

# S-Band Up/Down Mixer

EE 525.787 – MMIC Design

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# Abstract

The following report details a monolithic microwave integrated circuit (MMIC) S-Band up/down mixer design. The mixer was designed for a radio frequency (RF) input range of 2.3 – 2.5 GHz. The local oscillator (LO) design frequencies range from 2.2 – 2.6 GHz with an up/down-converted intermediate frequency (IF) of 100 MHz. Based off a rat-race coupler design, the s-band mixer incorporates TriQuint modeled PHEMT transistors as switching diodes. Design simulations verified acceptable results: conversion loss less than 9 dB, RF/LO isolation greater than 20 dB, voltage standing wave ratio (VSWR) better than 2.5:1. The mixer meets all design requirements at an LO power of +4dBm with optimal performance at +7dBm.

## 1 Introduction

With intentions of creating a configurable S-band duplex transceiver, an up/down mixer was designed to cover the wireless communications service (WCS) and industrial, scientific, and medical (ISM) frequencies. The up/down mixer incorporates a 180° lumped element rat-race coupler with diode configured transistors. An ideal lumped element model of the design is shown in Figure 1.

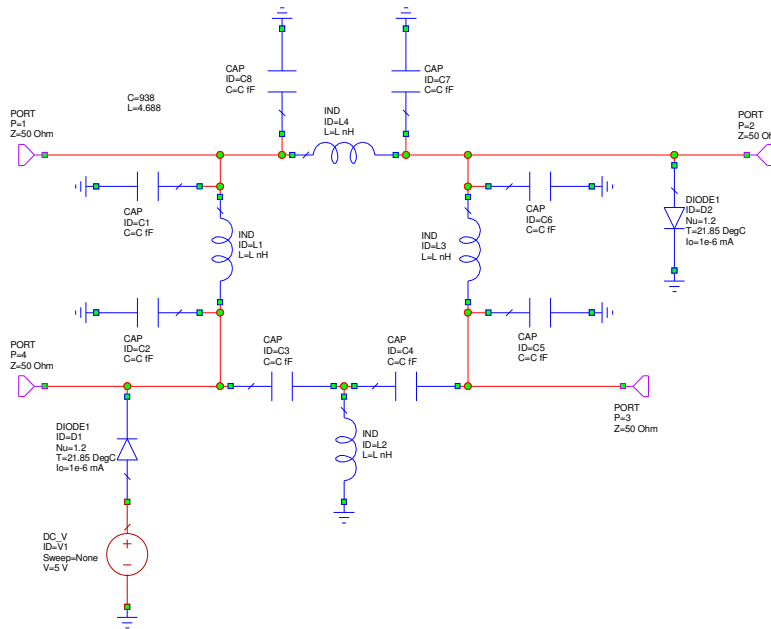


Figure 1: Ideal lumped element S-band up/down mixer

The mixer RF frequencies range from 2.3 – 2.5 GHz and the LO frequencies range from 2.2 – 2.6 GHz. The design targeted a maximum LO power of +7dBm with simulations showing a functional design at +4dBm. Simulations demonstrate conversion loss approximately 8dB, RF/LO isolation approximately 25dB, and a VSWR ranging from

1.2:1 – 2.3:1. A layout file was designed around a 60x60mil TriQuint anachip. Tradeoffs were made between layout size and circuit design for optimal performance characteristics.

## 2 Design Approach

As a subsystem of a configurable duplex transceiver, requirements must be specified prior to design implementation. Table 1 outlines these requirements.

Table 1: S-band up/down mixer design requirements

| <b>Mixer Property</b> | <b>Minimum Requirement</b> | <b>Design Goal</b> |
|-----------------------|----------------------------|--------------------|
| RF frequency          | 2.305 – 2.497 GHz          | 2.3 – 2.5 GHz      |
| LO frequency          | 2.205 – 2.397 GHz          | 2.2 – 2.6 GHz      |
| IF frequency          | 100 MHz                    | 100 MHz            |
| Isolation (RF/LO)     | 10 dB                      | 16 dB              |
| LO power              | +7 dBm                     | 0 dBm              |
| VSWR                  | 2.5:1                      | 1.5:1              |
| Conversion Loss       | 10 dB                      | 7 dB               |

Several design steps were taken in order to effectively design a mixer meeting all of the predefined requirements. An ideal model of the rat-race coupler was designed followed by a TriQuint element based design. Upon optimizing the coupler, the diode configured PHEMT devices were incorporated into both the ideal and non-ideal models.

Optimization was performed on the switching diode mixer designs. A layout file was then created and a final optimization was performed through layout property extraction. These steps are detailed in the following sections.

### 2.1 Rat-race Coupler Design

The 180° rat-race coupler was designed with both ideal and non-ideal components. In order to optimize the coupler, an equivalent power split between the coupling ports is desired. Additionally, theoretical phase requirements are desired. Figure 2 shows the non-ideal model with optimized coupled power. The non-ideal phase measurements were within the desired range.

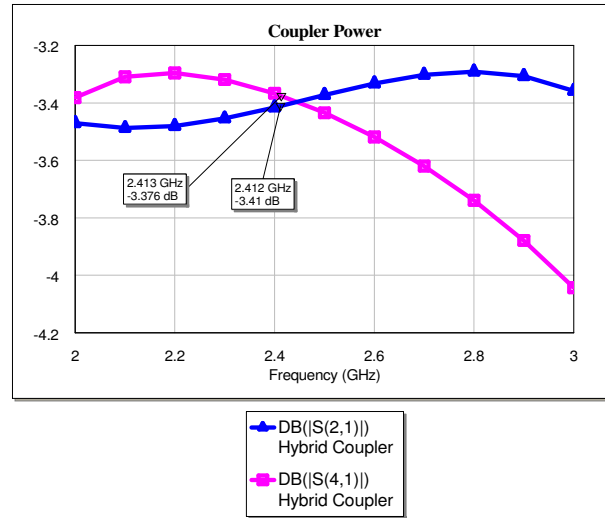
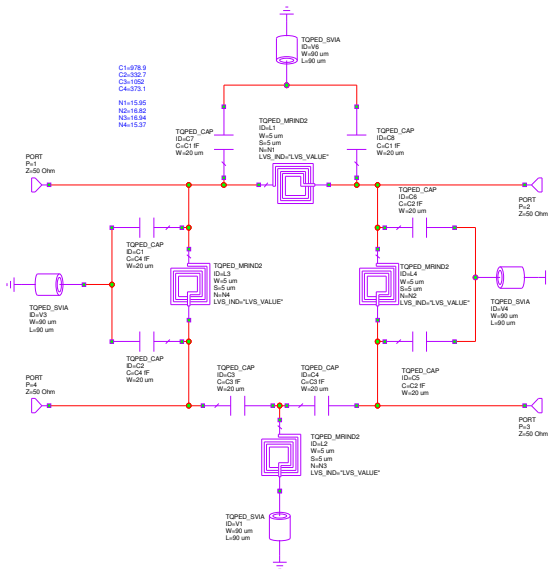


Figure 2: Non-ideal rat-race coupler (left), non-ideal coupled power (right)

## 2.2 PHEMT Diode Configuration

The TriQuint PHEMT devices were optimized to reduce the effect on the rat-race coupler when incorporated into the design. In order to function as a diode, the PHEMT drain and source terminals were connected and acted as the diode cathode. The gate terminal was used as the anode. Ideally, the diode should look like a 50 ohm terminal when introduced into the coupler. In order to simplify the design, PHEMT width dimensions and finger count of 50  $\mu\text{m}$  and 2 respectively were used. Without implementing a diode matching network, these dimensions control optimization of the diode match. A direct current (DC) bias voltage source was used to reduce the overall LO drive power needed to turn the diodes on and off. The 0.7V bias was optimized in the final design.

## 2.3 Mixer Design

The diode configured PHEMT devices were incorporated into the coupler design to create the up/down mixer configuration. One diode was placed from coupler port 4 (anode) to ground (cathode). The other diode was configured from DC bias (anode) to coupler port 2 (cathode).

The initial mixer design approach was geared toward isolation optimization. S-parameters of the mixer were optimized during this process. Final design configurations were tuned to meet all requirements. Figure 3 shows the optimized S-parameters.

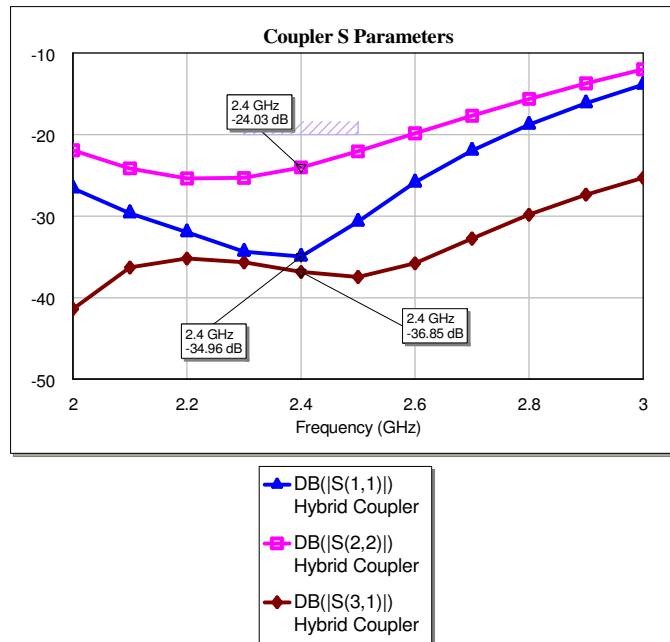


Figure 3: Optimized S-band mixer s-parameters.

### 2.3.1 RF/LO/IF Isolation

With an ideal coupler based mixer design, the IF port can be inserted into the design in several configurations yet have no effect on performance. In order to do this, a large series inductor was used between the IF port and the other mixer circuitry.

In order to isolate the DC bias from the RF and LO ports, large series blocking capacitors were inserted between the RF/LO ports and the other circuitry.

### 2.4 Trade-offs

Many of the design trade-offs were a result of the 60x60mil area constraint. The RF/LO blocking capacitors were optimized for performance yet limited to reduce area consumption. Similarly, the inductor dimensions were limited.

Another trade-off involved the PHEMT diode circuitry. Introducing diode matching networks would enhance the performance of the mixer. Due to area constraints, the matching circuitry was left out of the design and the transistor dimension optimization was used to best match the device.

### 3 Simulations

A summary of the simulated results are shown in Table 2.

Table 2: Simulated results summary

| Mixer Property    | Simulated Results | Minimum Requirement |
|-------------------|-------------------|---------------------|
| Isolation (RF/LO) | > 25 dB           | 10 dB               |
| LO power          | +4 dBm            | +7 dBm              |
| VSWR              | 1.2:1 – 2.3:1     | 2.5:1               |
| Conversion Loss   | ~ 8 dB            | 10 dB               |

#### 3.1 Conversion Loss

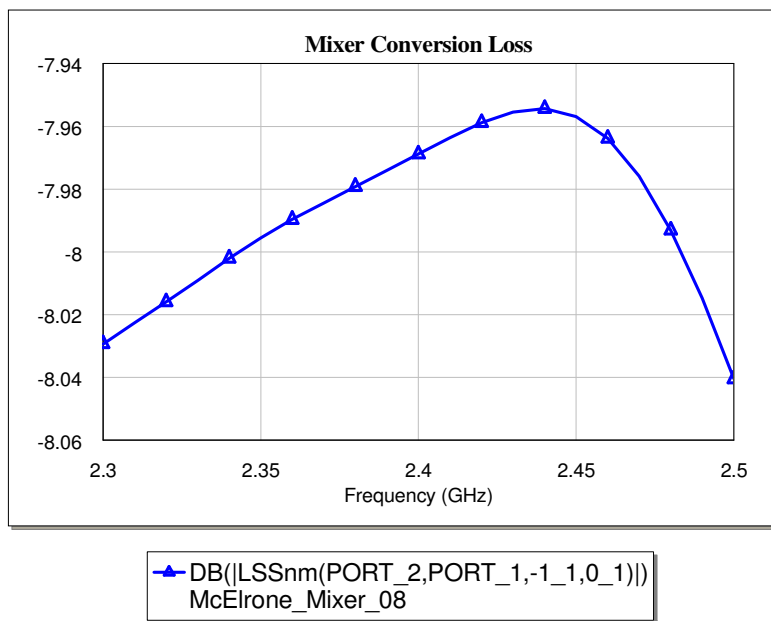


Figure 4: S-band up/down mixer conversion loss

### 3.2 RF/LO Isolation

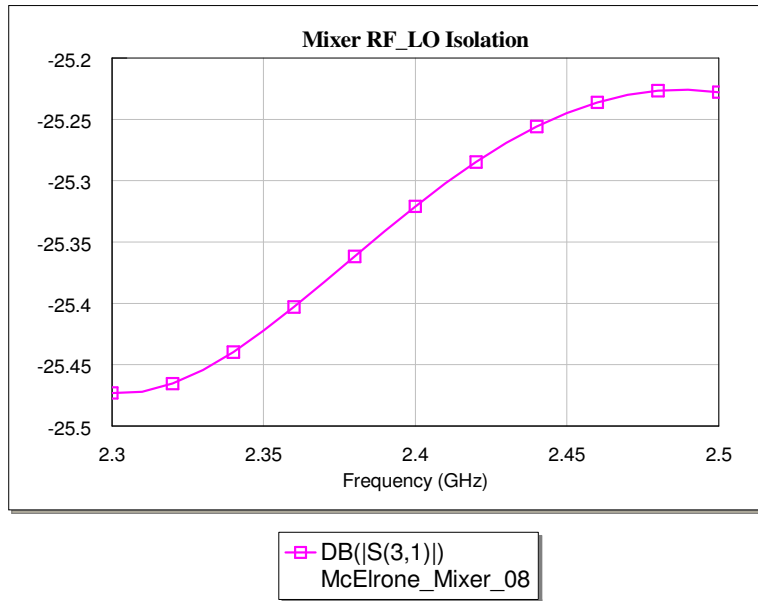


Figure 5: S-band up/down mixer RF/LO isolation

### 3.3 VSWR

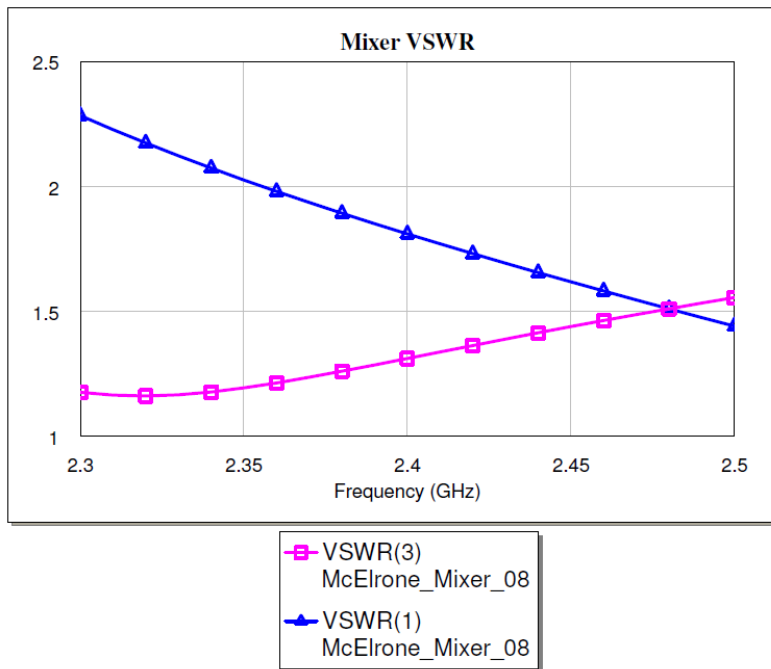


Figure 6: S-band up/down mixer VSWR

### 3.4 IF Spectral Analysis

#### 3.4.1 Up Mixer

##### 3.4.1.1 High Band

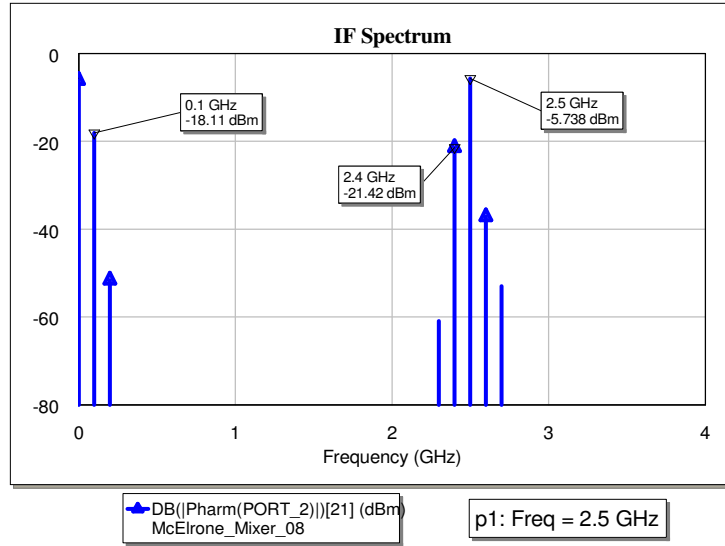


Figure 7: IF spectrum, mixer in high band of up mixer mode

##### 3.4.1.2 Low Band

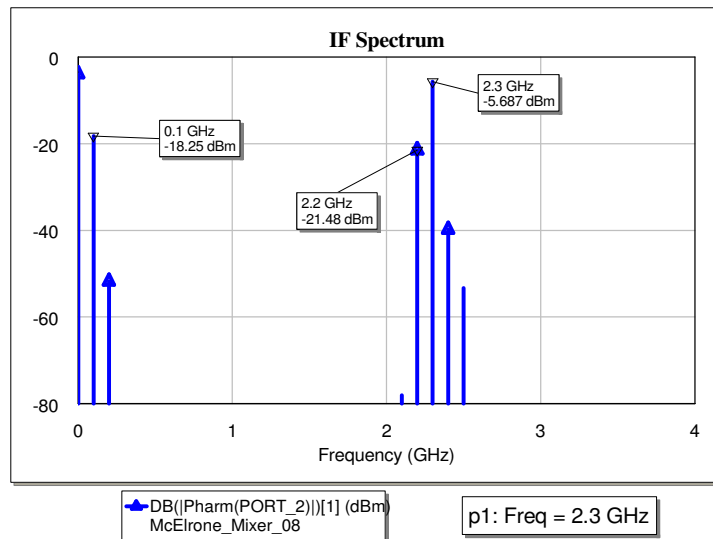


Figure 8: IF spectrum, mixer in low band of up mixer mode

### 3.4.2 Down Mixer

#### 3.4.2.1 High Band

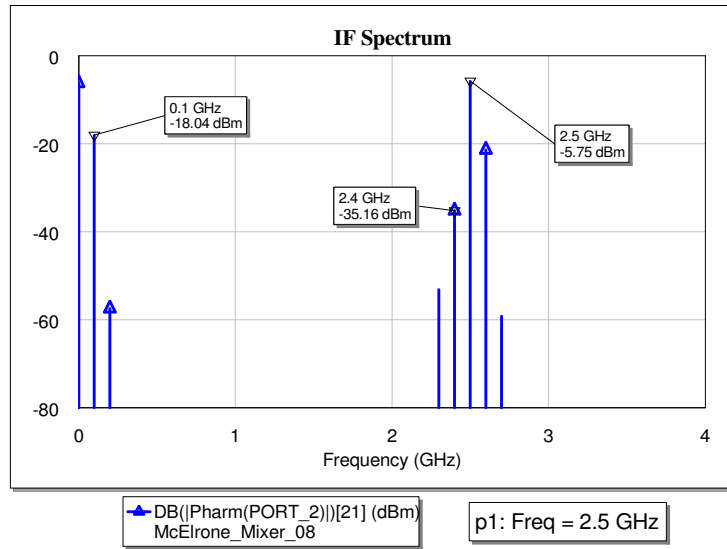


Figure 9: IF spectrum, mixer in high band of down mixer mode

#### 3.4.2.2 Low Band

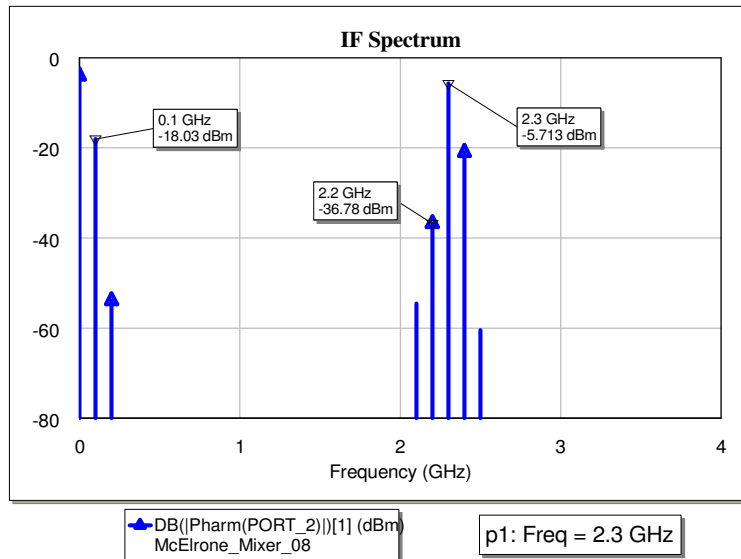
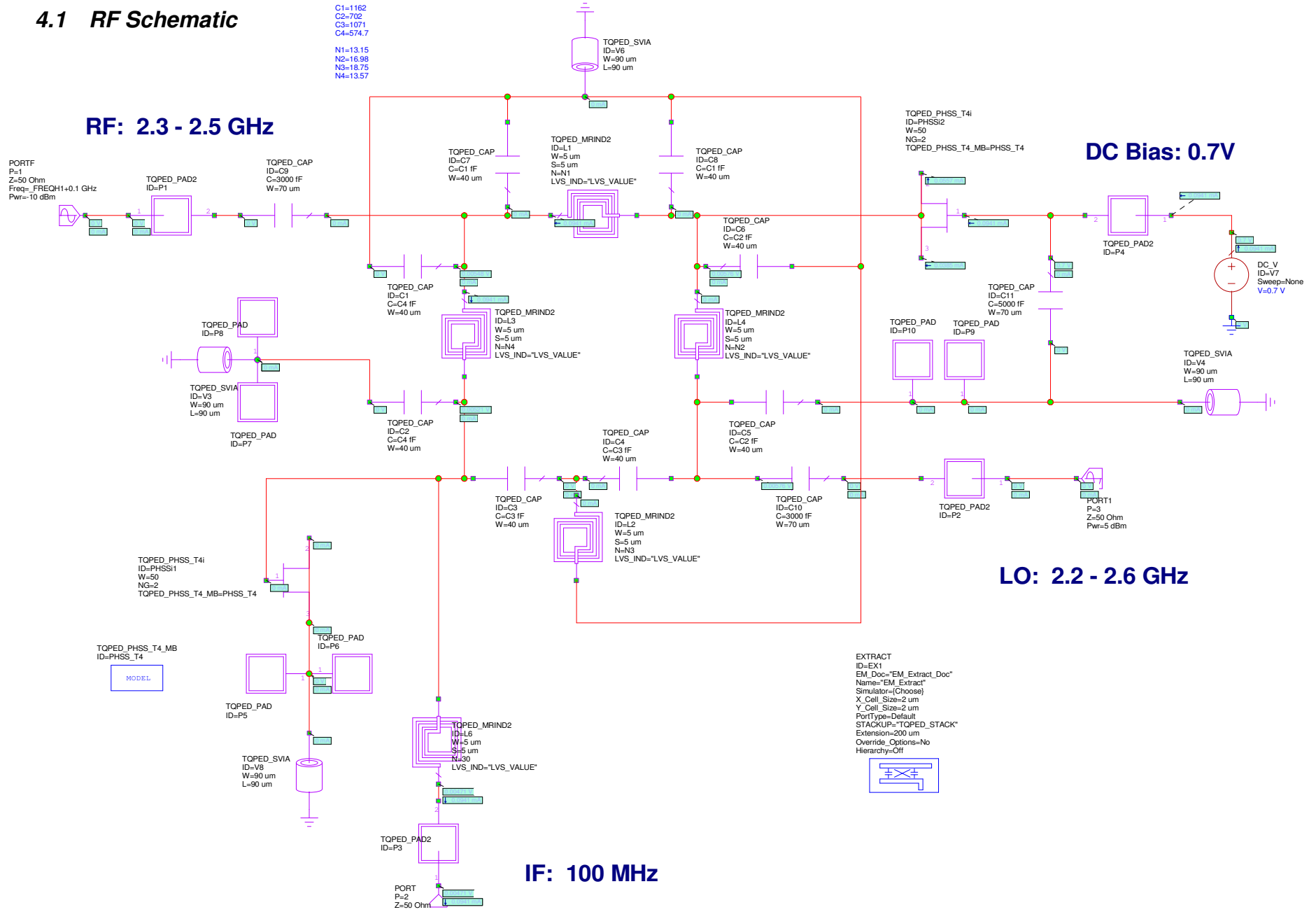


Figure 10: IF spectrum, mixer in low band of down mixer mode

# 4 Schematic

## 4.1 RF Schematic



## 4.2 DC Schematic

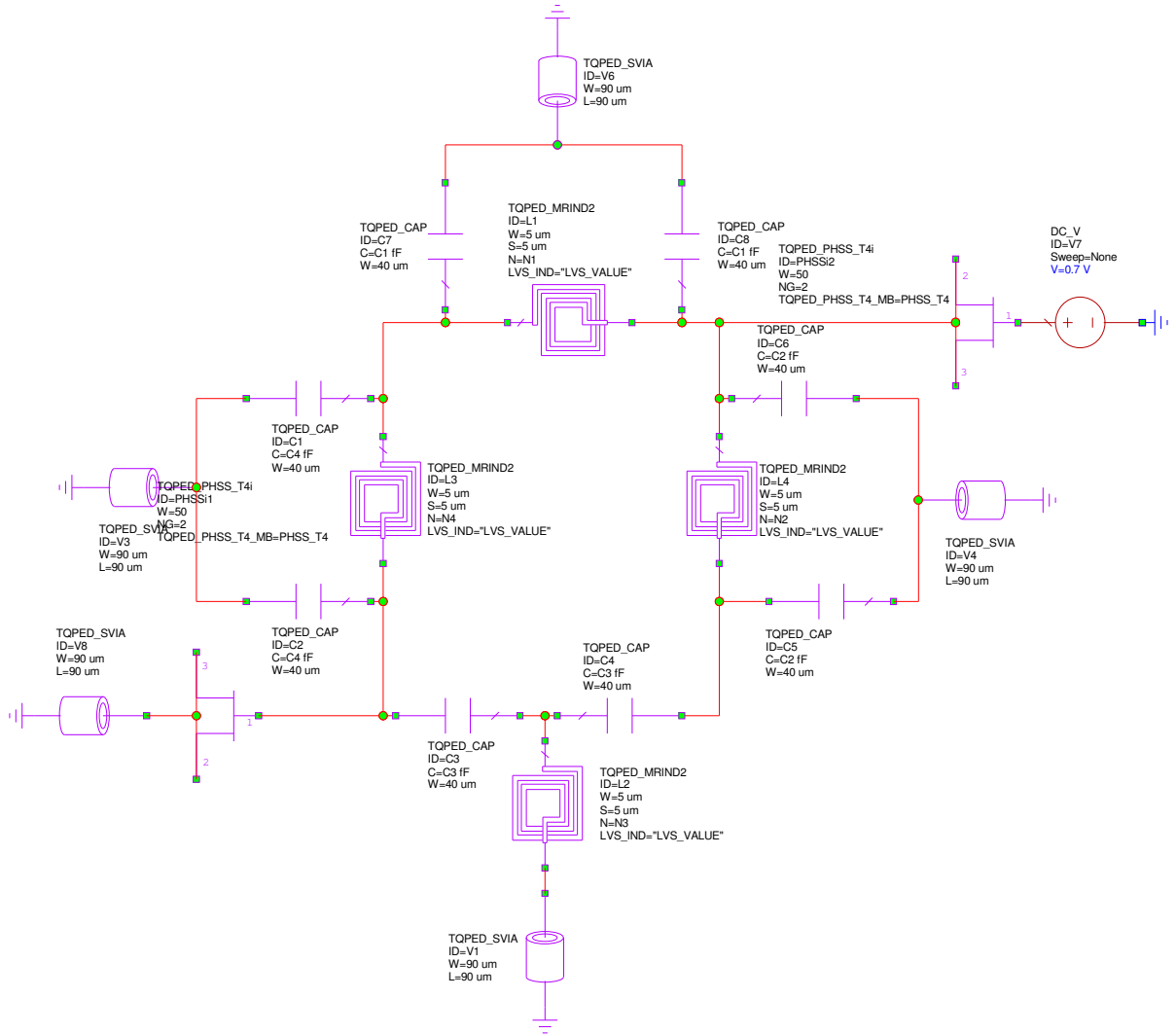


Figure 11: S-band up/down mixer DC schematic

## 5 Layout

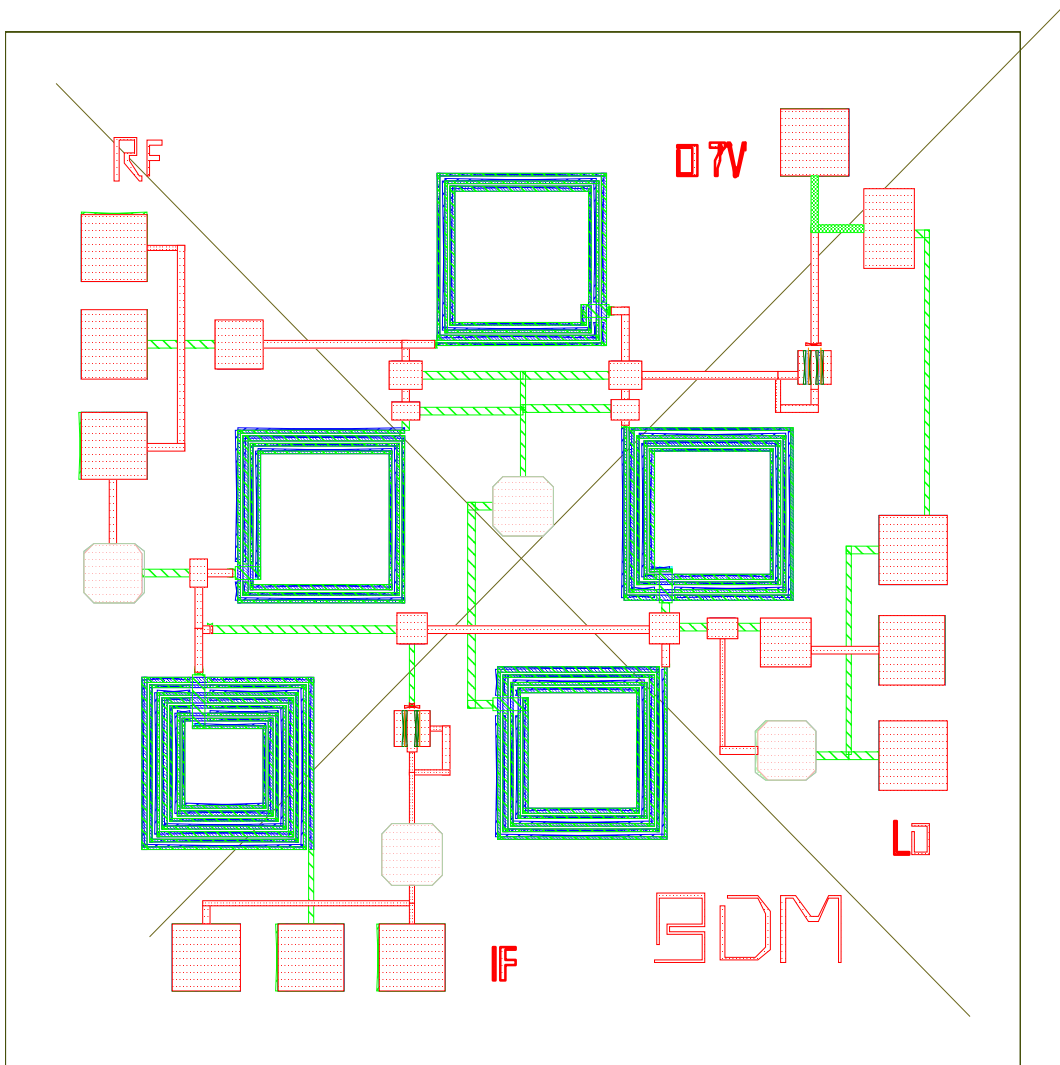


Figure 12: S-band up/down mixer layout

## **6 Test Plan**

### **6.1 S-parameter Testing**

1. Connect network analyzer to the appropriate ports. Use RF as port 1 and LO as port 2. Setup to sweep from 2.3 – 2.5GHz.
2. Terminate IF port into a 50 ohm load
3. Apply 0.7Vdc to the DC bias terminal
4. Measure the s-parameters

### **6.2 Up Mixer Testing**

1. Connect a signal generator to the LO port. Setup to sweep from 2.2 – 2.4 GHz in 0.05GHz increments. Set power output to +7dBm.
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 0.7Vdc to the DC bias terminal
5. Measure RF output power at each LO frequency

### **6.3 Down Mixer Testing**

1. Connect a signal generator to the LO port. Setup to sweep from 2.2 – 2.6 GHz in 0.05GHz increments. Set power output to +7dBm.
2. Connect a signal generator to the RF port. Setup to sweep from 2.3 – 2.5 GHz in 0.05GHz 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 0.7Vdc to the DC bias terminal
6. Measure the 100MHz IF output power at each frequency interval

## **7 Summary and Conclusions**

As detailed in the document, the S-band up/down mixer met all design requirements. Optimizing the rat-race coupler circuitry was beneficial to the overall performance of the mixer. The design was successfully optimized for the area constraint. With the addition of diode matching networks, the mixer performance could be further optimized. The DC bias source effectively reduced the LO input power requirement.