System Modelling, Numerical Simulations and Experimental Validation of High Capacity FSO Data Transmission in DWDM Communication employing Optical Frequency Comb

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***Abstract*—Dense Wavelength Division Multiplexing (DWDM) optical technology allows transmission of many wavelengths in a single optical channel. In this paper, system modelling and numerical simulations are demonstrated for high-capacity data transmission using an Optical Frequency Comb (OFC). An OFC is generated using fiber loop modulation technique and simulations are carried out using commercially available simulation software – OptiSystem. An OFC with excellent flatness is obtained, which is essential for noise and error reduction. Each comb line is modulated with data and the DWDM multiplexed signal is transmitted over a free-space optical (FSO) channel. The system performance is assessed in terms of Bit Error Rate (BER) and range of the FSO channel. Our experimental results demonstrate that our system aligns well with simulation and can generate an OFC confirming the potential of our approach for applications such as optical communication networks.**

Keywords—OFC, Fiber loop modulation, DWDM, FSO

I. Introduction

The exponential growth of data usage is reshaping optical communications networks and driving researchers to look for innovative technologies. Increased bandwidth, faster speeds, scalability are some of the requirements for today's telecommunication systems. High capacity optical communication systems can be implemented using DWDM technique, which combines data carried over different wavelengths of lasers chosen on a standard grid. OFCs with equally spaced comb lines generated from a single laser source proven to be a novel technique that substitute the many lasers used in the DWDM system leading to a reduced energy consumption, system complexity, scalability and cost. Flat OFC generation by fibre loop modulation is a technique used for the generation of stable and broadband optical frequency combs with equidistant frequency spacing [1, 2]. This method involves modulating an optical signal with a sinusoidal waveform and propagating it through a fibre loop. As the modulated signal continually passes through the modulator in the fibre loop, a comb like spectrum is generated [3]. Fig. 1 shows the configuration of the fibre loop system used in this work to generate an OFC. A dual drive Mach-Zehnder modulator (MZM) is driven with a 29 dBm signal to introduce phase modulation to the optical carrier of the laser. New frequency components are generated by continually passing the signal through the modulator in the loop where the fundamental frequency of the loop is a subharmonic of the modulator drive frequency. A 50/50 optical coupler (OC) has been used to inject the seed laser to the loop cavity. Half of the optical signal in the loop is extracted from the output of the OC resulting in an OFC. An optical amplifier with 15dB gain is used within the loop to compensate for the loss of the OC and MZM. Two simulation setups are investigated. One to compare the simulation with an experiment for validation of the used software and the other one is used generate an OFC with many lines for transmission over FSO channel.

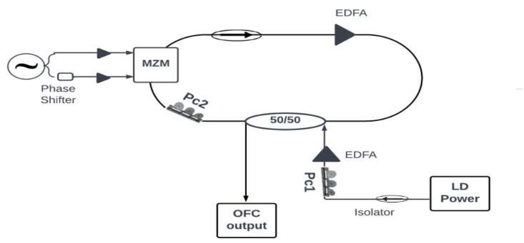

Fig. 1. Fibre loop modulation setup. LD: Laser diode; EDFA: Erbium doped fibre Amplifier; PC: Polarization controller; MZM: Mach-Zhender modualtor; OFC: Optical frequency comb.

II. OFC Numerical Simulation Generation and Experimental Validation

A. Numerical Simulations of OFC generation

Simulations have been performed in the commercially available software – OptiSystem to generate an OFC. The setup used in the simulation is identical to the experimental based setup. A 1532 nm laser is injected into the fibre ring as a seed. The circulating light is modulated each round-trip by a 12 GHz sinusoidal signal to generate the frequency comb. The generated comb spectrum consists of around 16 lines on both sides of the seed laser with ~6 dB flatness. The line spacing of the simulated OFC shown in Fig.2 is 12 GHz.

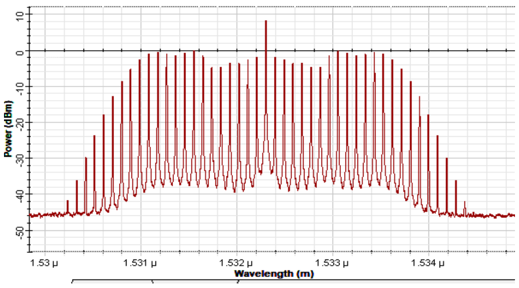

Fig. 2. Simulation result of the generated OFC.

B. *Experimental Validation of OFC*

Fig. 3 shows the experimentally generated OFC. The used total fiber loop length is 50m, giving a cavity fundamental frequency of ~4 MHz. The OFC has 17 lines and 16 lines on the right and left side of the seed laser, respectively. The generated OFC free spectral range (FSR) is 12 GHz, which is limited by the bandwidth of the MZM used in the experiment. The seed laser amplitude is remarkably high compared to amplitude of the comb lines because of the use of a 3-dB OC, meaning half of the injected optical power is sent to the output. In addition, the maximum RF signal power that can be applied to the modulator limits the power per OFC line generated.

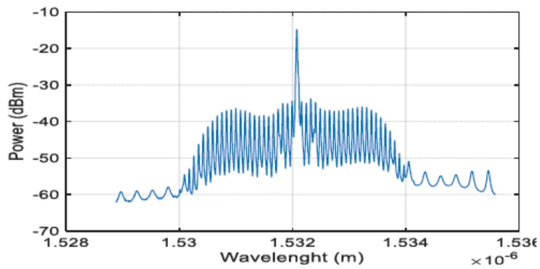

Fig. 3. Experimentally generated OFC.

Fig.4 shows the comparison between the generated OFC using the simulation and the experiment. A fitting factor of 20 dB for the amplitude and 0.21 nm for wavelength are used. A good agreement is obtained between the two results. The amplitude difference is due to the loss of the MZM and the wavelength is due to the used seed wavelength in the simulation.

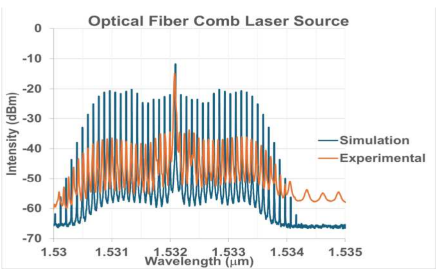

Fig. 4. OFC generation comparison between simulation and experiment.

III. Transmission of OFC over FSO Channel

Fig. 5 shows the block diagram of a setup used in the simulation to generate an 89-line OFC with 50 GHz FSR and transmit data over FSO channel. The lines of the OFC source are demultiplexed using an 89-channel demultiplexer with 10 GHz filter bandwidth. Each output channel is modulated with 10 Gbps data using non-return zero (NRZ) pulse format. The modulated optical carriers are multiplexed and transmitted over the FSO channel with varying distance up to 1 km. The received signal is demultiplexed followed by a direct detection and 3R regenerator. A BER analyzer is used to assess the quality of each received channel. The transmitted data over 1 km range has BER below 1×10^{-4} for most of the channels.

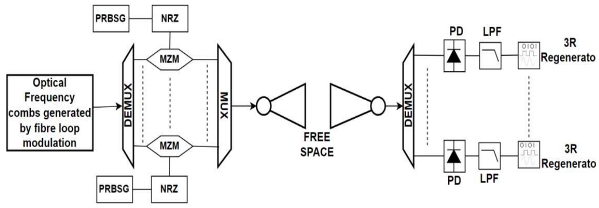

Fig. 5. Data Transmission using OFC over FSO channel. PD: Photo diode; LPF: Low pass filter; PRBSG: Pseudo random bit sequence generator.

Fig. 6 shows the minimum BER of three (Channel no. 25, 40, 50) of the 89 channels for different ranges of the FSO channel. The BER values indicates that the proposed OFC is capable of supporting high-capacity FSO communication systems. We recommend further studies on the performance of the system with respect to varying environmental conditions of the FSO channel including using different modulation techniques.

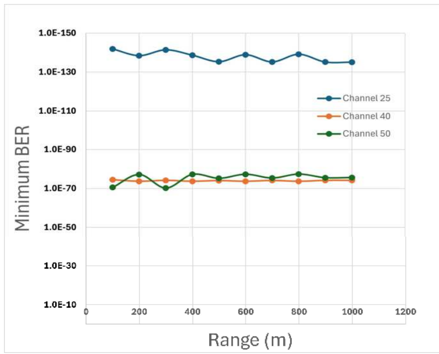

Fig. 6. Performance analysis in terms of BER and range of FSO channel.

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