INTEGRATED COPLANAR MM-WAVE AMPLIFIER WITH GAIN CONTROL USING A DUAL-GATE InP HEMT

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ABSTRACT

A variable gain mm-wave amplifier, based on InP HEMT devices, is demonstrated. The measured gain control range of 14 dB is the largest reported in the mm-wave range for a monolithically integrated variable gain amplifier. The two stage circuit consists of a single gate transistor and a dual-gate transistor. The circuit has a maximum gain of 22 dB at 44 GHz and a bandwidth of 14.6 GHz. The circuit was fabricated in coplanar technology.

INTRODUCTION

Microwave systems are advancing towards mm-wave frequencies because of the need for higher data rates which in turn require large bandwidths. Wireless applications are also planned in the mm-wave range because of limited number of available frequency bands at lower frequencies. Furthermore, the high attenuation in the air at mm-wave frequencies can be advantageous for the efficient use of allocated frequencies (e. g. multiple use of the same frequency bands within a building). In such microwave systems, the variable gain amplifier (VGA) is an essential component for controlling the power of the transmitted and received signals. In MMIC amplifiers gain control has been realized by controlled feedback or dual-gate cascode FETs. For mm-wave frequencies, feedback can cause stability problems, therefore the dual-gate HEMT is preferable. Furthermore, the cascode circuit has a high reverse isolation. VGAs have been demonstrated up to 20 GHz [1-4]. In the mm-wave range little has been published on VGAs [5].

This work demonstrates a monolithically integrated two-stage VGA for the frequency range 25-50 GHz. The second stage uses a dual-gate InP HEMT device, which controls the gain.

FABRICATION

The single and dual-gate HEMT devices with $0.2{\bullet}150\,\mu m^2$ T-gates were fabricated on an AlInAs/GaInAs structure. The T-gates of both devices are processed with the same three layer resist system and the same exposure pattern [6]. The T-gates of the dual-gate HEMT are separated by 1.4 µm. Fig. 1 shows the current gain (h_{21}) and the maximum available gain (f_{max}) for both single gate and the dual-gate devices. The single gate transistor has a higher current

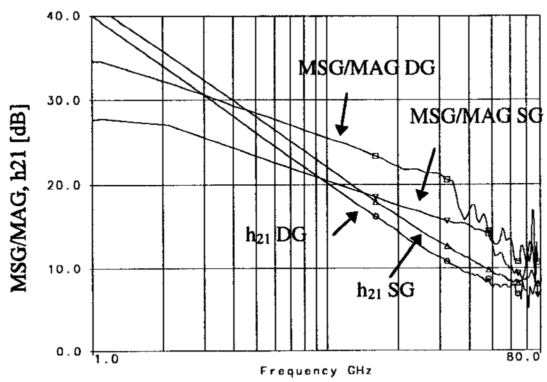

Fig. 1: Current gain (h_{21}) and maximum available gain (maximum stable gain respectively) for a single gate (SG) and a dual-gate (DG) HEMT.

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gain than the cascode whereas the cascode device has a higher maximum available and maximum stable gain.

The use of coplanar technology simplifies the process since no wafer thinning and no via holes are required. To suppress any parasitic slotline mode on the CPW, bonding wires are used to connect the grounds. A photograph of the circuit is shown in Fig. 2. The consumed chip area is only 1.9 x 1.3 mm^2. This area could be further reduced by optimizing the bias and matching networks.

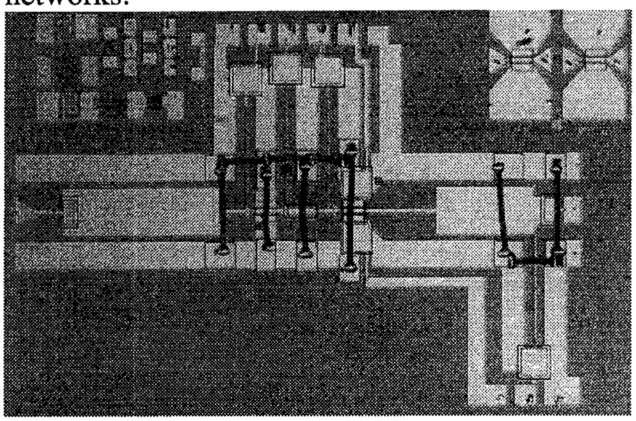

Fig. 2: Chip photograph of the dual-gate mm-wave HEMT amplifier (chip size: 1.9 x 1.3 mm^2).

DESIGN

The presented mm-wave amplifier consists of two stages. The first stage is a standard HEMT device. The second stage is a dual-gate HEMT in a cascode configuration where gate 3 is RF-grounded (Fig. 3). The advantage of the

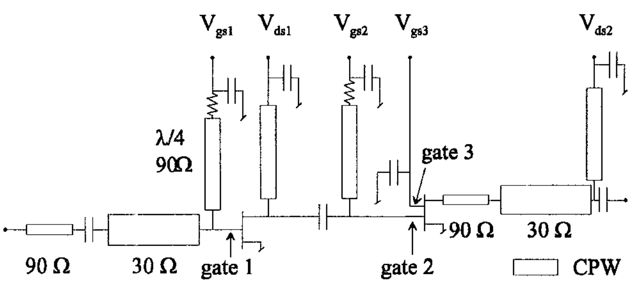

Fig. 3: Circuit schematic of the fabricated dual-gate HEMT amplifier.

dual-gate device is the higher gain, lower feedback and the possibility to vary the gain. The gain is controlled by the DC voltage applied to gate 3. The small signal model used for the simulations is described in [7]. The amplifier was designed for maximum gain and a wide range of gain variation. Series coplanar transmission lines (CPW) were used as matching networks. The bias is applied on-chip through λ/4 transmission lines which are RF-shorted with MIM capacitors. The DC blocking capacitors are also on-chip. The S-parameters of the coplanar T-junctions were calculated with an electromagnetic "3D planar" simulator. The bias lines also had to be analyzed using the electromagnetic simulator, since they are so closely spaced (cf. Fig. 2) that significant coupling between lines is obtained at mm-wave frequencies.

Stability is a critical issue in multi-stage amplifier circuits. Therefore, each stage was carefully analyzed for stability by plotting the k-factor and the stability circles. 40 Ω resistors in the gate bias lines were necessary to ensure the stability of the entire circuit.

MEASUREMENTS AND RESULTS

The S-parameters, output power and noise figure of the dual-gate HEMT amplifier were measured. The circuit was also tested for oscillations using a spectrum analyzer. No oscillations were observed over the whole possible bias range. The S-parameters were measured with an HP8510C and an LRRM calibration. Fig. 4 shows the gain for a bias range at gate 3 between 0 and -1.6 V. The maximum gain is 22 dB at 44 GHz with a 3 dB bandwidth of 14.6 GHz and a controllable gain range of 14 dB. The measured S_{12} is smaller than -37 dB. This compares well with previous results from Kashiwa [5], although in that work the amplifier consisted of cascaded LNA and VGA MMICs. Table 1 shows a comparison between this work and [5].

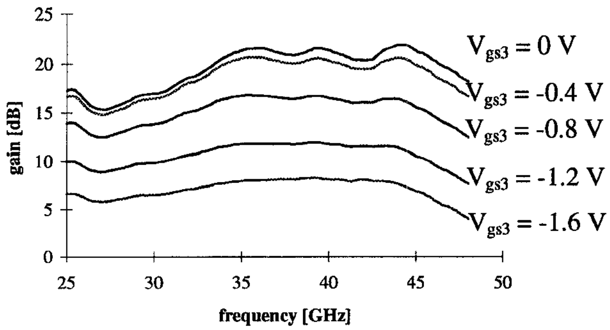

Fig. 4: Gain for different gate voltages V_{gs3} (V_{ds1} = 1 V, V_{ds2} = 2 V).

	[5]	**This work**
technology	GaAs pHEMT	**InP HEMT**
stages	3	**2**
gain [dB]	24.5	**22**
control range	30 [dB]	**14 [dB]**
chip area [mm^2]	6.8	**2.5**

Table 1: Comparison between previous and this work.

The output power was measured at 44 GHz with an HP8487A power sensor. Fig. 5 illustrates the measured output power vs. input power for V_{ds1} = 1.5 V and V_{ds2} = 2 V. At this bias, a small signal gain of 25 dB and a maximum output power of 10.4 dBm is obtained. The 1 dB compression point is at an output power of 5 dBm.

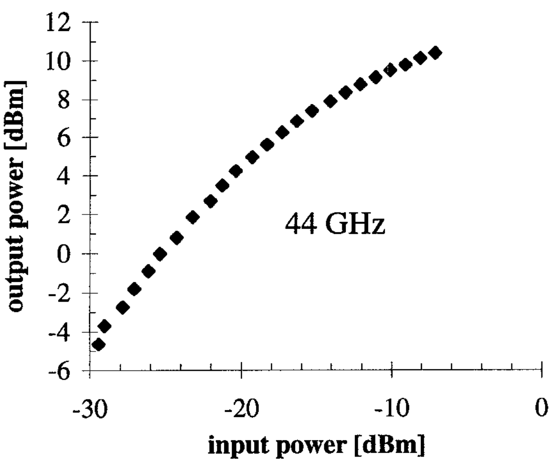

Fig. 5: Output power of the dual-gate amplifier (V_{ds1} = 1.5 V, V_{ds2} = 2 V).

The measured noise figure (Fig. 6) is 4.5 dB at 40 GHz. This compares favorably with a reported conventional cascode (two transistors) traveling wave amplifier [4] with a gain control range of 5 dB and a noise figure of 4.1 dB at 20 GHz. In the measurement set-up used [8], the noise source is assumed to be perfectly matched. This is, however, not the case and a ripple in the noise figure curve is observed.

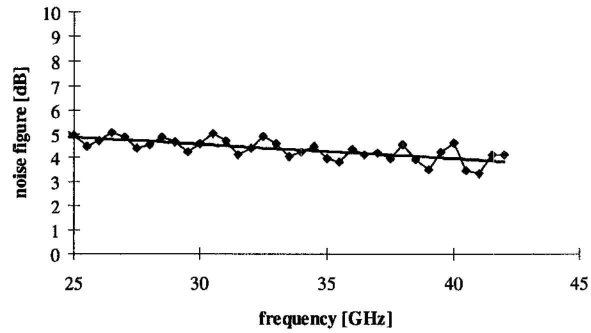

Fig. 6: Measured noise figure (V_{ds1} = 1 V, V_{ds2} = 2 V).

CONCLUSION

A mm-wave two-stage variable gain amplifier with a gain control range of 14 dB has been demonstrated. This is the highest gain control range reported for a mm-wave MMIC based on InP HEMT devices. The variable gain is achieved using a dual-gate HEMT in the second stage. The gain control range could be further improved by incorporating a dual-gate transistor in the first stage. As well as providing gain control, the dual-gate HEMT improves the isolation (>37 dB) from the output to the input. The maximum gain at 44 GHz is 22 dB with a noise figure of 4.5 dB. Since the bias and the decoupling capacitors are on-chip, this amplifier is suitable for mm-wave systems.

ACKNOWLEDGMENTS

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