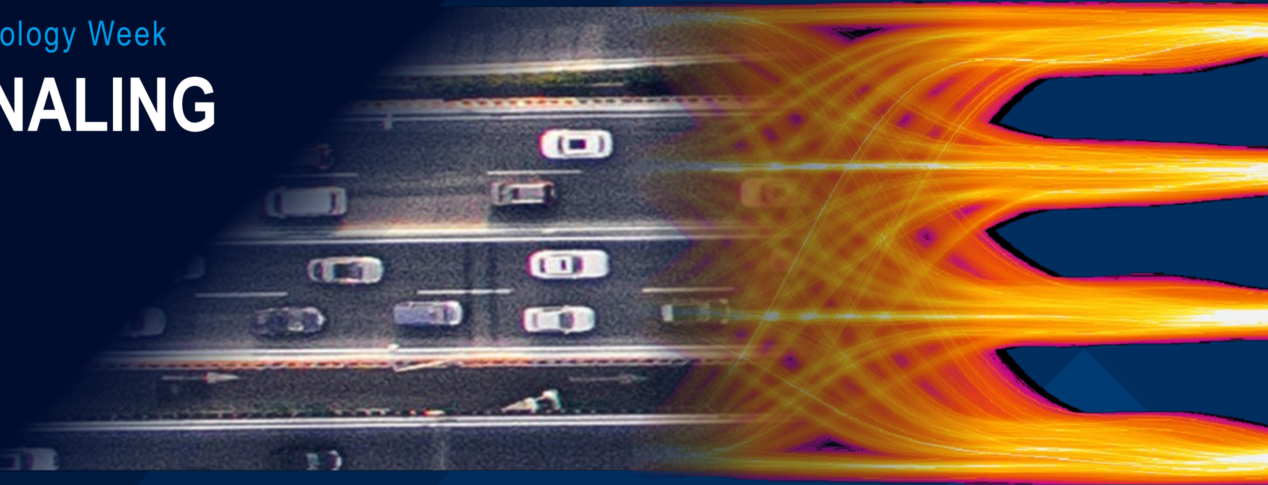
2021 Ethernet & IP @ Automotive Technology Week

TESTING PAM4 SIGNALING FOR 10GBASE-T1 AUTOMOTIVE ETHERNET



Curtis Donahue

Technology Manager for High Speed Digital Applications

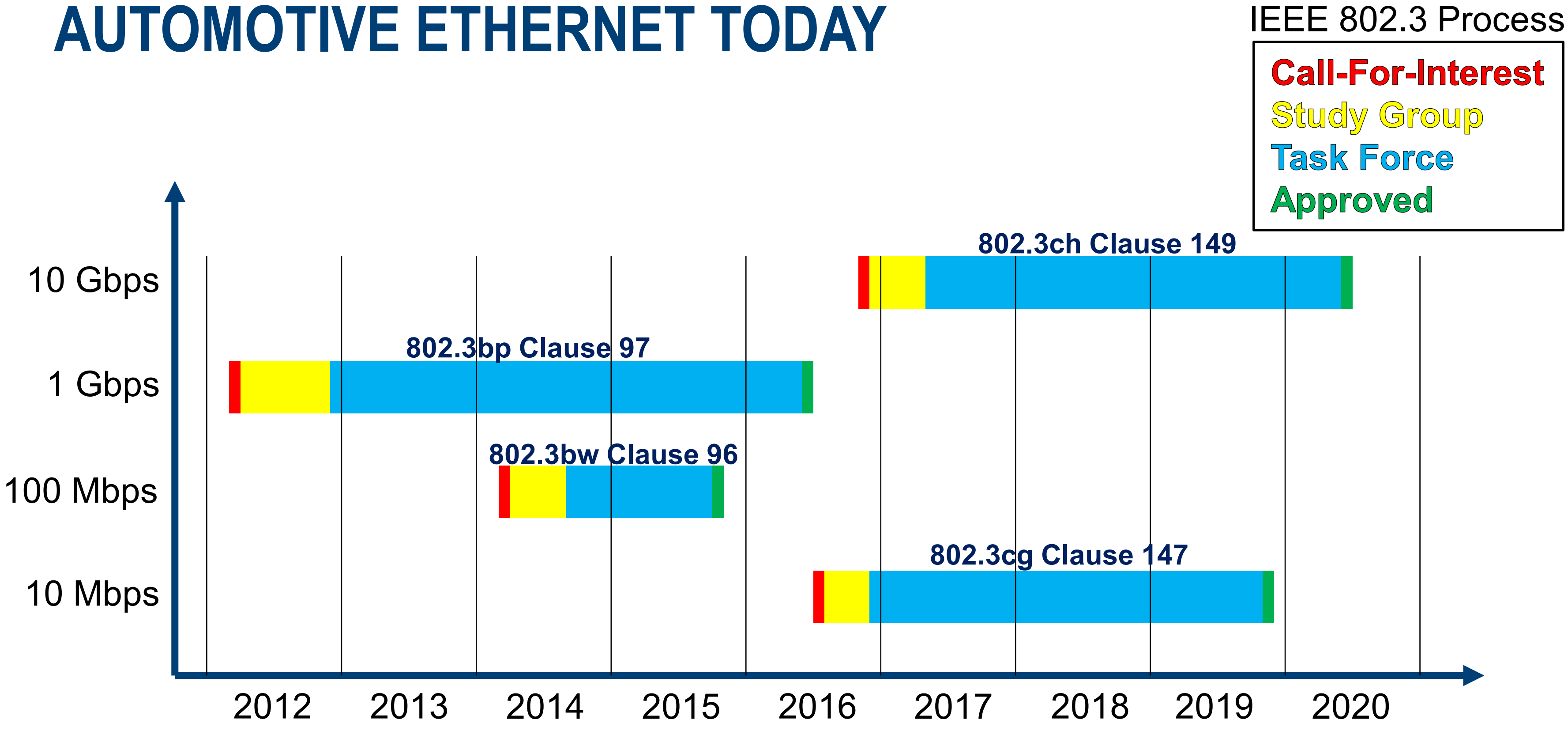
ROHDE & SCHWARZ

Make ideas real

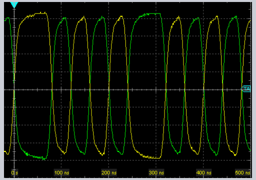
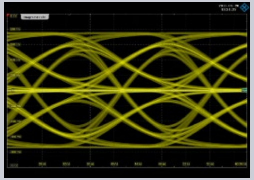
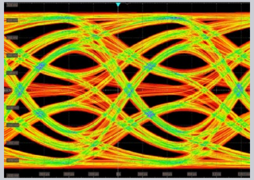
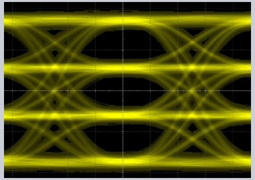
AGENDA

- AUTOMOTIVE ETHERNET TODAY
- CLAUSE 149 PMA
  ELECTRICAL SPECIFICATION
- TRANSMITTER
  DETERMINISTIC JITTER
- TRANSMITTER
  LINEARITY / DISTORTION
- CONCLUSION

AUTOMOTIVE ETHERNET TODAY



AUTOMOTIVE ETHERNET TODAY

	10BASE-T1S	100BASE-T1	1000BASE-T1	2.5GBASE-T1	5GBASE-T1	10GBASE-T1
IEEE 802.3 Reference	802.3cg-2019 Clause 147	802.3bw-2015 Clause 96	802.3bp-2016 Clause 97	802.3ch-2020 Clause 149		
OPEN Alliance PHY Compliance Tech Committee	TC14	TC1 (Closed)	TC12	TC15		
Bit Rate (Mbps)	10	100	1000	2500	5000	10000
Baud Rate (MBd)	12.5	66.66	750	1406.25	2812.5	5625
Encoding	2-Level DME 	PAM3 		PAM4 		
Cabling	UTP		UTP (STP optional)	STP		

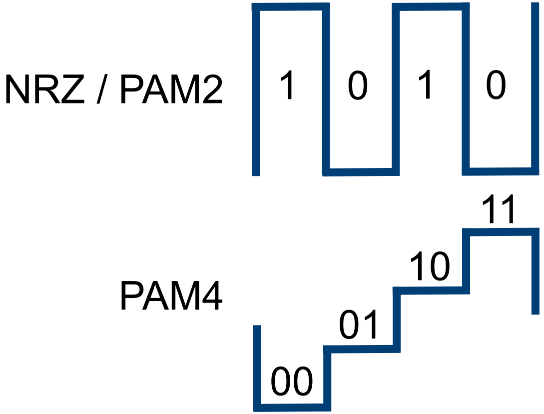
AUTOMOTIVE ETHERNET TODAY

Why change the encoding scheme of the transmitter output?

Simple answer is bandwidth!

15m Cable	PAM2	PAM3	PAM4	PAM5	PAM6	PAM8	PAM16
Baud Rate (GBaud)	11.2	7.5	5.6	5.0	4.5	3.7	2.8
Nyquist Freq. (GHz)	5.6	3.75	2.8	2.5	2.2	1.8	1.4

https://www.ieee802.org/3/ch/public/may18/Pandey_3ch_01c_0518.pdf

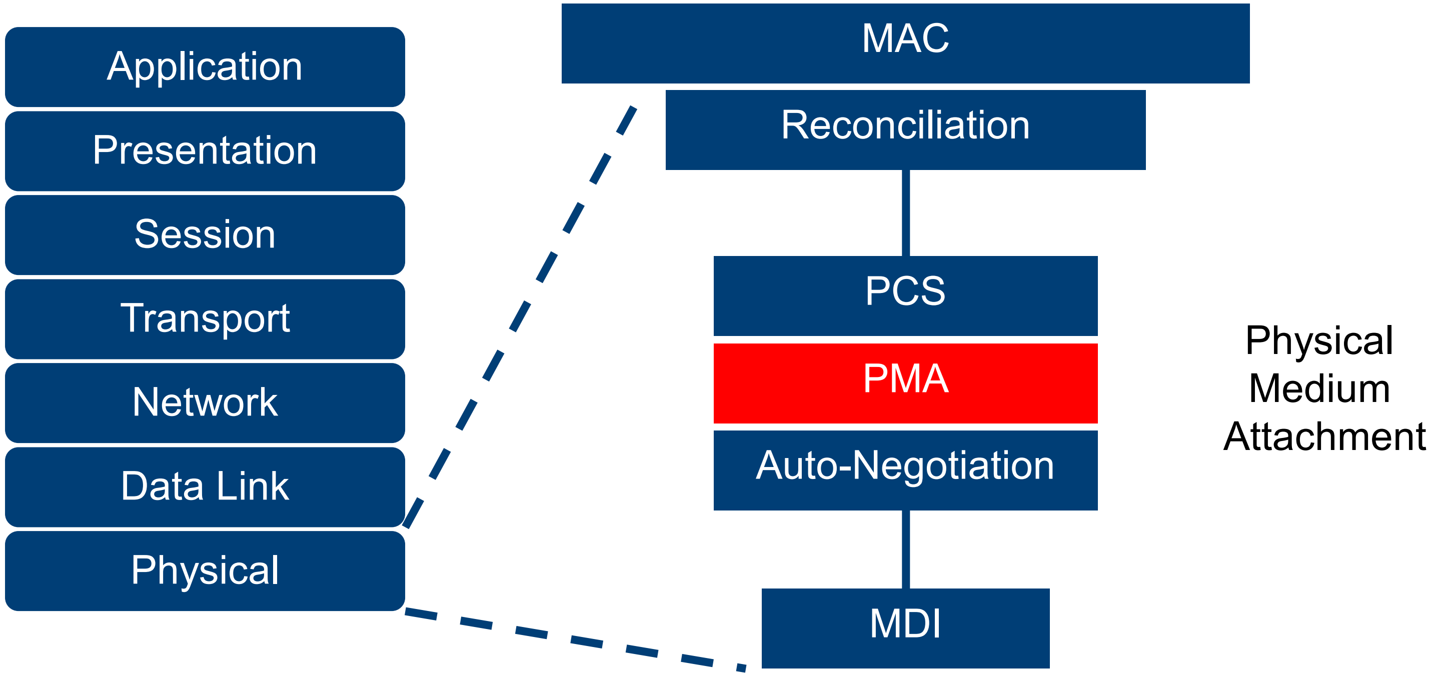


For a given Baud Rate,
As the number of voltage levels increases

The Nyquist Frequency decreases

But SNR also decreases

CLAUSE 149 PMA ELECTRICAL SPECIFICATION



CLAUSE 149 PMA ELECTRICAL SPECIFICATION

Maximum Output Droop

Transmitter Linearity

Transmitter Timing Jitter

Transmitter PSD & Power Level

Peak Differential Output

Transmitter Clock Frequency

OPEN ALLIANCE

TC15
IEEE 2.5G/5G/10GBASE-T1
Physical Medium Attachment (PMA)
Test Suite Draft

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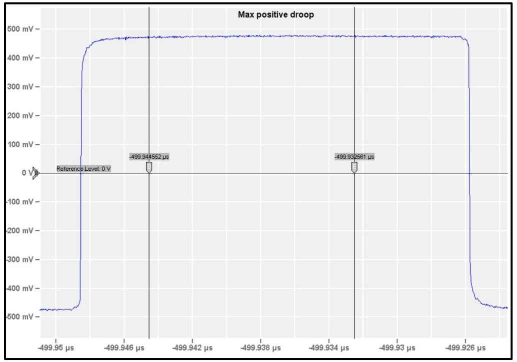
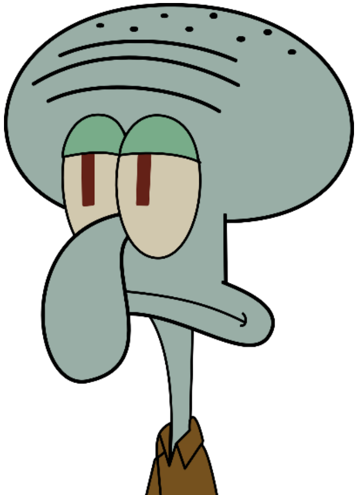
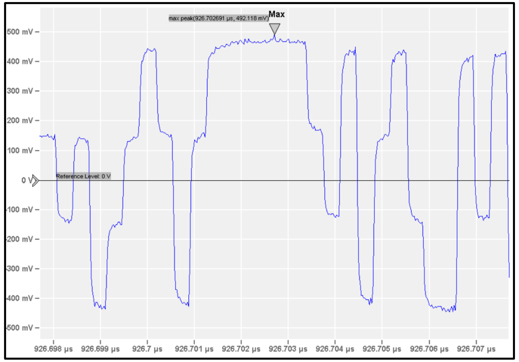
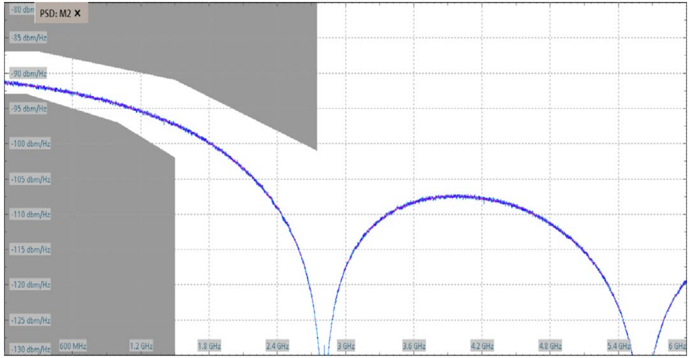


Boring







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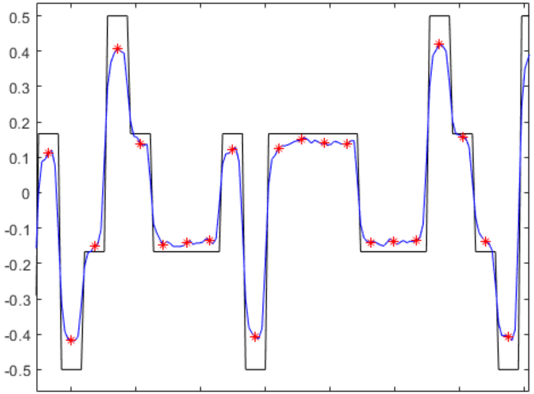

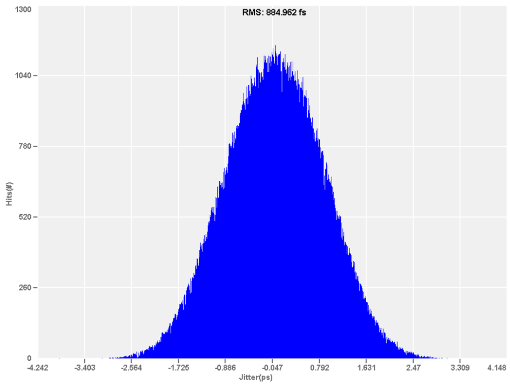

Interesting

TRANSMIT JITTER

There are actually 5 unique Jitter parameters that need to be measured for 10GBASE-T1 PHYs:

- **Transmitter Timing Jitter (TX_TCLK_175): MASTER Mode**
- **Transmitter Timing Jitter (TX_TCLK_175): SLAVE Mode**
- **Transmit MDI Random Jitter**
- **Transmit MDI Peak-to-Peak Deterministic Jitter**
- **Transmit MDI Peak-to-Peak Even-Odd Jitter**

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The TX_TCLK Jitter and MDI Random Jitter are relatively unchanged from other Ethernet PHYs. These are still Time Interval Error (TIE) based measurements, performed with 2-level test patterns

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- Transmitter Timing Jitter (TX_TCLK_175): SLAVE Mode
- Transmit MDI Random Jitter
- **Transmit MDI Peak-to-Peak Deterministic Jitter (DJ)**
- **Transmit MDI Peak-to-Peak Even-Odd Jitter (EOJ)**

The DJ and EOJ parameters are unique to Clause 149. Adopted from high speed serdes Ethernet PHY definitions, similar to the new TX Linearity requirement.

But due to time constraints, we'll look at just the Deterministic Jitter procedure!

TRANSMITTER DETERMINISTIC JITTER

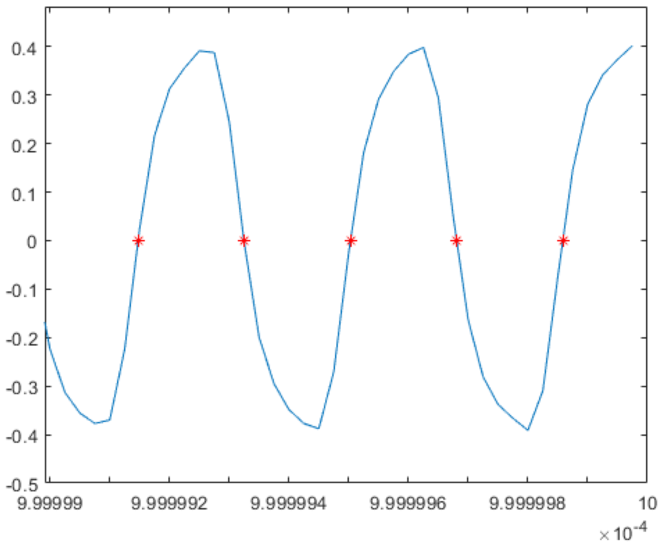
The IEEE specification provides a very detailed procedure for how to calculate the TX DJ!

CRJrms and CDJ are determined using the following procedure:

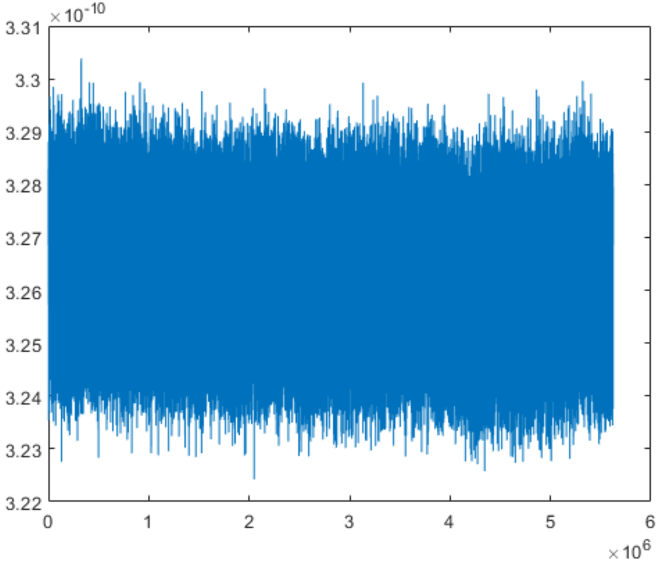
1) CRJrms and CDJ are measured using the JP03A test pattern (94.2.9.1).
2) Using appropriate test equipment and procedure, capture the zero-crossing times, $T_{ZC}(i)$, of a pattern of length, N, of 10^7 symbols or greater.
3) Determine the average pulse width ΔT_{Avg} using Equation (94–14).
4) Determine the jitter series, $\tau(k)$, using Equation (94–15).
5) Apply the effect of a high-pass filter with the response given by Equation (94–16) to the jitter samples to obtain $\tau_{HPF}(k)$, where f is the frequency in MHz, f_n is 2.12 MHz, T is 0.0286 µs, and $j = \sqrt{-1}$.
6) Create a CDF as a function of $\tau_{HPF}(k)$.
7) From the CDF, determine J_5 as the difference between τ_{HPF} at the $(1–0.5 \times 10^{-5})$ and 0.5×10^{-5} probabilities, respectively, and J_6 as the difference between τ_{HPF} at the $(1–0.5 \times 10^{-6})$ and 0.5×10^{-6} probabilities, respectively.
8) Calculate CRJrms and CDJ using the relationship in Equation (94–17).

TRANSMITTER DETERMINISTIC JITTER

Measure the 2812.5 MHz sine wave test pattern

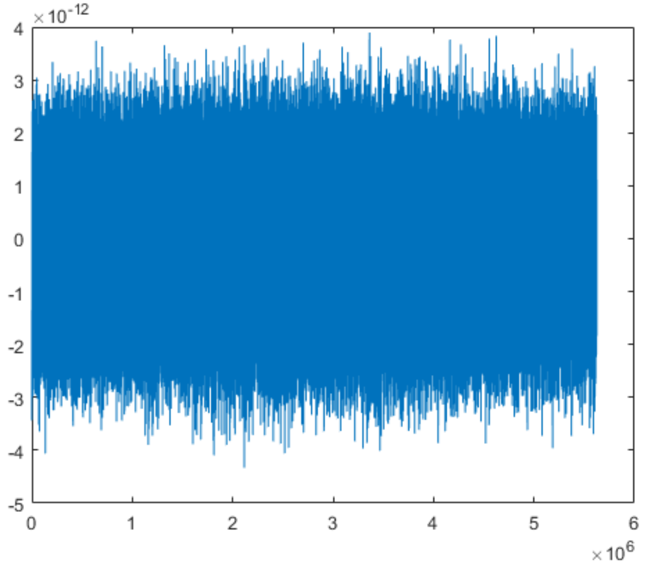


Calculate the Jitter series based off the zero-crossing values

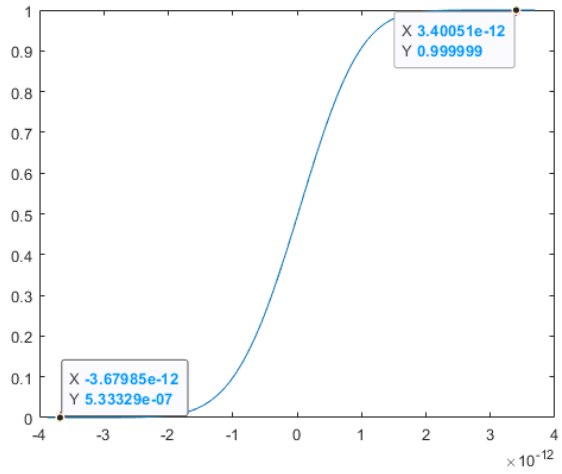


TRANSMITTER DETERMINISTIC JITTER

Apply a high pass filter with 1 MHz cutoff to the Jitter series



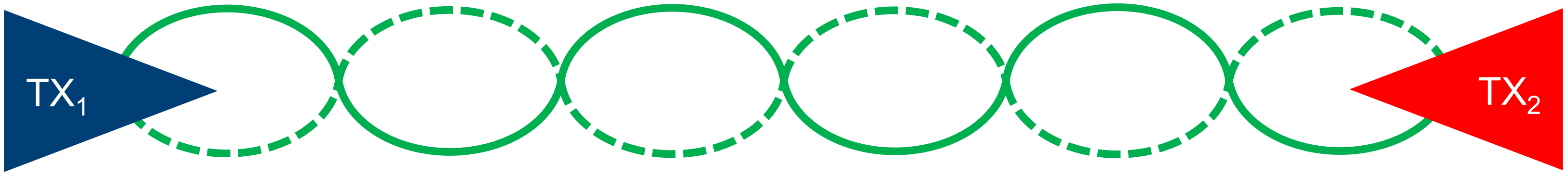
Derive the J5 and J6 values from the cumulative density function (CDF)



$$\begin{bmatrix} CRJrms \\ CDJ \end{bmatrix} = \begin{bmatrix} 1.0538 & -1.0538 \\ -9.3098 & 10.3098 \end{bmatrix} \begin{bmatrix} J_6 \\ J_5 \end{bmatrix}$$

TRANSMITTER LINEARITY / DISTORTION

- With the exception of 10BASE-T1S half duplex mode, all Automotive Ethernet PHYs operate in full duplex transmission across a single pair of conductors
- This means in a link up scenario there are two distinct transmit signals combined on the wire
- The TX Distortion test has been used for several Ethernet PHYs to quantify the linearity of a PHYs transmitter implementation in the presence of additional transmitters



TRANSMITTER LINEARITY / DISTORTION

For 100BASE-T1 and 1000BASE-T1 the TX Distortion test required several pieces of equipment to perform accurately!

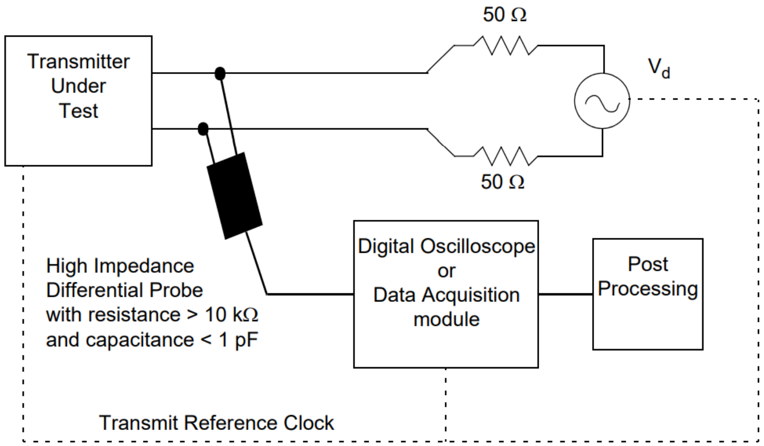
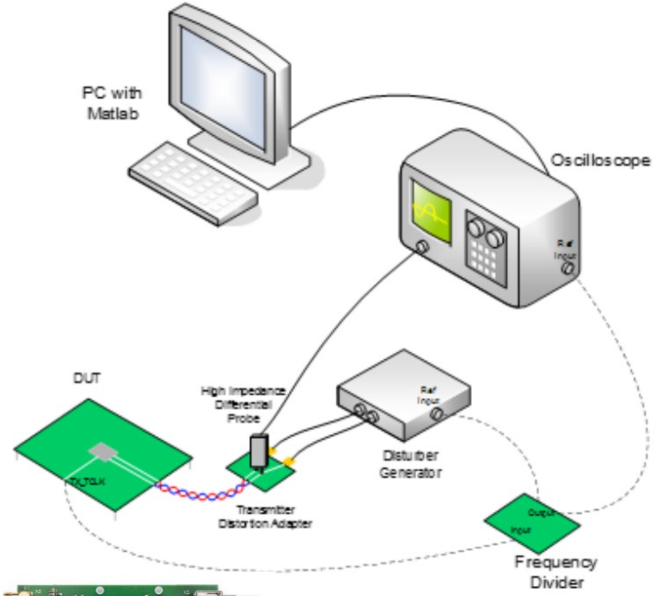


Figure 96–21—Transmitter test fixture 2: Distortion



RT-ZF3/6 Frequency Converter
Needed for Reference Clock Generation

TRANSMITTER LINEARITY / DISTORTION

However, since 10GBASE-T1 adopted PAM4 encoding the 802.3ch Task Force looked for inspiration at existing PAM4 Ethernet PHY specifications, and replaced the “injected disturber” approach with the Signal to Noise-and-Distortion Ratio (SNDR) metric instead.

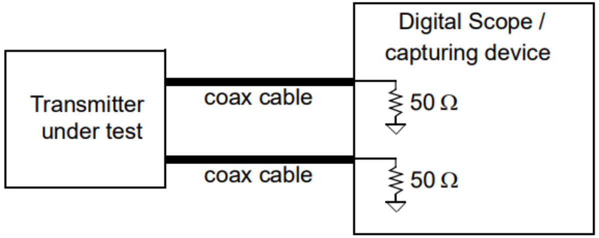


Figure 149–35—Transmitter test fixture 1 for transmitter droop measurement and transmitter linearity measurement

TRANSMITTER LINEARITY / DISTORTION

Using the measured PRBS13Q waveform, SNDR is calculated using the following equation:

P_{max} is the peak of the linear fit pulse response of the measured PRBS13Q output waveform

$$SNDR = 10 \times \log_{10}\left(\frac{{P_{max}}^2}{({\sigma_e}^2) + ({\sigma_n}^2)}\right)$$

σ_n is the RMS deviation from the average voltage value measured at locations of consecutive identical symbol transmission (i.e. Noise)

σ_e is the standard deviation of the linear fit error (i.e. Distortion)

TRANSMITTER LINEARITY / DISTORTION

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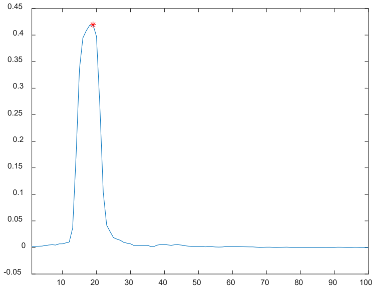
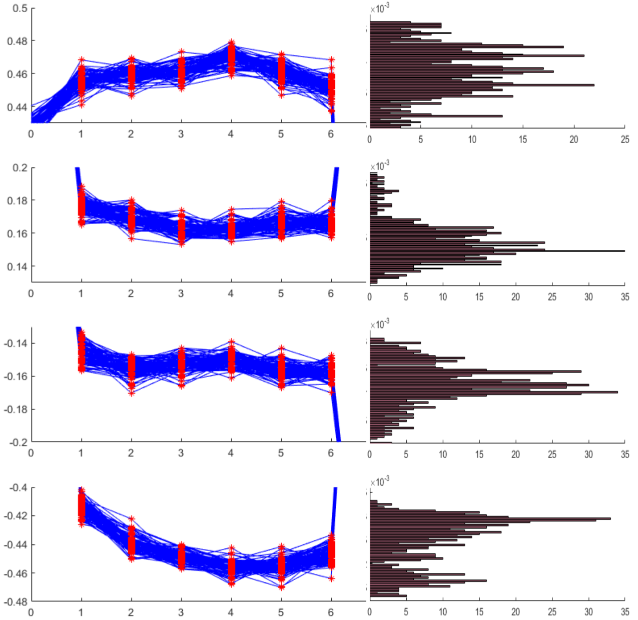
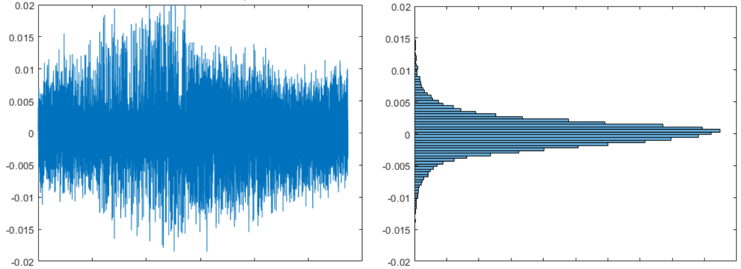


$$SNDR = 10 \times \log_{10}\left(\frac{{P_{max}}^2}{({\sigma_e}^2) + ({\sigma_n}^2)}\right)$$





CONCLUSION

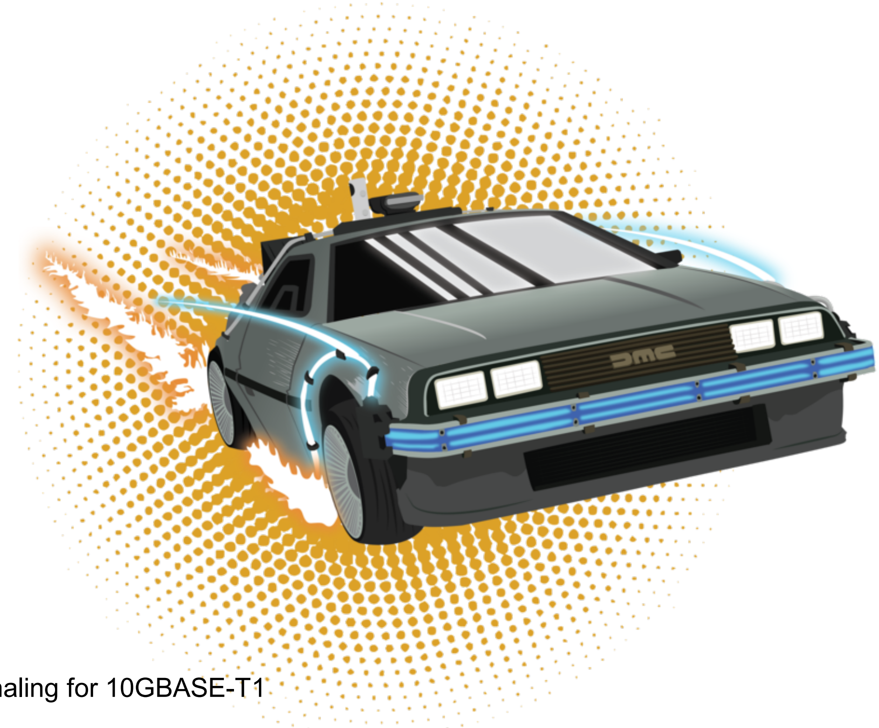
- Various Automotive Ethernet PHY specifications have been developed in IEEE 802.3 for the last ~10 years
- OPEN Alliance has been the industry leader for Automotive Ethernet test specifications

- 10GBASE-T1 adopted PAM4 encoding, which required changes to the electrical specification
- Presenting unique test setup and measurement algorithms not present in previous Automotive Ethernet PHYs

- In 2.5/5/10GBASE-T1, difficult TX Distortion test setup has been replaced by SNDR method
- Higher bandwidth instruments with larger memory depth are necessary to perform the mathematically heavy algorithms defined by IEEE

OUTATIME

Thank you!



ROHDE & SCHWARZ AUTOMOTIVE ETHERNET TEST SOLUTIONS

R&S RTP

R&S ZNB

- Support OPEN Alliance
  - TC1, TC8, TC9, TC12, TC14, TC15
- PMA Compliance Test Coverage:
  - 10BASE-T1S
  - 100BASE-T1
  - 1000BASE-T1
  - 2.5G/5G/10GBASE-T1
- Trigger & Decode Capabilities
- Automatic test execution
- Automated controlling of Scope, VNA, and signal generator


TEST IT. TRUST IT.