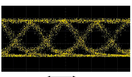
Wybrane zagadnienia transmisji światłowodowych z prędkością „gigabitową”



25ps

Efekty nieliniowe w światłowodzie

- nieliniowość Kerra
- wymuszone rozpraszanie Brillouina (SBS)
- wymuszone rozpraszanie Ramana (SRS)

Nieliniowość Kerra

$$\mathcal{P} = \varepsilon_0 \chi E + 4\chi^{(3)} E^3$$

$$\Downarrow$$

$$n(I) = n + n_{NL} I$$

dla SiO_2 $\quad n_{NL} = 3{,}2 \cdot 10^{-14}$ $[cm^2/W]$

w światłowodzie jednomodowym 1 ~ kW/mm² !!!

Nieliniowość Kerra powoduje m.in.:

-SPM Self-Phase Modulation

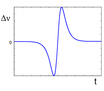
-CPM Cross-Phase Modulation

-FWM Four-Wave Mixing

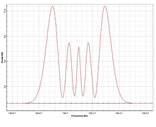
Własna modulacja fazy (SPM)

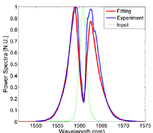
$$\Phi_{NL} = \frac{2\pi}{\lambda} \frac{n_{NL}}{A_e} P L_e$$

$$\Delta B = \frac{2\pi}{\lambda} \frac{n_{NL}}{A_e} L_e \frac{dP}{dt}$$

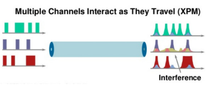


kłopoty rosną ~R^2

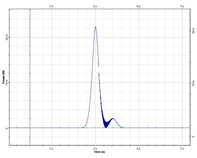


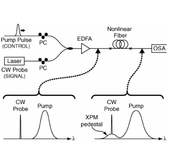


Cross-Phase Modulation



(bardzo niedoskonała ilustracja)

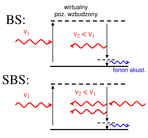


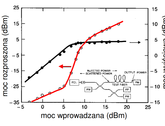


Mieszanie czterofalowe (FWM)

ω_i , ω_j , ω_k ⇒ $\omega_{ijk} = \omega_i + \omega_j - \omega_k$

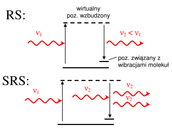
Wymuszone rozpraszanie Brillouina (SBS)

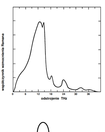


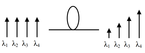


- sygnał rozproszony propaguje się **wstecznie**
- Δf = 10 GHz
- migotanie lasera redukuje SBS
- SBS występuje oddzielnie w każdym kanale WDM

Wymuszone rozpraszanie Ramana (SRS)



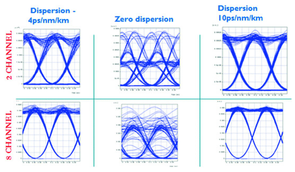




- proces szkodliwy z punktu widzenia multipleksacji WDM
- ale też wykorzystywany we wzmacniaczach optycznych
- zachodzi zarówno dla fal współ- jak i przeciwbieżnych

Dyspersja chromatyczna
redukuje szereg
negatywnych skutków
efektów nieliniowych!!!

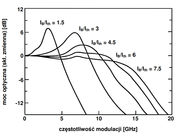
(szczególnie CPM, FWM, SRS)



1. NADAWANIE

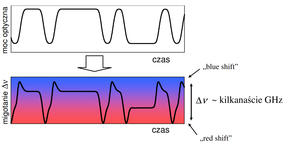
A. Bezpośrednia modulacja lasera

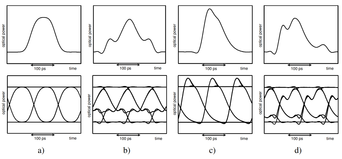
- pasmo modulacji



- migotanie (ang. chirp)

$$\Delta\nu(t) = \frac{\alpha}{4\pi}\left(\frac{1}{P(t)}\frac{dP(t)}{dt} + \kappa P(t)\right)$$



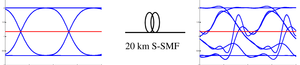


a) b) c) d)

Przebieg 10 Gb/s po 15 km światłowodu; (a) niezniekształcony, (b) zniekształcony przez migotanie dynamiczne, (c) przez adiabatyczne, (d) przez obydwa składniki migotania

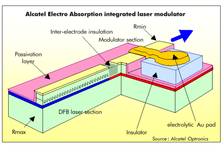
kłopoty rosną ~R^2

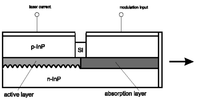
Czy migotanie zawsze poszerza impuls???

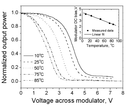


B. Zewnętrzna modulacja lasera

- modulator elektroabsorpcyjny

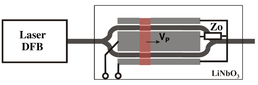




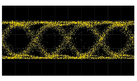


efekt Franza-Keldysh'a

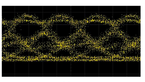
- modulator Macha-Zehndera



2. DYSPERSJA CHRONATYCZNA



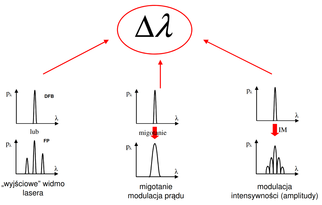
0 km

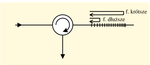


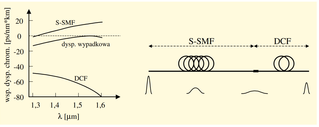
8 km

„rozmycie impulsów":

$$\Delta t_{CHR} \approx z D_{CHR} \Delta\lambda$$



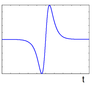




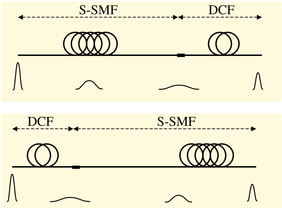
KOMPENSACJA DYSP. CHROMATYCZNEJ
A WŁASNA MODULACJA FAZY

$$\Phi_{NL} = \frac{2\pi}{\lambda}\frac{n_{NL}}{A_e} P L_e$$

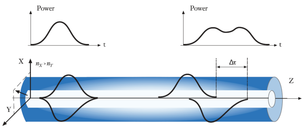
$$\Delta B = \frac{2\pi}{\lambda}\frac{n_{NL}}{A_e} L_e \frac{dP}{dt}$$



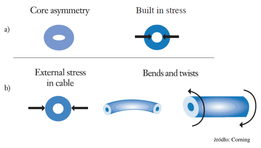
kłopoty rosną ~R^2



3. DYSPERSJA POLARYZACYJNA POLARIZATION-MODE DISPERSION



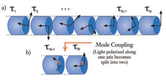
źródło: Corning

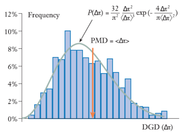


źródło: Corning

zniekształcenie	dwójłomność Δn_g	PMD ps na 1 km	zależność
eliptyczność rdzenia 1%	5×10^{-6}	1.25	proporcjonalna
nacisk 1 g/cm	7×10^{-6}	0.23	proporcjonalna
zagięcie 10 cm	5×10^{-6}	0.17	$1/R^2$
skręcenie 1 obr./m	2.3×10^{-7}	~0	proporcjonalna

PMD jest zjawiskiem losowym!!!

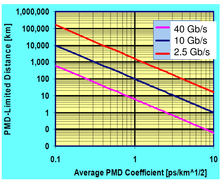




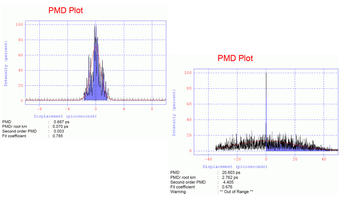
PMD rozumiana jako parametr liczbowy to średnia z DGD (*Differential Group Delay*); jednostką jest

$$ps/\sqrt{km}$$

Istotność PMD rośnie dramatycznie przy szybkiej modulacji



Zainstalowane światłowody charakteryzują się bardzo różnymi wartościami PMD



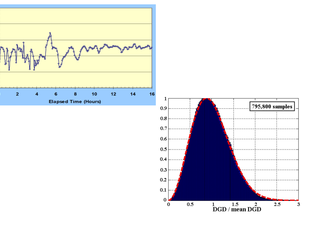
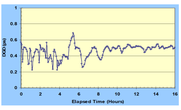
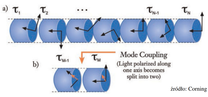


Fig. 1: PMD results of Brazilian newly installed fibers collected by FiberWork - *compilation summary*

Differential Group Delay (DGD) zmienia się w czasie, zależy od λ



Budując linię z szeregu zespawanych odcinków kabla tego samego typu, możemy otrzymać bardzo różne PMD, zależnie od np. przypadkowego wzajemnego „skręcenia" kabli



źródło: Corning

Link design value (LDV) is a useful design parameter for calculating the worst-case contribution of the fiber toward the overall system PMD of a link. LDV, also referred to as PMD_Q, is a term developed in standards bodies used to evaluate the impact of fiber related PMD where cabled fibers are deployed in concatenated sections. That is, in building a network typically 2-10 km sections of cable are spliced together. The LDV is the worst case PMD of the end-to-end link made up of randomly chosen cable sections spliced together. Thus the LDV represents the worst case PMD of a fiber path in a cabled and deployed span. PMD standards indicate that LDV should be calculated from nominally 20 to 24 sections and have a maximum cumulative distribution Q of nominally 0.001 to 0.0001. This implies that 0.1% or 0.01% of all spans (made up of concatenated sections) would be above this level of PMD.