High-Gain Cascode MMIC's in Coplanar Technology at *W*-Band Frequencies

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***Abstract*— Compact high-gain *W*-band multistage amplifier MMIC's have been developed in coplanar technology using 0.15-μm AlGaAs/InGaAs/GaAs PM-HEMT's. The conventional dual-gate HEMT has been modified to include an additional interstage network between the common-source and the common-gate HEMT. The effect of stabilizing circuit elements has been investigated. A gain of 10 dB per cascode stage is obtained at 94 GHz. Multistage amplifier MMIC's with up to 40-dB gain have been realized.**

***Index Terms*— Cascode, coplanar waveguide, MMIC, PM-HEMT, *W*-band.**

I. Introduction

In the past, dual-gate field-effect transistors (FET's) have been used successfully in a number of MMIC applications, such as gain-controlled low-noise amplifiers [1], power amplifiers [2], ultrawide-band distributed amplifiers [3], and highly integrated millimeter-wave circuits [4]. The MMIC's described below make extensive use of a cascode amplifier, illustrated schematically in Fig. 1. It differs from a dual-gate device [1]–[4], since now an interstage network physically separates the common-source and the common-gate high-electron mobility transistors (HEMT's). This amplifier is easier to stabilize and still offers significant advantages in gain versus chip area, compared to a conventional two-stage common-source amplifier. This cascode connection has been practiced in the past and was applied to vacuum tubes and recently to HEMT's [5]. We have systematically investigated the effect of circuit and substrate on this type of cascode circuit, and demonstrate its application in high-gain MMIC's with gains up to 40 dB at 94 GHz.

II. Technology

An MBE-grown double-doped pseudomorphic (PM) AlGaAs/InGaAs/GaAs HEMT structure was used to realize the active devices. The 0.15-μm mushroom gates were written with e-beam, and the recess was dry etched [6]. The HEMT's typically had an f_t of 110 GHz and an $f_{\max}$ of 160 GHz. With 25% indium in the channel, a current density $J_{\rm sat}$ of 900 mA/mm and an extrinsic transconductance of 800 mS/mm were achieved. Coplanar lines of 3-μm thickness and 50-μm ground-to-ground spacing were used. Broad-band models of the coplanar components are described in detail in [7].

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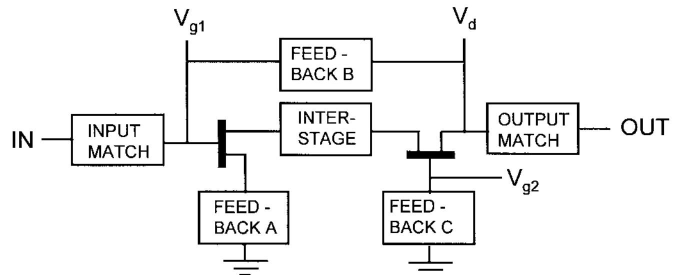

Fig. 1. Schematic representation of a cascode HEMT single-stage amplifier with an interstage matching network between the common-source and the common-gate HEMT's and feedback for improved stability.

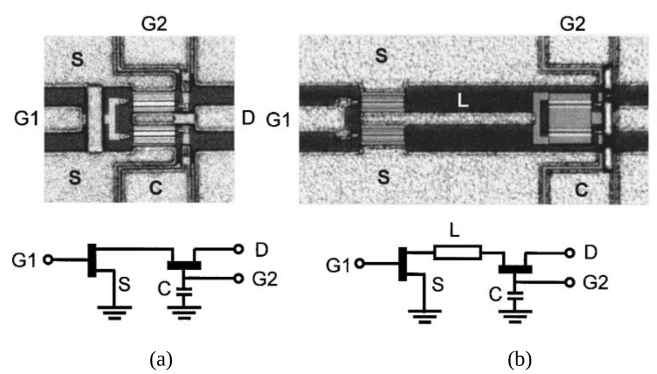

Fig. 2. (a) Coplanar dual-gate HEMT and its schematic representation and (b) coplanar cascode HEMT with interstage network, a short length of transmission line L.

III. Circuits

The conventional dual-gate HEMT, illustrated in Fig. 2(a), inherently suffers from a large feedback capacitance, the drain–source capacitance of the common-gate transistor. This makes it more prone to be unstable and thus more difficult to use in an amplifier circuit than a common-source HEMT. However, since the cascode amplifier configuration clearly requires less chip area per unit gain, we investigated the effect of an interstage network as well as various feedback networks on stability. The coplanar cascode HEMT with possible matching and feedback networks is illustrated in Fig. 1. Feedback A was used for low-noise applications, resulting in a pronounced decrease in gain. Feedback B has not been considered, because of its difficulty of implementation in a coplanar environment. Simulations with resistors in the gate or drain line of the common-gate HEMT indicated unconditional stability, but resulted in severe gain reduction. Good results were obtained with a capacitive element in the gate line of the

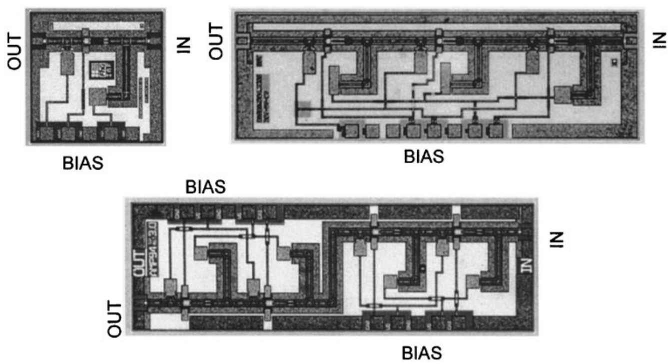

Fig. 3. Coplanar cascode HEMT single-, three-, and four-stage amplifiers. The chip sizes are 1×1 and 1×3 mm^2, respectively.

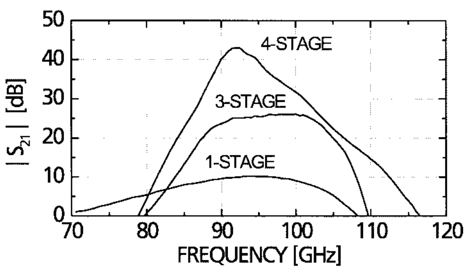

Fig. 4. Power gain performance of coplanar cascode HEMT single- and multistage amplifiers.

common-gate HEMT and an inductive element as an interstage network.

So far, the value of the capacitance C was chosen very large (4–10 pF), to achieve good radio frequency (RF) grounding for the second gate. This large capacitance made it difficult to stabilize the circuits [8]. Our simulations and measurements have shown that a reduction of the value of C to less than 1 pF results in unconditional stability for both dual-gate and cascode HEMT amplifiers. Fig. 2(b) illustrates the cascode HEMT with separate common-source and common-gate HEMT's, connected by a short section of high-impedance coplanar line L. This simple network represents an inductor and improves the matching of the two HEMT's. Transistor model parameters were extracted from the HEMT's and used in the design of single- and multistage small-signal amplifiers. One-, three- and four-stage amplifiers are illustrated in Fig. 3, measuring 1×1 mm^2 and 1×3 mm^2, respectively. Typical bias voltages are 4 V on the drain, 0 V on gate 1, and 2 V on gate 2. Their power gain performance is illustrated in Fig. 4. The three-stage amplifier was designed for broad-band operation and the four-stage amplifier for high gain. Both the common-source and the common-gate HEMT contribute about 5-dB gain each, resulting in 10-dB gain of the single-stage amplifier. Because of the existence of parasitic modes in the substrate, excited by the coplanar lines and discontinuities, feedback is provided within the substrate. Special precautions and packaging techniques to suppress these undesired modes had to be exercised [9] to achieve stable operation for the three- and the four-stage amplifiers. This was possible by thinning the MMIC's to 50 μm and mounting them on microwave absorbing material.

IV. Summary

Stabilizing methods for dual-gate HEMT's were investigated, resulting in a cascode connection of a common-source HEMT, an inductive interstage matching network, and a common-gate HEMT. This configuration was used to realize 94-GHz coplanar multistage amplifiers with gains up to 40 dB.

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