Signal Transmission Performance at 1550nm Using Directly Modulated VCSEL over G.652 and G.655 fiber links

G. K. Yegon[1], D. W. Waswa[1], G. M. Isoe[2], S. K. Rotich[3], T. B. Gibbon[2], A. W. R. Leitch[2]

Abstract—We experimentally characterized and optimized the performance of a vertical cavity surface-emitting laser (VCSEL) in a communication link. VCSEL at 1550 nm transmission windows was chosen for data rate of 10 G bps for metro networks due to its wavelength tune ability, cost and energy efficiency. The optical link was evaluated through Bit Error Rate (BER) measurements for 17 km over G.652 traditional fiber and compared to 24.69 km of Single Mode Fiber-Reduced Slope (SMF-RS) at 5.5 m A bias current. The corresponding eye diagrams at telecommunication BER threshold of 10^{-9} were captured on the scope. The BER for the two measurements were then compared. Transmission over 24.69 km on G.655 SMF-RS was achieved with a penalty of 1.39 dB with respect to B2B. The G.652 fiber at 1550 nm yields non optimal performance due to its high dispersion coefficient of 17 ps/(nm.km) and this therefore provided a better platform to compare performance of the two fibers. The maximum transmission distance of 74.91 km was achieved over G.655 fiber with a penalty of 0.717 dB with respect to Back to Back (B2B). At transmission distance of 24.69 km a power penalty of 0.131 dB was incurred while at 49.42 km a power penalty of 0.391 dB was incurred. This therefore proved that shorter distances yielded better results which ware observed with high receiver sensitivity. Therefore, with the increase in distance high power is needed to compensate for dispersion effects. This study is vital in enhancing awareness on the effects of CD on the already laid fibers and hence looking for methods to mitigate the effects for the next-generation optical fiber networks.

***Keywords*:** VCSEL, BER, CD

G. K. Yegon, University of Eldoret, Kenya

G. M. Isoe, Centre for Broadband Communication, Nelson Mandela University, South Africa

S. K. Rotich, Moi University, Kenya

I. INTRODUCTION

A vertical-cavity surface-emitting laser (VCSEL) is a semiconductor-based laser diode that emits a highly efficient optical beam vertically from its top surface.The cavity is formed by two highly reflective Distributed Bragg's Reflector (DBRs) (~99.5%), with a forward biased pn-junction sandwiched between them providing optical gain [1].They have several attractive properties such as large modulation bandwidth, wavelength tune ability, easy packaging and low power consumption[2].They have therefore become attractive light sources for high speed optical communication links using intensity modulation/direct detection technique[3]. VCSELs have gained reputation as a superior technology for short reach applications such as fiber channel, Ethernet and intra-systems links. Optical links that use long-wavelength VCSELs and on-off keying (OOK) modulation are limited in transmission reach by chromatic dispersion of optical fibers due to frequency chirping caused by direct modulation of the VCSEL and large occupied bandwidth of signals [4].

II.

(A) VCSEL characteristics

VCSEL used in this experimental work is a 10 G bps 1550 nm. It has low threshold current between 1-2m Afigure2(a). The VCSEL operate in m A range showing the energy efficiency of the device. Ease of direct modulation in VCSEL is cost effective as opposed to using external modulation. VCSEL can be tuned to different channels using the bias current. Therefore, if VCSEL with similar characteristics are to be used, then each wavelength within the tune ability range could be dedicated to each device. The wavelength stability and tune ability allows for wavelength multiplexing which is used to increase the data rate over a single fiber in the array. Transmission at 1550 nm window is currently favoured as it makes use of the minimum attenuation and its application in wavelength division multiplexing (WDM). Generally optical sources emitting at 1550 nm are suited for use on a G.655 fiber but it can also be used on a G.652 fiber with penalty.

Frequency chirping and dispersion are two major defects experienced by VCSELs during norm Al operation. Chirping is the instantaneous change of wavelength with varying optical powers. This results in time dependent instantaneous frequency changes. Dispersion dictates how the optical spectrum of a laser broadens during fiber transmission. A number of techniques for reducing and limiting chirping have been reported. These include injection locking and filter off setting to narrow the spectrum. The relationship between chirping and optical power is expressed as [5]

$$\Delta v(t) = -\frac{\alpha}{4\pi}\left(\frac{d}{dt}\ln P(t) + kP(t)\right) \qquad (1)$$

Where the first term represents the transient chirp that relates to the time derivative of power (P), the second term is the adiabatic chirp due to instantaneous optical power, α is the line enhancement factor and k is related to the geometry of the device and its non-linear gain.

The material composition of VCSEL used as transmitters in this studyareInAlGaAs, InGaAs and InAlAs which offers the VCSEL high reliability, reflectivity, low loss current confinement, reduced thermal impedance and low series resistance for long wavelength emissions. The emission wavelength of VCSEL can be adjusted by varying the drive in bias currents as shown in figure 2(b) below.

(B) Chromatic dispersion

This is the broadening of light pulses over fiber. It is a very critical factor limiting the quality of signal transmission over optical links. Single-mode fibersused in high-speed optical networks are subject to Chromatic Dispersion (CD) that causes pulse broadening depending on wavelength. Excessive spreading will cause bits to “overflow” their intended time slots and overlap adjacent bits[6]. The receiver may then have difficulty discerning and properly interpreting adjacent bits, increasing the Bit Error Rate. The Chromatic Dispersion of a fiber is expressed in ps/(nm.km), representing the differential delay, or time spreading (in ps). It depends on the fiber type, and it limits the bit rate or the transmission distance for a good quality of service.Chromatic dispersion coefficient determines the size of the CD and is described by the equation (2)[6]

$$D(\lambda) = \frac{dt_g}{d(\lambda)}, \left[\frac{ps}{nm \times km}\right] \qquad (2)$$

Chromatic dispersion coefficient $D(\lambda)$ expresses group delay t_g per km of the signal change per wavelength. The pulse width increases with an increase in coefficient of chromatic dispersion $D(\lambda)$, spectral width of the light source and the length of the fiber. The light components with longer wavelengths are delayed longer in the fiber compared with those of the shorter wavelengths.

III. METHODOLOGY

(A) Experimental setup for high speed VCSEL transmission over G.652 and G.655 optical fibers

The experimental setup was as shown figure 1 below. The VCSEL biasing was performed by varying the current using the laser diode controller (LDC) and directly modulating the VCSEL with the 10 G bps NRZ PRBS (2^7-1)Pattern Generator (PPG) via a Bias-Tee (BT). The VCSEL was biased above the threshold current at 5.5m A. The modulated signal from the VCSEL was then transmitted over the fiber under test (FUT). In this experiment, the FUT comprised of 17km G.652 fiber and 24.69km of G.655 fiber. A variable optical attenuator (VOA) was used to vary the optical signal power entering the photodiode to mimic the typical losses in a fiberlink.The receiver consisted of Positive Intrinsic Negative (PIN) photodiode and an Electrical Amplifier (EA). This EA was used to amplify the electrical signal to meet the operational requirements of a (Bit Error Rate Tester) BERT. The quality of the transmitted signal was then evaluated by the eye diagram and BER measurements using an oscilloscope and BERT respectively. The BERT determines the number of errors received and compares the errors to the total number of transmitted bits. A clock signal from the PPG was used to synchronize the 10 G bps transmitted and received data signals. Then finally the quality of the optical signal was characterized by observing the electrical data eye diagrams, BER measurements and penalties.The optical communication system tolerance to the effects of dispersion were measured for the two fibers. The G.652 fiber used has low attenuation but has very high CD parameter of 17 ps/nm.km at 1550 nm compared to 0.35 ps/nm.km at 1310 nm.

(B) Intensity Modulation at 1550nm window at different fiber lengths

In this setup the laser operating at 1550nm was used. A Non Return Zero (NRZ) pulse generator which operates as a laser driver is modulated by a pseudorandom bit sequence (PRBS) generator. The laser was then connected to the Mach-Zender Modulator (MZM) via Polarization Coupler (PC) which was then connected to the SMF. The modulated signal was then transmitted through the fiber. The different fiber-links used were m Ade up of SMF G.652 and G.655 Truewave-Reduced Slope (TW-RS) fiber. The G.652 fiber had a 17ps/(nm.km) while the G.655 fibers had a coefficient of 4.5ps/(/ (nm. km) dispersion coefficients at the 1550 nm transmission window. Moreover, the PMD coefficient of G.652 and TW-RS G.655 fibers are $\leq 0.2\ \mathrm{ps/km^2}$ and $\leq 0.1\ \mathrm{p\,s/km^2}$ respectively. G.655 is optimized for 1550nm transmission window where it experiences minimum chromatic dispersion.

The fiber output was then connected to a variable optical attenuator (VOA) which varies the optical power to emulate typical power loss in a fiber link.

The output was then fed to an optical receiver Positive Intrinsic Negative (PIN) Photodiode with the error-free sensitivity of -19 $\pm$1dB for 10 G bps at 10^{-9} BER threshold. The optical power was then varied so as to establish bit errors at different power levels. The electrical output from the PIN was then connected to an EA to boost the signal so as to satisfy BERT operation voltage. A data recovery module is connected at the end of the link, in order to observe and measure the quality of the link through its eye diagram and bit-error rate (BER) characteristics. The binary signal input of the data recovery module was connected to the PRBS (a pseudo random binary sequence was used as a model data to test a high-speed serial interface device for emulating a transmission mode) output and the electrical signal input was connected to the sequence generator. This was to enable the data recovery module to compare the transmitted and received signal for BER analysis. The optical power meter was connected to the attenuator output to measure the received optical power (known as sensitivity at BER = 10^{-9}).

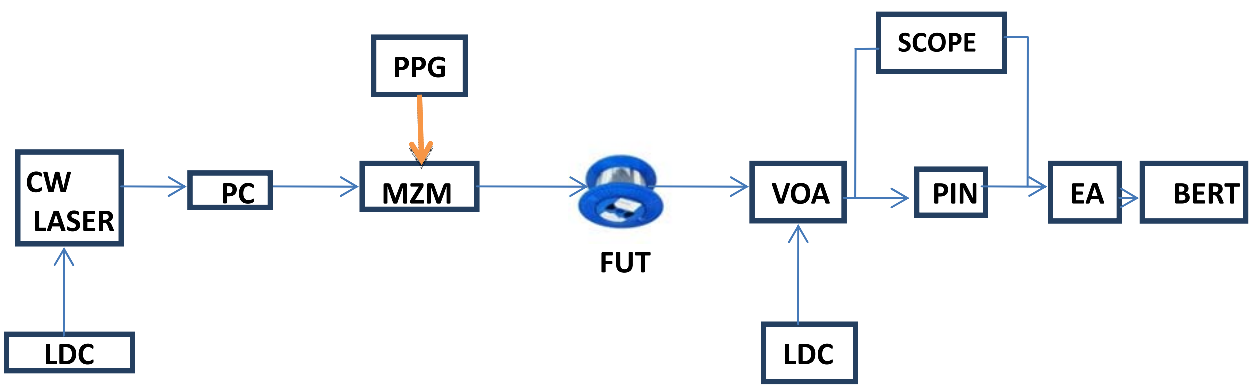

Figure 1: External Intensity modulation at 1550 nm using the MZM

IV. RESULTS AND DISCUSSIONS

(A) VCSEL biasing and Tuneability

The VCSEL was biased above its threshold current to give sufficient output power. The emission wavelength was tuned between 1303.48 nm to 1307.58 nm by increasing the bias current from 3.5 to 8.5mA. This implied that by biasing the VCSEL with 3.5-8.5mA, a 4.1nm (512.01GHz) wavelength tune ability range was achieved. Therefore, we can create 10Gbps tuneable channels operating within a 512.01GHz bandwidth using VCSEL which can allow 10 DWDM channels at 50GHz spacing. This characteristic of the VCSEL makes it an important component for DWDM and flexible spectrum applications and in systems where wavelength tuning is required.

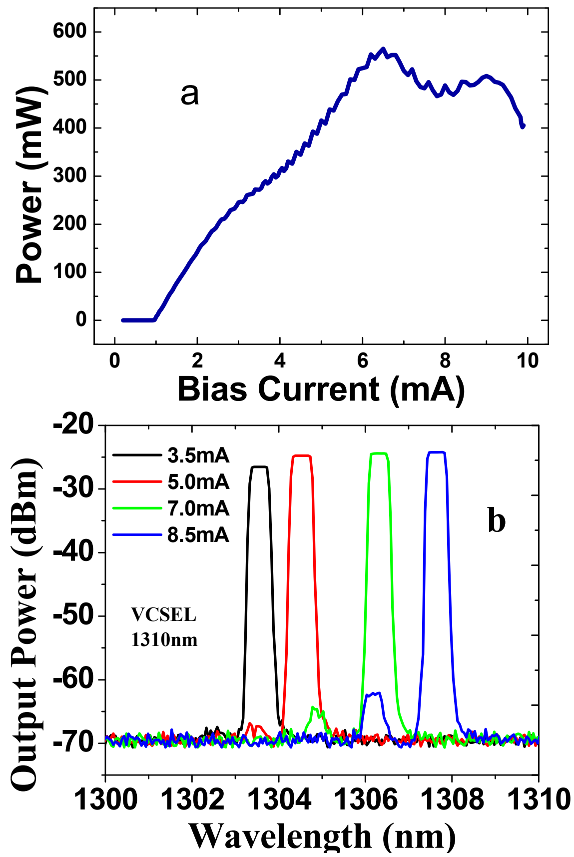

Figure 2: (a) Un-modulated VCSEL bias characteristics (b) VCSEL tune ability

(B) VCSEL transmission over G.652 and G.655 optical fibers

To evaluate the system performance, BER measurements as a function of the received power were performed for B2B, 17km over G.652 fiber and transmission over 24.69 km SMF-RS as shown in the figure 3 below.

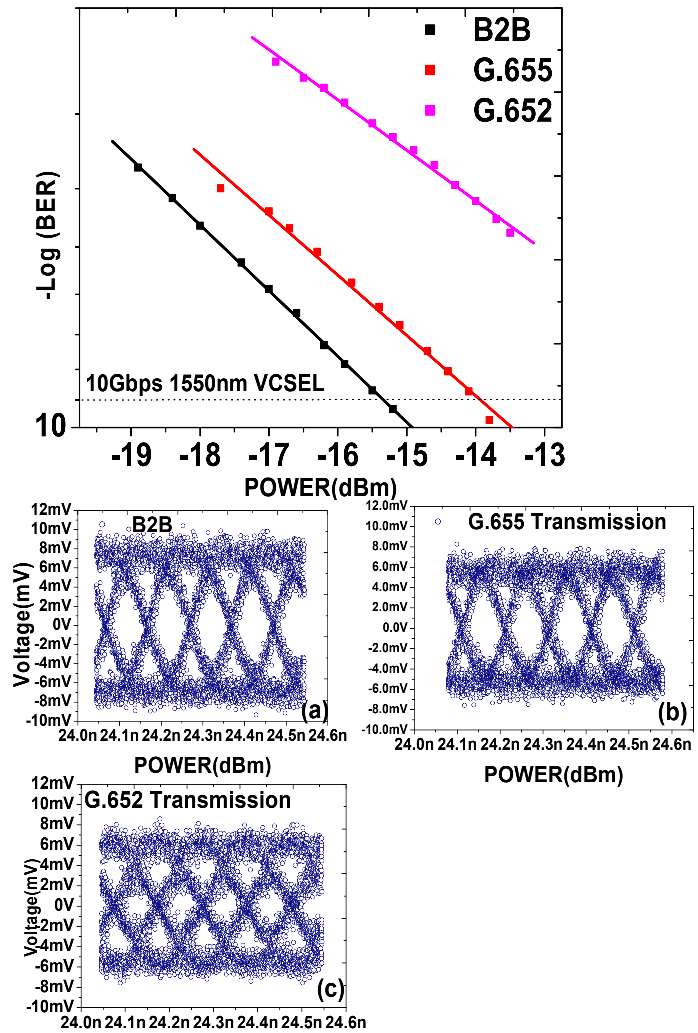

Figure 3: 1550 nm VCSEL transmission on different fibers (a) B2B (b) 24.69km G.655 SMF-RS fiber (c) 17km G.652 fiber

Transmission over 24.69 km on G.655 SMF-RS was achieved with a penalty of 1.39dB at BER of 10^{-9} with respect to B2B.An error free transmission was achieved for 24.69 km SMF-RS before getting an error transmission for G.652 fiber. The error transmission is graphically indicated by the failure of the BER graph to cross the minimum threshold BER of 10^{-9} as shown above. The error floor is independent of the received optical power; hence no matter how much optical is introduced into the system it will never cross the minimum threshold BER value. Despite increase in power, the transmission distance is limited by high linear penalties. In this setup the error floor was mainly attributed to the high CD parameter of 17ps/nm.km for the G.652 at 1550 nm wavelength which resulted in increased number of error-bits received. It's therefore evident that 1550nm signal transmission are best suited for long distance G.655 fiber since dispersion effects are lower at 1550nm transmission window.The eye diagram for B2B, transmission over 24.9 km G.655 SMF-RS and 17km G.652 SMF in the above diagrams clearly show the effect of dispersion on the modulated signal. Increasing the distance to 24.69km induces a penalty of 1.39dB in receiver sensitivity.A wide and open eye represented an error free transmission. When the eye was open the receiver was able to distinguish between the 1's and 0's and therefore few errors were detected. The eye diagram for G.652 is smaller than for G.655fiber though it has a shorter length. This was due to high dispersion coefficient of G.652 on 1550 nm window at 17ps/nm.km. It was also noted in figure (c) above that the eye diagram does not have a good separation ofsignal levels. The big number of values between the lowest and the highest levels was the source of blurred diagram and was due to high chromatic dispersion on G.652 at 1550 nm window. It's therefore clear that the G.655 fiber is optimized for 1550nm transmission window.

(C) Transmission at 1550nm window at different lengths

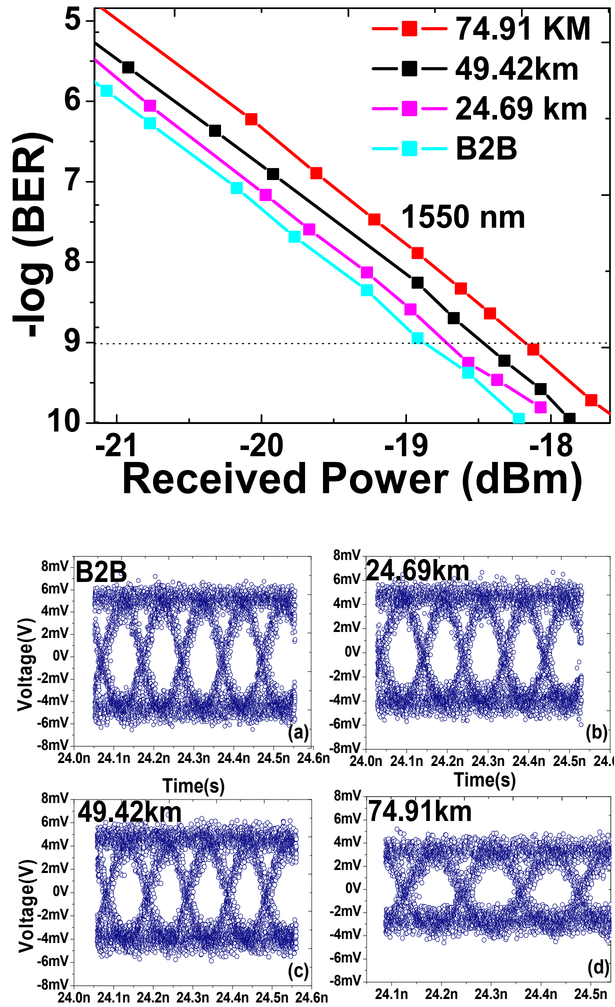

Figure 4: BER graphs and their eye diagrams at different lengths for 10G bps

Figure 4 shows the BER curves at different lengths for different fiber combinations. For B2B the receiver sensitivity was observed at -18.858dB. When the signal was transmitted through a distance of 24.69km over a SRS fiber the receiver sensitivity was observed to be -18.727dB which gives a power penalty of 0.131dB with respect to the B2B. When the transmission distance was increased to 49.42km of SRS and RS fiber the receiver sensitivity of -18.467dB was attained with a power penalty of

0.391dB with respect to B2B while at 74.91 km, the receiver sensitivity was observed to be -18.141dB giving a power penalty of 0.717dB with respect to B2B. This increase in power penalty as the distance increases signifies the power loss due to the effects of dispersion along the fiber link. The eye diagrams for B2B, transmission over 24.69 km SRS, 49.42 km (24.69 km SRS +24.73 km RS) and 74.91 km (24.69 km SRS +24.73 km RS+25.49 km SRS) SMF are clearly shown in the above diagrams. Because of the dispersion along the link, the eye tends to close with increasing transmission distance, degrading the signal quality. This can be attributed to the fact that increase in distance resulted in pulse broadening and hence increase in bit errors due to the overlapping of bits. However, even at 74.91 km a sufficient open eye was still obtained with an error free performance at BER of 10^{-9}. Increasing the distance to 74.91 km induces a penalty of 0.717dB in receiver sensitivity

V. CONCLUSIONS

We have successfully demonstrated chromatic dispersion using VCSELs over 17 km G.652 and 24.69 km G.655 fiber link at 1550nm transmission window. The optical communication system tolerance to the effects of dispersion was measured for two different types of fibers at different. As a result, chromatic dispersion based onvertical-cavity surface emitting lasers (VCSELs) has been successfully demonstrated. Since G.655 fibers are optimized for 1550nm transmission window, transmissions over G.652fiber yielded a non-optimal performance due to the high effects of CD andtherefore gave a better platform to compare the performance of the two fibers. An experimental analysis of the performance degradation due to Fiber length was also demonstrated, revealing how increasing the lengthof the fiber affects the BER performance. It was therefore noted that there was betterreceiver sensitivity at shorter lengths. This was attributed to the fact that at long distances there is cumulative dispersion effects and hence high power is required to compensate for the same. Therefore, for any communication channel, transmission of undistorted signal to the end user remains the primary role. The Quality of Signal and Quality of Transmission should always be maintained when the signal is transmitted for longer distances. This requires that the transmitters, fibers and receivers are all optimized for realization of better end-to-end transmission.

VI. ACKNOWLEDGMENT

We are grateful for research funding and support from: Nelson Mandela University, African Laser centre (ALC)and University of Eldoret, Kenya.

VII. REFERENCES

[1]. Haglund, E., VCSELs for High-Speed, Long-Reach, and Wavelength-Multiplexed Optical Interconnects. 2015: Chalmers University of Technology.
[2]. Hofm Ann, W., et al., 40 Gbit/s modulation of 1550 nm VCSEL. Electronics Letters, 2011. 47(4): p. 270-271.
[3]. Chatterjee, S., et al. Optimizing the performance of a vertical-cavity surface-emitting laser after optical excitation. in Lasers and Electro-Optics, 2006 and 2006 Quantum Electronics and Laser Science Conference. CLEO/QELS 2006. Conference on. 2006. IEEE.
[4]. Zhang, B., et al. Adjustable Chirp Injection-Locked 1.55-μm VCSELs for Enhanced Chromatic Dispersion Compensation at 10-Gbit/s. in Optical Fiber Communication Conference. 2008. Optical Society of America.
[5]. Koch, T. and R. Linke, Effect of nonlinear gain reduction on semiconductor laser wavelength chirping. Applied Physics Letters, 1986. 48(10): p. 613-615.
[6]. Štěpánek, L., Chromatic dispersion in optical communications. International Journal of Modern Communication Technologies & Research, 2012. 7.