Simulation of Connectors in 10Gb/s Multimode Fiber Link for IEEE 802.3aq

Yu Sun, PhD, Optium Corporation
Channel Ad-Hoc Sub Task 4 Chair
11/3/04

1. Review of previous simulation approach used in TIA study

It is known that a perfect multimode fiber transmits its guided modes without energy conversion to the other possible guided modes or continuous spectrum. However, the perturbation to the index profiles and imperfections introduce the power coupling among different modes. In the previous TIA work, one of the assumptions is the mode coupling between mode groups is completely absent and that coupling within a group is 100%. Therefore, the coupling amplitude from input mode $\Psi_{l,m,v}$ (mode from the first fiber) to the output mode $\Psi_{l',m',v'}$ (mode in the second fiber) is calculated as [1]:

$$a_{l',m',v'}^{l,m,v}(\mathbf{r}) = \int_A d^2\mathbf{x}\Psi_{l',m',v'}^{*}(\mathbf{x})\Psi_{l,m,v}(\mathbf{x}-\mathbf{r}) \tag{1}$$

where **r** is the offset vector. The power coupled into output mode is calculated by:

$$w_{l',m',v'}^{out} = \sum_{l,m,v} w_{l,m,v}^{in} \left| a_{l',m',v'}^{l,m,v}(\mathbf{r}) \right|^2 \tag{2}$$

where $w_{l,m,v}^{in}$ is the power in mode *l,m,v*. Based on the assumption that the modes within one modal group have 100% mode mixing, the power in mode *l,m,v* can be written as:

$$w_{l,m,v}^{in} = \frac{w_u^{in}}{N_u} \tag{3}$$

where N_u is the number of modes present in that modal group.

2. Proposed IEEE 802.3aq link and simulation considerations

In previous TIA work, the above formulas were used in the simulation of long fiber and short fiber patch core as well. In previous 1Gb/s Ethernet work, using offset launch, the modal delay after propagation is relatively small compared to the bit period. Hence the potential power variation between different modal groups does not introduce dramatic pulse distortion in time domain. Therefore, it is reasonable to ignore the fact that in short fiber the modes within a modal group are not mixed completely in a short fiber.

However, if fiber is not long enough, the equation (3) is not a good simplification, as energy redistribution among modal group cannot be ignored. In 10Gb/s system, modal delay of different modal group after propagation is comparable to the bit period or even larger. The variation of power coupling of different modes will introduce pulse distortion. Therefore the assumption of 100% mode mixing in one modal group needs to be reexamined, depending on the setup of MMF link.

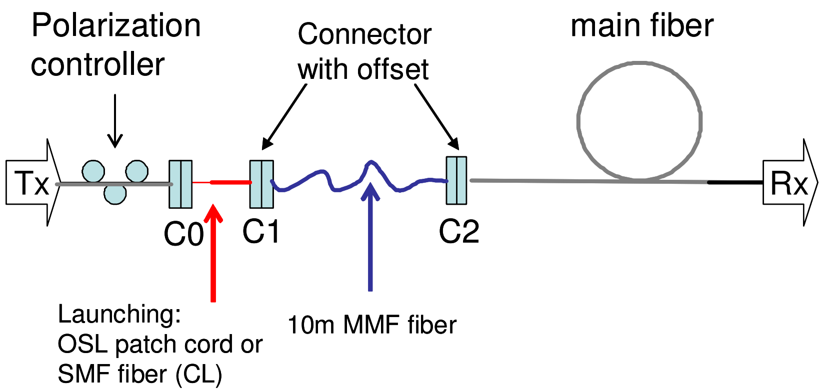


Fig. 1. Schematic diagram of the multimode link

The proposed MMF link is shown as Fig 1. The typical length scale of mode coupling within mode groups is hundreds meters. The first piece of multimode fiber in the proposed fiber link, as shown in Fig. 1, is only 10 meters, which is much shorter than the length scale that allows mode coupling with mode groups to happen. Therefore, every individual mode needs to be considered separately at the connector C2.

In addition, equation (2) suggests that the coupled power from modes in the previous fiber to the same mode in the second fiber is added incoherently. Therefore, the speckle pattern at the end of the first fiber is radial symmetric. However, under restricted launch conditions, the speckle pattern depends on the interference of individual modes and may not be radial symmetric after a short length of fiber [2].

Furthermore, at given time the electrical field (composite modal field) in the first fiber has to be matched to the electrical field of the second fiber. Based on this observation, the modes coupled to one mode in the second fiber should be treated coherently [3]. The mode coupling coefficient is calculated as

$$c^{out}_{l',m',v'} = \sum_{l,m,v} c^{in}_{l,m,v} a^{l,m,v}_{l',m',v'}(\mathbf{r}) \tag{4}$$

where $c^{in}_{l,m,v}$ is the mode coupling coefficient of the modes in the first fiber. It is calculated by overlap integral of the input beam to the modal fields. Then the power coupling coefficient is calculated by

$$w^{out}_{l',m',v'} = \left| c^{out}_{l',m',v'} \right|^2 \tag{5}$$

3. Simulation approach of connectors in MMF link

Due to phase differences between modes yield a speckle pattern at the end of the fiber. The speckle pattern varies with the perturbation of the link. However, if the variation of the speckle pattern is not fast enough that the detector only experiences an average effect, possible speckle patterns need to be consider in the simulation.

The input electrical field profile to the second fiber can be obtained by superposing the modal fields of the first fiber. We can write:

$$E_{1\rightarrow 2} = \sum_{l,m} c_{l,m} E_{l,m} \quad (6)$$

where $c_{l,m}$ is the mode coupling coefficient, taking into account an off-centered launching condition. For a given modal group, the field profile is not symmetric around the fiber core any more. An example of output field profile is given in Fig. 2.

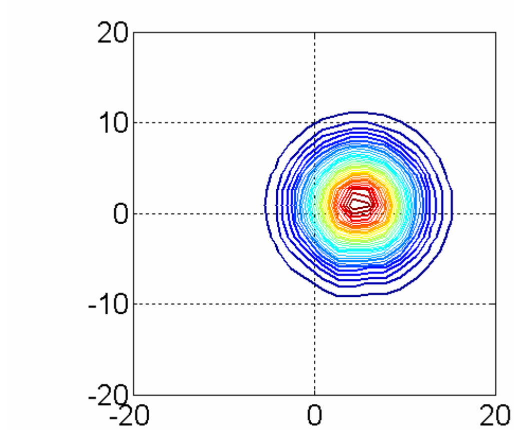


Fig. 2, an example of the output field profile after 10 m fiber with 5 μm offset at the input

In considering the offset at C2, one can write $E_{l',m'} = G(r,\theta,r_0,\varphi)$, where parameters r_0 and φ define the offset center. Therefore, to simulate possible impulse response due to an offset r_0, one needs to consider varying φ from 0 to π, as illustrated in Fig. 3.

In Fig. 3, the dashed circle and the solid circle are represented two possible offset with magnitude of r_0. It is clear that the overlapping of the composite modal field from the first fiber to these of the second fiber depends on the offset center.

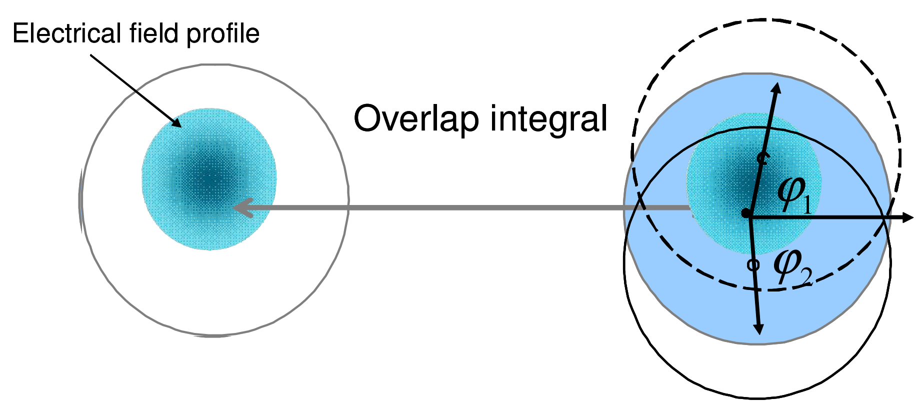


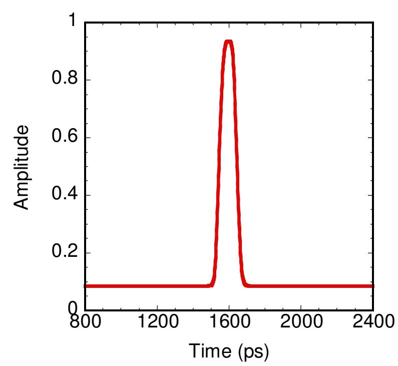
Fig. 3. Illustration of connect offset

In summary, for simulation of IEEE802.3aq links we propose:

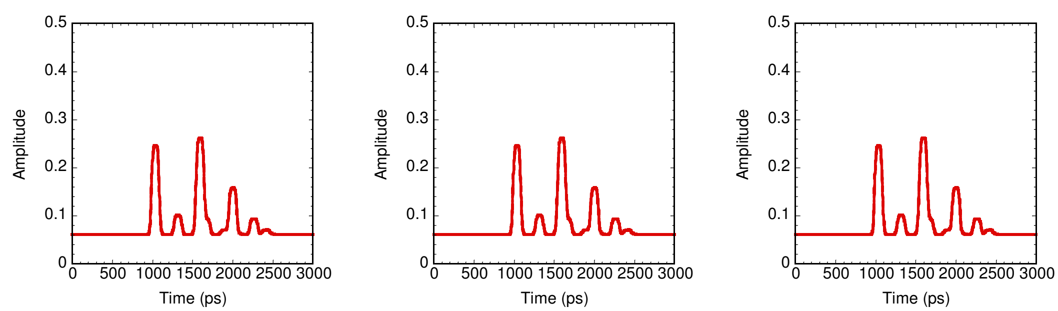
1) Due to the short length of the first MMF in the proposed link, modes within one modal group need to be treated individually.
2) The modal field profile at the end of first MMF varies with time and is not symmetric around the fiber core with an off-centered launching condition.
3) The overlap of modal fields at the connector depends on the relative location of the offset center to the reference coordinates and the pulse response will change accordingly.

4. Comparison of pulse shape after 300 m, using TIA method and proposed method

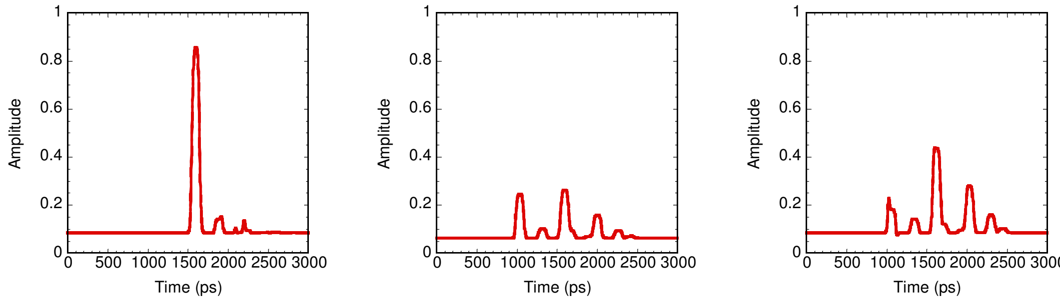
The simulation setup is shown in Fig. 1. In the calculation, center launch is considered and the offset of the two connectors, C1 and C2 are 5 μm respectively.



(a)



(b)



(c)

Fig. 4 Comparison of pulse shape using TIA method and proposed method. (a) input pulse, (b) pulse shape calculated using TIA method $\varphi = 0, 2/\pi, \pi$ respectively; (c) pulse shape using proposed method $\varphi = 0, 2/\pi, \pi$, respectively.

References:

1. P. Pepeljugoski, S. Golowich, A. J. Ritger, P. Kolesar and A. Risteski, "Modeling and simulation of next-generation multimode fiber links," J. Lightwave Technol., vol 21, no. 5, pp. 1242–1255, 2003.
2. G. Papen and G. Murphy, "Modal noise in multimode fbers under restricated launch conditions," J. Lightwave Technol., vol. 17, no. 5, pp. 817-822, 1999.
3. K. Petermann, "Nonlinear distortions and noise in optical communication systems due to fiber connector," IEEE J. Quantum Electronics, vol. QE 16, no. 7, 1980.