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Tuesday Technical Sessions 15:30–17:10

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TU4A: Advanced Techniques for Wireless Power Amplifier Efficiency and Linearity Enhancement

Chair: Chuck Weitzel
Cochair: Vikram Krishnamurthy
HCC 311

TU4A-01: A Gated Envelope Feedback Technique for Automatic Hardware Conditioning of RFIC PAs at Low Power Levels
N. G. Constantin, M. N. El-Gamal, McGill University, Montréal, Canada; P. J. Zampardi, Skyworks Solutions Inc., Newbury Park, USA

TU4A-02: Design Approach for Realization of Very High-Efficiency Power Amplifiers
C. Roff, J. Benedikt, P. J. Tasker, Cardiff University, Cardiff, UK

TU4A-03: A Novel High Efficiency and Linearity Power Amplifier with Over-Voltage Protection
H. Zhang, TriQuint Semiconductor, Chelmsford, USA; H. Gao, G. Li, University of California Irvine, Irvine, USA; Y. Ma, Rockwell Scientific Co., Thousand Oaks, USA

TU4A-04: An HBT 4-Cell Monolithic Stacked Power Amplifier
Z. Tsai, M. Lei, H. Wang, National Taiwan University, Taipei, ROC

TU4A-05: Distributed Amplifier with Narrowband Amplifier Efficiency
S. A. Olson, B. M. Thompson, B. E. Stengel, Motorola, Plantation, USA

TU4A-06: Single-Chip Dual-Mode Power Amplifier MMIC using GaAs E-pHEMT for WiMAX/WLAN Applications
Y. Hsu, S. Wang, C. Chen, Industrial Technology Research Institute, Hsinchu, Taiwan; W. Ho, C. Lin, WIN Semiconductors Corp., Tao Yuan, Taiwan

TU4A-07: Quad-Band GSM Silicon PA Module on LTCC Embedding a Coupler-Based RF Power Controller
A. Pallotta, F. Pidala', L. Labate, A. Moscatelli, STMicroelectronics, Cornaredo, Italy

TU4B Hybrids and Couplers II

Chair: Peter Russer
Cochair: Guiseppe Macchiarella
HCC 312

TU4B-01: Miniaturized Rat-Race Coupler with Microstrip-to-CPW Broadside-Coupled Structure and Stepped-Impedance Sections
J. Kuo, Y. Chiou, J. Wu, National Chiao Tung University, Hsinchu, Taiwan

TU4B-02: Multilayer Multisection Broadband LTCC Stripline Directional Couplers
M. M. Fahmi, K. A. Zaki, University of Maryland, College Park, USA; J. A. Ruiz-Cruz, Universidad Autónoma de Madrid, Madrid, Spain; A. J. Piloto, Kyocera America, San Diego, USA

TU4B-03: Design of Dualband Microstrip Rat Race Coupler with Circuit Miniaturization
C. Hsu, C. Chang, J. Kuo, National Chiao Tung University, Hsinchu, Taiwan

TU4B-04: Low Insertion Loss Broadside Coupler in a Multilayer Above-IC Technology for K-Band Applications
N. Do, D. Dubuc, K. Grenier, R. Plana, Laas CNRS, Toulouse, France

TU4B-05: A Software-Configurable Coupler with Programmable Coupling Coefficient
S. Wang, Industrial Technology Research Institute, Chutung, Taiwan, ROC; C. Chang, National Chiao-Tung University, Hsinchu, Taiwan, ROC; J. Lin, University of Florida, Gainesville, USA

TU4B-06: Novel Substrate Integrated Waveguide Fixed Phase Shifter for 180° Directional Coupler
C. Yujian, H. Wei, State Key Lab of Millimeter Waves, Nanjing, China; W. Ke, Poly-Grames Research Center, Montréal, Canada

TU4C: Multi-GHz Circuits and Systems for Communication and Instrumentation

Chair: A. Konczykowska
Cochair: Koichi Murata
HCC 316B

TU4C-01: An 18 GHz Bandwidth, 60 GS/s Sample Rate Real-Time Waveform Digitizing System
P. J. Pupalaikis, LeCroy Corp., Chestnut Ridge, USA

TU4C-02: Antenna-Based Signal Processor Using Reconfigurable Receiver
L. Zhou, A. S. Daryoush, Drexel University, Philadelphia, USA

TU4C-03: A Novel Analog Decision-Feedback Equalizer for 10 Gb/s Multimode Fiber Dispersion Compensation
S. Chandramouli, F. Bien, H. Kim, E. Gebara, J. Laskar, C. Scholz, Georgia Electronic Design Center, Georgia Institute of Technology, Atlanta, USA

TU4C-04: Electrical Dispersion Compensator for a Gigabit Passive Optical Network System with Fabry-Perot Laser
H. Kim, F. Bien, S. Chandramouli, J. de Ginestous, C. Scholz, E. Gebara, J. Laskar, Georgia Institute of Technology, Atlanta, USA

TU4C-05: A 2 Gb/s Delta-Sigma Directly Driven Wireless Link
Q. Mu, L. Sankey, Z. Popovi , University of Colorado, Boulder, USA

TU4C-06: Odd Phase Switching Prescaler Based on Injection-Locked Frequency Divider
X. Yan, X. Yu, Zhejiang University, Hangzhou, P.R. China; M. Do, W. Lim, K. Yeo, Nanyang Tech. Univ., Singapore, Singapore

TU4D Microwave Photonic Devices

Chair: Dieter Jaeger
Cochair: Asher Madjar
HCC 316A

TU4D-01: All-Dielectric Wireless Receiver
R. C. Hsu, A. Ayazi, B. Houshmand, B. Jalali, University of California Los Angeles, Los Angeles, USA

TU4D-02: Traveling-Wave Spatial Quantized Analog-to-Digital Conversion
M. Jarrahi, T. H. Lee, Stanford University, Stanford, USA

TU4D-03: 2nd Order Distortion Cancellation in Photonic Time Stretch Analog-to-Digital Converter
S. Gupta, B. Jalali, University of California Los Angeles, Los Angeles, USA

TU4D-04: CMOS-Compatible 60 GHz Harmonic Optoelectronic Mixer
H. Kang, W. Choi, Yonsei University, Seoul, Korea

TU4D-05: Optically Injection-Locked Self-Oscillating HBT MMIC Optoelectronic Mixer for Bidirectional Fiber-Fed Wireless Links
J. Kim, W. Choi, Yonsei University, Seoul, Korea; H. Kamitsuna, M. Ida, K. Kurishima, NTT Corp., Atsugi-shi, Japan

TU4D-06: Optimization of Optical Delay Lines based on Photonic Crystal Coupled Cavity Waveguides
A. Gujjula, J. Sabarinathan, University of Western Ontario, London, Canada

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TU4E Advanced Components for Wireless Systems

Chair: Bernard D. Geller
Cochair: Chang-Ho Lee
HCC 315

TU4E-01: Ultralinear Dualband WLAN Front-End Module for 802.11a/b/g/n Applications with Wide Voltage and Temperature Range Operation
C. P. Huang, C. Masse, C. Zelley, C. Christmas, T. Ted Whittaker, J. Soricelli, W. Vaillancourt, A. Parolin, SiGe Semi., Methuen, USA

TU4E-02: A Complete Antenna-to-CMOS 4×6 mm Front End Module for Dualband 802.11abgn WLAN
H. T. Morkner, M. Vice, M. Karakucuk, W. Abey, L. D. Nguyen, J. F. Kessler, G. Carr, Avago Technologies, San Jose, USA

TU4E-03: Coexistence of an Electronically Tunable DVB-H Antenna with the GSM Transmitter in a Mobile Phone
L. Huang, W. L. Schroeder, BenQ Mobile, Kamp-Lintfort, Germany; P. Russer, Technische Universität München, Munich, Germany

TU4E-04: A Compact Triband PIFA with Multiple-Folded Parasitic Elements
D. Kim, J. Lee, C. Cho, Hankuk Aviation University, Goyang, Korea, South; J. Kim, Information and Communications University, Taejon, South Korea

TU4E-05: Complementary Bipolar Devices for Base Station Applications
E. Tiiliharju, Microelectronics Lab, Turku, Finland; H. Pellikka, Nokia Mobile Phones, Salo, Finland

TU4E-06: High-Level Integrated ICs for Low-Cost, Compact WiMAX Dualband RF Modules
C. Yuen, K. Laursen, D. Chu, M. Adams, H. Nguyen, Epic Communications Inc., Sunnyvale, USA

TU4F Applied Frequency Domain Techniques

Chair: Abbas Omar
Cochair: Luca Perregrini
HCC 314

TU4F-01: Short-Open Calibration Technique for Field-Theory-Based Parametric Extraction of Planar Discontinuities with Nonuniform Feed Lines
S. Sun, L. Zhu, Nanyang Technological University, Singapore, Singapore

TU4F-02: A New SCN-based Frequency-Domain TLM Node and its Applications with the Diakoptic Method
K. Sung, Z. D. Chen, Dalhousie University, Halifax, Canada

TU4F-03: A Nondisjoint Hexahedral Space Discretization for the Finite-Volume Technique
K. Krohne, R. Vahldieck, ETH Zürich, Zürich, Switzerland

TU4F-04: Fully Automatic HP Adaptivity for Electromagnetics, Application to the Analysis of H-Plane and E-Plane Rectangular Waveguide Discontinuities
L. E. Garcia-Castillo, Univ. Carlos III de Madrid, Leganes, Spain; L. F. Demkowicz, D. Pardo-Zubiaur, Univ. of Texas, Austin, USA

TU4F-05: An Incremental Fullwave EM Simulator for RF and Microwave Design
F. Ling, W. Harris, X. Wang, A. Dengi, Cadence Design Systems, Tempe, USA

TU4F-06: Optimizing the FDFD Method in Order to Minimize PML-Related Numerical Problems
P. K. Talukder, F. Schmuckle, W. Heinrich, FBH, Berlin, Germany; R. Schlundt, WIAS, Berlin, Germany

TU4G: Special Session A Tribute to Dr. Leo Young

Chair: Robert J. Trew
HCC 317A, B

TU4G-01: A Tribute to Dr. Leo Young
R. Trew, North Carolina State University, Raleigh, USA

Dr. Leo Young passed away at the age of 80 in September 2006. He pioneered the development of microwave filter technology, publishing 14 books and over 100 technical articles, and receiving 20 patents on various aspects of microwave technology. In 1964 together with his colleagues, George Matthaei and E.M.T. Jones, Leo wrote *Microwave Filters, Impedance-Matching Networks, and Coupling Structures,* included in the Microwave Hall of Fame and generally considered "the bible" for microwave filter design. Leo's extensive professional activities included serving as President of the IEEE and the MTT-S. He received numerous awards, including the Microwave Prize, Distinguished Service Award, and the Microwave Career Award. Leo was a Life Fellow of IEEE, a member of the National Academy of Engineering, and a Foreign Member of the UK Royal Academy of Engineering. Leo was the U.S. DoD's Director of Research and established many of its policies and programs that define support for basic research.

TUESDAY

Fiber-fed millimeter-wave wireless system
Broadband Wireless LAN
Wireless PAN / Home Network

CMOS-compatible 60 GHz Harmonic Optoelectronic Mixer

Hyo-Soon Kang and Woo-Young Choi

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134 Shinchon-dong, Seodaemoon-gu, Seoul 120-749, Korea

***Abstract* — We present 60GHz harmonic optoelectronic mixers based on Si avalanche photodetectors (APDs) fabricated by the standard complementary metal-oxide-semiconductor (CMOS) technology. The characteristics of APDs and harmonic optoelectronic mixers are investigated in order to optimize their performances. At the avalanche on-set voltage of APD, efficient harmonic optoelectronic mixing at 60 GHz band is obtained. In order to demonstrate the feasibility of applying harmonic optoelectronic mixers for fiber-supported millimeter-wave communication systems, down-link data transmission of 5 MS/s, 32 quadrature modulation (QAM) signals in 60 GHz band is successfully performed.**

***Index Terms* — Avalanche photodiodes, CMOS compatible photodetectors, millimeter wave communication, optoelectronic mixers.**

I. INTRODUCTION

Fiber-supported millimeter-wave communication technology is a promising technology for next generation broadband communication systems. It can take advantages of both low-loss, huge bandwidth of fiber-optic technology, and large bandwidth, high directivity, and high frequency reusability of millimeter-wave wireless links. In these systems, large bandwidth data and high-frequency signals are distributed to many base stations through optical fiber and then radiated to free-space. As a consequence, implementation of simple and low-cost base stations is very important. Several approaches for achieving this have been reported. For the remote up-conversion method, optical devices such as semiconductor optical amplifier (SOA) and electroabsroption modulator (EAM) [1] and InP-based phototransistors including high electron-mobility transistors (HEMTs) [2] and heterojunction phototransistors (HPTs) [3] are utilized. Although these approaches can significantly simplify the base station architecture, InP-based components are, as of yet, not very cost-effective.

In another approach, photodetectors such as GaAs metal-semiconductor-metal photodetectors [4], InGaAs p-i-n photodiodes [5], and Si avalanche photodiodes (APDs) [6, 7] have been used for simultaneous photodetection and frequency mixing. However, the optoelectronic mixers based on theses photodetectors require output signal amplification to compensate conversion loss and it is not an easy task to integrate these photodetectors with necessary electronic circuits in a cost-effective manner.

As a possible solution for this problem, we have previously proposed CMOS-compatible OptoElectronic Mixer (CMOS-OEM) and demonstrated frequency up-conversion into 30 GHz band [8]. In this paper, we demonstrate that operation of CMOS-OEM can be extended to 60 GHz as a harmonic optoelectronic mixer. Our harmonic CMOS-OEM is based on CMOS-compatible Si APD, which realized with the standard 0.18 ㎛ CMOS process. We optimize the performance of the harmonic CMOS-OEM and demonstrate the data transmission of 5 MS/s 32 QAM baseband signals, which is harmonic frequency up-converted into the 60 GHz band.

II. AVALANCHE PHOTODETECTOR STRUCTURE

Fig. 1 shows cross-sectional diagram of fabricated avalanche photodetectors. In order to eliminate the slow diffusion current in substrate, we only adopt the vertical P+/n-well junction [9]. The multi-finger electrodes with narrow (0.5 ㎛) finger spacing are formed to collect photogenerated carriers effectively without going through the lateral diffusion path. Furthermore, this vertical PN junction structure can mitigate the edge breakdown in the avalanche regime. The active area of the APD is about 30×30 ㎛^{2} and the salicide process is blocked for the optical window.

III. AVALANCHE PHOTODETECTOR CHARACTERISTICS

For the APD characterization, 850 nm optical signal from a Fabry-Perot LD was injected into the device using a lensed-fiber. Fig. 2 shows I-V characteristics with and without optical illumination. The incident optical power was 1 mW measured at the end of the lensed fiber. In Fig. 2, the avalanche breakdown can be observed at the reverse bias voltage of about 10.4 V under dark condition. The fabricated APD has maximum responsivity of 0.36 A/W and avalanche gain of 86

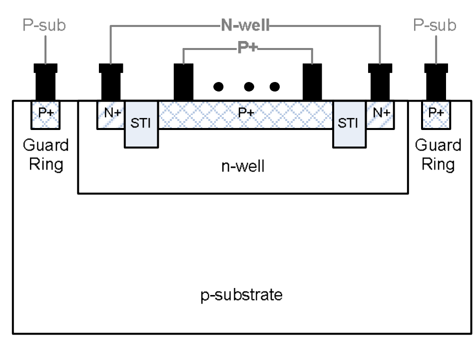

Fig. 1. Schematic cross-section of fabricated APD.

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at the reverse bias voltage of 10.4 V under 1 mW optical illumination.

For measurement of optical modulation frequency response, a 20 GHz electro-optic modulator and a vector network analyzer were used. Fig. 3 shows optical modulation responses of the fabricated APD at different bias voltages. When the applied reverse voltage increases, the responsivity of the photodetector increases as the bias voltage approaches the reverse breakdown voltage. At the reverse bias voltage of 10.4 V, 3-dB bandwidth of fabricated photodetector is about 2 GHz, which indicates that the harmonic optoelectronic mixer based on CMOS-APD can be utilized for broadband Gb/s data transmission.

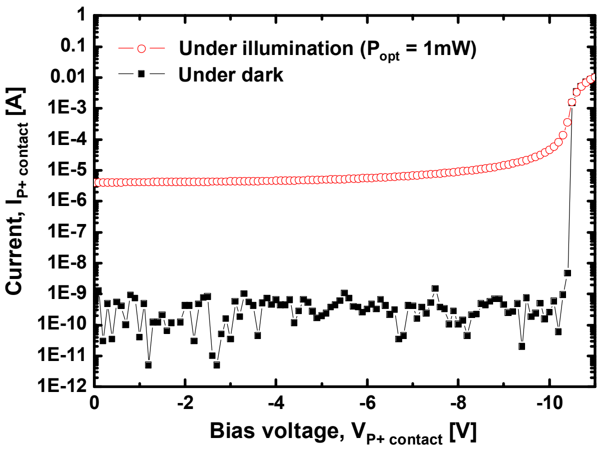

Fig. 2. Current-voltage (I-V) characteristics of the APD under dark and illumination condition. The incident optical power is 1 mW.

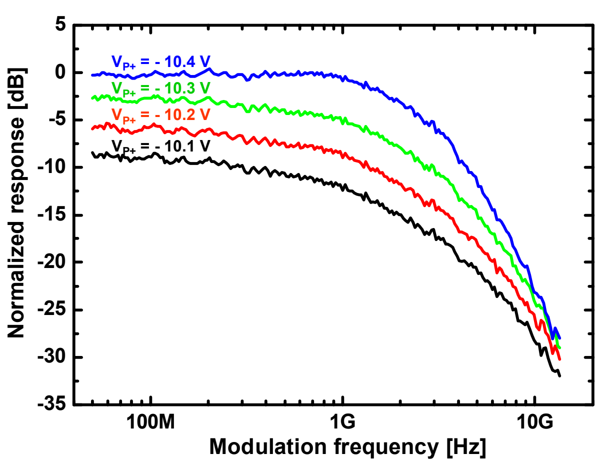

Fig. 3. Optical modulation frequency response of the APD at different bias voltages.

IV. Harmonic Optoelectronic Mixing

Harmonic frequency up-conversion using the CMOS-OEM is implemented in the manner shown in Fig. 4. Electrical LO signal is injected to the RF port which is tied to n-well contact and modulated optical IF signal is illuminated to the device. Frequency up-converted signal is taken out from the P+ contact to eliminate the slow diffusion components in substrate region. With the help of nonlinear characteristics of photodetectors due to the avalanche process [6, 7], harmonic CMOS-OEM can perform photodetection and frequency conversion simultaneously. Fig. 4 also shows the up-converted signal spectrum of harmonic CMOS-OEM when 30.25 GHz electrical LO and 500 MHz optical IF signals are applied to the device. Second harmonic LO at 60.5 GHz ($2 \cdot f_{LO}$), upper side band (USB) at 61 GHz ($2 \cdot f_{LO} + f_{IF}$) and lower side band (LSB) at 60 GHz ($2 \cdot f_{LO} - f_{IF}$) are clearly observed.

In order to optimize harmonic CMOS-OEM, bias voltage dependence of frequency up-converted signal powers (USB and LSB) were measured and the results are shown in Fig. 5. As the reverse bias voltage increases, frequency up-converted signal power increases and has maximum value at 10.4 V. This is because at this voltage CMOS-APD has maximum avalanche gain and, therefore, maximum photodetected signal power.

We also measured fundamental frequency up-converted signal powers ($f_{LO} + f_{IF}$ and $f_{LO} - f_{IF}$) as well as harmonic one for comparison and the results are shown in Fig. 5. The conversion efficiency for the second-order mixing is about 11 dB lower than the fundamental mixing owing to the small second-order harmonic nonlinear coefficient of I-V curve and cable loss used in the experiment at 60 GHz band. In the experiment of second harmonic frequency up-conversion, 35.5 dB gain amplifier was used for boosting up the second-order

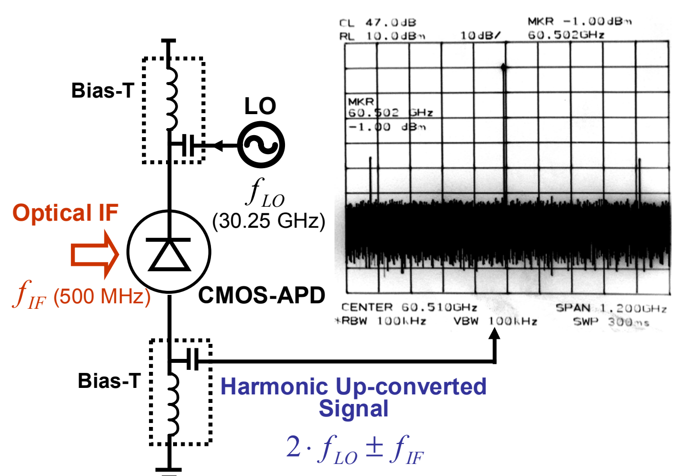

Fig. 4. Schematic diagram of optoelectronic frequency mixing utilizing the CMOS-APD and the spectrum of harmonic frequency up-converted signal when 30.25 GHz electrical LO and 500 MHz optical IF signals are injected to the device.

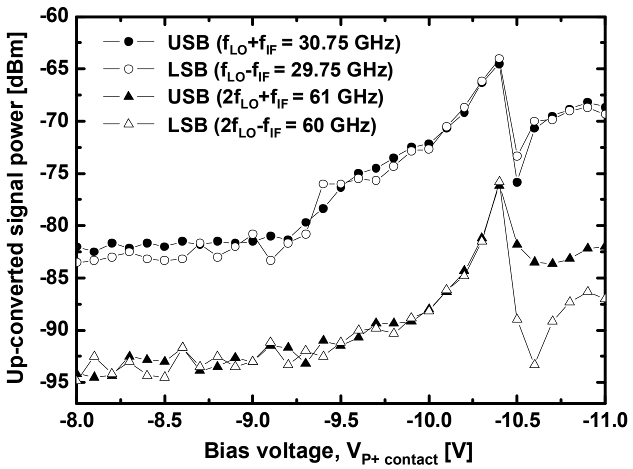

Fig. 5. Fundamental and harmonic frequency up-converted signal powers as a function of reverse bias voltage.

harmonic up-converted signal power.

V. Data Transmission Demonstration

Utilizing millimeter-wave harmonic CMOS-OEM, 60 GHz remote up-conversion downlink data transmission was performed. Fig. 6 shows the experimental setup. In the central office, 850 nm light was modulated by 5 MS/s 32 QAM data at 500 MHz IF signal using an EOM and transmitted through 2 m standard single-mode fiber. At the antenna base station, optical IF was photodetected and frequency up-converted to 60 GHz band by CMOS-OEM. The revere bias voltage of 10.4 V was applied since this provides the maximum frequency up-converted signal power as shown in Fig 5. Although this bias voltage is much larger than typical bias voltages used for CMOS circuits, CMOS circuit techniques such as dc-dc up converters [10] can easily solve this problem. The harmonic up-converted signal was passed through amplifier and band pass filter (BPF) for amplification and undesired signals rejection, respectively. The incident optical power at CMOS-OEM was about 1 mW. To examine the performance of harmonic CMOS-OEM, 60 GHz band signal is frequency down-converted using a sub-harmonic electric mixer and then demodulated by a vector signal analyzer (VSA). In our experimental setup, LO signal generated by a frequency synthesizer was divided by an RF power splitter and used for both harmonic CMOS-OEM and electric mixer. Fig. 7 shows the 60 GHz output signal spectrum at the output of antenna base station, and constellation and eye diagram of the demodulated 5 MS/s 32 QAM data signal at the VSA. The measured EVM was approximately 5.42 %, which corresponds to about 21.3 dB SNR.

VI. Conclusion

A 60 GHz harmonic optoelectronic mixer based on a CMOS-APD is implemented and optimized. At the bias voltage of avalanche breakdown on-set voltage, harmonic frequency up-converted power is enhanced due to the enhanced avalanche gain. Using the harmonic CMOS-OEM, 5 MS/s 32 QAM data signal was successfully up-converted to 60 GHz band and transmitted with 5.42 % EVM. Harmonic CMOS-OEM can be easily integrated with other necessary CMOS circuits, and, consequently, provides a possibility for system-on-chip (SoC) realization of base stations.

Acknowledgement

We acknowledge that EDA software used in this work was supported by IDEC (IC Design Education Center) of Korea. .

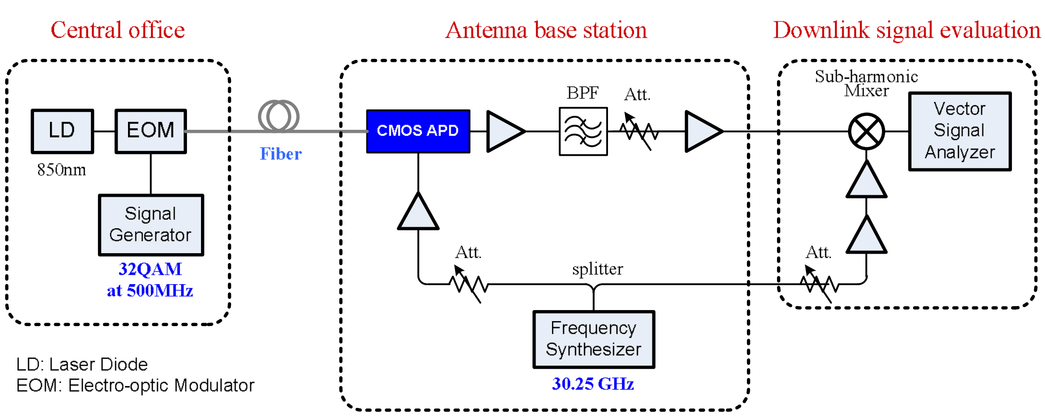

Fig. 6. Experimental setup for 60GHz downlink data transmission using harmonic optoelectronic mixer based on CMOS-APD.

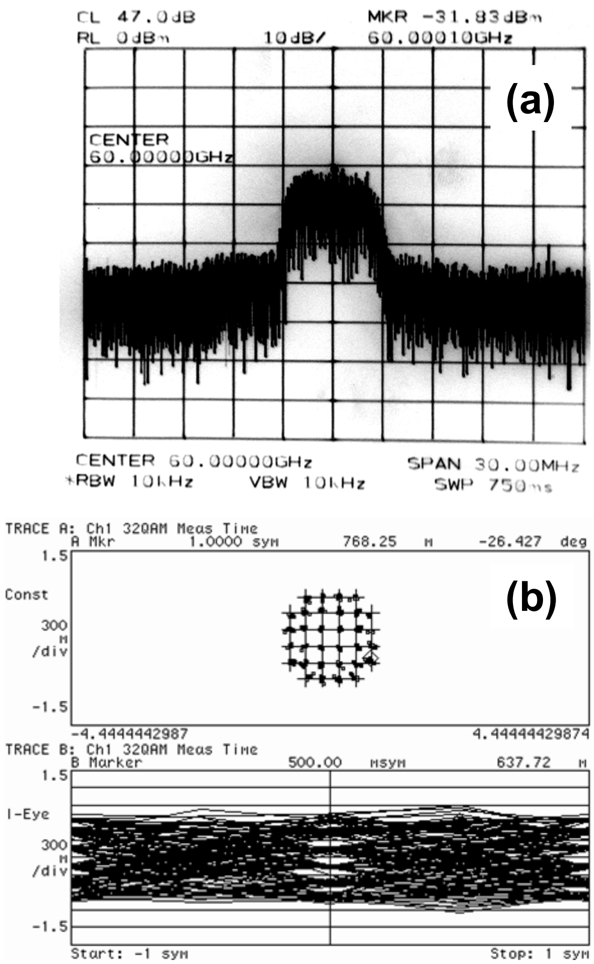

Fig. 7. (a) Harmonic frequency up-converted signal spectrum at the output of antenna base station. (b) Constellation and eye diagram of demodulated downlink data (5 MS/s 32 QAM) signal.

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