Gain and Bandwidth Enhancement of Directly Modulated Analog Fiber Optic Links Using Injection-Locked Gain-Coupled DFB Lasers

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Abstract

We report on the experimental demonstration of directly modulated analog fiber optic links with gain-coupled DFB lasers under strong optical injection locking. Successful transmission of BPSK signals up to 18 GHz has been achieved.

I. Introduction

Sub-carrier-multiplexed (SCM) fiber optic systems have received much attention for local access networks, fiber radios, and cable television distributions [1]. With SCM, multiple channels of analog videos and digital telephony/data can all be simultaneously transmitted by a single optical carrier and detected by the same photodetector. Direct modulation of semiconductor lasers is a simple, low-cost approach for the SCM systems. However, its performance is often limited by the modulation bandwidth and the slope efficiency of the lasers. At present, the modulation bandwidths of typical commercial semiconductor lasers are in the range of several gigahertz, and the slope efficiencies vary from 0.1 to 0.4 W/A. Injection locking has been widely studied to improve the dynamics of semiconductor lasers since 1982. Recently, strong injection locking has been shown to be a very effective way to enhance the modulation bandwidth of index-coupled distributed feedback (IC-DFB) laser [2]-[5]. The nonlinear distortion is also reduced by strong optical injection locking [6].

Gain-coupled DFB (GC-DFB) lasers offer many advantages over conventional IC-DFB lasers for direct modulations [7]. They have higher single mode yield, lower chirp, and better resistance to external reflections. In this paper, we report on the experimental demonstration of directly modulated analog fiber optic links employing injection-locked *gain-coupled* DFB (GC-DFB) lasers. Strong optical injection locking enables the link to operate up to 18 GHz, which is much higher than the relaxation oscillation frequency (7 GHz). In addition, the RF modulation efficiency has also been enhanced by 8 dB.

II. Experiments

The experimental setup is shown in Fig. 1. The master laser is a commercial external-cavity tunable laser diode (ECT-LD) with a wavelength of 1.55 μm and a linewidth of < 200 kHz. The CW light from the ECT-LD is first amplified by a high-power erbium-doped fiber amplifier (EDFA) and then injected into the slave laser through an optical isolator. An optical attenuator (ATT) is inserted before the slave laser to control the injection ratio. The slave laser is a 1.55-μm single-longitudinal mode GC-DFB laser with an absorptive grating made by Bell

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Laboratories. The laser structure and performance have been published previously [8]. The threshold current of the laser is 12.5 mA. An externally triggered pattern generator (HP 70843A) provides a baseband signal with 2^{23}-1 pseudo-random bit sequence (PRBS) at 120 Mb/s. The data is first modulated by BPSK on to a sub-carrier at frequency f_m using a double balanced mixer, and then sent to the GC-DFB laser through a bias-T. The GC-DFB laser is biased at 50 mA, and the RF power level before the bias-T is – 4 dBm. At the receiver end, the optical signal is detected by a Lightwave Converter (HP 11982A) with a responsivity of 300V/W for 50-Ω load. The RF signal is amplified by a low noise microwave amplifier (MWA) with 25-dB gain. The resulting BPSK signal is downconverted to baseband PRBS signal by mixing it with a replica of the original microwave carrier. A low-pass filter is added to filter out noise and to shape pulse waveforms. The bit error rate (BER) of the link is monitored by an HP bit error rate test set (HP 70843A).

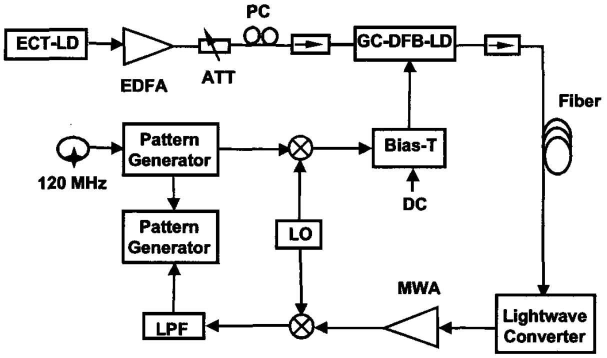

Fig.1. Experimental setup of an analog fiber optic link using an injection-locked gain-coupled DFB laser source.

Stable injection locking is determined by observing the reduction in the linewidth of the GC-DFB laser using the modified delayed self-homedyne (MDSHM) scheme [9]. The injection locking range is plotted in Fig. 2 as functions of injection ratio and detuning frequency. Stable injection locking is observed in the region bounded by the two solid curves: the top curve is the Hopf bifurcation boundary and the bottom curve is the lock-unlocking boundary described in [4].

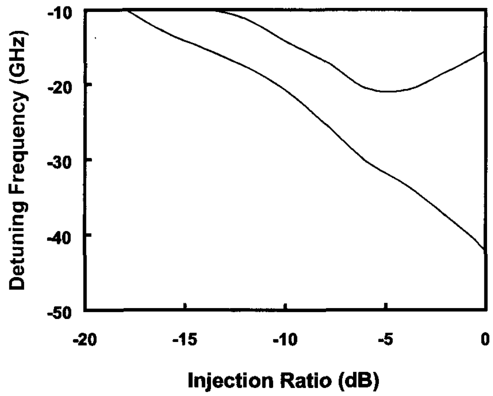

Fig.2. Stable locking range of the GC-DFB laser as functions of injection ratio and detuning frequency.

Figure 3 shows the relative frequency responses of the GC-DFB laser for three different injection ratios. The response of the free-running laser is also shown for comparison. The detuning frequency is fixed at – 25.0 GHz. All of the injection conditions are within the stable injection locking range. The free-running laser does not exhibit a clear resonant peak due to the electrical parasitics of the laser. By measuring the relative intensity noise (RIN), the relaxation oscillation frequency of the free-running laser is estimated to be 7 GHz. With injection locking, the relaxation oscillation frequency increases steadily with the optical injection ratio, similar to what we reported earlier for IC-DFB lasers. The resonant peak is over 18 GHz at –2 dB injection ratio. In contrast to IC-DFB laser, however, the modulation response of the injection-locked GC-DFB laser is also increased by 8 dB. The mechanism for this increase is still under investigation.

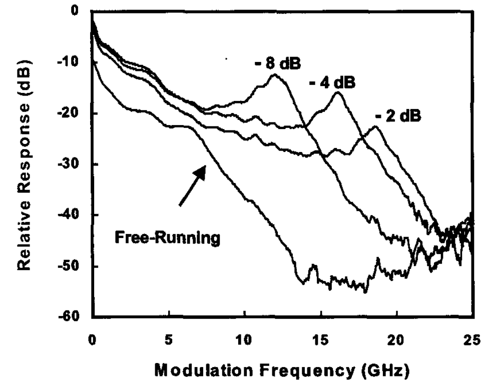

Fig.3. Frequency responses of GC-DFB laser for various injection ratios. The detuning frequency is fixed at - 25 GHz

Figure 4 shows the measured BERs of the link with and without injection locking as functions of the receiver optical power at carrier frequencies of 6 and 18 GHz. The injection ratio and the detuning frequency are fixed at –2 dB and –25 GHz, respectively. The BER of the free-running laser degrades rapidly when the carrier frequency is higher than the relaxation oscillation frequency (7 GHz). No useful signals can be received at sub-carrier frequency of 18 GHz. On the other hand, with injection locking, we are able to achieve a BER of 10^{-9} up to 18 GHz, which is well beyond the bandwidth limitation of the free-running laser. The receiver sensitivity at 18 GHz is only 2 dB lower than that at 6 GHz carrier frequency. Furthermore, the receiver sensitivity at 6 GHz carrier frequency is also improved by 1.2 dB by optical injection. This is attributed to the higher modulation response when the laser is injection locked.

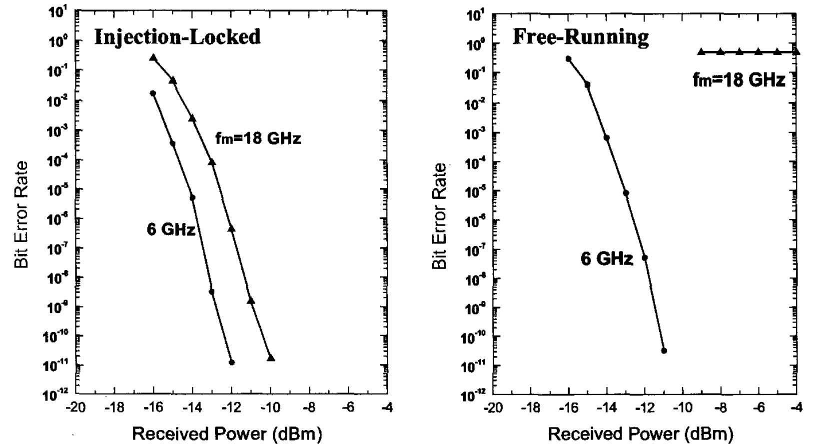

Fig.4. Measured bit error rate (BER) as a function of the received optical power.

III. Conclusions

We have experimentally demonstrated a high-speed directly modulated analog fiber optic link that uses an injection-locked gain-coupled DFB laser. Good BER performance has been obtained at carrier frequencies up to 18 GHz, which is well beyond the relaxation oscillation frequency of the free-running laser (7 GHz). The link loss and the receiver sensitivity are also improved.

IV. Acknowledgment

This work is partially supported by ONR MURI on RF Photonics.

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