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## Requirements for low mode coupling.

From coupled mode theory [1, 2] the amount of power coupled between two modes $LP_{ab}$ and $LP_{xy}$ is given as

$$2\alpha_m = \sum_{p=1}^{\infty} C^2 \Phi\left(\beta_{ab} - \beta_{xy}\right), \tag{1}$$

Where C is the coupling coefficient given by below overlap integral

$$C^2 = \frac{k^2}{2} \frac{\left(\int_0^{\infty} \frac{dn}{dr} E_{ab} E_{xy} r dr\right)^2}{\int_0^{\infty} E_{ab}^2 r dr \int_0^{\infty} E_{xy}^2 r dr}, \tag{2}$$

Where k is the wavenumber and $E_{ab}$ and $E_{xy}$ are the field distribution of $LP_{ab}$ and $LP_{xy}$, further $\Phi$ is power spectrum of the deformation of the fiber axis:

$$\Phi_f(\Omega) = \left(\frac{1}{2L}\right)^2 \left| \int_{-L}^{L} f_f(z) \exp(-i\Omega z) dz \right|^2, \tag{3}$$

where $f_f(z)$ is the position of the fiber along the length of the fiber (z). Due to the stiffness of the fiber and the filtering effect of the coating the deformation spectrum will be largest for small angular frequencies ($\Omega$). Therefore, it is from (1) seen that the mode coupling is maximum when the difference between the propagation constants

$$\boldsymbol{\beta_{ab} - \beta_{xy} = k\left(n_{eff,ab} - n_{eff,xy}\right) = k \cdot \Delta n_{eff} \approx 0}, \tag{4}$$

I.e. when the effective index difference $\Delta n_{eff}$ is close to zero the mode coupling is maximized. This is further confirmed by experimental data. Ryo Maruyama et al. [3] have measured the mode coupling coefficient h

$$\boldsymbol{h = \frac{P_2}{P_1 L}}, \tag{5}$$

where $P_2$ is the amount of power in mode 2 coupled from mode 1 with power $P_1$ over the length L. The measured coupling coefficient by Ryo Maruyama et al. for different few mode fibers spooled on a spool with a diameter of 300 mm with a winding tension of 0.7 N versus $\Delta n_{eff}$ is shown in Figure 1 by blue diamonds.

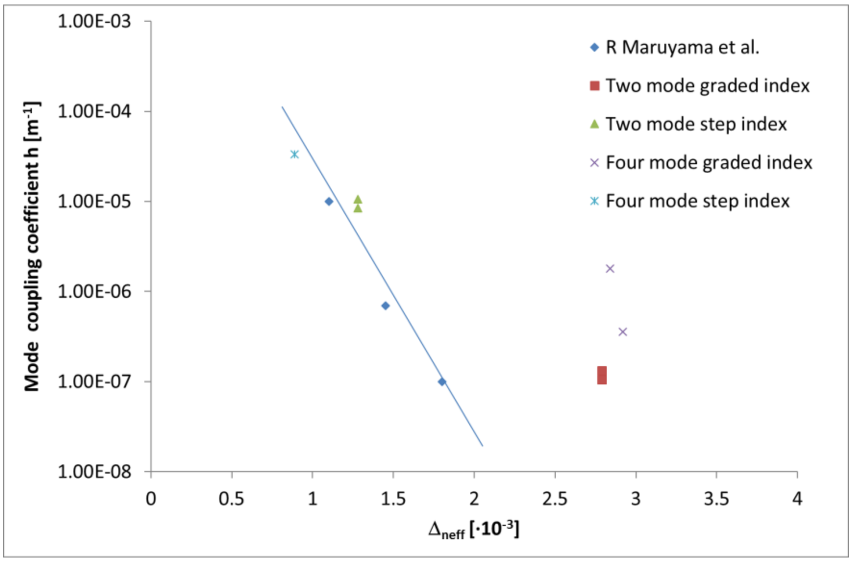


**Figure 1. Measured mode coupling coefficient versus $\Delta_{neff}$ for different fibers**

Measurements by OFS [4] on different OFS fibers are show as well in Figure 1 by red squares, green triangle's, pink crosses and light blue double crosses. The OFS measurements are done on spools with a diameter of 180 mm and a winding tension of 0.2 N. Even though the winding conditions are much different for the OFS fibers it is observed that the two-mode step index fiber and the four-mode step index fiber are on the same line as the Maruyama measurements. The OFS two and four mode graded index fibers are far from the line, but the mode coupling on these fibers were so low that they were close to the detection limit of our measurement set up.

1 D. Marcuse, "Microdeformation losses of single-mode fibers," Applied Optics, Vol. 23, No. 7, pp. 1082-1091 (1984)
2 D. Gloge, "Optical-Fiber Packaging and Its Influence on Fiber Straightness and Loss," The Bell System Technical Journal, Vol. 54, No. 2, pp. 245-262 (1975)
3 Ryo Maruyama, Nobuo Kuwaki, Shoichiro Matsuo, and Masaharu Ohashi, "Experimental Investigation of Relation Between Mode-Coupling and Fiber Characteristics in Few-Mode Fibers," Proceedings of OFC, paper M2C.1 (2015)
4 Cosign deliverable D2.3, pp. 8-10. http://www.fp7-cosign.eu/wp-content/uploads/2015/09/COSIGN-deliverable-D2-3-submitted_final_v4.pdf