Mixed Signal
Electronic Dispersion Compensation

Andrew Baek
Andrew_baek@hotmail.com
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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 $\alpha$-profile.
- Fiber transfer function generated assuming overfilled launch (OFL).

Mixed Signal Equalizer
FDDI-grade Multimode Fiber at 850 nm

- 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

- 160/500 MHz·km 62.5μ 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

<table>
<thead>
<tr>
<th>Item</th>
<th>Gates</th>
<th>Power (mW)</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Feed-Forward Filter</td>
<td></td>
<td>60</td>
<td>200 x 100 micron (7.8 x 3.9 mil)</td>
</tr>
<tr>
<td>MUX</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>CDR</td>
<td></td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Digital Control Circuit</td>
<td>20K</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>DACs</td>
<td></td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>ADCs</td>
<td></td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>JTAG and Other Logic</td>
<td>20K</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>705</td>
<td>Pad Limited</td>
</tr>
</tbody>
</table>

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})