PHY Enhancement for 100BASE-T1L

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Purpose

- Preliminary FEC consideration for 3dg PHY.
- Other alternatives for performance enhancement.

PHY Objectives Review

Basic PHY Objectives

Consensus:

1. Preserve the IEEE 802.3/Ethernet frame format at the MAC client service interface.
2. Preserve minimum and maximum frame size of the current IEEE 802.3 standard.
3. Do not preclude meeting FCC and CISPR EMC requirements
4. Support for optional single-pair Auto-Negotiation
5. Do not preclude the ability to survive industrial fault conditions (e.g., shorts, overvoltage, EMC)
6. Do not preclude working within an Intrinsically Safe device and system as defined in IEC 60079
7. Support optional Energy Efficient Ethernet optimized for Operational Technology (OT) applications, including very low power devices
8. Support fast-startup operation which enables the time from power_on=FALSE to a state capable of transmitting and receiving valid data to be less than 500ms

11/10/2021 IEEE 802.3 Greater than 10 Mb/s Long-Reach SPE Study Group Page 2

EMC immunity is very important for a PHY system working in industrial environment.

There are different ways to improve the system’s noise tolerance:

- Increasing the transmit signal amplitude;
- Reducing the insertion loss of the cable;
- Improving shielding;
- Extra mechanism such as forward error correction or retransmission...

10BASE-T1L with No FEC

Noise measurement results showed that the noise level will not cause communication issues for the 4B3T coded PHY.

Conclusion

- Several examples of noise sources within our facility have been measured.
- Due to the use of a shielded twisted pair cable the measured differential mode in-band noise is quite low.

- The maximum differential mode noise level measured in all four measurement locations has been 25.20 mV_{pp}, applying a gain correction factor of 1.5.
- It is expected, that this noise level will not cause communication issues in conjunction with the proposed 4B3T coded PHY.

- The maximum common mode noise level is significantly higher than the differential mode noise level.
- It is in the range of 300 mV_{pp} or even higher, applying a gain correction factor of 1.5.
- Nevertheless because a symmetric differential receiver is being used, common mode noise within this amplitude range is not expected to be an issue.

IEEE P802.3cg 10 Mb/s Single Twisted Pair Ethernet Task Force 4/24/2017 20

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The 802.3cg defines mode conversion for unshielded link segments and coupling attenuation for shielded link segments, both up to 20MHz:

Table 146–5—Differential to common mode conversion

	Frequency (MHz)	E_1	E_2
TCL	$0.1 \le f \le 10$	≥ 50 dB	≥ 50 dB
TCL	$10 < f \le 20$	$\ge 50 - 20\log_{10}\left(\frac{f}{10}\right)$ dB	$\ge 50 - 20\log_{10}\left(\frac{f}{10}\right)$ dB

Table 146–6—Coupling attenuation

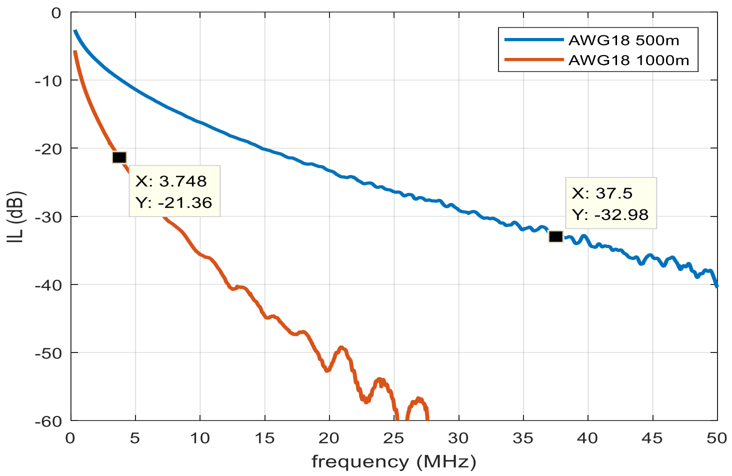
Frequency (MHz)	(dB)		
	E_1	E_2	E_3
0.1 to 20	≥ 50	≥ 50	≥ 60

The 10BASE-T1L system with the required shielding performance is sufficient in E3 environment, even without FEC.

Signal and Noise for 100BASE-T1L

Compared with 10BASE-T1L, 100BASE-T1L faces a different situation due to 10x bandwidth.

- More signal attenuation/lower received signal power @ Nyquist bandwidth (take 3.75MHz * 10 for PAM3 as an example).



- Larger external EMI/RFI noise on the cable as Mode conversion loss/Coupling attenuation will get worse at higher frequency band. (need measurement based evaluation)

- Also, a burst impulsive noise will affect more symbols for a higher symbol rate.

If we leave all these requirements only to link segment, it can be aggressive for cable/connectivity vendors, which seems not good for reusing existing cable system.

On the other side, further increasing transmit power may violate FCC and CISPR EMC requirements.

Therefore, there is a need to consider PHY enhancement to ensure 100BASE-T1L performance.

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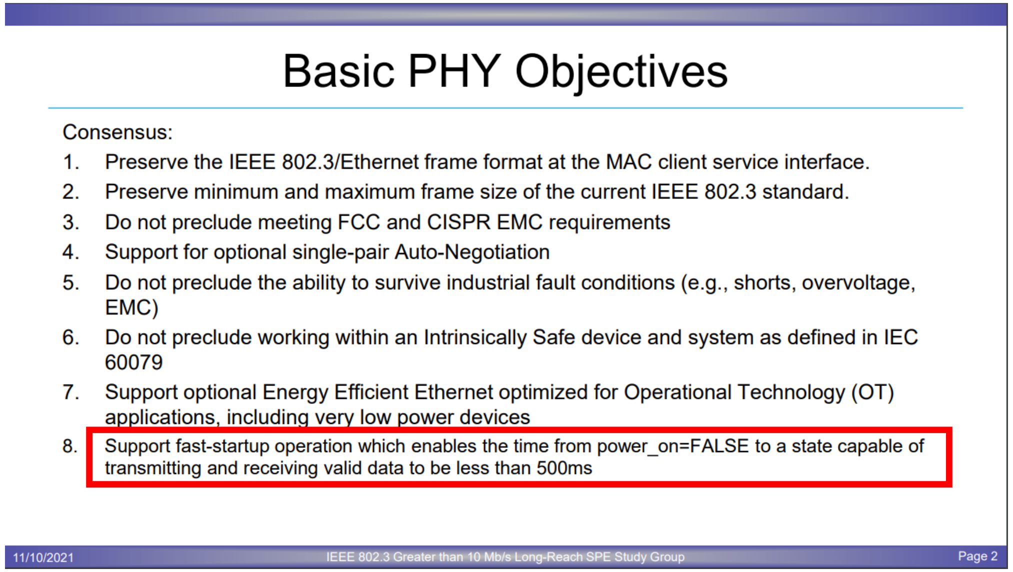
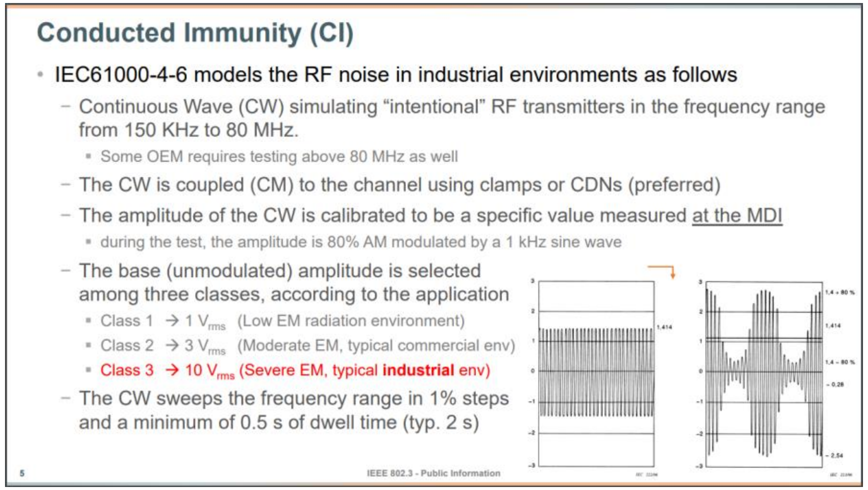
Equalization and Coding

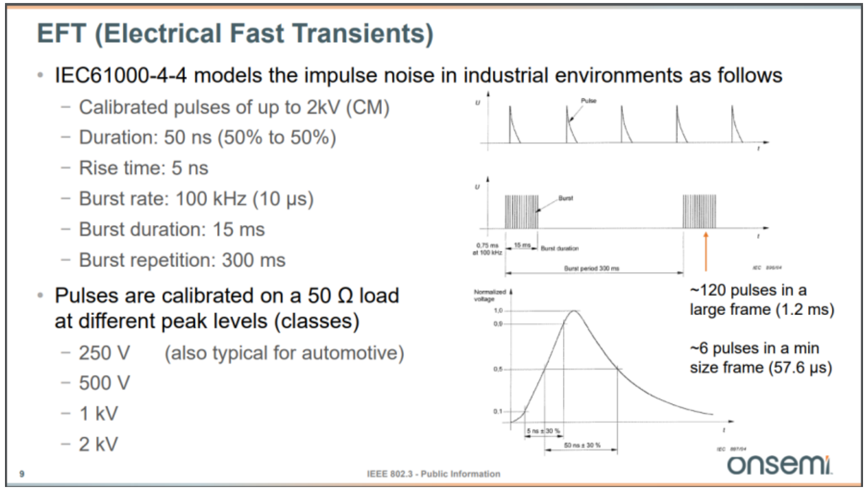


Try to avoid use of PBO or THP as in 2.5/5GBASE-T and 10GBASE-T:

- SPE does not have in-pair FEXT issue, PBO is not so necessary.
- Exchanging coefficients and re-adapting slows things down, not very suitable for fast link up.

It is better to use DFE instead of THP.
(Similar with Automotive SPE)





Two major noise sources in industrial environments are:

- RFI Noise: need heavy DFE instead of linear equalization; DFE can cause error propagation.
- Transient Impulse Noise: can cause burst error.

Reed-Solomon FEC is a good choice for solving the burst error problem.

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RS-FEC Considerations

Basic concept of RS-FEC:
RS(N,M,k):
- Single RS frame consists of N symbols, and M of them are data (M < N)
- Each RS symbol consists of k bits ($N < 2^k$)
- Max number of correctable RS symbols is (N-M)/2

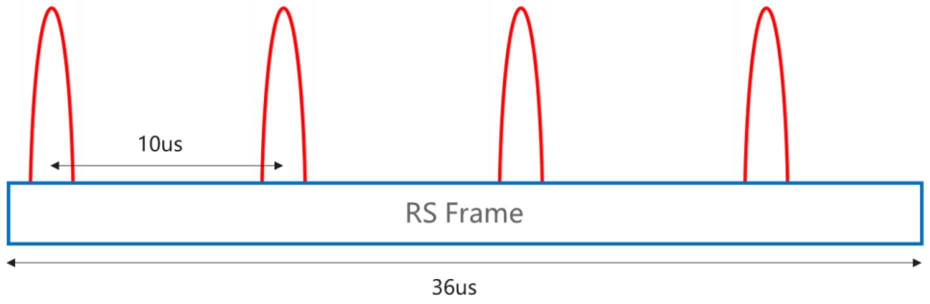
Key features of RS-FEC:
- Coding gain
- Coding overhead
- Correcting length
- Latency

RS-FEC used in SPE PHY:
- 1000BASE-T1: RS(450,406,9)
- 2.5/5/10GBASE-T1: RS(360,326,10) with interleaving
- 25GBASE-T1: RS(936,846,10) with interleaving

Take RS(450,406,9) as an example:

Achieve coding gain >6dB @ 1e-10;
If shifted from 1Gbps to 100Mbps: RS frame length = 36us, correcting length = 1.76us.

According to IEC61000-4-4 impulse noise model: duration = 50ns, burst rate = 100kHz (10 µs).



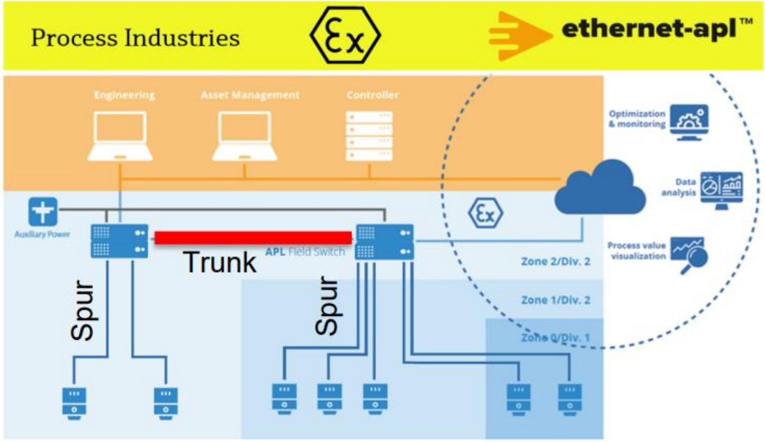
Worst case:
4 pulses are included in a single RS frame;
total error length = 50ns * 4 = 200ns << 1.76us, but the FEC latency reaches 40us. (<10us for 3cg)

For 100BASE-T1L, if RS-FEC is used, the code parameters need to be well designed to balance different metrics.

Performance vs. Latency

From the perspective of performance and latency requirement, we have two typical use cases:

USE CASE 1: Process Industry
- 500m reach @ 100Mbps
- Lower SNR, more susceptible to external noise
- No specific latency requirement
- Shielding may be not enough, FEC is likely to be required



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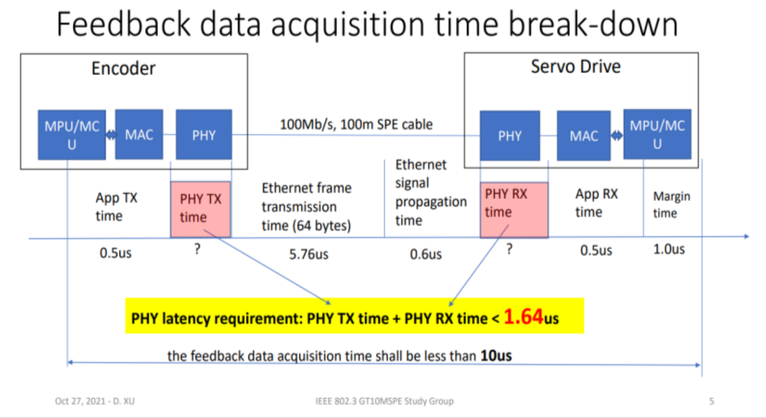
USE CASE 2: Servo Motor Control
- 100m reach @ 100Mbps
- Higher SNR, less susceptible to external noise
- Low latency requirement, FEC should not be enabled
- Good shielding protection must be ensured



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When FEC is used, how does 100BASE-T1L satisfy both applications?

Two Modes for One PHY

There are some IEEE examples that support different modes in one PHY:

802.3bp: Different link segment operation mode

The 1000BASE-T1 PHY operates using full-duplex communications over a single twisted-pair copper cable with an effective rate of 1 Gb/s in each direction simultaneously while meeting the requirements (EMC, temperature, etc.) of automotive and industrial environments. The PHY supports operation on two types of link segments:

a) An automotive link segment supporting up to four in-line connectors using a single twisted-pair copper cable for up to at least 15 m (referred to as *link segment type A*)

b) An optional link segment supporting up to four in-line connectors using a single twisted-pair copper cable for up to at least 40 m to support applications requiring extended physical reach, such as industrial and automation controls and transportation (aircraft, railway, bus and heavy trucks). This link segment is referred to as *link segment type B*.

802.3cg: Different PMA operation mode

When tested with the test fixture shown in Figure 146–20 with the transmitter in test mode 1, the transmitter output voltage shall be 2.4 V + 5%/– 15% peak-to-peak (for the 2.4 Vpp operating mode) and 1.0 V + 5%/– 15% peak-to-peak (for the 1.0 Vpp operating mode). Transmitter output voltage can be set using the management interface or by hardware default set-up.

802.3ck: Dual FEC operation mode

100GBASE-CR1/KR1 FEC Support

- One option is to support both RS 544 FEC mechanisms:
  - Non-Interleaved RS FEC using 4:1 bit muxing (Clause 91)
  - Interleaved RS FEC based on nicholl_3ck_01b_0519
- Operation would be as follows:
  - All implementations implement both FECs for TX and RX
  - AN is used to negotiate which FEC is used for a given link
    - The chosen FEC is used in both directions on that link
  - Default FEC is TBD
- Best of both worlds
  - Lowest latency with non-interleaved FEC for those links that don't have burst error concerns
  - More robust interleaved FEC for those links that want it
  - Minimal impact to designs

Page 2

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As a reference, 100BASE-T1L can include different PCS operation modes based on applications:

- Normal mode (enable FEC);
- Low-latency mode (bypass FEC);
- Modes can be determined through Auto Negotiation or manual configuration.

FEC Alternative: PHY Retransmission

- Physical layer retransmission can be seen as a “FEC function” enabled only when needed, which is more flexible;
- The data should be retransmitted in the form of a defined packet;
- TX retransmission can be triggered by different signals from RX, such as received data without acknowledgement or retransmission request;
- Retransmission should be designed under the overall latency limit;
- Example: ITU 998.4 DSL, MIPI A-PHY ……

Summary

- 3dg is obviously different from 3cg due to bandwidth expanding, and some PHY enhancement is required for better immunity;
- Noise type of industry is similar with vehicle, so RS can be a good choice for FEC coding;
- Different PCS operation modes (w/ and w/o FEC) can be designed to adapt to different applications;
- Physical layer retransmission can be an alternative of FEC.

Thank you.