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Transmission of a 120GBaud PM-NRZ Signal Using a Monolithic Double-Side EML

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***Abstract*—A 120GBaud polarization multiplexed NRZ (PM-NRZ) signal is generated using a monolithic double side electro-absorption modulated DFB laser (DS-EML). Using a pre-amplified direct detection receiver and direct detection faster than Nyquist (DD-FTN) technique, optical receiver sensitivities of -18.3dBm and -13.5dBm are obtained for a 240Gbit/s (Net data rate of 200Gbit/s with 20% soft-decision FEC) PM-NRZ signal at back-to-back and after 2km transmission, respectively. To the best of our knowledge, this is the highest baud rate transmission reported to date for single channel polarization multiplexed signal generated by a single device for short reach applications and the longest transmission distance (2km) at baud-rate >100GBaud IM/DD system without CD compensation at 1.55um.**

***Index Terms*—Electro-absorption modulated DFB laser, direct detection, faster than Nyquist.**

I. Introduction

Optical short reach transmission links with high capacity is desired with the fast increasing bandwidth demands of data center and other optical inter-connect applications. Small form factor, power consumption and cost are important factors to be considered in such systems. Intensity modulation with direct detection (IM/DD) is a promising way to meet these requirements. Recently, short reach transmission systems with bit-rate of 100Gb/s or above have been demonstrated [1-3] employing low cost EML and IM/DD. Due to the bandwidth limitations of optical devices and difficulties in generating ultra-high frequency electrical signal, multi-lane or dual-polarization were employed to increase capacity of optical transmission system[4,5]. However, multiple lasers with individual modulators were used, which increase the system cost, power consumption and difficulty of thermal management. Single chip with dual or more outputs, which enables modulating two or more individual signals in a monolithic chip is more favorable approach for increasing the system capacity while keeping system cost low.

In this paper, we experimentally demonstrate the generation and transmission of a single channel 120GBaud PM-NRZ (240Gb/s, net data rate is 200Gbit/s with 20% soft-decision FEC) signal employing a monolithic double side electro-absorption modulated DFB laser (DS-EML) and direct detection. Transmission over 2km SMF without any optical CD compensation was successfully achieved with a receiver sensitivity of -13.5dBm at 20% FEC threshold with DD-FTN technique. To the best of our knowledge, this is the highest baud rate transmission reported to date for single channel polarization multiplexed signal generated by a single device for short reach applications and the longest transmission distance (2km) at baud-rate >100GBaud IM/DD system without CD compensation at 1.55um.

II. Double Side Electro-absorption modulated DFB laser (DS-EML)

The structure of the double-side Electro-absorption modulated DFB laser (DS-EML) is shown in Fig.1 (a). The DS-EML comprises a DFB laser with EAMs located on both sides of the laser. The emission wavelength of the DFB laser is in the C-band. Two EAMs are realized with a ground signal ground contact pad configuration. Tilted waveguides are employed for the EAMs in combination with anti-reflection (AR) coating for a low facet reflection. Active InGaAlAs-MQW structure is used for both the DFB and the EAMs [6]. The DS-EML was fabricated by HHI. More detail of the DS-EML can be found in ref [7]. Fig.1 (b) shows the frequency responses for both DS-EML sides with an injected current of 70mA and a bias voltage of -1V at temperature of 20ºC. It can be seen that the two sides of DS-EML are symmetric and 3dB bandwidth of 35GHz was demonstrated for both sides of the DS-EML. The output power from EML chip is around 3dBm for each side. However, in this experiment, we used a packaged module instead of the chip. Due to the imperfection of the optical

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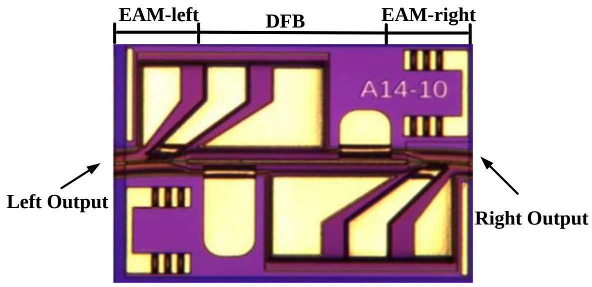
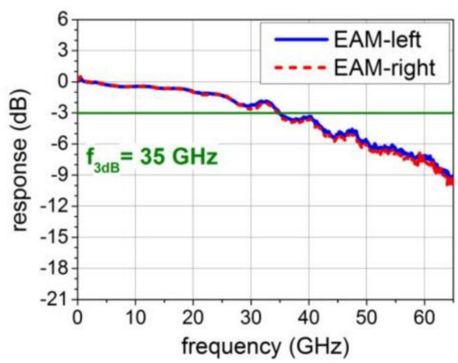


(a)



(b)

Fig.1. (a) Microscopic view of the DS-EML chip. (b) Frequency response for both DS-EML sides. Current=70mA, Bias voltage=-1V, T=20ºC.

coupling during the packaging process, there is about 4 dB loss for each port. The output power of the DS-EML module were measured to be -1dBm and -0.8dBm for the right and left output of DS-EML respectively with a bias voltage of 0V and an injection current of 70mA.

III. Experimental Setup and Results

The experimental setup is shown in Fig. 2. Two copies of pseudo-random bit sequence (PRBS) of length 2^{15}-1 at 60GBaud/s are generated and de-correlated by a bit pattern generator (SHF 12104A). The generated two NRZ signals are fed into a 2:1 MUX to obtain the 120Gbaud/s NRZ signal. The eye-diagrams of the generated 120Gbaud electrical NRZ signal are shown in the inset (a) of Fig.2. Then the two NRZ signals are amplified to a peak-to-peak of 1.8V and used to drive the double side EML TOSA. The bias voltages are optimized to -0.7V and -0.7V for the two RF signals, respectively. The eye-diagram of the generated 120GBaud optical signal is also shown in the inset (a) of Fig.2. Due to the limited bandwidth of the DS-EML, large inter-symbol interference (ISI) can be investigated. The power of the two optical signals at the output of the DS-EML is -8.5dBm and -8.3dBm, respectively. The two optical signals are designed to be polarization orthogonal to each other. The power of the PM-NRZ signal is -5.7dBm. The optical spectrum of the PM-NRZ signal is shown in the inset (b) of Fig. 2. The center wavelength of optical signal is 1555.74nm. Then 120GBaud PM-NRZ signal is launched into a 2 km standard single mode fiber transmission link. A variable optical attenuator (VOA) is used to adjust the received signal power prior to a pre-amplifier receiver consist of an erbium doped fiber amplifier (EDFA) and a 50GHz PIN detector. For the purpose of this demonstration, a polarization control (PC) and a polarization beam split (PBS) were used to manually demultiplex the PM-NRZ signal as in [5, 8]. We note that in practice, automatic demultiplexing can be achieved using a low speed control signal [9]. In addition, the recently proposed stokes vector direct detection (SV-DD) in [10]can be applied for polarization de-multiplexing in practical DD-systems. The received signal power is measured prior to the EDFA. Then, the demultiplexed signal is detected by a 50GHz PIN detector and sampled by a digital oscilloscope with a sampling rate of 160GS/s and a bandwidth of 63GHz. The received data is processed off-line. The received signal is first re-sampled to 2 samples per symbol. Then a digital square and filtering algorithm is employed for clock timing recovery. A feed-forward equalizer (FFE), adapted via a least mean square (LMS) algorithm is used for channel equalization. The number of taps for linear equalizer is set to be 101. The complexity of the linear equalizer can be reduced by implementing frequency domain equalization (FDE) [11].

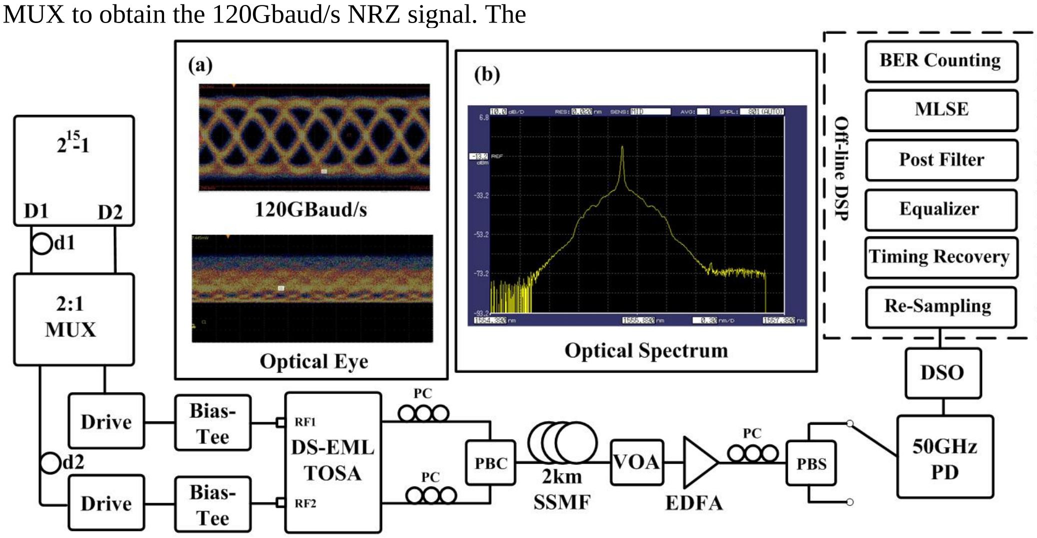
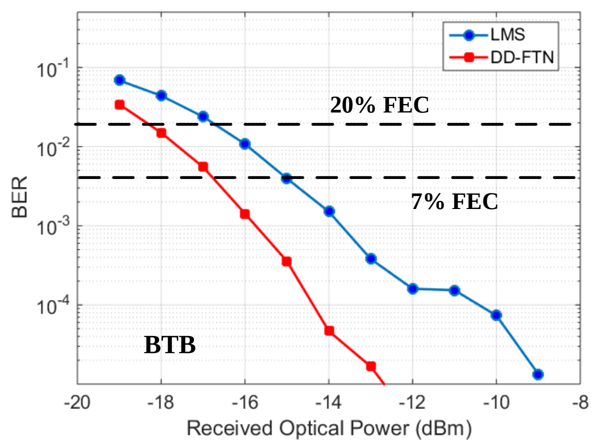
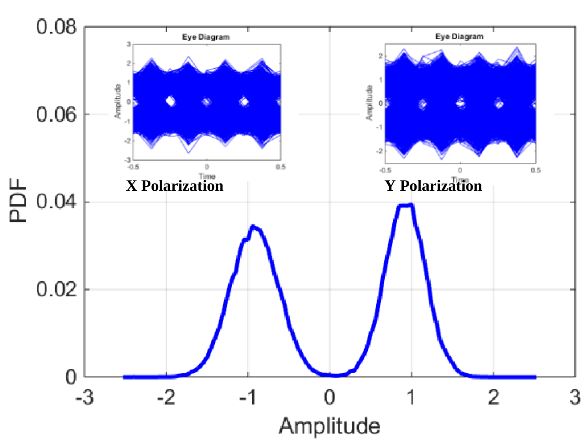


Fig. 2: Experimental setup for the 120GBaud PM-NRZ transmission system. DS-EML TOSA: Double side Electric-Absorption modulated laser transmitter optical sub-assembly. MUX: multiplexer. PC: polarization controller. PBC: Polarization Beam Combiner. VOA: variable optical attenuator. PBS: Polarization beam splitter EDFA: erbium doped fiber amplifier. PD: Photo-Detector. DSO: digital storage oscilloscope.

In our system, the bandwidth of transmitter and receiver is 35GHz and 50GHz, respectively, which is even smaller than the Nyquist bandwidth of the transmitted signal (60GHz for 120Gbaud/s). In [9], we have proposed a direct detection faster than Nyquist technology (DD-FTN) to recovery severely filtered signal. It is well known that the linear equalizer would enhance the noise in the high frequency components of signal in a bandwidth limited optical transmission system. First, a 3-taps post filter was placed after the linear equalizer for noise suppression. The response of the post filter has a transfer function in z-transform of $H(z) = \alpha z+1 + \alpha z^{-1}$. The tap coefficient α is introduced to facilitate the optimization of the frequency response of the post filter. Following the optimization process described in [2], the coefficient of 3 taps post filter is optimized to be [0.25 1 0.25]. Then, maximum likelihood sequence estimation (MLSE) with a sequence length of 20 is implemented to eliminate the strong inter-symbol interference (ISI) induced by the post filter and recover the signal. The bit error rate is calculated by error counting. A total number of 1 M bits are used for bit error counting for each received power.



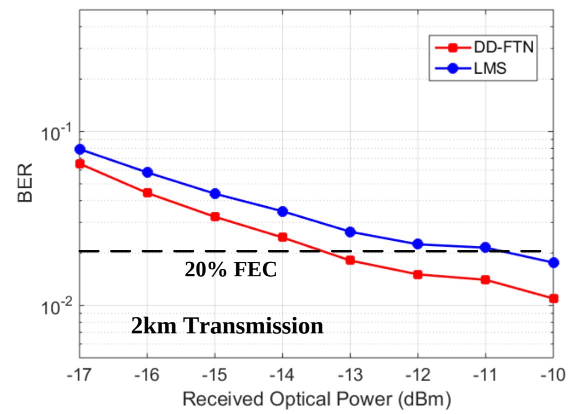
(a)



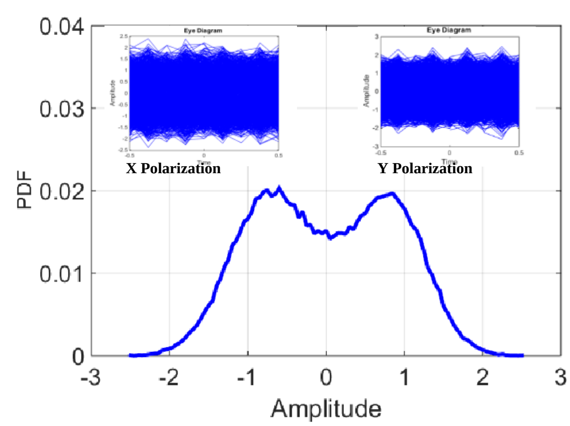
(b)

Fig. 3 (a) BER vs Received optical Power for back-to-back transmission. (b) amplitude histogram of recovered signal. Inset: eye-diagram of recovered signal. The received optical power is -13dBm.

Fig.3 (a) shows the measured bit error rate as a function of the received optical power in a back to back system with and without DD-FTN. It can be seen that DD-FTN can significantly improve the BER performance. Receiver sensitivities at the 7% over head forward error correction (FEC) limit of 3.8×10^{-3} are -15dBm and -17dBm for linear equalization and DD-FTN, respectively. Receiver sensitivities at the 20% over head forward error correction (FEC) limit of 2×10^{-2} are -16.8dBm and -18.3dBm for linear equalization and DD-FTN, respectively. Fig.3 (b) shows the amplitude histogram the recovered signal with 1Samle/Symbol. The insets of Fig.3 (b) show the recovered eye-diagram of 120Gbaud/s PM-NRZ signal for X polarization and Y polarization with a received optical power of -13dBm. It can still demonstrate some eye-opening. The BER is 1.6×10^{-3}.



(a)



(b)

Fig. 4 (a) BER vs Received optical power for 2km transmission. (b) amplitude histogram of recovered signal. Inset: eye-diagram of recovered signal. The received optical power is -13dBm.

Fig.4 (a) shows the measured bit error rate as a function of the received optical power in a 2km SMF transmission system with and without DD-FTN. It can be seen that the DD-FTN can improve the BER performance. Due to the chromatic dispersion (CD) of the fiber, worse performance is expected without any optical CD compensation. However, we still can achieve BER below 20% FEC threshold with powerful DSP. Receiver sensitivities at 20% over head forward error correction (FEC) limit of 2×10^{-2} are -10.9dBm and -13.5dBm for linear equalization and DD-FTN, respectively. An improvement of 2.6dB in terms of receiver sensitivity was demonstrated using DD-FTN. Fig.4 (b) shows the amplitude histogram of the recovered signal with 1Samle/Symbol. The insets of Fig.4 (b) show the recovered eye-diagram of 120Gbaud PM-NRZ signal for X polarization and Y polarization with a received optical power of -13dBm. The BER is $1.8x10^{-2}$.

IV. Conclusion

In this paper, we experimentally demonstrated a single channel 120Gbaud PM-NRZ signal (Net data rate of 200Gbit/s with 20% soft-decision FEC) transmission over 2km SMF without any optical CD compensation enabled by a monolithic double side EML and direct detection. DD-FTN technique is employed to compensate the bandwidth limitation of optical link. A receiver sensitivity of -13.5dBm at 20% FEC threshold was achieved for 2km transmission. To the best of our knowledge, this is the highest reported baud rate of single channel polarization multiplexing signal generated by a single device and the longest transmission distance (2km) at baud rate >100Gbaud IM/DD system without CD compensation at 1.55um.

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