A W-BAND SUBHARMONICALLY PUMPED RESISTIVE MIXER BASED ON PSEUDOMORPHIC HETEROSTRUCTURE FIELD EFFECT TRANSISTOR TECHNOLOGY

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Abstract

This paper describes the first sub-harmonically pumped resistive mixer (SPRM) based on HFETs, operating in the W-band (75-110 GHz). Two HFET devices, specially designed for this application, were integrated together with a coupler, 180° phase shifter, and an IF-filter.
Both theoretical and experimental results are presented in this paper. A minimum conversion loss of about 22 dB was experimentally obtained at an LO-power of 10 dBm.

Introduction

The first sub-harmonically pumped resistive mixer (SPRM) based on HFETs was demonstrated at X-band (8-12 GHz) two years ago [1]. This mixer had a high inherent isolation of 37 dB between the LO and RF-ports, a conversion loss, L_C, of 6.5 dB, and a flat IF-response. Due to the topology of this mixer, the LO-port and the RF/IF ports are separated, which simplifies the diplexer circuit. Compared to other HFET and MESFET mixers, this type has the advantage of zero dc-power consumption and guaranteed electrical stability. Last year we reported on a SPRM working at 40-45 GHz with 10 dB conversion loss at an LO-power of 8 dBm [2].

This paper describes for the first time an SPRM based on HFETs, operating in the W-band (75-110 GHz). The possibility of integrating amplifiers and mixers on the same epitaxial material makes this mixer interesting to use in low-cost millimeterwave monolithically integrated circuits (MMICs). Since the LO frequency is halved, the local oscillator may possibly be integrated on the same chip in a future application. The mixer presented in this report is based on a mixed MMIC/hybrid solution.

Mixer design

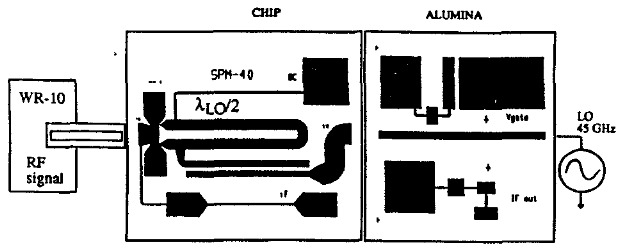

Fig. 1: Schematic block diagram of the mixer circuit.

The RF is fed via a W-band waveguide, a waveguide-to microstrip transition and a microstrip line to the MMIC (Fig. 1). The waveguide to microstrip transition was analysed and designed by solving Maxwell-equations in three dimensions using HFSS from Hewlett-Packard. The transition design was verified with measurements on a scaled model.
The MMIC chip includes two paralleled HFET devices, a $\lambda_{LO}/2$ long microstrip line which ends connect to a gate each, and a finger coupler that is connected to the line in order to provide DC isolation to the LO input port. This arrangement ensures the same LO amplitude at the gates but with opposite (180°) phases. The conductance waveform of the combined two HFETs in parallel will therefore have a fundamental frequency component which is two times the LO-frequency. The resulting IF-signal of the mixing process is extracted from the drains through an IF-filter integrated on the chip. In addition, a gate bias filter is integrated. The LO is connected to the chip via bonding wires to a 50 ohm microstrip line which is in contact with a Wiltron V-connector. The IF is fed out to a contact through a microstrip line and a blocking capacitor. A photo of the mixer block with all components mounted is shown in figure 2. The substrate used for the probes and lines is 5 mil thick alumina.

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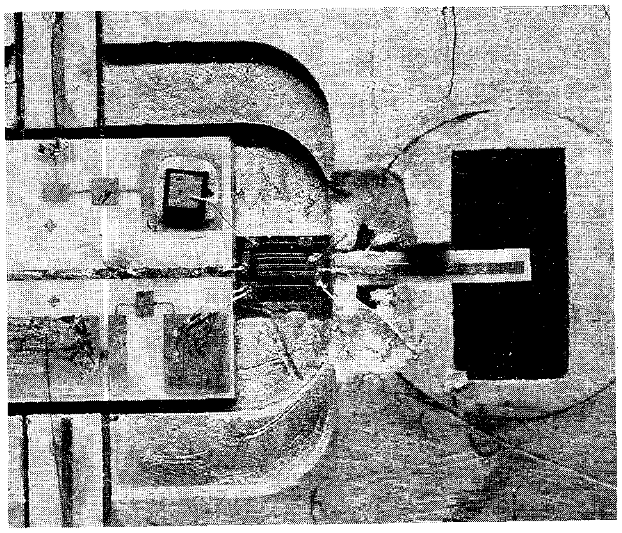


Fig. 2: Photo of the mixer.

HFET design

To obtain a low L_c a number of important HFET device parameters have to be considered: the minimum drain-to-source resistance, R_{ds}, the maximum-to-minimum R_{ds}-ratio, the capacitive components C_{ds}, C_{gs} and C_{gd} and their bias dependence. A previously reported model for the transistor [1,2] was used in the non-linear simulation as basis for designing the mixer circuit. Since one of the key parameter is a low R_{ds}, we have, from the device fabrication point of view, concentrated on minimising the parasitic drain and source resistance as well as the channel resistance by using a specially tailored pseudomorphic semiconductor structure (Fig. 3).

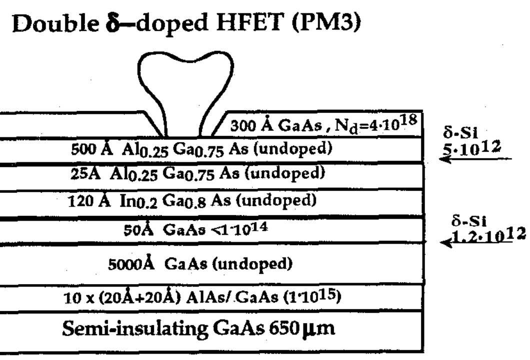


Fig. 3: Cross-section of the structure used for the HFET-mixer

This structure employs double δ-doping to achieve a high 2-DEG concentration. In addition, the undoped AlGaAs layer ensures a high reverse gate breakdown voltage and a saturated C_{gs} and C_{gd} vs. gate voltage characteristic as opposed to MESFET's and HFETs with a doped AlGaAs layer. Hall measurements at RT indicates a carrier concentration of $3.5 \cdot 10^{12}$ cm^{-3} and a mobility of 4800 cm/Vs on material with an etched cap layer. Transistors were fabricated by standard techniques and by using E-beam lithography for the definition of 0.18 µm gate length mushroom gates. Devices on this material have typically a relatively high maximum saturated drain current of 600-700 mA/mm, a minimum R_{ds} of 1.7 ohm·mm with an associated C_{gs} of 600 fF/mm for a 0.18 µm gate length device with a source-to-drain spacing of 2.5 µm.

Parameter extraction for a non-linear model (Fig. 4) was performed from S-parameters (0.04-62.5 GHz) measured at different gate-to-source voltages, Vgs. The model was then used in the non-linear simulation of the mixer circuit.

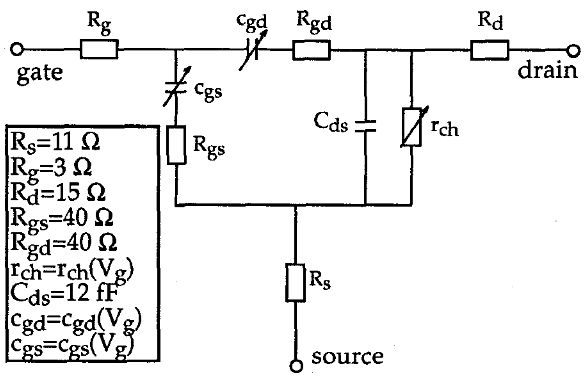
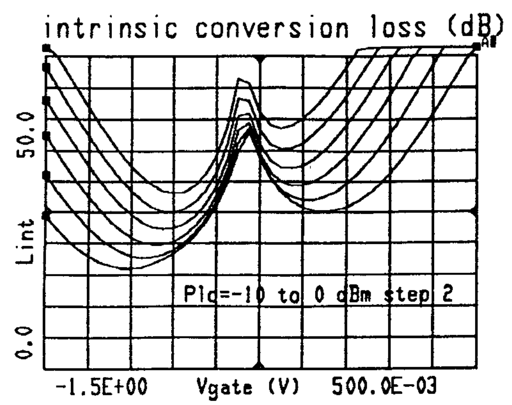


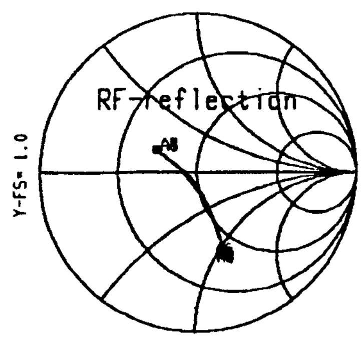
Fig. 4: Equivalent circuit of the HFET used in the non-linear simulation of the mixer

Results

The simulated intrinsic conversion loss, L_{int}, (i.e. excluding losses in the RF coupling and IF-filter), and reflection losses at the RF is plotted as a function of gate bias voltage and LO power, P_{LO} (Fig. 5). In the simulations the RF is 95 GHz and the LO frequency is 45 GHz.



a



b

Fig. 5: Theoretical L_c as a function of gate bias, Vg, and P_{LO} (a), and RF reflection coefficient at the drain as a function of Vg and P_{LO} (b).

The L_c cannot be calculated at higher local oscillator power levels (>0 dBm) due to convergence problems. The RF reflection coefficient (fig 5b) was also calculated vs. V_g and P_{LO} . Evidently, a good RF-match is possible.

Figure 6 shows the experimental set-up for L_c measurements at 88-98 GHz.

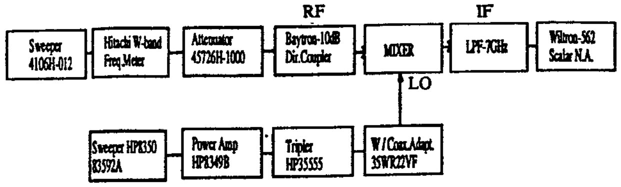


Fig. 6: Experimental set-up for the conversion loss measurement

The RF is generated by a Hughes Impatt sweeper, and the LO by an HP 8350B sweeper combined with an HP 83555A tripler. The IF response was measured with a fixed LO frequency of 46 GHz and an RF from 88 to 98 GHz (Fig. 7).

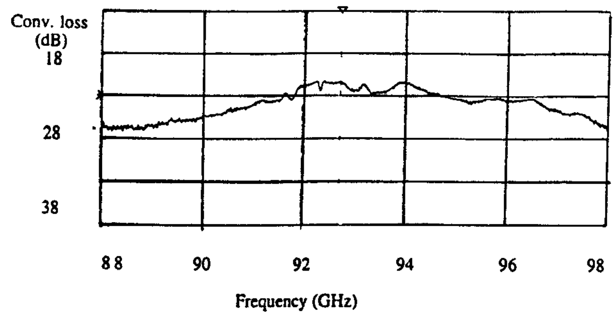


Fig. 7: Measured conversion loss vs frequency.

A minimum conversion loss of about 22 dB was obtained at an LO-power of 10 dBm (Fig. 7). This comparatively high conversion loss is mainly due to the high bonding inductance's from the source to the ground. By using a via-hole technique for the sources it should be possible to decrease the conversion loss to approximately 12 dB.

Conclusions

The performance of the SPRM is expected to improve significantly by decreasing the effects of the bonding inductance's by grounding the sources using a via hole technique. The resistive losses of the microstrip lines on the chip are high due to poor metalization. This will be improved by evaporating or plating a thicker gold layer.
The results show on the possibility of designing and fabricating a MMIC including both mixers and amplifiers at W-band.

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