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Design of a C-Band Image Reject Mixer as a GaAs MMIC

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This article describes the design process and performance results for a 5.2-5.8 GHz image reject mixer IC, developed as part of a university MMIC design course

As in many engineering decisions there is the tradeoff between simple and straightforward versus complex but higher performance. In many radio frequency (RF) systems a desired signal is down-converted to a lower frequency then converted to digital signals with an analog-to-digital converter for further processing. One tradeoff is the bandwidth and frequency of this conversion. A higher bandwidth or higher intermediate frequency requires a higher speed A/D converter and higher power consumption. In this article, an example of a diode based image reject mixer at C-Band is described along with a discussion of some of the performance tradeoffs in deciding on an appropriate intermediate frequency.

Image Reject Mixer

A standard mixer combines a received RF signal with a fixed frequency local oscillator (LO) signal to generate a sum and difference signal (Figure 1). The low frequency difference signal or intermediate frequency (IF) is then low pass filtered and decoded into the desired data stream. With the standard mixer, there is no differentiation between an RF signal that is higher or lower than the LO frequency by the desired IF rate.

An image reject mixer provides a means of selecting the upper side band (USB) or lower side band (LSB) relative to the LO to limit interference from other unwanted sources. Ideally, the rejection between the USB and LSB would be infinite but in practice a minimum of 20 dB (often more) is desirable.

A block diagram of an image reject mixer (Figure 2) can be found in many textbooks such as *Microwave Engineering* by David Pozar. The RF signal is split with a 90 degree hybrid and fed to two identical mixers supplied with a common LO signal. Outputs of the two mixers are then combined in another 90 degree hybrid at the IF frequency providing USB and LSB outputs. The amount of rejection of a signal into the proper side band depends on the balance of the circuits, particularly the 90 degree phase difference of the RF and IF hybrids.

In the tradeoff of integration, size, and performance, the choice of the IF frequency deter-

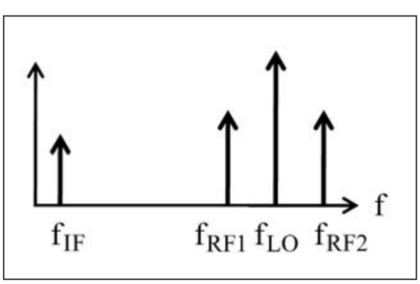

Figure 1 · Spectrum of a down-conversion mixer ($f_{IF} = f_{RF2} - f_{LO} = f_{LO} - f_{RF1}$; f_{RF1} = LSB; f_{RF2} = USB).

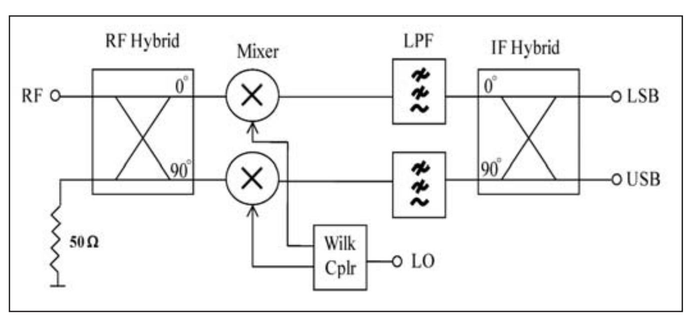

Figure 2 · Block diagram of an image reject mixer with 0° and 90° phase shifts applied to RF and IF.

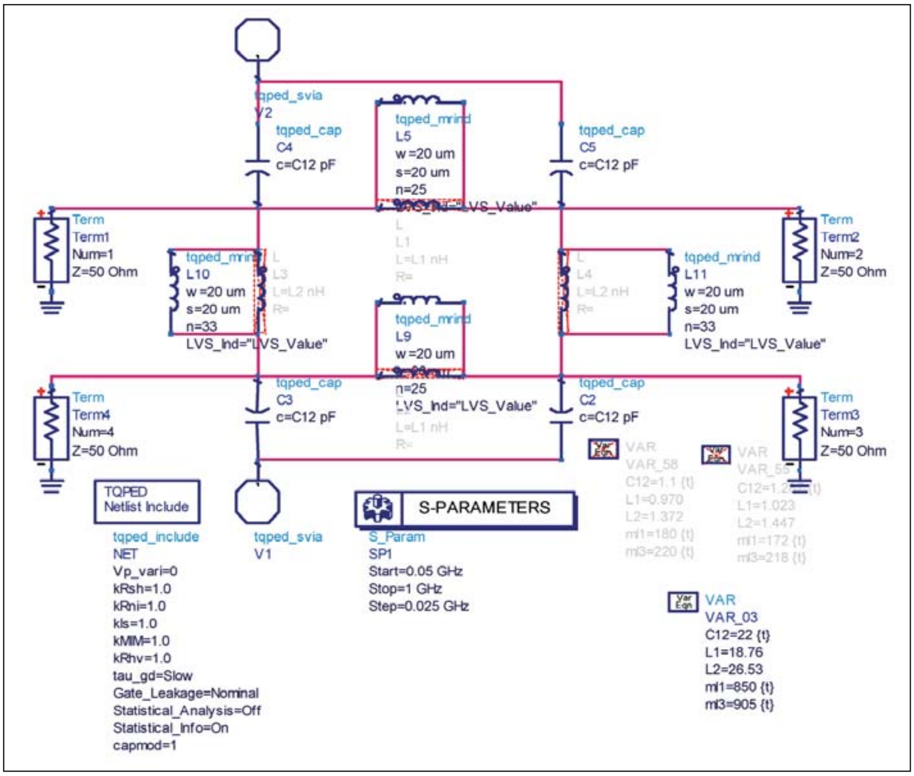

Figure 3 · Schematic of 300 MHz IF Hybrid (uses TriQuint TQPED library).

mines whether the IF 90 degree hybrid can be implemented on the MMIC, or whether it should use discrete chip components. A lumped element implementation of the 90 degree hybrid requires four inductors and four capacitors. Since the inductors become larger at lower frequencies, an image reject mixer with an IF of 300 MHz was chosen for integration on a GaAs MMIC. The tradeoff for these inductors is size versus loss in designing the hybrid on a single GaAs die. Initially, a 300 MHz lumped element hybrid was designed and tested on a 54 × 84 mil GaAs die fabricated with the Prototype Wafer Option (PWO) from TriQuint Semiconductor using their TQPED 0.5 µm PHEMT process. The IF hybrid was fabricated as one of the test circuits for the 2006 Johns Hopkins University MMIC Design Course (ECE 787). In the 2007 JHU MMIC class design submissions, the IF hybrid was reused to create a full C-Band image reject mixer on a 54 × 114 mil GaAs die.

The image reject mixer without the IF hybrid was also fabricated and tested on a separate 54 × 54 mil GaAs die using available space on the quarter tile from the 2007 JHU MMIC Design class.

IF Hybrid

A lumped element implementation of a hybrid coupler consists of four equal value capacitors and four inductors which have paired values to correspond to the 35 and 50 ohm transmission lines in the distributed hybrid coupler. Figure 3 shows the schematic of the 300 MHz IF hybrid coupler where ideal inductors are replaced by TriQuint TQPED spiral inductors. The IF hybrid was fabricated on a 54 × 84 mil GaAs die and measured with a probe station show-

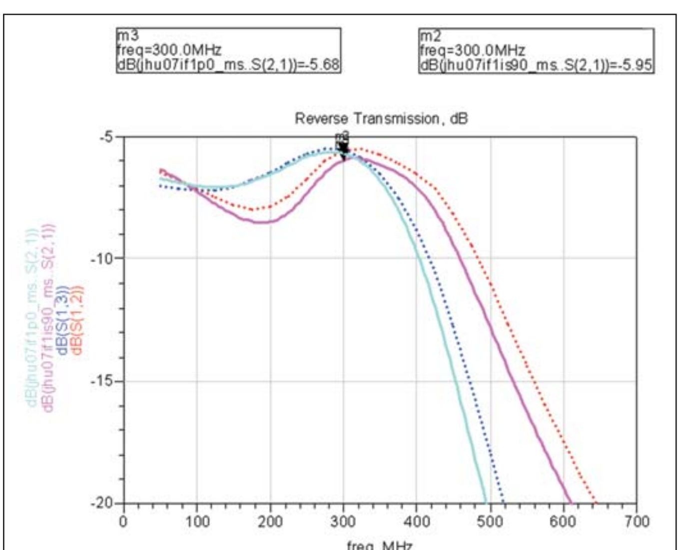

Figure 4 · Measured (solid) versus simulated (dotted) direct and coupled ports for the 300 MHz hybrid.

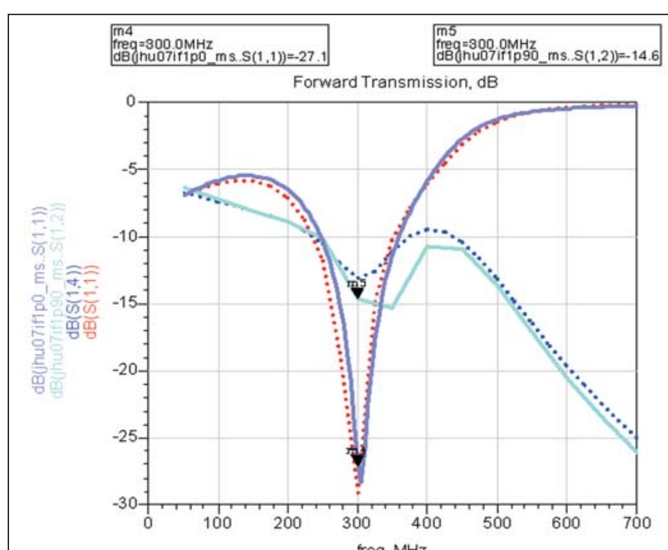

Figure 5 · Measured (solid) versus simulated (dotted) return loss and isolation for the 300 MHz 90 degree hybrid.

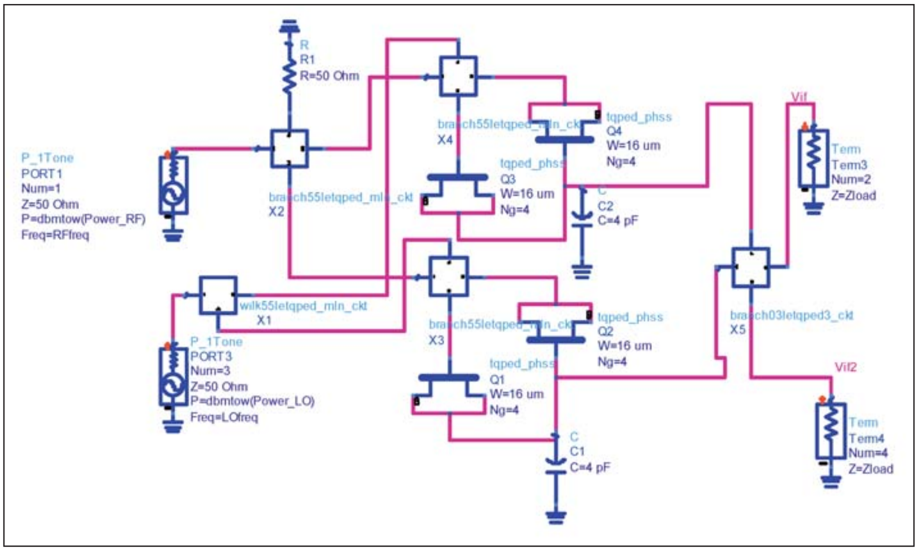

Figure 6 · Schematic of 5.5 GHz C-Band mixer without IF hybrid (uses TriQuint TQPED library).

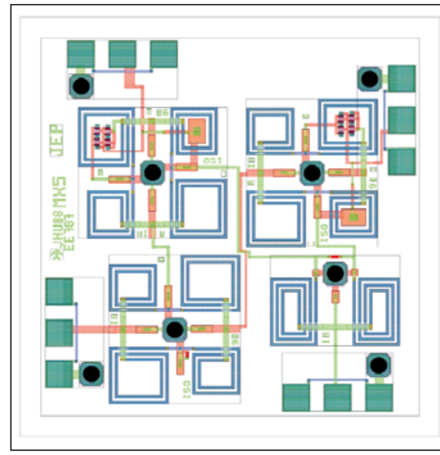

Figure 7 · Layout of the C-Band IR mixer without IF combiner (54 × 54 mil die).

ing good agreement with the original simulations (Figures 4 and 5). Insertion loss was about 5.5 dB as expected which is 2.5 dB worse than an ideal hybrid coupler. For the full image reject mixer, the IF hybrid layout was slightly modified to squeeze into the available die space.

5.5 GHz 90 Degree Hybrid

The LO was chosen to be about 5.5 GHz so that the bands around 5.2 GHz and 5.8 GHz could be received as the USB and LSB outputs. A lumped element hybrid was implemented using four capacitors and four inductors, identical to the IF hybrid schematic (Fig 3.) but with the appropriate values for the higher frequency. In the image reject mixer, this hybrid is used to split the RF (or the LO) into equal signals with a 90 degree phase shift, and is also used to create the standard mixer with the addition of anti-parallel diodes.

5.5 GHz Wilkinson

A Wilkinson splitter is used to provide an equal in phase split of the LO (or RF) to the two mixers. The lumped element Wilkinson coupler is created with two series inductors, three shunt capacitors, plus a 100 ohm resistor for isolation between the direct and coupled ports.

To allow the USB and LSB signals to combine or cancel at the outputs of the IF hybrid, the required 90 degree phase difference can be applied to either the LO or the RF, while the other (RF or LO) gets the in-phase split of the Wilkinson coupler.

Image Reject Mixer MMIC

Figure 6 shows the high level schematic of the image reject mixer which consists of one RF Wilkinson coupler, three RF hybrid couplers, four diodes for the two standard mixers, and an IF hybrid to provide the USB and LSB outputs. Since the lower frequency IF hybrid takes up a lot of space with its large inductors, the first layout (Figure 7) of the image reject mixer on a 54 × 54 mil die consists of the entire image reject mixer minus the IF hybrid—three C-Band lumped element hybrids, four diodes to create the mixers, and a C-band Wilkinson coupler. Adding the IF hybrid coupler to the image reject mixer required a 54 × 114 mil die as shown in Figure 8. Simulations (Figure 9) show an expected rejection of about 18 dB between USB and LSB at the image reject mixer outputs. The measured results agree well with these simulations with about 17 dB of measured image rejec-

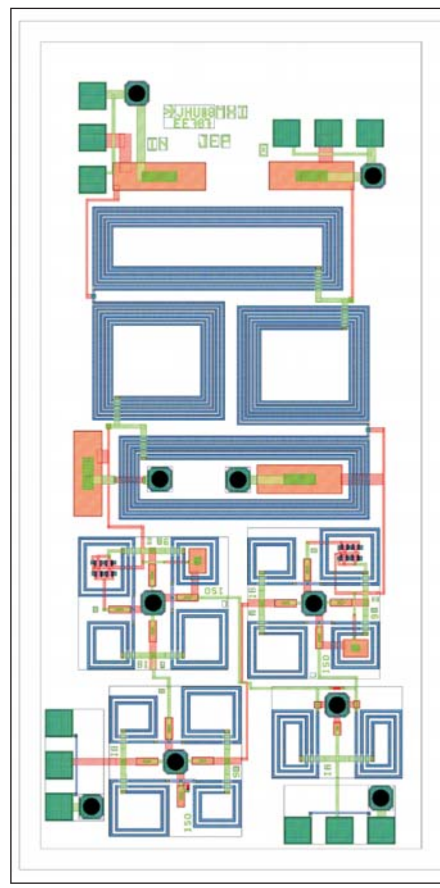

Figure 8 · Layout of the C-Band image reject mixer with IF hybrid (54 × 114 mil die).

tion. Comparing the mixer conversion loss with and without IF hybrid showed about a 3 dB difference in conversion loss which agrees with the additional 2.5 dB of insertion loss of the IF hybrid over an ideal split. The LO drive during measurements was lower than ideal resulting in a higher conversion loss than could be achieved according to simulations. The measured 17 dB conversion loss correlates with the lower LO drive of the test, but should be a much better 11 dB with 3 dB more LO drive. A simple modification that could lower the LO power required for good conversion loss would be to forward bias the diodes in the mixers near their threshold voltage. An extra input for a small DC voltage with a 2k ohm resistor to limit forward current would be a simple modification.

Summary

The approach of combining the IF combiner on the MMIC chip of the image reject mixer may have sacrificed some loss due to the limited Q of on chip passive components, but it makes for a simplified single chip, reliable image reject mixer design. Performance of the measured 54 × 114 mil GaAs MMIC agreed well with simulations. The author would like to acknowledge TriQuint Semiconductor for their support of the Johns Hopkins University MMIC Design Course since 1989.

Author Information

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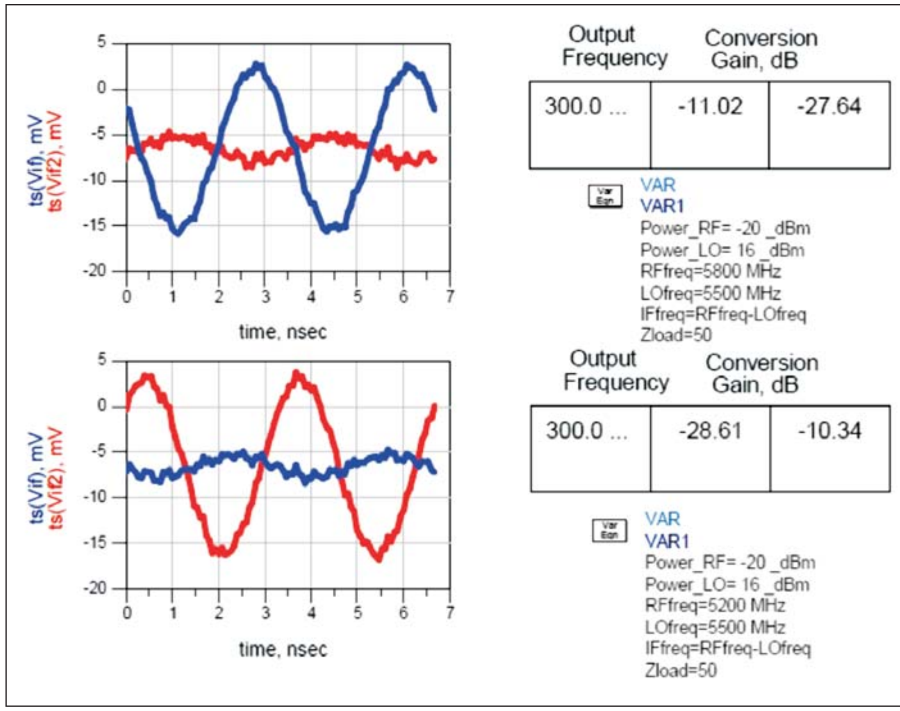

Figure 9 · Simulation of USB and LSB signal paths of the mixer with an LO of 5.5 GHz, RF of 5.2 and 5.8 GHz.