Subharmonic Gate Mixer Based on a Multichannel HEMT

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***Abstract*—This paper presents the realization and simulation of a new subharmonic gate mixer based on a multichannel HEMT. This device gives the possibility of tailoring the transconductance profile. Two peaks separated by a valley can be obtained. Biasing the device at the bottom of the valley, the IF signal comes from the mixing of the RF signal and the second LO harmonic. This mixer uses half the normal LO frequency and has a minimum conversion loss of 10 dB.**

I. Introduction

HEMT's have several demonstrable and potential advantages over passive diodes for their use in millimeter-wave mixers. The difficulty and the cost relevant to millimeter-wave oscillators motivate the use of subharmonic mixers with local oscillators operating at lower frequencies [1]. This paper presents a new subharmonic gate mixer based on a multichannel HEMT. In the gate mixer, the profile of the transconductance versus gate-to-source voltage is the dominant factor in the frequency process. The gate is usually biased near its turn-on voltage. But the multichannel HEMT's give the possibility of tailoring the transconductance profile [2]. A very nonlinear transconductance profile can be obtained. Such a MC HEMT exhibiting two peaks of transconductance has been realized in our laboratory. For the subharmonic mixer application, the device has to be biased at the minimum of the transconductance. In consequence, the IF signal comes from the mixing of the RF signal and the second LO harmonic. Thus, the required LO frequency is divided by 2.

Compared with the conventional HEMT gate mixer, the expected advantages of this type of mixer are the following:

- The required LO frequency is only half the normal LO frequency, which can be very interesting at millimeter wave frequency.
- A better LO to RF isolation due to the important frequency difference between the two signals.

II. Device Processing

Obtaining a very nonlinear transconductance profile mainly relies on the layer design. Therefore a specific effort has been performed so as to obtain a suitable transconductance. The layer structure consists of two GaAs quantum wells separated by AlGaAs. The thickness of that layer has been increased up to 200 Å so as to decouple the two quantum wells as much as possible.

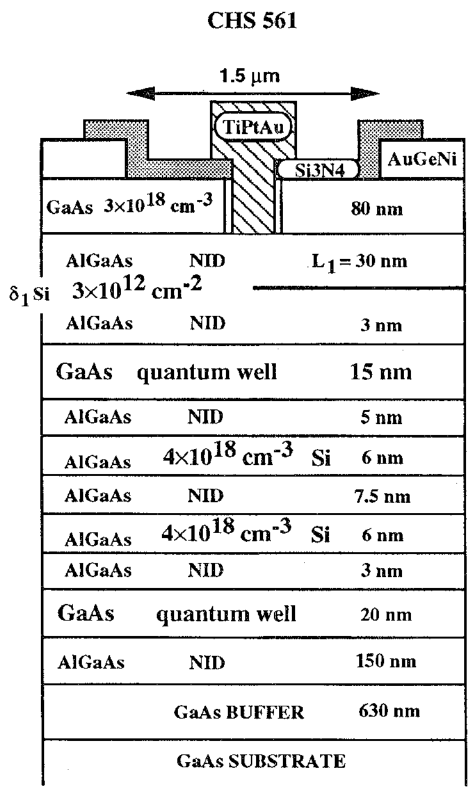

Fig. 1. Two quantum-well AlGaAs/GaAs structure.

The layer was grown on a 2-in. substrate in a RIBER 32 MBE system. After a 6300 Å GaAs buffer, a 1500 Å AlGaAs layer is grown to reduce buffer injection. Then comes the active zone of the struture, as shown in Fig. 1, this one consists of two GaAs quantum wells separated by an AlGaAs region with an Al content of 23%. The two bulk doped AlGaAs layers in this region result in a high decoupling of the charge control of the two quantum wells by the gate. The delta doping at the top of the structure ensures the necessary compactness for the frequency response [3]. This structure is thought to be optimum for the desired transconductance profile. The grown layer was characterized by Van Der Pauw measurements after the removal of the cap layer. The room temperature results were respectively 2.8×10^{12} cm^{-2} and 3600 cm^2/V.s for the Hall electron density and mobility. At 77 K, 1.7×10^{12} cm^{-2} and 14500 cm^2/V.s were measured.

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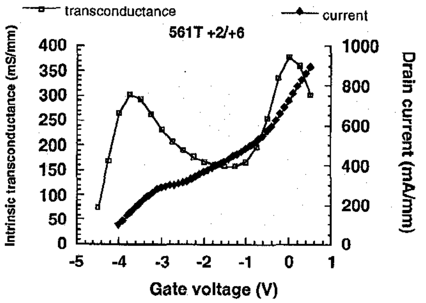

Fig. 2. RF transconductance and drain current of sample CHS 561

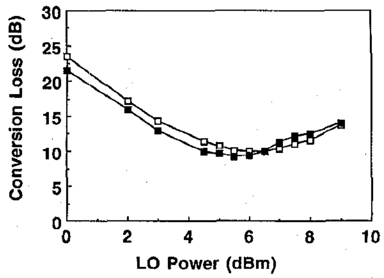

Fig. 3. Conversion loss simulated (—■—) and measured (—□—) versus LO power.

The process starts by depositing the Ni/AuGe/Ni ohmic contacts. Then the MESA is chemically etched. A 1000 Å silicon nitride layer is deposited by plasma at 300°C. The 0.3 μm gate window is opened in the nitride by a CF_4 plasma. Finally the cap layer is selectively etched on AlGaAs by a CCl_2F_2 plasma and the TiPtAu gate is deposited. Then a thick TiAu plating layer is deposited on the ohmic contact. This layer designs a waveguide compatible with Cascade probe measurements. The device is passivated with 1500 Å silicon nitride. The device shows a maximum current density of 900 mA/mm at Vgs = +0.5 V. The pinch-off gate voltage is −4.5 V. The RF transconductance extracted from S parameters is shown in Fig. 2. The profile is very nonlinear. The maximum transconductance is 375 mS/mm and the minimum between the two peaks is 155 mS/mm. For subharmonic mixer operation the device will be biased at −2 V where the transconductance is minimum, for maximum benefit from the nonlinearity.

III. SIMULATION

The nonlinear model for the MC HEMT is based on the experimental values of the small signal dynamic parameters measured in the microwave frequency range. The Dambrine procedure [4] is used to determine, at different biasing conditions, the transconductance, the output conductance and the gate-to-source capacitance. These elements are extracted from S parameters measured in the 1–40 GHz range. Thus, the two main nonlinearities of the MC HEMT are taken into account: the drain current generator I_D (that is transconductance G_m and output conductance G_d) and the gate-to-source capacitance C_{gs}. The other circuit elements are assumed to be constant. The interpolation of the measured data, using high order polynomial expressions, provides an accurate description of the MC HEMT nonlinearities in a CAD software. We have used the nonlinear harmonic balance simulator MDS (Hewlett-Packard) to implement this nonlinear MC HEMT model.

The basic simulated circuit comprises a LO and RF input matching and a low pass filter at the output. This filter provides a purely resistive load impedance of 100 Ω at IF and presents a short-circuit at LO, RF and their first harmonics. The RF, LO, and IF frequencies chosen for this test were respectively 18, 8, and 2 GHz. Fig. 3 shows the simulated conversion gain versus LO power.

IV. EXPERIMENTAL RESULTS

To verify the validity of the results obtained from simulation, the MC HEMT under test was inserted into a measurement set-up including two adjustable tuners. The MC HEMT was mounted in a low loss microstrip test fixture with K connector terminations. The mixer measurement set-up also contained two bias tees, a 10 dB coupler for the RF and LO combination, and a mechanical tuner just placed before the test fixture for the MC HEMT input matching at 18 GHz. Measurement results in Fig. 3 demonstrate that the device effectively operates as a subharmonic mode mixer. Its conversion loss is 10 dB. This measured performance is close to the simulated performance calculated by MDS. We think that the performance could be improved with a transconductance profile exhibiting higher peaks and a valley dropping to zero. This might be approached with an accurate optimization of the structure and with a shorter gate length (0.35 μm here). On the other hand, investigating material systems other than AlGaAs/GaAs, in particular InP based HEMT's, could offer more efficient solutions.

V. CONCLUSION

This paper presents the realization and simulation of a new subharmonic mixer based on HEMT technology. It provides a clear demonstration of the feasibility and potential interest of the proposed HEMT structures and leads us to expect very promising performance with devices with shorter gate lengths and accurately optimized.

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