Introduction

When network managers decide on a cabling system, they make a decision which is basic to the network infrastructure, and long term in its horizon. Today, network managers are asking hard questions about 1000BASE-T for Gigabit Ethernet on Category 5 copper because they want to future proof their network infrastructures. Most of the cabling installed today inside buildings is Category 5. Migration of this Category 5 installed base to higher speed Ethernet is the primary focus of the IEEE 1000BASE-T Task Force. While networking equipment can easily be pulled from a rack, horizontal cabling can be very difficult to replace since it is located inside a wall, ceiling, or raised floor and dispersed across many wiring closets. Various copper and fiber choices are available on the market today. This document addresses directly the questions about Gigabit Ethernet operation over the installed base of Category 5 UTP.

1000BASE-T (Gigabit Ethernet over Copper) and Category 5 Cabling

Network managers and planners will be able to run 1000BASE-T over the Category 5 cabling. The IEEE is writing the 1000BASE-T specification for Gigabit Ethernet operation over the Category 5 cabling systems installed according to the specifications of ANSI/TIA/EIA-568A (1995). There should be no need to replace existing Category 5 cabling to use 1000BASE-T. The technical goal of the IEEE 1000BASE-T Task Force since its inception has been to support the legacy Category 5 cabling. According to the industry experts that make up the IEEE 1000BASE-T Task Force, any link that is currently using 100BASE-TX should easily support 1000BASE-T.

Gigabit Bandwidth over Category 5 Cabling

Fast Ethernet (100BASE-TX) achieves 100 Mb/s operation by sending three-level binary encoded symbols across the link at 125 Mbaud. (A 125 Mbaud symbol rate is required because 100BASE-TX uses 4B5B coding.) 100BASE-T uses two pairs: one for transmit, one for receive. The next step up in speed, 1000BASE-T also uses a symbol rate of 125 Mbaud, but it uses all four pairs for the link and a more sophisticated five-level coding scheme. In addition, 1000BASE-T sends and receives simultaneously on each pair. Combining 5-level coding and 4 pairs allows 1000BASE-T to send one byte in parallel at each signal pulse. 125 M symbols/second X 1 Byte (across four pair)/symbol = 1 Gb/s. Of course, it isn’t quite this simple. In addition to moving the symbols across the link, 1000BASE-T must also deal with the effects of insertion loss and link-induced interference caused by echo and crosstalk. (See the GEA 1000BASE-T white paper for more details.)

Qualifying Category 5 Cabling

In addition to existing performance criteria for Cat 5 field testing as specified in ANSI/TIA/EIA TSB 67, users planning to use existing Cat5 cabling for 1000BASE-T are advised to test each link for return loss and Equal-Level Far End Crosstalk (ELFEXT) as specified in 1000BASE-T. These recommendations will be published in ANSI/TIA/EIA TSB-95 the Additional Transmission Performance Guidelines for 100 ohm 4-Pair Category 5 Cabling.

Return loss is a measure of the reflected energy caused by impedance mismatches in the cabling system. Far-End Crosstalk is noise on a wire pair at the far end from the transmitter (i.e., at the receiver) caused by signal leakage from adjoining wire pairs. It is measured at each wire pair as Equal Level Far-End Crosstalk (ELFEXT) or as Power Sum ELFEXT (PSELFEXT) which sums the total noise from all adjacent wire pairs.

Return loss and Far-End Crosstalk have negligible impact when a Category 5 link is used to carry 10BASE-T signals, but they can significantly affect 1000BASE operation. (Return loss and ELFEXT can also affect the operation of 100BASE-TX.) Testing for return loss, ELFEXT, and PSELFEXT before using the link for high-
speed protocols (and bringing the link up to the required level of performance if it is substandard) just makes good sense. Basic cable testing information is provided by ANSI/TIA/EIA-TSB-67- "Transmission Performance Specifications for Field Testing of Twisted Pair Cabling System." The additional test requirements for ELFEXT, PSELFEXT, and return loss will be published in ANSI/TIA/EIA-TSB 95.

Testing Installed Cabling
Automated return loss and ELFEXT tests are incorporated into the current versions of cable test tools (see list below.) These tools will automatically cycle through all tests required to certify links for performance standards (e.g., Cat5, TSB-95, Cat5e, etc.) or applications (e.g., 1000BASE-T.) To perform the test, you specify the cabling or application test (or test suite) and initiate it. The cable test tool will automatically perform the required suite of tests and return a PASS or FAIL rating. (Before testing, you should verify that the field tester is accurate and operating properly.)

The GEA has identified five vendors of hand-held testers: Datacom/Textron, Hewlett Packard/Scope, Fluke, Microtest and Wavetek. (This list should be considered incomplete.) Each of the cable test tools listed below can also be set to perform individual tests. Some cable test tools may provide additional diagnostic capability to help you determine the source of the problem if you get FAIL. When selecting a tester to certify cabling for 1000BASE-T ensure that it will meet the field tester accuracy requirements specified in ANSI/TIA/EIA-TSB 95.

Datacom/Textron (www.datacomtech.com)--LANcat® System 6 (with C5e Performance Module)
Fluke (www.fluke.com/nettools/)--DSP4000
Hewlett Packard/Scope (www.scope.com)--Wirescope 155
Microtest (www.microtest.com)--OmniScanner
Wavetek (www.wavetek.com)--LT8155

You may be able to upgrade existing cable test tools. Upgrade capabilities are vendor specific and we recommend that you check with your cable test tool vendor. If you have in-house cable testers and testing expertise, you should be able to self-test links. You need to make sure that your cable test tool will test for all required 1000BASE-T test parameters (see the list above.) If you want to outsource cable testing, most reliable cable installers and consultants provide link testing and certification. You should request certification links according to ANSI/TIA/EIA TSB 67 and 1000BASE-T (IEEE802.3ab) or, when published, ANSI/TIA/EIA TSB 95.

Assessing the Risk
Some network managers might ask what are the odds that Category 5 links in their cable plant won't pass the return loss and ELFEXT tests. The 1000BASE-T Task Force (and the cabling companies) estimate that less than 10% of the installed base of Category 5 cable was improperly installed, i.e., not in accordance with the installation instructions contained in ANSI/TIA/EIA568-A (1995). This improperly installed cable may not support 1000BASE-T. It is critical to observe that such cable also won't support 100BASE-TX. That being said, such substandard links are not a product of the Category 5 cable itself, but rather a product of the connectors in the link. Solutions to these connector problems are discussed below.

Correcting Problem Cable Installations
Corrective measures are outlined in IEEE802.3ab (the 1000BASE-T standard) and in this document. Three types of corrective measures can be applied: switching to high-performance patch cables, reducing the number of connectors in the link, and reconnectorizing some or all of the connectors in the link. (See Figures 1 and 2 below.)
ANSTI/TIA/EIA TSB-95 (proposed) defines five corrective actions that can be taken to improve return loss and Far-End Crosstalk performance. Before testing you should verify that the field tester is accurate and operating properly. The link should be re-tested after each corrective action is implemented.

- Replace the patch cord with a cord constructed from patch cable that meets the Enhanced Category 5 specification.
- If the link has a cross-connect, reconfigure the cross-connect as an interconnect.
- Remove the transition point connector.
- Replace the work area outlet with an outlet that meets the Enhanced Category 5 specification.
- Replace the interconnect with an interconnect that meets the Enhanced Category 5 specification.

Figure 2 shows the same Category 5 horizontal cabling system shown in Figure 1 after the five options described above have been implemented.

Specifications for New Installations
The GEA recommends that all new cable installations should be Cat5e, which is specified in an addendum (proposed) to ANSI/TIA/EIA568-A (1995). Cable system planners wanting extra bandwidth "headroom" might want to consider Cat6, but they should be aware that existing products are pre-standard.

The principal difference between Cat5 and Cat5e is that the standard for Cat5e includes performance requirements for return loss and ELFEVTX and performance enhancements to Cat5 which will result in additional margin over the worst case 1000BASE-T link requirements. This means that cable installers who certify their Cat5e installations incorporate return loss and ELFEVTX performance in their certification. ANSI/TIA/EIA-568A Cat5 installations do not incorporate return loss and ELFEVTX performance guarantees. These return loss and ELFEVTX measures are specified in IEEE802.3ab and will be specified in...
ANSI/TIA/EIATSB-95 (proposed), which contains additional recommendations for a minimally compliant Category 5 cabling system.

Cat6 is a high performance cable specified to 250MHz. The Cat6 standard is in development but not complete, although some vendors already offer Cat6 solutions. As stated above, cable system planners wanting extra bandwidth "headroom" might want to consider Cat6, but they should be aware that existing products are pre-standard.

Cat7 cabling is extreme high performance copper cabling specified to 600MHz. The Cat7 standard is still in development. The mechanical and electrical requirements for a Cat7 connector have not been specified.

**Topology Rules**

Topology rules should be the same as those used for 100BASE-TX. Category 5 link lengths are limited to 100 meters by the TIA/EIA-568-A cabling standard. Half-duplex collision domains should be the same as 100BASE-TX; however, each half-duplex collision domain can support only one half-duplex repeater.

**Cabling Systems: Category 5, Enhanced Category 5, Category 6, Category 7**

The Table below summarizes the differences between the balanced cabling systems.

<table>
<thead>
<tr>
<th>Cable type</th>
<th>Bandwidth (MHz)</th>
<th>Connector Type</th>
<th>Standard Status</th>
<th>Testing</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 5 E (enhanced)</td>
<td>100</td>
<td>RJ45</td>
<td>In development by TIA TR-42 as Standards Proposal 4195-A. Will be Addendum to TIA/EIA568-A.</td>
<td>Also defined in SP4195-A</td>
<td>Recommended for new installations to insure that installers incorporate Return Loss and ELFEXT requirements in their certification.</td>
</tr>
<tr>
<td>Category 6</td>
<td>200</td>
<td>RJ45</td>
<td>In development by TIA TR-41.8.1.</td>
<td></td>
<td>Products labeled Category 6 today may not be in compliance with the final specification.</td>
</tr>
<tr>
<td>Category 7</td>
<td>600</td>
<td>RJ-45 (2 pr), 4 pr TBD</td>
<td>In development</td>
<td></td>
<td>Expected in ISO/IEC 11801-2000</td>
</tr>
</tbody>
</table>
The Importance of Choosing a Strong Cabling Partner

Selection of a reliable, competent cable contractor is very important. It’s important that your contractor be trained to install and test cabling as per the current ANSI/TIA/EIA standards. This training (and certification) is available from individual cable and connector vendors and from BICSI--A Telecommunications Association. In addition to providing cabling-related training for telecommunications professionals, BICSI provides information and training for end users, including a new course (DD100: Introduction To Voice/Data Cabling Systems) which teaches end users what they need to look for in a contractor. Contact BICSI at:

BICSI  
861- Hidden River Parkway  
Tampa, FL  33637-1000  
Voice: 800-242-7405 or 813-979-1991  
Fax: 813-971-4311  
URL: www.bicsi.org

Expected Dates for Products

Many component companies have already announced various physical layer and other devices that are embedded in systems. The networking industry is expected to start shipping 1000BASE-T switches and NICs to end user customers within the next six to nine months.

Conclusion

Only a few years ago many industry experts and pundits claimed that 10 Mbps Ethernet would never operate over twisted pair cabling. Similar claims were made with 100 Mbps. Today, these claims are being repeated by various vendors about 1000 Mbps (Gigabit Ethernet). Marketing hype aside, the IEEE 1000BASE-T Task Force is specifying Gigabit Ethernet for operation over the installed base of Category 5 cabling. According to the industry experts that make up the IEEE 1000BASE-T Task Force, any link that is currently using 100BASE-T should easily support 1000BASE-T.

DEFINITIONS OF TERMS USED

**Crosstalk** is unwanted signals coupled between adjacent wire pairs. Since 1000BASE-T uses all four wire pairs, each pair is affected by crosstalk from the adjacent three pairs. Crosstalk is characterized in reference to the transmitter.  
**Near-end crosstalk** (NEXT) is crosstalk that appears at the output of a wire pair at the transmitter (near) end of the cable.  
**Far-end crosstalk** (FEXT) is a measure of the unwanted signal coupling from a transmitter at the near-end into a neighboring pair measured at the far-end.  
**Equal level far-end crosstalk** (ELFEXT) is a measure of the unwanted signal coupling from a transmitter at the near-end into a neighboring pair measured at the far-end relative to the received signal level measured on that same pair.  
**Power sum equal level far-end crosstalk** (PSELFEXT) is a computation of the unwanted signal coupling from multiple transmitters at the near-end into a pair measured at the far-end relative to the received signal level on that same pair.


For more information on the Gigabit Ethernet Alliance, Gigabit Ethernet, or 1000BASE-T, see the GEA web page at: [http://www.gigabit-ethernet.org/](http://www.gigabit-ethernet.org/). For specific white papers, see: [http://www.gigabit-ethernet.org/technology/whitepapers/](http://www.gigabit-ethernet.org/technology/whitepapers/).