Commissioning cabling infrastructure for OT networks
- including Single Pair Ethernet and Ethernet-APL™

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Storyline

Outline
• Standards for specification of OT network wiring systems including power delivery
• Network topologies and wiring practices
• Specific commissioning tests for point-to-point links to identify non-compliant cabling and bad connections, as well as routine workmanship issues
• Measurement properties and associated industry standards for physical infrastructure
• Re-purposing legacy cabling for industrial Ethernet

Storyline
• With the widespread implementation of Ethernet, it’s now possible to apply routine best-practices from IT networking to save time and add value in the industrial space.
• One such practice, cable testing, leads to more reliable operations and less troubleshooting.
Industrial Protocol Market Shares - 2020

- Fieldbuses are in decline, wireless is stable, Industrial Ethernet share at 64%, up from 59% in the previous year
- EtherNet/IP and Profinet are the dominant Industrial Ethernet variants with 17% market share each
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’s cabling infrastructure
- 60% of plant floor nodes are on a variant of Ethernet

*source: ISA

Today’s topic: Effective network planning and testing for faster commissioning, increased uptime and improved OEE
50% of OT Network Problems

Common defects

- Wrong cable for the application
- Re-terminated on-site (too long)
- Damaged during installation or operation
- Wired incorrectly
- Pair separation causing noise ingress
- Poorly connected shields

Environment makes matters worse

- Vibration, Flex, Moisture, Oxidation, Temperature, EMI

High number of intermittent problems (not repeatable)

- A few lost or damaged frames can stop a machine
- Time consuming to diagnose

Problems Reported

- Cable 20%
- Connectors 20%
- Noise in cables 20%
- Configurations and Devices 20%
- Length 10%
- Other 10%
- 10%
Standards applied to OT networks
Applicable Standards

- **Information and Communications Technology (ICT)**
- **TIA/EIA-568** Defines cabling types, distances, connectors, cable system architectures, cable termination, 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
- The **ANSI/TIA-1005** industrial standard is explicitly supported by the 568-cabling standard series

The Telecommunications Industry Association (TIA)
TIA-1005-A adds to the TIA-568 Series

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

<table>
<thead>
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<th>Office (Clean) to Industrial (Dirty)</th>
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<tbody>
<tr>
<td>Mechanical</td>
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<tr>
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<tr>
<td>Electromagnetic</td>
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<td>E¹ E² E³</td>
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TIA Developments for SPE

• **TIA-568.5** cabling and component standard
  – minimum requirements for balanced single twisted-pair cabling channels and components (cable, connectors, connecting hardware, and cords) used in commercial buildings
  – also specifies measurements for all transmission parameters.

• **TIA-1005 rev.B** premises standard for industrial environments
  – drafted this past year and deferred pending SPE additions
  – includes the new End-to-End link type

• **TIA-568.7 new!** Industrial Single-Pair Ethernet (SPE) project
  – 1st Committee Ballot circulating soon
  – Includes M.I.C.E. requirements for SPE

• **TIA-5071 new!** Requirements for SPE Field Test Instruments
Applicable International Standards

- Information and Communications Technology (ICT)
- ISO/IEC 11081 governs all premises types
- ISO/IEC 11081-3 covers the specifics of Industrial premises cabling
- ISO/IEC TR11801-9902 specifies End-to-End link configurations
- ISO/IEC 14763-2 defines planning, installation, and acceptance testing
- ISO/IEC 14763-3 defines Testing of optical fiber cabling
- IEC 61918 Installation of communication networks in industrial premises
Global Developments for SPE

- **ISO/IEC 11081-3 Amd1:2021** Industrial premises cabling
  - Amended to include performance of single-pair Ethernet links
- **IEC 61918/AMD1** Installation of communication networks in industrial premises
  - Amendment to support all current IEEE BASE-T1 (1000/100/10)
  - Forecast publication next year
- **IEEE P802.3de** Time Synchronization for Point-to-Point Single Pair Ethernet Task Force
- Of particular interest is **IEC/IEEE 60802** TSN Profiles for Industrial Automation
  - New project approved Nov-2020, targeting 2023 publication
Network Infrastructure & Topology
TIA-1005 Model

Structured cabling for industrial premise

Physical infrastructure model for cabling and connectivity design

Flexible and scalable

Defines interconnects (to switch) and testable links/channels

D = Distributor (MDF, IDF, Access layer)

EO = Equipment Outlet
Why Structured Cabling 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

Terminal Strips

1492-IFM
Structured and Point-to-Point Cabling

Point-to-Point Cabling
- Stranded cable field-terminated with plugs
- Infrequently tested
- No standard exists to define the measurement method
- If the lights blink, it’s assumed it will work!

Structured Cabling
- Solid horizontal cable terminated with jacks
- Typically installed and left in place; measured and warranted performance
- Connection to equipment with flexible patch cords
End-to-End link configurations

Plug terminated channels

- Specific industrial use
- 2 to 6 connections
- Total cabling channel
- Added with TIA 1005-B and ISO/IEC 11081-3 Amd1; both in 2021

Standardized point-to-point cabling channel for use where outlet jacks are impractical
Structured Cabling within Zone Enclosures

Test points (uplink)

Test points (downlink)
Benefits of Choosing M.I.C.E Rated Components

• Certified to withstand the severity of the associated M.I.C.E element
• When choosing network cabling systems always consider components rated to withstand the worst-case environment for exposure
• Commercial grade network components (M₁I₁C₁E₁) can also be considered in applicable areas
Shielded Cable for Industrial Environments

- The better the “electrical balance” of a cable the more protection from EMI
- Shielded cabling provides added layer(s) of protection
- Managing interference is strongly tied to proper design and installation (especially 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
- Shielded DIN Rail Copper Patching Solution
- Shielded RJ-45 Jack
- Shielded RJ-45 Field Terminable Plug
- Shielded Wiring Duct
- M12 X-code Field Terminable Plug
- 600 V rated patch cords, rated for control panel use
- 600 V rated 2 pair and 4 pair copper cable
Section Take-Aways

• Review your internal standards for the network physical layer
  – Specify the latest norms for Industrial Ethernet
  – *Structure* for flexibility, testability and longevity

• Use the M.I.C.E. concept to improve designs and mitigate environmental factors in advance

• Learn and follow controls vendors Industrial Ethernet physical recommendations
Acceptance Tests for Cabling Infrastructure
Why test cabling as part of commissioning?

• To be sure that the installed cabling meets the performance you are paying for. An untested cable is a **source of uncertainty**.
  – Cat 6A Jack + Cat 6A Cable + Cat 6A Installer ≠ Cat 6A performance

• To run faster now *and* support future applications. Experience has shown that tested networks:
  – Reduce CRC/FCS errors that lead to re-transmissions
  – Reduce New Machine Start-up Time
  – Reduce intermittent Production Down Time
  – Have a longer service life

• To get paid for the job (if you are the installer or machine builder)

Beware of anyone offering to save $$ on installation by not testing
Commissioning & Performance Validation

Channel Testing with the TIA model

• Channel testing should be done at each cabling subsystem level
• This includes Subsystem 1, and field level 1-0 connections
• Testing is typically be done just prior to commissioning stage in a project
• ANSI/TIA/EIA 568 & 1152-A define testing & field test equipment
Acceptance tests

Engineering Guideline Ethernet-APL™ v1.0

- *During the acceptance test the integrity of the cabling should be measured and documented for later use and troubleshooting during the operation of the plant.*

EtherNet/IP Network Infrastructure Guide – ODVA Pub 35

- Testing is easily done with commercially available hand-held network testers. Special adapters may be necessary for sealed connectors. Testing output includes conformance to all electrical requirements including, but not limited to, attenuation, impedance, return loss, cross-talk, and cable segment length measurements.

- Each cabling segment (consisting of cable and connectors) must be tested to confirm that, after installation, the segments all conform to *The EtherNet/IP™ Specification* for performance. (*The CIP Networks Library, Vol. 1 and 2)*
Acceptance test results

- Simple pass/fail plus wire-map
- Or complete frequency sweep and guaranteed standards compliance
- Simple operation
- Wireless cloud storage for results and .pdf reports
Measurement Properties
What parameters are measured?

• The capacity of a cable to support high speed data is based on measurements of signal and noise.
• Continuity testing, or Wire-Map, is not sufficient assurance for even the slowest Ethernet.
• Signal Strength, or loss, is measured as attenuation a.k.a. Insertion Loss.
• Noise is measured with 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 and farther we can communicate.
Continuity - RJ45 or M12 D or X (or soon SPE)
Most Common Problem: Bad Wire Map

- Open Pairs
- Flipped Pair
- Short
- Crossed Pairs
- 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 perform to 100 meters
Noise – Return Loss

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

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

NEXT:

- In dB, the disturbed signal on an adjacent pair

\[ V_{\text{diff in}} \text{ INCIDENT SIGNAL} \]

\[ V_{\text{diff out}} \text{ NEXT} \]

NEXT is increased by:

- Connector geometries and pin configurations
- Defective / damaged cable or connectors
- Untwisting wire-pairs in the connector
- Wrong category of cable or connectors
SNR = ACR (Attenuation Crosstalk Ratio)

Combining I/L and NEXT parameters
  - In dB, signal to noise ratio of a given pair
ACR is a derived parameter
  - NEXT minus Insertion Loss across frequency
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
Reminder: ISO & TIA M.I.C.E. Classifications

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<th>M₂</th>
<th>M₃</th>
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<tr>
<td>EMI, ESD, RFI</td>
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These can be tested!

Increasing Environmental Severity

Office    Industrial
Electromagnetic interference:

Lost packets – CRC/FCS errors

- May cause excess network latency
- May cause retry/loss of connection
- A few frame errors can cause machines to stop
Shield Integrity –

- Modern test tools can determine if the shield continuously follows the path of the cable.
- If the shield does not follow the path of the cable an open shield will be reported (shown on the right).
- Even when both ends are grounded (shown here).
Reject EMI with Well Balanced Links

Balanced Cable
- Motor or VFD noise is equal across pairs
- Noise is rejected, devices get proper logic levels
  - Packets get through the 1st time

Unbalanced Cable
- VFD noise NOT equal across pairs
- Devices **WILL NOT** get proper logic levels
  - FCS and CRC errors. Re-tries and latency
  - Usually intermittent
TCL – Balance measurement 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 impedances of the pair’s conductors are balanced.
Re-purposing legacy control cabling

- Extend the cabling assets you already have
Cable Reuse?

- Potential for high quality, recent vintage, control cabling to perform well for SPE traffic
- Quickest and most certain way to tell is to test it
  - Certification tests – high accuracy, total parametric coverage, highest level of assurance
  - Verification tests – less parameters, slightly reduced accuracy, reasonable assurance
- Doesn’t mean you have to test every link
  - **Statistical sampling** is recommended for reuse of large populations
    * Given the supplier and age is fairly uniform
Statistical sampling methods

- ISO/IEC 14763-2 Cabling planning and installation standard
- Test to an equivalent acceptance quality level (AQL) of 0.4% as defined for link populations up to 500,000, per ISO 2859-1

<table>
<thead>
<tr>
<th>Installation size (No. of total links)</th>
<th>Sample size (No. of links to test)</th>
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<tr>
<td>3 – 33</td>
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<tr>
<td>34 – 3,200</td>
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<td>126</td>
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<td>35,001 – 150,000</td>
<td>201</td>
</tr>
<tr>
<td>150,001 – 500,000</td>
<td>315</td>
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Topology reuse

• SPE doesn’t change the way you install
  – Homerun wiring
  – Fieldbus wiring

• SPE will improve on the fieldbus trend of replacing control boxes with switches and addressing the end-nodes (IP)

• Small field switches can connect directly to edge devices (sensors, actuators, counters)

• Design your wiring on CAD, not in the field

• Faster and easier commissioning - therefore faster project completion
Recap

• Summary of key take-aways
Quick Recap

• Fieldbuses are in decline; Industrial Ethernet is now more than 60% and SPE/APL are here to wire the remainder
• Review your internal standards for the network physical layer and specify the latest norms for Industrial Ethernet
• Use the MICE concept to improve designs and mitigate environmental factors in advance
• Greater than 50% of problems operating industrial ethernet can be traced to cabling problems
• Assessment tests are a recommended best-practice that can catch most common defects and provide the greatest assurance over the lifetime of the network
THANK YOU
It has been a great pleasure
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