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RADIO-OVER-FIBER TRANSPORT SYSTEMS BASED ON DFB LD WITH MAIN AND −1 SIDE MODES INJECTION-LOCKED TECHNIQUE

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Abstract—Full-duplex radio-over-fiber (ROF) transport systems based on distributed feedback laser diode (DFB LD) with main and −1 side modes injection-locked technique is proposed and demonstrated. Improved performances of bit error rate (BER) over a-40 km single-mode fiber (SMF) transmission for down-link, and over an-80 km SMF transmission for up-link were achieved. The characteristic of our proposed systems is the use of one DFB LD with main and −1 side modes injection-locked technique, it reveals a prominent alternative with better performances.

1. INTRODUCTION

To meet the accelerating demands in communication systems, the integration of optical network and wireless radio is a promising solution. Radio-over-fiber (ROF) transport systems have the potential to offer large transmission capacity, significant mobility and flexibility, as well as economic advantage due to its broad bandwidth and low attenuation characteristics [1–4]. The design of microwave signal generation plays an important role for the successful deployment in full-duplex ROF transport systems. The feasibility of employing an Fabry-Perot laser diode (FP LD) with an optical band-pass filter (OBPF) at

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the central station (CS); and employing an optical circulator (OC) with a fiber Bragg grating (FBG) at the base station (BS) was demonstrated previously [5]. However, the performance of systems can be further improved by using distributed feedback (DFB) LD with main and −1 side modes injection-locked technique. In this paper, a full-duplex ROF transport system based on DFB LD with main and −1 side modes injection-locked technique is proposed and demonstrated. Previous study has verified that slave laser can be enhanced with better performance as injection-locked by master laser [6]. −1 side mode injection-locked technique, which can greatly enhance the resonance frequency of DFB LD, is expected to have good performance in full-duplex ROF transport systems [7, 8]. Main and −1 side modes of DFB LD are injection-locked, one is used as the down-link light source, and the other is used as the up-link one. DFB LD with main and -1 side modes injection-locked in practical implementation of ROF transport systems has not been proposed. To the best of our knowledge, it is the first time to transmit down/up-link ROF signals simultaneously employed one DFB LD with main and -1 side modes injection-locked. Down/up-link ROF transport systems are envisioned to have two DFB LDs should be wavelength-selected for each channel and controlled to operate at a specific wavelength. However, this process will increase the cost and complexity of systems. For a practical implementation of down/up-link ROF transport systems, it is necessary to develop optical sources with low cost and low complexity. One DFB LD with main and −1 side modes injection-locked is a feasible scheme. It is attractive because it avoids the need of two DFB LDs with selected wavelengths. This proposed scheme used two modes for microwave transmission (WiMAX; 70 Mbps/10 GHz). Improved performances of bit error rate (BER) over a-40 km single-mode fiber (SMF) transmission for down-link, and over an-80 km SMF transmission for up-link were achieved.

2. EXPERIMENTAL SETUP

The experimental configuration of our proposed full-duplex ROF transport systems based on DFB LD with main and −1 side modes injection-locked technique is shown in Figure 1. For down-link transmission, the DFB LD, with a central wavelength of 1545.1 nm (λ), is directly modulated at 70 Mbps data stream mixed with 10 GHz microwave carrier (WiMAX). For light injection part, light are injected in the counter-propagation direction through optical isolators and 3-dB optical coupler. The wavelengths of the injected light are 1545.22 (λ_0) and 1543.86 (λ_{-1}) nm, respectively. The wavelengths of the injected light have been carefully chosen to match with two modes (main

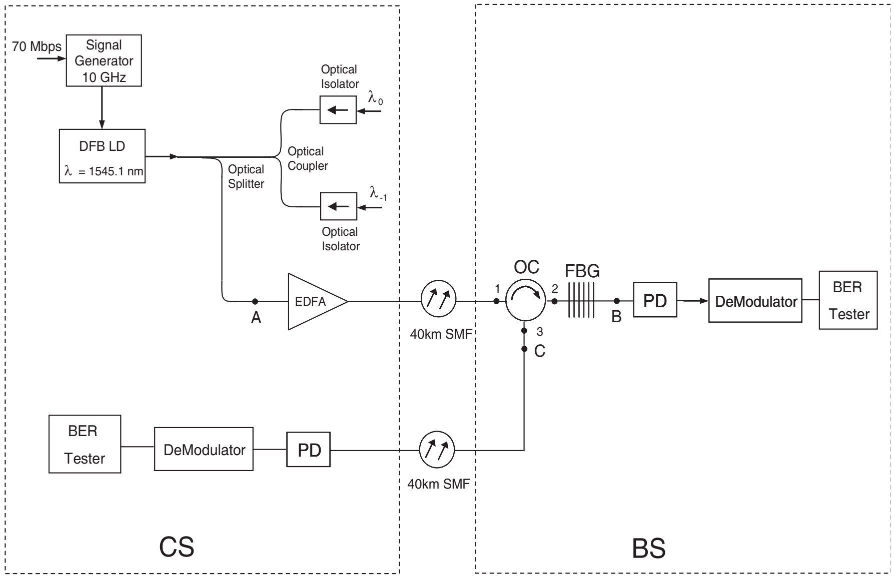


Figure 1. Experimental configuration of our proposed full-duplex ROF transport systems.

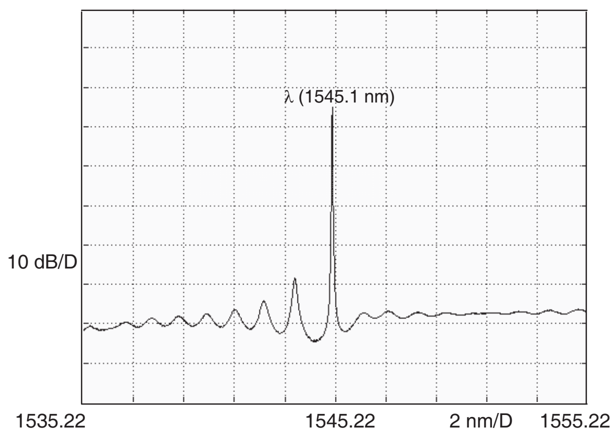
and −1 side modes) of DFB LD. The optical power levels of these two injection-locked modes are amplified by an erbium-doped fiber amplifier (EDFA). For down-link transmission, the generated signal at the CS is distributed to the BS over a 40-km SMF transport. At the BS, the received signal is fed into a 3-port OC. The transmission optical signal is coupled into the port 1 of OC, the port 2 of OC is connected with a FBG with a central reflective wavelength of 1543.86 nm, and the port 3 of OC is connected with a-40 km SMF link. The FBG exhibits a sharp cutoff in the reflection spectrum, with a 3-dB bandwidth of 0.3 nm and a 35-dB bandwidth of 0.44 nm. OC in combination with FBG are used to take on two roles: one is to pick up the optical wavelength for down-link light source (λ_0), and the other is to reflect the optical wavelength for up-link one (λ_{-1}). The down-link data signal is detected by a broadband photodiode (PD), and applied to a demodulator. 70 Mbps down-link data signal is fed into a BER tester for BER analysis after demodulation. As to the up-link transmission, the up-link optical signal is transmitted to the CS over a 40-km SMF transmission from the port 3 of OC, detected by a PD, and fed into a BER tester for BER analysis after demodulation.

3. EXPERIMENTAL RESULTS AND DISCUSSION

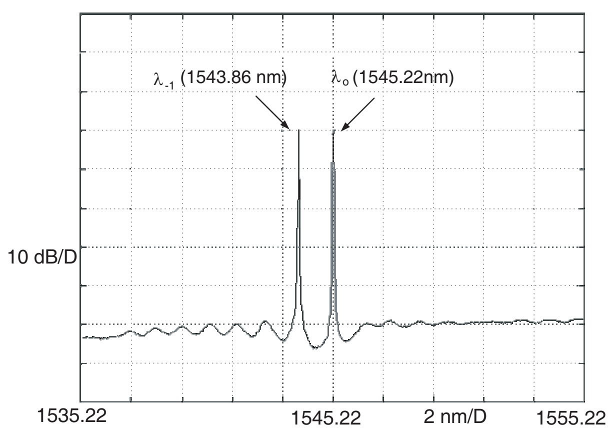
The injection-locked range for laser under light injection is given by [9]

$$-\sqrt{1+\alpha^2}\cdot k\cdot\left(\frac{A_{inj}}{A_0}\right)\leq\Delta\omega_L\leq k\cdot\left(\frac{A_{inj}}{A_0}\right) \tag{1}$$

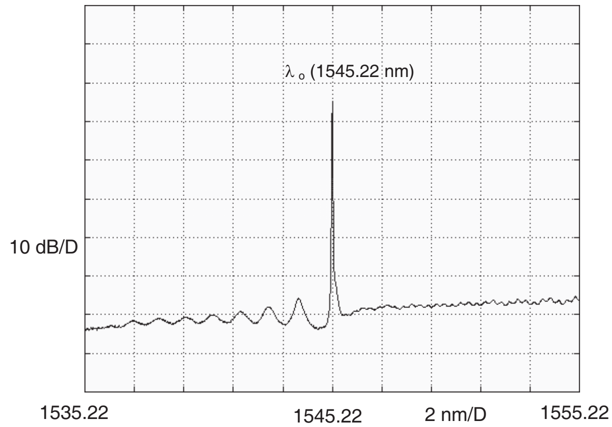
where α is the linewidth enhancement factor, k is the coupling coefficient, A_{inj} is the field amplitude injected into the slave laser, A_0 is the steady-state amplitude of the slave laser under light injection, and $\Delta\omega_L$ is the range of detuning frequencies ($\Delta\omega$) that result in a locked state. Within the locking range, the frequency of slave laser is locked nearly to that of the master laser. At the CS, the optical spectra of



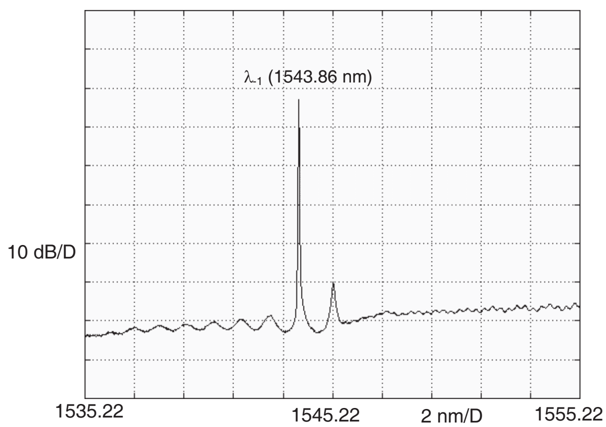
(a)



(b)



(c)



(d)

Figure 2. (a) The optical spectrum of the free-running DFB LD. (b) The optical spectrum of the injection locking DFB LD locked at λ_0 and λ_{-1}. (c) The optical spectrum transmitted by the FBG (λ_0). (d) The optical spectrum reflected by the FBG (λ_{-1}).

the free-running DFB LD as well as locked at λ_0 and λ_{-1} (Figure 1, point A) are present in Figures 2(a) and (b), respectively. For main mode injection locking, the condition is found as the detuning between λ_0 and λ is $+0.12$ nm ($1545.22-1545.1 = 0.12$). At the BS, the optical spectra transmitted (Figure 1, point B) and reflected (Figure 1, point C) by the FBG are present in Figures 2(c) and (d), respectively.

The resonance frequency f_0 in an injection-locked LD can be

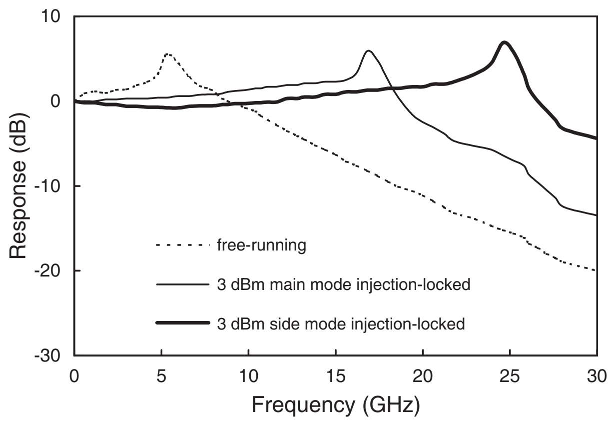


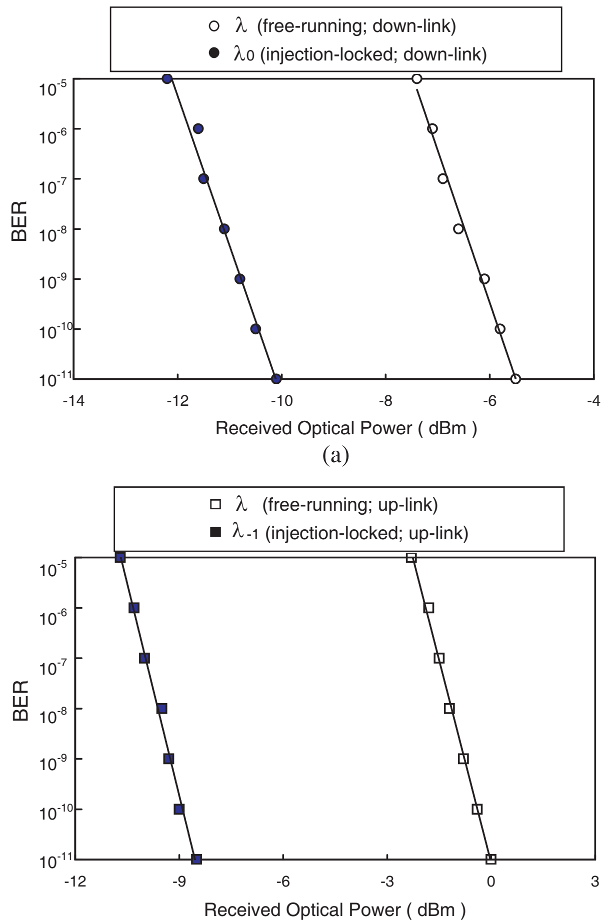
Figure 3. The frequency response of DFB LD for free-running, with 3 dBm main mode injection-locked, and with 3 dBm −1 side mode injection-locked.

expressed as [10]

$$f_0 \approx \frac{1}{2\pi}\left(\frac{F_a G_a G_{a,n}}{\Gamma} - \frac{f^2 F_I}{4F_a}\right)^{1/2} \tag{2}$$

where F_a and F_I are the average photon densities of the mode a and of the injected light, G_a is the modal gain of the mode a, $G_{a,n} = dG_a/dn$, f is the intermodal spacing in the frequency domain, and Γ is the confinement factor. f_0 is enhanced with injection into negative side mode, thereby, the laser resonance frequency under −1 side mode injection-locked is larger than that under main mode injection-locked. The frequency response of DFB LD for free-running, with 3 dBm main mode injection-locked, and with 3 dBm −1 side mode injection-locked is present in Figure 3. In the free-running case, the laser resonance frequency is around 5.3 GHz. With 3 dBm main mode injection-locked, the laser has a resonance frequency of about 17.8 GHz. With 3 dBm −1 side mode injection-locked, the laser resonance frequency is increased up to 24.6 GHz, which is more than 4.6 times ($24.6/5.3 \sim 4.6$) laser resonance frequency of free-running case.

The measured down-link (λ and λ_0) and up-link (λ and λ_{-1}) BER curves as a function of the received optical power level are plotted in the Figures 4(a) and (b), respectively. For down-link transmission (40 km SMF) and at a BER of 10^{-9}, in the free-running, the received optical power level is −6.1 dBm; with 3 dBm injection-locked, the received optical power level is −10.8 dBm. A 4.7-dB received optical



(b)

Figure 4. (a) The measured down-link (λ and λ_0) BER curves as a function of the received optical power level. (b) The measured up-link (λ and λ_{-1}) BER curves as a function of the received optical power level.

power reduction is achieved as main mode injection-locked technique is employed. For up-link transmission (80 km SMF; CS $\rightarrow$ BS $\rightarrow$CS) and at a BER of 10^{-9}, in the free-running (the FBG used in the experiment has been changed with a central reflective wavelength of 1545.1 nm), the received optical power level is -0.8 dBm; with 3 dBm injection-locked (FBG with a central reflective wavelength of 1543.86 nm), the received optical power level is -9.3 dBm. An 8.5-dB received optical power reduction is achieved as -1 side mode injection-locked technique is employed. Since the laser resonance frequency under −1 side mode injection-locked is larger than that under main mode injection-locked, the reduction of the received optical power under −1 side mode injection-locked is larger than that under main mode injection-locked. Moreover, due to longer fiber transmission length, the up-link transmission exhibits power penalties of 5.3 (free-running) and 1.5 (3 dBm injection-locked) dB compared to down-link transmission.

4. CONCLUSION

We proposed and demonstrated a full-duplex ROF transport system employing DFB LD with main and −1 side modes injection-locked technique. Improved performances of BER both for down-link and up-link were achieved. The feature of our proposed systems is the use of DFB LD with main and −1 side mode injection-locked technique, it reveals an outstanding one with better performances.

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