STABLE AND HIGH-POWER LASER DIODE MODULE FOR MILLIMETER-WAVE GENERATION

Toshiaki Kuri and Ken-ichi Kitayama
Communications Research Laboratory (CRL),
Ministry of Posts and Telecommunications
4-2-1, Nukui-kitamachi, Koganei, Tokyo 184, Japan

Abstract

A 60GHz-band millimeter(mm)-wave signal generation using a long-term frequency-stabilized 60GHz MLLD module will be presented. The output optical power of the MLLD module is more than 6.0dBm. The generated 60GHz mm-wave signal with the 3dB linewidth of less than 300Hz over 2.9km-long optical fiber link is successfully demonstrated.

Introduction

Millimeter(mm)-wave frequency region will become necessary for supporting future radio-based broadband access services because of the expected shortage of currently available microwave frequency region. As the electrical delivery of mm-wave signals to the remote antenna units dose not seem to be realistic, the fiber-optic transport is a strong candidate due to not only the extremely wide bandwidth but also an availability of optical amplifiers. Therefore, many techniques for generating and distributing mm-wave signals over fiber-optic links have been studied [1] $\sim$ [7]. The authors have proposed a 60GHz millimeter-wave generation technique using stabilized mode-locked laser diode (MLLD) with optical frequency demultiplexing switch [8, 9]. The MLLD, however, requires position alignments and a fine tuning for the repetition rate, and it still needs further improvements.

In this paper, we will present a practical generation and transport technique of mm-wave signal over fiber-optic links using a long-term stable and high-power MLLD module. This MLLD module is alignment free, highly stable in the repetition rate within 100Hz, and of high power larger than 6.0dBm. The optical generation and transport of 60GHz-band mm-wave with very narrow linewidths of less than 300Hz over an optical fiber link is successfully demonstrated, and also the high stability of the MLLD module is confirmed. This technique would be practically applicable for fiber-optic radio-based broadband multi-access networks.

System Configuration

Figure 1 shows the configuration of the proposed fiber-optic radio-based broadband access network. The multi-frequency coherent lightwaves with an equi-frequency interval of a desired mm-wave carrier frequency are emitted from a 60GHz MLLD module stabilized by a sub-harmonic optical injection from the master laser diode [10]. As shown in the photograph of Fig. 1, the test 60GHz MLLD module is compact (90mm(W) $\times$ 32mm(D) $\times$ 26mm(H)) and the optical input and output are connected with polarization maintaining fibers. The MLLD module is pulled into exactly the 6th harmonic of the repetition rate of the master distributed feedback (DFB) laser diode (LD) driven at about 10GHz. The output lightwaves are intensity-modulated with a payload data signal by using a Mach-Zehnder interferometer-type $LiNbO_3$

0-7803-4603-6/97/$5.00 (c) IEEE

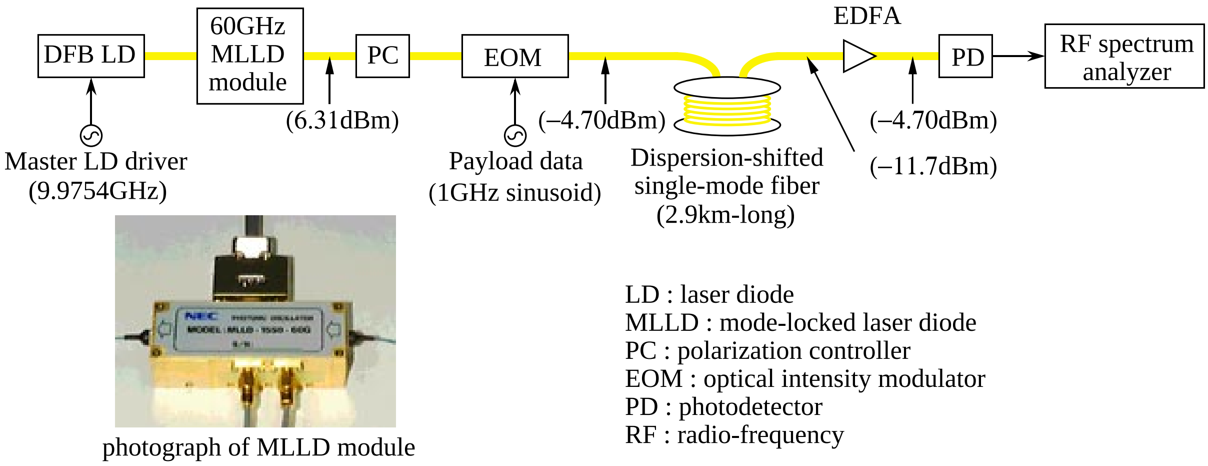


Figure 1: Configuration of the proposed system and photograph of 60GHz MLLD module (90mm(W) × 32mm(D) × 26mm(H)).

waveguide modulator (EOM). After the propagation in the dispersion-shifted single-mode fiber (DSF) link, all the transmitted lightwaves are simultaneously amplified by an Erbium-doped fiber amplifier (EDFA) and are optically self-heterodyned with a high-frequency photodetector (PD) with the 3dB bandwidth of 50GHz [11]. The output of the PD is the coherent sum of all beat signals only with a desired mm-wave carrier frequency, 60GHz, due to the bandwidth limitation.

Experimental Results

The optical power spectrum of the MLLD module output is shown in Fig. 2. The master DFB LD is oscillated at 1.54μm and is modulated by applying 9.9754GHz sinusoidal wave signal. The output optical power is as high as 6.31dBm. The optical loss and the dispersion of the 2.9km-long DSF used in the experiment are 0.20dB/km and 0.09psec/km/nm at λ=1.56μm, respectively.

Figure 3 shows the radio-frequency (RF) spectrum of a generated mm-wave signal before and after the 2.9km-long propagation. As the payload data signal is 1.0GHz sinusoidal wave, the sidebands apart by 1.0GHz from the generated mm-wave carrier frequency of 59.8524GHz are seen in Fig. 3. As shown in Fig. 4, the spectrum linewidth of the generated mm-wave is less than 300Hz, which is limited by the resolution of the bandwidth of the RF spectrum analyzer. This fact shows an excellent frequency stability of the MLLD module output. The carrier-to-noise power ratio (CNR) of more than 30dB is also obtained.

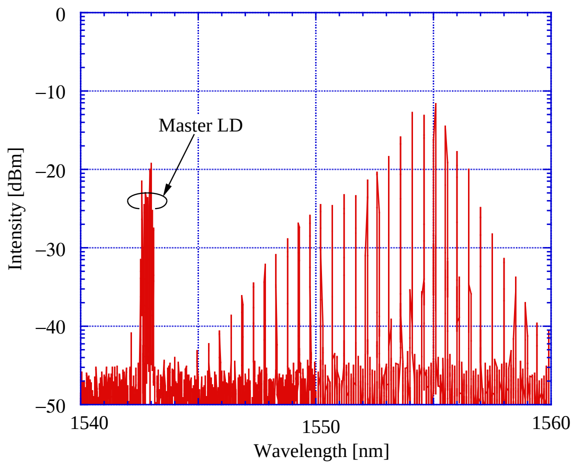
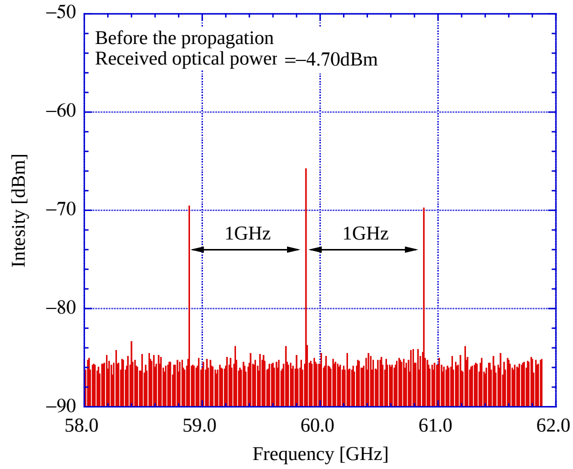
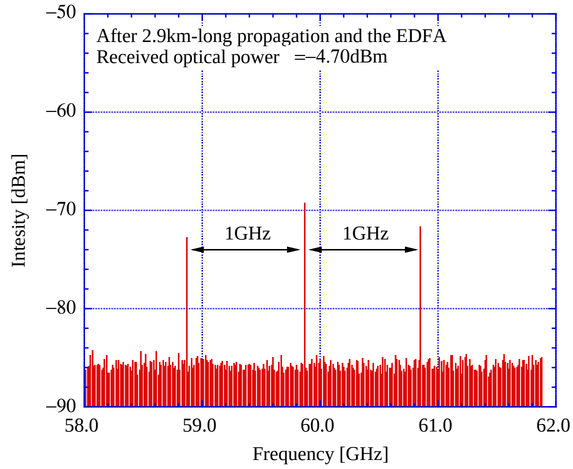


Figure 2: Optical power spectrum of the MLLD module output

Figure 5 shows the long-term stability of the MLLD module as a function of time. The MLLD module is



(a) Before propagation.



(b) After 2.9km-long propagation.

Figure 3: Generated mm-wave signals.

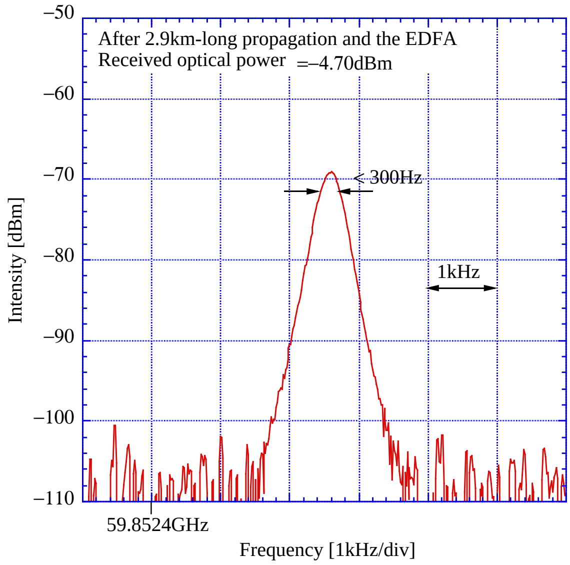


Figure 4: Spectrum of the carrier of the generated mm-wave.

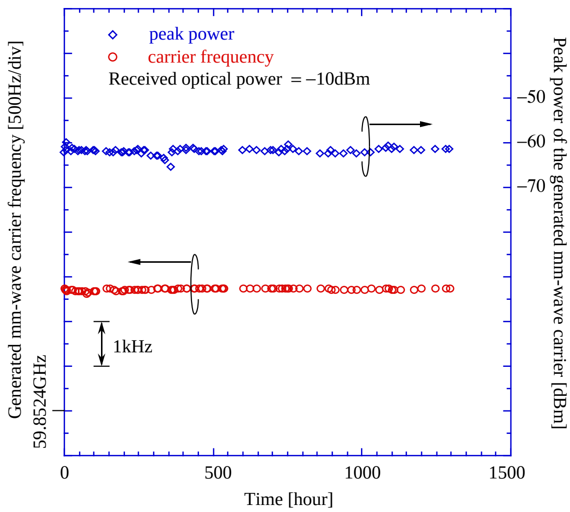


Figure 5: Stability of the MLLD module.

packaged with a Peltier device and thermister to control the temperature of MLLD. The operation is carried out at the room temperature without an automatic frequency control (AFC) and an automatic gain control (AGC) at the receiver. It is confirmed from Fig. 5 that both the frequency and the power of the generated mm-wave carrier are highly stable over 1000 hours. Especially, the frequency stability of less than 100Hz is obtained even if there is no AFC. This is an encouraging sign of the applicability of the MLLD module to the optical mm-wave generation.

Conclusion

The 60GHz-band mm-wave signal generation using the 60GHz MLLD module has been presented. The optical generation and transport of the mm-wave signal over 2.9km-long optical fiber link has been successfully demonstrated. The output optical power of the MLLD is 6.3dBm. A high frequency-stabilized mm-wave signal with a 3dB linewidth of less than 300Hz has been obtained. The long-term stable operation of the MLLD module over 1000 hours has been also confirmed. So, this MLLD module would be applicable for the optical mm-wave generation.

Acknowledgments

The authors wish to thank H. Yokoyama of NEC Opto-Electronics Research Lab. for providing the MLLD module. Their thanks are also due to T. Shiomi and Y. Furuhama of Communications Research Lab. for their encouragement.

References

[1] J. J. O'Reilly, P. M. Lane, and R. Hofstetter, "Optical generation of very narrow linewidth millimetre wave signals, " *Electron. Lett.*, vol. 28, no. 25, pp. 2309–2311, Dec. 1992.

[2] R. Heidemann, and R. Hofstetter, "A novel optical mm-wave generation and transport system," Proc. of MIOP'93, *7th Exhibition and Conference for Ultra High Frequency Technology*, pp. 251–254, 1993.

[3] K. Y. Lau, "Narrow-band modulation of semiconductor lasers at millimeter wave frequency (>100 GHz) by mode locking, " *IEEE J. Quantum Electron.*, vol. 26, no. 2, pp. 250–261, Feb. 1990.

[4] R. Nagarajan, S. Levy, A. Mar, and J. E. Bowers, "Resonantly enhanced semiconductor lasers for efficient transmission of millimeter wave modulated light, " *IEEE Photon. Technol. Lett.*, vol. 5, no. 1, pp. 4–6, Jan. 1993.

[5] J. B. Georges, M. Kiang, K. Heppell, M. Sayed, and K. Y. Lau, "Optical transmission of narrow-band millimeter-wave signals by resonant modulation of monolithic semiconductor lasers," *IEEE Photon. Technol. Lett.*, vol. 6, no. 4, pp. 568–570, Apr. 1994.

[6] D. Novak, Z. Ahmed, R. B. Waterhouse, and R. S. Tucker, "Signal generation using pulsed semiconductor lasers for application in millimeter-wave wireless links, " *IEEE Trans. Microwave Theory Tech.*, vol. 43, no. 9, pp. 2257–2262, Sep. 1995.

[7] D. Wake, C. R. Lima, and P. A. Davis, "Optical generation of millimeter-wave signals for fiber-radio systems using a dual-mode DFB semiconductor laser, " *IEEE Trans. Microwave Theory Tech.*, vol. 43, no. 9, pp. 2270–2276, Sep. 1995.

[8] K. Kitayama, T. Kuri, H. Yokoyama, and M. Okuno, "60GHz millimeter-wave generation and transport using stabilized mode-locked laser diode with optical frequency DEMUX switch," *IEEE Proc. of GLOBECOM'96*, London, pp. 2162–2169, Nov. 1996.

[9] T. Kuri, and K. Kitayama, "60GHz millimeter-wave signal generation and transport over optical frequency division multiplexing networks," *Electron. Lett.*, vol. 32, No. 23, pp. 2158–2159, Nov. 1996.

[10] X. Wang, H. Yokoyama, and T. Shimizu, "Synchronized harmonic frequency mode-locking with laser diodes through optical pulse train injection," *IEEE Photon. Technol. Lett.*, vol. 8, no. 5, May 1996.

[11] K. Kato, S. Hata, K. Kawano, J. Yoshida, and A. Kosen, "A high-efficiency 50GHz InGaAs multimode waveguide photodetector," *IEEE J. Quantum Electron.*, vol. 28, no. 20, pp. 2728–2735, Feb. 1992.