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15.6 Gb/s Transmission over 1km of Next Generation Multimode Fiber

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15.6 Gb/s Transmission Over 1km of Next Generation Multimode Fiber

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***Abstract*-- We report on a 15.6 Gb/s transmission over 1km of next generation multimode fiber. The short wavelength VCSEL transmitter module used a SiGe bipolar VCSEL driver. The multimode fiber was almost ideal and had a total DMD width of only 0.056ps/m. We also achieved 20 Gb/s transmission over 200m.**

***Index Terms*—10 Gb/s Ethernet, Optical Communications, Multimode fibers.**

I. INTRODUCTION

The 10 Gigabit Ethernet standard in development (IEEE 802.3ae) included the short wavelength VCSEL based solution as one of the physical media dependent layers. This has lead to the development of new high-speed multimode fiber (MMF), with minimum bandwidth greater than 2000 MHz*km, and capable of reaching at least 300m with optical transceivers operating at a wavelength range of 840-860 nm. Samples of the new 50 ?m MMF are available from several fiber manufacturers, and standardization of this fiber type is in progress. The Telecommunications Industry Association (TIA) fiber optics group FO-2.2.1 who has worked for over 2 years to find the fiber and laser specifications to achieve the 300m-distance target, conducted several round robin measurements and generated a draft specifications for the laser and the fiber. The high data capacity is achieved by controlling both the laser launch conditions and the fiber maximum differential mode delay (DMD).

The laser specification is for the encircled flux, which is the fraction of the total power launched in the fiber inside a given radius. It is specified to be more than 86% at 19 microns, and less than 30% at 4.5 microns. The fiber specifies the allowable differential mode delay. It has three regions: inner, middle and outer. The final specification makes a trade-off between the requirements of the inner and outer specs and the middle mask – more tolerant middle mask means more restrictive inner and outer mask. The proposed fiber specification has 6 sliding DMD masks.

In this paper we present results that far exceed the requirements for 10 Gigabit Ethernet This paper reports on experiments driving VCSEL based optical links at speeds up to 20Gb/s. We report on a 1 km long link operating at 15.6 Gb/s, and 200m link operating at 20 Gb/s over a next generation high-speed multimode fiber. The longer distance and the higher bit rate is achieved by using a fiber whose DMD profile is virtually flat, and using lasers whose encircled flux was more restricted than the IEEE 802.3ae specifications. This shows the 10 Gb Ethernet Standard to be conservative and the potential of this technology to be used in the future Ethernet standards operating at 40 Gb/s.

II. HIGH SPEED FIBER CHARACTERIZATION

The standard FDDI grade multimode fiber is optimized for operation at 1300 nm. While for the 1 Gb/s applications this 1300 nm optimized fiber was still usable at other wavelengths, the 10 Gb/s applications, like 10 Gigabit Ethernet and Fibre Channel, need a fiber that is optimized for the lowest cost technology that is actually used in high volumes, which in this case is 850 nm. Figure 1 illustrates the effect of profile optimization on the fiber bandwidth.

In our measurements an experimental fiber is used with close to ideal properties at 850 nm. The production of these very accurate profiles are possible due to the proprietary Plasma activated Chemical Vapour Deposition (PCVD) process [2]. This fiber is characterized by a DMD measurement (Figure 2) as defined in the draft FOTP-220 currently under discussion in the TIA (FO 2.2.1. [3]). The total DMD width is 0.056 ps/m for the inner radii compared to the maximum allowed 0.22 ps/m in this area to fulfill the proposed standard to reach at least 300 m at 10 GbE speed.

The fiber bandwidth was measured using the time domain approach [4]. By gain-switching a VCSEL, we generated a repetitive pulse train, whose pulse width was less than 20 ps. This pulse was launched into the fiber and the output pulse was recorded. The bandwidth of the fiber was calculated after deconvolving the effect of the input pulse, the detector and the communication signal analyzer. The measured bandwidth was greater than 10000 MHz*km, which far exceeded the requirements for 10 Gigabit Ethernet.

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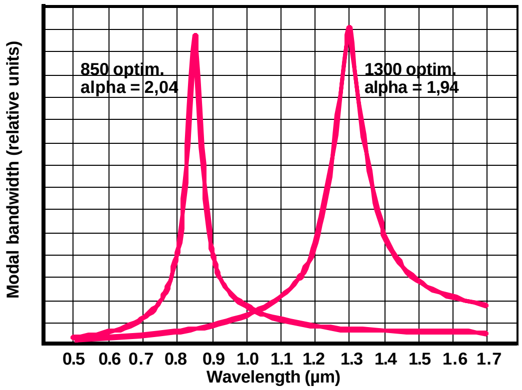

Figure 1: Examples of calculated modal bandwidth for 50 ? m MMF, optimized at 850 nm and at 1300 nm, depending on the profile shape parameter (alpha) [1]

We also investigated the effect of the offset on the fiber bandwidth. This is necessary since the main advantage of multimode fiber links over single mode links in LAN environment is the easy alignment of the optics. However, it is well documented [5] that offset of the source relative to the fiber can produce bandwidth degradation. Furthermore, any connector offsets cause mode mixing, thus potentially further degrading the bandwidth of the fiber. The degrading effects of mode mixing are due to two factors: first, the transfer of power from one mode group to the neighboring mode groups causing widening of the impulse response of the fiber; second, when the connector mode mixing occurs further down the fiber, the modes are delayed with respect to each other, thus causing temporal spreading as well. This was the case in general for the FDDI grade fiber. However, the fiber that we used did not have any bandwidth degradation when the source was offset, confirming that the fiber indeed has a very flat DMD profile.

III. DATA TRANSMISSION EXPERIMENT

Our data transmission experiments were performed using experimental modules. The modules used the same VCSEL driver, but had different VCSEL designs.

The VCSEL driver is implemented in a 0.5?m 50GHz f_T SiGe bipolar technology. The driver utilizes fully differential circuits including an on-chip AC coupling network to the VCSEL load. DC bias control is also provided on the driver thereby eliminating the need for any external passives between the driver and VCSEL. This permits the use of an unterminated network between the two parts since the lack of any off-chip passives allows for very small physical separations. The total power dissipation running at 10 Gb/sec is typically 180mW at 3.3 V. To optimize the circuit design, we used a rate equation based model of the VCSEL implemented in Spice, including an impedance model similar to that in [6].

Experiments were performed using three different VCSELs from three vendors. Laser A is an oxide confined VCSEL with a 15?m diameter, I_{th} = 2.0mA, slope efficiency = 0.37 mW/mA, and series resistance of 31 Ohms. At a DC bias current of 14.5mA the center wavelength is 852.1nm and the RMS spectral width is 0.44nm. Approximately 8 transverse modes are lasing under this condition. The small signal bandwidth at 20.0mA is 10.1GHz. Open eyes are obtained with a DC bias of 15mA and +/- 9mA modulation current resulting in an extinction ratio of 5.5dB.

Laser B is also an oxide confined VCSEL with a 15?m diameter, I_{th} = 0.9mA, slope efficiency = 0.2 mW/mA, series resistance = 49 Ohms. At a bias current of 13mA the center wavelength is 842.2nm with an RMS spectral width of 0.687nm. Approximately 9 transverse modes are lasing under this condition. Open eyes are obtained with a DC bias currents ranging from 11 to 14mA with modulation currents ranging from +/-6mA to +/-9mA.

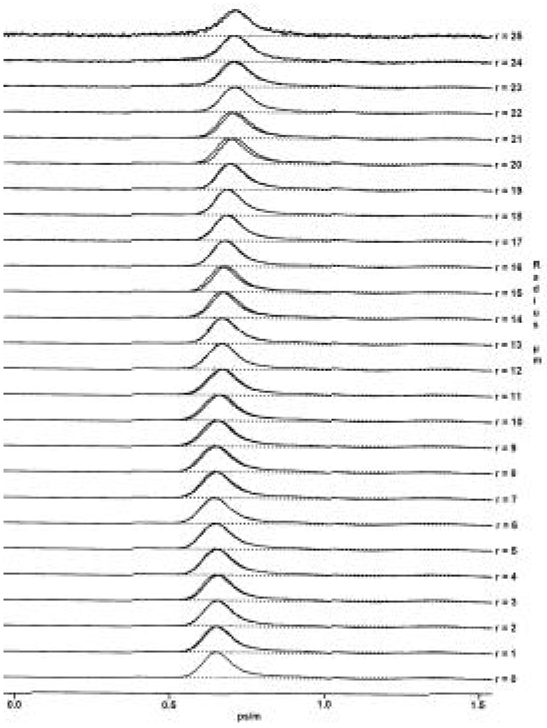

Figure 2: DMD measurement on a fiber sample

The fastest bit rate of 20 Gb/s was achieved with Laser C, which was an oxide-confined device with an 8?m oxide aperture. The device is fabricated on a semi-insulating substrate with two planar topside contacts. At room temperature the threshold current is 0.3mA and the slope efficiency is 0.29mW/mA. Thermal rollover begins at 6.2mA due to the high thermal impedance of 1700 K/W. The maximum CW optical power is 1.3 mW. The series resistance in the range of operation is 145 Ohms. The device is primarily single mode at 843nm although three side modes exist at -10, -11 and -18dB down respectively under cw and ac conditions. At 6.2mA the -3dB frequency is 15.4GHz. The modulation efficiency is 13.7 GHz/$(mW)^{0.5}$ up to 1.2mA (10GHz) and then begins to saturate. The device is directly connected to the driver IC through two short (500?m) wirebonds.

While we observed much cleaner eye diagrams with Laser B, Laser A yielded longer distances because it had a smaller rms linewidth. For these speed, fiber length and DMD profile, the large chromatic dispersion at 850 nm quickly becomes the limiting factor.

The modules were driven with a 15.6 Gb/s 2^{31}-1 data pattern. The light was butt-coupled into the experimental multimode fiber and detected using a commercially available 14 GHz photodiode. No amplifier was used after the photodiode. Averaging was used on the communication signal analyzer to eliminate the noise from the signal waveform. The recorded signal was then used to construct the eye diagram folding the signal over a few bit intervals. We recorded the eye diagrams at several distances, as well as the reference link.

The reference intersymbol interference penalty (ISI) in a link 5m long was 3.05 dB, with 24 ps deterministic jitter (DJ). The large DJ and ISI originated at the pattern generator, which was overdriven beyond its maximum rating at 12.5 Gb/s. In the 1km long links we measured an ISI penalty of 3.85 dB at the system output, with DJ of 24 ps and retiming window of 14.5 ps, as seen from the eye diagram on Figure 3. We can observe that there is only small increase in the ISI penalty after the 1km long link (0.8 dB), indicating that much longer distances are possible if we are not limited by the rise/fall times of the pattern generator. Our results also suggest that the VCSEL driver and the laser itself are capable of achieving much higher data rates.

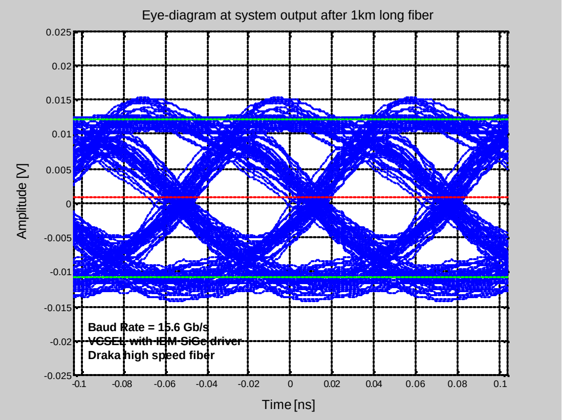

Figure 3. 15.6 Gb/s eye diagram at the output of a 1km long Draka high-speed multimode fiber. The VCSEL A was driven by IBM SiGe driver.

We also modulated Laser C at 20 Gb/s using a 2:1 multiplexer after the after the pattern generator and a faster (>15 GHz) photodiode. Figure 4 shows the back-to-back optical eye diagram from Laser C (top trace) and the electrical signal that is fed to the driver IC (bottom trace). The deterministic jitter (DJ) of the source is 9.5ps, the rise and fall times (20-80) are 20 ps and the intersymbol interference (ISI) is 0.93dB. At 2m, the DJ from the VCSEL is 15.5ps and the ISI is 2.64dB. Some eye closure (ISI) is expected from the VCSEL as the 15GHz bandwidth of the device attenuates all harmonics of the driving signal. The accumulated ISI over 200m is only 1dB and the final DJ is 20.2 ps.

IV. CONCLUSION

We fabricated a VCSEL driver in SiGe bipolar technology, capable of driving VCSELs at speeds up to 20 Gb/s. The transmitter module was used for data transmission on experimental fiber that had a bandwidth in excess of 10 GHz*km, resulting in successful data transmission over 1km long fiber at 15.6 Gb/s and 200m at 20 Gb/s. The bandwidth of this fiber and the range of operating wavelengths are large enough to support two coarsely spaced WDM channels operating at 20 Gb/s over premises distances for the next 40 Gb/s Ethernet standard.

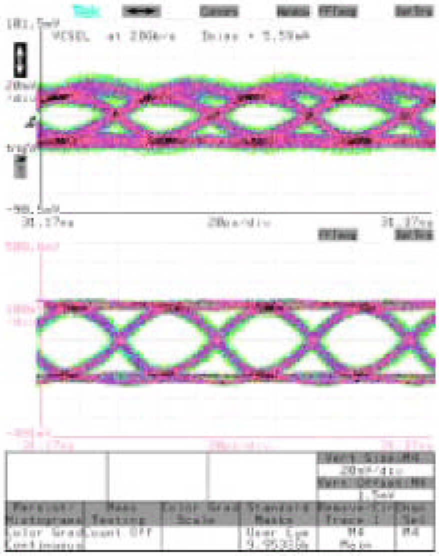

Figure 4. VCSEL eye diagram at 20Gb/s (top) and electrical input waveform (bottom)

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