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S k e w   A n a l y s i s   f o r   M u l t i m o d e  
4 0 G / 1 0 0 G   E t h e r n e t  
P a r a l l e l   L i n k s

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N o v e m b e r   2 0 0 9



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## Executive Summary

There is a prevailing perception in the market that ribbon cables have substantial benefits for 40G and 100G Ethernet due to skew over traditional multimode loose tube constructions. Nexans Data Communications Competence Center in New Holland evaluated the skew of various fiber constructions and clarified its impact upon the proposed IEEE 802.3ba specification. With the IEEE standardization work well underway for 40G and 100G Ethernet, and the focus on 4x and 10x parallel multimode optics, skew, the propagation delay difference between the fastest and the slowest legs in a parallel link, became an important parameter. However, skew is not viewed as a technical roadblock because the electronics for handling it are very well developed.

Measurements and analysis of standard loose tube, micro-tube and standard ribbon cables showed that all cable types demonstrate skew well below the worst case calculated 45.4 ps/m level, which is significantly lower than the 790 ps/m IEEE proposed requirement. As part of this work, skew measurements for loose tube and micro tube cables are also analyzed to distinguish skew resulting from numerical aperture and cable process parameters, excess fiber length, and tube length variations due to stranding. Current Nexans standard loose tube and micro loose tube products exceed skew requirements. With the additional benefit of smaller size for the Nexans micro loose tube, and mechanical flexibility for both standard loose tube and micro loose tube, these cable constructions provide a better solution than ribbon cables to comply with upcoming 40G and 100G Ethernet requirements. In fact, this white paper will show that standard loose tube, micro tube and ribbon cable constructions are all capable of far exceeding the draft IEEE skew requirements for 40G and 100G Ethernet, allowing end users to choose a cable based on other features such as flexibility, size or ease of termination.

## Introduction

IEEE standardization for 40G and 100G Ethernet is well underway, targeting an approved standard in 2010. This standard will be the first time that multimode parallel optical solutions for short reach LAN applications for both 40G and 100G are proposed, based on four and ten lanes, respectively, of 10 Gb/s. With the adoption of a multi-lane solution, several technical issues affecting cabling and electronics manufacturers are being resolved. One of these issues is the delay skew between parallel links.

Skew is a well known issue for high speed links; an essential parameter of twisted pair copper cables, and an established requirement for 4x, 8x and 12x Infiniband double data rate systems. Skew is not a new parameter and the electronics for handling skew are very well developed. For the IEEE 40G/100G Ethernet standard development, it is understood that skew is not a road block and is easily compensated for. The proposed skew budget for

multimode links, as explained below, is generous and easily satisfied by the calculated worst case cabling skew. Despite this general understanding, there has been a perception in the industry that ribbon cables will be required or at a minimum provide a substantial advantage for 40G and 100G applications. Nexans Data Communications Competence Center in New Holland examined the skew from a fiber optic cable point of view and clarified the impact of skew for cable manufacturing and process aspects of various cable constructions.

## Skew in 40G/100G Ethernet Standardization

Skew has been addressed by the IEEE to be easily compensated for by the transceiver electronics. The technical team working on this issue preliminarily identified the worst case expected skew for any type of cable design, and then proposed a budget to be much larger than the expected worst case, in order to have available margin for future extensions. The optical skew for parallel multimode links was studied by IEEE based on five skew contributors as shown in *Table 1*, with a distinction between static and dynamic skew.

Skew Contributor	Worst Case (ps/m)	Maximum Dynamic (ps/m)
Numerical Aperture (NA)	13.6	0
Strand Length	25.0	0
Fiber Stress/Strain	4.4	4.4
Differential Mode Delay	0.3	0.3
Chromatic Dispersion (Group Delay)	2.1	2.1
Total	45.4	6.8
Proposed Cabling Skew	790	26

*Table 1: Skew factors for parallel multimode links*

Among these contributors, numerical aperture and fiber strand length difference are static, while cabling stress effects, differential mode delay and effect of wavelength fluctuations on group delay are dynamic effects.<sup>1</sup>

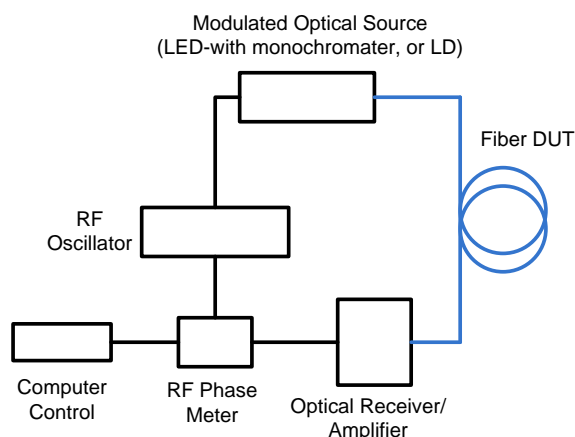
The numerical aperture contribution is based on the OM3 fiber requirement in international standards; 0.200 +/- 0.015 (e.g. TIA-492AAAC.) Similarly, the contribution from fiber stress, the effect of differential mode delay (DMD) and the effect of chromatic dispersion are based on OM3 fiber requirements. The above total skew for multimode links correspond to 4.54 ns for a 100 meter link length, the proposed OM3 link length standard. In the current IEEE-802.3ba Draft 2.1, the maximum skew for transmission link is set to 80 ns, with 79 ns assigned to the fiber link, which is much larger than the calculated worst case 4.54 ns.

<sup>1</sup> Increase in static skew capability does not affect latency, it increases the buffer depth. Increase in dynamic skew capability does increase latency

## Cabling Skew Measurements and Modeling

### Measurement Background

Currently there is no industry standard for skew measurement applicable to 40G/100G cabling,<sup>2</sup> standards exist for optical phase and fiber strain measurements that can be applied to skew measurements for 40G/100G characterization, such as TIA FOTP-133 and FOTP-38. Skew measurements can be performed in time domain, time-of-flight or in frequency domain, by measuring the phase difference of a modulated signal.



Quadrature phase shift method:

- Launch RF modulated optical signal down each fiber using single mode optics
- Measure the phase difference of received RF signal with the reference, using a precise phase meter: propagation delay
- Calculate maximum delay difference

**Figure 2: Skew measurement method**

After evaluating different methods and several vendors' test equipment, the competence center decided to use the phase measurement method. This method is well established for conducting fiber strain measurements in manufacturing environments. Skew-strain measurement systems based on phase measurement use single mode launch and receive, and therefore minimize the differential mode delay contribution of skew. As for the effect of chromatic dispersion, an estimated 0.4 ps/m chromatic dispersion contribution does not significantly impact the measurement results. The accuracy of the phase measurement system is better than  $\pm 0.05$  ps/m, which is suitable for these measurements.

The independent factors in *Table 2* constitute the measured skew for a parallel fiber link, connectorized with 12-fiber MPO connectors. The skew contribution due to DMD and chromatic dispersion is neglected as explained in the previous paragraph. Fiber stress/strain causes changes in both fiber length and NA. Therefore, skew due to stress/strain is part of excess fiber length and NA factors.

<sup>2</sup> TIA FOTP on skew measurement is initiated

Measured Skew Factors:
Tube process (excess fiber length) ( $\sigma_{\text{excess}}$ )
Stranding process (tube-to-tube length) ( $\sigma_{\text{tube}}$ )
Fiber NA ( $\sigma_{\text{NA}}$ )
Connector ( $\sigma_c$ )
Measurement error ( $\sigma_{\text{meas}}$ )

**Table 2: Skew factors; chromatic dispersion and DMD effects neglected**

Stranding process or tube-to-tube length difference applies only to micro tube cable because each tube has 4 fibers, and 3 tubes are needed to connect to a single MPO connector. This parameter does not apply to standard loose tube cables.

Ignoring the skew contributions due to measurement error and the connectors, and assuming independent factors, the measured skew standard deviation for any cable type can be calculated as:

$$\sigma_{\text{tot}}^2 = \sigma_{\text{excess}}^2 + \sigma_{\text{tube}}^2 + \sigma_{\text{NA}}^2$$

## Measurement Results and Modeling

A series of standard loose tube, micro-tube and ribbon cables with 12, 48, 72 and 144 fibers with MPO connectors were tested for optical skew at the competence center. *Table 3* summarizes the measurement results. The largest skew variation among the samples was found in 144, 72 and 48 fiber loose tube cables. Maximum skew observed among the loose tube cables was 8.33 ps/m, with an average of 5.6 ps/m. For micro tube cables, the maximum was 13.1 ps/m with an average of 4.4 ps/m.

From the table, note that the 12-fiber micro tube and the ribbon cables showed similar skew levels, contradicting the perception in the industry that ribbon cables are required to control skew for 40G/100G Ethernet. The competence center did not test any multi-layer stacked ribbon cables to compare with multi-tube loose tube and micro tube cables; however the maximum skew levels reported in *Table 3* do not indicate an advantage for ribbon as compared to loose tube, micro-tube cables from skew point of view. Moreover, the loose tube and micro tube cables have mechanical flexibility benefits compared to ribbon constructions.

Cables Tested	Worst skew measured (ps/m)
100m 144 fiber loose tube	7.94
100m 72 fiber loose tube	8.33
100m 48 fiber loose tube	6.39
100m 72 fiber micro tube (1)	13.1
100m 72 fiber micro tube (2)	3.35
100m 48 fiber micro tube(1)	6.79
100m 48 fiber micro tube(2)	6.86
300m 12 fiber loose tube	3.9
100m 12 fiber loose tube	3.95
300m 12 fiber micro tube	2.57
100m 12 fiber micro tube (1)	1.88
300m 12 fiber ribbon	2.18
100m 12 fiber ribbon	3.43
100m 12 fiber micro tube (2)	3.98
100m 12 fiber micro tube (3)	4.27

**Table 3: Cables tested and summary of the results**

From the above measurements, statistical analysis of the data was used to estimate excess fiber length process variation for loose tube and micro tube cables, and tube-to-tube length variation for micro tube cables. Tube-to-tube length variation for standard loose tube cables is not a factor since the fibers in the same tube are always connected to a single MPO connector. This configuration is not the same for micro tube cables for 100 Gbps application, where fibers in neighboring 4-fiber tubes are connected to the same MPO connector for the same transmitter or receiver.

For loose tube cables, an excess fiber length process window of 0.153 % was estimated based on  $\pm 3\sigma$  of measured data. This number corresponds to 7.65 ps/m skew and 15.3 cm strand length difference for a 100m link. This figure should be compared to skew due to NA only, calculated in the worst case of 13.6 ps/m based on OM3 standard, and about 7.5 ps/m for  $\pm 3\sigma$  typical in the industry. For the 144, 72 and 48 fiber loose tube cables tested, the excess fiber length and NA had an almost equal contribution to total skew.

For micro tube cables, a window of 1.29 ps/m was estimated for excess fiber length variation, corresponding to 2.6 cm fiber length difference in a 100m link. For the 48-fiber and 72-fiber micro tube cables, tube-to-tube length variations are estimated to be 1.5 ps/m and 4.73 ps/m respectively, corresponding to 3 cm and 9.5 cm length differences in 100 m link.

Figures 3 and 4 summarize the worst case expected skew variation for loose tube and micro tube cables. In Figure 3, the effect of NA variation is shown, by plotting total skew as a function of excess fiber length in percent, at different NA skew levels.

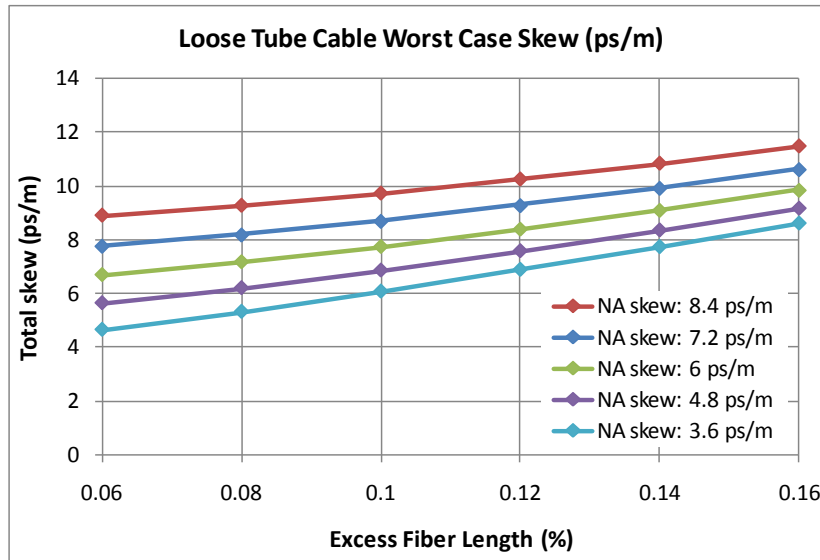


Figure 3: Loose tube cable skew variation

In Figure 4, expected total skew for different micro tube cable designs is plotted as a function of skew due to NA, based on measured excess fiber length and worst case tube-to-tube length variation.

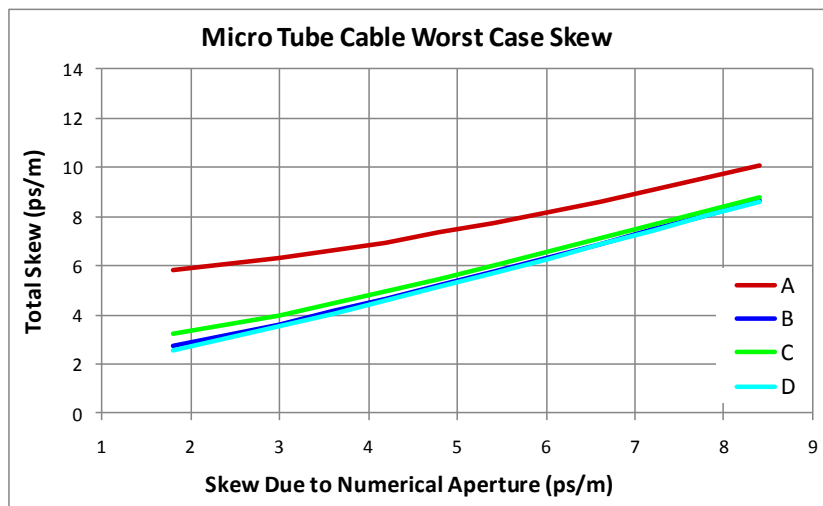


Figure 4: Micro tube cable skew variation as a function of numerical aperture, for different cable designs of varying fiber counts

In both graphs, it is shown that skew for loose tube and micro-tube cables may vary as part of the cabling process and selection of fibers with varying NA. However, these variations are significantly lower than the 40G and 100G Ethernet application requirement.

## Conclusion

Skew measurements on standard loose tube, micro-tube and standard ribbon cables at the competence center showed values much smaller than the proposed 40G/100G Ethernet standard, IEEE-802.3-ba Draft 2.1. Predictions for worst case loose tube and micro tube cable performance based on estimated process windows also showed skew values well within the IEEE draft proposal. Measurements demonstrated that ribbon cables had slightly smaller skew as compared to loose tube and micro loose tube cables. Current electronics compensate for these small differences rendering them to be negligible, however design changes are underway to render equivalent to superior performance over ribbon. In addition, standard and micro loose tube cables offer greater mechanical flexibility than ribbon cables, and micro loose tube cables have the extra advantage of smaller cable size. In conclusion, ribbon cables are not necessary to comply with upcoming 40G and 100G Ethernet skew requirements.

### **Data Communications Competence Center**

Nexans' Data Communications Competence Center, located at the Berk-Tek Headquarters in New Holland, Pennsylvania, focuses on advanced product design, applications and materials development for networking and data communication cabling solutions. The Advanced Design and Applications team uses state-of-the-art, proprietary testing and modeling tools to translate emerging network requirements into new cabling solutions. The Advanced Materials Development and Advanced Manufacturing Processes teams utilize sophisticated analytical capabilities that facilitate the design of superior materials and processes. The Standardization and Technology group analyzes leading edge and emerging technologies and coordinates data communication standardization efforts to continuously refine Nexans' Technology Roadmap. An international team of experts in the fields of cable, connectors, materials, networking, standards, communications and testing supports the competence center. The competence center laboratories are a part of an extensive global R&D network that includes six competence centers, four application centers and two research centers dedicated to advanced technologies and materials research.



Global expert in cables and cabling systems