A Ka-Band 4-Channel CMOS Beamforming Front-End IC with Built-in Linearizer for Data Relay Satellite System

Seong-Mo Moon
Satellite Payload Research Section
ETRI
Daejeon, South Korea
smmoon@etri.re.kr

Junhan Lim
Satellite Payload Research Section
ETRI
Daejeon, South Korea
flawnsgks@etri.re.kr

Wonseob Lee
Department of ICT Convergence System Engineering
Chonnam National University,
Gwangju, South Korea
lws3492@jnu.ac.kr

Euijin Oh
Department of ICT Convergence System Engineering
Chonnam National University,
Gwangju, South Korea
dmlwls48@ jnu.ac.kr

Dongpil Chang
Satellite Payload Research Section
ETRI
Daejeon, South Korea
dpjang@etri.re.kr

Jinseok Park
Department of ICT Convergence System Engineering
Chonnam National University,
Gwangju, South Korea
jinseok131@jnu.ac.kr

***Abstract*—A *Ka*-band 4-channel CMOS beamforming front-end IC for data relay satellite system is introduced. A differential 4-way power combiner and differential SPDT switches are used to reduce parasitic ground inductance effect. Also, an active phase shifter with variable gain function is integrated, which reduces both chip size and DC power of the 4-channel beamforming IC. A built-in PA linearizer is integrated, which improves linearity of the PA. The PA has OP_{1dB} of 19.5 dBm, peak PAE of 34%, and AM-PM distortion of less than 1 degree at 27 GHz.**

***Keywords*—beamforming, CMOS, linearizer, PA, phase shifter, power divider, receiver, SPDT switch, transmitter**

I. Introduction

Recently, the number of low Earth orbit (LEO) satellites for communication has increased significantly due to various advantages such as large coverage and low transmission delay. Accurate beamforming is one of the key technologies for data relay satellite systems. Although CMOS-based beamforming ICs have many advantages such as high integration and low cost [1]-[8], CMOS beamforming ICs have high phase error during beam control and have low linearity. In this paper, a *Ka*-band 4-channel CMOS beamforming front-end IC (BFIC) with an analog linearizer and an active phase shifter with variable gain function is introduced.

II. 4-Channel Beamforming IC Structure

Fig. 1 shows the block diagram of the RF BFIC. The 1-channel BFIC introduced in [5] is expanded to 4-channel IC by using differential 4-way power divider, differential SPDT switches, and gain amplifiers in the common nodes. Since all differential structures are adapted, the IC is less sensitive to the parasitic ground inductance effect. An active phase shifter with variable gain function based on [8], [9] is used for phase and gain control. Differential NMOS and PMOS alternating SPDT structure in [10], [11] are used for all SPDT switches in the 4-channel IC to reduce insertion loss and to improve power handling capability of the switch. The simulated insertion loss of the differential SPDT switch was less than 1.1 dB at 26 GHz.

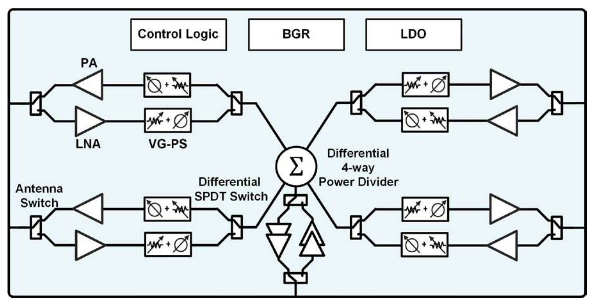

Fig. 1. Block diagram of the 4-channel RF BFIC.

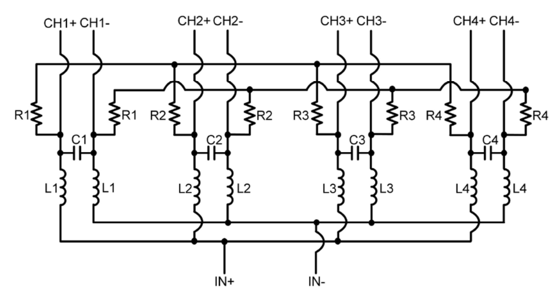

Fig. 2. Schematic of the 4-way differential power divider.

The schematic of the 4-way power combiner/divider is shown in Fig. 2. Differential power divider structure in [13] is adapted. The simulated insertion loss of the differential 4-way power divider was less than 1.3 dB at 26 GHz. A PA linearizer based on [6], [12] is integrated in each channel, which reduces both AM-AM distortion and AM-PM distortion of the PA.

III. Implementation and Measurement Results

The 4-channel RF BFIC was implemented using a 65-nm RF CMOS process. Fig. 3 shows a photograph of the fabricated 4-channel BFIC. SPI, BGR, and LDO are integrated. Simulated gain of the BFIC is 27 dB at 26.5 GHz.

This work was supported in part by Institute for Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korean Government (MSIT) (No. 2018-0-00190, Development of Core Technology for Satellite Payload), and in part by National Research Foundation of KOREA (NRF) grant funded by the Korea government (MSIT) (RS-2023-00211916) (Corresponding author: Jinseok Park.)

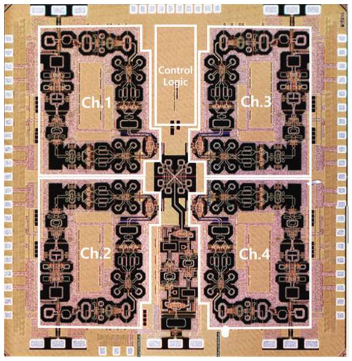

Fig. 3. Chip photograph of the 4-channel BFIC.

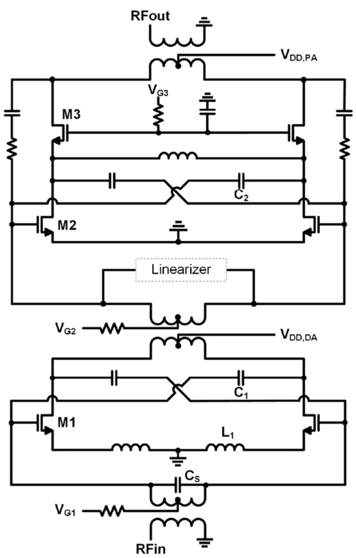

Fig. 4. Schematic of the 2-stage power amplifier

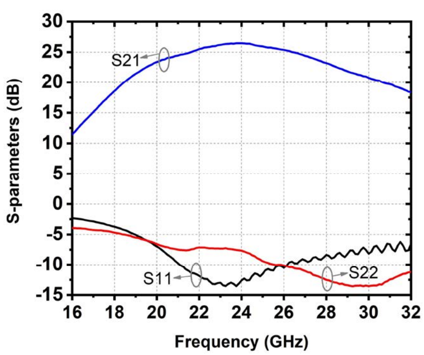

Fig. 5. Measured S-parameter of the power amplifier

The simulated 3-dB bandwidth of the 4-channel BFIC was 23.5 to 30.5 GHz. Simulated RMS phase error was less than 2.5 degree.

A two-stage PA standalone block integrated with the linearizer is also fabricated to verify the performance of the PA and the linearizer. The schematic of the PA is shown in Fig. 4. The measured gain of the PA is 25.5 dB at 25 GHz with the 3-dB bandwidth of 7.7 GHz. The measured OP_{1dB} of the PA was 19.5 dBm. The measured peak PAE was 34.4%, and AM-PM distortion was less than 1 degree at 27 GHz.

IV. Conclusion

A CMOS 4-channel BFIC for data relay satellite system was introduced. The active phase shifter with variable gain function offers 6-bit phase and 6-bit gain control function. It reduces both size of the chip and DC-power. All differential SPDT switches and power divider allow to have less sensitive characteristics to parasitic ground inductance. The analog PA linearizer improves AM-PM distortion as well as AM-AM distortion of the PA. Thanks to these components, the implemented 4-channel BFIC achieves comparable phase and gain control resolution, low RMS phase error, high OP_{1dB}, and high transmitter efficiency and linearity.

References

[1] K. Kibaroglu *et al.*, "A Low-Cost Scalable 32-Element 28-GHz Phased Array Transceiver for 5G Communication Links Based on a 2 x 2 Beamformer Flip-Chip Unit Cell," *IEEE J. Solid-State Circuits*, vol. 53, no. 5, pp. 1260-1274, May 2018.

[2] J. Park *et al.*, "A 28-GHz Four-Channel Beamforming Front-End IC With Dual-Vector Variable Gain Phase Shifters for 64-Element Phased Array Antenna Module," in *IEEE Journal of Solid-State Circuits*, vol. 58, no. 4, pp. 1142-1159, April 2023.

[3] H. Kim *et al.*, "A 28-GHz CMOS Direct Conversion Transceiver with Packaged 2 x 4 Antenna Array for 5G Cellular System," *IEEE J. Solid-State Circuits*, vol. 53, no. 5, pp. 1245-1259, May 2018.

[4] A. Natarajan, A. Komijani and A. Hajimiri, "A fully integrated 24-GHz phased-array transmitter in CMOS," in *IEEE Journal of Solid-State Circuits*, vol. 40, no. 12, pp. 2502-2514, Dec. 2005.

[5] J. Park, S. -M. Moon, J. Lim, S. Hong, D. Chang and B. -S. Lee, "A Ka-Band CMOS Beamforming Front-End IC for RF Inter Satellite Link System," *2022 27th Asia Pacific Conference on Communications (APCC)*, Jeju Island, Korea, Republic of, 2022, pp. 184-186.

[6] J. Park *et al.*, "Design of a Ka-Band Cascode Power Amplifier Linearized With Cold-FET Inter-Stage Matching Network" in *IEEE Transactions on Microwave Theory and Techniques*, vol. 69, no. 2, pp. 1429-1438, Feb. 2021.

[7] S. Shakib *et al.*, "A Highly Efficient and Linear Power Amplifier for 28-GHz 5G Phased Array Radios in 28-nm CMOS", *IEEE J. Solid-State Circuits*, vol. 51, no. 12, pp. 3020-3036, Dec. 2016.

[8] J. Park *et al.*, "A 28GHz 20.3%-Transmitter-Efficiency 1.5°-Phase-Error Beamforming Front-End IC with Embedded Switches and Dual-Vector Variable-Gain Phase Shifters," *IEEE International Solid-State Circuits Conference (ISSCC) Dig. Tech. Paper*, pp. 176-178, Feb 2019.

[9] S. Wang *et al.*, "A K-Band Variable-Gain Phase Shifter Based on Gilbert-Cell Vector Synthesizer With RC–RL Poly-Phase Filter," in *IEEE Microwave and Wireless Components Letters*, vol. 31, no. 4, pp. 393-396, April 2021.

[10] J. Park *et al.*, "A Small-Size K-Band SPDT Switch Using Alternate CMOS Structure With Resonating Inductor Matching," in *IEEE Microwave and Wireless Components Letters*, vol. 30, no. 11, pp. 1093-1096, Nov. 2020.

[11] J. Park, S. Lee and S. Hong, "A 24–40 GHz Differential SPDT Switch With an NMOS and PMOS Alternating Structure and Leakage-Canceling Capacitors," in *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 70, no. 1, pp. 86-90, Jan. 2023.

[12] G. Cho *et al.*, "A 25.5-dB Peak Gain F-Band Power Amplifier with an Adaptive Built-In Linearizer," *IEEE Microwave. Wireless Component. Lett.*, vol. 30, no. 1, pp. 106-108, Jan. 2020.

[13] S. Lee *et al.*, "Millimeter-Wave Multi-Band Reconfigurable Differential Power Divider for 5G Communication," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 70, no. 1, pp. 886-894, Jan. 2022.