Very High Bit Rate Transmission for NGPON using AMOOFDM Direct Modulation of Linear Laser

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Abstract: Experimental demonstration of a bit rate as high as 32 Gbit/s is achieved over 20 km SMF for NGPON in a temperature range of 5°C-60°C using AMOOFDM direct modulation of a linear laser.

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1. Introduction

Today, we are witnessing an increased interest in the entertainment possibilities offered through improved networks. We will soon approach the limits of the presently standardized PON (Passive Optical Network) equipment such as the GPON (Gigabit PON) and the EPON (Ethernet PON). Indeed, bandwidth-hungry services such as Ultra-High Definition Video, Video-on-Demand, Video conferencing and interactive online gaming will require upgraded capacity through increased bit rate. Already, standards on 10 Gbit/s are well under way which have led to the emergence of prototypes that are being evaluated by several operators over the world. Higher bit rates are being targeted fuelled by the progress in the component industry. In order to meet the twin constraints of low-cost and high performance for the access network, direct modulation seems the most convenient way provided that the propagation penalties that distort the signal are diminished. Novel modulation formats such as CDMA (Code Division Multiple Access) and duo-binary modulation for the access network have been reported [1, 2]. Among these solutions, OFDM (Orthogonal Frequency Division Multiplexing) has been demonstrated as a promising way to limit fiber chromatic dispersion effects [3, 4]. In this paper, we demonstrate that a bit rate as high as 32 Gbit/s was achieved over more than 20 km SMF by the use of a linear laser which is directly modulated by an AMOOFDM (adaptively modulated optical OFDM) signal combined with a power/bit loading algorithm. The laser is a prototype developed by 3S Photonics and is designed for analogue applications. These results demonstrate the potentiality of direct modulation to obtain high bit rate NGPON by the combination of low-cost laser with digital signal processing (DSP).

2. Linear laser technology and module characteristics

- *Laser technology*

The emitter is based on the 1550 nm DFB laser previously developed in GaInAsP material [6]. The technology is based on 3S Photonics set of qualified building blocks. AlGaInAs has been used in place of GaInAsP. It is based on a ridge waveguide technology. BenzoCycloButene (BCB) is used as dielectric material under the laser bond pads to reduce the capacitance. The length of the device is 300 µm and typical laser width is 2.5 µm. High and Low Reflection (HR and LR) coatings are used for DFB lasers in order to maximize DFB yield and output power from the front facet. Using a combined HR/LR coating SMSR higher than 40dB is observed & no Fabry-Perot modes are noticed even at high laser current, which is a prerequisite to get low RIN (Relative Intensity Noise) characteristics.

- *Module Characteristics*

The laser has been packaged in a standard Butterfly module. The laser threshold current is 20 mA and more than 10 dBm output power is available. Fig. 1-left shows typical evolution of RIN. For a current exceeding 100 mA, RIN values are below -150 dB/Hz over the full frequency range. The bandwidth and input return loss (S_{11}) are shown on fig. 1-right. As can be seen from this figure, the electrical bandwidth of laser is around 17 GHz. This high bandwidth makes this component suitable for future optical access network, especially in the application of novel architectures such as OFDMA (OFDM Access) to support multi-service for converged fixed-mobile solution.

- *Linearity tests*

Using the DFB laser and a Ku receptor, a RF link has been realized using the set up described in [7]. With a bias current of 150 mA, the total gain of the link is -22 dB and -33 dB at 2 GHz and 18 GHz respectively as. The compression points are 21.0 dBm and 26.8 dBm at these two frequencies. The third order interception points were determined to be 29.9 dBm and 28.7 dBm. This result demonstrates the good linearity of these sources.

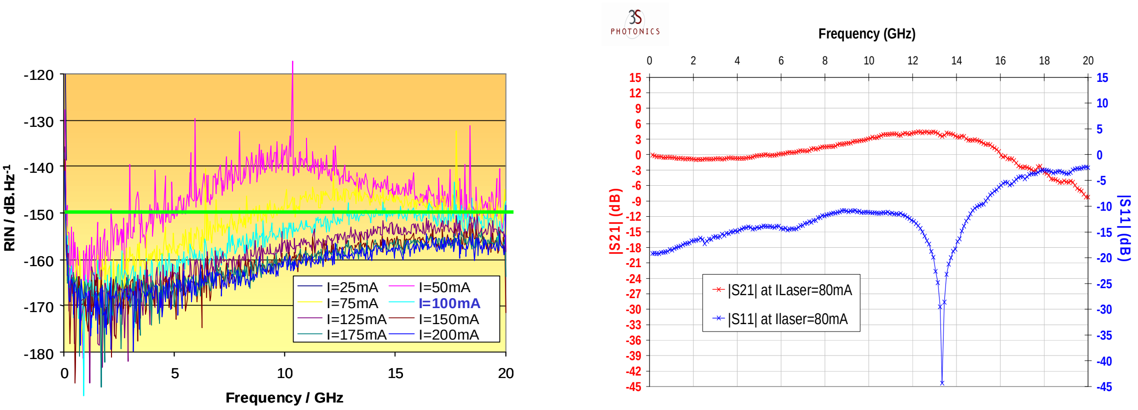

Fig. 1: RIN measurements at 25°C (left); Laser bandwidth and input return loss parameters (right)

3. Experimental set up

Fig. 2-left depicts the experimental set up for AMOOFDM over SMF fiber with direct detection. The laser is directly modulated by the output of the arbitrary waveform generator (AWG) at 12 GSample/s. The AWG has two different analogue outputs which can be combined to achieve transmission over 12 GHz electrical bandwidth. At a bias current of 60mA, the laser output power was 10 dBm. To directly modulate the laser, we applied a modulation signal with a peak to peak value of 2.6 V_{pp}. The signal is then transmitted over the link which consisted of SMF-28 fiber together with an attenuator which is used to control the optical power incident on the receiver. At the far end of this link, a PIN photodiode having 35 GHz bandwidth was connected. The received electrical signal was then sent to a real-time oscilloscope (OSC) running at 40 GSample/s.

For AMOOFDM transmission, MATLAB™ is used to emulate the digital AMOOFDM modulation and demodulation. In this experiment, we used 255 sub-carriers for AMOOFDM signal over 12 GHz. To overcome link dispersion, 8 samples in the time domain are reserved for cyclic prefix. Moreover, to maximize adaptively the throughput transported in the transmission link for a given symbol error rate (SER) (i.e. for a target QoS), we have combined the AMOOFDM modulation technique with Levin-Campello (LC) algorithm [5].

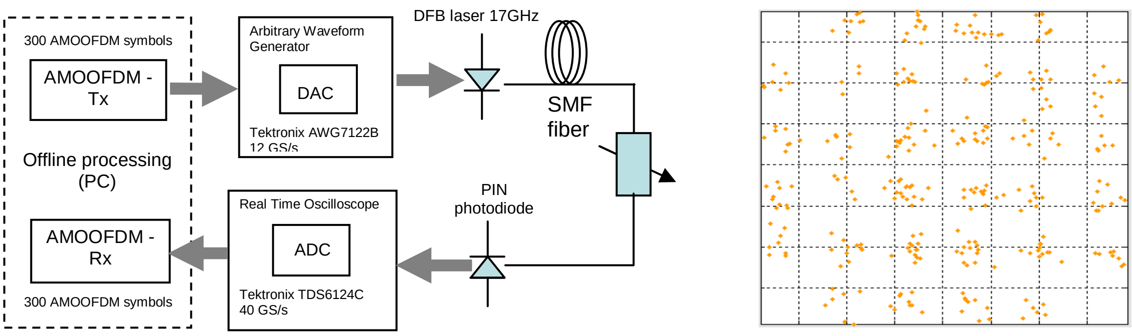

Fig.2: Experimental setup (left) and 32-QAM constellation diagram after 40 km optical fiber link (right)

4. Experimental results and discussion

Fig. 3 shows the results after 20 km link. Fig. 3(a) shows the EVM resulting from the probe signal. An SER of 10^{-3} was targeted which corresponds to a BER (Bit Error Rate) of 2.5×10^{-4} for 16-QAM. The LC algorithm generated an optimized signal by taking into account this probe signal result. Fig. 3(b) shows the bit allocation of the optimized signal. The QAM mapping varies from BPSK to 128-QAM according to the frequency response and noise of the transmission link. From the bit allocation, it can be calculated that 32 Gbit/s was achieved for 20 km link. Due to the power allocation shown in fig. 3(e), the measured EVM results of optimized signal are staircase-shaped as depicted in fig. 3(c), and the same quality in terms of BER was obtained for all subcarriers (fig. 3(d)). It is seen from fig. 3(d) that the BER value varies from 1.10^{-4} to 5.10^{-3} over 255 carriers; so that the average BER is still below the forward error correction (FEC) limit for error free transmission which is 1.10^{-3}. Moreover, the constellation after propagation through 40 km link is shown on fig. 2(right). Even though there is chromatic dispersion over this link, the constellation is quite clear showing that transmission is feasible.

The achievable data rate was then evaluated on a 20 km SMF configuration in a temperature range of 5°C-60°C at two different received optical powers (fig. 4). As can be observed on fig. 4, maximum data rates as high as 32 Gbit/s and 28 Gbit/s can be obtained at 3 dBm and -3.3 dBm received optical power, respectively. Furthermore, it is important to note that only a slight bit rate variation can be observed between 5°C and 60°C.

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This result shows that the laser could be used in an uncooled mode.

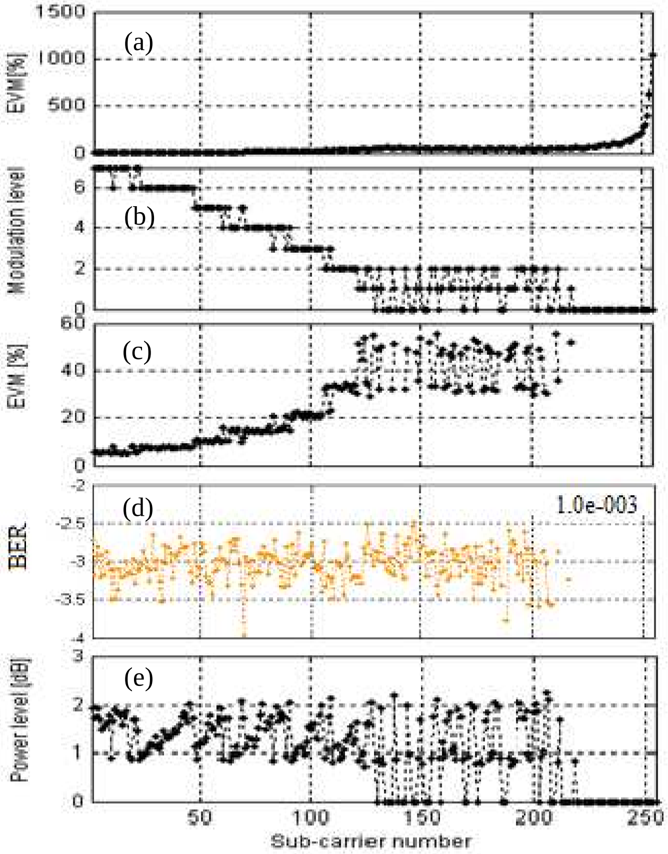

Fig. 3: Transmission results over 20 km optical fiber link: (a) Probing EVM results; (b) Bit allocation; (c) EVM results of optimized signal; (d) BER results of optimized signal; (e) Power allocation

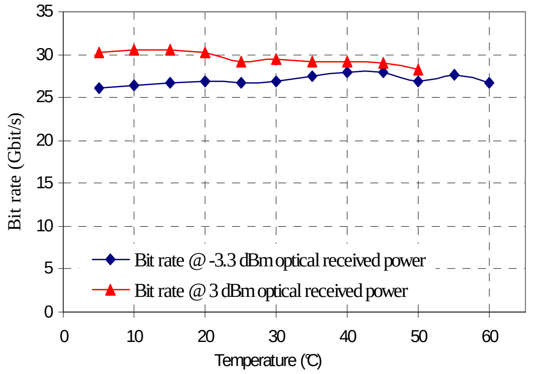

Fig. 4: Bit rate as a function of laser temperature (temperature range from 5°C to 60°C)

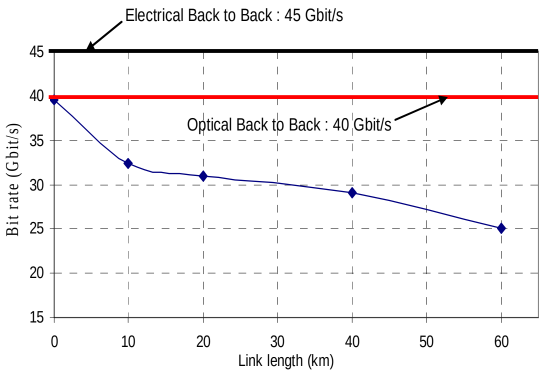

Fig. 5: Bit rate as a function of link length

Finally, we show on fig. 5 the achievable data rate as a function of transmission distance (the laser temperature is fixed at 25°C). With a required SER of 10^{-3}, a bit rate as high as 40 Gbit/s was achieved for optical back to back (BTB) transmission (DFB laser+PIN photodiode). We note that the system limit is the electrical back to back (AWG+OSC) bit rate which is 45 Gbit/s. The data rate is decreased by increasing the fiber length. Indeed, the bit rate decreases from 32 Gbit/s achieved for 20 km link to 25 Gbit/s for a transmission distance as far as 60 km. It should be noted that in our experiment, there is neither optical amplifier nor dispersion compensation in the link.

5. Conclusion

We experimentally demonstrated very high bit rate transmission using AMOOFDM modulation combined with LC algorithm over a linear DFB laser prototype having 17 GHz bandwidth. This laser allows us to achieve a bit rate as high as 40 Gbit/s for BTB transmission by direct modulation. Moreover, a bit rate of 32 Gbit/s was obtained over a link of 20 km and 25 Gbit/s was possible over an extended reach of 60 km without dispersion compensation. Furthermore, the results show only slight bit rate variation over a temperature range of 5°C-60°C. These results demonstrate a promising low-cost, potentially uncooled and high bit rate solution targeting 40 Gbit/s for future PON.

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