Dispersion and self-phase modulation compensation in multi-gigabit systems

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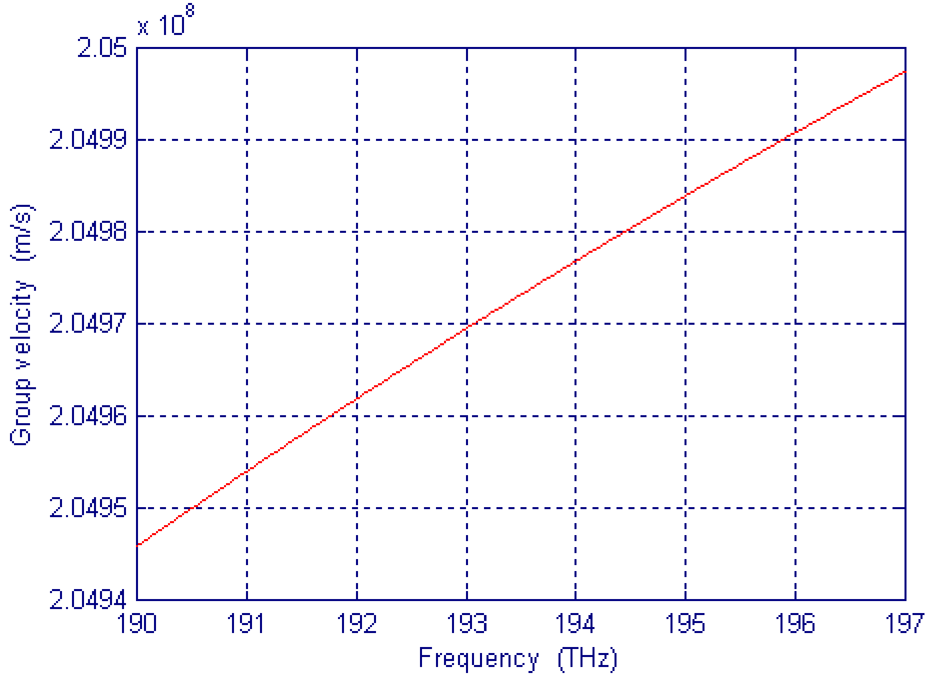
Limitations to the system performance

- Attenuation
- Dispersion
- Non-linear effects:
  - Self-phase modulation:
    - Pulse
    - Interaction between pulses
  - Cross-phase modulation
  - Four wave mixing
  - Stimulated Raman scattering
  - Stimulated Brillouin scattering
- Optical amplifiers ASE noise

Chromatic Dispersion



$L_a = 100$ km $\Delta f = 50$ GHz

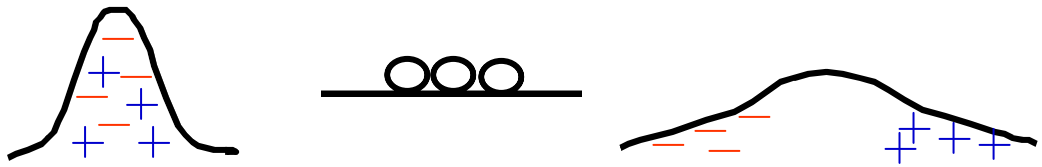
D = 17 ps/nm/km

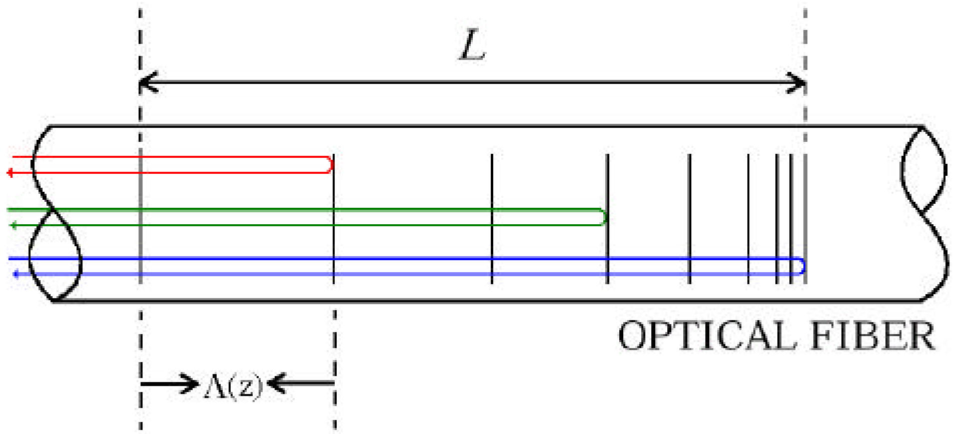
$\Longrightarrow$

TIME DELAY = 680 ps

SPACE DELAY = 14 cm

Dispersion compensation





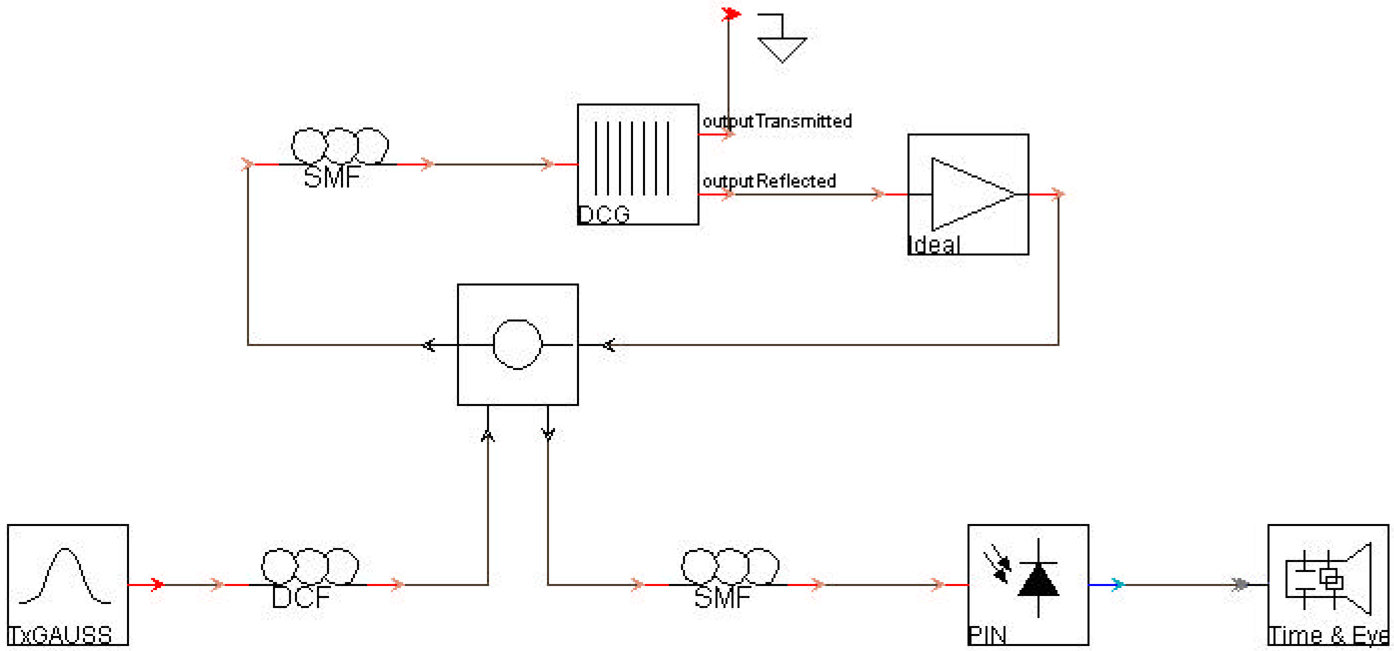
Limitations due to the dispersion

- Return to zero coding
- Pulse FWHM broadens to the extent of one bit slot time
- Standard fiber

Bit rate (Gbit/s)	Bit period (ps)	FWHM (ps)	Disp. length (km)
2.5	400	80	565
10	100	20	35
40	25	5	2.2
100	10	2	0.35

Prechirp+poscompensation+poschirp

- SYSTEM LAYOUT ON THE PTDS SIMULATION TOOL:



- A 100 ps^2 pre-chirp is attained with a negative dispersion fiber.

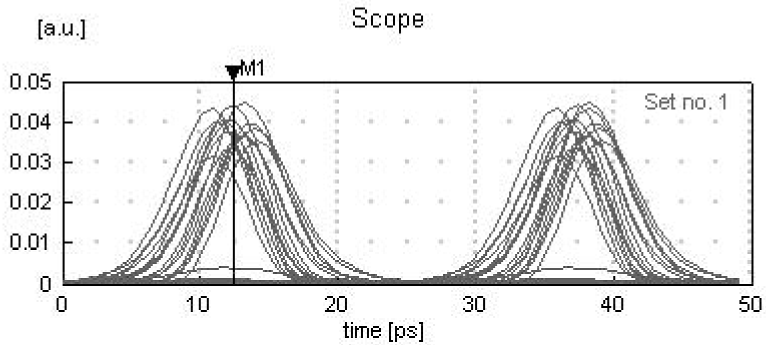
Prechirp+poscompensation+poschirp

- SYSTEM PARAMETERS:

Bit Rate	40 Gbit/s
Full width half maximum	5 ps
Wavelength	1553 nm
Spontaneous emission factor	2
Fiber attenuation	0.25 dB/km
Dispersion coefficient	- 20 ps^2/km
Gaussian pulse peak power	50 mw
Non-linear coefficient	1.3 W/km
Amplifiers spacing	100 km

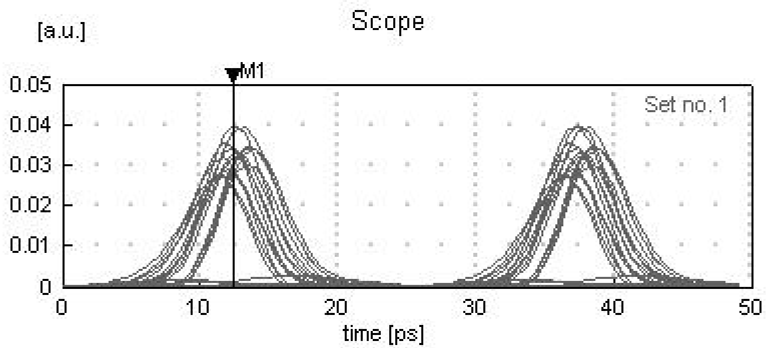
SIMULATION RESULTS FOR A MAXIMUM BER OF 10^{-9}

- Without pre-chirp a total distance of 1200 km was achieved:



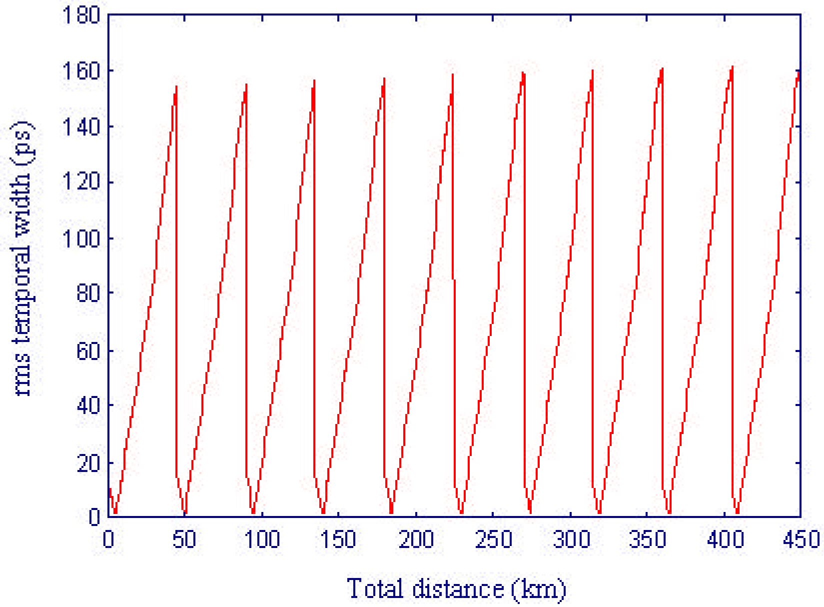
time [ps]	M1: 12.5	M2: -	D2-1: -
[a.u.]	-	M2: -	D2-1: -
Q = 6.49	BER = 3.35e-011	EyeOpening = -34.3 dB	

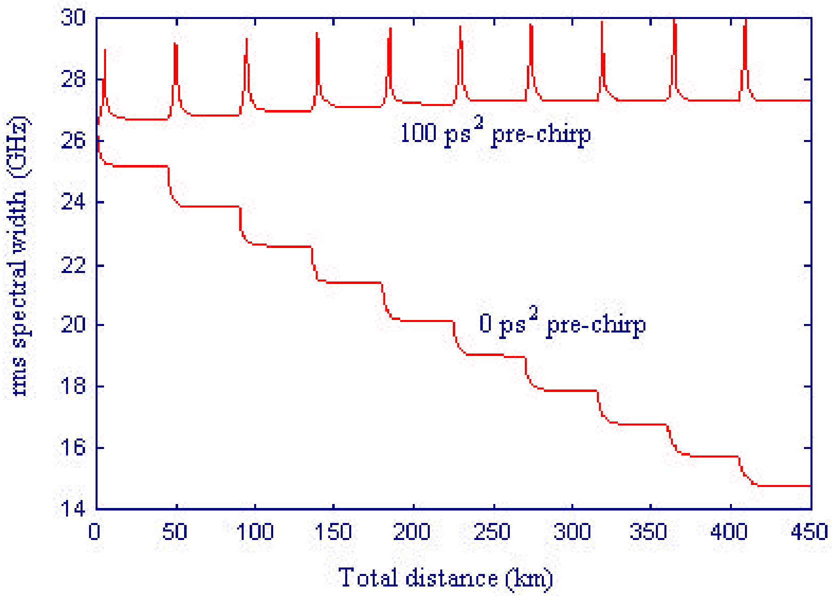
- With pre-chirp a total distance of 1800 km was achieved:



time [ps]	M1: 12.5	M2: -	D2-1: -
[a.u.]	-	M2: -	D2-1: -
Q = 6.11	BER = 3.17e-010	EyeOpening = -36 dB	

Self-phase modulation compensation





- Pre-chirp computation [Zitelli99]:

$$\frac{\exp\left(\alpha\left|\frac{T_0^2 C_{pr}}{\beta_2}\right|\right)-1}{\alpha\left|\frac{T_0^2 C_{pr}}{\beta_2}\right|}\,\frac{C_{pr}^2}{\left(1+\frac{C_{pr}^2}{4}\right)^{\frac{3}{2}}}=0.7698$$

ASE noise jitter

ASSUMPTIONS:

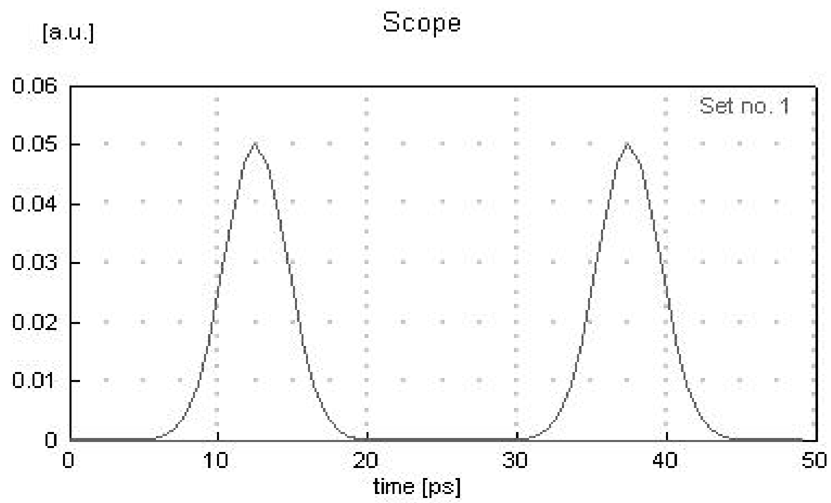
- Poscompensation of first order dispersion.
- No second order dispersion $\beta_3 = 0$.
- No non-linear pulse interaction.
- One channel at 40 Gbit/s.

HYPOTHESES:

- The timing jitter is a result of ASE noise addition to the signal.
- No Gordon-Haus effect since $\langle \beta_2 \rangle = 0$.

ASE noise jitter

- RESULTS FROM PTDS SIMULATION (TOTAL DISTANCE EQUAL TO 1800 KM):
  - Without adding ASE noise to the signal:

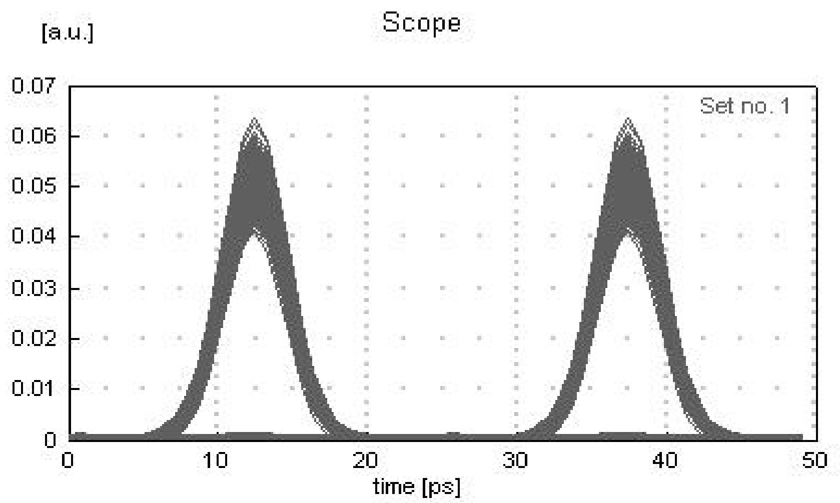


  - No timing jitter appear. Thus the source must be the ASE noise.

ASE noise jitter

- RESULTS FROM PTDS SIMULATION:

  – Attenuator + amplifier:

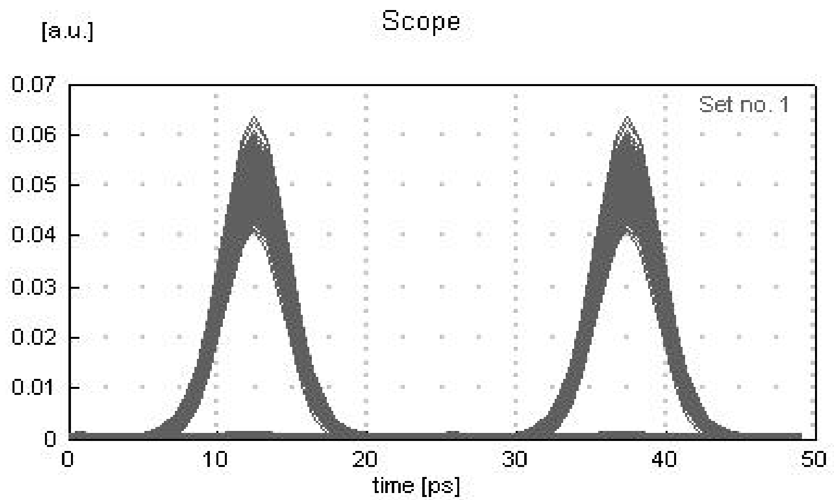


  – Timing jitter is equal to 0.14 (ps).

ASE noise jitter

- RESULTS FROM PTDS SIMULATION:

  - Dispersion poscompensation with fiber gratting:



  - Timing jitter is equal to 0.14 (ps).
  - The similar results between the two last configurations, allows to conclude that there is not Gordon-Haus effect in such a system.

ASE noise jitter

- Following the work done by [Georges93] we have for the pulse jitter at the output of the optical amplifier:

$$\sigma_t^2 = \frac{\pi^2 n_{sp}(G-1)T_0^2}{6A_0N_g}$$

- where N_g is the number of photons by gaussian pulse:

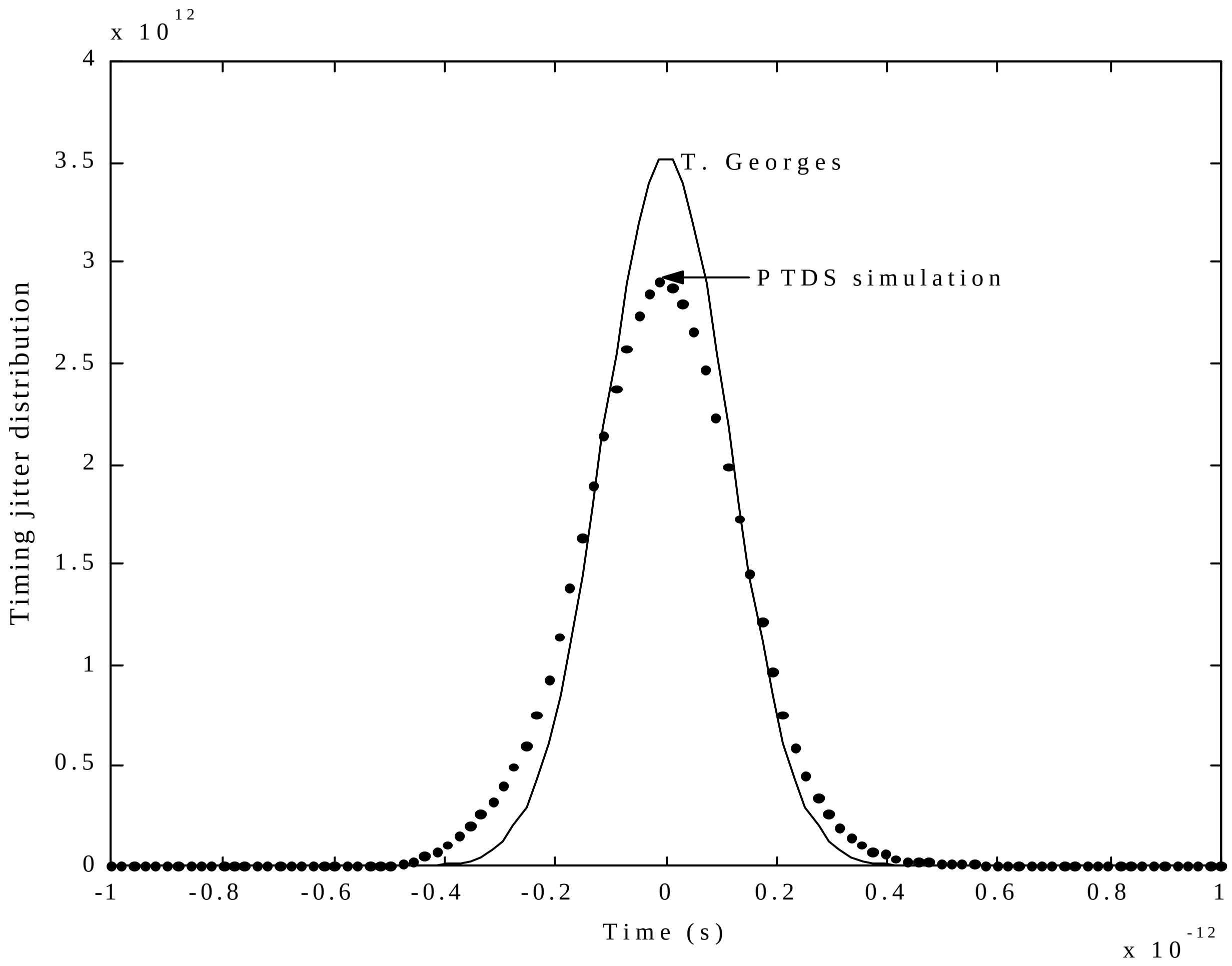
$$N_g = \frac{\text{Gaussian pulse energy}}{\text{Photon energy}} = \frac{2\sqrt{\pi^3}P_0T_0}{hf}$$

- Results to the timing jitter variance:

$$\sigma_t^2 = \frac{\sqrt{\pi}n_{sp}(G-1)hfT_0}{12P_0}$$

ASE noise jitter

- COMPARATION BETWEEN ANALYTICAL MODEL AND SIMULATION:



$$\sigma_{George} = 0.11 \quad (ps)$$

$$\sigma_{sim} = 0.14 \quad (ps)$$

Conclusions

- The major limiting factors at 40 Gbit/s are:
  - Dispersion
  - Non-linear interaction between pulses
- ASE noise jitter is negligible.
- Total dispersion compensation ⟹ No Gordon-Haus effect
- The source of ASE noise jitter is the time fluctuations at the optical amplifier.
- Fiber Bragg grating as dispersion compensation device
- Pre-chirp is a suitable technique to decrease the non-linear interaction