A Wideband 60 GHz Gm-Boosted Up-Conversion Mixer

Cheol So[1] and Song Cheol Hong[a]
School of Electrical Engineering, Korea Advanced Institute of Science and Technology
E-mail : [1]nimbus1112@kaist.ac.kr

Abstract - **In this paper, a wideband gm-boosted up-conversion mixer is presented, which is fabricated in 28-nm bulk CMOS process. It adopts a double-balanced structure for high isolation characteristics. The circuit employs a current bleeding path through PMOS to enhance the gm, resulting in a high conversion gain. The feedback resistor R enables impedance matching without an additional impedance matching network while providing wideband characteristics in the baseband. Furthermore, the symmetrical layout of the switching stage cells improves the LO to RF isolation performance. The measured peak conversion gain is 3.2 dB, and the 3-dB frequency bandwidth is more than 6 GHz. The power consumption is 6.38 mW at 1.1 V supply voltage. The chip size, including the pads, is 0.53 x 0.42 mm^2 and the core area is 0.2 x 0.26 mm^2.**

Keywords—**Current-bleeding, Feedback resistor, Gm-boosting, PMOS, Up-conversion mixer**

I. INTRODUCTION

Recently, the demand for high-speed data communication has been increasing. To increase data rates, high-order modulation and expanding bandwidth are used. High-order modulation allows for more data to be transmitted within the same frequency bandwidth. Still, it also requires more complex modulation and demodulation processes and results in strict hardware requirements. High linearity is necessary for the modulator, while the EIRP is lowered due to low linear output power. On the other hand, the demodulator suffers from noisy or long-distance environments as it requires higher SNR. An alternative method is to increase the bandwidth by selecting a higher carrier frequency. The 60 GHz band, in particular, is assigned a wide unlicensed frequency range, making it suitable for high-speed communication [1], [2], [3], [4], [5], [6].

The 60 GHz band, unlike the 4G or 5G communication frequency bands, presents challenges in terms of the lower MAG characteristics of active elements and higher loss characteristics of passive components due to the skin effects and parasitic capacitance. To address these issues, additional gain blocks are necessary, which increases the size of the chip and power consumption.

a. Corresponding author; schong1234@kaist.ac.kr

Manuscript Received Jan. 26, 2023, Revised Mar. 16, 2023, Accepted Mar. 21, 2023

In this paper, a wideband 60 GHz gm-boosted up-conversion mixer is proposed. It achieves a high conversion gain through the gm-boosting effect. Additionally, the feedback resistor R allows for wide bandwidth characteristics.

II. CIRCUIT DESIGN

Fig. 1 shows the schematic of the proposed wideband 60 GHz gm-boosted up-conversion mixer. The double-balanced structure is chosen for its high isolation characteristics. A baseband signal is applied to M_{1-4}, and an LO signal is applied to M_{5-8} as a switching stage. In contrast, in a traditional Gilbert cell up-conversion mixer, the baseband signal is applied to the gate of the NMOS or PMOS. The conversion gain of a Gilbert cell mixer is determined by the gm component in the gm stage and the harmonic component in the switching stage. In general, when bias voltage near the threshold voltage (VTH) is applied to the gate-source voltage (VGS) in the switching stage, the harmonic component increases, and thus the conversion gain of the mixer increases. However, the amount of DC current flowing at this time becomes smaller, so it doesn't have an enough gm in the gm stage. To overcome this, current bleeding techniques are widely used [7], [8], [9]. By separately generating a current bleeding path and supplying DC current to the gm stage, the switching stage can have a harmonic component by operating under the bias condition near VTH and get enough gm in the gm stage.

A. Current-reused, gm-boosted up-conversion mixer

The proposed up-conversion mixer introduced the current bleeding path using PMOS. DC current is applied to the gm stage by using this current bleeding path. Additionally, the gm of PMOS is added to the gm of the NMOS. As a result, the gm is boosted in the gm stage, leading to an increase in the conversion gain. The proposed up-conversion mixer also features a feedback resistor R that connects the gate and drain of the gm stage, resulting in wide bandwidth characteristics. This negative feedback allows the gain to be lowered in the gm stage while increasing the bandwidth. Generally, the gate of a MOSFET has high impedance characteristics. As the frequency increases, the impedance of real part decreases due to the parasitic capacitance. The low frequency of the baseband signal results in a high impedance at the baseband port. Therefore, an impedance matching balun with a large turn ratio is required, and bandwidth is reduced during the impedance transformation process.

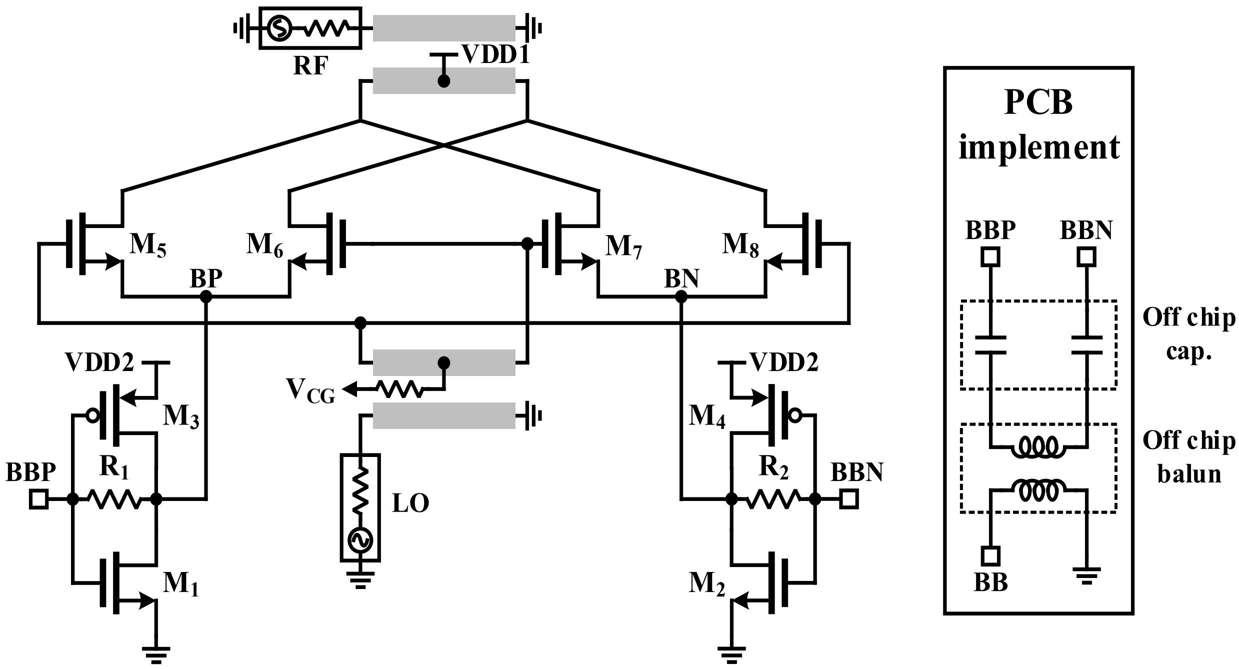

Fig. 1. Schematic of the proposed wideband 60 GHz gm-boosted up-conversion mixer

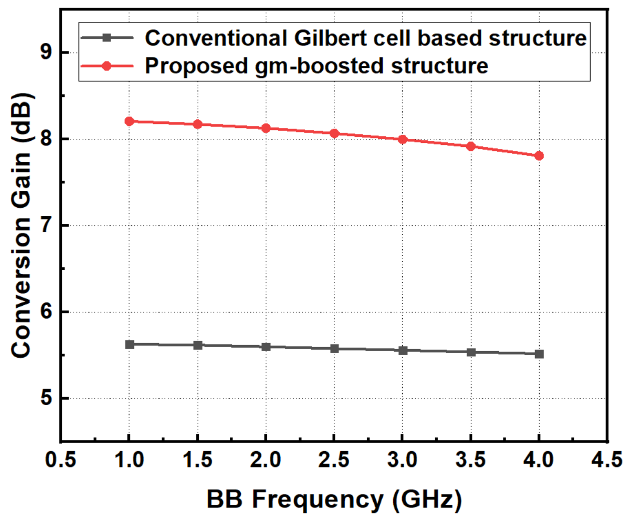

Fig. 2. Simulated conversion gain of the conventional Gilbert cell-based structure and proposed gm-boosted structure

However, by incorporating a feedback resistor R in the proposed structure, the input impedance can be expressed as [10]

$$Z_{in} = \frac{(r_{o,n} \| r_{o,p}) + R_1}{1 + (g_{m,n} + g_{m,p})(r_{o,n} \| r_{o,p})} \quad (1)$$

In this design, by carefully selecting the value of feedback resistance R, the input impedance of real parts can be reduced, resulting in improved return loss characteristics at the baseband port without an additional impedance matching network. Fig. 2 shows the simulated conversion gain of the conventional Gilbert cell based up-conversion mixer and proposed gm-boosted structure. For a fair comparison, both structures consume the same power, and the BB, LO, and RF ports are ideally conjugate impedance matched. The proposed up-conversion mixer shows an approximately 2.5 dB gain improvement.

B. Symmetric layout of the switching stage cells

Leakage in the up-conversion mixer can cause an offset on the constellation, decreasing EVM performance. To mitigate this, a double-balanced structure is chosen to prevent leakage. However, if a mismatch occurs during the layout, the differential characteristics of the circuit operation can be compromised, leading to leakage. Therefore, the cells of the switching stage symmetrically constructed the routing of each source drain gate, thereby improving the LO to RF leakage characteristics. Fig. 3 illustrates the layouts of cells in the switching stage that have been designed to minimize leakage.

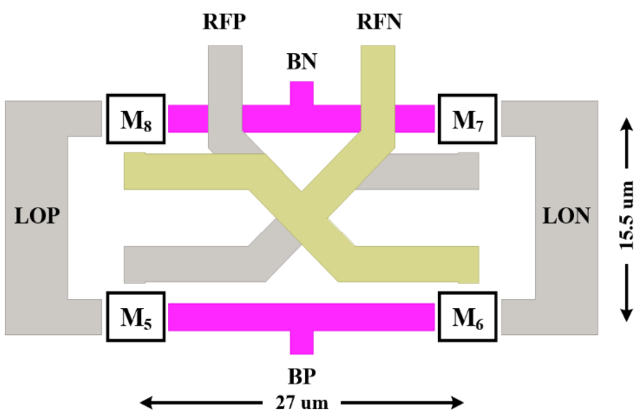

Fig. 3. Symmetric layout of the switching stage cells

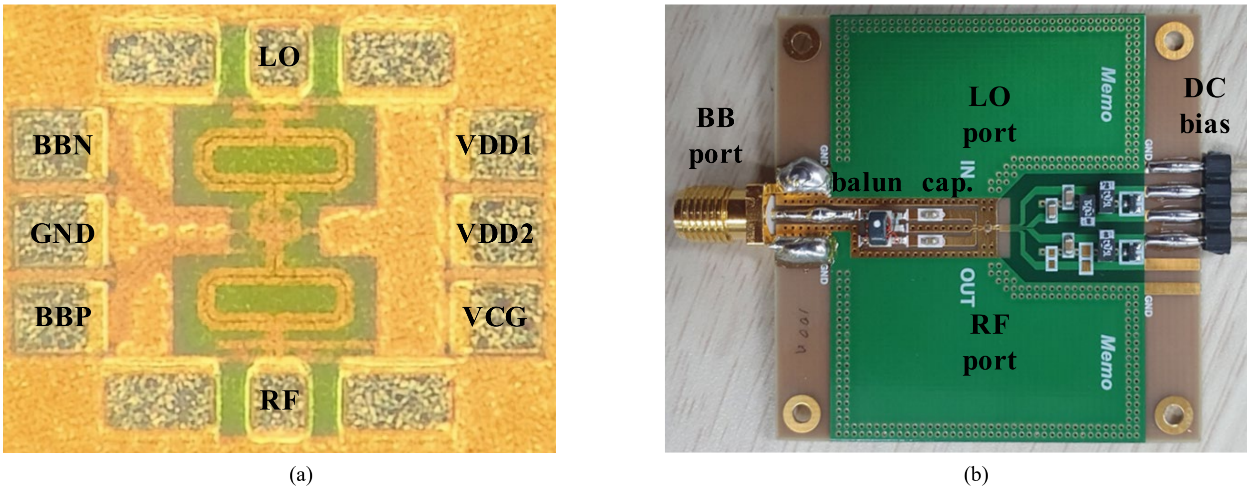

Fig. 4. (a) Microphotograph of the proposed wideband gm-boosted up-conversion mixer, and (b) PCB for measurement

Table I shows the size of the MOSFET, feedback resistance, and bias condition used in the proposed up-conversion mixer.

TABLE I. Design parameters of the proposed wideband 60 GHz gm-boosted up-conversion mixer.

Parameter	Value
M_{1-2}	72 um / 28 nm
M_{3-4}	72 um / 28 nm
M_{5-8}	36 um / 28 nm
R_{1-2}	256 ohm
VDD1	1.1 V
VDD2	1.1 V
V_{CG}	0.9 V

III. IMPLEMENTATION AND MEASUREMENT

The proposed wideband gm boosted up-conversion mixer is implemented using a 28-nm bulk CMOS process. The chip size, including the pads, is 0.53 x 0.42 mm^2 and the core area is 0.2 x 0.26 mm^2.

Fig. 4 illustrates a microphotograph of the implemented up-conversion mixer and the PCB for measurement. The chip is mounted on the PCB, RF, and LO signals are applied through a GSG probe, while DC bias and baseband signals are applied to the DUT via wire bonding. The baseband signal is converted from single to the differential via off-chip balun (TC1-1-13M+ from Mini-Circuit) and connected to an SMA connector. Off-chip capacitors are used as a DC blocking. The measured DC power consumption of the proposed wideband gm-boosted up-conversion mixer is 5.8 mA with a 1.1 V supply voltage.

Fig. 5 shows the S-parameter and power measurement setup. The S-parameter is measured using an Anritsu 37397D vector network analyzer. V-band LO signals are generated using the MG3694A signal generator from Anritsu, the MMD-3567L frequency doubler from Marki, the power amplifier from Mi-wave, and the 515 Attenuator from Mi-wave. The generated RF signal is measured using a Keysight N9030A signal analyzer. A Keysight 11970V harmonic mixer and a Keysight N9029AE13 duplexer are utilized for V-band measurements.

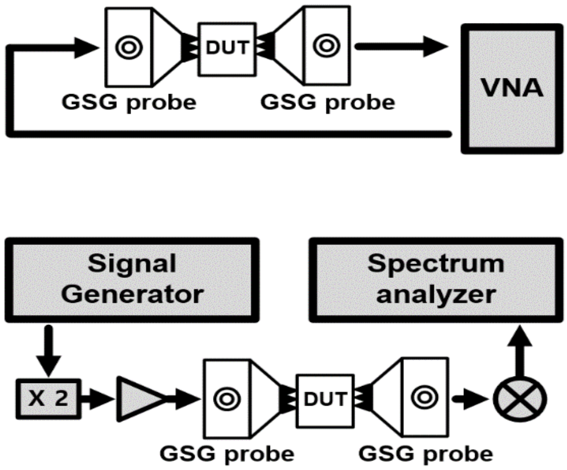

Fig. 5. S-parameter and power measurement setup

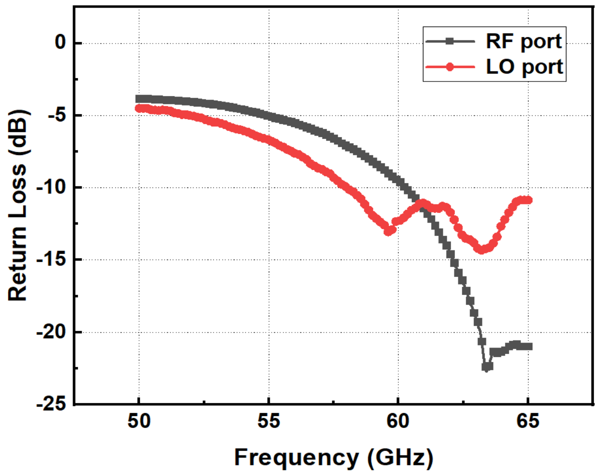

Fig. 6. Measured return losses

TABLE II. Performance summary and comparison

Reference	**This work**	[11]	[12]	[13]	[14]
Process	**28 nm CMOS**	65 nm CMOS	65 nm CMOS	90 nm CMOS	65 nm CMOS
Topology	**Current bleeding + gm boosting**	Conventional Gilbert cell	Dual gate	Drain pumped	Current bleeding + gm boosting
Frequency (GHz)	**60**	62.6	60	60	60
Power consumption (mW)	**6.38**	5.4	23	16.3	17.8
Conversion gain (dB)	**3.2**	4.3	-4.1	-5.1	6.2
LO power (dBm)	**-2**	5	6	0	0
Output P1dB (dBm)	**-6.5**	-8.7	-13.5	-16.4	-7.3
Bandwidth (GHz)	**6**	N / A	3	2	7.5

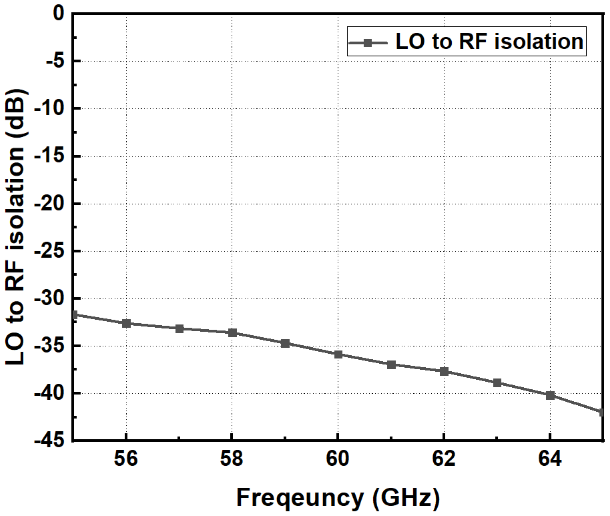

Fig. 7. Measured LO to RF isolation

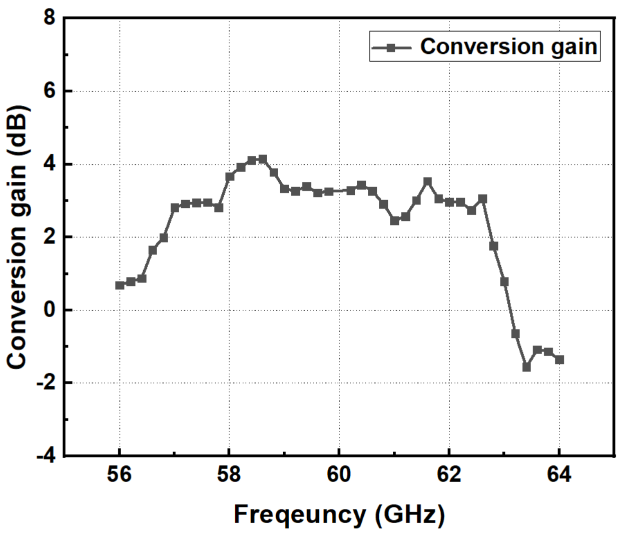

Fig. 8. Measured conversion gain versus frequency

Fig. 6 shows the measured return losses of the proposed up-conversion mixer, which is well-matched in the 60 GHz band. Fig. 7 shows the proposed up-conversion mixer's LO to RF isolation characteristics. It achieves less than -32 dB in 55 GHz to 65 GHz. Fig. 8 shows the conversion gain versus frequency. It has a gain of 3.2 dB at 60 GHz.

The measured 3-dB bandwidth is limited about 6 GHz because the bandwidth of the off-chip balun (Mini-Circuits TC1-1-13M+) at baseband input is 3 GHz. Fig. 9 shows output power and conversion gain according to input power. Conversion gain and output power of the upper sideband are measured when LO is applied at 60 GHz with 0 dBm and baseband at 0.5 GHz. The output P1dB of the up-conversion mixer is -6.5 dBm.

Table II summarizes the performance of the proposed wideband 60 GHz gm-boosted up-conversion mixer and compares with the other state-of-the-art designs.

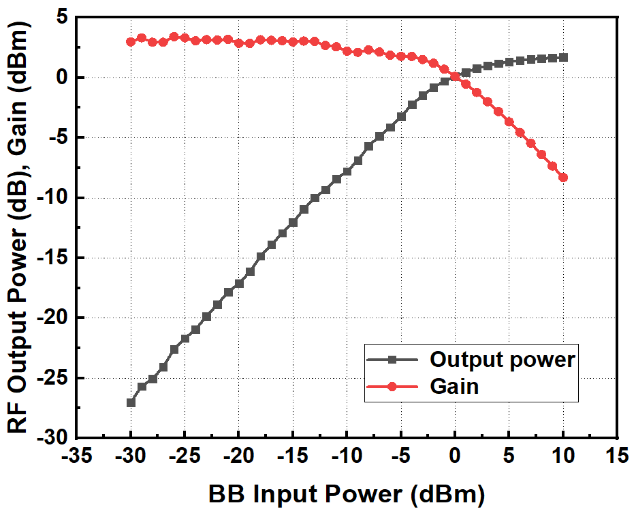

Fig. 9. Measured conversion gain and output power according to baseband input power

IV. CONCLUSION

The wideband 60 GHz gm-boosted up-conversion mixer is designed in a 28 nm bulk CMOS process. It utilizes a current bleeding path with PMOS to boost the gm of the circuit, resulting in a high conversion gain. The feedback resistance R allows for impedance matching without an additional matching network while achieving wideband characteristics. Additionally, the symmetrical layout of the switching stage cells improves the LO to RF isolation characteristics. The measured peak conversion gain is 3.2 dB, and the 3-dB frequency bandwidth is more than 6 GHz.

ACKNOWLEDGMENT

This work was supported by the Institute of Information & Communications Technology Planning and Evaluation (IITP) funded by the Korea Government, Ministry of Science and ICT (MSIT) under Grant 2019-0-00826. The Chip fabrication and EDA Tool were supported by the IC Design Education Center.

REFERENCES

[1] C. W. Byeon, C. H. Yoon, and C. S. Park, "A 67-mW 10.7-Gb/s 60-GHz OOK CMOS Transceiver for Short-Range Wireless Communications," *IEEE Transactions on Microwave Theory and Techniques,* vol. 61, no. 9, pp. 3391-3401, Sep. 2013, doi: 10.1109/TMTT.2013.2274962.

[2] R. Wu *et al*., "64-QAM 60-GHz CMOS Transceivers for IEEE 802.11ad/ay," *IEEE Journal of Solid-State Circuits,* vol. 52, no. 11, pp. 2871-2891, Nov. 2017, doi: 10.1109/JSSC.2017.2740264.

[3] J. Pang *et al*., "A 28.16-Gb/s Area-Efficient 60GHz CMOS Bi-Directional Transceiver for IEEE 802.11ay," *2018 IEEE Asian Solid-State Circuits Conference (A-SSCC)*, Tainan, Taiwan, 2018, pp. 77-78, doi: 10.1109/ASSCC.2018.8579258.

[4] Y. Wang *et al*., "A 60-GHz 3.0-Gb/s Spectrum Efficient BPOOK Transceiver for Low-Power Short-Range Wireless in 65-nm CMOS," *IEEE Journal of Solid-State Circuits*, vol. 54, no. 5, pp. 1363-1374, May 2019, doi: 10.1109/JSSC.2018.2889695.

[5] A. Valdes-Garcia *et al*., "A Fully Integrated 16-Element Phased-Array Transmitter in SiGe BiCMOS for 60-GHz Communications," *IEEE Journal of Solid-State Circuits*, vol. 45, no. 12, pp. 2757-2773, Dec. 2010, doi: 10.1109/JSSC.2010.2074951.

[6] A. Natarajan *et al*., "A Fully-Integrated 16-Element Phased-Array Receiver in SiGe BiCMOS for 60-GHz Communications," *IEEE Journal of Solid-State Circuits*, vol. 46, no. 5, pp. 1059-1075, May 2011, doi: 10.1109/JSSC.2011.2118110.

[7] S. Kong, C. -Y. Kim, and S. Hong, "A K-Band UWB Low-Noise CMOS Mixer With Bleeding Path Gm-Boosting Technique," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 60, no. 3, pp. 117-121, Mar. 2013, doi: 10.1109/TCSII.2013.2240792.

[8] J. Jang, J. Oh, and S. Hong, "A 79 GHz gm-boosted sub-harmonic mixer with high conversion gain in 65nm CMOS," *2015 IEEE Radio Frequency Integrated Circuits Symposium (RFIC)*, Phoenix, AZ, USA, 2015, pp. 11-14, doi: 10.1109/RFIC.2015.7337692.

[9] J. Jang, J. Oh, C. -Y. Kim, and S. Hong, "A 79-GHz Adaptive-Gain and Low-Noise UWB Radar Receiver Front-End in 65-nm CMOS," *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 3, pp. 859-867, Mar. 2016, doi: 10.1109/TMTT.2016.2523511.

[10] Don Huang, Shengxi Diao, Wiqiang Qian, and Fujiang Lin, "A resistive feedback LNA in 65nm CMOS with a gate inductor for bandwidth extension," *Microelectronics Journal*, vol. 46, pp. 103-110, 2015. doi: 10.1016/j.mejo.2014.10.012.

[11] Y. Tsukui, K. Okada, and A. Matsuzawa, "A 60 GHz up-conversion mixer using asymmetric layout with -41.1dBc LO leakage," *IEEE Fourth Latin American Symposium on Circuits and Systems*, Feb. 2013.

[12] Michael Kraemer, Daniela Dragomirescu, and Robert Plana, "A dual gate 60GHz up-conversion mixer with active IF balun in 65nm CMOS," *IEEE International Conference on Wireless Information Technology and Systems*, Aug. 2010.

[13] I. Song *et al*., "60GHz Double-balanced drain-pumped up-conversion mixer using 90nm CMOS," *IEEE MTT-S International Microwave Symposium Digest*, Jun. 2013.

[14] J. -G. Lee, H. -J. Lee, S. H. Kim, C. W. Byeon, and C. S. Park, "60GHz direct up-conversion mixer with wide IF bandwidth and high linearity in 65nm CMOS," *2017 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT)*, Seoul, Korea (South), 2017, pp. 74-76, doi: 10.1109/RFIT.2017.8048294.

Cheol So received the B.S. and M.S. degrees in electrical engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea, in 2015 and 2017, respectively, where he is currently pursuing the Ph.D. degree in electrical engineering. His current research interests include millimeter-wave integrated circuits and systems in silicon technologies and multiple-in-multiple-out (MIMO) and phased array for radars and wireless communications.

Song Cheol Hong received the B.S. and M.S. degrees in electronics engineering from Seoul National University, Seoul, South Korea, in 1982 and 1984, respectively, and the Ph.D. degree in electrical engineering and computer science from the University of Michigan, Ann Arbor, MI, USA, in 1989. He visited the EECS Department, Stanford University, Stanford, CA, USA, as a Visiting Professor in 1997. He was with Samsung Microwave Semiconductor, Milpitas, CA, USA. He served as the Dean of research affairs and the Director of KI-IT convergence with the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea, where he is currently a Professor with the School of Electrical Engineering and a KT-Chaired Professor. He has authored or coauthored more than 300 technical articles and holds 150 patents. His current research interests include RFICs and RF CMOS PAs and especially in millimeter-wave ICs for 5G communications and radars. Dr. Hong is currently a member of NAEK, KIEES, and KITE. He has served as a Board Member of Techno-Park of Daejeon Metropolitan city. He served as the General Chair for RFIT 2017 supported by the IEEE and the TPC Chair for APMC 2013 and GSMM 2014.