A Subharmonically Pumped Resistive Dual-HEMT-Mixer

Herbert Zirath

Dept. of Applied Electron Physics, Chalmers University of Technology
Göteborg, Sweden

ABSTRACT

A new subharmonically pumped High Electron Mobility Transistor (HEMT)-based resistive mixer is described. The mixer is based on a paralleled HEMT-configuration where the LO is applied to the gates with the same amplitude but with opposite phase. A mixer prototype was constructed at X-band. A conversion loss of 6.5 dB was measured at an LO-power level of 12 dB_m. A high LO-IF and LO-RF isolation is obtained intrinsically due to LO-cancellation. HEMT-devices were fabricated and characterized, and a nonlinear device model was developed and used in Harmonic Balance simulations.

INTRODUCTION

The subharmonically pumped mixer has the following attractive properties which makes it interesting as an alternative to fundamentally pumped mixers, especially at millimeter wavelengths: i.) The LO-frequency is only half of the frequency needed to pump a fundamental mixer ii.) the AM-LO noise is suppressed [1], iii.) and the RF- and LO-frequencies are widely separated which facilitates the construction of the diplexer [2]. Subharmonically pumped mixers (SPM) are generally based on two Schottky diodes in antiparallel, although attempts have been made to use planar doped barrier (PDB) diodes [3].

The mixer is based on a *paralleled* HEMT configuration i.e. the mixing element consists basically of two HEMTs where the sources, and drains are coupled together as shown in the block diagram of Fig. 1. Note that no drain bias is applied.

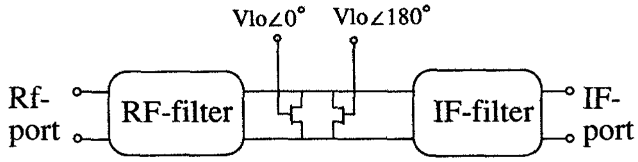

Fig.1 Block diagram of the dual-HEMT subharmonically pumped mixer.

The local oscillator signal is applied to both gates with the same amplitude, but 180 degrees out of phase. The RF-signal is applied to the drains. The frequency mixing occurs due to the time-variable channel conductance. The conductance waveform contains only even harmonics of the LO, shown in Fig 2.

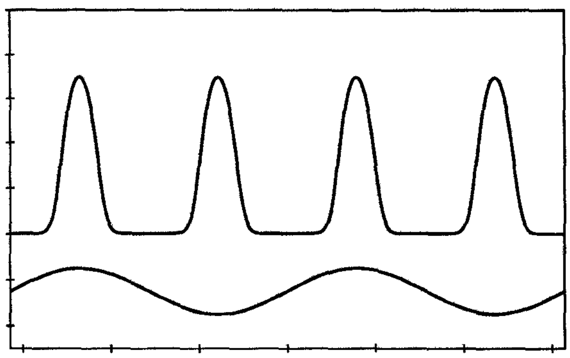

Fig. 2 A simulated conductance waveform of a HEMT-SPM. The bottom trace shows two periods of the LO-voltage.

The intermediate frequency signal is extracted from the drain through an IF-filter. With this mixer, the following advantages are obtained compared to the ordinary diode SPM:

1. The LO-circuit is separated from the RF and IF. The LO-leakage to the IF and RF-port due to the gate-drain capacitance is drastically reduced since the LO-signals are cancelled at the drains due to their phase relation.

2. The HEMT-SPM is expected to have better large-signal performance due to the relatively linear behavior of the channel resistance compared to the nonlinear barrier resistance of a diode. It was previously shown that resistive FET mixers have superior intermodulation properties and low LO-power requirement [4], [5], [6] .

3. The mixer is integrable with other HEMT-circuits like RF and IF-amplifiers due to the epitaxial compatibility.

DEVICE FABRICATION, MEASUREMENTS AND MODELLING

The HEMT-SPM concept was demonstrated at X-band, with mixer elements fabricated on pulse doped pseudomorphic AlGaAs-InGaAs-GaAs semiconductor material grown by Molecular Beam Epitaxy† (MBE). Mesa etching was done by wet etching and AuGe/Ni/Au ohmic contacts were evaporated, lifted off and annealed by standard methods and mushroom shaped gates were fabricated by using a JEOL JBX-5DII Electron Beam Lithography System. Gatelengths of approximately 0.2 μm were obtained. Ti/Pt/Au was used as gate-Schottky metallization. The fabricated transistors have a maximum oscillation frequency of approximately 180 GHz when biased for maximum available gain.

The equivalent circuit in Fig. 3 was used for simulating the mixing properties. The elements were extracted from DC-measurements and wafer probed S-parameter measurements as a function of gate bias, with V_{ds}=0V.

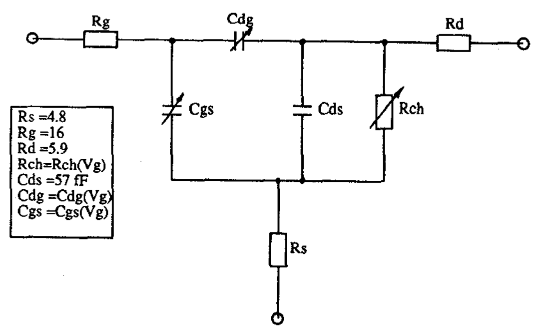

Fig. 3 Equivalent circuit of the fabricated HEMT.

This equivalent circuit is somewhat simplified since the forward and backward conduction of the gate-Schottky is not accounted for. A simplification which is justified in a large-signal simulation if the LO-power and dc-bias are within the 'safe area' for negligible gate current.
The bias-dependence of the components r_{ch}, c_{gs}, and c_{gd} are shown in Fig 4. The gatewidth of the HEMT is 200 μm.

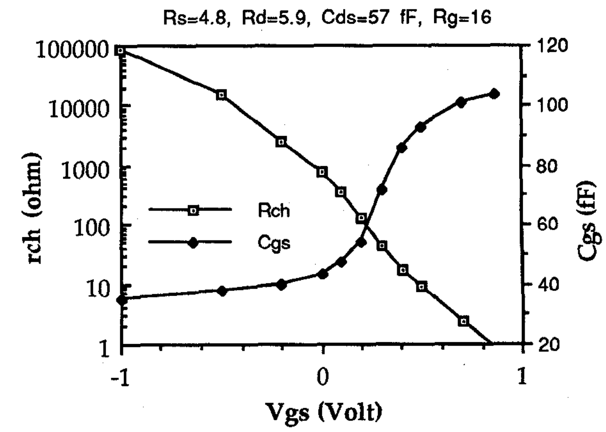

Fig. 4 r_{ch} and c_{gs} (=c_{gd}) as a function of V_{gs}

The behavior of c_{gs} is characterized by a relatively abrupt transition at 0.2-0.6 V as the channel is filled with electrons. For low conversion loss, the ratio r_{dsmax}/r_{dsmin} should be high [7].

MIXER DESIGN

The mixer circuit is shown in Fig. 5, and consists of an input network, basically a tapped transmission line, and an output network with the RF and IF-filters. The circuits are mounted in a test fixture and the signals are connected via K-connectors.

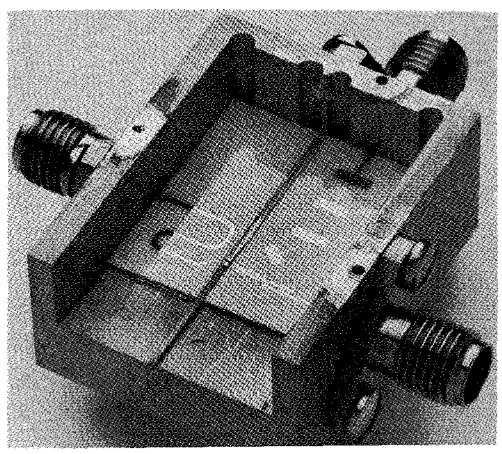

Fig. 5 Photograph of the subharmonic HEMT-mixer

The gate of the first HEMT is connected to the end of the transmission line, and the gate of the other HEMT is connected at $\lambda/2$ from the end of the line which gives the required phase difference of 180°. Simulations show that the loading of the line by the gates of the HEMTs is practically negligible.

The sources of the HEMTs are grounded, and the drains are connected to the output circuit. The output circuit consists of a 2-section coupled line resonator filter for the RF, with a calculated -1 dB bandwidth of 2 GHz and an insertion loss of 0.6 dB, and a stepped impedance IF-filter with a -3 dB bandwidth of 7 GHz. This relatively high IF-bandwidth facilitates more accurate LO-IF isolation measurements since the LO-frequency is within the IF-filter passband. The calculated insertion loss of the IF-filter is approximately 0.5 dB. The circuits were fabricated on 15 mil alumina substrates onto which the mixing elements were bonded. All circuits were analyzed and optimized on the commercial microwave network program, Microwave Design System™ from HP.

MIXER MEASUREMENTS

After the mixer was assembled, different DC-measurements were made to confirm the proper operation of the circuit. Also R_{ds} versus V_g was measured, to verify that a sufficiently high R_{dsmax}/R_{dsmin} ratio was obtained. In Fig. 6, R_{ds} versus V_g is plotted as well as I_d at V_d=0.05, 0.1, and 0.15 V. Obviously an R_{dsmax}/R_{dsmin} ratio of more than 10^4 can be obtained!

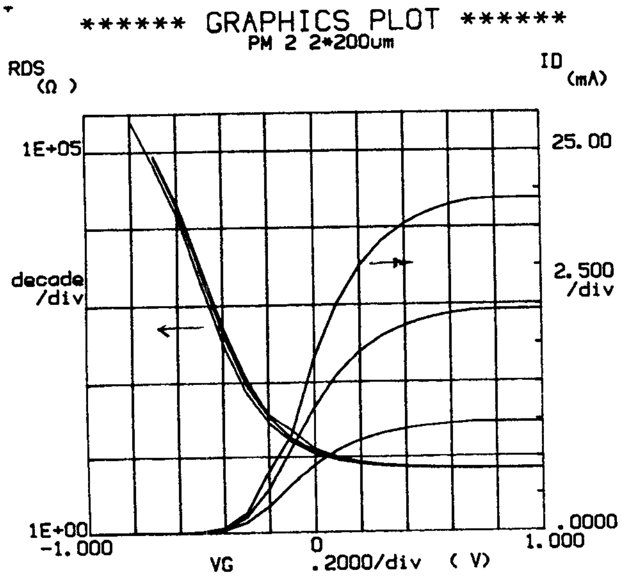

Fig. 6 The measured R_{ds} and I_d versus V_g at V_d=0.05, 0.1, and 0.15 V.

The conversion loss was measured, for different LO-power levels, with the RF-signal swept from 10-12 GHz with an LO-frequency of 5 GHz. In Fig. 7, the conversion loss versus LO-power is plotted. At each LO-power level, the gate bias was adjusted to minimize the conversion loss. It is important especially at high LO-powers to back bias the gate in order to obtain the proper conductance waveform and avoiding any rectified gate current. At Plo=12 dB_m the gate is biased to -3 V, it is therefore important that the HEMTs to be used have a high gate breakdown voltage if high LO-levels are to be used.

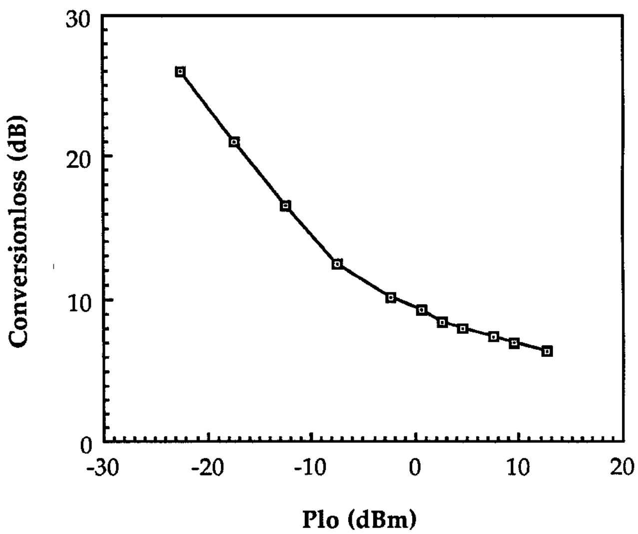

Fig. 7 The measured conversion loss of the mixer. The variation in the passband, 10-12 GHz, is only ±0.25 dB

The minimum conversion loss is 6.5 dB at a pumping power of 12 dB_m (this was the maximum output power of the LO-source). The response at the IF is extremely flat, the variation is within ±0.25 dB from 100 MHz to 2 GHz at P_{LO}>10 dB_m, and ± 0.5 dB at P_{LO} > -5 dB_m! The LO-IF isolation was measured to be 37 dB, which is the *intrinsic* isolation from the gate to the drain since the IF-filter is designed to cut *above* the LO-frequency. This high intrinsic isolation is due to the LO-cancellation mechanism (a similar *single* HEMT-mixer would give a value of 15-20 dB). The LO-RF isolation is approximately 65 dB. The isolation performance is maintained for LO-frequencies from 4.1 to 5.9 GHz. The -1 dB compression level P_{-1} (referred to the RF-input level) was also measured and was found to be 1.5 dB below the LO-power for P_{LO}=5-10 dB_m.

CONCLUSION

A novel subharmonically pumped resistive dual-HEMT mixer has been fabricated. A minimum conversion loss of 6.5 dB was obtained at a pumping power of 12 dB_m. Due to the topology of the mixer, high isolation is obtained between the LO, and the IF/RF. The IF-response was demonstrated to be very flat. These results are promising and attempts will be made to realize a mixer working at mm waves. In this case the two required HEMTs will be integrated to form a 'dual-gate HEMT cell' in order to minimize the bonding parasitics, and to obtain good parameter match.

ACKNOWLEDGMENT

The author would like to thank Bengt Johansson and Camilla Kärnfelt at Ericsson Radar Electronics (ERE) for help with the substrates and bonding, Niklas Rorsman and Hans Grönqvist for help with the fabrication of HEMT's, and Ingvar Samuelsson for help in the workshop. The Swedish Defence Material Administration (FMV) and the Swedish Board for Technical Development (STU) are acknowledged for financial support, and Prof. E. Kollberg, Dr Thomas Lewin, Lennart Alfredsson and Gunnar Ericsson for their strong support of this work.

REFERENCES

1. P. S. Henry, B. S. Glance, M. V. Schneider,'Local-Oscillator Noise Cancellation in the Subharmonically Pumped Down-Converter', IEEE Trans. Microwave Theory Tech., vol. MTT-24, pp 254-257, May 1976.

2. E. R. Carlson, M.V. Schneider, T.F. McMaster, 'Subharmonically Pumped Millimeterwave Mixers', IEEE Trans. Microwave Theory Tech., vol MTT-26,pp. 706-715, Oct. 1978.

3. R. J. Malik,'A Subharmonic Mixer Using a Planar Doped Barrier Diode with Symmetric Conductance', IEEE Electron Devices Lett., vol. EDL-3, pp. 205-207, July 1982.

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

5. S. Wiener, D. Neuf, S. Spohrer,'2 to 8 GHz Double Balanced MESFET Mixer with +30 dBm Input order Intercept', IEEE MTT-S Digest, pp.1097-1100, 1988.

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

7. A.A. M. Saleh,'Theory of resistive mixers', Research Monograph #64, The MIT Press, Cambridge, Massachusetts, and London, England.

†The pseudomorphic HEMT material was grown by Northeast Semiconductor Inc.