2λ x 100Gbps PAM-4 Wideband Fiber 100m Links using 850nm and 940nm VCSELs

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Abstract—We experimentally demonstrate 100Gbps PAM-4 transmission over 105m wideband MMF fiber at two separate wavelengths. The 107Gbps line rates allow a combined 200Gbps user rate with FEC. The link includes unpackaged 850nm and 940nm VCSELs designed for 25G operation and offline equalization and decoding.

Keywords—VCSELs, Higher Order Modulation Formats, SWDM, Wideband Fiber

I. INTRODUCTION

Short reach links are dominated by VCSELs with MMF and direct detection since these links offer excellent performance, low cost and high density. Existing IEEE 802.3bm standard efforts support 25Gbps and 10Gbps core rates in four fiber and ten fiber configurations to support traffic up to 100Gbps. However, a 400GbE solution as envisioned by the IEEE P802.3bs Task Force will require 16 fibers in each direction. Alternate solutions that require reduced fiber counts are needed to maintain the low cost and low power consumption of VCSEL MMF based links for 400Gbps and eventually 1Tbps interconnects. The path forward may include higher line rates and higher modulation formats [1] both enabled by significant signal processing. Additionally, short wavelength division multiplexing (SWDM) [2] in the 850nm to 940nm range is enabled by next generation wideband MMF [3].

Here we demonstrate 107Gbps PAM-4 signaling using 850nm and 940nm VCSELs over 105m of next generation wideband fiber. The two 107Gbps line rates allow a combined 200Gbps user rate with low latency forward error correction (FEC). These wavelengths correspond to the high (940nm) and low (850nm) edges of the new shortwave division multiplexing scheme for wideband MMF. The link includes unpackaged 850nm and 940nm VCSELs designed for 25G NRZ operation. Equalization strategies include transmitter based pre-emphasis and offline receiver based equalization and decoding. Furthermore, a raised cosine pulse shape was implemented to further limit channel bandwidth requirements. The VCSELs readily support 25G data rates and exhibit low RIN. The signal processing methods are within the capabilities of current generation SiCMOS [4].

II. EXPERIMENTAL SETUP

The 107Gbps electrical PAM-4 signal is created with a Keysight M8196A Arbitrary Waveform Generator (AWG). 7 percent overhead was included to allow for low latency Reed-Solomon FEC [5], requiring an uncorrected BER of 4.2x10^-4 resulting in a BER of 1x10^-12. The AWG implements pre-emphasis to partially compensate for channel response as estimated by the AWG calibration software. The adaptive filter at the receiver compensates the remaining channel distortions. Both the pre-emphasis filter at the transmitter and the adaptive filter at the receiver primarily add gain boost (<10dB) at the Nyquist frequency and can therefore be implemented with digital or analog filters of similar limited complexity. This pre-distorted signal is amplified and applied to the unpackaged VCSEL. 105m of next generation wideband fiber with ≥ 6GHz-km calculated effective modal bandwidth (EMBc) from 850nm to 950nm was used for the PAM-4 transmission experiments [3].

The custom differential receiver has an electrical bandwidth of 28GHz. The entire link is measured to have ~21GHz with the 850nm VCSEL and ~22 GHz with the 940nm VCSEL in the back to back configuration. The received signal is captured by both a sampling scope (DCA 81600D), and a real-time scope (DSA-X 96204Q).

III. OFFLINE EQUALIZATION AND DEMODULATION

The received optical signal is direct detected, digitized and equalized from the recorded waveforms of the real-time scope. We implemented the Oerder-Meyr [6]
algorithm which is effective in compensating for fractional baud rate errors due to RC pulse shaping. The signal is then low-pass filtered to suppress out-of-band noise. Our adaptive equalization technique uses a training sequence. We use a digital feedback equalizer (DFE) with 3 backward taps and feed forward equalizer (FFE) with 7 forward taps as an optimum tradeoff between implementation complexity and BER performance. The DFE filter coefficients are adaptively determined using the Least-Mean-Square (LMS) algorithm. The receiver signal processing complexity is consistent with currently available PAM-4 receivers although at a higher baudrate [4].

IV. RESULTS

The VCSELs were biased at 13.5 and 14.4mA, yielding RMS spectral widths of ~0.49nm and ~0.54nm for the 850nm and 940nm VCSELs respectively. Both VCSELs yielded >3dBm fiber coupled power at room temperature. The RIN of both VCSELs was measured to be <142dB/Hz. The recovered but unequalized PAM-4 eyes through wideband fiber are shown for 940nm, Fig. 2(a) and 850nm, Fig. 2(b). A slight eye skew of ~0.05 UI was observed in the back to back and fiber configurations with the 850nm VCSELs, but was not apparent with the 940nm VCSELs. Because similar voltage swings were used for each VCSEL, differences in eye skew can be attributed to damping differences between the VCSEL cavities. The 940nm and 850nm BER vs. received optical power for the back to back and 105m wideband fiber configurations were measured. In all cases, Fig. 2(c), the FEC limit was readily achieved and the waveforms contained no burst errors. These wavelengths represent the endpoints for SWDM, thus the wideband fiber likely supports 880nm and 910nm. The OM4 fiber was able to achieve the FEC limit at 850nm, but not 940nm with the limited equalization implemented.

We note that there was excess power available at the receiver with the 850nm and 940nm VCSELs and >2dB optical attenuation was required to avoid receiver nonlinearities. Fig. 2(c) reveals a small fiber-imposed power penalty of less than 1.3dB in the equalized signal for the wideband fiber. This power penalty was consistent for both VCSEL wavelengths. We observe a penalty of 4dB and 6dB from the 850nm and 940nm thermal limit, respectively. The majority of this penalty can be attributed to the lack of a driver and bandwidth constraints, but improvements can be made on both the commercial and research fronts. On the commercial side, small improvements in component bandwidths, including the use of packaged VCSELs, will significantly reduce the power penalty. On the research side, further study of optimal drive current and voltage swings will help eliminate eye skew issues and reduce the BER.

V. CONCLUSION

We have demonstrated 100Gbps PAM-4 transmission below the FEC threshold using 850nm and 940nm VCSELs over 100m wideband MMF. There was no evidence of a significant RIN or MPN penalty. We used signal processing strategies at both the transmitter and receiver that may soon be available in silicon electronics. The 100Gbps line rate may be combined with short wave multiplexing and the next generation wideband MMF to yield 400Gbps links with only a single fiber for each direction. These results demonstrate a path to 400Gbps single fiber solutions.

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REFERENCES
