A *V*-Band Four-Channel Beamforming Receiver IC for Very Low Earth Orbit Satellite Communication Systems

Jongho Yoo
Satellite Payload Research Section
ETRI
Daejeon, South Korea
pluto503@etri.re.kr

Eun-Taek Sung
Satellite Navigation Research Section
ETRI
Daejeon, South Korea
esung@etri.re.kr

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

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

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

***Abstract*—This paper presents a *V*-band four-channel beamforming receiver for very low Earth orbit satellite communication systems. Implemented in a 0.13 μm SiGe BiCMOS process, the IC integrates low-noise amplifiers, variable-gain phase shifters, and a 4-to-1 power combiner together with serial peripheral interface control logic and bias circuitry within a $2.0 \times 1.3\,\mathrm{mm}^2$ core. Except for the LNA input stages, the signal path is fully differential, and an on-chip RF balun converts the output to a single-ended signal. The simulated performance of the receiver shows a peak gain of 21 dB and a 3 dB bandwidth of 45–55 GHz (20% fractional), with a coherent noise figure of 2.7 dB. The phase sweep from 0° to 360° in 5.625° steps yields an RMS amplitude error of 0.21 dB and an RMS phase error of 1.3°.**

***Index Terms*—RF receiver, 6G, satellite communication, low-noise amplifier, front-end, phased array, phase shifter, beamformer.**

I. Introduction

Wireless communication has advanced through successive generations and is now transitioning to the sixth generation (6G). Unlike previous systems that relied solely on terrestrial base stations and user equipment, 6G is expected to incorporate low Earth orbit (LEO) satellite communication (SATCOM) to provide truly global coverage. In addition, Q/V-band links, which offer wider bandwidth and thus higher potential data rates than conventional K/Ka-band links, are anticipated to play a key role in very low-Earth orbit (VLEO) platforms [1]–[5]

This work presents a *V*-band four-channel beamforming receiver for VLEO SATCOM systems. The receiver operates over 45–55 GHz and integrates low-noise amplifiers (LNAs), variable-gain phase shifters, and a power combiner, together with an on-chip serial peripheral interface control and bias circuitry.

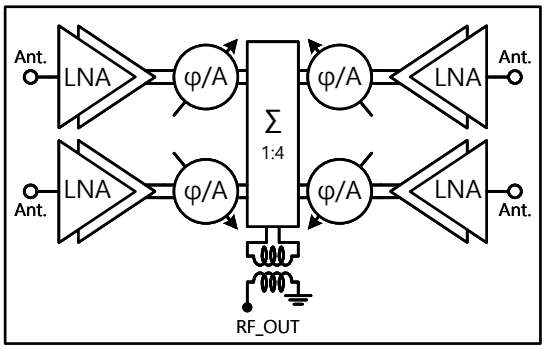

Fig. 1. Schematic diagram of the proposed V-band 4-channel beamforming receiver.

II. V-band Four-Channel Beamforming Receiver IC

Fig. 1 shows the schematic diagram of the proposed four-channel beamforming receiver. Apart from the input stage of each LNA, the entire signal path operates in fully differential mode. A variable-gain phase shifter is employed to reduce the overall die area. The integrated phase shifter employs an active architecture and supports a 6-bit, $5.625°$ resolution.

To minimize the footprint of the layout, a single 4-to-1 power combiner is adopted in place of three 2-to-1 combiners. The differential output of the combiner is converted to a single-ended signal by an on-chip RF balun.

The proposed beamforming receiver IC is designed in a $0.13\mu m$ SiGe BiCMOS process. The layout of the chip is shown in Fig. 2. The core occupies $2.0 \times 1.3\,mm^2$, and the

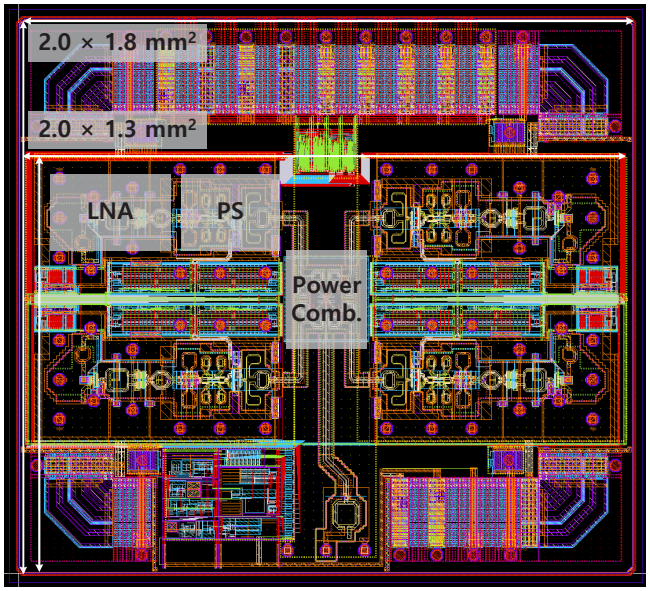

Fig. 2. Chip layout of the proposed four-channel beamforming IC.

overall die size, including pads, is $2.0 \times 1.8\,mm^2$.

III. Performance of the Beamforming Receiver

Fig. 3(a) presents the simulated gain and noise-figure performance of the proposed beamforming receiver when coherent inputs are applied to all four channels. The receiver delivers a peak gain of 21 dB and maintains a 3 dB bandwidth from 45 to 55 GHz, corresponding to a fractional bandwidth of 20%. Its coherent noise figure is simulated to be approximately 2.7 dB in the band.

Fig. 3(b) illustrates the simulated phase-shifting performance of the beamformer. When the phase control is swept from $0°$ to $360°$ in $5.625°$ steps, the root-mean-square (RMS) amplitude error remains below $0.21\,\text{dB}$, whereas the RMS phase error stays within $1.3°$. Nominal power consumption of the receiver is $0.29\,\text{W}$ with $2.4\,\text{V}$ supply voltage.

IV. Conclusion

A *V*-band, four-channel beamforming receiver for VLEO SATCOM systems is presented. Implemented in a $0.13\,\mu m$ SiGe BiCMOS process, the receiver achieved a small-signal coherent gain of 21 dB and a coherent noise figure of 2.7 dB in simulation. The proposed IC could be considered a viable candidate for incorporation into low-noise VLEO phased-array receiver systems.

V. Acknowledgement

This work was supported by the Technology Innovation Program (RS-2024-00452149, Development of Q/V-band RF components and reconfigurable active antenna components) funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea).

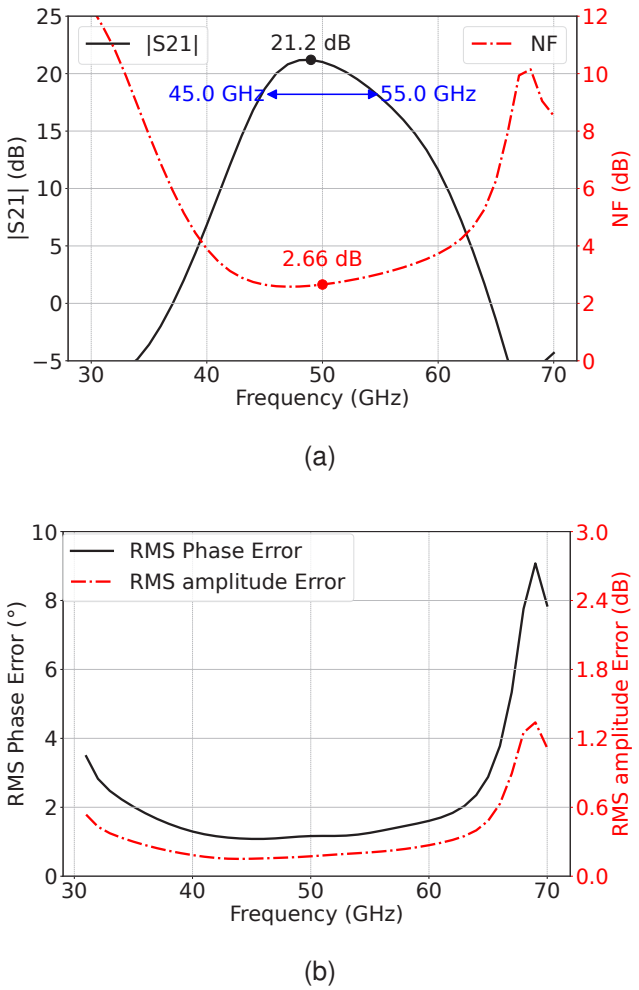

Fig. 3. Simulated RF performance of the Beamformer: (a) Coherent gain and noise figure versus frequency and (b) RMS amplitude and phase errors for phase control over $0° - 360°$ in $5.625°$ steps.

References

[1] S. R. Park, R.-N. Nguyen, S.-T. Nguyen, N. H. Chiang, and J. J. Sowers, "V-band receiver for commercial space applications," in *2017 IEEE MTT-S International Microwave Symposium (IMS)*, 2017, pp. 1830–1833.

[2] Q. Tian and D. Zhao, "A Q-Band Low-Noise Amplifier in 40-nm CMOS for Q/V-band satellite communications," in *2022 IEEE International Conference on Integrated Circuits, Technologies and Applications (ICTA)*, 2022, pp. 26–27.

[3] J. Ladkani, N. Agarwal, E. G. S, J. Thakkar, A. Jain, and D. K. Singh, "Space Qualified Q/V Band Receiver for High Throughput Communication Satellites," in *2022 IEEE Microwaves, Antennas, and Propagation Conference (MAPCON)*, 2022, pp. 259–263.

[4] H. Lee, I. Han, J. Hwang, and I. Ju, "An Efficient, High Power Q-Band SiGe HBT Power Amplifier With A Compact Four-Way Wilkinson Power Combiner Balun for Emerging Very Low-Earth-Orbit SATCOM," in *2024 IEEE Radio Frequency Integrated Circuits Symposium (RFIC)*, 2024, pp. 291–294.

[5] Y.-Q. Yang, S. Jin, D. Liu, B. Yang, J. Huang, Y. Cheng, C. Fei, B. Zhou, C. Mei, L. Liu, and L. Zhang, "Highly Integrated Q/V-Band Multi-Beam Phased Array Antenna for LEO Communication Satellite," in *2022 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP)*, 2022, pp. 1–3.