Link Training process and optimization

112G Serdes include equalization at both the Tx and Rx side. The equalizers at Rx and Tx are different types.

Link training only affects the Tx equalizers. The Tx equalizers for 112G Serdes are 5 tap FIR filters. This means that there are 5 coefficients (taps) of the filter that needs to be set to some values.

Presets

The IEEE802.3ck standard defines 5 Tx equalizer presets, that does not provide optimum performance but can be used to start the Link Training process from a well-defined starting point.

Table 1: IEEE Presets for Tx Equalizer.

Configuration	Taps				
	Post C(-3)	Post C(-2)	Post C(-1)	Main c(0)	Pre c(1)
Preset 1	0	0	0	1	0
Preset 2	0	0	0	0.5	0
Preset 3	0	0	-0.075	0.75	0
Preset 4	0	0.05	-0.2	0.75	0
Preset 5	-0.025	0.075	-0.25	0.65	0

Xena has defined a larger range of **Xena preset** Tx equalizer values that is meant to provide optimum performance for a given attached cable. The Xena presets are NOT the same as the IEEE presets and the Xena presets are NOT used as part of Link Training. The Xena presets have been found by meticulous manual testing of each type of cable. Xena automatically reads information about the cable type and length through the CMIS interface and chooses the appropriate Xena preset from a matrix table based on this information. Customers can see the Xena preset values in the "Serdes tap coefficient" menu in ValkyrieManager once the cable is inserted. Table 2 provides a matrix table that summarizes the preset values per cable type and length.

Table 2: Xena Presets for Tx Equalizer.

Configuration			Taps				
SFP	Cable type	Cable length (m)	Pre C(-3)	Pre C(-2)	Pre C(-1)	Main	Post c(1)
OSFP	Optical	Default	0	0	12	60	0
OSFP	DAC	0 (default)	0	0	15	68	0
OSFP	DAC	1	0	0	15	68	0
OSFP	DAC	2	0	0	18	68	0
QSFPDD	Optical	Default	0	0	0	42	0
QSFPDD	DAC	0 (default)	0	0	0	68	0
QSFPDD	DAC	1	0	0	22	86	2
QSFPDD	DAC	2	0	0	19-20[1]	86	11-15[1]

1) Tap setting slightly different for the different lanes

Coefficient values and step sizes

The IEEE defines the Tx equalizer values as a normalized number in the range -1 and +1 and the step size to be in the range from +/-0.05 to +/-0.025. This means that different vendors can choose to implement different step sizes and still be standards compliant.

Xena's Freya Tx equalizer uses the step sizes and coefficient values defined by the Xilinx Versal FPGA as outlined in Table 3 below. The coefficients are shown as an integer number. For c(0) this corresponds to a value in mV and one step is around 0.08-0.15 mV. For the other coefficients the values correspond to a change in dB and one step is approximately 0.2 dB.

Table 3: Definition of coefficient ranges for Freya Tx equalizer

Coefficient	Range	Parameter	Units	Range in units
C(0)	42 to 86	Peak-to-peak voltage	mV	507 to 998 mV
C(1)	0 to 38	Pre-emphasis	dB	0 to 18.69 dB
C(-1)	0 to 38	Pre-emphasis	dB	0 to 18.69 dB
C(-2)	0 to 24	Pre-emphasis	dB	0 to 7.09 dB
C(-3)	0 to 24	Pre-emphasis	dB	0 to 7.09 dB

For a detailed description of the relationship between emphasis and coefficient values see Appendix A.

Below you can see the lay-out of the coefficients in XOA and ValkyrieManager. Please ignore the RX CTLE field as it is only there for legacy reasons and is not part of the Tx equalizer setting.

Figure 1: XOA AN/LT test utility UI Tx Coefficients

Figure 2:ValkyrieManager UI Tx coefficients

Link Training

During Link Training each link partner trains the other link partner's Tx equalizer as sketched on Figure 3 in the case where the local link partner trains the remote link

partner. Since the channel is bidirectional, the local link remote is also training the local link partner but, the two training processes are completely independent.
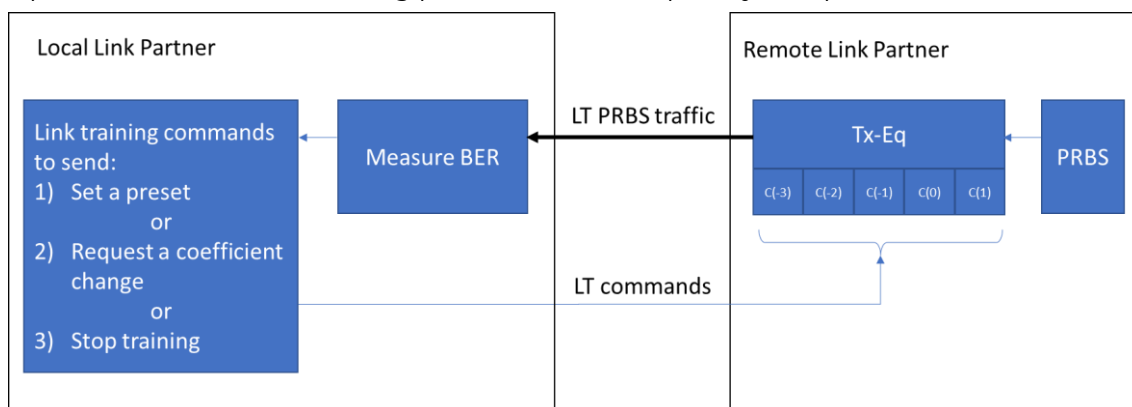

Figure 3: Illustration of Local Link Partner training the TX equalizer of the Remote Link Partner.

In Figure 3 the local link partner can request the remote link partner to change its coefficients to either one of the 5 IEEE presets or change one of its equalizer coefficients. During link training the remote link partner transmits a PRBS that the local link partner can use to estimate the signal performance. Xena uses the BER as measure of the signal performance during LT. Note that this PRBS is NOT the same as can be used manually in ValkyrieManager/scripting.

The local link partner does not know how the remote link partner has defined the coefficient step size but can only suggest to step each coefficient 1 step up or 1 step down.

It is worth noting that due to the relatively small amount of PRBS sequences transmitted per Link training frame the BER will be a crude estimate.

Also, since the Link training process only has 10-12 seconds to find the best performance and the algorithm is quite crude, the LT algorithm will in almost any case not find a Tx Equalizer setting that is as good as the Xena preset that matches the attached cable.

Xena LT algorithm.

The IEEE802.3 standard does not define a specific algorithm for LT so it is up to each vendor to make their own.

Xena's algorithm follows the approach shown on Figure 4.

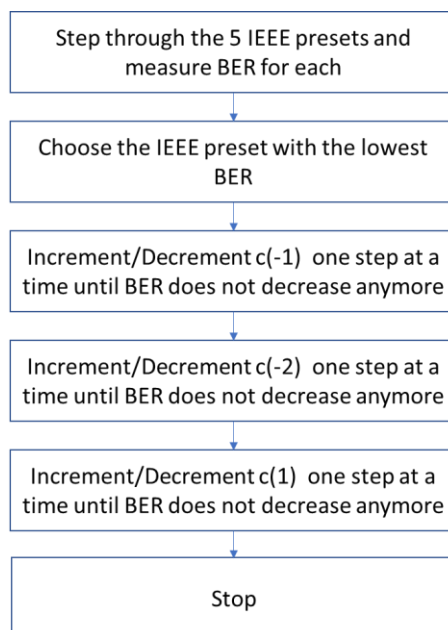For support please visit: https://xenanetworks.com/support/

Figure 4: Xena Link Training Algorithm.

Please, remember that it is the coefficients at the remote link partner that is being changed by Xena's algorithm. See Figure 5 for an example of how the Xena LT algorithm could look like.

step#	c(-3)	c(-2)	c(-1)	c(0)	c(1)	LT BER (PRBS-13)	Comment
0	0	0	0	1	0	4.5E-09	Try preset 1 and measure BER
1	0	0	0	0.5	0	6.7E-09	Try preset 2 and measure BER
2	0	0	-0.075	0.75	0	5.0E-08	Try preset 3 and measure BER
3	0	0.05	-0.2	0.75	0	6.0E-08	Try preset 4 and measure BER
4	-0.025	0.075	-0.25	0.65	0	8.0E-07	Try preset 5 and measure BER
5	0	0	0	1	0	4.5E-09	Preset 1 gives the lowest BER so it is chosen as starting point
	Δ	Δ	Δ	Δ	Δ		Changes are relative to preset 1
6	0	0	+1	0	0	4.0E-09	Step c(-1) 1 step up and measure BER
7	0	0	+2	0	0	3.5E-09	Step c(-1) 1 step up and measure BER
8	0	0	+3	0	0	3.0E-09	Step c(-1) 1 step up and measure BER
9	0	0	+4	0	0	3.2E-09	Step c(-1) 1 step up and measure BER
10	0	0	-1	0	0	3.0E-09	+3 step provided the lowest BER, so step down to this level again
11	0	+1	0	0	0	2.9E-09	Step c(-2) 1 step up and measure BER
12	0	+2	0	0	0	3.4E-09	Step c(-2) 1 step up and measure BER
13	0	-1	0	0	0	2.9E-09	+1 step provided the lowest BER, so step down to this level again
14	0	0	0	0	+1	2.8E-09	Step c(1) 1 step up and measure BER
15	0	0	0	0	+2	2.7E-09	Step c(1) 1 step up and measure BER
16	0	0	0	0	+3	3.3E-09	Step c(1) 1 step up and measure BER
17	0	0	0	0	-1	2.7E-09	+2 step provided the lowest BER, so step down to this level again

Figure 5: Example of Xena's LT algorithm with instructions to step the remote link partners Tx equalizer coefficients and measurements of BER.

Test scenarios

Figure 6 outlines three typical test scenarios. The key purpose of Xena's test equipment is naturally to test the LT algorithm of a DUT which is the bottom scenario.
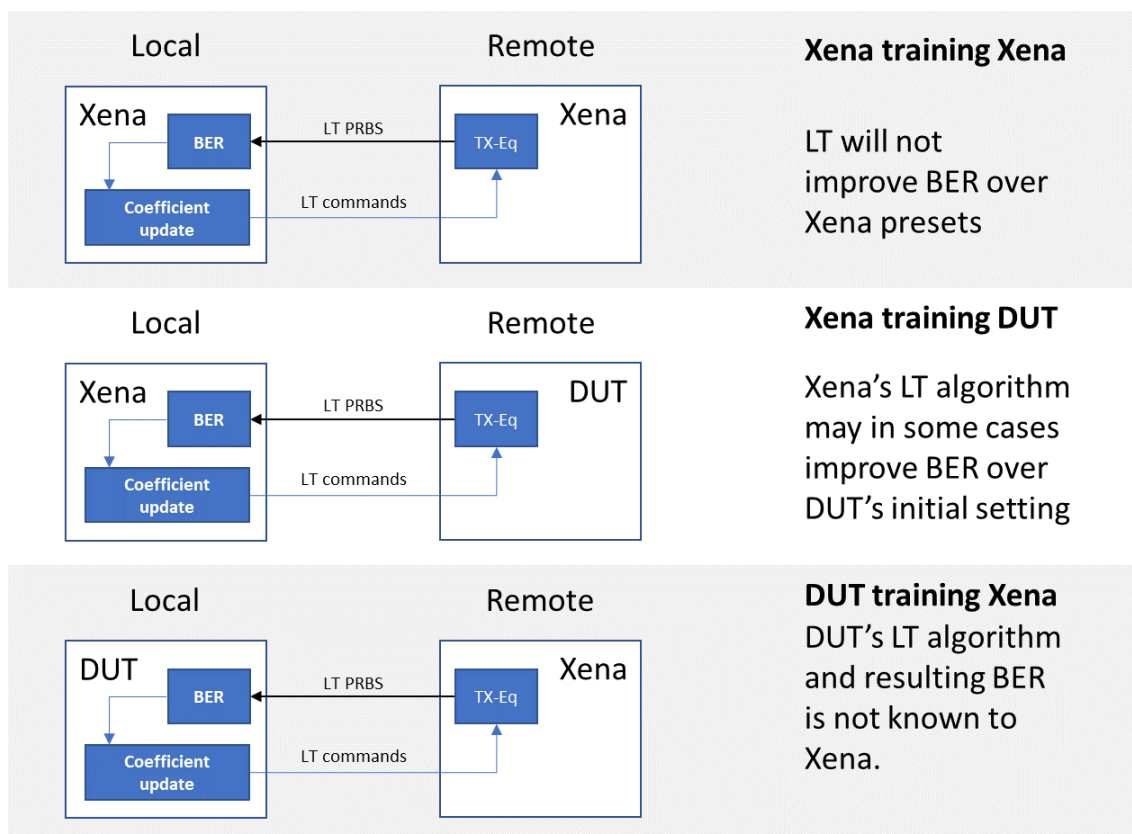
Figure 6: Typical use cases of the Xena TGA and how LT will affect the BER of the PRBS traffic in the two directions (local to remote and remote to local).

How to test the performance of a DUT's LT algorithm.

As explained in the previous sections, the Xena preset for a given cable type and length will in most cases be better than what the DUT's LT algorithm can find. To test that the DUT's LT algorithm can in fact improve BER it is therefore recommended to deliberately configure the Xena TX-FFE tap values to a setting that gives a low signal quality (high BER). The coefficients should be changed by the ValkyrieManager or XOA ANLT utility while the BER should be read from the DUT's management software.

Changing c(-1) and c(1) until the BER is around 10^{-7} will typically be a "good" starting point. It is important not to change the equalizer tap values too aggressively to ensure that the lanes are still in LOCK.

If the DUT's LT algorithm performs well it should be able to improve the BER.

Appendix A: Freya FIR filter tap definitions

Finite Impulse Response (FIR) filter tap coefficients are commonly specified as either a normalized numerical value in the range -1 to +1 or through an emphasis in dB. This appendix defines these parameters and outlines how to convert from coefficient values to emphasis and vice versa.

FIR filter

A FIR filter equalizes a signal by creating a weighted sum of symbol values from both preceding and succeeding symbols as illustrated by the example on Figure 7
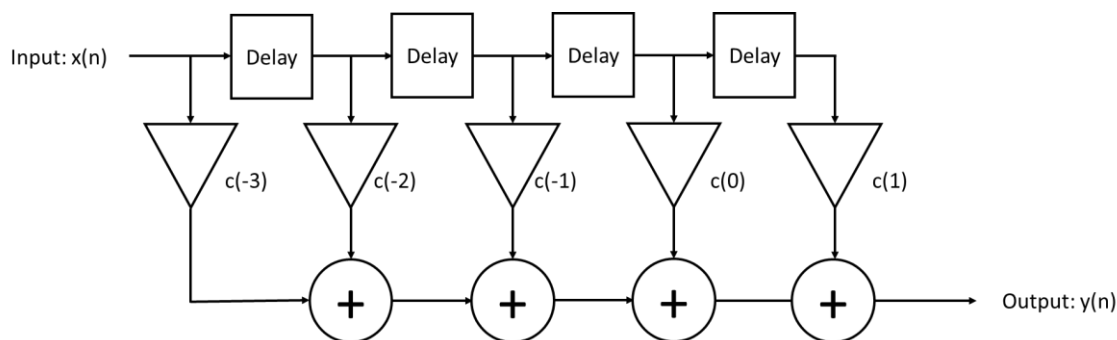
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Figure 7: 5-tap FIR filter.

The delay elements are typically equal to one Unit Interval (UI) and the coefficients *c*(i) are the weights. *C(0)* is normally called the main cursor and taps corresponding to symbol periods earlier (in time) than the main cursor is called pre-cursors whereas taps corresponding to symbol periods after the main cursor is called post-cursors.

For transmit FIR filters, the tap coefficients are constrained by the maximum voltage swing and power of the drivers and therefore, the sum of the absolute values of all coefficients must be 1:

$$\sum_{i=-N}^{M} |c(i)| = 1$$

where *N* is the number of pre-cursor taps and *M* is the number of post-cursor taps. In some cases only the pre- and postcursor values are provided and the main cursor is implied.

In Freya there are 3 pre-cursor taps and 1 post cursor as defined by IEEE 802.3ck for 112G Serdes-based Ethernet.

Relation between Emphasis and tap coefficients

High-speed Ethernet transmission over electrical connections uses differential signaling. The effect of the FIR filter is to reduce the voltage swing depending on the symbol pattern as illustrated for a simple two-tap filter on Figure 8.

The emphasis in dB is defined as the

$$Emphasis\ (dB) = 20 \log \frac{V_{min}}{V_{max}} \qquad \text{Equation 1}$$

In the simple case with only one tap the emphasis can be calculated from the pre- or post-cursor as:

$$Emphasis\ (dB) = 20\ log(1 - 2|c(i)|) \qquad \textit{Equation 2}$$

In the example on Figure 8 where c(1) = -0.15, the emphasis can be calculated to -3.1 dB.

Un-equalized: c(0) = 1, c(1) = 0

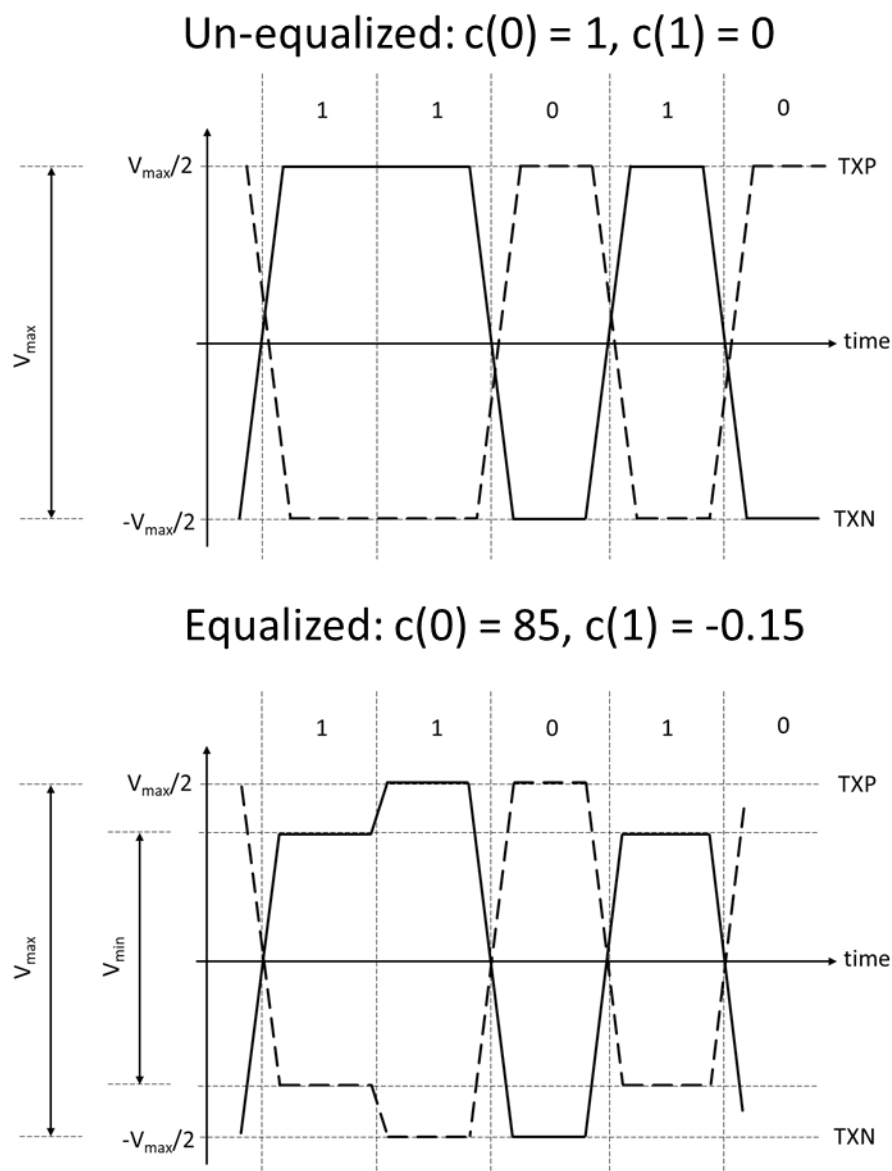## Equalized: c(0) = 85, c(1) = -0.15

Figure 8: Top graph show an un-equalized differential signal and bottom graph shows the effect of a two tap filter.

In Freya the Tx-FIR taps are defined by a maximum voltage swing V_{max} in mV combined with an emphasis in dB per tap. The emphasis can be converted to a coefficient value with the formula

$$|c(i)| = \tfrac{1}{2}(1 - 10^{Emphasis_i/2}) \qquad \text{Equation 3}$$

The main cursor c_0 can be calculated as 1 minus the sum of the absolute values of all other coefficient but c_0.

$$|c(0)| = 1 - \sum_{i<0}|c(i)| - \sum_{i>0}|c(i)| \quad \text{Equation 4}$$

Coefficient setting in Freya

The maximum voltage swing is configured by a number in the range between 42 to 86 corresponding to a voltage swing between 507 mV and 998 mV as outlined in Table 4.

Table 4: Maximum voltage swing settings in Freya Tx-driver.

Value	Vmax (mV)	Value	Vmax (mV)	Value	Vmax (mV)	Value	Vmax (mV)	Value	Vmax (mV)
42	507	52	602	62	724	72	850	82	961
43	515	53	614	63	738	73	860	83	970
44	527	54	626	64	752	74	871	84	980
45	540	55	638	65	765	75	881	85	989
46	552	56	650	66	777	76	892	86	998
47	560	57	662	67	790	77	902		
48	569	58	673	68	802	78	915		
49	577	59	685	69	814	79	927		
50	585	60	696	70	826	80	940		
51	594	61	710	71	838	81	952		

The pre- and post-cursors are configured by a number which defines an emphasis in dB and thereby also a coefficient value. The emphasis of $c(-1)$ and $c(1)$ can be configured in steps of ~0.2 dB in the range 0 dB to 18 dB whereas $c(-2)$ and $c(-3)$ can be configured in steps of ~0.2 dB in the range from 0 dB to 7 dB. Note that there is no configuration of $c(0)$ as the main cursor is calculated from Eq. 4.

Table 2 and 3 provides the possible setting of all the pre- and post-cursor taps in Freya.

Table 5: Possible settings of c(-1) and c(1)

step	dB	c(i)	step	dB	c(i)	step	dB	c(i)
0	0,000	0,000	13	-3,13	0,151	26	-8,06	0,302
1	-0,202	0,011	14	-3,42	0,163	27	-8,59	0,314
2	-0,414	0,023	15	-3,72	0,174	28	-9,15	0,326
3	-0,628	0,035	16	-4,04	0,186	29	-9,75	0,337
4	-0,848	0,047	17	-4,37	0,198	30	-10,39	0,349
5	-1,070	0,058	18	-4,71	0,209	31	-11,09	0,361
6	-1,310	0,070	19	-5,07	0,221	32	-11,84	0,372
7	-1,540	0,081	20	-5,43	0,232	33	-12,67	0,384
8	-1,780	0,093	21	-5,82	0,244	34	-13,58	0,395
9	-2,040	0,105	22	-6,22	0,256	35	-14,61	0,407
10	-2,300	0,116	23	-6,64	0,267	36	-15,77	0,419
11	-2,570	0,128	24	-7,09	0,279	37	-17,11	0,430
12	-2,84	0,139	25	-7,56	0,291	38	-18,69	0,442

Table 6: Possible settings of c(-2) and c(-3)

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step	dB	c(i)	step	dB	c(i)
0	0,000	0,000	13	-3,13	0,151
1	-0,202	0,011	14	-3,42	0,163
2	-0,414	0,023	15	-3,72	0,174
3	-0,628	0,035	16	-4,04	0,186
4	-0,848	0,047	17	-4,37	0,198
5	-1,070	0,058	18	-4,71	0,209
6	-1,310	0,070	19	-5,07	0,221
7	-1,540	0,081	20	-5,43	0,232
8	-1,780	0,093	21	-5,82	0,244
9	-2,040	0,105	22	-6,22	0,256
10	-2,300	0,116	23	-6,64	0,267
11	-2,570	0,128	24	-7,09	0,279
12	-2,84	0,139			

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