Ultra-low-jitter multiwavelength synchronised optical pulse source for C-, L- and U-bands

P. Devgan, J. Lasri, R. Tang and P. Kumar

A novel self-starting optoelectronic oscillator that uses a single electroabsorption modulator in a fibre-extended cavity to generate synchronised optical pulses simultaneously at multiple wavelengths is demonstrated. We have generated 10 GHz-rate optical pulses simultaneously at eight wavelengths in the C-band, each with the lowest timing jitter (42 fs in the 100 Hz to 1 MHz range) reported to date for self-starting sources. Potential for operation in the L- and U-communication bands is also demonstrated.

Introduction: Multiwavelength high-repetition-rate return-to-zero (RZ) optical pulse sources are becoming increasingly important for use in wavelength-division-multiplexing (WDM) networks. Various techniques have been demonstrated for creating such pulse sources, including spectral carving of supercontinuum [1], active modelocking of a semiconductor laser with intracavity etalon [2], four-wave mixing in highly-nonlinear fibre [3], and modulation of a multiwavelength Raman fibre laser's output with an electroabsorption modulator (EAM) [4]. An advantage of all these techniques is that the generated pulse streams are synchronised. However, a significant drawback is that they all require an external microwave-driving source the phase noise of which places a bound on the timing jitter performance of the generated pulses. Recently, we have demonstrated a novel self-starting (i.e. without an external microwave-driving source) optoelectronic oscillator (OEO) incorporating an EAM, an optical-fibre delay line, and optical detection in a closed-loop resonating configuration that converts a single CW input into a 10 GHz-rate optical pulse stream having the lowest timing jitter reported to date for self-starting sources [5]. In this Letter, we report the use of such an EAM-based OEO (EAM-OEO) to convert multiple independent CW input lasers into synchronised 10 GHz-rate optical pulse streams for use in the C-, L- and U-bands of the fibre-optic communication spectrum. The generated pulse stream at each wavelength of the multiwavelength output has the same ultra-low timing jitter property as in the single input case. This multiwavelength source is constructed entirely from commercially available components and the rate of each channel can be easily scaled to 40 GHz or higher by use of a higher-bandwidth EAM and other components in the optoelectronic cavity.

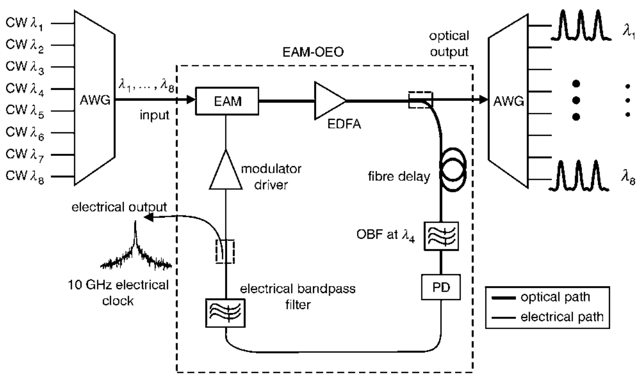

Fig. 1 *Experimental setup of multiwavelength pulse source*

EAM-OEO: electroabsorption-modulator based optoelectronic oscillator; AWG: arrayed waveguide grating; OBF: optical bandpass filter; PD: 10 GHz bandwidth photodiode

Experiment and results: The experimental setup is shown in Fig. 1. The EAM-OEO is similar to that we reported in [5]. To demonstrate the multiwavelength operation, CW light from eight DFB lasers, ranging in wavelength from 1546.7 nm to 1557.9 nm with 1.6 nm spacing between each wavelength, is introduced into the EAM via an arrayed-waveguide grating (AWG) multiplexer. The output of the EAM is amplified by an EDFA and after propagation through the delay fibre it is passed through an optical bandpass filter to select one of the wavelengths for oscillation in the OEO. As was described in detail in [5], the use of a high-Q electrical bandpass filter ($Q \sim 1000$) together with the sharp rectangular-shaped transmittance window of the EAM allows single longitudinal mode oscillation with 3 km of fibre in the optoelectronic loop. This yields a 10 GHz-rate, low-phase-noise microwave signal that is combined with a DC bias (−2.4 V) to drive the EAM, which gates the individual CW lasers simultaneously to generate synchronised 10 GHz-rate optical pulse streams at the injected wavelengths. The modulated multiwavelength light is optically tapped off from the OEO cavity as shown in Fig. 1. For diagnostic purposes the tapped-off light is separated into individual wavelength components by an AWG demultiplexer. The separated pulse stream at each wavelength exhibits the same low timing jitter of 42 fs in the 100 Hz to 1 MHz integration band as in [5].

Fig. 2 shows the optical spectrum of the multiwavelength output. One sees eight modulated features with 1.6 nm spacing corresponding to the wavelength separation of the input DFB lasers. Because the transmittance of the EAM (top right inset in Fig. 2) and the EDFA gain are not uniform over the entire wavelength range, the input power of the individual CW lasers is adjusted to equalise the power in the output RZ channels. We further characterise all eight channels at the output of the AWG demultiplexer in the frequency domain using an optical spectrum analyser (OSA) and in the time domain using a 50 GHz bandwidth photodetector/oscilloscope combination. Fig. 3*a* shows a composite of the close-ups of the optical spectra with 0.01 nm resolution for channels 2, 4, 7 and 8, respectively. The optical spectrum of the pulses in each channel is very symmetric with over 20 dB deep modulation of the 0.08 nm spaced peaks having an envelope of width $\Delta\nu \sim 0.18$ nm. Fig. 3*b* shows a composite of the time-domain traces of the power in each of the above channels. The pulse width in each channel is $\Delta\tau \sim 20$ ps, giving a time-bandwidth product $\Delta\nu\Delta\tau \sim 0.45$ that is almost transform limited for an assumed sech^2 pulse shape. Note that, although not shown, the pulse measurement results (both in frequency and time domains) are the same for the other channels. Furthermore, the 10 GHz electrical signal from the OEO (which sets the same ultra-low timing jitter for all the channels) is used to trigger the oscilloscope in time-domain measurements, which would not be possible unless the pulse streams in all channels are synchronised to each other.

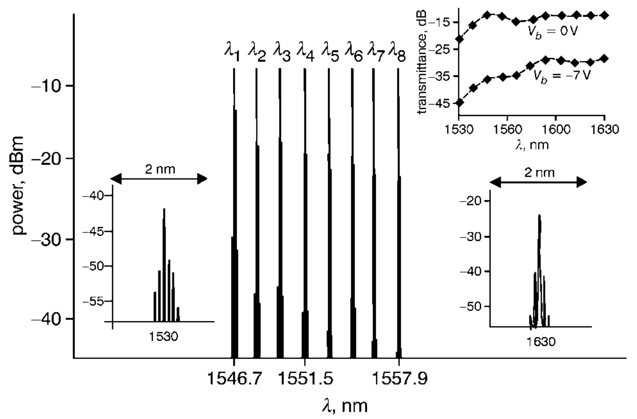

Fig. 2 *Optical spectra with 0.01 nm resolution for ten output wavelengths from multiwavelength RZ source*

Channels 1 through 8 were simultaneously passed through EAM-OEO
Top-right inset: Transmittance of EAM against wavelength for two bias voltage settings
Bottom-left and right insets: Optical spectra of resulting pulses at 1530 and 1630, respectively

To demonstrate operation over the entire C-, L- and U-bands, we injected into the EAM CW light at 1551.5 nm (channel 4 in above measurements that resonates in the OEO) along with light from a tunable CW laser parked at 1530 nm in one case and at 1630 nm in another. The bottom-left and bottom-right insets in Fig. 2 show the optical spectra of the resulting pulses at 1530 and 1630 nm, respectively. Owing to the fact that the EDFA does not provide gain at these wavelengths, the output power is smaller relative to the eight channels around 1550 nm. The optical spectra, however, exhibit similar shape and modulation depth of the 0.08 nm spaced peaks, illustrating the ability of the EAM-OEO to convert multiple CW inputs into multiwavelength RZ outputs over the entire C-, L- and U-bands. This is also apparent from the top-right inset in Fig. 2, where the flatness of the EAM transmittance around 1630 nm (for 0 and −7 V bias voltage, corresponding to the ~20 dB depth of modulation) implies that it could also modulate longer wavelengths. However, due to the lack of an appropriate CW laser source we were not able to demonstrate optical pulse generation at wavelengths longer than 1630 nm.

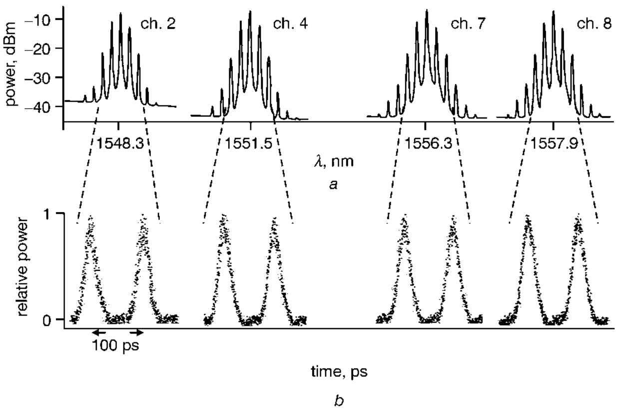

Fig. 3 *Output optical spectra, and time domain traces*

a Output optical spectra of channels 2, 4, 7, 8 measured with 0.01 nm resolution
b Time domain traces of power in channels 2, 4, 7, 8

Conclusion: We have demonstrated the use of a self-starting EAM-based optoelectronic oscillator to convert multiple independent CW sources to multiwavelength synchronised RZ sources at 10 GHz repetition rate. The 20 ps-wide pulse stream at each wavelength has >20 dB modulation depth and the lowest timing jitter reported to date for self-starting 10 GHz-rate pulse sources.

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