Mixed Signal
Electronic Dispersion Compensation

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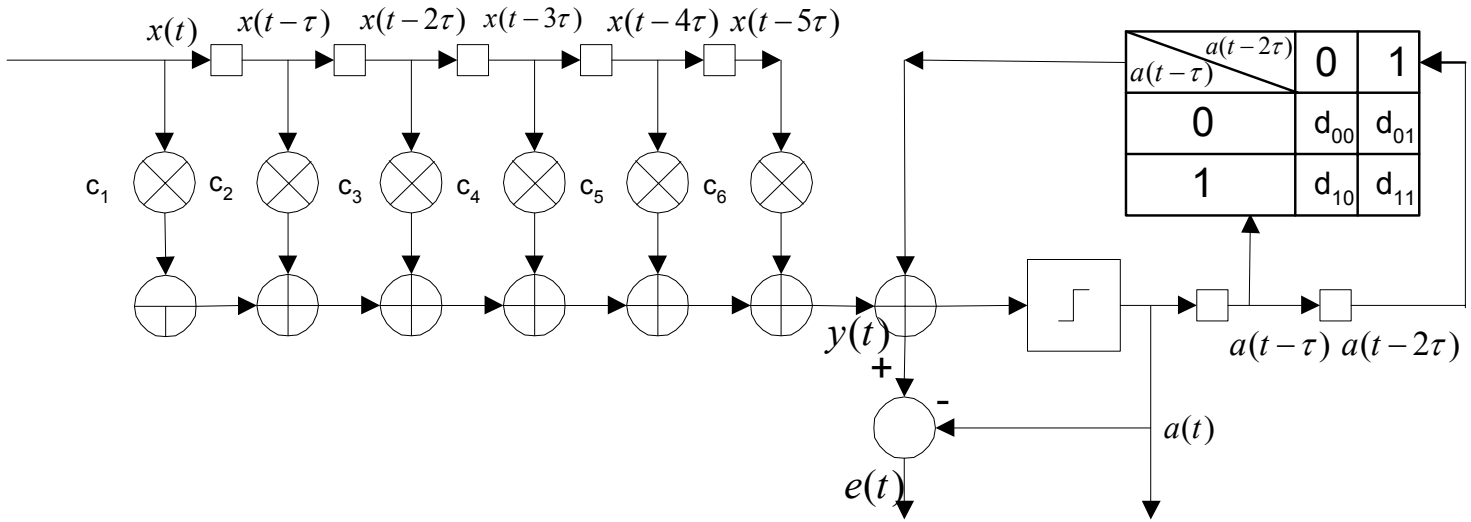
Overview

- Performance Goals: 10G transmission through FDDI-grade multimode fibers over 300m at 850 and 1300 nm.
- Intermodal dispersion is the dominant impairment for the MMF fibers.
- Implementation issues for pure digital equalization.
  - 20G ADC for the fractionally-spaced equalizer.
  - 10G digital multipliers.
- Mixed signal implementations to address the digital shortcomings
- The equalizer technology has been validated for single-mode applications.

Equalizer Technology
Features of Mixed Signal Equalizer

- Continuous-time analog transversal filter for feed forward
  - Eliminates the requirement for high speed A-to-D Converter
- Digital look-up table for feedback
- Digital coefficient control circuit
  - Compensates for temporal changes and non-ideal behavior of analog circuits
  - Averaging process allows slower operational speed to compute coefficient updates
- Clock is recovered after the forward transversal filter
  - More robust convergence

Equalizer Technology
Mixed Signal DFE
(Decision Feedback Equalizer)



- Analog implementation of feed forward taps
- Digital look-up table for feedback coefficients
- Digital control circuit provides the coefficient updates

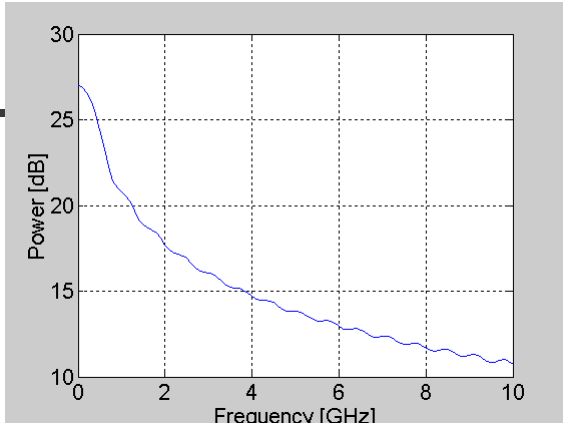
Modeling Multimode Fibers

- Based on linear systems analysis[1].
- Intermodal dispersion modeled as the major impairment.
- Graded- index characterized by the α-profile.
- Fiber transfer function generated assuming overfilled launch (OFL).

1. E. Walker, "A Model for the α-Provile Multimode Optical Fiber Channel: A Linear Systems Approach, Journal of Lightwave Technology, Vol. 12, No. 11, Nov. 1994.

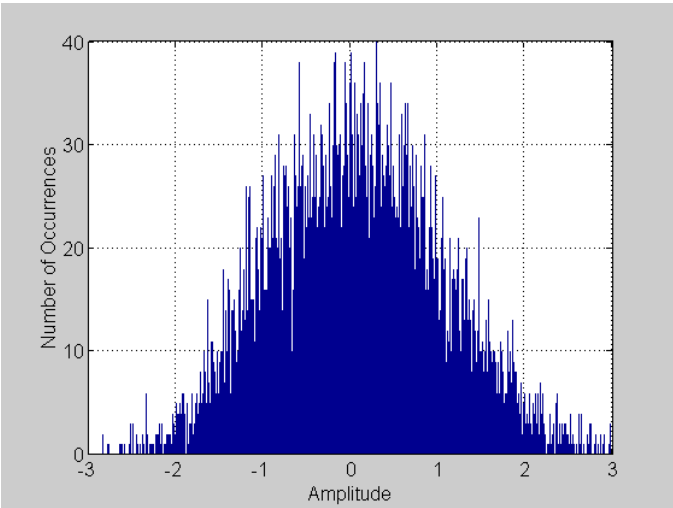
Mixed Signal Equalizer
FDDI-grade Multimode Fiber at 850 nm

Fiber Transfer Function

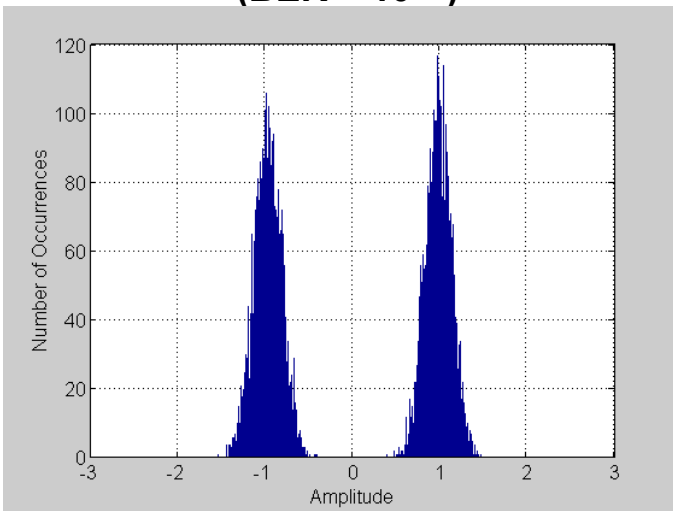


- **160/500 MHz*km 62.5u MMF**
- **3 dB BW: ~533 MHz**
- **Operating Wavelength: 850 nm**
- **Transmission Dist.: 300 m**
- **Channel SNR: 30 dB**

Original SNR at slicer = -1.0 dB

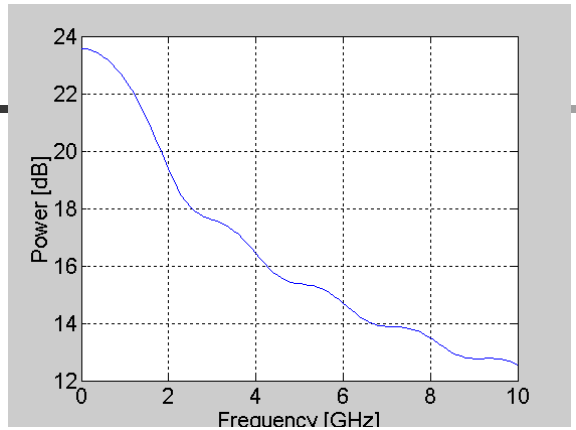


Equalized SNR at Slicer = 16.1 dB (BER = 10^{-10})



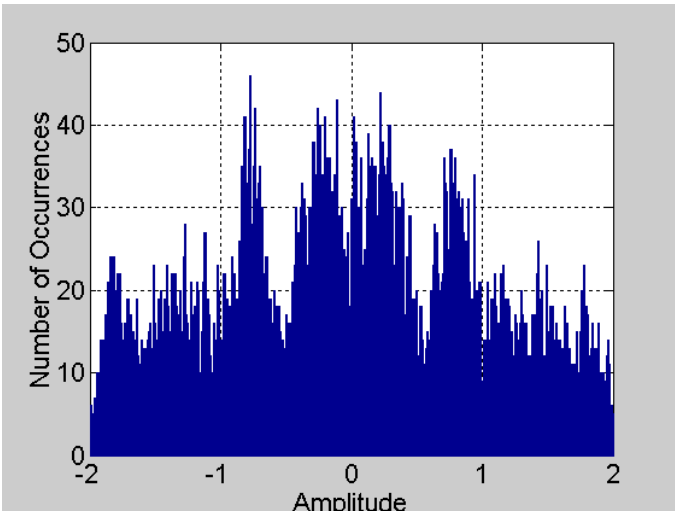
Mixed Signal Equalizer
FDDI-grade Multimode Fiber at 1310 nm

Fiber Transfer Function, Magnitude

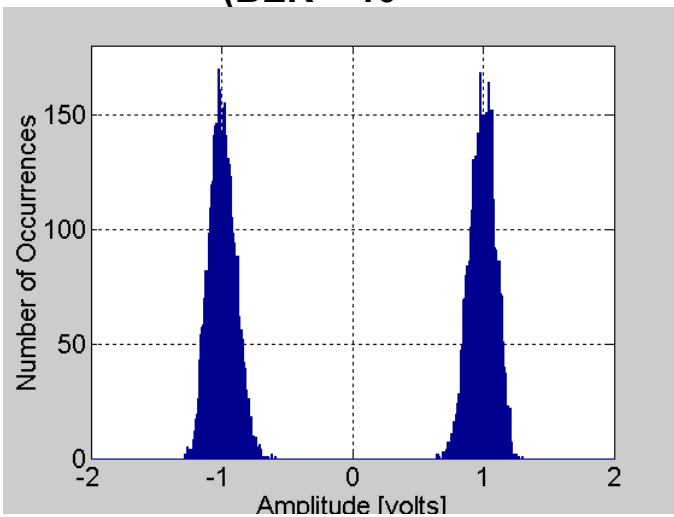


- **160/500 MHz*km 62.5u MMF**
- **3 dB BW: ~1.7 GHz**
- **Operating Wavelength: 1310 nm**
- **Transmission Dist.: 300 m**
- **Channel SNR: 30 dB**

Original SNR at the slicer = -3.3 dB



Equalized SNR at the Slicer = 20.0 dB
(BER < 10^{-20})



Equalizer Technology
DFE Power and Size First Order Estimates

Item	Gates	Power (mW)	Size
Analog Feed-Forward Filter		60	200 x 100 micron (7.8 x 3.9 mil)
MUX		50	
CDR		200[1]	
DigitalControl Circuit	20K	135[2]	
DACs		200[3]	
ADCs		60[4]	
JTAG and Other Logic	20K	0[5]	
Total		705	Pad Limited

1. Savoj and Rezavi, "Design of Half-rate CDR circuits For Optical Communication Systems," DAC 2001, Las Vegas, NV, June 18-22, 2001. 2 x 100mW with margin.
2. 7W/1.3 M Gates/80MHz*100%*20K Gates*100MHz = 135mW
3. I_out = 1V/50Ohm = 20mA. 20mA*2.5V(supply) * 4 = 200mW for core circuits.
4. 20MOSFETS/Comparator*4mW/20MOSFETS*7(3-bits)*4*50%duty = 56mW. 60mW with margin.
5. Test mode only—No power during operation.

Mixed Signal Equalizer Conclusions

- **Mixed signal architecture provides practical solution for 10G optical link.**
  - Analog feed forward transversal filter, digital look up table feedback.
  - Digital control compensates for non-ideal analog circuits.
  - Clock is recovered after the forward transversal filter for robust convergence.
- **System simulations demonstrate excellent performance.**
- **Implementation architectures realizable in 0.18 um CMOS technology.**
- **Power estimate below 1 Watt.**

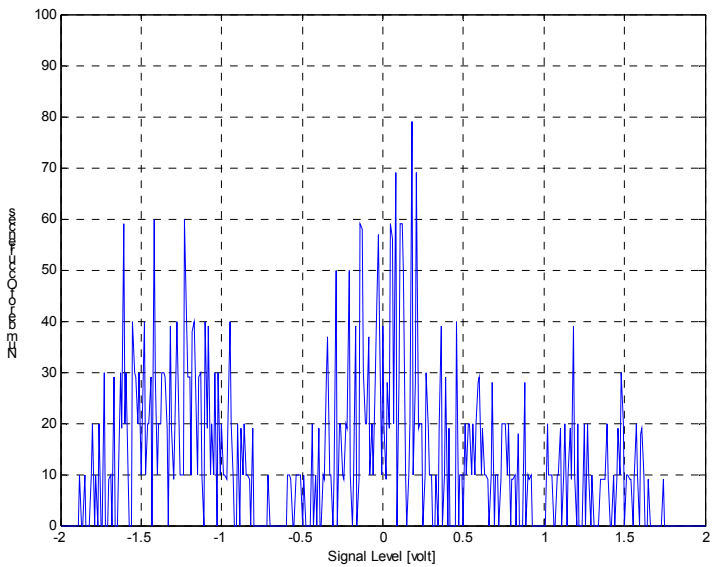
Backup Material

Mixed Signal Equalizer
Single Mode Applications

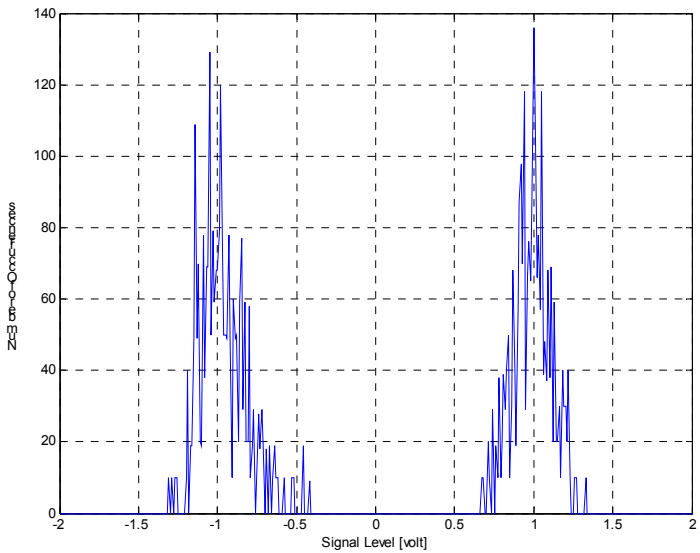
- Performance goals for equalized optical link
  - 10Gbps
  - 40km distance
  - Directly modulated 1550 nm DFB source
- Chromatic dispersion is the dominant impairment
  - Channel (fiber) delay dispersion
  - DFB chirp
  - Non-linear fiber distortions are negligible

Mixed Signal Equalizer
Simulation Result Based on Experimental Data Using DFE

Slicer input of the original signal, SNR = - 0.1 dB

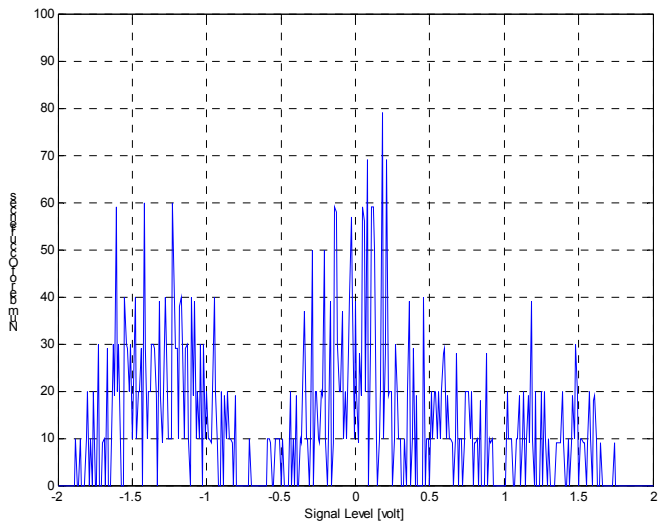


Slicer input of the equalized signal, SNR = 17 dB (BER = 10^{-13})

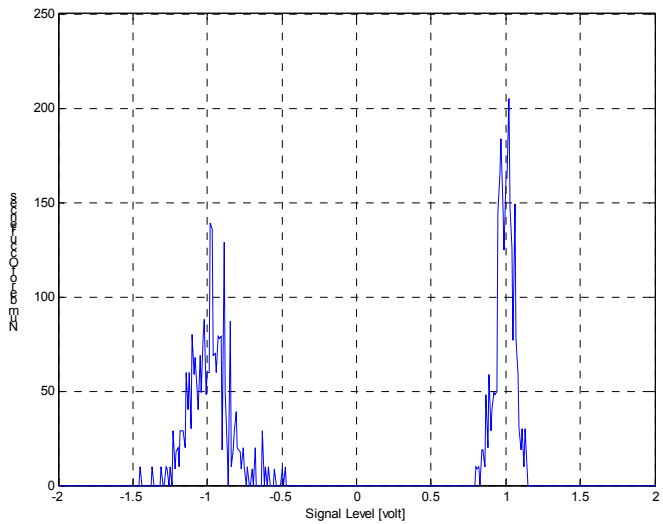


Mixed Signal Equalizer
Simulation Result Based on Experimental Data Using MLE (Maximum Likelihood Equalizer)

Slicer input of the original signal, SNR = - 0.1 dB



Slicer input of the equalized signal, SNR = 19 dB (BER = 10^{-20})

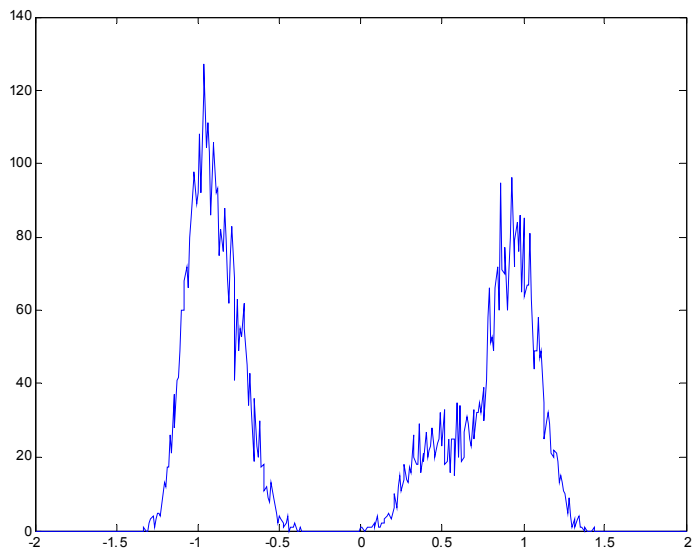


Mixed Signal Equalizer
Long Haul Application

- Performance goals for equalized optical link
  - 10Gbps
  - 140km distance
    - 2 x 25dB Power Amplifiers at 70km and 140km
  - Externally modulated 1550 nm DFB CW Lorentzian Source
    - 12dB Extinction Ratio
- Chromatic dispersion is the dominant impairment
  - Channel (fiber) delay dispersion
  - Non-linear fiber distortions are negligible
- BER of Equalized Link Must Exceed 10^{-15}

Mixed Signal Equalizer Simulation Results for DFE Over 140km

Slicer input of the original signal, SNR = 12 dB (BER=10^{-5})



Slicer input of the equalized signal, SNR = 19 dB (BER = 10^{-20})