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Palm-Shaped Optical Spectrum Generation for Fiber-Wireless Integrated Communication with Dual-Band Millimeter Wave Capability

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Abstract: We proposed and demonstrated a simple cost-effective palm shaped spectrum generation based on DPMZM in order to simultaneously generating dual-band MMWs and optical carrier, offering an alternative in integration of fiber and wireless communication in indoor and inter-building environments.

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1. Introduction

Millimeter-wave (MMW) frequency band is being considered for broad-band wireless access systems in order to avoid spectral congestion at lower frequencies. In the upcoming fifth-generation (5G) era, there exist all kinds of possibilities in standards and available bands. Among all those potential communication bands, 60-GHz and 120-GHz bands attract much attention. Generally, 60-GHz link is employed for indoor communication environment such as homes and small offices while 120-GHz millimeter wave wireless link has emerged as an affordable alternative solution for inter-building transmission like conference centers and hotels. High speed wireless communication system working at 60-GHz has been proven feasible [1]. 120-GHz MMW wireless link capable of 10-Gbit/s data was introduced in 2004 [2]. For the generation of such high MMW frequencies with data encoded, optical solution using fiber optical technology is quite promising due to electronic bottleneck in electrical devices. Traditionally, external modulation [3], remote heterodyning [4] and up-conversion approaches based on nonlinear effects [5] are mostly employed for generating radio frequency waves over fiber. Direct modulation is the simplest method but limited by the modulation bandwidth. Heterodyning technique requires relatively complex structure. Although nonlinear methods loosen the requirements for the input power, the complicated structure and high cost of the special fiber hinder its application. Meanwhile, it's difficult to generate dual-band MMW carriers (60-GHz and 120-GHz) simultaneously in single system. In this paper, we proposed a feasible scheme of generating palm shaped spectrum offering wired transmission and wireless communication on two MMW bands (60GHz & 120-GHz) simultaneously. We performed a 2.5-Gb/s data transmission via 25-km standard single-mode fiber (SMF) to validate the downstream performance of the central optical carrier. Furthermore, the simplified scheme is experimentally performed to investigate the feasibility of the whole system.

2. System configuration

The experimental set up is schematically illustrated in Fig. 1. Distributed feedback (DFB) laser and a dual-parallel modulator (DPMZM) are used to generate the optical palm. Microwave signal with the frequency f_m is produced by the RF source and split by a 50:50 power splitter (PS). Both arms of the DPMZM are driven by the signal. By adjusting the direct current (DC) voltage applied on the lower arm Mach-Zehnder modulator to the maximum point of its transmission curve, the output of the lower arm could be written as:

$$E_{out1}(t) = |E_{in}| * \{J_0(m_1) \cos(\omega_0 t) + J_2(m_1) [\cos(\omega_0 + 2\omega)t + \cos[(\omega_0 - 2\omega)t]]\} \quad (1)$$

Two second order sidebands apart from the central carrier are excited with $4\pi\omega$ frequency spacing.

At the same time, the upper arm is managed to be working at the lower part of the transmission curve produce 3 spectral lines with the frequency spacing f_m . The output optical field is denoted as:

$$E_{out2}(t) = |E_{in}| * \{J_0(m_2) \cos(\omega_0 t) + J_1(m_2) [\sin(\omega_0 - \omega)t + \sin(\omega_0 + \omega)t]\} \quad (2)$$

As a result, the optical output from both arms are combined and a superimposed palm shaped spectrum is obtained in which the middle finger can be used as the downstream optical signal carrier and the other four fingers are to be employed to generate MMW at frequencies of $2f_m$ and $4f_m$, respectively.

Fig. 1: Generation scheme of the palm shaped spectral and the spectrum evolution in generating the MMW. CW: continuous wave, OC: optical coupler, DC: direct current, PS: power splitter, PS: phase shifter, FBG: Fiber bragg grating, BSF: band stop filter, PD: photo detector, SMF: single mode fiber.

Two FBGs are used to separate the corresponding sidebands and the central carrier. Photodiodes (PDs) were employed to implement optical-to-electrical conversion to generate 60-GHz and 120-GHz MMW carriers. Upon that, we have established a hybrid wired-and-wireless transmission system that offers not only large capacity fiber communication to the user but also the high speed next generation in-door and out-door MMW communication links.

The reason why we choose palm instead of comb is as follows: Firstly, the comb generation by DPMZM requires one of the arms biased at the null point that will definitely reduce the total power of output and it will not be feasible for the tight power budget in access network applications. Secondly, to keep the comb flat, strict condition between m_1 , m_2 and ω_0 has to be satisfied which leads to inconvenience in real applications. The larger optical power of central carrier and flat sideband appeared in the palm spectrum will benefit fiber transmission and MMW generation, respectively.

3. Experimental setup and results

In this experiment, due to the facility limitations, we employed a WSS instead of the FBGs to select corresponding sidebands for MMW generation. As a proof of concept, we choose the f_m as 20-GHz thus the frequency spacing of four fingers are 40-GHz and 80-GHz, respectively. Two first-order sidebands are selected by the WSS to conduct the MMW generation by using the photomixing in a 43-GHz PD and monitored with a 40-GHz electrical spectrum analyzer.

As shown in Fig. 2, a CW light was generated by a tunable DFB laser at 1550.5nm with less than 100 kHz linewidth and was modulated by a DPMZM. A 20-GHz RF source was applied and was divided by a 50:50 power splitter to drive both arms of the DPMZM.

Fig.2: Experiment scheme of the dual-band MMW generation. WSS: waveshaper, PD: photo detector, ESA: electrical spectrum analyzer.

By tuning the bias voltage of DPMZM according to eq. (1) and (2), a central wavelength line with larger power is generated together with flattened first and second order sidebands, as shown in Fig. 3 (a). After an EDFA and a WSS, two first order sidebands are extracted with the optical extinction ratio larger than 35 dB, as shown in Fig. 3(b). The photomixed output is displayed in the ESA and Fig. 3(c) shows the measured MMW signal spectra in the full spectral range of 43 GHz. A clear and stable 40-GHz carrier frequency can be observed with more than 40 dB side mode suppression ratio (SMSR). In Fig. 3(d), the analyzer is set to 10-Hz resolution bandwidth with a span range of 10 KHz. The measured phase noise of the generated MMW is -92 dBc/Hz.

Fig.3: Optical spectrum of generated palm (a) and filtered two first order sidebands (b). Electrical spectrum of the down converted MMW in 43-GHz band (c) and 10-KHz (d).

For the evaluation of down link transmission using the central optical carrier, On-off-keying (OOK) transmission on the optical carrier is implemented as the scheme shown in Fig.4. 2.5-Gb/s pseudorandom-bit-sequence (PRBS) electrical signal with a word length of $2^{15}-1$ has been modulated on the palm via a Mach-Zehnder (M-Z) modulator. Fig.5 (a) shows the spectrum of the generated palm. After EDFA and 25 km SMF transmission, a tunable optical filter (TOF) is used to diminish the side bands and suppress amplified spontaneous emission (ASE) noise. The 3 dB bandwidth of TOF is set to 0.2 nm. Sampling oscilloscope is employed to detect the eye-diagram after filtering. Filtered central carrier spectrum and detected eye-diagram is shown in Fig.5 (b). The eye is widely open due to the large optical extinction ratio of 41.2 dB.

Fig.4: Modulation and transmission scheme of the central optical carrier of the palm

Fig.5: Optical spectrum of generated palm (a) and comb (c) demodulated optical carrier and eye-diagram of palm (b) and comb (d) after 25km communication.

To make a comparison, we adjust the bias voltage of the DPMZM in order to generate a flat, we adjust the bias voltage of the DPMZM in order to generate a flat comb and repeat the transmission experiment as in the palm case. The spectrum and eye-diagram is shown in Fig.5 (c) and (d). Degraded eye-diagram is observed because of the smaller variation between the central optical carrier and sidebands.

4. Conclusions

We have proposed a novel scheme of generating dual-band MMW and optical signal based on a single DPMZM. This methodology is a simple and cost-effective solution for the integration of wired and wireless access networks, offering the next generation wireless access communication of indoor (60-GHz) and inter-building (120-GHz) environments. Proof of concept experiment was implemented to demonstrate the feasibility of the proposed scheme. The palm shaped spectra generated via DPMZM was utilized to simultaneously produce MMW of double and quadruple of the driving frequency. 2.5 Gb/s OOK transmission on the central optical carrier with 25-km SMF was also implemented to compare the downstream transmission performance using our proposed palm line and the traditional comb line. Palm shaped system takes the advantages of larger signal power and higher optical extinction ratio and demonstrated improved transmitted eye-diagram. The proposed palm-shaped spectrum based system is thus promising for the next generation fiber-wireless converged system with multiple functionalities.

5. Acknowledgements

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