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Dispersion tolerant radio-over-fibre transmission of 16 and 64 QAM radio signals at 40 GHz

M. García Larrodé, A.M.J. Koonen, J.J. Vegas Olmos, E.J.M. Verdurmen and J.P. Turkiewicz

Generation of a 39.9 GHz microwave carrying 16 and 64 QAM radio signals up to 20 MS/s, exploiting FM-IM conversion through a periodic bandpass filter, is demonstrated. The dispersion tolerance of the approach is also investigated.

Introduction: Radio-over-fibre (RoF) techniques are attracting much attention from manufacturers and radio network operators for the deployment of flexible and cost-effective radio access systems. For the emerging broadband wireless standards, operating at carrier frequencies beyond 5 GHz, one of the main challenges of RoF techniques is the generation and remote delivery of microwave signals to the antenna stations, while maintaining the link simplicity. Heterodyning techniques have been proposed to generate microwave carriers all-optically, but they make use of several laser sources per link in complex optical injection locking schemes [1]. Techniques based on the harmonics generation by frequency modulation to intensity modulation (FM-IM) conversion in dispersive optical fibre links have the advantage of generating high microwave carriers with the use of one single laser source and low frequency electronics to produce the optical FM signal [2]. The FM-IM conversion can also be implemented with a periodic bandpass filter (e.g. a Mach-Zehnder interferometer) at the transmitter side to make the system independent of fibre length variations. This method has been mainly applied to 1310 nm systems with fibre lengths and RF carriers below 18 GHz [3], where the carrier suppression effects of chromatic dispersion in the direct transmission of microwave carriers are not an issue (considering typical dispersion values of 2–3 ps/nm·km of standard singlemode fibre (SSMF) at 1310 nm [4]). In this Letter, we present the generation of a 39.9 GHz microwave carrying 16 and 64 QAM radio signals up to 20 MS/s employing this method. The generated signals were transmitted over different fibre lengths to investigate the dispersion tolerance of the approach.

Experimental setup: A schematic of the experimental setup is depicted in Fig. 1. A laser source ($\lambda_0 = 1310$ nm) is frequency modulated by a sweep frequency $f_{sw} = 6.4$ GHz with a phase modulator (PM), generating an optical spectrum broadening of around 50 GHz. The radio data signal (16 or 64 QAM at different symbol rates) on a low frequency subcarrier $f_{sc} = 1.5$ GHz modulates the intensity of the optical FM with a chirp-free Mach-Zehnder intensity modulator (IM). The resulting optical signal is passed through a Mach-Zehnder interferometer (MZI) with 10 GHz free spectral range (FSR), launched into an SSMF link, and then recovered by a 40 GHz photodiode. The output of the photodiode is amplified and sent to a vector signal analyser for evaluation.

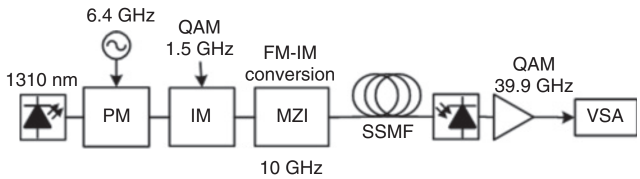

Fig. 1 *Experimental setup*

PM: phase modulator; IM: intensity modulator; MZI: Mach-Zehnder interferometer; SSMF: standard singlemode fibre

Results and discussion: Fig. 2 shows the RF spectra obtained at the output of the photodiode in the back-to-back system. Fig. 2*a* shows the harmonics of $f_{sw} = 6.4$ GHz generated at the output of the photodiode due to FM-IM conversion through the MZI. When a low frequency subcarrier ($f_{sc} =$ 1.5 GHz) modulates the intensity of the optical FM signal, it becomes upconverted double-sided along with the harmonics of f_{sw} to $f_{RF} = n \cdot f_{sw} \pm f_{sc}$ (where n is the nth harmonic); Fig. 2*b* depicts the sixth harmonic of f_{sw} ($f_{6th} = 38.4$ GHz), along with the upconverted subcarrier to $f_{RF} = 36.9$ GHz and $f_{RF} = 39.9$ GHz. As can be seen in the insets, both the generated harmonic and the upconverted subcarrier have a very pure linewidth (< 100 Hz), the phase noise of which depends only on the phase noise of the low frequency signal generator. When the low frequency f_{sc} carries QAM data signals, these are transparently upconverted to f_{RF} as well. Fig. 2*c* shows the spectrum of the QAM signals obtained at $f_{RF} = 39.9$ GHz, for symbol rates 4, 10 and 20 MS/s and 0.4 roll-off factor.

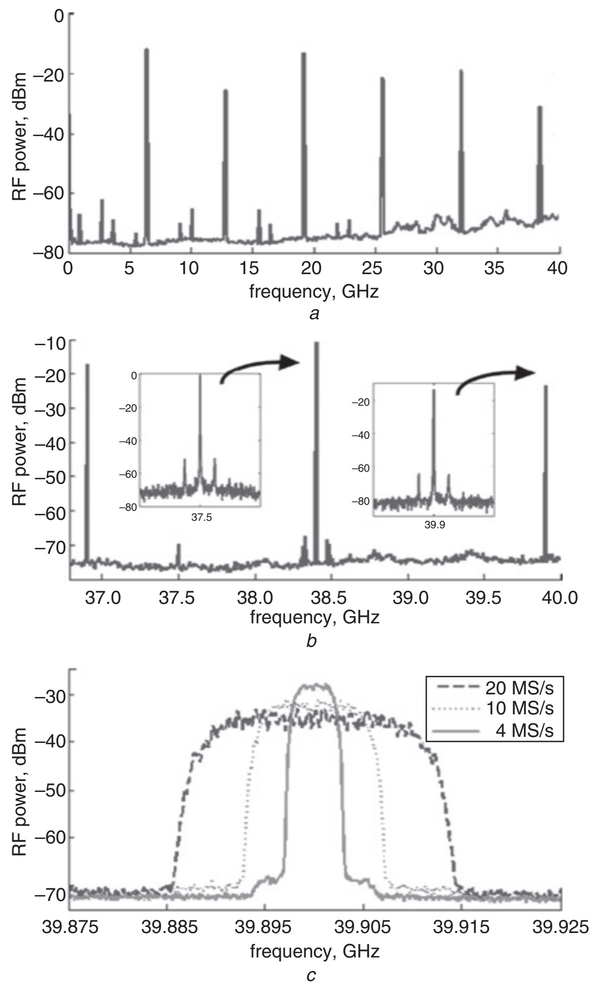

Fig. 2 *Spectrum measured at antenna site (back-to-back)*

a Multiple harmonics generated with sweep frequency 6.4 GHz (40 GHz broadband amplifier)
b Sixth harmonic (38.4 GHz) with subcarrier recovered at 36.9 and 39.9 GHz (40 GHz narrowband amplifier)
Insets: 100 kHz span
c QAM data signals (with symbol rates 4, 10, 20 MS/s) obtained at 39.9 GHz

To assess the quality of the QAM radio signals obtained at 39.9 GHz, the error vector magnitude (EVM) was measured and compared with the maximum transmitter constellation error specification of standard IEEE 802.11a for wireless signals in the 5 GHz band (i.e. 5.6 and 7.9% for 64 QAM with code rate 3/4 and 2/3, respectively; and 11.2% for 16 QAM with code rate 3/4). Fig. 3*a* shows the IQ constellation diagrams of the 16 and 64 QAM signals (20 MS/s) obtained at 39.9 GHz after 25 km of SSMF. The measured EVM values of the recovered QAM signals at $f_{RF} = 39.9$ GHz are depicted in Fig. 3*b* against the symbol rate for the back-to-back system (0 km) and after transmission over 25 km of SSMF, and compared with the EVM values of the input signals at $f_{sc} = 1.5$ GHz from the vector signal generator (VSG). As can be seen in the Figure, EVM does not depend on the modulation format, but on the signal bandwidth (symbol rate), which increases from 0.6 to 2.2% for 4 to 20 MS/s, respectively, for the input signals. In the back-to-back case, the recovered 20 MS/s 64 QAM signal at 39.9 GHz experiences an EVM value of 4.88%, which means a signal-to-noise ratio (SNR) degradation of ∼7 dB due to the upconversion with respect to the input signal at 1.5 GHz. After the 25 km

SSMF link, the measured EVM value is 6.23%, which adds an extra SNR degradation of 2.1 dB due to transmission.

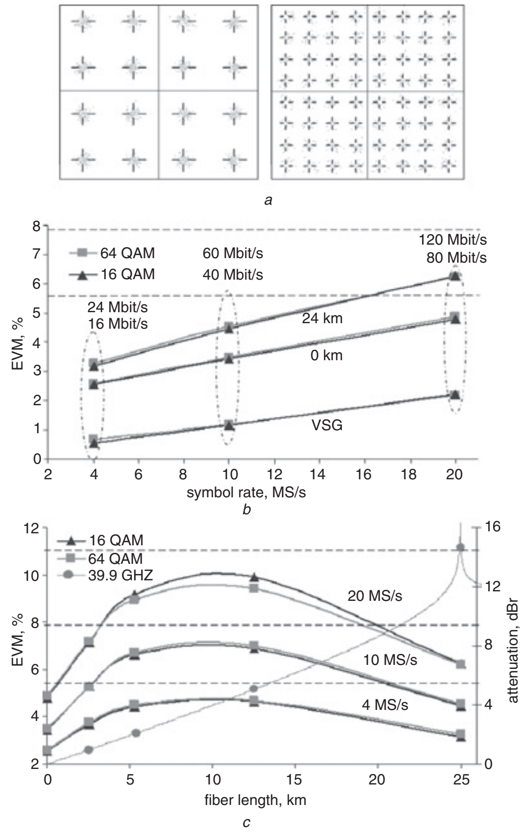

Fig. 3 *Error vector magnitude (EVM) performance (VSG: vector signal generator)*

a IQ constellation diagrams of 20 MS/s 16 QAM (80 Mbit/s) and 64 QAM (120 Mbits/s) signals recovered at 39.9 GHz after 25 km of fibre
b EVM against symbol rate: input signals at 1.5 GHz (VSG); recovered signals at 39.9 GHz after 0 and 25 km of SSMF
c EVM against fibre length (left axis); theoretical attenuation profile of direct transmission of 39.9 GHz carrier against fibre length (right axis)

To investigate the dependency on fibre length variations, the optical signal after the MZI was launched into SSMF links of different length (0, 2.5, 5.3, 12.5, 25 km) with the same average optical power (+3.5 dBm). The measured EVM values are depicted in Fig. 3*c*. For comparison, the theoretical attenuation profile of a directly transmitted 39.9 GHz carrier is also plotted (typical attenuation and dispersion values at 1310 nm: $\alpha = 0.38$ dB/km and D = 2.2 ps/nm·km), which shows an attenuation peak (carrier suppression) at 24.96 km. As can be observed, EVM increases initially with the fibre length due to fibre attenuation; however, it experiences an improving tendency with the 12.5 and 25 km fibre links, without carrier suppression effect. This happens due to the additional FM-IM conversion caused by chromatic dispersion, which enhances the FM-IM conversion of the MZI optimised for the selected harmonic. Thus, chromatic dispersion does not jeopardise system performance, and the link could be flexibly incorporated in 1310 or 1550 nm passive optical networks (PONs) provided that the power budget is properly dimensioned.

Conclusion: We have demonstrated the dispersion tolerant radio-over-fibre transmission of 16 and 64 QAM radio signals at 40 GHz exploiting FM-IM conversion through a periodic bandpass filter. The results obtained at 40 GHz meet the signal quality figures (EVM) specified in the IEEE 802.11a standard for the 5 GHz band. This approach enables a cost-effective RoF-based access infrastructure and a flexible convergence with wavelength division multiplexed PONs.

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M. García Larrodé, A.M.J. Koonen, J.J. Vegas Olmos, E.J.M. Verdurmen and J.P. Turkiewicz (*COBRA Research Institute, Eindhoven University of Technology, PT-11.27, PO Box 513, Eindhoven, MB NL 5600, The Netherlands*)

E-mail: m.garcia.larrode@tue.nl

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