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Demonstration of Raman-based, dispersion-managed VCSEL technology for fibre-to-the-hut application

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ABSTRACT

For the first time, we experimentally investigate the use of vertical cavity surface emitting lasers (VCSELs) in the fibre-to-the-home (FTTH) flavour for Africa, known as fibre-to-the-hut. Fibre-to-the-hut is a VCSEL based passive optical network technology designed and optimized for African continent. VCSELs have attracted attention in optical communication due to its vast advantages; low power consumption, relatively cheap costs among others. A 4.25 Gb/s uncooled VCSEL is used in a dispersion managed, Raman assisted network achieving beyond 100 km of error free transmission suited for FTTHut scenario. Energy-efficient high performance VCSEL is modulated using a 2^7-1 PRBS pattern and the signal transmitted on a G.655 fibre utilizing the minimum attenuation window.

1. Introduction

Fibre-to-the-hut (FTTHut) approach tailored for African continent, first reported in our work [1,2] seeks to put the third world and developing countries into the fibre-to-the-home (FTTH) context. FTTH technology is widely established in developed countries in Asian, European and American continents. FTTH network basically connects a number of end users to a common central point. Third world countries and developing countries dominating African continent experience different challenges which calls for appropriate technology to address the connectivity issue. Currently, the internet is expanding at an unprecedented rates because of the increasing number of users. The ever growing demand for internet is vital for the growth of any economy. This is because the connectivity implies accessibility to e-services such as e-learning, e-governance, e-health etc. The African continent is characterised by low income, poor infrastructure, sparsely populated settlements among others. Developed countries on the other hand, have high per-capita income with densely populated residential complexes. Fig. 1 gives an illustration of the different scenarios.

Like FTTH, FTTHut networks are based on passive optical network (PON) technology as depicted in Fig. 2. A PON is a point-to-point or a point-to-multipoint optical network where an optical line terminal (OLT) at the control office is connected to many optical network units (ONUs) through one or more optical splitters. The multiple splitter supports several ONUs. More information about types of networks, standards, designs and access technologies are provided in [3]. The two common multiplexing techniques used in access networks are time division multiplexing (TDM) and wavelength division multiple (WDM) [4,5]. WDM is cost efficient as it allows multiple wavelengths over a single mode fibre. The array waveguide gratings (AWGs) are used to multiplex and demultiplex wavelengths to or from ONUs. This wavelength alignment technology includes optical power monitoring and temperature insensitive AWG. With multiplexing, fibre connectivity therefore offers a high bandwidth and high data speeds as opposed to traditional digital subscriber line (DSL) technologies that were used to transmit over telephone lines. The landing of the submarine fibre-optic cables in the African continent since 2009 is the driving force towards this broadband connectivity. The fibre connection to homes is currently rolled out in major African cities, among the pioneers are Cape Town in South Africa, Harare in Zimbabwe, Mombasa in Kenya, Lagos in Nigeria among others.

Vertical cavity surface emitting lasers (VCSELs) have unique and vast advantages thus attracting a lot of interest in the recent past.

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Fig. 1. Residential homes in a developing and a developed country respectively.

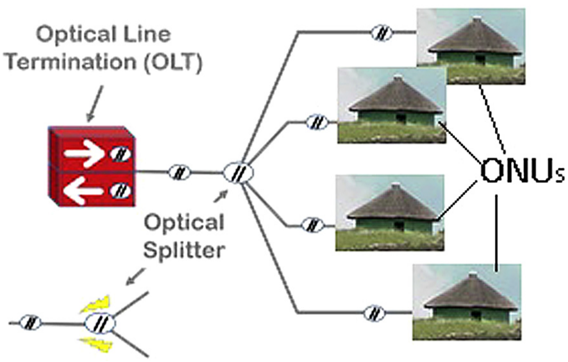

Fig. 2. Typical representation of a PON.

VCSELs offer high bandwidth, single mode operation within C-L bands, wavelength tune abilities, the convenience of direct modulation and energy efficiency at low drive currents [6]. VCSELs are ideal for relatively short distance high speed optical communication networks. High speed VCSELs at different transmission wavelengths have recently been reported; 40 Gb/s at 1550 nm [7], 12.5 Gb/s at 1310 nm [8] and 71 Gb/s at 850 nm [9]. This shows that effective transmission is achieved on all the transmission windows. The recent developments in VCSEL technology have boosted the growth and future of its applications. VCSEL operation is however limited by wavelength chirp and chromatic dispersion [10,11]. In this study, we experimentally demonstrate 4.25 Gb/s 1550 nm VCSELs with focus on link optimization so as to improve the reach to connect the remote users. Link optimizations in this work involve dispersion management and Raman amplification so as to achieve the longer reach in the sparsely populated villages and towns. Raman amplifiers have been preferred to Erbium doped fibre amplifiers (EDFAs) and other semiconductor optical amplifiers because they offer better optical signal to noise ratios, reduced nonlinear penalties which allow longer amplifier spans, higher bit rates, closer channel spacing, and operation near the zero-dispersion wavelength while giving high non-resonant signal gains [12]. Unlike erbium doped fibre amplifiers (EDFAs) which are slow and require special fibre, Raman gain processes are fast and SRS can occur in any optical fibre (does not need a special fibre). Semiconductor optical amplifiers (SOAs) gain is polarization dependent due to short lifetime of charge carriers leading to large crosstalk and inter-modulation distortion. Gain flatness in Raman can be obtained by using multiple pumps making the technique expensive [12–15].

This work is arranged as follows. The experimental design to investigate the FTTHut network is outlined in Section 2. Section 3 provides the results and discussion of the findings before the conclusion in Section 4.

2. Experimental design

The experimental set-up was as shown in Fig. 3. A signal at wavelength, ω_s = 1548 nm from a VCSEL was coupled into a fibre. Each wavelength represents an ONU in the network. Raman pumps of wavelength, ω_p = 1448 nm at different pump powers were multiplexed onto the fibre and the signal output monitored. In the forward pumping scheme, only P_1 was used while in the backward scheme only P_2 was used. For the bi-directional pumping, both pumps, P_1 and P_2 were used. Polarization controllers (PCs) were used to vary the signal and pump orientation states so as to ensure best coupling into the fibre. The on-off gain was established for various pump powers as well as the VCSEL wavelength tunability range. VCSEL was then modulated with a 4.25 Gb/s 2^7-1 pseudo-random bit sequence (PRBS) and the bit error rate (BER) measurements taken for different transmission distances. The variable optical attenuator (VOA) was used to vary the power received at the Avalanche photo diode (APD) receiver so as to measure the BER. EA amplified the received signal to the required voltage for BER measurements.

On the BER measurement, different G.655, True wave non-zero dispersion shifted fibres (NZ-DSFs) of about 25 km each were joined together using optical connectors giving the various transmission lengths while on the gain characterization, only 25.3 km True-wave Reach fibre was utilized in this experiment. The use of non-zero dispersion shifted fibre (NZDSF) reduced slope (RS) and submarine reduced slope (SRS) True-wave fibres was to achieve dispersion compensation. The NZDSF's fibres have low attenuation and low dispersion.

PPG is the programmable pattern generator, LDC is the laser diode controller, BT is the bias tee, PC is polarization controller, VOA is the variable optical attenuator, EA is the electrical amplifier and BERT is the bit error rate tester. PPG generates the sequence, LDC tunes the bias current of the VCSEL and BT couples the DC and data onto the device. RS-reduced slope fibre, SRS-submarine reduced slope fibre and Reach is a reach fibre.

3. Results and discussions

3.1. VCSEL characterization

A VCSEL is a power efficient device operating in the mA range as shown in Fig. 4. The lasing threshold is about 1.8 mA. The wavelength varies with change in the bias current.

On the inset, the bias current was tuned from 4 mA to 9 mA giving a wavelength tunability of about 4.5 nm (1545–1549.5 nm). The wavelength tunability is an important feature for WDM-PON applications. In addition, the low power device allows multiple channels over a single fibre with minimized nonlinear effects in the transmitted signals. WDM transmit over longer distances than