Transmission Restriction and Suppression of Radio over Fiber Communication System

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Abstract:
This article puts forward long-reach and high-performance Radio over Fiber (RoF) Communication Systems. Two schemes are proposed for solving the transmission restriction factors of the RoF system and verifies the system through experiments. One scheme is 40 GHz RoF system based on external modulation with odd-order sideband-suppressed. The other one is 40 GHz Optical Frequency Division Multiplexing (OFDM) system based on Optical Carrier-Suppression (OCS), external modulation. Both theory and experiment prove that the two systems allow not only low chromatic dispersion, but also long-distance transmission.

People have more and more demands on the voice, data, image and video multimedia communication along with the continuous development of communication technologies, which requires higher bandwidths for higher transmission capacities. In addition, people hope anyone can use network resources anytime and anywhere. The Radio over Fiber (RoF) system emerges based on the two demands. RoF combines two advantages to provide a great technical superiority. It is regarded as one of the best communication methods that can meet the requirements of multimedia communication[1].

The RoF system integrates all the radio system functions to a centralized data transceiver to allow all Base Stations (BSs) to connect to the Central Office (CO), which simplifies system architecture. If an entire feedback network is constructed using low-cost fibers, the cost of the system will be greatly reduced because of the low-loss and high-bandwidth features of fiber transmission.

There are many researches on the RoF system in the countries besides China[2-9]. The international researches on the RoF using the 40 GHz optical Millimeter-Wave (MM-Wave) are maturing. However, the (radio) connection between the RoF BS and the user end is still at the stage of experimental research. Restricted by photoelectric components, the experiment for the 40 GHz MM-Wave system using standard fibers can only support the transmission distance of 40 km. The experimental researches on the RoF system based on the 60 GHz MM-Wave are also not sophisticated. Only few laboratories in Japan and the U.S. make such researches.

The transmission distance of the RoF system is restricted by the factors such as chromatic dispersion and non-linearity. This article introduces the major factors that affect the transmission of the RoF system. Moremover, it puts forward two RoF experimental systems that are able to increase the system transmission distance, and analyzes their low-dispersion and non-linearity effectiveness.

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1 RoF System Transmission Suppression Factors

Factors that restrict the transmission of the RoF system include chromatic dispersion, non-linearity of fibers and crosstalk.

(1) Chromatic Dispersion

There are many forms of chromatic dispersions in option communications. Major dispersions include modal dispersion, Polarization Mode Dispersion (PMD) and chromatic dispersion. Modal dispersion generally occurs in multi-mode fibers. This article discusses the transmission over the single-mode fiber only. PMD is mainly caused by the ellipticity of fiber core. Different polarizations propagate with different group velocities. Optical communication is now developing to high rate and high capacity, so PMD has a severe effect on the high-rate systems. The effect of dispersion (chromatic dispersion) over the single-mode fiber on the system is now under consideration. Chromatic dispersion occurs because different frequency components in a pulse propagate with different group velocities over fibers and arrive at the other end of the link at different times. Chromatic dispersion causes the decline of system performance and intersymbol time-shift. In the RoF system, the decline caused by chromatic dispersion is reflected as the periodical changes of signal power in the transmission along fibers. Intersymbol time-shift may deteriorate signal quality and cause the eye pattern of signals to close along with the transmission over fibers.

(2) Fiber Non-Linearity

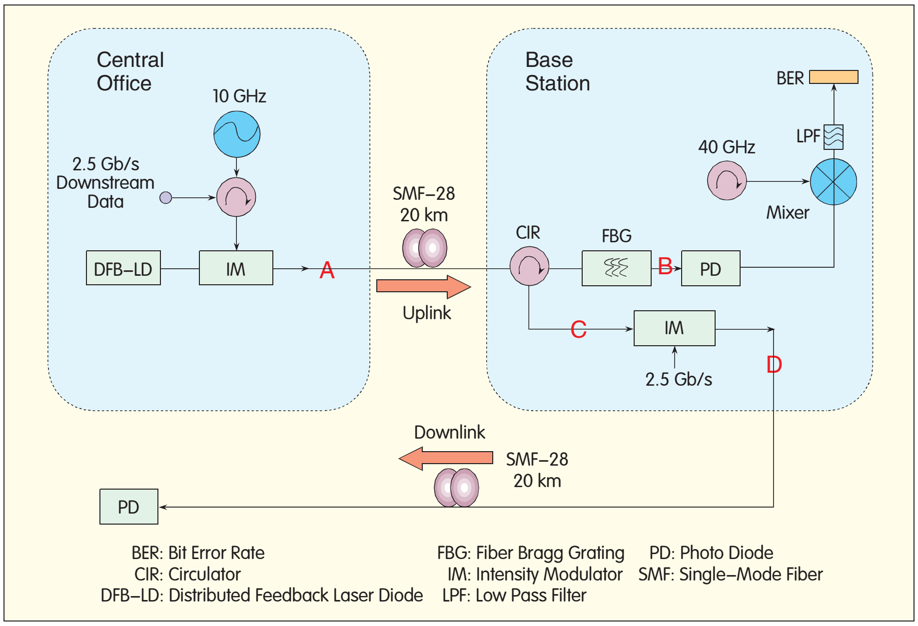
When the optical power over the fiber is very low in transmission, the fiber can be regarded as a linear medium, so the loss and refractivity of the fiber is unrelated to the signal power. However, when the power over the fiber is very high, non-linearity will have a great effect on the system, especially on the high-rate system. This article discusses two types of non-linearity: Stimulated Brillouin Scattering (SBS) and Stimulated Raman Scattering (SRS). One is an effect of scattering generated in the fiber media due to the interaction of light-wave and phonon in the silicon dioxide media. The other is because of the dependency of refractivity and optical power. It mainly includes Four-Wave Mixing (FWM), Self-Phase Modulation (SPM) and Cross-Phase Modulation (CPM). In the RoF system, the second type of non-linearity can be reduced by controlling the input power.

(3) Crosstalk

Crosstalk refers to the effect of other signals to the required signals. In a bidirectional RoF system, additional crosstalk to the system will occur when data are transmitted in two directions over a single fiber. In addition, the crosstalk inside channels caused by component leakage will also suppress the system transmission.

2 Two Solutions to Improve RoF System by Increasing Transmission Distance

According to the factors that suppress the transmission of the RoF system, which is discussed in the first part, the following introduces two solutions for improving system performance and increasing the system transmission



▲Figure 1. 40 GHz RoF full-duplex system.

distance. The analysis in Reference [10] shows that with the external modulation, the Optical Carrier Suppression (OCS) has a higher capability to resist the chromatic dispersion than Single-Sideband (SSB) and Double-Sideband (DSB).However, the 40 GHz RoF system using OCS requires 20 GHz Radio Frequency (RF). So this article recommends to use 10 GHz RF signals for a 40 GHz RoF experimental system, which provides a high capability to resist the chromatic dispersion.

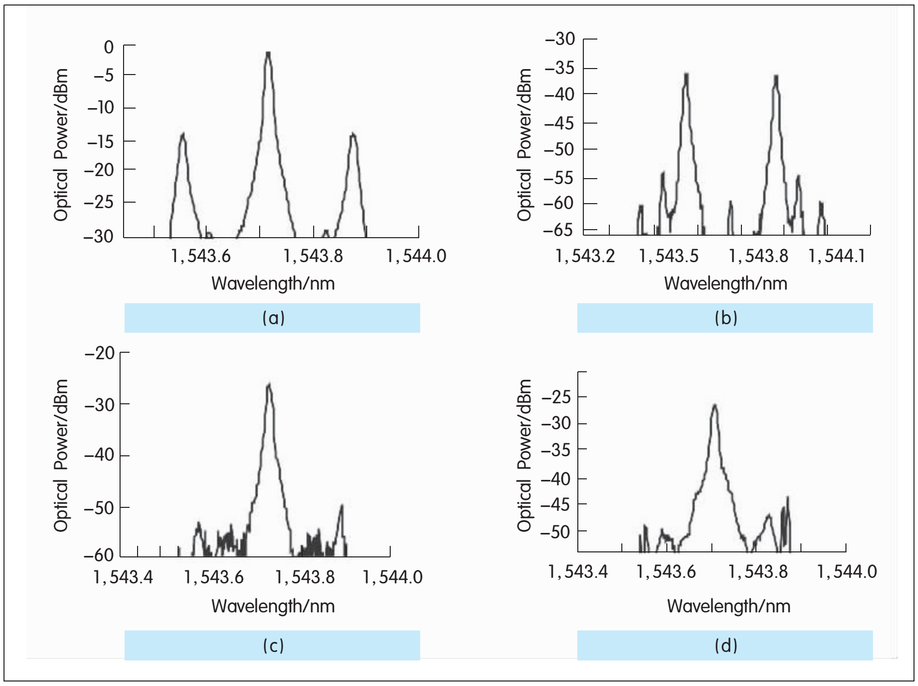
In recent years, the optical communication develops towards large capacity and long distance. So the solution for chromatic dispersion becomes more and more important. In 2005, the Optical Orthogonal Frequency Division Multiplexing (OOFDM) technology was put forward as a new optical transmission technology. OOFDM allows a high rate of fiber transmission without chromatic dispersion compensation. In 2007, DKKI in Japan developed a 4,160 km system transmitted using 52.5 Gb/s OFDM signals without chromatic dispersion compensation[11]. Therefore, the effect of chromatic dispersion on the system can be eliminated if OFDM signals are used for the RoF system.

The following sections describes two external modulation-based RoF and OFDM-RoF systems and their experimental results.

2.1 40 GHz RoF Full-Duplex Experimental System Based on Odd-Order Sideband Suppression

This article discusses an experiment of 40 GHz RoF full-duplex system based on the odd-order sideband suppression, as shown in Figure 1. On the CO, the Distributed Feedback Laser Diode (DFB-LD) generates optical continuous wave and inputs them in to the Intensity Modulator (IM). The 2.5 Gb/s downlink data are mixed with 10 GHz RF signals to generate electrical MM-Wave, which are used to drive the IM and modulate optical carrier waves to realize the modulation based on the odd-order sideband suppression. Figure 2(a) illustrates the resulted spectrum diagram, in which the frequency spacing between the two second-order sidebands is 40 GHz. The MM-Wave arrive at the BS after 20 km of Single-Mode Fiber (SMF)-28 transmission.

Figures 3(a) and 3(b) show the eye diagram of the downlink data before and after the fiber transmission. The carrier are filtered out through the cascaded circulators and Fiber Bragg Grating (FBG) filter. The frequency spectrum contains dual-band second-order sidebands only, as shown in Figure 2(b). The two second-order sideband optical MM-Waves with central carrier filtered



▲Figure 2. Spectrums corresponding to points A–D in Figure 1.

are converted into electrical MM–Waves through a high–speed photoelectric detector. The electric mixer mixes the 40 GHz Local Oscillator (LO) signals with the received MM–Waves for coherent demodulation to get baseband signals. These signals are detected for Bit Error Rate (BER) after passing a Low Pass Filter (LRF). The central carrier reflected by the FBG is output by a circulator as uplink carrier.

Figure 2(c) shows the frequency spectrum of uplink carrier on which 2.5 Gb/s uplink data are modulated. The spectrum after the modulation is shown in Figure 2(d). The data arrive at the receiver after 20 km of SMF–28 transmission, where they are demodulated and tested for BER. Figures 3(c) and 3(d) show the eye diagram of the uplink data before and after the transmission.

The following discusses the system transmission performance. The solution system that uses the odd–order sideband suppression discussed in this article is analyzed for the chromatic dispersion. It is found that the maximum transmission distance is 74 km. For the solution that generates a 40 GHz RoF system through carrier suppression using 20 GHz RF signals, when the value of chromatic dispersion parameter matches the length of central optical wave, the time difference of chromatic dispersion equals to that using the odd–order sideband suppression. This indicates the chromatic dispersion has the same effect on the performance of the two solutions. And the LO signals used in this article are only 10 GHz.

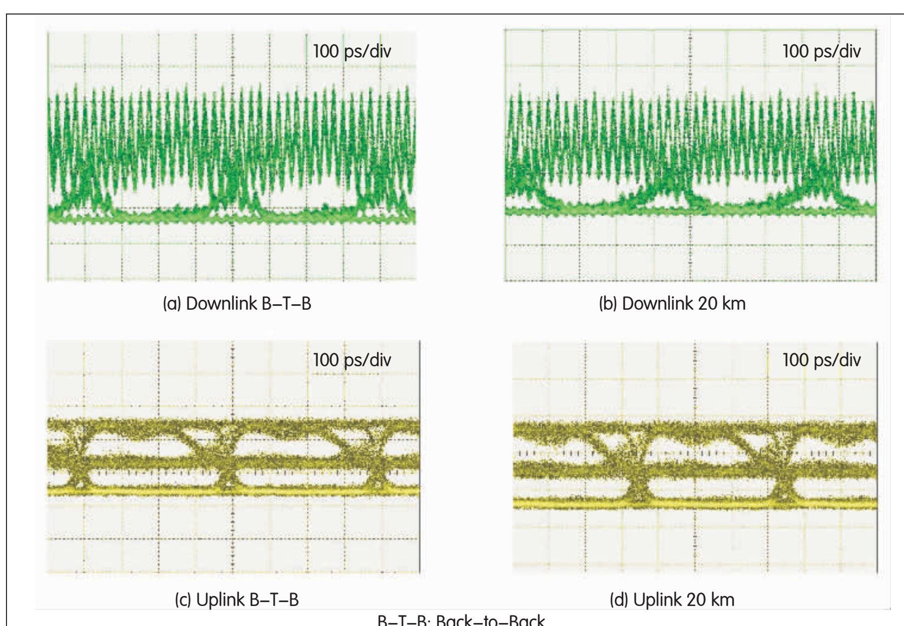
This solution reduces the bandwidth requirement of the modulator and system cost. It is a cost–effective solution to generate high–frequency MM–Waves. For the effect of non–linearity, the second type of non–linearity is considered in the article. The effect on the system can be controlled by controlling the input power of the fiber. In the experiment discussed in this article, the controlled input power is 2 dBm.

Figure 4 shows the eye diagram of the downlink data modulated after different distances of transmission. The eyes are still open after 40 km of fiber transmission, which indicates the system performance is good.

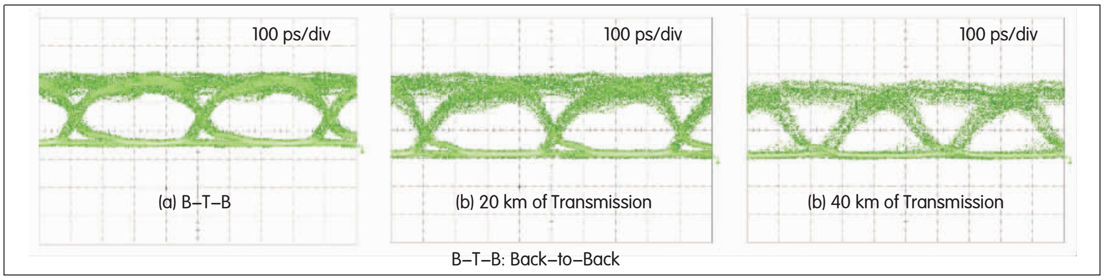
As for the eye diagram of the uplink data, because the carrier reflected from FBG still contains a part of second–order sidebands, that is, the so–called inter–channel crosstalk, there are two modes of eye diagram for the uplink data. But as viewed from the BER curve of the uplink data, the power penalty after 20 km of transmission is less than 1 dB. In summary, the transmission performance of the system is high.

2.2 Carrier Suppression–Based 40 GHz OFDM–RoF System

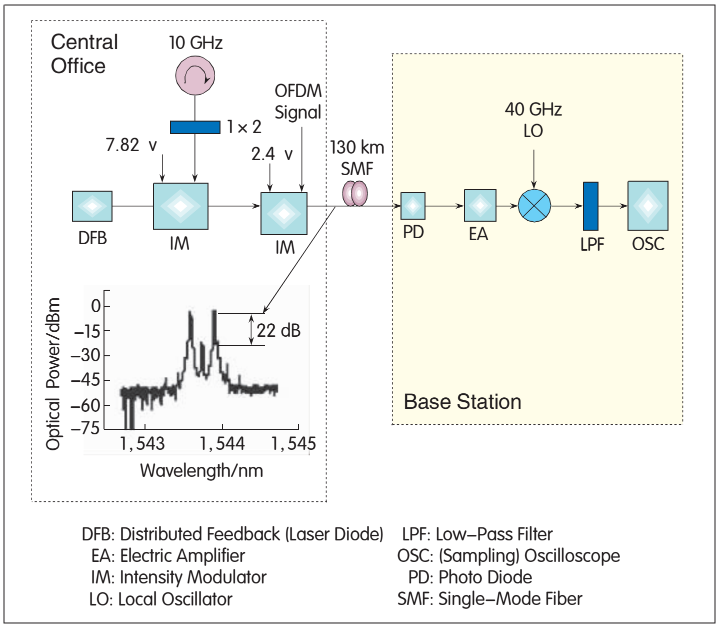
The RoF system generating 40 GHz OOFDM MM–Wave signals through the optical carrier suppression modulation is shown in Figure 5. On the CO, the DFB–LD generates optical continuous wave and inputs them in to the IM.



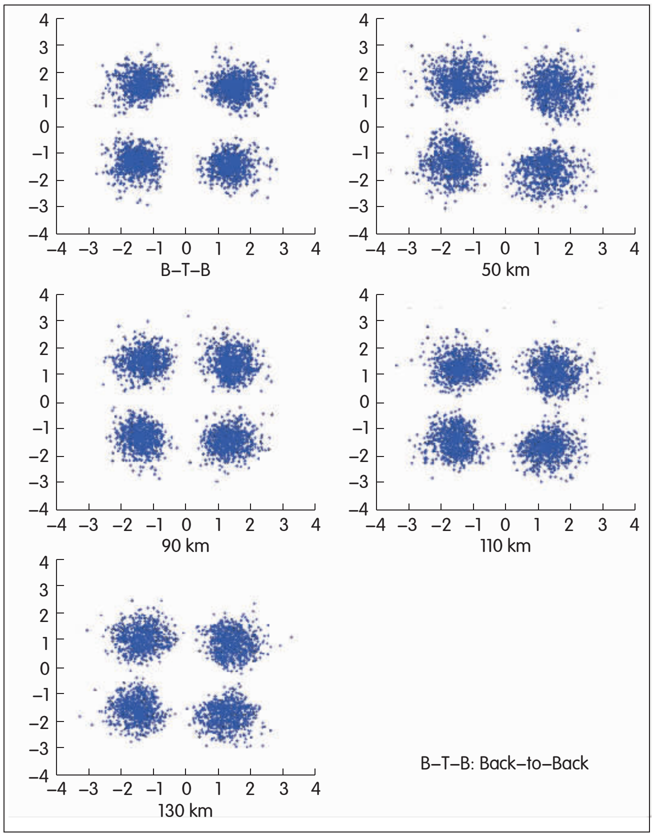
▲Figure 3. Eye diagram of downlink data and uplink data.



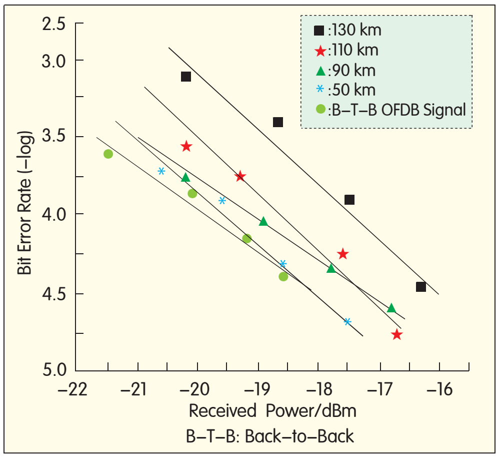
◀Figure 4.
Eye diagram of baseband signals after different transmission distance.



▲Figure 5. Carrier suppression-based 40 GHz OFDM-RoF system.



▲Figure 6. OFDM constellation diagrams after different distances of transmission.

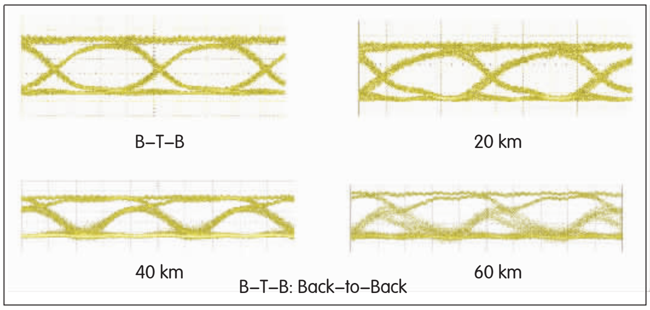


▲Figure 7. BER curves of OFDM signals transmitted in the carrier suppression-based 40 GHz RoF system.

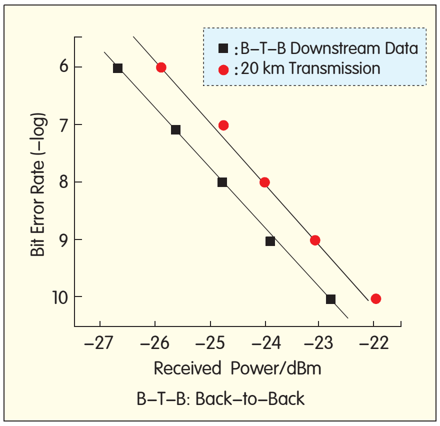
10 GHz RF signals are doubled to 20 GHz RF signals that drive the IM. Adjust the bias voltage of the driver to realize the carrier suppression modulation. Figure 5(a) shows the spectrum, which indicates the carrier-suppression ratio is 22 dBm. OOFDM signals are demodulated and received by a BS after 130 km of transmission over single-mode fiber.

Figure 6 shows the constellation diagram of the OFDM after different distances of transmission. It shows the effect of the constellation diagram of the signals is still good after 130 km of transmission. This is because the system bandwidth is used by N sub-carriers in the system where OFDM signals are transmitted. The symbol rate equals to $1/N$ in the single-carrier transmission mode. It is the low symbol rate that allows the OFDM system to resist the intersymbol interference spontaneously. Each subcarrier of the transmitted OFDM signals is orthogonal to each other, so when the protection interval of the OFDM signals is greater than the multipath delay, signal phase jump can be avoided within the Fast Fourier Transform (FFT) operation period. A small amount of phase-shifting will not affect the orthogonality of all the OFDM subcarriers upon reception. In Figure 6, the constellation diagram shows a bit of radiation after 50 km of transmission. This is because the phases of some subcarriers have shifted. But the radiation is small. So generally speaking, the constellation diagram shows very good effect.

This article also measures the BER after different distances of transmission. Figure 7 shows the BER curves.



▲Figure 8. Eye diagram of the demodulated NRZ signals transmitted in the carrier suppression−based 40 GHz RoF system.



▲Figure 9. BER curves of NRZ signals transmitted in the carrier suppression−based 40 GHz RoF system.

Compared with the B−T−B case, the corresponding receiving powers when the BER is 1×10^{-4}, after 50 km, 110 km and 130 km of transmissions over fibers, is −19.5, −18.5 and −17.5 dBm, which are calculated after the collected data are modulated in the case where OFDM transmits 1×105 points of data. The power penalties are 0.5, 1.5 and 2.5 dB, respectively, which indicate the intersymbol interference of OFDM signals is small. If the OFDM signals are replaced with the Non−Return−to−Zero (NRZ) signals transmitted at 2.5 Gb/s, the modulation eye diagram are in Figure 8, which shows that the eye diagram are distorted with severe intersymbol interference due to the effect of chromatic dispersion after 60 km of transmission.

Figure 9 illustrates the BER curves of NRZ signals. After 20 km of transmission, the corresponding receiving power is −23 dBm and the power penalty is 1 dB when the BER is 1×10^{-9}.

3 Conclusions

This article discusses the major factors that affect the transmission in the RoF system. It puts forward two RoF systems in terms of chromatic dispersion. One is the 40 GHz RoF full−duplex system based on the external modulation. The eye diagram of the downlink signals transmitted over 40 km of fibers using this system are still very good.

The other system is the 40 GHz OFDM−RoF system based on the external modulation. High−quality OFDM signals are generated through reasonable design. OFDM signals can resist decline, intersymbol interference and chromatic dispersion, so the constellation diagram after 130 km of fiber transmission is still very good.

When the BER is 1×10^{-4}, the corresponding receiving power is −17.5 dBm and the power penalty is 2.5 dB, which indicate the intersymbol interference of the OFDM signals is small. The system supports long−distance transmission. We transmit NRZ signals at 2.5 Gb/s using the system and get the eye pattern of demodulation and BER curves. The comparison of the NRZ and OFDM systems shows that the OFDM−RoF system has a higher capability to resist chromatic dispersion.

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