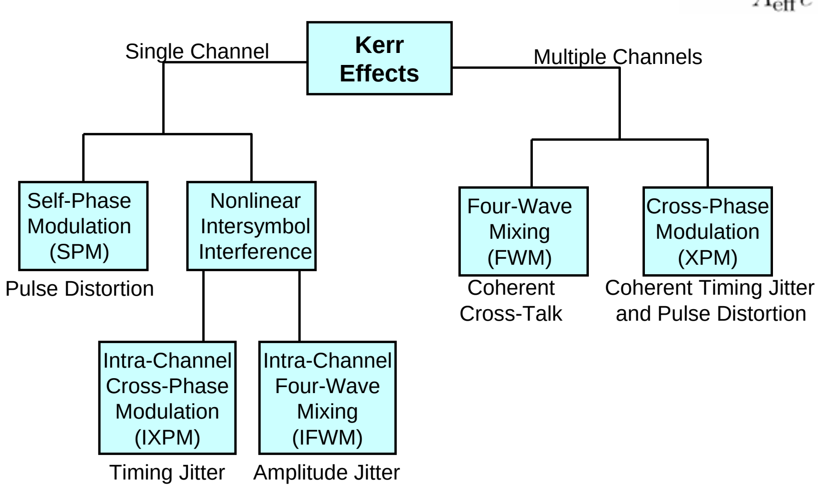
Fiber Kerr Effects

Keang-Po Ho

Nonlinear Kerr Effects

$$n'_r = n_{r0} + \bar{n}_2 (P/A_{\text{eff}}) \qquad \beta' = \beta_0 + \gamma P \qquad \gamma = \frac{\omega_0 \bar{n}_2}{A_{\text{eff}} c}$$

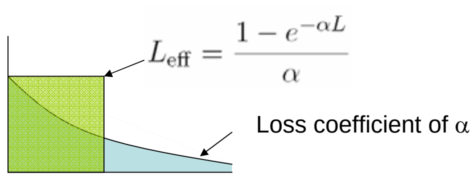


Self-Phase Modulation

- For a pulse of $p(t)$ in electric field, without dispersion, it becomes

$$p(t)\exp\left(j\gamma L_{\text{eff}}\,|\,p(t)\,|^2\right)$$

- What is L_{eff}



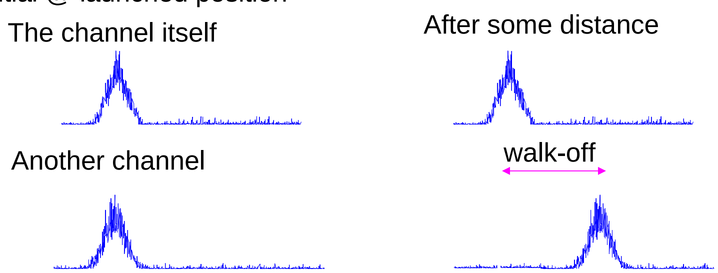
Cross-Phase Modulation

- From another wavelength or pulse, without dispersion

$$p_1(t)\exp\left(j\gamma L_{\text{eff}}\,|\,p_2(t)\,|^2\right)$$

With dispersion and walk-off

Initial @ launched position

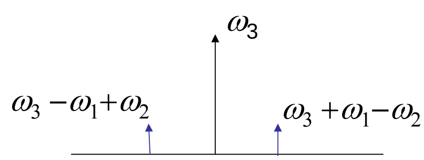


Four-Wave Mixing

- The combined power of two wavelengths is

$$P = |E_1 e^{j\omega_1 t} + E_2 e^{j\omega_2 t}|^2 = E_1^2 + E_2^2 + 2E_1E_2\cos(\omega_1 - \omega_2)t$$

- Kerr effect give $E_3 e^{j\gamma P}$ or

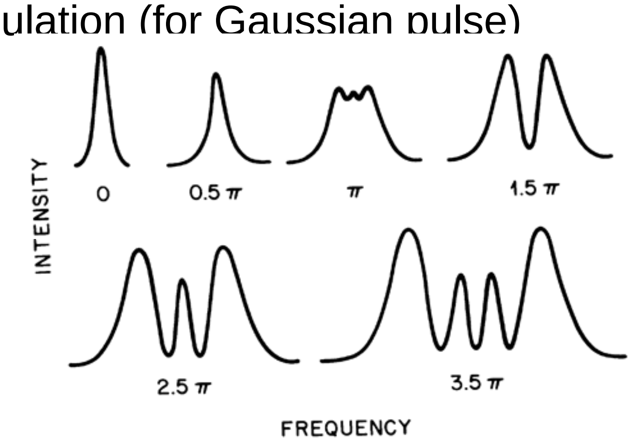


Self-Phase Modulation

Spectral Broadening

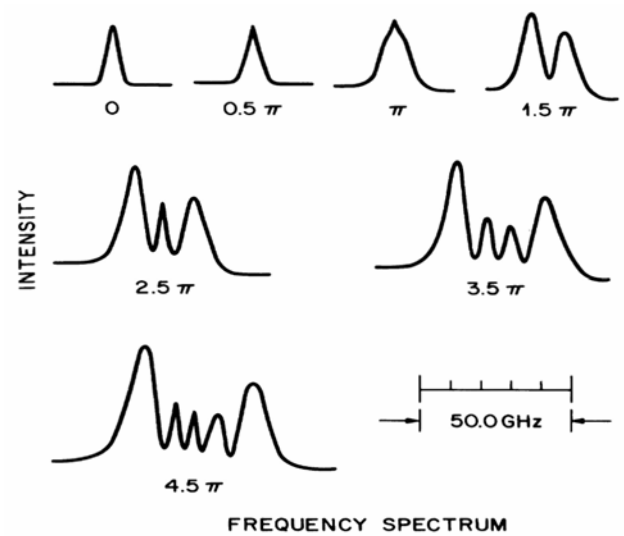
$$p(t)\exp\left(j\gamma L_{\text{eff}}\,|\,p(t)\,|^2\right)$$

- Calculation (for Gaussian pulse)



Self-Phase Modulation

Measured Spectral Broadening

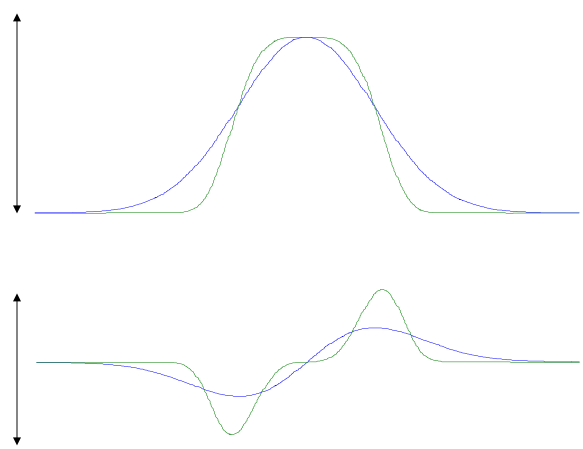


Self-Phase Modulation

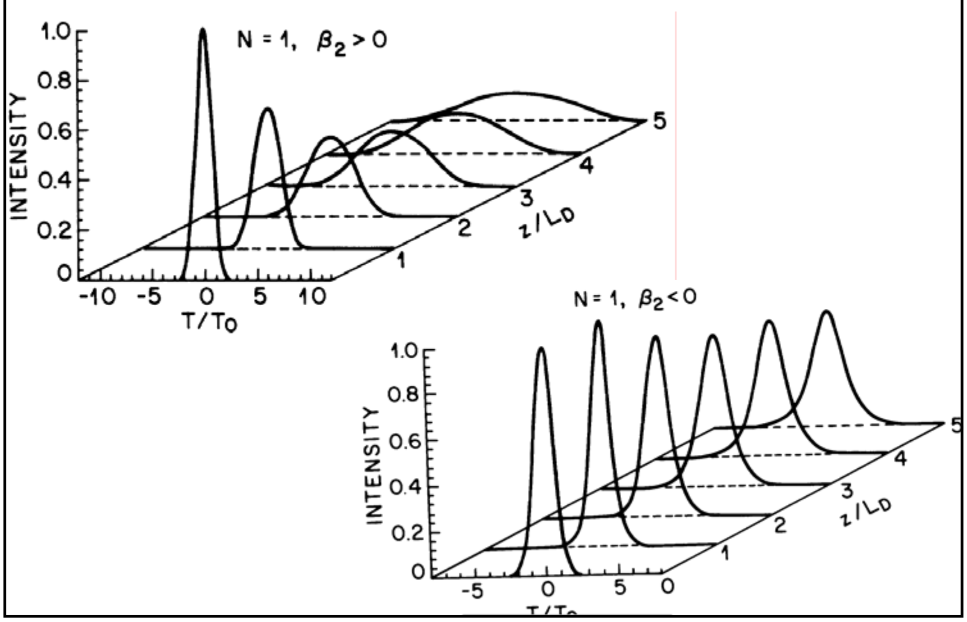
Frequency Chirp

Power
or
Nonlinear
Phase Shift

Frequency
chirp



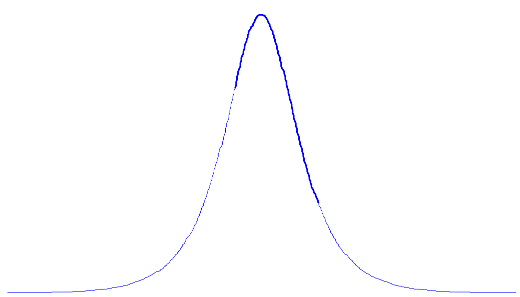
Pulse Evolution



Soliton

Balancing Self-Phase Modulation and Dispersion

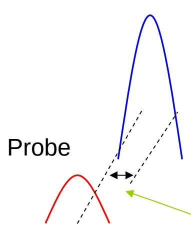
- A sech pulse of $\mathrm{sech}(t)$

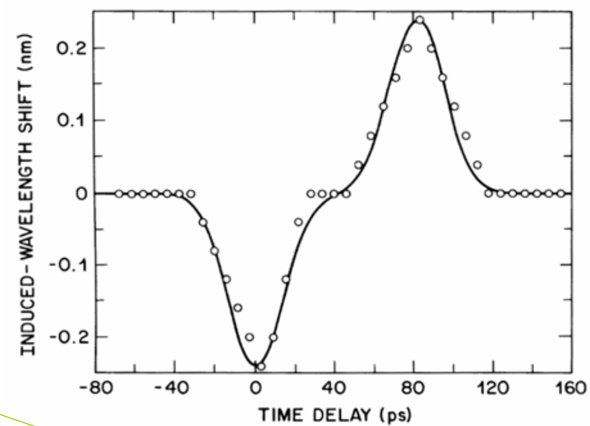


Cross-Phase Modulation

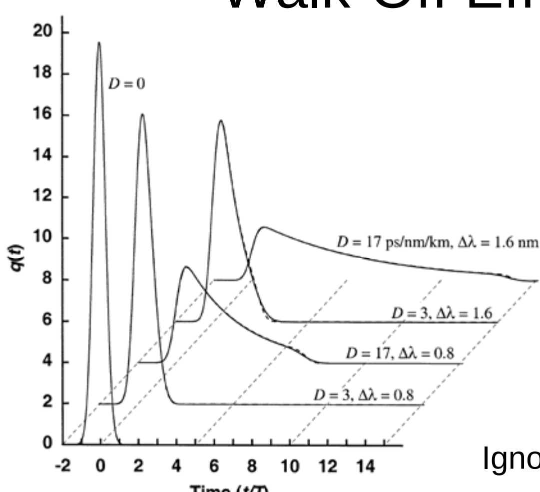
Spectral Shift

Without dispersion/Depending on temporal overlap





Walk-Off Effects



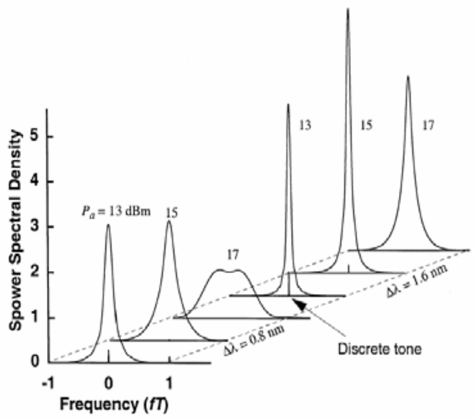
Ignored pulse overlap

$$\phi_{\text{XPM}}(t) = \sum_k b_k q(t - kT)$$

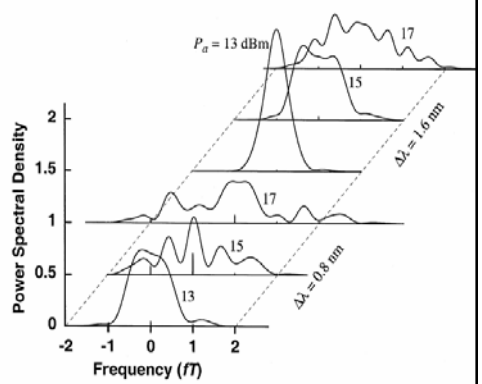
Spectral Broadening

Random binary OOK pump

17 ps/nm/km

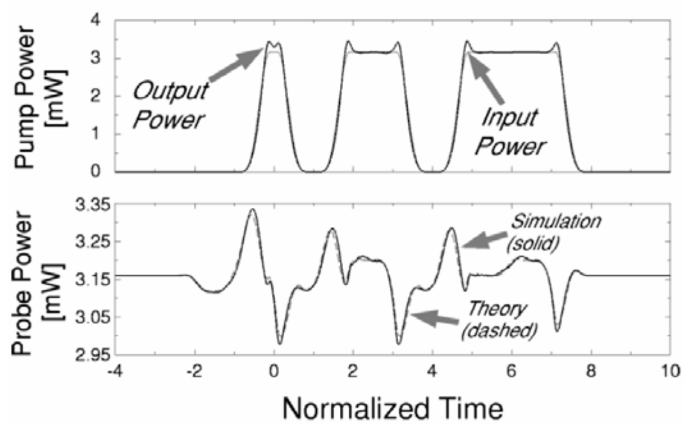


3 ps/nm/km



Phase to Intensity Noise Conversion

$$\frac{dP_{sp}(z,\omega)}{\langle P_s\rangle} = -2\sin\left[\omega^2\frac{\lambda^2}{4\pi c}D(L-z)\right]d\theta_{sp}(z,\omega)$$

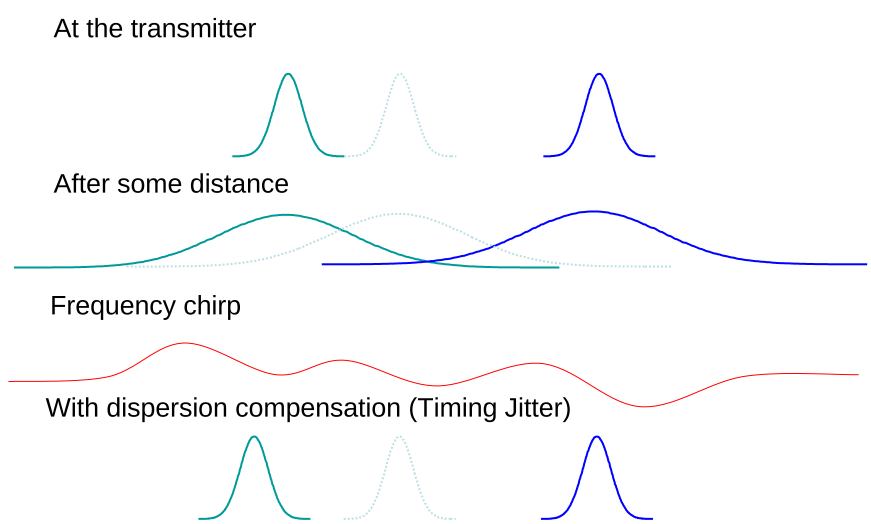


Four-Wave Mixing

- Ask Jen-An Huang

Intrachannel Cross-Phase Modulation

Timing Jitter for OOK Signal



Timing Jitter

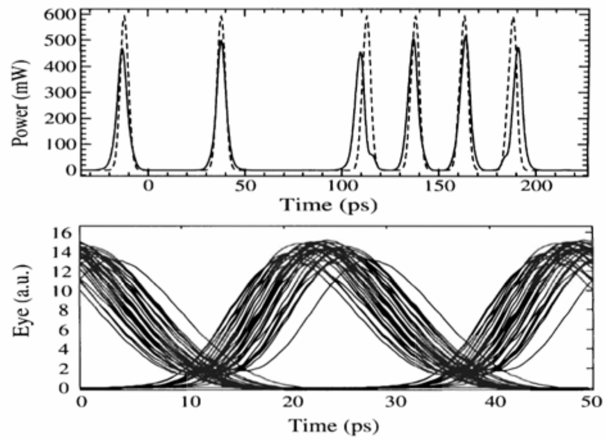
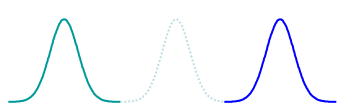


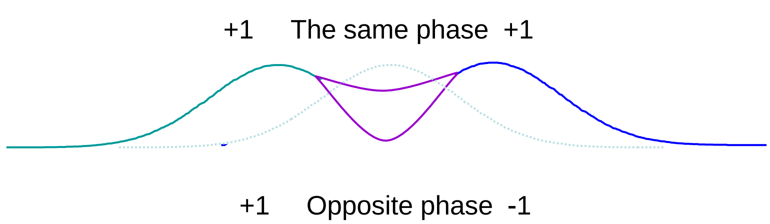
Fig. 6.13 Waveform and eye diagram after transmission of a PRBS sequence of 128 bits consisting of 5-ps Gaussian pulses. Transmission is over 80 km of TrueWave™ fiber ($D = 4$ ps/nm). The bit rate is 40 Gb/s, launch power 18 dBm, fiber loss 0.21 dB/km, and precompensation -17 ps/nm. The degradation in the eye diagram is from timing jitter caused by IXPM.

Intrachannel Four-Wave-Mixing

At the transmitter



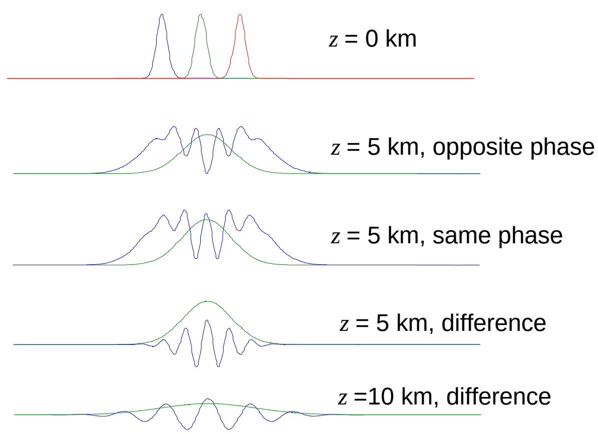
After some distance



Disclaimer: For illustration purpose, the actual physics is far more complicated than this simple picture.

IFWM & IXPM

$$u_k(z,t) = \frac{A_k T_0}{(T_0^2 - j\beta_2 z)^{1/2}} \exp\left[-\frac{(t-kT)^2}{2(T_0^2 - j\beta_2 z)}\right]$$



T_0 = 5 ps
D = 17 ps/km/nm
T = 25 ps

Ghost Pulses from IFWM

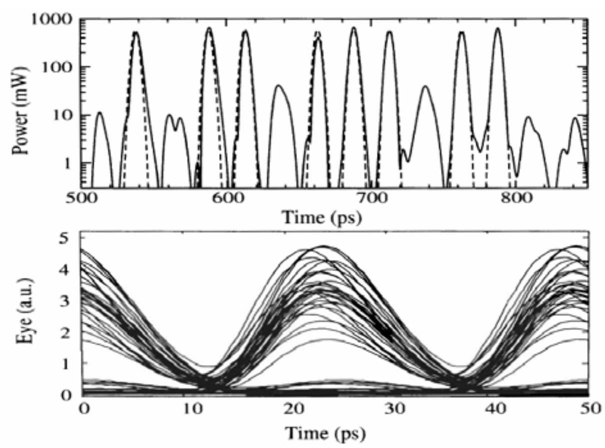


Fig. 6.18 Waveform and eye diagram after transmission for the same system considered in Fig. 6.13 except that TrueWave™ fiber has been replaced by STD unshifted fiber (D = 17 ps/nm) and the precompensation has been changed to −527 ps/nm. The degradation in the eye diagram is from amplitude jitter and shadow pulse generation caused by IFWM.