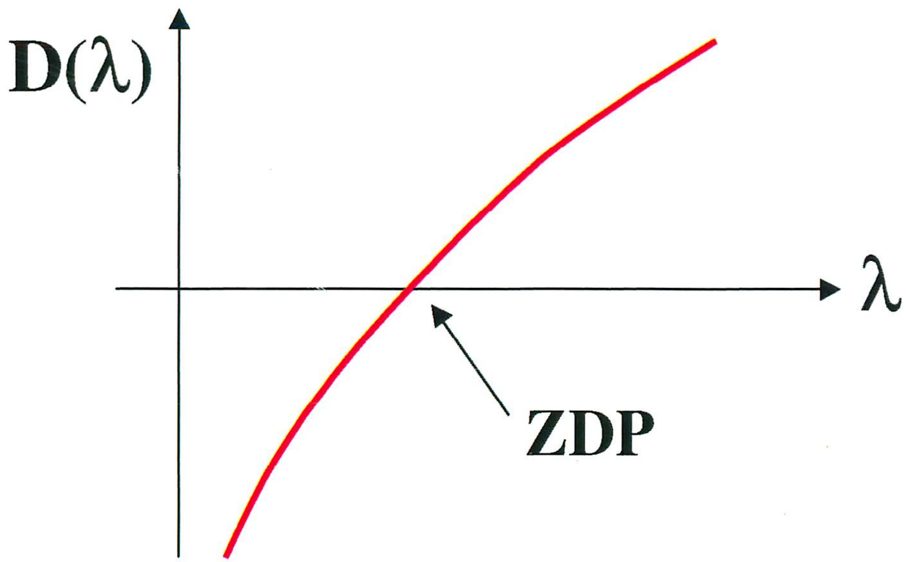
Long Distance Communication System

NRZ format :

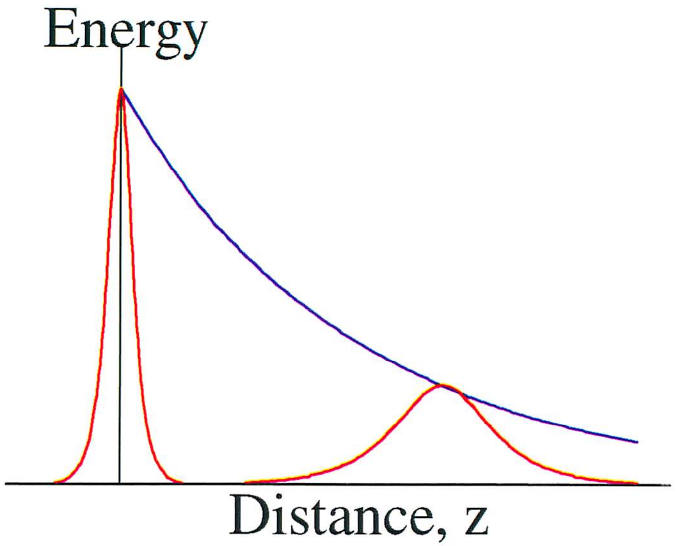
propagate near the zero dispersion point (ZDP)



variation of ZDP by as much as 1 nm

(Jopson *et al. Electron. Letts.*, **31**, p.2115, 1995.)

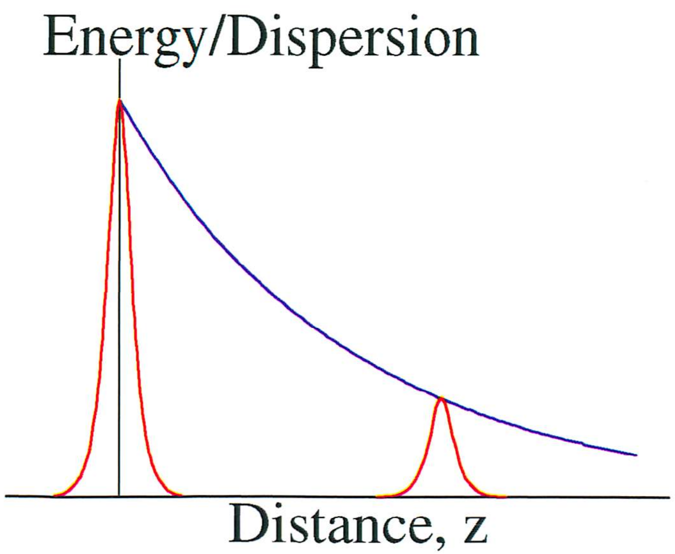
Soliton format :



Standard fiber

$$D(\lambda) = \text{constant}$$

- energy decreases exponentially
- pulse width increases exponentially



Dispersion decreasing fiber

$$D(\lambda) \sim e^{-\Gamma z}$$

- energy decreases exponentially
- pulse width remains constant

- need to determine the variation of chromatic dispersion along an optical fiber

- methods proposed recently :
  - M. Ohashi *et. al.*, *Electron. Lett.*, **29**, p.426, 1993.
    - estimated from mode-field diameter
  - S. Nishi *et. al.*, *Electron. Lett.*, **31**, p.225, 1995.
    - based on modulated-instability-induced-gain
  - R. Jopson *et. al.*, *Electron. Lett.*, **31**, p.2115, 1995.
    - phase-matching condition in four wave mixing
  - L. Mollenauer, *Opt. Lett.*, **21**, p.1724, 1996.
    - four wave mixing

Current Method

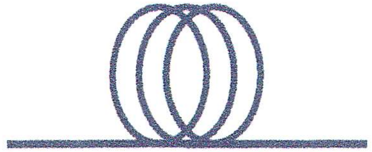
- output waveform carries information about the fiber
- determine fiber dispersion from a theoretical model of signal propagation in fiber

Advantage

- can be used to determine other fiber parameters if a suitable model is used

Theory and Algorithm

$q(z=0)$



$f_T(z)$

$q_T(z=L)$ (experiment)

Non-Linear Schrödinger Equation

$$i\frac{\partial q}{\partial z}+\frac{1}{2}f(z)\frac{\partial^2 q}{\partial t^2}+|q|^2 q=0$$

$q(z=L)$ (simulation)

❶ Guess $f(z)$

❷ Calculate $q(z=L)$

❸ Compare $q(z=L)$ and $q_T(z=L)$; adjust $f(z)$ accordingly

❹ Repeat step ❶ through ❸ until $f(z) \sim f_T(z)$

How to choose Δf ?

- Define an error function : $E[q(L,t), q_T(L,t)]$

e.g. 1. $E(q, q_T) = \int \left| q(L) - q_T(L) \right|^2 dt$

2. $E(q, q_T) = \int \left| |q(L)|^2 - |q_T(L)|^2 \right|^2 dt$

- Expand $$f(z) = \sum_{\mu=1}^{N} f_\mu \psi_\mu(z)$$

ψ_μ : orthogonal function

$$\Delta E = \sum_{\mu=1}^{N} \frac{dE}{df_\mu} \Delta f_\mu$$

Choose $\Delta f_\mu = -\alpha \dfrac{dE}{df_\mu}$

$$\Delta E = -\alpha \sum_{\mu=1}^{N} \left(\frac{dE}{df_\mu} \right)^2 < 0$$

Gradient Descent !

$$\frac{dE}{df_\mu} = \int \left(\frac{\delta E}{\delta q} \frac{\partial q}{\partial f_\mu} + \frac{\delta E}{\delta q^*} \frac{\partial q^*}{\partial f_\mu} \right) dt$$

and $\dfrac{\partial q}{\partial f_\mu}$, $\dfrac{\partial q^*}{\partial f_\mu}$ satisfy the linearized non-linear Schrödinger equation :

$$i\frac{\partial \varphi}{\partial z}+\frac{1}{2}f(z)\frac{\partial^2 \varphi}{\partial t^2}+2|q|^2\varphi+q^2\varphi^*=-\frac{1}{2}\frac{\partial f}{\partial f_\mu}\frac{\partial^2 q}{\partial t^2}$$

Δf can be determined from given $q(z=L)$ and $q_T(z=L)$

❶ The convergence of gradient descent algorithm is too slow, we use conjugated gradient instead.

❷ In feasibility test, $f_T(z)$ is also generated from the non-linear Schrödinger equation

Results

Without Loss

Target profile:

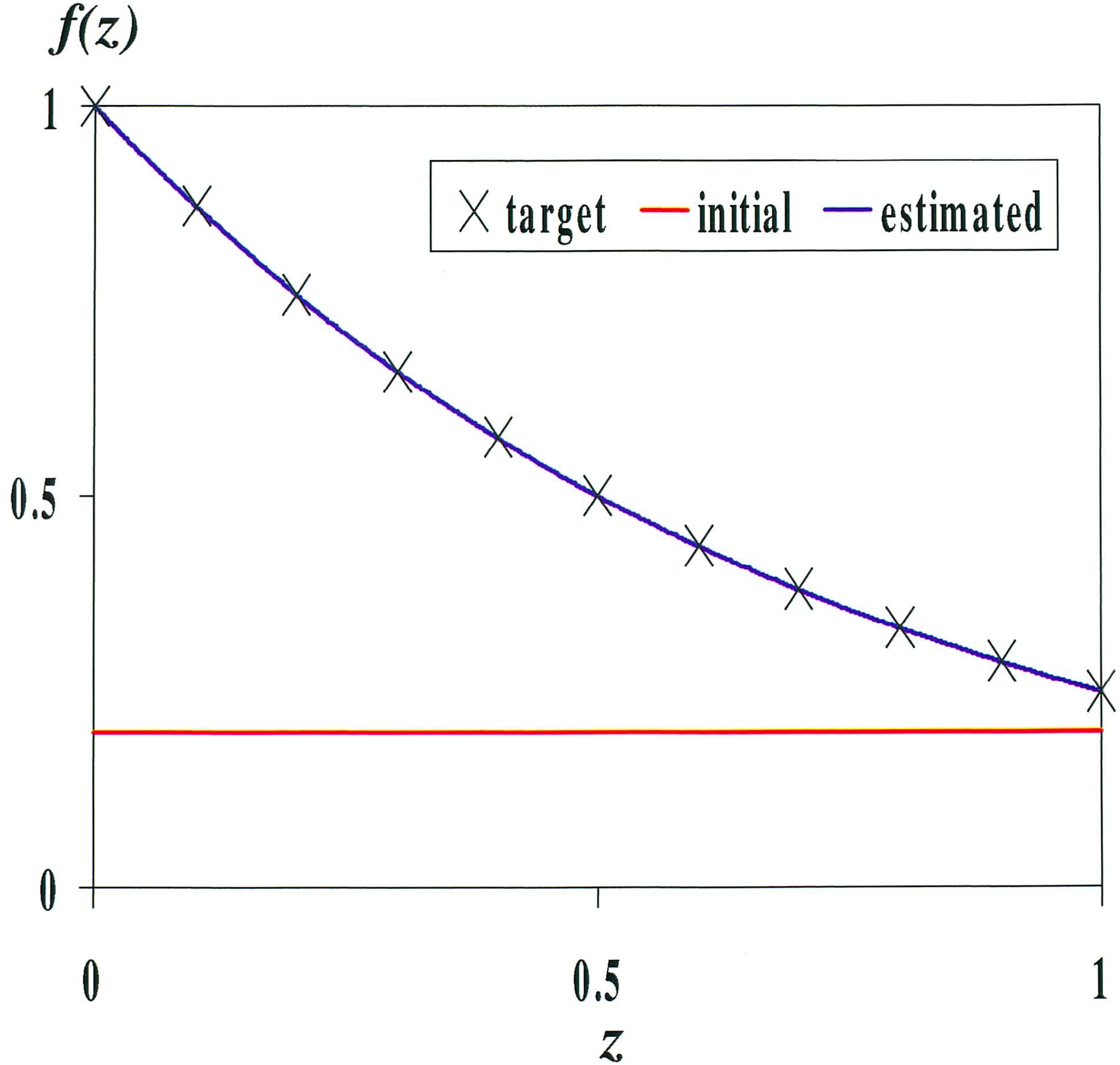
$f_T(z)=\exp[(\ln 0.25)\, z]$

initial guess:

$$f\,(z) = 0.2$$

input pulse:

$$\frac{0.5}{\sqrt{\sqrt{\pi}}}e^{-\frac{t^2}{2}}$$



With Loss (Γ=0.69)

Target profile:

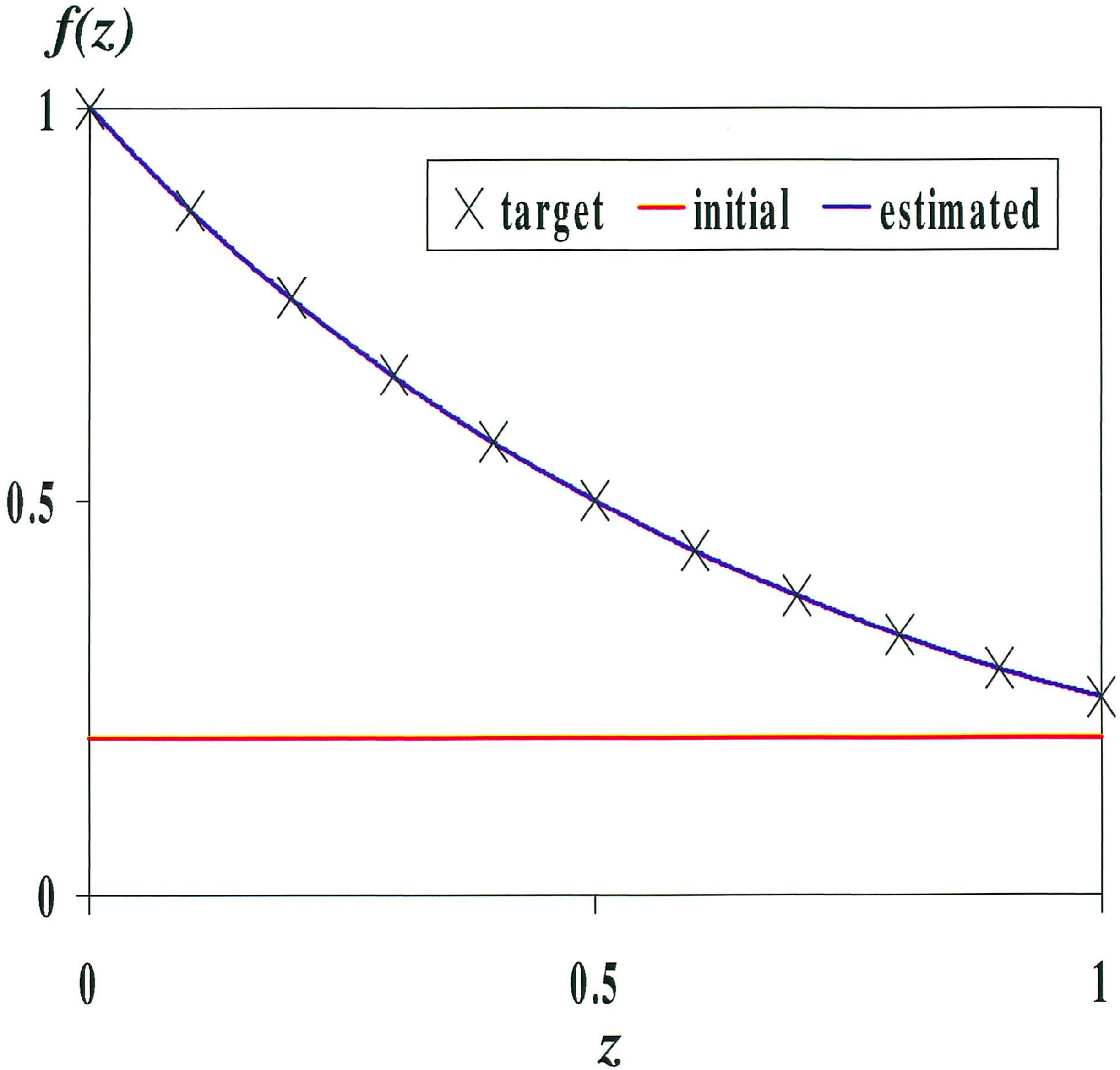
$f_T(z)=\exp[(\ln 0.25)\, z]$

initial guess:

$$f\,(z) = 0.2$$

input pulse:

$$\frac{1.5}{\sqrt{\sqrt{\pi}}}\, e^{-\frac{t^2}{2}}$$



With Loss and 3rd order dispersion (Γ=0.69 , β=1)

Target profile:

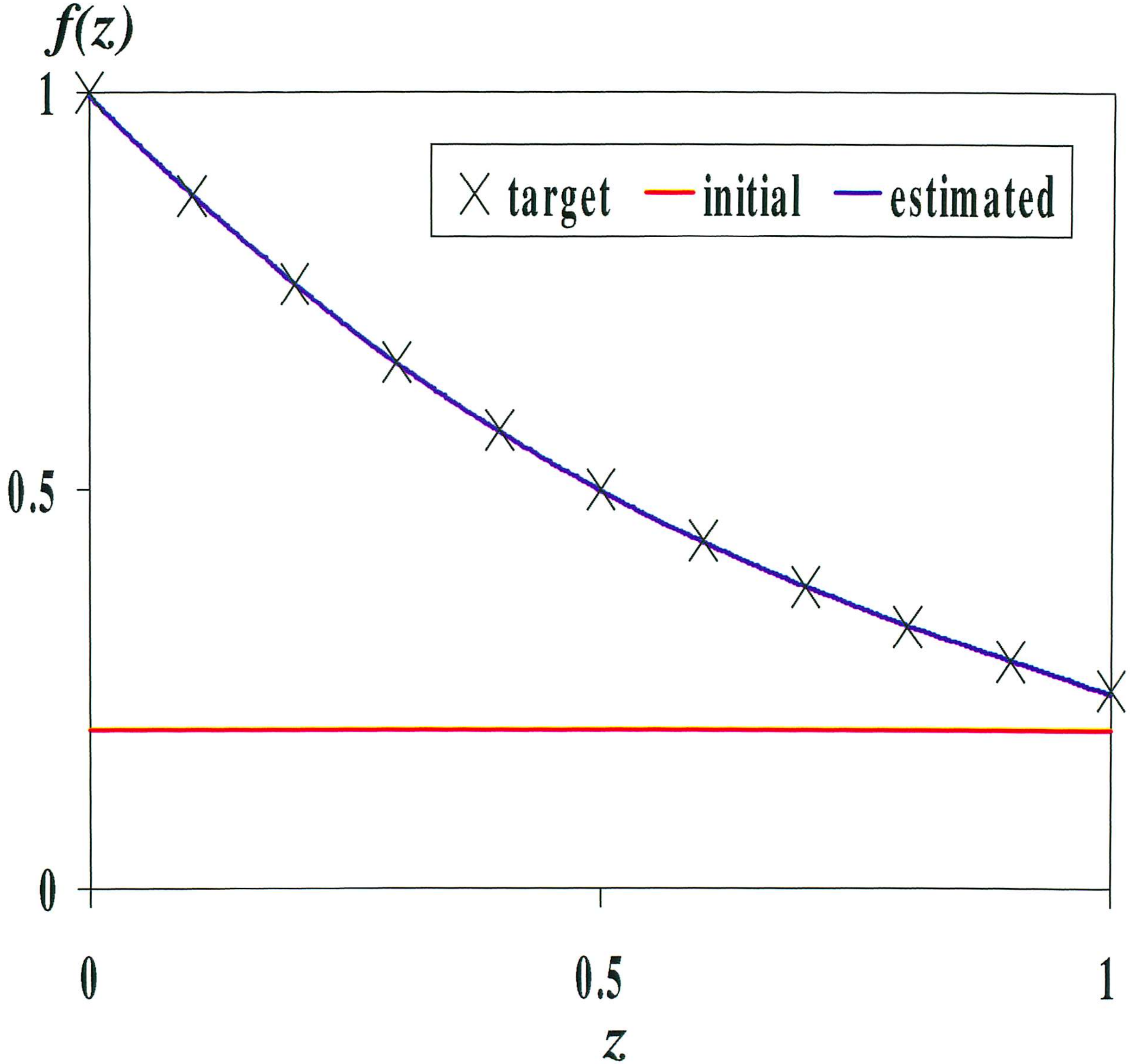
$f_T(z)=\exp[(\ln 0.25)\ z]$

initial guess:

$$f\,(z) = 0.2$$

input pulse:

$$\frac{1.5}{\sqrt{\sqrt{\pi}}}e^{-\frac{t^2}{2}}$$



Summary

Reconstruction of the dispersion profile from an input output pulse profile

Further Study

- Effects of timing jitters and amplitude jitters
- Experimental verification