A V-Band Downconversion Mixer in 90 nm GaN

Matthew LaRue, Ali Darwish, Sami Hawasli, Khamsouk Kingkeo
DEVCOM Army Research Laboratory
Adelphi, MD 20783
matthew.r.larue2.civ@army.mil

***Abstract*—This paper presents a V-band downconversion mixer in 90 nm Gallium Nitride (GaN). This mixer uses low-side local oscillator (LO) injection to downconvert 50-61 GHz radio frequency (RF) signals to a 12.8 GHz intermediate frequency (IF). The LO input requires a 7 dBm sinusoidal drive, and a single-balanced LO topology is implemented to improve the mixer's LO rejection. A novel Wilkinson-based LO to RF leakage cancellation circuit is implemented to provide a 22 dB isolation improvement at the mixer's RF input. A peak conversion gain of 12.6 dB and an average conversion gain of 5.3 dB is achieved. The average noise figure (NF) is 10.1 dB and output third-order intercept (OIP3) is 15.1 dBm. The mixer uses a 15 V drain supply and consumes 0.51 W. The design is currently being fabricated, with test results expected in late 2023.**

Keywords— mixers; gallium nitride; microwave circuits; radio frequency

I. Overview

Gallium Nitride (GaN) process technologies are a popular choice for RF amplifiers due to their high output power, thermal handling capability, survivability, and low noise figure. The continued scaling of GaN process nodes is further increasing the device f_T, allowing for more circuit topologies to be implemented in GaN. In particular, GaN is becoming an attractive alternative to Gallium Arsenide (GaAs) for high frequency downconversion mixers capable of achieving wideband conversion gain.

This paper presents a single-balanced downconversion mixer implemented in Qorvo's 90nm GaN process technology. This mixer is designed for 50-61 GHz RF frequency and a 37-48 GHz LO frequency, resulting in an output intermediate frequency (IF) of 12.8 GHz. The LO bias was selected to minimize LO drive requirements, with only 7 dBm LO drive needed across the entire frequency band. Despite the minimized LO drive, the LO input is still expected to be substantially larger than the RF signal. The single-balanced LO architecture is therefore implemented to improve the LO rejection at the mixer's IF output.

One particular challenge of the balanced LO mixer is the layout, shown in Fig. 1. The RF input signal must cross over one of the differential LO inputs, resulting in 30 dB LO to RF leakage. The Wilkinson combiner [1] based LO leakage

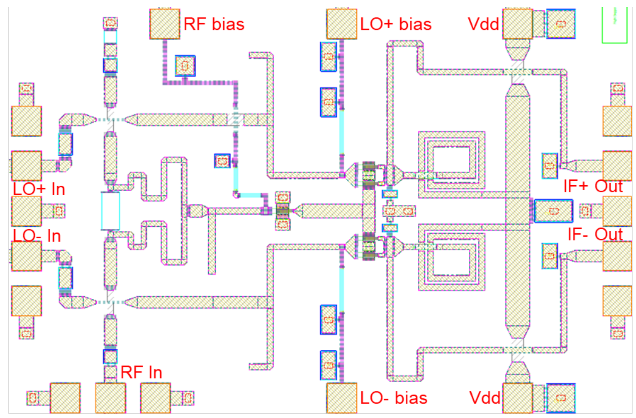

Fig. 1. Mixer layout, 2.1mm x 1.4mm

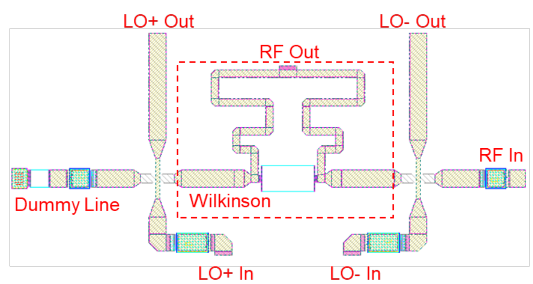

Fig. 2. Mixer input manifold layout with LO to RF leakage mitigation

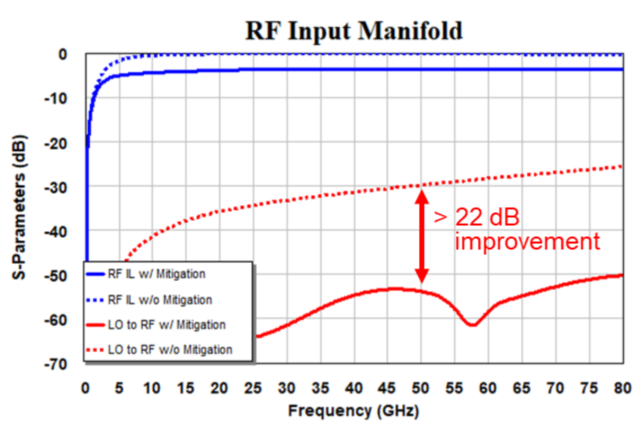

Fig. 3. Simulated RF manifold insertion loss (IL) and LO to RF leakage

DISTRIBUTION STATEMENT A. Approved for public release: distribution is unlimited.

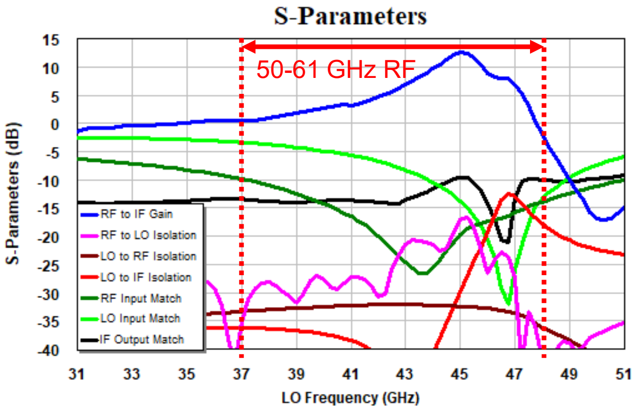

Fig. 4. Simulated mixer S-parameters

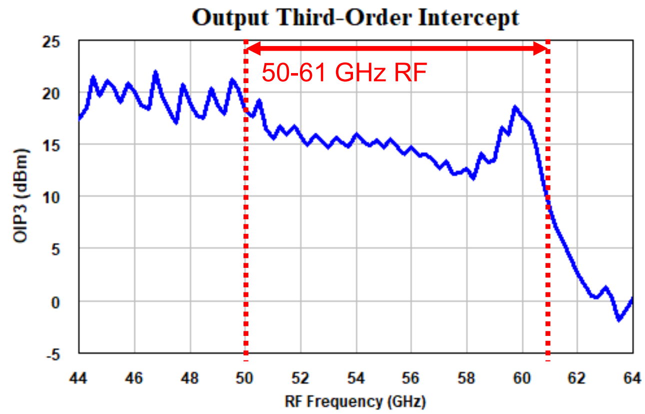

Fig. 6. Simulated output third-order intercept point

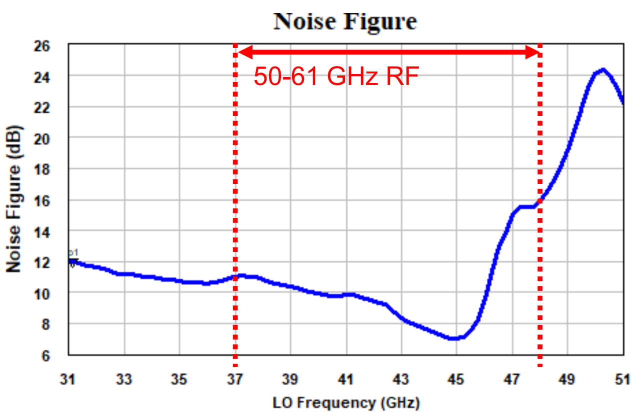

Fig. 5. Simulated noise figure

mitigation scheme shown in Fig. 2 is implemented to decrease this leakage. A dummy RF line crosses over the opposite polarity LO input line and then combines with the RF input signal through a Wilkinson combiner. The LO leakage components in the RF input line and dummy line are 180 degrees out-of-phase, so they are cancelled by the Wilkinson combiner. Fig. 3 shows the RF input manifold simulated with and without this mitigation technique. The LO to RF leakage is decreased by more than 22 dB across the target frequency band at the expenses of a 3.5 dB increase in RF insertion loss due to the Wilkinson combiner. This frontend insertion loss degrades the mixer's gain and noise figure but has the added benefit of improving the RF input match.

Following the input manifold, shunt and series transmission lines are used for the input match of the RF and LO devices. The LO device drains are connected to LC tanks tuned to the 12.8 GHz IF to increase conversion gain. The LO device drains are also connected to the mixer's differential outputs through series inductors followed by shunt capacitors, providing the output match and filtering out the unwanted high frequency RF and LO signals at the IF outputs.

II. Simulated Results

Fig. 4 shows the simulated large-signal S-parameters for the mixer. Across the 50-61 GHz RF band, a peak conversion gain of 12.6 dB and average conversion gain of 5.3 dB is achieved. The RF input return loss and IF output return losses are at least -10 dB across the entire band. The LO input return loss is better than -10 dB at the upper end of the frequency band but degrades to -4 dB at the lower end of the frequency band. Future work will focus on the co-design of the mixer and an integrated LO driver to mitigate this poor LO match.

The mixer achieves an average noise figure of 10.1 dB and a minimum noise figure of 7.0 dB at 58 GHz RF, as shown in Fig. 5. At the upper end of the band where the conversion gain decreases, the noise figure degrades to 16 dB. Fig. 6 shows the simulated output third-order intercept (OIP3). The mixer achieves and average OIP3 of 15.1 dBm across the frequency band. This OIP3 is limited by the LO drive and the voltage headroom required to keep the cascoded RF and LO devices in saturation. The mixer consumes 34 mA current from its 15 V drain supply, resulting in 0.51 W power dissipation.

The mixer is currently being fabricated, with test results expected in late 2023.

References

[1] E. J. Wilkinson, "An N-Way Hybrid Power Divider," *IRE Transactions on Microwave Theory and Techniques*, vol. 8, no. 1, pp. 116-118, January 1960