Cable Testing Means More Uptime
Standards and Testing of Industrial Ethernet Copper Cabling

Mike Berg, Sr. Business Development Manager, Panduit, mkbe@Panduit.com

Jim Davis, Regional Marketing Engineer, Fluke Networks, jim.davis2@fluenetworks.com
Section Summary

- Understanding TIA-1005-A Industrial Premises standard for ICT
- Concepts of M.I.C.E and dynamics on plant floor
- MICE rated product selection for the plant floor
- Applying structured cabling from Enterprise to control panel
Why worry about the Network Physical Layer?

- More than half of failures in the network are in the data link and physical layer*
- Switch hardware will turn over 4X or more over the life of the plant cabling infrastructure
- Nearly half of plant floor nodes are on a variant of Ethernet

*source: ISA

Todays topic: Effective network planning and testing for faster commissioning, increased uptime and improved OEE
Applicable Standards
Information and Communications Technology (ICT)

Telecommunications Standards

- TIA/EIA-568 Defines cabling types, distances, connectors, cable system architectures, cable termination standards and performance characteristics, cable installation requirements and methods of testing installed cable
- Defines the overall premises infrastructure for copper and fiber cabling
- Addresses components of the copper cabling system
- Addresses components of fiber optic cable systems
- ANSI/TIA-1005 is explicitly supported by the 568 cabling standard

The Telecommunications Industry Association (TIA)
TIA 1005 Model

Structured cabling in industrial premise

Physical infrastructure model for cabling and connectivity design

Flexible and scalable

Defines interconnects (to switch) and testable link/channel

D = Distributor (MDF, IDF, Access layer)

EO = Equipment Outlet
Industrial Networks and TIA-1005
Some Key Variations between TIA-1005-A and TIA-568 Series

- M12 D-code
- > 4 connector channel (6 connector)
- Introduction of Coupler/Adaptor
- M.I.C.E ratings

<table>
<thead>
<tr>
<th>Office (Clean) to Industrial (Dirty)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
</tr>
<tr>
<td>Ingress</td>
</tr>
<tr>
<td>Climatic</td>
</tr>
<tr>
<td>Electromagnetic</td>
</tr>
</tbody>
</table>
# Global Industrial Ethernet Technology Standards

<table>
<thead>
<tr>
<th>Ethernet</th>
<th>PROFINET</th>
<th>ETHERNET/IP</th>
<th>Modbus-IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61784-2 CPF3</td>
<td>IEC 61784-2 CPF2/2</td>
<td>IEC 61784-2 CPF15</td>
<td></td>
</tr>
</tbody>
</table>
Turning Standards into Solutions
Per TIA-1005-A

ISO/IEC 11801
IEC 60603-7
Benefits of Choosing M.I.C.E Rated Components

• Already tested to withstand the severity of the associated M.I.C.E element
• When choosing network cabling systems always consider the components that are able to withstand the worst case environment to which it is exposed.
• Commercial grade network components (M₁I₁C₁E₁) can also be considered when applicable
How Product Selection can be affected by M.I.C.E Classifications

“M.I.C.E” characteristics change as a result of the routing products and methods used.

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Protected?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hangers</td>
<td>No</td>
</tr>
<tr>
<td>Trays</td>
<td>No</td>
</tr>
<tr>
<td>Conduit</td>
<td>Yes</td>
</tr>
<tr>
<td>Lay-in Housing</td>
<td>Yes</td>
</tr>
<tr>
<td>Pull-thru Housing</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment</th>
<th>M.I.C.E Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean</td>
<td>1</td>
</tr>
<tr>
<td>Dirty</td>
<td>2</td>
</tr>
<tr>
<td>Very - Dirty</td>
<td>3</td>
</tr>
</tbody>
</table>
How M.I.C.E. Can Affect Product Selection

- Standard Enterprise Grade Patch Cord
- IP67 Industrial Grade Patch Cord
- Standard Enterprise Grade Equipment Cabinet
- NEMA Type 12 Pre-Configured Micro Data Center
Shielded Cable for Ethernet Applications

Industrial Environment

- The better the “electrical balance” of a cable the more protection from EMI
- Shielding cabling provides added layer(s) of protection
- Managing interference strongly tied to proper design and installation (including grounding & bonding)

Areas addressed in TIA-1005-A:
- Equipotential/Mesh grounding system (conductor sizing)
- Star Grounding System (with ground isolation)
- RC Device Termination (resistor capacitor)
Examples of Shielding Solutions for Ethernet Cabling

- SF/UTP Braided Screen & Foil Screen Around Unshielded Twisted Pairs
- 600 V rated 2 pair and 4 pair copper cable
- 600 V rated patch cords, rated for control panel use
- Shielded RJ-45 Field Terminable Plug
- Shielded RJ-45 Jack
- Shielded DIN Rail Copper Patching Solution
- Shielded Wiring Duct
- M12 X-code Field Terminable Plug
- Shielded RJ-45 Field Terminable Plug

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Structured and Point to Point Cabling

Point to Point Cabling
- Stranded cable field terminated with plugs
- Measurements infrequently done
- No standard exists to define the measurement method
- If the lights blink it’s assumed it works!

Structured Cabling
- Solid horizontal cable terminated with jacks
- Typically installed and left in place; measured and warranted performance
- Connected to equipment with flexible patch cords
Why Structured Cabling on the Plant Floor Is a Best Practice

- Same cabling concept is used with I/O and terminal strips
- Manage the backbone separate from the patch to the controller – through a terminal strip or IFM
- Predictable and eases MACs
Structured Cabling within Zone Enclosure

Test points (uplink)

Test points (downlink)
Commissioning & Performance Validation
Channel Testing with the TIA model

- Channel testing should be done at each cabling subsystem level

- This includes subsystem 1, including field level 1-0 connections

- Testing will typically be done just prior to commissioning stage in a project

- ANSI/TIA/EIA 568 & 1152-A cover testing & field test equipment (including channel testing, and wire map)
Section Summary

• Review your internal standards for the network physical layer
  – Reference TIA 1005-A (available at TIAonline.com)

• Use TIA 1005-A and the MICE concept to improve designs and to mitigate environmental factors

• Learn and follow controls vendors Industrial Ethernet physical recommendations
Field Testing of Installed Cabling for Industrial Environments

Jim Davis
Regional Marketing Engineer
Fluke Networks
In this session...

• Cable Performance basics
  – Signal to Noise ratio
• Specific cabling problems in E2 and E3 MICE environments and how to mitigate them
• Test equipment to certify cabling
Industrial Protocol Market Shares - 2018

- Fieldbuses are growing slightly but expected to decline over the next few years
- EtherNet/IP is the dominant Industrial Ethernet variant with 15% market share
Cabling Produces Half of Industrial Ethernet Problems

Typical Problems Found

- Connectors: 20%
- Cable: 20%
- Configurations and Devices: 20%
- Noise: 20%
- Length: 10%
- Other: 10%

Field Terminated Cables
- Wired wrong
- Untwisted causing noise susceptibility
- Shield Integrity
- Damaged during and after installation
- Loose connections

Pre-Terminated Cables
- Damaged during installation
- Damaged after installation
- Loose connections

Loose connections cause intermittent problems
- Vibration
- Moisture
- Oxidation
- Susceptible to noise
Tools to Solve Industrial Ethernet Cable Problems

- Network Discovery and analytics
- Packet capture and inspection
- Device LEDs Continuity

Not helpful for common cable problems, like distance to open. They do nothing for complex cable issues and noise (EMI) immunity defects that damage time sensitive packets (usually intermittent).

So, Install Bypass Cable
- Make or find a bypass cable
- Can take hours
- The cable is good ½ the time
- Hours wasted
Tools that will “Certify” or “Verify” vs tools that will “Qualify” or measure wire map/continuity

- Testing against the cabling standards requires a tool that can cover the frequency range, up to 500 MHz for Category 6a
- The test tools should be able to test to ANSI-TIA-568.2-D and/or TIA-1152-A standards
- They should measure Insertion Loss, NEXT and Return Loss
- They should meet, at a minimum, Level IIIe accuracy requirements
  • Preferably they will have third party verification of this from someone like ETL or UL
Qualification tools do not run a complete test

- These tools do not test against TIA-568 standards
- Testing “Ethernet” or IEEE 802.3 does not assure compliance to Category cable
- These tools can be very useful for day to day maintenance
Cabling Standards

- The ANSI/TIA-568 and ISO-11801 standards are based on the experience of the Telecommunications industry.
- Within the **Common Standard**, TIA-568, we find the **Premise Standard**, TIA-1005 for Industrial Environments.
- The International Premise Standard is the ISO-11801-3.
- These standards give guidance on product performance and instructions on how to test the products.
Why Certify Cabling?

• Be sure that the installed cabling meets the performance you are paying for. An untested cable is a source of doubt.
  • Cat 6a Jack + Cat 6a Cable + Cat 6a Installer ≠ Cat 6a
• To get paid for the job
• Experience has shown that Certified networks run faster and support future applications
  • CRC/FCS errors lead to re-transmissions
  • How long will that cable be in the wall?
  • Reduce New Machine Start-up Time
  • Reduce Production Down Time
• Beware of those who offer to save $ on the installation by not certifying
  • Or offering cheap low quality components
What parameters are measured?

- The capacity of a cable to support high speed data is based on measurements of signal and noise
- Continuity, or Wire Map, is not sufficient to support Gigabit Ethernet
- Signal Strength, or loss, is measured as Attenuation or Insertion Loss
- Noise is made up of two parameters, NEXT and Return Loss
- Putting together these measurements we get a Signal to Noise Ratio
- The greater the frequency where we can maintain a positive SNR, the faster we can communicate
First, Continuity
Most Common Problem

- Open Pairs
- Flipped Pair
- Short
- T568A vs T568B
- Split Pair
Signal Strength – Insertion Loss

Insertion Loss:
- In dB, the signal loss down the cable

Signal Loss increased with:
- Length
- Frequency
- Temperature
  - Cables in hot locations may not reach 100 meters
Temperature De-rating

• TIA-568 and ISO 11801 lengths are based on an ambient temperature of 20°C
• The standard does not permit the limits in the tester to be relaxed
• You may need to reduce the acceptable length of your links
  • Be sure to specify a maximum length in your bid documents if it is less than 100 meters for the channel

<table>
<thead>
<tr>
<th>Temperature (°C (°F))</th>
<th>Maximum horizontal unscreened cable length (m)</th>
<th>Maximum horizontal screened cable length (m)</th>
<th>Length de-rating (m) (unscreened)</th>
<th>Length de-rating (m) (screened)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 (68)</td>
<td>90.0</td>
<td>90.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>25 (77)</td>
<td>89.0</td>
<td>89.5</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>30 (86)</td>
<td>87.0</td>
<td>88.5</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>35 (95)</td>
<td>85.5</td>
<td>87.7</td>
<td>4.5</td>
<td>2.3</td>
</tr>
<tr>
<td>40 (104)</td>
<td>84.0</td>
<td>87.0</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>45 (113)</td>
<td>81.7</td>
<td>88.5</td>
<td>8.3</td>
<td>3.5</td>
</tr>
<tr>
<td>50 (122)</td>
<td>79.5</td>
<td>85.5</td>
<td>10.5</td>
<td>4.5</td>
</tr>
<tr>
<td>55 (131)</td>
<td>77.2</td>
<td>84.7</td>
<td>12.8</td>
<td>5.3</td>
</tr>
<tr>
<td>60 (140)</td>
<td>75.0</td>
<td>83.0</td>
<td>15.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>
Noise – Return Loss

Return Loss:
• In dB, the reflected signal on the same pair

\[ V_{\text{diff in}} \quad \text{incident signal} \]
\[ V_{\text{diff refl}} \quad \text{Reflected signal} \]

Return Loss increases with:
• Badly made / damaged cable
• Pairs being separated
• Water in the cable
  • The cable isn’t bad, it’s the wrong cable for this application
Noise – NEXT (Near-end Crosstalk)

NEXT:
• In dB, the disturbed signal on an adjacent pair

\[ V_{\text{diff in}} \quad \text{incident signal} \quad V_{\text{diff out}} \]

NEXT is increased by:
• The 4,5 pair being inside the 3,6 pair
• Badly made / damaged cable
• Not maintaining the twist of the pair in the connector
• Incorrect test limit / category of cable
SNR = ACR (Attenuation Crosstalk Ratio)

Putting I/L and NEXT together
  • In dB, the signal to noise ratio of a given pair

ACR is a calculation
  • NEXT minus Insertion Loss

Better ACR, faster communications
  • Category 5e to 100 MHz - Supports up to 5GBASE-T
  • Category 6 to 250 MHz - Can support 10GBASE-T to 55 meters
  • Category 6a to 500 MHz - Supports 10GBASE-T to 100 meters
How to read a test report.

The Logo of the Company that did the testing

**Cable ID:** of the port that was tested

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date / Time</td>
<td></td>
</tr>
<tr>
<td>Headroom 11.9 dB (RL 45)</td>
<td></td>
</tr>
<tr>
<td>Test Limit: TIA Cat 6 Perm. Link</td>
<td></td>
</tr>
<tr>
<td>Cable Type: affects the NVP</td>
<td></td>
</tr>
<tr>
<td>NVP: 69.0%</td>
<td></td>
</tr>
</tbody>
</table>

**Test Summary:** PASS

- **Operator:** of the test equipment
- **Software Version:** V5.0 Build 3
- **Limits Version:** V5.0
- **Calibration Date:**
  - Main (Module): 03/11/2016
  - Remote (Module): 03/11/2016

- **Model:** DSX-5000
- **Main S/N:**
- **Remote S/N:**
- **Main Adapter:** DSX-PLA004
- **Remote Adapter:** DSX-PLA004

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m), Limit 90.0</td>
<td>[Pair 45] 31.0</td>
</tr>
<tr>
<td>Prop. Delay (ns), Limit 498</td>
<td>[Pair 36] 161</td>
</tr>
<tr>
<td>Delay Skew (ns), Limit 44</td>
<td>[Pair 36] 11</td>
</tr>
<tr>
<td>Resistance (ohms)</td>
<td>[Pair 12] 5.08</td>
</tr>
<tr>
<td>Insertion Loss Margin (dB)</td>
<td>[Pair 12] 21.3</td>
</tr>
<tr>
<td>Frequency (MHz)</td>
<td>[Pair 12] 250.0</td>
</tr>
<tr>
<td>Limit (dB)</td>
<td>[Pair 12] 31.1</td>
</tr>
</tbody>
</table>

**Wire Map (T568A)**

- 1: PASS
- 2: 1
- 3: 2
- 4: 3
- 5: 4
- 6: 5
- 7: 6

**Insertion Loss (dB)**

- 0 dB: 0 Hz
- 50 dB: 100 Hz
- 100 dB: 200 Hz
- 150 dB: 300 Hz
- 200 dB: 400 Hz

**Worst Case Margin**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PASS</td>
<td></td>
</tr>
<tr>
<td>MAIN</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Pass</td>
<td></td>
</tr>
<tr>
<td>Main</td>
<td></td>
</tr>
<tr>
<td>Worst Case Value</td>
<td></td>
</tr>
</tbody>
</table>
Did the test pass?

Yes!
What test limit was passed?

**Category 6 – Permanent Link**
That is nice, but we are in a harsh environment; motors, transformers, arc welders, high temperatures...
TIA-1005 M.I.C.E. Classifications

- Mechanical: vibration, shock
  - $M_1$, $M_2$, $M_3$

- Ingress: water, dust
  - $I_1$, $I_2$, $I_3$

- Climatic/Chemical: temperature, humidity
  - $C_1$, $C_2$, $C_3$

- Electromagnetic: EMI, ESD, RFI
  - $E_1$, $E_2$, $E_3$

Increasing Environmental Severity

Office → Industrial
The big concern with E3 environments electromagnetic interference:

Lost packets – CRC/FCS errors

• May cause network latency
• May cause a loss of connection
• A few frame errors can cause machines to stop
CRC errors can slow down or even crash a network

- Caused by the checksum generated by the transmitting device not matching the one generated by the receiving device
- You may not know they are happening
- The Device will ‘throw out’ a defective frame and re-try
- They can be caused by bad cabling or a bad device configurations
- They can be caused by noise, and poor connections

A few bad frames can cause a machine to shut down
- Especially with high RPIs applications
An Ethernet frame:

<table>
<thead>
<tr>
<th>Source</th>
<th>Destination</th>
<th>Type</th>
<th>FCS Status</th>
<th>Frame Check Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMware_84:29:11</td>
<td>HewlettP_53:47:3a</td>
<td>IPV4</td>
<td>Unverified</td>
<td>0x3d03f7ca</td>
</tr>
</tbody>
</table>

Internet Protocol Version 4, Src: 167.28.133.253, Dst: 167.28.159.9

Tabular Data Stream

<table>
<thead>
<tr>
<th>Byte</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>00 11 08 53 47 3a 00 50 56 84 29 11 08 00 45 00</td>
</tr>
<tr>
<td>0010</td>
<td>00 fe 0e 47 40 00 08 06 17 01 a7 1c 85 fd 07 1c</td>
</tr>
<tr>
<td>0020</td>
<td>09 0f 90 0f 64 95 99 fd 0a 09 64 d9 77 bd 09 3a</td>
</tr>
<tr>
<td>0030</td>
<td>Fa fa 73 11 00 00 01 01 00 00 00 01 00 23 40 00</td>
</tr>
<tr>
<td>0040</td>
<td>45 00 08 00 00 02 00 00 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>0050</td>
<td>70 00 08 00 00 02 00 00 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>0060</td>
<td>60 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>0070</td>
<td>70 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>0080</td>
<td>60 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>0090</td>
<td>63 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>00a0</td>
<td>63 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>00b0</td>
<td>63 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>00c0</td>
<td>63 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
</tr>
</tbody>
</table>
Very simplified Ethernet frame:

<table>
<thead>
<tr>
<th>Destination Address</th>
<th>Source Address</th>
<th>Protocol</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>00 11 08 53 47 3a 00 56</td>
<td>08 10 00 45 00 60 66</td>
<td>IPv4</td>
<td>00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>00 0f 0f 0d 05 09</td>
<td>00 7d 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>00 5f 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>00 0e 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
<td></td>
<td></td>
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<tr>
<td>00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00</td>
<td></td>
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</tr>
</tbody>
</table>

EMI and CRC/FCS errors
EMI and CRC/FCS errors

Very simplified Ethernet frame:

<table>
<thead>
<tr>
<th>Destination Address</th>
<th>Source Address</th>
<th>Protocol</th>
<th>Data</th>
<th>CRC/FCS</th>
</tr>
</thead>
</table>

Transmit = 1010
Transmit = 1010

Switch

PLC
Two Common Ways to Avoid EMI: Shielded Cable and/or Well Balanced Cable
Shield integrity – Modern Certification tools can determine if the shield follows the path of the cable

- If the shield does not follow the path of the cable an open should be reported
- Even when the two connectors are touching
Avoid EMI with well balanced links

- 480V VFD EMI: 1000V, or higher pulses
- Industrial Ethernet: 2 volt pulses

Good Cable
- Motor or VFD noise is equal across pairs
- Devices still get a 2 volt signal (noise cancelled)
  - Packets get through the 1st time

Poor (unbalanced) Cable
- VFD noise NOT equal across pairs
- Devices WILL NOT get a 2 volt signal
  - FCS and CRC errors. Re-tries and latency
  - Usually intermittent

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- Good cables cancel out EMI. Poor cables let EMI reach devices.
- TCL and ELTCTL measurements identify resistance to EMI.
TCL – A measurement of Balance for Cabling

- Transverse Conversion Loss is the ratio (in dB) of a common-mode voltage measured on a wire pair relative to a differential-mode voltage applied to the same end of the pair. The TCL value shows you how well the cable avoids mode conversion.
The Basic TIA-1005 Limit has no TCL test
The E1 (+ALL) test includes TCL Limits and ELTCTL – TCL on the far end.
E1 vs E2 vs E3 – These are all Cat 6

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>TCL E1 (dB)</th>
<th>TCL E2 (dB)</th>
<th>TCL E3 (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>38</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>16</td>
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<td>200</td>
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<td>250</td>
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<tr>
<td>350</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

TCL Test Limits

Better noise immunity
What Test Limit Should I Specify in my Bid Document / Contract?

• Ask your Consultant/Architect/Engineer
• What is the performance of the components you are using?
• What applications are you planning to support?
• What is the M,I,C,E rating of the environment?
• One Cell of an Excel file specification:
  • Links shall be tested to ANSI/TIA-568.2-D limits for Category X (5e, 6, 6A)
  • “TIA 1005 Cat 5e Channel E1 (+ALL)” is a good starting point
  • TIA-1005 is the Premise Standard for industrial environments of the TIA-568 specification
In Summary, to avoid start up delays and minimize downtime

- Certify your installed cabling to ANSI/TIA-568 limits to make sure it meets your performance requirements
- Check the limit on your test reports
Thank you
Gracias
Obrigado

Jim Davis, Fluke Networks
Jim.Davis2@fluenetworks.com
6920 Seaway Blvd, Everett, WA 98271