Convergence of RoF and Baseband Transmissions Using Dual-Parallel Modulator

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***Abstract*- We demonstrate simultaneous delivery of wireless and baseband signals in converged optical networks. The baseband data and RoF signals are generated using integrated dual-parallel modulator.**

I. INTRODUCTION

With the increasing bandwidth demand and possible frequency congestion in low frequency band, the emerging radio over fiber (RoF) technique becomes a promising method in providing broadband wireless access over wide areas. Among RoF systems, multiband optical modulation technique is an attractive method, which simultaneously delivers baseband, micro-wave (MW) and millimeter-wave (MMW) signals [1]. It exhibits flexible application potential in future multiservice access since wireline and multiple wireless services are seamlessly converged in a common network. In addition, the convergence of video, voice and data into triple play service (TPS) in a single network is an effective solution for network service providers. Passive optical network (PON) technology is believed to be a promising scheme to provide TPS in an integrated platform with a cost-effective configuration [2]. Since PON has advantages including high capacity, security, and upgradeability, many efforts have been paid to enable broadcasting functions in PON [3], where single broadcast video service is overlaid over the downlink point-to-point data. With the growth of different emerging services such as video-on-demand, it is valuable to provide multiple broadcast services to the customers.

In this paper, we perform three demonstrations based on converged RoF and baseband transmission using integrated dual-parallel Mach-Zehnder modulator (DPMZM) [4]. The DPMZM comprises a pair of x-cut MZMs (MZMA, MZMB) embedded in the two arms of a main MZM structure. The two sub-MZMs have the same structure and performance, and the main MZM combines the outputs of the two sub-MZMs. The first demonstration is a multi-band transmission system to deliver baseband, MW, and MMW signals [5]. The second system is a PON which generates and sends video, voice and data from the central office [6]. The last one is simultaneous transmission of high-speed point-to-point data and double broadcast services in a PON system [7]. All these schemes are based on DPMZM, and upstream transmission is realized by employing carrier re-modulation method.

II. EXPERIMENTAL SETUP AND RESULTS

A. Simultaneous generation and transmission of down-stream multiband signals and upstream data in a RoF system

We demonstrate a full duplex RoF system to generate and transmit downstream wireline baseband data, wireless MW and

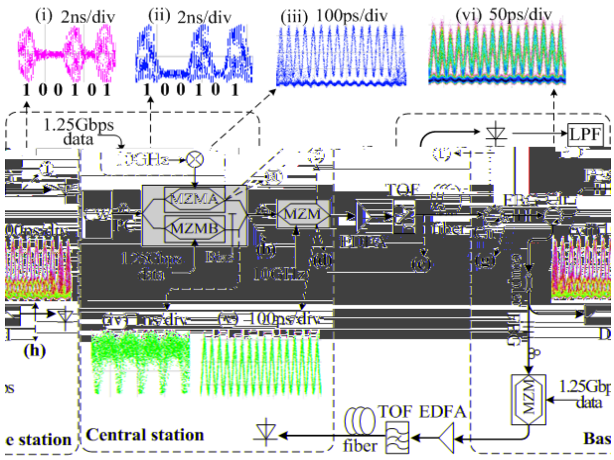

Fig. 1 Experimental setup of the presented multiband RoF systems

MMW signals on a single wavelength, using a DPMZM followed by a standard single-drive Mach-Zehnder modulator (SDMZM). Fig. 1 shows the experimental setup. A 10-GHz DPMZM is used to modulate a CW light from a tunable laser. A sub-carrier multiplexing (SCM) signal is obtained by mixing a 1.25-Gb/s PRBS data with a 10-GHz clock signal, the waveform is shown in inset (i) of Fig.1. The MZMA is biased at the null point and driven by the SCM signal to generate a carrier suppressed signal of 20-GHz rate; the waveform and the eye diagram are shown in Fig.1 as insets (ii) and (iii) respectively. MZMB is biased at the null point and driven by another 1.25-Gb/s PRBS data, the optical eye diagram of the generated DPSK is shown in Fig.1 inset (iv). A following 10-GHz SDMZM is biased at null point and driven by a 10-GHz clock signal to shift the frequencies of the DPMZM outputs thus resulting in multi-band signals. The baseband and 40-GHz MMW signals are generated by modulating the output of the MZMA. The 20-GHz MW signal is obtained by modulating the output of the MZMB, the eye diagram is indicated in inset (v) of Fig.1. The multi-band signals are amplified by an EDFA and a tunable optical filter (TOF) is used to suppress amplified spontaneous emission (ASE) noise.

After transmission over 25-km standard single-mode fiber (SMF), an FBG is used to separate the baseband data from the multi-band signals. The passing signals from the first FBG are injected into a second FBG to separate the optical MW and MMW signals, the eye diagram of the MMW signal are shown in inset (vi) of Fig.1. A 2.5-GHz PD is used to detect the baseband signal. The reflected MW signal is divided into two parts, one is converted into the intensity signal by a 1-bit Mach-Zehnder delay interferometer (MZDI), with the optical eye diagram after MZDI provided in Fig. 1 as inset (vii). The other part is sent into a third FBG to filter its lower sideband, which is employed for

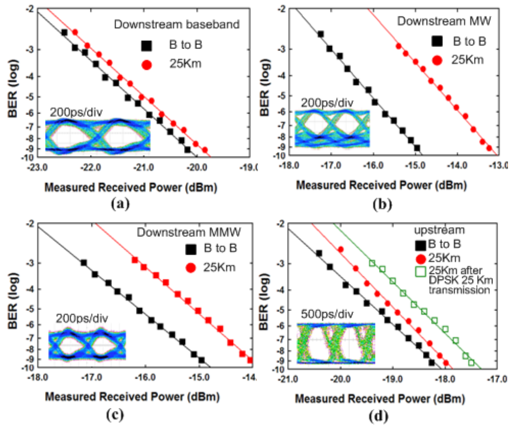

Fig. 2 BER performance and electrical eye diagrams

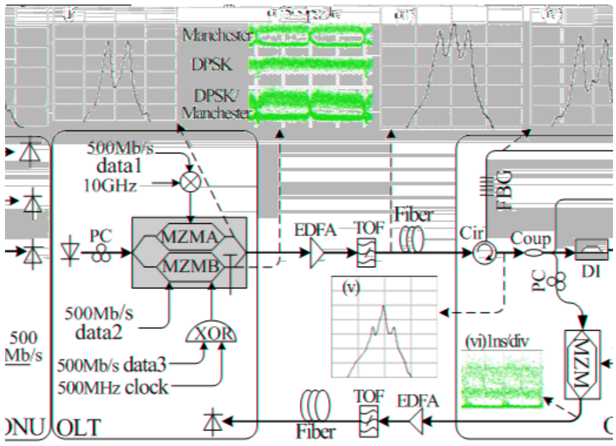

Fig. 3 Experimental setup of delivery of downlink TPS in a PON System

re-modulation using a 1.25-Gb/s PRBS data. After transmission over 25-km SMF, the upstream signal is detected by a 2.5-GHz PD. Fig.2 shows the measured BER results and electrical eye diagrams for the multi-band signals and the upstream signal. After the transmission over the 25-km SMF, for the baseband data, the power penalty is ~ 0.2 dB. For the MW signal, the power penalty is ~1.7 dB. A power penalty ~1.2 dB is observed for the MMW signal. Less than 1-dB power penalty is observed for the re-modulated upstream ASK signal. The electrical eye diagrams of the multi-band signals and the upstream signal are provided in insets of Fig.2.

B. Centralized delivery of downlink TPS in a PON System

In this scheme, the TPS signals are modulated using a single DPMZM, the MZMA is biased at its transmission null and driven by a RF carrier loaded with video signal to obtain a carrier suppressed optical SCM format. The data signal and a Manchester pre-coded voice signal are input into the RF port and the bias port of the MZMB, respectively. The RF port is used to encode the DPSK data, while the bias port is modulated by the voice signal to generate a Manchester format. Thus the voice signal is superimposed onto the DPSK data to form a hybrid DPSK/Manchester format by adjusting the bias point of the MZMB between the null and a small fraction of the switching voltage [8]. In this manner, the TPS signals are carried in the SCM, the DPSK and the Manchester format, respectively.

Fig. 3 shows the experimental setup. A CW light is launched into a 10-GHz DPMZM. The electrical SCM signal is obtained by mixing a 500-Mb/s PRBS data with a 10-GHz RF signal. The MZMA is biased at its transmission null and driven by the mixed SCM signal to generate an optical SCM signal of 20-GHz repetition rate, and the optical spectrum is shown in inset (i) of Fig. 3. The downstream orthogonal DPSK/ Manchester format is obtained by driving the RF port and the bias port of the MZMB using a 500-Mb/s PRBS data2 and a Manchester-coded signal of the same rate, respectively. The Manchester signal is generated by a logic XOR operation between a 500-MHz clock signal and a 500-Mb/s PRBS data3. The optical eye diagrams of the Manchester, the DPSK and the hybrid DPSK/Manchester format are provided in inset (ii) of Fig. 3. The output signals from the MZMA and the MZMB are constructively added and amplified by an EDFA before transmission. A TOF is used to suppress ASE noise, and the optical spectrum of the combined signals is shown in inset (iii) of Fig. 3.

After transmission over 25-km SMF, an FBG connected with an optical circulator is used to reflect the DPSK/Manchester signal and pass the optical SCM signal. The optical spectrum of the passing optical SCM loaded with data1 is indicated in Fig. 3 as inset (iv),

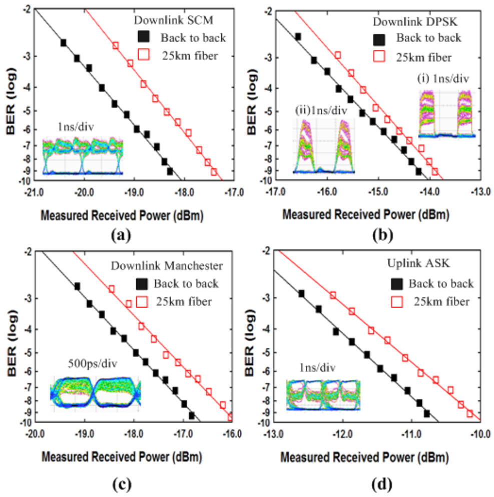

Fig. 4 BER performance and electrical eye diagrams

the SCM signal is converted into the electrical signal using a 2.5-GHz PD. The optical spectrum of the reflected DPSK/ Manchester format is shown in inset (v). Due to the imperfection of the FBG, there are some residual components in the separated SCM signal and the DPSK/Manchester signal, which are observed in the spectra shown in insets (iv) and (v) of Fig. 3, respectively. For the reflected DPSK/Manchester signal, it is divided into three parts by a coupler. Among them, the Manchester signal is directly detected using a 2.5-GHz PD, while the DPSK signal is converted into the intensity signal by a MZDI and then detected by a 2.5-GHz PD. Since the Manchester signal carries optical power at both the mark and the space symbols in each bit period, and the DPSK signal is a constant-intensity optical phase-modulated format, the DPSK/ Manchester modulation format can be considered as the optical carrier for upstream ASK signal re-modulation. The third part is re-modulated by a 500-Mb/s upstream data to produce an ASK format, the optical eye diagram of the re-modulated ASK signal is provided in inset (vi) of Fig. 3. The upstream ASK signal is amplified by a second EDFA, and another TOF filters the ASE noise. After transmission, the upstream ASK signal is detected using a 2.5-GHz PD. Fig. 4 shows the BER curves and the eye diagrams of the downstream and upstream signals, respectively. For the downstream SCM signal, the DPSK signal, and Manchester signal, the power penalties are ~0.9dB, ~0.3dB and 0.6dB, respectively. The optical eye diagram of DPSK signal after the MZDI demodulation is provided in Fig. 4(b-i). Since a 1.25-GHz

MZDI is used to demodulate the 500-Mb/s DPSK data, the eye diagrams show ~40% duty cycle. The electrical eye diagrams are shown in insets of Fig. 4(a).

C. Simultaneous transmission of high-speed point-to-point data and double broadcast services in a PON system

In this system, the downstream carrier is fed into a DPSK transmitter, which is driven by downlink point-to-point data to produce a DPSK format. The generated DPSK signal is launched into a following DPMZM as a double-broadcast services transmitter. The MZMA is biased at its null point and driven by a RF signal loaded with broadcast service_1 to obtain a carrier suppressed optical SCM format. Because the downlink data is phase-modulated on the optical carrier and the SCM signals are intensity-modulated by the DPSK signal, there is no crosstalk between two modulation formats. The MZMB is biased at the quadrature point of the negative slope of its transmission curve and driven by a RZ-shaped electrical signal to generate an inverse return-to-zero (IRZ) format for broadcast service_2. Then the generated IRZ signal is superimposed onto the DPSK signal to form an orthogonal DPSK/IRZ format [8].

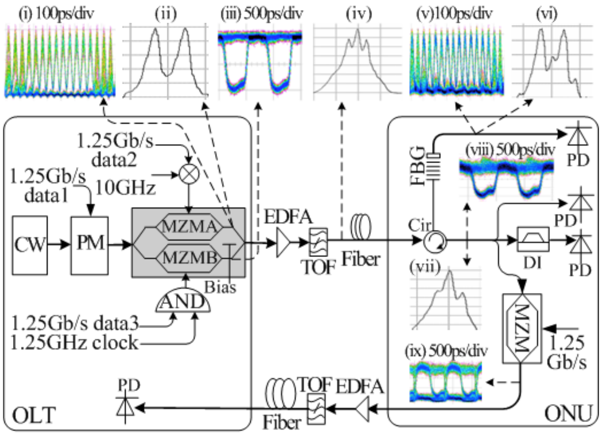

Fig. 5 The setup of transmission double broadcast services in a PON system.

Fig. 5 shows the setup of simultaneous transmission of high-speed point-to-point data and double broadcast services in a PON system. A phase modulator (PM) is driven by a 1.25-Gb/s PRBS data1 to obtain a DPSK signal, the generated DPSK signal was then fed into a following 10-GHz DPMZM The electrical SCM signal is obtained by mixing a 1.25-Gb/s PRBS data2 with a 10-GHz RF signal. The MZMA is biased at the null and driven by the mixed SCM signal to generate an optical SCM signal of 20-GHz repetition rate. The downstream orthogonal DPSK/IRZ format is obtained by driving the sub-MZMB using an RZ pulse-shaped signal, which is generated by a logic AND operation between a 1.25-GHz clock signal and a 1.25-Gb/s PRBS data3. The outputs from the MZMA and the MZMB are amplified by an EDFA). A TOF is used to suppress ASE noise. The optical spectra and the eye diagrams at the corresponding measured points are shown as insets (i)-(iv) in Fig. 5, respectively.

After transmission over 25-km SMF, an FBG with an optical circulator is used to reflect the DPSK/IRZ format and pass the optical SCM signals. The SCM signals are directly detected using a 2.5-GHz PD. The optical eye diagram and the optical spectra of the passing optical SCM signals with data2, and the reflected DPSK/IRZ format are shown in Fig.5 (v)-(viii), respectively. For the reflected DPSK/IRZ signals, it is divided into three parts. Among them, the IRZ signal is directly detected

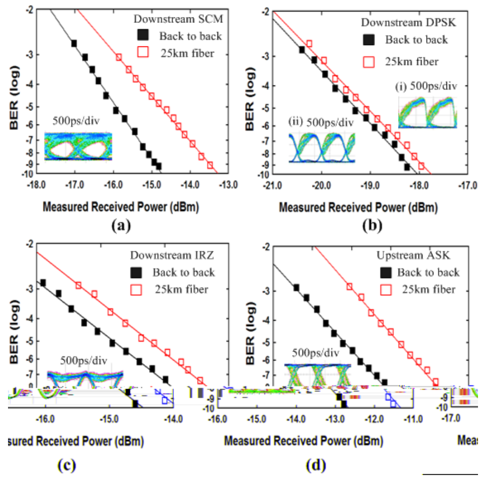

Fig. 6 BER performance and electrical eye diagrams

by a 2.5-GHz PD; the DPSK signal is firstly converted into the intensity signal by a 1-bit MZDI and then detected by a 2.5-GHz PD. Since the IRZ signal carries optical power at both the mark level and the space level in each bit period, and the DPSK signal is a constant-intensity optical phase-modulated format, the third part is re-modulated by a 1.25-Gb/s upstream data to produce an ASK signal, the optical eye diagram of the re-modulated ASK signal is provided in inset (ix) of Fig. 5. After transmission, the upstream ASK signal is detected using a 2.5-GHz PD. Fig.6 shows the BER curves and the eye diagrams. For the downlink SCM signal, the DPSK signal, and the IRZ signal, the power penalty is ~1.3 dB, ~0.2 dB, and 0.7-dB, respectively. The upstream signal suffers ~1.3-dB power penalty. Fig.6 (b-ii) provides the optical eye diagram of DPSK after the MZDI. The electrical eye diagrams are shown in insets of Fig.6.

III. CONCLUSIONS

We have proposed and demonstrated three systems for carrying converged RoF and baseband signals. The first system supports baseband, MW, and MMW signals, the second scheme delivers TPS signals, and the third one provides simultaneous transmissions of downlink point-to-point signal and double broadcast services, all based on a DPMZM.

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