10 Gigabit
Over AMP NETCONNECT™
Structured Cabling Systems

The XG Copper Cabling Solution

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Perspective

In less than ten years, LAN performance levels evolved from 10 Mbps Ethernet (10BASE-T) and 16 Mbps token ring to Fast Ethernet (100BASE-T) Ethernet and 155 Mbps ATM. Concurrently, twisted pair cabling system performance advanced from Category 3 through Category 4 to Category 5 to accommodate these applications. We have also seen the subsequent evolution of both Gigabit Ethernet (1000BASE-T), and a cabling standard for Enhanced Category 5 (Category 5e) to more readily accommodate this application. While Category 5e offers only a relatively minor improvement in performance over Category 5, new parameters and measurements were defined for Category 5e specifically to address Gigabit Ethernet. Shortly thereafter, a cabling standard for Category 6[1] was completed defining even more parameters and measurements that enabled a lower-cost variant of Gigabit Ethernet (1000BASE-TX).

The IEEE then began and subsequently completed a 10 Gigabit Ethernet (10GbE) Standard. Although there were several proposals to enable a copper-based PHY, the 10GbE Standard was published recognizing only optical fiber, including a new 50-micron multimode fiber (850nm laser-optimized 50/125µm per TIA-492AAAC), as acceptable media. Almost two years later, a 10GBASE-CX Standard was published enabling 10GbE on twinax cable (two-conductor coaxial cable), but only to a distance of 15 meters.

Today, a new project in IEEE hopes to define a 10GbE Standard on balanced (twisted pair) cabling. The purpose of this paper is to discuss issues related to 10 Gigabit applications and structured cabling systems. Because 10 Gigabit applications are not yet defined on twisted pair media, there is a continual stream of new product announcements and performance claims for twisted pair products. Trying to make sense of the claims, evaluate them on an even playing field, and selecting the best choice will make for an interesting challenge to say the least. This white paper will help make sense of what's real, what's hype and what you need to know to make the best decision.

Why even worry about 10 Gigabit?

To end users, it's simple: no one wants to wait – time is too valuable. All of that e-mail, those graphic-intensive multimedia files and web page downloads should fly through the network fast enough that each user feels as if he or she is on a real-time, no-delay, dedicated connection to the LAN. To the administrator, this need for speed equates to providing faster and faster data rates – more bandwidth. Data rates implemented on horizontal cabling systems have grown from 10 Mbps (megabits or millions of bits per second) to 100 Mbps, and to 1000 Mbps (or 1 *gigabit* per second) today. One-gigabit pipes in the horizontal will require more than a one-gigabit pipe in the backbones and in the data centers – hence the drive for 10-gigabit application standards.

[1] "Class E" is defined by ISO/IEC as 250 MHz twisted pair cable and connecting hardware and cabling systems (Class E). The ANSI TIA/EIA TR-42.7 standards body created a "Category 6" standard that includes cable, connecting hardware and cabling systems. Class E and Category 6 are defined similarly in these two standards.

What the Industry Wants

In an ideal world, the migration to 10 Gigabit Ethernet would be seamless on a generic cabling system. That means the application would be able to run on existing UTP cabling infrastructures up to a distance of 100 meters on balanced media (copper twisted pair) and up to 300 meters on multimode optical fiber. 10GBASE-SR and 10GBASE-LX4 are published standards that enabled the fiber solution to 300m, but the 100m distance on twisted pair media has proven to be difficult.

They solved it for Gigabit – they'll solve it for 10 Gigabit...right?

Actually, it's not that simple. Even when they "solved" it for Gigabit, they still needed to redefine Category 5 cabling – that's why there is Category 5e and Category 6 cabling. Category 5, even good category 5, couldn't always get to 1 Gigabit Ethernet (1000BASE-T) in a four-connector channel. Even with Category 5e cabling, there was still a lot of digital signal processing required to compensate for cross-talk and echo. Category 6 cabling relieved some of the digital signal processing load, so it can run a less-expensive variant of Gigabit Ethernet (1000BASE-TX). However, even Category 6 does not look to be sufficient for 10 GbE except at sub-100m lengths. Nor does Category 6 cabling with extra margin (some manufactures are offering "Category 6E" products (even though there is no such defined "6E" standard).

Why? Simply put, the higher symbol rate of 10G requires higher signal bandwidth. Cat 5e (Class D), if used, will be utilized beyond its specified frequency range. Even Cat 6 (Class E) will have to have its performance characterized beyond 250MHz (that's why TIA is preparing TSB-155).

Increasing the bandwidth, alone, still doesn't resolve all the issues. Compensation for cross-talk and echo can be addressed through brute-force digital signal processing, but at these data rates and using the faster encoding schemes, the radiated electrical noise (cross talk) from other cables becomes problematic. This "alien" cross talk (Alien NEXT or ANEXT) cannot be sampled, nor even easily measured, so it is not easily compensated (unlike internal cross talk like near-end and far-end cross talk).

Alien NEXT is agreed to be the limiting noise source, particularly since 10GBASE-T would be self-disturbing (noise from other 10G links adversely affects each 10G link). The worst case configuration is metal conduit filled to capacity with 10GBASE-T cabling links. Although there are various mitigation techniques proposed (some are based on modifying installation practices such as minimal cable separation, some are based on advanced signal processing based), the fact that alien NEXT cannot be directly cancelled remains. Accordingly, there is quite a bit of effort studying this parameter.

That can't be the end of it...what now?

Let's start with some basic facts for 10 GbE. First, the 10GbE Standard has been published for fiber – that means a 10-gig signal can be generated, transmitted and even tested at the board level. Second, the standard for twinax has been defined, so copper media can carry a 10-gig signal. Third, alien crosstalk is problematic and cannot be compensated using digital signal processing. That's about it until the IEEE proceeds further down the development process.

So...it’s all in the hands of the IEEE...

That’s true, more or less. As a consensus-driven standards body, the decisions can be made, unmade, revisited or set in stone at each meeting (usually every two months). But there is some indication of what the IEEE will be doing based on the objectives adopted for the Standard.

First, the desire to keep the 10G standard as an Ethernet standard is clear. That means preserving the 802.3/Ethernet frame format, preserving the minimum and maximum frame size, and supporting the star-wired local area network using point-to point links and structured cabling topologies.

Second, to build on the existing 10GbE Standards, the desire to support full duplex operation only and support a speed of 10.000 Gb/s at the MAC level is also clearly defined in the objectives.

Third, there is the desire to have a standard compatible with other efforts in 802.3 – specifically to support Clause 28 auto-negotiation, and support coexistence with 802.3af (DTE Power via Ethernet).

Uh, what does THAT really mean?

That means some educated predictions can be justified, although at this point the final outcome is many months away. To get to the 10-gig data rate, either a bandwidth-intensive, low-level modulation (like PAM-5, with 5-level pulse amplitude modulation) or a signaling-intensive, higher-level modulation (like PAM-12, with 12-level pulse amplitude modulation) will be required.

If a PAM-5 solution is selected, for example, the structured cabling would need to be characterized for a 1250 Mbaud signal, requiring an operational bandwidth of 625 MHz.

If a PAM-12 solution is chosen, also for example, the burden shifts somewhat to the electronics but the cabling would still need a bandwidth of about 430 MHz.

So, regardless of the signaling, the bandwidth will be beyond the 200 MHz frequency requirement of Category 6. Also, it is clear that far-end crosstalk (FEXT) will need to be cancelled for 10G, and there is still the alien crosstalk to consider as well.

So...Category 6 isn’t the answer, or is it?

Well, it will depend on the situation. There are two more specific IEEE project objectives. One is to support 55 to 100 meters on Category 6 cabling. So, assuming the objectives are met at the end of the project, Category 6 as it is currently defined will be able to support 10GbE to some extent.

The other objective is to support a distance of 100 meters on Class F cabling. Class F cabling is defined in ISO/IEC 11801 (basically the international equivalent to TIA-568). Class F cabling is a shielded cabling system characterized to 625 MHz. Obviously, the shielding makes a difference in performance and helps mitigate the alien crosstalk problem, hence the longer distance objective.

How were the distance objectives determined?

Needless to say, there has been a lot of recent study, research and development but the basis goes back to theoretical capacity. Claude Shannon, a Bell Labs scientist, developed a formula to determine the maximum capacity of a channel in a noisy environment...it's called Shannon's Law.

Shannon's Law

Shannon's Law shows that there is a theoretical maximum amount of information that can be transmitted over a bandwidth-limited carrier in the ever-present background noise.

$$C = W \cdot \mathit{log}(2(1 + S/N))$$

Where: C = bits per second (channel capacity, or "Shannon Capacity")

W = frequency (bandwidth)

S/N = signal-to-noise ratio

So, for a constant frequency, the capacity is basically determined by the signal-to-noise ratio (SNR). A higher SNR means more capacity. Higher noise means less capacity. Solving the equation for the bandwidth needed to support 10-gig yields a Shannon capacity number of 18-22, depending on the assumptions for SNR.

Testing Shannon's Law – Shielded Twisted Pair

To generate noise for the channel under test, six cables were placed around the measured cable at a length of 100m. A shielded (FTP, or PiMF - "pairs in metal foil") Category 6 channel was tested. Two encoding schemes (PAM-5 and PAM-10) were used; PAM-10 at ~833MHz and PAM-5 at ~1250MHz, and varying magnitudes of cancellation (echo, NEXT and FEXT) were applied. Finally, input powers from 5 dBm to 9 dBm were used for this testing.

Shannon Capacity Comparisons for FTP cable and Channel Connectorization

Symbol Rate (MHz)	Input Power (dBm)	Background Noise (dB)	ECHO Cancellation (dB)	NEXT Cancellation (dB)	FEXT Cancellation (dB)	Cable Shannon Capacity (Gb/s)	**Channel Shannon Capacity (Gb/s)**
833	7	-150	50	30	10	23.5	**20.7**
833	7	-150	55	40	25		**21.5**
833	7	-145	55	40	25		**19.4**
833	8	-150	50	30	10	23.9	**21**
1250	5	-150	50	30	10	26.1	**22.4**
1250	5	-150	50	40	0	25.8	**20.9**
1250	5	-150	55	40	25		**23.4**
1250	5	-145	55	40	25		**20.3**
1250	7	-150	50	40	10	27.6	**24**
1250	7	-150	55	40	25		**24.4**
1250	7	-150	60	30	10	27.6	**23.4**
1250	7	-145	55	40	25		**21.6**

Although, at first, this table seems to just show a bunch of numbers, here are the important conclusions from the testing. First, note that in all cases the Shannon capacity was well above 18.

Also, note that:

- A higher symbol rate had a strong negative effect on Shannon Capacity (SC)
- An increase in input power had a slight, positive effect on SC
- Even a slight increase in background noise had a strong negative effect on SC

This all validates Shannon's Law and demonstrates that an FTP solution is capable of handling a 10-gig application and justifies the IEEE objective.

Testing Shannon's Law – Unshielded Twisted Pair

Using a similar setup, a standards-compliant unshielded Category 6, 100m channel was tested.

Shannon Capacity Comparisons for UTP cable and Channel Connectorization

Symbol Rate (MHz)	Input Power (dBm)	Background Noise (dB)	ECHO Cancellation (dB)	NEXT Cancellation (dB)	FEXT Cancellation (dB)	Cable Shannon Capacity (Gb/s)	**Channel Shannon Capacity (Gb/s)**
833	8	-145	55	40	25	10.9	**9.9**
833	8	-150	50	30	10	10.9	**9.9**
1250	8	-150	55	40	25	10.9	**9.9**
1250	8	-145	55	40	25	10.8	**9.8**
1250	8	-150	50	30	10	10.9	**9.9**

In this table, it is easy to notice how much lower the Shannon Capacity is for unshielded twisted pair systems – far below the 18-22 value for 10G.

In this test, however, even large changes in variables had minimal effect on Shannon Capacity. This is because the noise becomes such a significant factor that even a reduction in bandwidth and increased cancellation are not enough to overcome its influence. This testing validates why the IEEE had to significantly reduce the predicted supportable distance on Category 6 cabling, and why IEEE has to consider a higher-level PAM. Thus, the bottom line is that Category 6 cable has to be improved significantly to overcome alien cross-talk and be able to support 10GbE to any appreciable distance.

Shannon's Law – Conclusions

This is a small sample set, but it provides a good representation of system performance. Clearly, STP and PiMF cables have roughly the same Shannon Capacity and, with conservative assumptions, both are sufficient for 10Gb/s. Standard Category 6 or even "enhanced" Cat 6 (Category 6 with NEXT headroom) UTP cable and channels do not have sufficient Shannon Capacity for 10GbE.

10G Today

If migration to 10 GbE is a consideration for a network installation today, there are some options.

Optical fiber provides a proven, available and cost-effective solution that will support standards-based structured cabling networks. Looking forward, there is little doubt that the shielded twisted pair (STP) system will also offer the necessary bandwidth to support the 10GbE Standard when it is published. Category 6, as it is currently defined, will likely support 10 GbE to some distance (remember the objective is at least 55 meters), and that may be enough to cover the network requirements.

So...what's next?

IEEE will determine the fundamental network standard in the 2006-2007 timeframe. Between now and then, there will be a lot of effort, research, development, testing, debate and confusion. However, if the Gigabit Ethernet Standard is any indication, there will be a broad effort of cooperation in IEEE, TIA, CENELEC and ISO. Several techniques, such as analog signal conditioning, alien noise suppression, and improvements in the cabling specification have already been presented in the IEEE study group. Already, work has begun in TIA to define an "augmented" Category 6 cabling – a Category 6 that might be capable of supporting a 100m distance – through the 568B.2 Addendum 10 document, which is still only in draft form.

One thing is clear, though; the debate over the assumptions and appropriate levels of compensation will be extensive. Specifically, the background noise assumptions (130dB vs. 150dB) are critical, as the advantages of using a lower noise value must be balanced with the noise encountered in the real world. If the assumptions are too low, there will be little guarantee of success when the application is run, or the requirements for cable separation will be impractical for today's networks.

How is Tyco Electronics solving the problem?

Tyco Electronics is determined to offer our customers solid, standards-based solutions. That's why the AMP NETCONNECT XG Copper Cabling Solution was released. The XG Copper Cabling System offers the best combination of shielding, Shannon Capacity and bandwidth to ensure this cabling solution will meet the needs of the 10 Gigabit Ethernet Application when it is published.

Why shielding, Shannon Capacity AND bandwidth?

The simple answer is, "It takes all three". Shielding, alone, is insufficient – although it goes a long way to solve ANEXT issues. Similarly, a high Shannon Capacity (18-22 Gbps) is good, but alone will not determine a cabling system's ability to support 10GbE, and neither will a high bandwidth (500 MHz or more).

So, a reasonable, conservative approach argues for all three, and that's just what the XG Copper System provides: shielding, a Shannon Capacity greater than 18 Gbps and a bandwidth higher than 500 MHz.

What about an unshielded system solution?

Rest assured that Tyco Electronics is actively participating in IEEE, TIA and ISO. The uncertainty surrounding an unshielded solution for 10GbE is evident in all of these standards bodies. That has not stopped other suppliers from offering unshielded systems and components defined to their own interpretations, but it has stopped Tyco Electronics from prematurely offering a solution that may not ultimately meet the requirements of these still developing standards. As the unshielded components, testing and systems become defined, we will be working on an unshielded solution to comply with the standards.

Conclusions

How the IEEE 10GbE Standard, as well as the related cabling standards, will eventually conclude is still too difficult to determine. Accordingly, educated evaluations of the objectives and currently-available product shows that STP or FTP solutions offer a very good cost/benefit balance for 10GbE even though these systems are not well-known outside of Europe. Similarly, optical fiber offers a great solution today for your 10 GbE applications of tomorrow. Fortunately, Tyco Electronics has a complete line of shielded and optical fiber cabling products in our AMP NECONNECT XG Fiber and XG Copper Cabling Systems.

The picture is less clear for UTP systems. Although end-user comfort level is high in North America, and there is a tremendous and growing installed base, the development path for a 10G UTP solution is the most difficult to confidently predict.

When considering the network cabling options that are available, it may help to consider each segment of the network individually. Just as most installations today use optical fiber in the backbone and twisted pair in the horizontal, it may make sense to combine two or more media types (fiber, STP, and UTP) rather than make the decision on an “all-for-one” basis.

Over the next two years, the development path and product requirements will develop and it will get easier to predict what will happen. Count on Tyco Electronics, an active participant and leader in the industry and standards to keep you informed.