107Gb/s DPSK-3ASK Optical Transmission over SSMF

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Abstract: We report on the transmission of a 107Gb/s DPSK-3ASK optical channel over 335km fiber (SSMF). DPSK-3ASK is targeted to meet the requirements of a metro network.

OCIS codes: (060.4510) Optical communications; (060.5060) Phase modulation ; (060.4080) Modulation

1. Introduction

Continuing growth in the demand for bandwidth in optical telecommunications networks is well recognized. As network traffic continues to grow, and because of difficulties with techniques such as link aggregation of lower per-channel transmission rates, the industry is standardizing and commercializing 100Gb/s Ethernet transport [1-3].

Network providers generally accept next-generation network equipment if lowered costs can be achieved while maintaining or improving end-to-end performance. Towards commercial 100Gb/s transport, several of the modulation and hardware techniques that have been introduced and discussed in the industry are explicitly designed and introduced to meet the needs of long-haul data transport [3-7]. Metro network platforms can differ from long-haul platforms in several aspects partly because lower costs can be realized by trimming performance to tailor a system to the specific requirements of a metro network. Here we report on laboratory transmission results of a combined differential phase shift keying (DPSK) and three-level amplitude shift keying (3ASK) modulation format for metro networks which is designed to reduce costs compared to long-haul transport solutions.

2. DPSK-3ASK modulation format

By encoding five information bits within two consecutive symbols, 100Gb/s (112Gb/s) serial transport can be accomplished with components manufactured for 40Gb/s (45Gb/s) optical transport. We introduced a so-called DPSK-3ASK modulation format, a six-symbol format that has information capacity of two-and-one-half bits per symbol, [8-11]. For DPSK-3ASK, the two phases of a DPSK signal can each be amplitude modulated to create three symbols per phase; the constellation diagram is shown in Fig. 1. Transport of 100Gb/s data as a six-symbol PSK 40-Gbaud signal without amplitude modulation has been reported by another group [12].

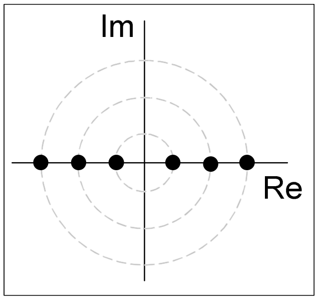

Fig. 1: DPSK-3ASK constellation diagram.

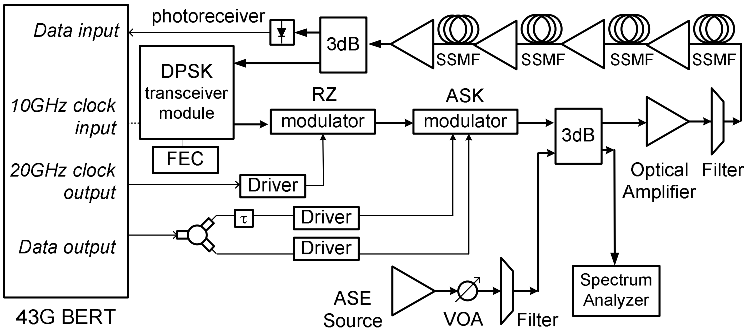

Fig. 2: Laboratory configuration for testing the DPSK-3ASK format.

In one setup of a DPSK-3ASK scheme, 107Gb/s data can be pre-coded into three 43Gbaud binary RF signals. After pre-coding, a first 43Gbaud signal drives a Mach-Zehnder Modulator (MZM) to modulate light in a DPSK format. The second and third 43Gbaud binary signals each drive a respective arm of a dual-drive MZM, combining to create three amplitude levels. An additional modulator can be used for the case of a Return-to-Zero (RZ) format. In another possible setup, the DPSK-3ASK format could be realized using a six-level signal to drive a single MZM.

The hardware configuration used in this work is shown in Fig. 2. A signal is initiated in a commercial DPSK transceiver which has a laser diode, RF driver, modulator, demodulator, balanced receivers, and control electronics built-in. The modulator within the DPSK transceiver is biased at the null of its transfer function, and is driven by a data signal with peak-to-peak amplitude $2V\pi$. The PRBS data signal driving the DPSK transceiver is a standard 2^7-1 pattern generated from a 40G Forward Error Correction (FEC) chip. The data rate is set to 43.018Gb/s.

After being launched from the transceiver module, the DPSK optical signal is sent through a second MZM, a so-called pulse carver, which is driven by an output clock of a Bit Error Ratio Tester (BERT) at a frequency equal to half the data frequency, with peak-to-peak amplitude of 2Vπ, and biased at the modulator's transfer function maximum to carve RZ-pulses with 33% duty cycle. To create the three-level ASK signal, a single 2^7-1 PRBS pattern is generated with a BERT at a 43.018Gb/s data rate, and this test pattern is then divided in the RF path, with the two resultant paths having a path length difference of approximately two bits. The two resultant paths emulate two independent 40Gbaud signals and each drives an input to a dual-drive MZM. The modulation signals were synchronized using tunable RF delay lines to yield alignment for improved performance.

For receiving the signal, the optical RZ-DPSK-3ASK signal is split into two branches, as shown in Figure 2. One path is sent to a photoreceiver to detect the ASK data and the resultant RF signal is analyzed in the BERT. The three-level amplitude data is sampled at decision thresholds in each the "upper" and the "lower" eye, non-simultaneously. Before the decision threshold is set in the BERT analyzer, a limiting amplifier in the photoreceiver is controlled to center the decision on a respective eye. In a future version, each eye can be detected simultaneously in parallel with respective photoreceivers. The second output of the optical splitter is directed back to the DPSK module, where standard DPSK detection occurs with a delay-line interferometer and a balanced photoreceiver. An adjustable decision threshold is available in the DPSK transceiver's control electronics.

3. Experimental Results

We tested the DPSK-3ASK format over fiber spans using commercial EDFA and DCM hardware available in our laboratory. We were constrained to 43.018Gb/s as a maximum data rate capability of the BERT.

After generating the DPSK-3ASK signal as described above in Section 2 and Fig. 2, the 1547.72nm (193,700GHz) signal passed through an EDFA and 1.2nm band-pass optical filter, and was launched into the standard single-mode fiber (SSMF) spools and amplifier chain. The fiber chain was constructed as follows: 90km SSMF followed by an EDFA with mid-stage hosting DCF; 80km SSMF plus DCF followed by an EDFA with no mid-stage; 85km SSMF followed by EDFA with mid-stage hosting DCF; and finally 80km SSMF followed by and EDFA with mid-stage hosting DCF. No optical filter was used before the receiver.

Results are shown in Fig. 3. The received data streams for each tributary (two ASK, one DPSK) were compared to the expected data sets, which were different for each tributary. The DPSK pre-FEC BER was measured via the DPSK transceiver and FEC chip utilizing standard G.709 compliant Reed-Solomon RS (255,239) FEC. The ASK BER measurements were made one-at-a-time with the BERT. After 170km of transmission in SSMF, the BER of the eyes were measured as follows: PSK 5.5×10^{-4}; lower ASK eye 4.7×10^{-4}; and upper ASK eye 9.8×10^{-4}. After 340km of transmission in SSMF, the BER of the eyes were measured as follows: PSK 2.4×10^{-4}; lower ASK eye 1.8×10^{-3}; and upper ASK eye 2.3×10^{-3}. Included in Fig. 3 is a DPSK-3ASK eye received on the ASK photo-receiver after 335km, as well as upper and lower ASK eyes after threshold adjustments were made to the limiting amplifier.

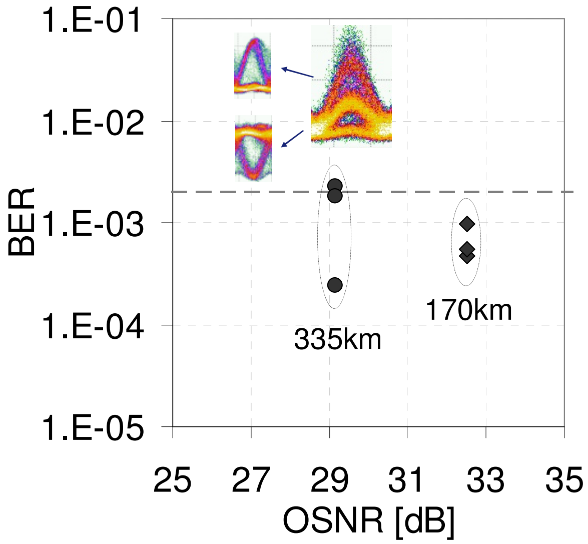

Fig. 3: DPSK-3ASK pre-FEC BER data for 170km and 335km SSMF. BER (bit error ratio); OSNR (optical signal-to-noise ratio)

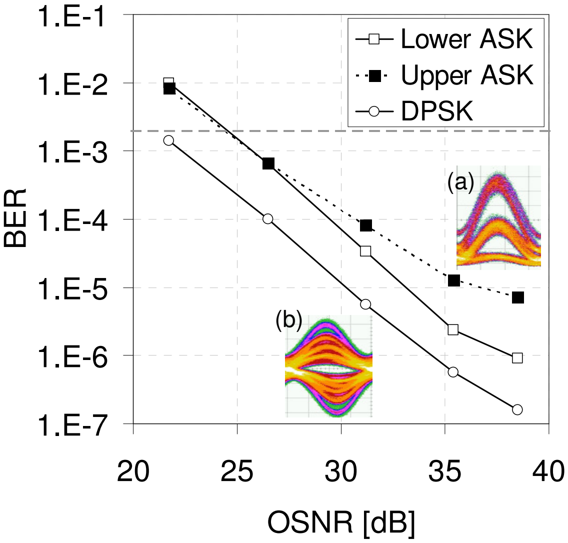

Fig. 4: Back-to-back performance and eye diagrams for (a) ASK-detection and (b) DPSK-detection

Figure 4 shows the measured back-to-back BER vs. OSNR (optical signal-to-noise ratio) results for DPSK and ASK detection. The OSNR was controlled by adding optical amplified spontaneous emission (ASE) noise, as depicted in the configuration shown in Fig. 2 but omitting the four SSMF spans and four optical amplifiers that immediately precede the 3dB splitter and receivers. Back-to-back measurements yield BER values below a typical 2×10^{-3} FEC threshold, depicted in Fig. 4 with a horizontal dashed line, at an OSNR value of 25dB.

Residual chromatic dispersion was corrected to within +/- 40ps/nm of optimum, and we note that we have measured a 1dB Q-factor penalty at 30ps/nm residual chromatic dispersion, and up to 2dB Q-factor penalty with 40ps/nm residual chromatic dispersion. This suggests that a significant amount of our penalty in the 335km transmission over SSMF was from residual chromatic dispersion.

Additional improvements are expected with further implementation efforts. No independent control of upper ASK eye vs. lower ASK eye opening has been implemented because to-date we are using passive splitting of an RF path of a binary PRBS pattern for testing the three-level ASK. In a future planned setup we will have two independent data patterns to create the three ASK levels, and with digital pre-coding we can eliminate redundancies in the middle ASK level, thereby enabling independent control of each ASK level and an expected improvement in transmission performance. Note also that the drive voltage and bias voltage of the ASK modulator alter the DPSK eye; we have reported on the tradeoffs and optimal eye openings previously [9].

4. Summary

We demonstrated generation, transmission, and detection of a DPSK-3ASK optical channel at a symbol rate of 43Gb/s to enable serial 107Gb/s data transmission. This DPSK-3ASK format utilizes hardware components that are readily available and qualified. A 44.8Gbaud symbol rate utilizing stronger FEC would enable 112Gb/s transmission. To our knowledge this is the first report of a DPSK-3ASK modulation format being transmitted over fiber. We realized 170km transmission over SSMF with BER values equal to or better than 9.8×10^{-4} for each component of the multi-level modulation format, and for 335km transmission we measured BER values near FEC error-free performance limits for each ASK eye. There are known possibilities for improvements, and in both transmission results, we were limited by residual chromatic dispersion. We expect to mitigate this penalty in the future with a tunable chromatic dispersion compensator.

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