# A High-Performance Ka-Band Monolithic Variable-Gain Amplifier Using Dual-Gate HEMT's

Takuo Kashiwa, *Member, IEEE,* Takayuki Katoh, Takao Ishida, Yoshiki Kojima, and Yasuo Mitsui, *Member, IEEE*

*Abstract—* **This letter describes the excellent performance of a Ka-band monolithic variable-gain amplifier monolithic microwave integrated circuit (VGA MMIC) using dual-gate AlGaAs/InGaAs pseudomorphic high electron mobility transistors (HEMT's). The dual-gate HEMT can be fabricated by the same process as a single-gate HEMT. To achieve low-noise performance, a single-gate HEMT is employed in the first stage of the VGA MMIC. However, in the second and third stages, dual-gate HEMT's are used for gain control performance with higher gain. The VGA MMIC achieves more than 30-dB gain with more than 50-dB gain control range from 30 to 35 GHz. A noise figure of 1.4 dB with an associated gain of 29.2 dB is achieved at 33 GHz when biased for a low-noise performance.**

## I. Introduction

MILLIMETER-WAVE is very attractive for future communication systems that require larger capacities. To satisfy the demand, monolithic microwave integrated circuits (MMIC's) have been widely investigated because they have advantages in terms of miniaturization, good reproducibility, and low cost in high production, without undesirable wire connections that strongly impact assembly yield and radio frequency (RF) performance for the millimeter-wave range.

Gain control technologies have also been widely investigated for temperature compensation in satellite communication systems, improvement of the sidelobe level in the phased-array radar systems, etc. [1], [2]. There are, however, few reports concerning variable-gain amplifiers (VGA's) in the millimeter-wave range [3], [4]. We have recently reported on the first millimeter-wave VGA that consists of a low-noise MMIC amplifier (LNA MMIC) and a VGA MMIC [3]. Our previous work indicated the potential for simultaneously fabricating the dual-gate high electron mobility transistor (HEMT) with the same process as the single-gate HEMT. In this work, we describe a monolithic Ka-band three-stage variable-gain amplifier that achieves high gain, low noise, and wide-gain control performance.

## II. Circuit Design, Fabrication, and Experimental Results

A microphotograph of the three-stage VGA MMIC is shown in Fig. 1. AlGaAs/InGaAs pseudomorphic HEMT's are used in the VGA MMIC. Epitaxial layers are grown by molecular beam epitaxy (MBE). A Si-planar-doped layer with sheet carrier concentration of $5 \times 10^{12}$ cm$^{-2}$ is inserted into the AlGaAs layer in order to obtain a high transcondutance. The 0.15-$\mu$m T-shaped gate is defined using photo/EB hybrid exposure with a double-layer resist [5]. This process is excellent in terms of wafer throughput because it utilizes step-and-repeat exposure to fabricate the wide head of the T-shaped gate structure. A narrow source-to-drain space of 1.5 $\mu$m in the single-gate structure is employed for reduction of bulk resistance in order to achieve high-gain and low-noise performance. The dual-gate configuration can be fabricated at the same time as the single-gate configuration by the same process. Noise performance of a dual-gate HEMT is usually inferior to that of the single-gate HEMT because of parasitic resistance. For this reason, a single-gate HEMT is utilized in the first stage of the multistage amplifier in order to obtain a high-gain low-noise monolithic variable-gain amplifier.

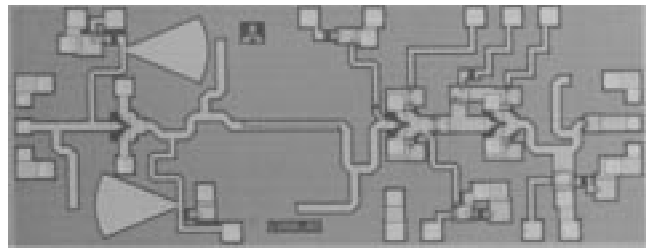

Fig. 1. Microphotograph of the VGA MMIC.

Small-signal equivalent parameters of the single-gate HEMT are extracted from $S$-parameters that are measured under hot and cold bias conditions [6]. Noise parameters are calculated from measured noise parameters at relatively lower frequency using the noise modeling [7], [8]. Small-signal parameters of the dual-gate HEMT's are obtained by cascode connecting two single-gate HEMT's and are compared with measured $S$-parameters of the monitor HEMT of the dual-gate configuration.

The first stage of the VGA MMIC utilized a single-gate HEMT with a gate width of 120 $\mu$m, considering the best noise performance for Ka-band [9]. A lightly series feedback is utilized in order to simultaneously achieve better noise figure and voltage standing-wave ratio (VSWR). A radial stub connected with a 1/4-wavelength high-impedance line is used for the bias circuit because of its low insertion loss and broad-band grounded characteristics.

The second stage and third stage of the VGA MMIC utilized dual-gate HEMT's. Each dual-gate HEMT is the same-size HEMT, with gate width of 100 $\mu$m. The second gate of the

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The authors are with Optoelectronic and Microwave Devices Laboratory, Mitsubishi Electric Corporation, Hyogo 664, Japan (e-mail: kashiwa@oml.melco.co.jp).

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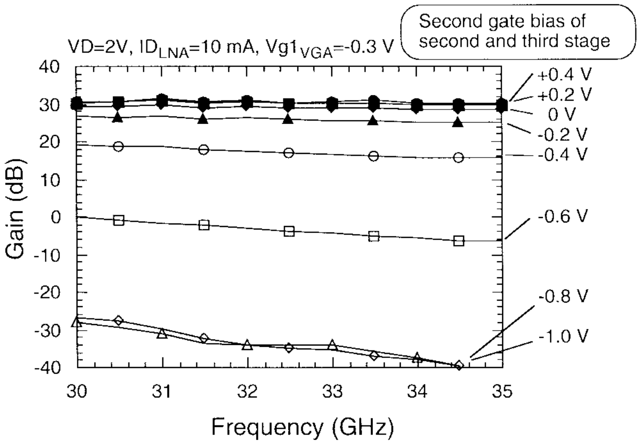


Fig. 2. Measured gain control performance of the VGA MMIC. $ID_{LNA}$ signifies the first stage drain current and $V_{g1\,VGA}$ signifies the voltage applied to the fist gates of the second- and the third-stage dual-gate HEMT.

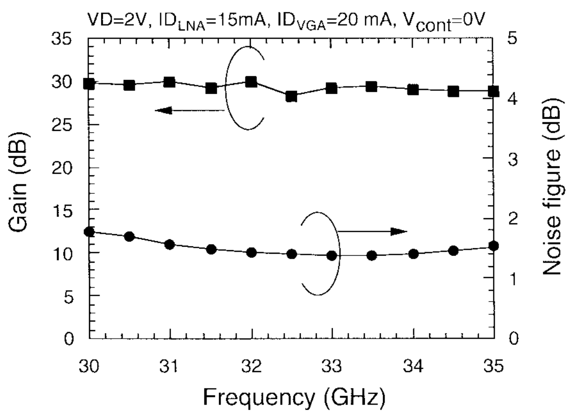


Fig. 3. Measured noise figure and associated gain of the VGA MMIC when biased for low-noise performance. $ID_{VGA}$ signifies the sum of the second- and third-stage drain currents.

dual-gate HEMT is radio frequency (RF) grounded by the metal–insulator–metal (MIM) capacitors. Interstage matching is conjugate because of size reduction. The edge-coupled line is employed for dc blocking and avoidance of undesirable lower-frequency oscillation.

The chip size of the VGA MMIC is 3.4 mm $\times$ 1.4 mm. Fig. 2 shows the measured gain control performance of the VGA MMIC. The maximum gain of 31.5 dB is obtained at 31 GHz. The gain is more than 30 dB from 30 to 35 GHz. The dynamic gain control range of more than 50 dB is achieved by controlling only the second gate bias of the second and the third stage. Fig. 3 shows the noise figure and the associated gain when biased for a low-noise figure. The minimum noise figure of 1.4 dB is obtained with the associated gain of 29.2 dB at 33 GHz. The noise figure is less than 1.8 dB with the associated gain of more than 28.9 dB from 30 to 35 GHz.

## III. Conclusion

A Ka-band high-gain low-noise monolithic three-stage variable gain amplifier has been successfully developed using dual-gate AlGaAs/InGaAs pseudomorphic HEMT's. The 0.15-$\mu$m gate dual-gate HEMT can be fabricated by the same process as a single-gate HEMT, and at the same time. Gain of more than 30 dB is obtained from 30 to 35 GHz. The minimum noise figure of 1.4 dB is achieved with the associated gain of 29.2 dB at 33 GHz when biased for a low-noise figure. This performance is well suited to millimeter-wave front-end components.

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