A New UWB Dual Pulse Transmission and Detection Technique

Xiaodai Dong

University of Victoria, Victoria, BC, Canada

Alfred Lee

Lei Xiao

University of Notre Dame, Notre Dame, IN, USA

`xdong@ece.uvic.ca`

Overview

- Introduction
- The UWB Channel Model
- The Transmitted Reference (TR) System
- The Novel Dual Pulse (DP) System
- The Improved DP (iDP) System
- Conclusion

Introduction

- Ultra-wideband (UWB) has been proposed as a physical layer candidate for low cost, short range wireless personal area networks.
- Estimating the UWB multipath channel and collecting multipath energy pose challenges to UWB receiver design.
- Transmitted reference (TR) systems employ autocorrelation receiver and waive the need to estimate channel path gains and path delays [Hoctor and Tomlinson, UWBST'2002].

Introduction (Cont'd)

- The TR system is simple and robust. Its variants have been proposed in various literature [Chao and Scholtz, Franz and Mitra, Zhang and Goeckel, Nekoogar and Dowla].
- Differential detection [Ho et.al.] and pilot waveform assisted modulation [Yang and Giannakis]
- We propose a novel dual pulse (DP) system that doubles the data rate of the TR system.

Features of the DP System

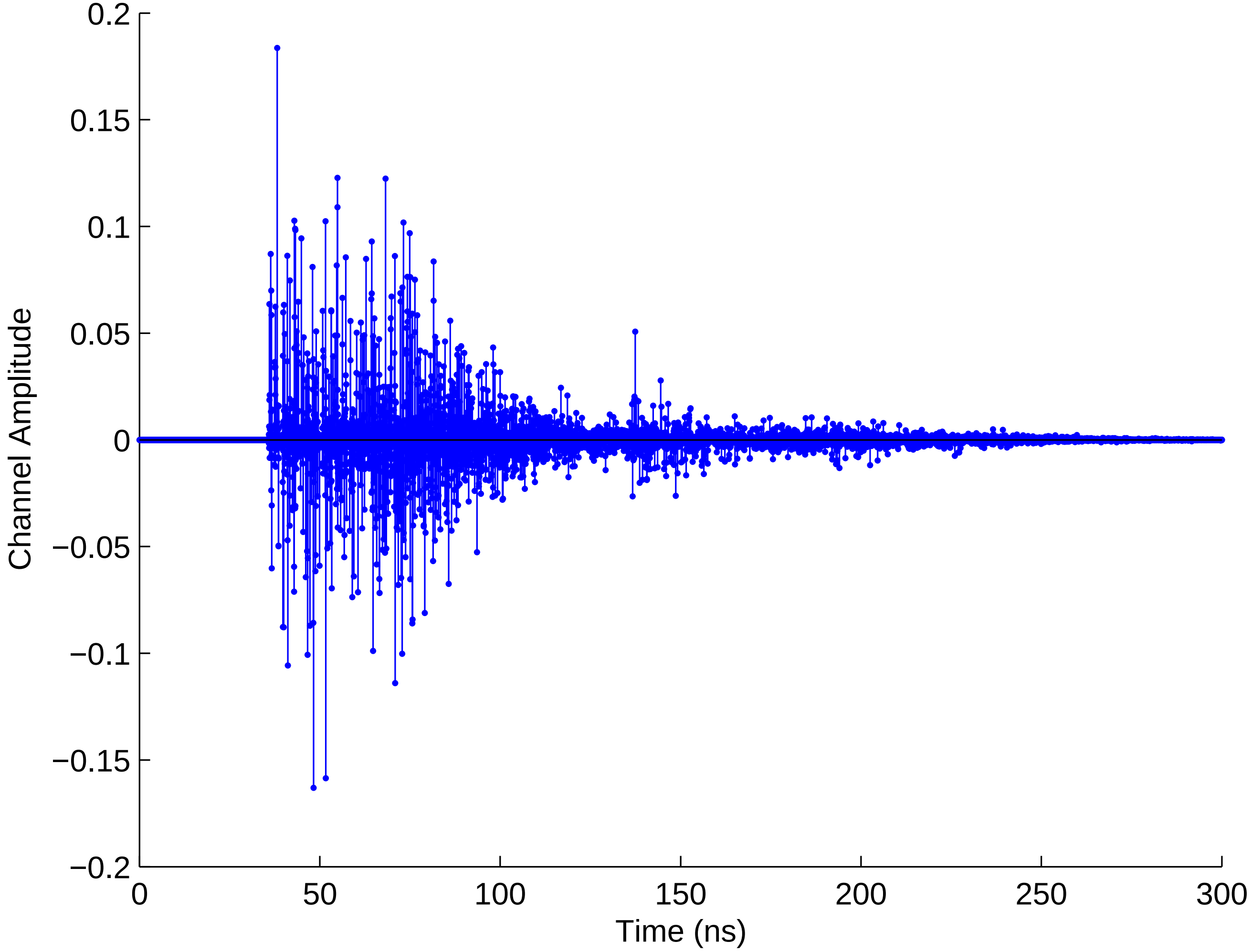
- The data rate of the DP system doubles the TR system, while achieving similar performance.
- The delay unit in the receiver is only half the dual-pulse width, $T_w/2$ and much shorter than the frame delay T_f in the TR system. Implementing accurate short delays is easier than long delays.
- The DP system is less sensitive to time variation of the channel. Within a fixed channel coherence time, there are more received reference sub-pulses to be averaged over to reduce the noise effect.
- The DP system retains the merits of the TR system, such as robust performance, simple implementation and easy timing acquisition.
- Inter-pulse interference in the DP system is not severe.
- The improved dual pulse (iDP) system eliminates the inter-pulse interference in the DP system.

The UWB Channel Model

- The UWB channel characterization is a subject area requiring extensive experiments and research
- The IEEE 802.15.3a task group gathered different UWB characterisation attempts and proposed the IEEE UWB channel model
- The IEEE UWB channel model can be represented by

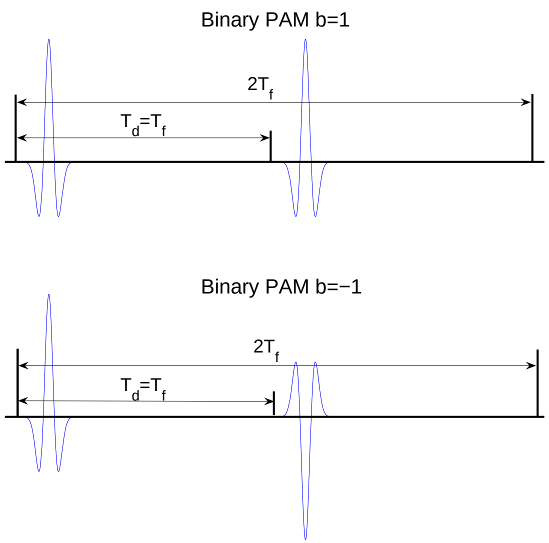
$$h(t) = X \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l} \delta(t - T_l - \tau_{k,l}) \tag{1}$$

Sample of the IEEE channel model



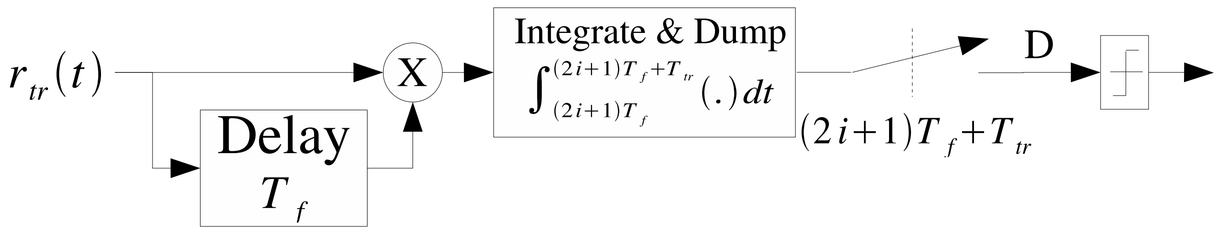
The Transmitted Reference (TR) System

- A coherent rake receiver must estimate the channel tap gains and tap delays.
- The shape of a UWB pulse may be altered after passing through the channel.
- The TR system uses a doublet



TR System (con't)

The autocorrelation receiver uses the reference pulse to demodulate the data pulse.



Output of the autocorrelator is represented as

$$D = \sum_{j=0}^{N_s-1} \int_{(2j+1)T_f}^{(2j+1)T_f+T_{tr}} r_i(t) r_i(t-T_f)\,dt \qquad (2)$$

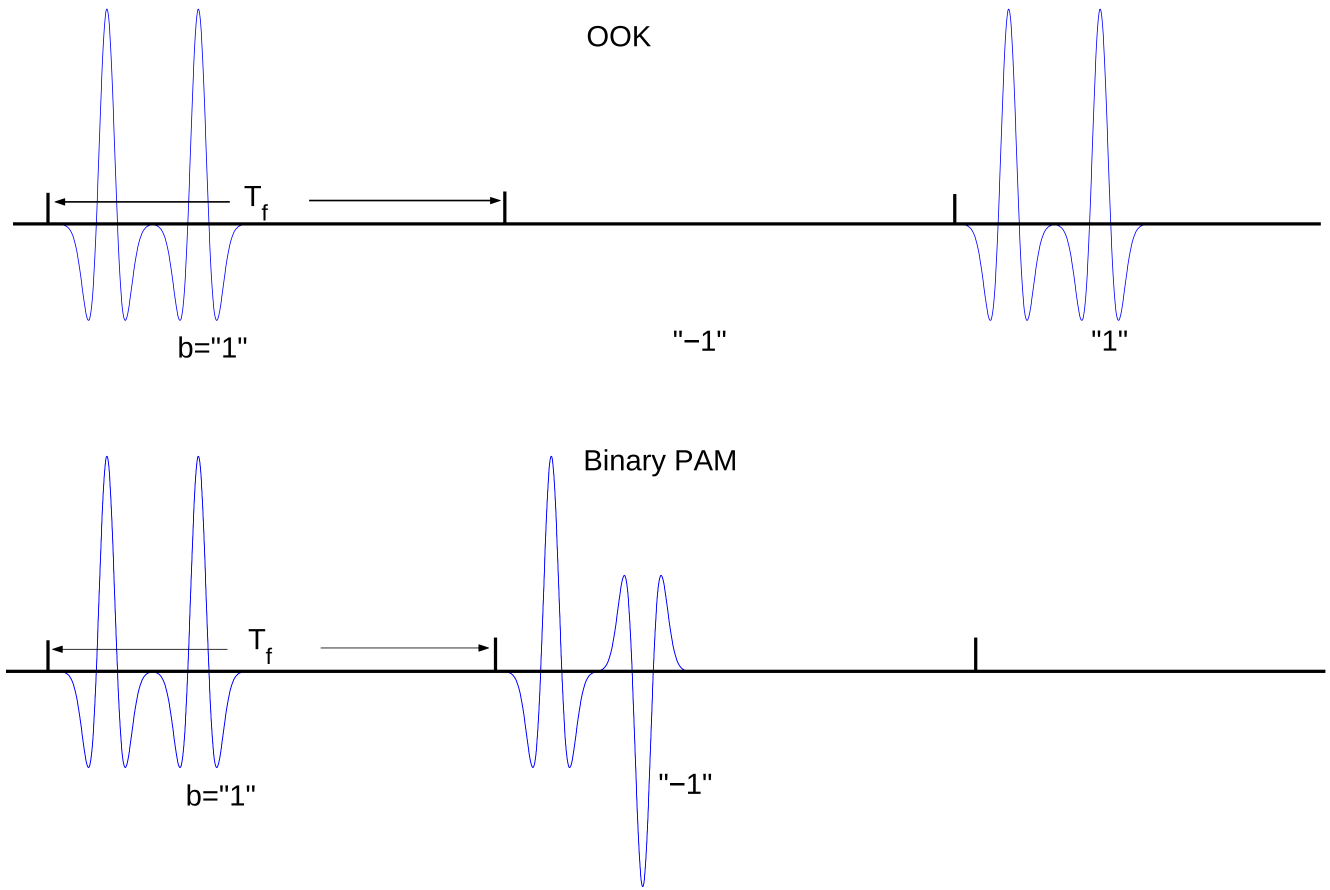
The Novel Dual Pulse (DP) System

- The DP system transmits a reference sub-pulse followed by a data sub-pulse as one pulse unit.
- The binary PAM modulated DP pulse is represented as

$$g_{dp}(t) = p(t) + b \cdot p(t - \frac{T_w}{2}),\ 0 \leq t \leq T_w \tag{3}$$

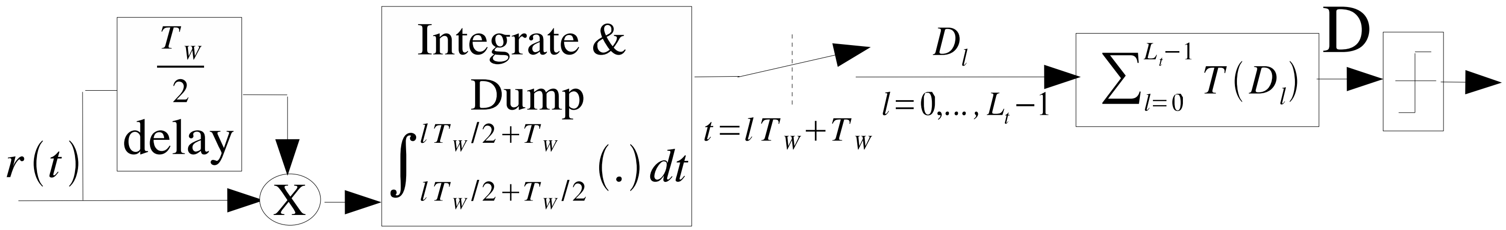
- The DP system requires only one time frame to transmit a data pulse, effectively doubles the tranmission rate when compared with the TR system.

Illustration of the DP pulse



DP System Receiver

- The receiver design for DP system can be illustrated as follows



- Where $T(D_l)$ is the test function defined by the different combining schemes
  - Generalized Selection Combining (GSC)
  - Absolute Threshold GSC (AT-GSC)
  - Normalised Threshold GSC (NT-GSC)

General Selection Combining (GSC)

- This method selects L largest $|D_l|$'s to form D
- The test function $T(D_l)$,

$$T(D_l) = \begin{cases} D_l, & \text{if } |D_l| \geq |D^{(L)}| \\ 0, & \text{if } |D_l| < |D^{(L)}| \end{cases} \quad (4)$$

- The conditional probability of error given by

$$P(e|\alpha,\tau) = P(D < 0|b = +1, \alpha, \tau) = \frac{1}{2\pi j} \int_{c-j\infty}^{c+j\infty} \frac{\Phi_{GSC}(s)}{s} ds \quad (5)$$

GSC (con't)

- Moment generating function (MGF) of GSC

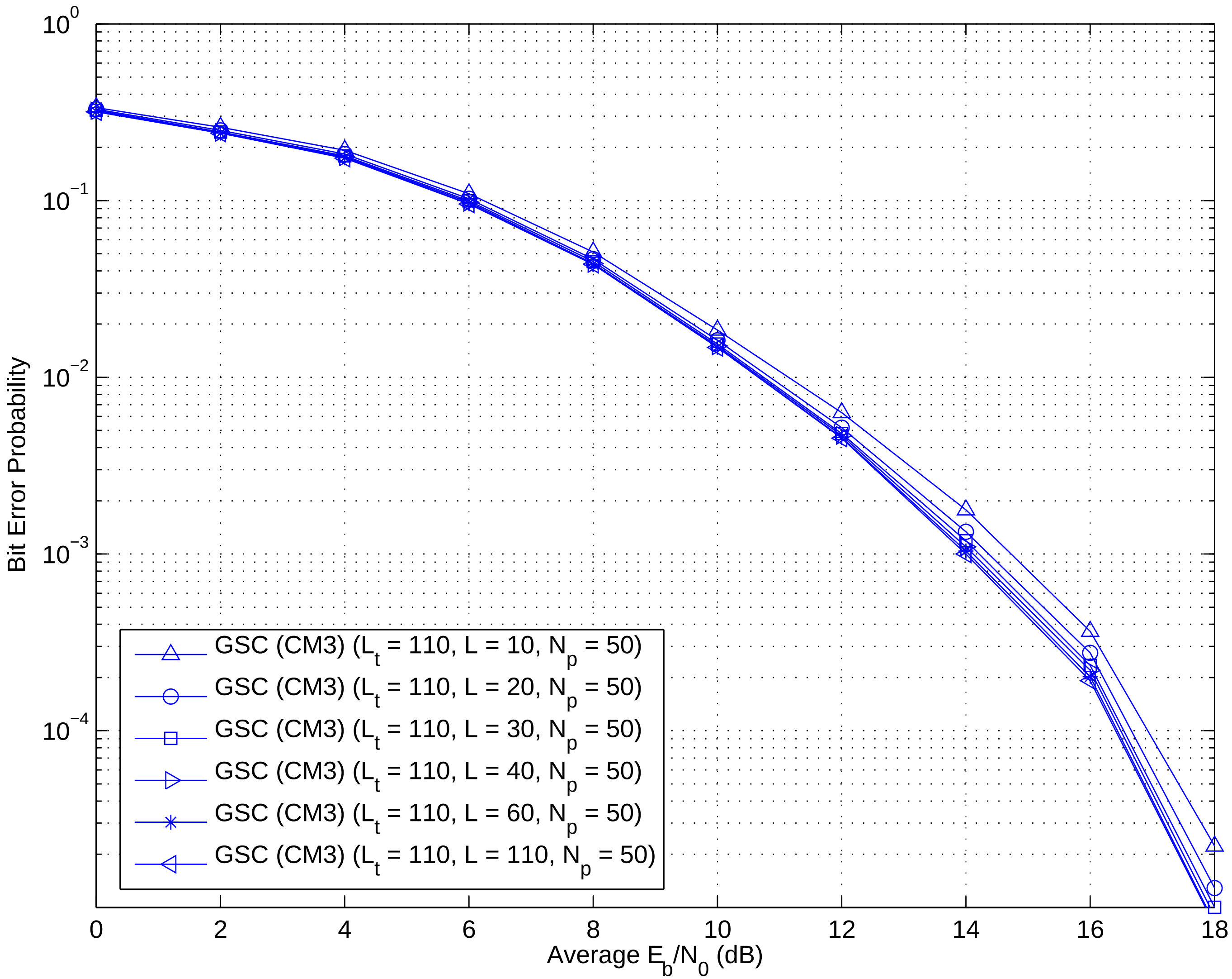
$$\Phi_{GSC}(s) = \sum_{i=0}^{L_t-1} \int_{-\infty}^{\infty} f_i(D_i) e^{sD_i} \sum_{\text{all } I_i} \prod_{l \in I_i} \Psi_l(s, D_i) \prod_{\substack{l' \notin I_i \\ l' \neq i}} [F_{l'}(|D_i|) - F_{l'}(-|D_i|)] dD_i \tag{6}$$

where

$$\Psi_l(s, x) = \frac{1}{2} e^{s\mu_l + \frac{\sigma_l^2}{2} s^2} \left[\text{erfc}\left(\frac{|x| + (\mu_l + \sigma_l^2 s)}{\sqrt{2}\sigma_l} \right) + \text{erfc}\left(\frac{|x| - (\mu_l + \sigma_l^2 s)}{\sqrt{2}\sigma_l} \right) \right] \tag{7}$$

$$I_i \subset \{0, 1, \cdots, L_t - 1\} - \{i\}$$

Effect of L on GSC



Absolute Threshold GSC (AT-GSC)

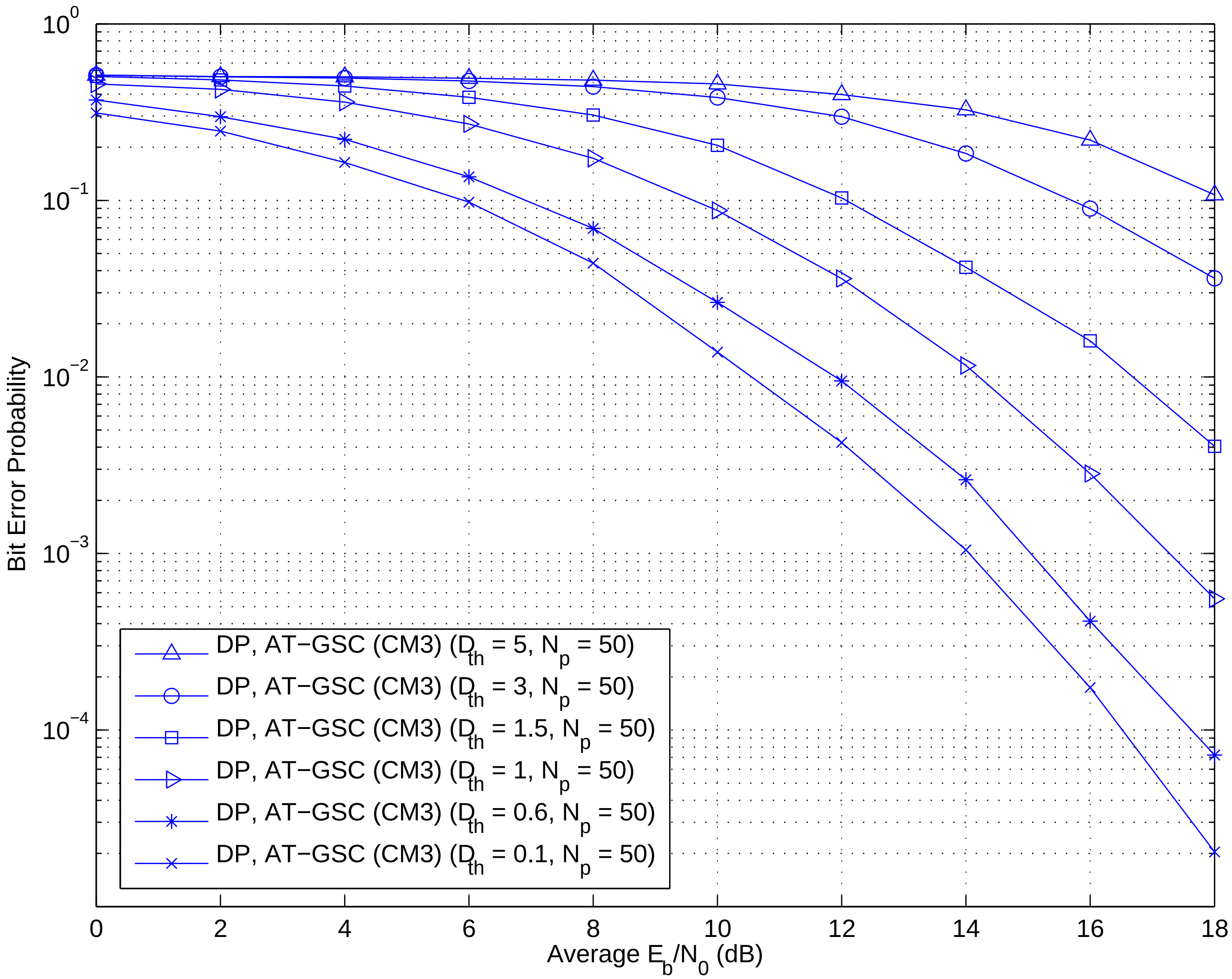
- This method combines D_l that has absolute value greater than D_{th} to form the decision variable

$$y_l = T(D_l) = \begin{cases} D_l, & \text{if } |D_l| \geq D_{th} \\ 0, & \text{if } |D_l| < D_{th} \end{cases} \tag{8}$$

- The MGF of AT-GSC is presented by

$$\Phi_{AT-GSC}(s) = \prod_{l=0}^{L_t-1} \Phi_{y_l}(s) = \prod_{l=0}^{L_t-1} [F_l(D_{th}) - F_l(-D_{th}) + \Psi_l(s, D_{th})]. \tag{9}$$

Effect of D_{th} on AT-GSC



Normalised Threshold GSC (NT-GSC)

- Like the AT-GSC, NT-GSC selects D_l that has absolute value higher than threshold $D_{th} = \eta_{th} D_{max}$ where $D_{max} = max|D_l|$

$$T(D_l) = \begin{cases} D_l, & \text{if } |D_l| \geq \eta_{th} D_{max} \\ 0, & \text{if } |D_l| < \eta_{th} D_{max} \end{cases} . \quad (10)$$

NT-GSC (con't)

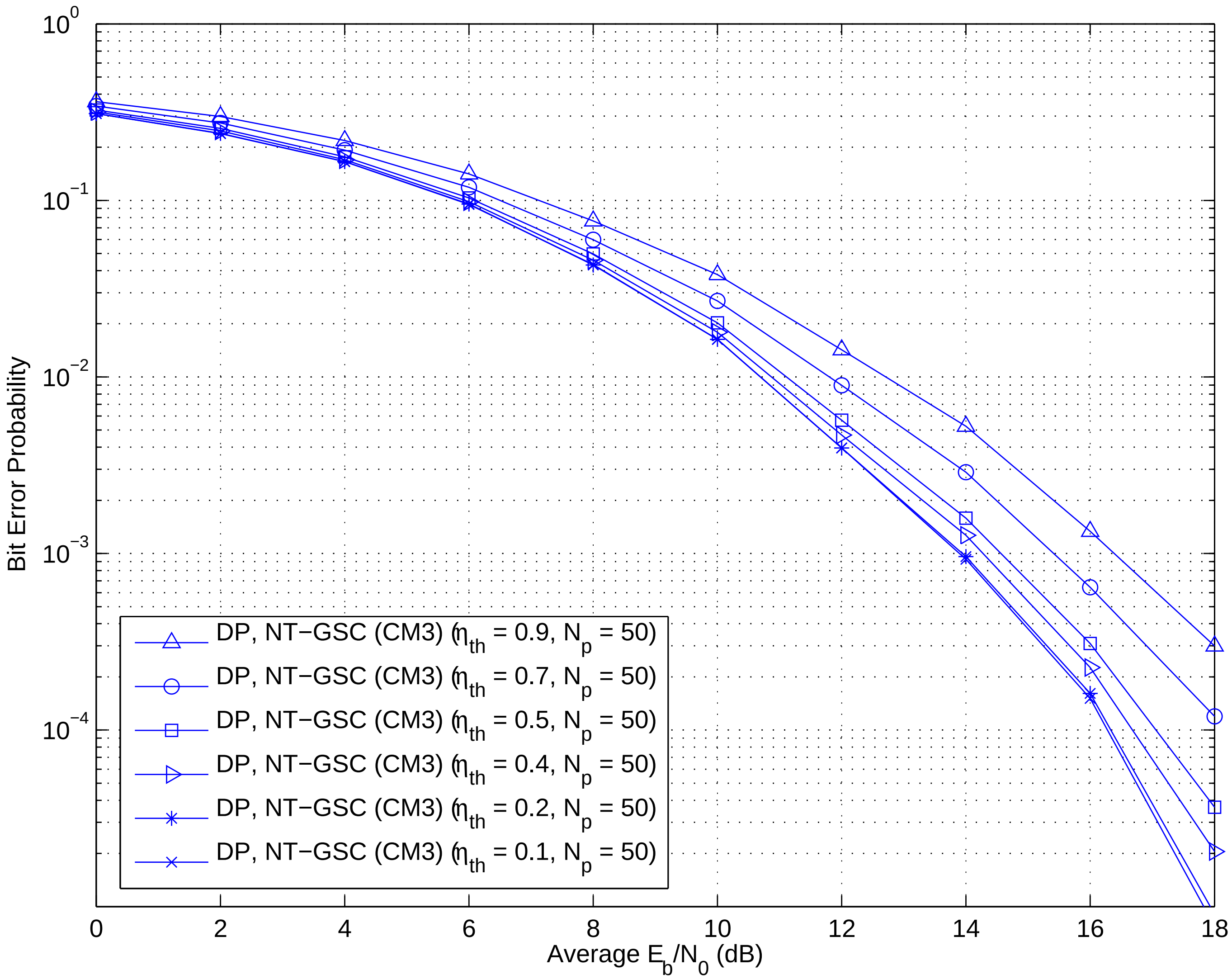
- The MGF of NT-GSC is represented by

$$\Phi_{NT-GSC}(s) = \sum_{i=0}^{L_t-1} \int_{-\infty}^{\infty} f_i(D_i) e^{sD_i} \times \prod_{\substack{l=0 \\ l \neq i}}^{L_t-1} \left[\tilde{\Psi}_l(s, \eta_{th} D_i, D_i) + F_l(\eta_{th}|D_i|) - F_l(-\eta_{th}|D_i|) \right] dD_i \quad (11)$$

- where

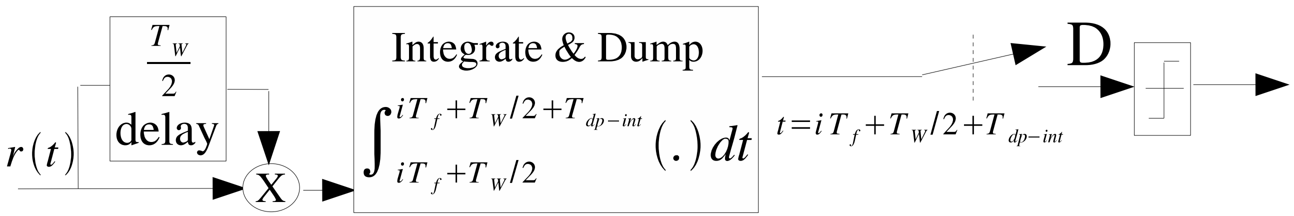
$$\tilde{\Psi}_l(s, x, y) = \Psi_l(s, x) - \Psi_l(s, y) \quad (12)$$

Effect of η_{th} on NT-GSC



Simple autocorrelation receiver for DP system

- Receiver of the DP system can also be represented by a simple autocorrelator

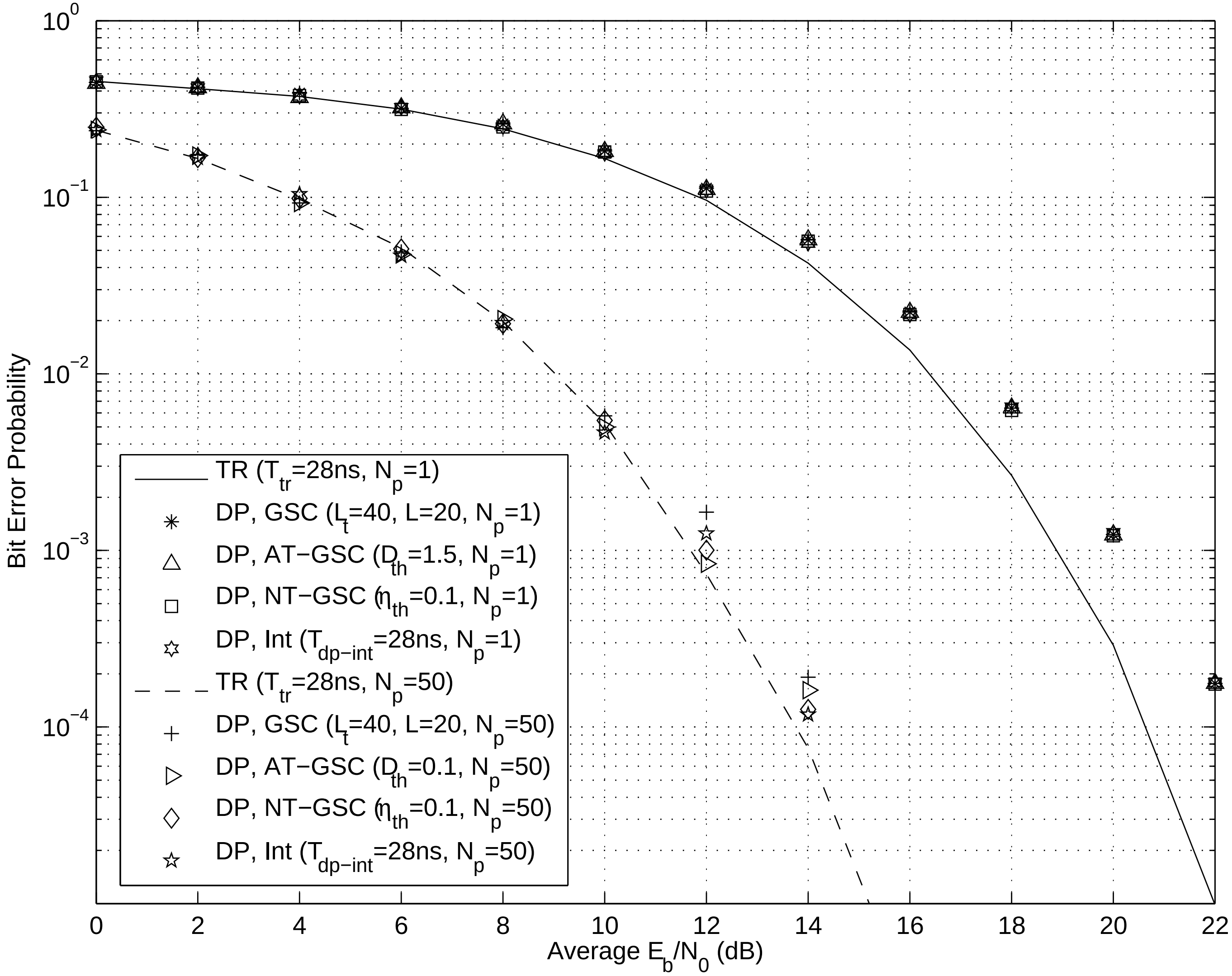


- Decision variable given by

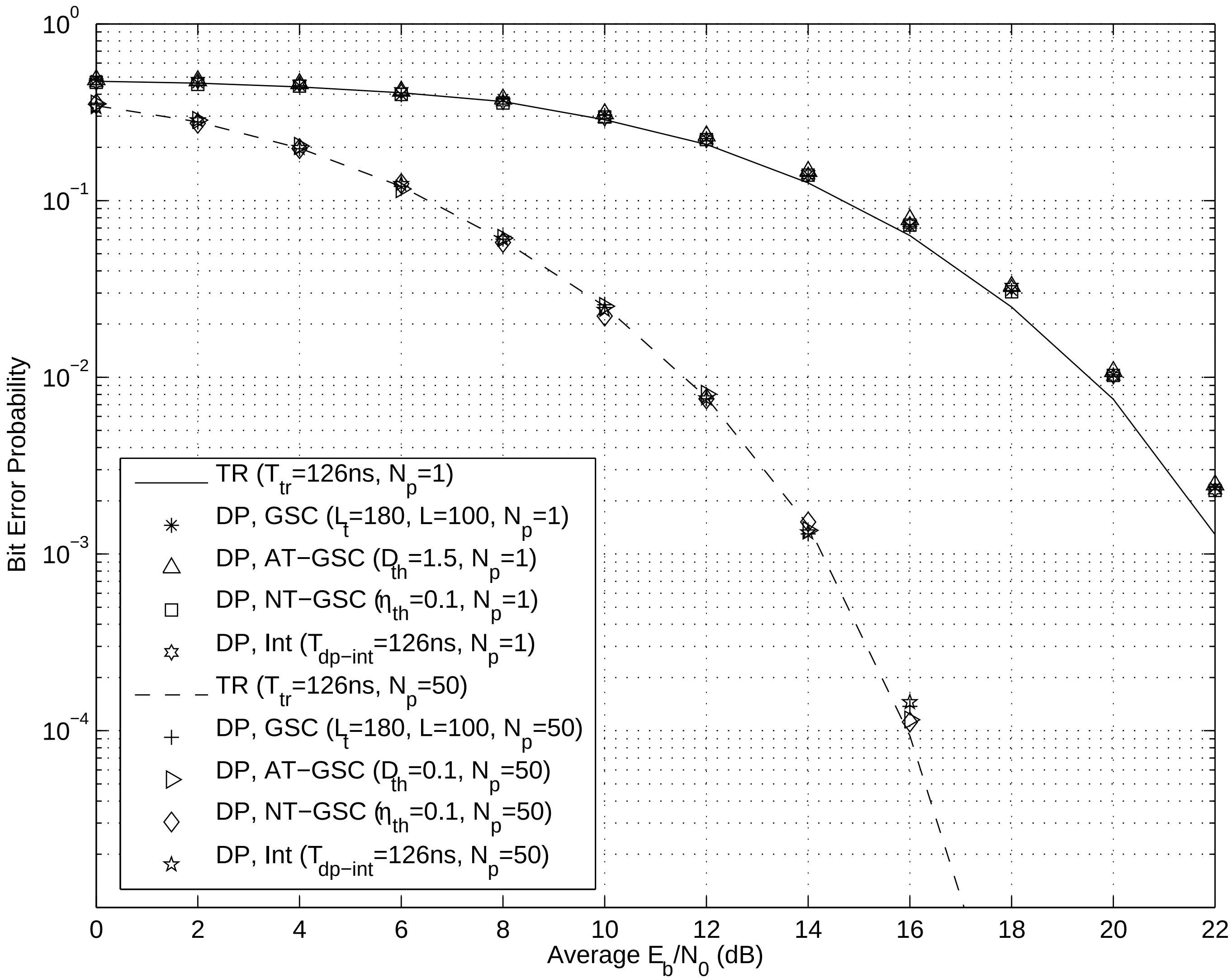
$$D = \sum_{j=0}^{N_s-1} \int_{jT_f+\frac{T_w}{2}}^{jT_f+\frac{T_w}{2}+T_{dp-int}} r(t)r(t-\frac{T_w}{2})dt \quad (13)$$

- The autocorrelation receiver design for the DP system is similar to the TR system receiver design, thus providing similar receiver complexity

Comparison between TR system and DP system, CM1



Comparison between TR system and DP system, CM4

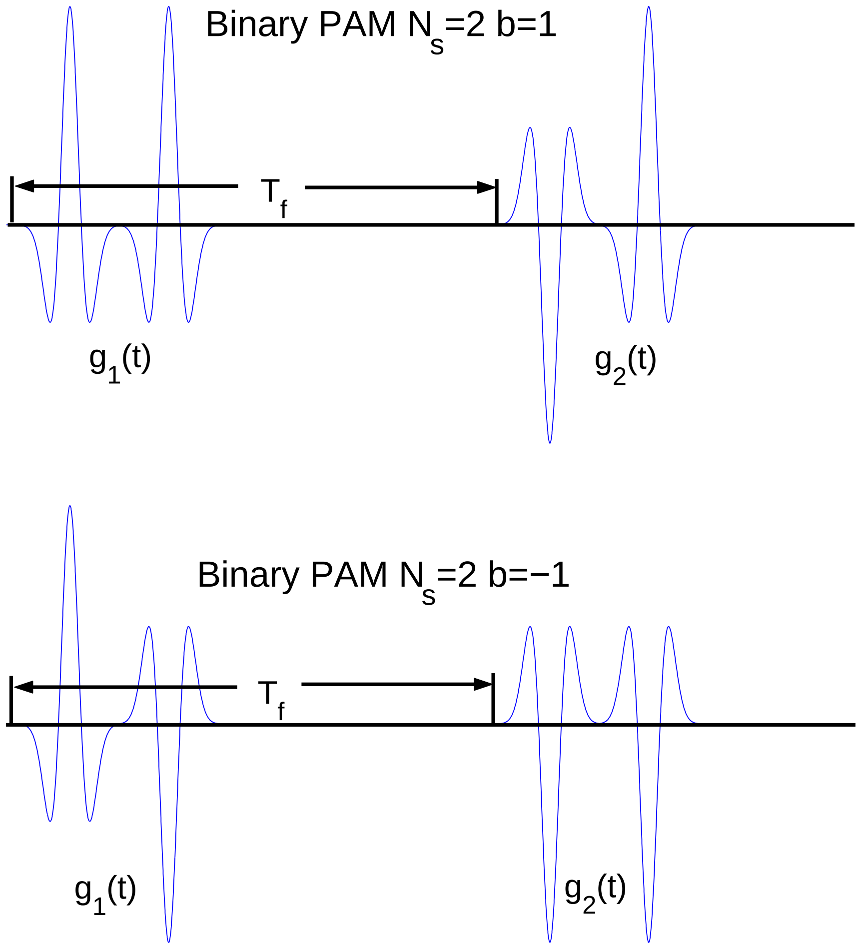


The Improved DP (iDP)System

- The performance of DP system is worse than the TR system due to the interference between the reference pulse and the data pulse
- The iDP system is designed to eliminate the performance degradation of the DP system
- The iDP system requires two pulse transmission for each data bit
- The iDP pulses are given by

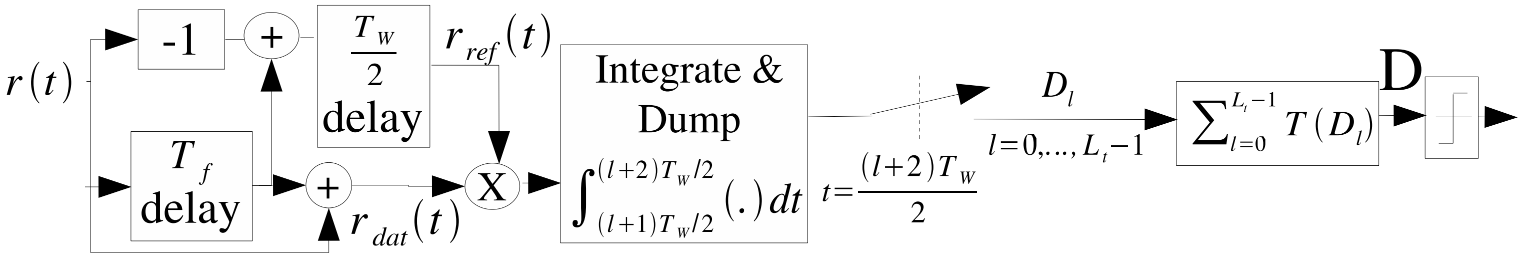
$$\begin{aligned} g_1(t) &= p(t) + b_1 \cdot p(t - \frac{T_w}{2}), \quad 0 \leq t \leq T_w \\ g_2(t) &= -p(t) + b_1 \cdot p(t - \frac{T_w}{2}), \quad 0 \leq t \leq T_w. \end{aligned} \tag{14}$$

Illustration of the iDP signal



iDP system receiver design

- The block diagram for iDP receiver design

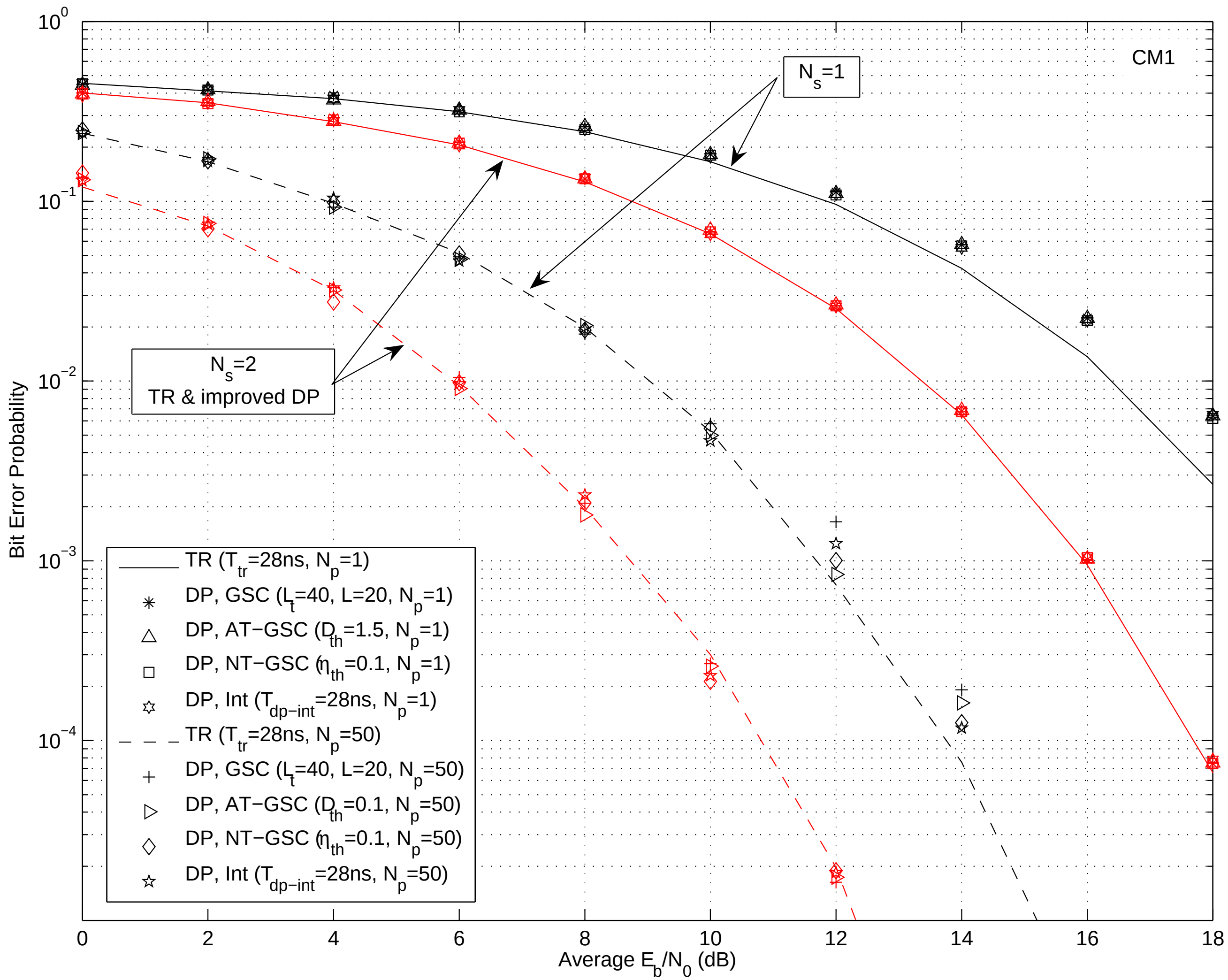


- where

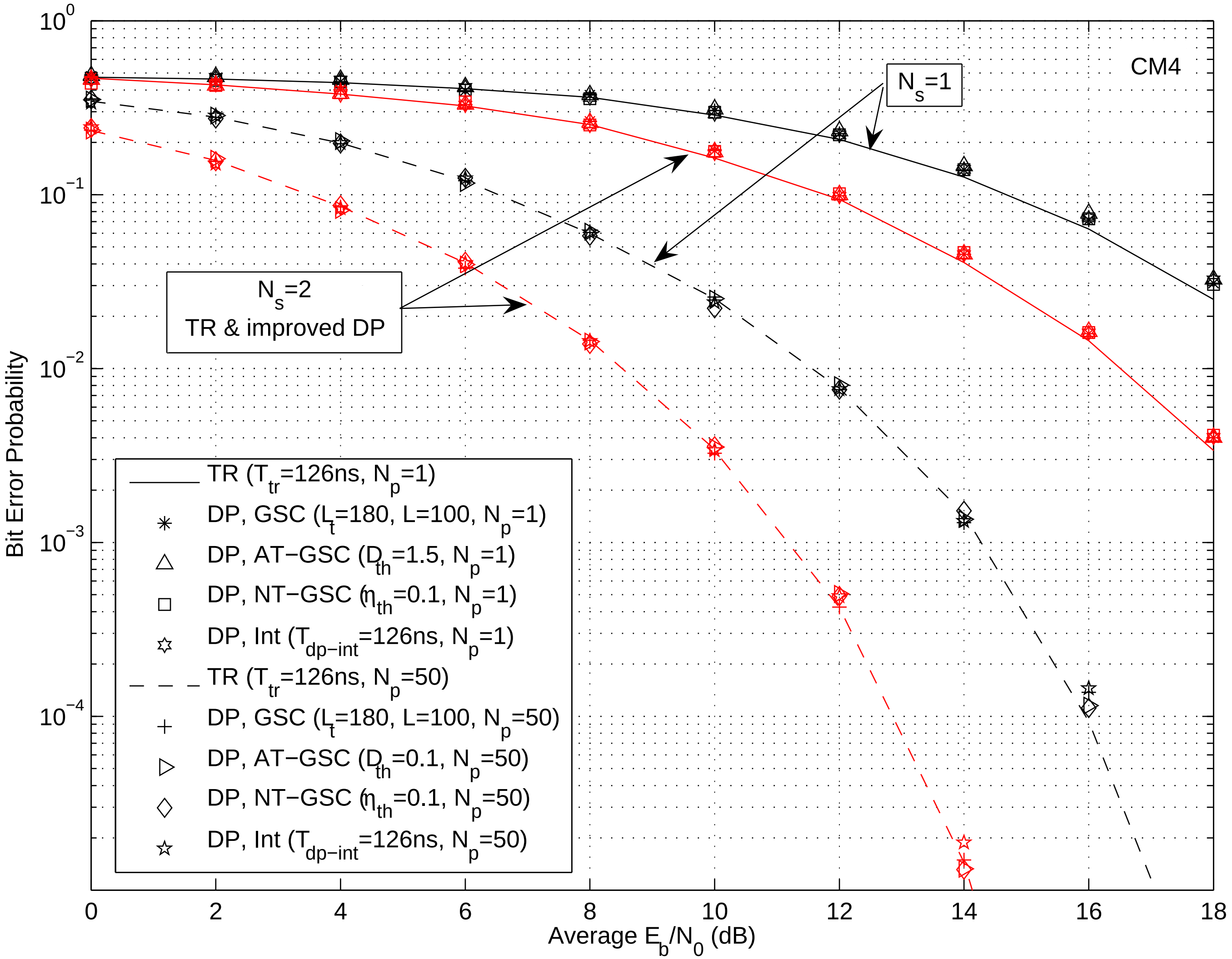
$$D_l = \int_{l\frac{T_w}{2}+\frac{T_w}{2}}^{l\frac{T_w}{2}+T_w} r_{ref}(t-\frac{T_w}{2})r_{dat}(t)dt. \quad (15)$$

$$\begin{aligned} r_{ref}(t) &= r_1(t-T_f) - r_2(t) \\ r_{dat}(t) &= r_1(t-T_f) + r_2(t) \end{aligned}$$

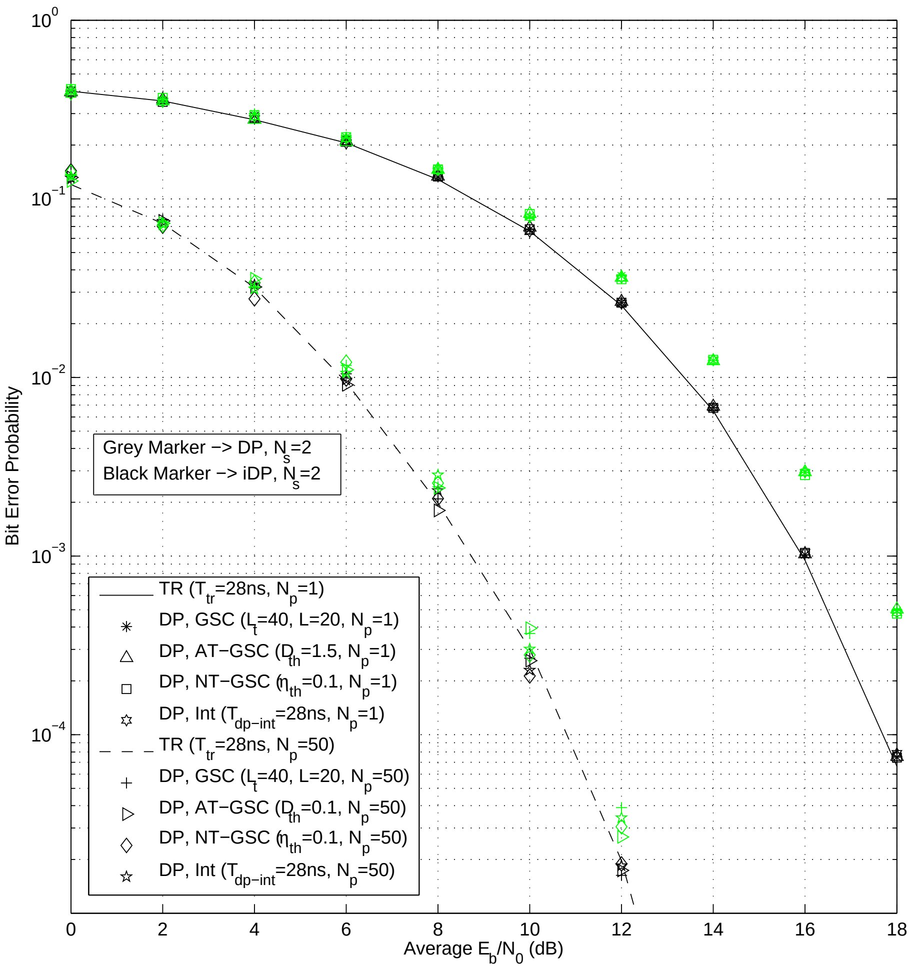
Performance comparison between TR, DP and iDP systems, CM1



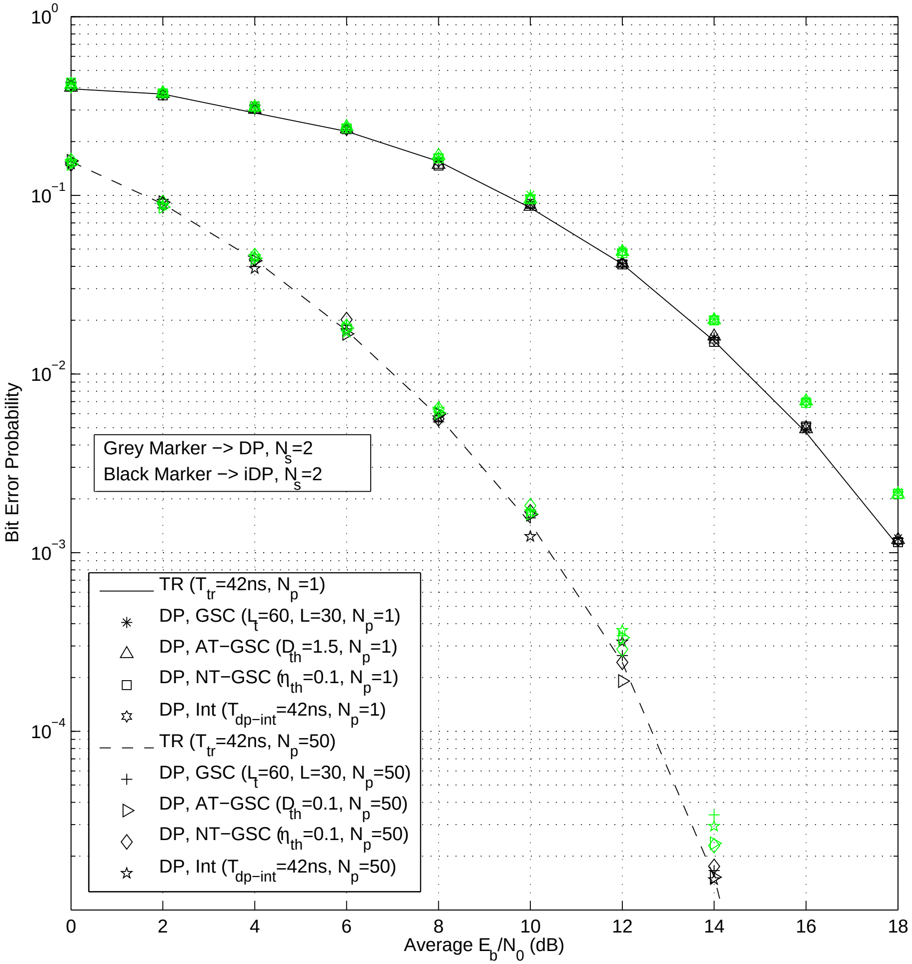
Performance comparison between TR, DP and *i*DP systems, CM4



Effect of IPI, CM1



Effect of IPI, CM2



Thank you!