Generation of 800 MHz Stable Train of Subpicosecond Solitons from a Figure-8 Fibre Laser

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Abstract. Subpicosecond optical pulse generation by harmonic mode-locking of an Yb/Er fibre laser is reported. Generation of 800 MHz regular train of 900 fs transform-limited pulses has been obtained.

Introduction. Harmonic mode-locking of fibre lasers has become a topic of great interest due to its potential applications in telecommunications. Both passive and active schemes were used for the pulse repetition rate stabilization. Passive stabilization of repetition rate in the Figure-8 fibre laser was obtained using the recirculating ring delay line [1] and using linear coupled cavity [2] however the generation of stable harmonic trains of single pulses has not been satisfactory demonstrated using these techniques. Active modulators within the ring fibre soliton lasers have been used to define the repetition rate [3,4] and to obtain stable active mode-locking at high harmonics with soliton mechanism of the pulse shaping [5]. In this work we report the use of an intracavity phase modulator to stabilize repetition rate within a passively mode-locked Figure-8 fibre laser. The scheme of Figure-8 laser differs from another passively mode-locking schemes in that it employs a high-contrast switching which is due to the properties of nonlinear amplifying loop mirror. The high-contrast switching combining with a dispersion in the cavity completely defines the pulse parameters and the modulator working leads just to the temporal regularity of the pulses.

Experiment. The laser configuration is shown in Fig.1. The laser has the basic form

![Figure 1](image)

Fig.1. Experimental setup. PC - polarization controllers; ISO - isolators; EF1, EF2 - active fibres; M - modulator.

of the conventional Figure-8 laser and is based on Er/Yb codoped fibre EF1 [6] allowing pumping at 1.064 μm. However, the laser contains two additional elements - a phase modulator and an additional Er/Yb codoped fibre amplifier EF2. These elements are positioned in the unidirectional loop. The lithium-niobate integrated optic phase modulator was capable of operating up to 1.0 GHz. The unit was placed immediately after
the 30% output coupler to minimize the light intensity in the modulator. An additional amplifier EF2 was placed immediately after the modulator to compensate for the 8dB insertion loss of the device. The system was pumped from an actively stabilised main-frame Nd:YAG laser, up to 100 mW and 600 mW of the pump power were available at the amplifier and laser respectively. In order to prevent optical damage to the modulator the average circulating power passing through the device was kept below 10 mW.

Results. Initially, the nonlinear loop had a length of 120 m. The fundamental laser repetition rate was 1.6 MHz. For suitable settings of polarisation controllers, the system was capable of mode-locking self-start with the modulator turned off although the self-start threshold was reduced with it on.

![Graphs A, B, C showing laser output](image)

**Fig.2. Oscilloscope traces (upper row) and spectra (lower raw) of the laser output. Pump power is decreasing from (A) to (C).**

If the pump power was suitably controlled stable harmonic trains of pulses could be obtained as demonstrated in Fig.2B. Being pumped by a power exceeding the optimal value, the laser had generated not fundamental pulses only, but double and multiple ones as well (see Fig.2A). When pump power decreased below the optimal value the laser generated trains of fundamental pulses and gaps, as shown in the Fig.2C. Autocorrelation traces of the laser output are presented in the Fig.3. Fig.3A corresponds to the case where multiple pulses were generated. It can be seen that the pulses have adopted a regular structure within a given time slot, the pulse separation corresponding to 8 ps. The periodic multiple structure is also reflected in the modulated spectrum shown in Fig.2A (lower row). We believe the time separation to be determined by some residual etalon within the modulator. The duration of fundamental pulses was about 900 fs, whether the modulator be on or off; pulses were closed to transform-limited ones.
Pure harmonic trains were obtained up to a frequency of 800 MHz (500th harmonics) during the course of these experiments, the maximum obtainable frequency being restricted only by the 10 mW limit on circulating laser power. That is why in subsequent experiment with the laser, generating shorter (and hence more intensive) pulses, stable harmonic trains were obtained to a frequency of only 400 MHz (124th harmonics). The laser cavity in this experiment was shortened, giving the round-trip frequency of 3.22 MHz and the pulse duration of 600 fs.

**Conclusion.** We have presented a scheme for controlling the pulse repetition rate within the Figure-8 fiber laser. The technique enables one to utilize the powerful pulse-forming effect which is intrinsic to this type of lasers and to obtain the repetition rate stability associated with the conventional active technique. We believe that the scheme reported can be improved to be used as a solitons source for telecommunications.

**References.**