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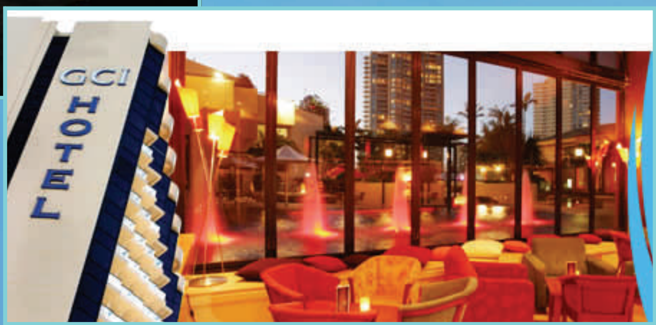

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Time: **Friday, October 3, 2008, 10:30 - 12:00**
Place: **Gallery, Level 1**
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Multi-Standard Radio-over-Fiber Systems Using CMOS-Compatible Si Avalanche Photodetectors

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***Abstract*—We present a radio-over-fiber (RoF) receiver using a Si avalanche photodetector fabricated with 0.18 ㎛ standard complementary metal-oxide-semiconductor (CMOS) technology. Using the device, multi-standard services including 2-GHz band wideband code division multiple access (WCDMA) and 5-GHz band wireless local area network (WLAN) signals are successfully transmitted. With error vector magnitude (EVM) measurements, interference between two signals in RoF system is analyzed.**

I. INTRODUCTION

Radio-over-fiber (RoF) systems have emerged as a promising solution for distributing radio signals to densely populated areas or shadow regions such as airport lounges, school campuses, shopping malls, and subway stations [1]-[4]. With such advantages of optical fiber as low loss, large bandwidth, and transparent characteristics, RoF systems can simultaneously support multi-standard applications including cellular services and wireless local area networks (WLANs) [1]-[3]. In order to realize wide-deployment of RoF systems, low-cost vertical-cavity surface-emitting lasers (VCSELs) and multi-mode fiber have been investigated [2]-[4]. Although these efforts can reduce the cost of the optical transmitter and transmission medium, cost-effective realization of RoF receivers is still a challenge.

We have demonstrated that CMOS technology can be adopted for RoF applications to realize cost-effective RoF receivers [5]. With the continuous development of CMOS technology for smaller transistors and higher level of integration, CMOS process has been dominantly used for all kinds of electronic circuits including digital, mixed-mode, and RF applications. Consequently, CMOS technology can enable the implementation of integrated optical receiver having a photodetector and necessary electronic circuits. In addition, we have demonstrated that the avalanche multiplication process can surmount the intrinsic problem of low responsivity and limited bandwidth for CMOS photodetectors [6]. Using a CMOS-compatible avalanche photodetector (CMOS-APD), we have realized RoF receivers for 5-GHz band WLAN applications [5].

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In this work, we extend the use of the CMOS-APD to multi-standard RoF systems. We demonstrate simultaneous RoF transmission of 2-GHz band WCDMA and 5-GHz band IEEE 802.11a WLAN signals. The interference between these signals in RoF system is also investigated.

II. EXPERIMENTAL SETUP

Fig. 1 shows the experimental setup for downlink RoF transmission of 2-GHz band WCDMA and 5-GHz band IEEE 802.11a WLAN signals. At the central station, optical modulation was performed using an 850-nm laser diode and a 20-GHz electro-optic modulator. Although we used an external modulator, a directly modulated VCSEL can be used for further cost reduction. For the generation of multi-standard signals, WCDMA at 2.1 GHz and WLAN at 5.2 GHz, two separate vector signal generators (Agilent E4432B, Anritsu MG3700A) were used. These signals were applied to an electro-optic modulator using a RF power combiner (Mini-Circuits ZN2PD-63+). The optically transmitted signals through 3-m long multi-mode fiber were injected into the optical receiver board on which the CMOS-APD is wire-bonded to a transimpedance amplifier (Analog Devices ADN2882) using a lensed fiber. After photodetection, output signals of the optical receiver board were boosted up by 18-dB gain broadband amplifier to compensate wireless link loss. The wireless link consists of two 4-dBi gain omnidirectional antennas and about 0.6-m free space which has link loss about 38 dB and 32 dB at 2.1 GHz and 5.2 GHz, respectively, including antenna gains. At the mobile terminal, received signals were amplified with 24-dB gain low-noise amplifier (LNA). For WCDMA demodulation, LNA output signals were directly applied to a vector signal analyzer (Agilent 89600). For WLAN demodulation, LNA output signals were frequency down-converted to 200 MHz IF, and after 20-dB amplification, applied to the vector signal analyzer.

The CMOS-APD used in our experiment was fabricated with 0.18 ㎛ standard CMOS technology without any process modification or special substrates. The details of the device structure and photodetection characteristics are given in [5]-

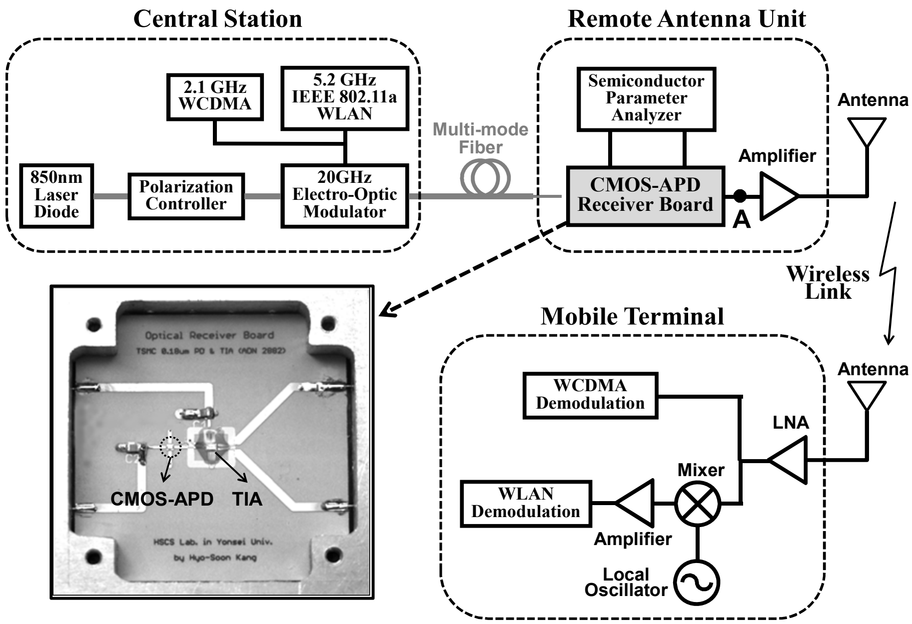

Figure 1. Experimental setup for RoF downlink data transmission of 2-GHz band WCDMA and 5-GHz band IEEE 802.11a WLAN signals.

[6]. Fig. 1 also shows the photograph of optical receiver having the CMOS-APD and a transimpedance amplifier.

Fig. 2 shows the photodetection frequency response of the optical receiver. It has 3-dB bandwidth of about 4 GHz when the bias voltage is optimized for maximum photodetection. For photodetection of WLAN signals at 5.2 GHz, about 10-dB loss compared with WCDMA signals at 2.1 GHz is inevitable.

III. ROF SYSTEM DEMONSTRATION FOR WCDMA AND WLAN APPLICATIONS

A. Single Standard RoF System

Single standard RoF transmission for 2-GHz band WCDMA or 5-GHz band WLAN was initially performed. For this, only one of standard signals from vector signal generators was applied to the electro-optic modulator.

Fig. 3 shows the dependence of rms error vector magnitude (EVM) on input RF signal power to the electro-optic modulator when only WCDMA signals at 2.1 GHz were used. The chip rate of WCDMA signal was 4.096 Mcps and the incident optical power to the optical receiver was 2 dBm. With increasing input signal power, rms EVM decreases at first and has the minimum value of about 3.26 % at the input signal power of -10 dBm due to the increased optical modulation index. Beyond this condition, EVM starts to

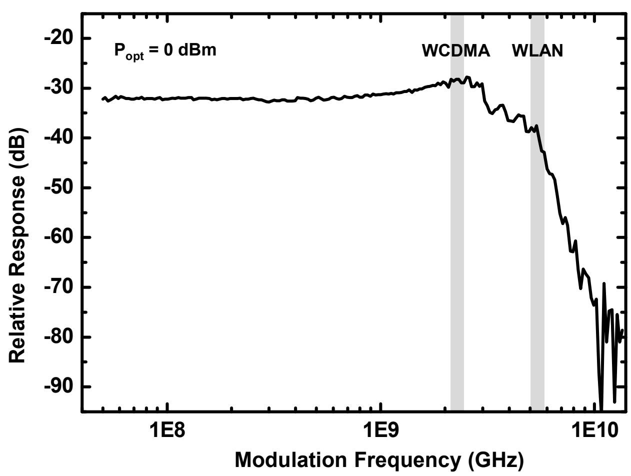

Figure 2. Photodetection frequency response of the optical receiver having the CMOS-APD and a transimpedance amplifier. The bias voltage of the CMOS-APD is optimized for maximum photodetection.

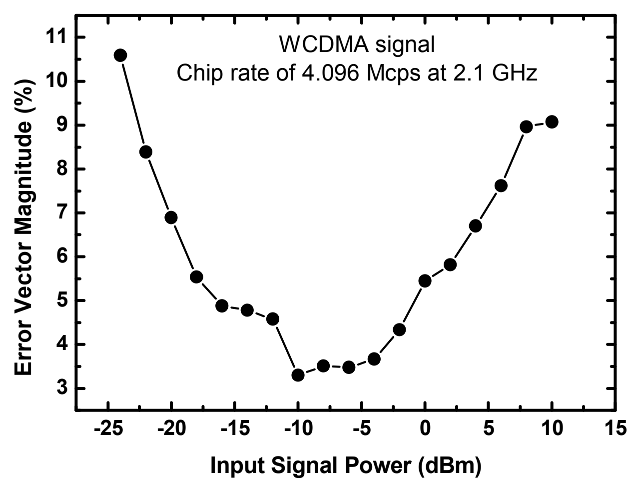

Figure 3. EVM as a function of input RF signal power to electro-optic modulator when only WCDMA signals at 2.1 GHz are applied. Incident optical power to the optical receiver was 2 dBm.

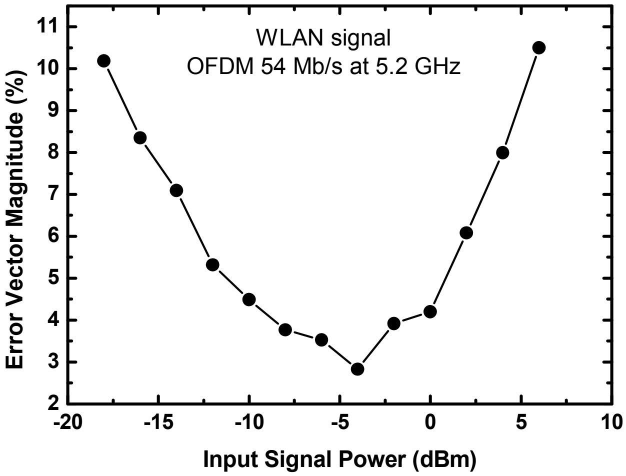

Figure 4. EVM as a function of input RF signal power to electro-optic modulator when only IEEE 802.11a WLAN signals at 5.2 GHz are applied. Incident optical power to the optical receiver was 2 dBm.

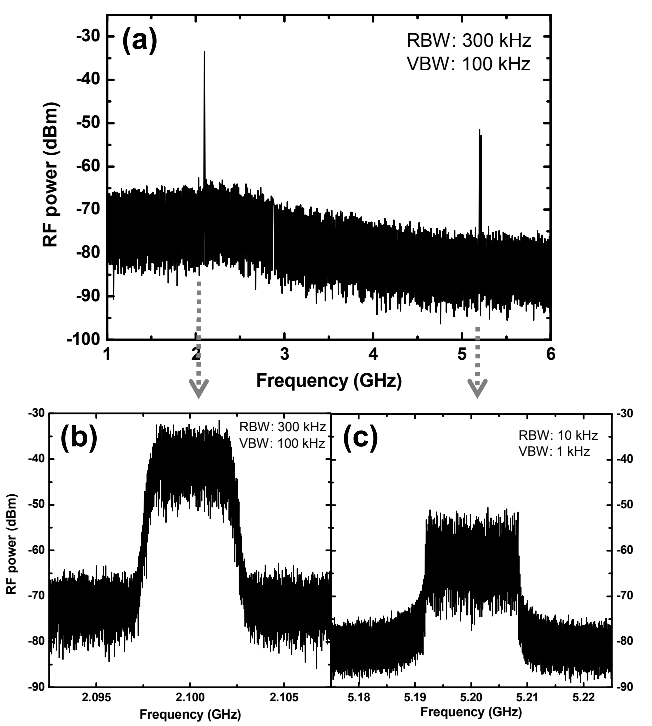

Figure 5. Output spectra of the optical receiver at point A in Fig. 1 when both WCDMA and WLAN signals are RoF transmitted. Incident optical power to the optical receiver was 2 dBm.

increase. The degradation of EVM is due to inter-modulation distortion caused by the nonlinearity of the electro-optic mudulator.

Fig. 4 shows measured rms EVM of demodulated WLAN signals as a function of input signal power when IEEE 802.11a orthogonal frequency division multiplexing (OFDM) signals at the maximum data rate of 54 Mb/s were transmitted.

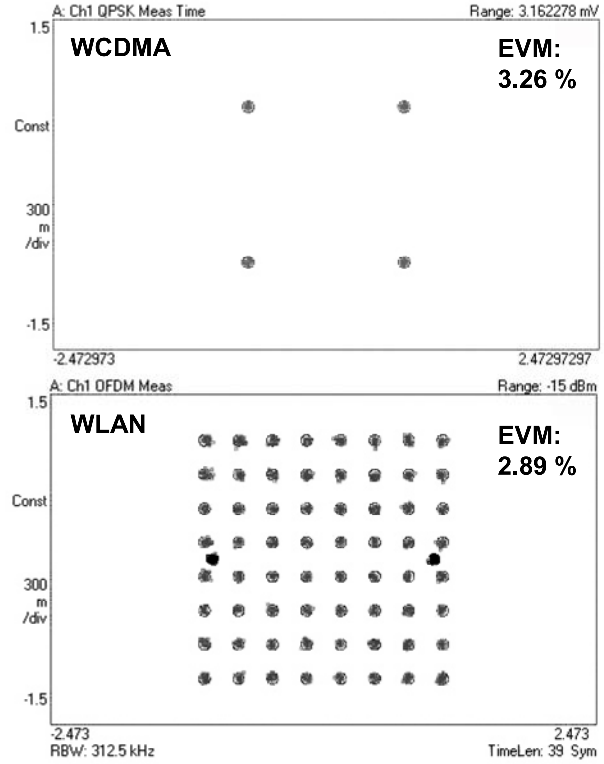

Figure 6. Constellations of demodulated signals at the vector signal analyzer when both WCDMA and WLAN signals are RoF transmitted with wireless link. Incident optical power into the optical receiver was 2 dBm.

The dependence of EVM on the input signal power is similar to the WCDMA case. The minimum rms EVM of 2.89 % was obtained at input signal power of -4 dBm. For RoF transmission of WLAN signals, input signal power should be set from -12 dBm to 1 dBm to meet the EVM requirement of 5.6 % [7] for 54 Mb/s, 64 quadrature amplitude modulation (QAM) signal transmission.

B. Multi-Standard RoF System

WCDMA signals at 2.1 GHz and WLAN signals at 5.2 GHz were combined and applied to the electro-optic modulator. Fig. 5 shows the output spectra of the optical receiver (Point A in Fig. 1) when -10 dBm WCDMA and -4 dBm WLAN signals were injected. WCDMA signals were stronger than WLAN signals due to the frequency roll-off of the CMOS-APD. The measured signal-to-noise ratio (SNR) was about 30 dB for WCDMA and 25 dB for WLAN signals when the incident optical power to the optical receiver was 2 dBm. Fig. 6 shows constellations of demodulated WCDMA and WLAN signals. In our experiment, rms EVMs of 3.26 % and 2.89 % were obtained for WCDMA and WLAN RoF transmission, respectively.

To investigate the influence of co-existing signals in the RoF system, dependence of EVMs on interfering signal powers was measured and the results are shown in Fig. 7 and Fig. 8. The incident optical power was 2 dBm. When WCDMA signals were RoF transmitted with WLAN signals as an interferer, EVM starts to degrade when WLAN signal power was above 0 dBm. For WLAN RoF transmission with

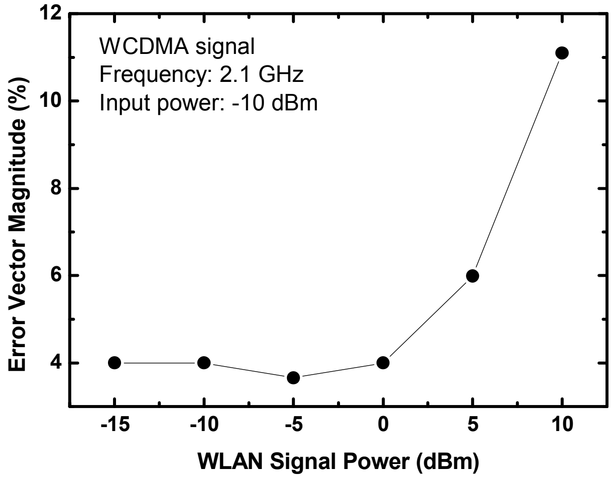

Figure 7. EVM of demodulated WCDMA signals as a function of WLAN signal power to the electro-optic modulator in the central station. Incident optical power was 2 dBm.

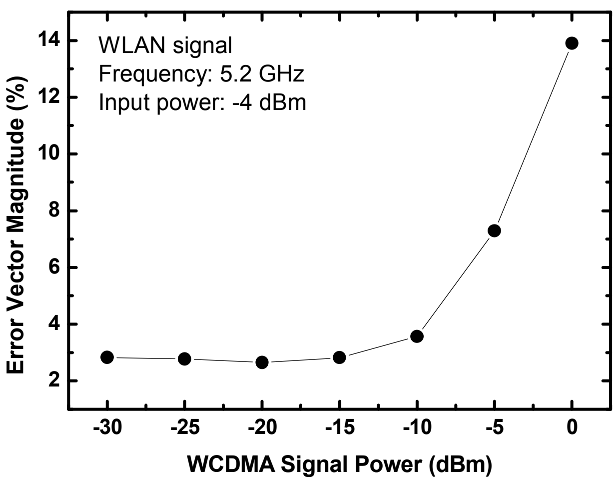

Figure 8. EVM of demodulated WLAN signals as a function of WCDMA signal power to the electro-optic modulator in the central station. Incident optical power was 2 dBm.

interference of WCDMA signals, EVM increases at the WCDMA signal power above -10 dBm. EVM degradation with high interfering signal power is caused by nonlinear characteristics of optical components as well as saturation of the optical receiver and RF components in the remote antenna unit. In the experiment, RoF transmission of WCDMA signals is more tolerant to interfering signals than WLAN case because of higher SNR and narrower bandwidth of WCDMA signals. For multi-standard RoF transmission, optimization of each signal power and careful design of optical receivers and RF components are required for best performances.

IV. CONCLUSION

We present multi-standard RoF systems for 2-GHz band WCDMA and 5-GHz band WLAN signals using the CMOS-APD. The CMOS-APD was fabricated with 0.18 μm standard CMOS technology and an optical receiver was implemented using a transimpedance amplifier connected to the device. Using this optical receiver, 4.096 Mcps WCDMA signals together with 54 Mb/s IEEE 802.11a OFDM signals were successfully transmitted. With EVM measurements, influence of co-existing multi-standard signals in RoF link is also investigated.

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