



IEEE 802.3ae Meeting, New Orleans,
Sep. 12-14, 2000



Implementation of SiGe IC solution for 10G equalization of PMD (Polarization Mode Dispersion)

Henning Bülow

Alcatel Corporate Research Center

Stuttgart, Germany

hbuelow@rcs.sel.de



1 Outline

- u Position of our work
- u PMD induced distortion
- u Numerical analysis of equalization
- u SiGe equalizer ICs
- u PMD mitigation experiments
- u Adaptation schemes

1 Conclusion

1 References



- u $\geq 10\text{Gb/s}$, SONET (OC-192)
- u Long link length, $> 100\text{km}$
- u Single-mode fiber !
- u Optical amplification (EDFA, $1.55\mu\text{m}$)

- u Transmission limited by
 - Optical noise (OSNR limited)
 - Chromatic dispersion (GVD)
 - Fiber non-linearity (SPM, FWM, XPM, Raman)
 - **PMD** (some fibers)

- u Mitigation of these impairments
 - Optical signal processing (e.g. DCF,...)
 - **Post-detection electronic signal processing**

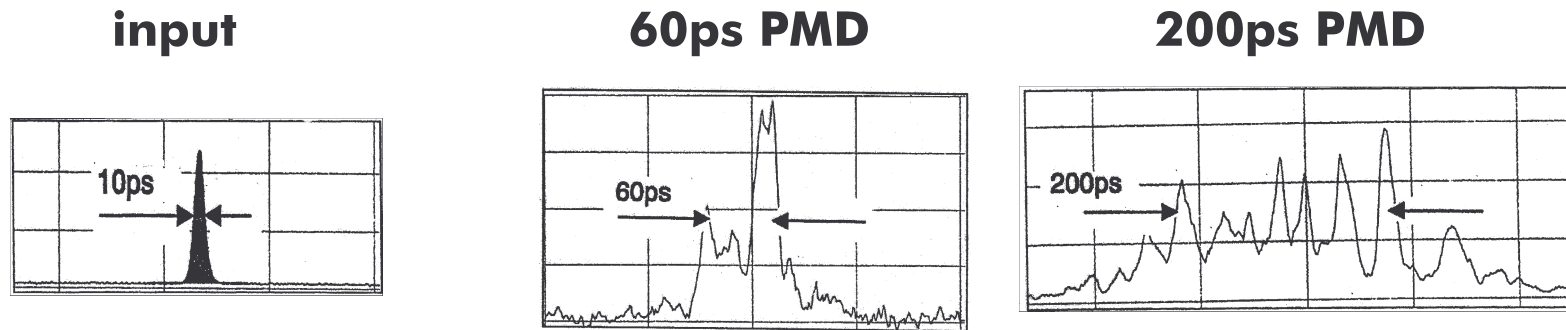


- u PMD model = cascaded optical birefringences of transmission fiber
 - w. signal splitting at butt coupling points
- u leads to multi path propagation

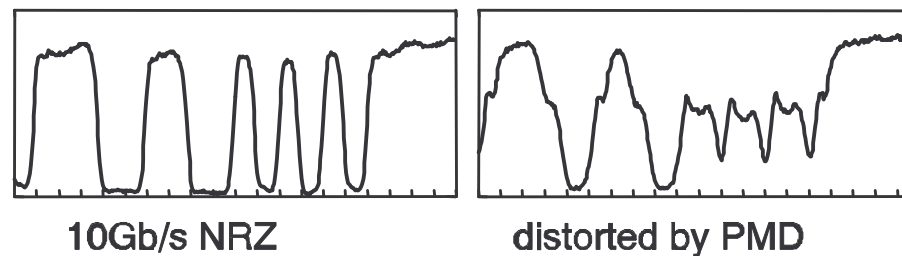


- u Similar to DMD where the signal spreads among many waveguide modes (= paths) w. different group delays

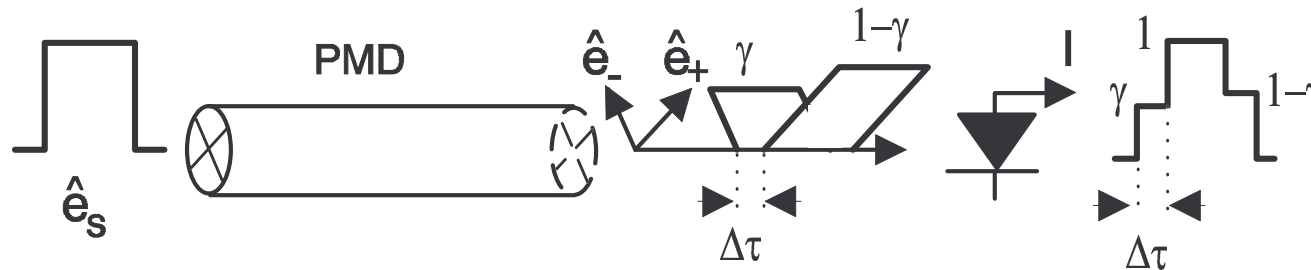
- u Pulse responses of high PMD lab fibers w. 60ps and 200ps PMD



- u First-order PMD leads to dual path propagation



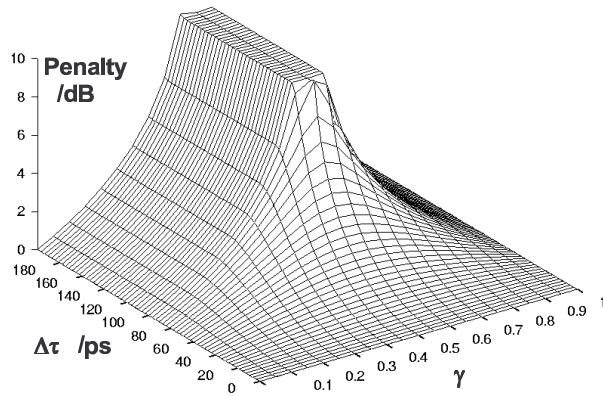
- u 1st-order PMD distortion quantified by
 - ▶ differential group delay (DGD) $\Delta\tau$
 - ▶ relative fast axis power γ



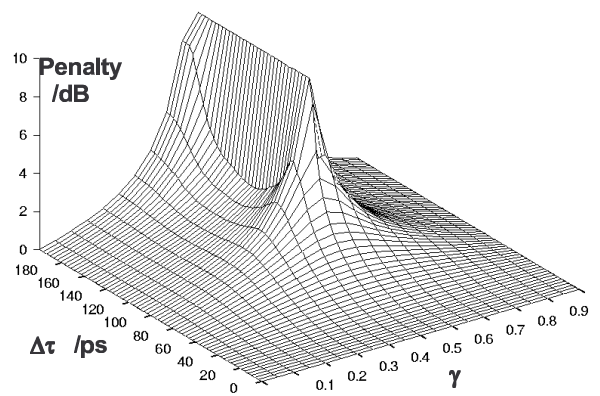


- Residual penalty (reduction of receiver sensitivity) vs. PMD distortion plane

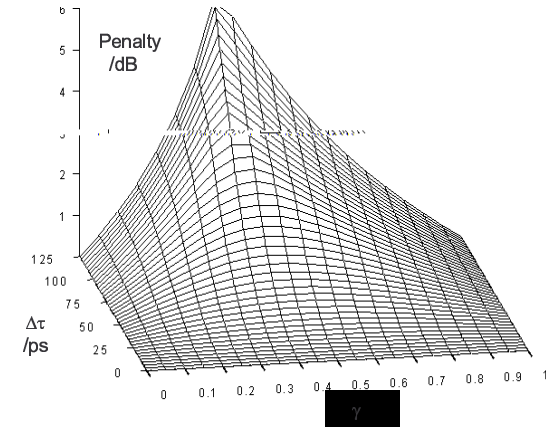
w/o. equalizer



FFE

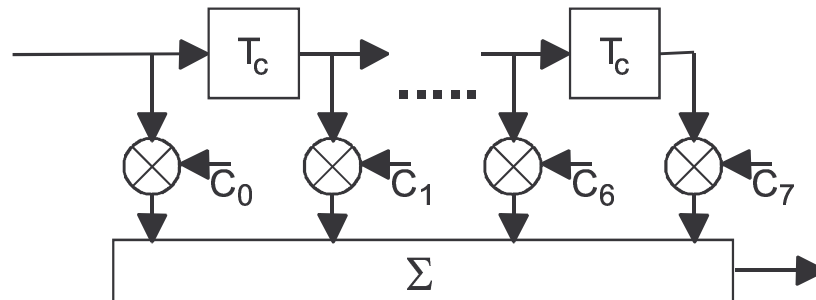


DFE
(1 feedback)



- PMD induced high penalty and penalty poles can be mitigated by electronic equalization

- u Transversal filter (TF) = Feed forward equ. (FFE)
 - 10Gb/s
 - 8 taps
 - 55ps spacing (fractionally spaced)
 - “analog” processing (HBT)
 - 1 delays by amp cascades
 - 1 \approx 200mV differential signals

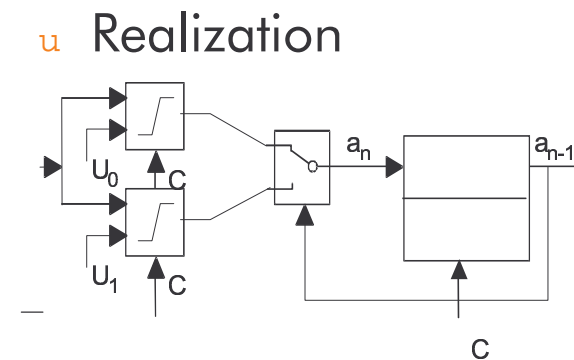
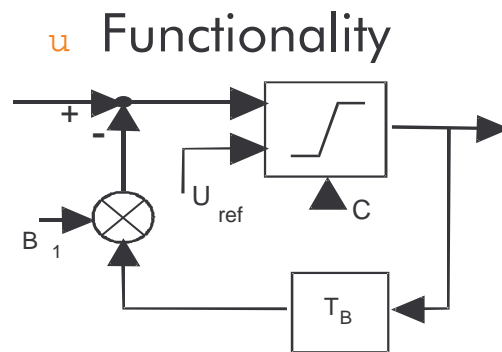




u Decision feedback equalizer

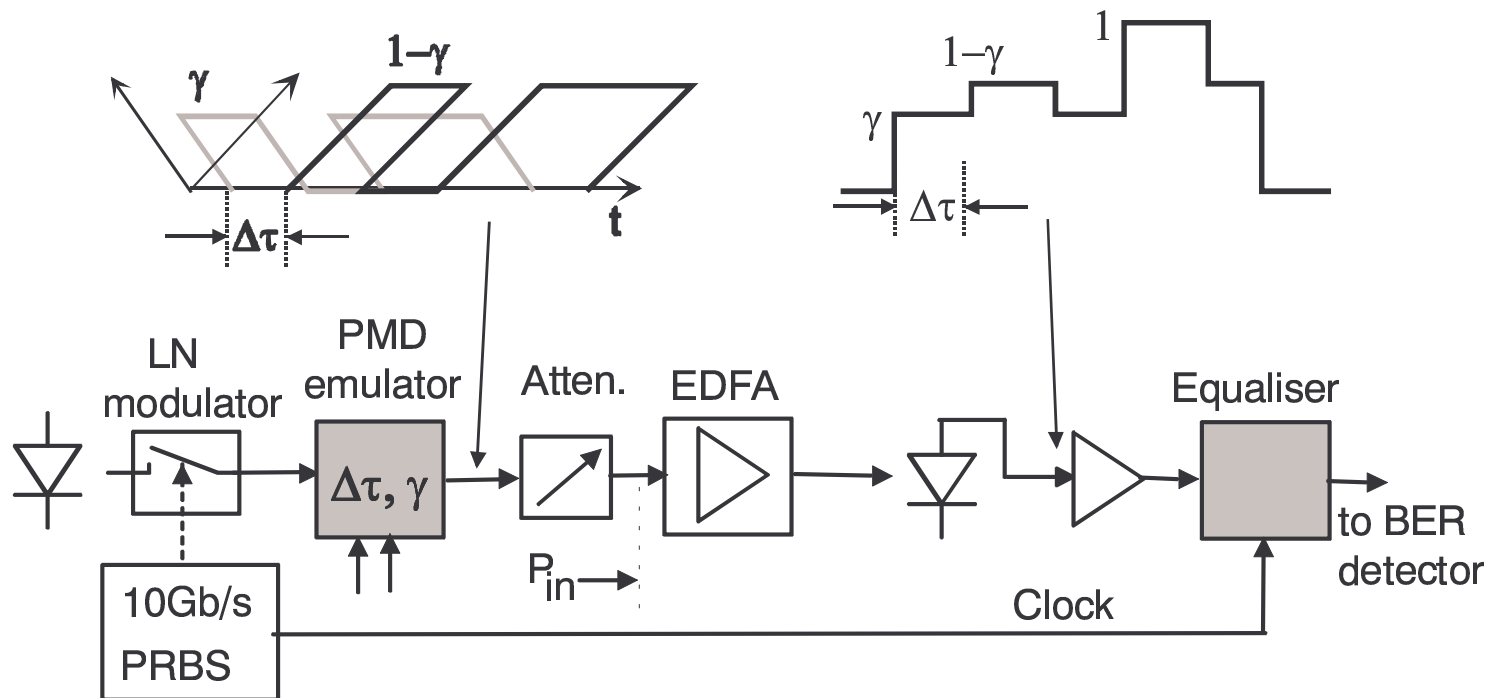
- ▶ 10Gb/s
- ▶ 1 feedback loop
- ▶ high-speed realization
- ▶ “analog” processing (HBT)

(S.Kasturia, J.H.Winters, J. on Select. Areas Commun., 1991, pp. 71)



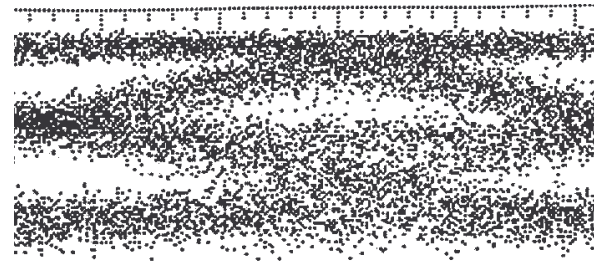
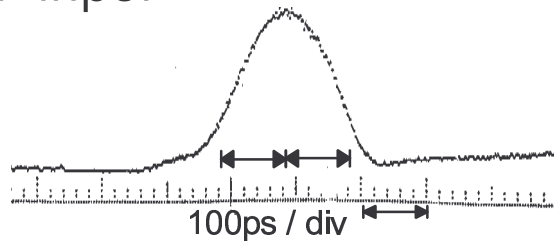


- u 10Gb/s
 - u 1st-order PMD emulator
 - u manual optimization of taps
 - u EDFA preamp determines noise (optical signal-to-noise ratio limited, OSNR)
- ⇒ penalty_{OSNR} ≈ 2x penalty_{thermal noise}

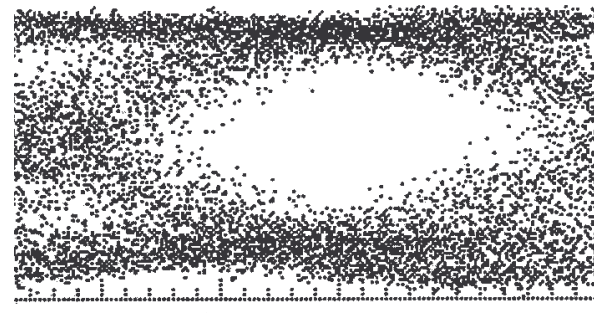
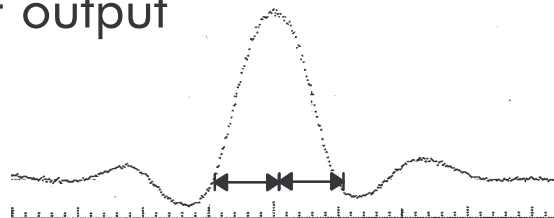


PMD distortion of $\gamma = 0.5$ and $\Delta\tau = 70$ ps

TF input

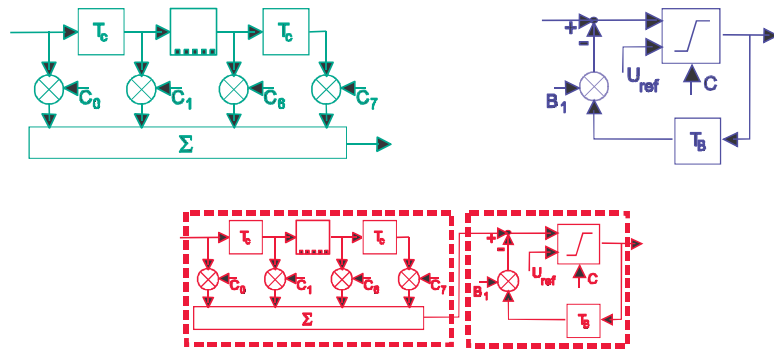


TF output

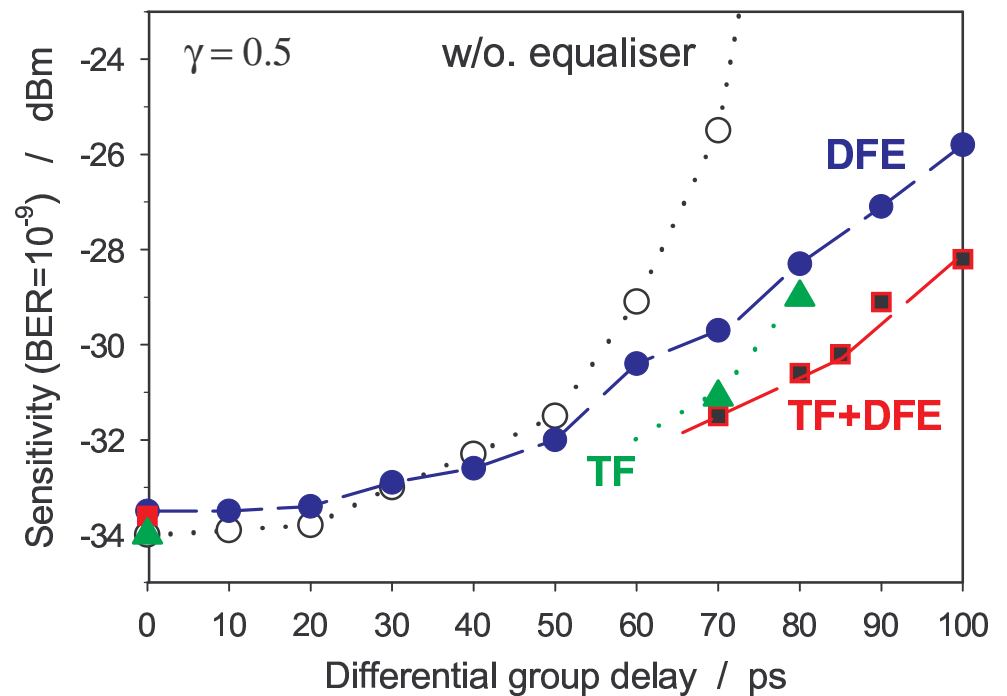




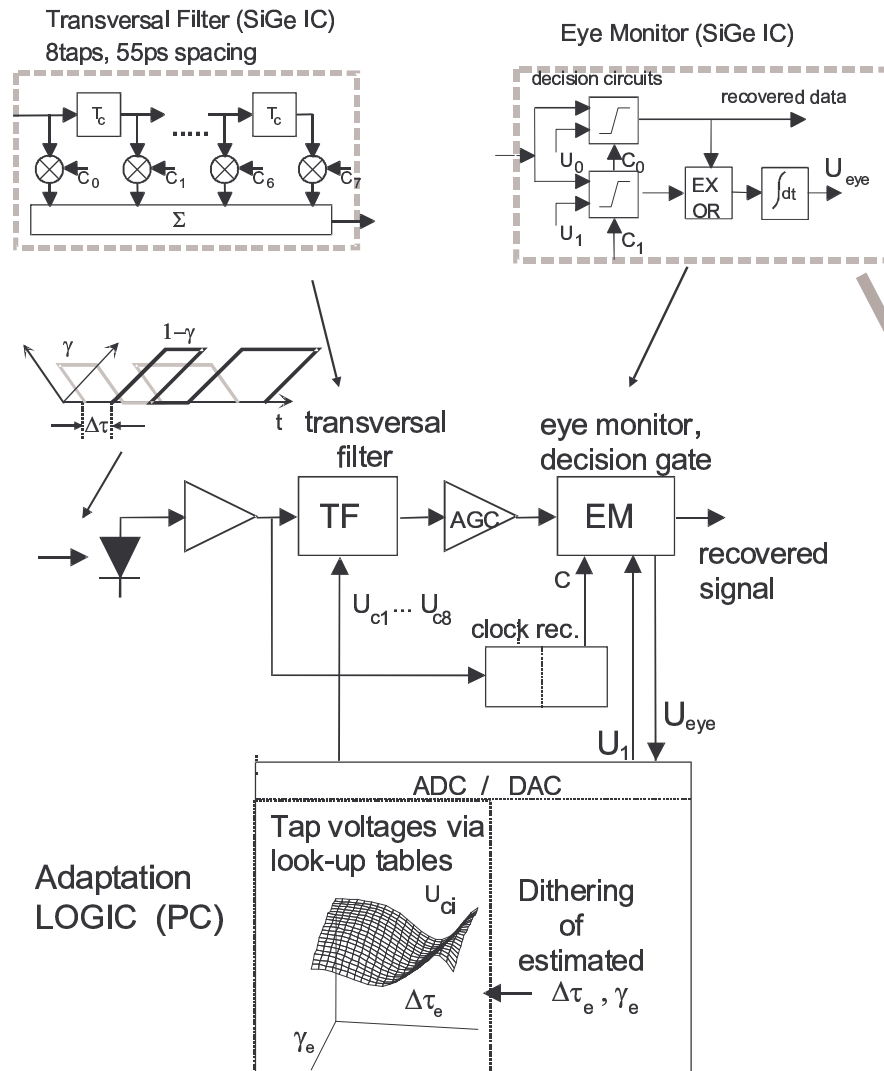
Since OSNR limited (EDFA)
 \Rightarrow more than 2x thermal noise penalty (dB)



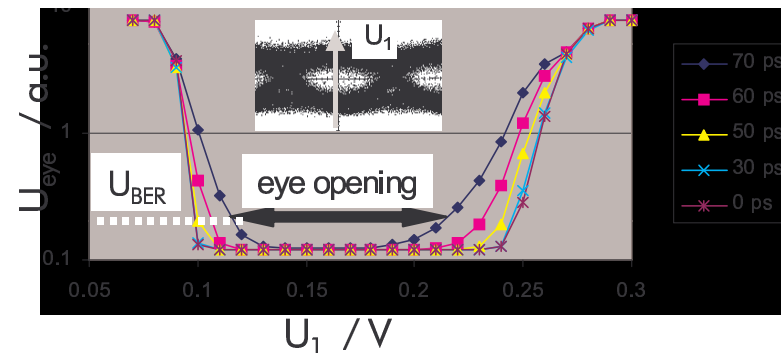
Electron. Lett., v.36, n.2, 2000, pp.163



u FFE (TF) + DFE superior to TF or DFE

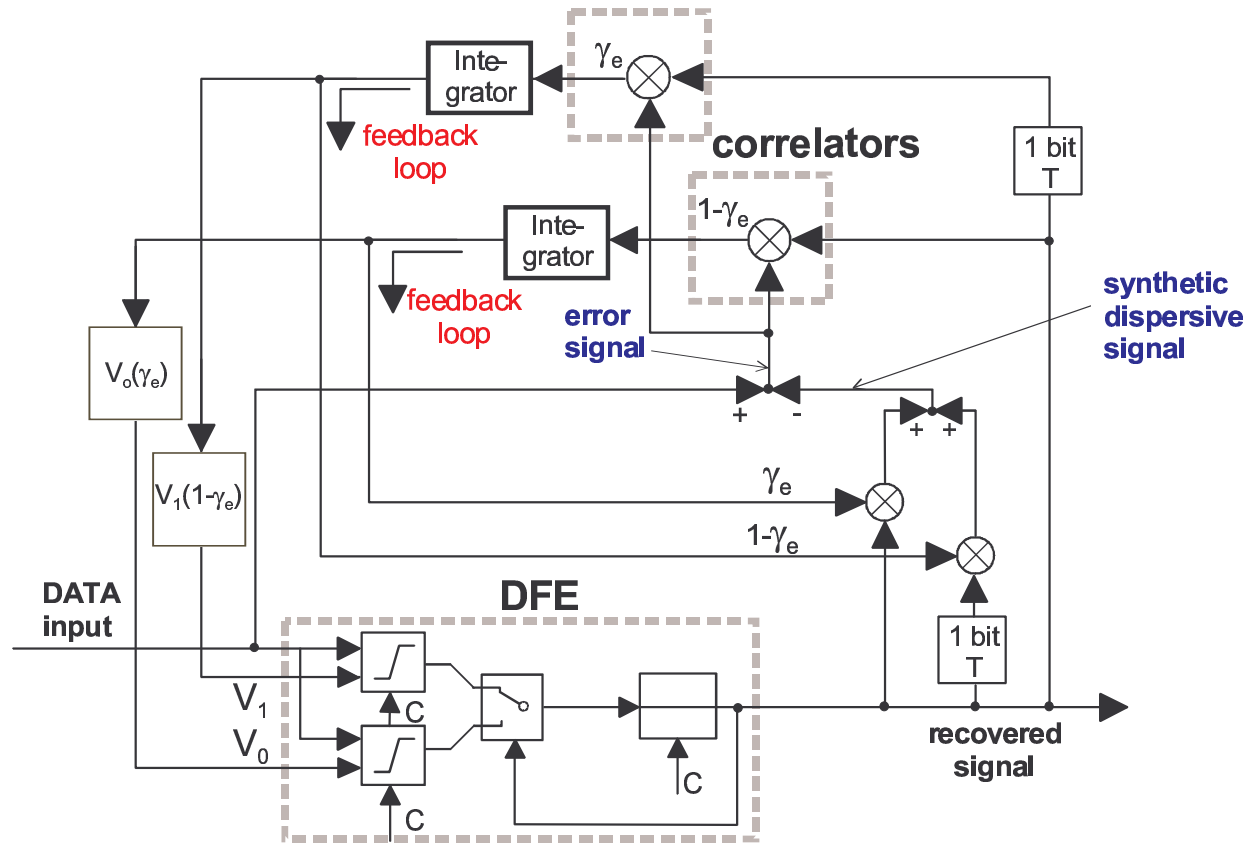


- u Transversal filter adaptation by optimization of output signal
 - TF output signal analyzed by eye monitor IC (SiGe)
- u Dithering of taps
 - some 10ms speed





- u DFE (+ 1 FFE tap) adaptation by zero-forcing scheme
 - hybrid setup for feasibility demo
 - speed well below 1ms (w/o. optimization of electronics)



- u Detected PMD of single-mode fiber \approx DMD of multi-mode fiber
 - u Post-detection signal processing can be applied to mitigate PMD
 - u Equalizers ICs in SiGe (HBT) have been manufactured for analog processing at 10G
 - 8 tap FFE
 - 1 bit delay DFE
 - u Concept confirmed experimentally by demonstration of strong penalty reduction
 - u First adaptation experiments
- ⇒ equalization at 10G works for PMD
- ⇒ attractive concept also for DMD mitigation



- [1] H.Bülow, R.Ballentin, W.Baumert, G.Maisonneuve, G.Thielecke, T.Wehren, “Adaptive PMD mitigation at 10 Gbit/s using an electronic SiGe equaliser IC”, proc. ECOC’99, Sep 26-30, Nice, France, 1999, We C3.4, pp. 138-139
- [2] H.Bülow, “Limitation of Optical First-Order PMD Compensation”, Techn. Dig. OFC/IOOC’99, San Diego, Feb. 1999, WE1
- [3] H.Bülow, W.Baumert, H.Schmuck, F.Mohr, T.Schulz, F.Küppers, W.Weiershausen, “Measurement of the Maximum Speed of PMD Fluctuation in Installed Field Fiber”, Techn. Dig. OFC/IOOC’99, San Diego, Feb. 1999, WE4
- [4] H.Bülow, "System Outage Probability Due to First and Second Order PMD", Photon. Technol. Lett., vol.10, no.5, 1998, pp. 696-698
- [5] H. Bülow, F. Buchali, W. Baumert, R. Ballentin, T. Wehren, “PMD mitigation at 10 Gbit/s using linear and nonlinear integrated electronic equaliser circuits”, Electron. Lett., v. 36, n. 2, 2000, pp. 163-164
- [6] H. Bülow, “PMD mitigation techniques and their effectiveness in installed fiber”, Techn. Dig. OFC’00, Baltimore, Mar. 7-10, ThH1, 2000, pp. 110-112
- [7] F. Buchali, H. Bülow, W. Baumert, R. Ballentin, T. Wehren, “Reduction of the Chromatic Dispersion Penalty at 10 Gbit/s by Integrated Electronic Equalisers”, Techn. Dig. OFC’00, Baltimore, Mar. 7-10, ThS1, 2000, pp. 268-270
- [8] H. Bülow, W. Baumert, F. Buchali, W. Kuebart, “Adaptation of an Electronic PMD Mitigator by Maximization of the Eye Opening”, proc. ECOC 2000, Sep 3-7, Munich, Germany, 2000, P3.10
- [9] F. Buchali, H. Bülow, W. Kuebart, “Adaptive Decision Feedback Equalization for 10 Gbit/s Dispersion Mitigation”, proc. ECOC 2000, Sep 3-7, Munich, Germany, 2000, 5.2.5
- [10] H. Bülow, F. Buchali, G. Thielecke, “Electronically Enhanced Optical PMD Compensation”, proc. ECOC 2000, Sep 3-7, Munich, Germany, 2000, 4.2.4