60 GHz GaAs MMIC mixers with integrated LO buffer

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***Abstract* — Using the 0.15 µm GaAs mHEMT process from WIN semiconductors, two 60 GHz down-conversion mixers have been designed, processed and measured. Both designs include a LO buffer amplifier to allow for a reduced external LO power level. With an LO power of +10 dBm, the measured RF input match is better than -15 dB at 60 GHz and the conversion loss is below 8 dB at 2 GHz intermediate frequency.**

I. Introduction

Within the framework of the Broadway project [1], several 60 GHz transceiver functions have been designed. Two different mixer designs will be presented in this article.

II. Device Modelling

The models for the transistors and diodes used in the mixer design were supplied by the foundry. All models were based on foundry measurements of the devices over a frequency range up to 50 GHz. Therefore the accuracy of the models at 60 GHz is limited, but expected to be useable for this purpose.

III. Mixer Design

The mixer has been designed to convert 60 GHz RF signals down to the 5 GHz ISM frequency band and is based on a low-side LO frequency (55 GHz).

For the first design, a commonly used mixer topology is chosen, using a quasi-balanced circuit based on a Branch-line coupler. The Branch-line is used to feed the LO and RF signals to the diodes while isolating the ports from each other. Both LO and RF signals are split into two branches with 90 degrees phase-difference. This topology has been chosen because of the straightforward design and layout. For the diodes, Schottky type diodes are used with 4 fingers of 20 µm length each. For this diode, a large-signal model was available from the WIN foundry. The diodes are embedded in a matching circuit optimizing the conversion of RF to IF signal power. The RF/LO matching circuit for each diode consists of a quarter wavelength transformer and a short-circuited stub. The single-ended IF output signal is extracted from the circuit through a λ/4 long high-impedance line and a λ/4 open stub. A picture of the realized mixer, including the LO buffer-amplifier, is shown in Figure 4.

The simulated conversion gain of the Branch-line mixer is shown in figures 1, 2 and 3.

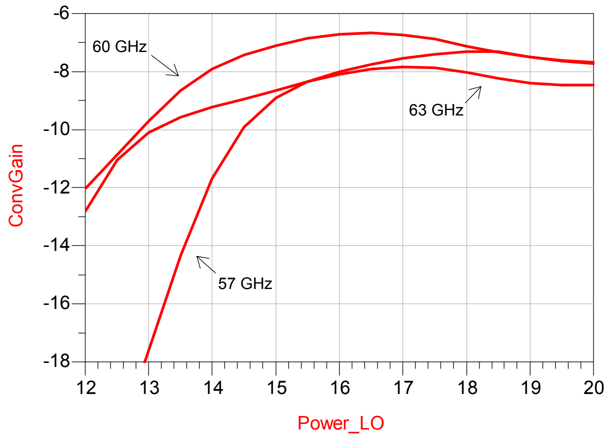

Fig 1. Branch-line mixer conversion gain versus LO power for different RF frequencies (IF = 5 GHz).

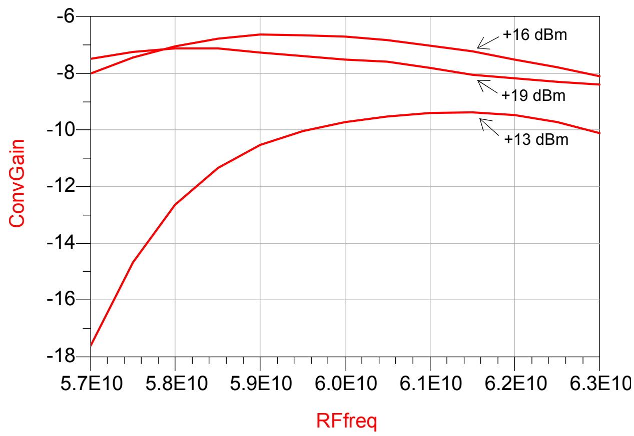

Fig 2. Branch-line mixer conversion gain versus RF frequency for different LO power levels (IF = 5 GHz).

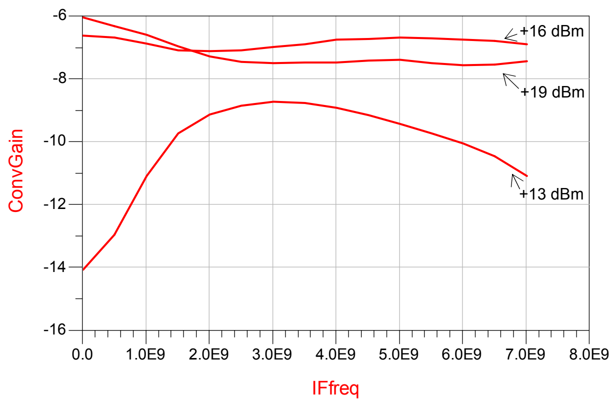

Fig 3. Branch-line mixer conversion gain versus IF frequency for different LO power levels (RF = 60 GHz).

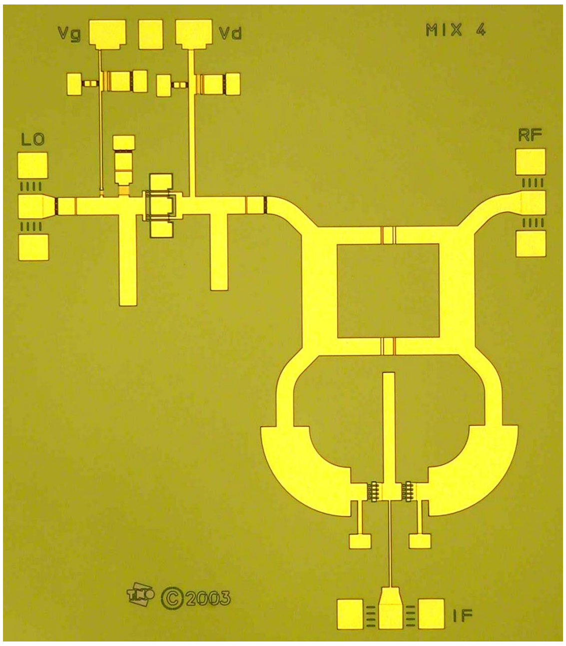

Fig.4. Photograph of the Branch-line Mixer.

The second mixer-design is a real single-balanced design which uses a Rat-race coupler to split and combine the RF and LO signals. In this case the RF signal is split into two signals with 180 degrees phase difference. The LO-RF isolation of this mixer is a lot better than that of the Branch-line type mixer. The layout has the disadvantage that one RF crossing is necessary as can be seen in the photograph shown in Figure 8. Apart from the Rat-race part, the design is identical to the Branch-line mixer.

The simulated conversion gain of the Branch-line mixer is shown in figures 5, 6 and 7.

Both mixers have been simulated using the Advanced Design System from Agilent. The Momentum EM simulator has been used to analyze the complex parts of the micro-strip layout. Both mixers were simulated without the LO buffer amplifier.

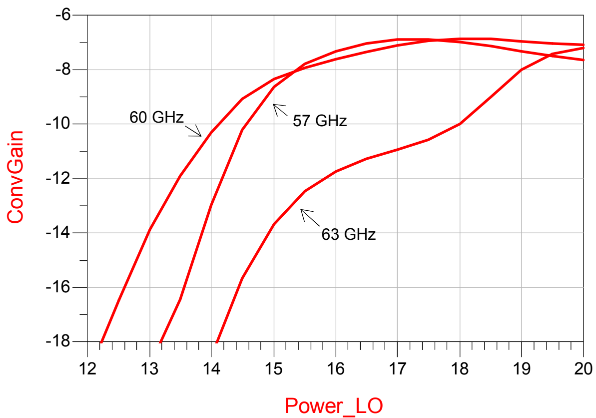

Fig 5. Rat-race mixer conversion gain versus LO power for different RF frequencies (IF = 5 GHz).

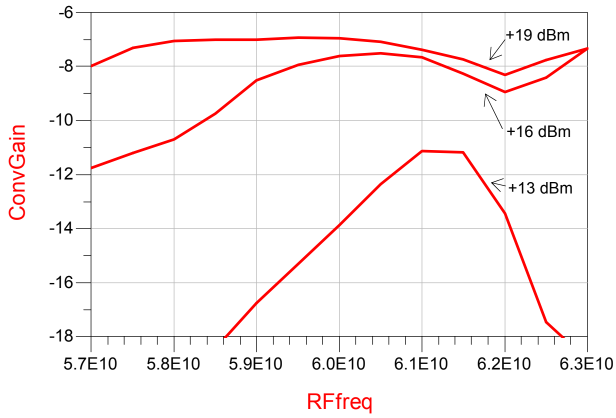

Fig 6. Rat-race mixer conversion gain versus RF frequency for different LO power levels (IF = 5 GHz).

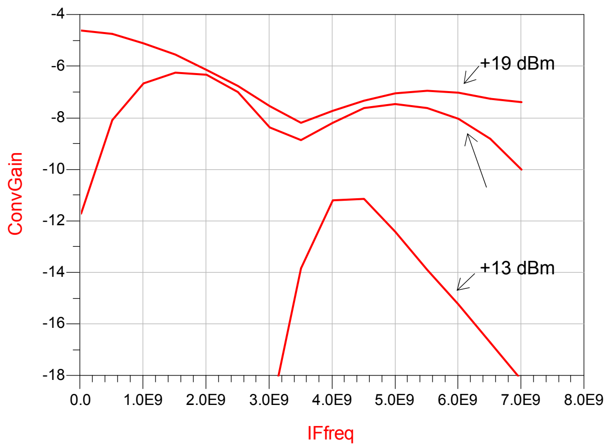

Fig 7. Rat-race mixer conversion gain versus IF frequency for different LO power levels (RF = 60 GHz).

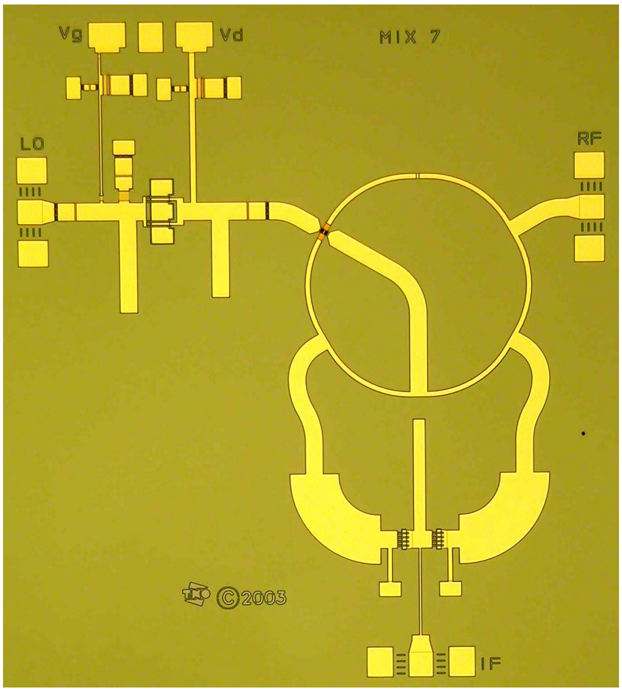

Fig. 8. Photograph of the Rat-race Mixer.

IV. LO BUFFER DESIGN

The buffer amplifier is a single-stub tuned single-stage design, and has been designed to deliver approximately 7 dB of linear gain and +16 dBm output power. Optimum operation of the mixer occurs at this power level due to the large forward voltage (1 Volt) of the GaAs diodes, which is three times larger than an average Schottky diode. A stabilization network has been added at the gate to ensure unconditionally stable operation of the amplifier.

V. MEASUREMENT SETUP

The devices have been tested on-wafer. The wafer is placed on a wafer-probe station and connections to the measurement equipment are made with coaxial probes and cables.

To generate the needed LO power sweep, an up-converter is used. This up-converter has a fixed output power of +12 dBm @ 58 GHz and +8.5 dBm @ 55 GHz. In order to make an LO power-sweep, a variable attenuator is placed between the DUT and the up-converter output. Figure 9 shows a schematic of the measurement setup.

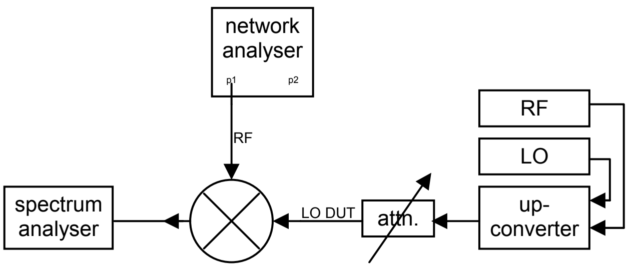

Fig. 9. Schematic of the measurement setup.

The RF input signal is generated by a 67 GHz vector network analyzer. This analyzer is also used for measuring the input reflection coefficient.
It was not possible to measure the IF power with a powermeter because of all the harmonics in the spectrum. Instead, a spectrum analyzer was used.

The calibration of this setup is quite complex. All absolute powers where measured with the spectrum analyzer. In order to gain calibrated power levels, a calibration table was made. This table is the difference between the measurement of a calibrated power meter and the un-calibrated spectrum analyzer of a clean RF signal. Values measured by the spectrum analyzer can be corrected later on by adding or subtracting the values from the calibration table.

Due to the loss in the attenuator, cables and probes, the maximum available power on wafer was +10 dBm. This has effect on the measurement results presented in the next paragraph.

VI. RESULTS

The LO buffer amplifier was measured in a separate test-cell and it was found that both the linear gain and the output power performance were approximately 2-3 dB below the simulated values. Because of this fact, and due to the maximum available on-wafer LO power level, the nominal LO power for the mixers (+16 to +17 dBm) can not be realized.

Figure 10 shows the measured conversion gain of the two mixer types. It can be seen that the branch-line mixer is the first to go into compression. This was also predicted in simulation. The Rat-race version is not yet saturated at the maximum available +10 dBm LO power. Extrapolation of the curves yields an estimated conversion loss of 8 dB at an LO power of 12 dBm.

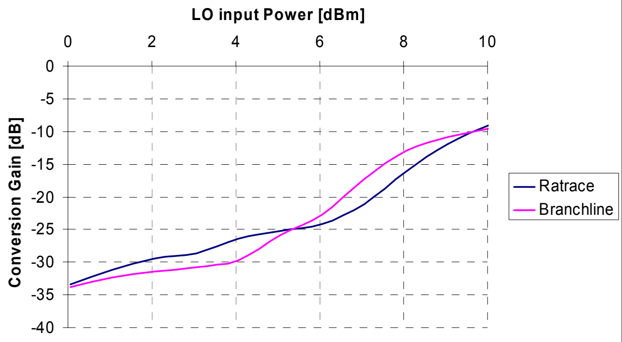

Fig. 10: Conversion gain comparison of Branch-line and Rat-race mixer (LO = 57 GHz, RF = 61 GHz).

The conversion loss of the Branch-line mixer at different RF and LO frequencies is given in figure 11. The LO power on-wafer is fixed at +9 dBm.

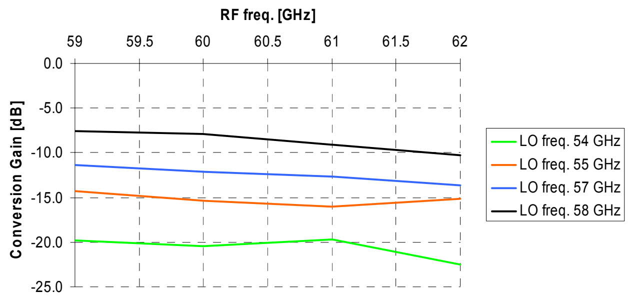

Fig. 11: Conversion gain of the Branch-line mixer, RF and LO frequency swept, LO = +9 dBm.

At LO frequencies of 58 and 57 GHz, the mixers show a useable performance. The best measured performance is seen at an LO frequency of 58 GHz and with the RF frequency around 60 GHz. The conversion loss will be less than 8 dB.

Measuring the isolation of the mixers proved to be difficult in the given setup. Measurements carried out predict the RF to IF isolation to be better than 15 dB and the LO to IF isolation better than 17 dB.

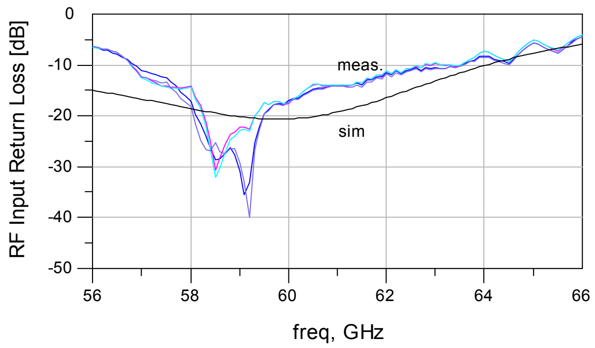

Fig. 12. RF input return loss.

Figure 12 shows the measured input return loss of the Branch-line mixer at the RF port (several samples), as well as the simulated performance. The RF input matching compares reasonably with the simulated performance and shows better than 12 dB return losses over a 57 – 62 GHz frequency range.

VII. CONCLUSION

Two versions of a 60 GHz GaAs MMIC mixer with LO buffer amplifier have been successfully realized using the 0.15 µm GaAs mHEMT process from WIN semiconductors.

The Rat-race mixer has the lowest conversion loss and needs slightly more LO-power than the Branch-line mixer. Due to the limitations of the measurement setup, the optimum LO power level for both mixers could not fully be determined.

The best performance for the Branch-line mixer is summarized in table 1. The results for the Rat-race mixer are expected to be comparable with even lower conversion loss.

The measured performance compares reasonably well with the simulations, although the model validity could not be fully verified due to the limited source-power available for the on-wafer measurements.

parameter	**measured value**
RF frequency range	59 – 62 GHz
LO frequency range	54 – 58 GHz
Conversion Loss	< 8 dB (RF=60GHz/LO=58GHz)
LO-RF rejection	Not measured
RF-IF rejection	> 15 dB
LO-IF rejection	> 17 dB
LO drive level	> +10 dBm

TABLE I
SUMMARY OF MEASURED PERFORMANCE

ACKNOWLEDGEMENT

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[1] Marc de Courville, Sven Zeisberg, Markus Muck, Jens Schoenthier, “BroadWay - the way to Broadband Access at 60 GHz”, International conference on telecommunications (ICT), Beijing, China, June 2002.