A 25-W 5-GHz GaAs FET Amplifier for a Microwave Landing System

KAZUHIKO HONJO AND YOICHIRO TAKAYAMA, MEMBER, IEEE

***Abstract*—A 25-W 29-dB gain 5-GHz GaAs FET amplifier has been developed which can be used for a transmitter in the Microwave Landing System. By using 10-W class practical internally matched GaAs FET's hermetically sealed in ceramic packages, the four-stage amplifier has been constructed simply. The amplifier provides 30-W power output with 18.5-percent power efficiency at 17-dBm power input level. It also exhibited an excellent AM/PM conversion of approximately 1°/dB, compared to 6°/dB for TWT amplifiers.**

I. Introduction

WITH THE RECENT significant progress of power GaAs FET's, it has become possible to replace 10-W class TWT amplifiers by solid-state FET amplifiers in some microwave communication systems [1]–[3]. However, the circuit configurations of these amplifiers are complicated and 10-W amplifier power output level is not high enough to use in such a system as the Microwave Landing System (MLS) used at airports. For the MLS amplifier, 15-W power output under linear operation at 100-mW power input over the 5031.0–5090.7-MHz band is required [4]. To push the TWT amplifier replacement still further, practical higher power devices under reliable operating conditions and simple amplifier circuit configuration are required.

The purpose of this paper is to present the design considerations and performance results on a 25-W 5-GHz GaAs FET amplifier for the transmitter in the Microwave Landing System. The amplifier for the TWT amplifier replacement has simple four-stage construction using practical internally matched GaAs FET's assembled in ceramic packages. The amplifier provides 25-W power output with 29-dB gain and 18-percent power efficiency over the 4.9–5.2-GHz range. At 17-dBm power input level, 30-W power output was obtained. The amplifier exhibited excellent AM/PM conversion of approximately 1°/dB, compared to TWT amplifiers.

II. Internal Matching for Power GaAs FET's

The power GaAs FET's used in the amplifier are newly developed V248 series devices [5] except for the NE 868496 in the first stage. The V248 FET gate length is 1.3 μm and

Manuscript received May 15, 1980; revised January 5, 1981. A condensed version of this paper has been presented at the 1980 IEEE-MTTS International Microwave Symposium, Washington, DC.

The authors are with Central Research Laboratories, Nippon Electric Company, Ltd., 1-1, Miyazaki, yonchome, Takatsu-ku, Kawasaki-city, Kanagawa 213, Japan.

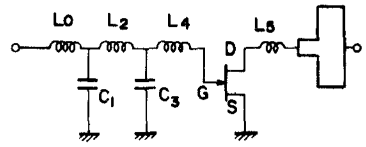

Fig. 1. Equivalent circuit for internally matched GaAs FET.

gate finger length is 190 μm. The single chip has an eight cell structure and 15.2-mm total gate width. The FET has graded recess structure, gate-source cross-over structure and chip-side metallization for source grounding. The real part of the single-chip input impedance is 0.58 Ω at 5 GHz. The single-chip FET measures 2.2×0.7 mm. In the amplifier, one V248A, two V248B's, and four V248B's are used in the second stage, the third stage, and the final stage, respectively. The V248A has one-chip structure and the V248B has two-chip structure with 30.4-mm total gate width. These V248 devices are hermetically sealed in "98" ceramic packages.

The equivalent circuit for the internal matching network is shown in Fig. 1 [6]. The input internal matching network has a lumped-element two section low-pass form. The output internal matching network has a one-section semi-distributed form. The matching networks were designed with a computer-aided design optimization, based on small-signal *S*-parameters. Based on this result, a trial device with the matching network was constructed. The output networks were experimentally optimized using the equivalent load-pull measurements for trial devices with the matching networks [7]–[9]. Fig. 2 is a photograph of the internally matched V248B in a "98" ceramic package. The input network consists of lumped-element inductors and low-loss capacitors. All inductors were realized by 30-μm diameter gold bonding wires. The low-loss capacitors were formed with a single 0.1-mm thick high-dielectric ceramic plate, whose main composition is $BaO-TiO_2$. Its relative dielectric constant is 39 and loss tangent is 2×10^{-4}. The electrodes were formed by thick film technique with Au paste. By this configuration, low-loss matching and phase uniformity within multichip devices were retained very well for the extremely low-impedance wide two-chip device, such as 30.4-mm gate-width device. The output network consists of bonding wires and microstrip stubs formed on a 1-mm thick alumina substrate.

The small-signal input and output impedances for internally matched V248B are shown in Fig. 3. Fig. 4 shows the

0018-9480/81/0600-0579$00.75 ©1981 IEEE

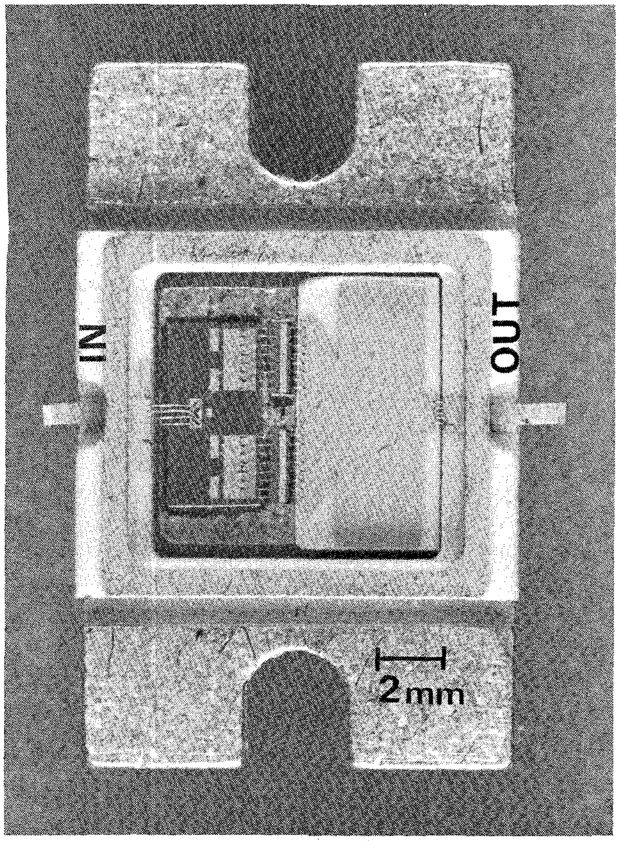

Fig. 2. Internally matched FET V248B assembled in ceramic package.

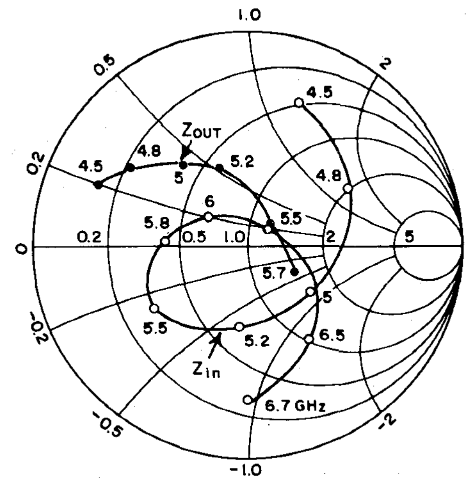

Fig. 3. Small signal input and output impedances for internally matched FET V248B, $Z_0 = 50\ \Omega$.

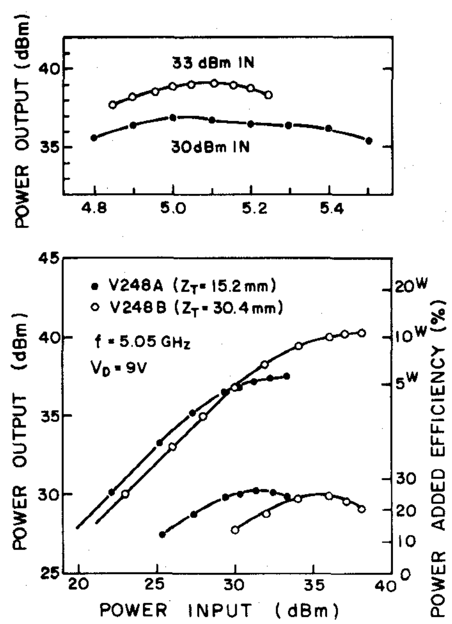

Fig. 4. Input–output response and output power response versus frequency for V248A and V248B internally matched power FET's.

input–output responses and output power responses versus frequency for the V248A and the V248B internally matched power FET's. The V248B FET has 8-W power output at 1-dB gain compression with 7-dB small-signal gain, over 4.9–5.2-GHz range, without any external matching. It also has 10-W saturated power output and 24.5-percent maximum power added efficiency. The internally matched power GaAs FET V248A has 4.4-W power output at 1-dB gain compression with 8-dB small-signal gain, without any external matching. It also has 5.7-W saturated power output and 26-percent maximum power added efficiency.

III. Amplifier Description

To achieve the requirement for the power output, the amplifier having 25-W power output at 1-dB gain compression was designed. Fig. 5 shows a block diagram and a level diagram for the four-stage 25-W amplifier. The first stage has an external matching circuit. By introducing the internal matching technique for higher power FET's, a multistage amplifier was constructed without external matching in the V248A and the V248B stages, except fine adjusting stubs for efficient power combining. The four-stage amplifier has a four-way power combining output stage consisting of four internally matched power FET's (V248B). Power dividing and combining are made with 3-dB branch-type microstrip couplers. A 0.5-dB loss is estimated on a single 3-dB branch-type coupler including a dc block capacitor.

In a microwave amplifier, low-frequency impedance depends on bias circuits. Bias circuits for GaAs FET amplifier have to suppress off-band parasitic oscillations without dc power dissipation and degrading RF characteristics. Fig. 6 shows an equivalent circuit for a gate-bias circuit of the MLS amplifier. The circuit consists of a microstrip-line quarter-wave transformer T (length l, characteristic impedance Z_{00}), multilayer ceramic-chip capacitors C_2, C_3, a feedthrough-type ceramic capacitors C_1, a thin-film resistor R_1, and a ferrite-core inductor L_1. The capacitances and the inductance measured at 1 MHz are $C_1 = 1000$ pF, $C_2 = 330$ pF, $C_3 = 1$ pF, and $L_1 = 1$ mH. The other circuit element values are $R_1 = 15\ \Omega$, $l = \frac{1}{4}\lambda_g$, and $Z_{00} = 100\ \Omega$ where λ_g is the wavelength at 5 GHz in the microstrip line. A self-resonance frequency of the 1-pF multilayer ceramic-

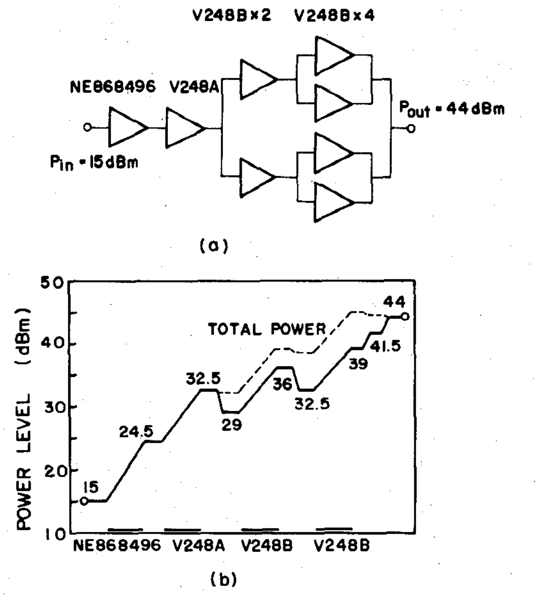

Fig. 5. Block diagram and level diagram for four-stage 25-W amplifier.

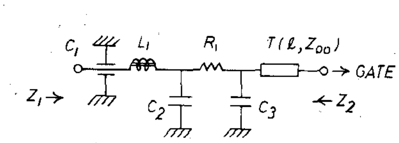

Fig. 6. Equivalent circuit for gate bias circuit.

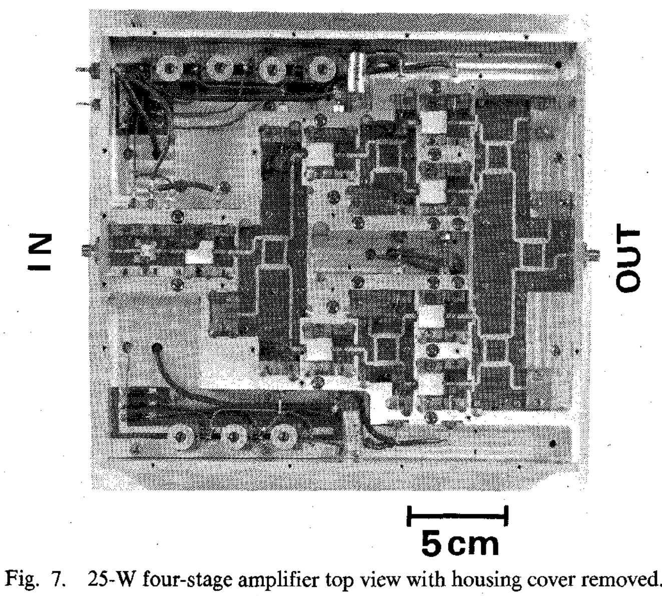

Fig. 7. 25-W four-stage amplifier top view with housing cover removed.

chip capacitor (C_3) is lower than 5 GHz, and the impedance of C_3 is nearly 10 Ω at 5 GHz. Therefore, the gate bias circuit output impedance Z_2 is high enough not to degrade the RF characteristics. The thin-film resistor R_1 causes no dc voltage drop, because there is no dc current in the gate bias circuit.

Fig. 7 is a top view of the 25-W four-stage amplifier with housing cover removed. Microwave microstrip circuits, including the 3-dB couplers and the first-stage matching

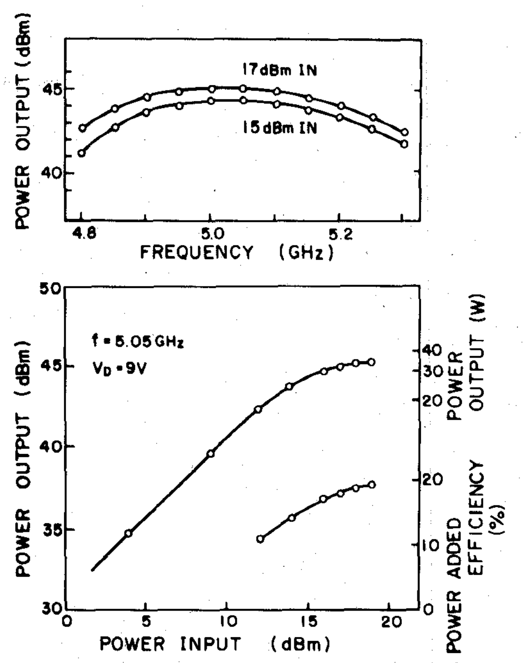

Fig. 8. Power output versus power input and frequency response for four-stage amplifier.

circuit, were fabricated on 0.6-mm thick glass-fiber substrates having 2.6 relative dielectric constant. Microstrip conductors have a Cu–Au metal system. As shown in the Fig. 7, each V248B FET is partitioned by metal walls to avoid mutual coupling. In the amplifier, six 50-Ω terminations are used. The allowable dissipation power of the single termination is 10 W. The amplifier requires 9 V for drain bias power supply and −5 V for gate bias voltage supply. The gate bias voltage for each FET was adjusted individually, considering power efficiency and nonlinearity. Power efficiency and nonlinearity depend largely on gate bias voltage.

Amplifier size, including the heat radiating fin, is 24×23 ×8.5 cm. The weight is 4.8 kg.

IV. Performance

Power output versus power input and frequency response for the four-stage amplifier are shown in Fig. 8. For 15-dBm input power level, the amplifier provides more than 25-W power output over the frequency range from 4.98 to 5.1 GHz and more than 20-W power output over the frequency range from 4.9 to 5.2 GHz. It also covers the 4.9–5.2-GHz range with more than 25-W power output, and has 30-W power output with 18.5-percent power-added efficiency at 5.05 GHz, for 17-dBm input power level. Output stage power combining efficiency is more than 90 percent.

Fig. 9 shows the AM/PM and AM/AM conversion characteristics for the FET amplifier. The AM/PM conversion for the amplifier is approximately 1°/dB over the 5–18-dBm input dynamic range. These demonstrate superior FET amplifier linearity, compared to 6°/dB for an equivalent TWT amplifier.

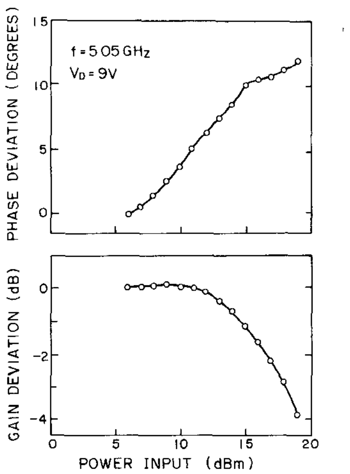

Fig. 9. AM/PM and AM/AM conversion characteristics for 25-W amplifier.

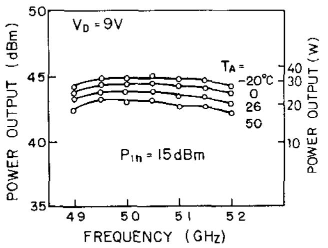

Fig. 10. Output power versus frequency for FET amplifier at $-20°C$ 0°C, 26°C, and 50°C.

The amplifier was evaluated over a wide ambient temperature range from $-20°C$ to 50°C under forced air cooling condition. Fig. 10 shows the output power versus frequency at four temperatures, $-20°C$, 0°C, 26°C, and 50°C. The variation in output power over the temperature range was 2 dB at 15-dBm input power level. DC power dissipation for a V248B FET is 21.1 W under no RF drive condition. Since its thermal resistance, measured from FET channel to package flange, is 27.5°C/W, the temperature rise is about 60°C. As the measured package flange temperature was 40°C at 27°C ambient temperature, the device channel temperature is estimated to be 100°C at 27°C ambient temperature and about 120°C at 50°C ambient temperature. Under normal RF operating conditions, V248 B FET power dissipation is lower than 21.1 W. For instance, assuming that drain current is constant under RF operating condition and power added efficiency is 20 percent, an 11.6°C channel temperature drop can be calculated, compared to the no RF driving state. Thus the channel temperature is estimated to be lower than 125°C, even at 50°C ambient temperature. The lifetime has been estimated to be 10^7 hours at 125°C channel temperature [10].

V. Conclusion

A 25-W 5-GHz GaAs FET amplifier for the transmitter in the MLS has been developed. By using the practical internally matched GaAs FET's, hermetically sealed in ceramic packages, the four-stage amplifier has been simply constructed. The amplifier provides 25-W power output at 1-dB gain compression with 29-dB gain over the MLS-band. At 17-dBm power input level, 30-W power output was obtained with 18.5-percent power efficiency. Compared to TWT amplifiers, the amplifier exhibited excellent linearity.

Acknowledgment

The authors would like to thank F. Hasegawa and A. Higashisaka for supplying GaAs FET chips and K. Ayaki and H. Katoh for their constant encouragement. They would also like to thank T. Koshio and G. Onodera of the Radio Application Division for their constant encouragement throughout this work.

References

[1] P. T. Ho, C. M. Pham, and R. L. Mencik, "A 10-watt, C-band FET amplifier for TWT replacement," in *1979 MTT-S Int. Microwave Symp., Dig. Tech. Papers*, pp. 128–130, May. 1979.

[2] B. Dornan, Y. Wu, H. Wolkstein, and H. Huang, "GaAs FET amplifier for a satellite transponder," in *1980 Int. Solid-State Circuit Conf., Dig. Tech. Papers*, pp. 162–163, Feb. 1980.

[3] Y. Arai, S. Murai, and T. Sakane, "High power GaAs FET amplifier for TWT replacement," *FUJITSU Scientific Tech. J.*, pp. 63–82, Sept. 1979.

[4] G. Onodera, T. Kobayashi, K. Okada, K. Kuroda, and T. Nishimura, "Development of approach elevation equipment in MLS," *NEC Res. Dev.*, no. 59, pp. 34–45, Oct. 1980.

[5] A. Higashisaka, K. Honjo, Y. Takayama, and F. Hasegawa, "A 6 GHz, 25 W GaAs MESFET with an experimentally optimized pattern," in *1980 MTT-S Int. Microwave Symp., Dig. Tech. Papers*, pp. 9–11, May 1980.

[6] Y. Takayama, K. Honjo, A. Higashisaka, and F. Hasegawa, "Internally matched microwave broadband linear power FET," in *1977 Int. Solid-State Circuit Conf., Dig. Tech. Paper*, pp. 166–167, Feb. 1977.

[7] K. Honjo, Y. Takayama and A. Higashisaka, "Broad-band internal matching of microwave power GaAs MESFET's," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-27, pp. 3–8, Jan. 1979.

[8] K. Honjo, Y. Takayama, T. Furutsuka, A. Higashisaka, and F. Hasegawa, "15-watt internally matched GaAs FETs and 20-watt amplifier operating at 6 GHz," in *1979 MTT-S Int. Microwave Symp., Dig. Tech. Papers*, pp. 289–291, 1979.

[9] Y. Takayama, "A new load-pull characterization method for microwave power transistors," in *1976 MTT-S Int. Microwave Symp., Dig. Tech. Papers*, pp. 218–220, June 1976.

[10] NEC field data involving 1096 power GaAs FET's.