OThN5.pdf

OFDM signal transmission by direct modulation of a doped fiber external cavity semiconductor laser

Runnan Liu [1,2], M. E. Mousa Pasandi [3], Sophie LaRochelle[3], Jianping Yao[4], Ke Wu[2] and Raman Kashyap[1,2]

[1] *Advanced Photonics Concepts Laboratory, École Polytechnique de Montréal, Montréal, Canada*
[2] *PolyGrames Research Center, École Polytechnique de Montréal, Montréal, Canada*
[3] *Centre d'optique, photonique et laser, Département de génie électrique et de génie informatique,Université Laval, Québec, Canada*
[4] *Microwave Photonics Research Lab, University of Ottawa, Ottawa, Canada*
raman.kashyap@polymtl.ca & *larochel@gel.ulaval.ca*

Abstract: A doped fiber external cavity laser (DFECL) exhibits high power, narrow linewidth and stable wavelength which may be tuned. We demonstrate IEEE 802.11 signal transmission by direct modulating the ultra long DFECL at ~2.5GHz.

OCIS code: 140.3500 Lasers, erbium, 060.5625 Radio frequency photonics, 060.2330 Fiber optics communications

1. Introduction

A doped fiber external cavity laser (DFECL) is constructed with a Fabry-Perot (FP) semiconductor laser, a length of doped fiber and a fiber Bragg grating (FBG). DFECLs with this simple structure have been shown to demonstrate high power, narrow linewidth, stable wavelength, and tunable wavelength [1-4]. Due to absorption bleaching [5], spatial hole burning creates a dynamic grating which has a strong influence on the oscillating mode inside the cavity, and therefore narrows the linewidth and stabilizes the laser [5,6]. This source can be of benefit for optical fiber data transmission. Direct modulation has the advantages of a simple structure, low cost, and high power. The biggest disadvantage of the long cavity for direct modulation is its low modulation bandwidth. Direct modulation bandwidth is limited by either the photon relaxation frequency, or the cavity resonant frequency. Beyond the resonant frequency, the modulation response decreases rapidly. The ultra long cavity of the DFECL has a very low resonant frequency which limits applications with the direct modulation approach. It was found that because of cavity mode locking, the transmission response may be sharply increased at a multiple of the resonant frequency [7]. Narrow bandwidth radio frequencies can thus be transmitted by modulation at the multiples of the resonant frequency. The direct modulation transmission response is therefore extended to several multiples of the cavity resonance frequency. As there is a saturable absorber in the laser cavity, resonance enhanced direct modulation may also available with the DFECL. The extended modulation bandwidth may thus be useful for applications in fiber optic communications.

Following the surge of interest in mobile access, implementing wireless local area network (WLAN) transmission links with radio-over-fiber (ROF) technology is in the limelight as a replacement for conventional, large-footprint, lossy and sophisticated RF-based components. Meanwhile the cost issue in ROF is believed to be the most significant barrier [8]. The DFECL can be considered as an important step towards achieving a cost-effective solution for ROF link by eliminating external modulators and associated electronics. To study the feasibility of the DFECL, it is important to have IEEE 802.11 compliant signals in a real ROF transmission link, the foremost WLAN modulation format. These signals are based on OFDM modulation with 20 MHz or 40 MHz bandwidth around the RF carrier frequency of 2.5 or 5 GHz. The bandwidth is divided into 52 sub-carriers with 48 data tones that can be multi-level quadrature amplitude modulated (QAM). The maximum transmission rate achievable for IEEE 802.11a is 54Mb/s, using a dense 64-QAM constellation, which is very sensitive to link noise and distortion.

In this paper, we report a study of a directly modulated DFECL for ROF transmission. It is shown that the frequency response of a DFECL is sufficient to allow the generation of high quality 802.11a. We present a signal generation experiment of DFECL direct modulation with error-vector-magnitude (EVM) measurement, a well-known performance metric of IEEE 802.11. To the authors' best knowledge, this is the first experiment of transmitted and detected OFDM signal using the ultra long DFECL. Our experimental results show that this DFECL is suitable ROF application using direct modulation.

2. Experiment

A DFECL for this experiment was built by using a JDS 3400 semiconductor laser diode (LD), CorActive erbium doped fiber (EDF), and an FBG. The laser diode was a high power FP pump laser with the front facet antireflection-coated. The FBG had a full bandwidth of ~0.2 nm and a peak reflectivity of 6 dB at its center wavelength. A 30cm long EDF was used. The cavity length was ~93 cm with a round trip time of ~9.2 ns equivalent to a resonant frequency of ~112 MHz.

The experimental setup for direct modulation of the DFECL is shown in Figure 1. During the experiment, only the semiconductor laser diode of the DFECL was placed on a temperature controlled ILX LDM4980RF laser diode mount, the other parts of the DFECL were at ambient temperature.. The laser's center wavelength was at 1489.89nm. The RF wave was directly applied to the laser diode via the ILX laser diode mount. The RF input to the DFECL was provided by a vector signal generator (VSG), and after an optical isolator and an amplified photodetector, the received signal was fed to a vector signal analyzer (VSA).

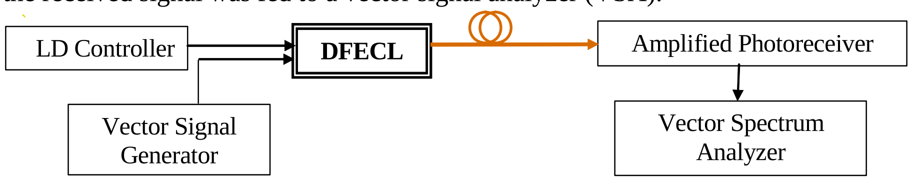

Figure 1 The setup for microwave transmission by DFECL.

During the experiment, the DFECL was biased at a drive current of 207.6 mA, and maintained at a temperature of 17.6° C. The output of the DFECL was ~5 dBm, at the wavelength of 1489.6 nm. Following the standard of IEEE 802.11a, the 64-QAM IEEE 802.11a with maximum rate of 54 Mb/s from the E4438C was set with a 20MHz bandwidth, and the RF carrier was carefully tuned to 2.4668 GHz, to achieve the best transmission response. The RF power fed to the laser diode was set to 0dBm, 5 dBm, 7.5dBm, and 10 dBm, respectively.

Figure 2 depicts the received signal spectrums which are 35 - 45 dB above the noise level. The highest RF input signal gave best signal to noise ratio. The IEEE 802.11 signal quality can be characterized by the EVM defined as

$$EVM_{dB} = 10\log_{10}\left((\sum_n |r_n - z_n|^2) / \sum_n |r_n|^2 \right) \quad (1)$$

where *r* represents the transmitted 64-QAM symbols and *z*, the received ones. IEEE 802.11a protocol specifies -25 dB as the maximum allowable EVM value for error free transmission. The signals were composed of frames with a synchronization symbol, a channel-response training symbol, and a payload of 16 OFDM-symbols. After detection, the 64-QAM symbols are extracted to measure the EVM. The EVM and detected RF power measurements were performed by a VSA as a function of the RF powers injected to the DFECL. For comparison, the same measurements were repeated with an externally-modulated source consisting of a DFB laser (with 5 dBm optical power) and Mach-Zehnder (MZ) modulator. In this case the MZ modulator bias was set at the quadrature point to suppress second harmonic distortion and increase the modulation efficiency. The detected optical powers on the photodetector were 3 dBm for direct modulation and -3.5 dBm for external modulation, a 6.5 dB difference because of the losses introduced by the external modulator. Figure 3 presents the EVM measurement results for the two laser sources and the electrical back-to-back EVM measurement with the VSG directly connected to the VSA. The EVM degradation with increasing RF power for an externally-modulated link is expected and is caused by the MZ third-order distortion as reported in [9]. Meanwhile the DFECL shows a completely different behavior with decreasing EVM as the RF power increases. A pronounced improvement in signal quality is noted for high RF power levels with EVM leveling off to the electrical back-to-back value at 10 dBm of input RF power. This confirms that the directly-modulated signal transmission quality is noise-limited rather than distortion limited and, therefore, by increasing the optical power (or carrier to noise ratio), signal quality is improved. For all input RF powers the DFECL's performance easily surpasses the error free transmission protocol threshold. Furthermore, it is evident that the DFECL generates a signal with equal or even slightly higher quality than the externally-modulated link for the ROF region of interest (around 5 dBm of input RF power). It should be noted that the semiconductor chip is a pump laser within a low frequency package. Meanwhile, the laser was driven at more than 200 mA with relative small RF signal which is why the detected RF signals are lower than -30 dBm (figure 2). We believe that this could be improved by designing a laser chip with the appropriate high frequency RF package.

OThN5.pdf

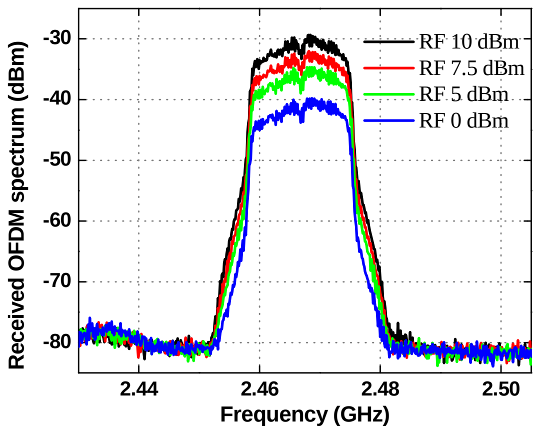

Figure 2 The received OFDM spectrum transmitted from directly modulating a DFECL

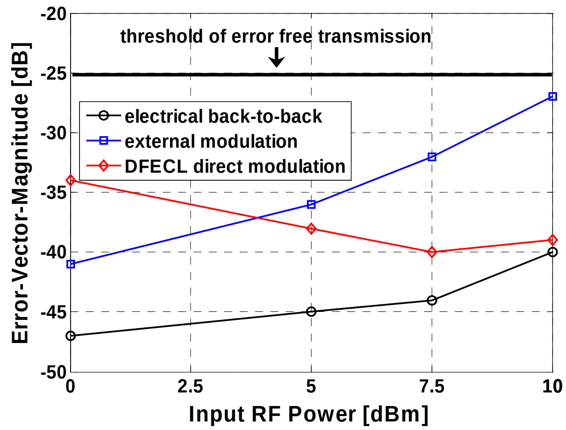

Figure 3 EVM measurement results versus different RF input power for the DFECL and externally-modulated DFB laser diode.

3. Conclusion

In this paper, we have presented experimental results on the OFDM signal transmission for direct modulation of an ultra long DFECL for a radio-over-fiber application. Although the DFECL has a cavity resonance frequency of only ~110 MHz, a high quality 64-QAM IEEE 802.11a signal at ~2.5 GHz can be applied to directly modulate this laser. This verifies that the enhanced direct modulation of the resonant cavity is available for radio over fiber application. A benefit of the narrow linewidth and stable wavelength, the OFDM signal transmission by direct modulation of the DFECL shows very good EVM performance; as has been demonstrated, it may be even better than external modulation in some operating conditions and always a lower cost solution in comparison.

Acknowledgements: The authors acknowledge the Canadian Institute for Photonics Innovation (CIPI) Technology Exploitation Grant for New Collaborations, Natural Science an Engineering Research Council's (NSERC) Strategic Grant's Program, the NSERC's Discovery Grants program and NSERC's Canada Research Chairs Program, for their support of the research. The authors would like to thank L. A. Rusch and M. M. Sisto for insightful discussions.

References

[1]. W.H. Loh, R.I. Laming, M.N. Zervas, M.C Farries, and U. Koren, "Single frequency erbium fiber external cavity semiconductor laser", Applied Physics Lett.,66(25), 3422-3424, (1995).

[2]. F.N. Timofeev and R. Kashyap, "High-power, ultra-stable, single-frequency operation of a long, doped-fiber external-cavity, grating-semiconductor laser", Opt. Express, 11(6), 515-520, (2003).

[3]. R. Liu, I. A. Kostko, K. Wu, and R. Kashyap, " Side mode suppression using a doped fiber in a long external-cavity semiconductor laser operating at 1490 nm", Opt. Express, 14(20), 9042-9050, (2006).

[4]. R. Liu, I. A. Kostko, K. Wu, and R. Kashyap, "Stable and continuous wavelength tuning of a hybrid semiconductor laser with an erbium-doped fiber external cavity", Optics Lett. 32(12), 1635-1637, (2007)

[5]. R.N. Liu, I.A. Kostko, R. Kashyap, K. Wu, and P. Kiiveri, "Inband-Pumped, Broadband Bleaching of Absorption and Refractive Index Changes in Erbium Doped Fiber", Optics Commun., 255, (1-3), pp.65-71, (2005).

[6]. I. Kostko and R. Kashyap, "Dynamics of ultimate spectral narrowing in a semiconductor fiber-grating laser with an intracavity saturable absorber", Opt. Express 14(7), 2706-2714, (2006).

[7]. B. Georges, D.M. Cutrer, O. Solgaard, and K.Y. Lau, "Optical transmission of narrowband millimeter-wave signals", IEEE, Trans. Microwave Theory Tech., 43(9), 2229-2240, (1995).

[8]. M. M. Sisto, S. LaRochelle, and L.A. Rusch, **"**Gain optimization by modulator bias control in radio-over-fiber links**",** J. of Lightwave Technol., 18, 1840-1842 (2006).

[9]. N. Horvath and I. Frigyes, "Effects of the nonlinearity of a Mach–Zehnder modulator on OFDM radio-over-fiber transmission," IEEE Commun. Lett., vol. 9, no. 10, pp. 921–923 (2005).