A Millimeterwave Subharmonically Pumped Resistive Mixer based on a Heterostructure Field Effect Transistor Technology.

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Abstract

A subharmonically pumped resistive mixer (SPRM) working at millimeterwaves based on a HFET technology is described for the first time. Nonlinear simulations of the mixer were performed and a special dual HFET chip was developed and fabricated for the demonstration of this mixer. Mixer circuits were fabricated and operational characteristics at 40-45 GHz were investigated.

Introduction

The resistive FET-mixer has previously proven to have good intermodulation properties, due to the relatively linear behavior of the channel resistance compared to the nonlinear barrier resistance of a diode [1], [2]. The mixer in this paper is based on a dual HFET configuration i.e. the mixing element consists basically of two HFETs where the sources and drains are connected in parallel. The local oscillator signal is applied to both gates with the same amplitude, but 180 degrees out of phase. The combined resistance waveform therefore has a fundamental frequency of twice the local oscillator (LO) frequency. The RF-signal is applied to the drains, where frequency mixing occurs due to the time-variable channel resistance. The intermediate frequency signal is extracted from the drains through an IF-filter. This concept was demonstrated for the first time last year at X-band frequencies [3]. With this mixer, the following advantages are obtained compared with the ordinary resistive FET-mixer:

1. The LO-frequency is only the half of the normal LO-frequency which makes this mixer type attractive at millimeter waves since mm wave LO-sources are expensive.

2. The intrinsic LO-leakage to the IF and RF-port due to the gate-drain feedback capacitance is reduced since the LO-signals are cancelled at the drains due to their 180 deg phase difference.

The use of HFETs instead of diodes facilitates further integration with other HFET circuits like amplifiers etc.

Design of the mixer

In order to obtain good parameter matching between the two transistors, a special SPRM-element was developed, see Figure 1, which shows a photo of the chip.

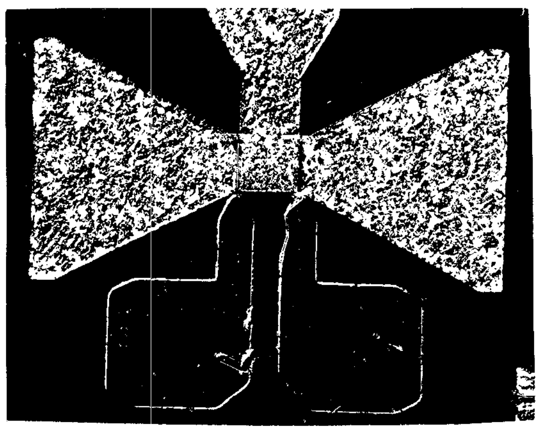


Figure 1 Photo of the dual-HFET device used for the subharmonically pumped mixer

It consists of two separate HFET cells which are connected in parallel. The gate width of each element is 50 μm. The mixing elements were fabricated on ∂-doped pseudomorphic AlGaAs-InGaAs-GaAs semiconductor material grown by Molecular Beam Epitaxy (MBE)‡. The AlGaAs layer is undoped in order to obtain a high gate breakdown voltage which is necessary for optimum operation of this mixer type [3] at high LO-power. Figure 2 shows the material cross section.

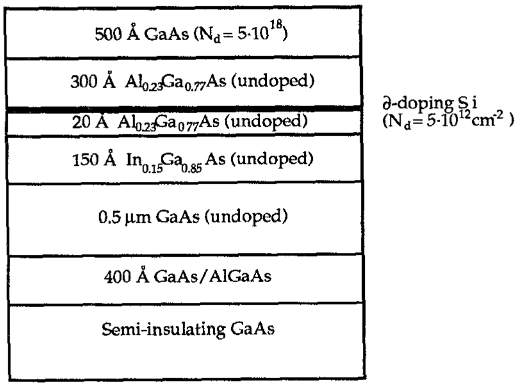
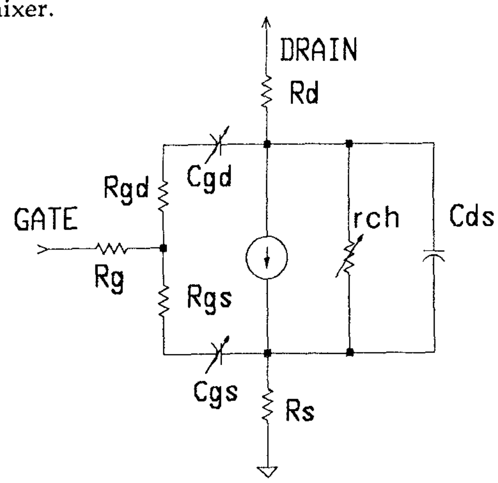


Figure 2 The epitaxial structure of the HFET material used in this study

Mushroom shaped gates were fabricated by using Electron Beam Lithography. A gatelength of approximately 0.15 µm was obtained. From S-parameter measurements on ordinary HFETs made on the same material, a maximum oscillation frequency of the order of 130 GHz and an f_T of 100 GHz was estimated.

A nonlinear model for this device was developed from DC-measurements and wafer probed S-parameter measurements up to 60 GHz as a function of gate bias. The measurements were made on a HFET structure suitable for wafer probing, with two 25 µm wide gates connected in parallel, made on the same material as above. The model was then used in the nonlinear simulation of the SPRM. The equivalent circuit in Figure 3 was used in the harmonic balance simulations of the mixer.



R_s	R_d	R_g	C_{ds}	R_{gs}	R_{gd}
11	15	2.7	12 fF	39	39

Figure 3 Equivalent circuit of a 50 µm HFET-cell with component values.

At V_d=0, the transconductance g_m is zero, and C_{gs} and C_{gd} have equal values. Figure 4 shows C_{gs} and r_{ch} versus gate voltage obtained from the bias dependent S-parameter measurements. For the simulation of this mixer we have used MDS from HP.

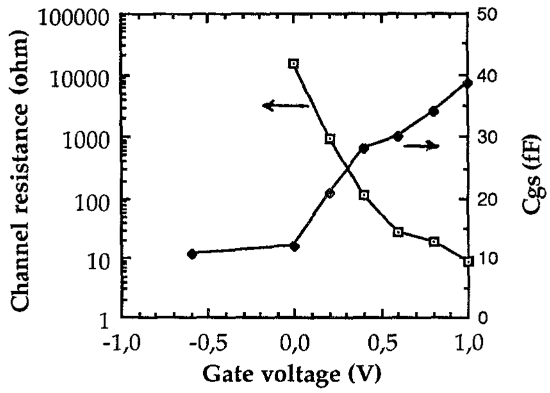


Figure 4 C_{gs} and r_{ch} as a function of V_{gs}.

The range of values for the source-drain resistance r_{ds} , i. e. the sum of the source, channel and drain resistances, $R_s+R_d+r_{ch}$, is of special interest since the minimum intrinsic conversion loss is dependent on the maximum and minimum values of r_{ds} [4]. The DC-values of r_{ds} were measured with a HP 4145 parameter analyzer. In Figure 5, r_{ds} is plotted as a function of gate voltage at a low drain voltage (50 mV). The minimum value of r_{ds} is only 1.6 Ω mm i.e. 32 Ω for a 50 µm gatewidth device. Since the output conductance in some FET-devices has shown frequency dispersion, we also compared the DC-values of r_{ds} with the real part of the output impedance obtained from S-parameter measurements at f=100 MHz. No frequency dispersion effect was noticed up to at least 1 kΩ. The maximum value of r_{ds} is of the order of 10^6 Ω.

To be able to perform a nonlinear simulation of the mixer, the dependence of r_{ch} with V_{gs} have to be known. This dependence is relatively well described [5] by

$$r_{ch}=R_0 \exp(-K_1 \cdot V_{gs})+R_1$$

where R_0 , R_1, and K_1 are parameters related to the design of the transistor. These parameters where extracted from DC measurements. The measured and modeled S_{22} of the HFET chip are shown in Figure 6 at different gate voltages from 0 (pinch off) to 1 V, from 0 to 50 GHz. In the mixer simulation, this relation was used to model a voltage dependent resistor by using a 'SDD'-model (Symbolically Defined Device).

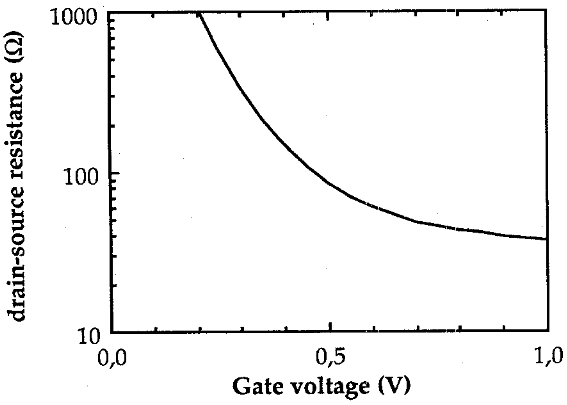


Figure 5 r_{ds} measured at DC as a function of gate voltage at V_{ds}=50 mV.

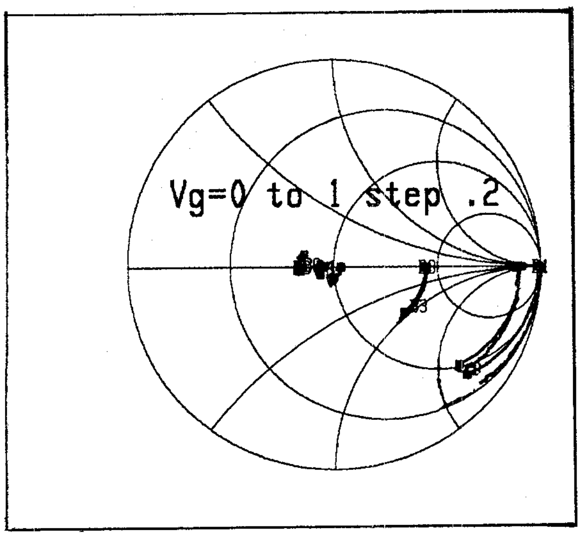


Figure 6 Measured and modeled S_{22} of the HFET chip

Another critical parameter is the gate-drain capacitance, since it determines the LO-leakage from the gate to the drain and also introduces some loss of the RF-signal (from the drain to gate). C_{gd} varies between 10 and 40 fF from pinch-off to a fully conducting channel.

The final mixer circuit is shown in figure 7. It consists of an input network, basically a tapped transmission line (which gives the required phase shift of 180 deg), and an output network including a 50 Ω, 3-section coupled line resonator RF filter. The IF filter is a lowpass filter with 100Ω impedance at the device side and 50Ω at the IF output connector. The simulation shows that the SPRM cell could be relatively well matched to the chosen impedance by proper gate bias adjustment.

The circuits are mounted in a test fixture and the signals are fed through V-connectors. The circuits were fabricated on 5 mil alumina substrate onto which the mixing element were bonded.

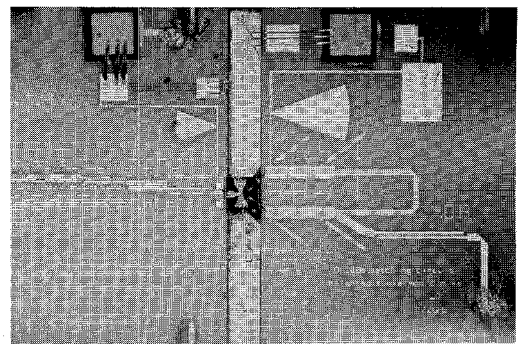


Figure 7 Photo of the mixer circuit

Experimental results and discussion

The mixer was tested for conversion loss in the frequency band 40 to 45 GHz. Figure 8 shows the measured conversion loss versus LO-power at an LO-frequency of 21 GHz. The gate voltage is adjusted for minimum conversion loss and is also plotted in the figure.

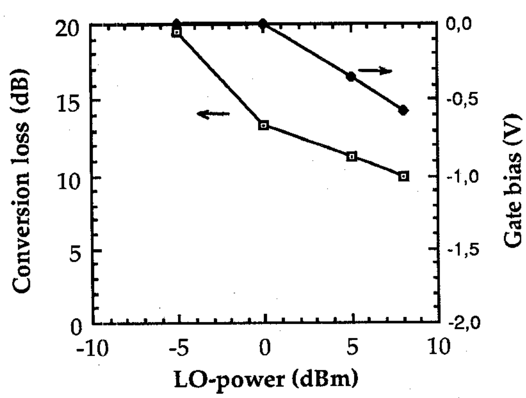


Figure 8 The measured minimum conversion loss of the mixer versus local oscillator power, and the corresponding gate bias.

The IF response is flat within 1 dB between 1 and 2.5 GHz. The LO-frequency is not a critical parameter and can be adjusted several GHz without severe degradation of the conversion performance. A minimum conversion loss of 10 dB was obtained at an LO-power of 7 dB_m , which was the maximum available power from the LO-source and not a limitation of the maximum withstandable LO-power of the mixer. Approximately 1.6 db of the conversion loss is due to losses in the RF circuit and 1.4 dB is due to losses in the IF-filter. The noise figure was measured by using a HP 346C-K1 noise source and the HP 8970A noise figure meter. The noise figure was found to be approximately equal to the conversion loss, within 0.5 dB.

The saturation performance was also characterized at different LO-power levels and in Figure 9 the -1 dB compression point referred to the input RF-power level and the output IF-power is plotted as a function of LO-power.

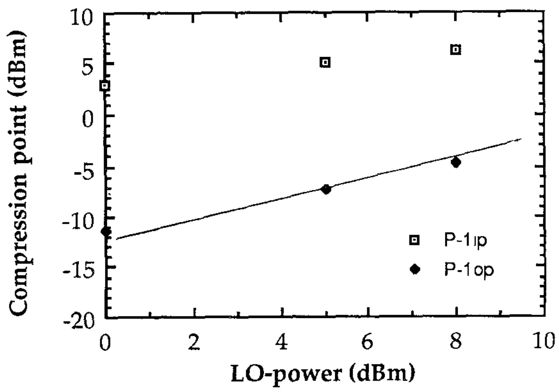


Figure 9 Measured -1 dB compression level referred to the input and the output as a function of the LO-power.

Conclusions

We have fabricated a dual HFET device for use in subharmonically pumped resistive mixers, and shown that this mixer can be used at millimeterwaves, 40-45 GHz. This mixer gives an uncorrected conversion loss of approximately 10 dB at an LO-power of 7 dB_m. This mixer is also suitable for integration. It is possible to increase the LO to IF/RF isolation further by compensating the gate-drain capacitance by an external inductance as was demonstrated in [6].

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References

1. S. A. Maas,'A GaAs MESFET Mixer with very low Intermodulation', IEEE Trans. Microwave Theory and Tech., Vol. MTT-35, pp. 425-429, 1987.

2. K. W. Chang et al,'Zero bias GaInAs MISFET mixers', IEEE MTT-S, pp. 1027-1030, 1989.

3. H. Zirath,'A Subharmonically Pumped Resistive Dual-HEMT Mixer, IEEE MTT-S Digest, pp. 875-878, 1991.

4. A.A. M. Saleh,'Theory of Resistive Mixers', Research Monograph #64, The MIT Press, Cambridge, Massachusetts, and London, England.

5. H. Zirath, N. Rorsman,'A resistive HEMT-Mixer with very low LO-power requirements and low intermodulations', Proceedings of the 21st European Microwave Conference, pp 1469-1474, 1991.

6. J. Geddes, P. Bauhahn, S. Swirhun,'A Millimeter Wave Passive FET Mixer with low 1/F Noise', IEEE MTT-S Digest, pp. 1045-1047, 1991.

‡The pseudomorphic HFET material was grown by Quantum Epitaxial Designs, Inc.