Is MPI New To 802.3?

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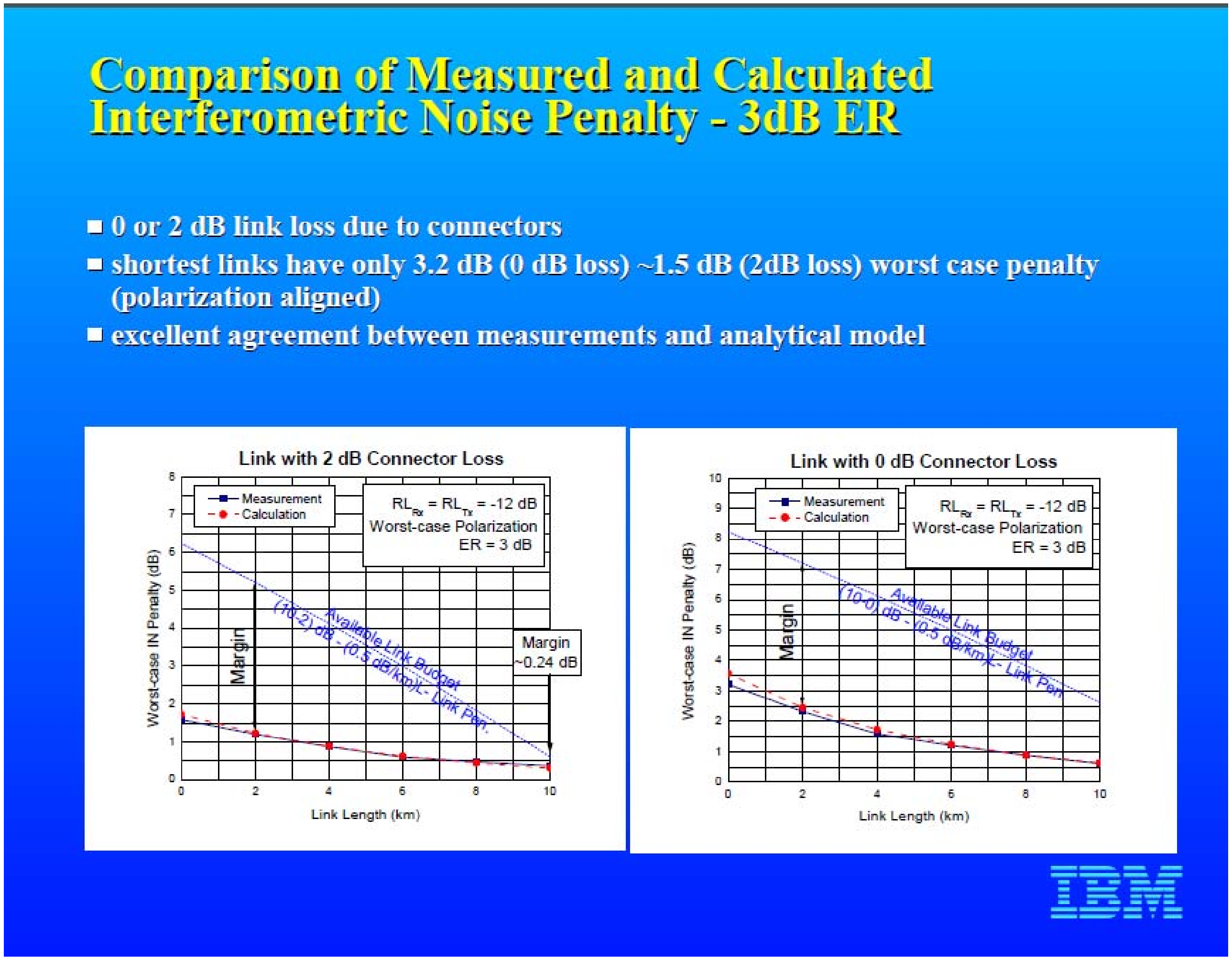
A little bit of history

- For 2000-2001 interferometric noise (IN, aka MPI) was a hot topic discussed over several meetings
  - the issue was reflection specification for RX
- Lot of material, some applicable, some not
  - Statistical approach to analysis
  - Comparison of experimental results and analytical results

Pointers: How to treat IN (or MPI)

- Statistical approach to Analysis:
  - Document on IEEE site with some useful formulas: http://www.ieee802.org/3/ae/public/adhoc/serial_pmd/documents/useful_IN_formulas.pdf
- Comparison of experimental and analytical results:
  - March 2001 plenary presentation: http://www.ieee802.org/3/ae/public/mar01/pepeljugoski_2_0301.pdf

Slide 6 from March 2001 presentation



- Need to consider jitter: we observed it during measurements
- Expect PAM to be worse than NRZ

Sample pages with formulas

receiving node is small enough. The nature of the interferometric noise has been studied in [1-3]. It was shown that this excess noise can cause bit-error-rate floors [6], and the system performance has been evaluated as a function of the number and magnitude of the reflections [7].

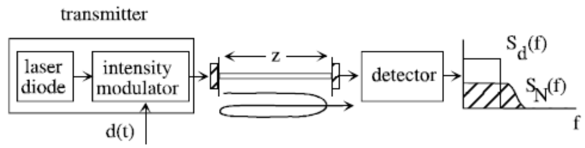


FIGURE 1. Fiber-optic link experiencing multiple reflections from fiber interfaces (connectors, fiber ends etc.). The graph right of the detector shows schematically the data spectrum $S_d(f)$ accompanied with the interferometric noise, whose power spectral density is $S_N(f)$.

2.0 Introduction to interferometric noise

As was mentioned before, the results derived in this section are well known [1-3], but are repeated here for the sake of defining the symbols used here.

Consider the intensity noise generated in a single mode (SM) fiber optic link through interferometric FM-AM conversion due to, for example, double reflection between two pairs of connectors (Figure 1). The laser is assumed to be single-mode, and it is also assumed that the data is intensity modulated.

The electric field at the input of the fiber is given by:

$$E(t) = \sqrt{P(t)}exp[j\Omega_0 t + \varphi(t)] \qquad \text{Eq.2.1}$$

The electric field at the fiber output will be:

$$E_{out}(t) = \sqrt{P_0 d(t)}exp[j\Omega_0 t + \varphi(t)] + \psi\sqrt{P_0 d(t)}exp[j\Omega_0(t-\tau) + \varphi(t-\tau)] \qquad \text{Eq.2.4}$$

Then, the intensity at the output of the fiber is:

$$i(z,t) = |E(t)|^2 + \psi^2|E(t-\tau)|^2 + 2\psi Re\{E(t)E^*(t-\tau)\} \qquad \text{Eq.2.5}$$

We can identify the signal $i_S(z,t)$ and the noise part $i_N(z,t)$ of $i(z,t)$ as:

$i_S(z,t) = P_0[d(t) + \psi d(t-\tau)] \approx P_0 d(t)$ where we have assumed $\psi \ll 1$ and

$$i_N(z,t) = 2\psi P_0\sqrt{d(t)d(t-\tau)}\cos[\Omega_0\tau + \varphi(t) - \varphi(t-\tau)] \qquad \text{Eq.2.6}$$

Because of the random processes involved, the impact of the noise has to be treated through the standard communications theory, i.e. autocorrelation function of the noise term. The worst case approach to calculating the impact of the interferometric noise gives overly pessimistic results, and better upper bound on the probability of error can be found. Because of the fast changes cosine in the interferometric noise, can't sustain its value for more than one instance, not to talk about the entire interval.

The laser phase noise $\varphi(t)$ is modeled to follow Gaussian probability density function and $\varphi(t)$ and $\varphi(t-\tau)$ are correlated in such a way that [1]:

$$\langle(\varphi(t) - \varphi(t-\tau))^2\rangle = \frac{|\tau|}{\tau} \qquad \text{Eq.2.7}$$

$$R_N(\delta\tau) = E\{i_N(z,t)i_N(z,t+\delta\tau)\} = 2\psi^2P_0^2R_{dd}(\delta\tau)[R_-(\delta\tau) + R_+(\delta\tau)\cos(\Omega_0\tau)] \qquad \text{Eq.2.9}$$

where E{} denotes statistical averaging and $R_d(\delta\tau)$ is the autocorrelation function of d(t), and

$$R_{dd}(\delta\tau) = E\{\sqrt{d(t)d(t-\tau)d(t+\delta\tau)d(t-\tau+\delta\tau)}\} \qquad \text{Eq.2.10}$$

The corresponding power spectral densities are denoted by $S_d(f)$ and $S_{dd}(f)$. To compute $R_{dd}(\delta\tau)$ one needs to specify the data statistics. The expression in [] in Eq. 2.9 is recognized as that due to the interferometrically converted laser phase noise of a cw laser in the absence of data modulation. The expressions R_+ and R_- are given by:

$$R_-(\delta\tau) = \langle\cos[\varphi(t) - \varphi(t-\tau) - \varphi(t+\delta\tau) + \varphi(t+\delta\tau-\tau)]\rangle \qquad \text{Eq.2.11}$$

$$R_+(\delta\tau) = \langle\cos[\varphi(t) - \varphi(t-\tau) + \varphi(t+\delta\tau) - \varphi(t+\delta\tau-\tau)]\rangle \qquad \text{Eq.2.12}$$

and have been previously calculated [1,2]. The variations of the term $R_+\cos[\Omega_0\tau]$ are of the order of the laser wavelength. We are interested in the macroscopic variations, which are on a much bigger scale than those due to the term involving $R_+(\delta\tau)$. For this reason the term including $R_+(\delta\tau)$ will be neglected.

$R_-(\delta\tau)$ is given by [1]:

$$R_-(\delta\tau) = exp\left[-\frac{1}{2\tau}(2|\tau| - |\tau-\delta\tau| - |\tau+\delta\tau| + 2|\delta\tau|)\right] \qquad \text{Eq.2.13}$$

$$R_N(\delta\tau) = 2\psi^2P_0^2R_{dd}(\delta\tau)R_-(\delta\tau) \qquad \text{Eq.2.14}$$

Its power spectral density is given by:

$$S_N(f) = 2\psi^2P_0^2S_{dd}(f) \otimes S_-(f) \qquad \text{Eq.2.15}$$

where ⊗ denotes convolution.

The power spectral densities are schematically illustrated in Figure 3. The signal to noise ratio S/N can be easily calculated as:

$$\frac{S}{N} = \frac{P_0^2\int S_d(f)df}{2\psi^2P_0^2\int S_{dd}(f) \otimes S_-(f)df} = \frac{1}{2\psi^2R_-(0)} \qquad \text{Eq.2.16}$$

where for small a modulation index *m* it was assumed that $S_d(f)=S_{dd}(f)$. Eq. 2.16 illustrates clearly the deleterious effect of interferometric FM - IM noise on the maximum achievable S/N ratio of the transmitted data. In the event of large signal modulation, Eq. 2.16 has to be calculated without the above asumption, and most likely need to be evaluated numerically.

- Don't try to read above, read the original document