A Robust PRML Read Channel with Digital Timing Recovery for Multi-Format Optical Disc

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Introduction

1. Channel characteristics of optical disc
2. Digital timing recovery
3. PRML
   - Adaptive equalizer
   - Viterbi decoder with adaptive PR-level
4. Simulation results
5. Conclusion

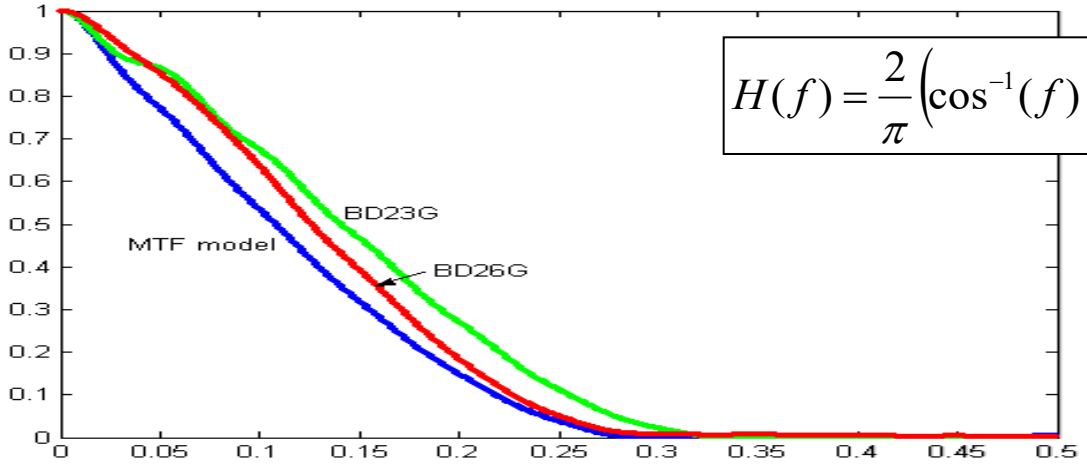
Optical Disc Characteristics

- Disc Characteristics
  - » Increase the data density
  - » Narrower track pitch

	DVD	BD
Wavelength of laser diode	630 nm	405 nm
Channel bit length	133.3 nm	74.5 nm
Channel bit frequency (x1)	26.15625 MHz	66 MHz
Maximum signal frequency (x1)	26 / 6 = 4.4 MHz (3T)	66 / 4 = 16.5 MHz (2T)
Optical cut-off frequency (x1)	6.44 MHz	20.64 MHz
Signal asymmetry	-0.05 ~ 0.15	-0.10 ~ 0.15
Modulation (Run-length limit)	EFM+, RLL(2,10)	17PP, RLL(1,7)
Ideal maximum defect length	About 6 mm	About 9 mm

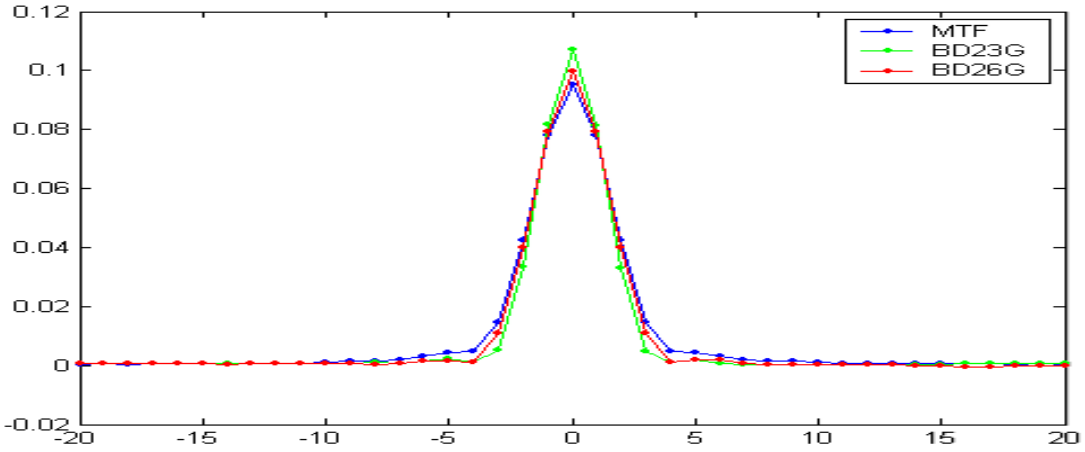
Optical Disc Characteristics

❖ Channel modeling



$$H(f) = \frac{2}{\pi}\left(\cos^{-1}(f) - f\sqrt{1-f^2}\right), \qquad F_{cut} = \frac{2NA}{\lambda}|\upsilon|$$

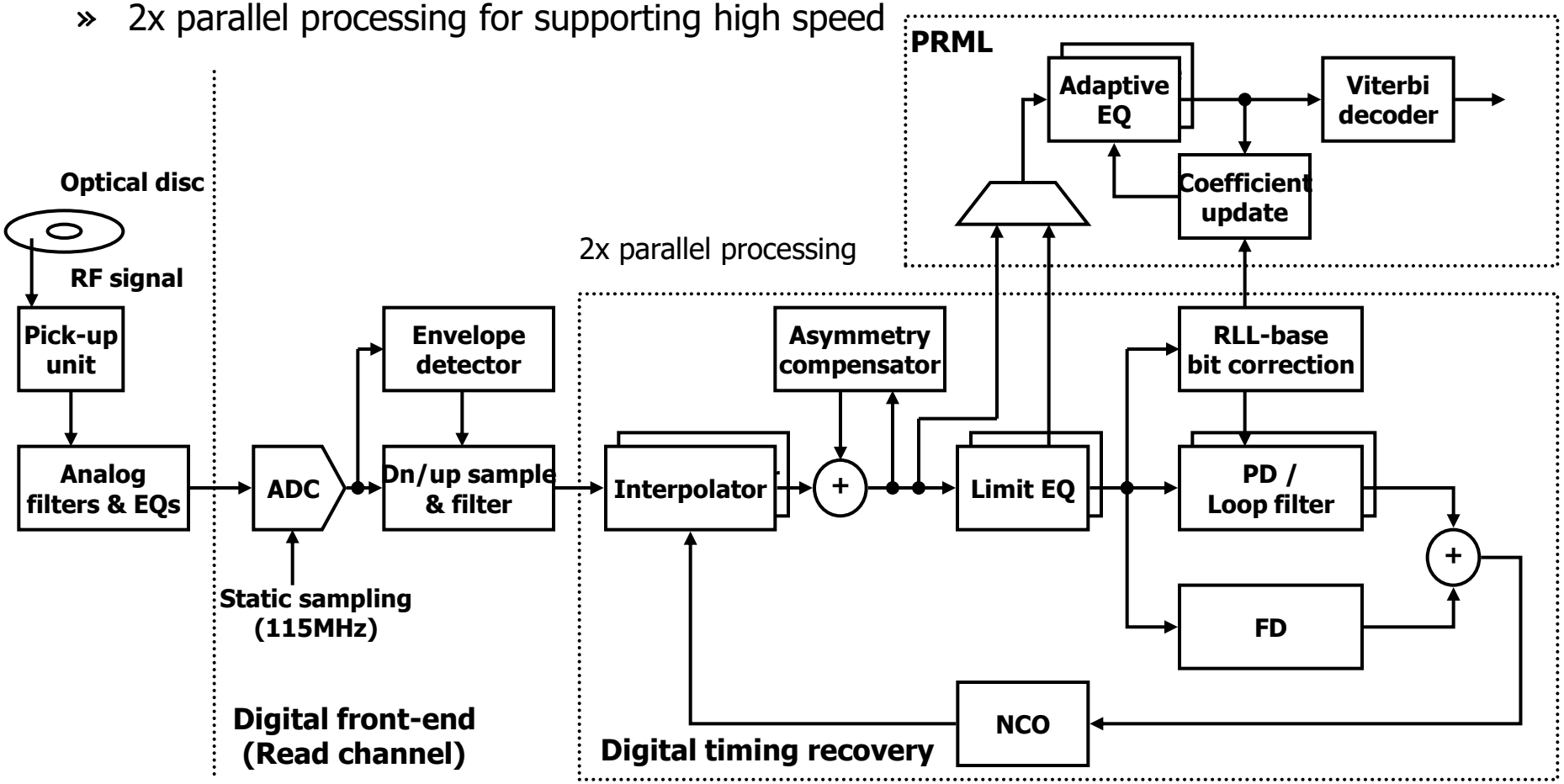
<Frequency response>



<FIR-form modeling>

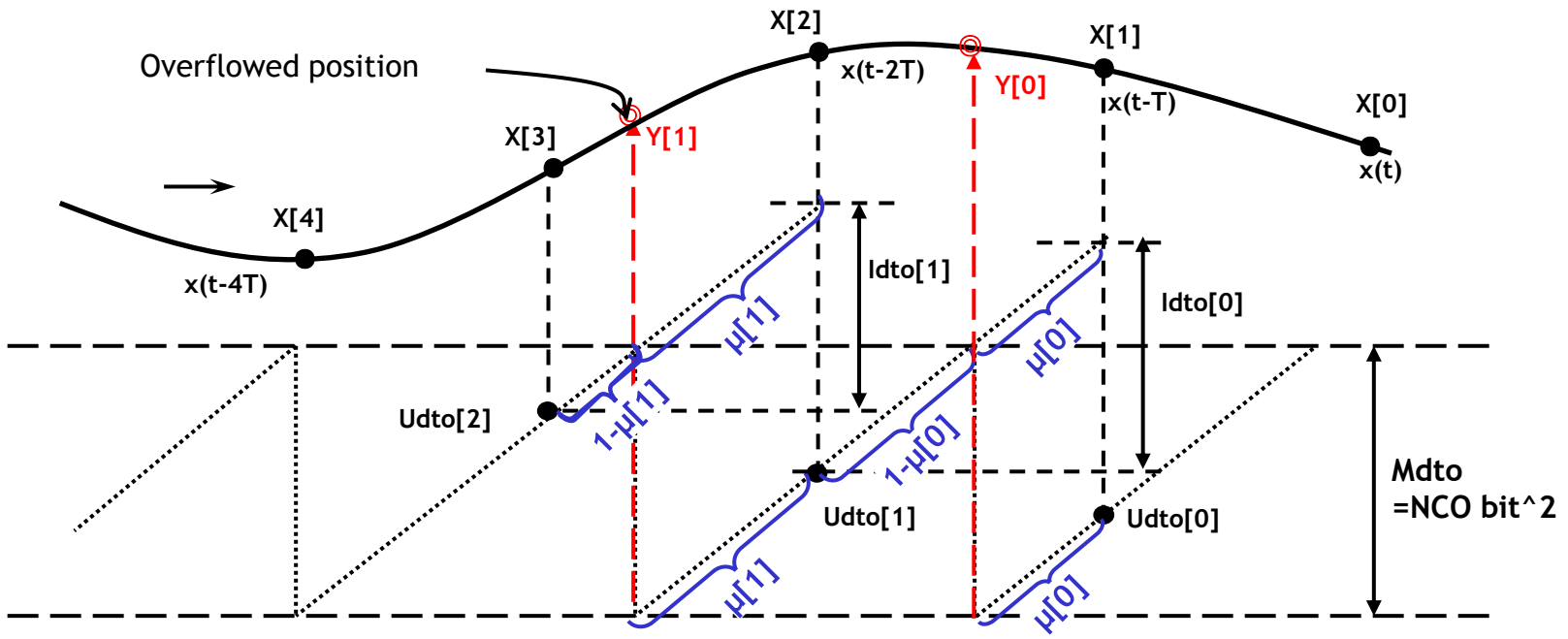
Overall Architecture

- Read channel for optical disc
  - » Digital timing recovery + PRML
  - » Use static 115MHz system clock – all digital processing
  - » 2x parallel processing for supporting high speed



Digital Timing Recovery

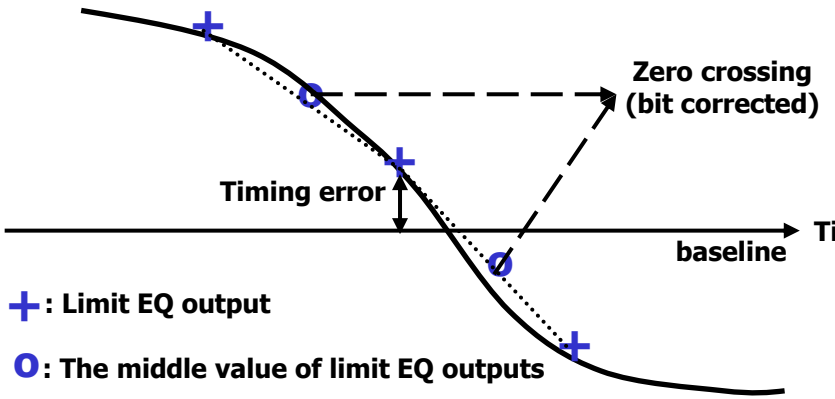
- NCO (Numerically controlled oscillator)
  - » Accumulates feed-backed timing error & control the timing matched position
- Interpolator
  - » Calculates timing matched data with interpolation scheme using 4-sampling data



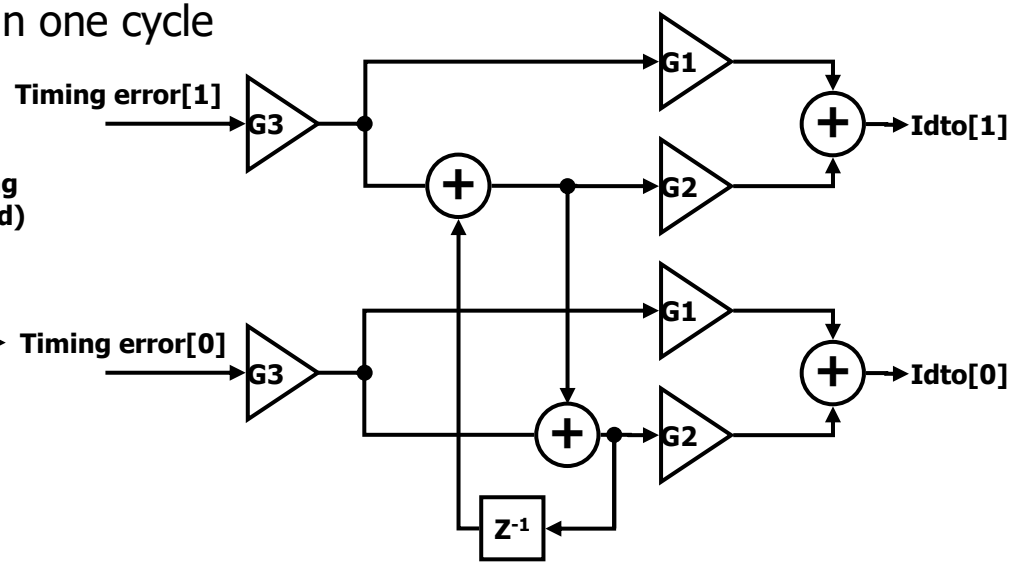
- $Y[0] = \mu[0]^2 \times 0.5 \times (X[3] - X[2] - X[1] + X[0]) + \mu[0] \times 0.5 \times (-X[3] + 3X[2] - X[1] - X[0]) + X[1]$
- $Y[1] = \mu[1]^2 \times 0.5 \times (X[4] - X[3] - X[2] + X[1]) + \mu[1] \times 0.5 \times (-X[4] + 3X[3] - X[2] - X[1]) + X[2]$
- $\mu[0] = Udto[0] / Idto[0]$, $\mu[1] = Udto[1] / Idto[1]$
- At overflow point, $Udto[0] = Udti[1] + Idto[0] - Mdto$, Idto = output of loop filter

Digital Timing Recovery

- Frequency detector
  - » Reduce the locking time of the timing recovery
  - » Detect the sync duration and adjust the accumulation value of NCO
- Timing error generation
  - » Limit EQ output between zero crossing points
  - » RLL-based corrected bit is used to determine zero crossing
- Loop filter
  - » 1st IIR filter structure
  - » Process maximum 2 timing error in one cycle



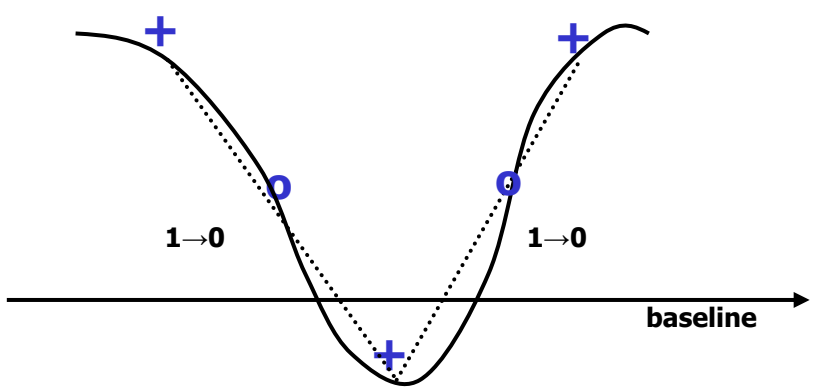
<Timing Error>



<Loop filter>

Digital Timing Recovery

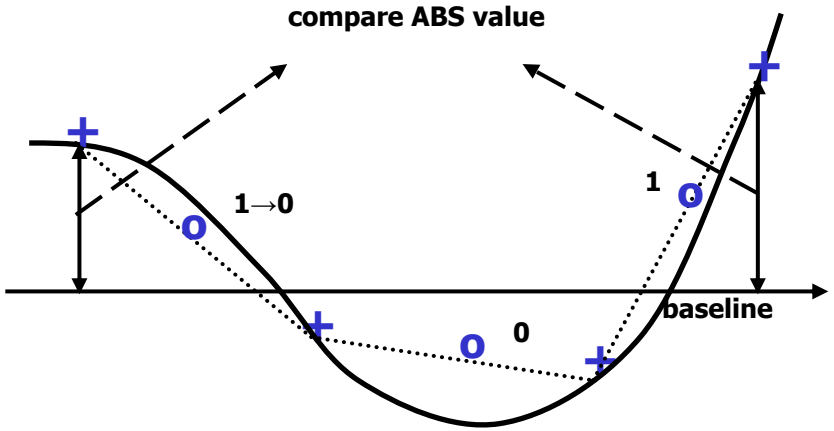
- RLL-based bit correction
  - » Many bit errors of high frequency signals by ISI
  - » Correct the miss-detected bits violating the minimum run-length
  - » Corrected bit is used for generated reference level of adaptive-EQ



Bit detection: ..., 1, 1, ...

Corrected: ..., 0, 0, ...

(a)



Bit detection: ..., 1, 0, 1, ...

Corrected: ..., 0, 0, 1 ...

(b)

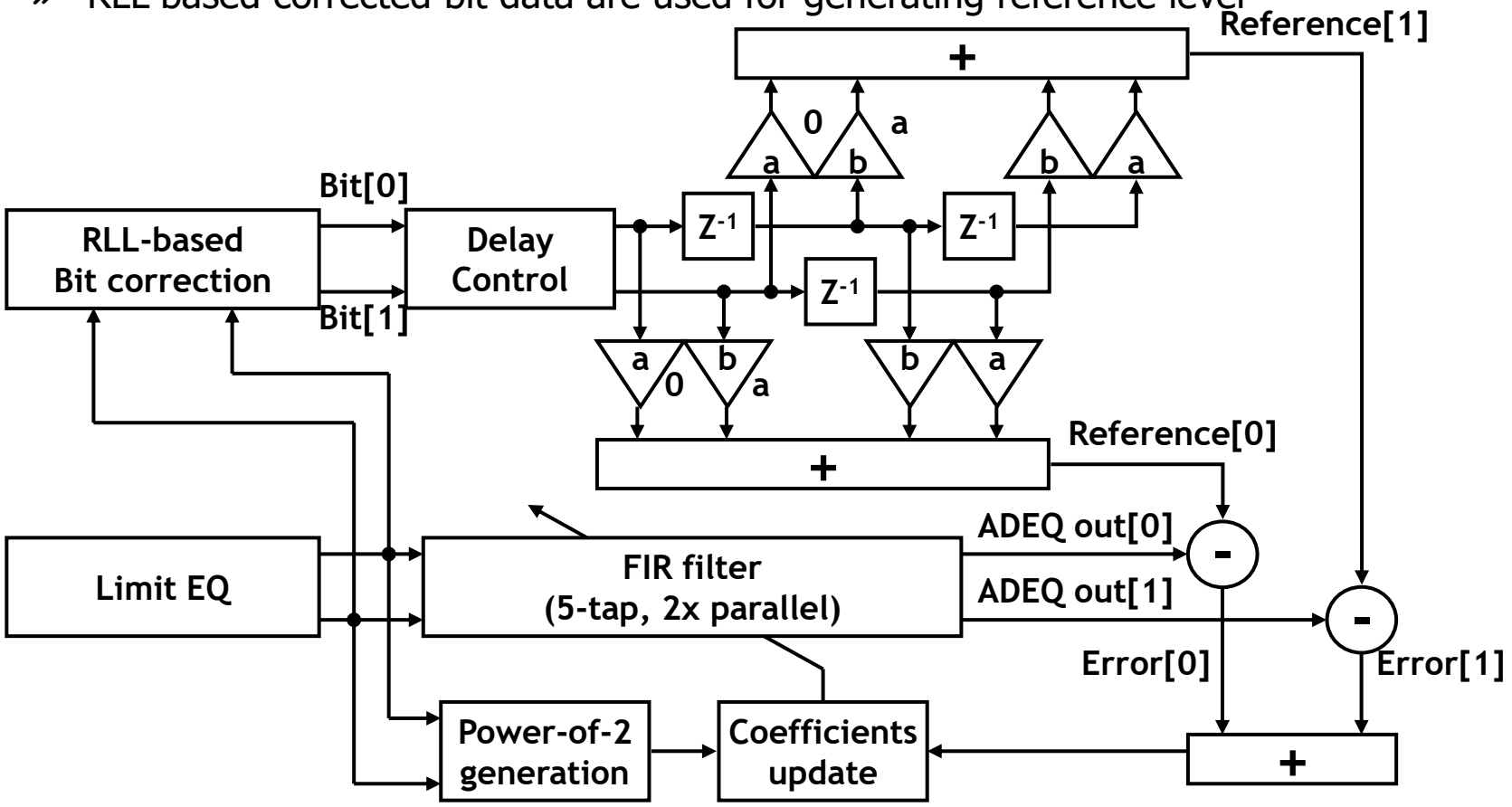
<RLL-based bit correction>

+ : Limit EQ output

o : The middle value of limit EQ outputs

Adaptive Equalizer

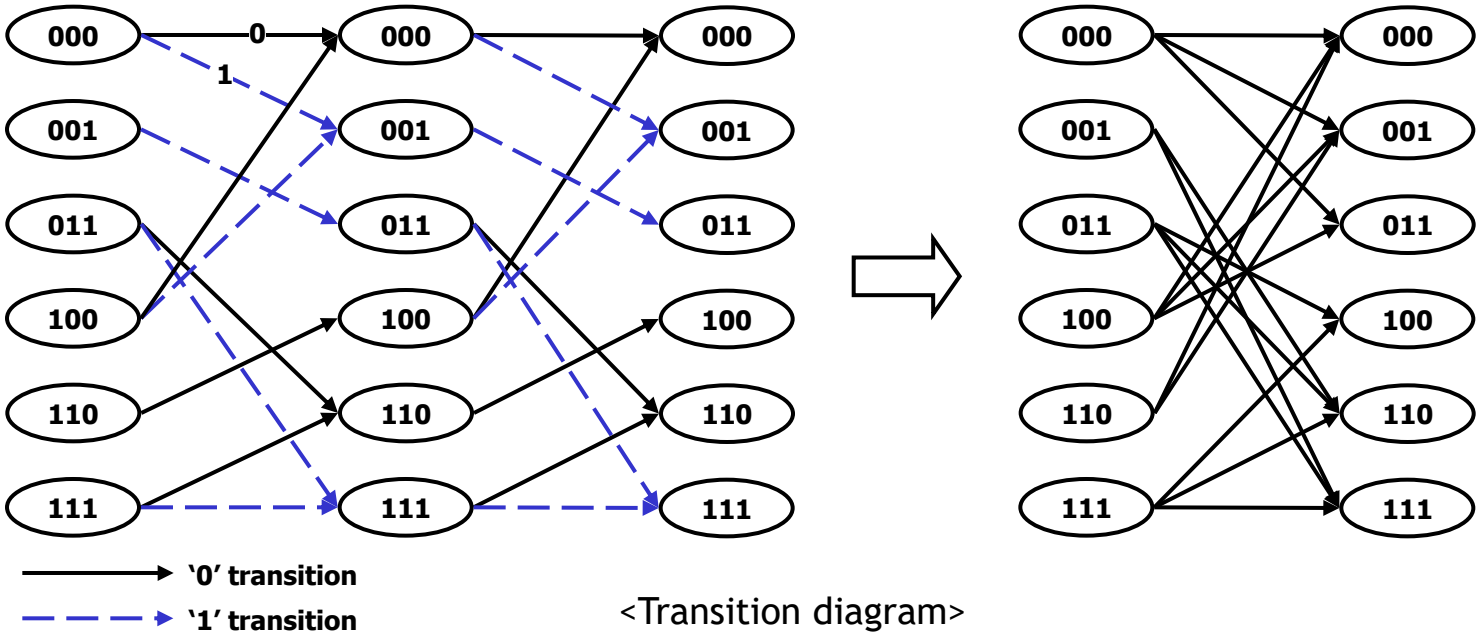
- Adaptive equalizer
  - » Generates defined partial response (PR) signal
  - » LMS algorithm applying power-of-2 method
  - » RLL-based corrected bit data are used for generating reference level



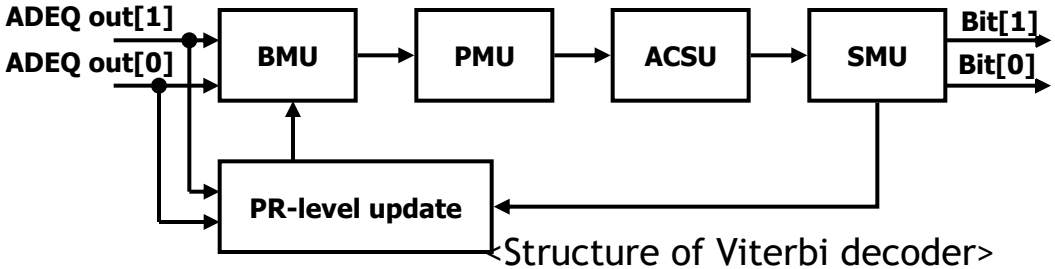
<Structure of adaptive equalizer>

Viterbi Decoder

- Viterbi decoder with adaptive PR-level adjusting
  - » Process two bits in one flag cycle – modified transition diagram
  - » Adjust the PR-level adaptively for compensating signal asymmetry



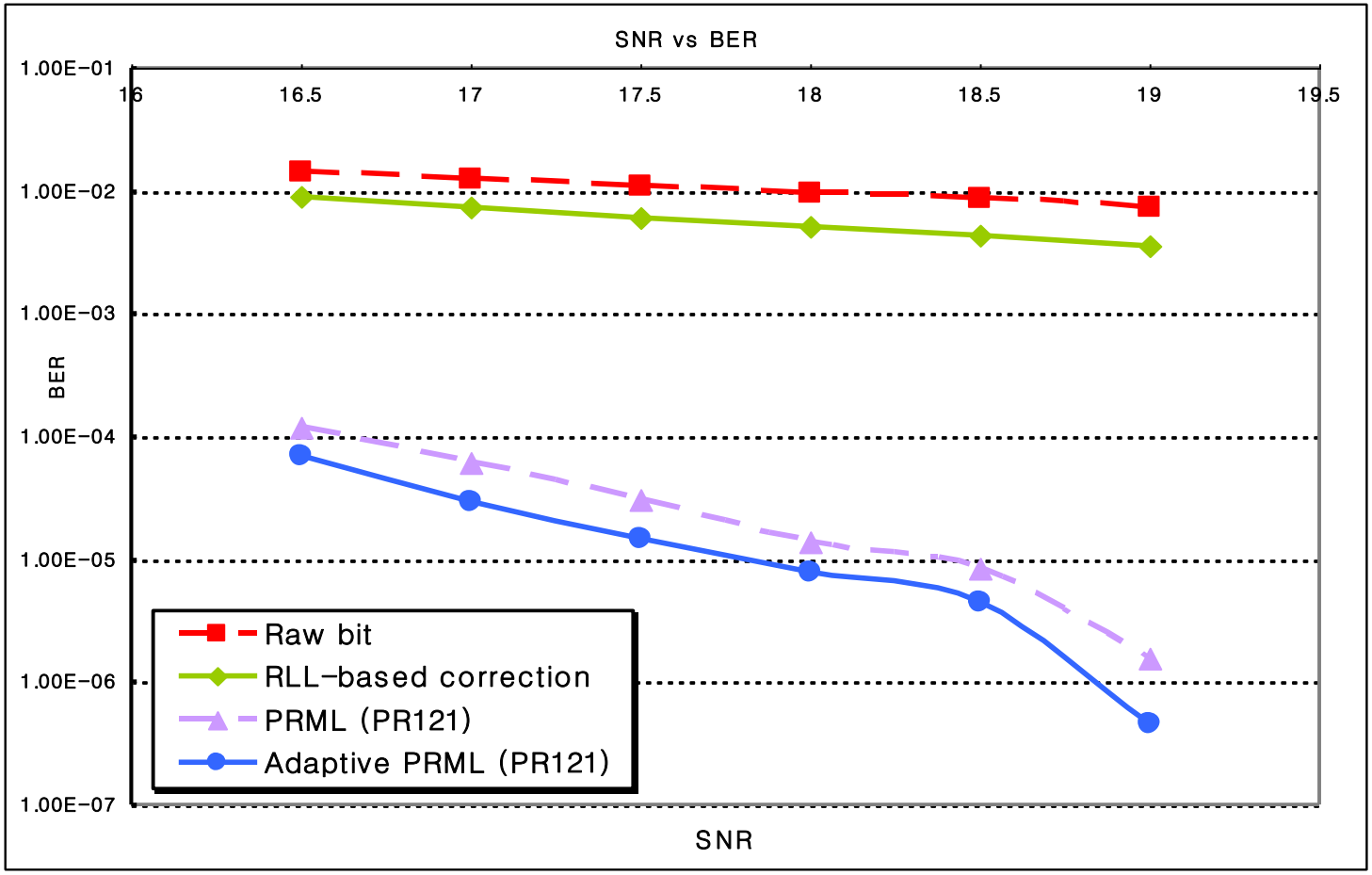
<Transition diagram>



<Structure of Viterbi decoder>

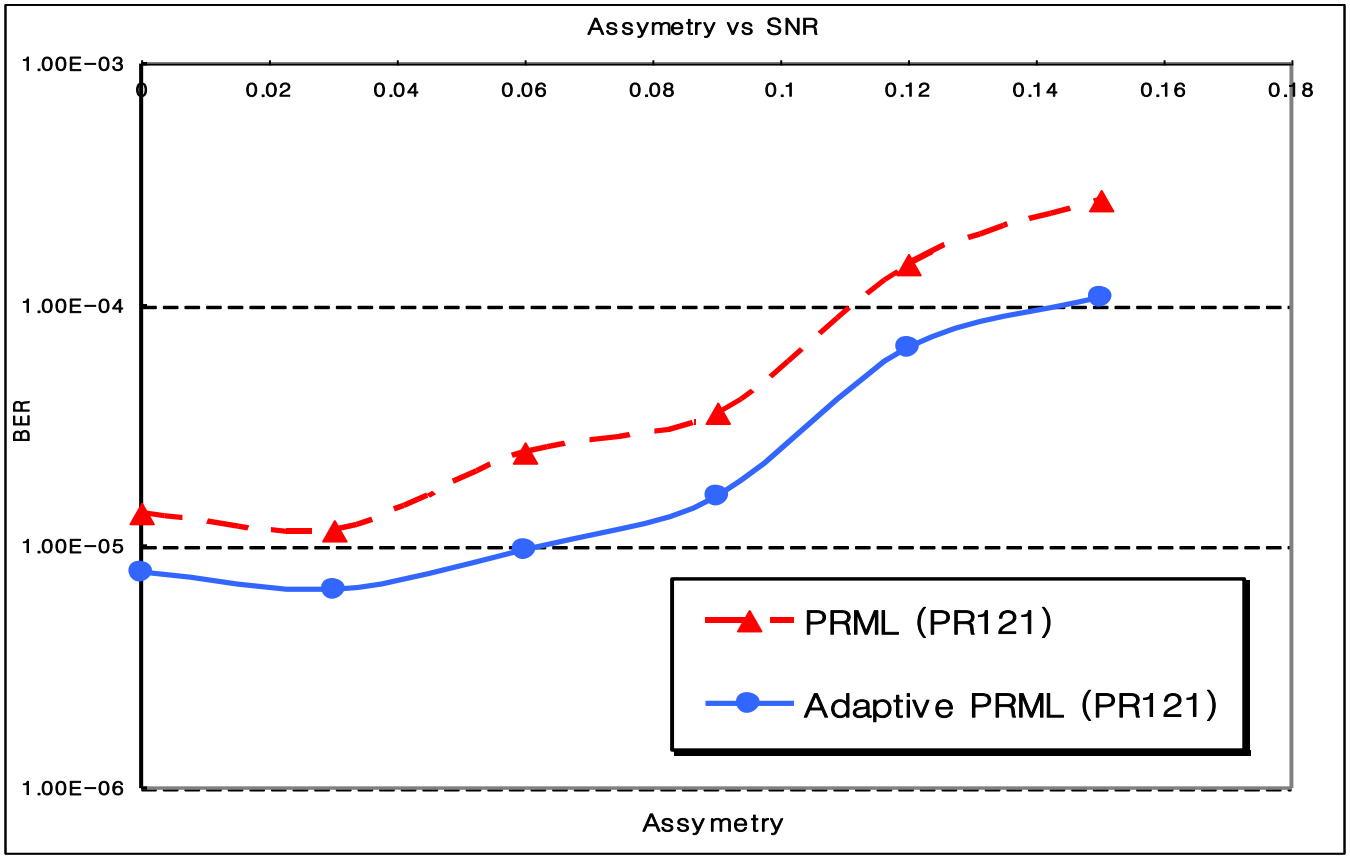
Simulation Results

❖ Simulation for Gaussian noise (2x BD)



Simulation Results

❖ Simulation for asymmetry defect*



* Asymmetry model is from “Modeling and Compensation of Asymmetry in Optical Recording” by H. Pozidis

Conclusion

❖ Summary

Supporting media & speed	BD (~3x), DVD (~8x) & CD (~ 210 Mbit/s)
ADC bit resolution	8-bit (ENOB > 7)
Operating clock	115 MHz
Process technology	0.18-um TSMC digital library
Area (except ADC)	70k gates (about 0.70mm^2)