A Passive Filter Aided Timing Recovery Scheme

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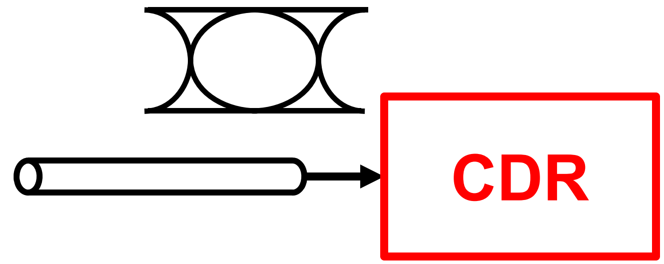
Outline

- Introduction
- Baud-rate timing recovery (TR) schemes
- Passive filter
- Measurement Results
- Conclusions

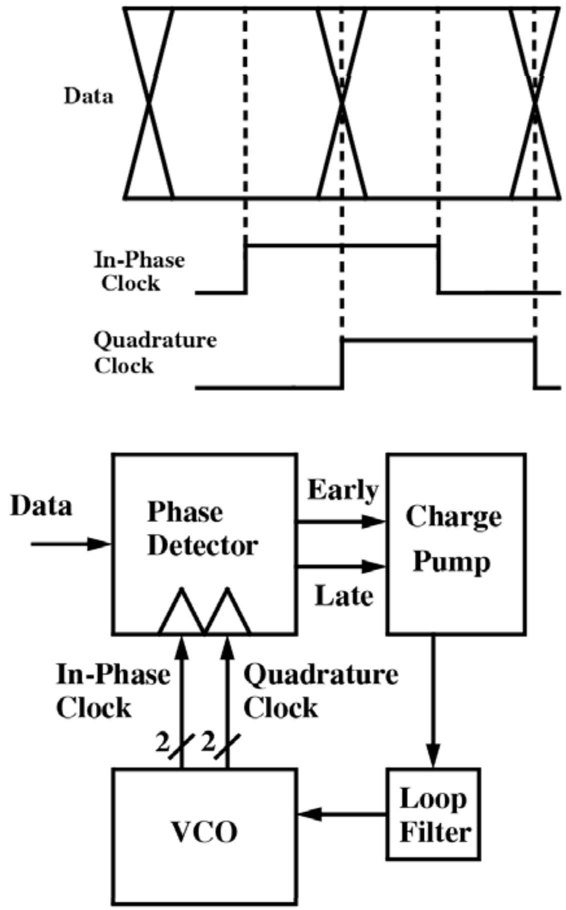
Introduction



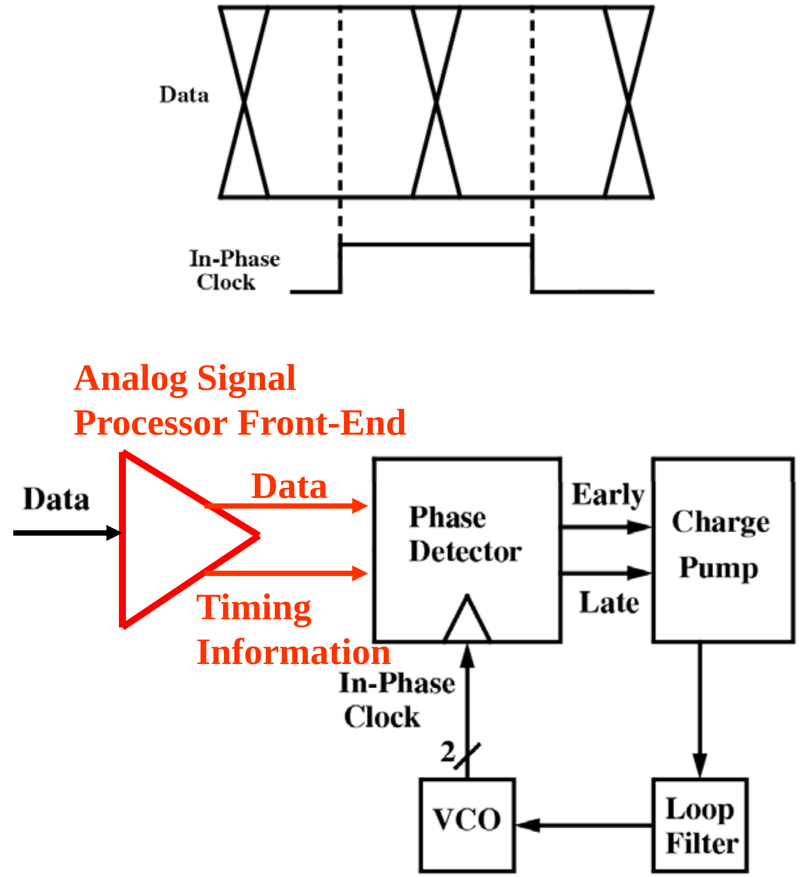
Timing Recovery Techniques

- **Deductive (e.g. non-linear spectral line)**
- **Inductive**
  - **Linear (e.g. Hogge)**
  - **Non-linear or Bang-bang**
    - **Edge-sampled**
    - **Baud-rate (focus of this work)**

Introduction



Edge-sampled



Baud-Rate

Introduction

- Why baud-rate over edge-sampled?

1. Reduced clock sampling phases results in less power in the VCO and phase detector.
2. Better performance in the presence of ISI and random noise.
   [F. Musa and A. Chan Carusone,``Modeling and Design of Multilevel Bang-bang CDRs in the Presence of ISI and Noise,'' *IEEE Transactions on Circuits and Systems I: Regular Papers*, Vol. 54, No. 10, October 2007.]

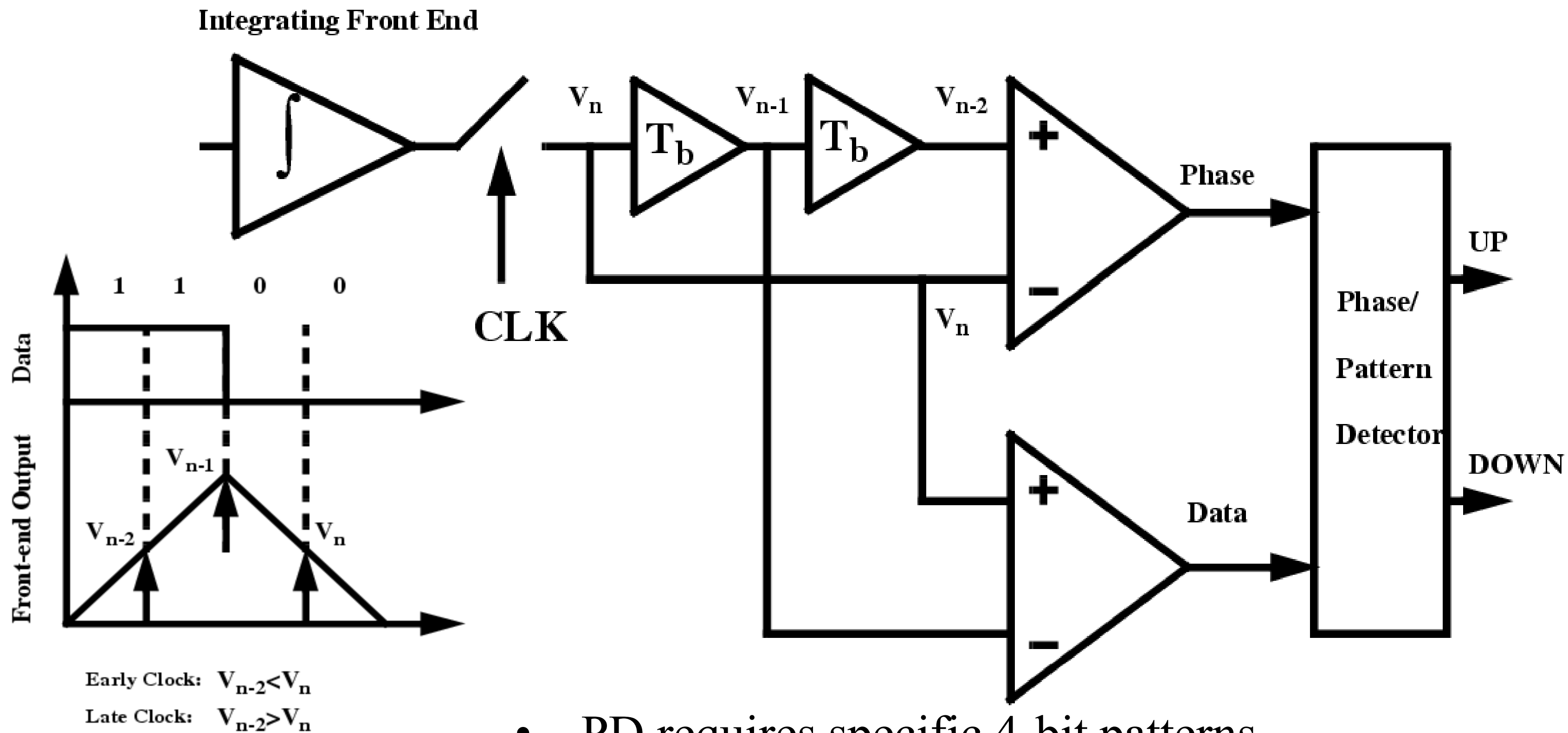
Baud-Rate TR Schemes

- Baud-rate architectures for serial links:

1. Integrating front-end based clock recovery
2. Mueller-Muller PD based clock recovery
3. Minimum Mean-Squared Error (MMSE) timing recovery [This work]

Baud-Rate TR Schemes

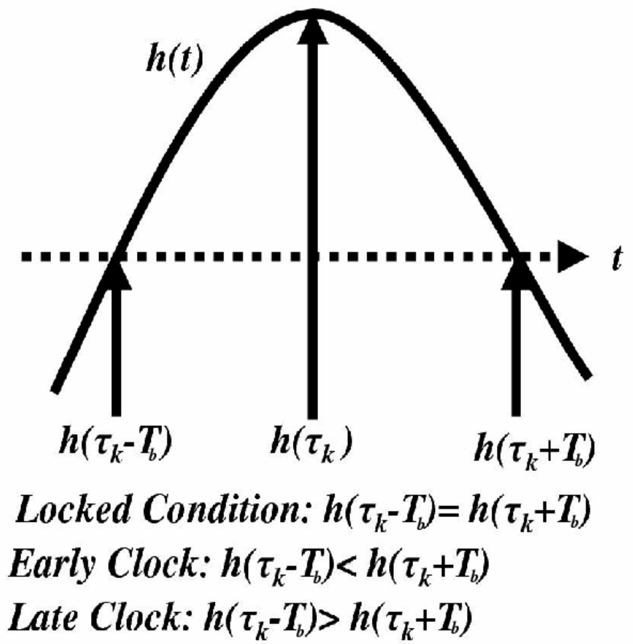
- Integrating Front-End Based PD
  [Emami-Neyestanak, A.; Palermo, S.; Hae-Chang Lee; Horowitz, M.;, *VLSI Symposium* 2004] :



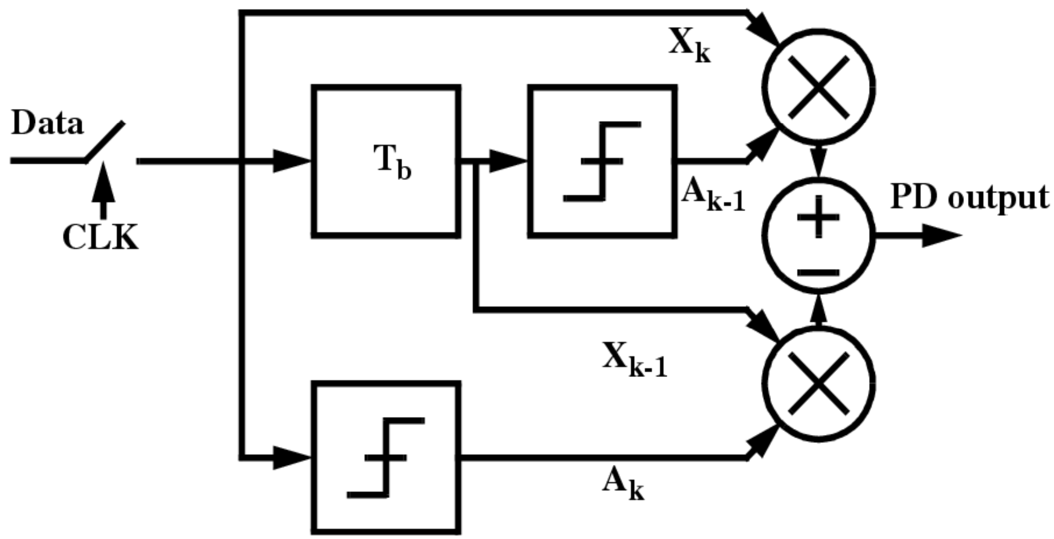
- PD requires specific 4-bit patterns

Baud-Rate TR Schemes

- Mueller-Muller Timing Recovery
  [*IEEE Trans. on Comm.*, 1976; Balan *JSSC 2005*]



(a)



(b)

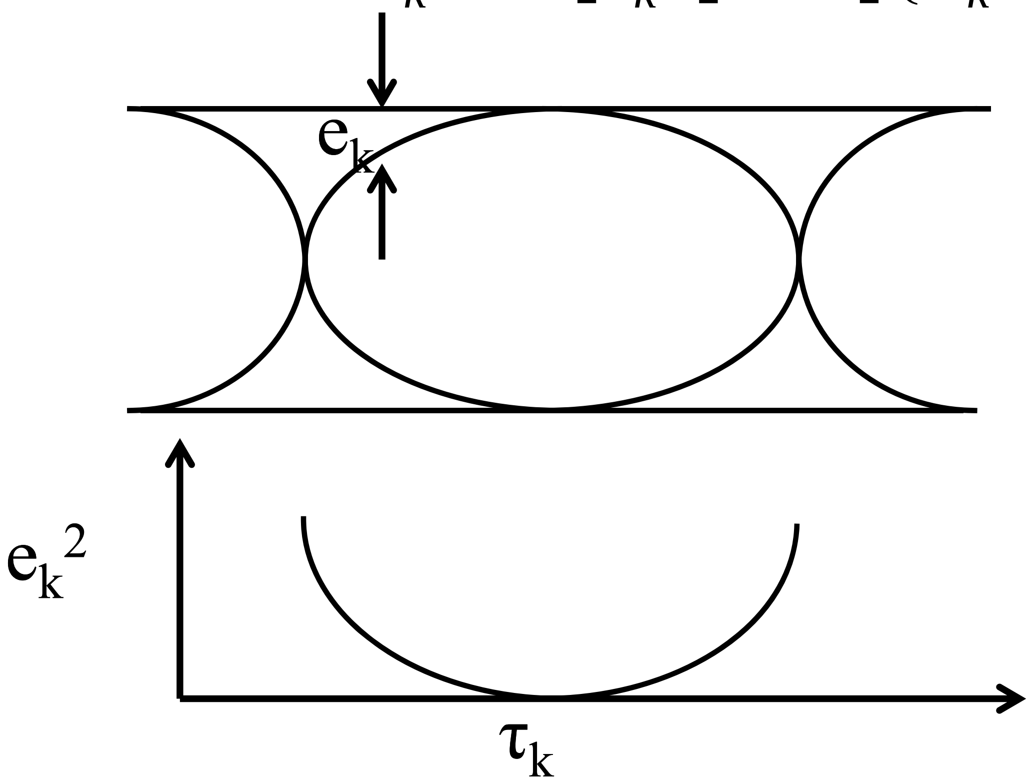
$$X_k A_{k-1} - X_{k-1} A_k \approx A^2 \left[h(\tau_k + T_b) - h(\tau_k - T_b) \right]$$

- True only for uncorrelated random data

Baud-Rate TR Schemes

- MMSE PD based CDR (This work):

$$E_k = E[e_k^{\ 2}] = E[\{A_k - y(kT_b + \tau_k)\}^2]$$

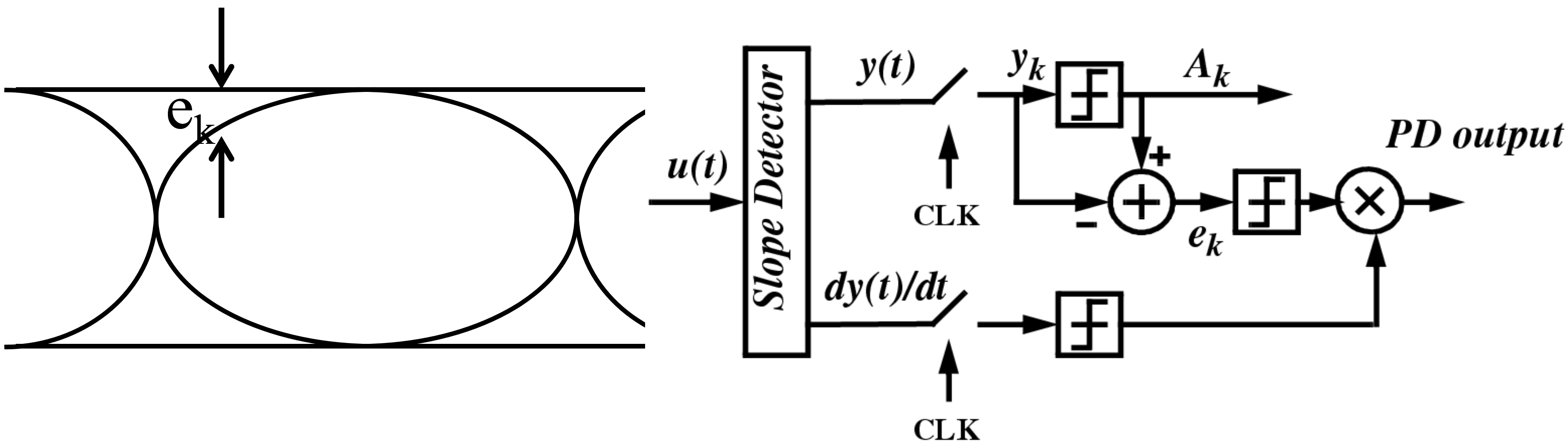


- MMSE updates the sampling phase, τ_k to minimize e_k^2:

$$\tau_{k+1} = \tau_k - \frac{dE[e_k^{\ 2}]}{d\tau_k}$$

$$= \tau_k + 2\mu e_k \frac{dy(kT_b + \tau_k)}{d\tau_k}$$

Sign-Sign MMSE



$$\tau_{k+1} = \tau_k + 2\theta_{bb}\,\mathrm{sgn}[e_k]\,\mathrm{sgn}\left[\frac{dy(kT_b + \tau_k)}{d\tau_k}\right]$$

$\Rightarrow$ Bang-bang timing recovery

Baud-Rate TR Schemes

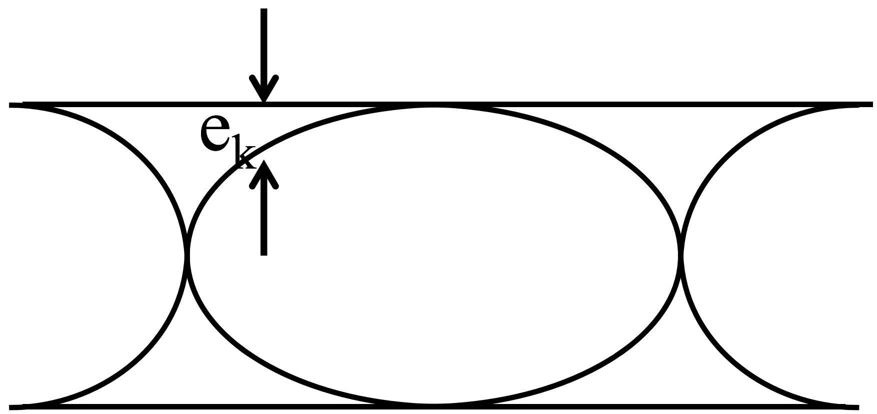
- Advantages of MMSE:

  More robust than other baud-rate techniques since there are no constraints on the input data.

- Disadvantages:

  Requires slope and error information.

Error-Signal Free Sign-Sign MMSE



$$\tau_{k+1} = \tau_k + \theta_{bb}\,\mathrm{sgn}[e_k]\,\mathrm{sgn}\left[\frac{dy(kT+\tau_k)}{d\tau_k}\right]$$

$$\approx \tau_k + \theta_{bb}\,\mathrm{sgn}[y(kT+\tau_k)]\,\mathrm{sgn}\left[\frac{dy(kT+\tau_k)}{d\tau_k}\right]$$

$$\tau_{k+1} \approx \tau_k + \theta_{bb}\,\mathrm{sgn}\left[y(kT+\tau_k)\frac{dy(kT+\tau_k)}{d\tau_k}\right]$$

Error-Signal Free Sign-Sign MMSE

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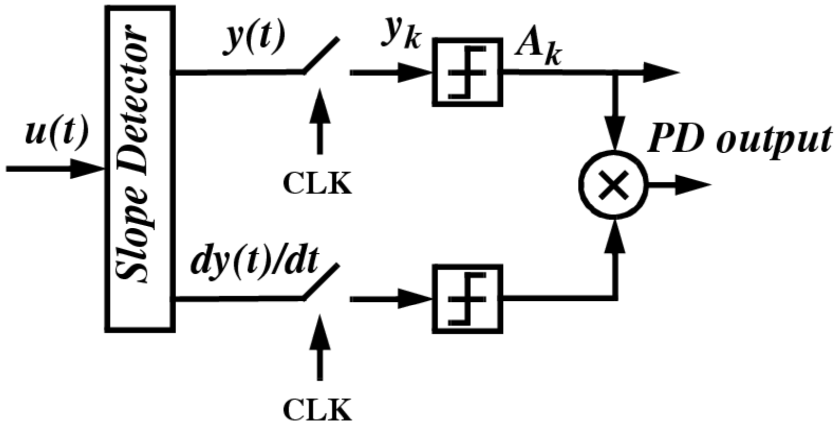

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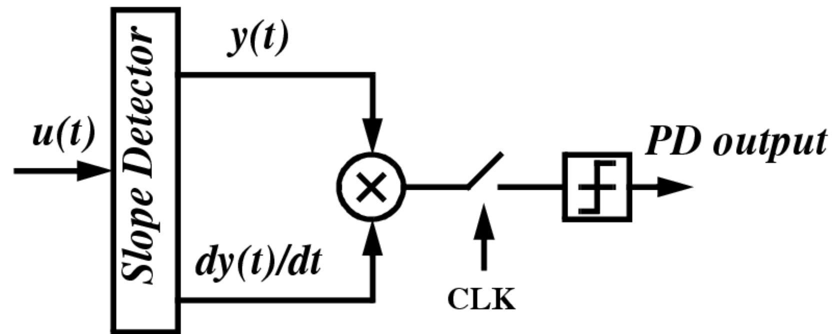
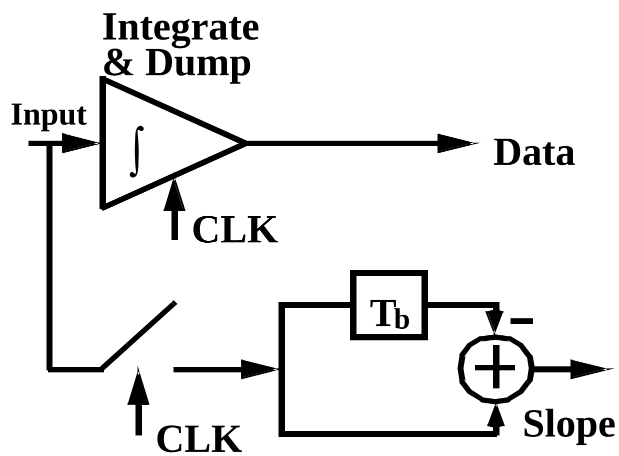


(b)

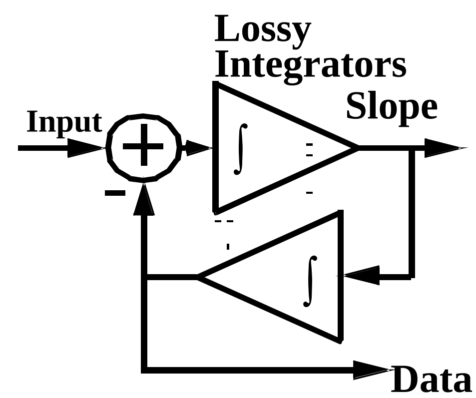
This work

Slope Detection Schemes

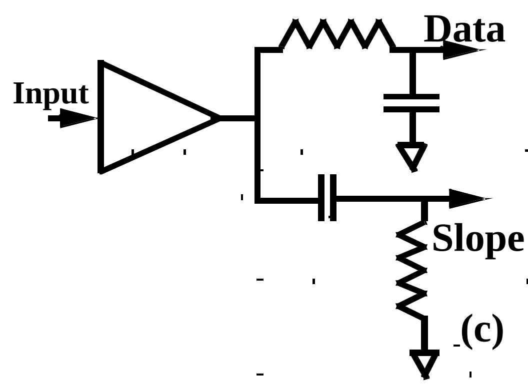
Integrate and Dump
aided Slope Detector



(a)



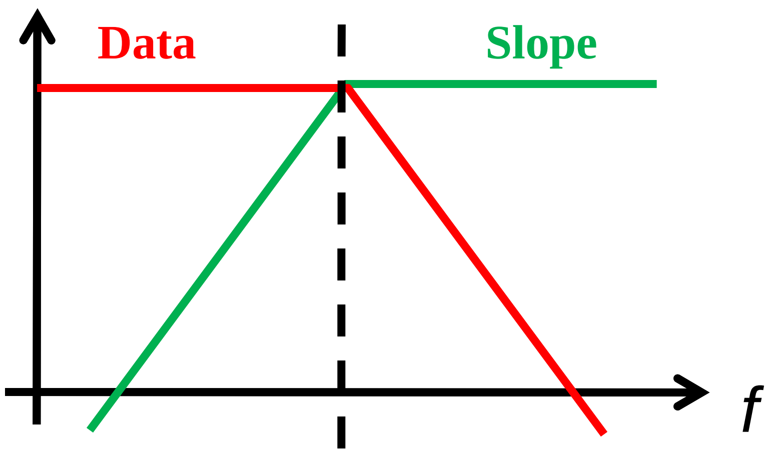
(b) Active Filter aided
Slope Detector



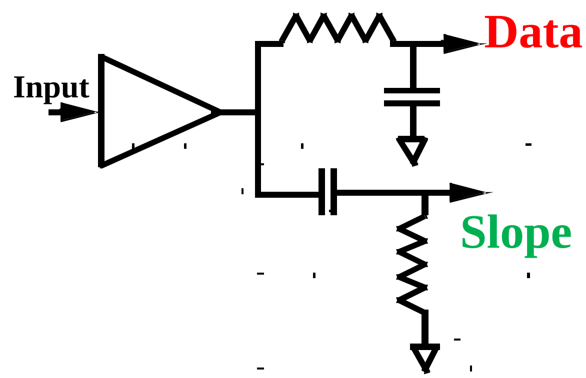
(c) Passive Filter aided Slope Detector
[This work]

Choice of RC time constant

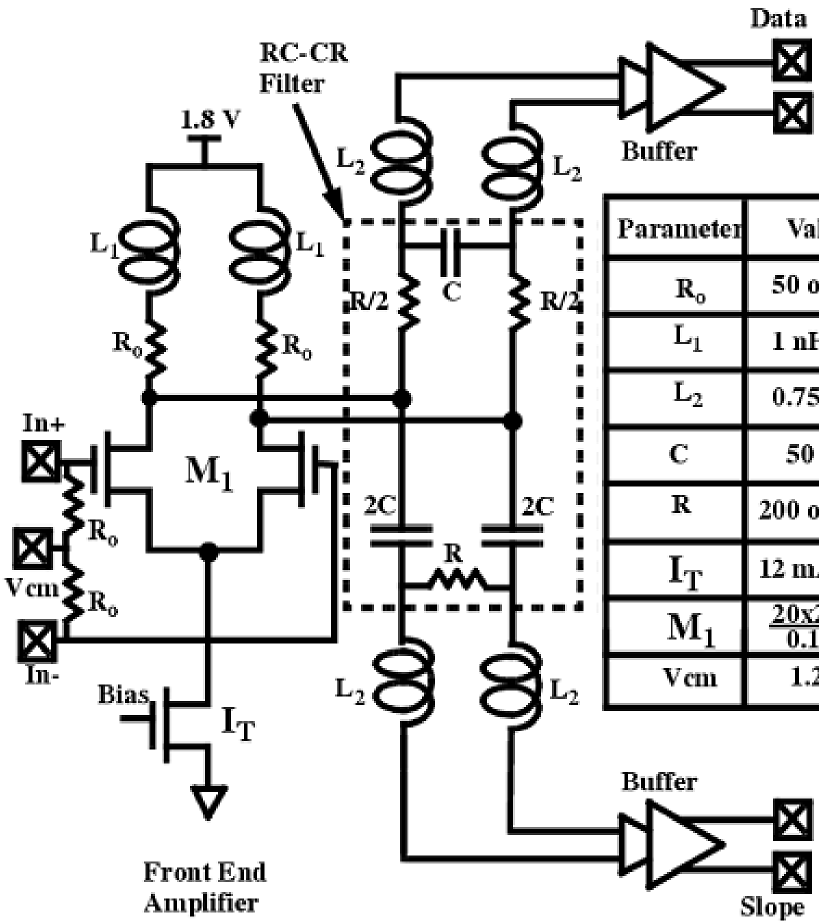
- For 10-Gb/s data, the RC time constant was chosen to be 10ps: R = 200 Ω, C = 50 fF



$1/2\pi RC >> 0.5f_{bit}$



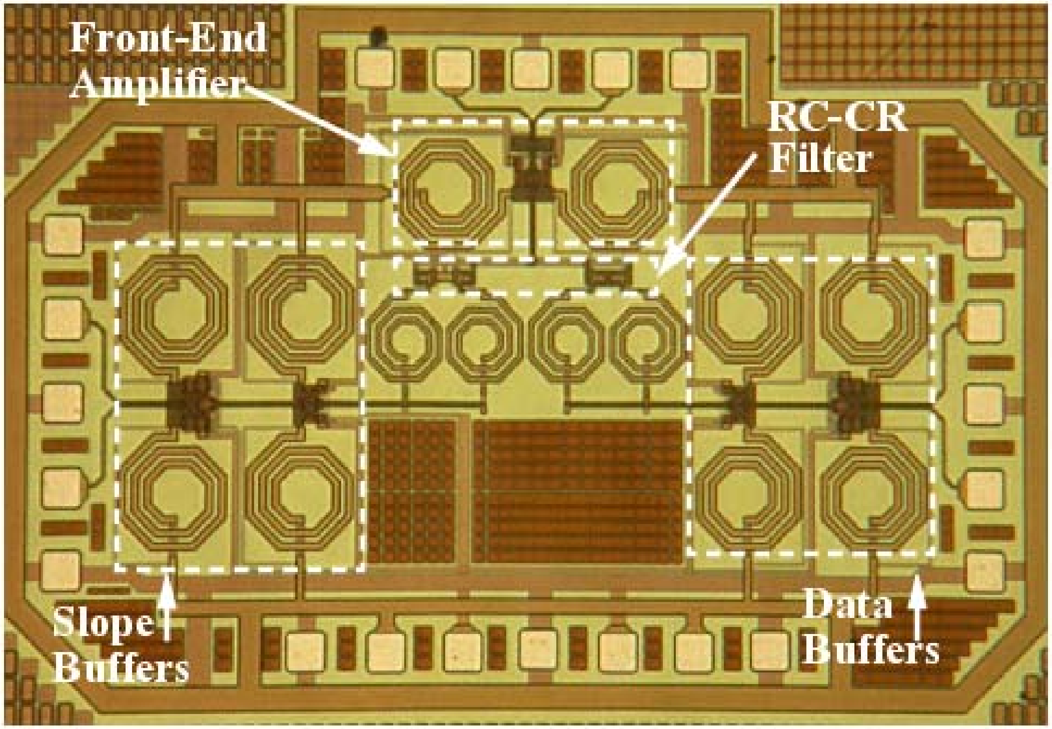
Passive Filter



Parameter	Value
R_o	50 ohms
L_1	1 nH
L_2	0.75 nH
C	50 fF
R	200 ohms
I_T	12 mA
M_1	$\frac{20x2u}{0.18u}$
Vcm	1.2 V

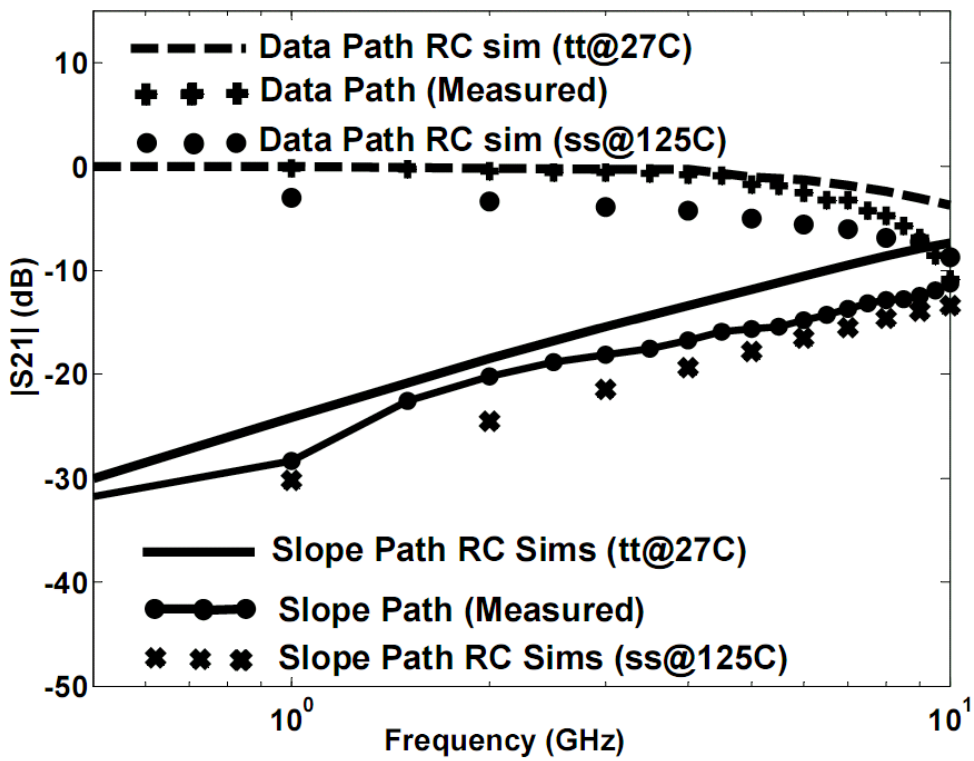
- **Inductors improve bandwidth without compromising the relative phase shift between the data and slope paths.**

Die Photo



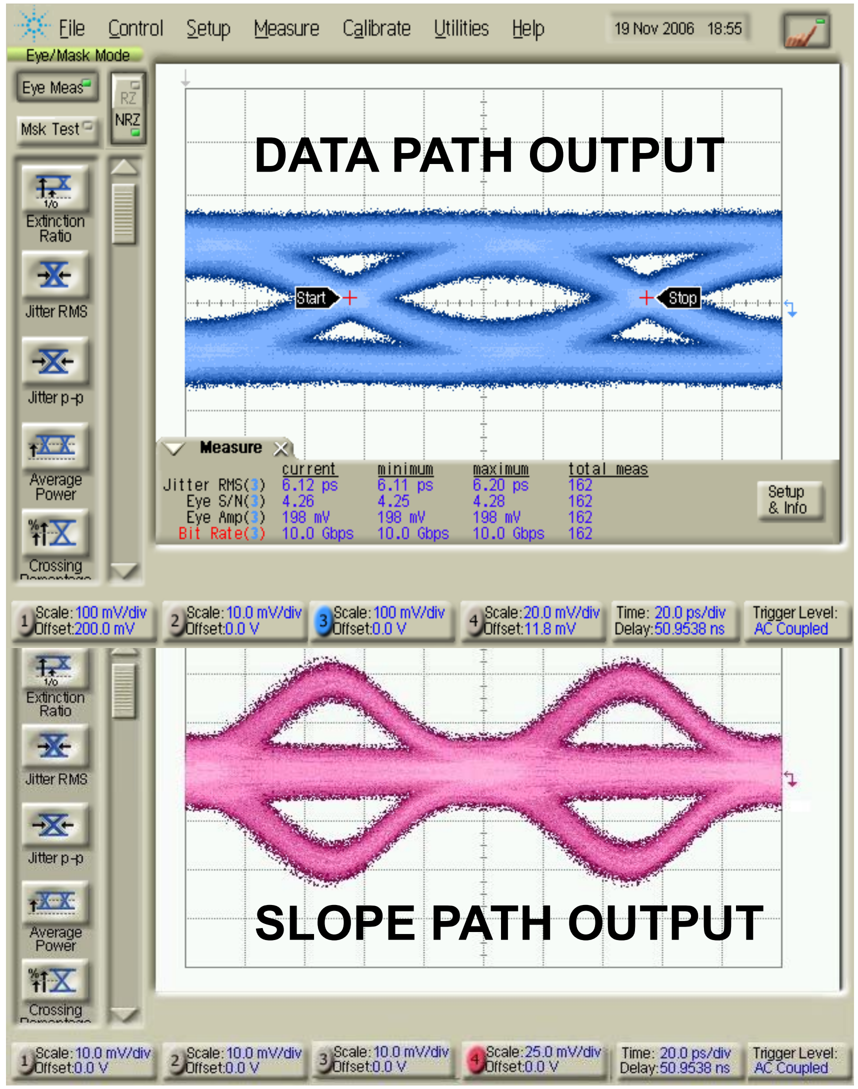
0.18 µm CMOS; Die area=1.1 mm^2

Measurement Results



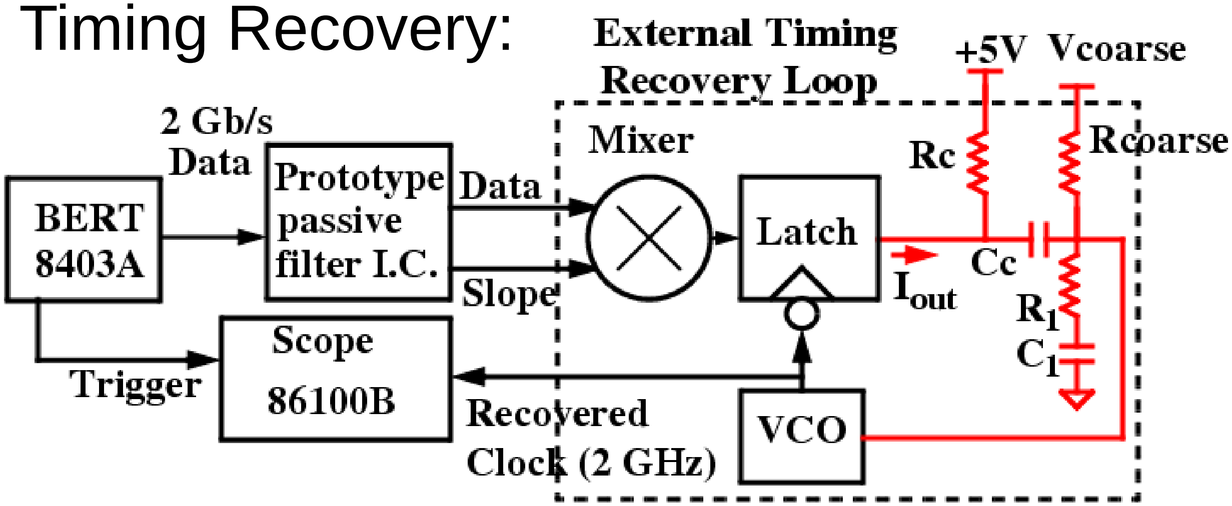
Network Analyzer Measurements:
Data Path Bandwidth (Measured)=6-GHz.
S_{21} in Slope Path increases @ 20dB/dec.

Measurement Results

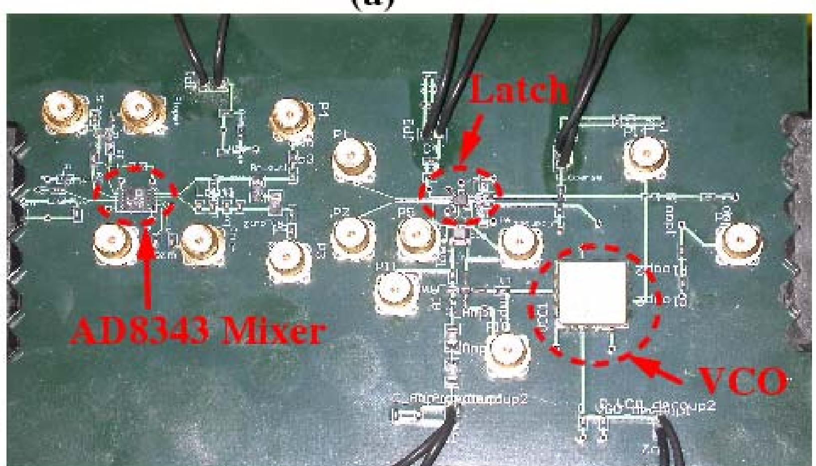


Measurement Results

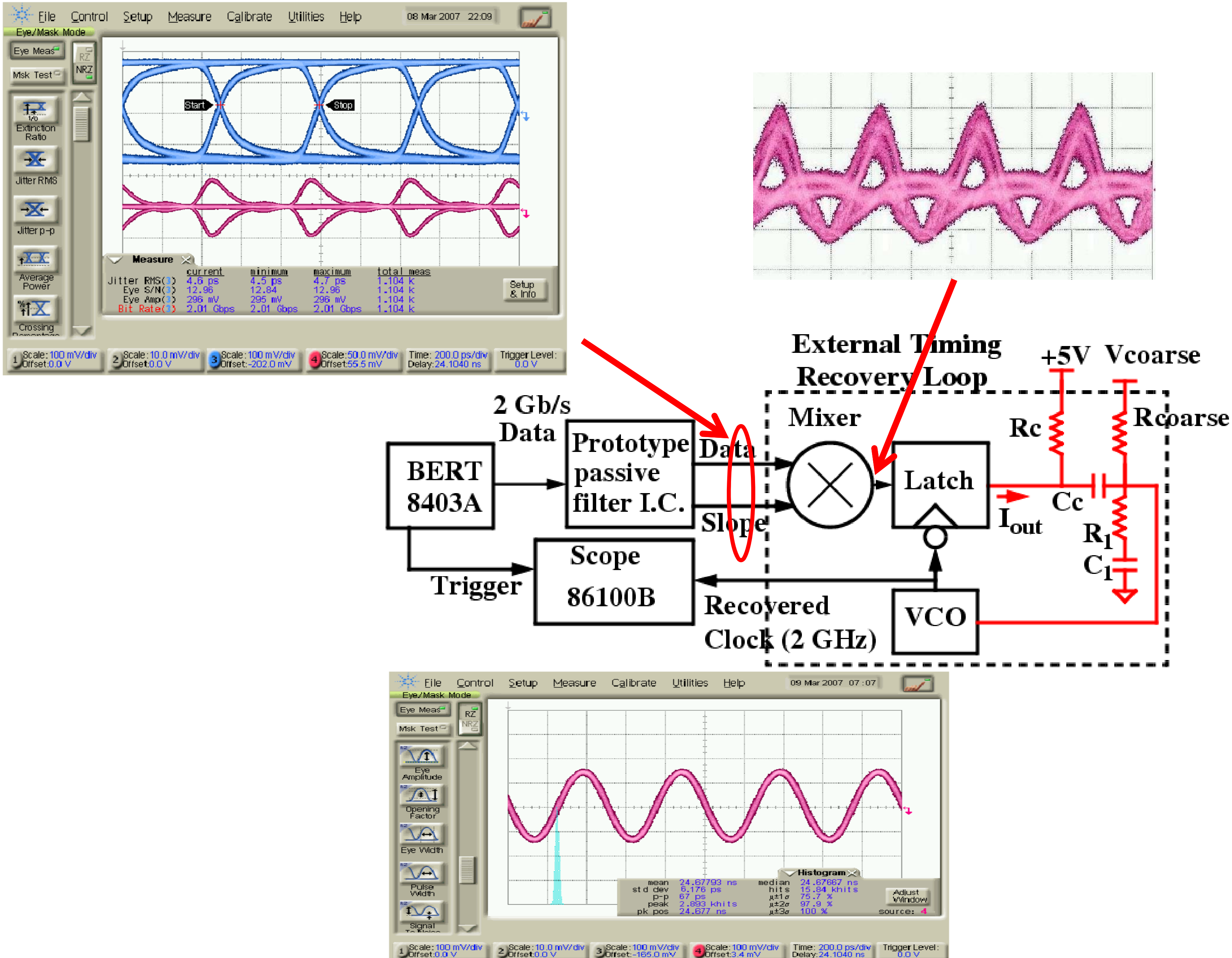
- External Timing Recovery:



(a)



(b)


External Timing
Recovery Loop
+5V
Vcoarse
Mixer
Rc
Rcoarse
2 Gb/s
Data
BERT
8403A
Prototype
passive
filter I.C.
Data
Slope
Latch
Cc
I_{out}
R_1
C_1
Scope
86100B
Trigger
Recovered
Clock (2 GHz)
VCO

Conclusions

- A passive filter that provides simultaneous low-pass and high-pass characteristics was presented.
- The high-pass transfer characteristic is utilized to provide slope information that is aligned with the low-pass data output.
- Data and slope signals from the passive filter can be used to recover a clock based on modified MMSE timing recovery.
- Prototype passive filter was used with external components to recover a 2-GHz clock from a 2-Gb/s 2^{31}-1 random data sequence.

Thank you

Passive Filter