Modeling and Design of Soliton Propagation in WDM Optical Systems

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Contains

- Introduction
- What is 5G
- Soliton (its history, its types)
- Optical soliton, its generation and its balance (GVD,SPM)
- The Schrödinger equation and numerical solution (SSF)
- Interaction of the soliton
- Filtering
- Simulation
- Conclusion

Optical links in the 5G networks

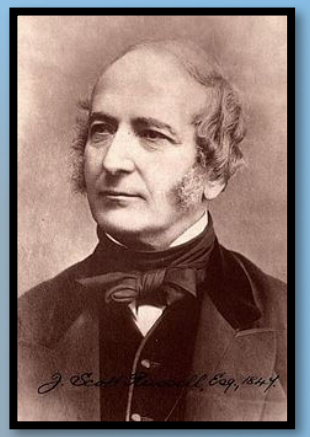
- **The 5G mobile networks refers to the next and newest mobile wireless standard based on the IEEE 802.11ac standard of broadband technology and utilize a very dense cellular structure which requires high capacity optical systems for signal transport**
- **The wavelength division multiplex (WDM) type optical communication offers a significantly increased transmission capacity.**
- **For that purpose of signal transmission the optical soliton method can be a proper choice.**

What are the offers of the 5G?

- Real wireless word with no more limitation more than 10Gbps connections
- Capacity 1000x bandwidth per unit area,10-100x number of connected devices
- Large phone memory , dialing speed clarity in audio and video …etc.
- Up to ten year battery life for low power, machine-type devices 90% reduction in network energy usage
- (Perception of) 99.999% availability
- (Perception of) 100% coverage

Solitons

The solitons waves in hydrodynamics were discovered by John Scott Russell in 1834.
It is a localized wave which propagates without deformation, i,e preserves its shape and speed.



Soliton types

Hydraulic soliton

Tsunami in Japan at 11 mars 2011

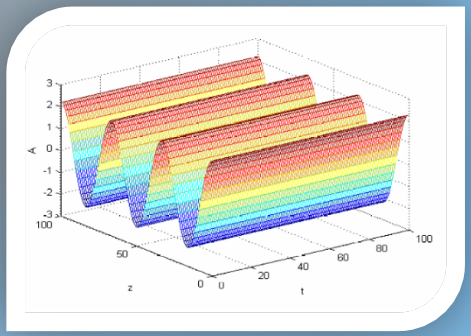
mechanical chain

Soliton Kink generated along a chain of coupled pendulums

Morning Glory

Morning Glory In Australie

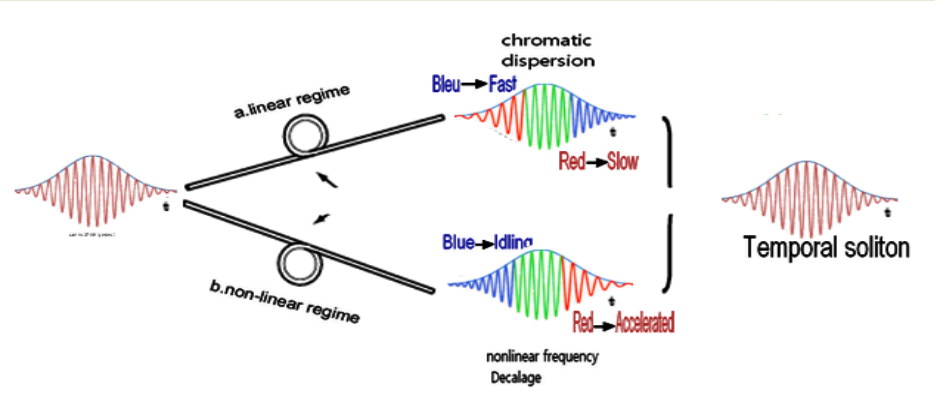
Optical soliton



Secant parabolic wave

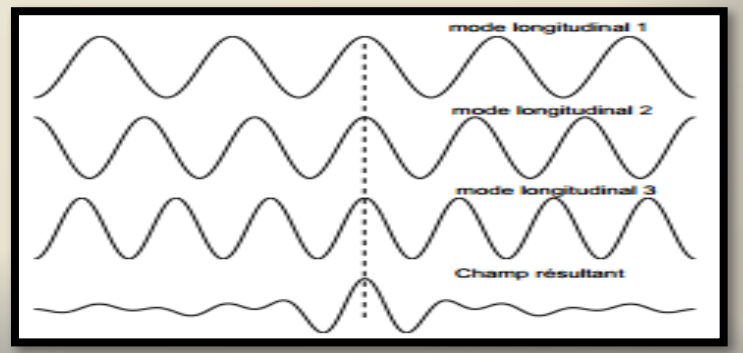
Optical soliton

-The soliton is a pulse that has the remarkable property of being able to spread without alteration over extremely long distances through mutual compensation of linear and nonlinear effects $A(z=0,\tau)=N.sech(\tau)$



Soliton propagation

- A semiconductor laser is used to generate soliton pulses. Locking mode is introduced into the laser cavity by an element that causes interaction between the longitudinal modes and synchronizes them with each other.
- This locking(active mode and passive mode) between modes generates the soliton pulse.



Mode-locking principle

Kerr effects and the consequences

It occurs when very short and intense pulses pass through the core of single mode fiber

$$\gamma = \frac{n_2 . w}{c . A_{eff}}$$

SPM

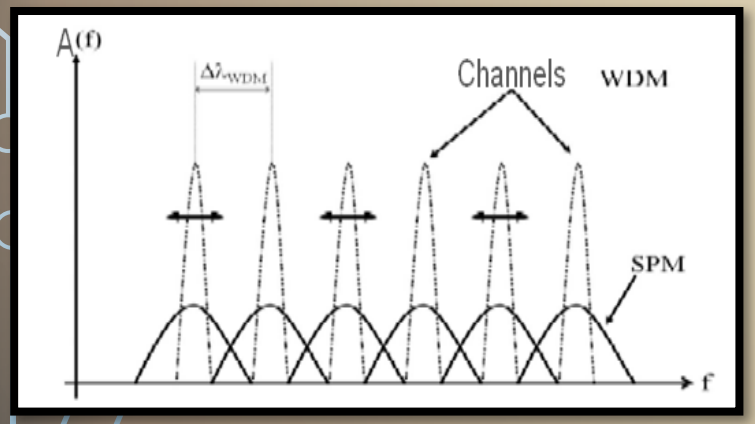
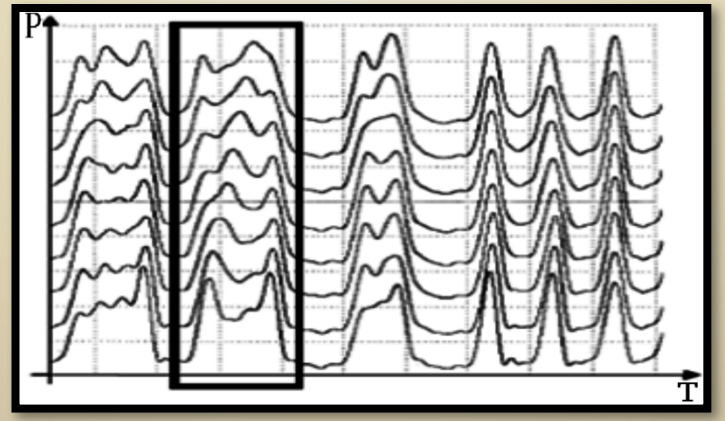


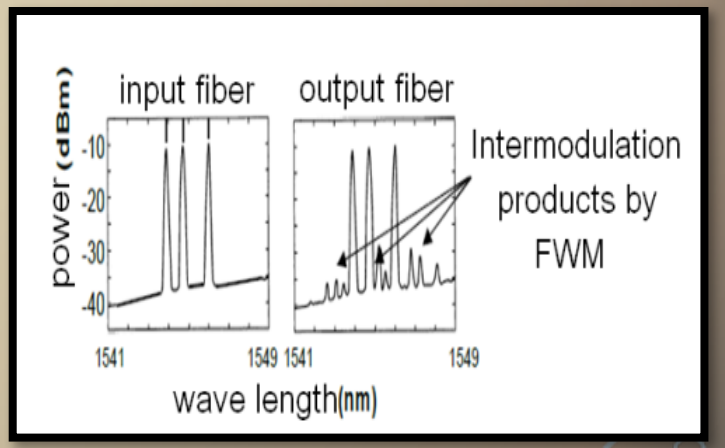
Illustration impact of SPM on WDM

XPM



Example of deformation to the XPM

FWM



Example FWM intermodulation product

Propagation modelling of solitons in optical fibers

Propagation in a single mode optical fiber is modelled by the following equation, said nonlinear Schrödinger:

$$i\frac{\partial A(z,t)}{\partial z}+\frac{i}{2}\alpha A(z,t)-\frac{1}{2}\beta_2\frac{\partial^2 A(z,t)}{\partial t^2}+\gamma|A(0,t)|^2A(z,t)=0$$

A(Z,t) : slowly varying electric field the envelope
Z : the propagation distance
t : the time
α : attenuation
β : chromatic dispersion of order 2
Ɣ : nonlinearity

Analytical dispersive solution

$L_D>>>L_{NL}$ *we consider that the system is purely dispersive*

$$i\frac{\partial A}{\partial Z}=\frac{\beta_2}{2}\frac{\delta^2 A}{\delta t^2}$$ In the domain frequency $\Longrightarrow i\frac{\delta\tilde{A}}{\delta Z}=-\frac{\beta_2}{2}w^2\tilde{A}$

$$\tilde{A}(Z,w)=\tilde{A}(0,w)\exp\left(i\frac{\beta_2}{2}w^2\right).Z$$

This expression shows that the effects of the dispersion do not affect the spectrum

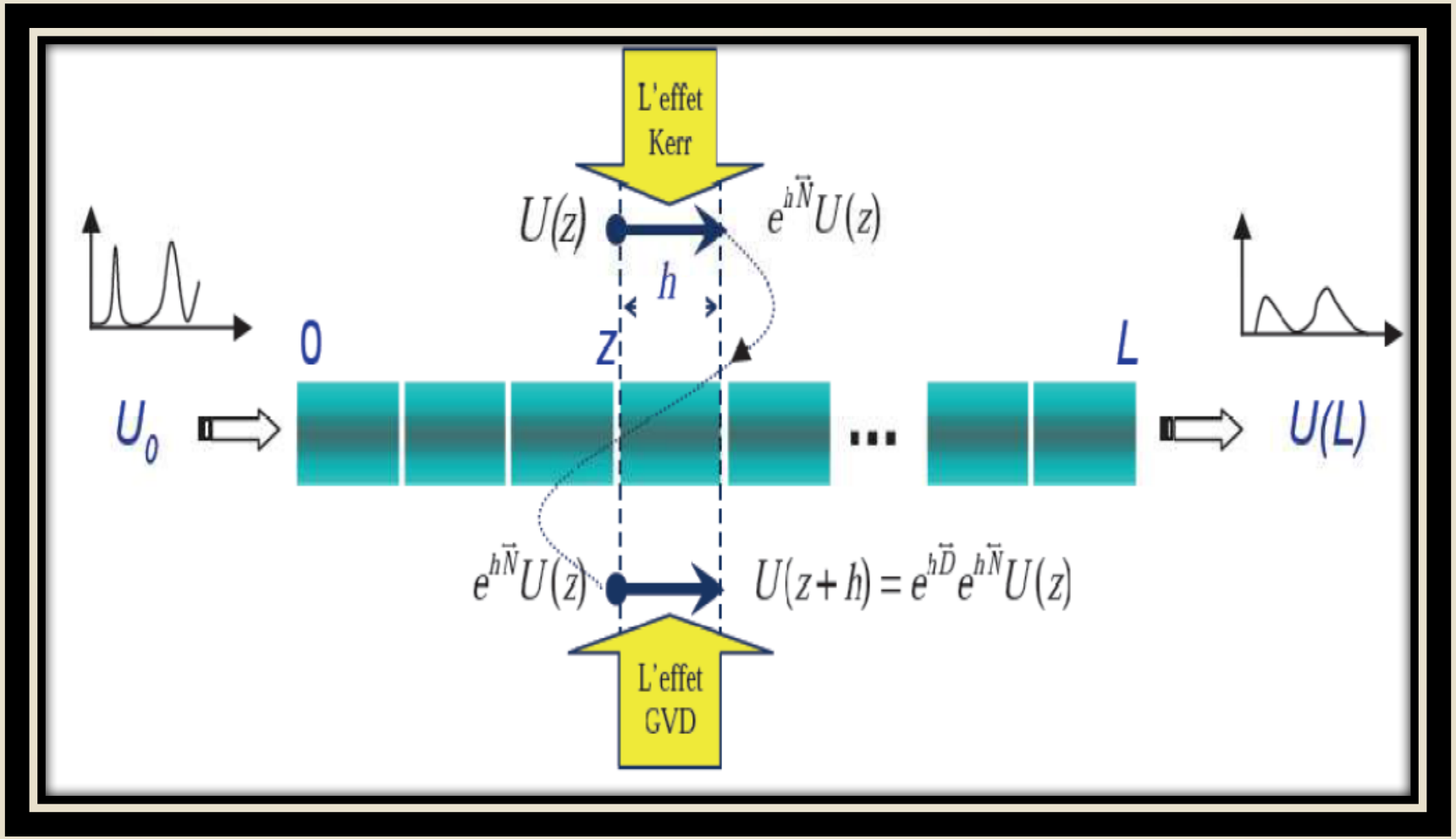
Analytical dispersive solution

$L_D<<<L_{NL}$ In this case the dispersive effects is neglected beside the nonlinear effects ($\beta_2=0$)

$$i\frac{\delta A}{\delta Z}=\gamma|A^2|A$$ the solution is $\Longrightarrow A(z,t)=A(0,T)\exp\left(i\gamma|A(0,t)|^2Z\right.$

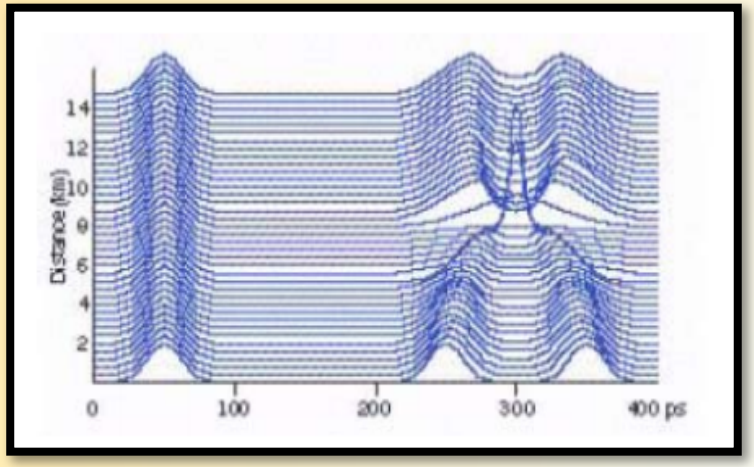
The non-linear effects do not modify the temporal profile of the pulse

The Fourier method using fiber s ections



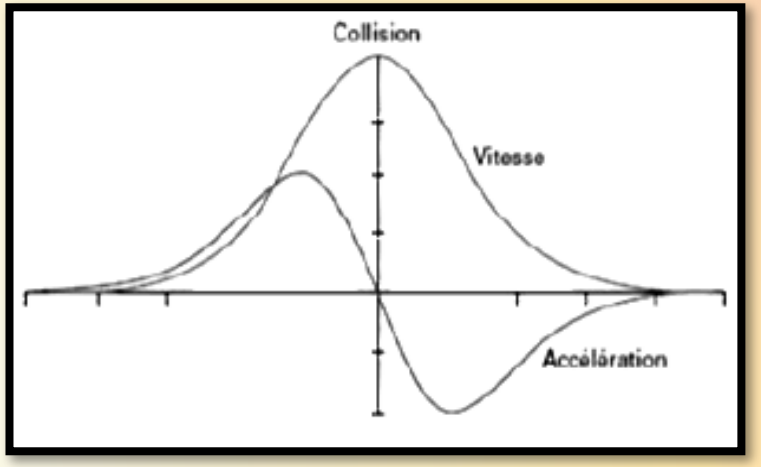
The schematic illustration of the division of the fiber length.

Interaction between two adjacent soliton



Spread over 14,000 km of the waveform soliton associated with the message "1011"

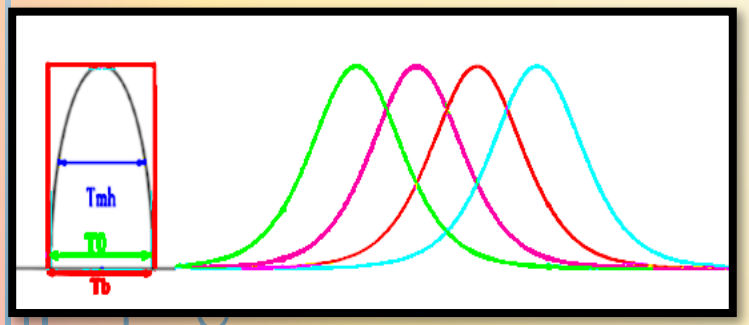
Soliton collision

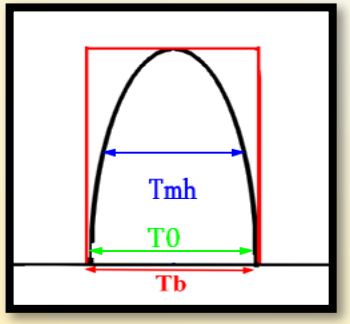


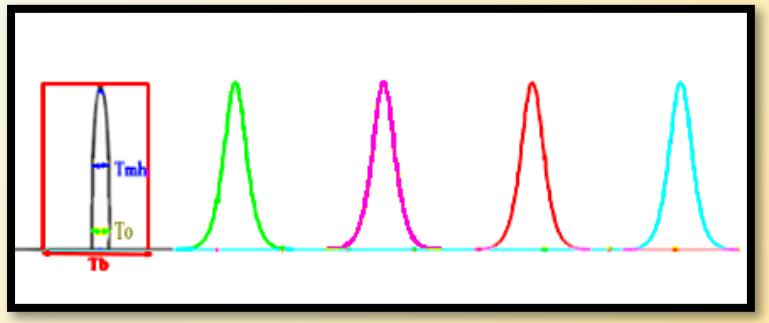
$$L_{collision} = \frac{2T_{FWHM}}{D\,\Delta\lambda} exp(q_0)$$

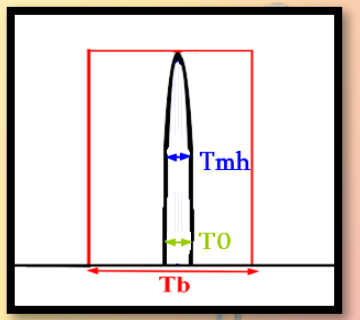
q_0: relative separation

T fwhm : full width at half maximum



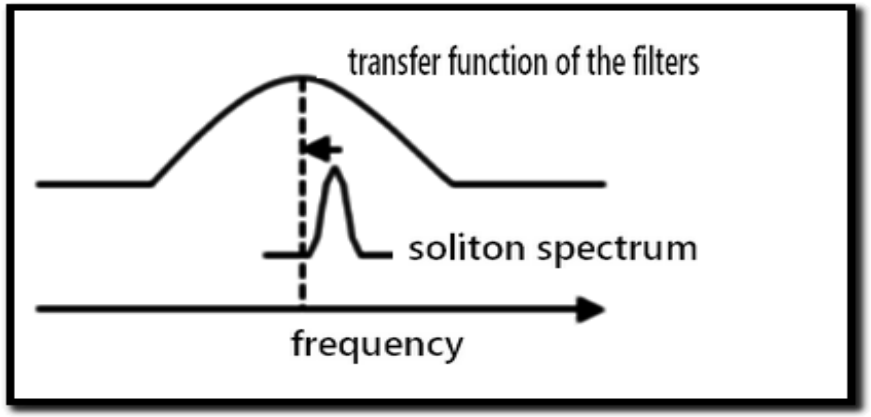






Online Filtering

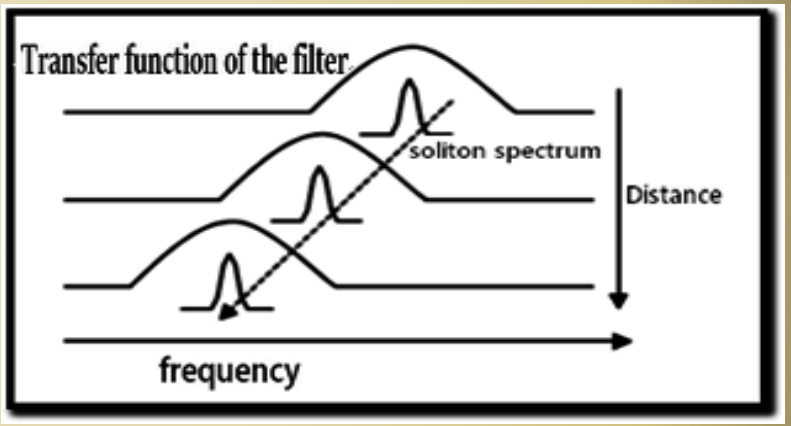
Filtering guiding



Filtering

- ✓Stabilizes the amplitude
- ✓Adjust the spectral width
- ✓Determine the amplitude factor
- ✓Reduces the time gig

Filtering shifting



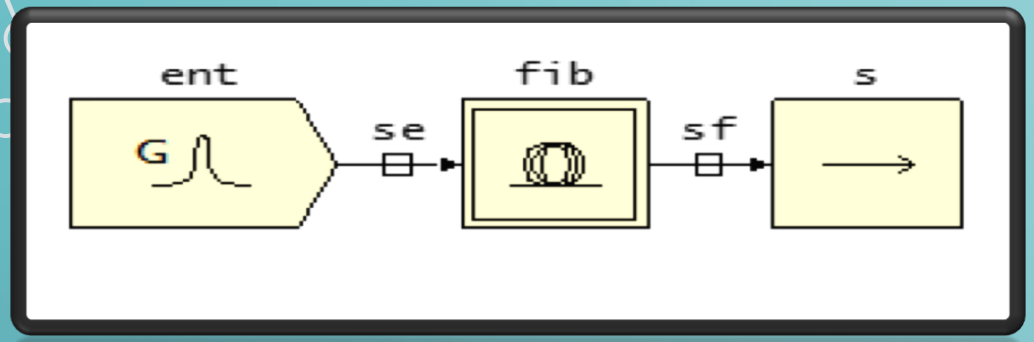
Guiding filtering priciple

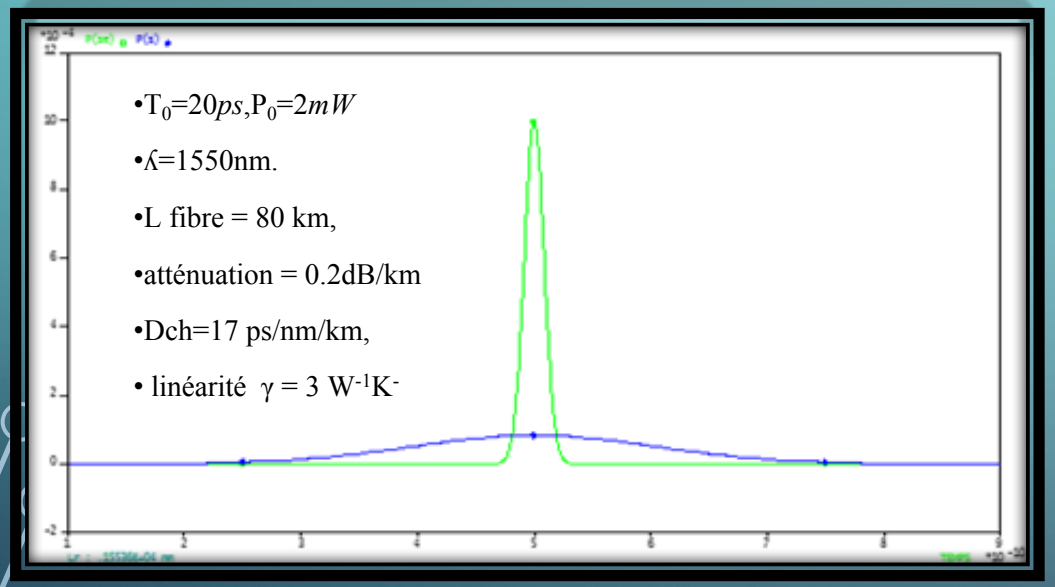
If a soliton sees its centre frequency shifted by the nonlinear interaction and with the spontaneous emission noise., the filtering will tend to remove the spectrum part that is far from the initial frequency

Filtering shifting principle

The principle is to slightly shift the centre frequency of the filters along the transmission line, e.g. Fabry Perot filter.

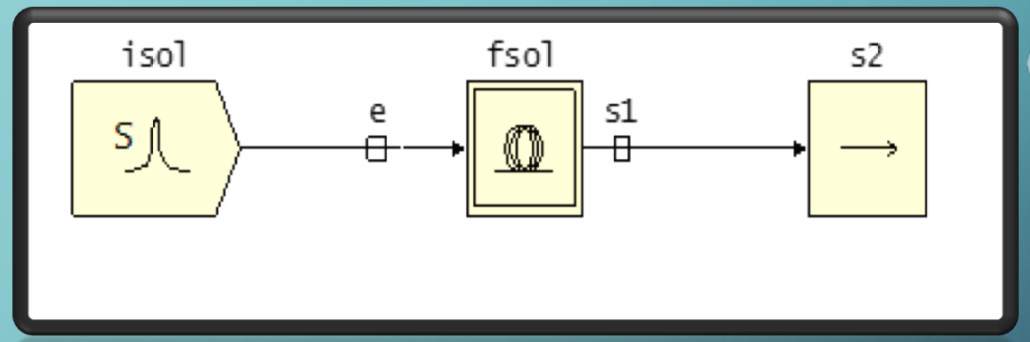
Schematic of an optical link based on a Gaussian pulse

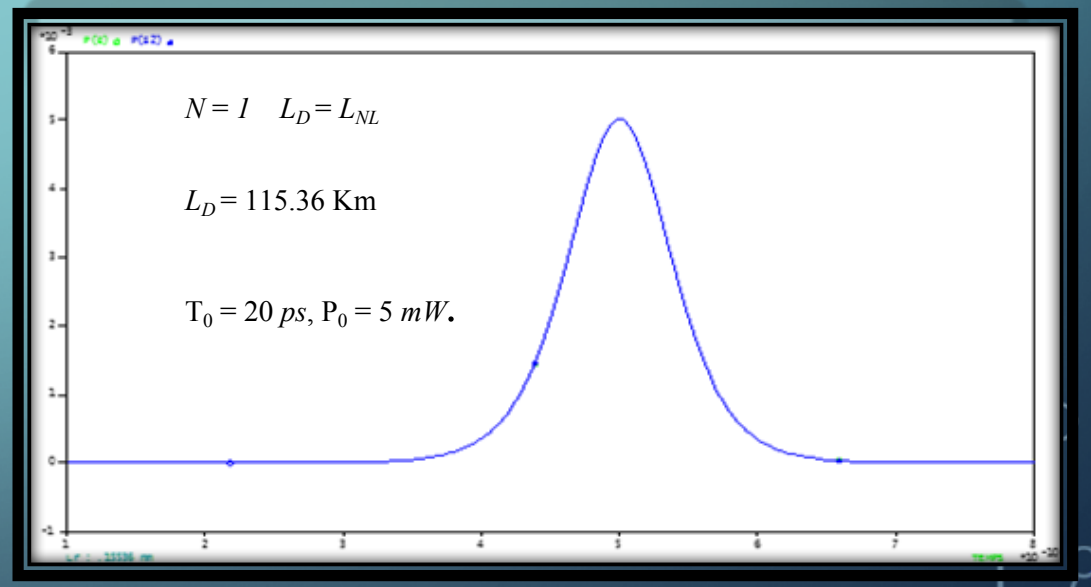




Temporal representation of a Gaussian pulse before (green) and after (blue) propagation in the optical fiber

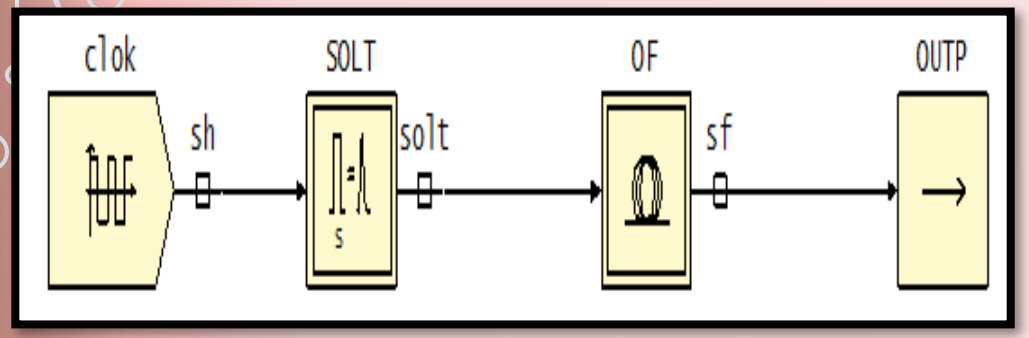
Block diagram of an optical link based on a soliton pulse

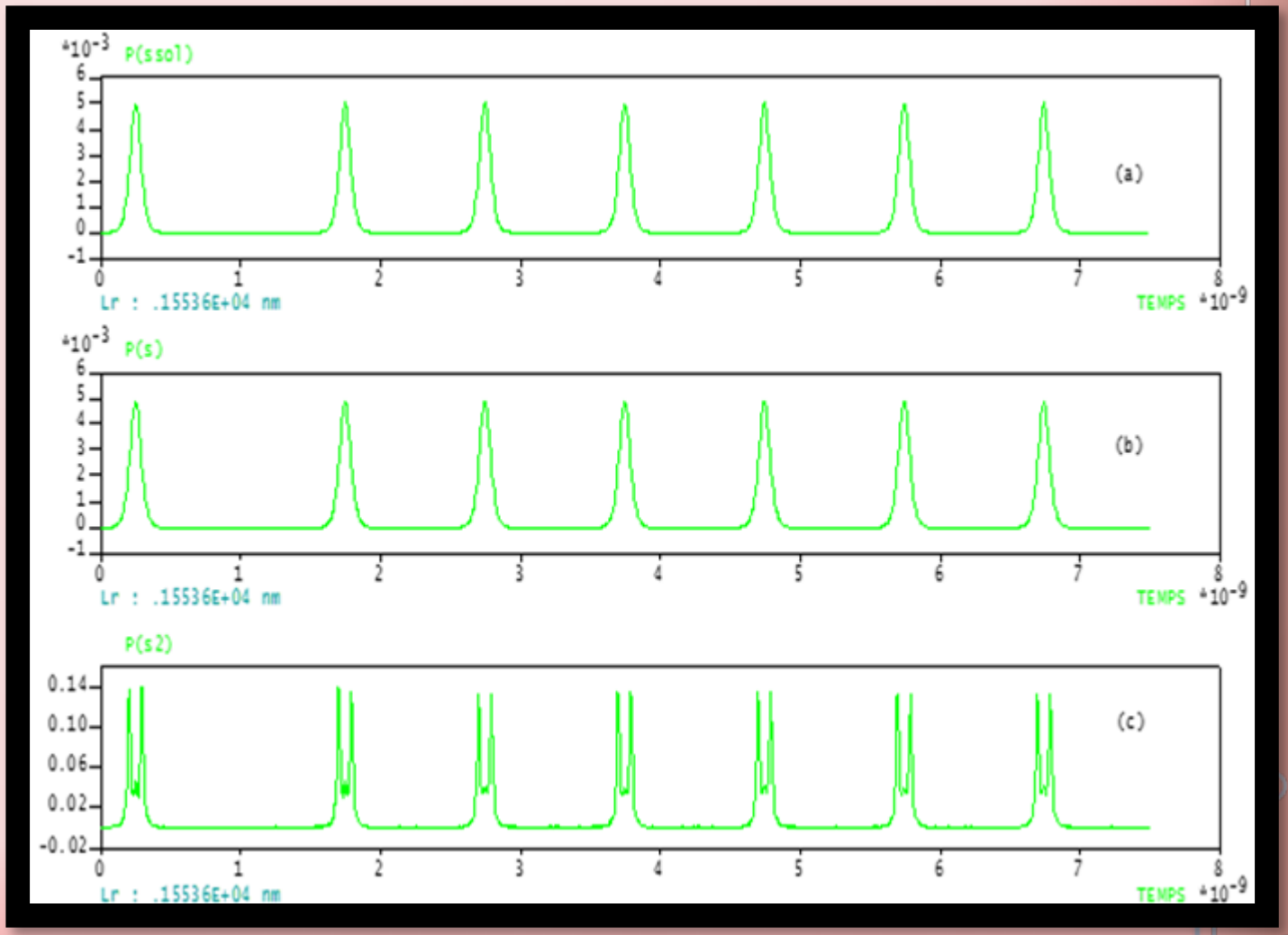




Temporal representation of a soliton pulse before and after propagation through the optical fiber

Diagram of an optical link based on a stream of soliton order pulses

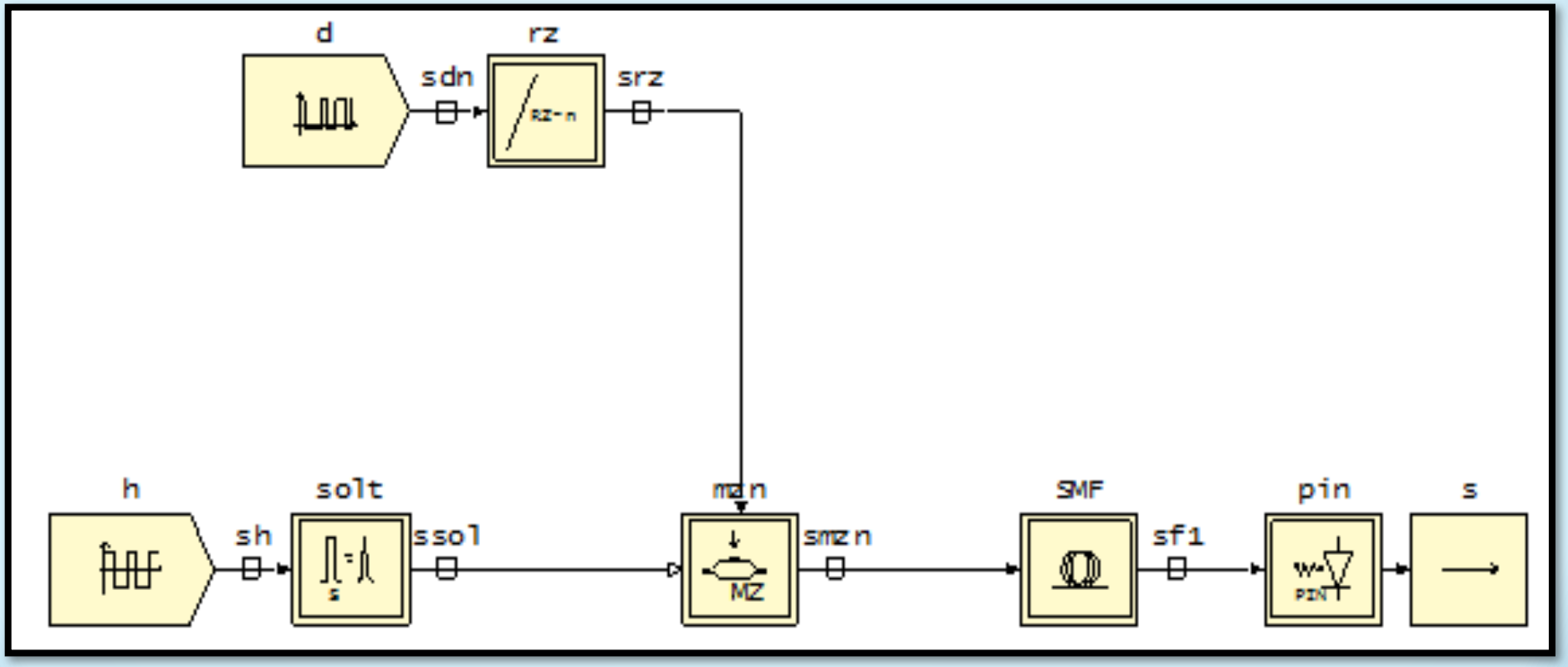




Evolution of power profile of a soliton pulse train with the propagation distance LD = 100 km,

- ***a: initial soliton train***
- ***b: train of fundamental solitons*** N = 1 for P_0 = 5 mW
- ***c: third order soliton train.*** N=3 for power P_0 = 15 mW

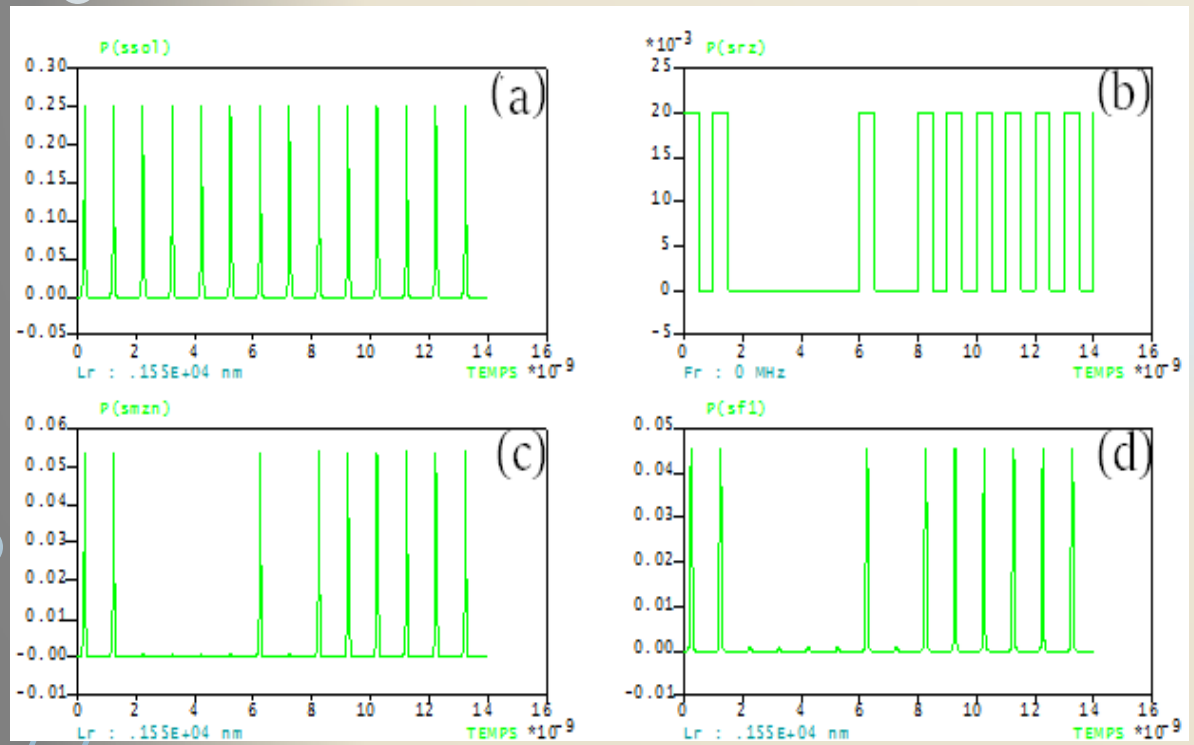
Block diagram of a single-channel connection using the soliton as an information carrier in short and long distance



Effect of the width of the soliton pulse with D = 1000 Mbit / s, bit sequence = 40% (1.0), duty ratio = 0.5, L = 115.36 km, a = 0,56ns.

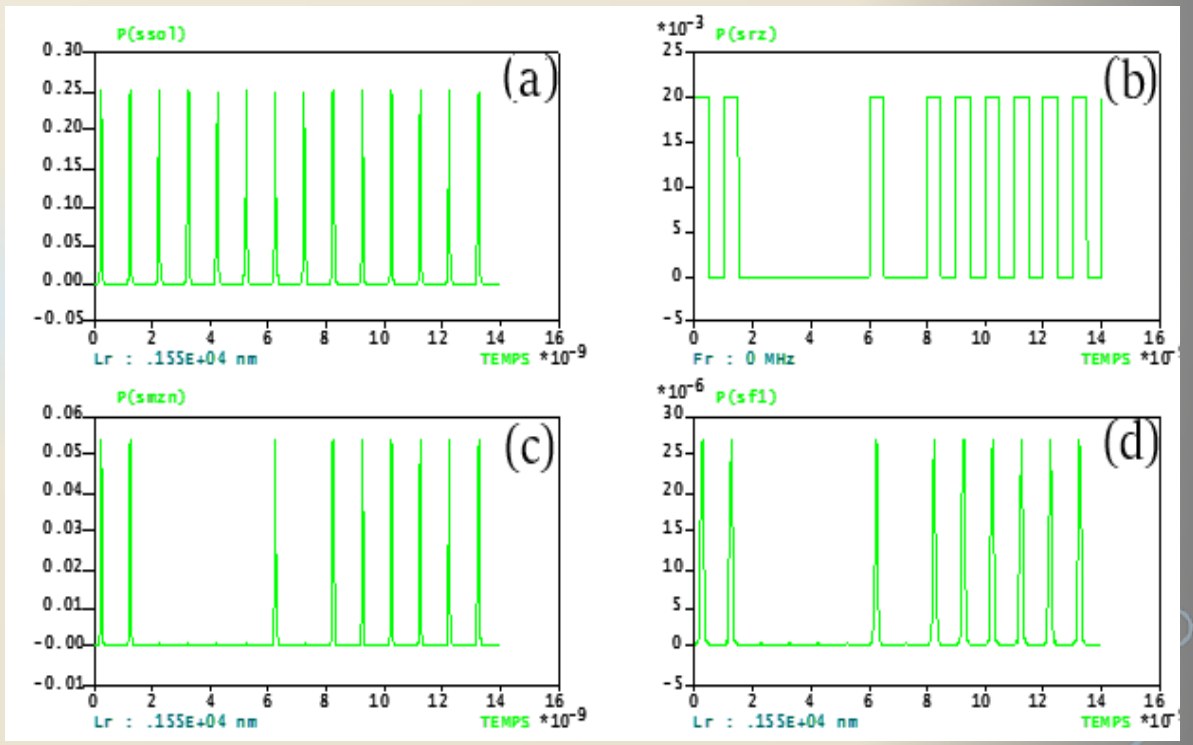
Simulation results

The outputs from different blocks of the link in the case of L=4 km.



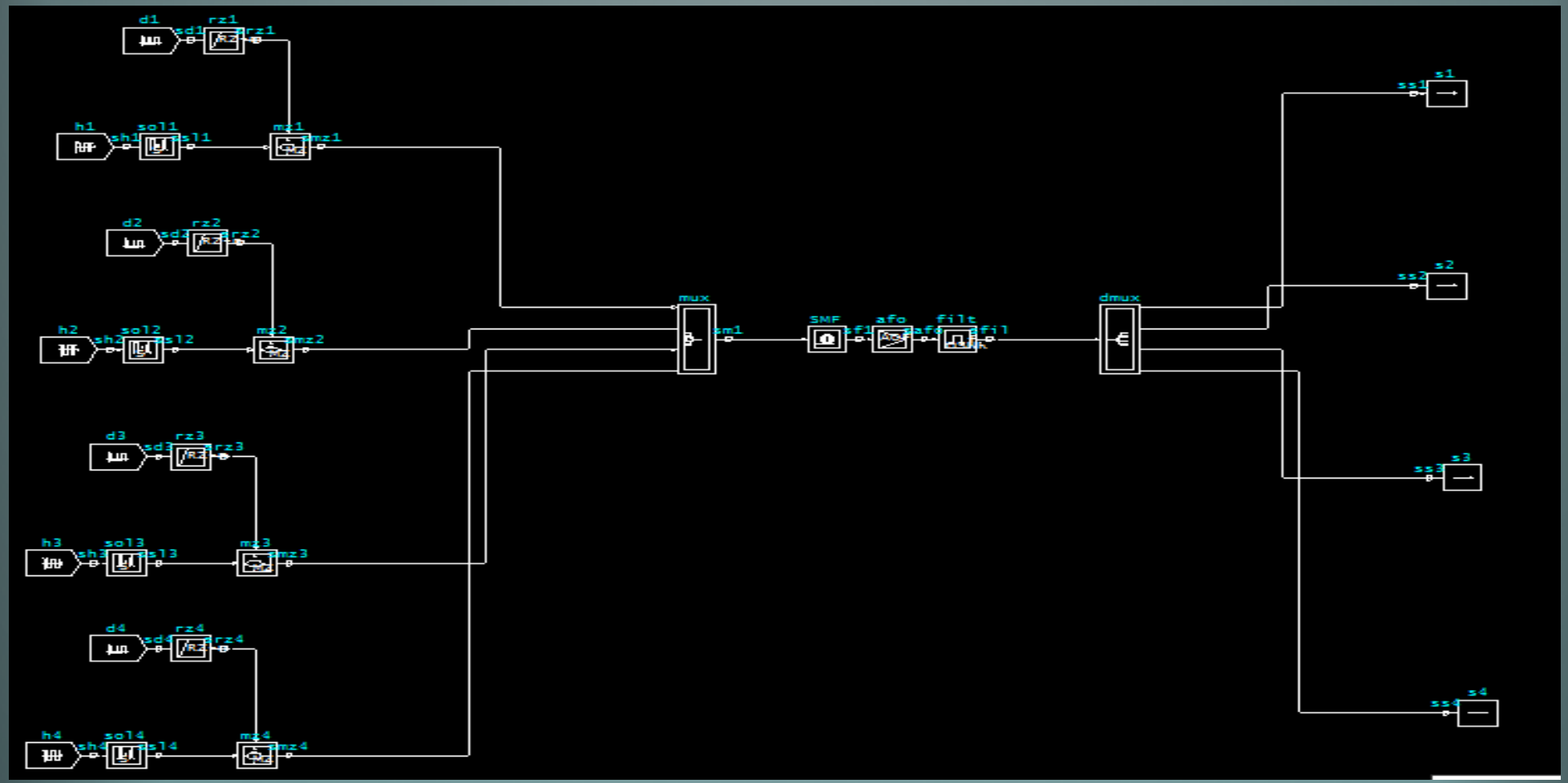
a): stream of solitons (optical carrier), b): the bit sequence, c): the outputs of the modulated signal, and (d) soliton stream modulated at the input of the fiber

The outputs from different blocks of the link in the case of L=100 km.



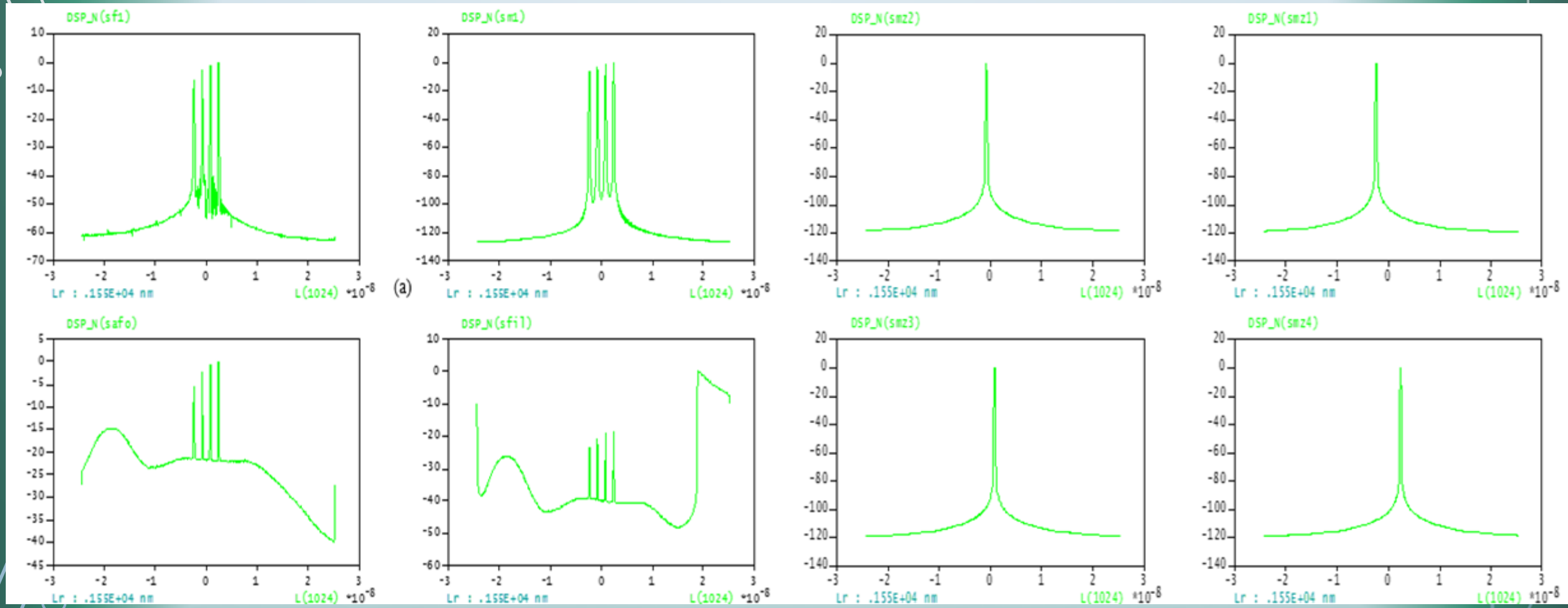
a): stream of solitons (optical carrier), b): the bit sequence c): the outputs of the modulated signal and (d) soliton stream modulated at the input of the fiber

Soliton transmission in a multichannel system



The wavelengths of 4 solitons are between 1549.4 nm and 1556.8 nm with spacing of 1.6 nm (200 GHz). EDFA: gain
G = 30 dB and the optical filter bandwidth is 20 GHz.

Simulation results of the WDM system with 4 soliton channels, a: 4 multiplexed solitons in each block of the link, b: 4 channelssolitons transmission and reception



a): 4 multiplexed soliton channels in the blocks of the link

b): -transmission and reception of the 4 multiplexed soliton channels.

CONCLUSION

In this presentation the evolution of soliton pulses has been discussed.

- **The 5G mobile networks system needed a high capacity and without limitation for that the optical soliton method can be a proper choice for the optical transmission**
- **We have determined that the soliton wave is well adapted for a wide range of very high speed transmission applications**
- **Our feasibility study has shown that the interaction between adjacent solitons can be avoided in the same channel or adjacent channels in the presence of nonlinear and linear effects (GVD, SPM, XPM, 4WM, etc.). It is seen how the compensating point (SPM + GVD≅0) is found to properly retain the soliton wave in the transmission.**
- **We have proved the principles of solition transmission without distortion in long and short distances (shape and speed).**

~ The End ~

Köszönöm

Thank you for your attention