Photonic microwave up-conversion using optoelectronic oscillator based on polarisation modulator

Pei Zhou, Zhenzhou Tang, Shilong Pan, Shuhong Cai, Dan Zhu and De Ben

An optical up-conversion scheme using an optoelectronic oscillator based on a polarisation modulator is proposed and demonstrated. A baseband signal with a bandwidth as large as 5 or 10 GHz is successfully up-converted to a 10 or 20 GHz carrier without any replacement of the devices in the scheme. The conversion loss is independent of the wavelength of the laser source. The stability of the operation is also investigated.

Introduction: Radio-over-fibre (ROF) systems are of great importance in radars, wireless communication systems, antenna remoting, software defined radios and modern instrumentation [1]. The optical up-conversion technique is one of the key technologies in an ROF system to avoid the use of wideband microwave mixers. Several approaches to realise optical up-conversion have been reported recently [2–6]. In [5], all-optical signal up-conversion was realised by using cross-gain modulation (XGM) in semiconductor optical amplifiers (SOAs). This approach, however, is too complex since it needs two laser sources and a dedicated microwave generator. In addition, the output signal from the SOA is seriously chirped and therefore unsuitable for long-distance-transmission in singlemode fibre (SMF). In [6], Shin *et al.* demonstrated the up-conversion of a 1.25 Gbit/s optical baseband data using a frequency-doubling optoelectronic oscillator (FD-OEO). However, the wavelengths of the incident lightwave are fixed at 1310 and 1550 nm as the FD-OEO is constructed based on the wavelength dependence of the half-voltage of a Mach–Zehnder modulator (MZM). Since wavelength is an important resource in a communication system, it is highly desirable that the photonic microwave up-conversion can be performed on a single arbitrary wavelength.

In this Letter, we present a novel approach to up-convert a baseband signal with a bandwidth as high as 5 or 10 GHz to a 10 or 20 GHz carrier using a polarisation-modulator-(PolM)-based OEO [7]. The OEO not only produces the high-quality local oscillator (LO) signals, but also implements the photonic microwave up-conversion simultaneously. Since the OEO can be selectively operated at 10 and 20 GHz, the up-conversion can be made to a 10 or 20 GHz carrier without any replacement of the devices in the scheme.

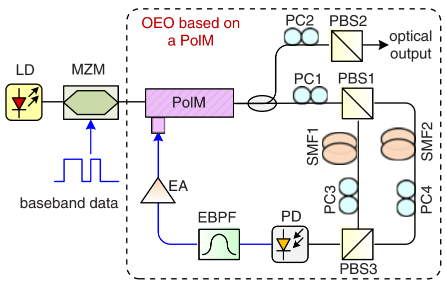

Fig. 1 *Schematic diagram of proposed photonic microwave up-conversion system*

LD: laser diode; PC: polarisation controller; MZM: Mach-Zehnder electro-optic modulator; PolM: polarisation modulator; Pol: polariser; PBS: polarisation beam splitter; SMF: singlemode fibre; PD: photodetector; EBPF: electrical bandpass filter; EA: electrical amplifier

Principle: Fig. 1 shows the schematic diagram of the proposed photonic microwave up-conversion system. An optical carrier from a laser diode (LD) is sent to an MZM. The MZM is biased at the quadrature point, which is driven by a baseband electrical signal. The modulated signal is then introduced into a PolM-based OEO. The OEO has a similar structure as that in [7]. In the OEO, the PolM, an optical coupler, two polarisation controllers, and two polarisation beam splitters (PBS) form a dual-output-port intensity modulator. When a continuous-wave (CW) optical signal is introduced into the OEO, the upper branch of the dual-output-port intensity modulator will output a high-purity microwave signal at either one or two times the oscillating frequency in the OEO cavity. On the other hand, when a baseband-signal modulated optical carrier is injected into the OEO, the oscillation of the OEO will not be disturbed since the baseband signal will be effectively eliminated by the high-Q electrical bandpass filter (EBPF) in the OEO loop. As a result, the upper branch of the dual-output-port intensity modulator would output an up-converted signal at either one or two times the fundamental frequency because of the optical mixing in the intensity modulator. Thus, the proposed scheme is able to perform up-conversion of a baseband signal to a 10 or 20 GHz frequency carrier without any replacement of the devices. In addition, a PolM is a special phase modulator that can support both TE and TM modes with opposite phase modulation indices in a large wavelength range [7], so the proposed scheme is wavelength independent and free from bias drifting problems.

Experimental demonstration: An experiment based on the setup shown in Fig. 1 has been carried out. The key parameters of the devices used in the experiment are as follows: the photodetector (PD) in the OEO loop has a 3 dB bandwidth of 10 GHz and a responsivity of 0.88 A/W. The electro-optic bandwidth of the MZM and the PolM is 40 GHz. The bandwidth of the EBPF is 12.80 MHz centred at 9.953 GHz. The power gain of the electrical amplifier (EA) is about 45 dB. A second PD, which has a 3 dB cutoff frequency of 40 GHz and a responsivity of 0.65 A/W, is used to convert the optical signal to the microwave signal. The electrical spectrum is measured by an electrical spectrum analyser (Agilent E4447A), and the optical spectrum is monitored by an optical spectrum analyser (YOKOGAWA AQ 6370B).

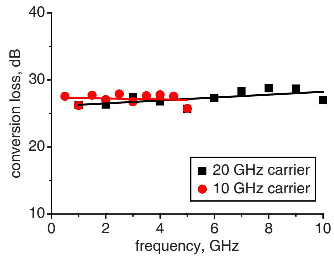

Fig. 2 *Measured frequency response of proposed photonic microwave up-conversion scheme*

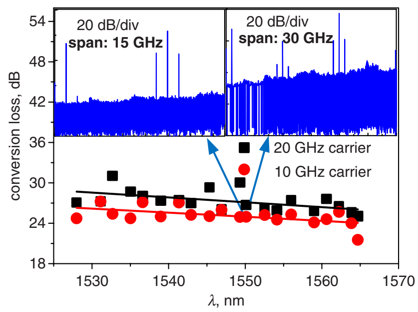

Fig. 3 *Measured wavelength dependence of proposed photonic microwave up-conversion scheme*

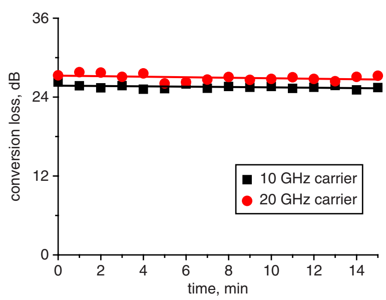

Fig. 4 *Measured time stability of proposed photonic microwave up-conversion scheme*

To investigate the frequency response of the proposed photonic microwave up-conversion scheme, a sinusoidal microwave signal with electrical power of −1 dBm is introduced to the MZM. Fig. 2 shows the measurement results. The wavelength and power of the incident

CW light is fixed at 1552.524 nm and 13 dBm, respectively. An almost constant conversion loss of 27 dB is obtained in a frequency range from DC-5 GHz or DC-10 GHz when the scheme is operated to upconvert the signal to a 10 or 20 GHz carrier, indicating that the bandwidth of the baseband signal for upconversion can reach 5 or 10 GHz in the proposed photonic microwave up-conversion scheme.

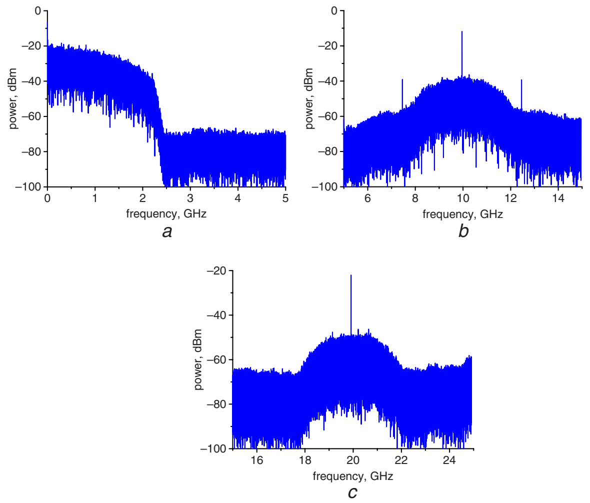

Fig. 5 *Up-conversion of 2.5 Gbit/s optical data signal*

a Electrical spectrum of 2.5 Gbit/s data signal
b Electrical spectrum of up-converted signal at 10 GHz carrier
c Electrical spectrum of up-converted signal at 20 GHz carrier

The wavelength dependence of the proposed photonic microwave up-conversion has also been investigated. In the measurement, the frequency and the electrical power of the sinusoidal microwave signal is 1 GHz and −1 dBm, the output power of the CW lightwave is fixed at 13 dBm, and the wavelength varies from 1528 to 1565 nm. Fig. 3 shows the measured conversion loss against the wavelength of the incident lightwave. As can be seen, the conversion loss is almost constant with a value of 25 dB for a 10 GHz frequency carrier and a value of 27 dB for a 20 GHz frequency carrier. The insets in Fig. 3 give the electrical spectrum of the generated signal by applying the optical signal at the PD. The 1 GHz sinusoidal microwave signal is successfully upconverted to 11 or 21 GHz. To study the stability of the operation, we let the scheme be operated in a laboratory environment and measured the conversion loss for 15 min with a time interval of 1 min. Fig. 4 shows the measurement result. The variation of the conversion loss is within ±0.8 dB, showing that the proposed system has a good stability.

Fig. 5 shows the electrical spectra of a 2.5 Gbit/s pseudorandom-bit-sequence (PRBS) signal before and after the proposed photonic microwave upconversion system. The baseband signal in Fig. 5*a* is successfully upconverted to a 10 GHz carrier (Fig. 5*b*) and a 20 GHz carrier (Fig. 5*c*), respectively.

Conclusions: We propose and have experimentally demonstrated a novel photonic microwave up-conversion scheme using a PolM-based OEO. Successful up-conversion of a 2.5 Gbit/s optical data to the 10 GHz band or the 20 GHz band has been experimentally verified. Compared to previously reported optical up-conversion schemes, the proposed photonic microwave up-conversion scheme has three unique features: 1. flexibility: a baseband signal can be up-converted to one or two times the fundamental frequency (10 GHz) without any replacement of the devices; 2. broad bandwidth: the bandwidth of baseband signal can reach 5 or 10 GHz corresponding to a 10 or 20 GHz carrier; and 3. stability: the conversion loss is wavelength independent and free from bias drifting problems.

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One or more of the Figures in this Letter are available in colour online.

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