

High-Speed PAM-4 Signal Transmission with Multi-Mode Fabry-Pérot Laser for Data Center Networks

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Abstract— We report 800 Gbit/s system capacity by exploiting multiple longitudinal modes of a free-running Fabry-Pérot laser and an EAM. The BER below the HD-LDPC decision limit is obtained with a T-spaced 31-tap FFE after C-band 100 Gbit/s/mode PAM-4 signal transmissions over 1 km.

Keywords— *Fabry-Pérot Laser, electro-absorption modulator, pulse amplitude modulation*

I. INTRODUCTION

In recent years, optical data centers (DCs) have become a key technology enabler for many Internet-based applications and services such as the Internet of Things (IoT), 4K/8K video streaming, social networking, cloud services, etc, requiring high-speed transmission, intensive computing, and processing. To cope with the DC traffic growth rate, the incorporation of higher-order modulation formats, digital signal processing (DSP), and powerful forward error correction techniques are proposed and standardized [1,2]. However, the single-frequency laser approach might not be a viable solution in the mid-/long-term to meet the data rate requirements, as a photonic integrated circuit (PIC) with laser arrays can be costly and complex to produce. The optical frequency comb emits mutually coherent and equispaced laser frequencies that could catapult data rates to unparallelled levels. In our previous work, we demonstrated that a simple Fabry-Pérot (FP) laser can be utilized as a comb source and the system capacity of Terabit/s using a Mach-Zehnder modulator (MZM) [3]. However, the use of an electro-absorption modulator (EAM) can be ideally suited for DC networks, considering the material, cost, and integrability of the proposed solution.

In this paper, we experimentally demonstrate 800 Gbit/s system capacity by utilizing multiple modes of a free-running FP laser and an EAM to modulate 4-level pulse amplitude modulation (PAM-4) signals. To the best of our knowledge, this is the highest data rate reported in the C-band considering a free-running FP laser and an EAM.

II. EXPERIMENTAL SETUP

The experimental setup is illustrated in Fig. 1. In this work, we utilize multiple longitudinal modes of a free-running FP laser each individually carrying 100 Gbit/s PAM-4 signals to realize the next-generation DC networks. At the transmitter, the ten modes of the butterfly-packaged FP laser with a flatness of 8 dB, attained by tuning the temperature and bias current, are individually filtered by using a 1 nm tunable optical bandpass filter (TOBPF), which increases the relative intensity noise (RIN) of each FP mode due to the mode partition noise (MPN). To suppress the RIN at a low frequency, we utilize the high-pass filtering effects of a semiconductor optical amplifier (SOA) by amplifying each filtered mode of the FP laser with an SOA operating in the gain saturation region [4]. We note that the optical output power of each filtered mode ranges between -6 dBm and 2 dBm, large enough to saturate the quantum-well SOA which exhibits a 3 dB gain saturation for an input power of -9 dBm, when biased at 150 mA.

Next, each amplified mode of the laser is externally modulated with an EAM, which is driven by 100 Gbit/s PAM-4 signals with a peak-to-peak voltage of $\approx 2V$. For the generation of RF signals, the digital PAM-4 data are 1.7 times upsampled, pulse-shaped using a root-raised cosine (RRC) filter with 0.1 roll-off factor, and pre-distorted to mitigate the nonlinear response of the EAM before loading it to a 32 GHz arbitrary waveform generator (AWG). Next, 100 Gbit/s PAM-4 signals with an optical power of 1 dBm are launched into a 1 km single-mode fiber (SMF). At the receiver, a variable optical attenuator (VOA) is utilized to adjust the received optical power (ROP) of the incoming signal before detecting it by a 70 GHz photodetector (PD) followed by RF amplification employing a 55 GHz amplifier, which is captured with a 33 GHz real-time oscilloscope (RTO) running at 100 GSa/s for offline processing. The offline DSP includes an RRC matched filtering, time synchronization, resampling to 1 Sa/sym., and equalization using a 31-tap feed-forward equalizer (FFE).

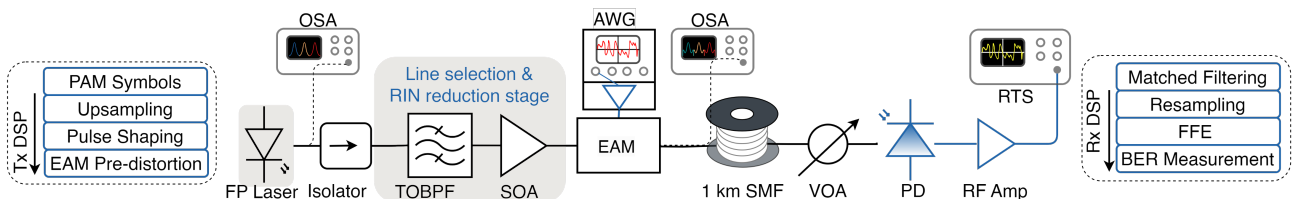


Fig. 1. Experimental setup for the demonstration of 800 Gbit/s system capacity using a free-running FP laser and an EAM.

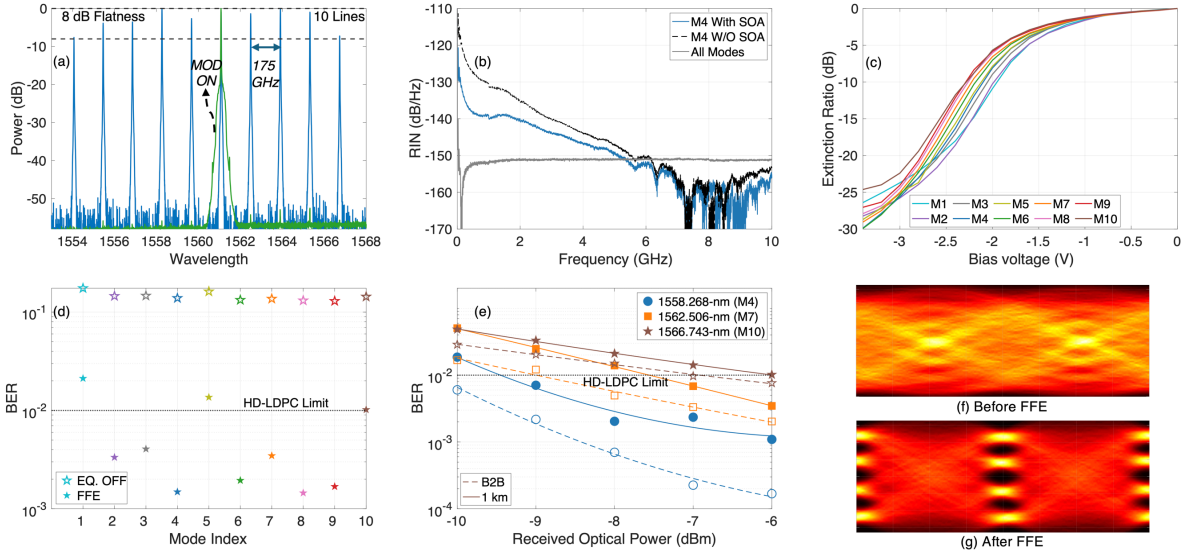


Fig. 2: (a) Optical spectra of modulated (M6) and unmodulated FP modes. (b) RIN reduction with an SOA. (c) Transfer curve of the EAM. (d) BER versus mode index at ROP = -6 dBm. (e) BER versus ROP of M4, M7, and M10 after B2B and 1 km transmissions. Eye diagrams (f) before and (g) after FFE.

III. EXPERIMENTAL RESULTS

In Fig. 2(a), we superimpose the spectra of the unmodulated free-running FP laser and one of the modulated FP modes (M6: at 1561.08 nm), when operating the laser at a constant current and temperature of 120mA and 10.5°C, respectively. While maintaining a flatness of 8 dB, the laser produces a frequency comb of 10 modes in the C-band, ranging from 1554.07 nm to 1566.74 nm, with a free-spectral range of about 175 GHz.

Fig. 2(b) shows the relative intensity noise (RIN) spectra of the FP laser. The RIN is about -151 dB/Hz, including all the modes of the laser. A significant degradation of the RIN in one of the filtered longitudinal modes (M4) is noticed, specifically in the low-frequency region (0 to 6 GHz). This is triggered due to an increase in the mode partition noise (MPN) instigated by spectral filtering. We can see that the operation of an SOA in the saturation region can block the low-frequency components, which helps in reducing the RIN spikes at the low frequency.

Fig. 2(c) presents the measured extinction ratio of the EAM as a function of reverse bias voltage for 10 longitudinal modes of the FP laser. We notice that the extinction ratio of the EAM depends on the wavelength as the absorption coefficient of the semiconductor material changes according to wavelength, and a higher extinction ratio is noticed for a shorter wavelength.

In Fig 2(d), we plot the unequalized and equalized BER performances of the 10 longitudinal modes of the FP laser at an ROP of -6 dBm after 100 Gbit/s/mode PAM-4 transmissions over a 1 km SMF. In the figure, the SOA-based RIN reduction technique is individually applied to each FP mode. A receiver-side T-spaced 31-tap FFE is applied for signal equalizations, which enables the 8 modes of the FP laser to reach the hard-decision low-density parity check (HD-LDPC) BER limit of 1.0×10^{-2} ; demonstrating a record-high 800 Gbit/s system capacity with a free-running quantum-well FP laser and monolithically integrable EAM transceiver for the application in the DC networks.

In Fig. 2(e), we plot the equalized BERs of M4, M7, and M10 after back-to-back (B2B) and 1 km transmissions. We can see that all three depicted modes can reach the HD-LDPC BER limit after fiber transmission. The M4 mode produces the best performance, as the RIN of M4 is found to be lower compared with other modes. A sensitivity penalty of about 0.8 dB -1 dB is observed at the HD-LDPC decision limit after 1 km transmission for all three modes due to the impact of chromatic dispersion and EAM-induced chirp. Figs. 2(f) and 2(g) present the unequalized and equalized eye diagrams of the PAM-4 signals at an ROP of -6 dBm after 1 km transmissions, respectively. The unequalized eye diagrams manifest severely distorted PAM-4 signals. However, clear eye openings are observed for 100 Gbit/s PAM-4 signals after a 31-tap FFE, which justifies the requirements for DSP to realize high-speed multi-level signal transmissions.

IV. CONCLUSIONS

We report a record-high 800 Gbit/s system capacity in the C-band when using multiple modes of an FP laser and an EAM. The proposed solution can be integrated on a single chip, which can offer disruptive advances in transceiver design choices for next-generation DC networks.

V. REFERENCES

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