

Improved Performance of a Hybrid Radio/Fiber System Using a Directly Modulated Laser Transmitter With External Injection

A. Kaszubowska, *Student Member, IEEE*, P. Anandarajah, *Student Member, IEEE*, and L. P. Barry, *Member, IEEE*

Abstract—A directly modulated laser diode with external light injection is used to generate microwave optical signals for a hybrid radio/fiber system. The external light injection greatly enhances the frequency response of the laser, and thus, significantly improves the overall performance of the hybrid system. Experimental results show a 14-dB improvement in system performance for the externally injected laser in a hybrid radio/fiber communication link used for distributing 155-Mb/s data signals.

Index Terms—External light injection, microwave photonics, modulation bandwidth, optical communications, optical systems, semiconductor laser diode.

I. INTRODUCTION

AS THE DEMAND for broadband mobile services such as video-on-demand and mobile computing increases, so does the need to develop high-capacity mobile communication networks, which are capable of delivering broadband signals to remote areas “over the air.” High-capacity mobile networks of the future will probably use high frequency microwave signals as the access medium (15 – 60 GHz), as this offers a large bandwidth for data transfer. These high-capacity microwave access networks are likely to employ an architecture in which signals are generated at a central location and then distributed to remote base stations using optical fiber, before being transmitted over small areas using microwave antennas [1], [2]. Such an architecture should prove to be highly cost efficient, since it allows sharing the transmission and processing equipment (remotely located in the central control station) between many base stations.

To develop an optically fed microwave wireless network of this type, requires the amalgamation of many different technologies. On the transmission side, the main technical challenge is to generate the microwave optical data signals using semiconductor laser diodes. The simplest technique available to generate optical microwave signals, involves direct modulation of the laser with the microwave data carrier. However, the limited bandwidth of laser diodes means that we are normally unable to use high frequency RF carriers (>10 GHz), which could be employed to transmit very broadband data signals. This difficulty with direct modulation has resulted in the use of more complicated techniques for optical microwave signal generation in hybrid radio/fiber systems [3], [4], such as employing external

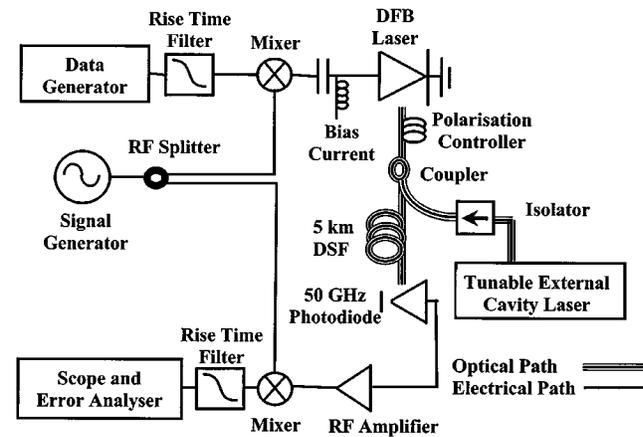


Fig. 1. Experimental setup for hybrid radio/fiber system using directly modulated laser with external injection.

modulators or dual mode laser diodes. However, it has recently been shown [5], [6], that by using external injection into a laser diode, its modulation response can be significantly enhanced. In this letter, we demonstrate that this enhancement of the modulation response allows us to greatly improve the performance of an optically fed microwave system based on direct modulation of laser diodes. A 14-dB improvement in system performance is obtained with a hybrid radio/fiber system used for distributing 155-Mb/s data signals on an 18-GHz RF carrier.

II. EXPERIMENTAL SETUP

The experimental setup to examine the use of a directly modulated laser diode with external injection in a hybrid radio/fiber system is presented in Fig. 1. An Anritsu pattern generator produces a 155-Mb/s nonreturn-to-zero (NRZ) data stream, which is initially mixed with an 18-GHz RF carrier to generate the binary phase-shift keying (BPSK) data signal. The resulting microwave data signal is then used to directly modulate a single-mode laser diode from NTT Electronics. The laser used is a distributed feedback (DFB) multiple-quantum-well device with a threshold current of 26 mA, a central emission wavelength of 1543.2 nm, and a 3-dB electrical bandwidth of 8 GHz. The 18-GHz RF data signal can be applied either to the free-running laser, or it can be applied to the laser diode into which light is injected from a tunable external cavity laser (ECL). In both cases, the RF data signal is combined with a dc bias current of 55 mA. The resulting optical microwave data

Manuscript received June 20, 2001; revised October 26, 2001.

The authors are with the School of Electronic Engineering, Dublin City University, Dublin 9, Ireland (e-mail: liam.barry@dcu.ie).

Publisher Item Identifier S 1041-1135(02)00491-3.

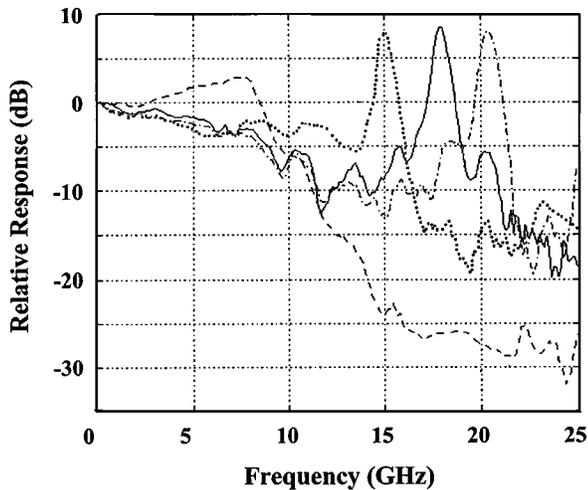


Fig. 2. Modulation response of single-mode laser measured under free running conditions, and with external injection levels of -3 dBm (dotted line), 0 dBm (solid line), and 3 dBm (dashed line) from ECL. The dc bias current was 55 mA in all cases.

signal from the laser is then passed through 5 km of dispersion-shifted fiber (to minimize chromatic dispersion effects that may cause severe RF power degradations in the system [8]) before being detected with a 50 -GHz pin photodiode. In a complete system, the output signal of the detector would be transmitted through an RF antenna to the mobile network stations, where the data is received by down converting the incoming signal using a local oscillator. However, in our experiment, we have concentrated on the optical part of the system, hence, the down conversion takes place after the photodiode, by mixing the data signal with an 18 -GHz local oscillator. The resulting 155 -Mb/s data signal may then be displayed on the oscilloscope, or fed into the Anritsu error analyzer to determine the bit-error rate (BER) of the received signal.

III. EXPERIMENTAL RESULTS

The improvement in the modulation bandwidth of a laser diode that can be obtained by external injection has recently been demonstrated both theoretically and experimentally [5], [6]. In our setup, we use external injection from an ECL into a single-mode laser to greatly enhance the bandwidth of the laser diode, the complete experimental set-up for the external injection is similar to that described in [7]. The wavelength of the injected signal must be accurately tuned to ensure that the optimal enhancement in modulation response is obtained. Fig. 2 displays the modulation response of the device under free running conditions, and also when the external injection level from the ECL is set to -3 , 0 , and 3 dBm. The wavelength of the injected light from the ECL was set to 1543.24 nm. By varying the injected power level, we can optimize the lasers response at any specific frequency (up to approximately 22 GHz). For this experiment, we set the injection power level to 0 dBm, as this gave us maximum response at 18 GHz, which is the frequency we are using in our hybrid fiber/radio system demonstration. Propagation of the resulting optical microwave data signal over 5 km

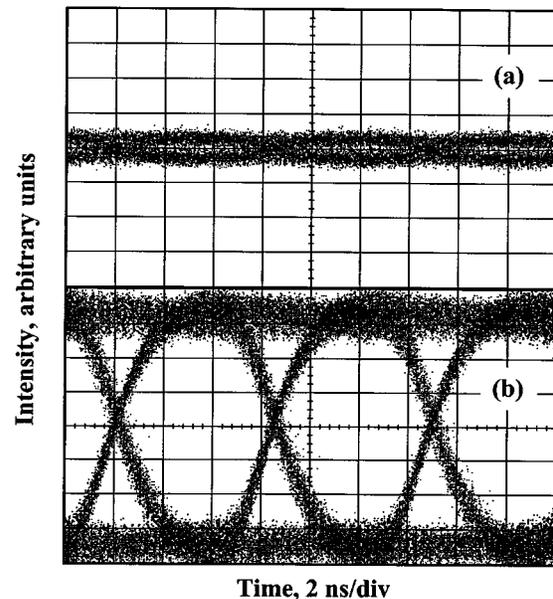


Fig. 3. Received eye diagrams of 155 -Mb/s data signal from the optically fed microwave system using (a) free running laser diode. (b) Laser diode with the external injection level of 0 dBm. Received optical power (before photodiode) was -12 dBm in both cases.

of dispersion-shifted fiber does not greatly effect the system performance, as the total dispersion in the transmission fiber is negligible at the operating wavelength (-9 ps/nm). For transmission over longer distances, or over standard single-mode fiber, chromatic dispersion may cause severe RF power degradations in the system [8], due to the double side-band nature of the signal from the directly modulated laser diode. However, in a real system, we expect that this problem may be overcome by employing an optical filter to select out the optical carrier and one signal side-band, before the optical signal is detected. Clearly, the transmission characteristic of this filter will need to be as close to square shaped as possible, with a bandwidth slightly larger than the RF carrier frequency. Custom designed fiber Bragg grating type filters should be suitable for this application.

Fig. 3 displays the received eye diagrams for the cases when the directly modulated laser was 1) free running, and 2) had an external injection level of 0 dBm from the ECL. The received optical power (before the photodiode) in both cases was -12 dBm. The major improvement in system performance when external injection is employed can be clearly seen. We then placed a variable attenuator before the photodiode and measured the received BER as a function of received optical power, with and without external injection. These results are presented in Fig. 4, which shows that there is a 14 -dB improvement in system performance, for a received BER of 10^{-9} , when external injection is applied to the directly modulated laser. This improvement in system performance is less than would be expected (16 dB) from the enhanced electrical frequency response shown in Fig. 3. This is attributed to the fact that the external injection not only improves the laser bandwidth, but also reduces the laser threshold, thus, increasing the average optical output power from the device.

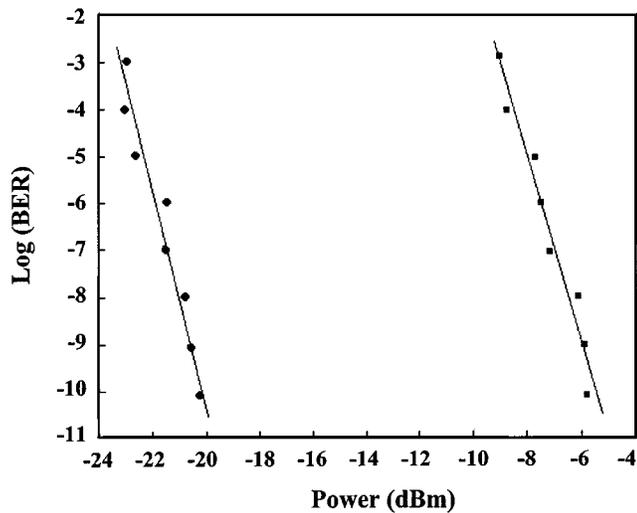


Fig. 4. BER versus received optical power using directly modulated laser with (circles) and without (squares) external injection.

IV. CONCLUSION

The future development of hybrid fiber-radio systems is highly dependent on the use of simple and efficient technologies to generate the optical microwave signals at the central station for distribution over fiber to remote base stations. Direct modulation of a laser diode with the RF data signal is the simplest technique available, but the limited bandwidth of laser diodes is a major constraint with this technique. In this letter, we have shown that by using external injection into the directly modulated laser, we can enhance the modulation response of the laser, such that the system performance of a radio over

fiber distribution network is significantly improved. By varying the power level of the external injection, we can also vary the microwave frequency at which the modulation response is enhanced. We have demonstrated an overall improvement in system performance of 14 dB when using this technique to distribute a 155-Mb/s data signal on an 18-GHz RF carrier in an optically fed microwave system.

REFERENCES

- [1] R. P. Braun, G. Grosskopf, H. Heidrich, C. von Helmolt, R. Kaiser, K. Kruger, U. Kruger, D. Rohde, F. Schmidt, R. Stenzel, and D. Trommer, "Optical microwave generation and transmission experiments in the 12- and 60-GHz region for wireless communications," *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 320–330, Apr. 1998.
- [2] Z. Ahmed, D. Novak, R. B. Waterhouse, and H.-F. Liu, "37-GHz fiber-wireless system for distribution of broad-band signals," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 1431–1435, Aug. 1997.
- [3] T. Kuri, K. Kitayama, A. Stohr, and Y. Ogawa, "Fiber-optic millimeter-wave downlink system using 60 GHz-band external modulation," *J. Lightwave Technol.*, vol. 17, pp. 799–806, May 1999.
- [4] K. Sato, A. Hirano, N. Shimizu, T. Ohno, and H. Ishii, "Optical millimeter-wave generation by dual-mode operation of semiconductor modelocked lasers," *Electron. Lett.*, vol. 36, pp. 340–342, 2000.
- [5] G. Yabre, "Effect of relatively strong light injection on the chirp-to-power ratio and the 3 dB bandwidth of directly modulated semiconductor lasers," *J. Lightwave Technol.*, vol. 14, pp. 2367–2373, Oct. 1996.
- [6] X. J. Meng, T. Chau, and M. C. Wu, "Experimental demonstration of modulation bandwidth enhancement in distributed feedback lasers with external light injection," *Electron. Lett.*, vol. 34, pp. 2031–2032, 1998.
- [7] L. P. Barry, P. Anandarajah, and A. Kaszubowska, "Optical pulse generation at frequencies up to 20 GHz using external-injection seeding of a gain-switched commercial Fabry-Perot laser," *IEEE Photon. Technol. Lett.*, vol. 13, pp. 1014–1016, Sept. 2001.
- [8] G. H. Smith, D. Novak, and Z. Ahmed, "Overcoming chromatic – dispersion effects in fiber-wireless systems incorporating external modulators," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 1410–1415, Aug. 1997.