X-Band GaN MMIC Power Amplifier for the SSPA of a SAR System

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***Abstract*—An X-band monolithic microwave integrated circuit (MMIC) power amplifier for Synthetic Aperture Radar (SAR) systems has been implemented using a 0.25 μm AlGaN/GaN HEMT process on a SiC substrate. The MMIC power amplifier has an output power of 45 dBm (30 W) to 46 dBm (40 W) and a power-added efficiency of 38–44 % from 8.8 to 10.4 GHz with an associated power gain of 17 dB under the pulsed bias condition of a 10% duty cycle and 100 μs pulse width. The developed MMIC power amplifier will be applied to the solid-state power amplifier (SSPA) for future satellite SAR systems.**

Keywords—MMIC power amplifier; GaN HEMT; X-band; solid-state power amplifier (SSPA)

I. Introduction

Highly reliable monolithic microwave integrated circuits (MMICs) have been used primarily in military radar systems and satellite communications payloads and are currently being applied to a wide variety of systems, including sensors in unmanned automotive systems. A MMIC high-efficiency and high-power amplifier is a key component in an integrated microwave transmitter. A traveling wave tube amplifier (TWTA) has been mainly used in the transmitter because it has an efficiency of more than 50 % and can deliver an output power of hundreds of watts in a microwave region, but suffers from a low linearity and a high failure rate. In addition, it is bulky and heavy because it requires a traveling wave tube structure and an electronic power conditioner. For this reason, a GaAs- or GaN-based solid-state power amplifier is recently preferred as a microwave power amplifier. Especially a GaN high electron mobility transistor (HEMT) is actively used for this purpose because of its high breakdown voltage, high current density, low parasitic capacitance and high thermal conductivity that result in a superior power performance in the microwave region [1], [2].

In this paper, an X-band GaN MMIC power amplifier that is based on a 0.25 μm AlGaN/GaN process is presented for a satellite synthetic aperture radar (SAR) system. The measured power performance of the MMIC power amplifier shows an output power of more than 45 dBm (30 W) and a power-added efficiency (PAE) of 38–44 % from 8.8 to 10.4 GHz.

II. MMIC Design and Fabrication

A. Device Technology

A 0.25 μm AlGaN/GaN HEMT on a SiC substrate of the GH25-10 process that is provided by United Monolithic Semiconductors (UMS) is used for design and fabrication of the X-band high power amplifier (HPA) MMIC in this work. The breakdown voltage of the HEMT is above 100 V and the pinch-off voltage and the saturated drain current at a zero gate voltage are around -3.5 V and 480 mA/mm, respectively. The f_{max} and f_T of the 8×150 μm HEMT are about 68 and 43 GHz, respectively. The SiC substrate is thinned to 100 μm and the metal line with the thickness of 6.8 μm is utilized for a low loss and high current density [3].

B. HPA MMIC Design

The HPA MMIC is designed to have a small-signal gain of 20 dB or more, an output power of 30 W or more, and a PAE of more than 30 % or more in 9-10 GHz. The 8×150 μm HEMT is selected as a basic transistor unit for the last stage of the amplifier considering high power amplification and a gain response. For the reliability and thermal stability, a little de-rating is applied to the drain voltage and the bias point of a 28 V drain voltage and 90 mA/mm drain current is chosen for the class AB operation. A parallel RC network is inserted at the gate of the HEMT to unconditionally stabilize the active device. The loadpull simulation for the stabilized 8×150 μm HEMT is performed using the nonlinear transistor model provided by UMS, and its results at 9.5 GHz are shown in Fig. 1. The compromised output power and PAE are 37 dBm and 58 % at the load impedance of 11.3 + j25.5 Ω, respectively.

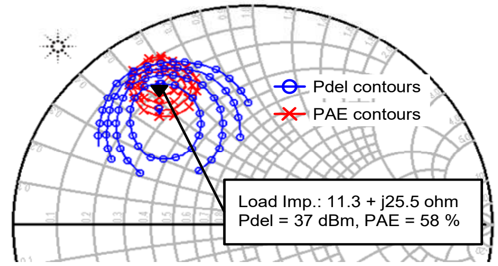

Fig. 1. Loadpull simulation results at 9.5 GHz of the stabilized 8×150 μm HEMT at the bias point of V_{DS} = 28 V and I_{DS} = 110 mA.

The HPA MMIC is designed in a two-stage configuration for a high linear gain of 20 dB at an X-band region. The driver stage consists of four 8×100 µm HEMTs and the output stage is made up of eight 8×150 µm HEMTs as shown in Fig. 2. The periphery ratio of the output stage and the driver stage is 3 (9.6 : 3.2), which still provides a sufficient driving margin.

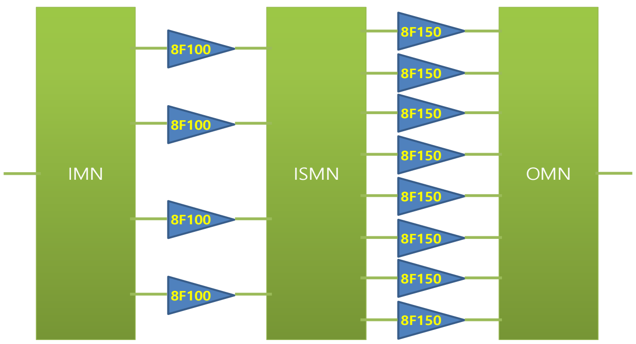

Fig. 2. Circuit topology of the X-band HPA MMIC

The output matching network (OMN) uses a corporate structure for optimal load matching and power combining, and double-layer metal microstrip lines with the thickness of 6.8 µm for the loss minimization. The inter-stage matching network (ISMN) has a low-pass matching circuit of microstrip lines and shunt capacitors, in addition to a drain bias circuit of the driving stage and a gate bias circuit of the output stage. The input matching network (IMN) transforms an equivalent input impedance of the driving stage to a system impedance (50 Ω) using high impedance meander lines. While providing a proper bias condition, the gate and drain bias networks also play a role of the impedance matching that achieves a desired impedance at the fundamental frequency and gives a highly reflective load at the second harmonic frequency.

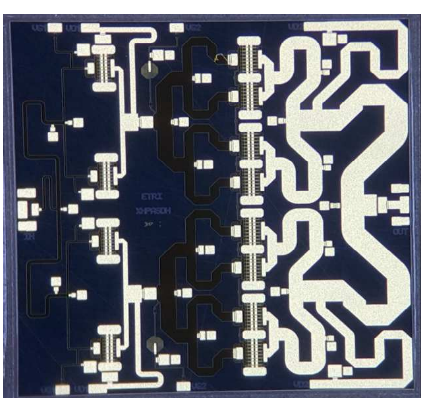

Fig. 2. Photograph of the fabricated X-band HPA MMIC. The chip area is 4.5 mm × 4.6 mm (20.7 mm^2).

After the circuit simulation using schematic elements, electromagnetic (EM) simulations are conducted for the OMN, ISMN, and IMN to include physical layout effects. To consider bonding wire effects, three 300 µm long bonding wires with the 18 µm diameter on the RF input and output pads are also electromagnetically simulated. A photograph of the fabricated HPA MMIC is shown in Fig. 2, and the chip occupies an area of 4.5 mm x 4.6 mm.

III. Measured Results

The performance of the fabricated MMIC power amplifier is measured using a test jig that includes Au bonding wires with the 18 µm diameter, two sections of 50 Ω microstrip lines on a 10 mil thick alumina substrate, and 2.92 mm (K) coaxial connectors. The quiescent bias point is a drain-source voltage of 28 V and a drain current of 1080 mA. The RF measurements are performed under the pulsed bias condition of a 10 % duty cycle and 100 µs pulse width.

The simulated and measured S-parameters of the MMIC power amplifier are shown in Fig. 3. The measured results (solid lines) are in reasonable agreement with the simulation results (dotted lines). The measured small-signal gain is 24–26 dB, and the input return loss is more than 7 dB from 8.8 to 10.8 GHz, while the output return loss is better than 11 dB in the same frequency band.

The large-signal measured results of the MMIC power amplifier over the bandwidth are shown in Fig. 4 with an available input power of 28 dBm; in the frequency band of 8.8–10.8 GHz, the output power is 45–46 dBm, the PAE is 38–44 %, and the associated gain is 17–18.4 dB.

Some state-of-the-art X-band MMIC power amplifiers that were fabricated using the 0.25 µm GaN HEMT process have the saturated output power of 9–45 W and the PAE of 32–52 %. Our work is compared with the previous state-of-the-art results and is summarized in Table I. From the viewpoint of the output power and PAE, it is noticeable that our X-band MMIC power amplifier is very competitive, compared with the state-of-the-art results.

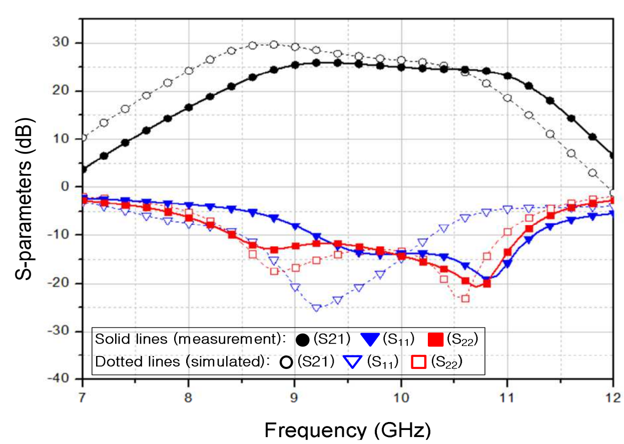

Fig. 3. Measured and simulated *S* parameters of the MMIC power amplifier.

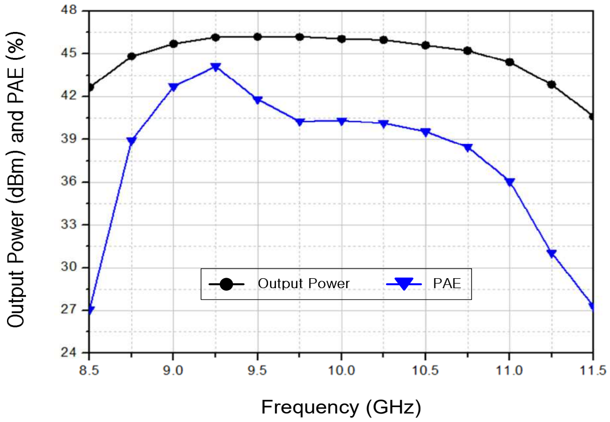

Fig. 4. Measured large-signal performance of the MMIC power amplifier at V_{DS} = 28 V with an available input power of 28 dBm.

TABLE I. COMPARISON OF X-BAND MMIC POWER AMPLIFIERS

Ref.	Technology	Freq. (GHz)	Pulse /Duty (µs/%)	V_{DS} (V)	P_{OUT} (W)	PAE (%)	Area (mm^2)
This work	0.25 µm GaN	8.8–10.8	100/10	28	30–40	38–44	20.7
[4]	0.25 µm GaN	8.8–10.4	50/15	26	14–15	38–43	18
[5]	0.5 µm GaN	8.6–10.6	20/ 1	25	15.8	33	9.25
[6]	0.25 µm GaN	9–11	20/10	25	35–45	40–52	18
[7]	0.25 µm GaN	9–12	10/10	30	8.9–14.8	38.6–51.1	7.2
[8]	0.25 µm GaN	10	-	28	9	32	8

IV. CONCLUSION

The X-band MMIC power amplifier for the SAR system was demonstrated using the 0.25 µm AlGaN/GaN HEMT process and its small-signal and large-signal measured results were presented. The fabricated MMIC showed the output power of 45 dBm (30 W) to 46 dBm (40 W) and the PAE of 38–44 % in 8.8-10.8 GHz with the associated power gain of about 17 dB. The developed MMIC power amplifier will be applied to the SSPA for future satellite SAR systems.

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REFERENCES

[1] D. Runton, B.Trabert, J. Shealy, and R. Vetury, “History of GaN : High-Power RF Gallium Nitride (GaN) from Infancy to Manufacturable Process and Beyond,” IEEE Microwave Magazine, vol. 14, issue 3, May. 2013, pp. 82–466.

[2] R. Pengelly, S. Wood, J. Milligan, S. Sheppard, and W. Pribble, “A Review of GaN on SiC High Electron-Mobility Power Transistors and MMICs,” IEEE Transactions on Microwave Theory and Techniques, vol. 60, issue 6, June 2013, pp. 1764–1783

[3] C. Florian, R. Cignani, A Santarelli, and Fabio Filicori, “Design of 40-W AlGaN/GaN MMIC High Power Amplifiers for C-band SAR Applications,” IEEE Transactions on Microwave Theory and Techniques, vol. 61, no 12, Dec. 2013, pp. 4492–4504

[4] D. Resca, A. Raffo, S. D. Falco, F. Scappaviva, V. Vadala, and G. Vannini, “X-band GaN power amplifier for future generation SAR systems,” IEEE Microw. Wireless Compon. Lett., vol. 24, no. 4, pp. 266–268, Apr. 2014.

[5] R. Giofre, P. Colantonio, and F. Giannini, “X-band MMIC GaN power amplifier for SAR systems,” Microw. Opt. Technol. Lett., vol. 55, no. 11, pp. 2611–2616, Nov. 2013.

[6] S. Piotrowicz et al., “43W, 52% PAE X-band AlGaN/GaN HEMTs MMIC amplifiers,” in IEEE MTT-S Int. Dig., May 2010, pp. 505–508.

[7] S. Masuda, M. Yamada, Y. Kamada, T. Ohki, K. Makiyama, N. Okamoto, K. Imanishi, T. Kikkawa, and H. Shigematsu, “GaN single-chip transceiver frontend MMIC for X-band applications,” in IEEE MTT-S Int. Dig., June 2011, p. 1–3.

[8] E. Ersoy, C. Meliani, S. Chevtchenko, P. Kurpas, M. Matalla, and W. Heinrich, “A high-gain X-band GaN-MMIC power amplifier,” In Microwave Conference (GeMiC), 2012 The 7th German (pp. 1-4). IEEE.