E-band 1 W-class GaAs PHEMT Power Amplifier MMIC

Koji TSUKASHIMA*, Akira OTSUKA, Miki KUBOTA, Tsuneo TOKUMITSU
and Shoichi OGITA

E-band wireless communication systems are expected to be used for fiber extension in the fixed network in order to support internet data transmission increased by the introduction of 3G/4G, LTE (Long Term Evolution), and other mobile backhaul services. The E-band communication system works in the 71-76 GHz and 81-86 GHz bands, enabling high data rate transmission of 10 Gbit/s or more. This system requires power amplifiers of an output power of 0.5 W (27 dBm) or higher to transmit high-order modulation signals over a long distance. This report introduces an E-band 1 W (30 dBm) class amplifier MMIC (monolithic microwave integrated circuit) incorporating a stabilization design and GaAs PHEMT (pseudomorphic-high-electron-mobility-transistor) technology.

Keywords: E-band radio communication system, High-power amplifier, MMIC, and 5G

1. Introduction

E-band wireless communication systems are expected to be increasingly used for fiber extension in fixed networks in order to support internet data transmission increased by the introduction of the third and fourth generation (3G/4G) of wireless mobile telecommunications technology, Long Term Evolution (LTE), and other mobile backhaul services.[(1)-(3)] In addition, many companies are developing 5th Generation (5G) wireless communication technologies with the frequency bands assigned to communications with millimeter wave frequencies (30-90 GHz). This E band is also one of the frequency candidates. The E-band communication system works in the 71-76 GHz and 81-86 GHz bands, enabling high data rate transmission of 10 Gbit/s or more. This system requires power amplifiers of an output power of 0.5 W (27 dBm) or higher to transmit high-order modulation signals over a long distance.

This paper introduces an E-band 1 W class amplifier MMIC (monolithic microwave integrated circuit) incorporating a stabilization design and the GaAs PHEMT (pseudomorphic-high-electron-mobility-transistor technology) of SEDI (Sumitomo Electric Device Innovations, Inc.).

2. Design of Unit Amplifiers

Figure 1 shows photos of the unit amplifiers. The sizes of these amplifiers are 1/4 of the amplifier used for the last stage of the MMIC. Verifying the characteristics and stability of these unit amplifiers is important to achieve the final MMIC properties. The tip size is 1.4 mm x 1.0 mm.

Figure 2 shows the circuit diagram of the unit amplifiers. With the exception of the supply terminal, the circuit is a vertically symmetric shape, with the line between RF-in and RF-out terminals assuming the role as the axis of symmetry.

As Fig. 2 shows, in the configuration in which the amplifiers are connected in parallel, an oscillation in the

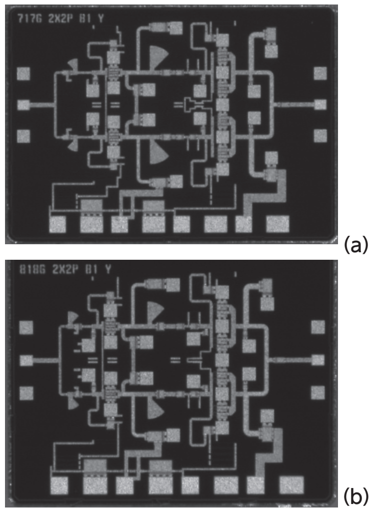

Fig. 1. (a) 71-76 GHz unit amplifier and (b) 81-86 GHz unit amplifier

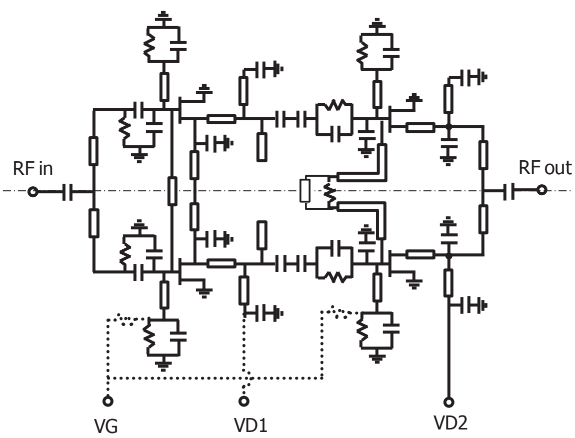

Fig. 2. Circuit diagram of the unit amplifiers

band may be caused due to odd mode excitation. To prevent oscillation, optimized stub resistors are located in the FET gate circuit on the RF-out side of this circuit. These resistors and wiring suppress out-of-band oscillations.

Figure 3 is the simulation model, which incorporates stub resistors, for checking stability. Figure 4 shows the simulation results. The model is composed of serially connected two stages of FETs and two parallel combined FETs. FET1 is 200 µm in size and FET2 is 400 µm. The wire connecting the FET2 gate is divided in the middle of it to create Port1 and Port2 terminals. For this model, the stabilization conditions are represented by the following formulas.(4),(5)

A1 = Mag (S21+ (S11*S22)) / (1-S12)) < 1 ·········· (1)

A2 = Angle (S21+ (S11*S22) / (1-S12)) = 2nΠ ···· (2)

A1 shows a loop gain, and A2 shows a phase. At around 20 GHz where A2 becomes zero, A1 is up to 1, showing that this unit amplifier is stable.

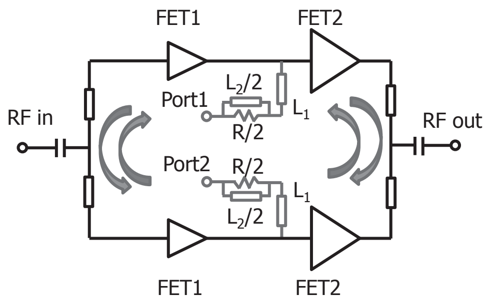

Fig. 3. Model simulating the stability of the unit amplifier

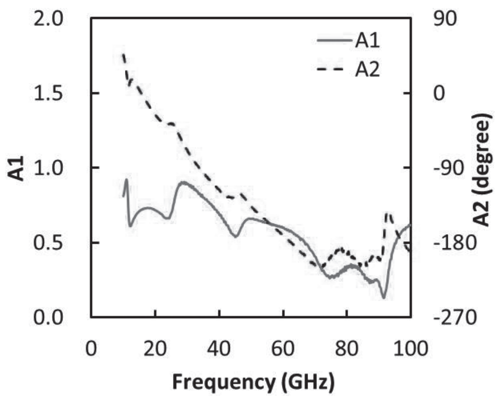

Fig. 4. Simulation results of the stability of the unit amplifier

Figure 5 shows the small signal characteristics of this unit amplifier and its frequency characteristics of the saturation output power (Psat). Over a bandwidth from 81 to 86 GHz, the amplifier obtained a gain of 9 dB and a Psat of 24 dBm, exhibiting high output characteristics.

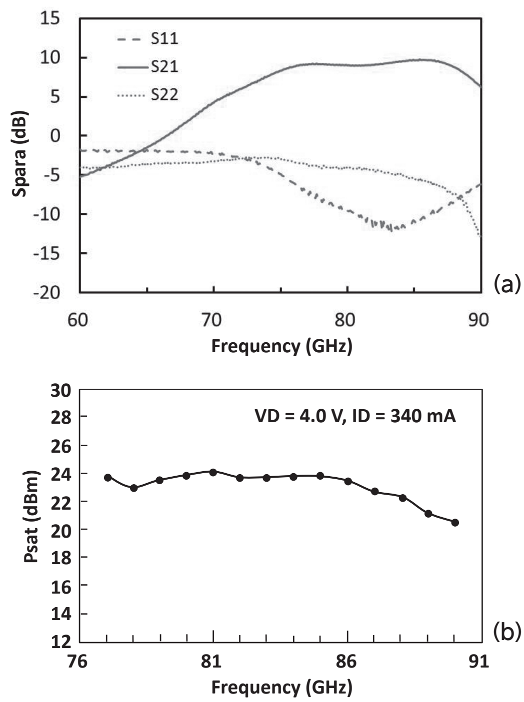

Fig. 5. Small signal characteristics (a) and saturated output characteristics (b) of the unit amplifier

3. 1 W-class Amplifier MMIC

Figure 6 shows a photo and block diagram of the 71-76 GHz band amplifier MMIC. The size of the chip is 3.0 mm x 3.9 mm. At the output part, four parallel combined unit amplifiers are used. In front of them, amplifiers for the driver are arranged in two series to obtain a gain. A power detector circuit is inserted into the output part of the amplifier MMIC and has the function of detecting output power.

Figure 7 shows the small signal characteristics of the amplifier MMIC. S21 lines, which show the gains of the MMIC in the two frequency bands, reach and exceed 20 dB, while S11 and S22 lines, which show the input-output reflectance properties, fall below -10 dB, exhibiting satisfactory results.

Figure 8 shows the input-output power characteristics and power added efficiency (PAE) characteristics of the amplifier MMIC, and Fig. 9 shows the frequency characteristics of the P1dB*3 and Psat. The amplifier MMIC achieved a saturation power exceeding 28 dBm in each band, a maximum output of 1 W at 71 GHz, and a PAE of 7% or more.

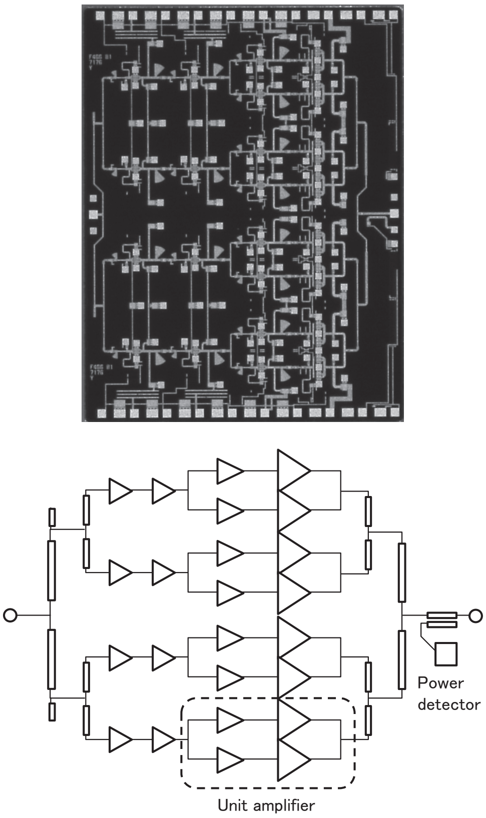

Fig. 6. Photo and block diagram of the amplifier MMIC

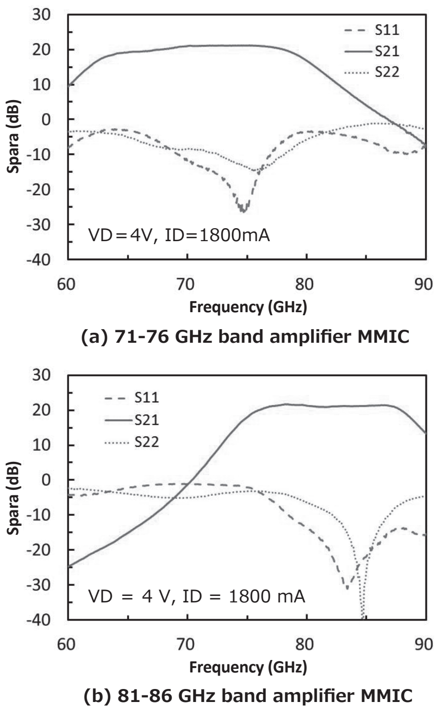

Fig. 7. Small signal characteristics of the amplifier MMIC

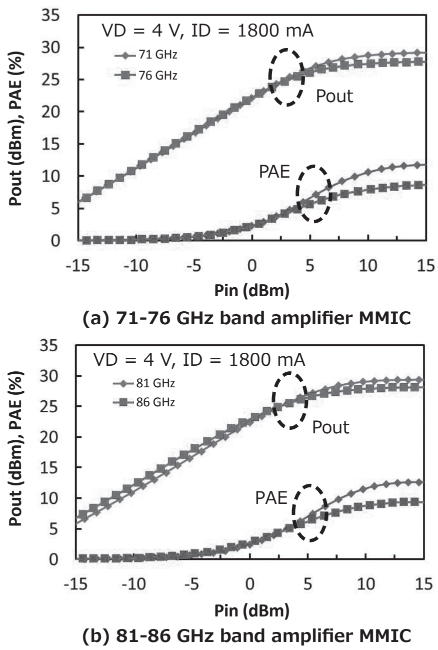

Fig. 8. Input-output power characteristics and PAE characteristics of the amplifier MMIC

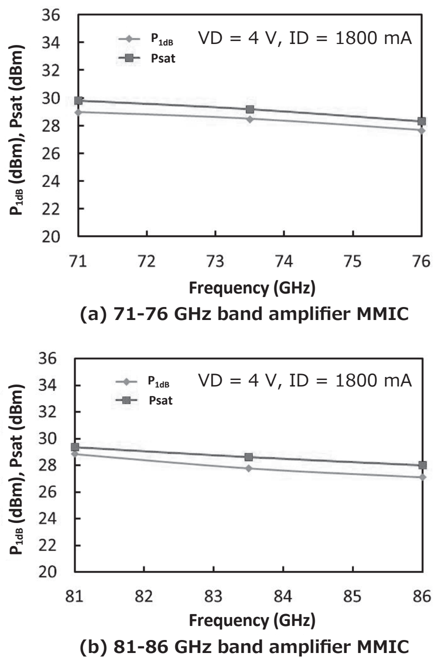

Fig. 9. Frequency characteristics of the P1dB and Psat of the amplifier

4. Conclusion

Sumitomo Electric Industries, Ltd. has developed an E-band 1 W class amplifier MMIC (71-76 GHz and 81-86 GHz) to which the GaAs PHEMT technology of SEDI has been applied and which incorporates a stabilization design. At 71 GHz, the trial product of the amplifier MMIC achieved a 28 dBm of P1dB and a saturation power of 30 dBm. Through the cooperation with SEDI, Sumitomo

Electric will continue expanding its lineup of millimeter-wave band products.

Technical Terms

∗1 Pseudomorphic-high-electron-mobility-transistor technology (PHEMT): This is a field-effect transistor with a channel that is the two-dimensional electron gas produced on the semiconductor heterojunction interface. It excels in high frequency properties and noise characteristics.

∗2 Monolithic microwave integrated circuit (MMIC): A microwave circuit on which a monolithic semiconductor is integrated.

∗3 P1dB: 1-dB gain compression point. This shows the output level of the point at which the gain is reduced by 1 dB from the ideal characteristics with a gain straight line. The larger the P1dB value, the better the linear line the amplifier can produce.

References

(1) M. Piloni, G. Montiron, and A. G. Milani, “E-band microwave transceiver using MWgSP technology for PtP radio equipment,” in Proc. of the 40th European Microwave Conference, Paris, pp. 28-30 (Sept. 2010)

(2) K. Tsukashima, M. Kubota, A. Yonamine, T. Tokumitsu, and Y. Hasegawa, “E-band radio link communication chipset in cost effective wafer level chip size package (WLCSP) technology,” in Proc. of the 6th European Microwave Integrated Circuits Conference, Manchester, pp. 29-32 (Oct. 2011)

(3) T. Kawasaki, M. Kubota, K. Tsukashima, T. tokumitsu, and Y. Hasegawa, “A full E-band low noise amplifier realized by using novel wafer-level chip size package technology suitable for reliable flip-chip reflow-soldering,” in IEEE International Microwave Symposium Dig., Tampa Bay, TU3G-1 (June 2014)

(4) Y. Tarui, K. Fujii, Y. Itoh, “Calculation Method for Loop Oscillations of Microwave Power Amplifiers with Several Closed Loop Circuits and Split-Cell Matching Method for High Stability” in IEICE C, Vol.J82-C1 No.7 pp.429-438 (June 1999)

(5) S. Mizuno, K. Naito, Y. Tateno, S. Sano, T. Tokumitsu, “Novel Instability-Probing Simulation for Power Amplifiers” in EuMA2006, pp. 1284-1287 (Sept. 2006)

Contributors

The lead author is indicated by an asterisk (∗).

K. TSUKASHIMA*

• Assistant General Manager, Transmission Devices Laboratory

A. OTSUKA

• Transmission Devices Laboratory

M. KUBOTA

• Group Manager, Transmission Devices Laboratory

T. TOKUMITSU

• Senior Specialist
Ph. D.
IEEE Fellow
Chief Engineer, Transmission Devices Loboratory

S. OGITA

• Ph. D.
Department Manager, Transmission Devices Laboratory