Photonic Vector Modulation of 3.6 Gb/s 16QAM at 39 GHz for Radio-on-Fibre Systems.

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Abstract *The experimental generation of a 3.6Gb/s-16QAM 39GHz carrier employing Photonic Vector Modulation is reported for the first time. The quadrature condition is introduced using an optical delay line. EVM is estimated from measured eye-diagrams.*

Introduction

The increasing capacity demand of wireline and wireless access networks is pushing the development of solutions for wireless transmission of Gb/s data rates, mainly in the mm-wave frequency band. Millimeter wave photonic systems have been intensively investigated as a solution that can overcome the current limitations of purely electrical architectures, due to the inherent benefits of photonic components and optical fibres, such as huge bandwidth, scalability employing wavelength multiplexing techniques, compactness, or low transmission loss [1-5]. Due to the high data rates envisaged, techniques to reduce the occupied spectrum are desireble, for instance using multi-level modulation formats [6-8].

Photonic vector modulation (PVM) of baseband data is one of the most promising techniques as allows the generation of the multi-level signals directly at the mm-wave carrier frequency and the remote delivery of the modulated carrier and baseband data. The generation of 3 Gb/s QPSK and 8QAM signals at 39 GHz has been previously demonstrated using PVM [9, 10].

In this paper we present the generation of a 3.6 Gb/s 16 level quadrature amplitude modulated 39 GHz mm-wave carrier employing directly modulated lasers (data) and external modulators (mm-wave carrier). The quadrature condition between the inphase and the quadradure components of baseband data is achieved using an tunable optical delay line (ODL), with the advantage of fiber transmission induced delay compensation. Error vector magnitude (EVM) of the 16 QAM signal is estimated using the statistical data of the demodulated signals.

Operating principle and experimental set-up

Four different baseband data (I_1, I_2, Q_1, Q_2) streams are used to directly modulate four lasers of different wavelengths. Different wavelengths are chosen to avoid coherent phase noise after photo detection. I1 and I_2 are combined resulting in a four level baseband ASK signal, where I_2 is attenuated by 3 dB. Similarly Q_1 and Q_2 are combined. The outputs of the two 3 dB couplers are the in-phase (I) and quadrature phase (Q) 4 ASK signals as shown in figure 1.

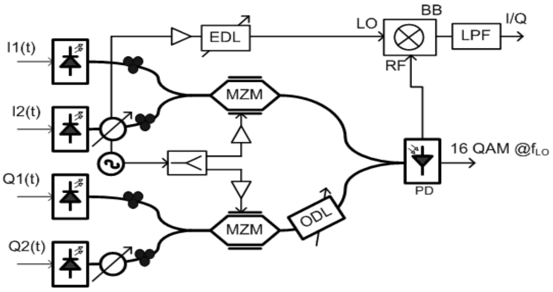
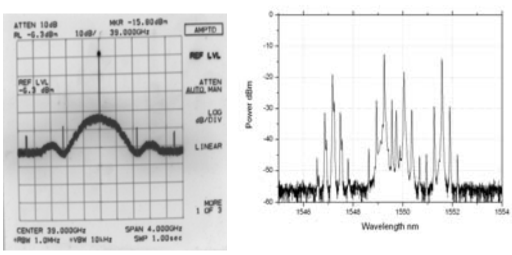


Figure 1: The schematic of the 16QAM PVM system.

The RF carrier is modulated on the I and Q components using two Mach-Zehnder modulators (MZM) biased at the quadrature point. Then a tunable electrical delay line (EDL) is used to induce a 90º phase shift between the I and Q components by setting $\Delta t = f_{LO}/4$, where f_{LO} is the carrier frequency.

Mesurements Description

Four DFB lasers of 1 GHz 3dB bandwidth are used to modulate four PRBS sequences of 900 Mb/s each. The four lasers denoted by I_1, I_2, Q_1 and Q_2 are lasing at 1551.53 nm, 1549.32 nm, 1550.1 nm and 1547.23 nm, respectively. Low pass filters with a cut-off frequency of 1.65 GHz were used to filter noise before direct modulation of lasers. Laser I_1 and I_2 are mixed using a 3-dB coupler, and electrical delay line was used in one of the arms to synchronise the pulses. The same procedure was used for the Q1 and Q2 components.



(a) (b)

Figure 2: Spectrum of 16QAM signal at 39 GHz: Scale X: 400 MHz/div Y: 10 dB/div (a), Optical Spectrum (b)

Two MZM were used to modulate the 39 GHz carrier. The carrier was amplified to +15 dBm before modulation. The Q component was delayed by $1/4f_{LO}$ using an EDL, where f_{LO} is the local oscillator frequency, to induce a 90º phase shift between the I and Q components, which were next added using another 3-dB coupler resulting in 3.6 Gb/s 16 QAM at 39 GHz after photodetection. Figure 2 shows the optical spectrum and the electrical spectrum of the 16 QAM signal.

The QAM signal was demodulated by mixing with the same LO carrier amplified to +7 dBm. Another EDL was used with the LO before mixing, to synchronise and induce the 90º phase shift for detecting the I and the Q components. A baseband amplifier and a low pass filter with cut-off frequency of 1 GHz were used before estimating the EVM. Figure 3 shows the downconverted signals.

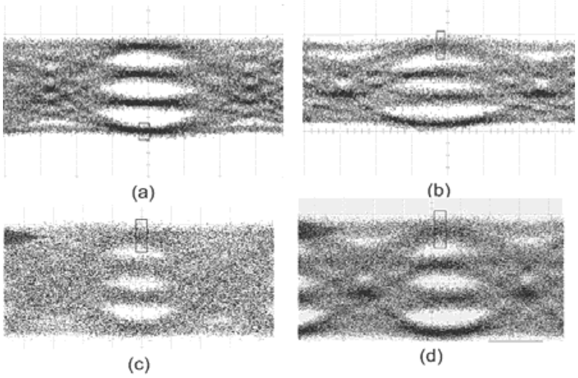


Figure 3: Eye diagrams for 4ASK back to back quadrature (a), inphase (b), demodulated quadrature (c), inphase (d).

Results

The four electrical baseband data were amplified to 1.8 V p-p, and used to directly modulate the lasers. To determine the quality of the signal EVM is measured by measuring the mean (μ), and standard deviation (σ) from the eye diagram. The downconverted I and Q components eye diagrams were captured using an oscilloscope, and the histogram of each level was plotted and the μ and σ were extracted. These values were later used to generate a Gaussian distribution, and calculate the EVM as

$$EVM = \sqrt{\frac{1}{MN}\sum_{j=1}^{N}\frac{\sigma_{I,j}^{2}+\sigma_{Q,j}^{2}}{\mu_{I,j}^{2}+\mu_{Q,j}^{2}}} \qquad 1,$$

Where M is 16 (16QAM), and N is the number of samples captured by the oscilloscope. The constellation diagram of the downconverted 16QAM signal is shown in Figure 4. The EVM of the 16 QAM signal was calculated as -18.33 dB, using 1200 samples of the scope. It can be seen that the I component is more degraded than the Q component; this is because of lack of availability of an appropriate EDL to synchronise the bits of the multilevel signal. Another issue is the interference of higher order sidebands of lasers I_2 (1549.32) and Q_1 (1550.1).

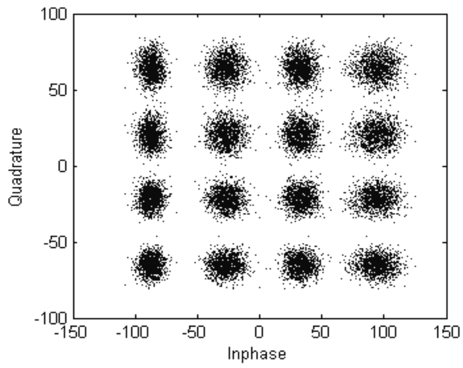


Figure 4: Constellation of the 16QAM signal.

Conclusions

The generation of 3.6 Gb/s 16-QAM 39 GHz signal employing a PVM technique is demonstrated for the first time to the authors knowledge. The PVM arrangement is based in direct modulation of the I and Q components and external modulation of the mm-wave carrier. Hardware limitations impaired the generated signal quality but can easily overcome, e.g. by using bandwidth matched filters and additional EDL. Finally, although not shown in this paper, this scheme is suitable for remote antenna applications by using dispersion management in the fibre span by tuning the ODL shown in Fig. 1, as reported [11].

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