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Optical frequency multiplication using fibre ring resonator

Y. Shi, H. Yang, C.M. Okonkwo, A.M.J. Koonen and E. Tangdionga

High-order microwave harmonics are generated using a fibre ring resonator based on optical frequency multiplication using low frequency electronics of 1 GHz, thereby allowing transmissions of 20MS/s 64-QAM signals over singlemode, multimode and plastic optical fibres.

Introduction: Microwave signal generation has been a topic of interest in recent years owing to numerous applications [1]. One of the main challenges is the generation of high-order harmonics with low frequency electronics, while maintaining system simplicity. In this Letter, a microwave generation scheme based on a fibre ring resonator employing the optical frequency multiplication (OFM) technique [2] is demonstrated. A fibre ring resonator is employed for the frequency modulation to intensity modulation (FM-IM) conversion. The scheme exploits the tunable free spectral range (FSR) of the filter to achieve significant improvement of harmonics conversion efficiency. Compared to the conventional OFM approach based on two-beam interference devices such as a Mach-Zehnder [2] and a polarisation interferometer (PI) [3], this scheme utilises multi-beam interference and hence provides a significant carrier-to-noise ratio (CNR) improvement of up to 10 dB. The improved CNR is mainly attributed to the larger contrast ratio and the steeper slope of the fibre ring resonator frequency response when compared to [2, 3]. Moreover, we believe that the complexity of the system is largely reduced because only one optical modulator is employed in this scheme. The scheme is successfully tested for various transmission media, lengths, and bit rates that are typical for in-building access networks.

Experimental setup: An experimental setup to test the system performance of the proposed scheme is shown in Fig. 1. The optical signal generated from the tunable laser at 1310 nm was frequency modulated by a sweep signal of frequency f_{sw} of 1 GHz using a phase modulator. A 64 QAM data signal generated at a subcarrier frequency f_{sc} of 300 MHz was mixed with f_{sw} to drive the phase modulator. After the fibre ring resonator and transmission through the fibre link, radio frequency (RF) components at every harmonic of the sweep frequency f_{sw} were obtained at the photodetector. In addition to the harmonics, the data signal was upconverted to $f_{RF} = n \times f_{sw} \pm f_{sc}$ (where n indicates the n th harmonic of the sweep signal). The photodetector output was then analysed using a vector signal analyser.

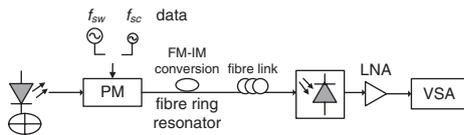


Fig. 1 Experimental setup

PM: phase modulator; LNA: low-noise amplifier VSA: vector signal analyser

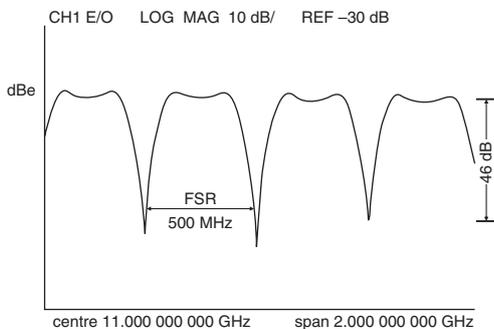


Fig. 2 Measured transmission spectrum for 40 cm fibre ring resonator

The FM-IM conversion was realised by the fibre ring resonator, which was constructed by connecting one output port of an optical coupler to one of its input ports. The FSR of the resonator is $\frac{c_0}{nL}$ (c_0 : light speed in vacuum; n : effective refractive index of fibre; L : length of the fibre ring

resonator) which indicates that the most suitable FSR value can be achieved by proper adjustment of the fibre ring diameter [4]. In this Letter, a 50/50 fibre coupler was used to construct the resonator with a ring length of 40 cm. Fig. 2 shows the measured transmission spectrum for this resonator.

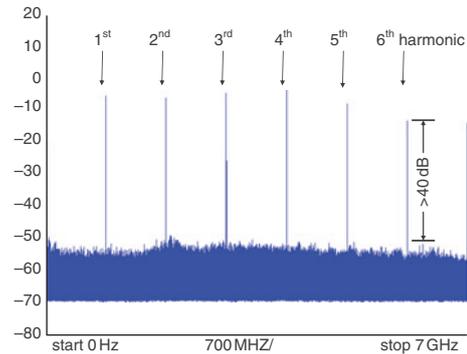


Fig. 3 RF harmonics generation

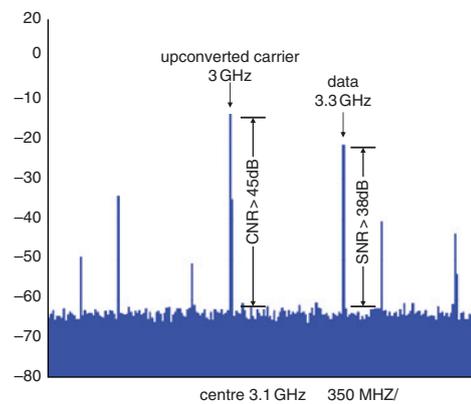


Fig. 4 Upconverted subcarrier

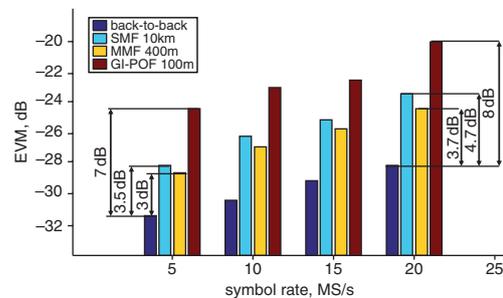


Fig. 5 EVM measurement in back-to-back system and transmission over SMF, MMF and GI-POF link

Results and discussion: First, we show in Fig. 3 that high-order harmonics are generated by setting f_{sw} to 1 GHz. The CNR of more than 40 dB is obtained until the sixth harmonic, proving that the setup can support multi-wireless standards such as WiFi (2.4 GHz), UWB (3.1–4.7 GHz) and WiMax (5.8 GHz). To demonstrate further the benefits of this OFM scheme, we focus on the performance of the data at the third harmonic ($3 \times f_{sw}$) with a corresponding CNR of 45 dB. Fig. 4 shows the spectrum with the data placed at f_{sc} of 300 MHz on both sides of the third harmonic. The signal-to-noise ratio (SNR) of the data signal at 3.3 GHz is more than 38 dB, which is sufficient for transmission. This high SNR value is due to the excellent performance of the resonator (see Fig. 2): high extinction ratio (> 23 dB), the narrow FSR (~ 500 MHz), the uniform spectral shape (< 1 dB flatness) and the steep response (> 0.55 dB/MHz). The above results can be attributed to the resonator employed for FM-IM conversion. In the fibre ring resonator, the light beam experiences interference with an infinite number of its delayed and attenuated copies. This unequal amplitude of interfering waves causes a deep notch (notch depth $\simeq 23$ dB) in the passband where destructive interference occurs and a flat top response.

In contrast, two-beam interference produces a sinusoidal filter response (notch depth $\simeq 7$ dB), meaning that the top of the passband is curved or Gaussian-like and the slope of the passband is shallow, which results in a much smaller FM-IM conversion efficiency. In Fig. 4, the signal beatings due to the sweep signal and the subcarrier signal are shown at 2.6, 2.9 and 3.4 GHz. This occurrence is highly related to the non-linearity of the electrical amplifier. The error vector magnitude (EVM) of the data signals at f_{RF} of 3.3 GHz are shown in Fig. 5 for the back-to-back and the transmission over 10 km glass singlemode fibre (SMF), 400 m glass multimode fibre (MMF) and 100 m perfluorinated graded-index plastic optical fibre (GI-POF). It is observed in Fig. 5 that EVM values increase for higher symbol rates when transmitted over the three different transmission media. Regarding the transmission distance, SMF performs much better than MMF and POF. Notice that performance of the 100 m POF transmission rapidly deteriorates after 15 MS/s symbol rate primarily due to the impact of multimodal effects and fibre losses in reducing the received data signal power. Taking the back-to-back EVM as the reference, the EVM penalties for SMF, MMF and POF are nearly constant as a function of the symbol rates. For example, if we consider the POF performance at 5 and 20 MS/s, the penalties with respect to the back-to-back case amount to be 7 and 8 dB, respectively. This small difference of around 1 dB can also be seen for SMF and MMF, showing that the OFM concept is generally scalable to the symbol rates of a radio-over-fibre system.

Conclusion: In this Letter, a cost-effective and high-performance OFM system employing a fibre-ring resonator has been proposed and demonstrated. We have presented an efficient high-order microwave harmonic generation and transmission over SMF, MMF and POF using relatively low frequency sweep signals. After upconversion to 3.3 GHz and transmission, the EVM performance of 20 MS/s 64 QAM signal is shown to

be acceptable. A single fibre ring resonator for the FM-IM conversion allows us to have high quality frequency upconverted signals at low costs owing to its favourable transmission profile and ease of alignment to the optical carrier. Exploiting this scheme, a robust, flexible and low-cost radio-over-fibre system for in-building networks is feasible.

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

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