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Radio-Over-Fiber Systems for WLAN Based on CMOS-Compatible Si Avalanche Photodetectors

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***Abstract* — We demonstrate radio-over-fiber (RoF) systems for IEEE 802.11a wireless local area network (WLAN) using Si avalanche photodetectors (APDs) fabricated in 0.18 ㎛ standard complementary metal-oxide-semiconductor (CMOS) process. In order to achieve high optic-to-electric conversion efficiency and low-noise characteristics, the APD bias voltage is optimized with the evaluation of error vector magnitude (EVM). Downlink data transmission of 20 Mb/s, 16 quadrature amplitude modulation data at 5.805 GHz with a wireless link is successfully performed.**

***Index Terms* — Avalanche photodetectors, CMOS-compatible photodetectors, error vector magnitude (EVM), radio-over-fiber (RoF) system, wireless local area networks (WLANs).**

I. INTRODUCTION

With rapidly growing data bandwidth and carrier frequency of wireless communication systems including cellular services and wireless local area network (WLAN), radio-over-fiber (RoF) systems have been regarded as a promising candidate for radio signal distribution to remote antenna units or access points [1-6]. Since optical fiber provides large bandwidth and low transmission loss characteristics, high-capacity data embedded on radio frequency (RF) can be easily distributed, thus coverage extended. For wide deployment of these systems to densely populated in-building or outdoor range, low-cost realization is essential. Especially, as the cell size decreases to pico-cell, large numbers of remote antenna units are required and reducing the cost is critical.

In order to achieve cost reduction of RoF systems for WLAN, there have been several approaches. Niiho *et al*. developed a 5-GHz RoF link using an inexpensive 2.5-Gb/s distributed feedback laser diode (DFB-LD) and p-i-n photodiode (PD) [3]. With sacrificing the optic/electric conversion efficiency due to roll-off of frequency responses in the narrow-band DFB-LD and PD at 5-GHz band, the system cost was reduced. Using these components, 5-GHz band IEEE 802.11a WLAN data are successfully transmitted through 1.3 ㎛ zero-dispersion single-mode fiber of 2-m length. Chia *et al*. presented RoF systems using multi-mode fiber (MMF) and vertical cavity surface emitting lasers (VCSELs) as a transmission medium and optical sources, respectively [4]. They evaluated transmission performance of IEEE 802.11g (2.4 GHz) and IEEE 802.11a (5 GHz) WLAN signal. Yee *et al.* also used VCSELs and 300-m MMF for RoF systems and transmitted 2.412 GHz IEEE 802.11g WLAN signal with cellular signals as interferers [5]. Finally, Das *et al.* analyzed transmission performance of 2.4 GHz IEEE 802.11b/g WLAN and cellular signals using VCSELs and 300 m MMF with a 5 m wireless link [6]. However, all the previous works only focused on the cost issues of central stations and transmission mediums despite the low-cost implementation of remote antenna units is also important.

For the realization of the remote antenna units in a cost-effective manner, CMOS compatible avalanche photodetectors (CMOS-APDs) can be an attractive solution. With mature CMOS technologies, photodetectors can be fabricated in low cost. The CMOS-APD can detect wavelength of 850 nm optical signals and provide high optic-to-electric conversion efficiency due to internal avalanche gain mechanism. In addition, CMOS process can provide single-chip solution for remote antenna units including the CMOS-APD and necessary electronic circuits such as RF amplifiers [7, 8].

In this work, we present RoF systems for IEEE 802.11a WLAN based on the CMOS-APD. The CMOS-APD is fabricated by 0.18 ㎛ standard CMOS technology without any process modification. To optimize the performance of CMOS-APDs in remote antenna units, bias voltage dependence of error vector magnitude (EVM) is investigated. We demonstrate downlink data transmission of 20 Mb/s, 16 quadrature amplitude modulation (QAM) data at 5.805 GHz with a 0.5 m wireless link.

II. SYSTEM CONFIGURATION AND EXPERIMENTAL SETUP

Fig. 1 shows schematic diagram of proposed downlink RoF systems for WLAN based on the CMOS-APD. In the central

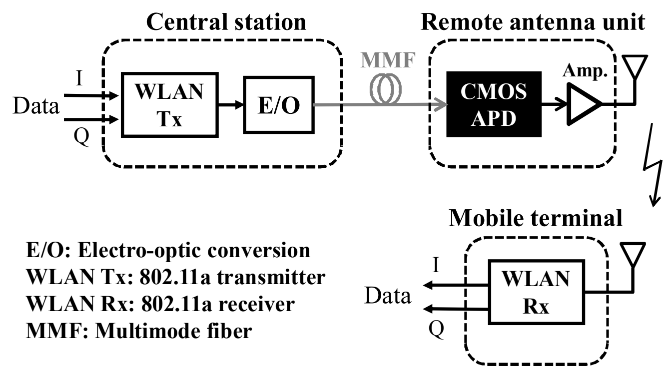

Fig. 1. Schematic diagram of RoF downlink systems for WLAN based on the CMOS-APD.

station, baseband data are frequency up-converted using WLAN transmitter and modulated to optical signals using an optical transmitter. At the remote antenna unit, transmitted optical signals through MMF are photodetected by the CMOS-APD, amplified, and then radiated via an antenna. The mobile terminal has no modification from the conventional WLAN receiver.

To investigate the performance of the CMOS-APD in RF region, we characterized photodetection frequency response of the device. Fig. 2 shows photodetection frequency response at different bias voltages. As the applied reverse bias voltage increases, photodetected signal power increases due to enhanced avalanche gain [9] and the fabricated device has 3-dB bandwidth of about 3 GHz. To utilize the CMOS-APD for 5-GHz band WLAN signal detection, about 10-dB loss due to roll-off of frequency response is inevitable. Fig. 3 shows photodetected signal power of 5.805 GHz continuous-wave (CW) signal as a function of bias voltage. The maximum photodetected signal power is obtained at the reverse bias voltage of 10.15 V. Above the maximum photodetection voltage, photodetected signal power starts to decrease because of the space charge effect and thermal heating [9].

In our experimental setup for downlink data transmission of RoF systems, an 850-nm laser diode and an electro-optic modulator were used for an optical transmitter at the central station. The optically modulated data at 5.805 GHz are transmitted through 2-m long MMF and then injected to the CMOS-APD. At the remote antenna unit, two cascaded discrete amplifiers, each has 20-dB gain, were used to boost up the photodetected signals and compensate the wireless link loss at the output of the CMOS-APD. The wireless link has about 40-dB loss including signal attenuation of 0.5 m free space and antenna gains of 4 dBi for each of transmitter and receiver. For the evaluation of system performance, received signals at the mobile terminal are frequency down-converted by WLAN receiver and baseband IQ data are examined using a vector signal analyzer (VSA).

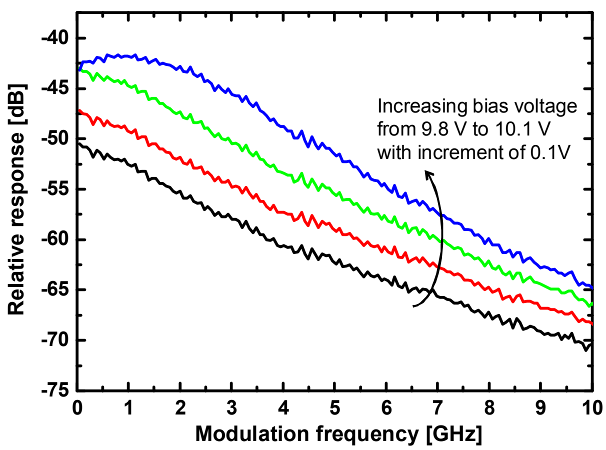

Fig. 2 Photodetection frequency response of the CMOS-APD at different bias voltages.

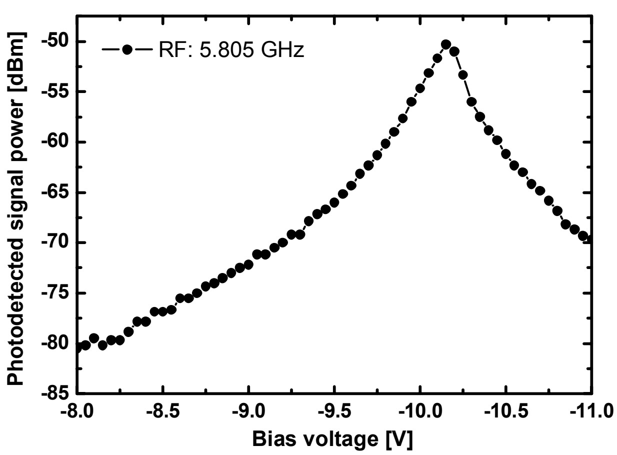

Fig. 3 Photodetected signal power of the CMOS-APD as a function of bias voltage when 5.805 GHz CW signal is modulated.

III. Measurement Results

Fig. 4 shows output spectrum of the remote antenna unit when 20 Mb/s, 16 QAM data at 5.805 GHz are transmitted through the downlink RoF system. It is seen that the signal-to-noise ratio (SNR) of transmitted data signals via the RoF link are above 20 dB. The incident optical power to the CMOS-APD was about 4 dBm and applied reverse bias voltage was 10.05 V, which is optimized for EVM characteristics as will be discussed. In the experimental setup, the incident optical power is relatively high because there are no pre-amplifier circuits such as a transimpedance amplifier (TIA) at the output

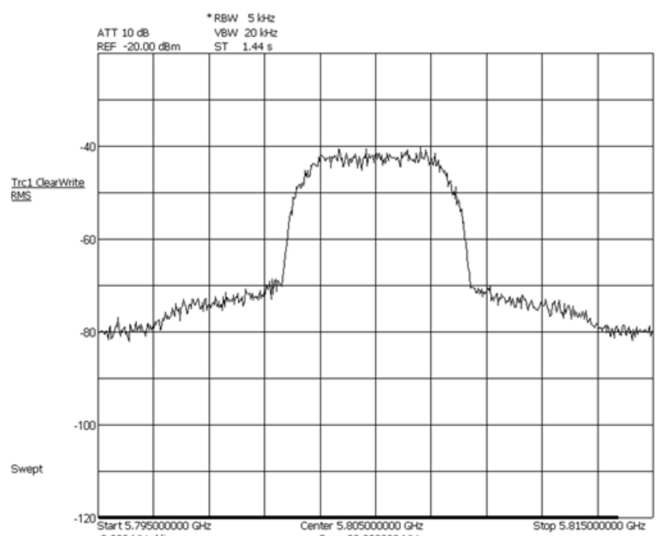

Fig. 4 Output signal spectrum of remote antenna unit when 20 Mb/s 16 QAM data signals at 5.805 GHz are transmitted.

of the CMOS-APD. It is believed that the required input optical power to the CMOS-APD can be significantly reduced if the TIA is integrated in a single chip. Fig. 5 shows the constellation and eye diagram at the mobile terminal after signal transmission of a 0.5 m wireless link. The measured EVM was about 5.5 %, which corresponds 22.5 dB SNR. These EVM results are comparable to the EVM results of 5.4 % without the wireless link by direct connecting the remote antenna unit to the mobile terminal.

For the optimization of the CMOS-APD performance, bias voltage dependences of EVM and photodetected signal power are experimentally investigated. Fig. 6 shows the measured results. The bias voltages for maximum photodetected signal power and minimum EVM have different values. As already shown in Fig. 3, photodetected signal power is maximized at the reverse bias voltage of 10.15 V, while the EVM is minimized at 10.05 V. This is attributed to increased noise in the avalanche regime. When the bias voltage of the CMOS-APD increases well into the avalanche region, the photodetected signal power increases due to avalanche gain, however noise also increases owing to multiplied dark currents. Thus, the bias voltage of the CMOS-APD should be determined to optimize the EVM performance. To investigate the system performance dependent on the distance of the optical link between the central station and the remote antenna unit, EVM and corresponding SNR are measured as functions of incident optical powers to the CMOS-APD as shown in Fig. 7. It is seen that the SNR is linearly proportional to incident optical power and these indicate that the remote antenna units are limited by shot noises and output power saturation of the CMOS-APD. Consequently, it is expected that required optical signal power can be significantly reduced by applying the TIA to the output of the CMOS-APD.

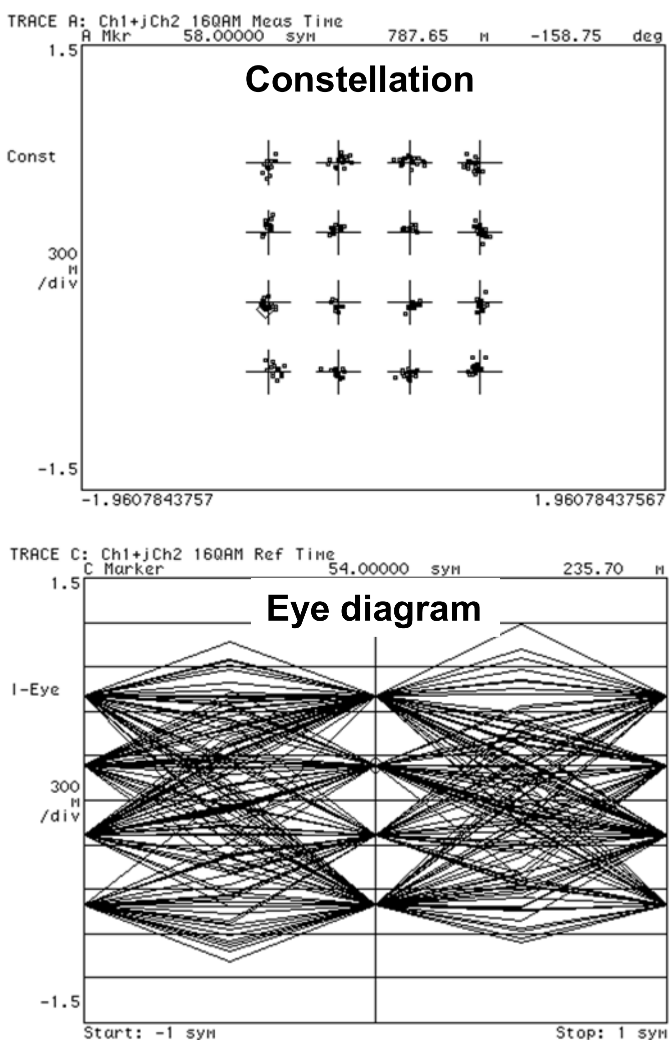

Fig. 5 Constellation and eye diagram of demodulated 20 Mb/s 16 QAM data at VSA.

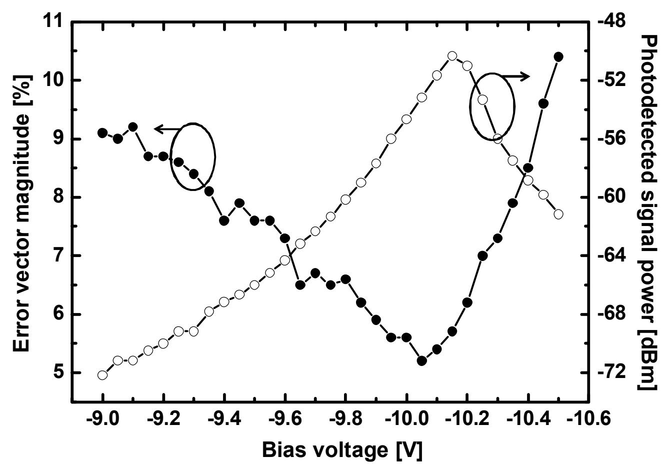

Fig. 6 EVM of demodulated data and photodetected signal power of 5.8 GHz CW signals as functions of bias voltages.

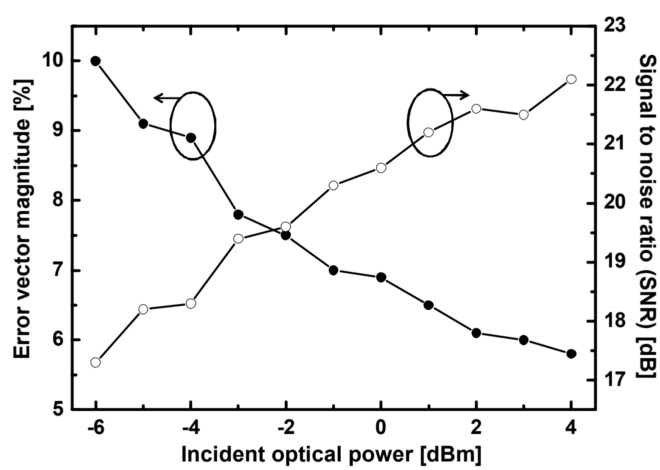

Fig. 7 EVM and SNR of demodulated data as functions of incident optical power into the CMOS-APD.

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IV. CONCLUSION

Radio-over-Fiber systems for IEEE 802.11a WLAN based on the CMOS-APD are presented. In order to optimize the CMOS-APD performance in the systems, bias voltage dependences of EVM are investigated. By applying the CMOS-APD to RoF systems for WLAN, downlink data transmission of 20 Mb/s, 16 QAM data at 5.805 GHz is successfully demonstrated with a 0.5 m wireless link. In the experiments, 5.5 % EVM corresponding to about 22.5 dB SNR is obtained. By exploiting the advantages of CMOS technology as a universal platform, integration of the CMOS-APD and necessary electrical circuits is possible and, consequently, cost-effective integrated remote antenna units can be expected.

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