

Five-Subcarrier Multiplexed M-QAM Transmission over a 50- μm Core Diameter Graded Index Perfluorinated Polymer Optical Fiber

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Quadrature Amplitude Modulation (QAM) together with subcarrier multiplexing technique can be used to deploy multiple transmission channels within a passband of multimode fiber (MMF), which is attractive for integrating different services in a single MMF platform. We present the experimental demonstration of simultaneous transmission of five subcarrier multiplexed signals in a 100 meter 50- μm core diameter graded index perfluorinated polymer multimode fiber link, where 16-QAM and 64-QAM were tested separately. The symbol rate of each subcarrier channel was 10 MBaud and the channel spacing was 20 MHz. The total bit rates for 16-QAM and 64-QAM were 200 Mbit/s and 300 Mbit/s, respectively. A passband region covering from 1.96 GHz to 6.04 GHz was used. Results showed bit error rate (BER) below 10^{-9} for each subcarrier channel. It shows the potential to reach a total capacity of 12.3 Gbit/s with 64-QAM by allocating more subcarrier channels which occupy the full passband. Further capacity increase is also possible by using higher symbol rate for each channel.

Introduction

The frequency response of multimode optical fibre (MMF) shows the existence of passbands in the higher frequency region beyond the -3dB baseband cut-off frequency. By Subcarrier Multiplexing, these passbands can be used to accommodate a number of transmission channels, each for a different service. In this way various groups of services may be integrated in a single MMF-based in-building or short-reach access network infrastructure [1]. Multi level Quadrature Amplitude Modulation (M-QAM) puts several information digits into one symbol and hence is very bandwidth efficient. Compared with binary phase shift keying (BPSK) [2], M-QAM can conveniently increase the transmission capacity within same bandwidth by operating at higher bit rate for a single channel. Alternatively, one may deploy multiple channels using subcarrier multiplexing [3], as demonstrated in the experiments over a silica MMF system [4]. In this paper we report on 5-subcarrier multiplexed 16- and 64-QAM transmission over a 50 μm -core-diameter graded-index perfluorinated polymer optical fiber (GIPOF). Each subcarrier channel operated at 10 MBaud and the channel spacing was 20 MHz; thus a total bit rate of 200 Mbit/s and 300 Mbit/s was achieved for 16-QAM and 64-QAM, respectively. The central subcarrier frequency of this group of five M-QAM signals varied from 2 GHz to 6 GHz. The eye diagram and constellation of each channel was measured, and the maximum error vector magnitude (EVM) of 2.8% for 16-QAM and 3.1 % for 64-QAM showed that a BER well below 10^{-9} has been reached for all channels.

Experimental setup

The setup of the transmission experiments is shown in Fig. 1. The multicarrier M-QAM signals were generated off-line by software. In the experiments, 5-subcarrier multiplexed M-QAM signals with equal carrier spacing were used. First, the in-phase and quadrature-phase components, I and Q, of each of the 5 M-QAM signals were generated separately. Then all I and Q signals were combined and saved in a data file which was loaded into the memory of a Vector Signal Generator (VSG). Fig. 2 shows the waveforms of the mixed I and Q of the 64-QAM experiment. A square-root raised cosine filter was used and the roll-off factor was set to be 0.1.

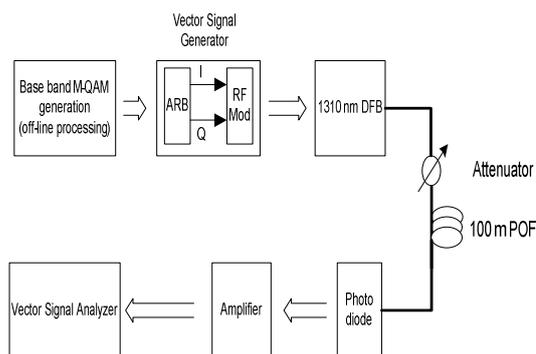


Fig. 1. Setup of the transmission experiments.

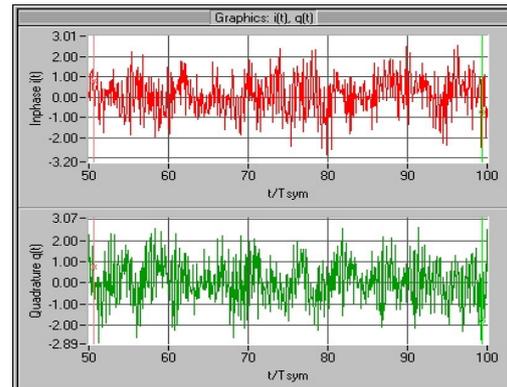


Fig. 2. 64-QAM Waveforms of combined I (top) and Q (bottom) signals.

An Arbitrary Waveform Generator (AWG) function in the VSG which has a bandwidth of 100 MHz has been used to produce the I and Q waveforms. The RF modulator which can operate up to 6 GHz up-converted the I and Q waveforms and mixed them with a phase difference of $\pi/2$. This mixed QAM waveform modulated a single-mode fiber pigtailed 1310 nm DFB laser directly.

After the transmission through an optical attenuator (which controlled the optical power injected into the 100 m perfluorinated 50 μm -core-diameter GIPOF) and through the GIPOF link itself, the signal was O/E converted by a PIN-detector which has a 50 μm -core-diameter MMF pigtail and a bandwidth of 25 GHz. The converted signal was amplified by a broadband RF amplifier with frequency range between 0.5 GHz and 18 GHz. A Vector Signal Analyzer (VSA) was used to demodulate the detected signal and to obtain the spectrum, eye diagram, signal constellation and EVM of each QAM signal.

Experiment results

Experiments were carried out with groups of 5 subcarriers. Due to the bandwidth limitation of the VSG, each time one group of 5-subcarrier multiplexed M-QAM signals was transmitted. The frequency band occupied by each group was 100 MHz. The center frequencies of a group was varied within the passband region of the GIPOF from 2 GHz to 6 GHz, where the RF response of the GIPOF drops gradually and smoothly beyond the -3 dB baseband region [2]. In total 41 groups of such 5-subcarrier multiplexed M-QAM signals were tested. The subcarrier spacing of neighboring channels was uniform and equal to 20 MHz. The RF power level of each subcarrier channel was equal and the total power at the output of the VSG was 0 dBm. From two-tone intermodulation

distortion measurements, the third-order intermodulation products of this GIPOF system were at least 35 dB lower than the tested signals, which means that these nonlinear products did not introduce significant degradation. The symbol rate for each M-QAM signal was 10 MBaud so the total capacity per band was 200 Mbit/s for 16-QAM and 300 Mbit/s for 64-QAM. The total system capacity may reach 12.3 Gbit/s with 64-QAM, if all the 41 groups of subcarrier multiplexed 64-QAM signals were generated and delivered to the system simultaneously.

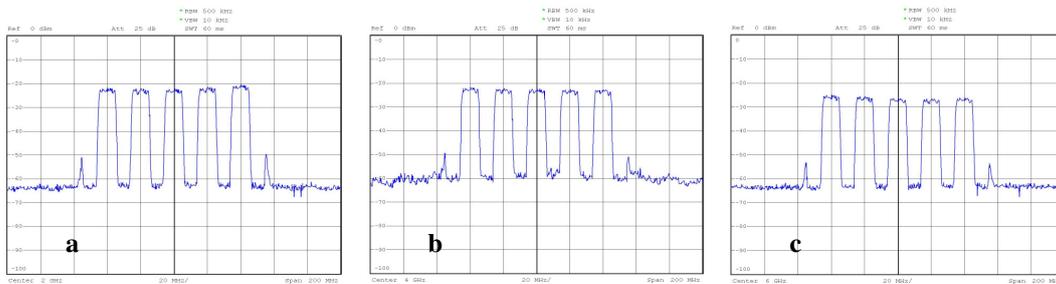


Fig. 3. Spectrum of detected 5-subcarrier multiplexed 64-QAM signal. Occupied band was 100 MHz and the frequency of the central subcarrier channel was a) 2 GHz; b) 4 GHz and c) 6 GHz.

Fig. 3 shows the received spectra for the cases with central subcarrier channel located at 2 GHz, 4 GHz and 6 GHz, respectively. The spectra of these 5 subcarrier channels were well separated after transmission. Therefore it is possible to reduce the channel spacing to accommodate more subcarrier channels in these bands. For all the other transmission experiments, similar spectra were obtained.

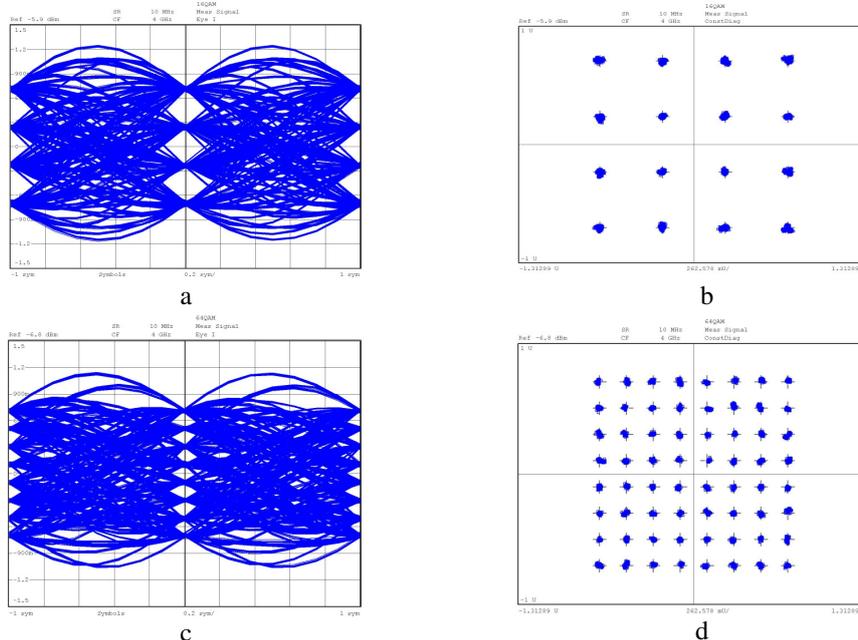


Fig. 4. Detected eye diagrams of 16-QAM (a) and 64-QAM (c); Detected constellation diagrams of 16-QAM (b) and 64-QAM (d). All for the subcarrier channel at 4 GHz.

As an example, the eye diagrams and constellation diagrams of the channel located at 4 GHz are shown in Fig. 4. Open and clear eye diagrams were obtained for all subcarrier channels. Meanwhile, the 16-QAM and 64-QAM symbols concentrated around the

reference constellations. These observations are in good agreement with the EVM measurement, which was used to evaluate the transmission performance. The EVM values of each subcarrier channel varied between 0.8% and 2.8 % for 16-QAM and between 1.1% and 3.1% for 64-QAM, as shown in Fig. 5. A BER of 10^{-9} requires an EVM of 7.2% for 16-QAM and 3.5% for 64-QAM. The maximum EVM obtained in the transmission experiments is well below these required values, which implies a BER smaller than 10^{-9} was achieved for all subcarrier channels without error correction coding.

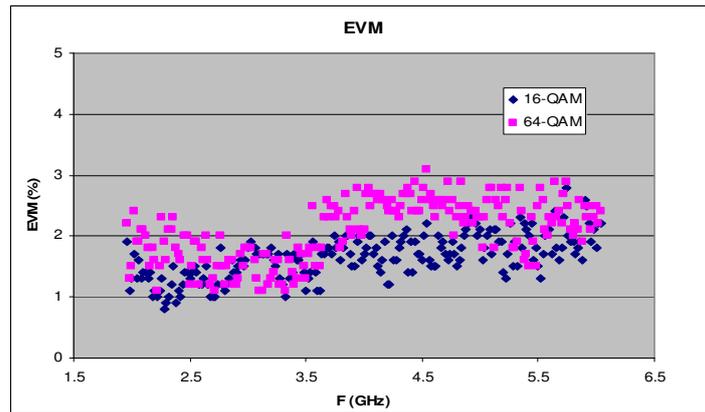


Fig. 5. EVM of each channel.

Conclusions

5-subcarrier multiplexed 16- and 64-QAM transmission experiments were conducted on a 100 m perfluorinated GIPOF link. A maximum EVM of 2.8% and 3.1% was reached with a total bit rate of 200 Mbit/s and 300 Mbit/s per band for 16-QAM and 64-QAM, respectively. A total capacity of 12.3 Gbit/s could be reached with 64-QAM and could be increased further by reducing the channel spacing to accommodate more subcarrier channels. These experiments demonstrated that subcarrier multiplexing is a convenient technique to integrate different high capacity services into one POF system.

Acknowledgement

This work is supported by the Dutch Ministry of Economic Affairs under the Innovation Oriented Research Program (IOP GenCom) "Full service access networks using multimode fibre" (project number: IGC 3009A).

References

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