

Frequency response equalization in phase modulated RoF systems using optical carrier Brillouin processing

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Abstract A novel method is demonstrated to tunably compensate dispersion effect in phase modulated radio over fiber (RoF) links using an optical carrier Brillouin processing technique, which is based on stimulated Brillouin scattering (SBS) to control the phase shift of optical carrier in the modulated lightwave signal. Since this phase shift can be dynamically tuned, frequency response can be tunably improved. Both simulation and experimental results show that a uniform frequency response ranging from 1–12 GHz with a fluctuation of less than ± 1 dB can be obtained by an optimal phase shift on the optical carrier.

Keywords frequency response, dispersion effect, phase modulation, radio over fiber link, stimulated Brillouin scattering

1 Introduction

In the last decade, analog photonic links have attracted considerable attention in broadband wireless access network, wideband signal processing, and antenna remoting, due to the advantages of low loss, small size, large bandwidth, and high immunity to electromagnetic interference [1,2]. Two kinds of external optical modulators, intensity modulator and phase modulator, are generally used for superimposing a radio signal onto an optical carrier. Major problem associated with the intensity modulator is the need for a sophisticated electrical circuit to control voltage bias and its high insertion loss [3]. Since optical phase modulator is free from the voltage bias-drifting and can provide more linear conversion between input radio signal and optical phase, it has been found great potential in recent radio over fiber (RoF) link applications [4]. However, the π -phase-difference of the ± 1 st-order

sidebands after phase modulation process will cancel each other while beating with optical carrier at a photodetector (PD); therefore, an effective and stable conversion of phase modulation (PM) to intensity modulation (IM) is indispensable in phase modulated RoF links. A number of schemes have been proposed including dispersive fiber [5], fiber grating [6], Brillouin amplification [7], and interferometer detection [8], etc. Amongst, utilizing a length of dispersive fiber is the easiest way to implement. Although the fiber dispersion can break original π -phase-difference of the ± 1 st-order sidebands, it will also result in a power degradation of radio frequency (RF) signal at some modulation frequencies, which is as same as the case in double sideband intensity modulation. The frequency response of this link is square of sine function with respect to the distance of fiber link, the modulation frequency and the fiber dispersion parameter. Undoubtedly the unevenness of the frequency response in the RoF link is deleterious for the broadband wireless system. For example, a uniform RF gain is highly expected in airborne radar systems, where a wide-band optical links operating up to 18 GHz is required. Till now it is seldom to compensate the dispersion effect in the phase modulated RoF link using a length of dispersive fiber to realize the PM-IM conversion.

Optical carrier Brillouin processing (OCBP) is a functional technique, which uses stimulated Brillouin scattering (SBS) to control the amplitude and phase of the optical carrier of a modulated lightwave signal. It was first proposed by Loayssa's group [9] and has been found many applications in the field of microwave photonic signal processing [10–13].

In this paper, a novel scheme is proposed and experiments demonstrated that this OCBP technique can tunably compensate the dispersion effect in the phase modulated RoF links. The phase difference caused by fiber dispersion will be successfully offset when beating with the optical carrier, and the frequency response of the link can be tunably improved.

2 Principle

When an optical carrier is phase modulated by a single frequency microwave signal, under small signal assumption the output optical signal is expressed as

$$E(t) = A_0 \exp(j\omega_c t) + A_1 \exp\{j[(\omega_c + \omega_m)t + \pi/2]\} - A_{-1} \exp\{j[(\omega_c - \omega_m)t - \pi/2]\}, \quad (1)$$

where ω_c is the angular frequency of the optical carrier, ω_m is the modulating microwave angular frequency, A_0 is the amplitude of the optical carrier while A_1 and A_{-1} are those of the ± 1 st-order sidebands, and $A_1 = A_{-1}$.

Clearly, the π -phase-difference of the sidebands will cancel each other while beating with the optical carrier at PD, and only a direct current (DC) could be obtained. When this optical signal transmits through an L km long single mode fiber (SMF) with a fiber dispersion constant of D pm/(km·nm), the optical signal can be expressed as

$$E(t) = A_0 \exp[j(\omega_c t + \varphi_0)] + A_1 \exp\{j[(\omega_c + \omega_m)t + \pi/2 + \varphi_1]\} - A_{-1} \exp\{j[(\omega_c - \omega_m)t - \pi/2 + \varphi_{-1}]\}, \quad (2)$$

where φ_0 , φ_1 and φ_{-1} are the phases induced by the fiber for the optical carrier and the two sidebands, respectively, and they are different owing to the fiber's dispersion effect. If this signal is then optically processed to modify just the optical carrier with a factor of $\exp(j\theta)$, the received RF power at ω_m after PD detection is

$$P_{RF} \propto (A_0 A_1)^2 \sin^2(\varphi - \theta), \quad (3)$$

where $\varphi = (\varphi_1 + \varphi_{-1})/2 - \varphi_0 = \pi L c D (\omega_m / \omega_c)^2$, c is the velocity of light in vacuum. It can be seen that the phase modulation can be changed to amplitude modulation through the dispersive fiber. The frequency response of the link is square of sine function with respect to L , ω_m , D , and θ . When $\theta = 0^\circ$, i.e., no optical carrier processing occurs, the RF power is very weak at the low frequency range and will vanish at some modulation frequency, where it meets $\varphi = n\pi$, $n = \pm 1, \pm 2, \pm 3, \dots$. However, by adding proper θ to the optical carrier, the frequency response at the lower frequency range can be greatly improved, yet the frequency of the RF power nadir will also be changed.

Figure 1 demonstrates the computational RF power with and without the phase change on the optical carrier in a phase modulated RoF links. Here, we choose a 25 km length fiber link with the fiber dispersion constant $D = 16$ ps/(nm·km). The optical carrier wavelength is 1550 nm. It can be found that the frequency response for a phase modulated RoF link is totally uneven during the frequency range of 0–20 GHz. It has a large notch at the lower frequency; the second RF power nadir induced by chromatic dispersion effects appears at 17.7 GHz. When a phase shift θ is imposed on the optical carrier, the

frequency response of the link can be dynamically tuned. By choosing an optimal θ , an even frequency response can be obtained. When $\theta = -\pi/6$, as shown in Fig. 1, the RF gain in this link is very flat from DC to nearly 12 GHz.

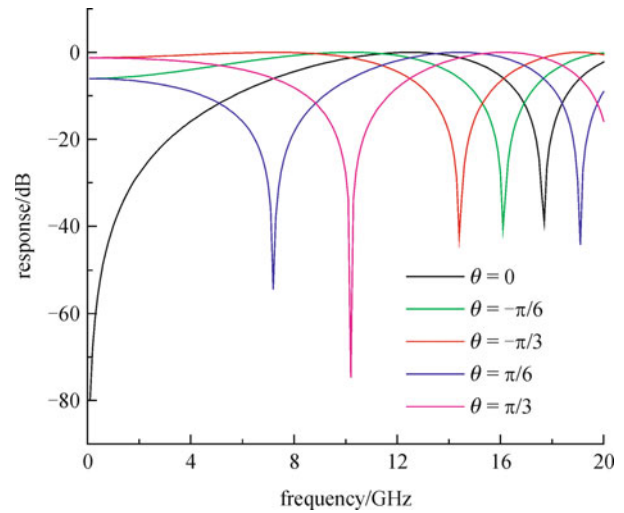


Fig. 1 Simulated frequency response of 25 km phase modulated RoF links with and without optical carrier Brillouin process

3 Experiment and discussion

Figure 2 is the experimental setup for the dispersion compensation in phase modulated RoF link using the optical carrier Brillouin processing. A tunable distributed feedback (DFB) laser is used as light source and is divided into two paths by an optic coupler. The upper path goes through a polarization controller (PC) and is modulated via a Mach-Zehnder modulator (MZM), which is driven by a microwave generator of frequency f_p and biased for minimum transmission to realize double sideband suppressed carrier (DSB-SC) modulation. When f_p is chosen to be within the linewidth of the Brillouin frequency of SMF, the upper sideband of this DSB-SC signals will act as a pump wave and the low sideband acts as a Stokes wave for the optical carrier in lower path through an optical circulator. The power of the DSB-SC signals is controlled by an Er-doped fiber amplifier (EDFA). The lower path also goes through a PC and is phase modulated by a microwave signal ranging from 1–20 GHz generated by a vector network analyzer (VNA, ES8722, Agilent). The phase modulated signals are then launched into a 25 km SMF and interacts with the pump and Stokes wave counter-propagating from the circulator. The transmitted signal is finally detected by a PD, whose output is in turn connected to another port of the vector network analyzer.

According to the principle of stimulated Brillouin scattering [14], if the power of the DSB-SC signals is large enough, Brillouin gain and loss will occur simultaneously on the optical carrier in the lower path. By

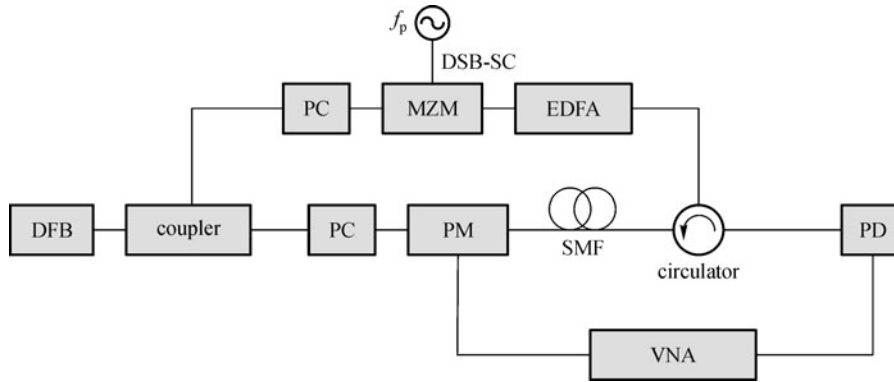


Fig. 2 Experimental setup for dispersion compensation

adjusting the frequency f_p , the amplitude of the optical carrier keeps unchanged through the compensation of the Brillouin gain and loss while the tunable phase shift is obtained from both the Brillouin gain and loss spectra. Hence, the dispersion effect for the frequency response of the phase modulated RoF links can be tunably alleviated through this optical carrier Brillouin process. Since SBS is a nonlinear effect resulting from the interaction among a pump wave, an acoustic wave, and a Stokes wave, Brillouin gain and loss spectra can be adjusted by both the frequency difference between the pump wave and a Stokes wave (f_p as in the experiment) and the amplitude of the pump wave [11], the tunable phase shift on the carrier in this scheme can also be tuned by the amplification of the modulated signal of f_p . However, it is hard to only tune the amplitude of the modulated signals to realize the totally compensation of the Brillouin gain and loss, resulting in the amplitude modification of the optical carrier. Therefore, the optical carrier Brillouin process is realized by adjusting the modulating frequency f_p in our experiment.

Figure 3 shows the experimental frequency response of the 25 km phase modulated RoF links with and without optical carrier Brillouin process. It can be observed that the original phase modulated 25 km-SMF RoF link has a large DC-notch frequency response. The received power at 1 GHz is about 30 dB lower than the maximum power at 12 GHz. The second power nadir is near 18 GHz, both of which is due to the fiber dispersion and coincide with the computational results in Fig. 1. By adjusting the frequency of f_p , different phase is added on the optical carrier and the frequency response of the phase modulated RoF link is greatly improved. When $f_p = 10.843$ GHz, a uniform RF gain is obtained ranging from 1–12 GHz with a fluctuation of about ± 1 dB. However the second RF power nadir is shifted to the lower frequency of 16 GHz.

Figure 4 indicates the measured RF spectra at 2, 12 and 17.71 GHz with and without the optical carrier Brillouin process when $f_p = 10.843$ GHz, respectively. It can be found that the RF gain in the lower frequency is much increased when the optical carrier Brillouin process is

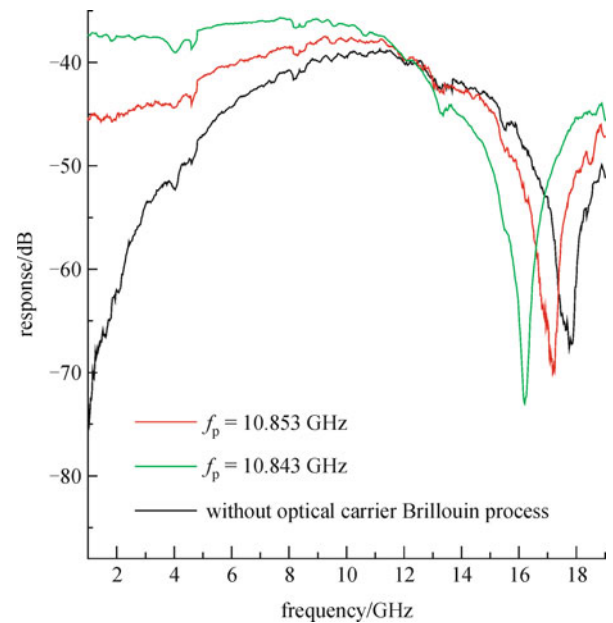


Fig. 3 Experimental frequency response of 25 km phase modulated RoF links with and without optical carrier Brillouin process

carried on. The power at 2 GHz is improved about 24 dB. When the RF frequency is 12 GHz, the power of the RF signal is nearly the same, while at 17.71 GHz, the RF signal cannot be discriminated from noise owing to π -phase-difference induced by the fiber dispersion. However, by adding the phase to the optical carrier, about 30 dB of the RF signal is obtained by compensating the dispersion effect.

4 Conclusion

In conclusion, a new way has been proposed to compensate the fiber dispersion effect in phase modulated RoF links based on an optical carrier Brillouin process. The proposed scheme is highly tunable by dynamically tuning the external electrical control. Also, experimental

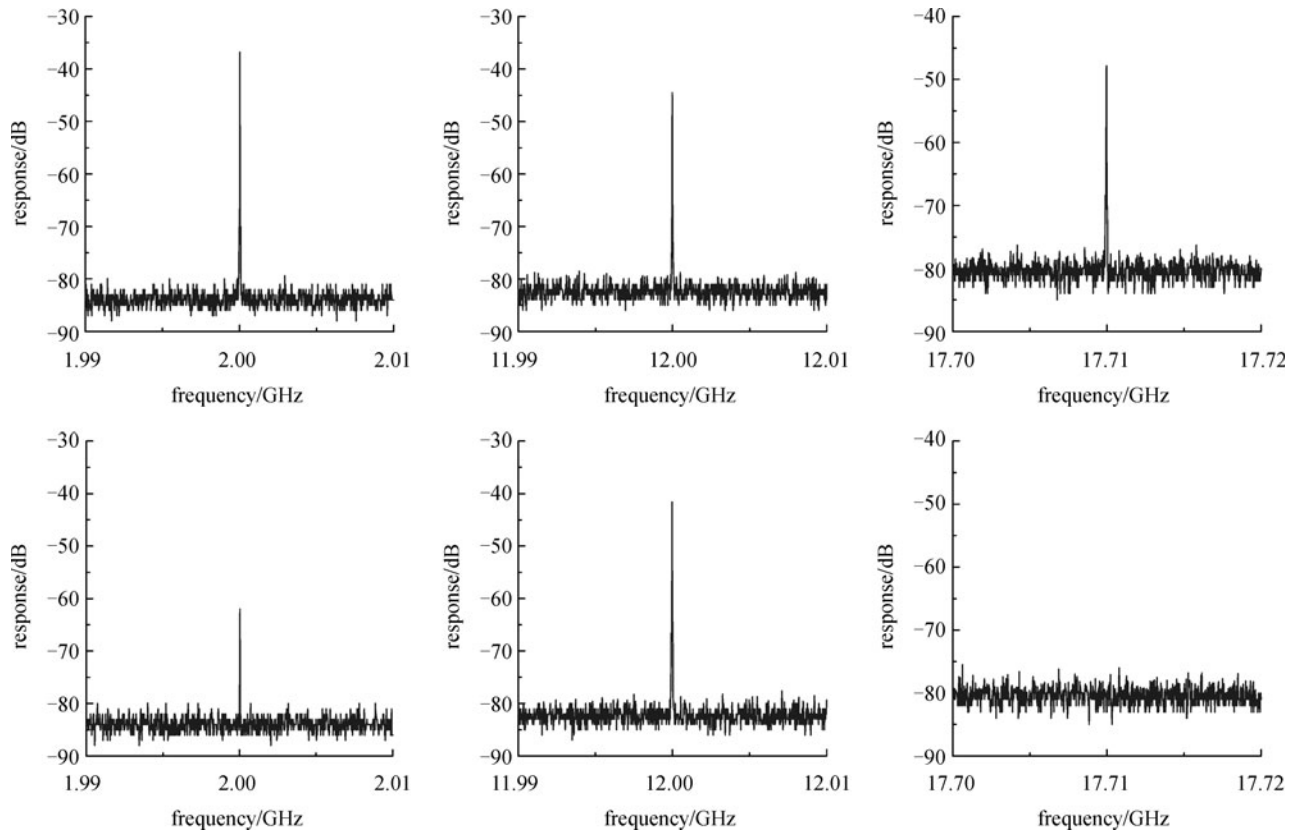


Fig. 4 Measured RF spectra at 2, 12 and 17.71 GHz with (above) and without (bottom) optical carrier Brillouin process when $f_p = 10.843$ GHz, respectively

results have demonstrated an even frequency response of this RoF link ranging from 1–12 GHz and characteristics of the RF signals at different frequency by this method.

Acknowledgements This work was supported in part by the National Natural Science Foundation of China (Grant Nos. 60801003 and 60871011), and the Natural Science Foundation of Zhejiang Province of China (No. R1090354).

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