Investigation of transmission performance of single sideband radio over fiber link

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Abstract. We have presented a detailed investigation of the impact of group velocity dispersion (GVD) on the single sideband (SSB) radio over fiber (RoF) links. The theoretical and simulated results show that the transmission distance of the SSB RoF link is limited by the time shifting of the codes due to the GVD, and the code distortion could be suppressed if only one of optical carriers is modulated with baseband data. Moreover, the transmission performance of the SSB RoF link could be further improved by reducing the power of the optical carrier to optimize the carrier-to-sideband ratio.

1. Introduction

Radio over fiber (RoF) [1, 2] is a type of communication technology which combines millimeter wave with optical communication, which can avoid interference and also can meet the requirements of broad-band access network. RoF provides large bandwidth, low loss, and easy to install. It will play a pivotal role for the broad-band access network in the future communication.

The optical generation of the RF signal is the key technology to achieve radio over fiber link. Now, many approaches to generate millimeter waves have been proposed, mainly including external intensity modulation [3], optical heterodyne [4] and optical frequency multiplication [5]. The preferred technique for the optical generation of mm-wave is an intensity external modulation by using an external modulator [3, 6]. In order to overcome the problem of the power penalty, the use of single sideband (SSB) modulation has been proposed with a DD-MZM modulator [3]. Though the SSB mm-wave has good ability in anti-noise, the data signals carried by the optical carrier and its sideband will also get distortion because of the group velocity dispersion (GVD) [7] when they are transmitted along the fiber for a further transmission distance.

In the note, we perform theoretical analysis and simulation of the transmission performance of the SSB RoF links, and the effects of fiber chromatic dispersion on the SSB links are evaluated and
discussed. In addition, the schemes to extend the transmission distance are put forward as well.

2. SSB modulation principle and the impact of fiber dispersion on the SSB RoF links

In ROF system, the output amplitude of DSB modulation is periodic fluctuation with the fiber length [8]. Now, theoretical analysis and experimental results have shown that SSB modulation could eliminate this effect. The principal diagram of SSB optical millimeter-wave generation and transmission is shown in Figure 1.

![Diagram of the optical mm-wave link](#)

Figure 1. The diagram of the optical mm-wave link. LD, directly modulated laser measured; D-MZM, LiNb Mach-Zehnder Modulator; RF, radio frequency source; PS, phase shifter; SMF, single mode fiber; PD, photo detector; Mixer, Electrical Multiplier; LPF, Low Pass Gaussian Filter.

As shown in Figure 1. The implementation of SSB modulation is to use a DD-MZM biased at quadrature point \( \frac{\pi}{2} \), in which a RF signal is split into two branches, which drive the two arms of the MZM with \( \phi = \phi_0 + \frac{\pi}{2} \), and, \( V_{\alpha_1} - V_{\alpha_2} = \frac{V}{2} \). Then we can implement the SSB modulation. The output after DD-MZM can be written as [3]:

\[
E(t) = \frac{E_0 X(t)}{2} \left\{ J_0(\alpha \pi \omega) \cos(\omega_0 t) - J_1(\alpha \pi \omega) \sin(\omega_0 t) \right. \\
+ 2 J_1(\alpha \pi \omega) \cos(\omega_0 + \omega_{RF}) t \} 
\]

(1)

The power-spectral density, \( P(f) \):

\[
P(f) = \frac{\pi E_0^2 X(t)}{4} \left\{ J_0^2(\alpha \pi \omega \delta \omega_0 + \omega_{RF}) + 2 J_1^2(\alpha \pi \omega \delta \omega_0 + \omega_{RF}) \right\} 
\]

(2)

In the optical receiver, only one sideband beat with the optical carrier, so, there is no superimposition destructively when the signal beats. The output power of RF signal after photoelectric detector is approximately equal as:

\[
P_{RF} \propto m \sin(\omega_{RF} t + \frac{\pi D L}{c} \lambda^2 f_{RF}^2) 
\]

(3)

Where \( m \) is constant based on the system parameters. From (3), the amplitude of \( P_{RF} \) is not periodic variation, and the dispersion effect in phase. Though the SSB mm-wave has good ability in eliminating the attenuation effect, the group velocity dispersion (GVD) cannot be ignored when they are transmitted along the fiber for a further transmission distance [9]. After optical-millimeter wave is transmitted over a L-length fiber, we can get the following formula [9]:

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3rd International Photonics & OptoElectronics Meetings (POEM 2010) IOP Publishing
Journal of Physics: Conference Series 276 (2011) 012091
doi:10.1088/1742-6596/276/1/012091
\[ E(L, t) = \frac{E_0 X(t - \tau)}{2} \left[ J_1(\alpha \pi) \cos(\omega_c(t - \tau)) - J_0(\alpha \pi) \sin(\omega_c(t - \tau)) \right] \\
+ 2 E_0 X(t - \tau) J_1(\alpha \pi) \cos(\omega_c + \omega_{RF})(t - \tau) \]

(4)

Where \( \tau = \frac{\beta(\omega_c) L}{\omega} \), \( \tau_c = \frac{\beta(\omega_c + \omega_{RF}) L}{\omega + \omega_{RF}} \), is the time delay caused by the GVD after a length fiber link. \( \beta(\omega) \) is the propagation constant. From (4), the different time delay \( \Delta \tau \) is existence after the data modulated by the carrier and the sideband is transmitting a L-length fiber. Ultimately cause serious distortion. \( \Delta \tau \) can be approximated by:

\[ \Delta \tau = \tau_c - \tau = 1 \omega_{RF} \beta'(\omega_c) L = \frac{Df_{RF} L c}{f_c} \quad (5) \]

To make SSB modulation get better application, the approach is that modulate signal after separation of carrier and sideband [10]. The principal diagram of optical millimeter-wave generation and transmission is shown in Figure 2. The data is only loaded into the sideband. From (4), after optical-millimeter wave is transmitted over a L-length fiber, we can get:

\[ E(L, t) = \frac{E_0 X(t - \tau)}{2} \left[ J_1(\alpha \pi) \cos(\omega_c(t - \tau)) - J_0(\alpha \pi) \sin(\omega_c(t - \tau)) \right] \\
+ 2 E_0 X(t - \tau) J_1(\alpha \pi) \cos(\omega_c + \omega_{RF})(t - \tau) \]

(6)

3. Simulation

In order to verify the correctness of the theory, the SSB simulation calculation has been respectively performed for the following three different situations by using the commercial software package OptiSystem.

In the first situation, the principal diagram is shown in Figure 1. The system parameters are set as follows: The center frequency of LD is 193.1 THz, 10dB power and 10 MHz linewidth. The data rate is 2.5 Gbit/s and the RF frequency is 40GHz. We assume modulator is the ideal LiNb Mach-Zehnder Modulator and the two Modulation voltages are set to 1.02. Single-mode optical fiber attenuation can be compensation by amplifier, so the attenuation can be set to 0. The dispersion of the fiber is set to 16.75 ps/(nm.km). The responsivity of photodetector is 1 A/W. The eye pattern of SSB electrical signal
after the PD is shown as Figure 3. Under the requirement of BER of $10^{-9}$, we can get that SSB electrical signal is able to transmit over 60 km as most of the literatures mentioned, which greatly exceeds the DSB modulation.

![Figure 3. The eye pattern of SSB electrical signal after the PD](image)

In the second situation, the principal diagram of scheme I is shown in Figure 2. The data modulate sideband after the carrier and sideband is separated by using WDM Demux, and then transmits in fiber after coupled by WDM Mux. The light is using CW laser with 193.1 THz and the power is 0 dBm. The other parameters are all the same as the first situation. The eye pattern of SSB electrical signal after the PD is shown as Figure 4. Under the requirement of BER of $10^{-9}$, the SSB electrical signal is able to transmit over 90km. The transmission performance is improved obviously.

![Figure 4. The eye pattern of SSB electrical signal after the PD](image)
In the third situation, we consider that the power difference of the carrier and sideband may also affect signal transmission distance. So we get a further improvement base on the second project. The diagram of scheme II is shown as Figure 5. The attenuation of optical attenuator is set to 10 dBm. The other parameters are all the same as the second situation (scheme I).

![Diagram of scheme II](image)

**Figure 5.** The diagram of scheme II to improve the transmission performance of SSB RoF link.

The eye pattern of SSB electrical signal after the PD of the third situation is shown as Figure 6. Under the requirement of BER of $10^{-9}$, the SSB electrical signal is able to transmit over 180km. Our guess is verified, but also need to do further work.

![Eye pattern of SSB electrical signal](image)

**Figure 6.** The eye pattern of SSB electrical signal after the PD of the scheme II

4. Conclusions

In conclusion, the impact of fiber dispersion on the transmission performance of the SSB RoF link is theoretical analyzed and simulated. The results show that it is able to suppress the performance degradation due to group velocity dispersion (GVD) if only sideband is modulated with baseband data, and the transmission distance could be further extended by optimizing the carrier-to-sideband ratio. In addition, the corresponding simulations were carried out using the commercial software package OptiSystem with the simulation parameters following the theoretical values to access the validity of the theoretical analysis.

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