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Session S4: Student Paper Contest II (System and Applications)

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16:30 - 16:45	#2172	All-Optical Controllable Microwave Phase Inverter based on the Cascaded Polarization Modulator and Electro-optic Phase Modulators *J. Niu, K. Xu, Y. Li, Z. Wu, J. Wu, J. Lin, Beijing University of Posts and Telecommunications, Beijing, China*
16:45 - 17:00	#2219	Tomographic Imaging Using Photonically Generated Low-coherence Terahertz Sources *T. Isogawa[1], T. Kumashiro[1], H. Song[2], K. Ajito[2], N. Kukutsu[2], K. Iwatsuki[3], T. Nagatsuma[1], [1]Osaka University, Toyonaka, Japan, [2]NTT Corporation, Atsugi, Japan, [3]NTT Corporation, Musashino, Japan*
17:00 - 17:15	#2183	InP-based Ultra-Fast Photodetectors for Millimeter-Wave Sub-harmonic Mixers *E. Rouvalis, M. J. Fice, C. C. Renaud, A. J. Seeds, University College London, London, United Kingdom*
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17:30 - 17:45	#2176	Separate Carrier Tuning Scheme for Integrated Optical Delay Lines in Photonic Beamformers *M. Burla[1], M. R. Khan[1], D. A. Marpaung[1], L. Zhuang[1], C. G. Roeloffzen[1], A. Leinse[2], M. Hoekman[2], R. Heideman[2], [1]University of Twente, Enschede, Netherlands, [2]LioniX BV, Enschede The Netherlands, Netherlands*
17:45 - 18:00	#2181	2pi Microwave Photonic Phase Shifter based on Single Semiconductor Optical Amplifier *J. Sancho, J. A. Lloret, I. Gasulla, S. Sales, J. Capmany, Universidad Politécnica de Valencia, Valencia, Spain*

Session S5: Microwave Photonic Sources and Pulse Generation

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Thursday, October 20, 2011 | 08:30 - 10:30

Chair: Woo-Young Chol, Yonsei University, Korea

08:30 - 09:00	*Invited*	High Finesse External Cavity VCSELs: From Very Low Noise Lasers to Dual Frequency Lasers *Ghaya Baili[1], Mehdi Alouini[1,2], Loic Morvan[1], Fabien Bretenaker[3], Isabelle Sagnes[4], Daniel Dolfi[1], [1]Thales Research & Technology France, [2]Institut de Physique de Rennes, France, [3]Laboratoire Aimé Cotton, C. N. R. S., France, [4]Laboratoire de Photonique et de Nanostructures, France*
09:00 - 09:15	#2194	Monolithic Dual Wavelength DFB Lasers for Narrow Linewidth Heterodyne Beat-note Generation *F. van Dijk, A. Accard, A. Enard, O. Drisse, D. Make, F. Lelarge, III-V Lab, Palaiseau, France*
09:15 - 09:30	#2189	Oscillation Power of Opto-Electronic Oscillator Limited by Nonlinearities of Mach-Zehnder Modulator and Microwave Amplifier *J. Hong[1], C. Yang[1], X. Zhang[1], W. Xie[2], [1]Southeast University, Nanjing, China, [2]State Micro Electronics Co., Ltd, Shenzheng, China*
	#2101 *Invited*	Optical Comb and Pulse Generation from CW Lightwave *T. Sakamoto, University of California, Davis, United States*
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10:15 - 10:30	#2155	Frequency Tunable Millimeter Wave Pulse Generation Using Mach-Zehnder-Modulator-Based Flat Comb Generator *I. Morohashi, T. Sakamoto, T. Kawanishi, I. Hosako, National Institute of Information and Communicatinos Technology, Tokyo, Jamaica*

A Monolithically Integrated Optical Receiver With a Silicon Avalanche Photodetector for Fiber-Wireless IEEE 802.11 WLAN Applications

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***Abstract*—We present a monolithically integrated optical receiver fabricated with standard silicon processing technology for fiber-wireless IEEE 802.11 wireless local area network (WLAN) applications. The receiver contains a silicon avalanche photodetector and a transimpedance amplifier and has up to 5.6-GHz photodetection bandwidth. Using this integrated optical receiver, transmission of 54-Mb/s WLAN signals at 2.4-GHz and 5-GHz bands is successfully achieved with 2.6-% and 3.0-% error vector magnitude, respectively.**

Keywords—Avalanche photodetector (APD); fiber-wireless; IEEE 802.11; microwave photonics; optical receiver; radio over fiber; silicon photodetector; wireless local area network (WLAN).

I. INTRODUCTION

With rapidly growing demands for high-speed data transmission in wireless local area network (WLAN) and cellular applications, fiber-wireless systems are a very attractive solution having such advantages of fiber as very high bandwidth, low loss, high flexibility, light weight, and, potentially, low cost. Fiber-wireless systems based on 850-nm vertical-cavity surface-emitting lasers (VCSELs) and multimode fibers (MMFs) have been actively investigated for system cost reduction that can provide wide deployment of fiber-wireless systems [1]–[2]. Furthermore, there is a demand for cost-effective realization of optical receivers that are used in remote access points (APs).

We have investigated optical receivers for fiber-wireless applications that are based on silicon technology. Silicon, the most popular platform for any electronic applications, is capable of detecting 850-nm optical signals and provides the possibility of monolithically integrated optical receivers. In order to enhance the performance of silicon photodetectors fabricated with standard silicon processing technology, we have investigated silicon avalanche photodetectors (APDs) that provide high gain and large photodetection bandwidth [3]–[4]. Using these silicon APDs along with commercially available discrete transimpedance amplifiers (TIAs), we have successfully demonstrated fiber-wireless links for 2.4-GHz band IEEE 802.11g WLAN signals [5].

In this paper, we present a monolithically integrated optical receiver that can be used for both 2.4-GHz and 5-GHz WLAN applications. Compared with our previous work [6], this work achieves better performance due to performance improvement both in the silicon APD and TIA. Using the integrated optical receiver, we successfully demonstrate transmission of 54-Mb/s 64-quadrature amplitude modulation (QAM) orthogonal frequency-division multiplexing (OFDM) WLAN signals at 2.4-GHz and 5-GHz bands.

II. MONOLITHICALLY INTEGRATED OPTICAL RECEIVER

We designed and fabricated a monolithically integrated optical receiver using standard 0.25-μm silicon-germanium (SiGe) bipolar complementary metal-oxide-semiconductor (BiCMOS) technology without any process modification. Fig. 1 (a) shows a simplified block diagram and microphotograph of the fabricated optical receiver. It is composed of a silicon APD, DC compensation circuits, single-ended TIA with a capacitive degeneration block, single-to-differential amplifier with low-pass filter, and output buffer. The core of the optical receiver excluding the output buffer occupies the area of 480 by 150 μm^2 and consumes about 30 mW with the supply voltage of 2.5 V [7].

For realization of high-speed and high-responsivity photodetectors, the silicon APD based on P^+/N-well junction is used [3], and the measured photodetection bandwidth of the APD is about 3.5 GHz. As shown in Fig. 1 (b), the TIA consists of DC compensation circuits, shunt-feedback amplifier, and buffer with a capacitive degeneration block. The capacitive degeneration technique is employed to enhance the photodetection bandwidth of the optical receiver. Details of the optical-receiver characteristics are given in [7].

Fig. 2 shows the measured photodetection frequency response of the fabricated optical receiver. As shown in this figure, the optical receiver has large 3-dB bandwidth of about 5.6 GHz, and consequently we can use the optical receiver for 5-GHz band WLAN application without signal degradation as well as 2.4-GHz band.

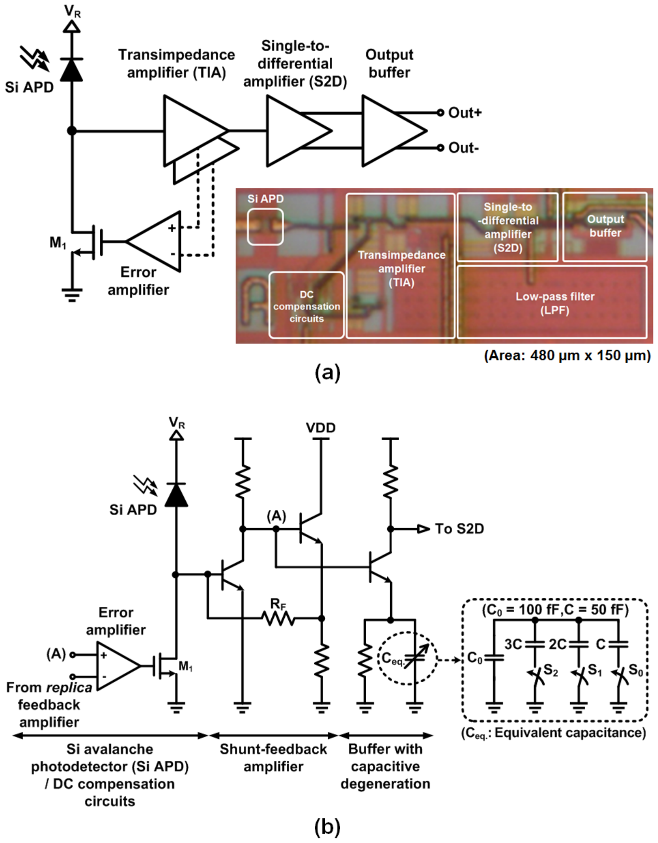

Figure 1. (a) Simplified block diagram and microphotograph of the monolithically integrated optical receiver. (b) Circuit diagram of the TIA and DC compensation circuits.

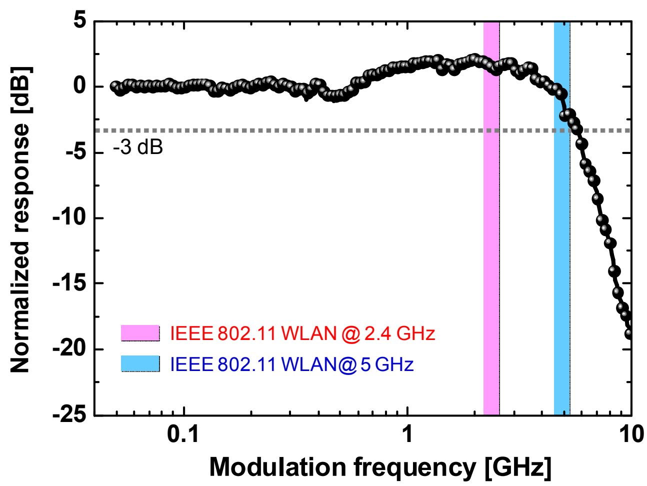

Figure 2. Photodetection frequency response of the monolithically integrated optical receiver. The optical-receiver bias voltage for the silicon APD is about 12.3 V for maximum photodetection bandwidth.

III. Fiber-Wireless System Demonstration Using a Monolithically Integrated Optical Receiver for IEEE 802.11 WLAN Applications

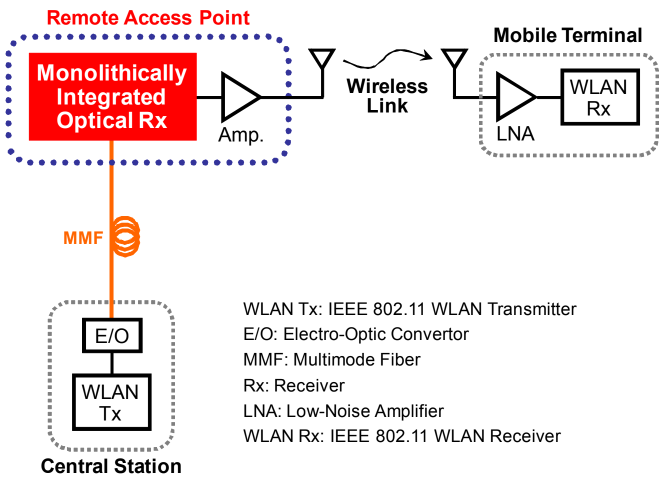

Figure 3. Schematic diagram of the fiber-wireless system for IEEE 802.11 WLAN applications using the monolithically integrated optical receiver.

Fig. 3 shows a schematic diagram of a fiber-wireless system for IEEE 802.11 WLAN applications using the monolithically integrated optical receiver. At the central station, WLAN data signals are converted into optical signals using an electro-optic converter and transmitted to the remote AP through MMF. The transmitted optical signals are photodetected and converted into voltage signals with amplification using the monolithically integrated optical receiver at the remote AP. Then, the signals are radiated by an omnidirectional antenna into the mobile terminal via wireless link.

The link performance was assessed in both 2.4-GHz and 5-GHz bands with error vector magnitude (EVM) measurements using a vector signal generator as the WLAN signal source. The IEEE 802.11g and 11a WLAN data employ OFDM modulation with 64 QAM at 2.4-GHz and 5-GHz bands, respectively. 54-Mb/s WLAN signals were converted into optical signals utilizing an 850-nm laser diode and an electro-optic modulator. The transmitted optical signals via MMF were injected into the integrated optical receiver. At the remote AP, output signals of the optical receiver were amplified by a 24-dB gain amplifier to compensate wireless-link loss. Including 4-dBi gain omnidirectional antennas, the 1.5-m wireless link has transmission losses about 36 and 42 dB at 2.4 GHz and 5 GHz, respectively. At the mobile terminal, transmitted WLAN signals were amplified by a 24-dB gain low-noise amplifier (LNA), and the output signals of LNA were applied to a vector signal analyzer (VSA) for demodulation. For 5-GHz band WLAN signals, the output signals were down-converted to 200-MHz band, and after 20-dB amplification, applied to the VSA due to upper frequency limitation of our VSA.

Fig. 4 shows the output spectra of the integrated optical receiver at the remote AP. The signal-to-noise ratio (SNR) is above 25 dB when the incident optical power to the optical receiver is about -6 dBm and APD bias voltage is about 12.3 V. In order to optimize the receiver performance, bias-voltage dependence of EVM was experimentally investigated. Fig. 5 shows EVMs of demodulated data as a function of optical-

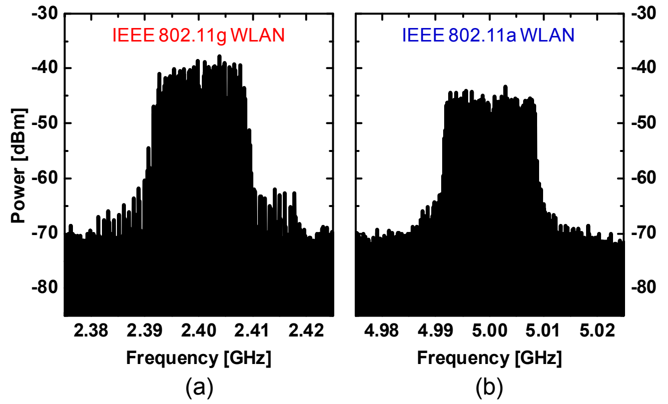

Figure 4. Output spectra of the monolithically integrated optical receiver at the remote access point: (a) IEEE 802.11g WLAN signals at 2.4 GHz and (b) IEEE 802.11a WLAN signals at 5 GHz. Incident optical power into the integrated optical receiver is about -6 dBm, and the optical-receiver bias voltage for the silicon APD is about 12.3 V.

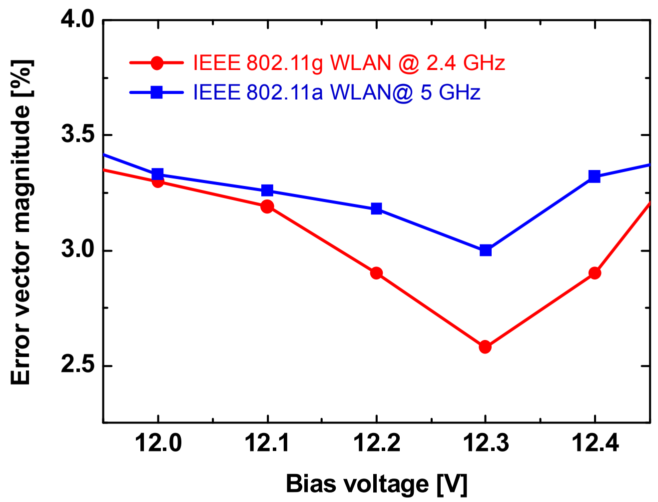

Figure 5. EVMs of demodulated data as a function of optical-receiver bias voltage for the silicon APD. Incident optical power into the monolithically integrated optical receiver is about -6 dBm.

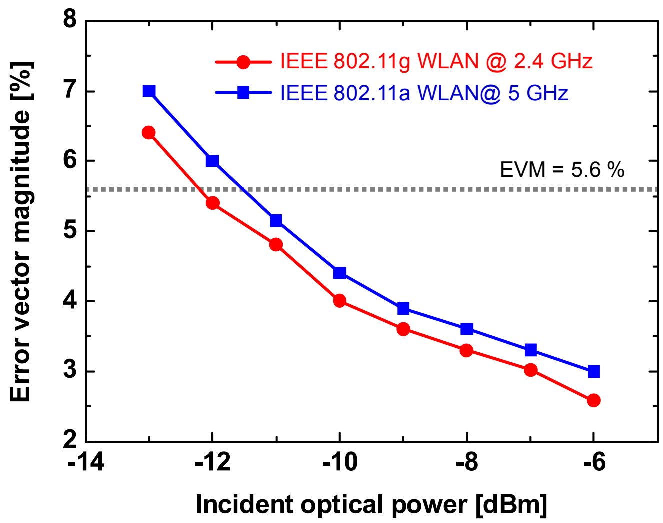

Figure 6. EVMs of demodulated data as a function of incident optical power into the monolithically integrated optical receiver. The optical-receiver bias voltage for the silicon APD is about 12.3 V.

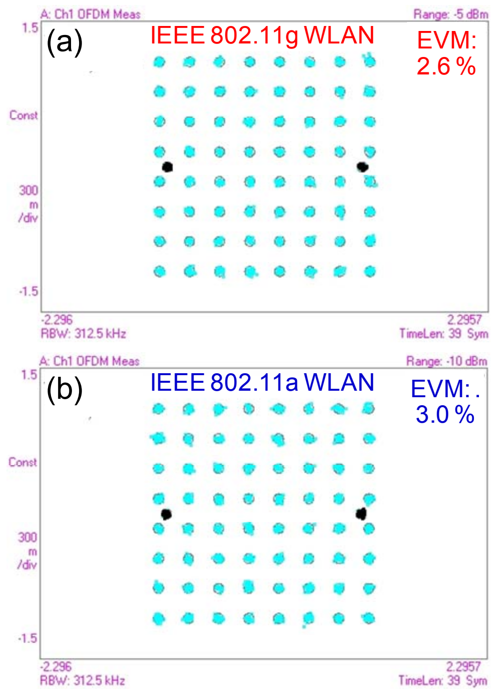

Figure 7. Constellations of demodulated data: (a) IEEE 802.11g WLAN signals at 2.4 GHz and (b) IEEE 802.11a WLAN signals at 5 GHz. Incident optical power into the integrated optical receiver is about -6 dBm, and the optical-receiver bias voltage for the silicon APD is about 12.3 V.

receiver bias voltage for the silicon APD. With the increasing bias voltage, the EVM decreases until it reaches the minimum value at the bias voltage of 12.3 V for both 802.11g and 11a WLAN signals due to enhanced avalanche gain of the APD. However, the EVM starts to increase beyond this optimum APD bias voltage due to increased noises of the APD. In order to investigate the system performance along with incident optical power into the optical receiver, EVMs were measured as a function of incident optical power and the results are shown in Fig. 6. As expected, EVMs decreased with increasing incident optical power reaching the minimum values at the incident optical power of -6 dBm. The measured constellations at this condition are shown in Fig. 7. These experimental results demonstrate that our monolithically integrated optical receiver is good enough for 2.4-GHz and 5-GHz band WLAN applications.

III. Conclusion

We demonstrate a monolithically integrated optical receiver fabricated with standard silicon processing technology for fiber-wireless IEEE 802.11 WLAN applications. The integrated optical receiver is composed of a silicon APD and a TIA with a capacitive degeneration block for photodetection-bandwidth enhancement. The optical receiver can successfully detect both 2.4-GHz and 5-GHz band WLAN signals. In particular, transmission of 54-Mb/s 64-QAM OFDM WLAN signals at 2.4-GHz and 5-GHz bands are successfully achieved with EVM well below 5.6 %, IEEE 802.11g/a standard limitation. It is expected that our receiver can be useful for cost-effective realization of WLAN fiber-wireless systems.

ACKNOWLEDGEMENT

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