100BASE-T1L for Motor Feedback Communication

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Purpose of this presentation

• Introduce servo control use case
• Introduce motor feedback communication
• Explain advantages of 100BASE-T1L for motor feedback
• Explore market potential of 100BASE-T1L for motor feedback
• Discuss requirements for 100BASE-T1L for motor feedback
• Assess technical feasibility of requirements
• Propose actions
Motion Control Applications

Motion Control:

- Is the process of controlling a change in position of machinery or equipment
- Provides machine movement that is accurate (exact) and precise (repeatable)
Servo control system

- Servo Drive
- Servo Motor
- Motor Cable
Servo control basic principle

- Encoder measures current motor position and sends the position data back to drive via **motor feedback communication**
- Drive calculates the next position and modulates main power output to move the motor to next position
- At stop state, drive can control the motor brake to hold the motor

![Diagram of Servo Drive and Motor Connections](image-url)
Motor feedback system is a sub-system of servo control system
100BASE-T1L for motor feedback communication

Today’s technology variants

A. 2-wire power
   2-wire RS485

B. Power and RS485
   over single pair

C. 2-wire power
   4-wire fast Ethernet

Potential technology trend

Single Pair Ethernet to
Motor, Enabling
Smart Motor

Reduce 2 wires and
increase performance

Increase performance

Reduce 4 wires

100BASE-T1L potentially enables motor feedback technology advancement
# of motor feedback communication ports

- **31M** feedback comm. ports in 2020, **44%** of them (**13.6M**) require very low latency transceivers (<1.5us)
- **20%** annual growth

**Servo Control provides significant market potential for 100BASE-T1L**

Data source: Omdia (former IHS), July 2021
Requirements for motor feedback comm.

**PHY**
- 100Mb/s, Full Duplex
- BER: <= 10e-10
- PHY latency (TX+RX): <= 1.5us

**Link segment**
- Length: up to 100m
- Shielded single twisted pair cable in motor cable
- Up to two inline connectors

**Noise**
- Operation under servo drive PWM noise

**Power**
- Power delivery over SPE pair
- 12VDC desirable, 24VDC acceptable
- Up to 500mA
Maximum feedback data acquisition time

Position sampling 
Feedback data acquisition

Drive executes control algorithm and then outputs the modulated voltage/current to move motor to next position

Data update cycle time: **31.25us**, 62.5us or 125us

Feedback data acquisition time shall be less than or equal to **10us**

Note 1: only single encoder on the servo motor in the real system, this encoder entity is only for showing the cyclic information flow in a chronological order.
Maximum PHY latency (TX+RX)

PHY latency (TX+RX) shall be less than or equal to 1.5us

Encoder

- MCU
- MAC
- PHY

- App TX latency: 0.5us
- PHY TX latency: ?

Servo Drive

- PHY
- MAC
- MCU

- PHY RX latency: 0.6us
- App RX latency: 0.5us
- Margin time: 1.0us

100Mb/s, 100m SPE cable

- Ethernet frame transmission time: 5.76us (72 bytes)
- Ethernet signal propagation time: 0.6us
- Feedback data acquisition time <= 10us

PHY latency (TX+RX) <= 1.64us = (10 – 0.5 – 5.76 – 0.6 – 0.5 – 1.0) us
Disabling FEC to achieve 1.5us PHY latency

• Most likely FEC is required for the 100BASE-T1L PHY to achieve the link segment objective of “supporting up to 5 inline connectors for up to at least 500m reach” for process automation use cases, refer to 100BASE-T1L Reach and Connectors for more details

• FEC would possibly add at least 3-5us latency for 100BASE-T1L PHY, as a result, exceeding the maximum 1.5us PHY latency threshold for servo control

• Providing the capability to disable the FEC function is mandatory to achieve low latency operation if 100BASE-T1L PHY requires the FEC function
  • This technique has been proven in available PHY chips (e.g., 1000BASE-T1 PHY chip)

100BASE-T1L standard shall specify a standard way to enable low latency operation mode (e.g., disable FEC function)
Link segment: SPE cabling instead of RS485 cabling

- Shielded AWG22 single twisted pair in motor cable
- Up to 100m (e.g., 90m main cable + 10m extension)
- Up to 2 inline connectors (extension cable connector and motor connector)

Motor cable

SPE cable instead of RS485 cable

Connector might be reused?
Process automation link segment specification would cover motor feedback link requirement

- About 6dB loss from PAM3 to PAM5 and 4.5dB gain with FEC
- More than 6dB@12.5MHz, 11dB@25Mhz margin for motor feedback link segment

Refer to S. Graber’s presentation: 100BASE-T1L Reach and Connectors

Adjusted only by the factor of \((L/1000)*\sqrt{0.82305/A}\);

\[ L = 100 \]

\[ A(\text{AWG22}) = 0.325526 \]

\[ A(\text{AWG24}) = 0.204722 \]

- \(18.4\, \text{dB} @ 12.5\, \text{MHz (Nyquist/2)}\)
- \(26.1\, \text{dB} @ 25\, \text{MHz (Nyquist/2)}\)
- \(15.3\, \text{dB}\)
- \(10.8\, \text{dB} @ 12.5\, \text{MHz (Nyquist/2)}\)
- \(7.6\, \text{dB} @ 12.5\, \text{MHz (Nyquist/2)}\)

Process Automation

Motor Feedback

- AWG18, 1000m @PAM3, w/o FEC
- AWG18, 400m @PAM5, w/ FEC
- AWG16, 500m @PAM5, w/ FEC
- AWG24, 100m @PAM5, w/o FEC
- AWG22, 100m @PAM5, w/o FEC
- AWG18, 400m @PAM5, w/o FEC
- AWG16, 500m @PAM5, w/ FEC
- AWG24, 100m @PAM5, w/o FEC
- AWG22, 100m @PAM5, w/o FEC

Process automation link segment specification would cover motor feedback link requirement
Robust shielded cable (>85% braided shield + foil shield) and shielded connectors minimize the cross talk from power wires to data wires and protect signal integrity of digital feedback communication.
Power over SPE pair

It is feasible to power the encoder from a 100m AWG22 cable with a 12V power source according to the above calculation example.
Summary

• Servo Control use case provides significant market potential for 100BASE-T1L while gaining technology advancement from 100BASE-T1L

• A list of requirements including latency, link segment, noise environment and power shall be considered and are assessed when 100BASE-T1L is applied for motor feedback communication

• <=1.5us PHY latency is the most critical requirement based upon the technical feasibility study on requirements

• Proposed action: develop a standard method to enable low latency (<=1.5us) operation mode (e.g., disable FEC function) as part of 100BASE-T1L specification