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Published in:
Proceedings of the European Conference on Optical Communication (ECOC) 2011

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Zhao, Y., Pang, X., Deng, L., Yu, X., Zheng, X., Zhang, H., & Tafur Monroy, I. (2011). Digital Predistortion of 75-110GHzW-Band Frequency Multiplier for Fiber Wireless Short Range Access Systems. In Proceedings of the European Conference on Optical Communication (ECOC) 2011 (pp. Tu.5.A.3). Optical Society of America.

Digital Predistortion of 75-110GHz W-Band Frequency Multiplier for Fiber Wireless Short Range Access Systems

Ying Zhao[1,2†], **Xiaodan Pang**[2], **Lei Deng**[2,3], **Xianbin Yu**[2], **Xiaoping Zheng**[1‡], **Hanyi Zhang**[1] **and I. Tafur Monroy**[2]

[1]*Department of Electronic Engineering, Tsinghua National Laboratory for Information Science and Technology,*
Tsinghua University, 100084 Beijing, China.
[2]*DTU Fotonik, Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark.*
[3]*School of Optoelectronics Science & Engineering, HuaZhong Univerity of Science & Technology., Wuhan, China.*
†yinzh@fotonik.dtu.dk ‡xpzheng@mail.tsinghua.edu.cn

Abstract: We present a digital predistortion technique to effectively compensate high nonlinearity of a sextuple multiplier operating at 99.6GHz. An 18.9dB adjacent-channel power ratio (ACPR) improvement is guaranteed and a W-band fiber-wireless system is experimentally investigated.

OCIS codes: (060.4510) Optical communications, (060.5625) Radio frequency photonics, (350.4010) Microwaves.

1. Introduction

The Federal Communications Commission (FCC) has opened the commercial use of spectra in the 71-75.5GHz, 81-86GHz, and 92-100GHz bands [1], which are recommended for ultra high-speed fiber-wireless access and broadband millimeter-wave (MMW) applications [2]. Generally, costly wideband active devices such as unitraveling-carrier photodiode and W-band power amplifier are necessary for Radio-over-Fiber (RoF) transmission system within these bands. By introducing a frequency multiplier functioning as a frequency translator in the receiver of the fiber link, the bandwidth requirements, the power consumption and the complexity of the receiver can be significantly decreased. Since frequency multiplier is highly nonlinear device, predistortion is of great use to compensate the multiplying nonlinearity and obtain correct digital modulation information after frequency translation. By performing baseband signal transformation in the digital domain, predistortion takes into account modifications of multiplier input signals to counteract the distortion that arises from gain compression (AM-AM distortion) and phase deviation (AM-PM, PM-PM distortion). In this way, the distortion of the upconverted signals output from the multiplier is consequently suppressed.

Digital predistortion technique is usually applied to linearize the power amplifiers in modern mobile base stations and frequency doublers in dual-band RF front-end systems [3]. In MMW regime, predistortion technique for up to 77GHz [4] power amplifiers was reported. In this paper, we present and demonstrate a digital predistortion scheme applied to a 75-110GHz W-band sextuple frequency multiplier. The scheme is based on a QPSK training sequence and recursive least squares (RLS) algorithm. Furthermore, a 99.6GHz fiber-wireless system with QPSK transmission over 26km fiber and up to 4m wireless distance is built to validate our proposed digital predistortion scheme. An 18.9dB adjacent-channel power ratio improvement after predistortion for QPSK signals at 99.6GHz is successfully achieved. The bit error rate (BER) performances of fiber and wireless channels are investigated, respectively.

2. Principle

When a bandpass waveform is fed to a frequency multiplier, its output contains the harmonic and intermodulation components of the desired order. Consider a n-order frequency multiplier whose output $Y(t)$ can be expressed by

$$Y(t) = Re\{A[r(t)]e^{j\left[n\omega_0 t + n\cdot\varphi(t) + P[r(t)]\right]}\} \tag{1}$$

where $r(t)$ and $\varphi(t)$ are the amplitude and phase of the complex baseband input signal and ω_0 is the carrier frequency. In general, the distortion arising from the frequency-multiplication process can be partly represented by polynomial functions $A[\cdot]$ and $P[\cdot]$, which are corresponding to nonlinear AM-AM and AM-PM distortion. Another distortion applying n times of $\varphi(t)$ phase deviation is called PM-PM distortion. To counteract the baseband distortion, digital transformation of input complex signal needs to be implemented as an inverse model of the frequency multiplier distortion. As shown in the inset (a) of Fig.1, the digital predistortion processing is achieved based on two parallel iterative loops, one of which is for amplitude distortion and the other serves for phase deviation. Since the influence of the multiplier can be represented by polynomial-based functions, we can extract the coefficients of $A[\cdot]$ and $P[\cdot]$ by pre-measurement of AM-AM and AM-PM distortion [5]. Then based on the known distortion characteristic of the multiplier, adaptive and robust algorithm can be adopted to derive the predistortion function, in other words, the

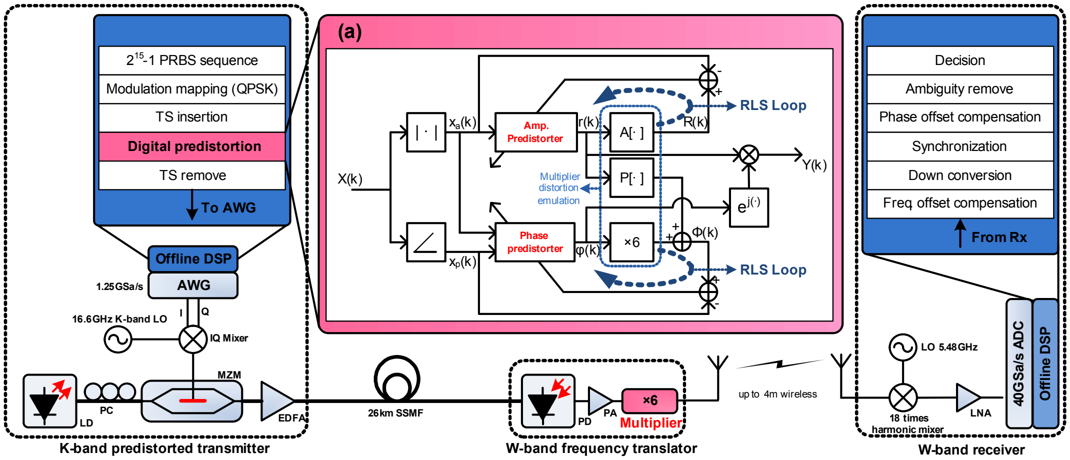

Fig. 1. Experimental setup of a digital predistorted W-band wireless access system. Inset: **(a)** offline digital predistortion for the sextuple frequency multiplier. PA: power amplifier. LNA: Low noise amplifier.

inverse characteristic of the multiplier. In our system, RLS algorithm based on QPSK training sequence is applied to make the iterative loop converge to the inverse property of the multiplier distortion.

3. Experimental setup

Based on the digital predistortion for Agilent E8257DS15 sextuple frequency multiplier, we construct the experimental setup of a W-band fiber-wireless system, as shown in Fig.1. At the transmitter side, offline digital signal processing (DSP) is performed by MATLAB to generate the predistorted QPSK baseband signal, which is stored in a 1.25GSa/s arbitrary waveform generator (AWG). A transmitted data stream consisting of PRBS with a length of $2^{15}-1$ is mapped to a symbol sequence with QPSK modulation. 1000 training symbols for predistortion and another 100 symbols for synchronization are inserted at the beginning of the symbol sequence, forming the predistortion input sequence $X(k)$. As shown in the inset (a) of Fig.1, the amplitude part $x_a(k)$ and the phase part $x_p(k)$ of sequence $X(k)$ are extracted and the first 1000 symbols are used to drive the predistorters for amplitude RLS loop and phase RLS loop. Both predistorters are 4-term polynomials so that the 8 coefficients are updated with the algorithm iterations. By combining the loop outputs $r(k)$ and $\varphi(k)$, the predistorted complex baseband signal $Y(k)$ is obtained. After removing the training sequence of the predistortion, the predistorted baseband time waveform is mixed with a 16.6GHz K-band local oscillator (LO) in an IQ modulator. The upconverted signal then is modulated on an optical carrier at 1549.3nm by a Mach-Zehnder modulator (MZM). The optical signal is launched into a 26km standard single mode fiber (SSMF) and then translated to a 96.6GHz W-band wireless signal after frequency multiplication in the multiplier. Subsequently, the signal is radiated through up to 4m wireless distance using a pair of W-band hone antennas. At the receiver side, the signal is mixed with the 18^{th} harmonic of a 5.48GHz LO in a 18-order harmonic mixer (Agilent 11970W) to be downconverted to 960MHz. The bandwidth of the harmonic mixer is ~600MHz, which is the main limitation to achieve higher data rate. The downconverted signal is digitalized with a 40GSa/s digital oscilloscope and the waveform is processed offline for demodulation. In the digital domain, frequency offset compensation, digital downconversion and synchronization are performed followed by QPSK phase offset compensation and ambiguity resolving. Finally, the BER is obtained by using direct error counting of 2×10^5 bits.

4. Experimental results

Fig.2(a) shows the demodulated QPSK constellation in the receiver and the predistorted QPSK constellation in the transmitter. For the received constellation, it qualitatively shows a good magnitude uniformity and angle orthogonality, which implies the effectiveness of the digital predistortion for high-order frequency multiplier. The confined predistorted clusters in a limited area verify the inverse characteristic of the predistorter. Fig.2(b) shows the measured 312.5Mb/s QPSK spectra in the transmitter with and without predistortion. We can see that without the predistortion, the signal is spread over 500MHz and it is impossible to be demodulated due to the intermodulation distortion in the multiplier. With the digital predistortion, the ACPR quantitatively performs an 18.9dB improvement at 312.5MHz offset from the center frequency. We expect this improvement can be increased by treating more terms in the polynomial predistorters. Fig.3 shows the transmission performance of the fiber-wireless system. The measured BER curves against the optical power before PD for fixed 1m wireless transmission distance are shown in Fig.3(a). There is a ∼0.25dB negligible power penalty after 26km fiber transmission at a BER of 2×10^{-3} (FEC limit), and 0.3dB power penalty appears when increasing the data rate from 312.5Mb/s to 625Mb/s due to the bandwidth limitation of the harmonic mixer. Fig.3(b) shows the BER curves versus the wireless transmission distance while the optical power after fiber transmission is fixed at -10dBm. To keep the BER below the 2×10^{-3} threshold, the maximal wireless distances for 312.5Mb/s and 625Mb/s are 3.25m and 2m, respectively.

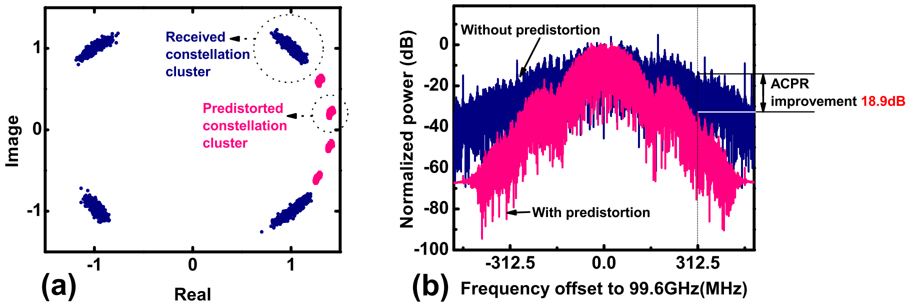

Fig. 2. Digital predistortion performance. **(a)** QPSK constellation after predistortion (red) and at the receiver end (blue). **(b)** QPSK spectrum with (red) and without (blue) predistortion.

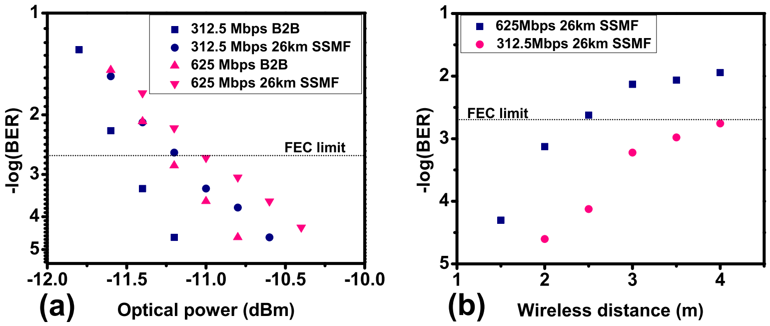

Fig. 3. 99.6GHz fiber-wireless transmission system performance after predistortion. **(a)** BER vs optical power before the PD. **(b)** BER vs 99.6GHz wireless transmission distance. FEC: forward error correction.

5. Conclusions

We have presented a digital predistortion scheme applied for high order W-band frequency multiplier. The experiment demonstrated a 99.6GHz fiber wireless system without using costly wideband PD and amplifier. An 18.9dB ACPR improvement confirmed the capability of the proposed predistortion scheme to counteract nonlinear distortion in the W-band broadband wireless short range access systems.

6. Acknowledgements

This work was supported in part by National Nature Science Foundation of China (NSFC) under grant No. 60736003, 61025004, 61032005 and National 863 Program under grant No. 2009AA01Z222, 2009AA01Z223.

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