A Fully Integrated MMIC chip set Employing InGaP/GaAs HBT for Application to Ku band Satellite Communication System

Young-Bae Park[1], Han-Nah Joh[1], Se-Ho Kim[1], and Young Yun[1], Kyu-Ho Park[2], and Kwang-Ho Ahn[2]

[1] Radio Communication Engineering, Korea Maritime University, Korea

#1, Dongsam-dong, Youngdo-gu, Busan, Korea

[2] Korea Electronics Technology Institude, Korea

#68, Yatap-dong, Bundang-gu, Seongnam-si, Gyeonggi-do, Korea

E-mail: yunyoung@hhu.ac.kr

Abstract: A highly integrated monolithic microwave integrated circuit (MMIC) chip set employing InGap/GaAs/GaAs heterojunction bipolar transistor (HBT) were developed for satellite communication applications. Concretely, using InGap/GaAs/GaAs HBT, downconverter MMIC and an active balun were developed. The downconverter MMIC showed a conversion gain of 9.5 dB and an LO suppression of -30 dBc. The fabricated chip, including a mixer, 2 stage IF amplifier, and LO rejection filter, exhibited a small size of 0.8×2.4 mm^2. The size of the active balun was about 31.6 % of conventional passive branch-line coupler.

1. Introduction

For satellite communication applications, the Ku band RF devices have been reported in various literatures. In conventional satellite communication system [1-4], downconverter MMIC was fabricated using a high electron mobility field effect transistor (HEMT) for low noise characteristics, which prevented a realization of one chip transceiver solution because power amplifier was generally fabricated using heterojunction bipolar transistor (HBT) due to its high power and high efficiency characteristics. In addition, for power coupling and splitting in satellite communication system, passive coupler have mainly been employed However, the passive device such as branch-line coupler occupies a very large area in RF circuit.

In this work, we developed a highly integrated downconverter MMIC including a mixer, IF amplifiers, and LO rejection filter using HBTs. In addition, a highly miniaturized active balun circuit employing InGaP/GaAs HBT was also developed.

2. Highly Integrated Downconverter MMIC

Figure 1 shows a cross-sectional view of the InGaP/GaAs HBT. Figure 2 shows a layout of the downconverter MMIC. As shown in this figure, the mixer, IF amplifiers, and LO rejection filter were integrated on the downconverter MMIC.

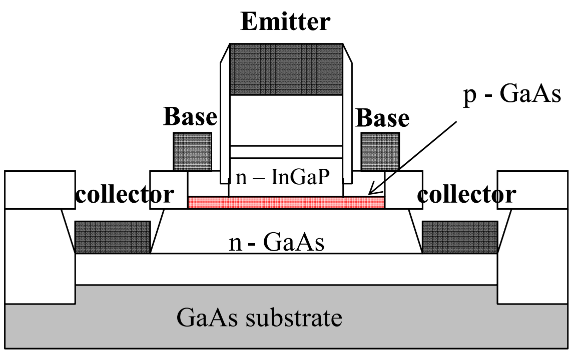

Fig. 1. A cross-sectional view of the InGaP/GaAs HBT

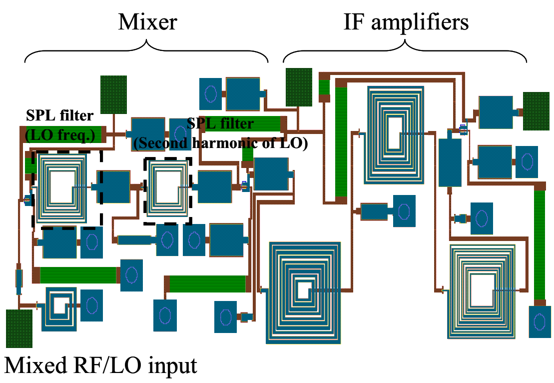

Fig. 2. shows a layout of the downconverter MMIC

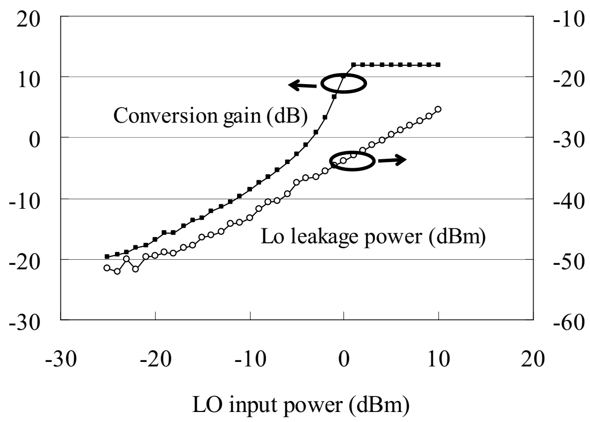

Fig. 3. An LO input power dependencies of conversion gain and LO leakage power

For the fabrication of mixer and amplifier, InGap/GaAs/GaAs HBTs were employed. For the mixer, mixed signal (RF + LO) was applied to the base of the HBT, and IF output signal was extracted from the collector of the HBT. For an LO leakage power suppression at IF output, a spiral inductor which has band-rejection characteristics in the vicinity of LO frequency (11 GHz) was integrated on the MMIC (the layout of the spiral inductor for LO rejection is shown in Fig. 2, and it is connected at the collector of the HBT). The line width, the space between lines and size were designed to have self-resonance frequency in the vicinity of 11 GHz. The LO input power dependencies of conversion gain and LO leakage power at IF output are shown in Fig. 3, respectively. As shown in Fig. 3, at a LO power of 0 dBm, the conversion gain reaches 9.5 dB, and the LO leakage power at a LO power of 0 dBm exhibits a low value of –35 dBm due to the LO rejection characteristics of the spiral inductor. Therefore, additional LO rejection filter is not required for the normal operation of the downconverter MMIC, which enables a realization of fully integrated transceiver including on-chip filters.

3. Active baluns for power splitting

Figure 4 and 5 show a schematic circuit and layout of the active balun employing InGaP/GaAs HBT. As shown in Fig. 4, the size of the active balun for power splitting is 1.67 mm × 0.87 mm, which is 31.6% of a conventional passive branch-line coupler (if passive branch-line coupler with an operation frequency of 12 GHz is fabricated on GaAs MMIC, its size is 2.11 mm × 2.18 mm).

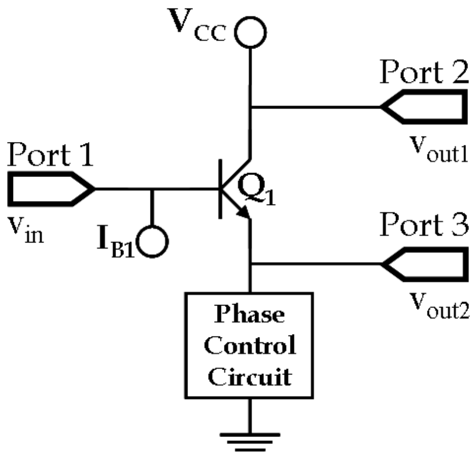

Fig. 4. A circuit structure of active balun for power splitting

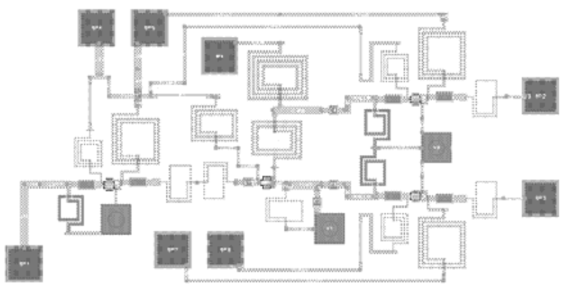

Fig. 5. A photograph of the active balun employing InGaP/GaAs HBT for power splitting

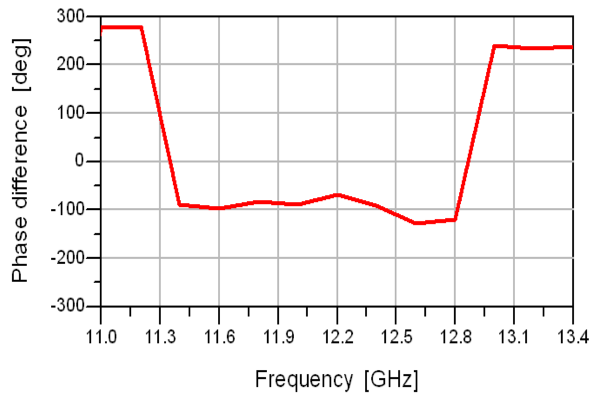

Fig. 6. Measured phase difference between S_{21} and S_{31} of active balun for power splitting

Figure 6 shows a measured phase difference between S_{21}

and S_{31} of active balun for power splitting. As shown in this figure, a phase difference characteristic of -90 ± 3.0° is observed from 11.8 GHz to 12.1 GHz. An output gain (S_{21} and S_{31}) of about 10 dB was observed at 12 GHz. Concretely, the proposed active balun for power splitting shows a gain of 10 ± 1 dB from 11.5 GHz to 12.7 GHz.

4. Conclusion

In this work, we developed highly integrated MMIC chip set employing InGap/GaAs/GaAs heterojunction bipolar transistor (HBT) for satellite communication applications. Concretely, using InGap/GaAs/GaAs HBT, downconverter MMIC and an active balun were developed. From the downconverter MMIC, we observed a conversion gain of 9.5 dB and an LO suppression of -30 dBc. The fabricated chip, including a mixer, 2 stage IF amplifier, and LO rejection filter, exhibited a small size of 0.8×2.4 mm^2.

The size of the active balun was about 31.6 % of conventional passive branch-line coupler. Form the active balun, we could observe good RF performances comparable to passive branch-line couplers.

Acknowledgement

This work was supported by ETRI SoC Industry Promotion Center & Human Resource Development Project for IT SoC Architect. This work was also supported by KETI, Korea.

References

[1] T. Sugiura et al., “12-GHz-band GaAs dual-gate MESFET monolithic mixers”, IEEE Trans. Microwave Theory & Tech., Vol. MTT-33, (1985), p 105-110, 1985.

[2] K. Hubbard et al., ”A family of low cost high performance HEMT MMICs for commercial DBS applications”, IEEE MTT-S Digest, Vol.3, (1995), p 1649-1652.

[3] P. Bacon et al., “A dual-channel Ku-band DBS downconverter”, IEEE GaAs IC Symp. Tech. Digest, (1993), p 233-236.

[4] Y. Yun et al., “A High Performance Downconverter MMIC for DBS Applications,” *IEICE Trans. Electron.*, vol.E84-C, no. 11, (2001), p.1679-1688.

[5] S. A. Mass, *Microwave mixer*. Reading, MA: Artec h House, 1986.

[6] T. Sugiura, K. Honjo, and T. Tsuji, “12-GHz-band GaAs dual-gate MESFET monolithicmixers,” *IEEE Trans. Microwave TheoryTech.*, vol. MTT-33, pp. 105-110, Feb. 1985.

[7] E. Camargo and W. Kennan, “An E-mode GaAs F ET operating as a single balanced gate mixer,” *IEE E Trans. MTT-S Int Microwave Symp. Dig.*, vol. 2, pp. 951-954, 1996.

[8] K. Hubbard, K. MacGowan, C. Kau, D. Smith, an d S. Mass, “A family of low cost high performanc e HEMT MMICs for commercial DBS application,” *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 32, no. 5, pp. 340-344, Mar. 2002.

[9] T. Kaneko, T. Miya, and S. Yoshida, “A Ku band converter IC,” *IEEE MTT-S Int. Microwave Symp. Dig.,* vol. 1, pp. 451-454, Jun. 1992.

[10] M. Chongcheawchamnan, GN. siripon, and I. D. R obertson, “Design and performance of improved lu mped-distributed Wilkinson divider topplogy,” *Elect ron. Lett.,* vol. 37, pp. 501-503, 2001.

[11] A. S. Sedra, K. C. Smith, *Microelectronic Circuit s.* MA: Oxford University Press, 2004.

[12] S. Kudszus, M. Neumann, T. Berceli, and W. H. Haydl, “Fully integrated 94-GHz subharmonic inject ion-locked PLL circuit,” *IEEE Microw.Wireless Co mpon. Lett.*, vol. 10, no. 2, pp. 70-72, Feb. 2000.

[13] M. Sokolich, C. H. Fields, S. Thomas III, B. Shi, Y. K. Boegeman, M. Montes, R. Martinez, A. R. Kramer, and M. Madhav, “A low-power 72.8-GHz static frequency divider in AlInAs/InGaAs HBT tec hnology,” *IEEE J. Solid-State Circuits*, vol. 36, no. 9, pp. 1328–1334, Sep. 2001.

[14] H. Knapp, M. Wurzer, T. F. Meister, K. Aufinger, J. Bock, S. Boguth, and H. Schafer, "86 GHz sta tic and 110 GHz dynamic frequency dividers in Si Ge bipolar technology,” *IEEE MTT-S Int. Microwa ve Symp. Dig.*, 2003, pp. 1067–1070.

[15] Z. Lao, A. Thiede, J. Hornung, M. Schlechtweg, H. Lienhart, W. Bronner, A. Huelsmann, T. Jakobu s, J. Seibel, M. Sedler, and G. Kaufel, “55-GHz d ynamic frequency divider IC,” *Electron. Lett.*, vol. 34, no. 20, pp. 1973–1974, Oct. 1998.

[16] C. Rauscher, “Regenerative frequency division with a GaAs FET,” *IEEE Trans. Microw. Theory Tech.*, vol. MTT-32, no. 11, pp. 1461–1468, Nov. 1984.

[17] J. Sarkissian, M. Camiade, P. Savary, A. Suarez, R. Quere, and J. Obregon, “A 60-GHz HEMT–-M MIC analog frequency divider by two,” *IEEE J. So lid-State Circuits*, vol. 30, no. 10, pp. 1062–1067, Oct. 1995.

[18] S. Kudszus, W. H. Haydl, M. Neumann, and M. Schlechtweg, “94/47-GHz regenerative frequency di vider MMIC with low conversion loss,” *IEEE J. S olid-State Circuits*, vol. 35, no. 9, pp. 1312–1317, Sep. 2000.

[19] K. Honjo and M. Madihian, “Novel design approa ch for X-band GaAs monolithic analog 1/4 frequen cy divider,” *IEEE Trans. Microw. Theory Tech.*, vo

l. MTT-34, no. 4, pp. 436–441, Apr. 1986.

[20] J. Jeong and Y. Kwon, "V -band harmonic injecti on-locked frequency divider using cross-coupled FE Ts," *IEEE Microw.Wireless Compon. Lett.*, vol. 14, no. 10, pp. 457–459, Oct. 2004.

[21] C. J. Madden, D. R. Snook, R. L. Van Tuyl, M. V. Le, and L. D. Nguyen, "A novel 75 GHz InP HEMT dynamic divider," *GaAs IC Symp. Dig.*, 19 96, pp. 137–140.

[22] T. Ohira and Y. Suzuki, "Novel frequency division technique for very low power GaAs monolithic m icrowave prescalers," *IEEE MTT-S Int. Microwave Symp. Dig.*, 1999, pp. 193–196.

[23] H. R. Rategh and T. H. Lee, "Superharmonic injec tion-locked frequency dividers," *IEEE J. Solid-State Circuits*, vol. 34, no. 6, pp. 813—821, Jun. 1999.

[24] F. Ramirez, M. Elena de Cos, and A. Suarez, "No nlinear analysis tools for the optimized design of h armonic-injection dividers," *IEEE Trans. Microw. T heory Tech.*, vol. 51, no. 6, pp. 1752–1762, Jun. 2 003.

[25] R. Adler, "A study of locking phenomena in oscill ators," *Proc. IEEE*, vol. 61, no. 10, pp. 1380–1385, Oct. 1973.

[26] J. Kim and Y. Kwon, "Intermodulation analysis of dual-gate FET mixers," *IEEE Trans. Microw. Theor y Tech.*, vol. 50, no. 6, pp. 1544–1555, Jun. 2002.

[27] K. Kanazawa,M. Hagio, M. Kazumura, and G. Kan o, "A 15 GHz single stage GaAs dual-gate FET m onolithic analog frequency divider with reduced inp ut threshold power," *IEEE Trans. Microw. Theory Tech.*, vol. 36, no. 12, pp. 1908–1912, Dec. 1988.

[28] K. Kurokawa, "Injection locking of microwave sol id-state oscillators," *Proc. IEEE*, vol. 61, no. 10, p p. 1386–1410, Oct. 1973.