Interferometric noise, OMA and reflection specs

Krister Fröjdh, Peter Öhlen

Krister.Frojdh@optillion.com

Abstract: Interferometric noise must be considered in the 1300 nm PMD for 10GE due to the current return loss specifications of 12 dB. In some cases interferometric noise might generate a total link failure and in all cases an extra margin of at least 0.7 dB must be reserved. I recommend changing the reflection specs for the receiver to 20 dB, a minimum of 12 dB (preferable 20 dB) for the transmitter and imposing a minimum ER of 3 dB to remove the problem.

I. WHY THIS DOCUMENT

The IEEE802.3ae 10 Gigabit serial PMD group had a telephone conference on the 19 of December 2000. At this conference, I said that we must put a minimum value on the extinction ratio to avoid problem with interferometric noise and its implications. I was asked by Mike Dudek and Pierce Dawe to write some document with a description of interferometric noise.

This document is my and Peters best effort to explain interferometric noise and its impact on the standard. To generate a quick document I have made little effort to search for references and its only bases on my and Peters own best knowledge. Please consider and keep in mind that it might contain errors.

II. BACKGROUND

In the current proposal for 1300 and 1550 nm PMDs OMA is introduces as a measure for optical power with a rather large freedom for choosing extinction ratio (ER). For the 1300 nm case, a rather high return loss of 12 dB is accepted for the receiver and is unspecified for the transmitter.

In the 10GE, single mode DFB lasers will be used with single mode fiber. The bit rate is also 8 times faster than the 1 GE.

Below I want to explain why this combination will give problem with interferometric noise.

III. INTERFEROMETRIC NOISE

Interferometric noise it a variation in the intensity that is due to interference between the signal and reflected light from multiple reflection. Interference between two optical signals can in general (ignoring polarisation) be written as

$$P = P_A + P_B + 2\sqrt{P_A P_B}\cos(\gamma)$$

Assuming a simple fiber optic link (see fig. 1) with a reflection of R_{RX} and R_{TX} at each end of a fiber of length L and attenuation A

If we ignore multiple reflections that only will give a minor correction, the power out of the fiber to the receiver can be expressed as

$$P_{RX} = AP_{TX}(t-\Delta t) + A^3 R_{RX} R_{TX} P_{TX}(t-3\Delta t) + 2\sqrt{AP_{TX}(t-\Delta t)A^3 R_{RX} R_{TX} P_{TX}(t-3\Delta t)}\cos(\gamma)$$

(Eq. 1)

The second term above is small and can be neglected.

$P_{TX}(t)$ is the signal from the transmitter and γ is the phase shift between the signals. The length of the fiber will give a delay of the signal of

$$\Delta t = \frac{Ln_g}{c_0}$$

The phase shift γ varies in a random way due to temperature variation and wavelength variation in the range 0-π why the interferometric noise will have a non gaussian distribution

$$\rho(x) = \arcsin(x)$$

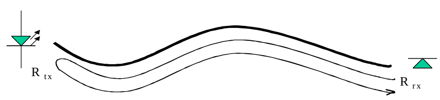

Fig. 1 A simple fiber optical link with the path of the reflected light indicated.

IV. LASER COHERENCE LENGHT

Assume that the reflected pulse train will have traveled a distance much longer than the pulse length (correspond to 20 mm. It will be delayed with 2Δt and assume that this time is longer than the coherence length. We will now add two random pulse trains. A first thought would be that one could add the pulses as two incoherent sources:

$$P_{RX} = AP_{TX}(t-\Delta t) + A^3 R_{RX} R_{TX} P(t-3\Delta t)$$

This is however not applicable in this case:

Over the short duration of a bit, 100 ps, we will have interference if the frequency

ν(t-Δt) differs from the frequency for ν(t-3Δt) with less than the bandwidth of the receiver filter

$$\Delta\nu < \frac{1}{T} = 10 \text{ Ghz}$$

Which corresponds to a wavelength difference of about 0.05 nm. The interference can easily be explained in a simple way: If the phase between the two pulse train vary less than 2π during the bit, there will at least be some coherent effect. There will actually be some coherent effect even for larger frequency differences. Normal lasers will typical have a smaller frequency variation than this over long pulse train. The frequency might vary between "0" bits and "1" bits but should be rather small between two "1" bits over a rather long time-span. A very similar phenomena, coherent cross talk, is a problem for DWDM system and is discussed in [1],[2]. In [2], fig 2, on can clearly see a steep increase in penalty at a cross talk level of –24 dB, corresponding to the return loss of 12 dB for the 1300 nm PMD.

V. WORST CASE

An approximate worst case can be calculated as follows:

The worst case situation is when we have constructive interference for a received "0" and destructive interference for a received "1"

Without interferences, the distance P_{Q0} between the decision level (assuming decision at average level) and upper eye ceiling is given by

$$P_{Q0} = \frac{OMA_r}{2}\delta$$

Here δ is a power penalty due to eye-mask limits (The high speed ER in the eye mask is lower than the low speed ER used for OMA definition) and dispersion. See also fig 2.

The worst case reduction due to interferometric noise is when a received "1" bit with a minimum eye-opening, P_A have interference from a reflected "1" bit with a maximum eye-opening P_B and the phase shift give destructive interference

$$\cos(\gamma) = -1$$

Using (Eq. 1) and neglecting the second term we get the received power as

$$P_{RX} = AP_A - 2\sqrt{AP_A A^3 R_{RX} R_{TX} P_B}$$

were

$$P_A = P_{av} + \delta\frac{OMA}{2}$$

$$P_B = P_{av} + \frac{OMA}{2}$$

See fig 1 for an example signal with the powers indicated.

Here P_{av} is the average power and is

$$P_{av} = \frac{ER+1}{ER-1}\frac{OMA}{2}$$

where

$$ER = \frac{P_1}{P_0}$$

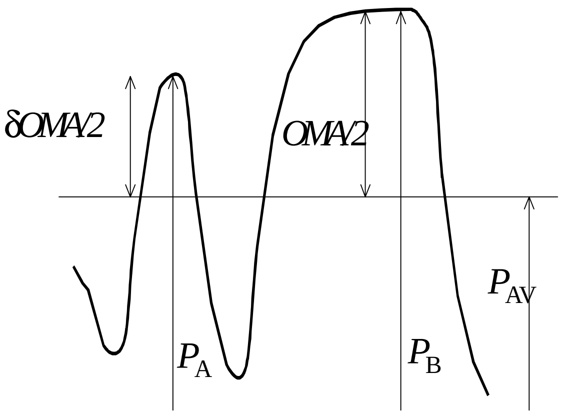

Fig. 2 Example signal with indication of the different levels used in the calculation of worst case.

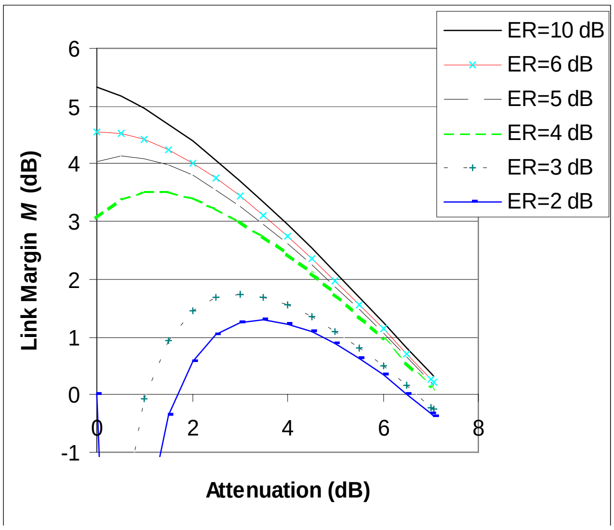

Fig. 3 Link margin as a function of fiber attenuation for different extinction ratios.

The effective modulated signal P_Q (expressed in OMA/2) is the difference between the received power and the decision level. The decision level is assumed to be at the average power.

$$P_Q = P_{RX} - P_{av}$$

This gives us

$$P_Q =$$

$$= A\frac{OMA_{TX}}{2}\delta\left[1-2A\sqrt{R_{RX}R_{TX}}\,\frac{\sqrt{2ER[\delta(ER-1)+ER+1]}}{\delta(ER-1)}\right]$$

In the above expression we can identify a penalty due to interferometric noise of

$$1-2A\sqrt{R_{RX}R_{TX}}\,\frac{\sqrt{2ER[\delta(ER-1)+ER+1]}}{\delta(ER-1)}$$

Eq. 2

An interesting parameter is the link margin *M* that can be expressed as

$$M = \frac{P_Q}{P_{\min}}$$

Where $P_{\min}$ is the nominal sensitivity of the receiver. For a working link we need a positive link margin and it is 0.69 dB for 1300 nm in the current draft.

Using the following values for 1300 nm PMD

Description	**Symbol**	**Value**
Return loss transmitter	R_1	-12 dB
Return loss receiver	R_2	-12 dB
Min output power OMA/2	Pt	-6.23 dB
Receiver sensitivity OMA/2	Pmin	16.23
Power penalty	δ	-2.25 dB
Fiber attenuation	A	0-6 dB

In fig 3, the link margin *M*, is plotted as a function of fiber attenuation *A* for different extinction rations *ER*. As one can see, the impact of interferometric noise is strong and will totally destroy the link for low values of *ER*. and always give a considerable penalty.

If we use the values above in eq 2,together with A=0 dB and ER=2.27 dB, we get 0, that is an infinite penalty. With increased attenuation, this penalty will actually be reduced but effect from receiver noise will increase. As one can see the ER must be at least 4 dB to have a positive margin. Even at an ER of 10 dB we will have a penalty of 0.4 dB due to interferometric noise.

For 1550 nm, the interferometric noise has no practical effect, as the reflection specification is much better. It is however unclear what reflection that is valid for the transmitter. However, even for 12 dB return loss of the transmitter, there will be a penalty of only 0.05 dB at ER=3 dB.

VI. Really worst case?

Is the above the worst-case situation?

No not really, the situation can actually be worse.

1. We can have an overshoot in the reflected signal
2. We might have small reflections from several connectors (-25 dB) that could slightly increase the total reflectance. A single -25 dB reflection changes –12 dB to –10.35 dB in the worst case
3. We have no spec for the return loss of the transmitter.
4. If the user has an air-gap in the link, both the transmitter and the receiver must have a low return loss.
5. Interference can give us a base-line wander that could give further penalty.

VII. WHAT TO DO

The results above clearly indicate that the interferometric noise cannot be ignored for the 1300 nm PMD and that is has no practical implication for 1550 nm. For multimode fiber, this is also not an issue as this problem is specific for single mode fiber.

Some possible actions for the 1300 nm PMD are:

1. Reduce the return loss of at least the receiver to 20 dB and impose a limit for the return loss of the transmitter of 12 dB
2. Increase return loss of transmitter to 20 dB
3. Impose minimum attenuation of link and increase power margin,
4. Increase the power margin with 0.7 dB, and specify a minimum ER of 4 dB. A more careful study of interferometric noise where reflections from connectors are needed.
5. Leave it as it is and hope that I am wrong

I recommend the first choice together with a minimum ER of 3 dB; otherwise we need a major revision of the link model.

VIII. REFERENCES

[1] P. Öhlen "Noise and crosstalk limitation in optical cross-connects with reshaping wavelength converters" *J. Lightw. Technol.* vol 18, no 8, pp 1294-1301, 1999

[2] E. L. Goldstein and L. Eskildsen "Scaling limitations in tranparent optical networks due to low-level crosstalk" *IEEE Phot. Technol. Lett.* vol 7, no 1, pp 93-95, 1995.