A COMPACT COPLANAR W-BAND VARIABLE GAIN AMPLIFIER MMIC WITH WIDE CONTROL RANGE USING DUAL-GATE HEMTs

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***Abstract* - A W-band variable gain amplifier MMIC with 37 dB gain at 94 GHz and a gain control range of over 70 dB has been developed. The circuit consists of four dual-gate HEMT stages, using a 0.15 µm AlGaAs/InGaAs/GaAs PM-HEMT technology. The chip was realized in coplanar technology and requires an area of only 1 x 3 mm^2. The resulting power gain density is 12 dB/mm^2 at 94 GHz.**

I. INTRODUCTION

The need for all-weather operation has stimulated the development of commercial and military phased array radar systems in the frequency range of the third atmospheric window around 94 GHz. The demand for small size, light weight and low cost is a very important issue for system applications. These requirements are met by use of monolithically integrated millimeter-wave circuits, which are very attractive for millimeter-wave radar systems [1].

Within phased arrays, variable gain amplifiers (VGA) are required to compensate for the loss of phase shifters and to reduce the sidelobes of the antenna. However, up to now only few publications about VGAs in the millimeter-wave range can be found [2,3]. This work demonstrates a monolithically integrated W-band four-stage amplifier using dual-gate HEMTs, with 37 dB gain and a very wide gain control range of over 70 dB.

II. MMIC FABRICATION

The presented amplifier circuit consists of four dual-gate AlGaAs/InGaAs/GaAs HEMT stages, which were realized on s.i. 3 inch wafers. A scanning electron microscope photograph of one dual-gate device is shown in Fig. 1.

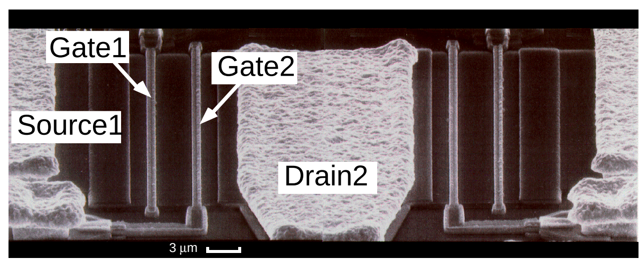

Fig. 1 Scanning electron microscope photograph of a dual-gate PM-HEMT (w_g = 2 x 15 µm).

The T-shaped gate fingers have a length of 0.15 µm and a width of 40 µm each. The gates were written by e-beam and the recess was dry etched. The distance between the first and the second gate is 4 µm. To reduce the extrinsic parasitics, an ohmic metal area is used between the gates.

The advantage of the dual-gate devices is that they exhibit high gain and high reverse isolation and offer the possibility of gain variation via the DC-voltage on the second gate. The dual-gate HEMT requires the same chip area as a conventional HEMT in common source configuration, which is most commonly used for amplifier designs. The fabrication of the dual-gate HEMT requires no additional process steps. The VGA circuit, shown in Fig. 2, is realized in coplanar technology to enable a very compact design. The over-all chip size is 1 x 3 mm^2.

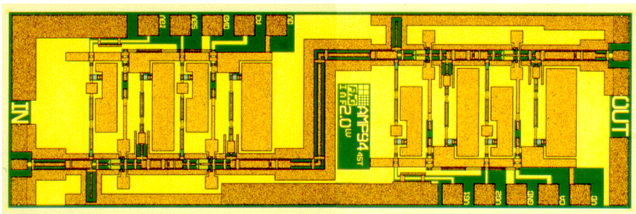

Fig. 2 Chip photograph of W-band four-stage VGA MMIC (chip size: 1 x 3 mm^2).

III. CIRCUIT DESIGN

The presented VGA (Fig. 2) consists of a series connection of two two-stage amplifiers. To facilitate packaging, one of the two-stage amplifiers was flipped. In Fig. 3, the schematic diagram of a two-stage amplifier is depicted. The second gate of each stage is internally RF-grounded via MIM (metal-insulator-metal) capacitors. Airbridges at every discontinuity are to supress any undesired slotline mode on the CPW. The amplifier gain is controlled via the DC-voltage of the second gate V_{g2}.

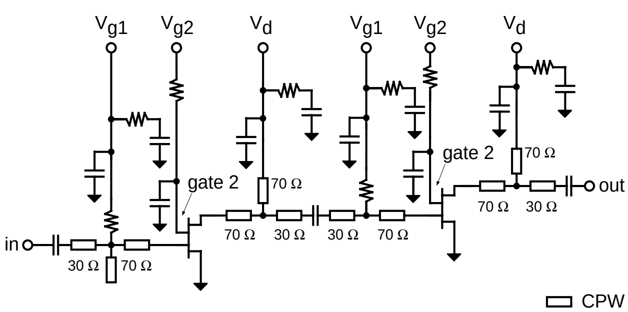

Fig. 3 Schematic of the dual-gate W-band two-stage amplifier circuit.

The key elements of the amplifier are the dual-gate HEMTs [4,5]. These can be considered as a series connection of a HEMT in common source and one in common gate configuration. For small signal modelling of the dual-gate device, the extrinsic and intrinsic circuit elements of single gate HEMTs in common source and common gate configuration are extracted, using a similar procedure as reported in [6]. The coupling between the first gate and the second drain is accounted for by an additional parasitic feedback capacitance. The parasitic inductances and resistances of the first drain and second source, now embedded between the two gate fingers, are reduced. To validate the model, we measure the S-parameters of a dual-gate HEMT with the same gate width as the single gate devices. The good agreement between measured and modelled S-parameters over the entire frequency range from 0.5 to 118.5 GHz is shown in Fig. 4.

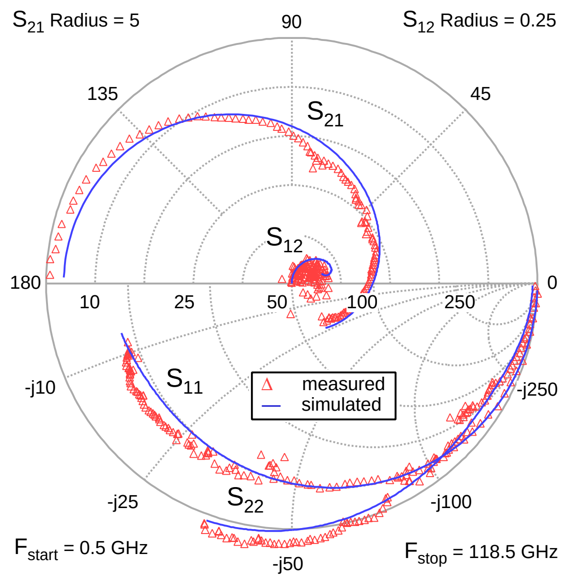

Fig. 4 Measured and modelled S-parameters of a 2 x 30 µm dual-gate HEMT in the 0.5 GHz to 118.5 GHz frequency range.

It is to note, that the dual-gate HEMT is not unconditionally stable, due to its high available gain. We obtain unconditional stability of the amplifier circuit via a reduction of the MIM capacitor at the second gate. So far, a large value (~10 pF) for the capacitor was chosen, to achieve good RF-grounding for the second gate. In this design, however, the value of the capacitor is only 1.5 pF. Additionally, we use resistors and capacitors in the bias lines. The presented VGA has a minimum k-factor of more than 2.8 over the entire bias range.

For the simulation of the coplanar components, we use simple but highly accurate and very broadband models which were extracted by means of experimental test structures [7].

IV. MEASUREMENTS AND RESULTS

The amplifier chip was measured with a W-band measurement system using an LRM calibration. To avoid circuit degradation, due to excitation of parasitic parallel plate modes, the measurements were made under special packaging conditions [8]. Fig. 5 shows the measured gain control performance of the VGA from 80 to 110 GHz. The maximum gain is 41 dB at 90 GHz. The control range at 94 GHz extends from 37 dB to -35 dB. It is varied via a common bias at the second gate of each stage.

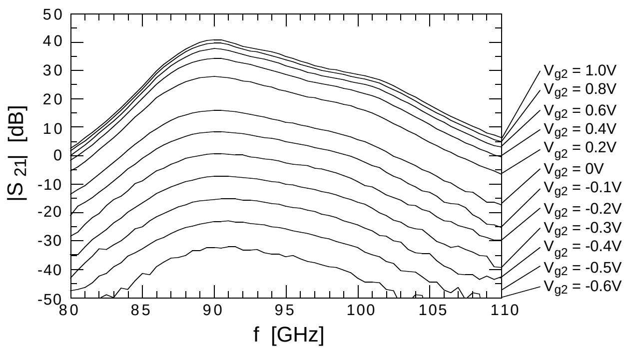

Fig. 5 Measured gain control range of W-band four-stage VGA MMIC for different gate voltages V_{g2} (V_d = 4 V, V_{g1} = 0 V).

The pinch-off voltage of the PM-HEMTs is -1.1 V. The measured isolation S_{12} is at the resolution limit of the measurement system at -60 dB. The amplifier gain and the associated phase shift at 94 GHz are illustrated in Fig. 6, as a function of the second gate voltage V_{g2}.

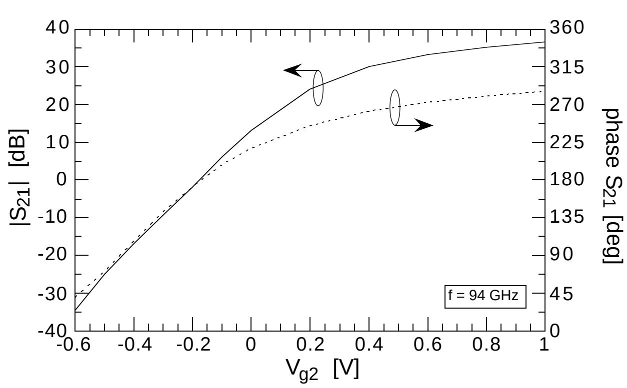

Fig. 6: Amplifier gain and associated phase shift at 94 GHz versus gate voltage V_{g2}.

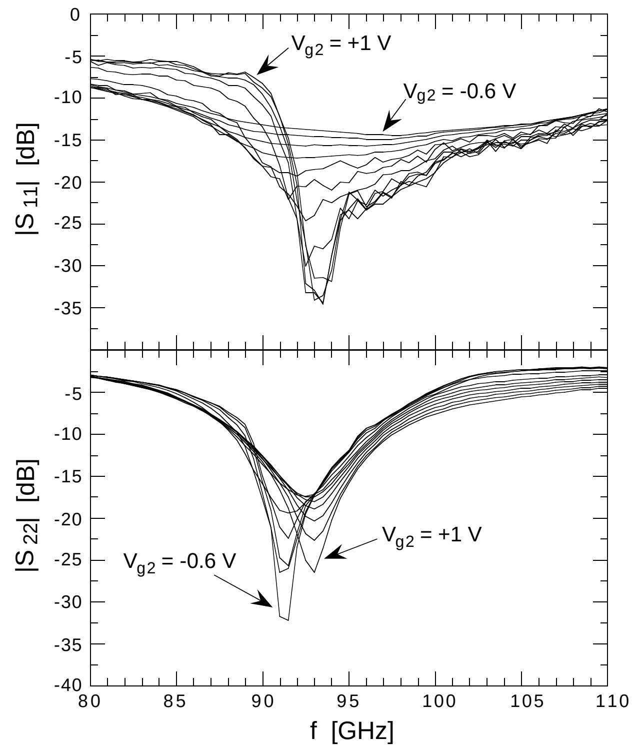

Fig. 7 Measured input and output return loss of W-band four-stage VGA MMIC from 80 to 110 GHz.

The input and output return loss of the circuit are shown in Fig. 7. Within the entire control range, input and output are matched better than 14 dB at 94 GHz. The saturated output power characteristic of the amplifier, as a function of the second gate voltage V_{g2} is illustrated in Fig. 8. The output power of 9 dBm at 94 GHz was obtained with V_d = 4 V, V_{g2} = +1 V and V_{g1} = 0 V. The output power at the 1 dB compression point is 7 dBm.

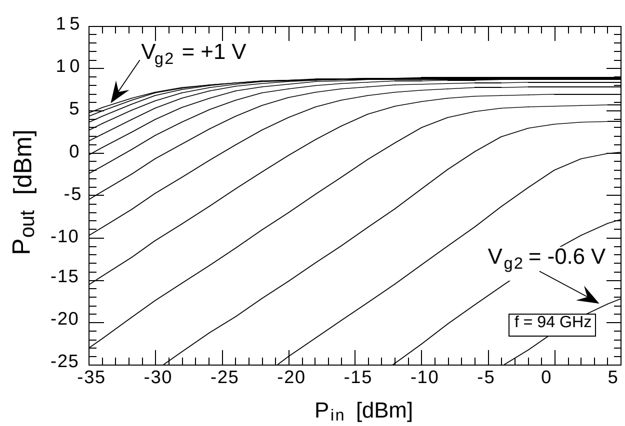

Fig. 8 Measured output power versus input power for the four-stage VGA MMIC (V_d = 4 V, V_{g1} = 0 V).

The noise figure of the amplifier is 6.6 dB at 94 GHz (Fig. 9), with a maximum gain bias of V_d = 4 V, V_{g2} = 1 V and V_{g1} = 0 V. An improvement of the noise performance should be possible by using a single gate HEMT stage or a specially matched cascode stage at the amplifier input.

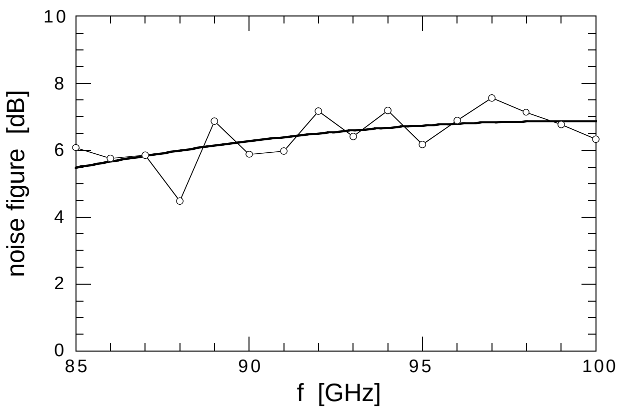

Fig. 9: Measured noise figure of W-band four-stage VGA from 85 to 100 GHz.

VI. CONCLUSION

A four-stage W-band variable gain amplifier MMIC using 0.15 µm AlGaAs/InGaAs/GaAs PM-HEMT has been successfully developed. The amplifier circuit achieves 37 dB gain at 94 GHz and a very wide gain control range of over 70 dB. The compact coplanar design results in a chip size of only 1 x 3 mm^2, corresponding to a power gain density of 12 dB/mm^2. The noise figure is 6.6 dB at 94 GHz.

VII. ACKNOWLEDGMENTS

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