Generation of 10 GHz pulse packets from an actively mode-locked fiber ring laser

Bengt-Erik Olsson and Daniel J. Blumenthal
Optical Communication and Photonic Networks Laboratory
University of California, Santa Barbara, CA 93106, USA
1 (805) 893-5832, 1 (805) 893-5707, beo@ece.ucsb.edu

1. Introduction

Future ultra high-speed optical networks will probably rely on optical packet switching, where packets of high-speed data can be routed to any node in the network [1]. To allow packet generation at bit rates >40 Gbit/s, return to zero (RZ) data format will most likely be used which also allows the use of solitons in a transmission link. This will, however, require a very high quality pulse source to generate transform limited short pulses. The most versatile high quality pulse source is today the mode-locked fiber ring laser which has the advantage of being tunable in wavelength, giving short transform limited pulses and high output power [2-4]. Packet generation can, in principle, be accomplished by generating a clock sequence of pulses and subsequently encode data packets using e.g. a $LiNbO_3$ modulator. However, a problem with this method is that in practice a very high extinction ratio is required between the packets to accommodate guard bands between packets and address tags that may be tied to the packed at possibly a lower bit-rate, and packet multiplexing. Typically, a data encoding modulator is followed by a high extinction ratio gate, like an acousto-optic modulator, with gate rise times on the order of 100 ns, limiting the ability to provide a flat packet of high speed pulses. In this communication we describe a method to generate packets of pulses directly from an actively mode-locked fiber ring laser. The main advantage is that pulses are now present only during the time slot where data is to be encoded and no output power comes from the laser during guard band time or address tag time.

The basic idea is to have a round trip time in the laser cavity ring that is equal to the packet repetition rate and switching on and off the driving microwave (RF) signal that mode-locks the laser with a pulse sequence that defines the packets. By exactly matching the repetition rate of the packet frequency to the cavity round trip time, the laser can be mode-locked for only a certain number of pulses, i.e. a second mode-locking process is achieved for the packets at the fundamental cavity frequency. Thus an arbitrary number of pulses can be generated in a packet with a repetition rate given by the cavity round trip frequency. Here we demonstrate the concept by generation of 150 ns packets with 30 ns guard band in

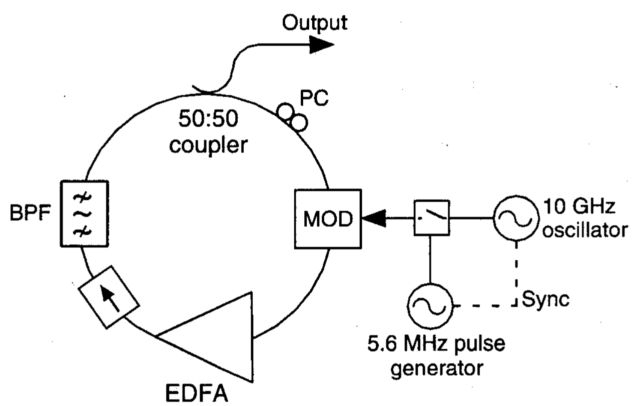

Figure 1. Experimental set-up. MOD: $LiNbO_3$ modulator; EDFA: erbium-doped fiber amplifier; BPF: 0.6 nm optical band-pass filter; PC: polarization controller.

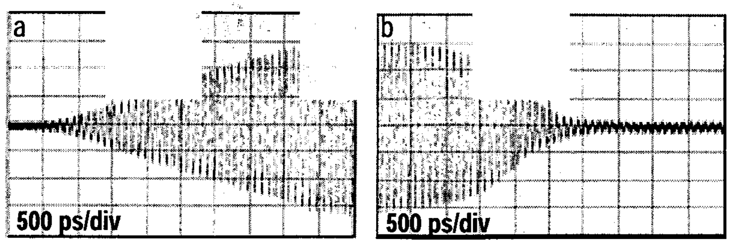

Figure 2. Beginning (a) and end (b) of the electrical drive signal to the ring laser.

between from a 35 m long fiber ring laser. In a practical packet switched network approximately 1 μs clock packet will be needed which can easily be accomplished by using a longer (200 m) laser cavity. A problem is that the rise and fall times of the low frequency electronics used to modulate the high frequency RF signal will give rise to unequal amplitudes of the output optical pulses in the beginning and the end of the optical packet. However, the rise and fall times of the optical packet will be substantially improved compared to the electrical packet due to the thresholding effect in the laser. We also demonstrate that it is possible to achieve immediate turn-on and turn-off as well as determining the number of pulses in a packet by detuning the RF drive frequency from to the multiple of the fundamental round trip frequency of the laser cavity.

The ideal RF frequency f_{RF} should be a multiple of the fundamental cavity frequency f_f, $f_{RF} = N \times f_f$ where N is an integer. When this condition is fulfilled the laser gives a continuous pulse train at the output. If the RF signal has a fixed start time which always occurs at a repetition time equal to the round trip time, i.e. the RF signal is switched off for a short time to create a well defined starting point of the packet, and N is an integer, the packet generation process described previously will occur. If f_{RF} is detuned from the ideal condition, i.e. N is not an integer, mode-locking will still occur for a certain number of pulses after the turn on. However, after a number of pulses given by frequency detuning, the overlap between the switch window through the modulator and the arriving pulse will be very small and no mode-locking will occur. In this way the number of pulses actually supported in the laser cavity will be determined by the amount of frequency detuning and the switching window in the modulator.

2. Experiments

Figure 1 shows the experimental set-up. The laser was built with standard non-polarization maintaining fiber optic components, consisting of an EDFA with a saturated output power of +14 dBm and a noise figure of 5 dB, a 0.6 nm optical band pass filter, a 50:50 fiber coupler to couple light out, and a $LiNbO_3$ electro-optic modulator with a bandwidth of 10 GHz. The total cavity length was 35 meters which corresponds to a fundamental round trip frequency of 5.6 MHz. When the laser was driven at 10 GHz, f_{RF} was the 1761th harmonic of the cavity frequency, i.e. 1761 pulses were contained in the laser cavity ring. The pulse width could be varied between 8-15 ps by adjusting the modulator bias with a time-bandwidth-product (TBP) of 0.37. The timing jitter, as measured over several minutes with a 40 GHz detector on a 50 GHz sampling oscilloscope, was estimated to be below 0.9 ps, and the super mode suppression was

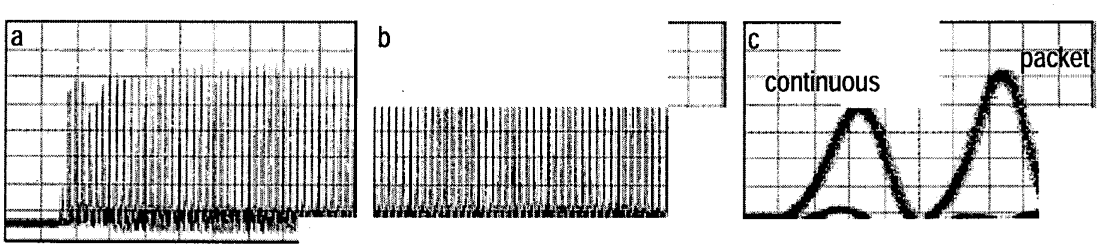

Figure 3. Optical output from the laser. a and b shows the beginning and the end of the packet, and c shows the 10 ps pulse from the laser in continuous mode and in packet mode.

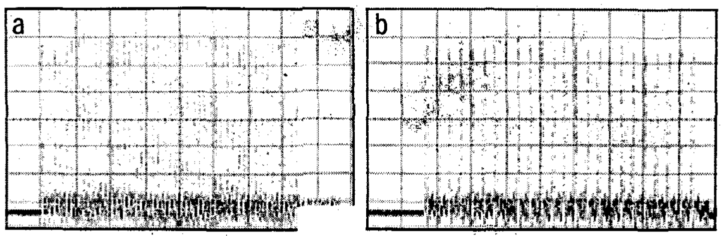

Figure 4. a: 4.5 ns pulse packet (300 ps/div), b: a packet containing 24 pulses using an electrical modelocking frequency detuned from fundamental cavity frequency (600 ps/div).

>65 dB, as measured with an electrical spectrum analyzer. To create a pulsed RF drive signal the RF signal generator was gated using an external pulse generator with a repetition frequency adjusted to match the fundamental cavity frequency of the laser. Figure 2 shows the beginning and end of the electrical RF drive signal into the laser and the rise and fall time of the RF signal is very slow. In figure 3 the 150 ns output packet is shown. Figures 3a and 3b show the beginning and end of the packet, respectively. Even though a few pulses in the beginning and the end of the packet have lower peak power, it is a significant improvement in rise and fall time compared to drive signal. Figure 3c shows an optical pulse in the packet that has a pulse width of 10 ps and the same pulse when the laser runs in continuous mode. No difference in pulse shape or pulse width in the packets was observed compared with the laser in non-packet mode, apart from the beginning and ending pulses with different peak power. To demonstrate the concept of packet generation by detuning the drive frequency from a multiple of the fundamental cavity frequency, the same conditions as above were used with the RF frequency slightly detuned. Figure 4 shows two different very high quality packets. The individual pulse quality is the same as before but now the rise and fall times are instantaneous and all pulses in the packet are the same. Figure 4a shows a 4.5 ns packet containing 45 pulses and figure 4b shows a packet of only 24 pulses. The small after-ringings are due to the detector. The number of pulses can in practice be changed in a number of ways. Primarily by adjusting the RF frequency but also to a certain extent by adjusting the modulator-bias and thus change the shape of the modulator switching window. An important feature of this packet generation process is that the available power from the EDFA in the ring laser is fully utilized. The average power out of the laser is +12 dBm regardless of the number of pulses in the packet and the pulse peak power changes according to the number of pulses in the packet. It is actually possible to make only one short pulse traveling in the laser cavity, which will have an output peak power of approximately 280 W.

3. Conclusion

A method for generating packets of short high quality pulses directly from an actively mode-locked fiber ring laser is demonstrated by locking the packet repetition frequency to the fundamental laser cavity frequency. This technique can be particularly useful in future high-speed packet based optical networks, both for generation of data packets and as a clock source for decoding and controlling circuits, e.g. all-optical address recognition where only a certain number of clock pulses are required.

The authors would like to thank G. Rossi and P. Öhlén for helpful discussions. This work was supported under the DARPA sponsored Center for Multidisciplinary Optical Switching Technology (F49620-96-1-0349)

4. References

[1] P. Gambini et al, "Transparent Optical Packet Switching:...", *IEEE J. Sel. Areas in Comm.*, vol. 16, pp.1245-1259.

[2] M. Nakazawa et al, "Ultra stable harmonically and regeneratively modelocked polarisation-maintaining erbium fibre ring laser," *Electron. Lett.*, vol. 30, pp. 1603-1605, 1994.

[3] L. E. Nelson et al, "Ultra short-pulse fiber ring laser," *Appl. Physics B*, vol. 65, pp. 277-294, 1997.

[4] B. Bakhshi et al, "A Polarization-Maintaining and Dispersion-Managed 10 GHz Mode-Locked Erbium Fiber Ring Laser Providing Both sech^2 and Gaussian-Shaped Pulses," *Opt. Fiber Technol.* Vol. 4, pp. 293-303, 1998.