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Conference on
Ultrafast Transmission Systems in Optical Fibres

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Optical Soliton Communication Systems

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Role of Solitons in Fibers

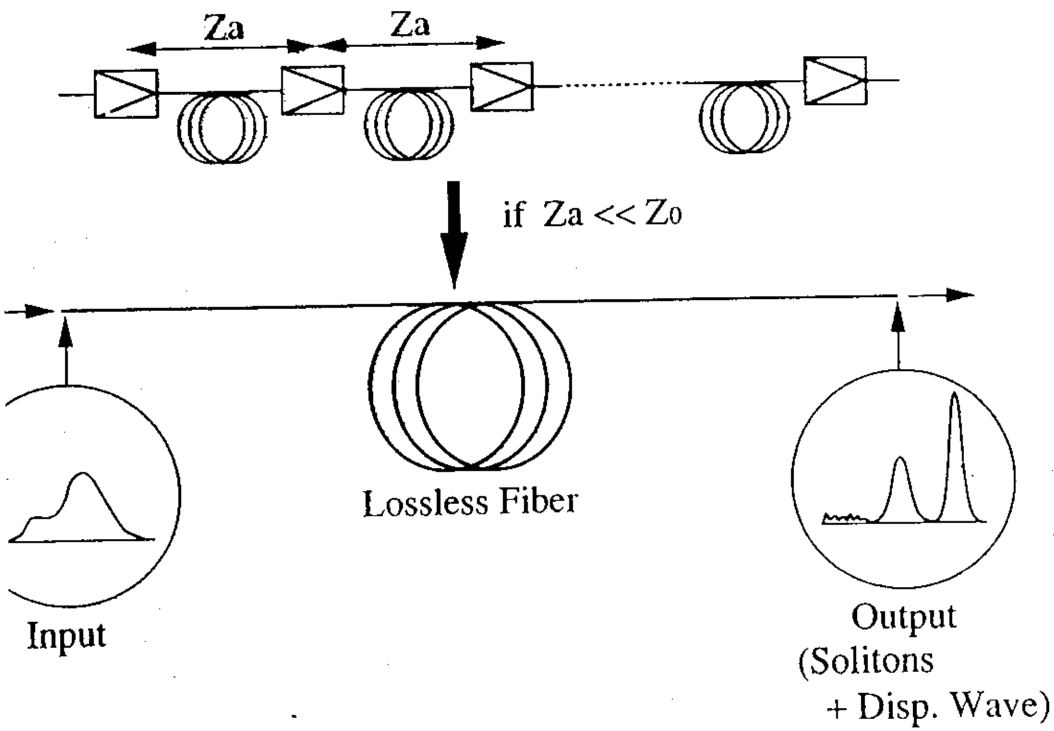
I. INTEGRABILITY

Input - Output Causal Relations

II. CONTROLLABILITY

Robustness of solitons
⇒ Soliton Parameters can be controlled without destruction

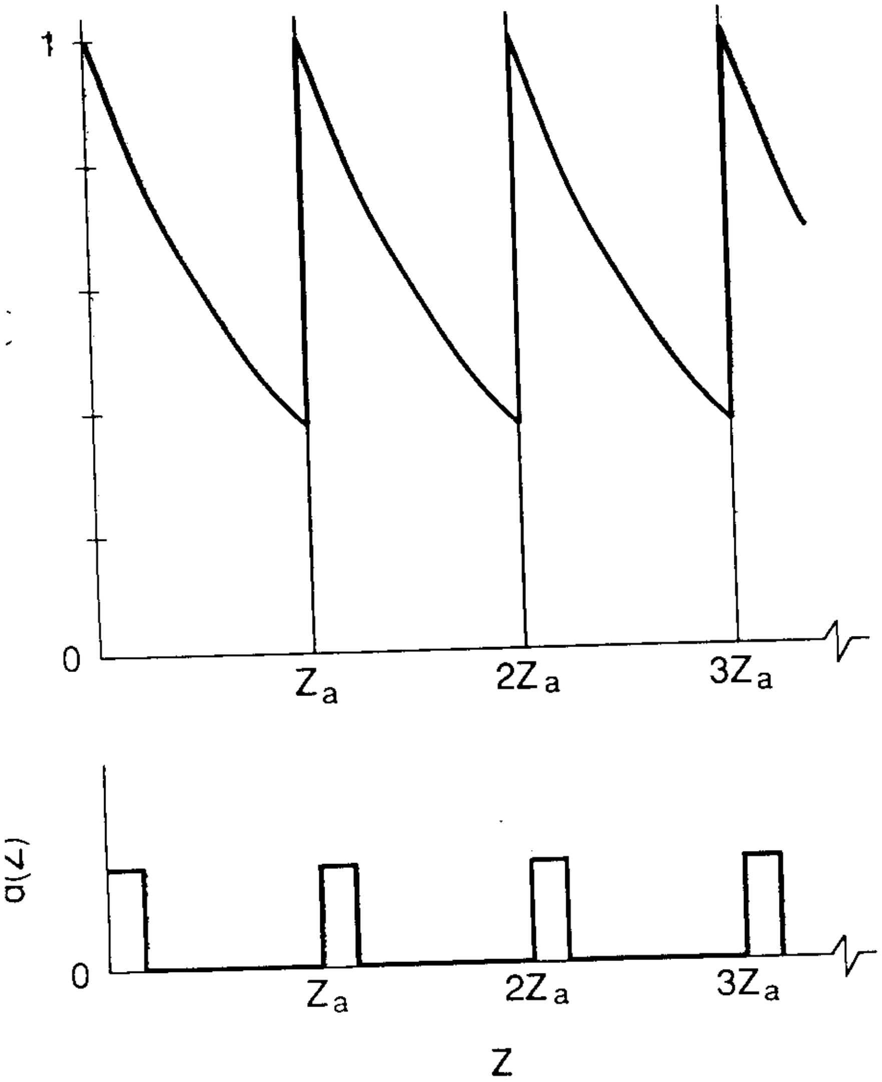
(Reduction to Finite Dimensional system)



Input - LossLess Fiber Output
Solitons + Disp. Wave

1.1 Causal Relation
⇒Information Transfor

1.2 Reduction of Degrees of Freedom
(Finite # of soliton parameters ; robustness of information carried by solitons)



Consider periodically varying dispersion and amplitude.

$$i \frac{\partial q}{\partial Z} + \frac{1}{2} d(Z) \frac{\partial^2 q}{\partial T^2} + |q|^2 q = -i\Gamma q + iG(Z) q$$

Put $\quad q(T,Z) \equiv a(Z)\, u(T,Z)$

with $\quad \frac{da}{dZ} = -[\Gamma - G(Z)]\, a$

then u satisfies:

$$\frac{\partial u}{\partial Z} = i \frac{d(Z)}{2} \frac{\partial^2 u}{\partial T^2} + i a^2(Z) |u|^2 u \qquad \ldots (1)$$

AT&T

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2nd step: Apply Lie transformation

$$u \equiv e^{\vec{\Phi}\cdot\nabla} v$$
$$= v + \Phi[v, v^*; z]$$
$$+ \frac{1}{2}(\vec{\Phi}\cdot\nabla)[v, v^*; z]$$
$$+ \cdots$$

where $$\vec{\Phi}\cdot\nabla \equiv \sum_{n=0}^{\infty}\left[\Phi_{nT}\frac{\partial}{\partial v_{nT}} + \Phi^*_{nT}\frac{\partial}{\partial v^*_{nT}}\right]$$

$$\Phi_{nT} = \frac{\partial^n \Phi}{\partial T^n}, \quad v_{nT} = \frac{\partial^n v}{\partial T^n}$$

Consequently we obtain

$$\frac{\partial v}{\partial Z} = i\frac{1}{2}\frac{\partial^2 v}{\partial T^2} + i|v|^2 v + \beta_{20}[X_{0A}, [X_{0A}, X_0$$
$$+ O(Z_a^3)$$

$$u = v + \Phi_1 + \frac{1}{2}(\vec{\Phi}_1\cdot\nabla)\Phi_1 + \Phi_2 + O(Z_a^3)$$

∴ ① v satisfies NLSE to $O(Z_a^2)$ with constant coefficient

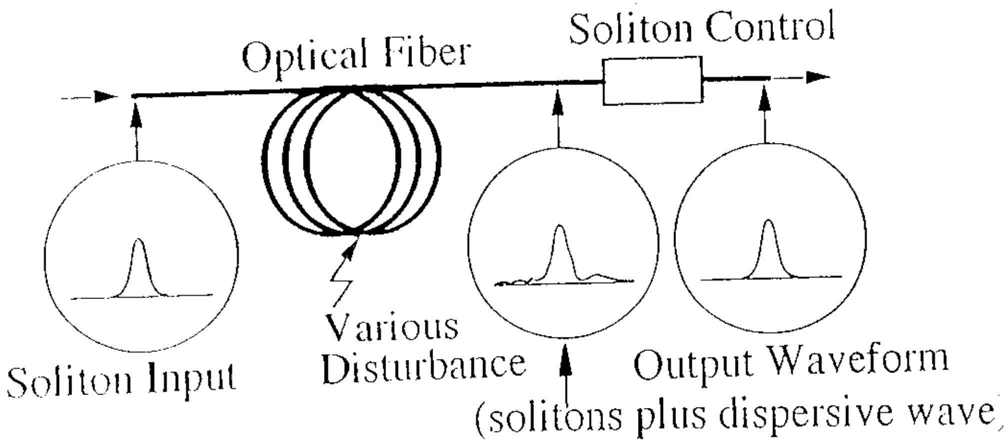
② u can be obtained from v and Φ

II. CONTROLLABILITY

Particle - like Proparty
⇒ Soliton parameters i.e., amplitude, positon(velosity), frequency, phase, can be controlled

2.1 Separation of Solitons from linear noise

2.2 Controlled breaking of the causal relations



If Lq $\neq$ 0, Dynamical equation for η and κ may be constructed.

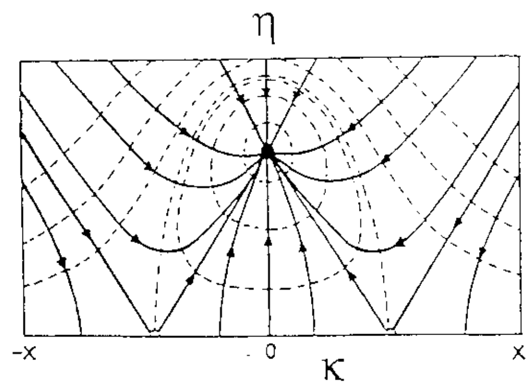
$$\frac{\partial \eta}{\partial Z} = f(\eta, \kappa)$$

$$\frac{\partial \kappa}{\partial Z} = g(\eta, \kappa)$$

If a singular point, (η_0, κ_0), for which $f(\eta_0, \kappa_0) = g(\eta_0, \kappa_0) = 0$ is stable, the point is a sink and the system self-organizes to (η_0, κ_0).

↓

Self Organization (Prigogine)



OPTICAL SOLITON
TRANSMISSION SYSTEMS

I. **NONADIABATIC REGIME** ($At_o \neq$const.)

$Z_0 (=|t_0/k''|) \gtrsim \gamma^{-1}$

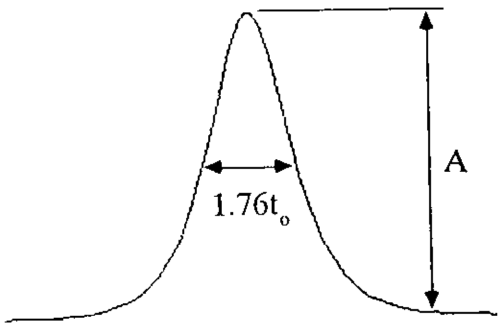
Example L $\sim$ 10,000km,
TR$\sim$10$\sim$20Gbit/s

II. **ADIABATIC REGIME** ($At_o =$const.)

$Z_0 \lesssim \gamma^{-1}$

Example L $\lesssim$ 1,000km,
TR $\gtrsim$ 50Gbit/s

Soliton Wave Form : q=Asech t/t_o



I. **NONADIABATIC REGIME**
(Guiding Center Soliton
or Average Soliton)

L.F.Mollenauer, et. al. (AT&T Bell Labo.), 10Gbit/s $\times$ 2 (WDM), L $\sim$14,000km, BER-$\lesssim 10^{-9}$ (Passive Control)

Nakazawa et. al. (NTT) 10Gbit/s, Unlimited error-free distance (Active Control)

Compare with NRZ 5Gbit/s, 9,000km, BER>10^{-9} ;
Limitation by Nonlinearity Even with D=0 fiber

II. ADIABATIC REGIME

Solitons

50Gbit/s, 1,000km (Simulation Results)

$\left.\begin{array}{l} \times 2(PDM) \\ \times 2(PSK) \end{array}\right\} \rightarrow$ 200Gbit/s, 1,000km

$L \lesssim (\text{Bitrate})^{-2}$

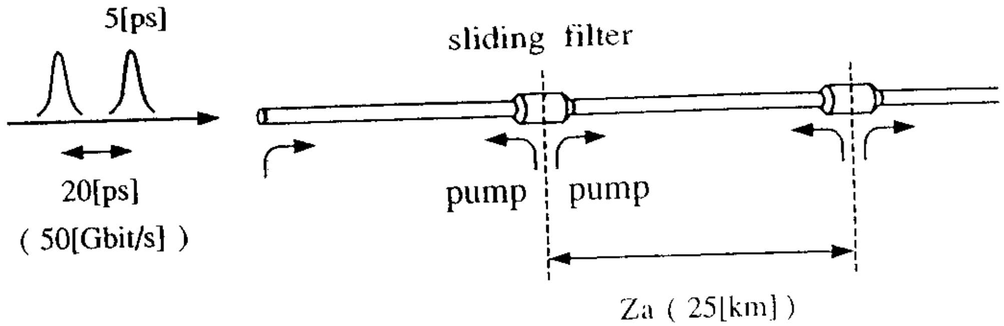
Linear Systems Limitation, (fiber with D=0)

Third Order Dispersion : $2t_o L^{-1/3} < 1.4 ps(km)^{-1/3}$

Example TR $\lesssim$ 130Gbit/s at 20km

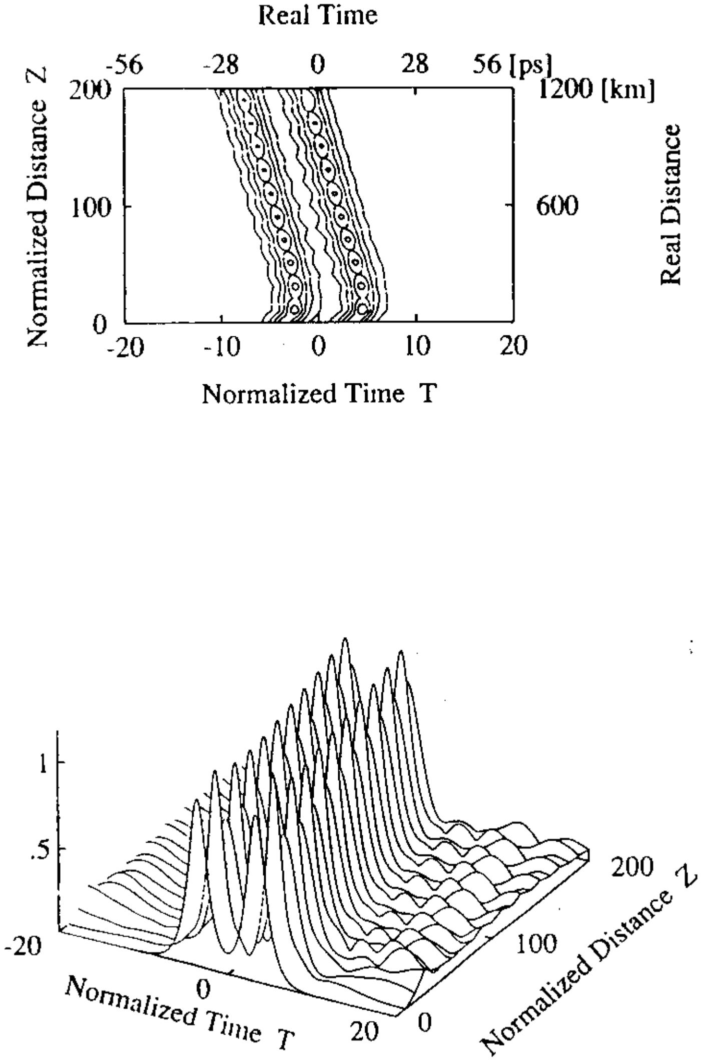
TR $\lesssim$ 65Gbit/s at 160km

$L \lesssim (\text{Bitrate})^{-3}$

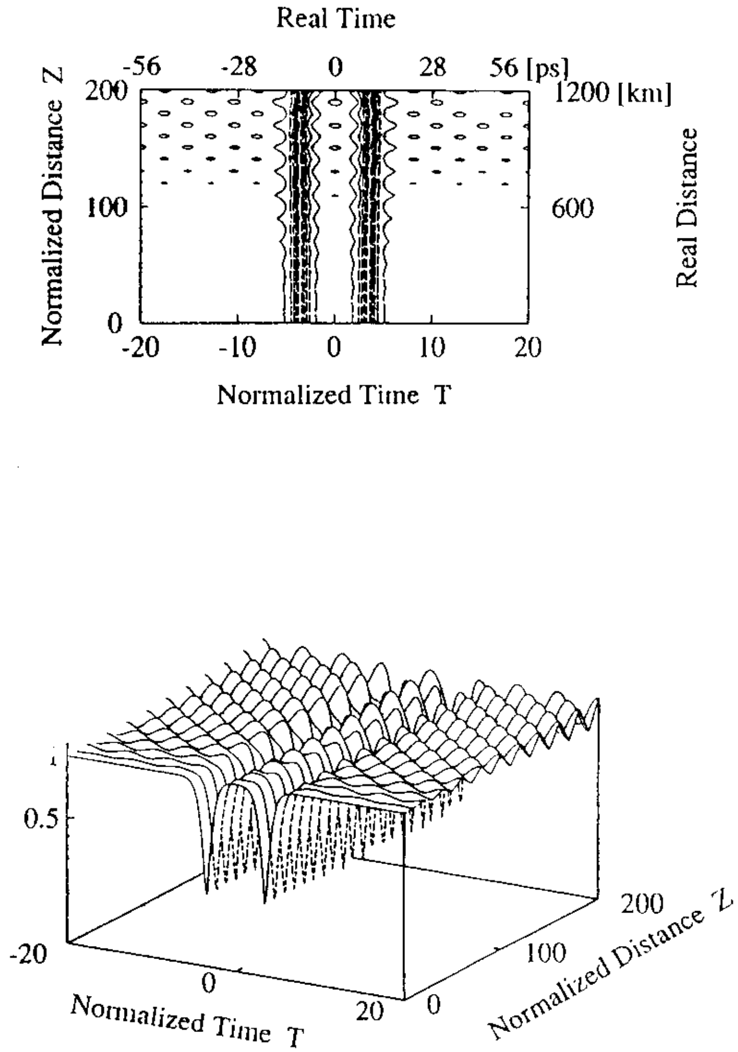


$$\left\{\begin{array}{lcl} \lambda & = & 1.55 \ [\mu m] \\ Soliton\ Power & = & 23 \ [mW] \\ Pump\ Power & = & 22 \ [mW] \\ D & = & 1.0 \ [ps/(nm \cdot km)] \\ S & = & 20 \ [\mu m^2] \\ \gamma & = & 0.3 \ [dB/km] \end{array}\right.$$

Picosecond Optical Soliton Transmission System
using the Raman Amplification



Propagation of bright solitons under the controlling by the sliding frequency filter



Propagation of dark solitons without any control