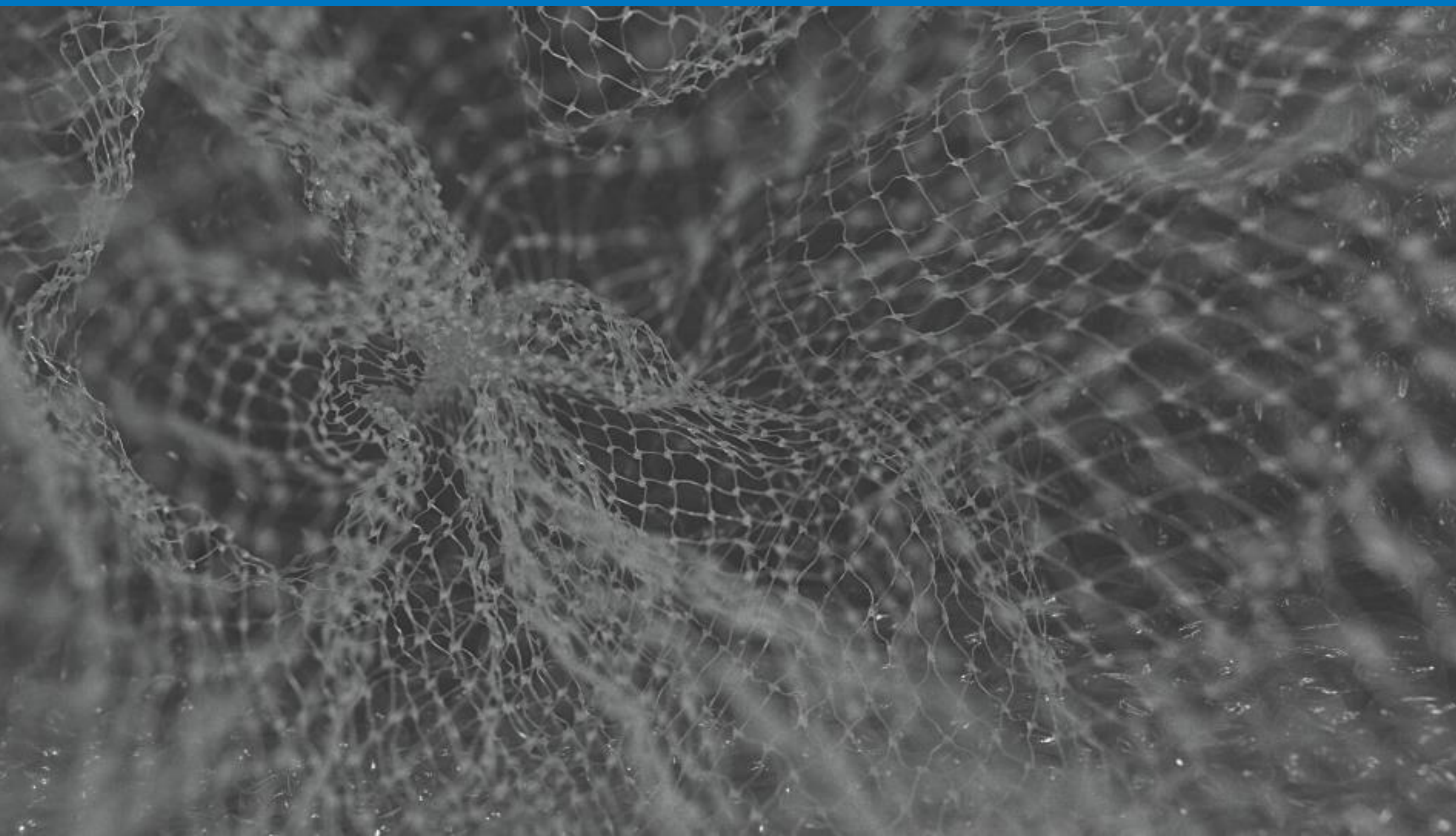
TELEDYNE LECROY
Everywhereyoulook™

AN/LT for 112Gbps SerDes



WHITE PAPER

Auto Negotiation & Link Training for
112G SerDes-based Ethernet

CONTENTS

Introduction

The constant increase in demand for bandwidth is leading to a move among Service Providers and Data Centers towards 25.6 Tbps switch architectures with 400, 800 Gbps and even 1.6 Tbps Ethernet interfaces. Some of the key challenges for data center owners are the density of connectors, the power consumption and cost.

To enable the higher port speeds there is a trend towards higher and higher per lane speed. The current maximum is 106.25 Gbps using four-level Pulse Amplitude Modulation (PAM-4) as defined for Ethernet in IEEE 802.3ck

Traditionally, high speed Ethernet is transmitted over optical fiber, but this solution is both power consuming and costly. Electrical cables can be an alternative for short inter-rack and top-of-the-rack connections of only a few meters. The benefit of electrical cables over fiber cables are that they enable both lower cost and lower power consumption.

Transmitting PAM-4 signals at 106.25 Gbps over electrical cables leads to severe degradations of the signal in frequency dependent loss, inter-symbol-interference, and cross talk. For this reason, both equalizing and Forward Error Correction (FEC) become mandatory to maintain a sufficient Bit Error Rate (BER).

Auto Negotiation (AN) and Link Training (LT) are key elements of Ethernet transmission over electrical connections and can reduce overall installation time, minimize the risk of configuration mistakes and optimize the performance. During the AN process, two connected devices exchange information about their transmission speed and FEC abilities and agree on a common set of transmission parameters. LT is then used to automatically tune the transmit equalizer settings at each device for minimum BER at the selected transmission speed.

In this White Paper we will provide a tutorial of AN and LT for 112G SerDes based 100 Gbps, 200 Gbps, and 400 Gbps Ethernet, and guidelines for when AN and LT is needed.

Brief background on 100G, 200G and 400G Ethernet using 112G SerDes

Ethernet transmission at 100 Gbps, 200 Gbps and 400 Gbps based on a SerDes speed of 112 Gbps is being standardized in IEEE 802.3ck.

A common modulation format used for Ethernet is Non-Return-to-Zero (NRZ) where each symbol period carries information about a single bit – i.e either a “1” or a “0”. However, in IEEE802.3ck the modulation format is 4-level Pulse Amplitude Modulation (PAM4) with each symbol holding a two-bit value – i.e. “00”, “01”, “10” or “11”. The symbol rate is 53.125 GBaud leading to a data rate of 106.25 Gbps on a single PMD lane.

The Serializer-Deserializer (SerDes) used for 106.25 Gbps Ethernet is designed for 112 Gbps transmission to support the ITU-T recommendation G.709 Optical Transport Network (OTN) standard and therefore, the SerDes is referred to as 112G even though the actual speed for Ethernet is 106.25 Gbps.

As the signals are being transmitted, they get distorted which eventually leads to bit errors at the receiver. At a SerDes rate of 112 Gbps and a bit error rate (BER) of 10^{-12} a bit error will occur every 10 seconds. For this reason, the BER requirement for 100 Gbps is being increased to 10^{-14} in the IEEE802.3ck standards work. To obtain these low levels of BER, Forward Error Correction is mandatory. Forward Error Correction is a coding technique used to detect and correct errors in a bitstream by adding redundant bits forming an error-correcting code at the transmitter. At the receiver the FEC decoder uses these extra bits to detect erroneous bits and correct them. In IEEE802.3ck the FEC is defined to be two symbol-interleaved Reed-Solomon (RS) (5440,5140, t=15) referred to as 100GBASE-R RS-FEC-Int, where the symbol length is 10 bits.

Another method to improve the signal integrity is to incorporate equalizers at both the transmitter and the receiver. Since the content of this white paper is Link Training and LT only affects the transmitter equalizer, we will only consider this here.

The transmitter equalizer is a Feed Forward Equalizer (FFE) implemented as a Finite Impulse Response (FIR) filter. Figure 1 shows the FIR filter defined in IEEE802.3ck for 112 Gbps SerDes. As can be seen, the FIR filter has 5 taps and this is an extension from the earlier versions of the standard which had fewer taps defined.

The input digital data propagates through a series of delay lines. Each delay is equal to one symbol unit time interval. The output of the filter is a weighted sum of the current symbol (c(0)), the preceding symbol (c(+1)) and the three following symbols (c(-1), c(-2) and c(-3)). This scheme enables the equalizer to adjust for errors arising from Inter Symbol Interference.

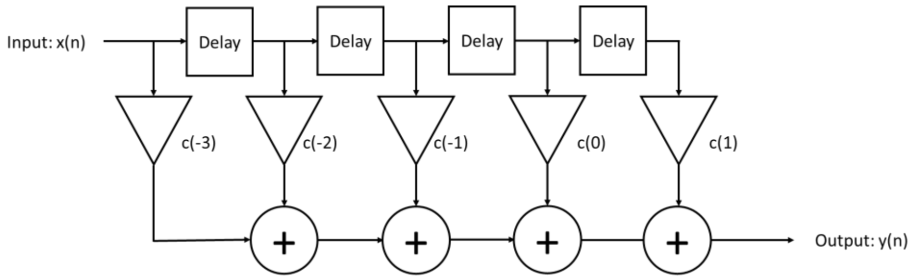


Figure 1: Discrete FIR filter with five taps.

Basics of Auto Negotiation

The main purpose of Auto Negotiation (AN or sometimes ANEG) is for two connected devices at the end-points of a link to communicate together and agree on a common set of transmission parameters. This is a feature of Ethernet that we use every day at home and in the office when connecting devices with different port abilities.

AN is handled by the Physical layer (PHY) of the OSI model as shown on Figure 2.The first thing to check of course is, whether both end points have AN enabled. If one of the end points does not support AN, the process will naturally fail.

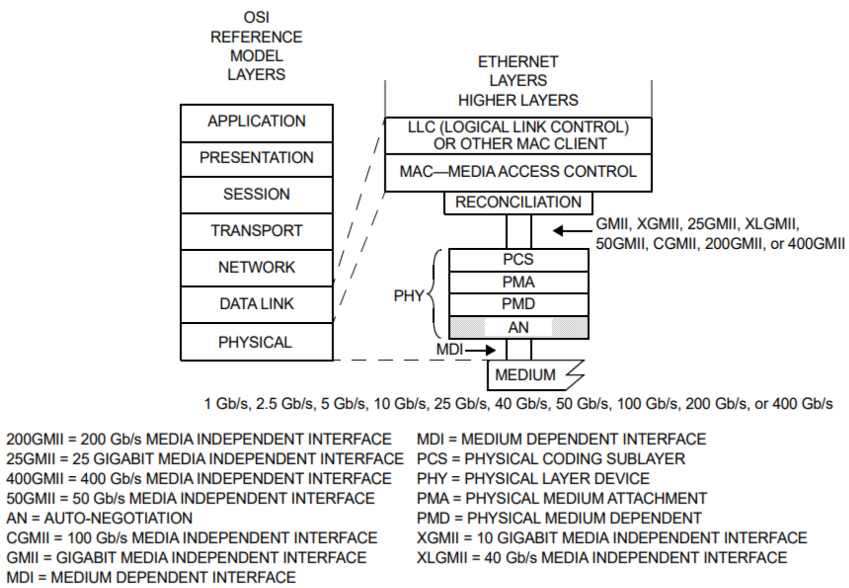


Figure 2: Location of AN in the OSI stack.

Originally, the AN process was standardized in IEEE 802.3 clause 28 and required the two devices to negotiate on a set of predefined abilities regarding transmission speed (Technology ability), duplex mode (Duplex ability) and flow control (Pause ability). In Clause 28, AN was only defined for twisted-pair electrical wires at 10 or 100 Mbps BASE-T and later extended to 1, 2.5, 5 and 10 Gbps BASE-T. With the change to a completely different signaling format for higher speed Ethernet over Twin-axial Cable (-CR) and back-planes (-KR), many more speed options, multi-lane transmission and Forward Error Correction, the AN standard has been expanded and is now described in IEEE 802.3 clause 73.

The AN protocol uses Link Code Words (LCWs) for the communication. When two devices are connected over a cable or back-plane they exchange LCWs to negotiate and agree on a common set of transmission parameters. For Terabit Ethernet this very often reduces to the speed and maybe the FEC ability.

Base Page and Next Pages

The main differences between clauses 28 and 73 are that the modulation scheme and speed has been changed to Differential Manchester Encoding (DME) and the LCW messages has been extended to 48 bits. The LCWs are often referred to as Base Pages and Next Pages (or DME pages). As new speeds and FEC options get added to the standard clause 73 must be updated with these new technology abilities but the underlying protocol remains unchanged.

The AN process communicates at a bit rate of 156.25 Mbps. Since this is obviously much lower than the actual speed, that the cable is designed for (which can be up to 100 Gbps per lane), the DME signaling will be transmitted with high quality and no errors.

For multi lane connections AN is done on lane 0 only and the remaining lanes have their SerDes disabled during AN.

The DME scheme is illustrated on Figure 3. Every odd numbered transition in the signal is used for clock recovery and the even numbered transitions encode the actual data bits of the DME page. A transition encodes a “1” and the absence of a transition encodes a “0”.

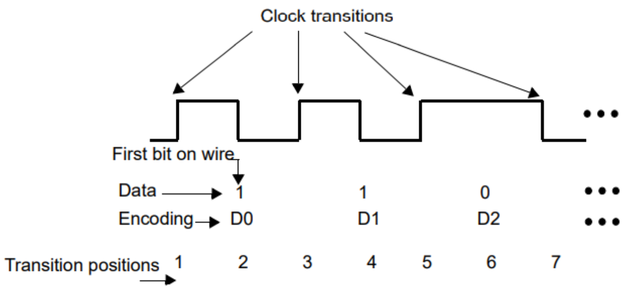


Figure 3: DME scheme.

DME Base Page (IEEE802.3 clause 73)

The 48 bits of the Base DME page are defined in the IEEE 802.3 standard clause 73 (see Figure 4).

D 0	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15
S 0	S 1	S 2	S 3	S 4	E 0	E 1	E 2	E 3	E 4	C 0	C 1	C 2	RF	Ack	NP

D 16	D 17	D 18	D 19	D 20	D 21	D 22	D 23	D 24	D 25	D 26	D 43	D 44	D 45	D 46	D 47
T 0	T 1	T 2	T 3	T 4	A 0	A 1	A 2	A 3	A 4	5	F 4	F 2	F 3	F 0	F 1

Figure 4: Link Code Word Base Page.

The first five bits give the selector field which determines which specific IEEE Standard is used. The binary value of 00001 signals that the DME page is IEEE 802.3 compliant. Bit D21 through D47 holds the Speed and FEC Technology Ability Field as specified in Table 1 and is encoded such that a 1 means the given ability is supported and a 0 means it is not supported.

Bit	Technology
A0	1000BASE-KX
A1	10GBASE-KX4
A2	10GBASE-KR
A3	40GBASE-KR4
A4	40GBASE-CR4
A5	100GBASE-CR10
A6	100GBASE-KP4
A7	100GBASE-KR4
A8	100GBASE-CR4
A9	25GBASE-KR-S or 25GBASE-CR-S
A10	25GBASE-KR or 25GBASE-CR
A11	2_5GBASE-KX
A12	5GBASE-KR
A13	50GBASE-KR or 50GBASE-CR
A14	100GBASE-KR2 or 100GBASE-CR2
A15	200GBASE-KR4 or 200GBASE-CR4
A16	100GBASE-KR or 100GBASE-CR
A17	200GBASE-KR2 or 200GBASE-CR2
A18	400GBASE-KR4 or 400GBASE-CR4
A19 – A21	Reserved for future technology
F4	100GBASE-P RS-FEC-Int Requested
F2	25G RS-FEC Requested
F3	25G BASE-R FEC Requested
F0	10 Gb/s per lane FEC Ability
F1	10 Gb/s per lane FEC Requested

Table 1: Technology ability field encoding.

Bits D5 through D9 and D16 through D20 are the Echoed and Transmitted Nonce (Number only used once) fields. These field can be used for authentication between the two end-points but, the specific usage is not defined by the standard. Pause ability is signaled by bits D10 through D12.

The Remote Fault (RF) bit D13 and Acknowledge (Ack) bit D14 are used by the Link partners to communicate status during the AN process.

Next Pages (IEEE802.3)

For IEEE802.3 clause 73 Auto Negotiation, generally the Base Page shown on Figure 4 needs to be exchanged only. However, the standard also defines an option to exchange so-called Next Pages. Since the Base Page has only three un-used technology bits left (A19 – A21), the IEEE is working to define specific bits of Next Pages to add more speed options is added in future standards.

If a link partner has a Next Page (NP) to transmit it will set the NP bit D15 to 1. Next Pages can be either Message Next Pages or Unformatted Next Pages as defined on Figure 5 and Figure 6, respectively.

D 0	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15
M 0	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	T	Ack 2	MP	Ack	NP

Message Code Field

D 16	D 17	D 18	D 19	D 20	D 21	D 22	D 23	D 24	D 25	D 26	D 44	D 45	D 46	D 47
U 0	U 1	U 2	U 3	U 4	U 5	U 6	U 7	U 8	U 9	U 10	U 28	U 29	U 30	U 31

Unformatted Code Field

Figure 5: Message Next Page

D 0	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15
U 0	U 1	U 2	U 3	U 4	U 5	U 6	U 7	U 8	U 9	U 10	T	Ack 2	MP	Ack	NP

Unformatted Code Field

D 16	D 17	D 18	D 19	D 20	D 21	D 22	D 23	D 24	D 25	D 26	D 44	D 45	D 46	D 47
U 11	U 12	U 13	U 14	U 15	U 16	U 17	U 18	U 19	U 20	U 21	U 39	U 40	U 41	U 42

Unformatted Code Field

Figure 6: Unformatted Next Page.

If both link partners have the NP bit set to 1 they can exchange next pages. In case a link partner has no Next Pages to send and its link partner has Next Pages to send, it will transmit Next Pages with Null message codes and the NP bit set to 0 while its link partner transmits valid Next Pages.

Next pages (Ethernet Technology Consortium)

The Ethernet Technology Consortium (ETC) has defined a proprietary extension to the IEE802.3 protocol. After the link partners have exchanged Base Pages with the NP set to 1, they exchange an Organizationally Unique Identifier (OUI) tagged formatted Next Page with the message field set to 5 (binary 101) as shown on Figure 7.

Next Page	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
	D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
	D32	D33	D34	D35	D36	D37	D38	D39	D40	D41	D42	D43	D44	D45	D46	D47
MP5 (D0 - D15)	1	0	1	0	0	0	0	0	0	0	0	T	0	1	ACK	1
(D16 - D31)	1	1	0	0	1	0	1	0	1	1	0	Reserved				
(D32 - D47)	1	1	1	1	1	0	1	1	0	0	1	Reserved				

message code #5

OUI [23:2]

Figure 7: OUI tagged Formatted Next Page with message code #5.

After that the link partners exchange an OUI tagged unformatted Next Page with an extended technology abilities field, as detailed on Figure 8. This enables devices to signal that they support technology abilities like 400GBASE-KR8/CR8 and LL-RS-FEC (Low Latency RS-FEC) which is not defined by IEEE802.3.

Code for extended technology abilities

OUI [1:0]

Next Page	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
	D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
	D32	D33	D34	D35	D36	D37	D38	D39	D40	D41	D42	D43	D44	D45	D46	D47
UP-1 (D0 - D15)	1	1	0	0	0	0	0	0	0	1	0	T	0	0	ACK	NP
(D16 - D31)	0	0	0	0	1	1	0	0	1	1	0	Reserved (=0)				
(D32 - D47)	Reserved (=0)		1			LF1	LF2	LF3	F1	F2	F3	F4	LFR	Reserved (=0)		

25GBASE-KR1

50GBASE-KR2

50GBASE-CR2

400GBASE-KR8 / CR8

25GBASE-CR1

FEC Control

LL-RS-FEC Request

LL-RS-FEC Ability

Figure 8: OUI tagged unformatted Next Page.

AN process

During the AN Process each link partners continuously sends the same DME page until the remote link partner has acknowledged the correct receipt of the DME page. If at least one link partner has Next Pages, they exchange those in the same manner until there are no more Next Pages to send.

As part of the AN process a number of time-outs are defined to avoid that the two link partners send DME pages endlessly.

Priority resolution

Once a device is aware of its link partner's abilities, it must decide what type of link to establish. In order to ensure that all devices will choose the same highest common ability, they must implement the Priority Resolution Function. This function simply ranks the possible technologies and requires a device to choose the highest one supported. Table 2**Fejl! Henvisningskilde ikke fundet.** shows an example of a Priority Resolution Table.

Each link partner performs an arbitration process whereby the local end remote technology ability is compared. If both support the highest priority technology the AN process can complete and the link can be established. If both link partners do not support the highest priority, they move down one step at a time in the priority table (Table 2) until they reach a technology ability, they both support.

Priority	Technology	Capability	Note
1	400GBASE-CR4 / KR4	400 Gbps 4 lanes	IEEE mode
2	400GBASE-CR8 / KR8	400 Gbps 8 lanes	Ethernet Consortium mode
3	200GBASE-CR2 / KR2	200 Gbps 2 lanes	IEEE mode
4	200GBASE-CR4 / KR4	200 Gbps 4 lanes	IEEE mode
5	100GBASE-CR or 100GBASE-KR	100 Gbps 1 lane	IEEE mode
6	100GBASE-CR2 or 100GBASE-KR2	100 Gbps 2 lanes	IEEE mode
7	100GBASE-CR4	100 Gbps 4 lanes	IEEE mode
8	100GBASE-KR4	100 Gbps 4 lanes	IEEE mode
9	100GBASE-KP4	100 Gbps 4 lanes	IEEE mode
10	100GBASE-CR10	100 Gbps 10 lanes	IEEE mode

Table 2: Priority Resolution Table for 100, 200 and 400 Gbps Ethernet.

Link Training

When high data rates are transmitted over electrical cables the received data stream can be severely distorted and require equalization before it can be recovered and sampled correctly. Equalizing takes places both at the transmitter and the receiver end.

Link Training (LT) is a process originally defined in IEEE802.3 clause 72 for 10 Gbps Ethernet over electrical cables whereby two end points communicate together in order to tune the settings of their respective transmitter equalizers for optimum transmission. The equalizers in each receiver are solely controlled by the receivers and is not part of the LT process. LT resides inside the PMD of the PHY (see Figure 2) and is also referred to as the PMD Control Function.

During LT, it is the weights of the coefficients c(-3), c(-2), c(-1), c(0) and c(1) of the transmitter equalizer on Figure 1 at each link partner that are being adjusted.

In contrast to AN, the LT protocol operates at the actual speed on the physical cable. Also, the FIR filters generally gets more and more taps as the speed increases. This means that the LT protocol has to be adapted each time a new speed and/or modulation format is introduced. LT for 100, 200, and 400 Gbps Ethernet over 112 Gbps SerDes is described in IEEE802.3 Clause 162.

Training Frames

The link partners use Training Frames to communicate during LT. A training frame consists of control information as well as a training data. The control words exchange information about equalizer settings and the training pattern is used to test the performance of a given equalizer setting.

A training frame consists of a Frame Marker, a Control Field, a Status Field and a Training Pattern Field as shown on Figure 9. The Training Frames are sent independently on all PMD lanes.

The Frame Marker, Control Field and Status Field are all sent using NRZ modulation with the high-level being PAM-4 “3” and low level equal to PAM-4 “0”. The Frame Marker consists of 16 consecutive PAM-4 “3”-symbols followed by 16 consecutive PAM-4 “0”-symbols and enables the receiver to identify the start of a Link Training signal.

The Control Field and Data Fields are sent using Differential Manchester Encoding as described earlier with the high-level being PAM-4 “3” and low level equal to PAM-4 “0”. The transmission speed of the Control and Status Fields is 1/8 of the full PAM-4 symbol rate per PMD lane i.e. 6.64 Gbps.

The Training Pattern is be a Pseudo Random Binary Sequence (PRBS) sent at full PAM-4 speed. The standard dictates that the training starts with NRZ (i.e. PAM-4 “3” and PAM-4 “0”) and ends in either PAM-4 with Gray-coding or PAM-4 with Gray-coding and pre-coding.

The end mode of LT (PAM-4 with or with-out pre-coding) is also the mode that the actual traffic will use after LT has completed.

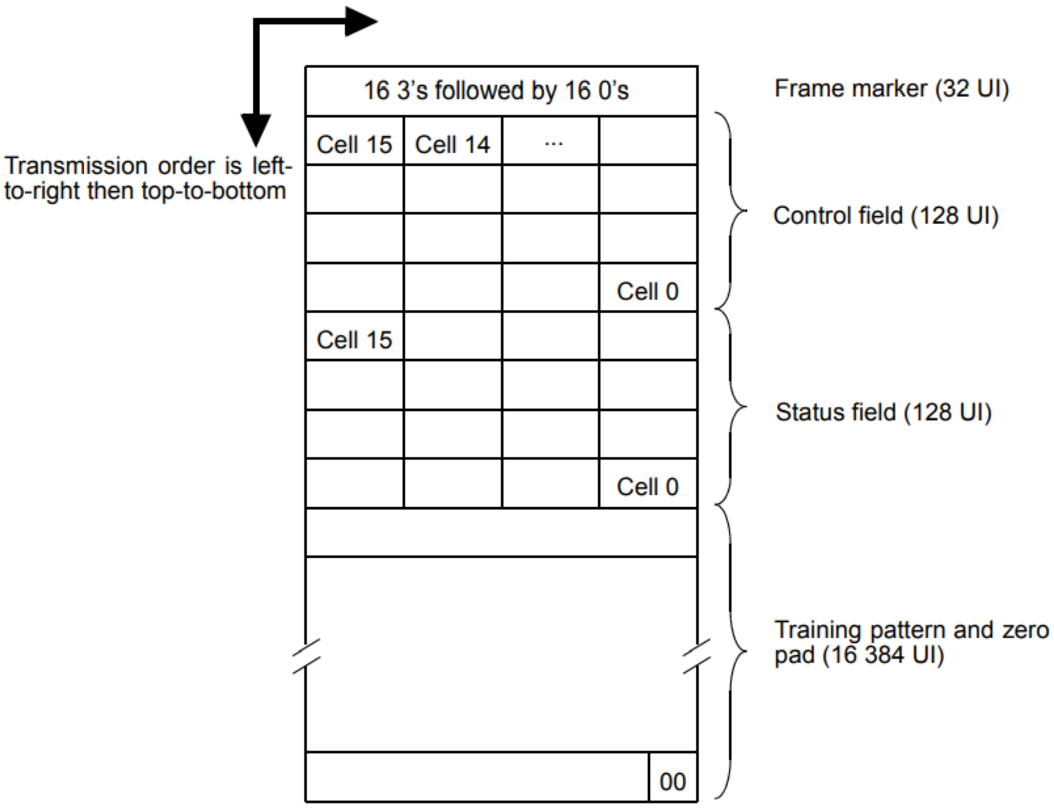


Figure 9: Training frame structure for 112 Gbps SerDes.

Figure 10 and Figure 11 specify the details of the Coefficient update and Coefficient status fields, respectively.

Bit(s)	Name	Description
15:14	Reserved	Transmit as 0, ignore on receipt
13:11	Initial condition request	13 12 11 1 1 1 = Reserved 1 0 1 = Reserved 0 1 1 = Preset 5 0 0 1 = Preset 4 1 1 0 = Preset 3 1 0 0 = Preset 2 0 1 0 = Preset 1 0 0 0 = Individual coefficient control
10	Reserved	Transmit as 0, ignore on receipt
9:8	Modulation and precoding request	9 8 1 1 = PAM4 with precoding 1 0 = PAM4 0 1 = Reserved 0 0 = PAM2
7:5	Reserved	Transmit as 0, ignore on receipt
4:2	Coefficient select	4 3 2 1 0 0 = Reserved 1 0 1 = $c(-3)$ 1 1 0 = $c(-2)$ 1 1 1 = $c(-1)$ 0 0 0 = $c(0)$ 0 0 1 = $c(1)$ 0 1 x = Reserved
1:0	Coefficient request	1 0 1 1 = No equalization 1 0 = Decrement 0 1 = Increment 0 0 = Hold

Figure 10: Format of Control field.

Bit(s)	Name	Description
15	Receiver ready	1 =Training is complete and the receiver is ready for data 0 =Request for training to continue
14:12	Reserved	Transmit as 0, ignore on receipt
11:10	Modulation and precoding status	11 10 1 1 = PAM4 with precoding 1 0 = PAM4 0 1 = Reserved 0 0 = PAM2
9	Receiver frame lock	1 =Frame boundaries identified 0 =Frame boundaries not identified
8	Initial condition status	1 =Updated 0 = Not updated
7	Parity	Even parity bit
6	Reserved	Transmit as 0, ignore on receipt
5:3	Coefficient select echo	5 4 3 1 0 1 = $c(-3)$ 1 1 0 = $c(-2)$ 1 1 1 = $c(-1)$ 0 0 0 = $c(0)$ 0 0 1 = $c(1)$
2:0	Coefficient status	2 1 0 1 1 1 = Reserved 1 1 0 = Coefficient at limit and equalization limit 1 0 1 = Reserved 1 0 0 = Equalization limit 0 1 1 = Coefficient not supported 0 1 0 = Coefficient at limit 0 0 1 – Updated 0 0 0 = Not updated

Figure 11: Format of Status field.

Link training process

During Link training each link partner will send suggestions to the other link partner for tuning it's coefficients in the transmit equalizer through the Coefficient Update Field. This can be a time-consuming process as each coefficient has to be tuned separately and the coefficients can only be stepped by 1 unit per training frame sent.

The BER derived from the PRBS training pattern can be used to test the signal quality for each training frame.

How to use AN and LT

When high speed Ethernet line cards are being installed it can be argued that the transmission speed of the two end points are known to be the same and for this reason at least AN is not required. In this section we will provide some guidelines for when AN and/or LT is required and when not.

A first thing to consider is whether the line cards are supplied from the same OEM vendor or not. If the line cards are from different vendors, testing interoperability is necessary. AN and LT which test the transmission at Layer 1 are a good place to start to check that the basic signal quality is sufficiently good. Even if the line cards are supplied from the same vendor, and interoperability is more or less guaranteed, both AN and LT can still be beneficial to ensure optimum performance.

Different vendors may have implemented the equalizing scheme differently. For instance, some implementations might be able to automatically detect specific types of electrical cables and adjust the transmit equalizer to a preset configuration accordingly. However, the true performance can only be determined from the received signal at the remote end. Hence, LT can be used to tell the transmitter if the preset equalizer setting is good or needs adjustment.

Secondly, you should consider if all the cards can be fixed at the same speed, say 400GBASE-CR4. If they can, AN should still be enabled during initial installation since you may have done some mis-configuration. If supported by all line cards, LT will help tune the equalizers at the PHYs. Once the system is commissioned you may disable AN but keep LT enabled to catch variation in transmission parameters due to cable exchanges or other external influences.

Conclusion

With the increased emphasis on electrical cables for high-speed, short distance connections in data centers, the basic Layer 1 signal integrity is becoming very critical. Furthermore, more and more combinations of speed, modulation format, Forward Error Correction and number of lanes are being standardized.

Therefore, basic Ethernet features like Auto Negotiation (AN) and Link Training (LT) continue to grow in importance. AN helps in determining the highest common technology ability (typically speed) supported by two link partners and Link Training helps the two link partners tune their transmit equalizers for lowest possible Bit Error Rate.

Teledyne LeCroy Xena and SierraNet Test Solutions

Teledyne LeCroy offers several solutions for capturing, testing, analyzing and debugging of the AN and LT protocols at 112Gbps.

Teledyne LeCroy Xena's Traffic Generators function as complete end-points enabling active interaction with a Device Under Test.

The Teledyne LeCroy SierraNet solutions are passive devices that can capture, analyze and debug the communication between two devices.

The FreyaCompact AN/LT Test Appliance

Teledyne LeCroy Xena's TGA platform now includes Z800 Freya, a series of test modules with the full functionality needed to actively test high-speed 112Gbps SerDes Ethernet devices and links at both Layer 1, Layer 2 and Layer 3. The modules function as complete end-points and can participate actively in both AN and LT.

For Layer 1 the relevant signal integrity parameters to test for 112 Gbps SerDes based systems includes Auto Negotiation, Link Training (for electrical cables), advanced PHY equalizer tuning, PRBS testing, pre-FEC error distribution and the signal integrity view.

For information on Teledyne LeCroy Xena's Z800 Freya test modules, see: https://xenanetworks.com/freya-800g-pam4-ethernet-testing-112gbps-serdes/

As clearly established in this White Paper, Auto Negotiation and Link Training (AN/LT) are critical Ethernet features for high-speed, short distance connections over electrical cables because they help establish a link between two devices prior to sending real L2/L3 traffic.

To help companies test and debug AN/LT protocols for 56/112Gbps SerDes based Ethernet, Teledyne LeCroy Xena offers a stand-alone product called the Z800 FreyaCompact AN/LT Test Appliance.

Unlike Teledyne LeCroy Xena's other Freya test modules, the Z800qac Test Appliance does **not** include the Traffic Generation & Analysis (TGA) capability.

Instead, the FreyaCompact AN/LT Test Appliance lets developers step through the protocols one message at a time enabling them to quickly and easily identify possible errors or timing issues in the implementation.

The FreyaCompact AN/LT Test Appliance can also test the true equalizer performance of a remote unit by disabling automatic equalizer adaptations in the tester unit.

These functions are available via two SW applications (provided with the hardware) which are based on Teledyne LeCroy Xena OpenAutomation (XOA), Teledyne LeCroy Xena's new open-source scripting and test automation platform.

1. The **AN/LT Protocol Test Utility** is an interactive command-line interface that makes it easy for AN/LT protocol development teams to single-step through AN/LT configurations.

2. The **AN/LT Protocol Test Suite** is aimed at labs that want to do performance and compliance testing of AN/LT, and therefore need configurable test scripts and test reporting.

There are two hardware versions of the FreyaCompact AN/LT Test Appliance – one for QSFP-DD800 and the other for OSFP.

The SierraNet M1288 Ethernet and Fiber Channel test platform

The SierraNet M1288 is designed to sit passively between devices to capture the communication between them for analysis and troubleshooting. It can be used in conjunction with the Xena solution as it exercises a device under test (DUT) or between two DUT devices. This includes the AN/LT protocol. The SierraNet software has several views designed specifically for AN/LT analysis that enable users to quickly diagnose the health of the link bring up process and determine if there opportunities to improve the speed and reliability of AN/LT.

For more information about the Teledyne LeCroy SierraNet M1288 Protocol Analyzer please visit: https://www.teledynelecroy.com/protocolanalyzer/fibre-channel/sierranet-m1288

The Teledyne LeCroy M1288 provides an overview of the LT process as each command is issued and responded to by the other side through a color-coded Timeline View. This enables the quick identification of common problems that arise during link training such as:

- Did Link Training occur?
- Was it sent in both directions?
- Did Link Training end with the 'Complete' on all lanes and directions?
- Did the link progress to PCS (Physical Coding Sublayer)?
- Are there 'Remote Faults'?
- How many training attempts were needed to establish a link?

- Are the timings within the specification?
- Were there any requests that cause the device to lose lock and need to start over?

To further analyze the AN and LT processes the M288 offers a Listing/State Diagram View which allows for quick visualizations to which states were entered as well as the time spent in each state.

The Navigation View shows all the states that were entered and whether or not physical coding sublayer (PCS) was achieved for each lane of every port.

All views of the M1288 are time synchronized with each other as well as with the Summary view making it easy to navigate to the right spot within the trace where issues occur.

Like the Teledyne LeCroy Xena solution, the M1288 solutions are available in both QSFP-DD and OSFP form factors.

Related White Papers:

1. ‘’Terabit Ethernet – Why?’’
2. “Terabit Ethernet – How?”
3. Testing 400GE using 112Gbps SerDes

Or book a tech briefing with a Teledyne LeCroy Xena expert.