Synopsis

Gigabit Ethernet posed many challenges in its bid to operate over installed twisted pair cabling but the final solution was accomplished with a 1 million transistor silicon chip. The networking industry has since repeated this accomplishment with a 10 Gigabit system. This white paper describes its design and provides an assessment of the market need for 10 Gigabit over copper.

1. A New Ethernet Standard in June 2006

In November 2002, a study group was formed within IEEE 802.3 to investigate the prospect of 10 Gigabit Ethernet over installed twisted pair cabling. The group spent 12 months studying technical/economic feasibility and market potential before making its recommendations to develop a new Ethernet standard. Committee 802.3an was sanctioned in January 2004 and IEEE 802.3an was approved on 08 June 2006. This new LAN is known as 10GBASE-T and is based on 4-pair cabling with links up to 100m. Extensive Digital Signal Processing (DSP) was necessary and the signal bandwidth is an astonishing 400 MHz.

2. Ethernet a 1000-times Faster

Let's examine the evolution of copper-based Ethernet technology. 1000BASE-T emerged about 10 years after 10BASE-T. The increase in bit rate may be explained by Moore's Law, which states that speed doubles every 18 months. While this alone is impressive, the real technical achievement has been an increase of 100-times in bit rate with an increase in cabling bandwidth of only 6-times (Cat 3 to Cat 5). This has been accomplished via multi-pair transmission, the use of more efficient "smart" codes, and DSP technology.

It's also interesting to examine the relationship between Ethernet standards and cabling lifecycles (see figure 1). 10BASE-T was designed to operate over the installed base of voice-grade Cat 3 cabling and became a huge market success. 100 Mbit/s Ethernet attempted to follow the same approach but met with considerable technical difficulty associated with the 4-pair Cat 3 signalling system defined for 100BASE-T4. Ethernet engineers then recognised the dramatic takeoff of Cat 5 cabling and adopted the simple 2-pair signalling system already defined for FDDI TP-PMD. 100BASE-TX then became another phenomenal market success and 100BASE-T4 was abandoned. Gigabit Ethernet also followed the overwhelming desire to re-use installed cabling, which was then dominated by Cat 5. The delivery of 1000BASE-T missed its target delivery date by over 12 months due to DSP complexity plus the need to characterise Cat 5 ELFEXT and return loss. As we know, Cat 5e later became the de facto cabling for 1000BASE-T.

By the time 10GBASE-T devices are expected to reach the market in early 2007, shipments of Cat 6 and Cat 7 cabling will have been underway for 7 years. Market presence of Cat 6, and also Cat 5e cabling will therefore be significant during the life of 10GBASE-T products.

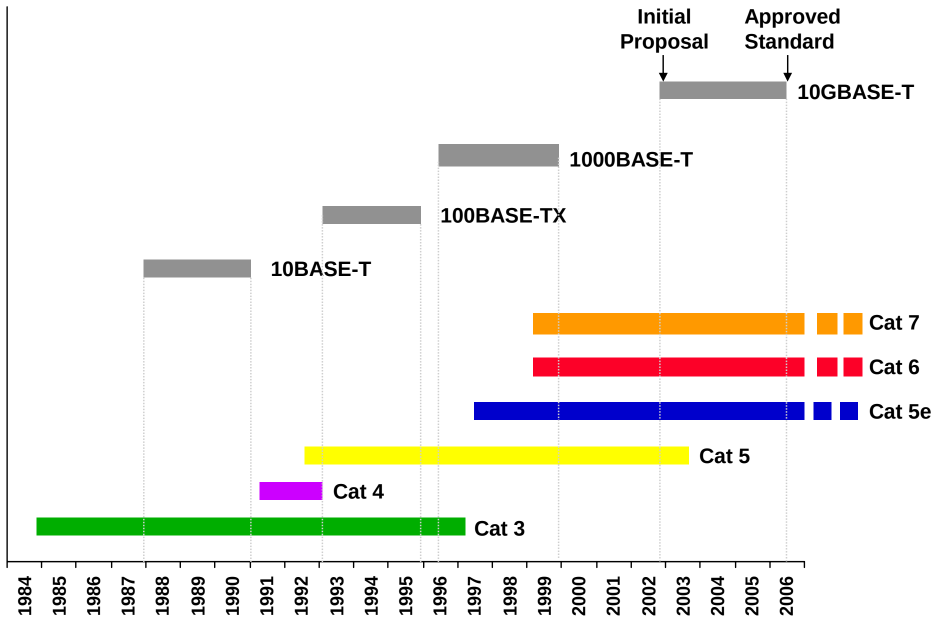

Figure 1: Relationship between Ethernet standards and cabling lifecycles

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3. Installed vs New Cabling

Estimates of worldwide installed cabling for December 2005 (see figure 2) indicated 50% penetration of Cat 5e/old Class D and 34% penetration of Cat 6/Class E. These estimates are based on BSRIA volume shipments and cable replacement rates from suppliers. While Cat 7 offers the best performance, its market presence is presently small. A new type of UTP cabling, known as "Class E_A" or "Category 6 Augmented", is also being introduced to support 10GBASE-T, however it's too early to predict deployment rates.

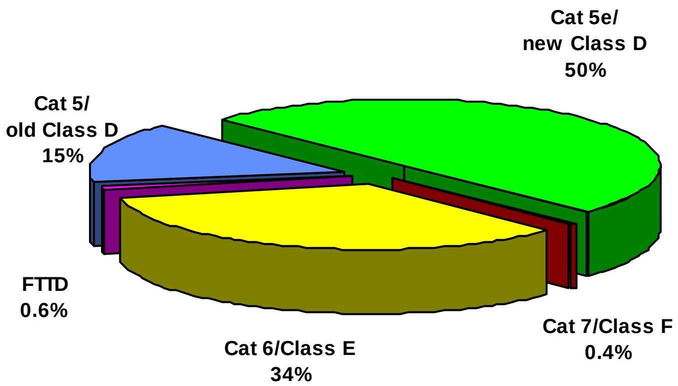

Figure 2: Worldwide Installed Cabling Forecast for Dec 2005 (source: LAN Technologies)

4. The Need for 10GBASE-T

Today's main application of 10 Gigabit Ethernet is Gigabit switch uplinks, used mostly for server clustering or data centre interconnect. The majority of these links are much less than 100m and the high cost of optical fibre implementations is presently the biggest obstacle to the deployment of 10 Gigabit Ethernet. 10GBASE-*fibre* products have not followed the traditional Ethernet *10x speed for 3x cost* model, and it's difficult to predict how quickly prices will fall. 10GBASE-T could represent significant cost-savings in this market space. Figure 3 shows relative cost trends for 10GBASE-T and 10 Gigabit over fibre; 10GBASE-T is forecast to cost approximately 40% of the cost of 10GBASE-F in 2006, reducing to 20% in 2008.

Data centre architecture is changing, as system architects plan to simplify the current model comprising 4 tiers (network comms, web servers, application services and backend storage) by collapsing network comms and web servers into a single tier. This new model would impose significant bandwidth pressure due to increased traffic aggregation. System designers stress that network performance is not simply a matter of sustained throughput. Latency is just as critical, and massive over-provisioning of cheap bandwidth may provide the most viable alternative to complex QoS features.

IT strategists also warn that ignoring 10 Gigabit to the desk may prove to be a mistake in the long term, as "today's server will become tomorrow's desktop". An interesting point, however this market could take some years to materialise.

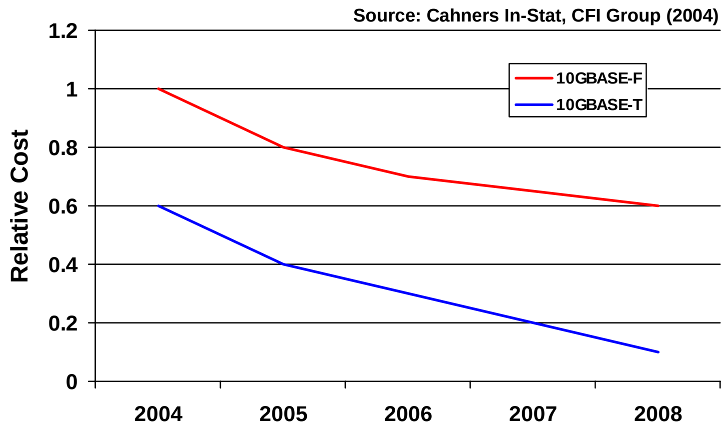

Figure 3: Relative Cost Trends of 10GBASE-T and 10GBASE-F

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5. 10GBASE-T Overview

10GBASE-T uses 4-pair transmission (shown in figure 4) and is designed to support up to 100 metres of high performance cabling (see below). The aggregate data rate of 10 Gbit/s is achieved by transmitting 2.5 Gbit/s over each pair. Hybrids and cancellers are used to facilitate simultaneous transmission in both directions (full duplex).

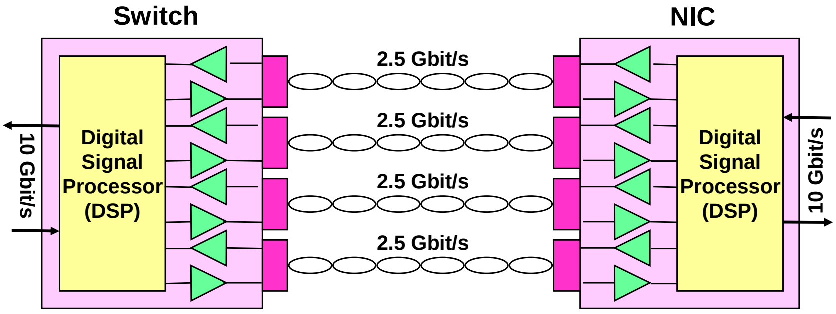

Figure 4: 4-pair full-duplex transmission used by 10GBASE-T

Just like 1000BASE-T, 10GBASE-T needs to take account of crosstalk and return loss impairments in the cabling, with near and far-end crosstalk having multiple disturbers. Channel limits are defined for PSNEXT, PSELFEXT and return loss. Due to the greater spectral bandwidth of 10GBASE-T signals, there is significantly more crosstalk from adjacent cables than 1000BASE-T (known as *alien* crosstalk and abbreviated as *AXT*). Consequently, channel limits are also defined for PSANEXT and PSAELFEXT, as these noise sources also involve multiple disturbers.

The DSP has been designed to provide the following levels of suppression with -150 dBm/Hz background noise:

- 55dB echo (i.e. return loss)
- 40dB NEXT
- 25dB FEXT

It is not practical to suppress AXT, as the DSP does not have access to the sources of disturbance. The DSP implementation will require at least 6 million transistors, which makes it at about 6-times larger than the chip developed for 1000BASE-T. Initial 10GBASE-T silicon implementations will use 65nm or 90nm geometry.

Code selection is a complex process, as designers need to balance robustness and bandwidth efficiency with implementation complexity. At one stage there were 6 candidates, including PAM5, PAM8, PAM10, PAM12 and PAM16. DSQ128 was eventually selected by IEEE.

10GBASE-T uses 16-level PAM (Pulse Amplitude Modulation) signalling in each pair. A two dimensional (2D) code is created using a pair of adjacent PAM16 symbols. This produces a constellation of 256 (16x16) values. Double SQuare 128 (DSQ128) is then constructed by pruning alternate points from the 16x16 array to produce 128 2D symbols (just like a checkerboard). The distance between adjacent points in the DSQ128 constellation is greater than that in a conventional PAM16 2D constellation, so increasing 10GBASE-T's immunity to noise.

The modulation rate of PAM16 symbols is 800 MSymbols/second (800Mbaud), which puts the Nyquist frequency for baseband signalling at 400 MHz. 10GBASE-T cabling is specified with an upper frequency of 500 MHz to provide adequate margin for transmission.

10GBASE-T uses Power Back-Off (PBO) to reduce AXT and also rf emission. PBO is used extensively with DSL to mitigate alien crosstalk and reduce rf emission. PBO discovers how long the channel is by measuring received signal power. Transmit power is then reduced for shorter channels to provide a better signal-to-noise ratio, as shown in figure 5.

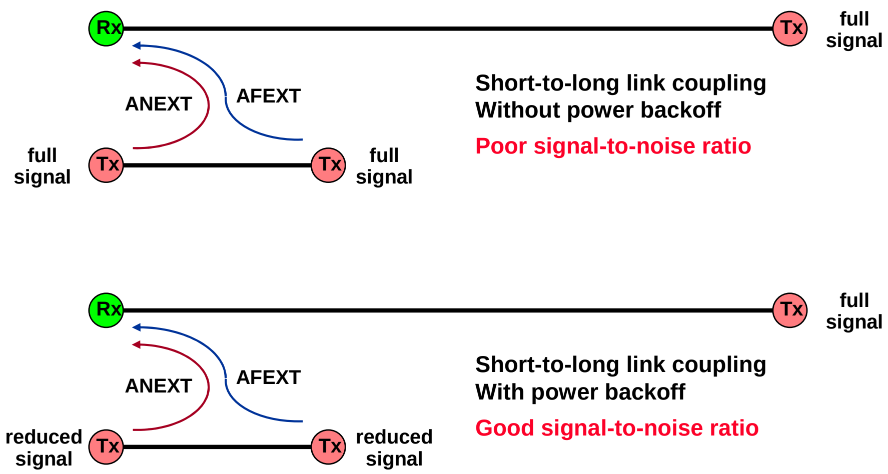

Figure 5: Power Back-Off

The choice of suitable cabling has been the subject of much debate. Installed cabling was characterised for performance at extended frequencies, including alien near-end and far-end crosstalk. Performance models were established for Category 5, 5e and 6, with a range of channel lengths for screened and unscreened cabling. This characterisation exercise was conducted with an upper frequency of 626 MHz in order to accommodate the most bandwidth-demanding code, PAM5. As previously stated, PAM5 was not selected.

Cabling models were first evaluated for Shannon capacity; this is a mathematical estimate of information capacity. A minimum Shannon capacity of 18 Gbit/s was agreed to be necessary to support 10GBASE-T, and it quickly became obvious that Category 5 cabling was not supportable. It was also clear that only very short lengths of Category 5e unscreened cabling were supportable. Consequently, Category 5 and Category 5e were removed as 10GBASE-T objectives. Screened cabling looked very promising at an early stage, due to the isolation of alien crosstalk. Category 7, screened Category 6 and even screened Category 5e were shown to be capable of supporting 100m operation, based on their Shannon capacity evaluation.

IEEE has worked closely with ISO/IEC and TIA to define appropriate cabling for 10GBASE-T, and a number of industry standards and guides are being produced by the cabling standards groups. Category 6, Category 7 and a new type of cabling known by ISO/IEC as “Class E_A” and by TIA as “Category 6 Augmented” are being specified for use by 10GBASE-T. Although there is no direct reference to Category 5e cabling, other types of cabling are allowed with a strong recommendation that links should be tested before 10GBASE-T devices are attached.

ISO/IEC is developing a Technical Report, TR-24750, to define installed Class E cabling up to 500 MHz, with the addition of alien crosstalk and test methods. This is expected to be approved early 2007. Class E_A and Class F_A cabling will be defined in ISO/IEC 11801 Edition 2.1. Specifications for Class E_A and Class F_A cabling are planned for 2008.

TIA is developing a Technical Systems Bulletin, TSB-155, to define installed Category 6 cabling up to 500 MHz, with the addition of alien crosstalk and test methods. This is also expected to be approved late 2006. Category 6 Augmented cabling will be defined in TIA568-B.2 Addendum 10, which is anticipated to be approved sometime during 2007.

A summary of cabling channel requirements for 10GBASE-T is as follows:

Insertion Loss: This is specified as Class E insertion loss extrapolated to 500 MHz, which is met by TR-24750. TSB-155 falls short at frequencies below 250 MHz, where the existing TIA insertion loss limit is used. The lower ISO/IEC Class E insertion loss limit is used above 250 MHz. Insertion loss requirements are exceeded by ISO/IEC 11801 Edition 2.1 and TIA 568-B.2 Addendum 10, which both use the lower Class F limit for insertion loss.

Return Loss: This is specified as Class E return loss extrapolated to 500 MHz, with a 6dB floor @ 400 MHz. This is met by TR-24750, TSB-155, TIA 568-B.2 Addendum 10, and ISO/IEC 11801 Edition 2.1 Class E_A.

NEXT: This is specified as Class E NEXT extrapolated to 330 MHz, then a steeper slope to 500 MHz. This is met by TR-24750 and TSB-155. It is exceeded by TIA 568-B.2 Addendum 10 Category 6 Augmented and ISO/IEC 11801 Edition 2.1 Class E_A, as shown in figure 6.

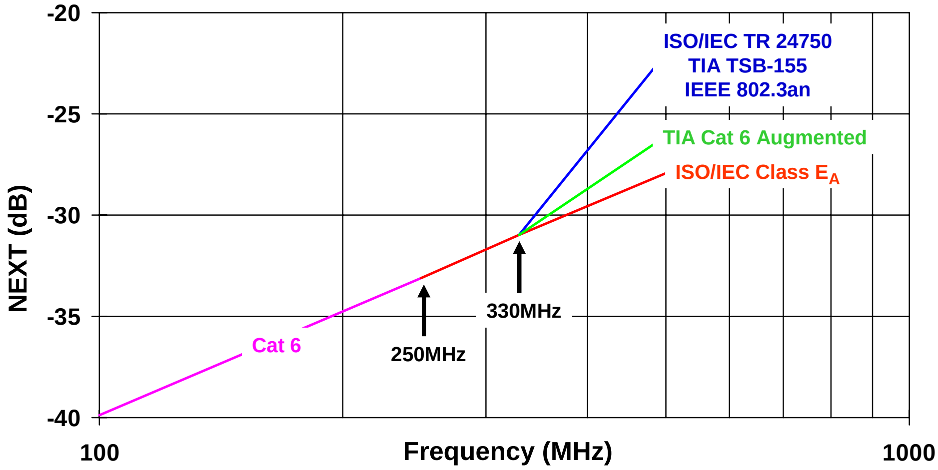

Figure 6: Channel NEXT Limits

PSNEXT: This is specified as Class E PSNEXT extrapolated to 330 MHz, a steeper slope to 500 MHz. This is met by TR-24750 and TSB-155. It is exceeded by TIA 568-B.2 Addendum 10 Category 6 Augmented and ISO/IEC 11801 Edition 2.1 Class E_A (refer to NEXT differences in figure 6).

ELFEXT: This is specified as Class E ELFEXT extrapolated to 500 MHz. This is met by TR-24750, TSB-155, TIA 568-B.2 Addendum 10 Category 6 Augmented and ISO/IEC 11801 Edition 2.1 Class E_A.

PSELFEXT: This is specified as Class E PSELFEXT extrapolated to 500 MHz. This is met by TR-24750, TSB-155, TIA 568-B.2 Addendum 10 Category 6 Augmented and ISO/IEC 11801 Edition 2.1 Class E_A.

PSANEXT: Power-Sum Alien NEXT limits are shown in figure 7. PSANEXT specifications are based on insertion losses at the channel lengths concerned. An explanation of the trade-off between insertion loss and PSANEXT follows. An additional 2.25dB is allowed for the PSANEXT average value of all 4 pairs.

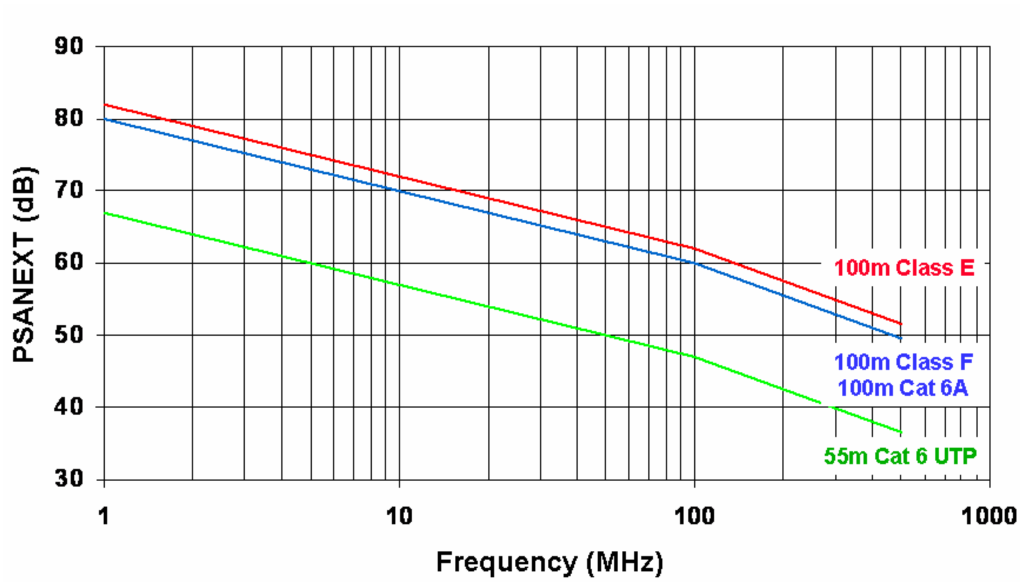

Figure 7: Channel PSANEXT Limits

Insertion Loss to PSANEXT Ratio: As signal-to-noise ratio is related to the ratio of insertion loss and PSANEXT, 10GBASE-T is designed to trade-off PSANEXT for insertion loss. In other words, more severe levels of PSANEXT may be accommodated at shorter channel lengths. PSANEXT to insertion loss ratio is specified by 10GBASE-T and is shown in figure 8.

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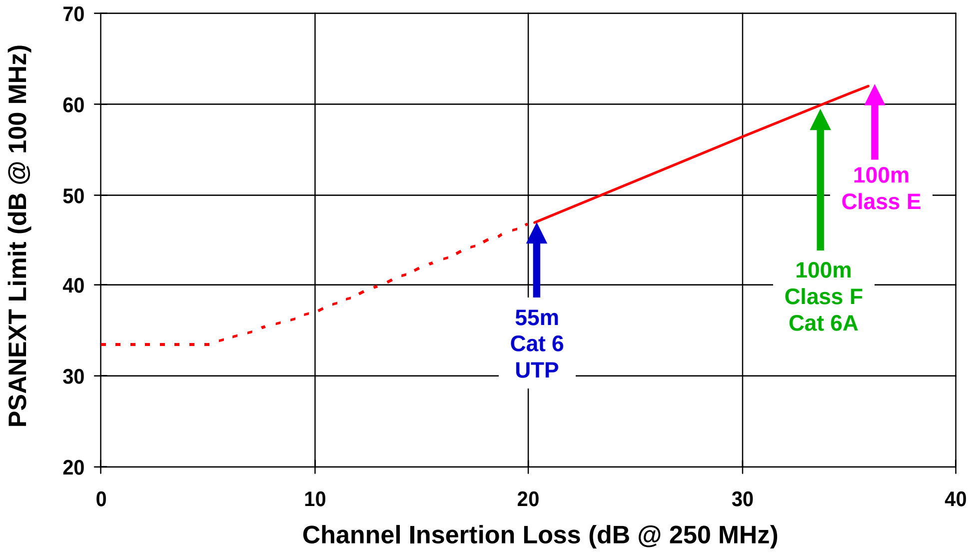

Figure 8: Channel PSANEXT to Insertion Loss Ratio

PSAELFEXT: Power-Sum Alien ELFEXT limits are shown in figure 9. PSAELFEXT specifications are based on insertion losses at the channel lengths concerned. An explanation of the trade-off between insertion loss and PSAELFEXT follows. An additional 4dB is allowed for the PSAELFEXT average value of all 4 pairs.

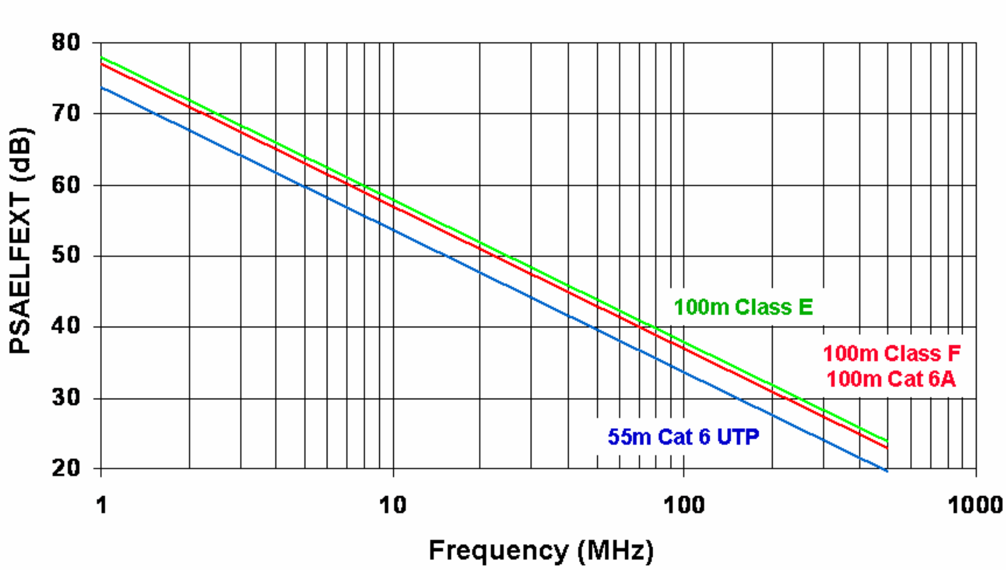

Figure 9: Channel PSAELFEXT Limits

Insertion Loss to PSAELFEXT Ratio: Signal-to-noise ratio is also related to the ratio of insertion loss and PSAELFEXT. 10GBASE-T is therefore designed to trade-off PSAELFEXT for insertion loss. As for PSANEXT, more severe levels of PSAELFEXT may be accommodated at shorter channel lengths. PSAELFEXT to insertion loss ratio is specified by 10GBASE-T and is shown in figure 10.

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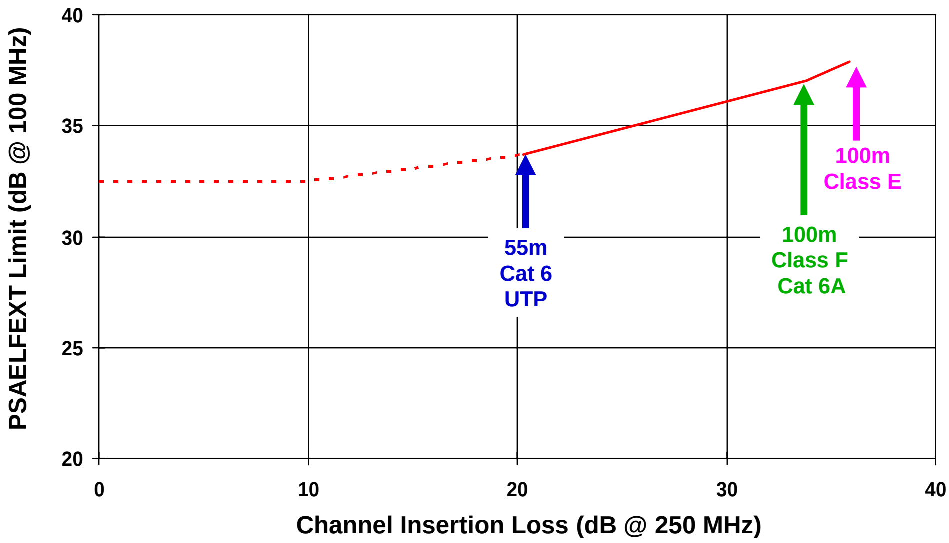

Figure 10: Channel PSAELFEXT to Insertion Loss Ratio

Cabling types and link distances supported by 10GBASE-T are summarised in Table 1. It is claimed that many installed Cat 6 unscreened links will require some alien crosstalk mitigation to support distances in excess of 55m.

Cabling	Supported Link Distances	Cabling References
Class E/Cat 6 unscreened	55m	ISO/IEC TR-24750/TIA TSB-155
Class E/Cat 6 screened	100m	ISO/IEC TR-24750/TIA TSB-155
Class F	100m	ISO/IEC TR-24750
Class E_A/Cat 6 Augmented	100m	ISO/IEC 11801 Ed2.1/TIA-568-B.2 AD10

Table 1: Cabling Types & Link Distances Supported by 10GBASE-T

Short Reach Mode: Early implementations of 10GBASE-T silicon are estimated to require up to 15 watts of electrical power, which makes high density packaging (such as X2 switch modules) impossible. As it could take several years for power levels to reduce below the 4 watts limit for an X2 switch module, an optional *short reach* mode has been defined for 10GBASE-T. Short reach mode is based on 30m Cat 7 or Cat 6_A cabling, including 10m cordage and 2 connectors. This facility is intended to provide 10GBASE-T devices to operate over shorter lengths of high performance cabling without the need for power-hungry elements such as NEXT and FEXT equalisers. No formal channel specification is provided

About Brand-Rex

Brand-Rex is a designer and manufacturer of copper and fibre based cabling systems, headquartered in Glenrothes, Scotland with facilities across Europe. Brand-Rex has two primary businesses: Connectivity and Speciality. Its Connectivity division designs and manufactures cabling systems (both copper and fibre) for data communications and is the No.2 player in Europe. The Speciality division exclusively produces cables that are used for control, communications, power and instrumentation within hostile environments.

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