WDM Optical Colorless Millimeter-wave Up-Conversion Using Frequency Quadrupling

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Abstract

A novel all optical WDM up-conversion system using frequency quadruple technique is proposed. The proposed system can be utilized in the future 60-GHz band WiMAX RoF system.

Introduction

With the increasing of the desire for bandwidth in wireless communication, optical millimeter-wave generation and up-conversion become an issue of great importance in radio-over-fiber (RoF) systems [1]. Many ideas are proposed to achieve this function. Among these ideas, the simplest and most cost-effective choice of optical millimeter-wave generation is to use optical external modulators.

Recently, millimeter-wave generation schemes with frequency three or four times of the driving signals have been demonstrated [2, 3]. By using these frequency tripling and quadrupling technique, optical millimeter-wave signals beyond 40 GHz can be generated easily using low frequency RF components and electrical driving signals. Nevertheless, these proposed systems need either two cased external modulators [2] or more than one narrowband optical filter, which increase system complexity and hinder the implementation of optical up-conversion in wavelength-division–multiplexer (WDM) RoF system.

In this paper, an optical WDM up-conversion system using frequency quadrupling approach has been experimentally demonstrated. 4 × 1.25 Gb/s optical carrier suppressed (OCS) WDM signal are generated and up-converted to 20 GHz simultaneously using only one external modulator and 5-GHz electrical driving signals. No narrowband optical filter is needed to eliminate undesired carrier or sidebands. The optical carrier suppression ration (OCSR) of the generated millimeter-wave signal in each channel is higher than 30 dB. After transmission of 50 km standard single mode fiber (SSMF), the power penalty is less than 0.5 dB. Since only one external modulator and low frequency RF components are employed, the proposed scheme can provide a cost-effective solution for the all optical WDM up-conversion system.

Concept and Theoretical Analysis

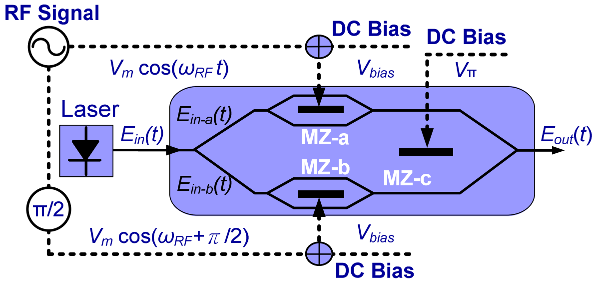

Fig. 1 Conceptual diagram of the optical millimeter-wave signal generation using frequency quadrupling without optical filtering.

The key of the proposed system is an optical millimeter-wave signal generation using frequency quadrupling technique and no filtering which employs a commercial integrated Mach-Zehnder modulator (MZM) [4]. Conceptual diagram is illustrated in Fig. 1. Assume the optical field of input signal is

$$E_{in}(t) = E_o \cos(\omega_o t)$$

Where E_o denotes the amplitude of the optical field and ω_o indicates the angular frequency of the optical carrier. The integrated MZM is composed of three sub-MZMs. One sub-MZM (MZ-a or MZ-b) is embedded in each arm of the main MZM (MZ-c). For frequency quadrupled optical millimeter-wave generation, MZ-a and MZ-b are both biased at the maximum transmission point. Electrical driving signals sent into MZ-a and MZ-b are $V_a(t)=V_m\cos(\omega_{RF}t)$ and $V_b(t)=V_m\cos(\omega_{RF}t+\frac{\pi}{2})$, respectively. Where ω_{RF} indicates the angular frequency of the electrical driving signal. In addition, MZ-c is biased at the null point which introduces 180° phase shift between the optical output signals of MZ-a and MZ-b. Therefore, the output optical field of the integrated MZM can be expressed as

$$E_{out}(t) = -E_o\{J_2(m)\cos[(\omega_o + 2\omega_{RF})t] + J_2(m)\cos[(\omega_o - 2\omega_{RF})t]\}$$

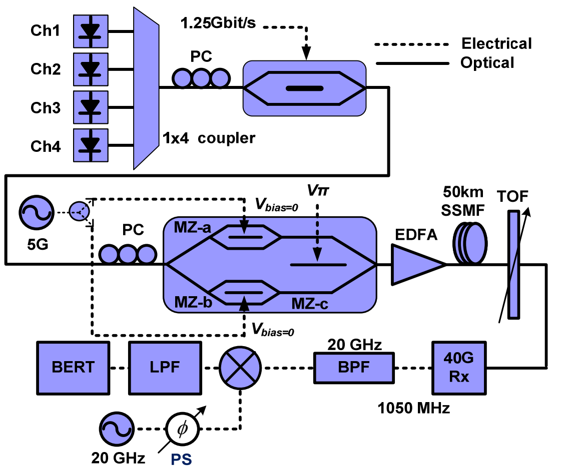

Fig. 2 Experimental setup of the WDM up-conversion system using frequency quadrupling.

where the phase modulation index m is $\pi V_m/2V_\pi$ and J_2 denotes the Bessel function of the first kind of order 2. After square-law detection using a photo diode, only the photocurrent with RF frequency four times of the electrical driving signal ω_{RF} will be observed.

Experimental Setup and Results

Fig 2 illustrates the experimental setup of the frequency quadrupled WDM up-conversion system. Four DFB lasers are used to achieve 4 wavelength signals from 1544.53 to 1546.92 nm with 100-GHz channel spacing. A 1x4 optical coupler is used to combine these four CW lasers. After the optical coupler, the CW lightwaves are modulated via a single electrode MZM driven by 1.25-Gb/s pseudo random bit sequences (PRBS) electrical signal with a word length of 2^{31}-1.

All channels of the WDM signals will be up-converted simultaneously after the integrated MZM. The up-converted WDM optical millimeter-wave signals are then amplified by an EDFA before they are transmitted over 50-km SSMF. At the remote node, a tunable optical filter (TOF) with 0.3 nm bandwidth is utilized to select the desired channel. The RF millimeter-wave signals are received by a photo receiver and down-converted to baseband. The down-converted signals are analyzed by a BER tester.

Fig. 3 shows optical spectra of WDM baseband (BB) OOK signals and up-converted OCS millimeter-wave signals. Only 2nd order optical sidebands are observed and the OCSR is higher than 30 dB using the proposed frequency quadrupling technique. Fig. 4 demonstrates the BER curves of the received 1.25-Gb/s OOK signals at 0 km and following 50-km SSMF transmission. The insets show the back to back and transmitted eye diagrams of RF millimeter-wave signals. The power penalty of the down-converted RF signals at 0 km and following 50-km transmission each channel are less than 0.5 dB.

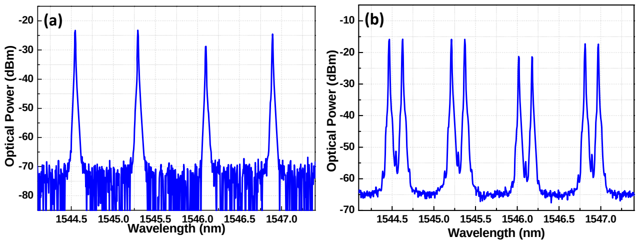

Fig. 3 Optical spectra of (a) WDM BB signals and (b) WDM up-converted signals.

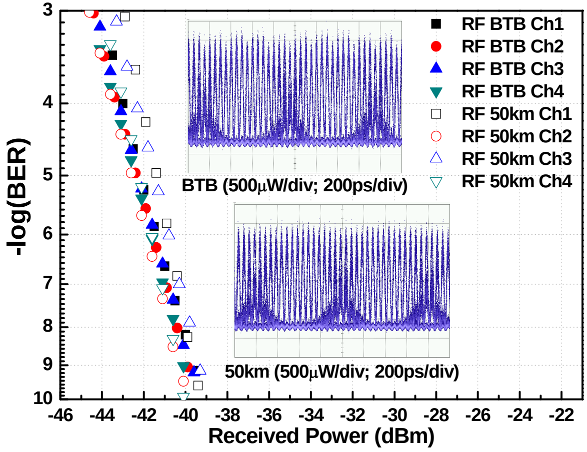

Fig. 4 BER curves and millimeter-wave signals of the back to back (BTB) and transmitted signals.

Conclusion

In this paper, an all optical WDM up-conversion system using frequency quadruple technique has been experimentally demonstrated. Only one commercial integrated MZM and no optical filter is employed. 4 × 1.25 GB/s BB WDM signals are up-converted to 20 GHz simultaneously using only 5-GHz electrical driving signal and RF components which significantly reduce the cost of the entire system. The OCSR of the generated optical millimeter-wave signal is higher than 30 dB which is more than enough for typical communication applications. Restricted by the receiver system in our laboratory, only 20-GHz signals are analyzed in this paper. However, 60-GHz OCS optical millimeter-wave signal can be easily achieved form 15-GHz electrical driving signal by using the demonstrated scheme. In summary, the proposed system provides a cost-effective, high receiver sensitivity and small power penalty choice for WDM up-conversion in the future 60-GHz band WiMAX RoF system.

References

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