ISM Band Up/Down Mixer

Design Project Final Report

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Abstract

This paper describes the design and simulation of an Industrial, Scientific and Medical (ISM) band up/down mixer using the TriQuint Oregon process (TQOR TQPED) for monolithic microwave integrated circuit (MMIC) fabrication. The mixer was designed for a radio frequency (RF) input range of 2.4 – 2.5 GHz. The local oscillator (LO) design frequencies range from 2.3 – 2.6 GHz with an up/down-converted intermediate frequency (IF) of 100 MHz. The design uses two E-mode PHEMT devices, configured as diodes, and a rat race 180° hybrid coupler. Design simulations verified acceptable results: conversion loss less than 14 dB, RF/LO isolation greater than 20 dB, RF/LO input match of 10 dB return loss for a VSWR less than 2.0:1. The mixer did not meet all design requirements at the specified LO power of +7dBm. The design was not able to achieve the 10 dB conversion loss requirement at +7 dBm. The total DC power consumption is 0.988 mW from one 1.89 V supply. All simulations were performed in Microwave Office version 9.01b build 4856 Rev 1 from Applied Wave Research, Inc. (AWR) with the TriQuint process library v1.1.21.11.

1. Introduction

This ISM band up/down mixer design is intended to be part of the chip set for an ISM band transceiver. The up/down mixer utilizes a lumped element 180° hybrid rat race coupler with two diode configured E-mode PHEMT transistors to perform the mixing. An ideal lumped element model of this mixer is shown below in Figure 1.

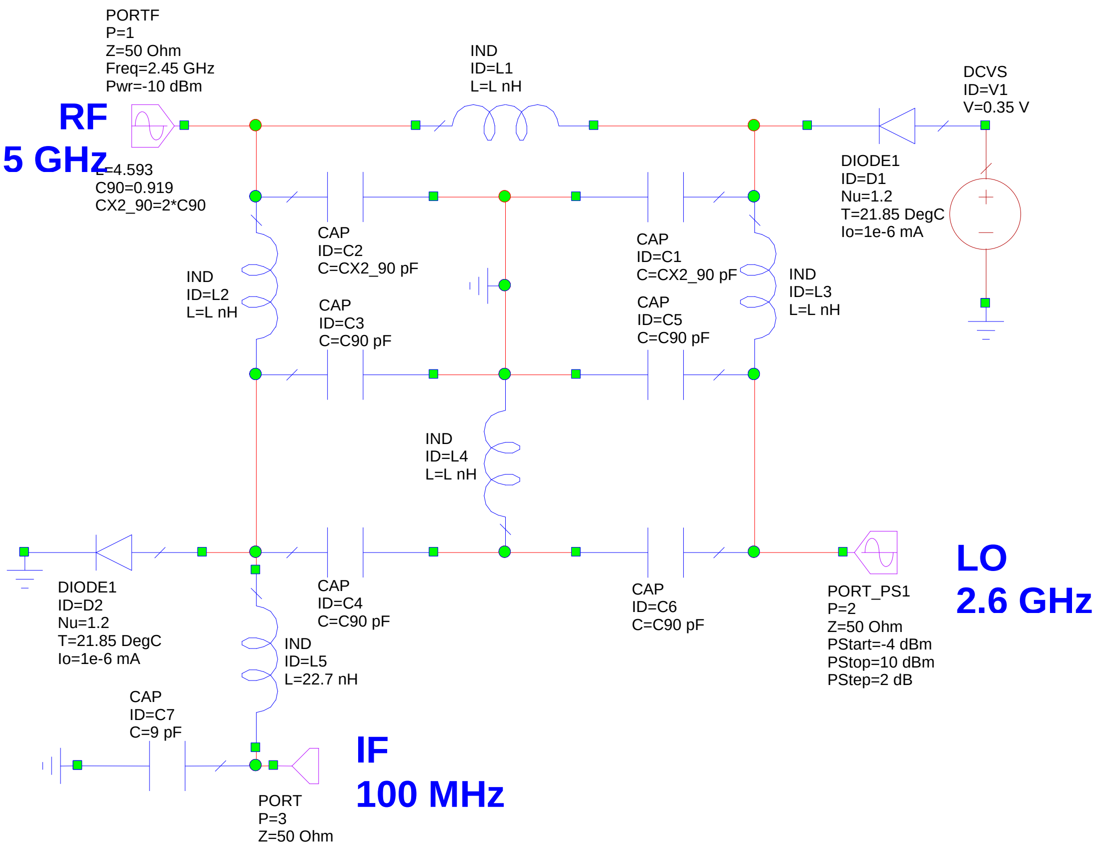

Figure 1: Ideal lumped element model of an ISM band up/down mixer

The designed ISM band up/down mixer RF frequency range is 2.4 – 2.5 GHz and the LO frequency range is 2.3 – 2.6 GHz with an IF design frequency of 100 MHz. The design goal of the mixer was to provide 10 dB of conversion loss with a LO input drive of +7 dBm. While the design is functional the above goal was not achieved. Design simulations show conversion loss is approximately 13.3 dB with -10 dBm RF input and +7 dBm LO input power. Optimal performance achieves 13 dB conversion loss with an LO input drive of + 12 dBm. The RF/LO input matches achieve 10 dB or greater return loss, with LO to RF isolation greater than 20 dB.

2. Design Approach

As part of the chip set for an ISM band transceiver, the up/down mixer must be designed to interface properly with the surrounding chips and packaging. This requires a block diagram with input/output (I/O) requirements defined for each MMIC chip. Often it is helpful to have a cascaded model of all the chips and packaging to identify any design aspects that need to be improved. However, due to time constraints, this was omitted and each MMIC chip designer was asked to consider this independently.

2.1. Block Diagram

Figure 2 below is the block diagram of the ISM band transceiver. This block diagram was used to define the basic I/O requirements for each MMIC chip design.

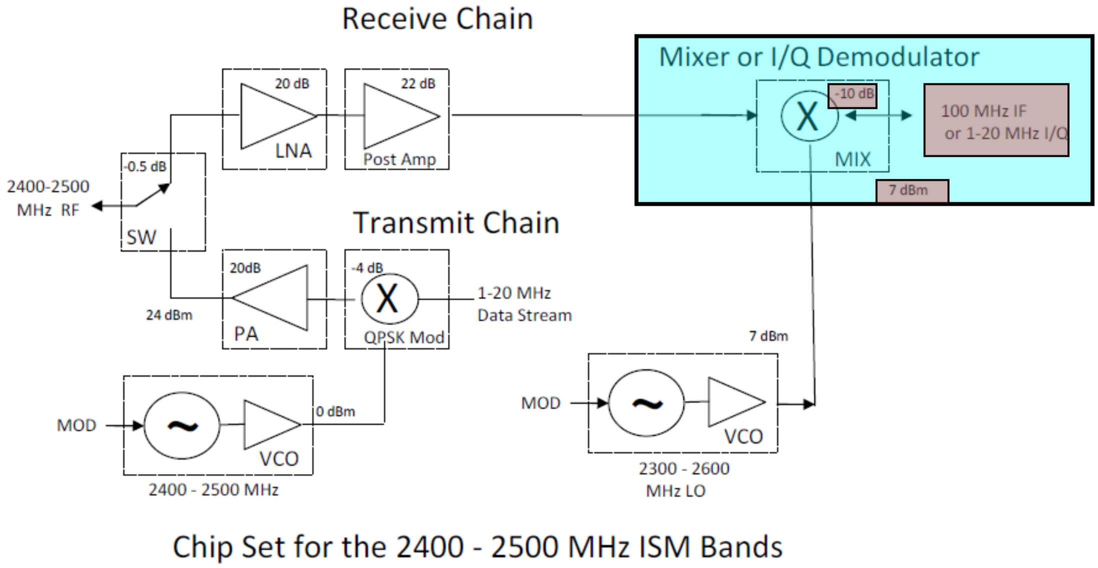

Figure 2: Block Diagram for ISM Band Transceiver Chip Set.

The ISM band up/down mixer and its basic requirements are highlighted in the block diagram in Figure 2 above. Other specific goals will be defined in the sections below.

2.2. Specific Goals

Using the requirements given in the block diagram in Figure 2 and basic RF performance knowledge, the following table of requirements and design goals were compiled to proceed with designing the ISM band up/down mixer.

Table 1: ISM band up/down mixer requirements and goals

Mixer Property	Minimum Requirement	Design Goal
RF Frequency Range	2.4 to 2.5 GHz	2.3 to 2.6 GHz
LO Frequency Range	2.3 to 2.6 GHz	2.3 to 2.6 GHz
IF Frequency	100 MHz	100 MHz
LO Input Power	+7 dBm	+7 dBm
Conversion Loss	10 dB	10 dB
Isolation (LO/RF)	Not Specified	20 dB
Return Loss/VSWR	Not Specified	9.54 dB/2.0:1 VSWR

In order to best meet the above design requirements, the following design approach was taken: Generate ideal models for each part of the design and slowly add non-ideal elements. This was done for the 180° hybrid rat race coupler, IF filter, diodes and finally the overall mixer with extracted RF traces in the finalized layout.

2.3. 180° Hybrid Rat Race Coupler Design

The rat race coupler was first designed ideally centered in the 2.3 to 2.6 GHz band or at 2.45 GHz. This ideal design was then implemented using non-ideal TriQuint elements. The figures below show the schematics and Sparameters for the non-ideal optimized circuit only.

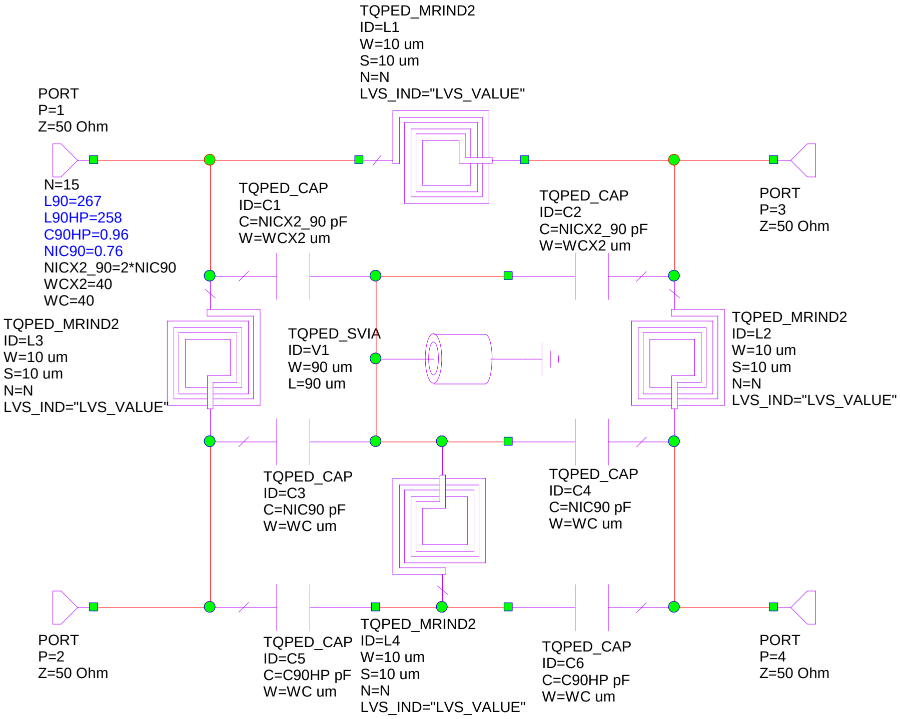

Figure 3: Non-ideal 180° Hybrid Rat Race Coupler

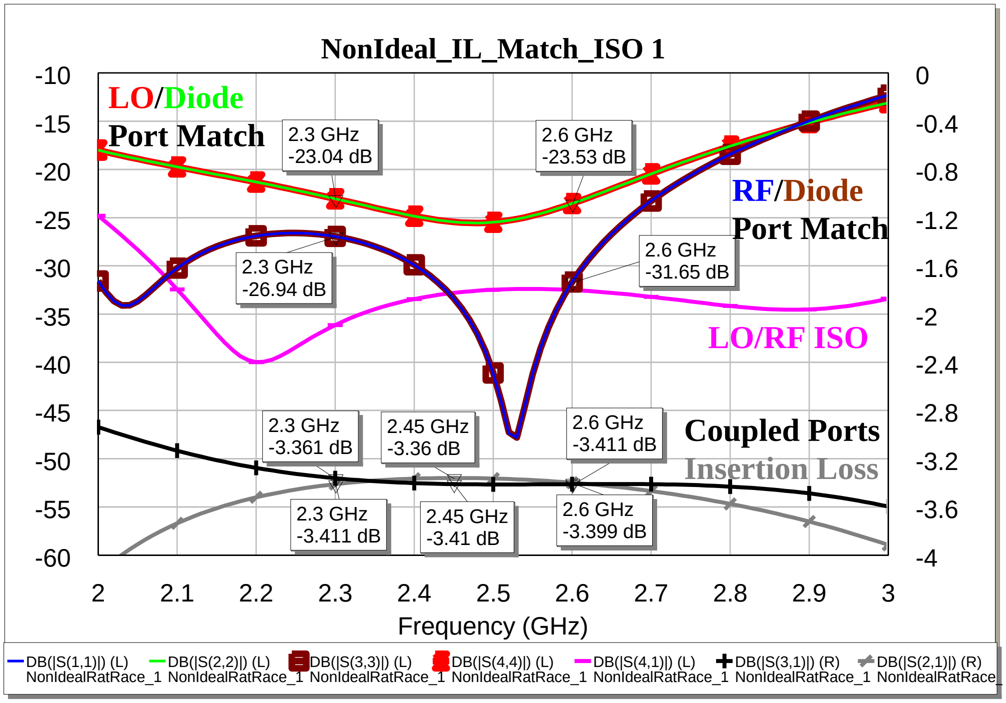

Figure 4: Sparameters for non-ideal rat race coupler design

2.4. IF Filter Design

Since a large inductor was required to create the IF port on the rat race coupler, a simple second order IF filter was designed to reduce the RF and LO present on the IF output. Ideal and non-ideal filter responses are plotted in Figure 5 below.

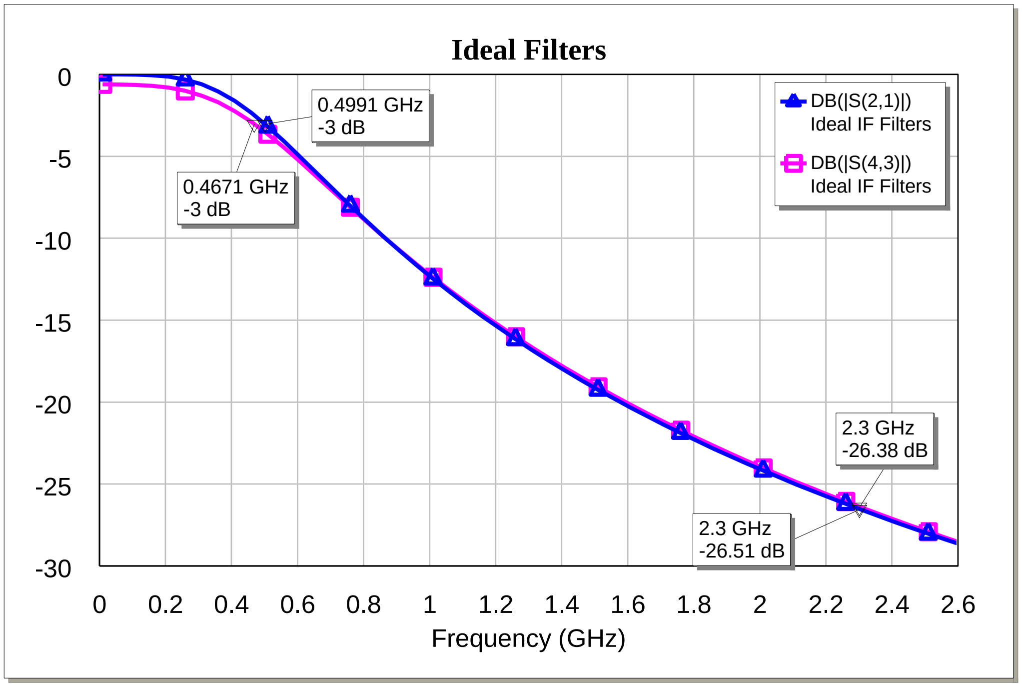

Figure 5: IF filter responses ideal (blue) and non-ideal (pink).

2.5. Diode Design

Both D-mode and E-mode PHEMT transistors were available for use in a diode configuration. Transistors can be utilized as diodes by shorting drain and source together to form the cathode and the gate becomes the anode. To have the least impact on the rat race coupler performance, the diodes would ideally look like 50Ω loads. However, these diodes look like low value series RC's when ploted on a Smith chart. Matching networks could be designed to match the diode to the 50Ω rat race coupler, but they consume valuable real estate on the 60 X 60 mil anachip layout. For this reason the periphery of the transistor was optimized to provide the best performance.

After simulating both D-mode and E-mode diodes with the rat race coupler, an E-mode diode was selected with three, 30um long gates (3x30um=90um periphery). The IV characteristic of this E-mode diode is plotted in Figure 6 below.

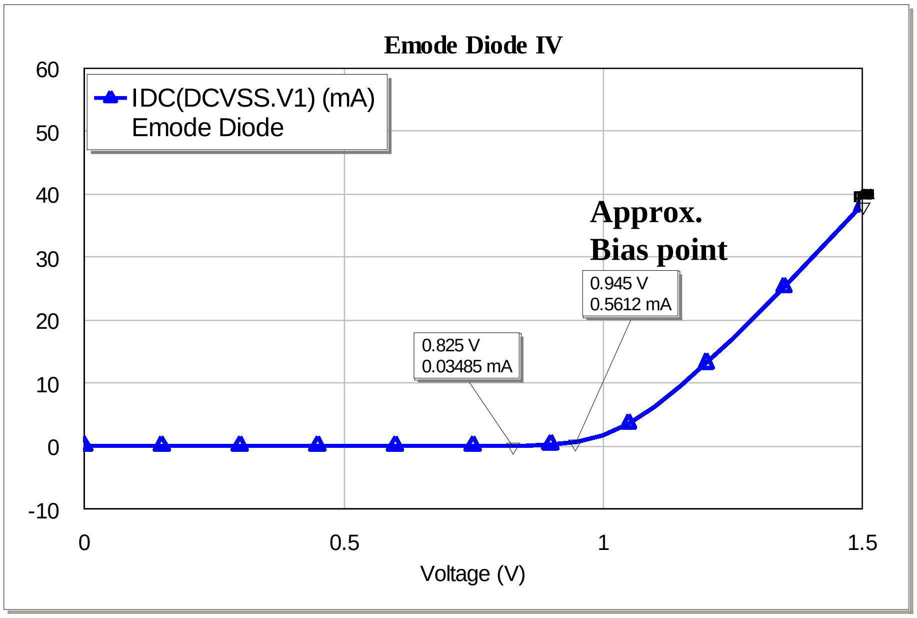

Figure 6: 3 x 30 um Emode diode bias point in mixer design.

2.6. Mixer Design

The E-mode diodes were added to the rat race coupler to create the ISM band up/down mixer configuration. The diodes were added to ports 2 and 3 in an anti-parallel configuration. The IF filter was also added to port 2 of the rat race coupler to create the IF port of the mixer. Diodes were biased at the turn on threshold in order to reduce the amount of LO input power required to turn them on and off. This diode bias made it necessary to add DC blocking capacitors to the RF, LO and IF ports to prevent the bias current from flowing into the RF terminations. This allowed the diodes to be properly biased, while preserving the RF performance of the mixer. Sparameters of the final mixer design are shown in Figure 7 below.

2.7. Trade Offs

Many trade offs had to be made during the design of the ISM band up/down mixer. The main performance trade made was the balance between conversion loss and port match. Diode size and bias could be optimized for conversion loss or port match, but not both. Ultimately, I chose to sacrifice the 10 dB conversion loss requirement in order to provide a better match to the rest of the ISM band transceiver. The 3 dB increase in conversion loss could be absorbed by an amplifier on either side of the mixer without impacting the overall transceiver performance. The lack of space on the anachip layout also impacted this performance trade by not having enough space to add diode matching networks.

3. Simulations

A summery of simulation results is shown in Table 2.

Table 2 : Summerized Simulation Results

Mixer Property	Simulated Result	Minimum Requirement/Goal
Conversion Loss	13.3 dB	10 dB
LO Input Power	+7 dBm	+7 dBm
Isolation (RF/LO)	> 24 dB	20 dB
Match/VSWR	9.9 dB/1.94:1 VSWR	9.54 dB/2.0:1 VSWR

3.1. Linear Simulations

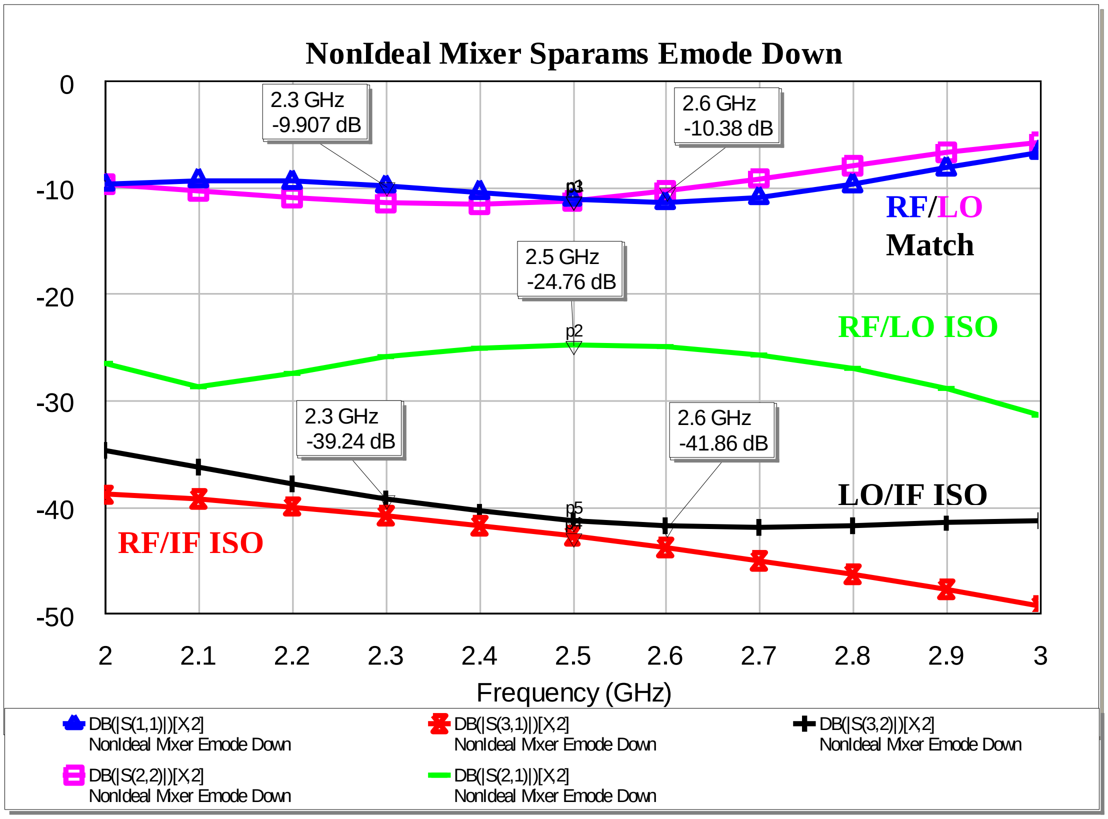

Figure 7: Final ISM band up/down mixer linear Sparameters.

3.2. Non-Linear Simulations

3.2.1. Up Conversion Loss

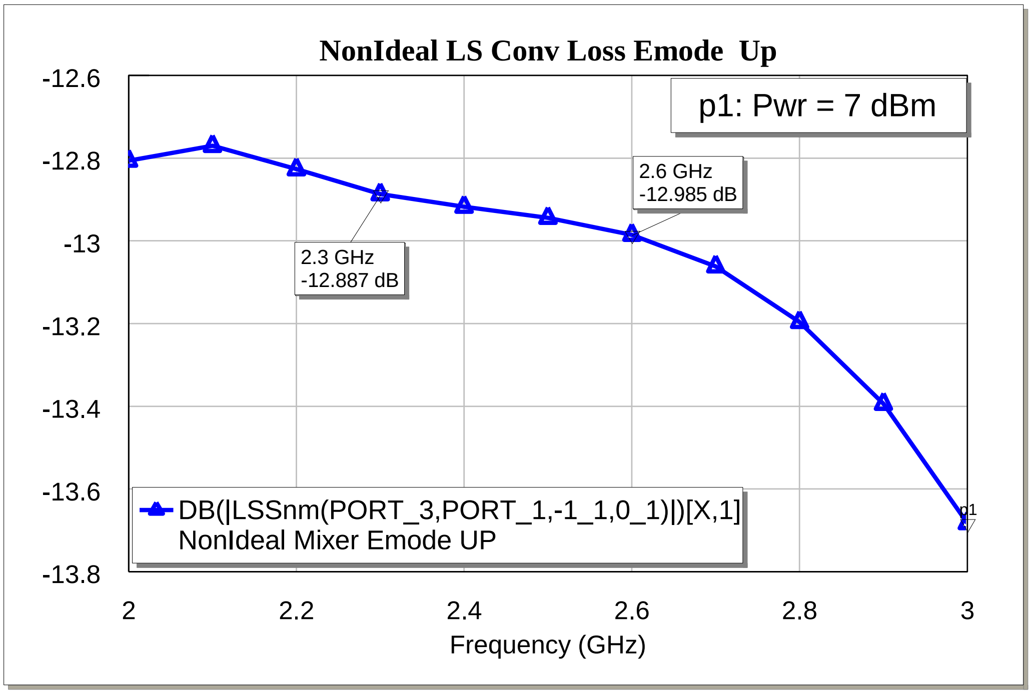

Figure 8: Up conversion loss vs. frequency

3.2.2.Down Conversion Loss

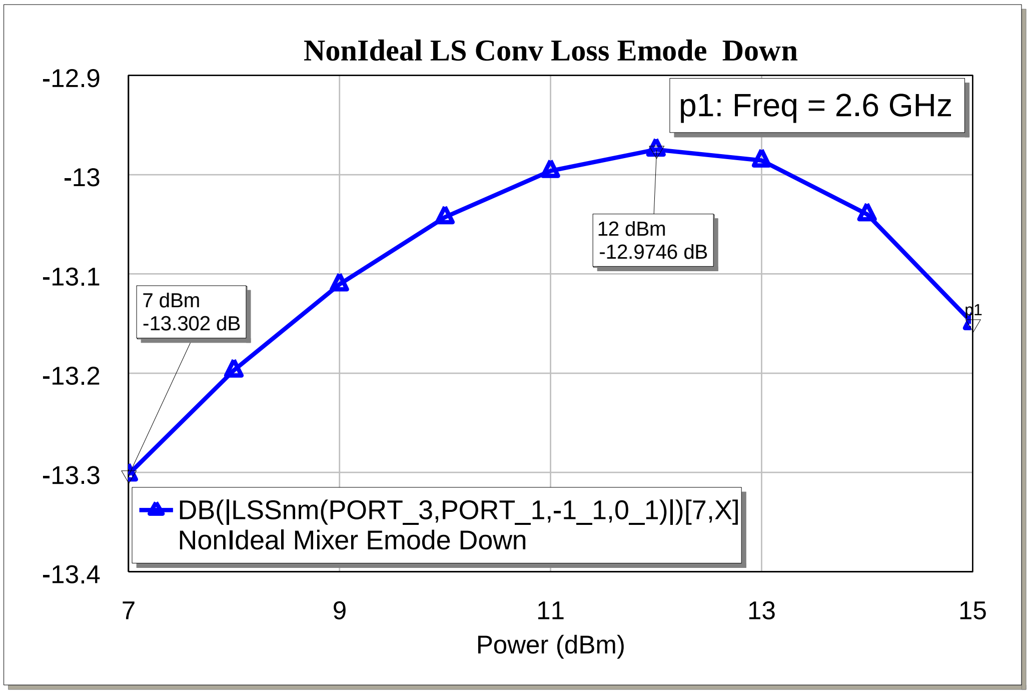

Figure 9: Down conversion loss vs. LO input power

3.2.3. Up Conversion RF Spectrum

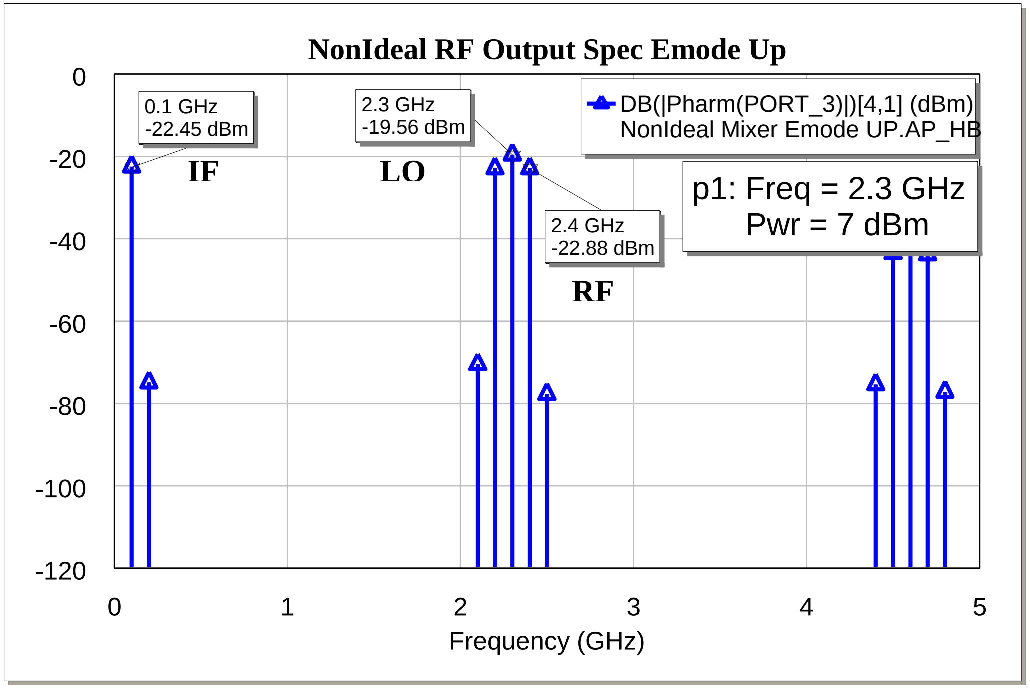

Figure 10: Low band Up conversion RF Spectrum IF=-10 dBm, LO=7 dBm

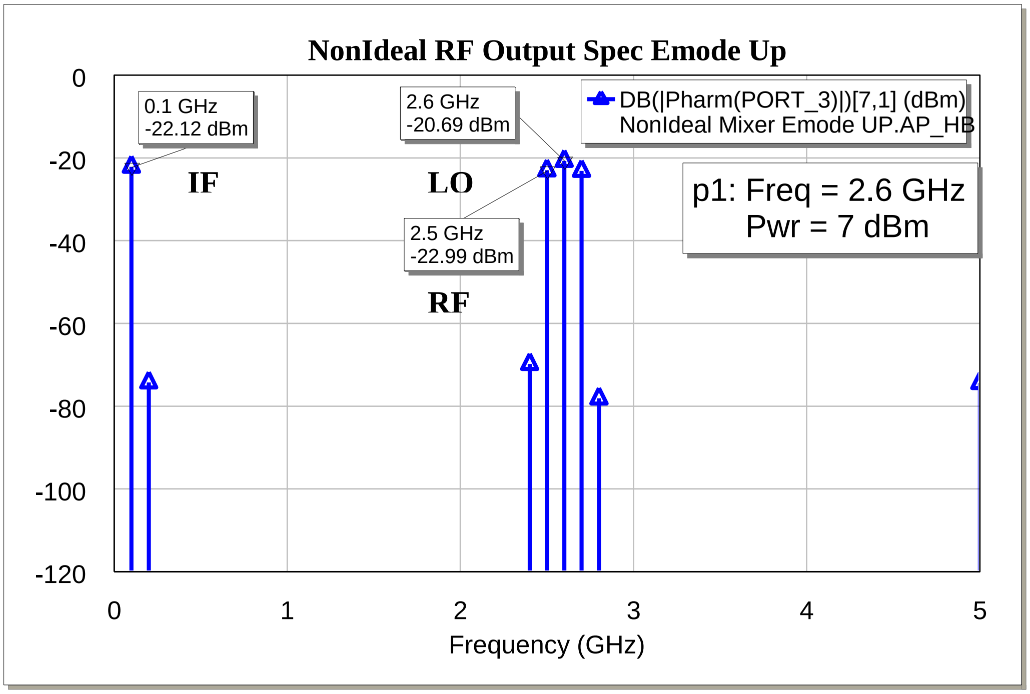

Figure 11: High band Up conversion RF Spectrum IF=-10 dBm, LO=7 dBm

3.2.4. Down Conversion IF Spectrum

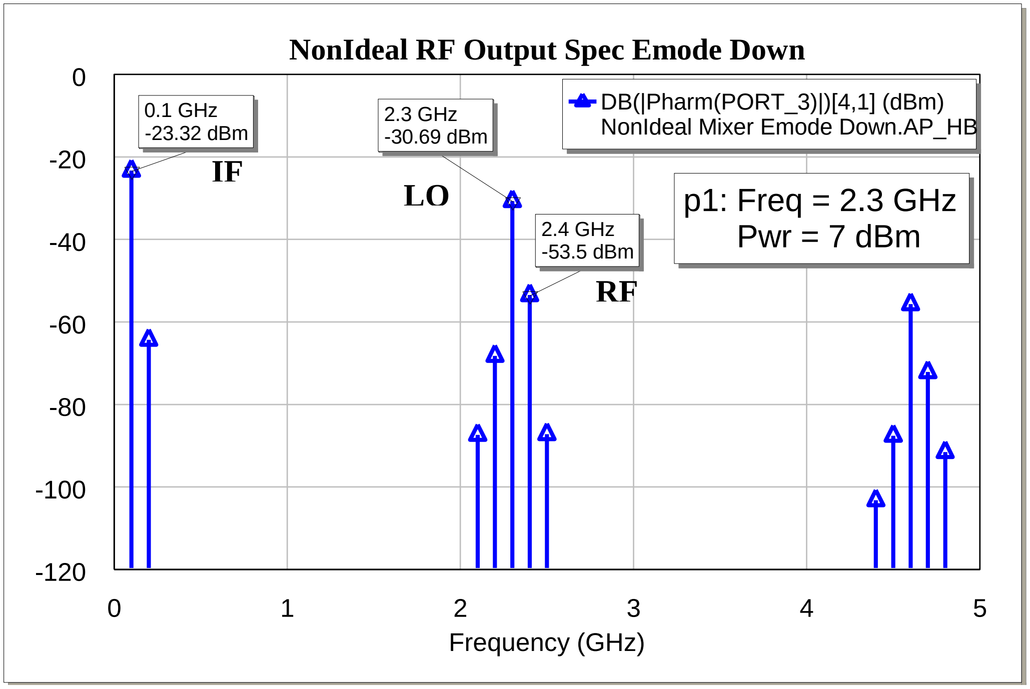

Figure 12: Low band Up conversion IF Spectrum RF=-10 dBm, LO=7 dBm

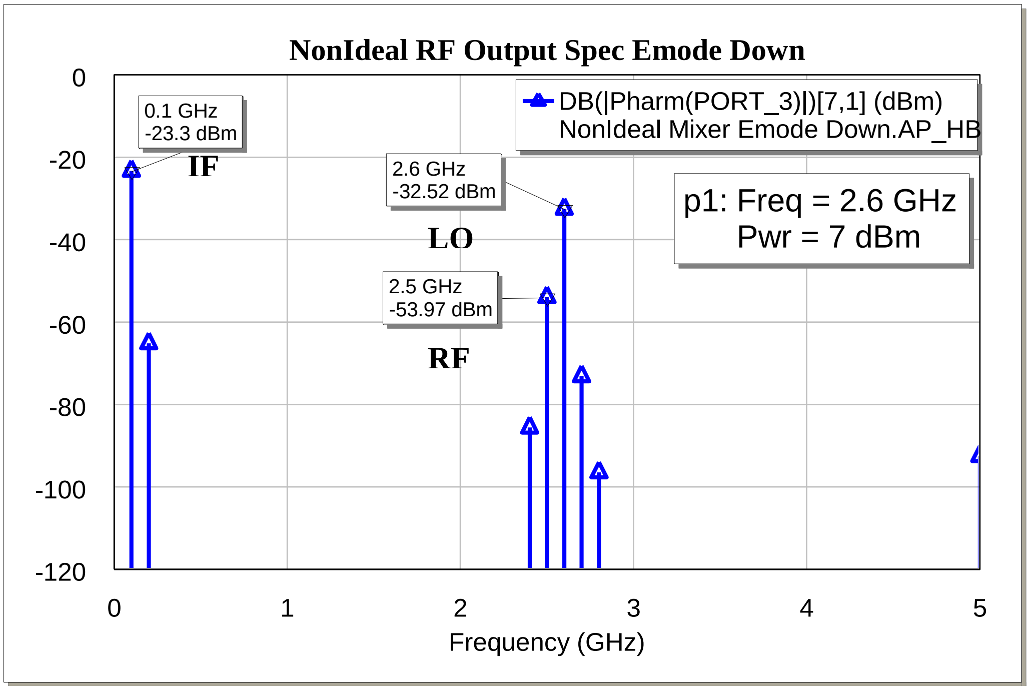

Figure 13: Low band Up conversion IF Spectrum RF=-10 dBm, LO=7 dBm

3.3. DC Bias (1.89V @ 0.528 mA)

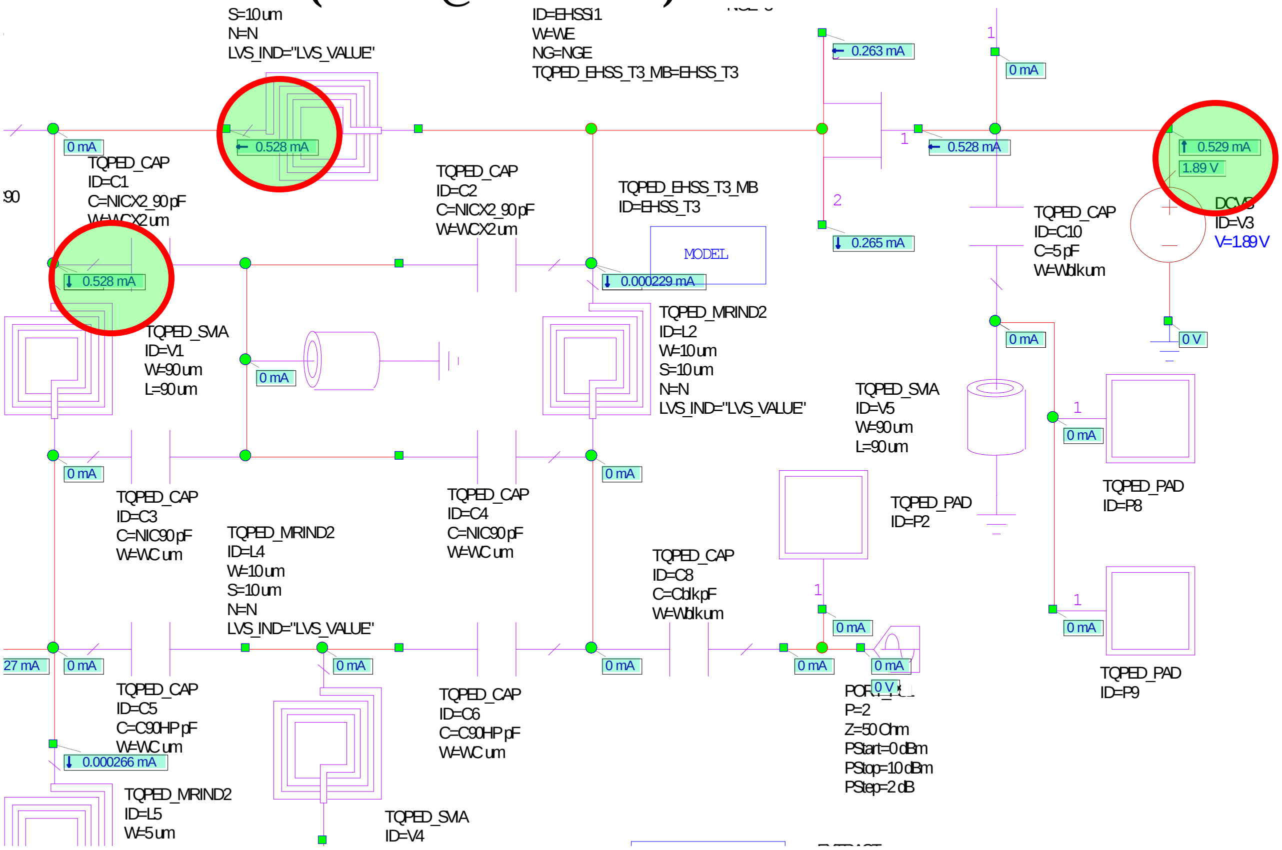

Figure 14: DC Bias Analysis

4. Schematics

4.1. RF Schematic

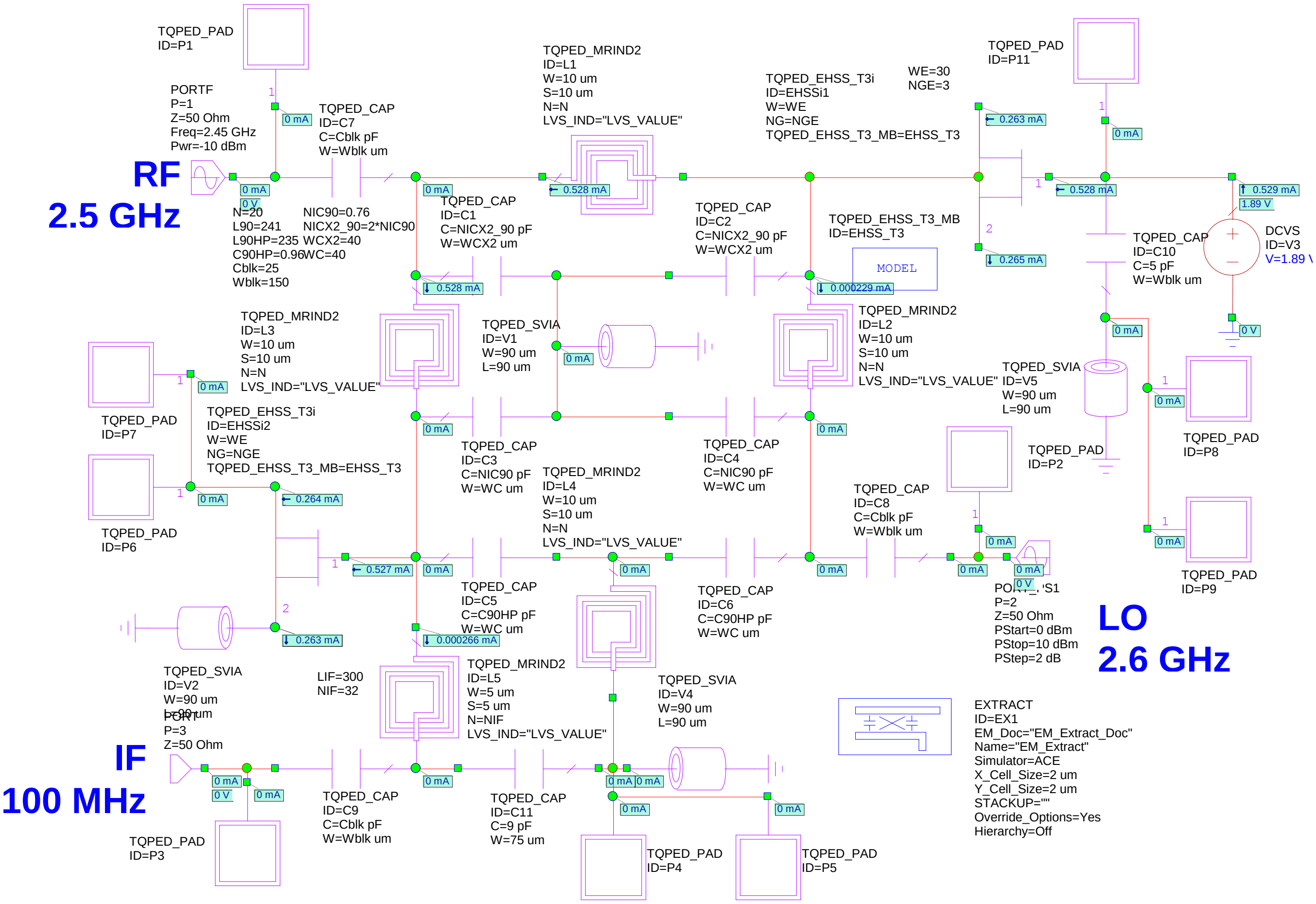

Figure 15: ISM band up/down mixer RF schematic

4.2. Simple DC Schematic

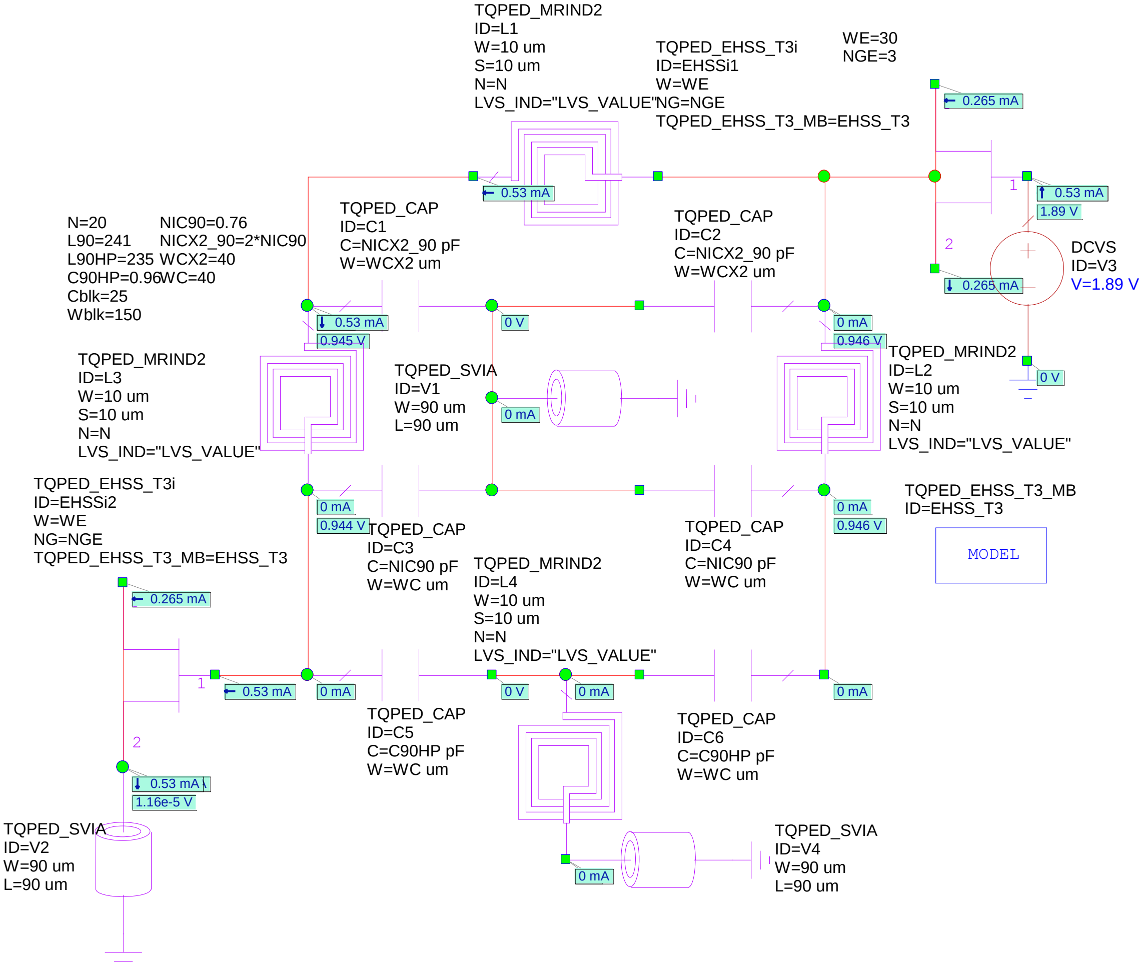

Figure 16: Simple DC schematic of ISM band up/down mixer

5. Layout

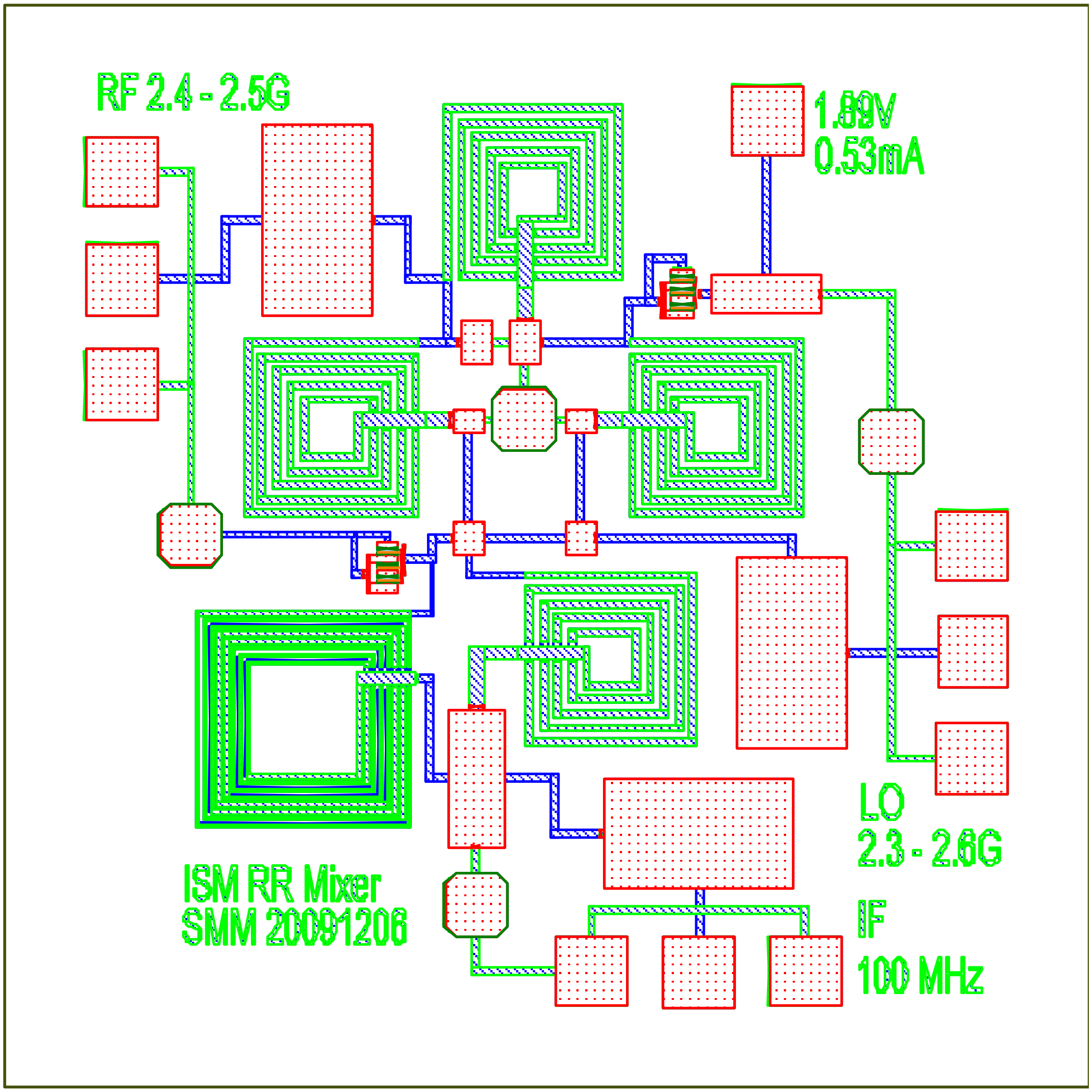

Figure 17: Final layout of ISM band up/down mixer on 60 x60 mil anachip.

6. Test Plan

6.1. Sparameter Testing

1. Connect network analyzer to the appropriate ports. Use RF as port 1 and LO as port 2. Setup to sweep from 2.0 – 3.0GHz.
2. Terminate IF port into a 50 ohm load
3. Apply 1.87 Vdc to the DC bias terminal. Should see 0.528 mA current draw.
4. Measure the s-parameters

6.2. Up Mixer Testing

1. Connect a signal generator to the LO port. Setup sweep from 2.3 – 2.6GHz in 0.1GHz increments. Set power output to +5dBm.
2. Connect a signal generator to the IF port. Set the frequency to 100MHz. Set power output to -10dBm.
3. Connect a spectrum analyzer to the RF port
4. Apply 1.89Vdc to the DC bias terminal. Should see 0.528 mA current draw
5. Measure RF output power at each LO frequency
6. Repeat above measurements for LO input powers of 7, 9, 11, and 13 dBm

6.3. Down Mixer Testing

1. Connect a signal generator to the LO port. Setup sweep from 2.3 – 2.6GHz in 0.1GHz increments. Set power output to +5dBm.
2. Connect a signal generator to the RF port. Setup to sweep from 2.4 – 2.5GHz in 0.1GHz increments. Set power output to -10dBm.
3. Note: Keep the RF and LO signals consistent with a 100MHz IF output signal
4. Connect a spectrum analyzer to the IF port
5. Apply 1.89 Vdc to the DC bias terminal. Should see 0.528 mA current draw.
6. Measure the 100MHz IF output power at each frequency interval
7. Repeat above measurements for LO input powers of 7, 9, 11, and 13 dBm

7. Summary & Conclusions

The ISM band up/down mixer design meets almost all requirements at +7 dBm LO input power. The requirement that could not be met was the 10 dB conversion loss requirement. The design could be further optimized to center the best conversion loss performance around +7 dBm LO input power and the center of the RF frequency band. However, I’m not completely sure that the 10 dB conversion loss requirement could be met. Future work would include further tuning of the rat race coupler to center the conversion loss performance. Additionally, a resistor network could be added to allow a standard battery supply voltage of 3.0 V or 3.6V to be used. Finally, given more space diode matching networks could be utilized to improve the LO and RF port matches.