TIA-1005 Industrial Ethernet Cabling Standard

The Effect on the 10/100 Industrial Ethernet Switch Performance

1005 Industrial Ethernet Cabling Sta
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Obtaining Standards Documents

TIA/EIA documents may be purchased through Global Engineering Documents at 1-800-854-7179 or www.global.ihs.com. IEEE documents may be purchased through IEEE, P.O. Box 1331, Piscataway, NJ 08855 or www.ieee.org. CSA documents may be purchased through the Canadian Standards Association at www.csa.ca or by calling 416-747-4000.

Abstract: Paper Premise

The Anixter Infrastructure Solutions Lab wanted to determine what effect the new TIA-1005 industrial cabling infrastructure standard would have on the data throughput performance of real Ethernet data packets running between SmartBits test cards and various manufacturers' 10/100 Ethernet switches in a real-world simulation. The test included five (5) different IP20-rated switches and three (3) different enterprise rack-mounted switches using various cabling channels made from both Category 5e and Category 6 cabling components and connector pairs that are allowable under the standard. The premise also asserts that the effect of the cabling channel interference will also vary from port to port and switch to switch because of the variable transmitter and receiver functionality.

Background: TIA-1005 Telecommunications Infrastructure Standard for Industrial Premises [1]

The TIA-1005 standard is intended for a factory installation of a viable and standards-based Ethernet. The defined cabling infrastructure must adhere to the same basic guidelines and rules that exist for installations in the enterprise space. Deviations from the existing enterprise standard are described by the new standard, especially where the environmental conditions of the factory vary widely from that of the enterprise. There are three principal areas that constitute the main purpose of the TIA-1005 standard:

- The standard enables the planning and installation of a telecommunications cabling infrastructure within and between industrial buildings.
- The potential exposure to hostile environments in the industrial space is the central concept of the standard in contrast to that of TIA-568[2], which addresses commercial buildings.
- The special cabling system requirements of industrial operations are also a prime design principle of the document.

The main differences between the TIA-1005 and TIA-568 standards are that the TIA-1005 standard:

- Allows for 2-pair cabling (M12) systems
- Defines an "automation island"
- Defines "automation" outlets and cables
- States that Category 6 or better cabling shall be used for the automation islands
- Defines environmental concerns in concrete terms
- Includes M_{123} I_{123} C_{123} E_{123} definitions

In order for the cabling infrastructure to operate effectively in the industrial environment, some basic changes in the way the wiring is defined and installed have to be incorporated into the cabling requirements and yet still maintain the same performance required by the IEEE standards for Ethernet over twisted-pair cabling.

The biggest change in the TIA-1005 standard over the TIA-568-B documents is the incorporation of a 2-pair cable for installation into the newly defined automation island. However, using only 2-pairs will limit the Ethernet capability to that of only 10 or 100 Mbps, or only to the IEEE 10BASE-T[4] and 100BASE-T[5] -PHY[6] definitions. Gigabit Ethernet must run on a 4-pair cabling system from end to end. To understand the reasons for the cabling designs and automation island designations, the MICE [3] concept is introduced and integrated into the design and performance requirements.

Annex C of the new TIA-1005 standard shows the allowed connectivity and cabling situation for connecting devices with network interface cards (NICs) on one end of a machine to the IP67-rated switch on the other end using M12 connections and traversing multiple environmental zones that require adaption to different connectivity. The test included a standard four (4) connector channel configuration and a more complex six (6) connection channel.

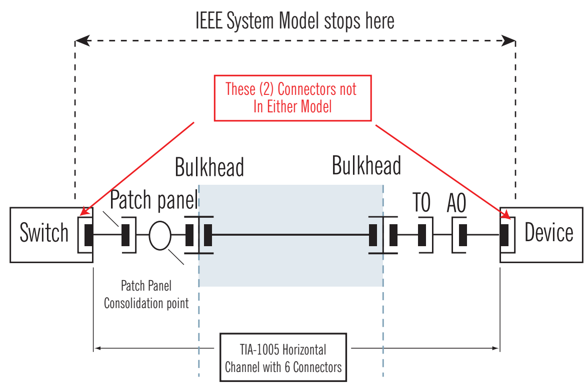


Figure 1 – An excerpt of Annex C, which shows the conditions that could result in such an arrangement. The highlighted area of the channel is not covered by either the IEEE standards or those of the TIA standards.

In setting up the six (6) connector model and cabling test beds for this procedure, the environmental temperature was an important issue. The TIA-568-B.2 document establishes the cabling channel performance based on the laboratory condition of 20ºC or 68ºF. Although in a well air-conditioned office environment this temperature may be possible, it is unrealistic for a factory setting. More appropriate temperatures of 30ºC and 40ºC were used, which gave a more reasonable range of 86ºF to 104ºF.

In order to simulate these two (2) separate temperature conditions, extra lengths were added to the cabling channels as the result of the temperature increase above the TIA-568 standard. The added cable length is directly proportional to the increase in attenuation due to the increase in the resistance value of the fixed copper gauge size as the temperature rises. The allowance for this temperature rise is a 4 percent increase for every 10ºC.

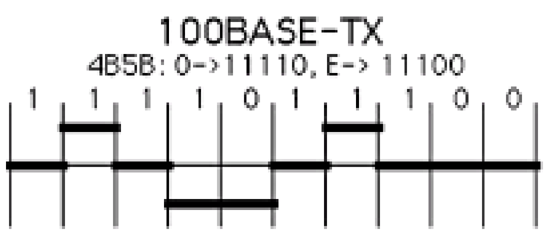
Thus, for a 328-foot channel, each 10ºC rise would equal another 13 or more feet of cable. The lengths used for this test were therefore 328 feet, 341 feet and 355 feet respectively.

The preceding discussion establishes these testing parameters:

- The factory environment is almost never the same as that of a lab.
  - The TIA-568 and TIA-1005 standards use the same 20ºC (68ºF) temperature performance for insertion loss as a required normative parameter.
  - They also allow for a temperature of up to 60ºC (140ºF) using an adjustment factor of 0.4 percent per degree Celsius factor for Category 5e cable.
- Most Ethernet switches will have variable transmitter and receiver performance from port to port, which can cause possible errors in higher temperature situations.
- Network interface cards typically are not as robust as switch ports and very few have "CRC" error trapping or indication.
- Category 5e cabling systems will probably not run error free in channels where there are more than four (4) connections and temperatures exceed 20ºC (68ºF).

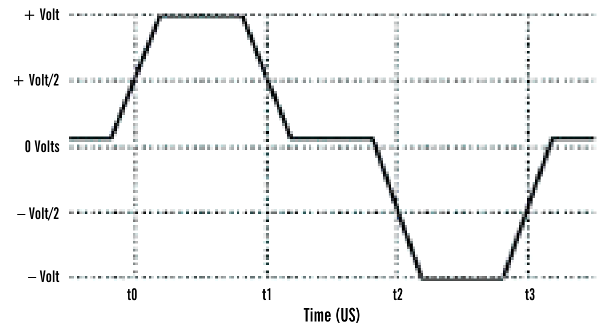
Technology Issues: IEEE 802.3u [7] Considerations

As background for understanding the principles in this throughput study, the makeup of the signal needs to be defined. The basic premise behind the encoding scheme for 100 Mbps Ethernet over copper was to use a four (4) symbol process and a frequency scrambler to keep from having a "killer packet" as was the case in 10BASE-T. By constantly moving the center frequency up and down the spectrum, it was thought that no constant data pattern could cause an increase in error rate. Figures 2 and 3 show the binary and multisymbol schemes used for Fast Ethernet transmission over copper cabling.



Source: Anixter Infrastructure Solutions Lab

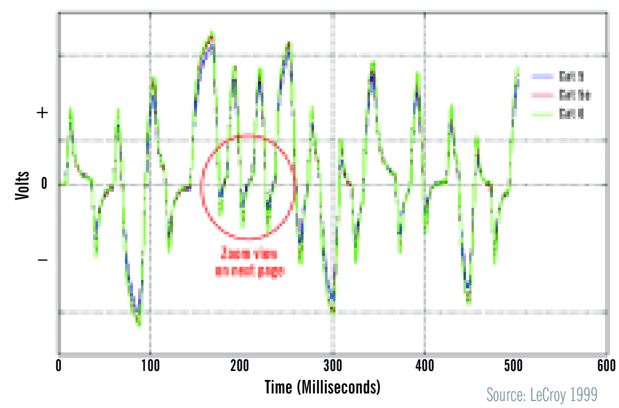
Figure 2[8] – Uses 4B-5B encoder and 25 MHz clock for 125 M baud and 100 Mbps. Fast Ethernet or 100BASE-TX uses a more complex encoding technique called MLT-3, which is similar to Manchester in its encoding process, but uses a three-state alternating wave to digitally encode the binary information. An example of an MLT-3 encoded signal is shown in Figure 3.



Source: Anixter Infrastructure Solutions Lab

Figure 3 – The MLT-3 encoded signal as shown produces four separate "symbols" or information bits for every megahertz of bandwidth used. The fourth symbol is obtained from the "direction" change that the voltage takes from its previous state.

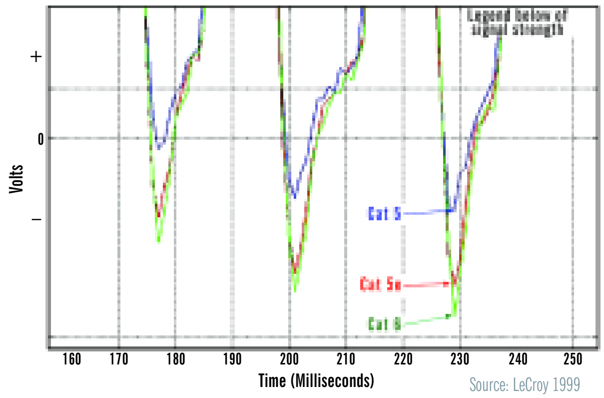
In a previous Lab procedure, three (3) instances of Ethernet packet transmission were used[9]. Each instance used exactly the same data patterns and was precisely timed so the analog signal traced on the digital oscilloscope (DSO) as an exact overlay. The three (3) instances were the transport over cable channels of Category 5, 5e and 6 performance. Figure 2 shows the difference in signal edge clarity and strength for each type of cable channel.



Source: LeCroy 1999

Figure 4 – Actual data signal over three different cable channels of Category 5, 5e and 6 (overlaid).

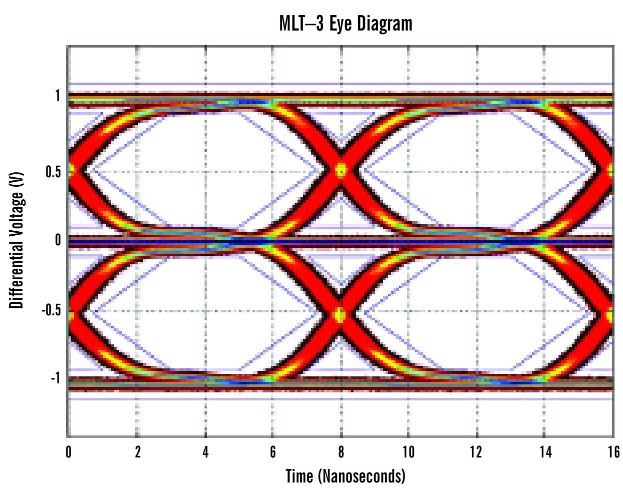
Figure 4a, on the next page, zooms into the three (3) center time pulses and shows clearly the distortion on signal caused by lesser performing cabling channels. The Category 6 wave shape is clear and sharp with no jitter, and the attenuation is far less then that of the Category 5 and 5e cabling. The Category 5 channel shows the actual edge breakdown in the pulse as well as major insertion loss deviation (ILD) effects. The original Fast Ethernet specification requires only Category 5 cabling performance, which has no return loss requirements and, therefore, is usually erratic in its bit error rate testing (BERT) performance. The equalization design of the receiver does not allow for ILD[10].



Source: LeCroy 1999

Figure 4a – Zoom of Overlaid Signals

In order to verify the transmitters of the 10/100 Ethernet switch are outputting the correct waveform specified in the IEEE 802.3u standard, a probe set is inserted between the transmitter port and the receiver port. The digital oscilloscope is set up to display a signal eye diagram MASK that is defined in the MLT-3 test procedures for the active output interface or (AOI) performance requirements. This MASK is designed to accurately portray the signal path that the time-varying voltage wave must traverse to be compliant. The signal can a be real-time, single pulse or repeating wave. For a more complete understanding of how the transmitter might vary over a time span, a persistent screen is usually used. Figure 5 shows the standardized MASK from The University of New Hampshire InterOperability Lab (UNH-IOL)[11].



Source: Anixter Infrastructure Solutions Lab

Figure 5 – InterOperability Lab MASK Spec

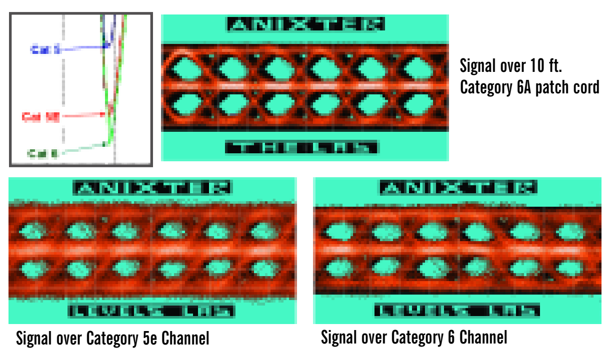
Figure 6 is the MASK that was used on the DSO in Anixter's Lab for the evaluation on the IP20 switch port transmitters.

Source: Anixter Infrastructure Solutions Lab

Figure 6 – MLT-3 MASK

Figure 7 is a representation of how the transmitted signal from a port on the Industrial Ethernet switch is modified by the actual cabling channel between the switch and the SmartBits card. The top MASK is the switch port connected to the card over the 6-foot test cord. The MASK on the left shows the signal after it passes through the Category 5e channel for 40ºC. The MASK on the right shows the signal after it passes through the Category 6 channel for 40ºC. In the upper left-hand image, is a distortion of the signal that is closely comparable to the previous test case using the overlapping signal traversing through standard Category 5, 5e and 6 channels of 328 feet.

In doing the AOI evaluation, every port on a switch had its own distinct transmitter output MASK pattern, which meant a single test receiver translated the signal differently for each one. The major objective was to validate this variability using real data.



Source: Anixter Infrastructure Solutions Lab

Figure 7 – MLT-3 MASKs of IP20 Switch – 5,700 Sweeps

The other major component of the transmission path is the receiver, which in most installations is a NIC or chip set as part of a computer or intelligent device used to output data over Ethernet. In a factory, this could be a PLC or smart I/O device. The NIC is essentially a single-port transceiver as are the individual ports of a switch. Figure 8, on the following page, shows a previous study of 17 different brands of NICs where eight (8) of them failed the rise-time test out of the box and all of them had different transmitter signatures even though all were compliant with the IEEE specifications.

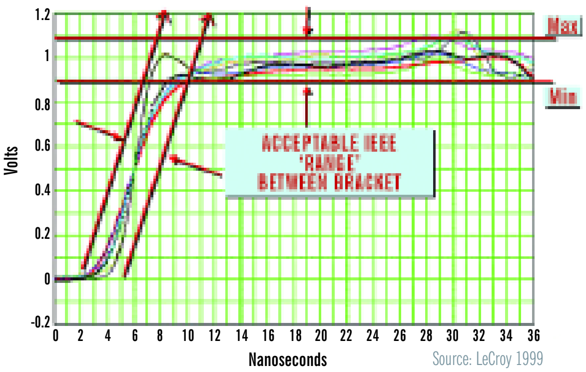


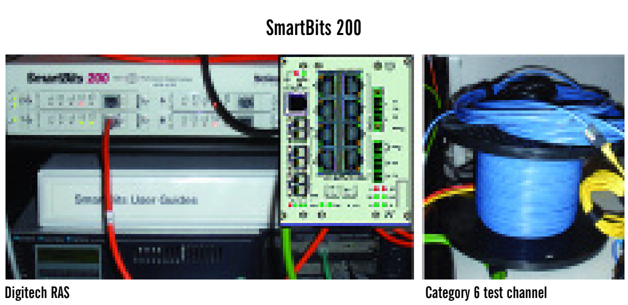
Figure 8 – 8/17 NIC cards sampled had rise times > 5 nanoseconds

Because over-the-counter Ethernet electronics can vary from manufacturer to manufacturer, this NIC test, which was done nearly six years ago when third-generation 10/100 network interface cards were hitting the market, shows how different the output characteristics can be on a new product. Add a few years of service at high temperature or temperature cycling in a normal on/off mode and the voltages will drift even more than shown here. Hardware qualification tests can only be performed on the transmitters, not the receivers. The only way to test a receiver is to use it. That is why SmartBits and the entire group of RFC throughput, back to back, latency and BERT performance suites were developed.

Testing Parameter and Procedures: Port Variability Test Methodology

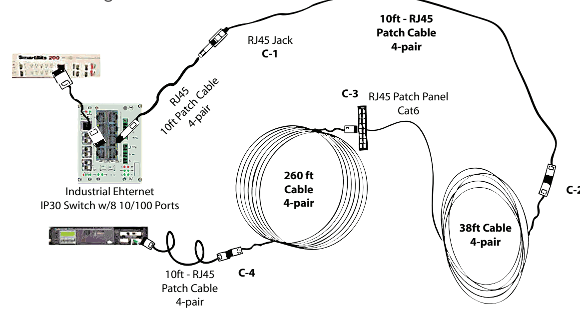
- Set up cabling test beds to show three (3) possible factory Ethernet conditions:
  - TIA standards-based channel at 20ºC (68ºF)
  - More typical factory temperature of 30ºC (86ºF)
  - Worst-case temperature of 40ºC (104ºF)
- Set up both Category 5e and Category 6 channels with both four (4) and five (5) connectors.
- Use SmartBits SB200[12] as source of 100BASE-T Ethernet packets.
- Use lab-grade RAS[13] or network sniffer for error trapping.
- Test all switch ports on all test beds, averaging the error counts of three (3) consecutive burst trials.

This is an actual picture (Picture 1) of the test setup in the Anixter Infrastructure Solutions Lab including the Category 6 at 40ºC (104ºF) channel.



Picture 1 – Actual Test Area Components

Figure 9 show the diagram of the test bed configurations used for all of the testing.



Test setup for Category 5e and 6 channels (30°C and 40°C equivalent of 341 ft. and 355 ft.) and five Category 6 connectors.

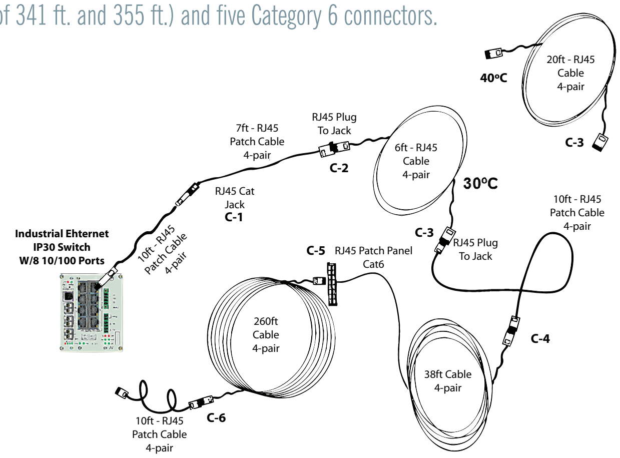
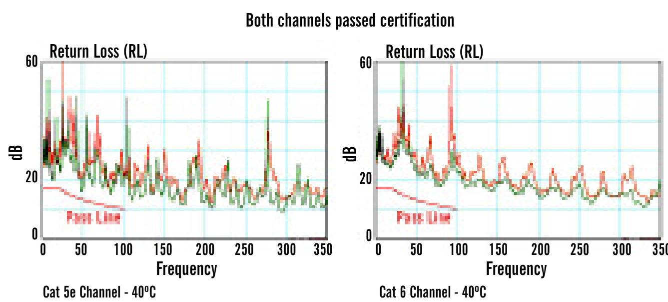


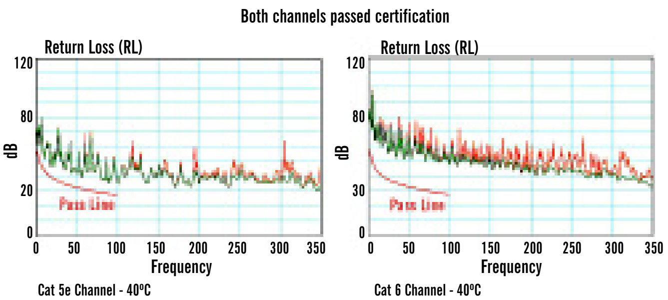
Figure 9 – Test setup for TIA standard Category 5e and 6 channels (20°C equivalent of 328 ft.) and four connectors.

In order to verify that the test-bed channels built for this test were compliant with the TIA-568-B.2 standard and the new TIA-1005 performance requirements for Category 5e, all configurations were tested using a Fluke DTX-1800 automated field test device, which is rated for Category 5 through Category 6A and up to 500 MHz resolution. Figures 9 and 10 show the worst-case results of these test, and all passed the channel requirements.



Source: Anixter Infrastructure Solutions Lab

Figure 10 – The Test Data: Channel Return Loss



Source: Anixter Infrastructure Solutions Lab

Figure 11 – The Test Data: Channel PSNEXT

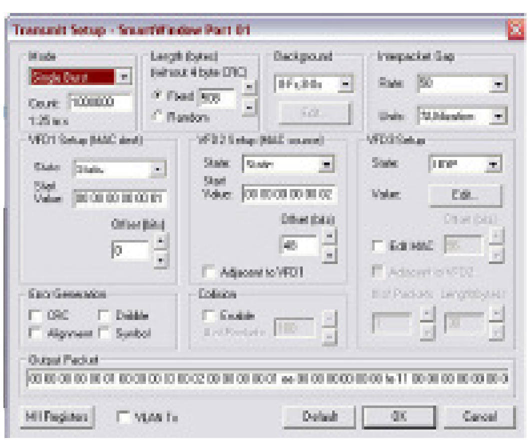
Test Setup: Data Transport

The actual testing was performed using two (2) test beds (Figure 9), which were flexible to alter the overall channel length and mated-connector pair count to simulate the best-case, typical-case and worst-case scenarios that were likely to appear in the factory environment. The test equipment used includes the Spirent SmartBits Ethernet packet transmission system using the ML-7710 cards and a Digitech network analyzer or RAS-remote access system/sniffer to simulate a receiver installed in a factory network. The actual transmitter or DUT was the individual port output from the IP67/M12-10/100 Ethernet.

Switch with the SmartBits Cards actually delivering the Ethernet packets to and through the switch. The packet transmissions were timed for exactly 1 million per trial and three (3) trials were average for the error count per port.

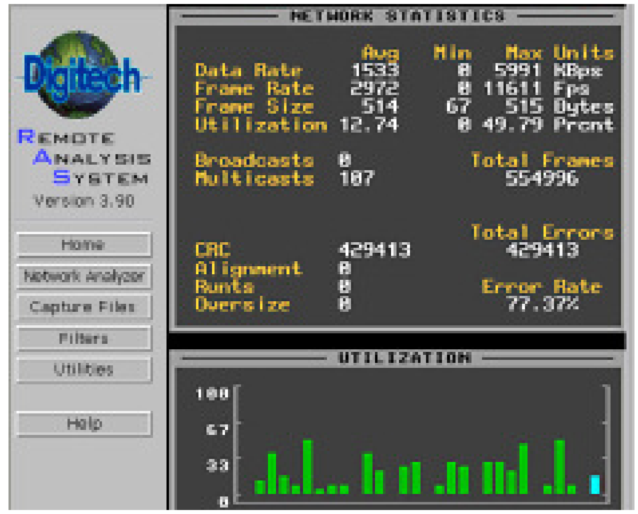
As shown in Picture 2, the cards were set up with the following parameters:

- Mode: single burst
- Count: 1 million packets
- Packet Length (less CRC): 508 bytes
- Background Data: All "5s"
- Utilization Rate: 50% or 50 Mbps
- VFD Setup: (1) UDP packet every 10



Picture 2 – Setup Window

The output of the received signal was trapped by the RAS and displayed through its user interface. Picture 3 shows this interface.



Picture 3 – In the case of the Category 5e x 40°C channel, the CRC's rate was so high (between 67 and 87 percent) that the receiver stopped listening and had to reinitiate. In order to get a full 1 million frame to run, continuous transmission mode was used.

The error results were tabulated in a spreadsheet then plotted per port by each test channel type. See Figures 11 and 12 for the patch cord and plug front leg and figures 13 and 14 for the adapter tests.

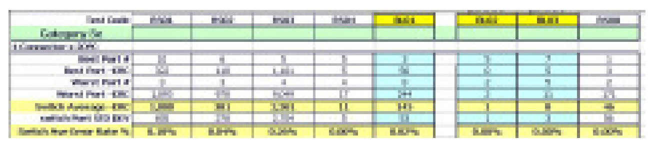


Figure 11 – Results Table

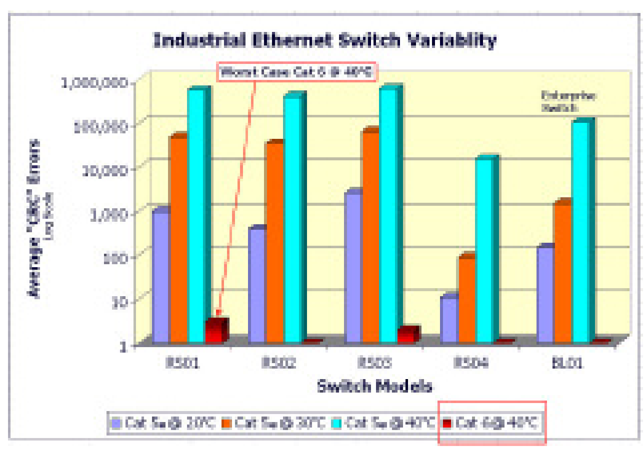


Figure 12 – Results Graph

Conclusions

1. The average CRC error rates are dramatically affected by the electrical performance design of the cabling channel components, with the Category 6 channels consistently close to error-free transmissions at these elevated temperatures.

2. All eight (8) of the 10/100 Ethernet switches had different transmission signatures from each port; the assumed cause is the combination of differing chip suppliers and the passive components that supply the actual output signal to the RJ45 jack.

3 During the running of the tests, it was observed that when the background data patterns were change to some other sequence, such as 808080s, the average CRC error rates also seemed to change. This, however, is a subject for further study.

4. As a follow up to the RAS testing, a validation test of one of the ports was performed between two of the SmartBits ML-7710 cards. The RAS is standard NIC based and more typical of the real-world testing for the paper, as apposed to the ML-7710 cards, which are precision-test devices with high-quality components and tend to have reliable receivers and transmitters. The result of this test also showed that the bit error rates were higher with the Category 5e channel then with the Category 6 channel.

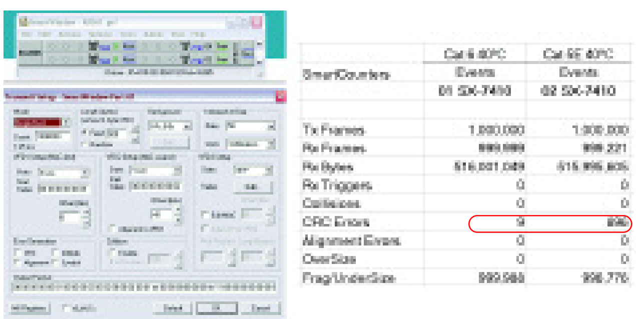


Figure 13 – SmartBits CRC Error Testing, Category 6 and 5e at 40°C

References

[1] ANSI/TIA-1005, formally SP-3-4822-REV H, Telecommunications Infrastructure Standard For Industrial Premises.

[2] ANSI/TIA/EIA-568-B.2-2–Commercial Building Telecommunications Cabling Standard. Balanced Twisted Pair Cabling Components. Transmission performance specifications for 4-pair Category 5e and Category 6 cabling.

[3] MICE – Environmental rating system from ISO/IEC 24702. CLC EN 50173-1. The suffixes for the four primary environmental criteria are either 1, 2 or 3.

[4] 10BASE-T: A 10BASE-T node (such as a PC) that transmits on pins 1 and 2 and receives on pins 3 and 6 to a network device is most often on a straight-through cable in the MDI wiring pattern where RX goes to RX and TX goes to TX. A 10BASE-T transmitter sends 2 differential voltages, +2.5 V or -2.5 V.

[5] 100BASE-T: A 100BASE-TX transmitter sends 3 differential voltages, +1 V, 0 V, or -1 V.

[6] PHY: connects a link layer device (often called a MAC) to a physical medium such as an optical fiber or copper cable. A PHY typically includes a PCS and a PMD layer. The PCS encodes and decodes the data that is transmitted and received. The purpose of the encoding is to make it easier for the receiver to recover the signal.

[7] IEEE 802.3u: 100BASE-T is any of several Fast Ethernet standards for twisted-pair cables, including 100BASE-TX (100 Mbps over 2-pair Category 5 or better cable), 100BASE-T4 (100 Mbps over four-pair Category 3 or better cable, defunct), 100BASE-T2 (100 Mbps over two-pair Category 3 or better cable, also defunct). The segment length for a 100BASE-T cable is limited to 100 meters (328 feet) (as with 10BASE-T and Gigabit Ethernet). All are or were standards under IEEE 802.3 (approved 1995).

[8] MLT-3: 100BASE-TX introduces an additional, medium dependent sublayer, which employs MLT-3 as a final encoding of the data stream before transmission, resulting in a maximum fundamental frequency of 31.25 MHz. The procedure is borrowed from the ANSI X3.263 FDDI specifications, with minor discrepancies.

[9] Bill Richardson, LeCroy R&D, Vigilent, 1997.

[10] ILD: has basically two components one which essentially represents an offset of the summed up operational attenuation of the components, and a second component, which is oscillatory in nature over frequency. "Look into the systematic behaviour of insertion loss deviation in data grade channels, its partial measurement and characterization as a specification requirement." Jörg-Hein (Jo) Walling, IEEE Proceedings, Science, Measurement and Technology, November 2003, Volume 150, Issue 6, p. 279–288.

[11] UNH-IOL: The University of New Hampshire, Interoperability Lab. "Fast Ethernet Consortium, Clause 25, Physical Medium Dependent (PMD), Test Suite 3.4."

[12] SB200: Spirent/SmartBits Test Equipment with ML-7710 Interface Cards for 10/100 Ethernet.

[13] RAS: Digitech/LeCroy Remote Access System.