EE5403 RF Design II
Mixer Design

Tan See Teck
Han Ming Kwang
Leong See Chuan

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1 Design of RF Mixer

This project involves the design of an RF mixer with IF operating at 300MHz using HP ADS software. The fabricated mixer performance is subsequently compared with the simulated design. Below are the design specifications.

Performance Criterion	Value
RF Frequency	1.8GHz
RF Power	-30dBm
LO Frequency	2.1GHz
LO Power	+7.0dBm
IF Frequency	300MHz
Conversion Loss	< 9dB
LO-RF Isolation	> 30dB
LO-IF Isolation	> 25dB
RF-IF Isolation	> 20dB
Input IP3 Intercept	> 12dBm
1dB Input Compression	> 0dBm

Table 1 Specifications of the mixer circuit

The subsequent sections describe the design methodology for the mixer sub modules. Section 2 describes the measurement results and discussions. Section 3 concludes the design project.

1.1 LO Input Balun

The LO balun forms the first part in the mixer design. Basically, it splits the un-balanced LO input into a differential LO signal for the diode ring. An important objective is to achieve maximum power into the diode ring and achieve 180° out of phase between LOP and LON as indicated in Figure 1 below.

Figure 1 shows the schematic of the LO Balun. It consists of an outer ¾ λ_{LO} and ¼ λ_{LO} which splits the LO signal into -270° and -90° respectively. It also has an inner structure of two ¼ λ_{LO} microstrips connected between LON and LOP and ground. This is use as a return path for the IF current. It will appear as open circuit at LO frequency and will not affect the LO Balun operation. Also, to simulate the actual loading of the RF side Balun, RF termination and IF termination, an approximate model of the RF Balun is designed using ideal transmission line and connected to the RF side of the diode ring.

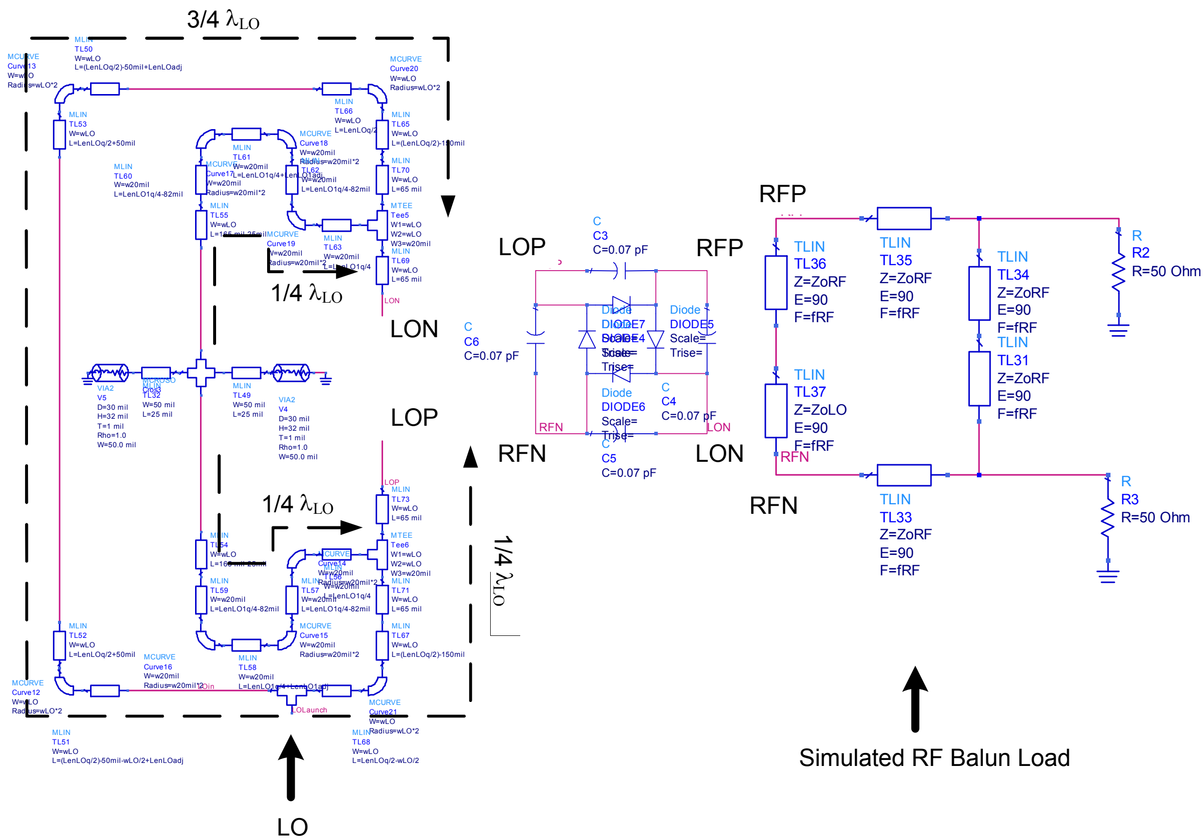

Figure 1 LO Input Balun

Figure 2 shows the result of HB simulation on the phase and magnitude of LON and LOP as well as their difference. The amplitude and phase balance (means 180°) achieved are 0.029dBm (Ref Figure 2 plot 3) and 180.22° (Ref Figure 2 Plot 4) respectively, which is good enough.

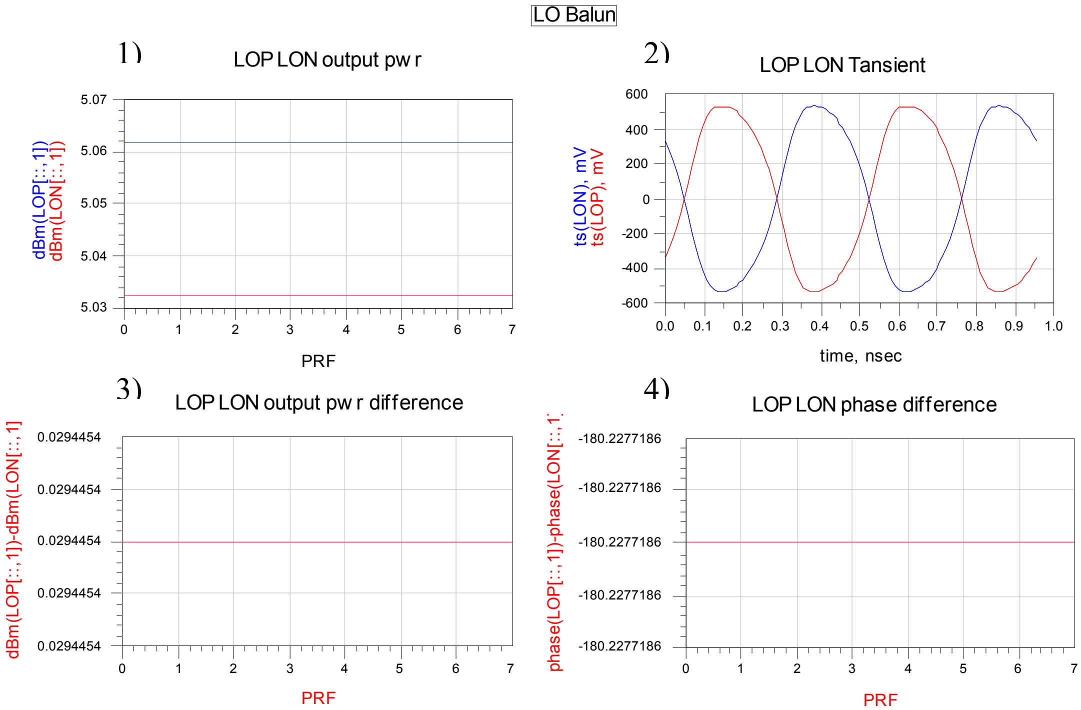

Figure 2 LO Input Balun Simulation result

1.2 RF Input Balun

The RF Balun design is similar to the LO Balun with the same requirement. On the right of the schematic shown in Figure 3 is the RF Balun and connected on the left is the LO Balun designed earlier and the diode ring. The latter two are connected to simulate a load. The simulation is done by injecting RF signal into the RF Balun with the LO termination (50Ω) at the LO Balun. The IF connection is actually not loaded with IF termination as shown in the diagram. This is in fact the desired situation as the IF port termination are not supposed to load the RF Balun.

The purpose of this simulation is to ensure that the RF Balun will provide a differential RF signal into the diode ring with good amplitude and phase balance (180°).

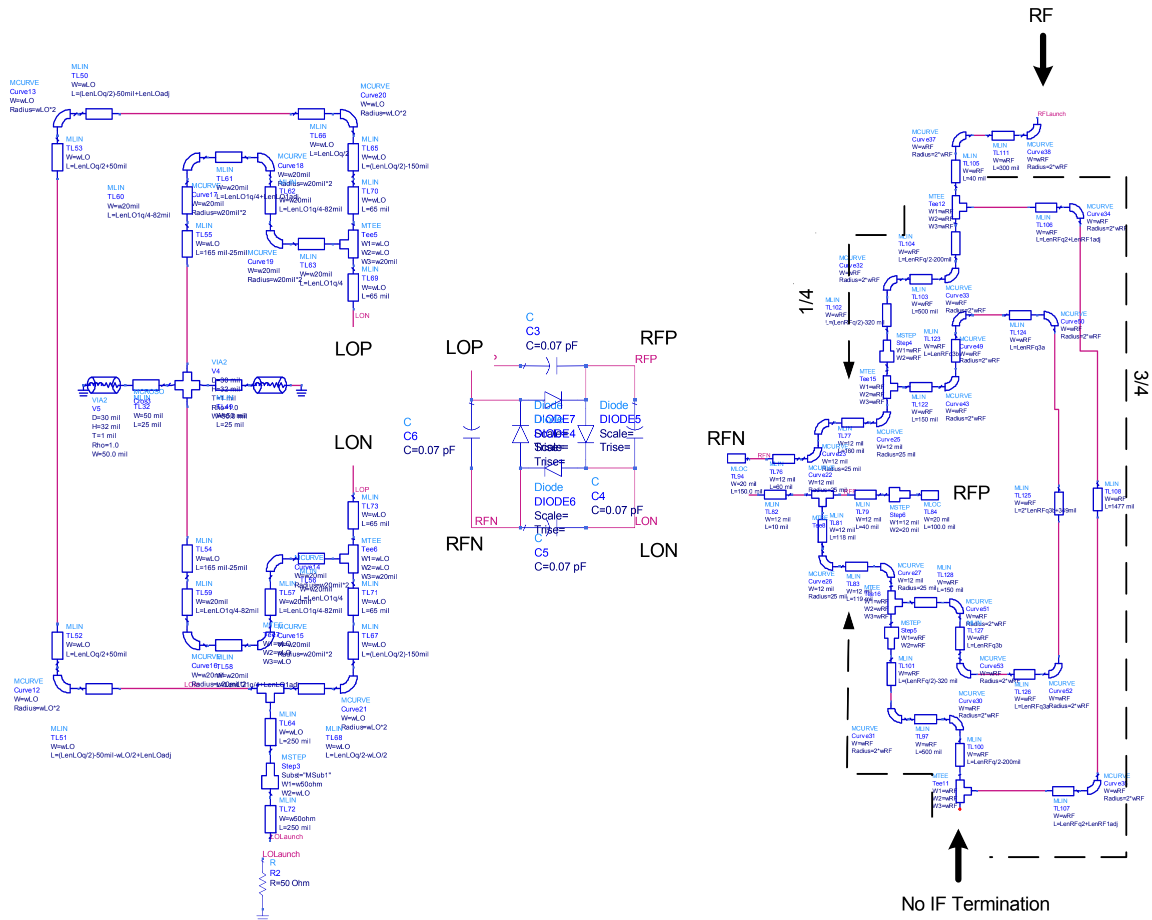

Figure 3 RF Input Balun

Figure 4 shows the simulation results of the RF input Balun. The magnitude and phase difference are approximately 0.461dBm (Ref Figure 4 Plot 2) and 179.6° (Ref Figure 4 Plot 3) respectively. Similarly, the results are adequate.

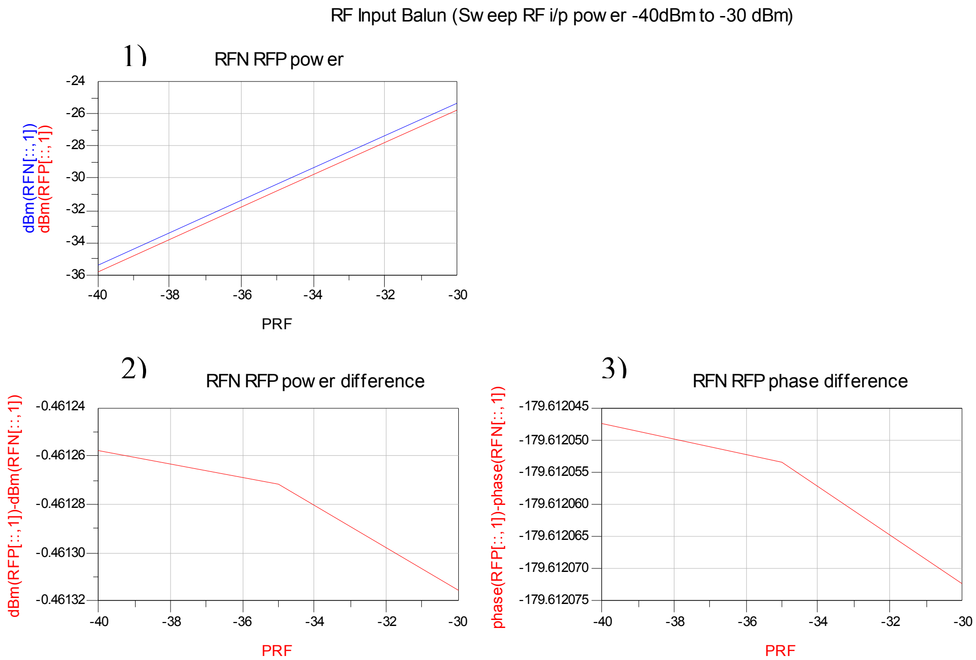

Figure 4 RF Input Balun Simulation Result

1.3 RF Input BPF

A 2nd order BPF filter is designed for the RF input. This is a simple coupled-line filter. For a coupled λ/4 section, the following equation applied:

$$Zo = \sqrt{ZooZee}$$

where *Zo* is the characteristic impedance, *Zoo* is the odd mode characteristic impedance and *Zee* is the even mode characteristic impedance.

By letting *Zo* = 50Ω, *Zoo* is tuned (*Zee* will change according to the equation) until a desired bandpass response is achieved. Take note that the two coupled-line sections are identical or symmetrical. Once the *Zoo* and *Zee* are found, LineCalc is used to find the correct width, length and spacing for the coupled-line. Figure 5 shows the schematic of the RF input bandpass filter.

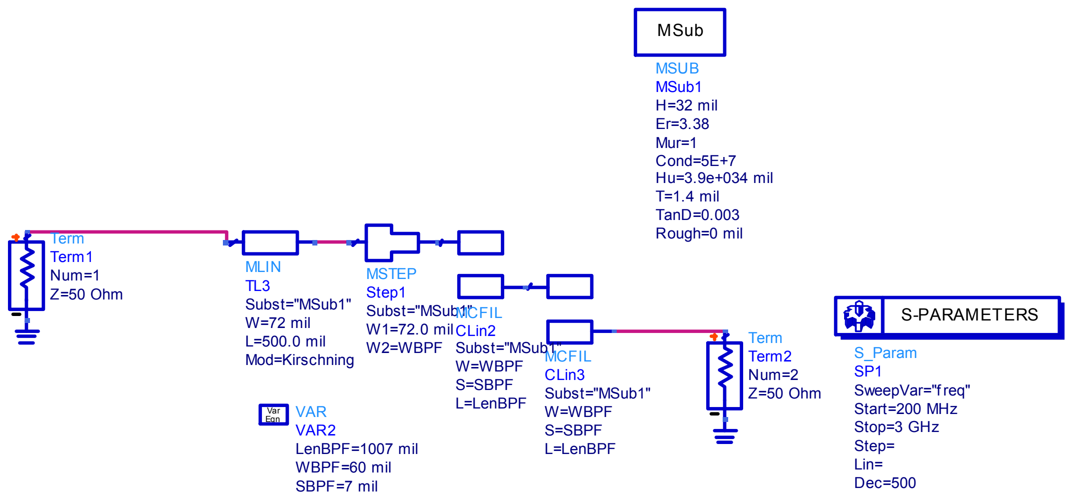

Figure 5 RF Input BPF

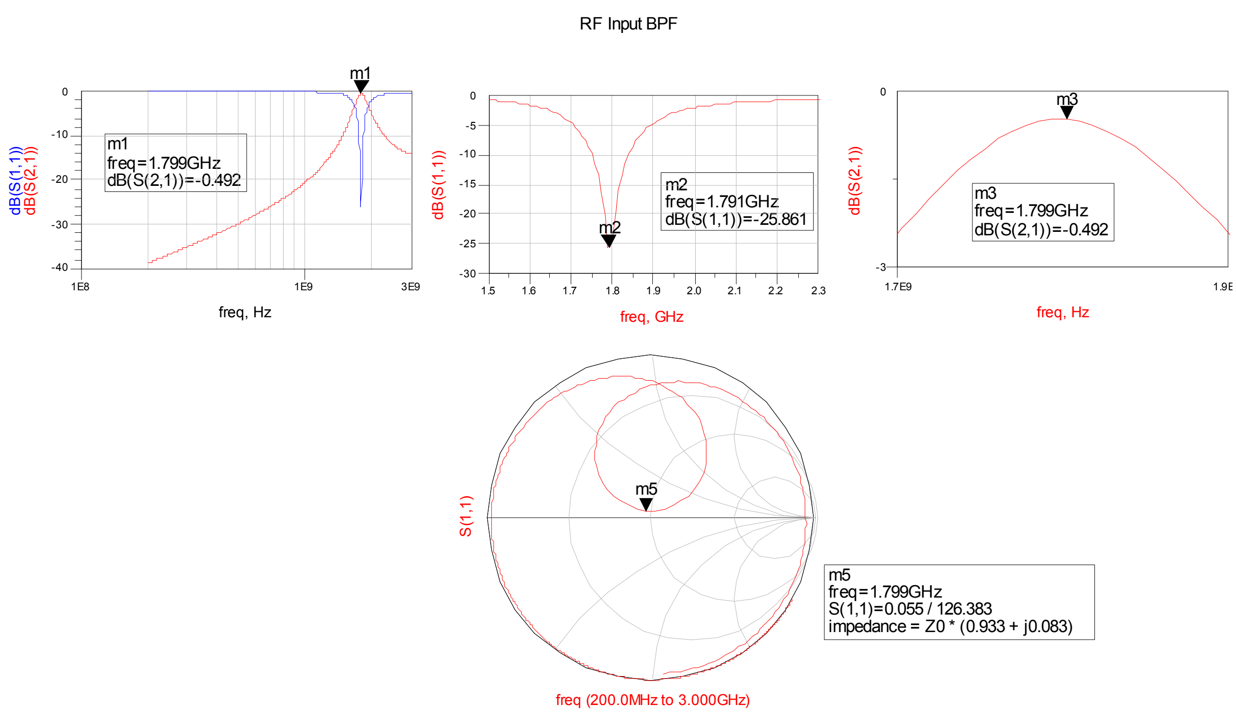

Figure 6 BPF Simulation Result

As shown in the diagram above, the BPF insertion loss is 0.49dB and return loss is 25.86dB at 1.8GHz (RF). The BPF will improve the isolation for LO-RF and IF-RF.

1.4 IF LPF

In order to filter out the RF component at the IF port, a simple LPF is design. The LPF is realized by using two ¼ λ_{RF} sections of transmission line. As shown in the diagram, the open stub will provide a short circuit after the ¼ λ_{RF} . The other ¼ λ_{RF} section will in turn provide an open circuit at the connection between the LPF and RF Balun. Hence the RF Balun is not loaded by the IF termination.

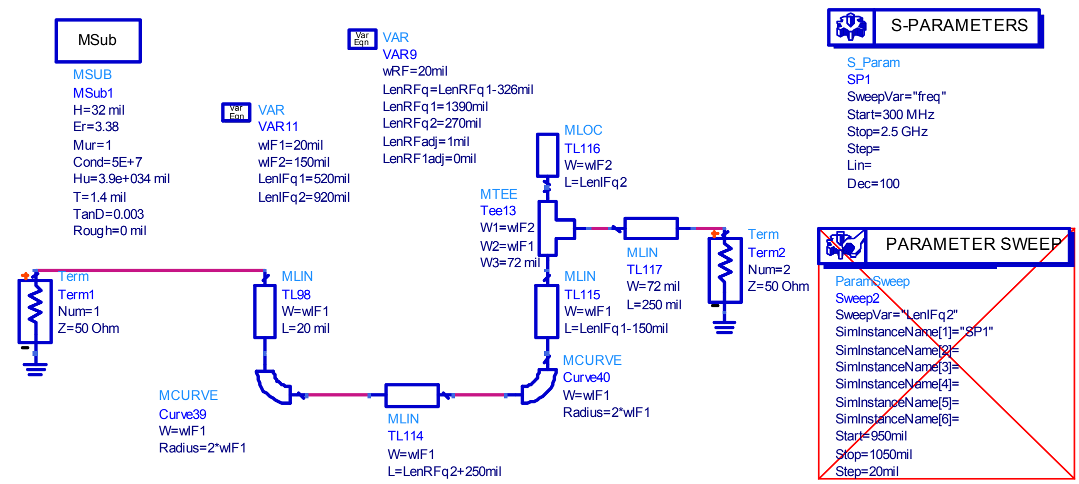

Figure 7 IF LPF

Likewise, the RF signal will not be able to reach the IF termination and this improves the RF-IF isolation.

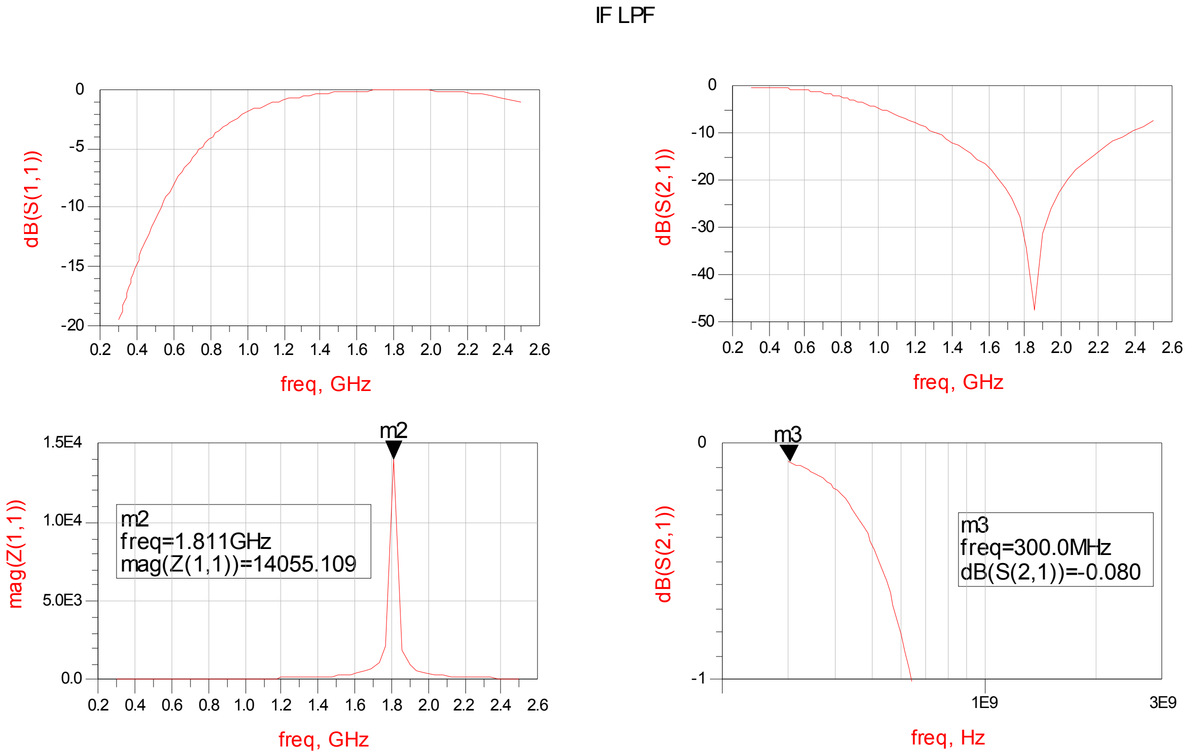

Figure 8 IF LPF Simulation Results

As shown in the diagram, the RF signal will be attenuated by about 35dB when it reached the IF port. The IF insertion loss is about 0.08dB. Also, the impedance at RF frequency is about 14KΩ, which presents a near open circuit to the RF signal and will not load the RF Balun.

1.5 Preliminary Mixer Simulation

The LO, RF Baluns, RF BPF and IF LPF are now combined with the diode ring. Simulation is performed to the whole mixer circuit. Figure 9 shows the simulation schematic circuit. Figure 10 shows the simulation results. Notice that the conversion loss for the IF is 6.415dB.

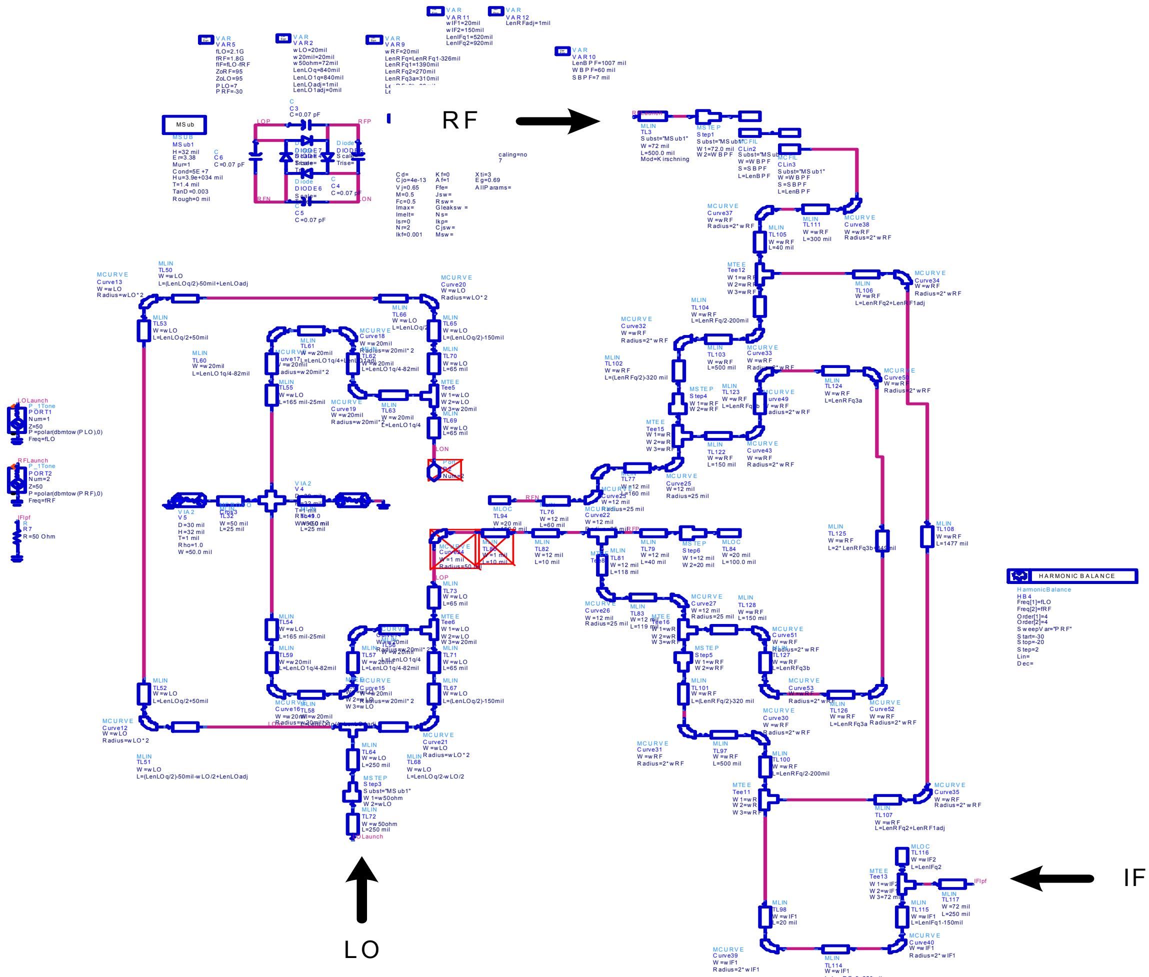

Figure 9 Preliminary Mixer

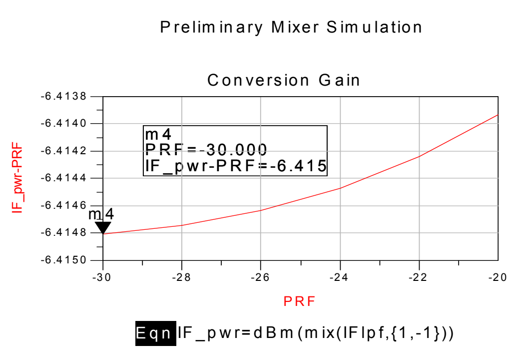

Figure 10 Results

1.6 Final Mixer Design

The final schematic is as shown in Figure 11. The schematic is similar to Figure 9 except that tuning is performed to improve on conversion loss.

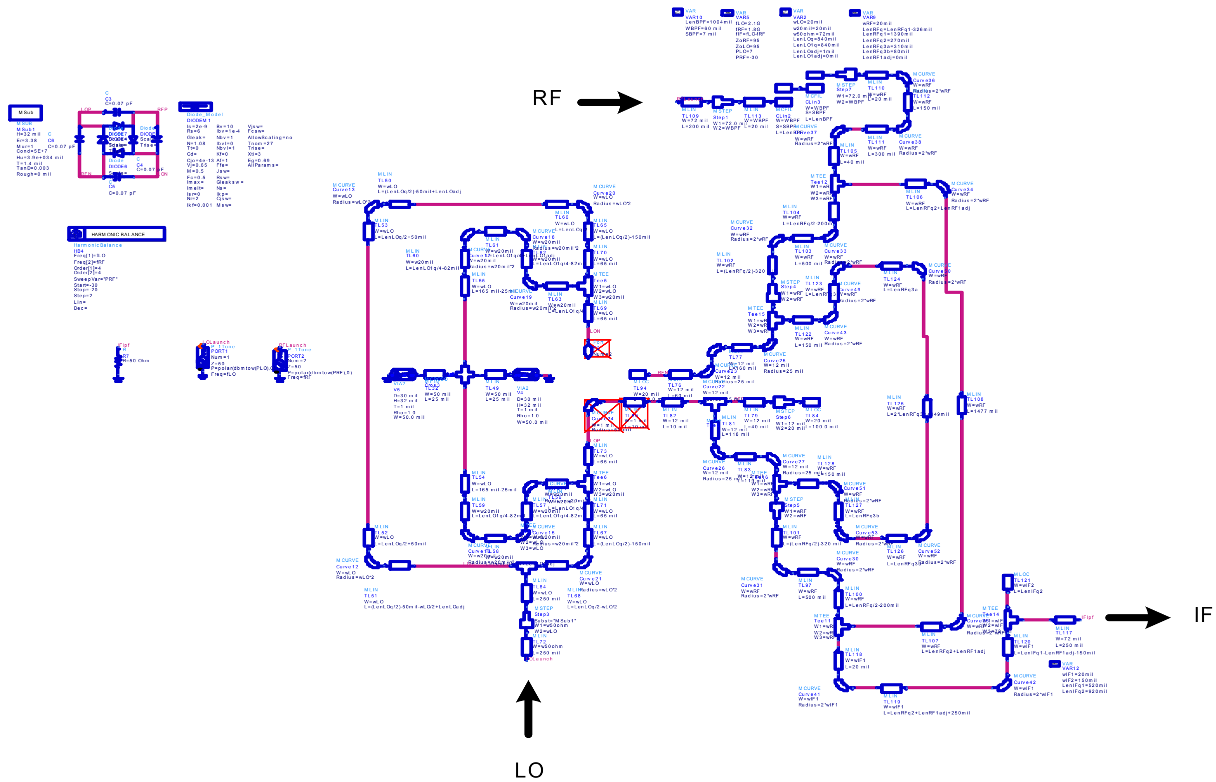

Figure 11 Final Mixer Design

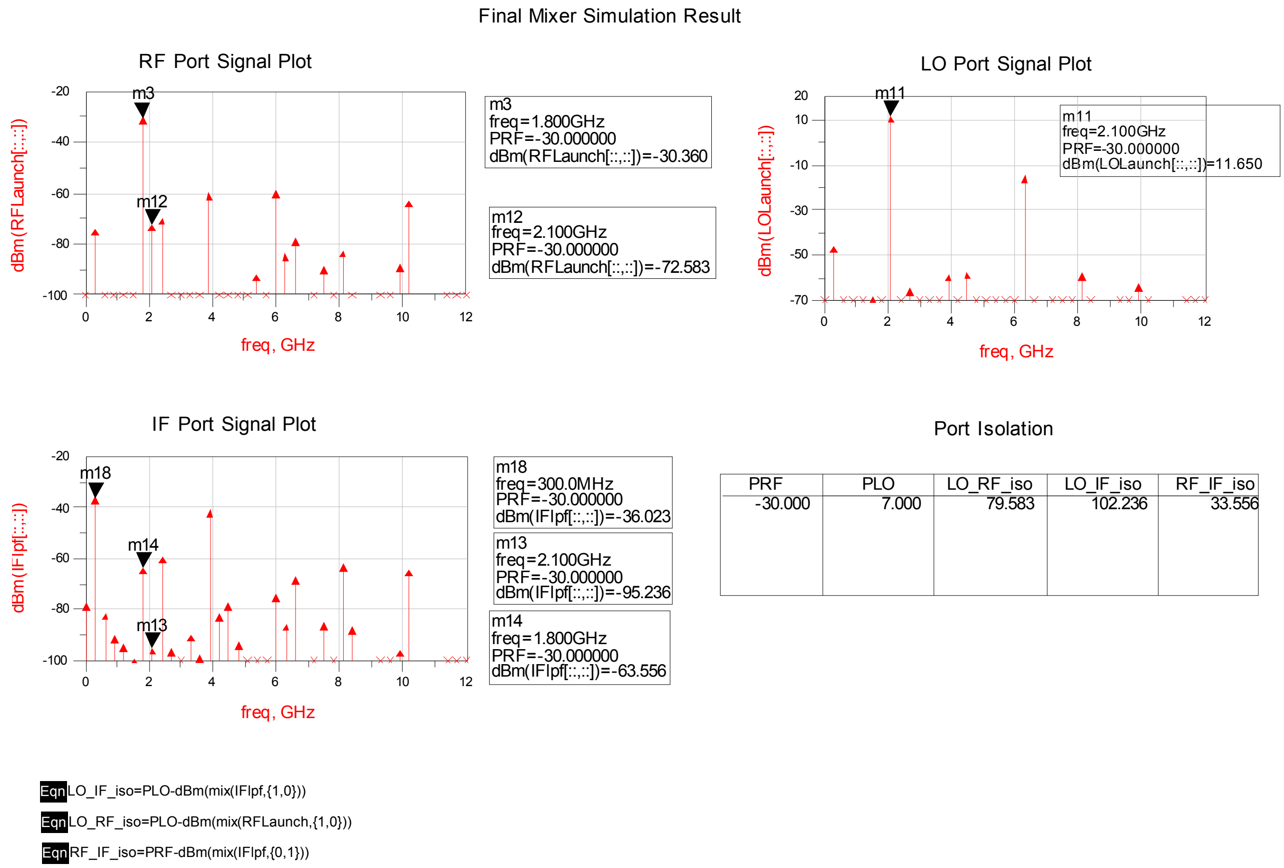

Figure 12 Simulation Result

The diagram above shows the signal magnitude plot at the RF, LO and IF port. Also the port isolation results are shown in the bottom right corner of the diagram.

LO-RF isolation is obtained by subtracting the magnitude of LO component at the RF port (marker : m12) from the input LO power of 7dBm (PLO = 7dBm). Result : 79.58dB.

LO-IF isolation is obtained by subtracting the magnitude of LO component at the IF port (marker : m13) from the input LO power of 7dBm. Result : 102.23dB.

RF-IF isolation is obtained by subtracting the magnitude of the RF component at the IF port (marker : m14) from the input RF power of -30dBm (PRF= -30dBm). Result : 33.56dB.

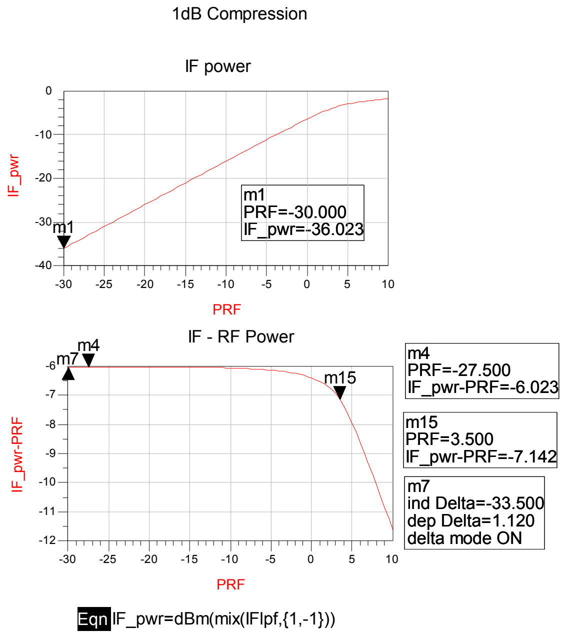

Figure 13 1dB Compression and Conversion Loss

Figure 13 shows the IF power and IF-RF power plot. 1dB compression is 3.5dBm (Ref marker : m15) and conversion loss is 6.023dB (Ref marker : m7). This shows that the conversion loss improves slightly after tuning.

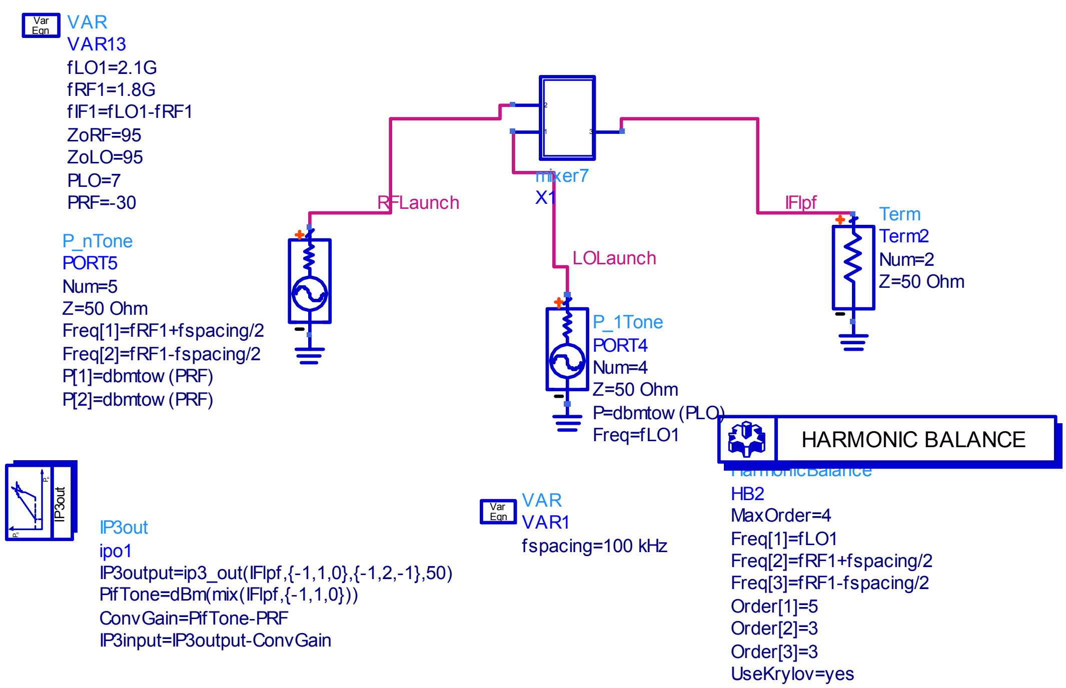

Figure 14 TOI Input Simulation

freq	ConvGain	freq	IP3input
300.0MHz	-6.084	<invalid>Hz	18.496

Figure 15 Input IP3 Intercept Result

With reference to the ADS design examples (RFIC->MIXERS_PRJ->MixerTOI.dsn), the IP3 intercept simulation circuit in Figure 14 is designed. The final mixer schematic (Figure 11) is represented by the symbol, mixer7, in the middle of Figure 14.

Referring to Figure 15 above, the input IP3 intercept is 18.496 dBm. Below is a summary of the all the simulation results.

Performance Criterion	Target Specification	Simulation Result
Conversion Loss	<9dB	6.023dB
LO-RF isolation	>30dB	79.58dB
LO-IF isolation	>25dB	102.23dB
RF-IF isolation	>20dB	33.56dB
Input IP3 intercept	>12dBm	18.496dBm
1dB input compression	>0dBm	3.5dBm

Table 2 Performance summary of simulated mixer circuit

1.7 Layout

Finally the mixer design in Figure 11 is used to generate the layout for fabrication (Ref Figure 16).

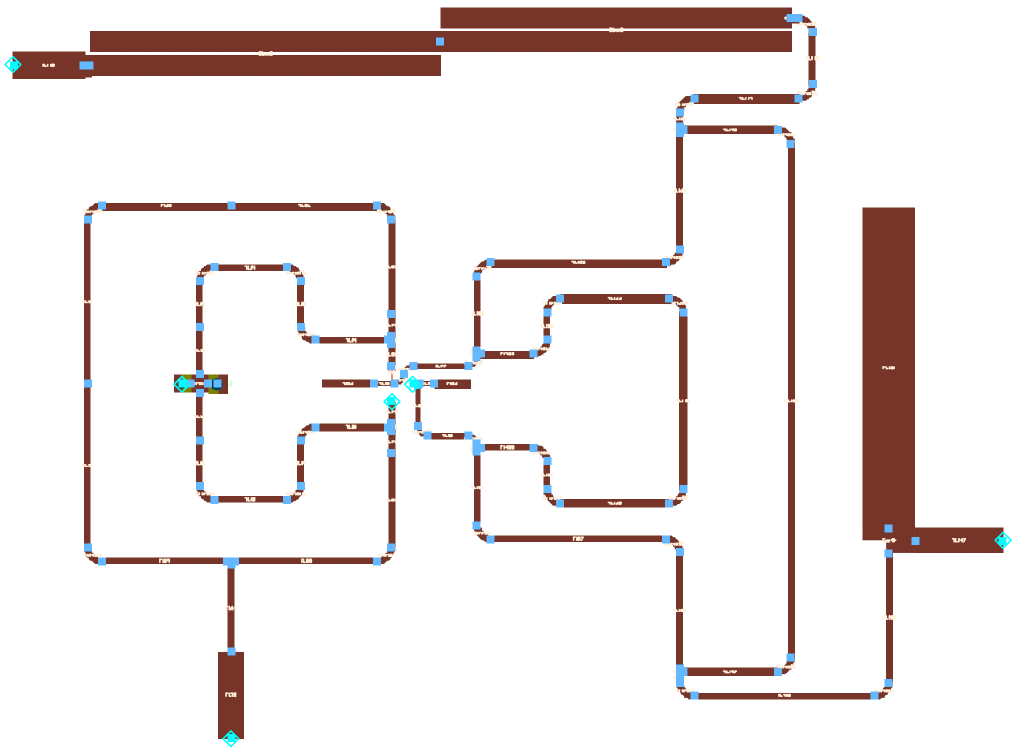

Figure 16 Final layout

2 Measurement Results and Discussion

This section discusses the measurement results.

2.1 Calibration

To obtain accurate measurement results, the cabling insertion loss and source power levels are calibrated. Using similar RF cables, the IF cable loss is determined by connecting the frequency generator directly to the spectrum analyzer at the IF frequency. The cable loss was determined to be 0.2dB. The RF and LO generator power are subsequently calibrated to provide to required datum level at the spectrum analyzer.

Port	Power level
RF	-29.16dBm
LO	+6dBm

Figure 17 Calibrated power levels at the RF and LO ports

2.2 Conversion Loss

From Figure 18, assuming a constant cable loss at 0.2dB, the IF power level is -36.48dBm. Therefore, the conversion loss is 30 - (-36.68) -0.2 dB = <u>6.48dB</u>.

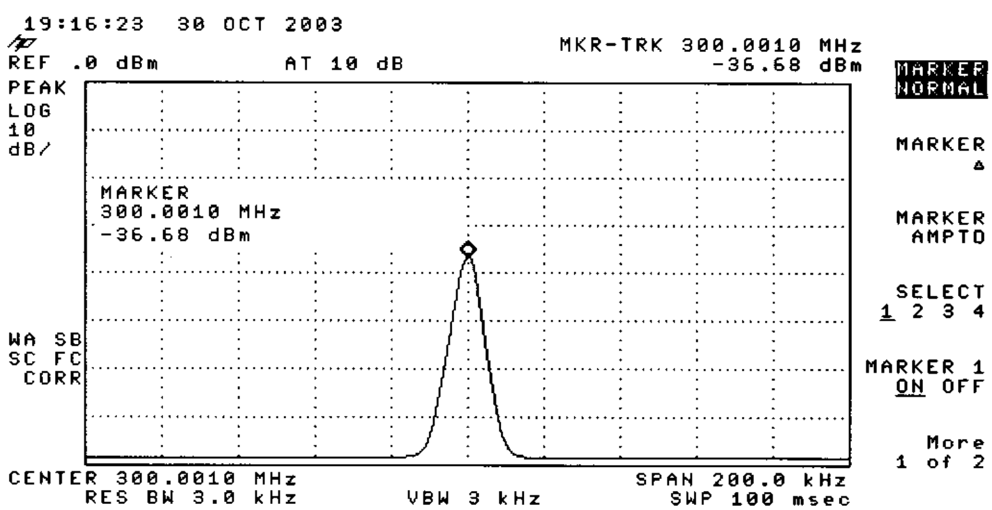

Figure 18 Conversion loss at IF port

2.3 Port Isolation LO-RF

To determine the LO-RF port isolation, the power levels at LO frequency is measured at the RF port. Figure 19, the LO-RF port isolation is 7 - (-54.16) -0.2 dB = 60.96dB.

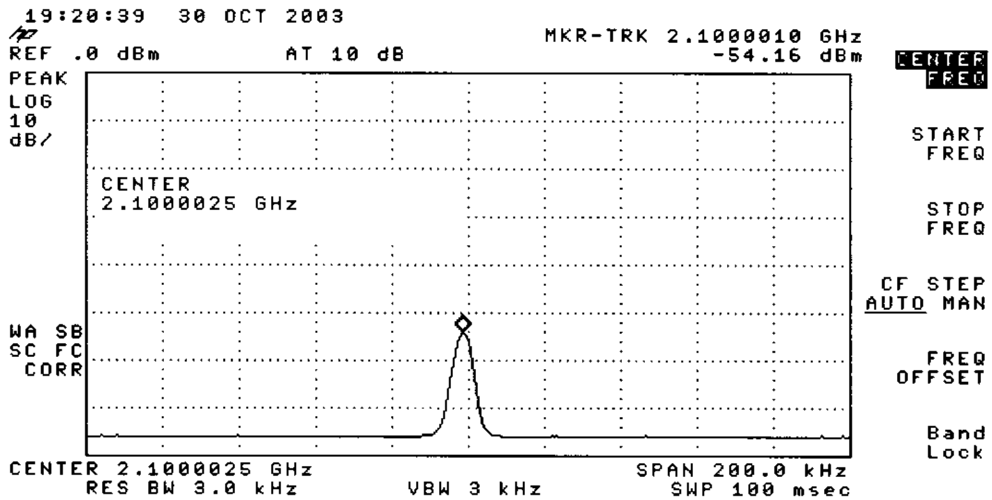

Figure 19 LO-RF isolation

2.4 Port Isolation LO-IF

The LO power levels at the IF port is measured as shown in Figure 20. The LO-IF isolation is 7 - (-41.78) -0.2dB = 48.58dB.

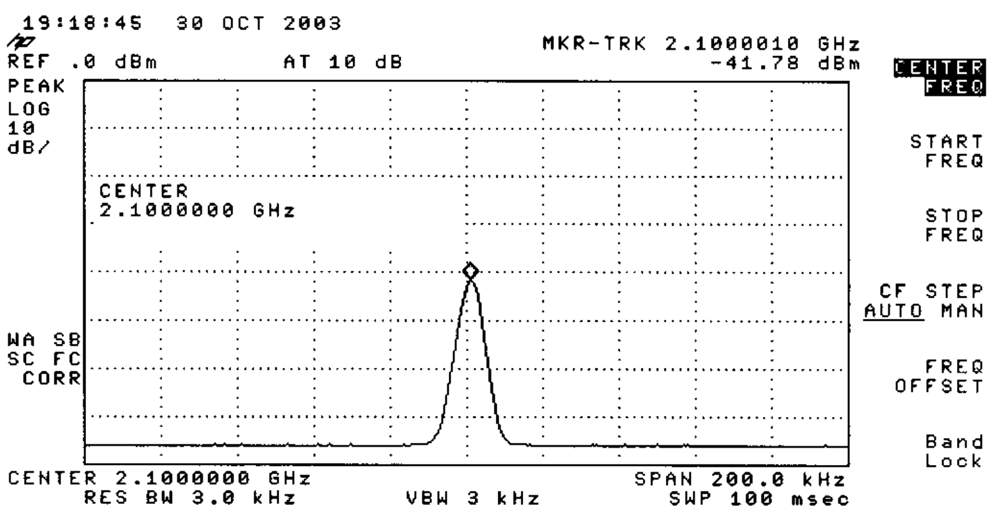

Figure 20 LO-IF isolation

2.5 Port Isolation RF-IF

The RF power levels at the IF port is measured as shown in Figure 21. The RF-IF isolation is -30 - (-60.91) -0.2dB = 30.71dB.

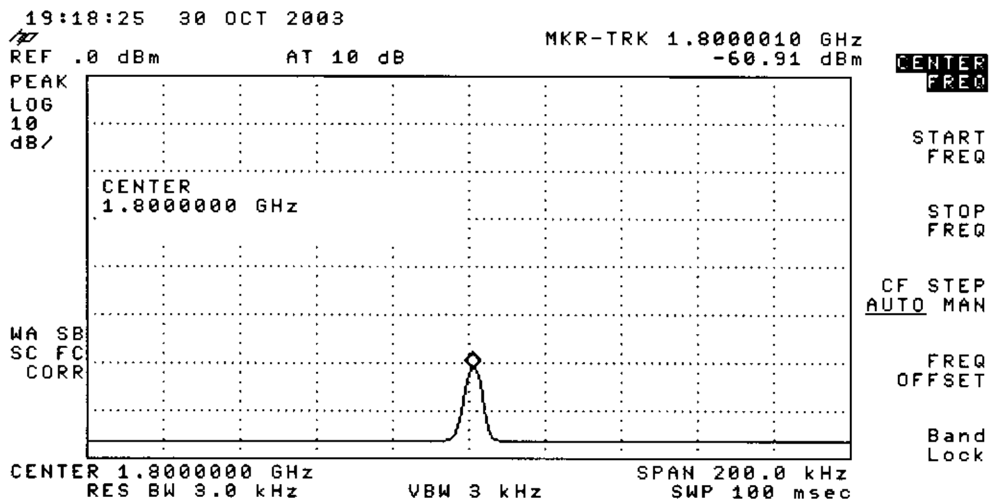

Figure 21 RF-IF isolation

2.6 1-dB Input Compression

For 1-dB input compression measurement, the RF input levels are slowly increased from -30dBm to 5dBm and the IF power levels are measured (Ref Figure 22). Figure 23 shows that that the 1-dB input compression point is at 2.2dBm. The output IF power level spectrum for RF input at -3dB is shown in Figure 24.

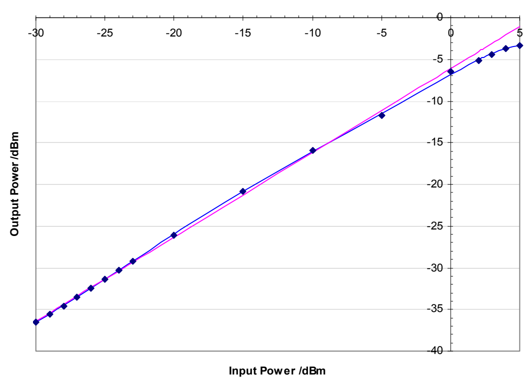

Figure 22 Plot of input and output power levels showing compression for inputs >0dBm.

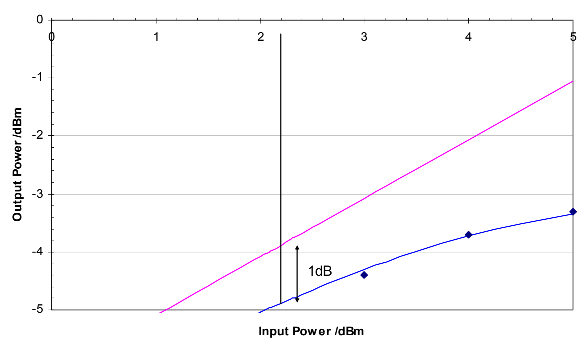

Figure 23 Enlarged figure showing 1dB compression point

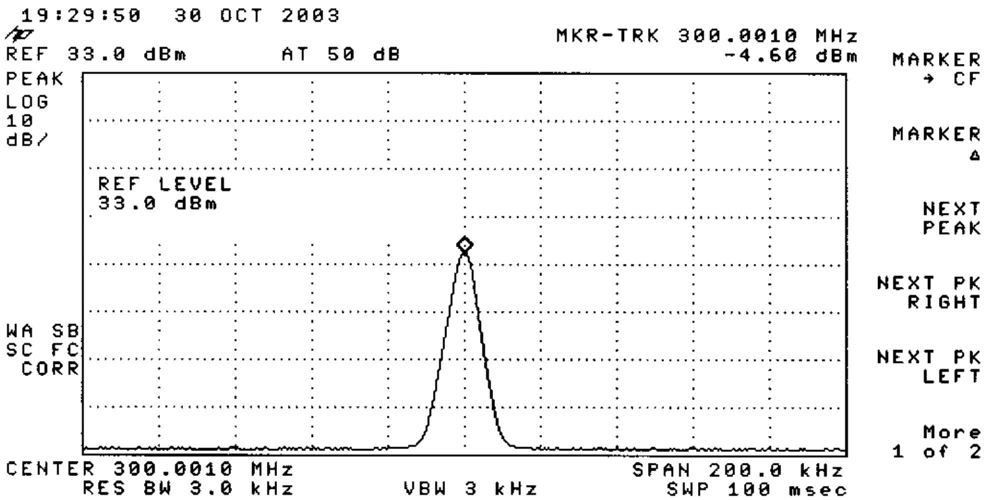

Figure 24 1-dB input compression

2.7 Input IP3 Intercept

To measure the input IP3 intercept, a RF 2 tone signal is required. Figure 25 shows the output 2 tone power levels after the combiner. The measured power levels for the 2 tones are approximately equal. The input power level is chosen to be sufficiently small (-10dBm) so that the higher order nonlinear terms are negligible. The frequency separation of the 2 tones is chosen to be small for negligible effects from the filters.

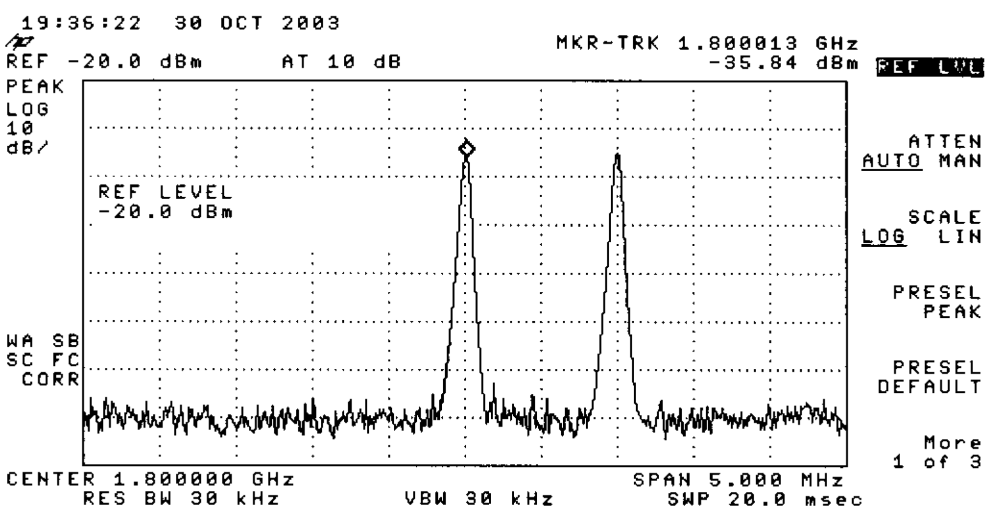

Figure 25 Output of 2 tone power levels after combiner

From Figure 26, with an input power level of -10dBm, the measured output power level at the 3rd order modulation product frequency is -70dBm. Therefore, the IIP3 is ½ (60.02) + (-10 + (-35.84 - (-30))) dBm = 14.17dBm.

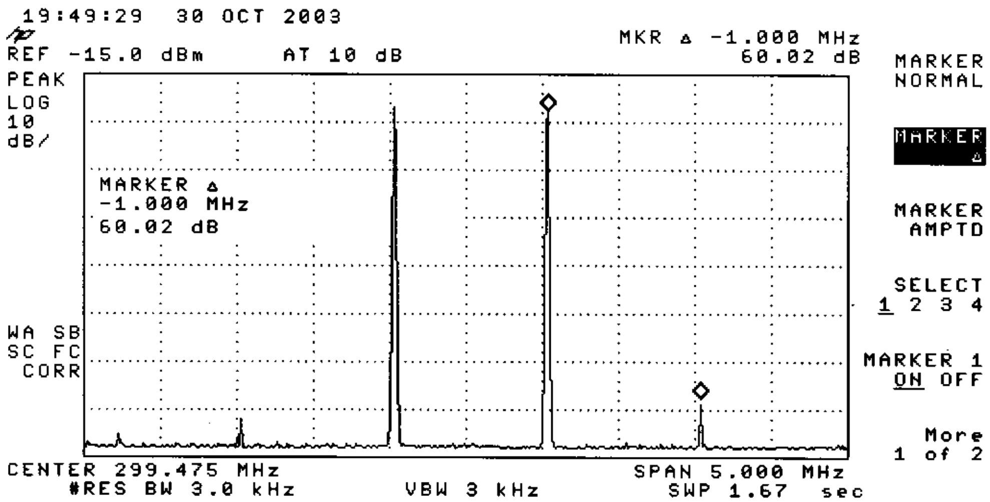

Figure 26 3rd order modulation product at 302MHz.

2.8 Fabricated Layout

Figure 27 shows the fabricated mixer design of dimensions 7 cm by 7 cm.

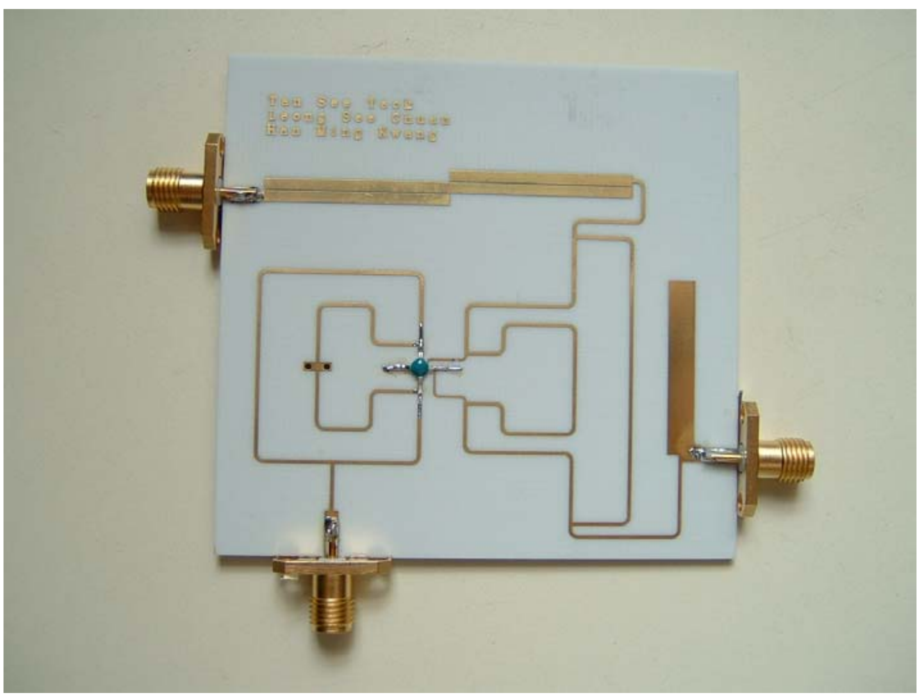

Figure 27 Photograph of final fabricated mixer design

3 Conclusion

The mixer circuit is design, fabricated and measured. Table 3 is a comparison of the simulated and measured performance of the mixer circuit with respect to the target specification. The measured conversion loss and 1dB compression point are closed to that of the simulated result. The differences between simulated and actual results for conversion loss and 1dB compression point are only 0.4 and 1.3dBm respectively. The isolations are less than the simulated result. This is due to the inter-microstrips coupling that are not modeled in the simulation.

Performance Criterion	**Target Specification**	**Simulation Result**	**Measured Result**
Conversion Loss	<9dB	6.023dB	6.48dB
LO-RF isolation	>30dB	79.58dB	60.96dB
LO-IF isolation	>25dB	102.23dB	48.58dB
RF-IF isolation	>20dB	33.56dB	30.71dB
Input IP3 intercept	>12dBm	18.496dBm	14.17dBm
1dB input compression	>0dBm	3.5dBm	2.2dBm

Table 3 Performance summary of fabricated mixer circuit

The designed mixer has therefore met all the required specifications.