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Linearization and dispersion tolerable technique for remote access unit in uplink RoF system based on gain-saturated RSOA cascaded EAM

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ABSTRACT

A novel scheme of a remote access unit which is based on an electroabsorption modulator cascaded by a gain-saturated reflective semiconductor optical amplifier is proposed to improve a transmission performance of uplink signal. The cascaded gain-saturated reflective semiconductor optical amplifier plays a role in enhancing linearity of the electroabsorption modulator as well as suppressing dispersion-induced carrier suppression in the uplink transmission using its nonlinear gain property. In the proposed scheme, carrier-to-interference ratio of transmitted 10-GHz band uplink signal was improved by 10.7 dB and the dispersion-induced carrier suppression of 5.65-GHz RF carrier was greatly mitigated by 33.4 dB through the 75.6-km optical link.

1. Introduction

In these days, data capacity of wireless communication has been dramatically expanded from voices and simple messages to multimedia in order to satisfy various demands of system users with evolutionary future services. In addition, the number of mobile subscribers has exploded in the last few decades. In these trends, the ubiquitous network has been considered as one of the most competitive systems by many research groups. Millimeter-wave (mm-wave) carriers have been promising as an attractive solution for wireless systems to construct the ubiquitous network because its relative bandwidth is much broader than that of a conventional wireless carrier. However, service coverage of the networks based on mm-wave carriers is curtailed because mm-wave carriers have a line-of-sight characteristic. This is why those systems based on mm-wave carriers have been called pico- or femto-cell networks. The number of required remote access unit (RAU) should be increased to maintain the service coverage. This may result in serious cost problem. Despite the advantage of mm-wave carriers, this issue has delayed an adoption of the mm-wave-based-systems into practical wireless communication systems. Radio-over-fiber (RoF) system has been attractive to solve this problem because of its various advantages, such as a large bandwidth supplement, a low attenuation loss, a centralized signal processing, simple RAUs, and so on. In RoF system, wireless downstream data are modulated by optical sources or external modulators into the optical domain at a central office (CO). Then, the modulated signals are transmitted to RAUs through the optical link and recovered to the wireless data. These are radiated by antennas to each subscriber. Meanwhile, upstream data are transmitted from each subscriber to the CO in the same manner [1–9].

An electroabsorption modulator (EAM) is a very fascinating device as an electro-optic transmitter in RAUs because it is easy to integrate this device with other optical devices. It can be also operated with low voltage consumption compared to a Mach–Zehnder modulator [10–12]. Furthermore, an EAM can be used as a photo detector as well as a modulator since it is based on a p–n junction semiconductor structure and operated by reverse bias voltage. In virtue of this advantage, it is able to reduce installation and maintenance cost of RAUs [13]. However, there are two critical drawbacks of using an EAM in an implementation of RoF system; one is the nonlinear property of an EAM as a modulator [10–12] and the other is the distance-dependent signal distortion which is known as dispersion-induced carrier suppression (DICS) [14,15].

In this paper, a novel scheme of a RAU, based on a gain-saturated reflective semiconductor optical amplifier (GS-RSOA) cascaded EAM, is proposed to improve the linearity of an EAM and mitigate DICS effect in the uplink transmission. These issues are firstly proved numerically with simulations. Then, their validities are confirmed with experimental demonstrations.

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2. Theoretical approach

Fig. 1 illustrates an overall outline of the RoF system, based on the proposed-RAU-scheme. There are two different light sources in the CO. These support bidirectional RoF transmission system. One is provided for the downlink channel and the other is for the uplink. The uplink channel, notated as λ_U, is coupled with the modulated downlink channel, notated as λ_D, and both channels are transmitted to the RAU. Then the downlink data is recovered by the EAM which works as a receiver. This signal is radiated by the antenna to each wireless subscriber. On the other hand, the uplink data, delivered from wireless subscribers, modulate to the uplink optical carrier, λ_U, and these signals are transmitted back to the CO. The optical bandpass filter (OBPF) is used to avoid the interference which possibly come from the downlink optical carrier, λ_D. Its passband is centered at λ_U. Then the uplink signal is recovered by the uplink receiver.

Fig. 2 explains how the proposed scheme linearizes the EAM for the uplink. It is inevitable that the uplink signal is distorted by the nonlinear transfer characteristic of the EAM. This is described as follows [16],

$$T(V) = \exp\{-\Gamma\alpha(V)L\} \tag{1}$$

where Γ is the confinement factor, α is the absorption coefficient, and L is the cavity-length of the EAM.

The number of the input carriers is supposed to two tones for simplicity of analysis. This is given by,

$$V - V_b + V_m = V_b[1 + m\{\cos(w_1 t) + \cos(w_2 t)\}] \tag{2}$$

where V_b is the bias voltage of the EAM, V_m is the signal voltage of the input carriers, and m is the modulation depth of the input signals [16].

Then the modulated output signal is expressed by Taylor series expansion [16],

$$\begin{aligned} P_{out,EAM} &= T^{(1)}(V_b)\cdot V_b\cdot m\{\cos(w_1 t) + \cos(w_2 t)\} \\ &+ T^{(3)}(V_b)\cdot(V_b\cdot m)^3 \frac{1}{3!}\frac{3}{4} \times [\cos\{(2w_1 - w_2)t\} \\ &+ \cos\{(2w_2 - w_1)t\}] + \cdots \end{aligned} \tag{3}$$

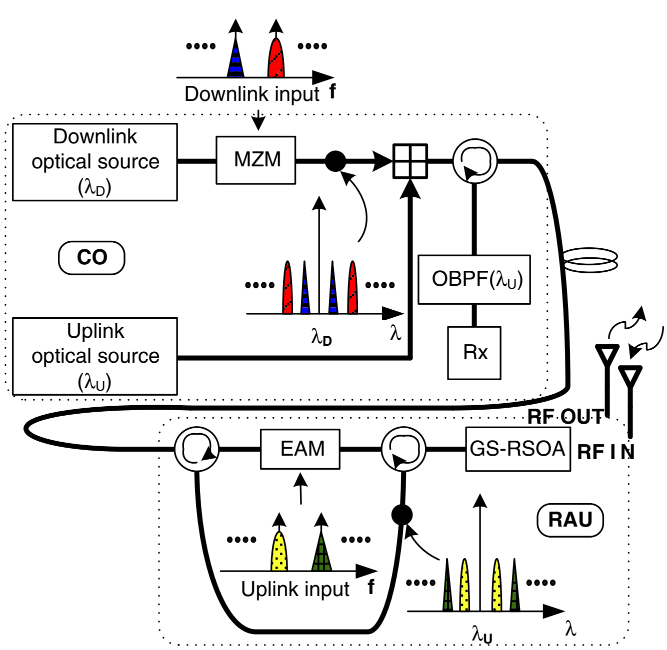

Fig. 1. The proposed RoF system.

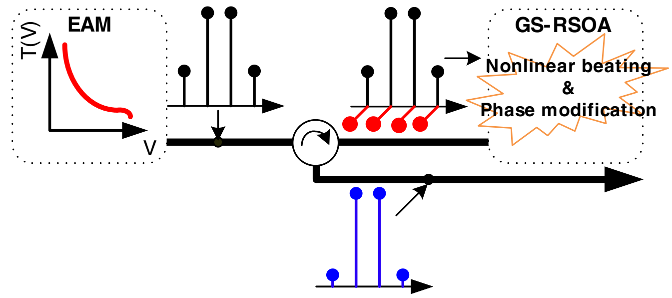

Fig. 2. Operation principle of the linearization of the EAM.

where $T^{(n)}$ is the *nth* order differential coefficient of the EAM-transfer-function [17].

This signal then passes through the GS-RSOA. As described in Fig. 2, the additional nonlinear distortion products, represented as red bars, are generated in the cavity of the GS-RSOA. The gain characteristic of the GS-RSOA is the reason of this phenomenon. It has the nonlinear gain curve. It mainly attributes to the gain saturation [18].

Volterra series expansion is applied to evaluate the output optical signal of the GS-RSOA because this method is generally considered as the best for understanding nonlinear feature of devices [19]. It usually describes the relationship between the input and output for certain nonlinear devices. In the GS-RSOA, there are some nonlinear interaction between electrons and photons inside the cavity. The output optical signal of the GS-RSOA can be indicated as follows,

$$\omega_1 : \left[\frac{T^{(1)}\cdot(V_b\cdot m)}{2}\right]\cdot G_1(f_1) + \left[\frac{T^{(1)}\cdot(V_b\cdot m)}{2}\right]^2\cdot\left[\frac{T^{(3)}\cdot(V_b\cdot m)^3}{8}\right]\times G_3(f_2,f_2,2f_2-f_1) \tag{4}$$

$$2\omega_1-\omega_2 : \left[\frac{T^{(3)}\cdot(V_b\cdot m)^3}{8}\right]^2\cdot G_1(2f_1-f_2) + \left[\frac{T^{(1)}\cdot(V_b\cdot m)}{2}\right]^2\cdot\left[\frac{T^{(3)}\cdot(V_b\cdot m)^3}{8}\right]\times G_3(f_1,f_1,f_2) \tag{5}$$

where $G_n(f_1,f_2,\ldots,f_n)$ is the nth order kernel of the Volterra series expansion.

As represented in Eqs. 4 and 5, the magnitude of the 3*rd* order intermodulation distortion products (IMD3) is modified by the GS-RSOA. Amount of its change is determined by the kernel of $G_3(f_1,f_1,f_2)$. This term is related to the operation condition of the GS-RSOA. The transfer matrix model of the GS-RSOA was used for the simulation we committed to analyze this mechanism numerically [20,21]. We firstly assumed that the main parameters of the simulation were the bias current of the GS-RSOA and the optical modulation depth of the input signal of the GS-RSOA. Carrier-to-interference ratio (CIR), recovered after the GS-RSOA, was calculated in terms of both parameters to estimate the magnitude variation of the uplink signal after the GS-RSOA. To estimate this mechanism evidently, it was supposed that the input optical signal of the GS-RSOA did not have any IMD3 products. If less CIR value was observed, that means more IMD3 products were generated by the GS-RSOA itself. The calculated result is illustrated in Fig. 3. By either increasing the modulation depth or decreasing the bias current, the CIR value became smaller. It is well known that the gain saturation of the GS-RSOA would be serious under these conditions. Therefore, it is estimated that the magnitude of the IMD3 products generated by the GS-RSOA itself is proportional to its gain saturation.

RF phase variation of the output optical signal of the GS-RSOA was also calculated in terms of the parameters it was mentioned previously, illustrated in Fig. 4. It was assumed in this calculation that the input optical signal of the GS-RSOA had only one RF tone because it would be very difficult to clarify the phase variation of the certain RF tone if the input had multi tones. The phase variation result