 

# RF Fading Circumvention Using a Polarization Modulator for Supporting W-Band RoF Transport from 85 to 95 GHz

**Run-Kai Shiu[1,2], Shang-Jen Su[2], You-Wei Chen[2], Qi Zhou[2], Justin Chiu[1], Guan-Ming Shao[1], Li Zhao[2], Peng-Chun Peng[1,*], and Gee-Kung Chang[2]**

*1.Department of Electro-Optical Engineering, National Taipei University of Technology, Taipei, Taiwan.*
*2.School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia, USA.*
*[*]pcpeng@mail.ntut.edu.tw*

**Abstract:** RF fading in an RoF system is circumvented by managing the frequency notch through the control of a polarization modulator. W-band signals centralized at 90 GHz with 10GHz operation bandwidth are fully utilized with stable EVM performance.
**OCIS codes:** (060.2330) Fiber optics communications; (250.4110) Modulators.

## 1. Introduction

Along with the rising demand for high-quality media applications, i.e., 8K streaming, the transmitted data rate of wireless broadband services becomes a crucial requirement on the 5G mobile network [1,2]. However, the conventional wireless spectra of below 6 GHz are already heavily congested. Therefore, the millimeter-wave (mm-wave) frequency bands, namely, 5G new radio (NR), have been considered as additional resources to provide extra bandwidth. In the recently released 3GPP standard, frequency band up to 52.6 GHz, aiming to provide extremely broadband services in the future, is specified by 5G-NR; W-band (75-110 GHz) with lower air absorption loss compared to V-band (45-75 GHz), would be an important RF band to alleviate the problem of bandwidth shortage. To deliver signals at such high-frequencies, photonic-aided radio-over-fiber (RoF) technique, which features a simplified remote radio unit (RRU) design and centralized management with low-latency data transmission, can be applied [3]. One single laser source is employed and driven by a Mach-Zehnder modulator in its carrier suppression mode to generate two coherent lights for carrying the desired W-band signal in the distributed unit (DU). Direct detection can be applied in the receiver-side to keep a simple hardware design of the RRU. However, radio frequency (RF) selective power fading, which is related to the transmission distance and the deliverable RF frequency, would happen. This issue is thus much more severe for high-frequency W-band signal even within a 25-km standard single-mode fiber (SSMF) in the mobile fronthaul, such that many frequency allocations in W-band are forbidden, as shown in Fig. 1. Hence, these forbidden bands cause the waste of valuable frequency resources in W-band. To address this issue, employing an optical bandpass filter to remove the unwanted optical sideband can mitigate the effect of RF fading at the cost of additional optical power loss and system complexity. Whereas, in our previous researches, we have achieved a photonic microwave filter for 27-GHz and 28-GHz mm-wave signals by using a polarization modulator (PolM) to shift the frequency response [4]. By tuning the input light polarization angle to the employed polarizer, the RF frequency response can be easily modified and therefore it hugely increases the available bandwidth in a direct-detected photonic-aided RoF system.

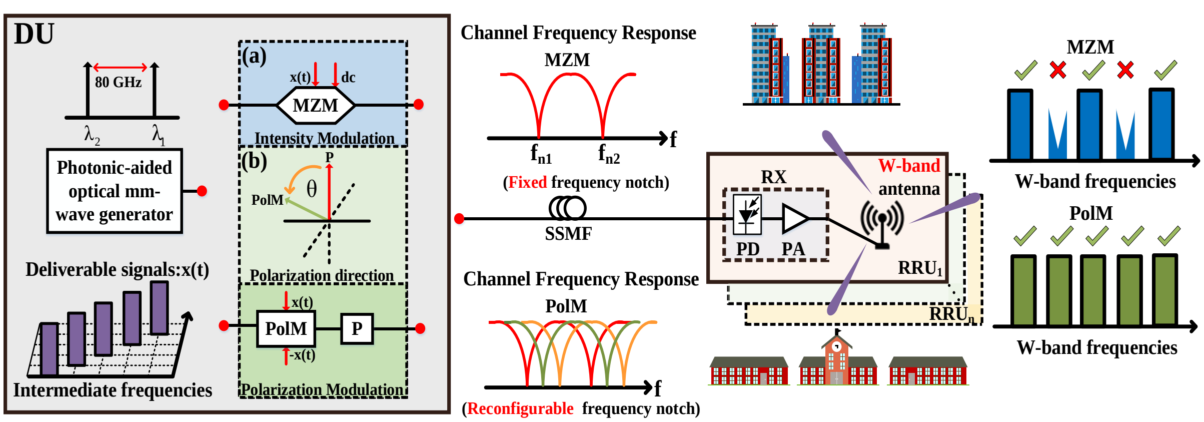


Fig. 1. Schematic diagram of W-band signal generation in an RoF system. DU: distributed unit, MZM: Mach-Zehnder modulator, PolM: polarization modulator, P: polarizer, SSMF: standard single-mode fiber, RX: receiver, RRU: remote radio unit, PD: photodetector.

In this paper, we propose and demonstrate an RF power fading circumvented W-band fiber-wireless convergence system based on a PolM for supporting a 10-GHz wideband operation from 85GHz to 95GHz. The RF frequency notch can be easily managed by a polarization controller, while the desired W-band signals can be arbitrarily assigned to fully explore the available bands. Compared to conventional MZM-based direct detection scheme, the proposed scheme can efficiently increase the usage of bandwidth in W-band.

## 2. Operation Principle

Fig. 1 gives the schematic diagram of the conventional MZM-based and the proposed PolM-based photonic-aided W-band signal generation in a fiber-wireless convergence system. To generate the W-band signal, the photonic-aided optical mm-wave generator, constructed by a laser source and an MZM which is operated in carrier suppression mode, provides optical tones that are separated by the desired frequency spacing, e.g., 80 GHz. For the conventional MZM-based scheme as shown in Fig. 1(a), wireless deliverable signals are up-converted to the intermediate frequencies (IF), and the IF should be arbitrarily assigned to dedicated RRUs or users depending on their requirements. After direct detection by a photodetector (PD), the wireless signals are generated through heterodyne beating and up-converted to the desired W-band frequencies. However, due to the chromatic dispersion, there are periodically RF notches at fn1 and fn2, which are constant frequencies when the transmission distance is fixed. It not only results in forbidden bands for data delivery, but also reduces the network flexibility. On the other hand, in our proposed scheme, we use a PolM to replace the MZM as shown in Fig. 1(b). By aligning the input polarization state at 45 degree to the X-pol axis of PolM, signals are concurrently modulated onto two polarizations, i.e., X- and Y-pol. By tuning the input angle of the successive polarizer, we can manipulate the ratio between the two polarized signal power, and thus manage the channel response [5]. This guarantees the desired W-band signal can always survive from the RF frequency notch in any IF arrangement.

## 3. Experimental Setup

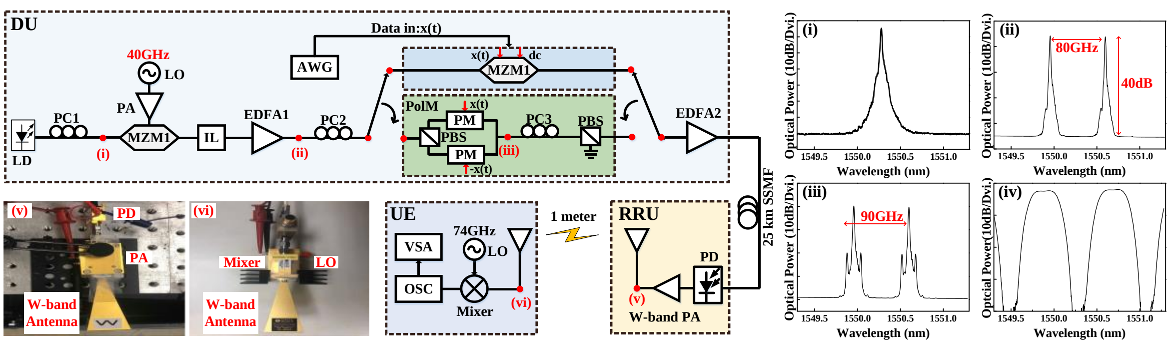


Fig. 2. Experimental setup of the proposed system. (i)-(iii) Measured optical spectra at the corresponding positions. (iv) Measured optical spectrum of the IL. (v) and (vi) are the photos of the W-band devices. LD: laser diode, IL: interleaver, LO: local oscillator, EDFA: erbium-doped fiber amplifier, PC: polarization controller, PBS: polarization beam splitter, AWG: arbitrary waveform generator, UE: user equipment, PA: power amplifier, OSC: oscilloscope scope, VSA: vector signal analysis software.

The experimental setup is shown in Fig. 2. In the DU side, a tunable laser emitted at 1550.27nm with 10dBm output power as shown in Fig. 2(a) is employed. To generate an 80-GHz W-band signal, MZM1 is driven with a 40-GHz RF signal and biased at its null point of 2.42V to suppress the optical carrier. Thus, frequency doubling is achieved and the frequency spacing between two optical tones is 80 GHz. To further suppress the optical carrier, a 50/100 GHz inter-leaver (IL) whose optical transmittance window is measured in the right bottom side of Fig. 2. is employed after the first MZM. With the aid of the IL, the central carrier suppression ratio can reach 40 dB as shown in Fig. 2(b). An EDFA with 13.7-dBm output power is used to compensate for modulation loss. To conduct the comparison of the received signal performance in W-band between the conventional and the proposed scheme, the dual-wavelength optical source is modulated by MZM and PolM, respectively. A PC and a PBS are utilized to replace a polarizer for PolM-based scheme. The testing QPSK signal with 1Gbaud is generated by an arbitrary waveform generator (AWG) with a sampling rate of 65 GSa/s and a bandwidth of 25 GHz. The root-raised cosine filter with the roll factor of 0.35 is applied to the QPSK signal to increase the frequency localization. To evaluate the RF power fading issue, the IF frequency of the QPSK signal is increased from the central frequency of 5 GHz to 15 GHz with an increment of 1 GHz. Before the DU output, an EDFA is employed to boost the optical launch power. After 25-km SSMF transmission, the QPSK-modulated signal is directly detected by a commercial PD and then up-converted to W-band. At RRU, a 35-dB gain W-band power amplifier cascaded with a 25-dBi gain horn antenna is employed to deliver the wireless data. After 1-m wireless transmission, the signals are received by a paired horn antenna and then down-converted to the IF band ranging from 11 GHz to 21 GHz through mixing with a 74-GHz LO. A real-time oscilloscope with a sampling rate of 80 GSa/s is used for analog-to-digital conversion. The received signal performance is then evaluated via the Keysight vector signal analysis (VSA) software with built-in functions to calculate error vector magnitude (EVM) and draw constellation diagrams.

## 4. Experimental Results

The received EVM and constellation diagrams of the conventional MZM-based and the proposed PolM-based scheme are shown in Fig. 3. In the conventional scheme as Fig. 3(a), the received EVM is strongly correlated to the RF power fading and it performs periodical in frequency. The required EVM to meet the FEC threshold of QPSK is 37.5% and thus forbidden bands of 88-90 GHz and 95 GHz are measured with the received optical power of -5dBm in this demonstration. 40% of valuable frequency resource in W-band is restricted and wasted. On the other hand, in the proposed PolM-based scheme, since we can shift the RF fading notch away from the desired signals by rotating the PC3 to change the angle between input polarization direction and the principal axis of the PBS, the received performance can immune from the periodical RF fading. As shown in Fig. 3(b), the measured EVM is relatively flat compared to the conventional scheme and the average EVM is around 12.5% after W-band transmission. The EVM fluctuation is around 6% within the 10-GHz wideband operation ranging from 85 to 95 GHz and the corresponding constellation diagrams are much clearer than the conventional scheme.

To further testify the achievable transmission capacity of the proposed PolM-based structure, QPSK signals with different data rate are carried by a fixed 90-GHz central frequency. The measured EVM curve versus received optical power is shown in Fig. 3(c), and the maximum achievable data rate under the specified FEC requirement is 8 Gb/s. Moreover, under this circumstance, the conventional MZM-based scheme cannot restore the transmitted data even with only 1-Gbaud rate. To make a more convincing comparison, the electrical spectra of 4-Gbaud QPSK signals at 90 GHz of both schemes are measured after down-conversion to 16 GHz as shown in the insets of Fig. 3(c). Severe signal degradation is observed of the MZM-based structure while the signal can be successfully recovered by the proposed PolM-based scheme.

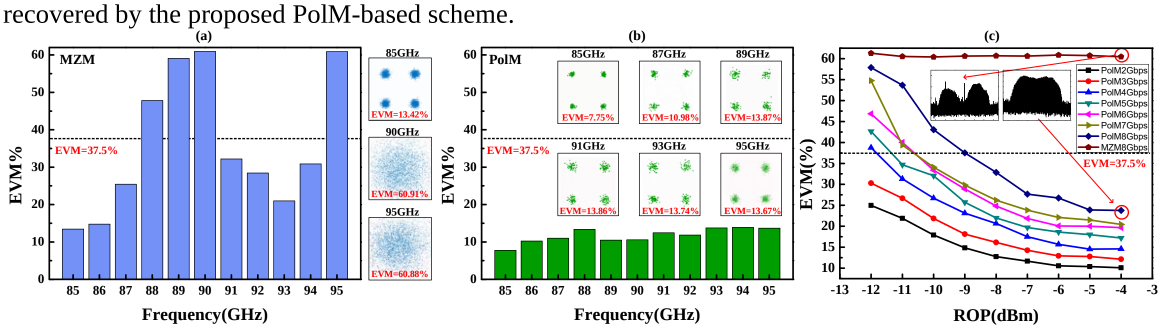


Fig. 3. Measured EVM and constellation diagrams from 85 to 95 GHz of (a) MZM-based structure and (b) PolM-based structure. (c) Measured EVM curve via different received optical power and electrical spectra.

## 5. Conclusion

We propose an RF fading circumvented RoF system based on polarization modulator and successfully demonstrate a 10-GHz widely available frequency range for W-band over 25-km SSMF and 1-m wireless transmission. In contrast to the conventional MZM-based scheme which encounters around 40% forbidden band due to RF fading, the PolM-based system performs stably within the frequency range from 85 to 95 GHz, and the over-the-air measured EVM of 1Gbaud QPSK signal meets the EVM requirement of 12.5%. Furthermore, 8-Gb/s QPSK signal located at 90 GHz is successfully transmitted which satisfies the FEC threshold at a high receiver sensitivity of -9 dBm.

## 6. References


[1] G.-K. Chang, P.C. Peng, “Grand challenges of fiber wireless convergence for 5G mobile data communications [Invited],” Proc. Opto-Electron. Commun. Conf., Jul. 2018.

[2] H. Elsawy, H. Dahrouj, T. Y. Al-Naffouri, M.S. Alouini, “Virtualized cognitive network architecture for 5G cellular networks,” IEEE Commun. Mag., vol. 53, no. 7, pp. 78-85, Jul. 2015.

[3] X. Li, J. Yu, J. Xiao, N. Chi, Y. Xu, “W-band PDM-QPSK vector signal generation by MZM-based photonic frequency octupling and precoding,” IEEE Photon. J., vol. 7, no. 4, Aug. 2015.

[4] R. K. Shiu, S Liu, P. C. Peng, W. C. Tang, S Shen, Q Zhou, and G. K. Chang, “Tunable Microwave Photonic Filter for Millimeter-wave Mobile Fronthaul Systems,” in Proc. IPC 2018. Conf., Sep.2018.

[5] S. Liu, P. C. Peng, L. Huang, C. W. Hsu, H. Tian, G.-K. Chang, “Bandwidth-Enhanced PAM-4 Transmissions Using Polarization Modulation and Direct Detection With a Tunable Frequency Range,” J. Lightw. Technol., vol. 37, no. 3, pp. 1014-1022, 2019.