Linearity Performance of Optoelectronic Frequency Down-conversion by Using Dual-series Polarization Modulator

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Abstract

We proposed and demonstrated a RF-to-Digital photonic link for relaying microwave signals over an optical fiber and linear converting the microwave signal to digital domain. The system uses two cascaded polarization modulators to achieve microwave-optoeletronic mixer. Two parallel polarization controllers (PC) and polarization beam splitter (PBS) are connected to the output of receiver PolM in order to realize I/Q intensity demodulation. We further show that by simply merging the coherent demodulation with DSP, the dynamic range of the system is significantly improved to 112dB-Hz$^{2/3}$ at 14 GHz. In this scheme, the fluctuation of optical phase noise has no impact on the stable performance of the system.

1. Introduction

The ideal RF digital receiver converts, without distortion or loss of bandwidth, the information encoded on an RF or microwave carrier to the digital domain. For many communication and RF sensor system applications requiring high dynamic range, this necessarily involves a down-conversion of the information on a microwave signal to an intermediate frequency suitable for input to available high dynamic range electronic digitizers [1].Compared to conventional microwave mixer, photonic technology can provide significant advantages in the areas of bandwidth, propagation loss, and immunity against electromagnetic interference.

Unlike intensity modulators, phase modulators allow an electrical signal to vary the phase angle of an optical carrier in a linear fashion and does not need for bias control circuitry at the transmitter. Recently, phase modulation has attracted more attention for all optical down-conversion applications [2]. Phase-modulation/digital-demodulation link emerges as a new class of APL [3,4]. However, the optical phase noise sensitivity is the primary issue in these phase-modulation link.

In this research, we show that by using two cascaded polarization modulators, a down-converted signal can be produced at the difference frequency. At the receiver, two parallel polarization controllers (PC) and parallel polarization beam splitters (PBS) are used to realize I/Q intensity demodulation of optical polarization encoded information. Because the frequency down-conversion is accomplished through EO mixing, the received coherent signals can be digitized with high-resolution analog-to-digital converters (ADC). Finally, we merge the coherent demodulation of optical phase encoded information with digital signal processing to achieve linear optoelectronic mixer.

2. Principle

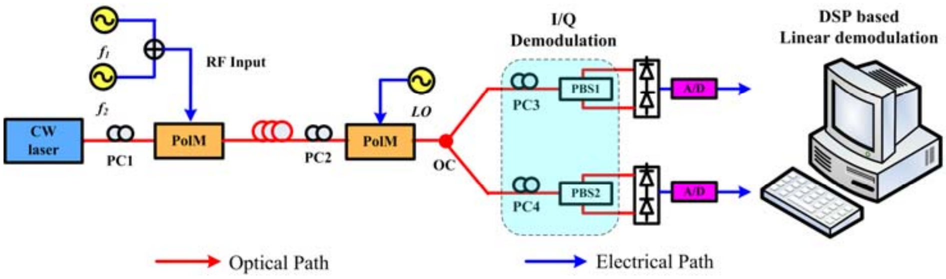

Fig. 1. Schematic diagram for the intensity-modulation I/Q-demodulation photonic link based on polarization Modulators. Components are as follows. PC: polarization controller; PolM: polarization modulator; OC: optical coupler; PBS: polarization beam splitter; I/Q: in-phase/quadrature; A/D: analog–digital converter; DSP: software digital signal processing.

The schematic of our scheme is shown in Fig. 1. A linearly polarized light wave from the CW laser source is sent to the transmitter PolM. The polarization state of the incident light is rotated at an angle of 45° to one principal axis of the PolM using PC1. The output of transmitter PolM is then transmitted over an optical fiber to the second modulator. PC2 is connected at the input of the receiver PolM, which adjusts the polarization direction of the light wave to have an angle of 45° to the principal axis of the PolM. The pair of serially cascaded modulators are driven by a microwave input signal and a strong microwave LO tone, respectively. Following the second modulator, the light is then split into two lights by a 3-dB optical coupler (OC). Each channel contains a PC and PBS. The PBS is connected to the PolM via a PC, which is equivalent to a dual-output-port intensity modulator. Mathematically, the optical intensity field at the output ports of the PBS can be expressed as:

$$P = \frac{P_{\text{in}}}{2}\left[1 \pm \cos\left(\varphi_{\text{sig}} - \varphi_{LO} + \varphi_{bias}\right)\right], \tag{1}$$

where P_{in} is the optical power at the input to the modulator, $\varphi_{sig}=\pi\bullet V_{sig}(t)/V_{\pi}((f_{sig}$), $\varphi_{LO}=\pi\bullet V_{LO}(t)/V_{\pi}$ (f_{LO}), $V_{sig}(t)$ and $V_{LO}(t)$ represent the time-varying signal voltage and LO signal applied on the modulators, responsivity, V_{π} is the RF half-wave voltage of the modulator, and φ bias is a static phase term introduced by PC. By choosing via tuning the PC in each channel, each is optically biased to produce the desired transfer functions. Thus, the coherent I/Q-demodulation signals can be obtained:

$$I_I = RP_{\text{in}} \cos\left[\varphi_{\text{sig}} - \varphi_{LO}\right], \tag{2}$$

$$I_Q = RP_{\text{in}} \sin\left[\varphi_{\text{sig}} - \varphi_{LO}\right], \tag{3}$$

where R is the responsivity of the photodiode. The detected photocurrents are digitalized separately by ADC. Finally, the sampled in-phase and quadrature signals are later processed in the software domain by using DSP which is described in the following. Using Eqs (2) and (3), we can form the complex quantity as $K(t)=\kappa\bullet I(t)+j\bullet Q(t)$,where κ is calibration factor for a path amplitude imbalance and I/Q products conversion loss imbalance. The phase-encoded signal can then be linear demodulated from the phase angle of the complex quantity *K(t)* to recover the analog signal $\theta_{sig}(t)=arg[K(t)]$.There has no small signal approximation and the quantity contains all of the information required to perfectly demodulate the phase encoded data through the relation.

3. Experimental Results and Discussion

An experiment is performed based on the setup shown in Fig. 1. A CW laser with 1550nm wavelength and 20dBm optical power is sent to the PolM. Polarization controller sets the polarization of the CW laser at 45º with the principal axis of the PolM. Two-tone analog probe signal (14.009GHz and 14.010GHz) is applied to the PolM at the transmitter. At the receiver, the second modulator serves as a mixer and places a local oscillator tone at frequency 14 GHz on the RF-modulated optical carrier. When this compound spectrum is incident on a square-law PD, an output signal is produced at the intermediate frequency of 9 MHz and 10MHz. The key device in the proposed system is the coherent optical receiver, which consists of two parallel PCs and PBSs in each two paths. The I/Q products are detected with separate balanced PD (U2T BPDV2120R), and then digitized by using a 14-bit, 100-MSPS two-channel card.

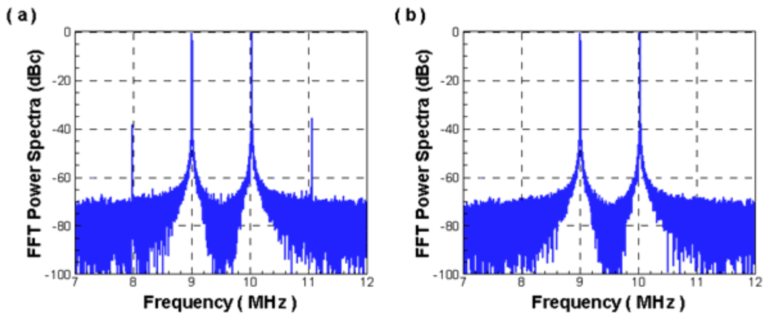

Fig. 2. The FFT spectra for a two-tone test. (a) quadrature signal only, (b) I/Q demodulated signal.

Figure 2(a) corresponds to the power spectrum of the phase demodulation using only Q-photocurrent and shows the dominant third order distortion products due to the nonlinear transfer function of the sinusoidal demodulation. Evidently, the IMD3 products of quadrature signal are clearly visible at frequencies of *8MHz* and *11MHz*. The nonlinear distortions could be as high as -40dBm. Fig. 2 (b) depicts the FFT power spectra of DSP based I/Q-demodulated signal for optimal linearity, where both Q- and I-photocurrents are used. The linearization technique shows that nonlinear distortions can be suppressed to below noise floor. Thus, the suppression of IMD3 by more than 30 dBc is obtained.

In Fig. 3, we plot the IF output power and IMD3 power as a function of the RF input power applied to the modulator. As expected, the output tone and IMD3 power increases with the input signal power. The received photocurrent is 2mA and the total receiver output noise is measured to be -164.4dBm/Hz. The largest contribution to the output noise is shot noise. It can be seen that the linearized system improves the Spurious Free Dynamic Range (SFDR) from 102.7dB-Hz$^{2/3}$ to 112.6dB-Hz$^{2/3}$.

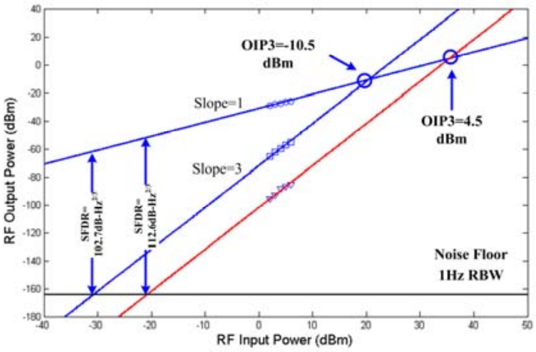

Fig. 3. IF output power versus RF input power for linearized microwave photonic link with optical down-conversion to intermediate frequency.

4. Conclusion

In this paper, we have experimentally investigated a RF frequency down-conversion system that employed two cascaded polarization modulators followed by DSP based in-phase/quadrature (I/Q) demodulation device for linear frequency down-conversion. The linearization leads to suppression of the third order intermodulation (IMD3) by more than 30dBc and improvement of spurious-free dynamic range (SFDR) by approximately 10dB compared to the nonlinearization case. Due to the Polarization-domain interferometer, the phase noise of the laser have no impact on the coherent I/Q signals. There is no need to track phase fluctuations via piezo fiber stretcher to equalize the reference and signal optical path. In addition, the other advantage of the link is that only one optical fiber is used compared to I/Q phase demodulation schemes, which can realize easier distribution of RF signals over long distances.

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