Experimental Demonstration of 25×25Gb/s O-band WDM Transmission over 55km G.652 Fiber

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***Abstract*— We experimentally demonstrate 25×25Gb/s WDM O-band signal transmission over 55km G.652 fiber using 25G DML-based IM-DD modules. The performance of the EML-based module has also been verified over 80km G.652 fiber.**

Keywords*— *O-band, DML-based IM-DD modules, EML

I. Introduction

With the continuous popularity of high-definition video, the Internet, data centers, and other businesses, global network traffic is growing rapidly. As more and more data has transmission requirement, the capacity improvement issue has been a long-term concern for researchers. Wavelength division multiplexing (WDM) can make the most of spectral efficiency, which is an effective way to meet the requirement of capacity expansion [1]. Over the past decades, the WDM transmission system has continuously evolved and matured with the invention and employment of erbium-doped fiber amplifier (EDFA), which is generally used for backbone transmission. Since EDFA can provide a higher gain for C-band optical signal, most of the current WDM systems are developed around C-band. To further light up the transmission capacity, the operating band of the system should be extended from C-band to other bands [2], such as O-band, L-band, etc. This indicates that corresponding devices need also to be investigated to work with other bands.

For 5G mobile front-haul and metropolitan area network (MAN) scenarios, it will run into issues with cost and scaling up if they adopt strategies identical to the backbone network. Consequently, O-band WDM technique has attracted the attention of researchers, which is a potential transmission way with the advantages of low cost and low dispersion coefficient [3]. The O-band WDM was first applied in 5G front-haul in recent years with the growing investments in 5G construction. The module's significant cost advantages are primarily due to the utilization of intensity modulation direct detection (IM-DD) modules. At present, high-speed transmission experimental verification and related optoelectronic devices are the key research areas of O-band transmission technology. In the investigation of related optoelectronic devices, the research of lasers, modulators, and others applied to the O-band has provided the foundation for the O-band transmission [4-5]. Nevertheless, in terms of high-speed transmission, the transmission system in current research are built on separate components [6-7]. As far as we are aware, there are few reports of WDM transmission systems based on optical modules.

In this paper, a 25×25Gb/s WDM signal transmission experimental system over 55km G.652 fiber in O-band using 25G pluggable IM-DD transceivers was established. We experimentally demonstrated that the WDM transmission system based on 25G directly modulated laser (DML) optical modules can achieve a 25.03 dB power budget and 55km of transmission. 25 wavelengths are separated into 3 groups and each is amplified by a semiconductor optical amplifier (SOA) in order to keep every wavelength within the optimal gain range. According to the power budget, the system enables a limit transmission distance of around 68 km. Besides, the DML optical module with a wavelength of 1284.2 nm was substituted by an electro-absorption modulated laser (EML)-based tunable optical module, which can realize 31.5 dB power budget and 80km transmission when bit error rate (BER) reached 5E-5. The EML-based optical module has higher receiving sensitivity under the same transmission distance and supports transmission over longer distances, which is a promising solution for 5G and MAN.

II. Experimental Setup And The Measurements Of Essential Devices

The experimental setup of 25×25Gb/s WDM signal transmission is shown as Fig.1. At the transmitter, 25 DMLs in 25G pluggable optical modules are used to generate 25 non-return zero (NRZ) signals with different wavelengths. We divide 25 wavelengths into three groups for amplification in order to keep every wavelength inside the ideal amplification range of the SOA. In the first two groups, there are a total of 5 and 16 wavelengths, which started from 1269.5 nm and 1284.2 nm respectively with about 100 GHz channel spacing between each wavelength. While the third group uses 4 wavelengths in the LAN-WDM, which is from 1304.1 nm with about 800GHz channel spacing. The signals to be

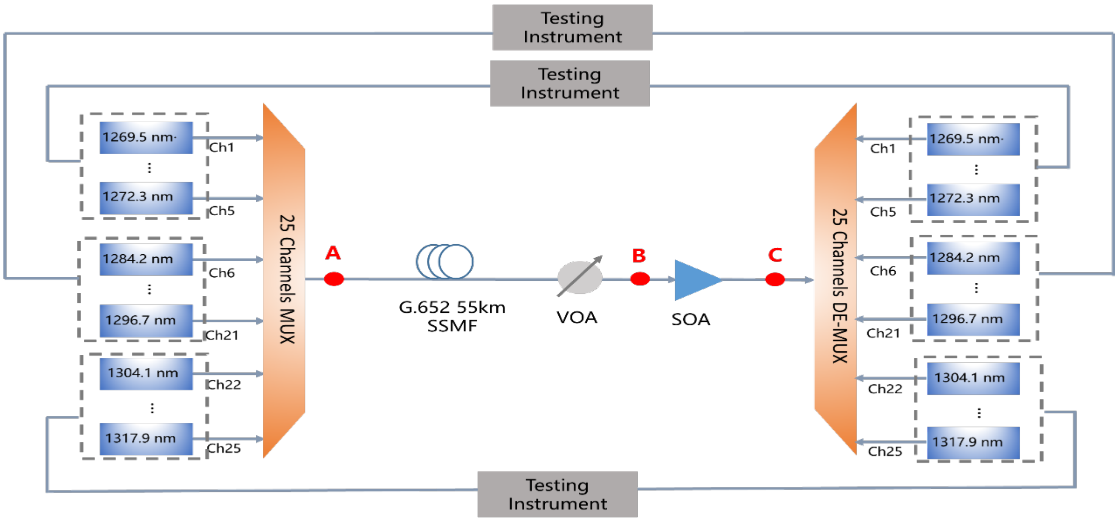

Fig.1. Experimental Setup of 25×25Gb/s transmission system

transmitted are sent to arrayed waveguide grating (AWG) to combine one lane. The average insertion loss of each port in the three multiplexers and de-multiplexers is 0.90/0.70 dB, 0.70/0.60 dB, and 1.63/1.78 dB at room temperature, respectively. Subsequently, 25 signals are simultaneously transmitted through 55km G.652 standard single mode fiber (SSMF) with a total of 18 dB fiber loss measured by an optical time-domain reflectometer at 1310 nm. At the receiver end, the optical power of the signal can be adjusted by a variable optical attenuator (VOA). The amplification gains provided by SOA for transmitting signals have contribution to the increase of receiving sensitivity of the module. Each signal is delivered to the corresponding module after de-multiplexing, in which the clock data recovery (CDR) units would process the receiving signals and restore them into the transmitting binary sequence. The network analyzer (VIAVI MTS-5800) is used as a test instrument to send services to each optical module at the 25G eCPRI test mode and monitor the transmission performance of the overall system. As shown in Fig. 1., we set three reference points in the whole transmission system to measure the optical spectrum.

A. The parameters measurement of 25G DML module

A 25G DML optical module is selected randomly and its essential characteristics are measured. The lasing wavelength is 1292.457 nm with a side-mode suppression ratio of around 45.01 dB, and it has a 0.03 nm jitter between the measured

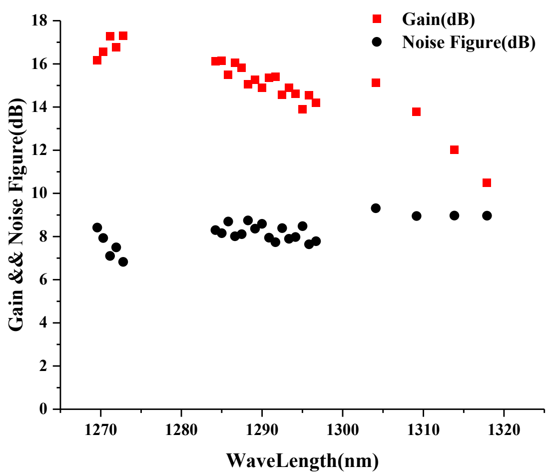

Fig.2. Gain and noise figure comparision at different wavelength

wavelength and the nominal wavelength in the WDM system. We obtained eye-opening with an extinction ratio (ER) of 4.312 dB for 25Gb/s NRZ signals. The output optical power is 3.94 dBm and the back-to-back receiving sensitivity is -17.97 dBm when BER reached 5E-5. The measured 3 dB bandwidth and 20 dB bandwidth are 0.13 nm and 0.35 nm respectively.

B. The gain and noise figure of SOA

Three groups of wavelengths are amplified by modifying the injection current of SOA in order to place each group of wavelengths within the best working range of SOA. The injection current of SOA for the three groups is 120 mA, 113 mA, and 165 mA, respectively. Fig.2. shows the comparison with the gains and noise figure (NF) obtained by SOA. The average amplification gain of SOA for the three group's wavelength is 16.82 dB, 15.14 dB, and 12.85 dB respectively. Nevertheless, the flatness of the gains for the third set of wavelengths is insufficient, and more optimization still should be required in the next stage. The measured average NF is 8.19 dB within the entire transmission band.

III. Experimental Results And Conclusions

In order to verify the performance of the overall system, we demonstrate 25×25Gb/s WDM signal transmission over 55km G.652 SSMF according to Fig.1. There are two 20/80 splitters, each with a loss of around 1 dB, are placed at the reference A and B points, respectively. The output optical power of the multiplexed signal at reference A point is 15.69 dBm. The size of receiving optical power at reference B point can be varied by adjusting VOA which has a background loss of around 0.8 dB and was measured by an optical power meter.

The overall BER of the transmission system reached 5E-5 when the link attenuation was set to 2 dB. The receiving optical power at reference B points is -9.34 dBm. Therefore, the power budget between the effective span is 25.03 dB. Under current conditions, the optical spectra at the three reference points are shown in Fig. 3 (a)-(c). It can be seen from Fig.3. that there is no obvious four-wave mixing effect. Meanwhile, there is a margin of around 4.8 dB when the insertion loss of some devices is taken into account. On the supposition that the BER requirements are met, it can be deduced that the system can achieve 68km G.652 SSMF transmission when the average attenuation coefficient of the O-band is 0.36 dB/km.

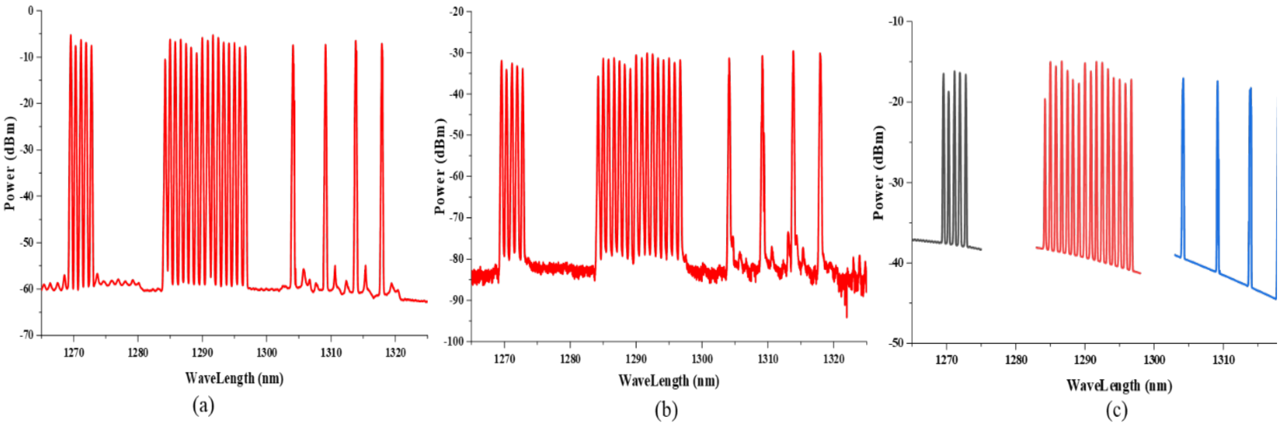

Fig.3. The optical optical spectrum at the three reference points

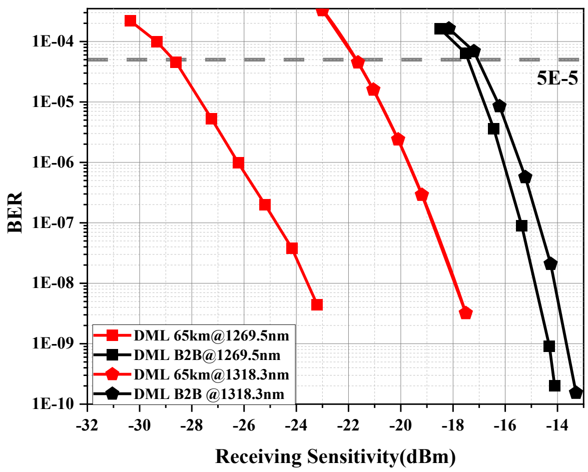

Fig.4. The BER versus receiveing sensitivity of DML module.

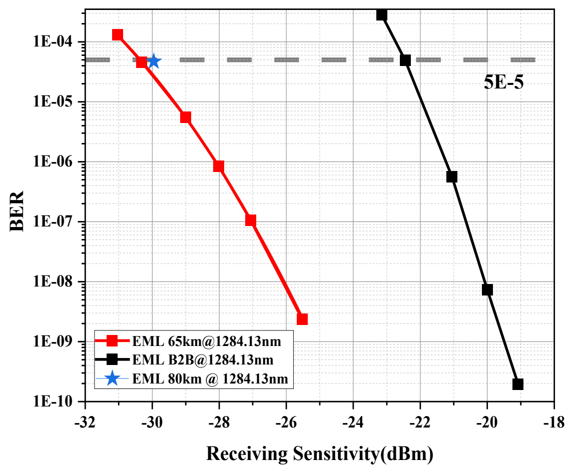

Fig.5. The BER versus receiving sensitivity of EML optical module

In order to confirm the aforementioned conclusions, we utilized optical modules of 1269.5 nm and 1318.3 nm to evaluate the transmission performance in back-to-back and 65km G.652 SSMF scenarios. The transmission optical power is 4.24 dBm and 3.74 dBm for 1269.5 nm and 1318.3 nm, respectively. It can be concluded from Fig.4 that two optical modules have increased receiving sensitivity primarily due to SOA offering of amplification gain for signal power when transmitting in 65km SSMF. 65km transmission has a receiving sensitivity of -28.6 dBm when BER approaches 5E-5. It has obtained 11.3 dB higher gains compared to back-to-back transmission.

EML can support longer transmission distances attribute to its high ER and small wavelength jitter. The current DML optical module is substituted for an EML-based optical module in order to extend the transmission range of this system. Nonetheless, with the limitation of existing technology, one EML tunable wavelength optical module with 1284.2 nm is employed in the system, while others still use DML.

We demonstrate the WDM signal transmission over 80km SSMF with a total of 25.5 dB loss. The transmission system has a power budget of 31.5 dB between reference A and B points when BER reaches 5E-5. We have investigated the BER versus receiving sensitivity of this module at back-to-back, 65 km, and 80km. When the BER is 5E-5 in the 65 km scenario, the receiver sensitivity is - 30.31 dBm, achieving a gain of 1.71 dB over the DML optical module under the same parameters as shown in Fig.5, while the system obtained 5.14 dB gains at back-to-back transmission. The receiving sensitivity is -29.95 dBm when transmitting over 80 km SSMF. The system is expected to achieve transmission of more than 85 km if the quantity of EML is raised and the power difference of optical sources is improved.

IV. Summary

We have demonstrated 25×25Gb/s WDM transmission over 55km G.652 fiber in O-band using DML-based and EML-based optical modules. EML-based optical modules have emerged as a promising solution for future advancements in the O-band capacity due to their high ER and low jitter.

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