

A 4W GaAs Power Amplifier MMIC for Ku-band Satellite Communication Applications

Keun-Kwan Ryu², Ki-Burm Ahn¹, and Sung-Chan Kim²

Abstract—In this paper, we demonstrated a 4W power amplifier monolithic microwave integrated circuit (MMIC) for Ku-band satellite communication applications. The used device technology relies on 0.25 μm GaAs pseudomorphic high electron mobility transistor (PHEMT) process. The 4W power amplifier MMIC has linear gain of over 30 dB and saturated output power of over 36.1 dBm in the frequency range of 13.75 GHz ~ 14.5 GHz. Power added efficiency (PAE) is over 30 %.

Index Terms—Power amplifier, MMIC, Ku-band, 4W, PHEMT

I. INTRODUCTION

Satellites can provide global, ubiquitous, and multi-point communications. It is hardly surprising satellite technology has become flexible and cost effective solution for domestic and international networks, irrespective of the user's geographic location. Satellite technology can become a kind of solution for some of the most complicated access problems, connecting cities across a large landmass, where copper or fiber would be cost prohibitive. Therefore there is a steady demand for satellite communications. Diverse purposes of satellite communication encompass wide area network communication, cellular backhaul, internet access, and television broadcasting. The demand for satellite

communication systems with Gbit/s up- and down-link capacity drives the needs for higher operating frequencies. Nowadays satellite communication systems are slotted in the Ku-band region.

Power amplifiers are one of the most critical components in almost all types of wireless applications. For each specific purpose, they are expected to provide suitable performance. In mobile or satellite communication systems, high linearity and efficiency are important while for radar applications output power is a first concern. Although the power amplifier techniques are well developed, the high performance monolithic power amplifier in higher operating frequencies is still popular research topic.

The GaAs-based power amplifiers have been in use for a long time, especially for the mobile and the satellite communications. They are limited to produce very high output power, however they have some advantages such as outstanding high frequency characteristics and mature manufacturing process technology compared with GaN-based power amplifiers. In recent years, GaAs-based power amplifiers in Ku-band with 1 ~ 2W output power have been demonstrated [1-6].

In this paper, we developed the high performance three-stage power amplifier MMIC based on GaAs substrate in the frequency range of 13.75 GHz ~ 14.5 GHz for block up converter (BUC) of very small aperture terminal (VSAT) outdoor unit (ODU) applications. The design specification of the power amplifier MMIC is set at the request of BUC companies for commercial products.

Manuscript received May. 21, 2015; accepted Aug. 3, 2015

¹R&D Division, ASB Inc., Daejeon 305-510, Korea

²Department of Electronics and Control Engineering, Hanbat National University, Daejeon 305-719, Korea

E-mail : sckim@hanbat.ac.kr

II. POWER AMPLIFIER MMIC DESIGN

The power amplifier was designed using the $0.25\ \mu\text{m}$ AlGaAs/InGaAs/GaAs pseudomorphic high electron mobility transistor (PHEMT) monolithic microwave integrated circuit (MMIC) process by Wireless Information Networking (WIN) Semiconductor foundry. The gates of the PHEMT are written using E-beam lithography. Front-side processing includes active-layer etching, two metal layers, thin-film resistors, and MIM capacitors based on microstrip transmission line technology. After front-side processing, wafer are thinned to $100\ \mu\text{m}$ thickness. The back-side processing features via-holes.

The first step in designing the power amplifier MMIC was to perform load-pull simulation using the large-signal device model. This helps to find the optimum output impedance. The output power of the PHEMT device with 8 fingers and gate width of $150\ \mu\text{m}$ was 28 dBm. The circuit was designed as a three-stage amplifier for an output power of a 4W. The third stage called as power cell comprises four $16 \times 150\ \mu\text{m}$ cells. The output was thus modeled as a 4-to-1 combiner. For the design of the output power matching network, each 16 fingers device was considered as two devices of 8 fingers each. The second stage is designed to provide enough power for driving the subsequent stage. It uses four $8 \times 150\ \mu\text{m}$ cells. Small signal gain, output power, and efficiency are considered simultaneously during the design of the second stage. The first stage is designed last. It functions to ensure proper input matching and overall gain response, which is achieved with two $4 \times 150\ \mu\text{m}$ cells.

The schematic diagram of the designed three-stage power amplifier is shown in Fig. 1. The output matching network is synthesized to provide transformation of the optimum output impedance to $50\ \Omega$. The inter-stage matching was designed for adequate power matching, small signal gain response, and power added efficiency (PAE). The PAE depends on the load reflection coefficients at harmonic frequency. Therefore, in order to obtain the high efficiency, the load reflection coefficients at harmonic signals were tuned by varying the length of the transmission lines. The input matching network contains a high-pass matching structure. The circuit is completed with drain and gate bias networks of $\lambda/4$

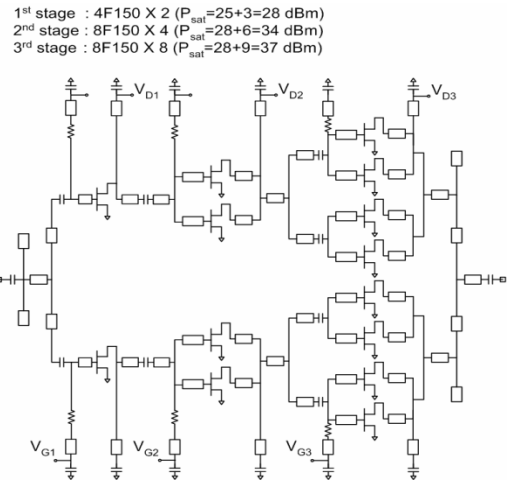


Fig. 1. Schematic diagram of the designed three-stage power amplifier MMIC.

short stub. The each DC bias feed line is used as the matching networks simultaneously. The final stage of the power amplifier MMIC is designed for output power of 37 dBm.

Stability of the power amplifier was analyzed by considering the K-factor for each stage. Small resistors are placed with the DC gate bias lines connecting each device and also placed between the drains in order to prevent odd mode instability.

The circuit were then refined using electro-magnetic simulation tool, Agilent's Momentum, in order to make sure that a minimum deviation between model and the actual circuit layout. From the EM simulation results, the output power of over 36.8 dBm and the small signal gain of over 30 dB are obtained in the frequency range of 13.74 GHz ~ 14.5 GHz.

III. MEASUREMENT RESULTS

The fabricated power amplifier MMIC is shown in Fig. 2. The chip dimensions are $3.4\ \text{mm} \times 2.6\ \text{mm}$.

The fabricated power amplifier MMIC is measured on the wafer state. A test board including DC bias supply is designed and the fabricated power amplifier MMIC is attached on the test board in order to measure the scattering parameters of the bare chip on probe station. The inductances of bonding wires at input and output ports are considered during the circuit simulation.

The K-type connectors and RO4003 substrate with 12 mil thickness provided by Rogers are used to minimize

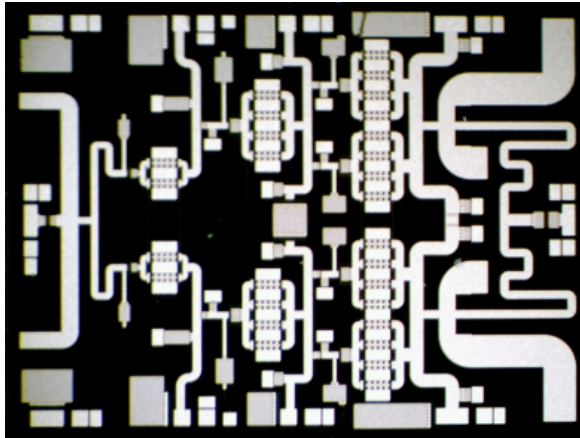


Fig. 2. Chip photograph of the fabricated three-stage power amplifier MMIC.

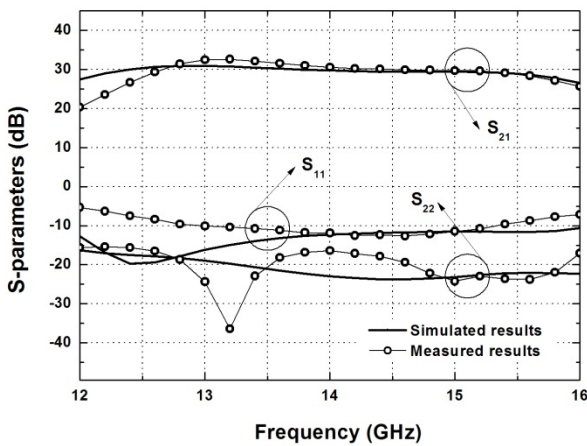


Fig. 3. The S-parameters characteristics of the fabricated three-stage power amplifier MMIC.

signal loss and a change of 50 Ω line widths between MMIC and RO4003 substrate during assembly of test jig for Ku-band. A single layer capacitor (SLC) of 100 pF is mounted at the DC bias point as a bypass capacitor for stable circuit.

Typical S-parameters of the fabricated three-stage power amplifier MMIC are shown in Fig. 3 at drain bias of 8 V and gate bias of -0.9 V. The small signal gain (S_{21}) is greater than 30 dB from 13.75 to 14.5 GHz. The input return loss (S_{11}) and the output return loss (S_{22}) are better than -10 dB over the entire frequency range. The simulated results are also plotted for comparison, exhibiting a good agreement with measurements.

The measured output power and drain current of the fabricated three-stage power amplifier MMIC are shown in Fig. 4. There is a sharp increase of the drain current around 5 dBm of the input power. It seems that there are

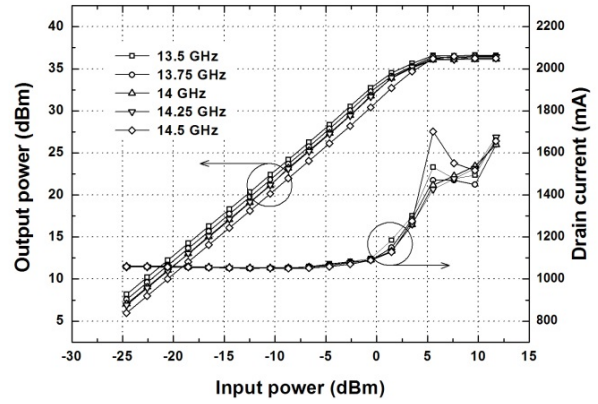


Fig. 4. The measured output power and drain current of the fabricated three-stage power amplifier MMIC.

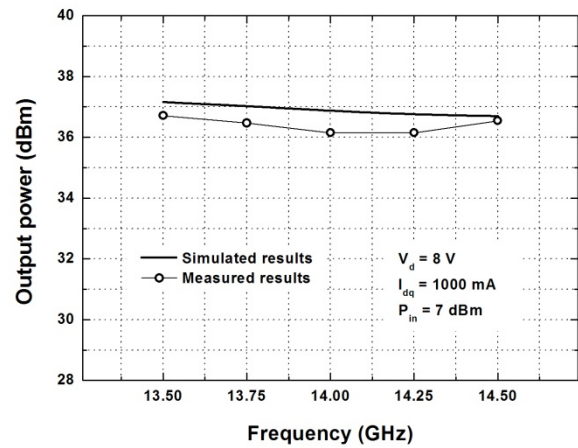


Fig. 5. The saturated output power characteristics of the fabricated three-stage power amplifier MMIC.

unexpected parasitic components caused by impedance matching for high power efficiency as well as high output power. Drain current at the saturated output power (P_{sat}) is a typical 1500 mA.

The simulated and measured saturated output power characteristics of the fabricated three-stage power amplifier MMIC are shown in Fig. 5. The measured data shows that saturated output power is better than 36.1 dBm at 8 V and 1000 mA quiescent bias conditions in the frequency range of 13.5 GHz ~ 14.5 GHz.

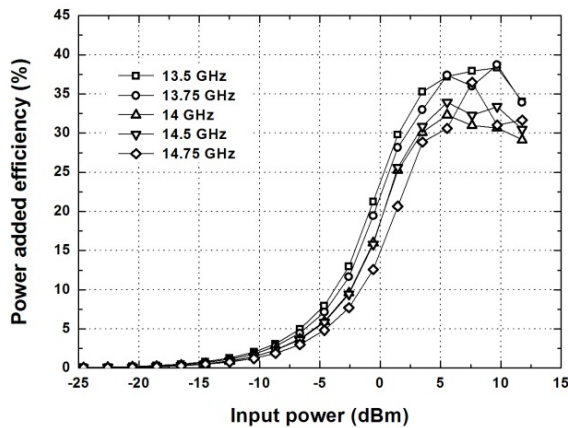
Fig. 6 shows the power added efficiency (PAE) versus input power over the entire band of 13.75 to 14.5 GHz. From the measurement results, PAE is better than 30% in the input power range of 5 dBm ~ 10 dBm.

The measurement results are satisfied with the design requirements of BUC companies.

Table 1 shows a comparison of the 4W power amplifier MMIC with other reported data. To our

Table 1. The comparison of the 4W power amplifier MMICs with other reported data

Reference	[7]	[8]	[9]	[10]	[11]	This work
Process technology	GaAs pHEMT	GaAs pHEMT	GaAs FET	GaAs pHEMT	GaAs FET	GaAs pHEMT
Frequency (GHz)	13.6 ~ 14.2	12 ~ 16	13.75 ~ 14.5	13 ~ 16	13.75 ~ 14.5	13.75 ~ 14.5
Saturated output power (dBm)	38	37	35	35.6	> 36	> 36
Gain (dB)	10.5	28	28	26	6.5	30
Drain bias voltage (V)	8	7	7	7	9	8
Supply current (mA)	2000	2400	1300	1300	1700	1000
Power added efficiency (%)	24	22	28	27	19	> 30

**Fig. 6.** The measured power added efficiency of the fabricated three-stage power amplifier MMIC.

knowledge, this is the highest power added efficiency reported by any GaAs-based 4W power amplifier MMIC over the band of 13.75 to 14.5 GHz for BUC of VSAT application. We expect the fabricated 4W power amplifier MMIC to be developed as a manufactured good by MMIC packaging technology.

IV. CONCLUSIONS

In this paper, we presented the 4W power amplifier MMIC for Ku-band satellite communication applications. The used device technology relies on $0.25\ \mu\text{m}$ GaAs PHEMT process. The 4W power amplifier MMIC has linear gain of over 30 dB and saturated output power of over 36.1 dBm in the frequency range of 13.75 GHz ~ 14.5 GHz. Power added efficiency (PAE) is over 30 %. To our knowledge, this is the highest power added efficiency reported for any reported GaAs-based 4W MMIC power amplifier from 13.75 to 14.5 GHz. The fabricated 4W power amplifier MMIC is expected to be applied for Ku-band VSAT transmitters as well as

satellite communication applications.

ACKNOWLEDGMENTS

This work was supported by the leading industry of IT Convergence and equipment of the Chungcheong Leading Industry Office of the Korean Ministry of Trade, Industry and Energy.

REFERENCES

- [1] A. Bessemoulin, M. Parisot, P. Quentin, C. Saboureau, M. van Heijningen, J. Priday, "A 1-watt Ku-band power amplifier MMIC using cost-effective organic SMD package," in *Proc. of the 34th European Microwave Conference*, pp. 349-352, 2004.
- [2] A. Dechansiaud, R. Sommet, T. Reveyrand, R. Quere, D. Bouw, C. Chang, M. Camiade, F. Deborgies, "Design of an integrated cascode cell for compact Ku-band power amplifiers," in *Proc. the 42nd European Microwave Conference*, pp. 1091-1094, 2012.
- [3] C. W. Huang, S. J. Chang, W. Wu, C. L. Wu, and C. S. Chang, "A Ku-band four-stage temperature compensated PHEMT MMIC power amplifier," *Microwave and Optical Technology Letters*, vol. 44, no. 5, pp. 480-485, March 2005.
- [4] J. G. Kim, H. M. Park, J. Y. Kim, S. I. Jeon, and S. C. Hong, "A 2-watt balanced power amplifier MMIC for Ku-band satellite communications," *Microwave and Optical Technology Letters*, vol. 42, no. 4, pp. 342-344, August 2004.
- [5] H. Liu, C. Lin, C. Chu, H. Huang, M. Houg, C. Chang, C. Wu, C. Chang, Y. Wang "A single-supply Ku-band 1-W power amplifier MMIC with

compact self-bias PHEMTs,” *IEEE Microwave and Wireless Components Letters*, vol. 16, no. 6, pp. 330-332, 2006.

- [6] H. Z. Liu, C. C. Wang, Y. H. Wang, J. W. Huang, C. H. Chang, C. L. Wu, C. S. Chang, “A four-stage Ku-band 1 watt PHEMT MMIC power amplifier,” in *Proc. of Gallium Arsenide Integrated Circuit (GaAs IC) Symposium*, Monterey, pp. 33-36, 2002.
- [7] C. Lin, H. Liu, C. Chu, H. Huang, C. Liu, C. Chang, C. Wu, C. Chang, Y. Wang, “A compact 6.5W PHEMT MMIC Power Amplifier for Ku-band Application,” *IEEE Microwave and Wireless Components Letters*, vol. 17, no. 2, pp.154-156, 2007
- [8] “HMC5879LS7,” Hittite microwave corporation data sheet [internet], Available: <http://www.hittite.com>.
- [9] “FMM5059VF,” Sumitomo electronic industries data sheet [internet], Available: <http://www.global-sei.com>.
- [10] “TGA2536-FL,” TriQuint semiconductor data sheet [internet], Available: <http://www.triquint.com>.
- [11] “TIM1414-252,” Toshiba microwave semiconductor data sheet [internet], Available: <http://www.toshiba.com>



Keun-Kwan Ryu received his B.S., M.S., and Ph.D. in the Department of Electronics and Communications Engineering from Kwangwoon University, Seoul, Korea, in 1992, 1994, 2000, respectively. From 2001 to 2002, he was with Electronics and

Telecommunications Research Institute (ETRI) as a senior research engineer. In 2003, he joined Department of Electronic Engineering, Hanbat National University, Daejeon, Korea, and is now a full professor. His research interests include high frequency active and passive circuits.



Ki-Burm Ahn received the B.S. and M.S. in the Department of Electronics and Communications Engineering from Kwangwoon University, Seoul, Korea, in 1998 and 2000, respectively. He was a research engineer with ASB Inc., Korea, from 2001 to 2005

and a senior research engineer with ETRI, Korea from 2005 to 2010. In 2010, he rejoined ASB Inc., where he has been working in the area of high frequency integrated circuit design. His interests include high frequency active and passive circuits.



Sung-Chan Kim received the B.S., M.S., Ph.D. degrees in the Department of Electronic Engineering from Dongguk University, Seoul, Korea, in 1999, 2001, and 2006, respectively. In 2007, he joined the Faculty of Electronic Engineering, Hanbat

National University, Daejeon, Korea, where he is currently an associate professor. His research interests include high frequency integrated devices and circuits using compound semiconductor technologies at microwave and millimeter-wave frequencies.