pHEMT and mHEMT Ultra Wideband Millimeterwave Balanced Resistive Mixers

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Abstract **Two ultra wideband millimeterwave single balanced resistive mixers utilizing a Marchand balun for the LO–hybrid are simulated, fabricated and characterized for 30-60 GHz in both up and down conversion. Two different versions of the mixer were manufactured in a commercial pHEMT-MMIC and a mHEMT-MMIC process respectively. A measured down conversion loss of approximately 6 to 12 dB over the whole band is obtained for both versions of the mixer with external IF power combining. In spite of the balanced design, the required LO power is quite low, 2 dBm is sufficient for low conversion loss. The LO-RF isolation is excellent, often more than 30 dB for both type of mixers. Low noise figure and high IIP3 figures are obtained. It is also shown that by applying selective drain bias, up to 5 dB improvement of IIP3 can be obtained for the mHEMT mixer with small LO powers.**

1. Introduction

In some application, such as up converting frequency mixers, the LO-RF isolation is a critical parameter, since the residual LO-power at the RF-port will be amplified by the following power amplifier. When linearity is considered, the resistive mixer is the preferred alternative [1]. In a single resistive mixer, the LO-RF suppression is of the order 10-15 dB. With a resonant network between the gate and the drain, forming a parallel resonant circuit, the isolation can be increased; an isolation of 30dB was measured at 60 GHz [2]. Filtering is also possible but the LO and RF is often close together thus making the filter complicated and expensive. An attractive solution, which can offer increased isolation over a larger bandwidth is the balanced mixer design, several solutions of such mixers for millimeterwave applications have been published in the literature [2-5]. In addition they can be made very broadband and can operate both as up-converter and down-converter. With regard to high LO-RF-isolation, the preferred single balanced mixer topology is operated with an 180^o hybrid for the LO. Such a mixer has demonstrated a rejection of 50 dB at 50 GHz utilizing a hybrid design [3]. This mixer was based on InP-HEMTs, a conversion loss of 8 dB was obtained at an LO-power of 5dBm. In the following design, we use a Marchand balun as a 180 hybrid, in order to achieve a large bandwidth.

2. MMIC-technology

Two different versions of this mixer have been fabricated with the manufactured process as only difference. The pHEMT process used in this work is a standard 0.14 µm gate length, 95 GHz f_T, 180 GHz f_{max}, commercial double delta-doped PHEMT process, D01PH, offered by the foundry OMMIC in France. The mHEMT process is offered by the same foundry and is similar to D01PH except for the metamorphic buffer which allows an active layer with high indium content for improved high frequency performance. The DC and RF-characteristics of the HEMTs has been described elsewhere [5]. In summary, the maximum current density is 700 mA/mm, the maximum transconductance 700 mS/mm. The minimum Rds, an important figure of merit for switching application, is 1.0 Ω·mm. The process is usable both for power and low noise applications.

3. Mixer design

The mixers are covering 30-60GHz and consists of two single resistive mixers utilizing a 180^o power splitter for the LO-feed, see Fig 1.

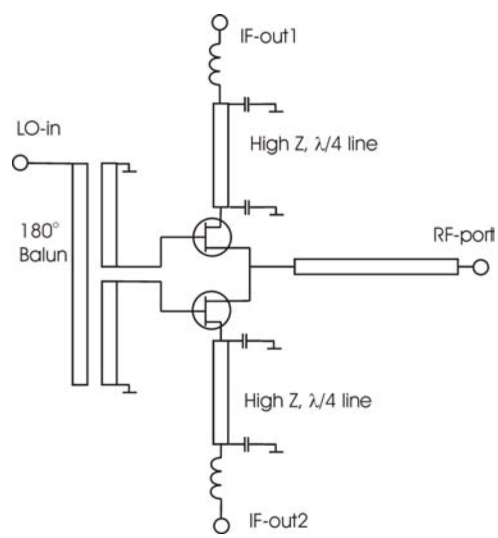

Fig 1 Schematic of the mixer

At the drain side, the residual LO-signals are out of phase and cancelled. The sources are RF-grounded through a small capacitor and a ground-via. The IF-signals are extracted from the sources. The two IF-signals are out of phase and are combined in a balun, off chip. A folded Marchand balun is used as an LO power splitter. The balun was optimized using circuit and electromagnetic simulators from Agilent. The complete circuit was then simulated and optimized by using a harmonic balance simulator, MDS from Agilent. The HEMTs were modeled according to [6]. Photos of the mixer are shown in Fig. 2. All four ports are accessible with coplanar probes for testing. The size of the 30-60 GHz MMIC balanced mixer is 2x1.5 mm.

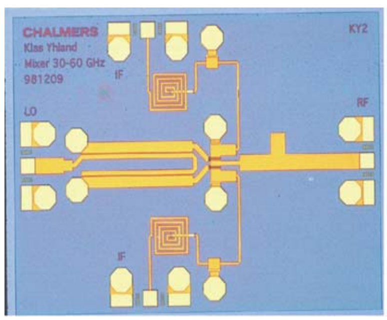

Fig 2 Photo of the MMIC balanced mixer.
The design was made by Klas Yhland at MC2.

4. Measured results

The mixer in its two versions were characterized as down and up converters from 30 to 60 and 30 to 50 GHz respectively. The IF frequency has been 1.5 GHz for all measurements. The measured conversion loss with external IF combining in a balun is plotted in Figs 3-8. The conversion loss is relative flat over the measured band. The corresponding conversion loss for the mHEMT design is similar to the pHEMT mixer and these results are therefore not shown. The optimal V_{GS} bias points were found to be -0.5 V for the pHEMT mixer and -0.7 V for the mHEMT mixer. For up conversion applications, the conversion loss is similar to down conversion for pHEMT but a few dB worse than the mHEMT mixer. The only difference is conversion loss with V_{DS} as parameter where, in direct opposite to the down conversion case, a high V_{DS} gives the lowest conversion loss.

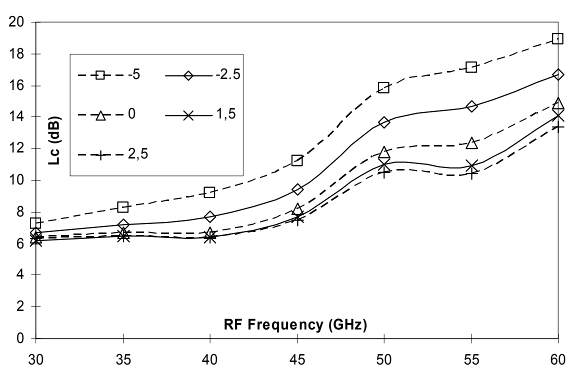

Fig 3 Down conversion loss of the pHEMT mixer with LO-power as parameter

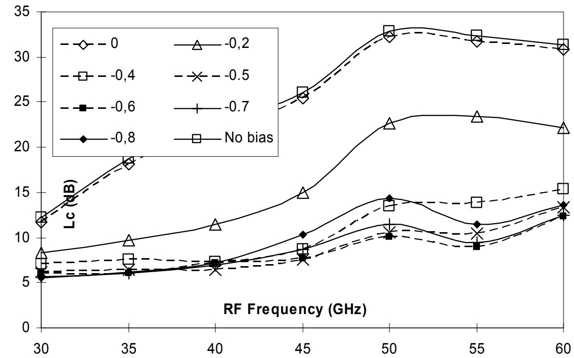

Fig 4 Down conversion loss of the pHEMT mixer with LO power of 2dBm and V_{GS} as parameter

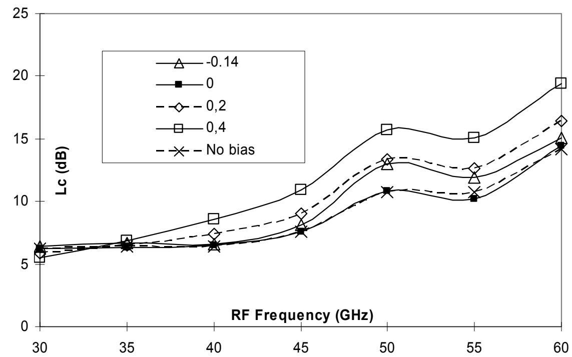

Fig 5 Down conversion loss of the pHEMT mixer with LO power of 2dBm and V_{DS} as parameter

The LO-RF isolation is especially crucial in up converter applications since the LO-signal in most cases should be suppressed. The isolation is plotted in Fig 6-7 and it can be seen that the pHEMT mixer employs around 6 dB better isolation compared to its mHEMT counterpart when using the earlier determined optimal V_{GS}, -0.5/-0.7 V for pHEMT/mHEMT respectively. The isolation is more than 30 dB in the full frequency band for the pHEMT mixer and for most of the frequency band for the mHEMT counterpart. An isolation better than 20-30dB is normally required.

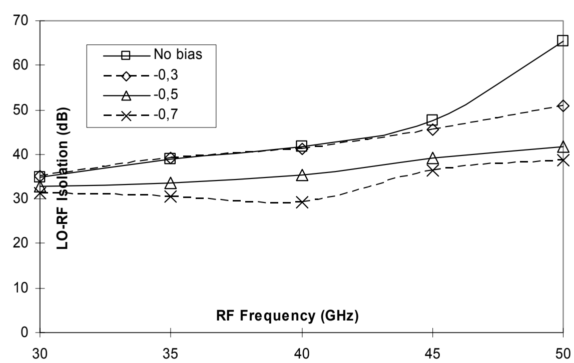

Fig 6 LO-RF isolation for the pHEMT mixer with LO power of 2dBm and V_{GS} as parameter

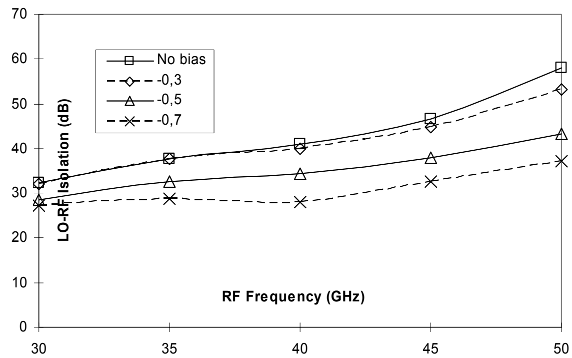

Fig 7 LO-RF isolation for the mHEMT mixer with LO power of 2dBm and V_{GS} as parameter

The input referred 1 dB compression point was also investigated and is plotted in Fig 8 for the down conversion case.

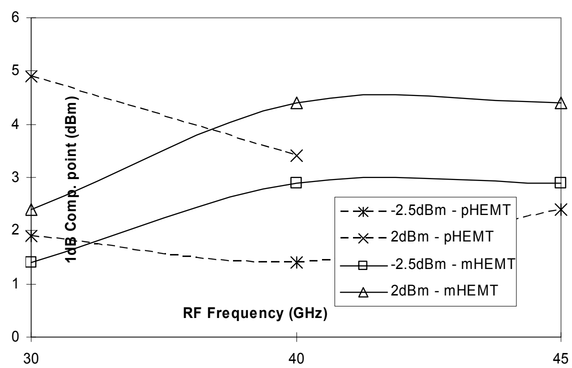

Fig 8 1 dB compression point for both the pHEMT and mHEMT mixer with LO-power as parameter

IIP3 was measured and the results are plotted in Fig 9-11. It is shown in [7] that by applying a selective drain bias of a resistive FET mixer, the IIP3 of the same mixer can be improved with several dB. This is clear from Fig 10-11 which show up to 5 dB of improvement of IIP3 by applying a small V_{DS} bias.

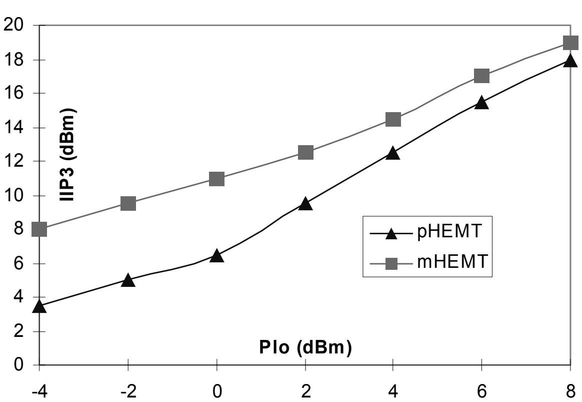

Fig 9 IIP3 with LO-power as parameter and no V_{DS} bias applied

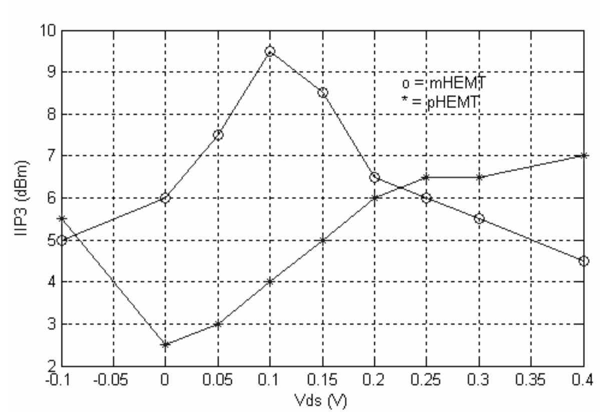

Fig 10 IIP3 with LO power of -8 dBm and V_{DS} as parameter

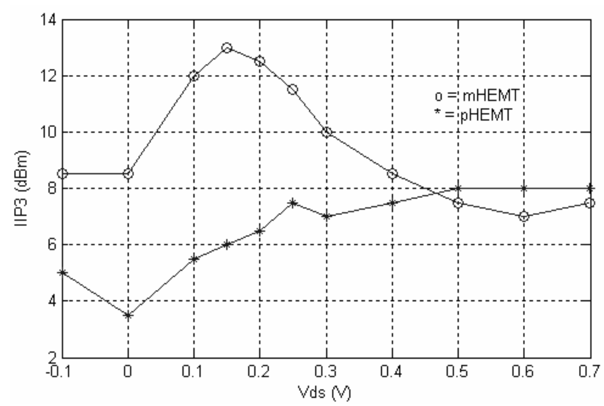

Fig 11 IIP3 with LO power of -4 dBm and V_{DS} as parameter

The double sideband noise figure, NF_{DSB} was measured when the mixers were used in a down conversion mode and the result for the pHEMT mixer is plotted in Fig. 12. It is seen that the minimum noise figure between is 5 and 8 dB and coincide with the earlier determined optimal V_{GS} bias of 0.5V. The results for the mHEMT mixer were similar but about 3dB worse compared to its pHEMT counterpart.

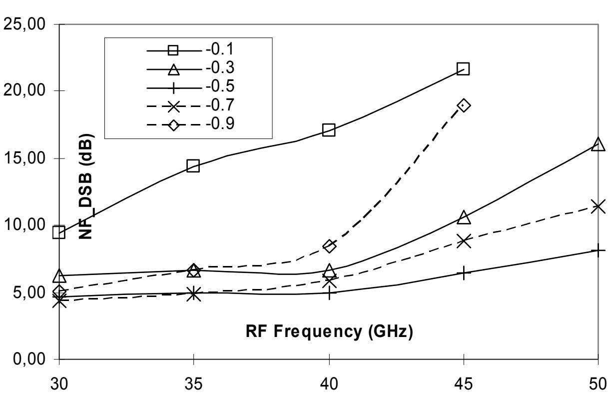

Fig 12 Down conversion NF_{DSB} of the pHEMT mixer with LO power of 2dBm and V_{GS} as parameter

5. Conclusions and discussion

Ultra broadband MMIC balanced resistive mixer designed for a high suppression of the LO-power have been simulated, manufactured, and experimentally verified. Conversion loss, noise figure, LO/RF port isolation, 1 dB compression point, IIP3 and noise figure are reported. Excellent conversion characteristics, 6-12 dB over the frequency band, at low LO-powers together with high LO-RF rejection, >30dB, are experimentally verified. This mixer topology is believed to be the preferred choice for the design of millimetre wave single sideband modulators requiring high carrier suppression. The double sideband noise figure is excellent with 5-8 dB for the pHEMT mixer in the measured frequency range up to 50GHz. The 1 dB compression point and IIP3 measurements was performed with limited maximum power from the test generator. Higher possible compression and IIP3 figures are expected at higher LO-powers since the experimental compression and IIP3 characteristics were not saturated with regard to LO-power. The IIP3 values are very good and it has been shown that a 5 dB improvement of IIP3 can be obtained by applying a small V_{DS} bias.

Down conversion	Conversion loss	Isolation	1dB CP	IIP3	Noise
pHEMT	Equal	Better	Equal		Better
mHEMT	Equal		Equal	Better	

Up conversion	Conversion loss	Isolation	1dB CP	IIP3
pHEMT	Better	Better		Better
mHEMT			Better	

Table 1 Comparison of the pHEMT mixer versus its mHEMT counterpart

Acknowledgements

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