Design and Characterization of a 67 GHz 0.3 µm AlGaAs/GaAs/AlGaAs HEMT Monolithic Amplifier in Coplanar Waveguide Technology

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Abstract— A three-stage V-band amplifier using only coplanar waveguide technology has been realized in a 0.3 µm AlGaAs/GaAs/AlGaAs HEMT technology. Its characteristic has been measured up to 75 GHz. A gain better than 15.2 dB has been achieved at 67 GHz and a very good concordance of experimental and simulation results is obtained in the whole band. The chip size including bias circuits is 3.0×1.5 mm^2.

I. INTRODUCTION

Monolithic amplifiers are essential elements in high performance millimeter-wave communication systems, especially in the 60-70 GHz frequency range dedicated to multiple applications as radiolocation, radionavigation, space research and future civil communications. For few years, the fabrication of V-band amplifiers using microstrip or coplanar technology have been reported (e.g. [1-4]), but they use complex and costly GaAs based PM-HEMT or InP HEMT processes. In this paper, we present the design and characterization of a 67 GHz amplifier realized in a conventional 0.3 µm HEMT technology. The achieved performance is comparable to that obtained using more complex technologies.

For the realization of this circuit, coplanar technology (CPW) has been used because of its better performance at millimeter-wave frequencies. Principally, CPW presents lower dispersion characteristics and lower radiation losses at very high frequencies. Moreover, it offers a cost effective solution to technical and technological problems encountered in the design of microstrip based circuits due to the ease of insertion of both shunt and series lumped elements and lower parasitic interconnections. Establishing an accurate database for passive elements (uniform lines and discontinuities), we have obtained good performance using a standard process technology.

II. AMPLIFIER DESIGN

A. Coplanar Passive Components

At millimeter-wave frequencies, the design of monolithic IC's in coplanar waveguide requires careful attention. Firstly, one has to ensure that there is only one propagating mode which is the quasi-TEM coplanar mode. This is achieved through the proper choice of line dimensions used all over the amplifier circuit (d=50 µm, h=500 µm) [5] and the proper design of airbridges that are placed wherever a line asymmetric discontinuity is encountered. The effects of the airbridges have been described by an analytical model that is based on the determination of an equivalent capacitance [6].

In our design, all the relevant structures of the circuit were modeled and included in the simulation using the foundry's design database (Fraunhofer Institute of Applied Solid State, FhG-IAF, Germany) or models developed from investigations of CPW discontinuities [7]. For transmission lines, we have employed a broadband model extracted from precise measurements of CPWs validated up to 120 GHz [8]. All the coplanar elements are made of CPW transmission line sections having characteristic impedances of approximately 30, 50 and 70 Ω. MIM capacitors and transitions were modeled using lumped and distributed elements to account for parasitic effects. For T junctions, a simple 5-lumped-element equivalent circuit was used [9]. Bias path as well as MIM shunt capacitors were also modelled and care was also taken to prevent line-to-line coupling.

B. Active Devices

We have used the AlGAs/GaAs/AlGaAs Double Pulse Doped Quantum Well HEMT technology of the FhG-IAF for the fabrication of the active devices. The transistors are double fingered HEMT of gate length L_g=0.3 µm. To achieve good performance at high frequencies, we have employed depletion transistors with a total gate width of 40 µm, that exhibit a current gain cutoff frequency f_T and maximum oscillation frequency f_{max} of 55 GHz and 110 GHz respectively, under V_{gs}=+0.4 V and V_{ds}=+1.5 V. A small signal equivalent model was used for the simulation of the devices.

C. Circuit Design

A three-stage band-pass topology was adopted in order to get a relative high gain due to the fact that the operation frequency is near the transistor cut-off frequency. It uses T-type reactive matching networks formed from lengths of transmission lines, including bias subcircuits. This provides a smaller and simpler alternative to π-networks. The matching networks include CPW elements, namely : a T junction, a series MIM capacitor and an independent bias network for each transistor. The bias networks are designed using large MIM shunt capacitors to ensure proper decoupling and unconditional stability of the amplifier (C//RC cells). These networks have been characterized using a precise electromagnetic simulation [7]. The interstage matching networks were designed to give a direct impedance transformation rather than a 50 Ω match, allowing also a gain roll-off compensation. It is interesting to mention that during the simulation, the amplifier has shown an instability near 30 GHz. So the stability criteria was included in the circuit optimization. The simulated K factor was maintained greater that 4 over the entire frequency range in order to face some eventual technological variations.

III. MEASUREMENT RESULTS

The circuit was fabricated by the FhG-IAF. A microphotograph of the circuit is shown in Fig. 1. The RF and bias probing pads are compatible respectively to 100-150 µm pitch probes and 6-contact bias probes. The bias conditions are identical for each transistor, namely V_{gs}=+0.4 V and V_{ds}=+1.5 V, although they can be adjusted separately. The drain current is typically 20 mA per stage.

The amplifier was characterized at V-band with a S-parameter measurement probesystem that uses a 50-75 GHz waveguide testset combined to a HP8510C network analyzer. We have used a LRM calibration method. A good concordance of experimental and simulation results is obtained in the whole band as shown in Fig. 2. At 67.5 GHz the gain is 15.2 dB and greater than 12 dB from 64 to 71 GHz (10% bandwidth), that is comparable to results of amplifiers fabricated using 0.25 µm HEMT process on InP [4] or 0.3 µm PM-HEMT on GaAs [9]. The reverse isolation is better than -35 dB over the entire measurement frequency range. Fig. 3 and 4 show the reflection coefficients S_{11} and S_{22} of the amplifier : the input and output return losses at 67 GHz are better than 10 and 8 dB respectively.

IV. CONCLUSION

We report the performance of a 67 GHz monolithic CPW amplifier in a 0.3 µm HEMT process on GaAs. Its performances are favourably comparable to previous results obtained using more complex technologies. Through this design, the potential of coplanar waveguides combined with 0.3 µm AlGaAs/GaAs/AlGaAs HEMTs is successfully demonstrated to realize V-band amplifiers up to the limit of this technology.

AKNOWLEGMENTS

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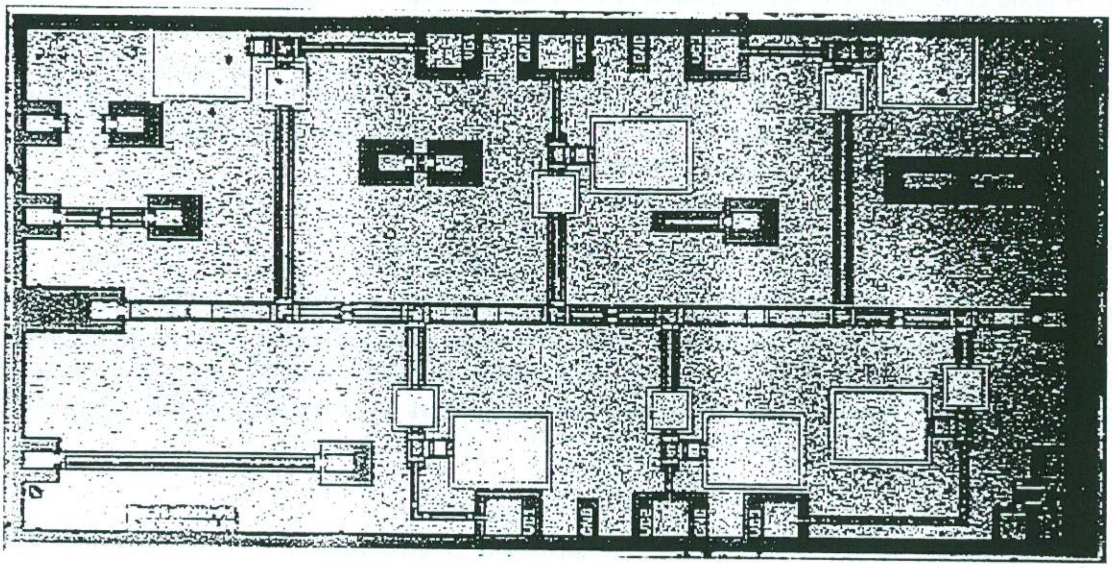

Fig. 1. Microphotograph of the 3-stage monolithic amplifier (chip size 3.0 × 1.5 mm^2)

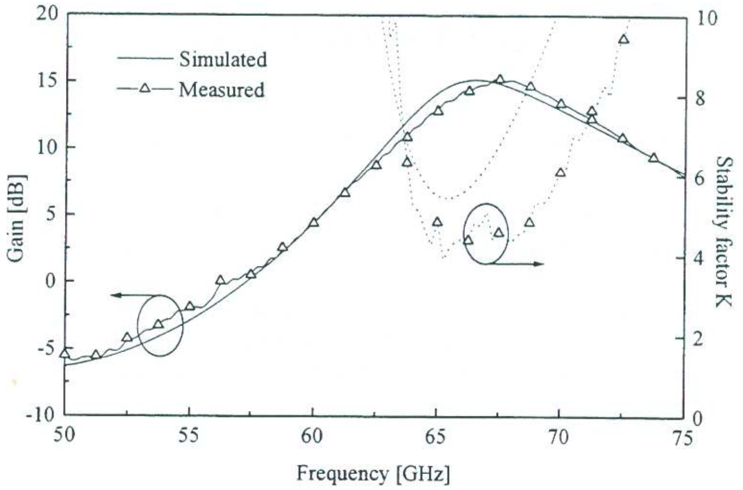

Fig. 2. Measured and simulated gain (S_{21}) of the amplifier in the 50-75 GHz range.

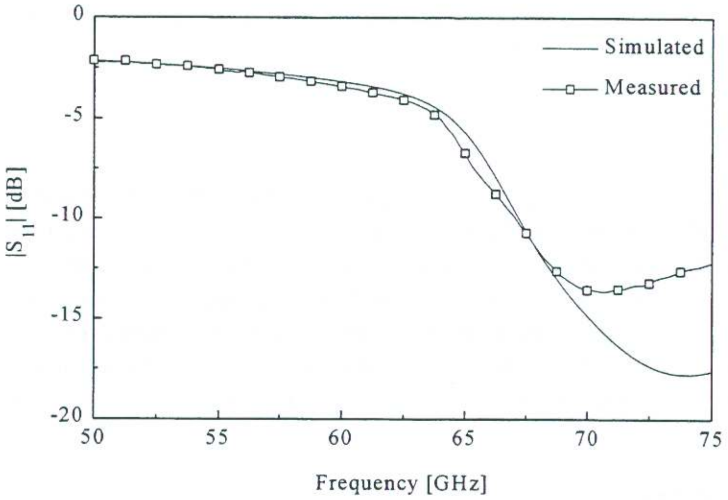

Fig. 3. Measured and simulated magnitude of S_{11}.

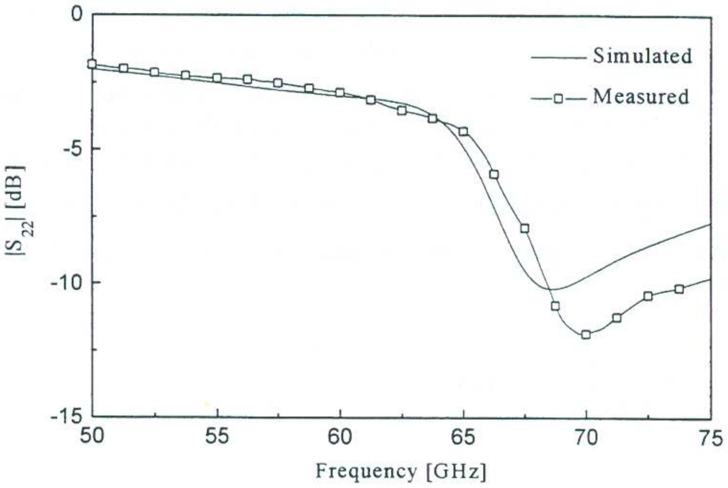

Fig. 4. Measured and simulated magnitude of S_{22}.