# 8192QAM Signal Transmission Over 20-m Wireless Distance at W-Band Using Delta-Sigma Modulation

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**Abstract:** We experimentally demonstrate a W-band photon-assisted millimeter-wave transmission system using delta-sigma modulation and envelope detection. The proposed IM/DD-MMW-RoF system can support 8192 QAM signaling over a 20-meter wireless link using DSM while meeting the SD-FEC threshold of $4.2\times10^{-2}$. © 2022 The Author(s)

## 1. Introduction

In the 5G era, ratio over fiber (RoF) and millimeter-wave (MMW) with large available bandwidth and strong signal direction has become a suitable choice for long-distance high-speed communication [1-3]. Ref. [4,5] show the feasibility of MMW long-distance high-speed signal transmission, and the signal transmission distance can reach 4.6 kilometers. However, most existing MMW-RoF schemes use coherent receivers to transmit signals, which is complex and costly [6,7]. IMDD scheme using the envelope detector can not only avoid complex and expensive high-speed mixers, millimeter-wave local oscillators and high-speed DACs to reduce equipment cost, but also avoid the frequency drift caused by the linewidth of the two lasers in the photon-assisted MMW system. [8]. However, IMDD systems using envelope detectors are prone to saturation and are not suitable for multi-level PAM or QAM signal reception. Multi-level PAM or QAM signals are distorted by saturation effects and require complex DSP algorithms. In order to solve this problem, delta-sigma modulation (DSM), which can reduce the signal quantization error and improve the signal-to-noise ratio (SNR), is introduced into the MMW-RoF system [9]. We modulate multi-level PAM or PAM signals into OOK format by DSM to avoid the influence of saturation effect in the process of envelope detection. This method can effectively improve SNR of the signal.

In this paper, we experimentally verify the MMW-RoF system using DSM in IM/DD channel for the first time. On the transmitter side, we use DSM to convert the DMT signal to OOK format, then it is modulated to an 87GHz frequency carrier generated by photon-assisted MMW to transmit over a 20m wireless channel. On the receiving end, the received signal is down-converted by an envelope detector. The 8192QAM signal can be transmitted when it meets the SD-FEC threshold of $4.2\times10^{-2}$.

## 2. Principle and experimental setup

Fig. 1 shows the schematic of the MMW-RoF system using DSM in IM/DD channel device. We use Matlab to simulate the DSM modulator with a modulation order of 4 and an oversampling factor of 10. The original DMT signal becomes an OOK signal after being modulated by DSM. The signal is sent to AWG, its data length is $2^{18}$, and the output voltage is $0.5V_{PP}$. This data sequence then drives the MZM through a 30dB electric amplifier. The MZM operates near the quadrature point. The signal amplitude remains within the linear drive voltage range of the MZM. Two 100kHz linewidth ECLs produce CW lightwaves at 1550 and 1550.7nm with a channel spacing of 87GHz. After the two laser beams are combined by PM-OC, they are sent to the MZM with a bandwidth of 40GHz as an optical carrier, and the insertion loss of the MZM is 9dB. The input optical power before photodiode (PD) is 0dBm. Fig. 1(I)-(IV) show the eye diagrams of the optical signal before entering the PD. The PD with 70GHz bandwidth at 6dB performs square-law detection on optical signals and outputs electrical signals. The W-band signal is amplified by a PA operating at 75-100GHz with a gain of 21dB and sent to free space through a horn antenna with a gain of 25dBi. The photos of the MMW transmitter, receiver, and 20m wireless link is shown in Fig. 2. In the wireless link, we used a pair of dielectric lenses (ie, lens1 with 10cm diameter and 20cm diameter focal length, lens2 with 30cm diameter and 50cm focal length) for focus collimation of MMW beams. Through 20m wireless transmission, signal is amplified by a horn antenna, lens2 and a W-band LNA at the receiving end, and the MMW signal is down-converted to a baseband OOK signal through an envelope detector. The signal is amplified by an EA with a gain of 30dB and sampled by a real-time oscilloscope (OSC) with a bandwidth of 16GHz and a sampling rate of 50GSa/s. In the Rx-side offline DSP, the sampled data is processed by 41-tap-T/2-spaced CMA equalization, 161-core second-order Volterra nonlinear equalization (VNLE) and 61-tap DD-LMS equalization. Finally, conventional DMT signal processing is performed. In this experiment, the FFT size of the DMT signal is 1024 and no cyclic prefix is used. We set the first subcarrier (DC component) to 0 and the following 500 subcarriers are filled with data. The remaining subcarriers are set to 0 for oversampling.

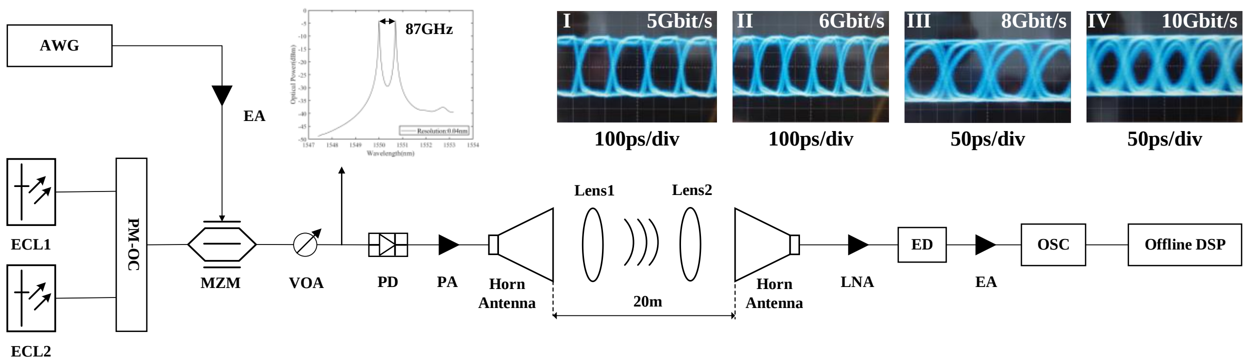



Fig. 1. Principle and experimental setup of MMW-RoF system using DSM in IM/DD channel

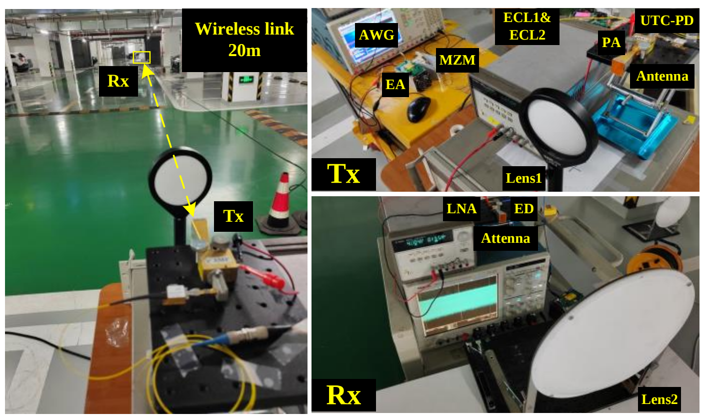



Fig. 2. Photos of experimental setup

## 3. Results and discussion

Fig. 3 shows the performance of the DSM modulator we used. Fig. 3(a) shows the amplitude-frequency response curve and pole-zero plot of the modulator. It shows the noise transfer function (NTF) of the DSM, which can represent its noise shaping performance. We can see that the quantization noise of the signal is pushed into the high frequency part and the quantization noise of the baseband part is suppressed. Fig. 3(b) is the signal spectrum after DSM, and it can be seen that the SNR of the baseband signal reaches 32dB. Fig. 3(c) is the spectrum of the DSM signal collected by the oscilloscope. Through optical fiber and wireless channel transmission, the signal quality deteriorates, but the SNR of the baseband signal remains above 15dB, which ensures the reliability of signal demodulation. Fig. 4 shows the BER performance of the signal at different transmission distances and baud rates.

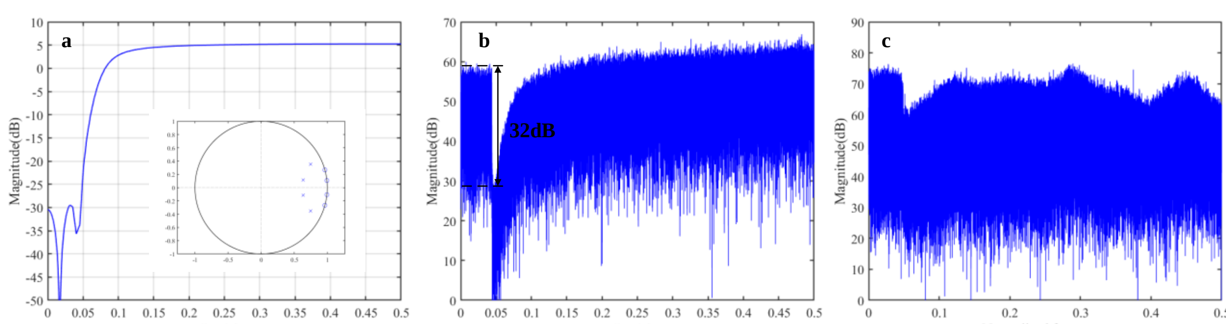
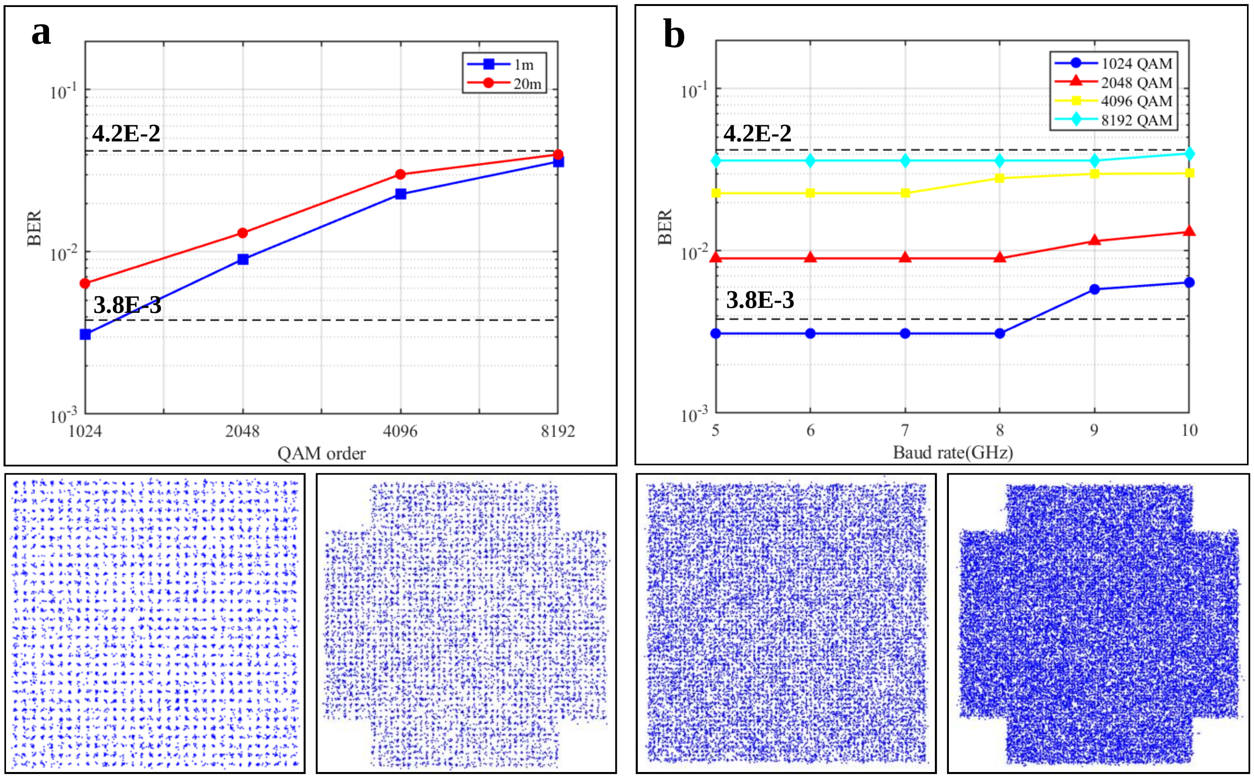



Fig. 3. Performance curves for DSM signals




**(c) 1024 QAM** **(d) 2048 QAM** **(e) 4096 QAM** **(f) 8192 QAM**

Fig. 4. (a) BER versus QAM orders at different transmission distances when the signal transmits at a baud rate of 10 GHz (b) BER versus baud rate for different QAM orders during a 20m wireless transmission (c)-(f) constellation diagrams for different QAM orders

Fig. 4(a) gives the measured BER versus QAM orders at different transmission distances when the signal transmits at a baud rate of 10GHz. In the experiment of 20m wireless link, we use both lens1 and lens2 to enhance the convergence of MMW signal. In the experiment of 1m wireless link, we only use lens1, which is equivalent to a back-to-back experiment. Therefore, it can be seen from Fig. 4(a) that the experimental results of 1m differ very little from the experimental results of 20m. Fig. 4(b) shows the measured BER versus baud rate for different QAM orders during a 20m wireless transmission. We use pre-FEC BER thresholds of $4.2\times10^{-2}$ @ 25% SD-FEC and $3.8\times10^{-3}$ @ 7% HD-FEC. It can be found that with the increase of the transmission distance and the baud rate, the BER performance of the signal has a certain deterioration phenomenon, but it always remains below the soft decision threshold. It shows that after optical fiber and 20m wireless transmission, when the signal baud rate reaches 10GHz and QAM order is 8192, post-FEC error free can be achieved. Fig. 4(c)-(f) show the corresponding constellation diagrams for different QAM orders. For MMW-RoF system using DSM in IM/DD channel, the line bit rate is $10\times500/1024/10\times13/(1+25\%)=5.078$Gbit/s.

## 4. Conclusion

We implement MMW-RoF using DSM in an envelope detection system for the first time. In this system, we transmit a 10Gbaud DSM signal up to 8192QAM over a 20m wireless link. DSM signals reach a line rate of 5.078Gbit/s. The proposed scheme provides a cost-controllable and promising candidate for MMW transmission of high-order QAM. *This work is supported in part by the NNSF of China with grant number of 62127802.*

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