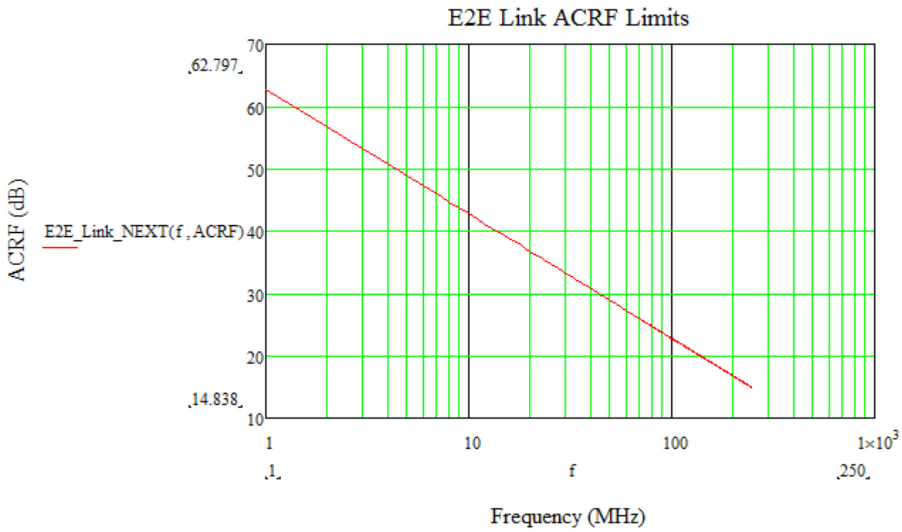


Figure 32 E2E Link Worst Case Class E ACR-F

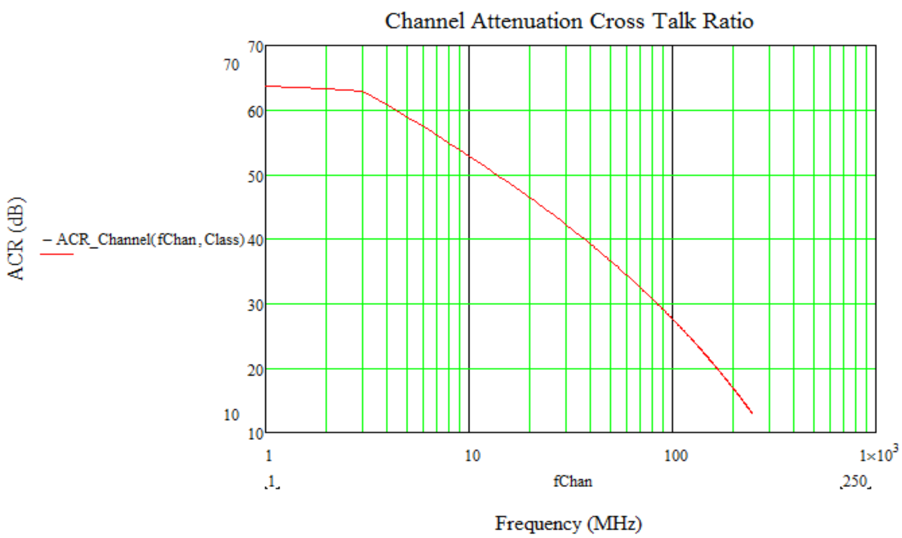


Figure 33 ISO Worst Case Class E Channel ACR-F

PSACR-F

Equation 11 Class D Worst E2E Link PSACR-F

Class D E2E link PSACR-F dB
$\left(-20 \cdot log\left(10^{\frac{60,8-20\cdot\log(f)}{-20}} + 4 \cdot 10^{\frac{72,1-20\cdot\log(f)}{-20}}\right)\right) - 1,12$

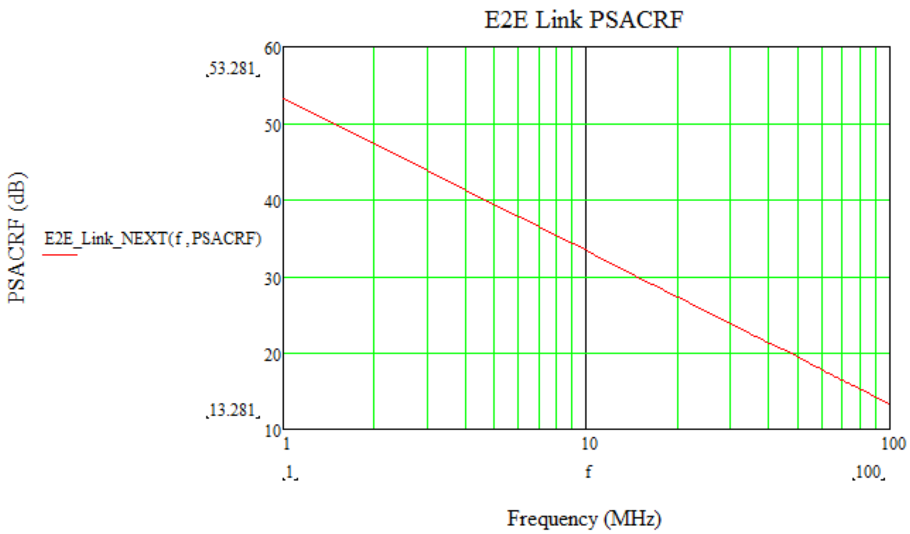


Figure 34 E2E Link Worst Case Class D PSACR-F

Equation 12 Class E Worst E2E Link PSACR-F

Class E E2E link PSACR-F dB
$\left(-20 \cdot log\left(10^{\frac{64,8-20\cdot\log(f)}{-20}} + 4 \cdot 10^{\frac{80,1-20\cdot\log(f)}{-20}}\right)\right) - 0,46$
NOTE Calculated values greater than 62 dB revert to 62 dB

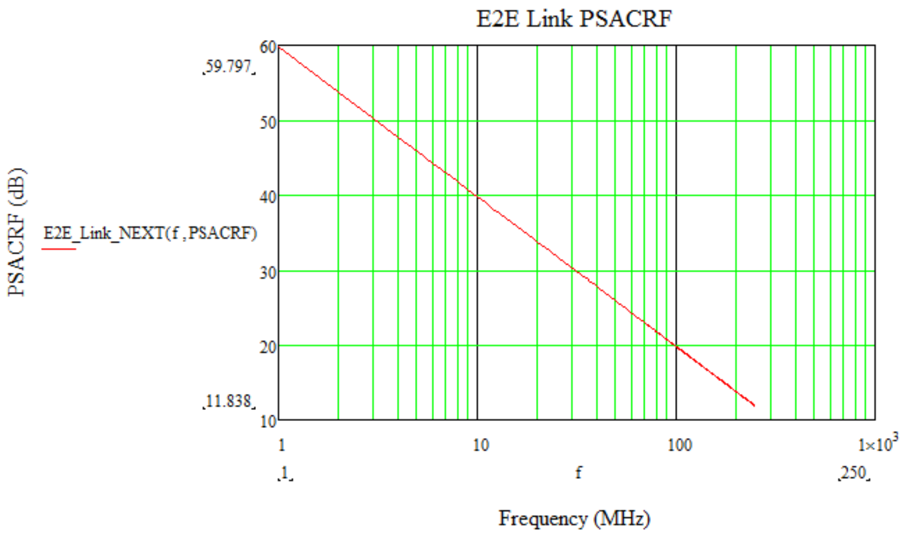


Figure 35 E2E Link Worst Case Class E PSACR-F

TCL (UN-Screened Cables)

Equation 13 Class D&E Worst E2E Link TCL for MICE Levels E1, E2 and E3

Class	**Frequency** MHz	**E2E link TCL** dB [a]		
		E_1	E_2	E_3
Class D & E	$1 \leq f \leq 30$ $30 \leq f \leq 100$	53-15log(f) 60,4-20log(f)	63-15log(f) 70,4-20log(f)	73-15log(f) 80,4-20log(f)

[a] TCL at frequencies that correspond to calculated values of greater than 40 dB revert to 40 dB.

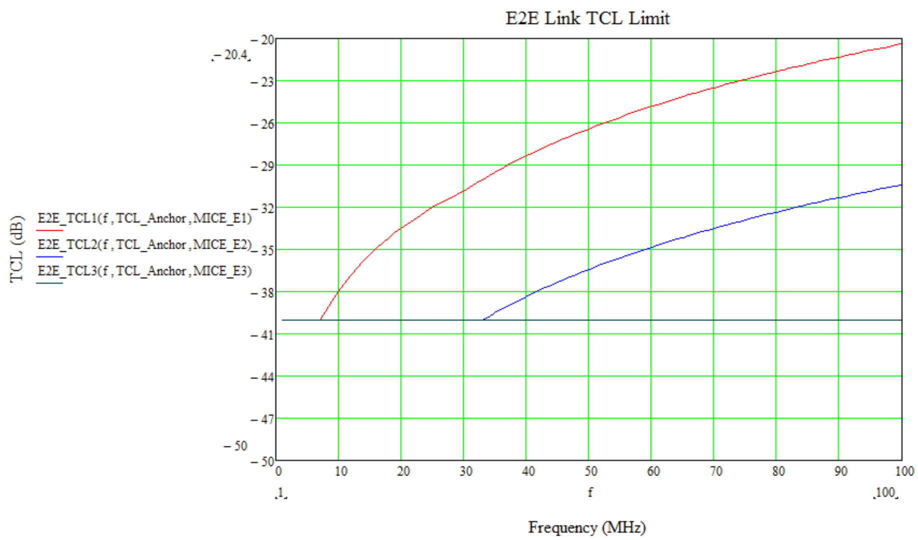


Figure 36 E2E Link Worst Case Class D TCL

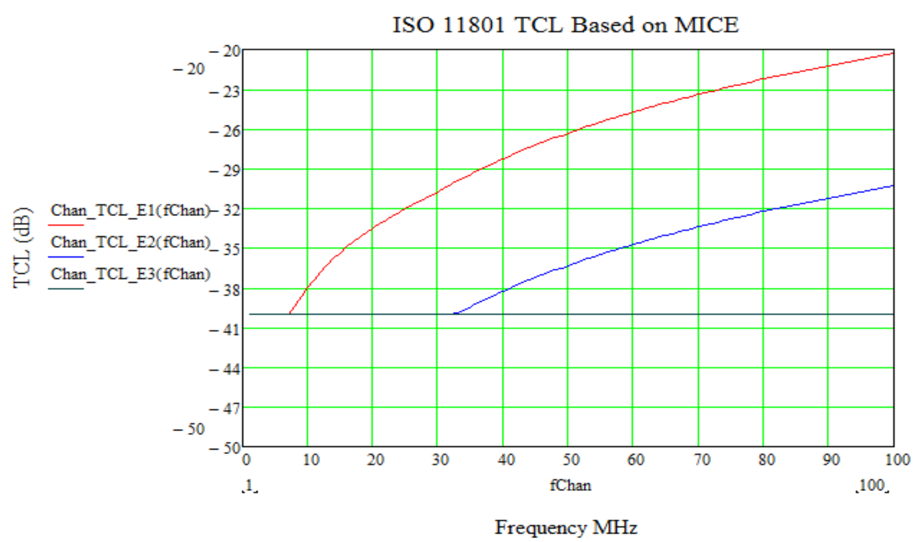


Figure 37 ISO TCL Class D Channel

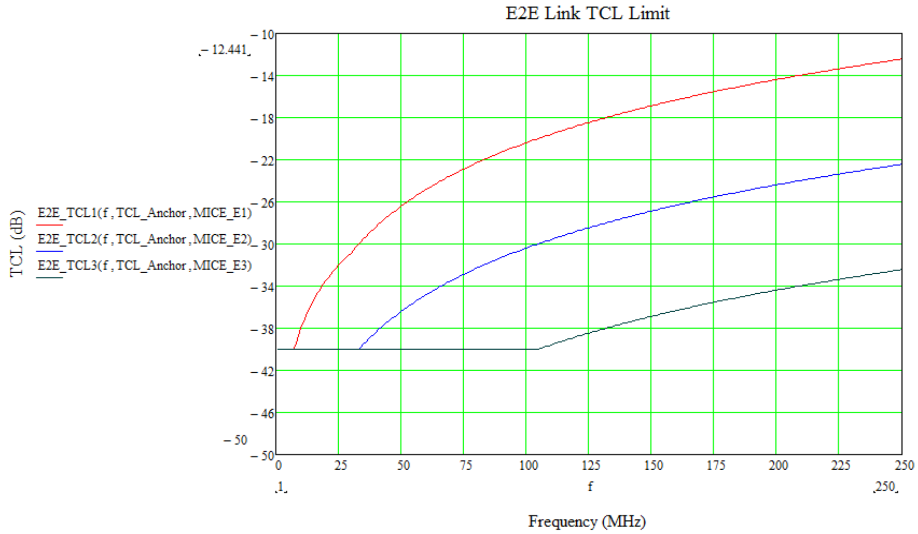


Figure 38 E2E Link Worst Case Class E TCL

ELTCTL (UN-Screened Cables)

Equation 14 Class D&E Worst E2E Link ELTCTL for MICE Levels E1, E2 and E3

Class	**Frequency** MHz	**E2E link ELTCTL** dB [a]		
		E_1	E_2	E_3
Class D & E	$1 \le f \le 30$	30-20log(f)	40-20log(f)	50-20log(f)
[a] ELTCTL at frequencies that correspond to calculated values of greater than 40 dB revert to 40 dB.				

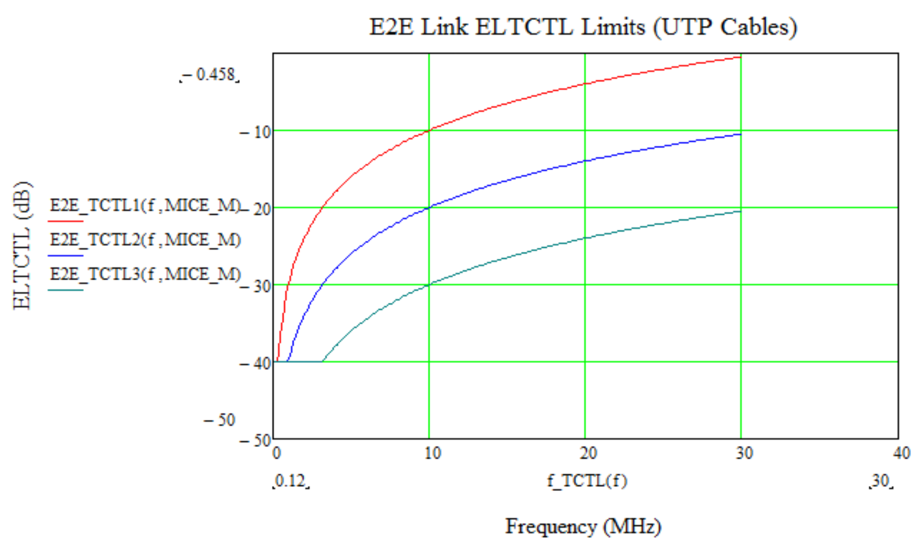


Figure 39 E2E Link Worst Case Class D & E ELTCTL

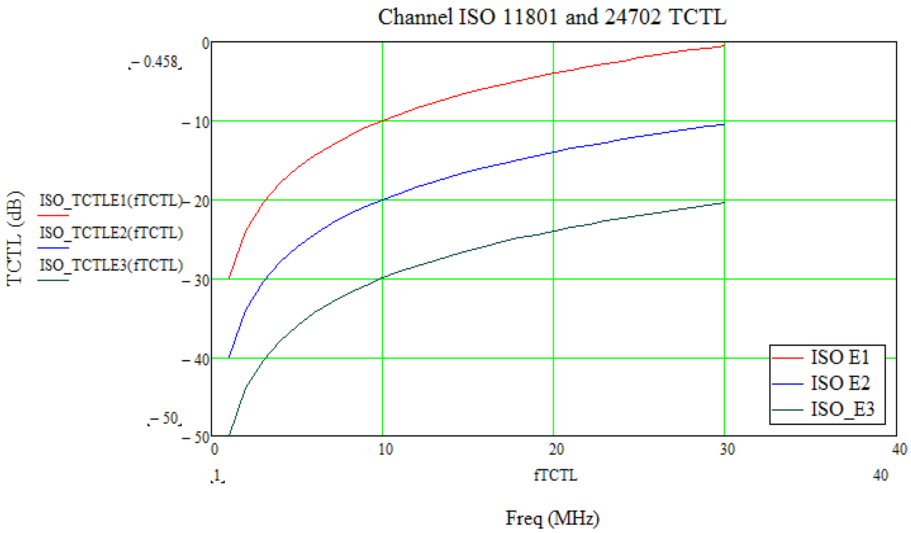


Figure 40 ISO Worst Case Class D & E ELTCTL

Coupling Attenuation (Screened Cables)

Equation 15 Class D&E Worst E2E Link CA for MICE Levels E1, E2 and E3

Class	**Frequency** MHz	**E2E link CA MICE E1, E2 and E3** dB		
		E_1	**E_2**	**E_3**
Class D & E	$1 \le f \le 30$	40	50	60
	$1 \le f \le 100$	80-20log(f)	90-20log(f)	90-20log(f)

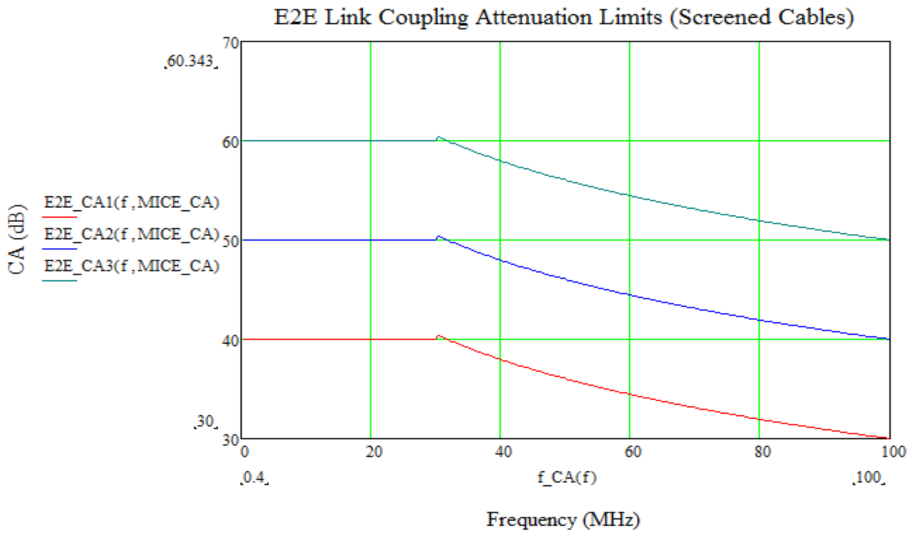


Figure 41 E2E Link Worst Case Class D & E CA

Testing of E2E Links

Field tester manufactures were quick to respond to the work in ISO/IEC in enhancing the field testers to include new limits for E2E Links. In some cases this requires a new test head since the tester is not providing part of the connection at the end of a link. This is very similar to P-Link testing where the tester provides a reference plug to interface with the P-Link jacks. The new releases of field testers now include the E2E Link limit lines and also TCL and ELTCTL measurement capabilities. This is a huge benefit to our customers who need to install, maintain and troubleshoot networks. Problems that exist but were not visible can now be found by the field testers supporting these capabilities.

Conclusion

The installation of E2E links is not new in industrial installations, what is new is the ability to test the links. The addition of this new set of cabling specifications effectively adds a new element to the cabling standards. We now have testable definitions for the Channel, E2E Link, P-Link and Cords that collectively make up a network. From a modeling perspective the greatest addition is the connection models being added to the Channel. The impact as seen in the comparative graphs above is in insertion loss and return loss. The addition of the two end connections adds additional losses. In general the greatest impact to RL is reflections occurring at the connection interfaces (including wire terminations within the plug and jack beck ends). It makes sense that the RL would be effected since the first interface a launched signal sees now is the connections at the end of the link. So we see a degradation in RL for an E2E Lind definition. It should be noted that this degradation is not new since all channels have the same problem except it is now visible in an E2E link measurement. NEXT is also effected by the modeling since there is a potential to see incorrect routing of the cord conductors within the back end of the plug of an end connection. This is the single greatest benefit of the E2E link definitions. The wire preparation during plug termination of field installed links is the single most important issue solved by the E2E link definitions. Unfortunately the balance specifications were not enhanced during this project. Since the cabling's TCL, ELTCTL are the most important parameters for high noise environments.

References:

SC25-11801-9902-Ed1-CDTR -- Information Technology – Generic Cabling for Customer Premises, Part 9902: Specifications for End-to-End Link Configurations

ISO/IEC 11801 Information Technology Generic Cabling for Customer Premises

ISO/IEC 29106 Information Technology Generic Cabling – Introduction to the MICE Environmental Classification