The AMP NETCONNECT
Category 6 Cabling System

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Perspective

In less than ten years we have seen twisted pair LAN performance levels evolve from 10 Mbps Ethernet (10BASE-T) and 16 Mbps token ring to Fast Ethernet (100BASE-T) Ethernet and 155 Mbps ATM. Concurrently, we have seen cabling system performance evolve from Category 3, through Category 4, to Category 5 in order to accommodate these applications. We have also seen the simultaneous evolution of both Gigabit Ethernet (1000BASE-T), and a new cabling standard for Enhanced Category 5 (Category 5e) to more readily accommodate this application. Category 5e offers only a relatively minor improvement in performance over Category 5 and there are even higher performance cabling standards for Category 6/Class E[1] under development. Although 1000BASE-T does not specify Cat 6/Class E performance as a requirement, the IEEE, the ATM Forum and others have asked cabling standards organizations to develop standards that will serve as the foundation for the next generation of twisted pair applications over the *next* ten years.

The purpose of this paper is to discuss the issues related to next generation applications and cabling systems, and to introduce you to the NETCONNECT Category 6 Cabling System.

Why Install Next Generation Cabling Systems?

To the end users it's simple – they don't want to wait. All of that e-mail, all of those graphic-intensive, multimedia files should fly through the network fast enough that each user feels as if he or she owns the LAN. To the administrator, this need for speed equates to providing faster and faster data rates. Over the last ten years the data rates implemented on the horizontal cabling system have grown from 10 Mbps (megabits or millions of bits per second) to 100 Mbps, with 1000 Mbps (or 1 *gigabit* per second) looming just over the horizon.

When we talk about the cabling system performance required to support these ever-increasing data rates, we talk in terms of *bandwidth*. Cabling system bandwidth is defined and measured across a particular, application-independent frequency range. For current UTP systems, this range is on the order of 1 to 100 MHz (megahertz or millions of cycles per second) for Cat 5/Class D systems or 1 to 250 MHz for Cat 6/Class E systems. While the bandwidth of the cabling system effectively limits the data rates that the system can support, the relationship is a complex one.

Megahertz vs. Megabits

As an example, let's consider current Category 5 specifications and applications. Category 5 cabling systems are specified from 1 to 100 MHz. However, the *usable* bandwidth of a system is roughly the point where its attenuation-to-crosstalk ratio (ACR) hits 8 to 10 dB. We'll define ACR later, but for now, it has been determined that a Category 5 system actually has a usable bandwidth of about 80 MHz. If a Cat 5 system only has an 80 MHz bandwidth, then how can we

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[1] Category 6/Class E is a proposed standard by the ISO/IEC standards organization for 250 MHz twisted pair cable and connecting hardware (Category 6) and cabling systems (Class E). The ANSI TIA/EIA standards body is simultaneously proposing a Category 6 specification that incorporates cable, connecting hardware and cabling systems under "Category 6".

be running 100BASE-T, or 155 Mbps ATM or even 1 Gbps Ethernet across it? The answer lies in the *encoding scheme*. The encoding scheme is the way in which data is represented on the medium, in this case copper wire, on which it is transmitted. Table 1 below illustrates the bandwidth requirements of several current LAN protocols.

Network	Cable Pairs	Full Duplex	Line Code	Minimum Signal Bandwidth	Coding Levels	Cabling Category
10BASE-T	2	No	Manchester	10 MHz	2	3
100BASE-TX	2	No	MLT-3	31.25 MHz	3	5
155 Mbps ATM	2	Yes	NRZ	77.5 MHz	2	5
1000BASE-T	4	Yes	TX/T2	62.5 MHz	5	5?

Table 1 – LAN Bandwidth Requirements

As you can see, even though three of the protocols provide data rates of 100 Mbps or more, none of them has bandwidth requirements in excess of 80 MHz. However, there is a notable difference between the first three applications on the chart and 1000BASE-T. The latter utilizes full duplex transmission, actually transmitting 250 Mbps in both directions simultaneously. It also utilizes all four pairs to accommodate the aggregate data rate of 1000 Mbps, and requires a significant improvement in signal-to-noise ratio (SNR) in order to achieve the Bit Error Rate (BER) necessary for satisfactory application performance. Improving SNR can be accomplished either by incorporating noise-canceling technology into the network interface cards and hubs and/or by improving the transmission performance of the cabling system. Based on these facts, it is not difficult to believe that 1000BASE-T will push Category 5 cabling to its limits. The question is – What comes next?

Planning for the Future

Currently the ATM Forum is developing specifications for 1.2, 2.5 and 10 Gbps applications. The initial plan is to develop these applications as backbone technologies using optical fiber as the transmission medium. However, the ATM Forum and the IEEE have communicated their interest to the International Standards Organization (ISO) and the Telecommunications Industries Association (TIA) in having a 250 MHz operating bandwidth cabling system to provide a development platform for next generation, high speed, twisted pair applications.

When specifying a building cabling system for a ten-year life, the cabling bandwidth requirements of these next generation applications need to be seriously considered.

The AMP NETCONNECT Category 6 System

The AMP NETCONNECT Category 6 System is *the* "next generation" cabling system, designed to exceed the requirements of the emerging Category 6/Class E specification. The TIA and the ISO began work on this specification in late 1997. The standard will probably not be formalized until sometime in 2001. The Category 6/Class E specification defines a cabling system with essentially twice the bandwidth (250 MHz) of a TIA Category 5 system. The NETCONNECT Category 6 System is designed to support all of the LAN applications being discussed today, plus those that have yet to be conceived.

Category 6 Components – the Parts That Make up the System

The Category 6 System is made up of four high performance components:

Category 6 cable – Category 6 cable is designed specifically to exceed the draft Category 6 specifications. It offers exceptional performance while maintaining high ease of use.

Category 6 jacks and patch panels – Category 6 connecting hardware is designed to provide matching Category 6 performance while improving on the density of existing NETCONNECT modular products. Category 6 jacks are compatible with all 110Connect and SL Series faceplates and accessories. Category 6 jacks and patch panels are color-coded for both T568A and T568B wiring patterns.

Category 6 patch cords – Category 6 patch cords are designed to continue the system's performance throughout the entire channel without sacrificing panel or hub density. Category 6 plugs are dimensioned to ensure ease of mating to high-density LAN hubs utilizing stacked jack interfaces.

Engineering the System

As we continue to push the limits of cabling performance, the concept of end-to-end systems engineering becomes increasingly important. As we move from 100 MHz to 250 MHz, minor differences in the performance of a component, such as a patch cord, have a much more profound effect on the overall performance of the cabling system. It is even possible to make a performance improvement in one component and then have the system performance get worse. Therefore, it is important that the system and all it's components be engineered as one continuous transmission path. End-to-end design ensures maximum system performance.

System Performance

What does a "step above Category 5" look like? Although this is still being defined, the following is a "snapshot" of the evolutionary process of a new cabling system. To fully explore the differences between Category 5 and Category 6 performance levels, we need to take an in-depth look at some technical performance characteristics.

Category 6 will be specified through 250 MHz, essentially doubling the bandwidth of Category 5. Therefore, the same performance parameters (NEXT, attenuation, etc.) that are specified for Category 5 are specified for Category 6; simply through a wider frequency range (250 MHz vs. 100 MHz). This will provide a "pipe" for data transmission that is basically twice as large as Category 5.

As cabling performance has evolved, the number of performance parameters we are interested in has grown, even for Category 5 systems. For those who are not electrical engineers, what follows is a quick definition of these important performance criteria. For each performance characteristic, separate requirements exist for cable, connecting hardware and installed systems.

Two-pair Performance Parameters

The first three criteria are considered the primary factors affecting transmission performance in two-pair (one transmit/one receive) applications. See Table 1 (pg. 4) for examples of two-pair applications.

Near End Crosstalk (NEXT)

As an electrical signal travels through connectors and cable, it generates an electromagnetic field around the conductive path. When that field intersects adjacent conductors, it generates an unwanted signal, adding noise to and degrading the desirable signals on those conductors. This situation is worst at the "near end", between the transmit and receive circuitry of the same device (i.e., a network interface card or LAN hub). NEXT is measured by injecting a signal onto a pair of the component or system and measuring the amount that is coupled onto the adjacent pairs (see Figure 1 on page 8). NEXT loss is expressed in decibels (dB), which represent a logarithmic ratio between the desirable signal and the noise, the higher the number the better.

Attenuation

As an electrical signal travels through the cabling system components, some of its energy is lost. This means that there is not as much of the signal left at the receiving end as we started out with at the transmitter. If the signal drops too close to the noise level, the receiver won't be able to "hear" it. Attenuation is measured by injecting a signal into one end of the component or system and measuring how much comes out the other end (see Figure 1). It is also measured in dB, which express the ratio between the received signal and the transmitted signal, the lower the number the better. Attenuation increases with the length of the system.

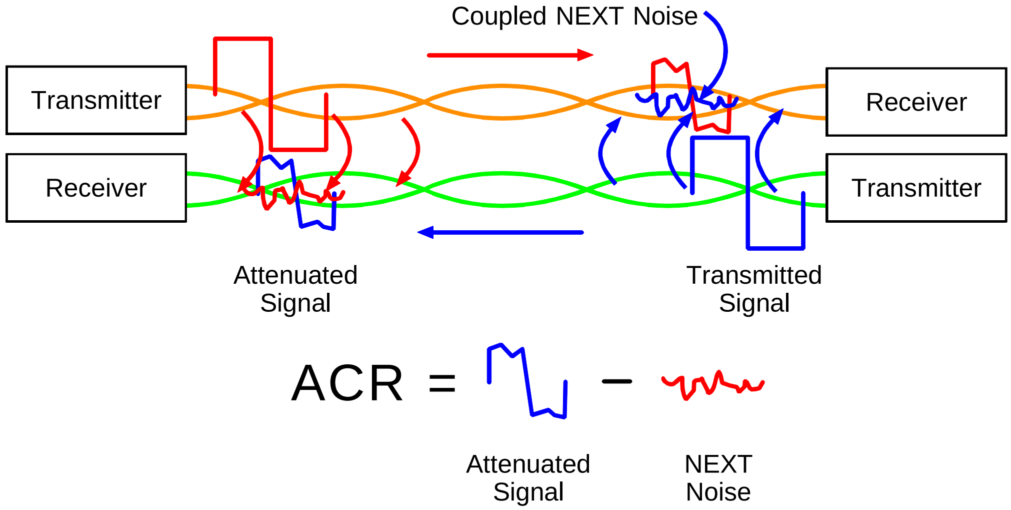


Figure 1 – Effects of NEXT and Attenuation

Attenuation-to-Crosstalk Ratio (ACR)

The attenuation-to-crosstalk ratio (ACR) is the difference between NEXT and attenuation measurements at a given frequency (see Figure 2 on page 9). ACR is a useful performance value as it expresses the relationship between the signal level at a device and the crosstalk noise level. For a two-pair system, ACR is essentially the only measurable aspect of the system's overall signal-to-noise ratio (SNR), which also includes any ambient noise and is the determining factor in network performance. Since it encompasses both attenuation and crosstalk, the ACR is also the true indicator of performance headroom. When the ACR goes negative, there is a higher level of noise in the system than there is of the desired data signal. Category 5 channel specifications designate a 3.1 dB ACR at 100 MHz for two-pair applications (4 dB for ISO Class D). Category 5e channel specifications designate a 6.1 dB pair to pair, or 3.1 dB power sum, ACR to ensure integrity for four-pair applications. Draft Category 6/Class E specifications designate a 3.2 dB ACR at 200 MHz, which doubles the usable bandwidth of the channel over Category 5.

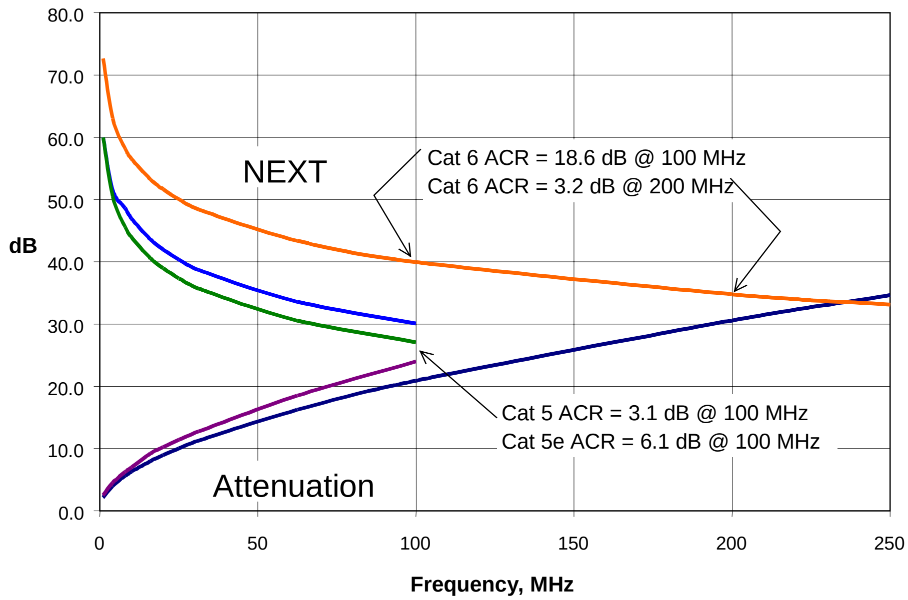


Figure 2 – Cat 5, Cat 5e and Cat 6 ACR Comparisons

Four-pair Performance Requirements

With the advent of new high-speed applications like 1000BASE-T, new performance parameters are required to ensure successful data transmission. Twisted pair cabling is now required to handle four-pair, full duplex transmission and an encoding scheme that demands much better signal-to-noise ratio than is typical with traditional Category 5 cabling (which was only designed to support two-pair transmission). The additional parameters include power sum ELFEXT, power sum NEXT, return loss and delay skew.

Equal Level Far End Crosstalk (ELFEXT)

FEXT is a measure of the unwanted signal coupling from a transmitter at the far end of the cabling system into neighboring pairs measured at the near end (see Figure 3 on page 10). FEXT becomes important in applications that use simultaneous bi-directional transmission, such as Gigabit Ethernet. Equal level far end crosstalk (ELFEXT) takes into consideration the relative level of the FEXT noise compared to the expected signal level and is expressed in dB. ELFEXT is specified in the latest ISO/IEC and TIA/EIA standards drafts for Category 6/Class E cabling.

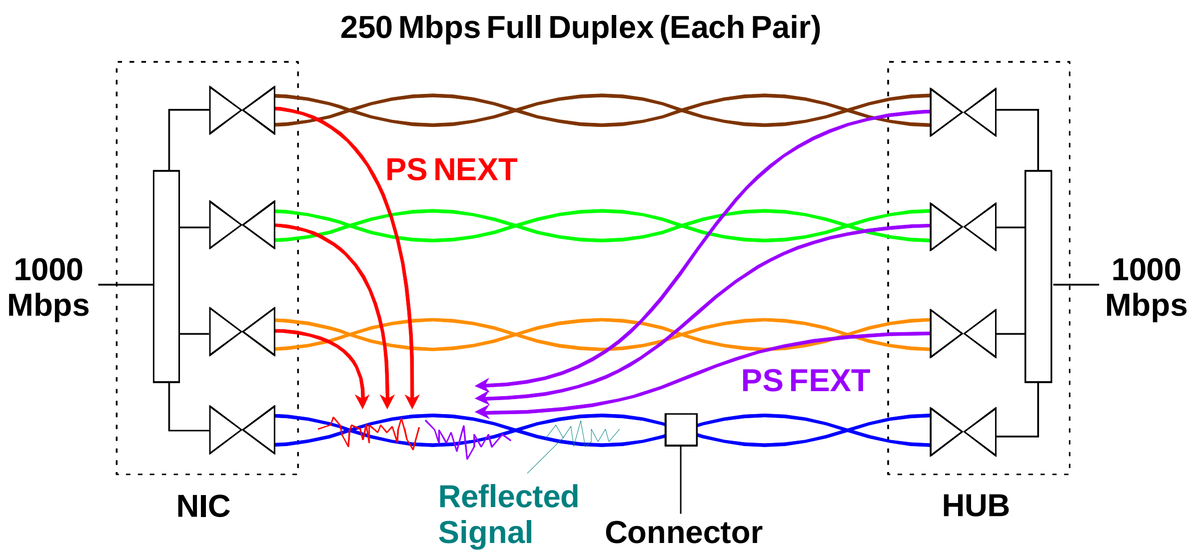


Figure 3 - The effects of PS NEXT, PS FEXT and Return Loss

Power Sum Crosstalk

Standard NEXT and FEXT measurements (pair-to-pair) reflect the traditional application of a device using one pair to transmit and one pair to receive. That's fine for 10BASE-T and token ring, even 100BASE-T and 155 Mbps ATM. However, faster LANs, such as 1000BASE-T, will utilize all four pairs to transmit and receive. Using more than one pair in a cable for transmission increases the crosstalk present in the cable. The pair-to-pair crosstalk measurements do not take this extra noise into consideration. Power sum crosstalk considers the effects of noise generated from three pairs onto the one remaining pair (see Figure 3). Power sum crosstalk requirements ensure that the cabling system will handle high data rate, multi-pair transmission protocols.

Return Loss

Whenever an electrical signal in a wire hits a connector pair, or another impedance mismatch in the cabling system, some of its energy is reflected back towards the transmitter (see Figure 3). Return loss is a measure of this reflected energy caused by impedance mismatches in the cabling system. Return loss is especially important for applications that use simultaneous bi-directional transmission, such as 1000BASE-T.

Delay Skew

Delay skew is the difference in propagation delay between the fastest and slowest pairs in a cable. Current industry standards specify channel requirements of $\leq$ 50 ns (nanoseconds) at 100 MHz. For systems that transmit on more than one pair, such as 1000BASE-T, it is important that the skew is within the specification to prevent data errors. The Category 6 System meets this requirement.

NETCONNECT Category 6 Performance

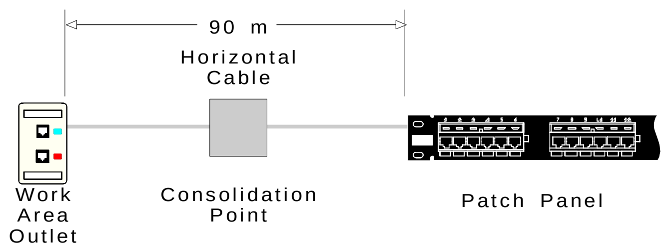
Now that we have defined the parameters, let's look at the actual performance of the NETCONNECT Category 6 System. In March of 2001, Intertek Testing Services (ETL) performed permanent link and channel testing on the AMP NETCONNECT Category 6 System. The limit criteria used were from TIA/EIA-568-B.2-1 Draft 7b,Transmission Performance Specification for 4 Pair 100 Ω Category 6 Cabling, dated February 2, 2001. The products tested were drawn from production inventory. The following equipment was employed in conducting the tests:

Equipment Used	Model Number	Serial Number	Calibration Date
Hewlett Packard Automatic Cable Test System	HP46152A	3903U01003	03/18/00

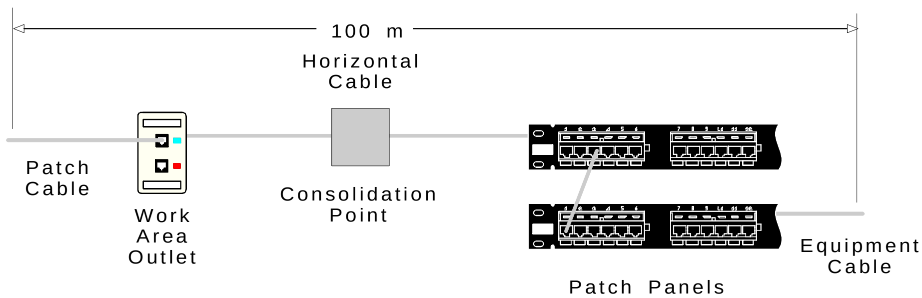
The following graphs show the worst-case performance, at each frequency, of all links and channels tested, compared to the proposed Category 6/Class E channel specifications. For ease of review the graphs are grouped into three sections:

- Traditional two-pair performance parameters: NEXT, Attenuation and ACR
- Power sum performance parameters for four-pair systems: PS NEXT, Attenuation and PS ACR
- Additional performance parameters for high speed systems: ELFEXT, PS ELFEXT and Return Loss

Figure 4 describes the test configurations used to measure the results.



Permanent Link



Channel

Figure 4 – Category 6 Test Configurations

Link Pair-to-Pair Performance

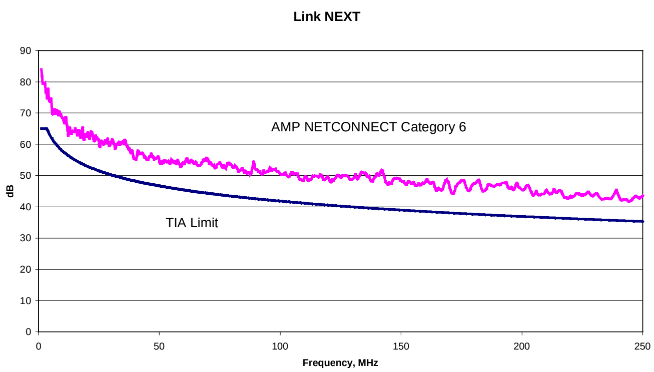


Figure 5 – Link Near End Crosstalk

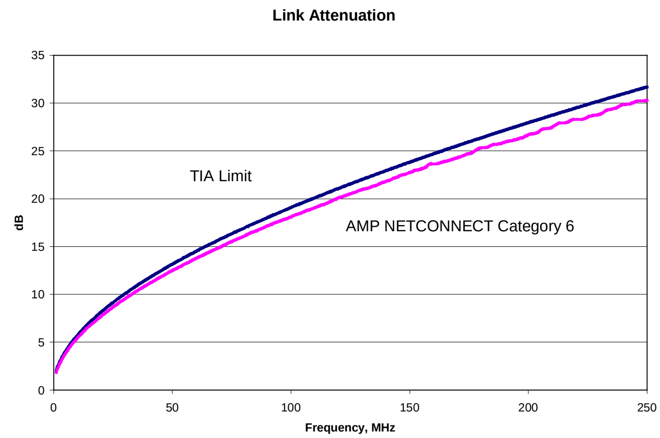


Figure 6 – Link Attenuation

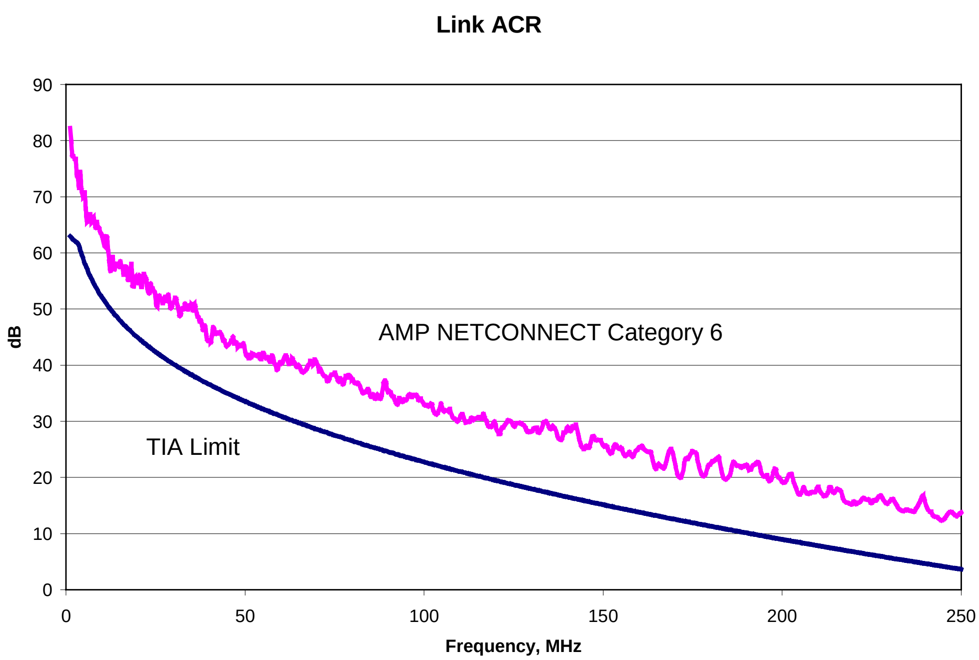


Figure 7 – Link ACR

Link Power Sum Performance

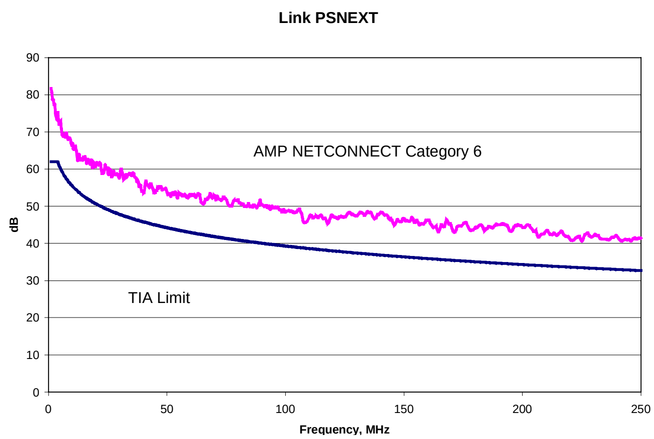


Figure 8 – Link PSNEXT

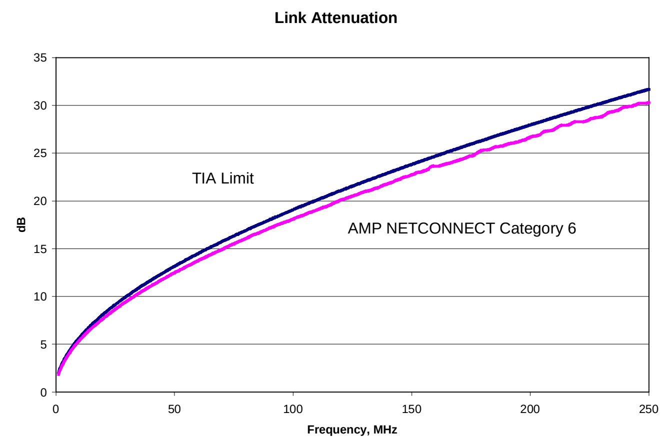


Figure 9 – Link Attenuation

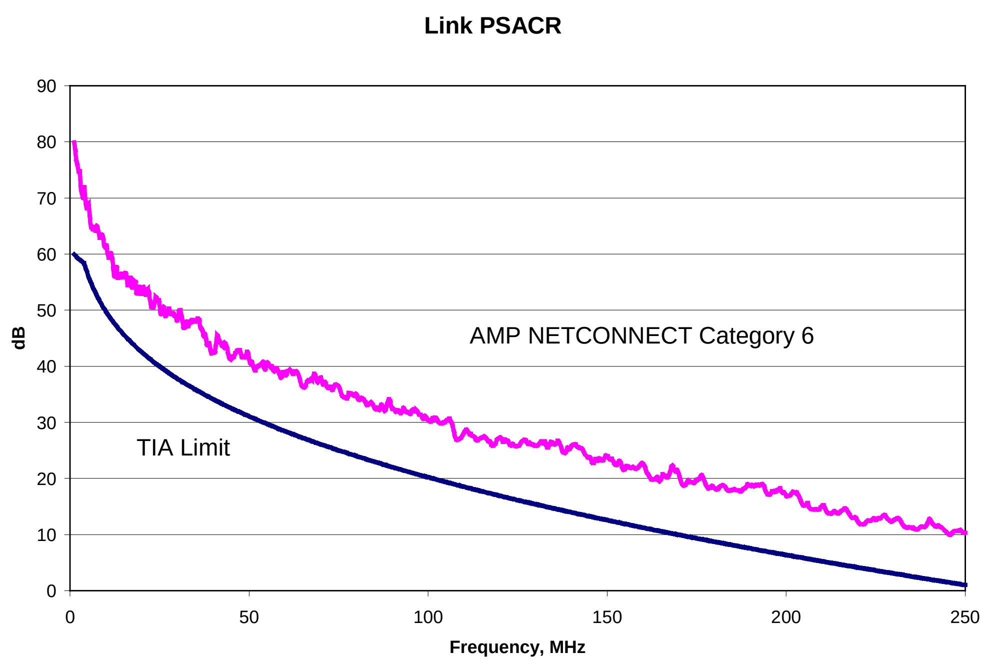


Figure 10 – Link PSACR

Link ELFEXT, PS ELFEXT and Return Loss

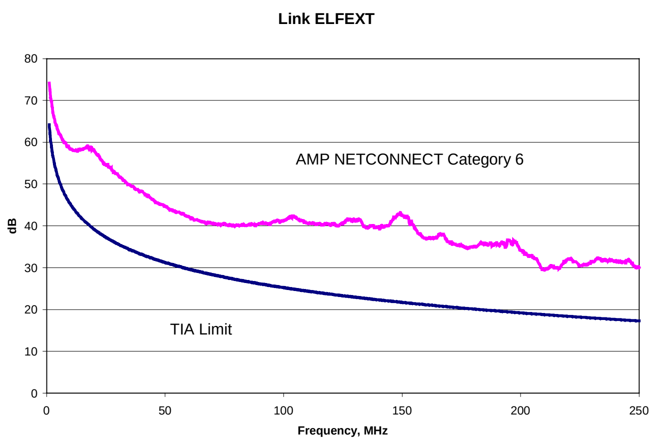


Figure 11 – Link ELFEXT

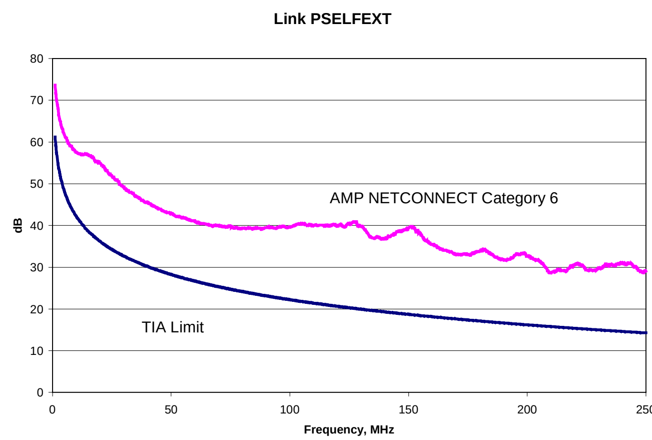


Figure 12 – Link PSELFEXT

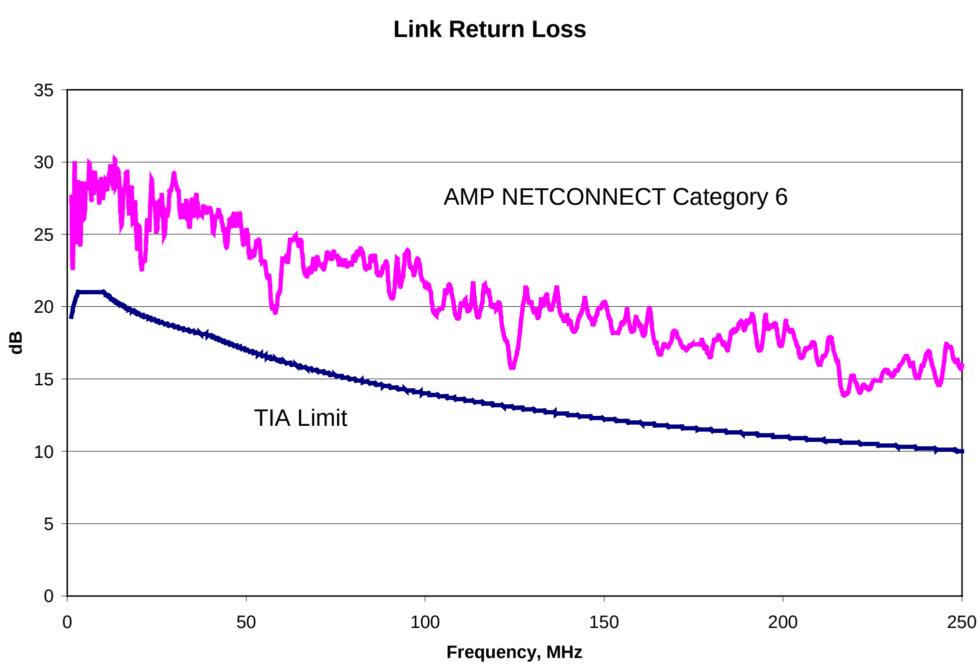


Figure 13 – Link Return Loss

Channel Pair-to-Pair Performance

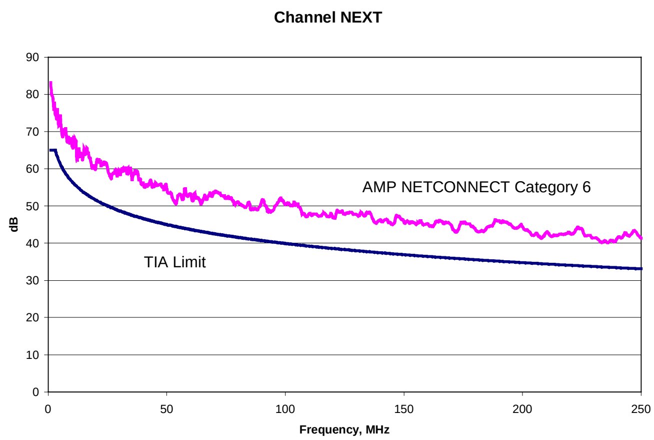


Figure 14 – Channel Near End Crosstalk

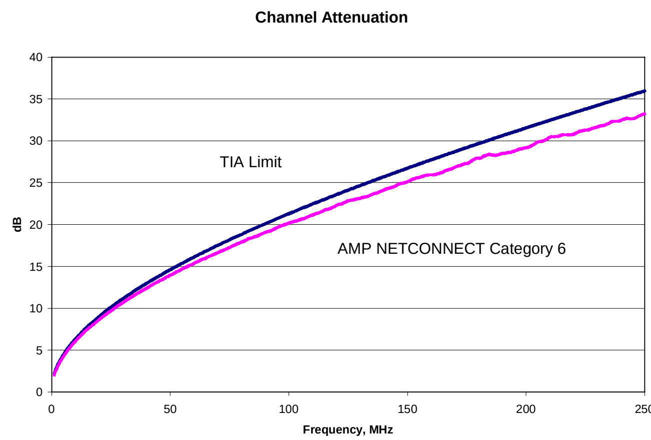


Figure 15 – Channel Attenuation

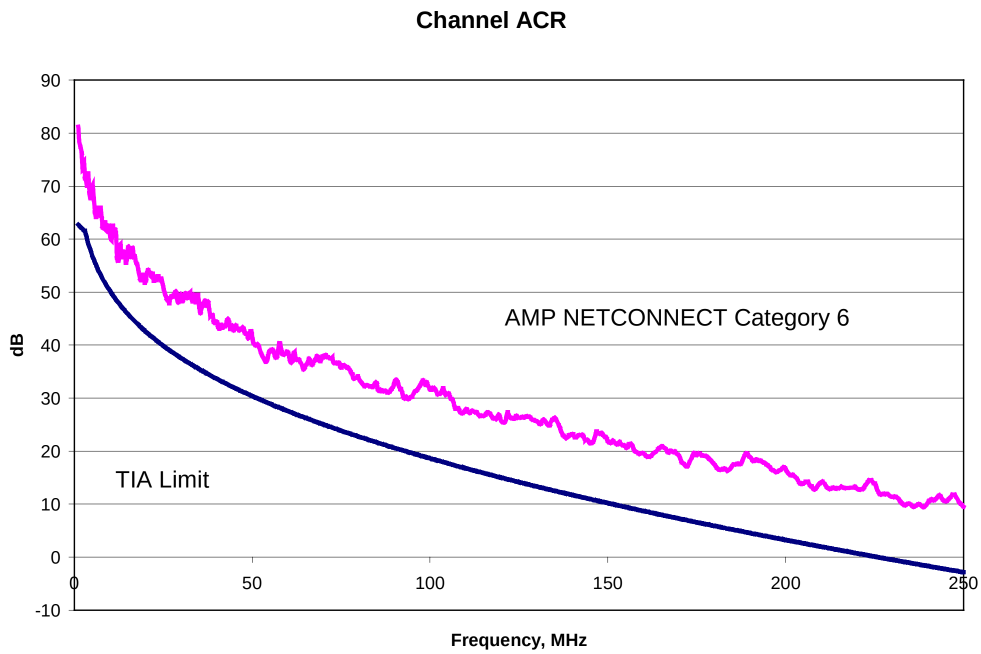


Figure 16 – Channel ACR

Channel Power Sum Performance

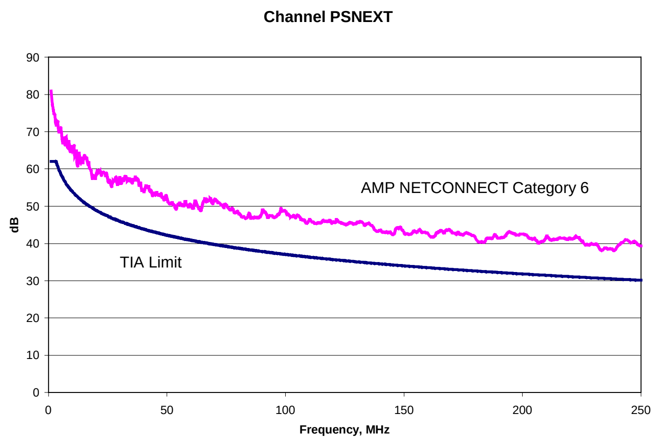


Figure 17 – Channel PSNEXT

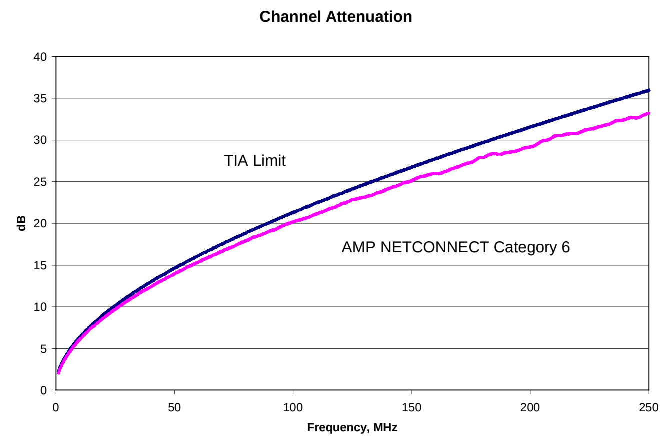


Figure 18 – Channel Attenuation

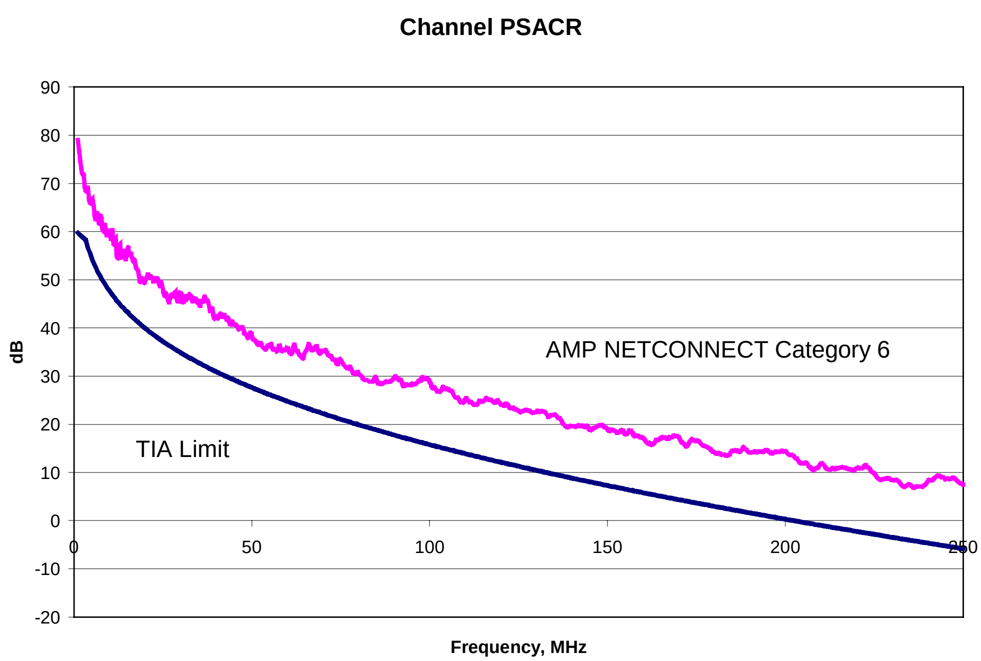


Figure 19 – Channel PSACR

Channel ELFEXT, PS ELFEXT and Return Loss

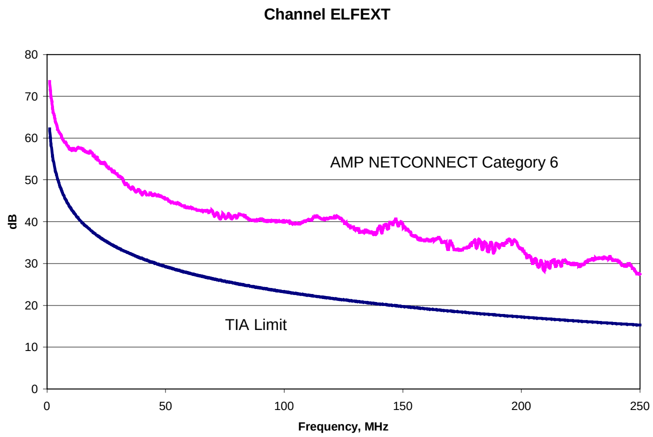


Figure 20 – Channel ELFEXT

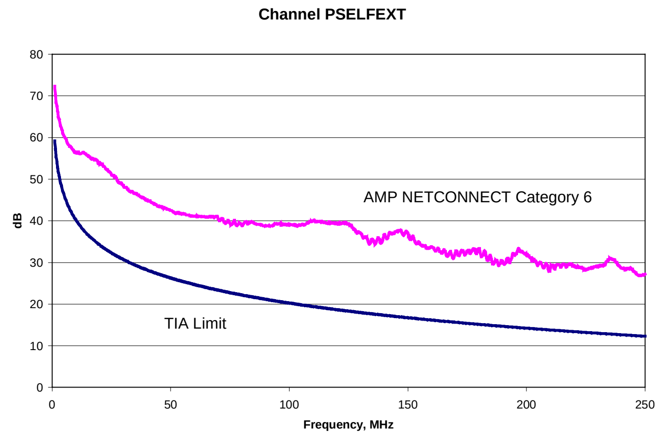


Figure 21 – Channel PSELFEXT

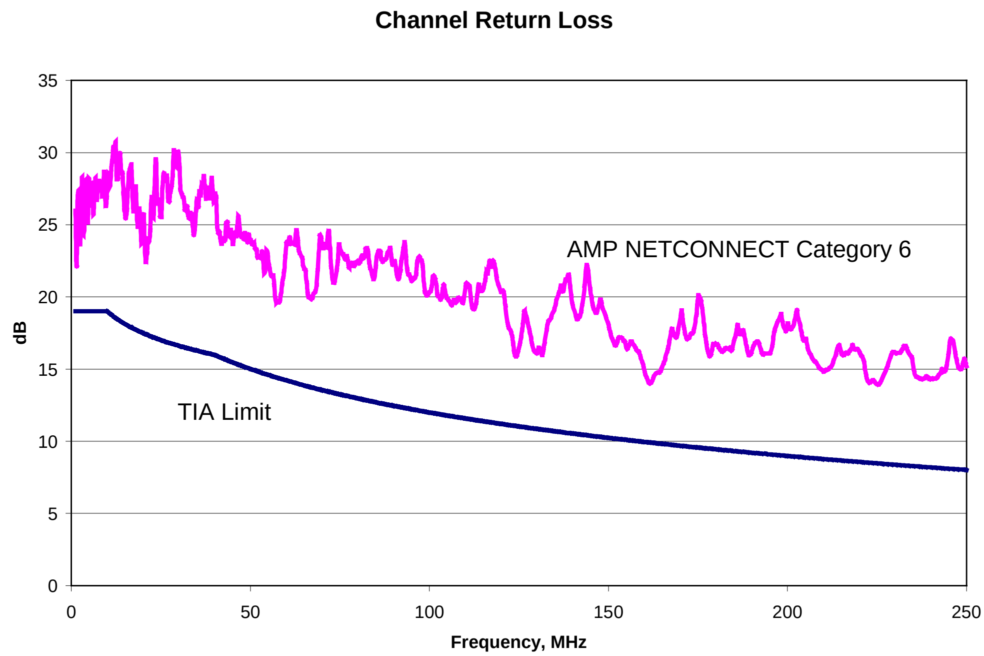


Figure 22 – Channel Return Loss

Link Performance Summary – 90-Meter/3-Connector Permanent Link

The following tables list the worst-case ETL test results at each frequency for 90-meter Category 6 links. The spec numbers are from Draft 10 of the TIA/EIA-568-B.2-1 Category 6 specification.

Frequency, MHz	Attenuation, dB		Return Loss, dB		NEXT, dB		PS NEXT, dB	
	Spec	AMP	Spec	AMP	Spec	AMP	Spec	AMP
1	1.9	1.9	19.1	27.6	65.0	84.0	62.0	81.7
4	3.5	3.4	21.0	26.6	64.1	77.7	61.8	75.2
8	5.0	4.8	21.0	28.7	59.4	70.2	57.0	68.6
10	5.6	5.5	21.0	27.9	57.8	68.2	55.5	66.9
16	7.0	6.9	20.0	28.2	54.6	62.9	52.2	61.6
20	7.9	7.7	19.5	25.5	53.1	62.8	50.7	61.2
25	8.9	8.7	19.0	25.4	51.5	59.4	49.1	58.8
31.25	10.0	9.8	18.5	26.8	50.0	59.9	47.5	58.5
62.5	14.4	14.1	16.0	24.6	45.1	54.3	42.7	52.8
100	18.6	18.1	14.0	21.3	41.8	50.4	39.3	48.6
200	27.4	26.7	11.0	17.8	36.9	45.4	34.3	44.3
250	31.1	30.3	10.0	15.9	35.3	43.6	32.7	41.4

Frequency, MHz	ELFEXT, dB		PS ELFEXT, dB		ACR, dB		PS ACR, dB	
	Spec	AMP	Spec	AMP	Spec	AMP	Spec	AMP
1	64.2	74.1	61.2	73.6	63.1	82.2	60.1	79.9
4	52.1	64.1	49.1	63.3	60.6	74.4	58.3	71.9
8	46.1	59.8	43.1	59.0	54.4	65.4	52	63.8
10	44.2	58.4	41.2	57.5	52.2	62.7	49.9	61.5
16	40.1	58.6	37.1	56.7	47.6	56.1	45.2	54.5
20	38.2	57.9	35.2	55.0	45.2	55.1	42.8	53.7
25	36.2	54.6	33.2	51.7	42.6	50.8	40.2	50.1
31.25	34.3	51.6	31.3	48.5	40	50.2	37.5	48.8
62.5	28.3	41.5	25.3	40.5	30.7	40.5	28.3	39.0
100	24.2	41.3	21.2	39.7	23.2	32.8	20.7	30.3
200	18.2	34.2	15.2	32.7	9.5	19.2	6.9	16.9
250	16.2	30.0	13.2	29.1	4.2	13.8	1.6	10.3

Channel Performance Summary – 100-Meter/4-Connector Channel

The following tables list the worst-case ETL test results at each frequency for 100-meter Category 6 channels. The spec numbers are from Draft 10 of the TIA/EIA-568-B.2-1 Category 6 specification.

Frequency, MHz	Attenuation, dB		Return Loss, dB		NEXT, dB		PS NEXT, dB	
	Spec	AMP	Spec	AMP	Spec	AMP	Spec	AMP
1	2.1	2.0	19.0	26.0	65.0	83.1	62.0	80.9
4	4.0	3.8	19.0	28.0	63.0	75.9	60.5	72.6
8	5.7	5.4	19.0	27.8	58.2	67.3	55.6	66.0
10	6.3	6.1	19.0	28.2	56.6	66.0	54.0	64.8
16	8.0	7.7	18.0	28.6	53.2	64.7	50.6	63.0
20	9.0	8.7	17.5	25.7	51.6	60.4	49.0	58.7
25	10.1	9.7	17.0	25.5	50.0	59.8	47.3	56.7
31.25	11.4	10.9	16.5	26.9	48.4	60.0	45.7	57.4
62.5	16.5	15.7	14.0	24.2	43.4	52.1	40.6	50.7
100	21.3	20.2	12.0	20.4	39.9	50.4	37.1	48.4
200	31.5	29.2	9.0	18.2	34.8	44.4	31.9	42.6
250	35.9	33.2	8.0	15.2	33.1	41.3	30.2	39.3

Frequency, MHz	ELFEXT, dB		PS ELFEXT, dB		ACR, dB		PS ACR, dB	
	Spec	AMP	Spec	AMP	Spec	AMP	Spec	AMP
1	63.3	73.6	60.3	72.3	62.9	81.2	59.9	79.0
4	51.2	63.4	48.2	62.2	59	72.4	56.5	69.1
8	45.2	58.8	42.2	57.6	52.5	62.3	49.9	60.8
10	43.3	57.3	40.3	56.3	50.3	60.2	47.7	59.1
16	39.2	56.8	36.2	55.2	45.2	57.6	42.6	55.3
20	37.2	55.5	34.2	53.7	42.6	52.2	40	50.1
25	35.3	53.3	32.3	51.0	39.9	50.6	37.2	47.6
31.25	33.4	50.6	30.4	48.0	37	49.7	34.3	46.5
62.5	27.3	43.0	24.3	41.1	26.9	37.2	24.1	35.3
100	23.3	40.0	20.3	39.0	18.6	31.6	15.8	28.4
200	17.2	33.3	14.2	31.7	3.3	16.4	0.4	14.4
250	15.3	27.5	12.3	27.2	-2.8	9.5	-5.7	7.5

Bit Error Rate

Intertek Testing Services also tested the AMP NETCONNECT Category 6 System for bit error rate using the IEEE 802.3ab Gigabit Ethernet physical layer parameters. The following equipment was employed in conducting the tests:

Equipment Used	Model Number	Serial Number
Netcom Systems Multiport Port/Stream/ Analysis System Chassis	Smartbits 2000	7605 Rev. C1
Netcom Systems Smartcard	GX- 1420B	N00280060
Netcom Systems Smartcard	GX- 1420B	N00280061

The Category 6 System passed the active testing, generating zero bit errors.

Backward Compatibility

The NETCONNECT Category 6 System is fully backward compatible. Once your Category 6 System is installed, the following performance levels can be expected:

- Category 6 link with Category 6 Cords ⟶ Category 6/Class E performance
- Category 6 link with Cat 5e cords ⟶ Category 5e/Class D performance
- Category 6 link with Cat 5 cords ⟶ Category 5/Class D performance

Conclusion

The AMP NETCONNECT Category 6 System provides a future-proof cabling infrastructure in a complete, installer-friendly system. It exceeds the performance and bandwidth requirements for the proposed Category 6/Class E. It also exceeds the performance requirements being written for Gigabit Ethernet – Category 6 will be the foundation for the design of the next generation of LAN applications.