An overview of the requirements, testing parameters, and applications for Gigabit Ethernet

Overview of Gigabit Ethernet (1000Base-T)

Ethernet was developed by the Xerox Corporation in the early 1970's and has emerged as the dominant networking protocol. When compared to the installed base of other networking protocols, such as Token Ring, FDDI, and ATM, Ethernet has, by far, the greatest number of installed ports. Ethernet also provides greater cost performance than any other protocol due to its wide availability and market penetration. When Fast Ethernet was developed, increasing Ethernet speed from 10 to 100 megabits per second (Mbps), it provided a reasonably simple, cost effective option for network managers to deploy bandwidth-intensive applications over their local area networks while maintaining their existing infrastructure.

Although the 10 Gigabit Ethernet Standard has recently been ratified, Gigabit Ethernet is the most popular Ethernet development. It provides for the data speed to 1000 Mbps or 1 gigabit per second (Gbps).

The Gigabit Ethernet Standard was ratified in June 1998 by the Institute of Electrical and Electronic Engineers (IEEE). The IEEE 802.3z standard defines the requirements for Gigabit Ethernet for optical fiber, and 150 ohm shielded twisted pair (STP) cabling. 1000 Base-CX defines the requirements for Gigabit Ethernet over a special balanced shielded twisted pair cable for a maximum distance of only 25 meters. Based on demand and technological gains, it was determined that it was both necessary and viable to develop a protocol to run Gigabit Ethernet over 100 meters of unshielded Category 5 cable. In June of 1999 the IEEE 802.3ab committee ratified the 1000 Base-T standard that defines the requirements for Gigabit Ethernet over Category 5 unshielded twisted pair (UTP) cabling.

More than 80 percent of the network cabling in buildings today is copper. Network managers and planners can implement 1000 Base-T for their LANs over the existing Category 5, Category 5e, and Category 6 infrastructures. This paper will address the technical fundamentals of implementing Gigabit Ethernet in a simple and cost effective manner.

1000 Base-T requires utilizing all four pairs in 100-ohm Category 5 or better UTP cable to transmit and receive data simultaneously, in other words full duplex transmission on all four pairs. Each pair can carry up to 250 Mbps of full duplex data signals encoded in a 5 level Pulse Amplitude Modulation (PAM-5) coding scheme. The physical layer device for a 1000 Base-T link consists of four identical transceivers, each with its own transmitter and receiver (Figure1).

Please refer to appendix for further detail and explanation of the encoding scheme.

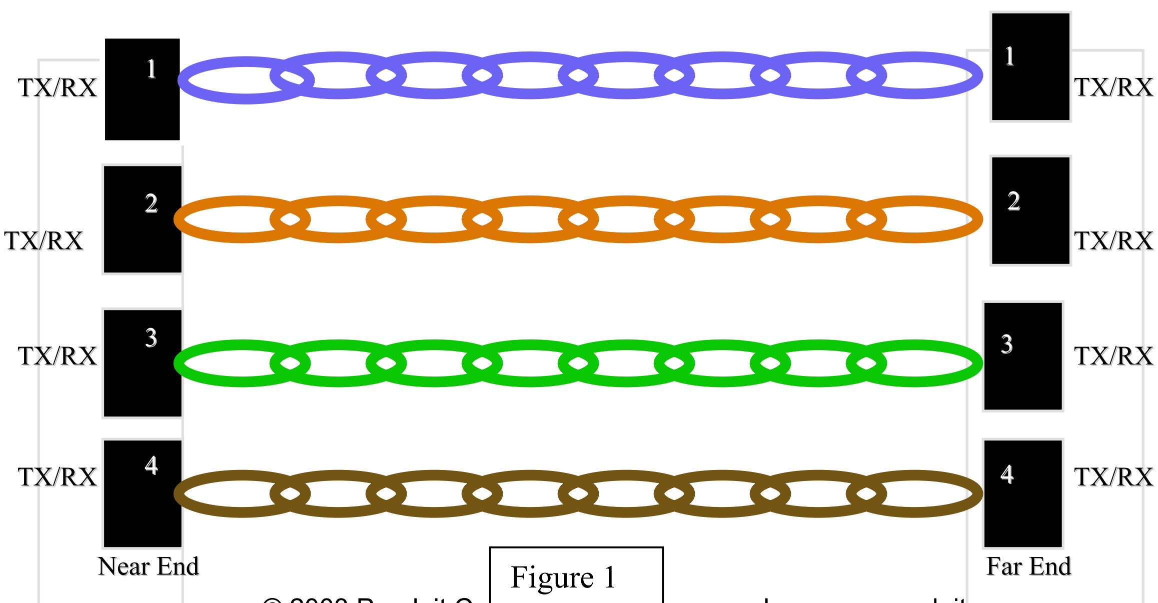

Figure 1

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Applications for Gigabit Ethernet

Applications are requiring more and more bandwidth as the throughput of computers increases. Applications that require high-resolution graphics, video, and other rich media data types are creating a greater demand for bandwidth. Amongst these applications are scientific modeling and engineering, desktop publishing, data warehousing, video conferencing, and the Internet.

These applications require the transmission of large files over the network. Scientific applications communicate 3-D visualizations of objects ranging from a small screw to an automobile. Engineers use electronic and mechanical design automation tools to work interactively in development teams that are located in different facilities all over the world. Medical facilities transmit MRI images over Local Area Networks (LANs) and Wide Area Networks (WANs).

Data warehousing provides enterprise data to be available to key decision makers for analysis and reporting while maintaining the performance, integrity, and security of the production systems. These warehouses are available to be accessed by thousands of users and may provide terabytes of data distributed over hundreds of platforms. To assure that the data remains real time for critical analysis and reports, it must be updated continuously.

The Internet continues to become more and more prevalent as a means of communications for organizations. Many companies use the Internet to develop private intranets for e-mail and as a resource for critical data through Web browsers. It is expected that in the near future there will be more applications for audio, video, and voice to go along with the current applications for text, graphics and images over the Web.

What are the system requirements for Gigabit Ethernet?

At the time that the IEEE standards workgroup defined the goal for Gigabit Ethernet over twisted pair copper cabling, Category 5 was the most common cabling system. Therefore the IEEE 802.3ab standard specifies that the electronic components of the network (network interface cards(NICs), and hubs or switches) shall be able to transmit over a copper channel that meets the Category 5 requirements as was defined in the Telecommunications Industry Association (TIA) 568-A standard. However 1000-Base-T utilizes all four of the pairs in the cable to transmit data rather than the traditional two pair method that was common when the TIA 568-A standard was drafted. Therefore an investigation was held to ensure that the performance parameters in the 568-A standard were sufficient for Gigabit Ethernet.

The performance parameters for the TIA/EIA 568-A standard were defined in TIA Telecommunications Systems Bulletin (TSB) 67. TSB 67 defined four sets of performance criteria: length, attenuation, wire map, and near-end crosstalk (NEXT).

Length: Verifies that the length of the installed horizontal cabling link does not exceed 90 meters (295 feet) for the permanently installed cable that is terminated in the Telecommunications Room at one end and at the work area outlet at the other. A channel is defined as the Permanent Link (90 meters max.) plus up to an additional 10 meters (33 feet) of patch cord in the Telecommunications Room and equipment cord at the work area outlet for a maximum distance of 100 meters (328 feet).

Attenuation: A measure of the strength of the signal at the receiver in proportion to the strength of the transmitted signal. A measurement of signal loss measured in dB. The lower the dB value the better the attenuation performance.

Wire Map: A continuity test. Assures that the individual wire pairs are properly connected from one end to the other without any breaks, short circuits, or miswiring.

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Near-End Crosstalk (NEXT): A measure of undesired signal coupling from one pair to another within the cable that causes disturbance of the transmitted signal. NEXT is the signal coupling measured at the end of the cable from which the signal is transmitted. Measured in dB, the higher the dB value the better the NEXT performance.

Due to the fact that 1000 Base-T utilizes all four pairs in the cable to carry signals simultaneously in both directions, additional sources of crosstalk and disturbance must be considered. It was determined that additional test parameters would need to be defined by the TIA standards committee. It was also recommended that any existing Category 5 installations would have to be re-tested to the newly defined parameters to assure that the requirements for 1000 Base-T are met. All of these new requirements were defined in a new document published as TSB 95 by TIA/EIA as an informative bulletin.

TSB 95

The noise at each of the four receivers in a 1000 Base-T device consists of near end crosstalk (NEXT), far-end crosstalk (FEXT), transmit echo (Return Loss), and ambient noise. The crosstalk disturbance on a wire pair for 1000 Base-T is no longer the result of only one other wire pair, as with 100 Base-T two pair transmission, but from all three of the remaining pairs in the cable. These factors led to the development of new tests for Gigabit Ethernet systems. These new tests were developed by the TIA and implemented as TIA/EIA TSB 95. TSB 95 defined the test parameters required for certifying existing and new Category 5 installations for 1000 Base-T. These were also the test parameters required for TIA/EIA 568-A-5, which was the standard that first defined the performance for Category 5e systems.

The test parameters defined in TSB 95 in addition to Attenuation and NEXT were:

Power Sum NEXT (PSNEXT): NEXT measurements require that each pair in the cable be measured against each of the other pairs for signal coupling. Power sum near end crosstalk is a calculation of an individual pair signal strength relative to the combined effect of coupling from the other three pairs in the cable. Measured in dB, the higher the dB value the better the PSNEXT performance.

Far End Crosstalk (FEXT): A measure of undesired signal coupling from one pair to another within a cable measured at the end opposite relative to the transmitted signal. Measured in dB, the higher the dB value, the better the FEXT performance.

Equal level Far End Crosstalk (ELFEXT): A FEXT measurement that also accounts for the attenuation factor that has occurred as the signal has been transmitted across the length of the cable. Measured in dB the higher the dB value, the better the ELFEXT performance.

Power Sum Equal Level Far End Crosstalk (PSELFEXT): An ELFEXT measurement that considers the combined effect of ELFEXT disturbance on one pair from the other three pairs in the cable. Measured in dB, the higher the dB value the better the PSELFEXT performance.

Return Loss: A measure of the signal that is reflected back to the transmitter due to any impedance changes in the cabling link. Measured in dB, the higher the dB value the better the Return Loss performance.

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The physical layer requirements for Gigabit Ethernet and Category 5 cabling are shown below in Table 1:

Table 1		
Channel Requirements @ 100 MHz	**1000 Base-T Gigabit Ethernet Physical Layer Requirements**	**TIA/EIA Category 5 Requirements**
PSNEXT (dB)	22.3	N/A
PSELFEXT (dB)	14.4	14.4
Return Loss (dB)	8.0	8.0
Propagation Delay (ns/100m)	570	570
Delay Skew (ns/100m)	50	50
Attenuation (dB)	24.0	24.0

Existing Links

Based on these new parameters, the installed base needed to be re-tested to ensure the links met the new specifications before the network was upgraded to Gigabit Ethernet. The reason for this concern is the limits for the parameters of the tests outlined in TSB 95 are equal to the limits of the IEEE requirements for Gigabit Ethernet at 100 MHz. This did not leave any margin for headroom in the system. There was a great deal of concern as to the number of existing Category 5 links that were improperly installed. Would these links pass the new requirements? *Studies found that less than 10 per cent of the installed base of Category 5 cabling was not installed in accordance to the TIA/EIA 568-A standard. In reality most Category 5 links will perform significantly better than minimum Category 5 requirements due to the quality of the components (cable and connecting hardware) and as long as proper installation practices were followed. Attenuation will vary according to the length of the cabling link*. The shorter the link, the less the signal is attenuated. Most channels are significantly less than the 100-meter maximum. Therefore, there is typically more margin for attenuation. Most of the problems are not with the cable itself, but are usually the result of the connectors in the link, cabling installation practices and bundling.

TIA/EIA defines five recommendations that can be taken to improve Return Loss and Far End Crosstalk of failing links. These recommendations are:

- Replace the existing patch cord with a Cat 5e or Cat 6 rated patch cord
- If a cross-connect has been implemented, reconfigure the cross-connect as an interconnect
- Remove the transition point connection
- Replace the work area outlet connector with a Cat 5e or Cat 6 rated device
- Replace the interconnect with interconnect components rated Cat 5e or Cat 6

New Installations

Since the ratification of Gigabit Ethernet over copper, all of the addenda and TSB's for the TIA/EIA 568 standard up to TIA/EIA 568-A-5 have been incorporated into the TIA/EIA 568 B standard. The 568 B standard is divided into three sections. TIA/EIA 568 B.1 lists the general requirements for installing cabling systems in commercial buildings. 568 B.2 lists the requirements for copper cabling systems. The TIA 568-B.2.1 standard lists the requirements for Category 6 cabling systems.

One of the major changes in this document is Category 5 is no longer a recommended standard. Category 5E has replaced Category 5 as the defacto standard for data communication installations. This was done because Category 5E offers significant improved performance over Category 5 that will reduce errors and improve the network performance. Also, IEEE has recommended that all future cabling installations that will run Gigabit

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Ethernet should minimally use Category 5E cabling. Category 5 cabling has been moved to an informative appendix of this document.

The conventional structured wiring model that is predominantly implemented today in commercial buildings utilizes optical fiber for the backbone cabling and UTP copper for the horizontal cabling. There is no reason to divert from this scheme unless there is a security issue, EMI/RFI is a concern, or the distance from the telecommunications room to the work area outlet exceeds 100 meters. It is not necessary to run optical fiber to the desk for Gigabit Ethernet. Primarily, optical transceivers are more expensive than copper transceivers. In addition to the cost factor, the IEEE 802.3 Data Terminal Equipment (DTE) Task Group is presently looking into developing a standard to provide power to network communications devices over UTP copper cabling. Such devices include LAN phones, IP phones, Web cameras, and other devices. At this time there is no technology available to provide power to these devices over optical fiber.

A few factors were not taken into account when it was suggested that any Category 5, Category 5E, or Category 6 cabling system would run Gigabit Ethernet. Three primary factors that will affect the performance of your cabling system are:

1. Poor installation practices can degrade the channel PSNEXT loss by approximately 2dB. This degradation is caused by untwisting of the pairs beyond the maximum allowed ½ inch when terminating the jacks, or routing the cable with multiple sharp bends in violation of the recommended 1 inch minimum bend radius, or adding any kinks to the cable and exceeding the maximum pulling tension on the cable during installation.
2. Bundling of multiple cable through the horizontal run can degrade the PSNEXT channel performance by approximately 3 dB due to coupling between pairs on adjacent cables (also known as alien crosstalk). It is important to note that current hand held field testers measure the coupling between pairs within a four-pair cable, but do not measure the coupling between pairs from multiple cables.
3. Four connector topologies (consolidation point option) offer further degradation of the channel return loss. In general, additional connectors provide some channel return loss degradation because of reflections between connectors.

As a result structured cabling systems intended to support 1000 Base-T should be enhanced beyond the physical layer requirements of 1000 Base-T. It is projected that the values described below and summarized in Table 2 should be the minimum considered in order to help ensure a successful 1000 Base-T implementation.

1. PSNEXT loss is increased by 5dB over the 1000 Base-T specification as compensation for 2-dB degradation due to poor installation practices, and 3-dB degradation due to cable bundling.
2. Return loss should be increased to 10dB as it is easily obtained with high quality Category 5E components and its performance is critical for 1000Base-T operation.

Table 2

Channel Requirements @ 100MHz	**TIA/EIA Category 5E Requirements**	**TIA/EIA Category 6 Requirements**	**Projected Requirements**
PSNEXT (dB)	27.1	37.1	27.3
PSELFEXT (dB)	14.4	20.3	14.4
Return Loss (dB)	10.0	12.0	10.0
Propagation Delay (ns/100m)	570	555	570
Delay Skew (ns/100m)	50	50	50
Attenuation (dB)	24.0	21.3	24.0

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To meet these more stringent requirements, Category 5E or Category 6 cabling should be used. Category 6 cabling represents the absolute best performance available today with industry standard RJ-45 connectors. Installing this capability today provides peace of mind and guards against obsolescence as the burden of the cabling system will continue to soar as a result of greater and greater networking requirements up to and beyond 1 gigabit per second. Also, it is projected that 1000 Base-T hubs/switches and NICs intended for use with a Category 6 cabling plant will be less complex and therefore less expensive than the 1000 Base-T hubs/switches and NICs designed for use with a Category 5 or Category 5E cabling system.

This does not mean that all users should abandon Category 5E and pursue only Category 6. A prudent strategy that could be used to choose between the two categories is to do a needs analysis of the projected network requirements that the cabling system will be called on to support in the foreseeable future. The analysis should include at a minimum a consideration of the following issues:

- Type of business
- Five year projected growth of the business
- General maturity of the industry.

For example, a Category 5E cabling system is probably sufficient if your business computing is dominated by word processing and simple spreadsheets in an industry which the products or services are not expected to drastically change. Conversely, if your business is a growing software-engineering firm or a worldwide financial firm where multiple users must transfer large data files and/or perform complex calculations, a Category 6 cabling system is probably a wise investment.

Summary

In order to remain competitive, commercial businesses are placing more and more reliance on their network. Vital, time sensitive business information must be efficiently communicated throughout the commercial office. IEEE had the foresight to develop a Gigabit Ethernet specification to support these business demands. Gigabit Ethernet over copper cabling will be a viable networking solution for years to come. It is a cost-effective way to easily upgrade your networking system to increase your throughput.

1000 Base-T is an important network solution for three reasons:

- The majority of the installed cabling plants in commercial buildings today is UTP copper, and much of that is still Category 5.
- 1000 Base-T electronic equipment is expected to remain less expensive than 1000 Base-F equipment for optical fiber.
- 1000 Base-T allows network managers to preserve their investment in existing Ethernet equipment.

It is easier to change network equipment at the rack and run the network over the existing cabling than to replace the cabling which is installed in cable trays in ceilings, inside walls, or raised floors and dispersed through many telecommunications rooms. 1000 Base-T can be implemented gradually. The initial applications will be switch uplinks and data-center switching. As 1000 Base-T desktop applications emerge, 1000 Base-T NICs will be installed at the workstations that demand the highest-speed access to the networks.

For existing network infrastructures, Gigabit Ethernet can be implemented if your cabling infrastructure is minimally Category 5 cabling. In order to run Gigabit Ethernet, it is required to retest the cabling system if it is Category 5 cabling, and to upgrade your NICs, hubs, and switches to Gigabit Ethernet. Some modifications of the cabling system, for example changing jacks or patch cords, may be required if there

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are failures. If the cabling infrastructure is Category 5e or Category 6, you just need to upgrade your NICs, hubs, and switches.

For new installations, it is recommended that all installations are constructed using Category 5E cabling minimally. This recommendation comes from both TIA and IEEE and also allows for other factors, for example installation practices that could affect the performance of your cabling system. Category 5E cabling offers some necessary headroom over Category 5 to insure that Gigabit Ethernet will effectively run on the cabling system. Installing Category 6 cabling is another option to increase headroom, reduce errors, and to further future-proof the cabling system.

Appendix – Encoding Scheme Description

1000 Base-T transmits at 125 Mbaud, which is the same clock speed that 100-Base-T transmits at. Baud rate is often confused with bits per second (bps). The baud rate measures the number of signal changes per second in an analog sine wave signal. Bits per second is a transfer rate that measures exactly how many bits of information are transmitted across the data line per second. The PAM 5 coding/decoding scheme allows the transmission to more than double the amount of data that is transmitted on 100-Base-T. Therefore 1000 Base-T can transmit 250 Mbps on each pair. Multiplying that by the 4 pairs in the cable allows for 1000 Mbps (gigabit) transmission. The following equations indicate the limits of the two standards.

- 1000 Base-T: 125 Baud x 2 bits = 250 Mbps
- 100 Base-TX: 125 Baud x 1 bit-symbol = 125 Bit-symbols/s

Please note that 125 Bit-symbols/s is equivalent to 100 Mbps because of the encoding scheme that is used for 100 Base-T. 100 Base-T uses a 4B/5B code. Four bits of data are translated into 5 bit-symbols before transmission on the wire; thus the effective throughput is 125 x 4/5 = 100 Mbps. Therefore the 4B/5B encoding scheme has a 20 percent bandwidth overhead (Figure 2).

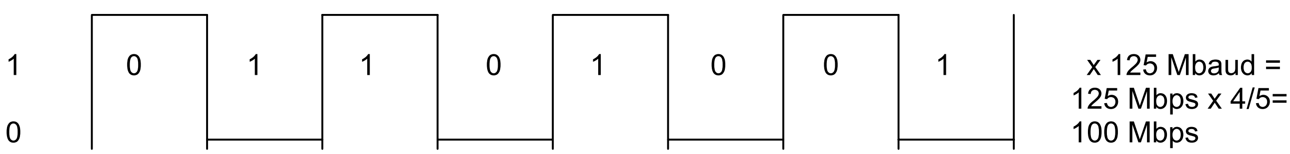

Figure 2

PAM 5 encoding utilizes 4 voltage levels to generate 2 bits per cycle because there are only 4 possible combinations of 2 bits – 00, 01, 10, 11 (Figure 3). The transmitter can send 4 combinations of 2 bits as 4 distinct voltages and the receiver can decipher each voltage level into the corresponding 2-bit combination.

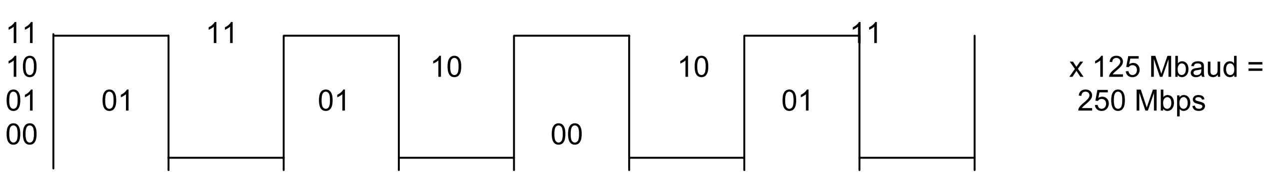

Figure 3

A binary (2 level) signal has one voltage transition every bit period where a 4 level signal has two voltage transitions every bit period. Therefore the transition rate, or symbol rate of a 4 level signal is double the rate of a 2 level signal. A 4 voltage level signal transmitted at 125 Mbaud generates a 250 Mbps data signal.

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The 5th level in the PAM 5 encoding scheme allows for redundant symbol states that are used for error correction encoding. 1000 Base-T provides closer consecutive signals and therefore has a greater sensitivity to transmission distortions than 100 Base-T. However, the reduced noise margin lost at the level of PAM 5 is recovered through the use of convolution coding. Convolution coding (also known as Trellis coding) allows error detection and correction by the receiver through a process called Viterbi decoding. These established, proven technologies have been utilized in modems for more than ten years. The use of Trellis coding and Viterbi decoding allows 1000 Base-T to be more resilient to external noise than 100 Base-T because 1000 Base-T transmits uncorrelated signals in the transmitted symbol stream. No correlation is allowed between symbol streams traveling in both directions on any pair combination, and no correlation is allowed between symbol streams on each pair. External noise pickup is generally correlated (common) to each pair. External noise can be cancelled statistically, allowing improvements in noise immunity that does not exist in 100 Base-TX. Digital Signal Processing (DSP) technology is implemented for crosstalk cancellation. DSP is a proven technology that has been used by many advanced modems and Digital Subscriber Line (DSL) devices. Adaptive equalizers are used to correct attenuation problems. Echo cancellation uses established, proven technologies derived from the telecommunications industry to correct Return Loss impairments.

1000 Base-T is designed to reliably transmit over Category 5 cabling in the same fashion as Fast Ethernet. This is possible due to the implementation of powerful signaling and coding/decoding methods that maintain the integrity of the signal transmitted over Category 5 cabling.

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