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Verification of ICN Usability in Characterizing System Crosstalk

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ICN Definition

- ICN (Integrated Crosstalk Noise) early defined in the 10GBase-CR4/10 cable standards is used in CEI-25G standard and nowadays discussed in 802.3bj standards.
- It is rarely seen the correlation document in reliability and usability of ICN in the industry, so verifying the usability of ICN in characterizing link crosstalk noise through test comparison is important for 25G system applications.

$$MDNEXT_{loss}(f) = -10 \times \log_{10}\left(\sum_{i=0}^{all\ NEXTs} 10^{-(NLi(f))/10}\right)(dB)$$

$$W_{nt}(f) = (A_{nt}^2/4f_b)\,\mathrm{sinc}^2(f/f_b)\left[\frac{1}{1+(f/f_{nt})^4}\right]\left[\frac{1}{1+(f/f_r)^8}\right]$$

$$\sigma_{nx} = \left(2\Delta f \sum_n W_{nt}(f_n) 10^{-MDNEXT_{loss}(f_n)/10}\right)^{1/2}$$

Where,
NLi(f) represents the individual crosstalk frequency responses. And MDNEXT represents the power-sum near end crosstalks.
W(f) gives the weight at each frequency f_n. It serves as a low-pass filter.
A_{nt} represents the peak-to-peak amplitude of aggressors in mV.

⇒ ICN-next calculation procedure.(Here takes near-end crosstalk ICN calculation for example.) Far-end crosstalk ICN is defined the same way.

$$\sigma_x = \sqrt{\sigma_{nx}^2 + \sigma_{fx}^2}$$

⇒ Total ICN of both near-end and far-end crosstalks, it is defined as the RMS sum of ICN-next and ICN-fext.

for 50 MHz ≤ f ≤ f_b (Integration range)

ICN Usability Questions

To learn whether ICN is usable in a PCB system or not, several questions should be answered:

1. Is ICN equivalent to time domain crosstalk noise?
2. Does the assumption of ICN -- RMS sum of single crosstalk noise results in a total crosstalk noise -- stand?
3. Does the total crosstalk noise from multiple aggressors equals to the RMS sum of each single aggressor crosstalk ICN? Which means that does the crosstalk power sum algorithm stand in the multi-crosstalk scenarios?

ICN Verification Method

The ICN verification procedure is quite straightforward and depends on the correlation with test.

1. ICN verification of Single crosstalk noise;

   1）Test the single-aggressor crosstalk noise RMS value n_i ;

   2）Test the amplitude and edge value of the single aggressor, calculate the single aggressor crosstalk ICN σ_i ;

   3）$\sigma_i \overset{?}{=} n_i$

2. Multi-Crosstalk noise RMS sum verification;

   1）Test the single-aggressor crosstalk noise RMS value n_i ;

   2）Test the multi-aggressor crosstalk total RMS noise N ;

   3）$N \overset{?}{=} \sum_i {}_{RMS\_sum} n_i$

3. RMS sum verification of single crosstalk ICN (i.e. crosstalk power sum verification of single crosstalk S- parameter) in calculating multi-aggressor total crosstalk noise.

   1）Calculate each single aggressor crosstalk ICN value σ_i according to each aggressor's amplitude and edge, then calculate the multi-aggressor crosstalk total noise ICN through RMS sum, $\sigma = \sum_i {}_{RMS\_sum} \sigma_i$;

   2）Test the multi-aggressor crosstalk total noise RMS value N ;

   3）$\sigma \overset{?}{=} N$

Verification Setup

Test environment (Instruments and boards):

	Tektronix Bertscope (working range:16~28G)
Test instruments	Agilent DCA-X 86100D + 86117A (equivalent sampling scope, bandwidth: 32/50GHz)
	Agilent DSA-X-93204A (real time sampling scope with 80G sample rate and 32GHz bandwidth)
SerDes	IBM 25G SerDes DEMO board
Passive link	WHISPER360 orthogonal connector test board
	XCEDEORTHOG 270oC 85ohm orthogonal connector test board

>> For crosstalk noise test:

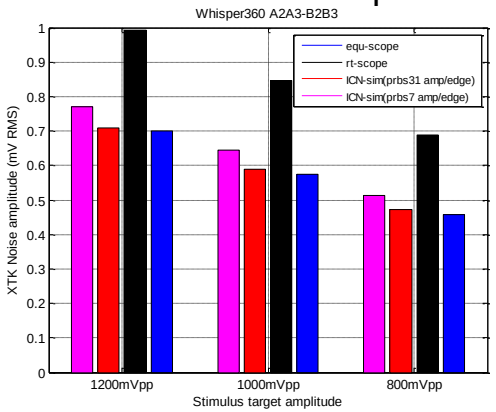
1) Equivalent sampling scope:
   - trigger in free run mode
   - noise RMS value is acquired through histogram measurement
2) Real time sampling scope (RT scope):
   - at least 50000UI time span's sample should be acquired
   - noise RMS value is acquired through histogram measurement

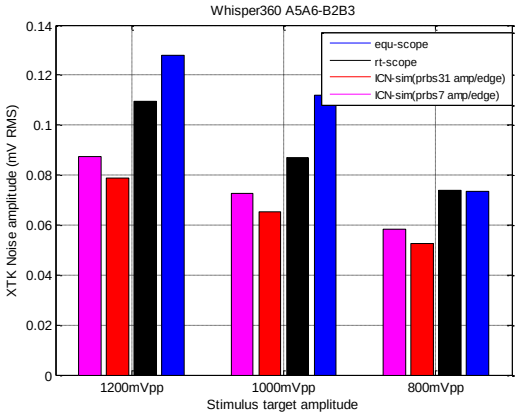
>> For stimulus amplitude / edge test:

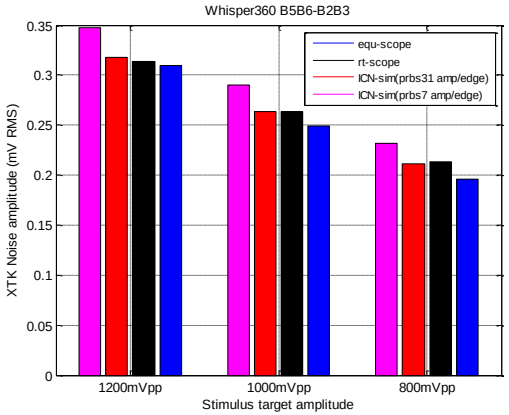
PRBS31 is used to emulate real traffic data. Amplitude / edge is acquired from multiple measurements for each case.

Single Crosstalk ICN Usability Test __Experiment1

Aggressor characteristics: Bertscope, 25Gbps, RBS31, PRBS7
Crosstalk channel: Whisper 360 connector test board







Note: 1) Scope test data in the figures above represent the test data manually peeled with noise floor (RT: 0.747mVRMS, Equi: 0.9mVRMS) of corresponding scope;
2) All the noise data in this experiment is close to or below the scope noise floor, it will be a main test error source.

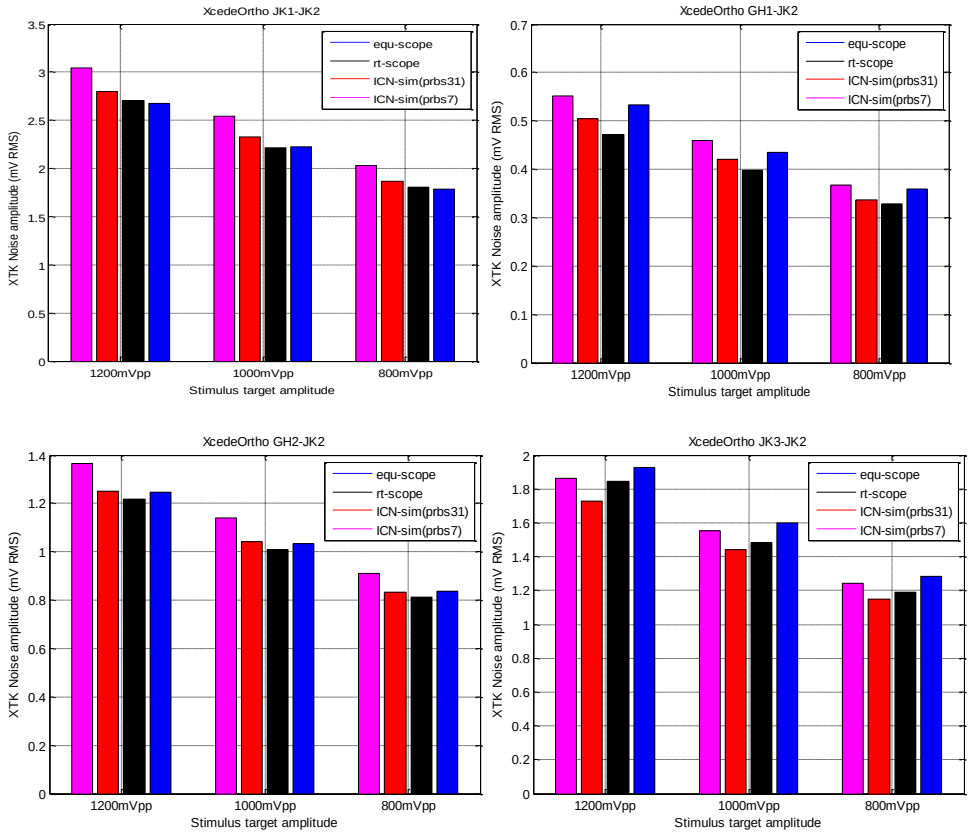
Difference(delta) between the crosstalk test data and calculated ICN value:

Aggressor		PRBS7 amp/edge		PRBS31 amp/edge	
aggressor	Amplitude	Equ_Scope	RT_Scope	Equ_Scope	RT_Scope
Whisper A2A3	1200	0.0711	0.2219	0.0088	0.2084
	1000	0.0686	0.2024	0.0145	0.2565
	800	0.0565	0.1745	0.0143	0.2167
Whisper A5A6	1200	0.0407	0.0223	0.0494	0.031
	1000	0.0392	0.0142	0.0468	0.0218
	800	0.0153	0.0158	0.0211	0.0216
Whisper B5B6	1200	0.0371	0.0339	0.0076	0.0044
	1000	0.04	0.0265	0.0143	0.0008
	800	0.03605	0.0178	0.0161	0.0022
Max Delta		0.0711	0.2219	0.0494	0.2565

1. Data in the green region of the table represents the difference (delta) between measured crosstalk noise data and calculated ICN data;
2. ICN calculation only uses aggressor amplitude, edge and crosstalk coupling S-parameter as inputs;
3. Data pattern(PRBS7 & PRBS31) only impacts aggressor amplitude and edge in terms of ICN calculation;
4. From the results, ICN and measured crosstalk noise data correlate in trends.

Single Crosstalk ICN Usability Test __Experiment2

Aggressor characteristics: Bertscope, 25Gbps, RBS31, PRBS7
Crosstalk channel: Xcede Orthogonal connector test board



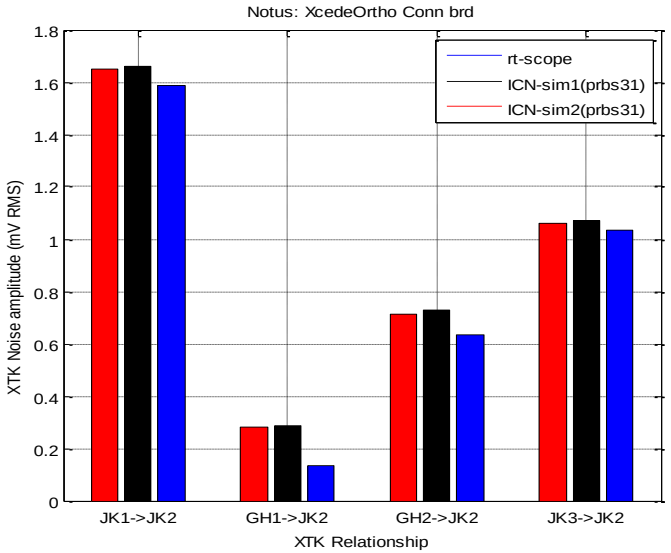
Difference(delta) between the crosstalk test data and calculated ICN value:

Aggressor		PRBS7 amp/edge		PRBS31 amp/edge	
Aggressor	Amplitude	Equ_Scope	RT_Scope	Equ_Scope	RT_Scope
XCEDE JK1	1200	0.3641	0.3342	0.1229	0.093009
	1000	0.3161	0.3225	0.1066	0.113036
	800	0.2434	0.225906	0.0799	0.062406
XCEDE GH1	1200	0.0187	0.078998	0.0276	0.032698
	1000	0.0246	0.063377	0.0157	0.023077
	800	0.009	0.039699	0.0223	0.008399
XCEDE GH2	1200	0.1183	0.147091	0.0038	0.032591
	1000	0.1041	0.129984	0.0043	0.030184
	800	0.074	0.096742	0.0035	0.019242
XCEDE JK3	1200	0.0633	0.013988	0.1965	0.119212
	1000	0.045	0.072692	0.16	0.042308
	800	0.0418	0.054597	0.1327	0.036303
Max Delta		0.3641	0.3342	0.1965	0.11921

1. In this experiment, crosstalk noise is mostly bigger than the scope noise floor, so the test results are much more stable;
2. From the results, ICN data matches pretty well with measured crosstalk noise data under single aggressor case;
3. In these experiments, it is recognized that the specific RT scope is working more stable and will be used for the following tests.

Single Crosstalk ICN Usability Test __Experiment3

Aggressor characteristics: IBM NotusV1, 25Gbps, PRBS31
Crosstalk channel: Xcede Orthogonal connector test board



	RT_Scope Test Data		Calculated ICN		Delta	
Aggressor	Raw Data Test	Noise floor peeled	Sim1: Calculated ICN under amp/edge 1	Sim2: Calculated ICN under amp/edge 2	Delta Between Sim1 and Test Data	Delta Between Sim2 and Test Data
JK1->JK2	1.7664	1.5871	1.6591	1.65	0.072	0.0629
GH1->JK2	0.797	0.135	0.2883	0.2813	0.1533	0.1463
GH2->JK2	1.00266	0.6355	0.7298	0.715	0.0943	0.0795
JK3->JK2	1.2905	1.0316	1.071	1.0579	0.0394	0.0263
				Max delta	0.1533	0.1463

Note:

1. Data in the green region of the table represents the difference (delta) between measured crosstalk noise data and calculated ICN data;
2. In this experiment, ICN data matches pretty well with measured crosstalk noise data under single aggressor case.

Summary of Single crosstalk ICN usability verification:

1. From the 3 experiments, ICN data can correlate pretty well with measured crosstalk noise data under single aggressor cases when crosstalk noise is not covered by scope noise floor;
2. For the cases when crosstalk noise is close to or covered by the scope noise floor, test accuracy is degraded. Still, it can be concluded that ICN calculation is still valid under single aggressor cases.

Multi-Crosstalk RMS Sum Verification

Multi-crosstalk RMS sum formula:

$$N = \sqrt{n_1^{\,2} + n_2^{\,2} + \ldots n_i^{\,2}}$$

Step1. Test the RMS value of each single crosstalk:

Aggressor Label	Test XTK Noise Data (Noise floor peeled)
A-> V	1.5871
B-> V	0.135
C-> V	0.6355
D-> V	1.0316

'Calculated Data' is acquired from the RMS sum of the single crosstalk RMS values.

Step2. Test the total noise RMS value of multiple crosstalks , then comparing to the RMS sum of each single crosstalk's RMS value:

	RT Scope Test Data		Calculated Data		Delta	
Aggressor Label	Original test Data	Noise Floor Peeled	Calculated XTK with Noise Floor Reserved	Calculated XTK with Noise Floor Peeled	Delta between the purple columns (abs)	Delta between the blue colums (abs)
A+B-> V	1.784	1.617	1.781	1.6139	0.003	0.0031
B+C-> V	1.0345	0.7091	1.0283	0.7	0.0062	0.0091
A+C-> V	1.9154	1.761	1.885	1.728	0.0304	0.033
C+D-> V	1.45447	1.24419	1.45	1.239	0.00447	0.00519
A+D-> V	2.04936	1.90588	2.0538	1.911	0.00444	0.00512
A+B+C-> V	1.91285	1.75827	1.89967	1.744	0.01318	0.01427
A+B+D-> V	2.08737	1.9467	2.066	1.924	0.02137	0.0227
B+C+D-> V	1.482205	1.2765	1.4679	1.26	0.014305	0.0165
A+C+D-> V	2.176625	2.042	2.15769	2.022	0.018935	0.02
A+B+C+D-> V	2.19125	2.0577	2.169683	2.0347	0.021567	0.023
				Max Delta	0.0304	0.033

>>Summary:

1. The delta error introduced by the crosstalk power sum algorithm is less than 1%.
2. Multi-crosstalk RMS sum algorithm is valid.

Multi-Crosstalk ICN RMS Sum Verification

RMS sum formula of multi-crosstalk ICN: $\sigma_x = \sqrt{\sigma_{nx}^2 + \sigma_{fx}^2}$

(The underlying meaning is that the power sum algorithm in the frequency domain stand.)

For the verification method, please refer to P3. In the table below:

1. Data in the 'RT Scope Test' column represents the multi-crosstalk noise measured results (scope noise floor is peeled);
2. Data in the 'Calculated ICN' column represents the calculated ICN data of multi-crosstalk noise through RMS sum of each crosstalk's ICN value.

	RT Scope Test	Calculated ICN		Delta	
Aggressor Label	Test Noise Data with Noise Floor Peeled	Sim1: Calculated ICN under amp/edge 1	Sim2: Calculated ICN under amp/edge 2	Delta Between Sim1 and Test Data	Delta Between Sim2 and Test Data
A+B-> V	1.617	1.68396	1.6738	0.06696	0.0568
B+C-> V	0.7091	0.78468	0.7683	0.07558	0.0592
A+C-> V	1.761	1.8125	1.7983	0.0515	0.0373
C+D-> V	1.24419	1.296	1.27686	0.05181	0.03267
A+D-> V	1.90588	1.97475	1.96	0.06887	0.05412
A+B+C-> V	1.75827	1.8353	1.82	0.07703	0.06173
A+B+D-> V	1.9467	1.995688	1.98	0.048988	0.0333
B+C+D-> V	1.2765	1.32769	1.30748	0.05119	0.03098
A+C+D-> V	2.042	2.10529	2.086355	0.06329	0.044355
A+B+C+D-> V	2.0577	2.12494	2.1052	0.06724	0.0475
			Max delta	0.07703	0.06173

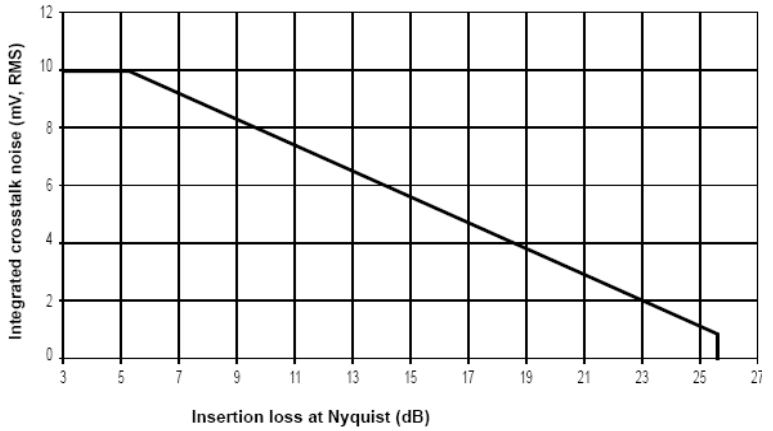
From this experiment, the 'RT Scope Test' data and the 'Calculated ICN' data matches pretty well, the delta error between the two is less than 1%. It can be concluded that multi-crosstalk ICN RMS sum algorithm is valid.

Summary

- ICN metric in quantifying link crosstalk is valid, under the condition that aggressor data pattern is PRBS31 alike (for example 64B/66B coding).
- It is recommended to measure the RMS value of crosstalk noise instead of the peak-to-peak amplitude. (The latter depends a lot on test time)
- In the cases that scope noise floor is bigger than or close to the target crosstalk noise under test, it is reliable to get the crosstalk noise data from ICN calculation.

ICN mask defined in current or upcoming 25G standards gives the relationship between the SerDes driving capability (described by through link insertion loss) and link crosstalk amount (ICN), it solves the partial ICR mask violation problem in certain extent.

ICN mask defined in CEI-25G-LR:



- It is recommended to use ICN as an input parameter for stress channel simulation in high speed links, to help the users generate ICN masks of their links using different SerDes models. ICN noise can be represented by a Gaussian white noise.

Thank you

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