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Over-10-dBm output uni-traveling-carrier photodiode module integrating a power amplifier for wireless transmissions in the 125-GHz band

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Abstract: A rectangular-waveguide output UTC-PD module integrating a HEMT power amplifier has been developed for operation in the 125-GHz band. The fabricated module exhibits maximum output power of more than 14 dBm with nearly flat frequency dependence in the 115-135 GHz range. A 10-Gbit/s error-free wireless transmission at 125 GHz with a minimum sensitivity of −34 dBm for a bit-error-rate of 10^{-12} is also demonstrated using the fabricated module.

Keywords: photodiode, HEMT amplifier, millimeter-wave, wireless transmission

Classification: Microwave and millimeter wave devices, circuits, and systems

References

[1] A. Hirata, T. Kosugi, M. Harada, H. Ito, T. Shibata, and T. Nagatsuma, "Exploring over-100-GHz technology for 10-Gbit/s wireless link," *Tech. Dig. Int. Joint Conf. 6th Topical Symp. on Millimeter Waves*, Yokosuka, Japan, pp. 51–54, Feb. 2004.

[2] A. Hirata, H. Takahashi, K. Okamoto, and T. Nagatsuma, "Low-phase noise photonic millimeter-wave generator using an AWG integrated with a 3-dB combiner," *Tech. Dig. Int. Topical Meeting on Microwave Photonics*, pp. 209–212, Ogunquit, U.S.A., Oct. 2004.

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[3] T. Ishibashi, N. Shimizu, S. Kodama, H. Ito, T. Nagatsuma, and T. Furuta, "Uni-Traveling-Carrier Photodiodes," *Ultrafast Electronics and Optoelectronics Topical Meeting*, Lake Tahoe, U.S.A, UWA2, March 1997.
[4] H. Ito, T. Furuta, A. Hirata, T. Kosugi, Y. Muramoto, T. Nagatsuma, and T. Ishibashi, "Pre-amplifier integrated uni-travelling-carrier photodiode module for operation in 120 GHz band," *Electron. Lett.*, vol. 41, no. 6, pp. 360–362, March 2005.
[5] T. Kosugi, T. Shibata, T. Enoki, M. Muraguchi, A. Hirata, T. Nagatsuma, and H. Kyuragi, "A 120-GHz millimeter-wave MMIC chipset for future broadband wireless access applications," *IEEE MTT-S Int. Microwave Symp. Dig.*, Philadelphia, U.S.A., pp. 129–132, June 2003.
[6] H. Ito, T. Ito, Y. Muramoto, T. Furuta, and T. Ishibashi, "Rectangular waveguide output unitraveling-carrier photodiode module for high-power photonic millimeter-wave generation in the F-band," *IEEE J. Lightwave Technol.*, vol. 21, no. 12, pp. 3456–3462, Dec. 2003.
[7] T. Kosugi, M. Tokumitsu, T. Enoki, M. Muraguchi, A. Hirata, and T. Nagatsuma, "120-GHz Tx/Rx chipset for 10-Gbit/s wireless applications using 0.1-mm-gate InP HEMTs," *IEEE CSIC Symp. Tech. Dig.*, Fort Worth, U.S.A., pp. 171–174, June 2004.

1 Introduction

Multi-Gbit/s class broadband wireless transmission systems has been attracting much attention for various services, such as fixed wireless access systems, hot-spot services, and temporary networks for events, remote medical diagnosis, and emergency situations. For such systems, millimeter(mm)-wave fibre-radio system is a promising solution, and 10-Gbit/s wireless transmission has already been demonstrated based on photonics technology [1, 2]. For practical applications, the generation of high-power RF signal by a simple and compact device at relatively low-cost is important. For this purpose, we proposed a uni-travelling-carrier photodiode (UTC-PD) [3] module [4] that integrates a HEMT power amplifier (PD-amp module). Another important issue is frequency regulation. We have selected the 125-GHz band from the unused (except for radio astronomy) frequency bands in Japan to ensure the necessary bandwidth for 10-Gbit/s data transmission, and obtained an experimental radio station license covering the 116.5-133.5 GHz range from the Japanese Ministry of Public Management, Home Affairs, Ports and Telecommunications.

Recently, we have improved both the maximum output power and frequency characteristics of the PD-amp module to increase transmission distance and decrease distortion, and demonstrated an improved error-free wireless transmission of 10-Gbit/s data at 125 GHz.

2 Module Fabrication

The fabricated PD-amp module has size (12.7 mm × 30 mm × 10 mm, excluding the optical fiber and leads) and configuration equivalent to those of conventional semiconductor optoelectronic (O/E) devices. It has an optical

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fiber input, leads for DC biases (PD and amplifier), and a WR-8 rectangular waveguide output port. In this module, the output port of a UTC-PD, which integrates a resonant matching circuit for operation at around 125 GHz, was electrically connected to the input port of a three-stage InP-based HEMT amplifier [5], and its output port was connected to a microstripline (MSL) fabricated on a quartz substrate. The MSL has an impedance transformer and a coupler connecting it to the WR-8 rectangular waveguide on the other side [4, 6]. The amplifier was designed to have a gain of more than 20 dB with flat frequency dependence at around 125 GHz.

3 Characterization

The relationship between the output power and the photocurrent for the PD-amp module at 125 GHz is shown in Fig. 1. In this figure, the result for an F-band UTC-PD module [6] that mounts the same PD chip is also shown for comparison. Here, the optical modulation index of the optical RF input signal was about 100%. The applied bias voltage and current for the amplifier were 1.5 V and 600 mA, and the bias voltage for the PD was −2.5 V. The output power increased linearly in proportion to the square of the photocurrent, and then tended to saturate, which contrasts to the nearly linear dependence for the UTC-PD module case. Thus, the saturation tendency is considered to be mainly due to the amplifier characteristics. The 1-dB compression output power is about 10 dBm with an average photocurrent of 3.5 mA and the maximum output power obtained is 14.3 dBm. To our knowledge, this is the highest output power ever reported for PD-amp module operating at around 125 GHz. The output power of the PD-amp module is more than 20 dB larger than that of the UTC-PD module in the linear region. The equivalent responsivity of the PD-amp module is as high as 2.7 A/W, which is about 6.8 times as high as that obtained by a UTC-PD module integrating the same PD chip. These results indicate that the fabricated module is suit-

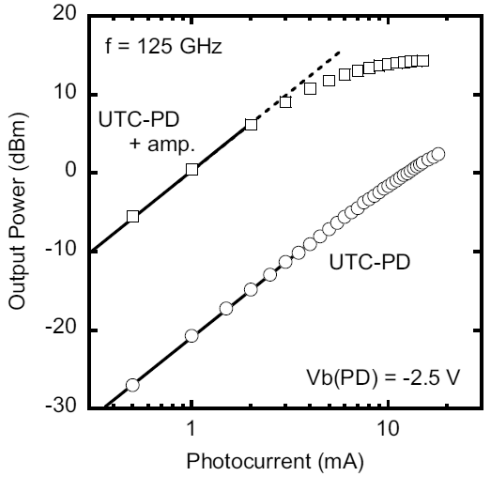

Fig. 1. Relationships between output power and photocurrent for the PD-amp and UTC-PD modules at 125 GHz.

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able for applications that require not only high output powers but also high efficiencies, such as high-frequency measurements, millimeter-wave imaging, and local signal supply for radio telescopes.

Fig. 2 shows the frequency characteristics of the output power for the PD-amp module at a photocurrent of 4 mA. The output power shows fairly flat dependence on frequency; the deviation in the frequency range from 115 GHz to 135 GHz is within ±1 dB. This is an important feature for low-distortion wireless transmission in our frequency band at around 125 GHz. In the figure, the result for the UTC-PD module is also shown for comparison. From these results, a high gain of the integrated amplifier of more than 17.5 dB is shown to be maintained throughout the measured frequency range.

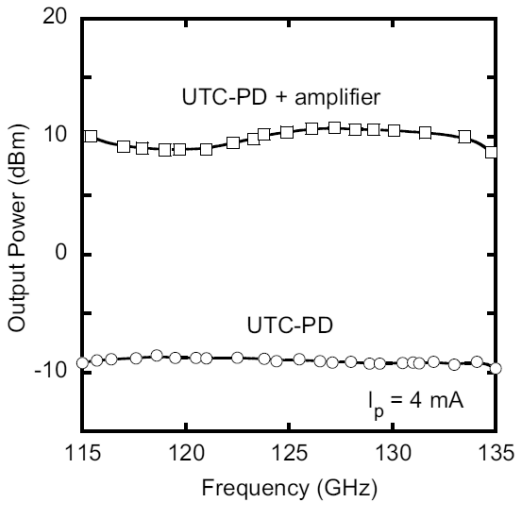

Fig. 2. Relationships between mm-wave output power and frequency for the PD-amp and UTC-PD modules.

Wireless data transmission using the fabricated module was also tested. The optically generated 125-GHz carrier signal [2] was ASK-coded by a $LiNbO_3$ Mach-Zehnder modulator at 10 Gbit/s and fed to the PD-amp module. Then, the transmitted signal was detected by a directly connected receiver MMIC [7] having a waveguide input port. As shown in Fig. 3, error-free transmission for a bit-error-rate of 10^{-12} was achieved with a very low received power of −34 dBm. From these results, the possible wireless transmission distance is considered to be on the order of 1 km for fine weather if we use appropriate high-gain antennas [1].

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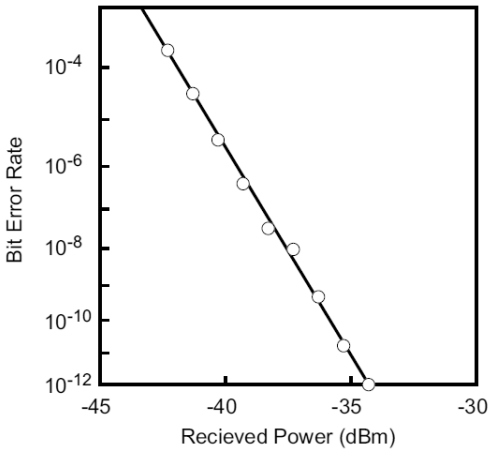

Fig. 3. Bit-error-rate curve for wireless transmission of 10 Gbit/s data on 125-GHz carrier signal using the fabricated PD-amp module.

4 Conclusion

A power-amplifier-integrated UTC-PD module with a rectangular-waveguide output port for the operation at 125-GHz band has been developed. The module exhibits the maximum output power of over 14 dBm at 125 GHz with a nearly flat frequency dependence in the 115-135 GHz range. A 10-Gbit/s error-free wireless transmission at 125 GHz was also demonstrated with a minimum sensitivity of -34 dBm for a bit-error-rate of 10^{-12}, indicating that the fabricated PD-amp module is promising for future ultra-wideband wireless communications systems.

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