# LOW COST HIGH CAPACITY DATA TRANSMISSION OVER PLASTIC OPTICAL FIBRE USING QUADRATURE AMPLITUDE MODULATION

J. Yang, X. Li, M.S. Alfiad, A.M.J. Koonen, H.P.A. van den Boom

COBRA Institute, Eindhoven University of Technology, The Netherlands

P.O. Box 513, NL 5600 MB Eindhoven, The Netherlands

Phone +31 40 2475653, fax +31 40 2455197, e-mail J.Yang@tue.nl

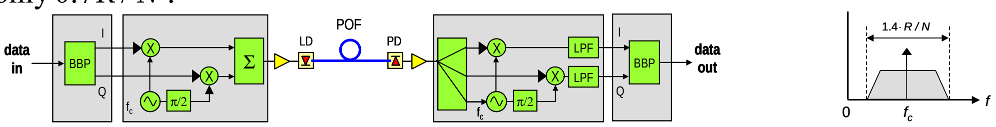
*While a data transmission system based on step-index multi-mode plastic optical fibre (POF) is potentially of very low cost, it is also severely bandwidth-limited. To circumvent the bandwidth limitation, Quadrature Amplitude Modulation (QAM) may be used to realize high capacity data transmission. Three different QAM systems with large-core step-index plastic optical fibre are proposed. They are Direct QAM, Baseband/subcarrier emulated QAM, and Wavelength-sliced emulated QAM. The performances of the three systems have been analyzed by computer simulations. Based on the simulation results, the technical feasibility for those system concepts is assessed in order to select the optimal configuration. A simple Direct QAM system has been set up. Measurements have been carried out with different optical sources; a 658 nm laser diode and a 520 nm SLED. A vector signal generator is employed as QAM modulator and the quality of the I and Q signals was measured by a vector signal analyzer. 90 Mbit/s over 100 meter step-index plastic optical fibre with a core diameter of 1 mm has been achieved with an error vector magnitude less than 3%.*

## Introduction

The 1 mm PMMA Step-Index Polymer Optical Fibre (SI-POF) is an attractive medium in short-range communication networks. It combines the advantages of the normal optical fibre (high bandwidth, EMI immunity) with the simple installation which makes it cost efficient [1]. The large 1mm core makes the handling of the optical access network by non-professionals possible while the cheap PMMA and the simple step-index structure give low fibre production costs. Hence, PMMA SI-POF with 1 mm core diameter will be investigated in the recently started European joint R&D project POF-ALL – "Paving the Optical Future with Affordable Lightening-fast Links" [2]. Since the target of the POF-ALL project is to realize at least 100Mbit/s over 300 meter length, QAM is considered due to the severely bandwidth-limited 1 mm PMMA SI-POF [3]. The QAM modulation scheme conveys data by coding the data on two orthogonal carrier channels. A larger eye opening can be expected for the QAM transmission with the same link power budget compared to other multi-level transmissions because of the more even distribution of the points in the modulation constellation. The other reason why QAM signaling is selected for the high capacity POF link is that QAM technology has been already widely deployed in wireless LAN standards, such as the IEEE 802.11x family, in digital video broadcast systems on coaxial cable networks (DVB-C), and for fast internet in cable modem systems such as DOCSIS. Thus, the high speed QAM signal modulation and demodulation chips can be lower cost thanks to the large market of wireless LANs and cable modems.

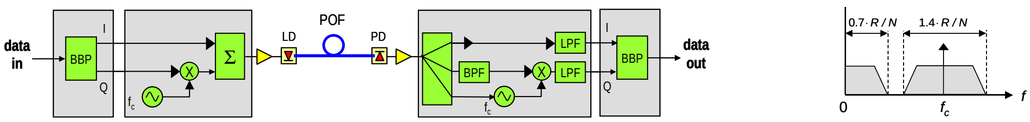
## QAM system implementation options

Three different QAM systems for the 1mm SI-POF system are proposed. They are Direct QAM, Baseband/subcarrier emulated QAM (SC-QAM), and Wavelength-sliced emulated QAM (WS-QAM) [3]. The first option Direct QAM is depicted in Fig.2a), and the spectrum allocation for Direct QAM is shown in Fig.2b). When the data rate is R and a QAM-$2^N$ scheme is used, the passband QAM signal spectrum is centred on the carrier fc and occupies in practice a bandwidth of about $1.4R/N$ . So the carrier frequency fc needs to be larger than $0.7R/N$, and therefore the bandwidth of the POF link should be at least $1.4R/N$ . The second option, termed 'baseband/subcarrier emulated QAM' (SC-QAM) and depicted in Fig.2a), emulates QAM by modulating I and Q signals on two different subcarriers., e.g. the I signal in baseband and the Q signal in a passband centred around the carrier frequency fc. The spectrum needed for SC-QAM is more than $2.1R/N$ as shown in Fig.2b) which is much wider than that for the Direct QAM option. The carrier frequency fc should exceed $1.4R/N$ while the bandwidth of the POF link should be at least $2.1R/N$ . The third option is 'wavelength-sliced emulated QAM' and is depicted in Fig.3a). Two SLEDs are used to generate two orthogonal channels by wavelength slicing. Crosstalk may occur due to overlap in the spectra. So additional signal processing has to be deployed to eliminate the crosstalk. The electrical signal spectra of the I and Q signal are both in baseband, as shown in Fig.3b). Hence this option requires the least bandwidth of the POF link, namely only $0.7R/N$ .



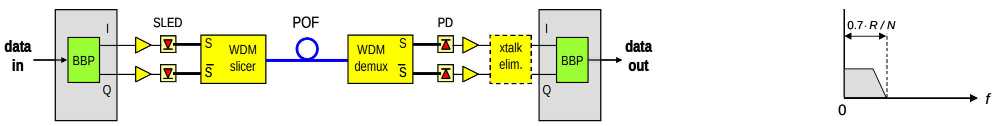

a) system concept b) spectrum

**Fig. 2 Direct QAM**




a) system concept b) spectrum

**Fig. 3 Baseband/subcarrier emulated QAM**



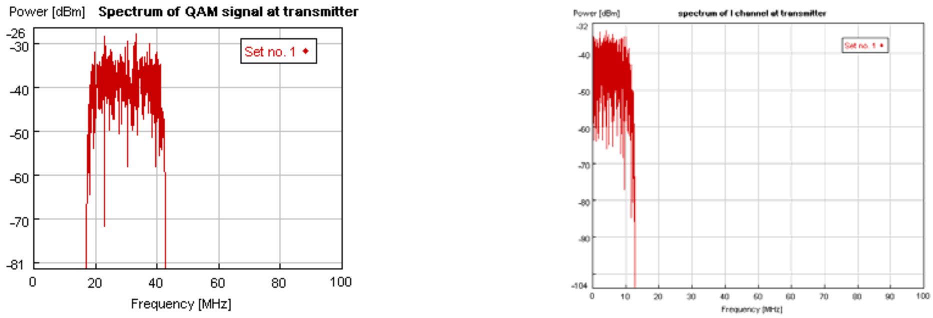

a)system concept b) spectrum

**Fig. 4 Wavelength-sliced emulated QAM**

## Performance analysis of QAM system options

The performances of the QAM system options have been analyzed by computer simulations. Based on the simulation results, the technical feasibility for those system concepts is assessed in order to select the optimal configuration. Due to the limitation of bandwidth, we focus on the Direct QAM and WS-QAM.

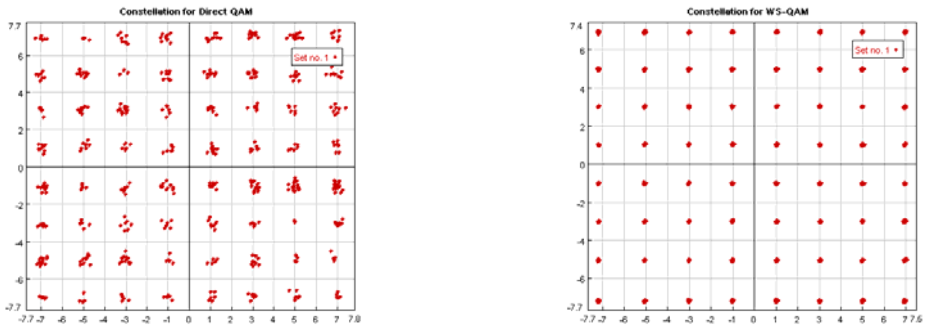
Within the simulation program VPI Transmission Maker, the two systems are both implemented with 100 meter multi-mode fibre. For a good comparison of Direct QAM and WS-QAM, the parameters are set to be the same. In both systems, the bit rate is set to be 128 Mbit/s using QAM-64 signals, implying a symbol rate of 21.3 MBaud. A laser diode with a wavelength of 650 nm and average output power of 5 mW was assumed. A raised cosine filter was used for pulse-shaping and has a roll-off factor β=0.2. The carrier frequency fc=30MHz for Direct QAM.




a) Spectrum of Direct QAM b) Spectrum I channel of WS-QAM

**Fig. 5 The spectrum of QAM signal after transmitter**

The first simulation results are shown in Fig.5. The occupied bandwidths of the two different QAM implementations in the transmitter have been calculated. From Fig.5a), the QAM signal makes use of 25.6MHz bandwidth. Since the Direct QAM is transmitted in the passband and the carrier frequency fc=30MHz, the needed bandwidth of POF link is around 42MHz while it can be 25.6MHz in an ideal case. On the other hand, the two orthogonal carriers for WS-QAM are separated by different wavelengths so the QAM signal can be transmitted as baseband signal. The required bandwidth in the transmitter is therefore not more than 13MHz, which is only half of the Direct QAM passband signal.




a) Constellation for Direct QAM b) Constellation for WS-QAM in I channel

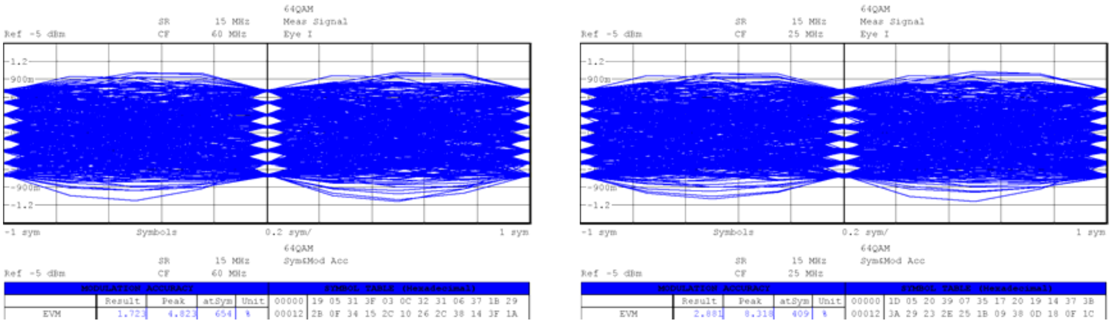
**Fig. 6 The Constellation for QAM signal after transmitter**

After the matched raised cosine filter, the constellation diagrams are shown for these two QAM implementations in Fig.6. Obviously, the constellation points of Direct QAM are more scattered than that of WS-QAM because the I and Q subcarriers are more independent to each other in the WS-QAM system, which implies more orthogonality in the transmission.

## Experiment Results

An experimental Direct QAM system has been setup for the measurement of the error vector magnitude (EVM) which is an indication of the quality of the QAM signal. The optical source is directly intensity-modulated by the 64-QAM signal and the optical signal is detected by a large-area silicon PIN photodiode. A 658nm Fabry Perot laser diode and a 520nm green SLED are both tested as the optical source, both emitting

5.5mW optical power. The symbol rate is fixed at 15.0 MS/s. So the bit rate of the system is 90Mbit/s since the number of bits per symbol *N*=6 for 64-QAM. The optimal cases in the experiments are shown in Fig.7. With the laser diode, the error free transmission can reach 100 meter and the measured EVM was 1.723%, well less than the limitation of 5% for error free transmission in case of 64 QAM. With the 520nm green SLED, the system can only achieve 50 meter for error free transmission while the measured EVM was 2.881%.




a) With 658nm laser diode, 100m POF b) With 520nm green SLED, 50m POF

**Fig. 7 The eye diagram and measured EVM**

## Conclusions

From theoretical analysis, the QAM technique may be a good option for realizing a low cost but high capacity POF link. The technical feasibility of system solutions employing Direct QAM and WS-QAM have been analyzed for data rates of 128Mbit/s on a 1 mm core SI-POF link with a length of 100 meter. The WS-QAM system scheme seems better because of the high bandwidth efficiency. Experiments with measurements have been carried out with a simple Direct QAM system according to the simulations. Error free 90Mbit/s QAM transmission has been realized with a 650nm laser diode over 100 meter while the system can reach 50 meter with a 520nm green SLED as the optical source.

## References

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