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Linearization of DFB LD by using Cross Gain Modulation of Reflective SOA in Radio-over-Fiber Link

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We proposed a novel linearization technique for a DFB LD in the RoF link. The proposed scheme is based on the cross gain modulation (XGM) effect of a reflective semiconductor optical amplifier (RSOA) with light injection. We experimentally demonstrated and evaluated the enhanced CIR performance using the proposed linearization scheme.

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I. INTRODUCTION

Wireless access networks have been demanded for various types of multimedia services as well as voice. To satisfy this network trend, high capacity of optical networks should be integrated with flexibility of wireless radio networks. Radio-over-Fiber (RoF) systems potentially have offered significant flexibility, economic advantage and large capacity in the access network [1].

When multiple RF signals using subcarrier multiplexing (SCM) are transmitted in RoF link, undesired harmonics and intermodulation distortion products are produced. These are due to nonlinearity of optical sources such as a distributed-feedback laser diode (DFB LD) or an external modulator. These products can lead to degradation of signal quality for adjacent channels. Especially, it is more important to minimize third-order intermodulation distortion products (IMD3) because they cannot be easily filtered for narrow band systems.

Numerous studies have attempted to improve linearity of optical sources using electrical, optoelectric and all-optical techniques. Feedforward, feedback, and predistortion schemes are well known techniques to linearize an optical transmitter using optoelectric method [2]. These techniques can be very attractive solutions for linearization due to good performance [3-5]. But there are some drawbacks to implement such as its complicated structure and the difficulty of operation control for reduction of intermodulation products. On the other hand, there are some all-optical linearization techniques such as a Fabry-Perot etalon based scheme [6][7] and injection locking methods [8]. These methods have many advantages for their simplicity compared to the opto-electric ones. However, it is difficult for these techniques to optimize the best conditions for IMD reduction. We have proposed a linearization scheme by using light injection based on cross gain modulation (XGM) but an optical filter is additionally required to implement this method [9].

In this paper, we propose a novel linearization technique of a DFB LD using the cross gain modulation (XGM) effect of a reflective semiconductor optical amplifier (RSOA) with light injection. The proposed scheme is a simple structure and easy to control the reduction of IMD3. In addition, an optical filter isn't needed as our previous work. It consists of a single RSOA and broadband phase shifters. A light of the DFB LD is injected into the RSOA and experienced the XGM effect in the RSOA. By utilizing this mechanism, it is possible to reduce IMD3 products by using optimization of input optical power to the RSOA, bias current of the DFB LD and phase of the RSOA signal. We experimentally demonstrated the enhanced carrier-to-interference ratio (CIR) and spurious-free dynamic range (SFDR) by using the proposed scheme.

II. OPERATION PRINCIPLE

The configuration and operation principle of the

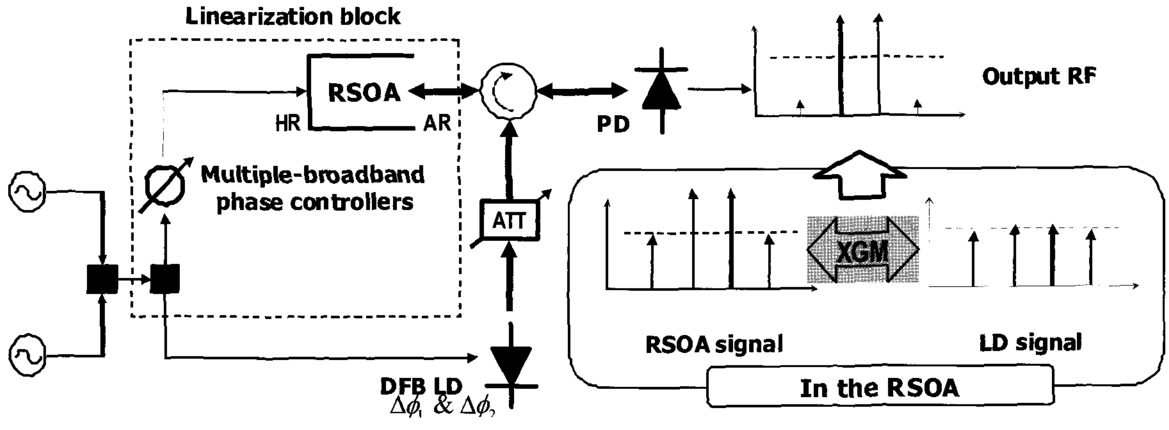

FIG. 1 The configuration and operation principle of the proposed scheme.

proposed linearization scheme for a DFB LD are shown in figure 1. It consists of a single RSOA, broadband RF phase shifters and an tunable optical attenuator. The light from the DFB LD is directly modulated by both RF signals ω_1 and ω_2. IMD3 signals are generated at frequency of $2\omega_1$-ω_2 and $2\omega_2$-ω_1 by the nonlinearity of the free-running DFB LD. The linearization block as the dot box is proposed to reduce these IMD3 products. The basic mechanism of the proposed scheme is the XGM effect which is generally used for the wavelength conversion in a semiconductor optical amplifier (SOA) [10]. The RSOA is also modulated by same RF frequencies whose phases are adjusted by the broadband RF phase shifter. The modulated optical signal from the DFB LD is injected into the RSOA. As shown in figure 1, it is possible to suppress IMD3 produced from the DFB LD by making these nonlinear products to have the same magnitude and the in-phase relationship compared to those of IMD3 generated from the RSOA because of XGM effect in RSOA.

Phase relationship to achieve linearization of the proposed scheme can be explained in detail as shown in figure 2. Supposed that the signal in figure 2 is upper IMD3 ($2\omega_2$-ω_1) in the time domain. For reducing this IMD3 product, we should control its magnitude and phase with adjustment of the DFB LD bias current, the optical attenuator, and the broadband RF phase shifter. The gain of the RSOA is affected by tuning with the fluctuations in input optical power to the RSOA. If the RF signal of the DFB LD is injected into RSOA as (A), the carriers in the cavity of the RSOA are depleted as (B) due to its gain-saturated operation. At the same time, when the RF signal of the RSOA is applied in-phase as (C), the magnitude of the RF signal can be reduced because applied RF signal to the RSOA is compensated by carrier depletion in the RSOA. Therefore, output XGM power no longer has high magnitude as (D) even if the power of the RF signal injected to the DFB LD is low and vice versa.

The same logic is applied for increase of RF signal

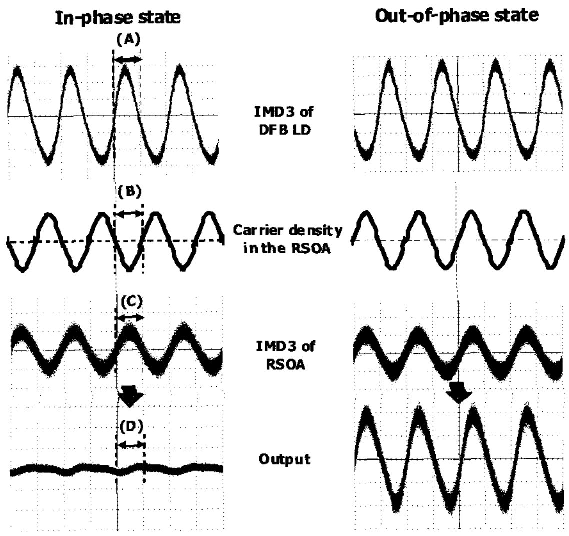

FIG. 2. Phase relation for increase or decrease of single-tone RF signal using XGM effect.

with out-of-phase state. We adopted this technique to the two tone RF transmission.

III. EXPERIMENTS AND DISCUSSIONS

To reduce IMD3 products, the XGM effect as mentioned above is applied to the proposed scheme. There are two factors to construct an effective XGM environment within the RSOA. The first one is input optical power to the RSOA and second is bias current of the RSOA. We experimentally analyzed dependence of the RSOA gain on these two factors. The gain characteristic according to the different input optical power of the RSOA is represented in figure 3 by sweeping the bias current of the RSOA. It was verified the gain of the RSOA was saturated gradually as increasing of its bias current. In addition, the XGM phenomenon was significantly affected according to the input optical power to the RSOA. We selected the input optical

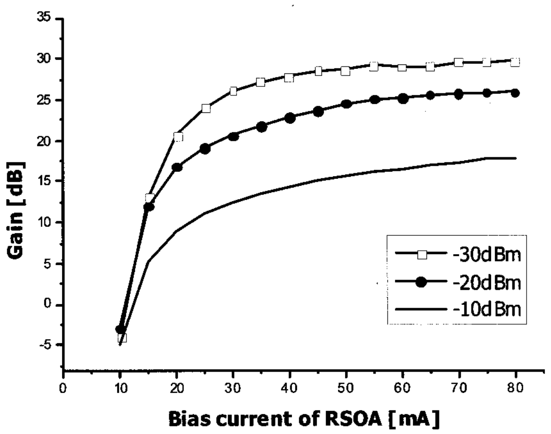

FIG. 3. The dependence of gain on bias current of RSOA with variation of input optical power.

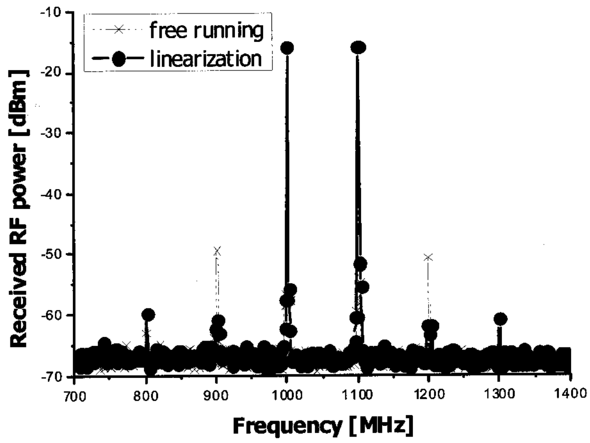

FIG. 4. Received RF spectrum for free running and linearized DFB LD.

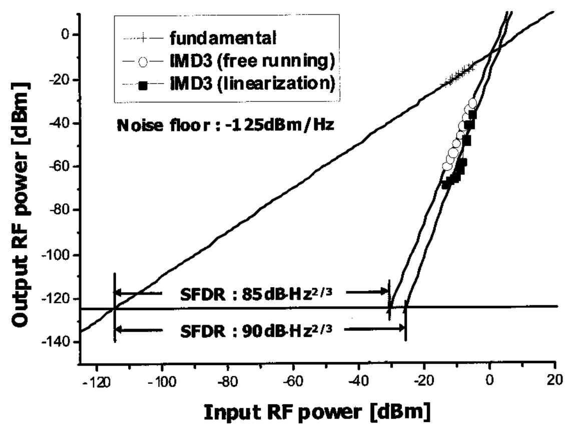

FIG. 5. SFDR of the link for free running and linearized DFB LD.

power of -22 dBm and the bias current of 24 mA to accomplish efficient improvement of the linearization performance and to equalize the received optical power in front of the PD for the proposed scheme compared to that of free-running case. Under these operation conditions, the gain of the RSOA was about 20 dB.

The received RF spectrum for free-running DFB LD is shown by the symbol of '-×-' in figure 4. In this case, the wavelength of the used DFB LD was 1543.13 nm and its threshold current was 10 mA. DFB LD was directly modulated by two tones of 1 GHz and 1.1 GHz with -10 dBm input RF power. The applied bias current of the DFB LD was 22.2 mA and its output optical power was set to be -1 dBm in front of the PD. Modulated optical signal was transmitted and detected by RF spectrum analyzer to estimate the linearization performance. As shown in this figure, the magnitude of upper and lower IMD3 products were about -50 dBm.

The experimental setup of the proposed scheme is as follow. RF carriers of 1 GHz and 1.1 GHz were combined and spit into two paths. Input RF power of the DFB LD was the same as that of the free running case (-10 dBm). Low biased (10 mA) DFB LD was directly modulated by these signals and the modulated optical signals passed through the optical attenuator and the circulator. As is well known, if the bias condition of the laser was sufficiently low, magnitudes of IMD3s can be relatively increased compared to those of the high bias condition, while signal power of the fundamental component are decreased due to clipping operation. RF signal of the other path was passed through the broadband phase shifter and applied into the RSOA. To suppress these IMD3 signals of the DFB LD, the IMD3-magnitudes of the DFB LD were set to the same as those of the RSOA and the IMD3-phases between the DFB LD and the RSOA was set to have just in-phase relationship as shown in figure 2. On the other hand, the magnitude of the fundamental signals was not affected by phase relations, because there was a great difference (> 30 dBm) of magnitude between them. Then, the modulated light containing these magnitude-optimized RF signals were injected into the RSOA with -22 dBm optical power. At this time, these signals would be affected by the XGM effects compared to the phase-optimized RF signal of the RSOA in the cavity of the RSOA. Output power of the proposed scheme was set to be -1 dBm which was the same as for the free running case. As shown in figure 4 (-●-), our experimental result tells us that CNR enhancement of 10 dBc was achieved with optimization of magnitude and phase compared to conventional operation. Figure 5 shows output RF power of the fundamental signal (1.1 GHz) and IMD3 (1.2 GHz) with variation of input RF power for both free-running and linearized DFB LD. With the proposed scheme, spurious-free dynamic range (SFDR) is improved from 85 dB ∘ $Hz^{2/3}$ to 90 dB ∘ $Hz^{2/3}$ by linear fitting.

IV. CONCLUSIONS

We presented the linearization technique of a DFB LD using XGM effect of a RSOA for RoF link. It was observed IMD3 could be suppressed as CIR enhancement of over 10 dBc and dynamic range could be expanded as 5 dB by using the proposed scheme compared to the free-running DFB LD case. We also found that our RSOA-based light injection scheme could be available for various frequency bands and their spacing. This scheme would be useful in SCM optical link where the multiple and broadband carriers are transmitted simultaneously.

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