

Optical Clock Repetition Rate Multiplier for High Speed Digital Optical Logic Circuits

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Abstract

Repetition rate multiplication has been shown using a fiber ring oscillator comprising of a semiconductor optical amplifier as the gain medium and using the fast saturation and recovery of the amplifier from an external optical pulse train. Repetition frequency multiplication up to 6 times has been achieved and up to 34.68 GHz.

The rapidly maturing technologies of high performance opto-electronic devices has helped to focus an intense effort by a number of research groups for the development of ultra-high speed, all-optical logic circuits [1,2,3]. One of the essential subsystems required for optical logic circuits is a high repetition frequency optical clock source. A large number of short pulse, high repetition rate laser sources have been demonstrated so far. Two of these promising techniques have relied on high frequency microwave sources to provide the signal [4] and on narrow frequency stabilized DFB laser sources and compression techniques [5]. Apart from the technical complexity that these approaches involve, they also do not have easily accessible low rate rf/electrical signals that may be used for external electrical data interfacing with the optical circuits.

Temporal synchronization of signals is a major issue in ultra high speed logic circuits. In order to ensure synchronization in an optical logic circuit, a single reference optical clock may be used throughout the circuit. Optical logic circuits are likely to consist of a small number of ultra high speed Boolean logic gates, synchronized to each other, but running at different rates depending on the logic function that they perform. The central optical logic processing units may be expected to run at rates of hundreds Gbps to keep the throughput of the circuit high, while optical processing units in the periphery of the optical circuit, input/output may be run at significantly lower rates. Examples of such optical circuits are the data insertion multiplexer and the data extraction demultiplexer circuits. Assuming that a single reference clock is used throughout the optical logic circuit, this may be at the high rate of the optical logic processing units, in which case the low rate signals at the input/output circuits will have to be obtained by local clock division. Alternatively the reference clock may be at the lower frequency rate of the input/output interfaces and the high rate optical signals required at the optical processing units will be obtained by local multiplication of the reference clock. The advantages of using the low frequency rate of the input/output interfaces as the reference clock are (a) repetition frequency multiplication is easier than repetition frequency division, (b) input/output data stream rates to/from the optical logic circuits will be lower than the optical gate processing rates and (c) it is preferable, easier and less costly to use low frequency rf components for the generation of the optical clock pulse train. In order to be able to use this low frequency rate, reference clock technique in high speed optical digital circuits, it is necessary to be able to multiply the repetition rate from a laser source. In this letter we report the demonstration of a simple optical clock multiplier circuit. We

show up to 6 times frequency multiplication from 5.78 GHz to 34.68 GHz and 19 times multiplication from 1.25 GHz to 23.75 GHz.

The principle on which repetition frequency multiplication is achieved in our circuit, relies on two key observations. The first is that the fast saturation of the gain of a semiconductor optical amplifier (SOA) by an externally introduced picosecond optical pulse train, may be used for gain modulation in fiber ring laser and the generation of stable, mode-locked picosecond pulse trains [6]. In this instance the externally introduced optical pulse and the comparatively slow gain recovery of the SOA, define a short temporal gain window within which the mode-locked pulse may form. The second observation is that by tuning the frequency f_{ext} of the externally introduced pulse train to $f_{\text{ext}}=(N+1/n)\delta f_{\text{ring}}$, it is possible to obtain an output pulse train at a frequency nf_{ext} . In this equation N is the order of harmonic mode-locking of the ring laser, δf_{ring} is the fundamental frequency of the ring laser oscillator and n is an integer number greater than 1. This technique for repetition frequency multiplication has been successful with lithium niobate modulators, in cavities which a SOA [7] and EDFA [8] as the active media and achieved up to 21 GHz and 200 GHz output pulse trains respectively.

Figure 1 shows the experiment layout. The optical frequency multiplier circuit was constructed entirely from fiber-pigtailed devices. Gain was provided from a 500 μm , bulk InGaAsP/InP ridge waveguide SOA. The SOA had a peak gain at 1535 nm and could provide 23 dB small signal gain with 250 mA dc drive current. Faraday isolators were used at the input and output of the SOA to ensure unidirectional oscillation in the ring.

As the SOA exhibited a 2 dB polarization gain dependence, a polarization controller was introduced at its input port. After the SOA a 3 dB fused optical fiber coupler was used to insert the external modulating signal and to obtain the output from the source. The externally introduced pulses were provided from a gain switched DFB laser operating at 1548.9 nm. The gain switched pulses were compressed to 8.3 ps with dispersion compensating fiber and after amplification in an EDFA, were introduced into the multiplier oscillator through the 3 dB fused fiber coupler. The polarization state of the external signal was adjusted with a polarization controller for optimum performance before introduction into the multiplier circuit. In order to allow the circulation of the external signal in the multiplier circuit and to select its oscillating wavelength, a tunable filter with 5 nm bandwidth was used. The output from the multiplier circuit was obtained through the 3 dB fused fiber coupler and was isolated from the external seeding signal using a 0.6 nm optical filter. The mode-locked pulses obtained directly from the multiplier circuit were compressed using a dispersion compensating fiber of total dispersion -11.4 ps/nm placed at its output. The total length of the multiplier ring cavity was 14.6 m corresponding to 13.9 MHz fundamental frequency.

When the frequency of the rf signal generator driving the DFB laser source was adjusted to a harmonic of the fundamental frequency of the ring cavity at 5.78 GHz and with the EDFA adjusted to provide 800 μ W into the cavity, the ring laser breaks into stable, mode-locked operation at this frequency producing 9 ps pulse trains. By changing the frequency of the signal generator by $13.9/n$ MHz with n varying from 2 to 6, the laser produces pulse trains at multiples of the 5.78 GHz repetition frequency. Figure 2 shows

from top to bottom the output pulse trains from the ring laser at 17.34 GHz, 23.12 GHz, 28.9 GHz and 34.68 GHz. Figure 2(a) shows the output pulse trains monitored on a 40 GHz sampling oscilloscope and figure 2(b) shows the corresponding second harmonic autocorrelation traces. Numerical fitting of the autocorrelation traces indicates that the output pulses have squared hyperbolic secant profiles. Figure 3 shows the optical spectrum of the signal from the multiplier circuit. The output power from the multiplier circuit was about 60 μ W. As the repetition frequency from the multiplier circuit increases away from the rate of the externally introduced pulse there is a gradual increase in the pulse width and merging between adjacent pulses as well as a weak pattern effect on the pulse train output. Figure 4 shows the variation of the pulse width and background-to-peak between pulses as a function of the repetition frequency assuming squared hyperbolic secant profiles. We have examined the rf bandwidth over which the multiplier circuit operated as the frequency of the the external pulse train was varied. This bandwidth was found to be about 300 KHz at 5.78 GHz, the frequency of the external pulse train and decreased to 140 KHz at 34.68 GHz. This large locking bandwidth is primarily due to the short cavity of the multiplier circuit.

The process by which the ring oscillator mode-locks in the presence of the external pulsed signal when its frequency is a harmonic of the ring oscillator, relies on the fast saturation of the SOA. The temporal gain profile from the SOA develops a sharp, periodic drop because of the saturation that the external pulse imposes on it, at the frequency rate of the external pulse train. The mode-locked pulse develops just ahead of the external pulse, at the point where the recovery from the SOA is maximum. When the

repetition rate of the external pulse train is adjusted to differ by $\delta f_{\text{ring}}/n$ from a harmonic of the fundamental of the ring cavity, the externally introduced pulse train becomes temporally displaced by T_{ext}/n on each recirculation through the ring cavity with respect to its previous position, where T_{ext} is the repetition period of the external signal. The external pulse generates the sharp gain drop in the SOA with a period T_{ext}/n and causes the repetition frequency of the output of the circuit to be multiplied to nf_{ext} . As it takes n recirculations through the ring cavity for the externally introduced pulses to recover their position, the small modulation in the output pulse train observed from the multiplier in figure 2a develops. It must be noted that compared to other multiplication techniques, the modulation on the multiplied output signal is very low and it never exceeded 6 %. This is a result of the mode-locking process that uses the gain modulation of the SOA which never presents loss and because the external pulse is allowed to circulate in the multiplier cavity nearly equalizing the gain of the SOA from pulse to pulse.

We have also examined repetition frequency multiplication, from even lower external signal frequencies and it has been possible to obtain up to 23.75 GHz output pulse trains from 1.25 GHz external input. This corresponded to a multiplication factor of 19.

In summary we have presented a technique for repetition frequency multiplication of a mode-locked, optical pulse train. The technique is based on the fast saturation of a SOA in a fiber ring cavity, induced by an externally introduced optical pulse train. With this technique it has been possible to demonstrate a factor of 6 frequency multiplication and up to 34.68 GHz at the output of the multiplier circuit. The circuit is expected to find

application in clock multiplication and temporal synchronization circuits for ultra high speed optical logic circuits.

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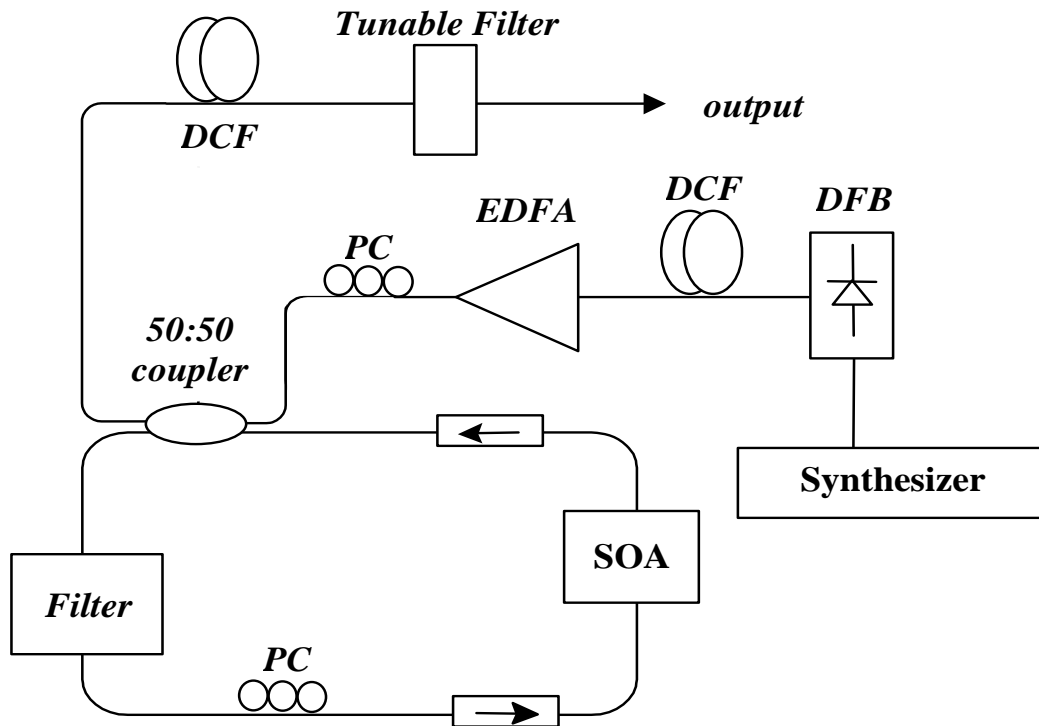
Captions

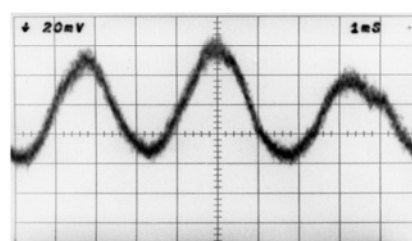
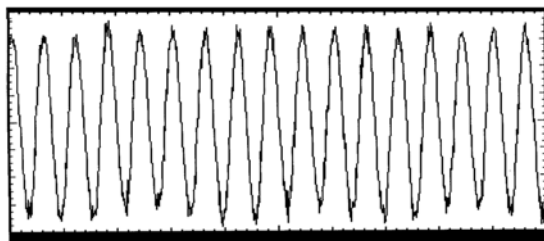
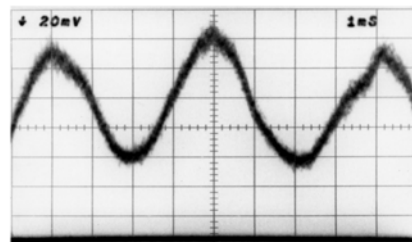
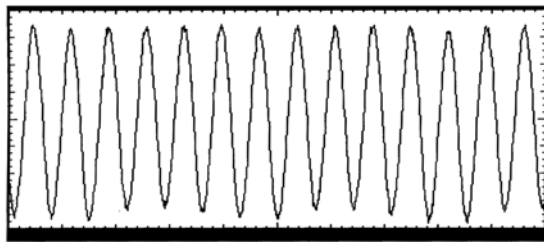
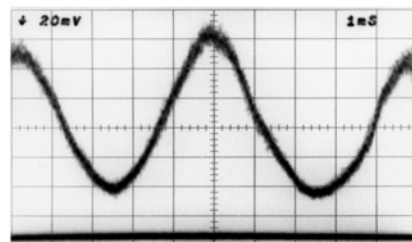
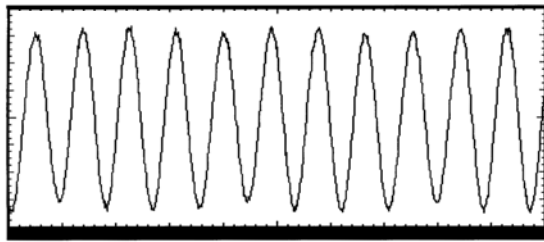
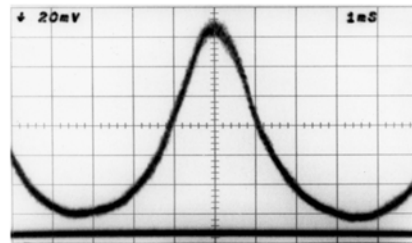
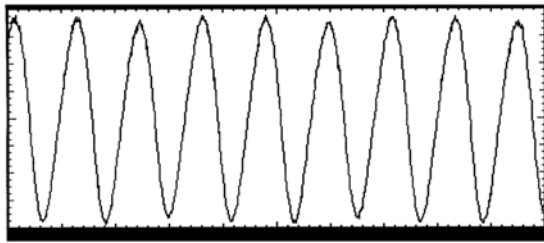
Figure 1 Experimental layout.

Figure 2 (a) Output optical pulse trains and (b) autocorrelation. From top to bottom: 17.34 GHz, 23.12 GHz, 28.9 GHz and 34.68 GHz. The time base in the autocorrelation traces corresponds to 8.3 ps.

Figure 3 Optical spectrum of the multiplier circuit output

Figure 4 Pulse width and background-to-peak change with multiplication frequency factor





(a) 50 ps/div

(b)

SPECTRUM

