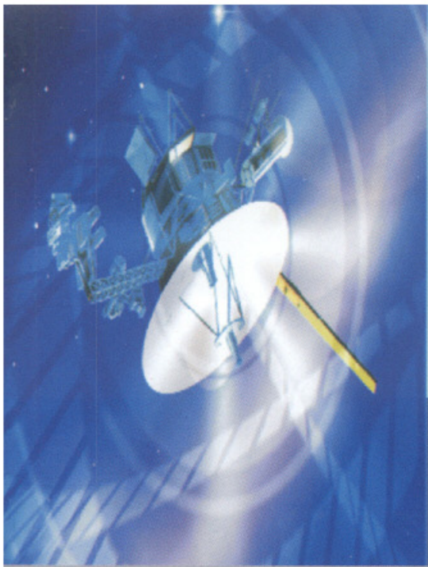

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대한전자공학회 마이크로파 및 전파전파연구회
한국전자파학회 마이크로파 및 전파연구회
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제주지식산업진흥원
♣ 후원 : 제주특별자치도, 제주대학교 첨단기술연구소

Session II **RFIC · MMIC/마이크로파 수동회로 분야**

▶장소 : 공대 3호관 C206

14:00~15:40		**좌장 : 서철헌 (숭실대)**	
[2-1-1]	14:00~14:20	Low-Power Folded Cascode CMOS Class-E Power Amplifier for 2.4GHz Wireless Sensor Network	황규석, 조춘식 (한국항공대)
[2-1-2]	14:20~14:40	CDMA/WLAN을 위한 0.18-um CMOS 이중 대역 저 잡음 증폭기에 관한 연구	송혜정, 김희중, 박창준, 윤제형, 이세경, 서희송, 김범만 (포항공대)
[2-1-3]	14:40~15:00	PCS/WCDMA/WiBro/Bluetooth 서비스용 광역 CMOS 저 잡음 증폭기 설계	장요한, 최영백, 최재훈 (한양대)
[2-1-4]	15:00~15:20	60GHz Self-Heterodyne 시스템을 위한 0.18um CMOS Schottky Barrier Diode	고민수, 강효순, 최우영 (연세대)
[2-1-5]	15:20~15:40	0.13-um CMOS 공정을 이용한 전하 영역 수동 주파수 변환기	박창준, 윤제형, 송혜정, 이세경, 서희송, 김범만 (포항공대)
	15:40~16:10	Coffee Break	
16:10~17:50		**좌장 : 이해영 (아주대)**	
[2-1-6]	16:10~16:30	3.6GHz-3.8GHz WiMAX 대역 5W SiC MESFET 전력 증폭기	김경환, 김재권, 범진욱 (서강대)
[2-1-7]	16:30~16:50	MMIC 응용을 위한 능동형 90° 전력 분배기 및 결합기에 관한 연구	박영배, 조한나, 김세호, 박찬섭, 한정우, 윤영 (한국해양대)
[2-1-8]	16:50~17:10	다중대역 저지 DGS를 이용한 마이크로파 증폭기의 소형화 및 선형성 증대기법	이광재, 우덕재, 김성지, 이택경 (한국항공대)
[2-1-9]	17:10~17:30	다구찌법을 이용한 나선형 인덕터의 품질계수 개선에 관한 연구	고재형, 김동훈, 김형석 (중앙대/경북대)
[2-1-10]	17:30~17:50	동축선-구형도파관 엔드론치형 어댑터 해석에 관한 연구	김동현, 양두영 (제주대)

60 GHz Self-Heterodyne 시스템을 위한 0.18 μm CMOS Schottky Barrier Diode

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0.18-μm CMOS Schottky Barrier Diodes for 60-GHz Self-Heterodyne Systems

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Yonsei University

Abstract

A Schottky barrier diode having a cut-off frequency of 250 GHz is fabricated in a 0.18-μm CMOS technology. Based on this diode, a square-law-type down-conversion mixer for 60-GHz self-heterodyne systems is implemented. The measured peak conversion gain is -26.8 dB when input RF and LO powers are -3 dBm. Using the mixer, 32 qaudrature amplitude modulation data transmission in a 60-GHz self-heterodyne system is successfully demonstrated.

I. Introduction

During the recent years, there have been lots of academic and commercial interests in high-speed, short-range, and license-free 60-GHz band communications. Research results on low-cost millimeter-wave RF transceivers, especially operating in 60-GHz bands, have been reported for CMOS technologies [1, 2]. Among building blocks of RF transceivers, 60-GHz mixers such as a 60-GHz active single-ended mixer [3], a 60-GHz resistive single-ended mixer [4], and a 25~75-GHz broadband Gilbert-cell mixer [5] also have been reported. These are fabricated in 0.13-μm or 90-nm CMOS technologies.

However, 60-GHz mixers in a more cost-effective 0.18-μm CMOS technology have not been addressed previously because of its low transit frequency, f_t, and maximum frequency of oscillation, f_{max}. The use of Schottky barrier diodes (SBD) is an alternative solution to overcome the limitation of the operating frequency. SBDs can be fabricated in a standard CMOS process, and have cut-off frequencies of several hundred GHz in a 0.18-μm CMOS technology [6]. Furthermore, due to their nonlinear characteristic, it is feasible to implement millimeter-wave nonlinear devices such as detectors [7], frequency doublers [8], and mixers [8] by using SBDs.

On the other hand, self-heterodyne systems enable simpler and more cost-effective RF transceivers [9]. In self-heterodyne systems, the transmitter transmits not only frequency up-converted RF signals but also a LO signal simultaneously, and the receiver performs frequency down-conversion of these signals to IF band by using a square-law mixer without a local oscillator. Moreover, performance requirements of the local oscillator at the transmitter are relaxed because problems caused by phase noise and frequency offset at the transmitter are eliminated at the receiver.

In this work, we fabricated and characterized a SBD in a 0.18-μm CMOS technology. And using this, we realized a 60-GHz down-conversion mixer for square-law detection in self-heterodyne systems. In addition, we demonstrated 25-Mb/s 32 qaudrature amplitude modulation (QAM) data transmission in a 60-GHz self-heterodyne system using the mixer.

II. Schottky Barrier Diodes in CMOS Technology

Fig. 1 shows a cross-sectional view of the fabricated SBD cell. In the SBD, there are two types of metal-semiconductor junctions, the anode Schottky junction and the cathode ohmic junction. The Schottky junction is formed between the cobalt salicide layer and the low-doped n-well layer.

The cut-off frequency, f_c, of the SBD is given by

$$f_c = \frac{1}{2\pi RC},$$

where R is the series resistance and C is the total capacitance of the diode [10]. The series resistance is mainly due to the n-well resistance, and the total capacitance comes from the Schottky junction capacitance and the contact parasitic capacitance. To reduce the capacitance, the Schottky junction area was chosen a minimum value of 0.2116 μm^2, allowed by the process. For the same purpose, metal layers of anode and cathode were spaced apart enough. To reduce the resistance, the spacing between the Schottky junction and the ohmic junction was chosen a minimum value of 0.32 μm. And multiple cells connected in parallel were used for decreasing the series resistance [6].

To extract parameters of the diode, on-wafer 1-port S-parameter measurements were performed. The pad-open-short deembedding technique [11] was used for accurate parameter

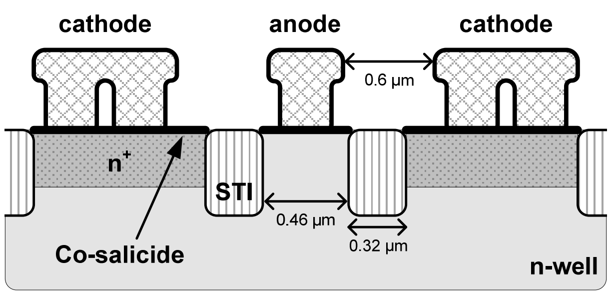

Fig. 1. Cross-sectional view of SBD cell

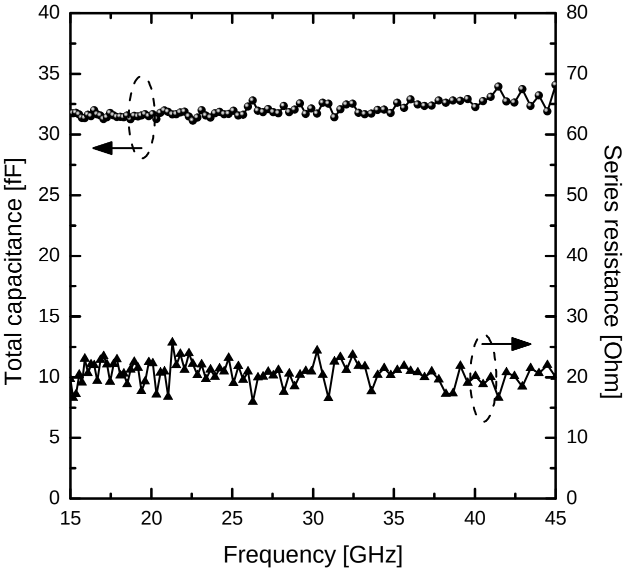

Fig. 2. Series resistance and total capacitance of SBD when Schottky junction voltage is zero

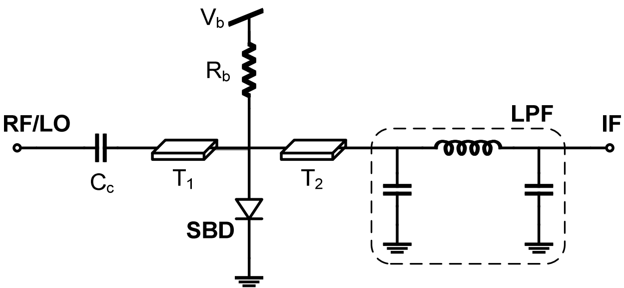

Fig. 3. Schematic of 60-GHz SBD down-conversion mixer

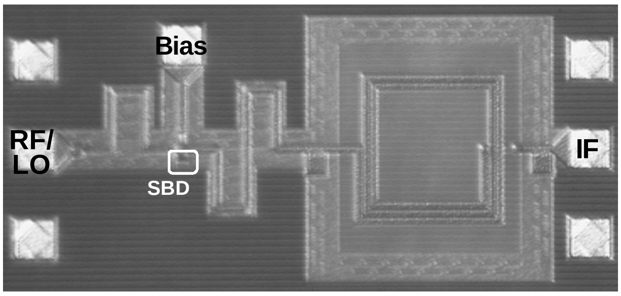

Fig. 4. Chip photo of 60-GHz SBD down-conversion mixer

extraction of intrinsic devices in very high frequencies range up to 50 GHz. Fig. 2 shows the series resistance and the total capacitance of the 25-cell SBD structure in the frequency range of 15 ~ 45 GHz when the Schottky junction voltage is zero. The measured resistance and capacitance were about 20 Ω and 32 fF with slight variations. The calculated cut-off frequency was approximately 250 GHz. From the results, the feasibility of SBD in a standard CMOS technology for millimeter-wave applications is examined.

III. 60-GHz Down-Conversion Mixer

We fabricated a square-law-type 60-GHz down-conversion mixer using the SBD in a 0.18-µm CMOS process. In comparison with mixers in heterodyne systems, down-conversion mixers in self-heterodyne systems have different characteristics. At the down-conversion mixer in self-heterodyne systems, the input signal contains both LO and RF signals. In addition, the LO power should be the same as the RF power to achieve a maximum SNR [9]. Therefore, separation of LO and RF port as in conventional mixer is not required.

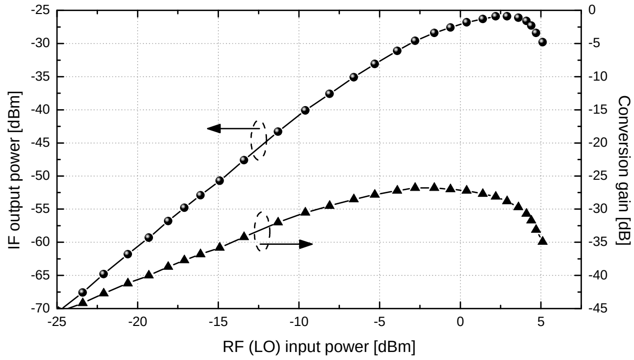

Fig. 5. IF output power and conversion gain versus input RF power (= input LO power)

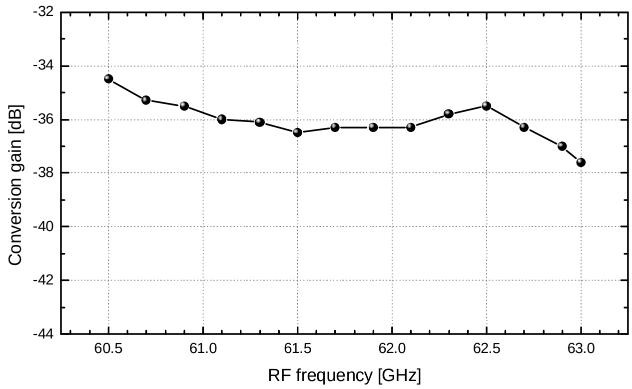

Fig. 6. Conversion gain versus RF frequency when input RF (LO) power is -13.1 dBm

Fig. 3 and Fig 4 show the schematic and the chip photo of the fabricated mixer. 25-cell SBD cells having a low series resistance are used, and a 0.7-V bias voltage, V_b, is applied to the diode to obtain enough conversion efficiency with the low LO power. The bias circuit is simply configured by using a 2-kΩ N+ poly resistor, R_b. A 100-fF coupling capacitor, C_c, and a low-pass filter (LPF) having a cut-off frequency of 4.5 GHz are used to isolate each port. All capacitors and inductors were fabricated using metal-insulator-metal (MIM) capacitors and spiral inductors. Transmission lines, T_1 and T_2, are microstrip lines for matching networks. Microstrip lines are realized using a top-metal layer for signal lines and a metal-1 layer for a ground plane. T_1 is an input conjugate matching network to apply the maximum power to the diode. And T_2 is a quarter-wavelength line at RF frequency to transform low input impedance of the LPF to high impedance at 60 GHz [12].

In order to examine the performance of the fabricated mixer, two-tone of LO and RF signals at 60-GHz are generated by a 60-GHz phase-locked oscillator (PLO), a 60-GHz LO-leakage mixer, BPF, and a power amplifier (PA). All the measurements were done using on-wafer probing. The LO frequency was fixed at 60.0 GHz, and the LO power was set to the same as the RF power. To characterize the intrinsic performance of the mixer, power losses from probes and cables were deembedded. Fig. 5 shows

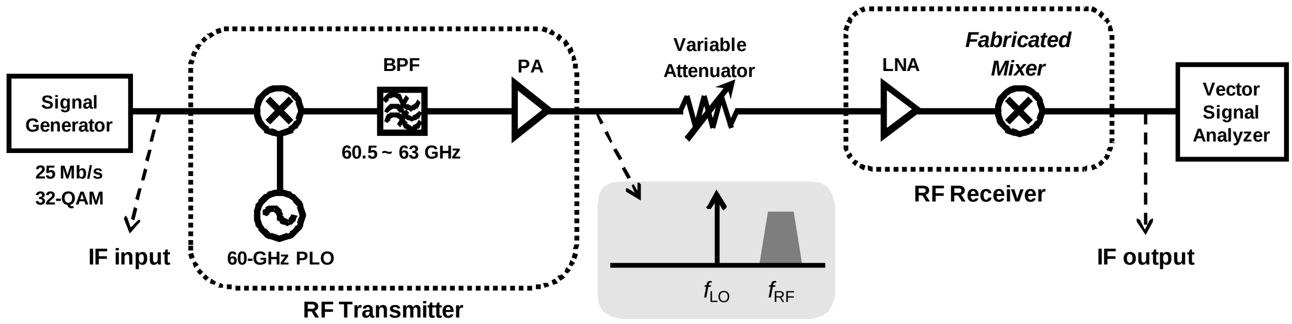

Fig. 7. Experimental setup for 60-GHz data transmission using self-heterodyne scheme

the measured IF output power and the conversion gain as a function of the input RF power when the RF signal of 60.5 GHz is applied. We observed that the IF output power was increased by a slope of 2 due to the square-law operation. The peak conversion gain was -26.8 dB when the RF input power was -3 dBm. Fig. 6 shows the conversion gain as a function of the RF frequency at the RF input power of -13.1 dBm. In the frequency range of 60.5 ~ 63.0 GHz, the variation of the conversion gain was within 3 dB.

IV. Data Transmission in 60 GHz

To investigate the feasibility of the fabricated mixer for self-heterodyne systems, we demonstrated 25-Mb/s 32-QAM data transmission in the 60-GHz self-heterodyne link using the mixer. Fig. 7 shows our experimental setup. The digitally-modulated IF input signal is generated by a signal generator. The output signal of the LO-leakage mixer contains the 60.0-GHz LO signal of -1.7 dBm and the double-sideband RF up-converted signal. And a BPF filters out the lower sideband of the RF signal with 20-dB attenuation of the LO signal. Finally, LO and RF signals of 3 dBm each are transmitted to the RF receiver through a power amplifier. A variable attenuator is placed between the RF transmitter and the RF receiver to control the transmitted signal power to the RF receiver. The RF receiver is simply configured only with a LNA and the fabricated mixer without a local oscillator. After signal amplification by the LNA, the received LO and RF signals are down-converted to the IF band, and then demodulated by a vector signal analyzer.

To evaluate the performance of the link, we measured error vector magnitude (EVM) of the IF output signal by using the vector signal analyzer. Fig. 8 shows the measured EVM as a function of the received RF power at the receiver, when the RF frequency is 60.5 GHz. In the range of -28 ~ -10 dBm, measured EVMs were below 5 %. The minimum EVM of 2.98 % is obtained when the received RF power was -20.5 dBm. At this optimum power, the constellation, the eye-diagram, and the spectrum of the IF output signal were shown in the inset of Fig. 8, and Fig. 9.

There are two main factors to degrade the EVM performance. First one is the input sensitivity of demodulator, which is the vector signal analyzer in our experimental setup. If the IF output power is small enough, the SNR is limited by the noise from the vector signal analyzer and linearly proportional to the IF output power. The result from this can be seen in Fig. 8 when the received RF power is less than the optimum point. This can be overcome by improving the RF receiver gain, including the conversion gain of the fabricated mixer. Second factor is the nonlinearity of the RF receiver. As the received RF power increases, the nonlinear components such as 3rd order inter-modulation products (IP3) can cause signal distortions. This can

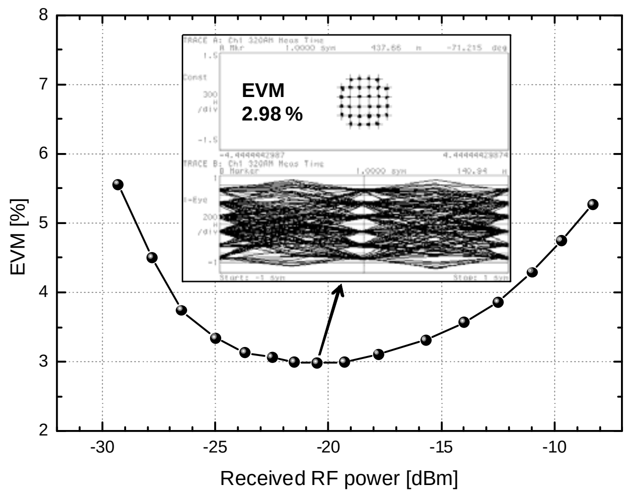

Fig. 8. Relationshp between received RF power and EVM when RF frequency is 60.5 GHz. Inset is constellation and eye-diagram at minimum EVM.

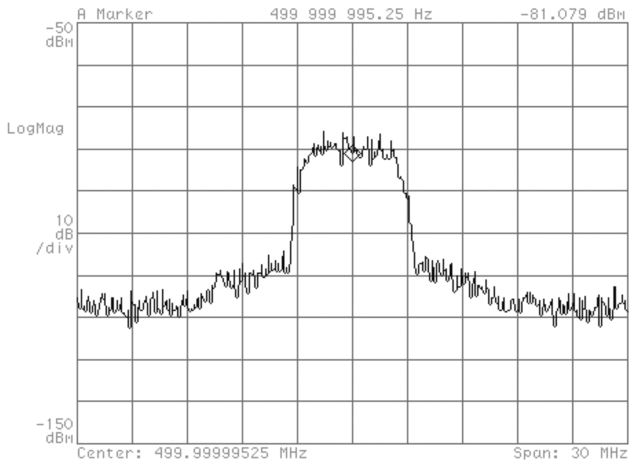

Fig. 9. Spectrum of IF output signal in optimum condition (received RF power = -20.5 dBm)

be also seen in Fig. 8 when the received RF power is more than the optimum point.

V. Conclusion

We fabricated the 60-GHz down-conversion mixer using Schottky barrier diodes having a cut-off frequency of 250 GHz. The fabricated mixer is for self-heterodyne systems, and we verified the mixer as a subsystem of the 60-GHz self-heterodyne link.

Acknowledgments

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References

[1] David Alldred, Brian Cousins, and Sorin P. Voinigescu, "A 1.2V, 60-GHz Radio Receiver with On-Chip Transformers and Inductors in 90-nm CMOS", *IEEE Compound Semiconductor Integrated Circuit Symposium*, pp. 51-54, Nov. 2006.

[2] Behzad Razavi, "CMOS Transceivers at 60 GHz and Beyond", *IEEE International Symposium on Circuits and Systems*, pp. 1983-1986, May 2007.

[3] Sohrab Emami Chinh H. Doan, Ali M. Niknejad, and Robert W. Brodersen, "A 60-GHz Down-Converting CMOS Single-Gate Mixer", *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium*, pp. 163-166, June 2005.

[4] Bahar M. Motlagh, Sten E. Gunnarsson, Mattias Ferndahl, and Herbert Zirath, "Fully Integrated 60-GHz Single-Ended Resistive Mixer in 90-nm CMOS Technology", *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 1, pp. 25-27, Jan. 2006.

[5] Jeng-Han Tsai, Pei-Si Wu, Chin-Shen Lin, Tian-Wei Huang, John G. J. Chern, and Wen-Chu Huang, "A 25-75 GHz Broadband Gilbert-Cell Mixer Using 90-nm CMOS Technology", *IEEE Microwave and Wireless Components Letters*, Vol. 17, No. 4, pp. 247-249, Apr. 2007.

[6] S. Sankaran and K. K. O, "Schottky Diode with Cutoff Frequency of 400 GHz fabricated in 0.18μm CMOS", *Electronics Letters*, Vol. 41, No. 8, pp. 506-508, Apr. 2005.

[7] Eunyoung Seok, Changhua Cao, Swaminathan Sankaran, Kenneth K. O, "A Millimeter-Wave Schottky Diode Detector in 130-nm CMOS Technology", *Symposium on VLSI Circuits*, pp. 142-143, June 2005.

[8] C. Mishra, U. Pfeiffer, R. Rassel, and S. Reynolds, "Silicon Schottky Diode Power Converters Beyond 100 GHz", *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium*, pp. 547-550, June 2007.

[9] Yozo Shoji, Kiyoshi Hamaguchi, and Hiroyo Ogawa, "Millimeter-Wave Remote Self-Heterodyne System for Extremely Stable and Low-Cost Broad-band Signal Transmission", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 50, No. 6, pp. 1458-1468, June 2002.

[10] Stephen A. Maas, *Microwave Mixers, 2nd ed.*, Norwood, Ma: Artech House, 1993.

[11] Luuk F. Tiemeijer, Ramon J. Havens, Andre B. M. Jansman, and Yann Bouttement, "Comparison of the "Pad-Open-Short" and "Open-Short-Load" Deembedding Techniques for Accurate On-Wafer RF Characterization of High-Quality Passives", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 2, pp. 723-729, Feb. 2005.

[12] Eric Chan, "Design of a 5-6 GHz Single Balanced Schottky Diode Mixer", *Asia-Pacific Conference on Applied Electromagnetics*, pp. 67-71, Aug. 2003

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- 국문 논문제목: 60 GHz Self-Heterodyne 시스템을 위한 0.18 µm CMOS Schottky Barrier Diode
- 영문 논문제목: 0.18-µm CMOS Schottky Barrier Diodes for 60-GHz Self-Heterodyne Systems

- 분야명: Microwave/Millimeter-wave 능동 및 수동회로 분야
- 발표양식: 구두