Fiber Equalization: Review of Technologies

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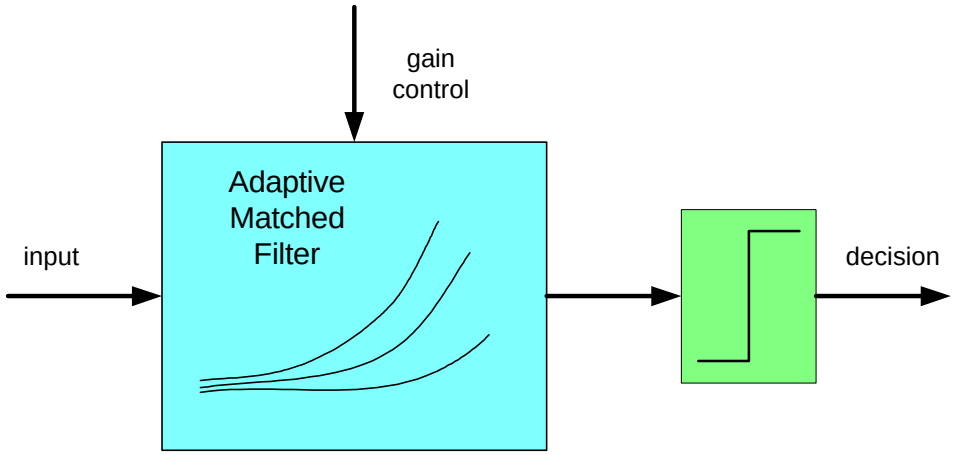
Proposed Fiber Equalization

- ON-OFF Keying at 10GHz
- Receiver Equalization (No Transmitter pre-emphasis)
- No special start-up requirements
- Continuously adapts to slow varying and different MMF fiber channels

Equalizer types

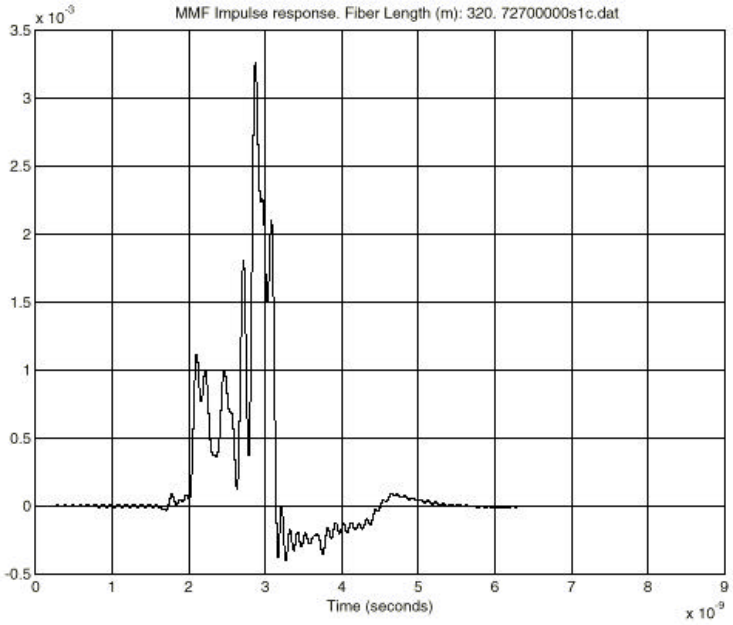
- Analog Matched Filter Equalizer
- Analog Transversal Filter Equalizer
  - linear filter
  - non-linear filter
- Digital Transversal Filter Equalizer
  - linear filter
  - non-linear filter

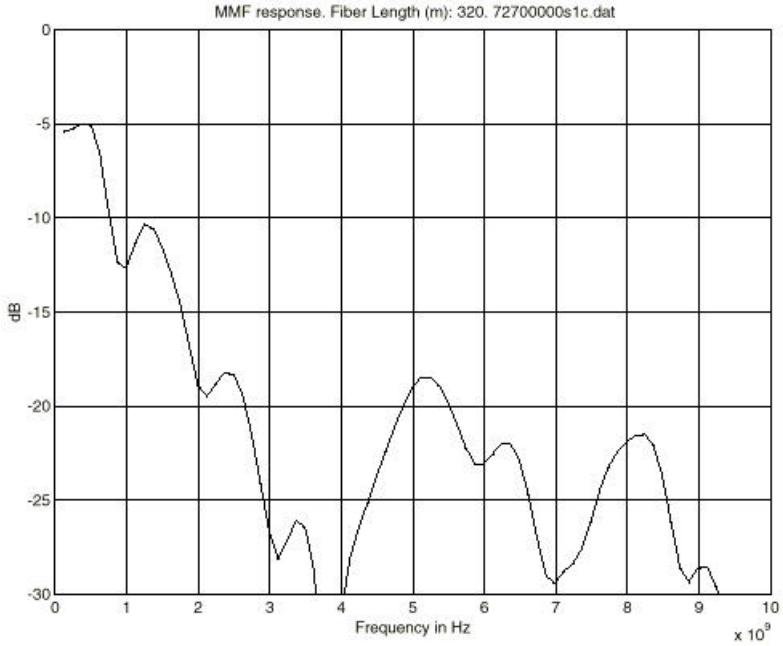
Analog Matched Filter Equalizer



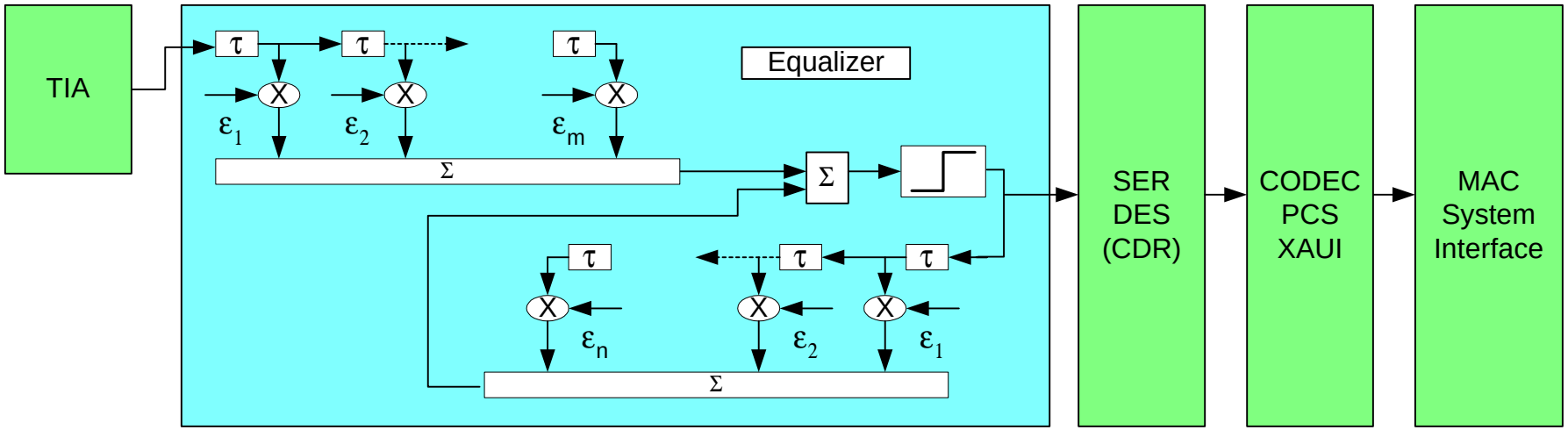
- Analog Matched Filter implementation
- Frequency response approximates the inverse of the channel
- Analog filter adapts to variations in the channels
- Limited degrees of freedom
- Works well for single-path channels like copper
- Not suited for multi-path channels like fiber

MMF Fiber response



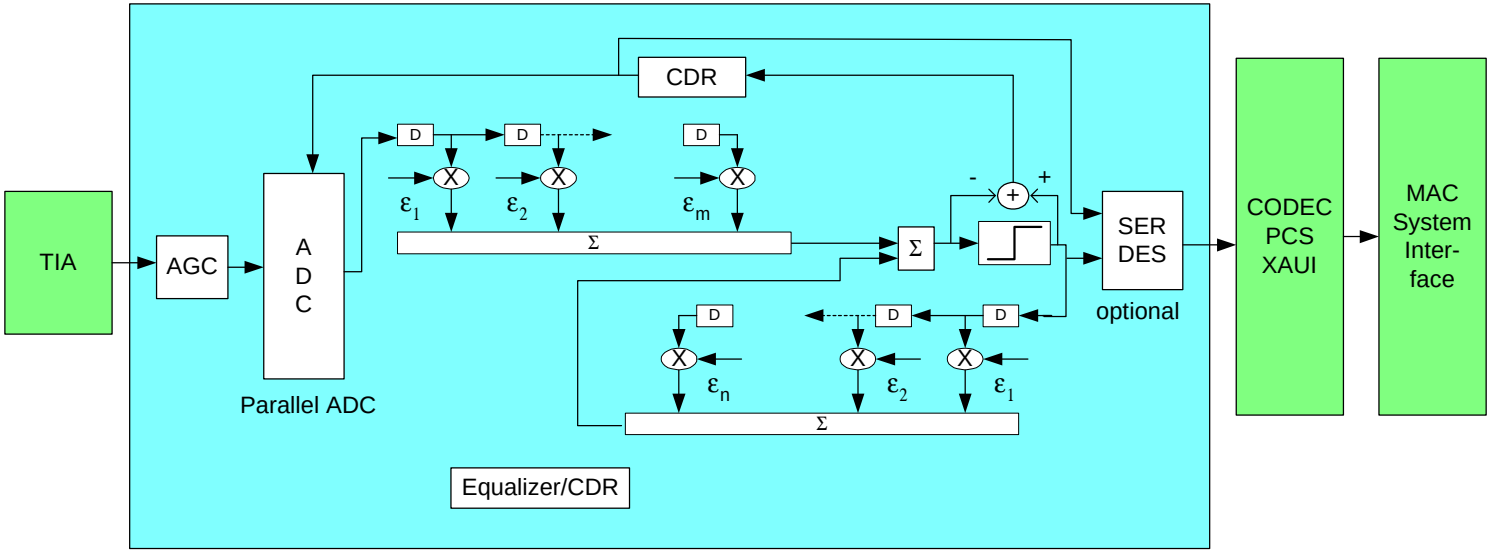


Analog Transversal Filter Equalizer



- Analog FFE/DFE implementation for 10GBits/s OOK
- Analog tap delays: τ < period. (No ADC required)
- Equalization and CDR are independent. No coupling.
- Analog multiply/adds
- Tap weights adapt to different fiber channels
- Analog BW > 5GHz. Constant group delay for f > 5GHz.
- AFE implemented in SiGe/CMOS.

Digital Transversal Filter Equalizer



- Digital FFE/DFE implementation for 10GBits/s OOK
- 10GS/s Interleaved ADC
- Resolution 4-6 bits?
- Equalization and CDR need to adapt together.
- Digital multiply/adds
- Tap weights adapt to different fiber channels
- ADC implemented in SiGe. DSP implemented in CMOS.

Non-linear equalizers

- One or more symbol decisions are used to:
  - switch between different feed-back paths (DFE)
  - switch between different feed-forward paths (FFE)
  - change the slicer threshold
- Can be used for compensating non-linearities in the channel.

Lets compare the following technologies..

	ON-OFF Fiber Equalization	1000 Base-T	Multi-level Fiber Equalization
Coding	ON-OFF NRZI • 2 levels	PAM5 with PR shaping and Trellis coding • 17 levels	PAM5 with Tomlinson-Harishima precoding with Trellis • Multi-level linear analog
Clock	10GHz	125MHz	5GHz
Echo Canceller	Simplex • No echo canceller required	Full Duplex • Requires complex echo cancellation	Simplex • No echo canceller required
Equalization	Adaptive receiver equalization	Adaptive receiver equalization	Adaptive (transmitter) Tomlinson-Harishima pre-emphasis

	ON-OFF Key Fiber Equalization	1000 Base-T	Multi-level Fiber Equalization
Next Cancellers	Not required	12 adaptive next cancellers	Not required
Start-up	NO special start-up protocol • Receiver adapts in < 1ms	Complex Start-up protocol • Master/Slave negotiation • Master/Slave clock resolution • Equalizer/Echo interactions	Complex start-up requirements • Need to send equalizer coefficients from receiver to transmitter during start-up
Auto-negotiation	Not required	Negotiation for 10/100/1000 Master and Slave	Not required

	ON-OFF Key Fiber Equalization	1000 Base-T	Multi-level Fiber Equalization
Link Linearity requirement	Low • Binary coding is tolerant to non-linearity • Non-linear equalization may be used for additional robustness	High • Multi-level • Full-duplex	High • Multi-level
Standards process	SIMPLE	COMPLEX	COMPLEX

Conclusions

- MMF Fiber electronic equalization is very attractive, feasible, and powerful.
- Low power SiGe/CMOS implementations are possible:
  - Analog FFE/DFE
  - Digital FFE/DFE
- Non-linear equalization may be used for additional robustness
- Simpler to implement and standardize than 1000Base-T and Multi-level Fiber Equalization. Will lead to robust performance.