2.4 GHz Low Noise Amplifier

EE 525.787 MMIC Design

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ABSTRACT

The purpose of the low noise amplifier is to take in a weak signal acquired by a RF receiver antenna, and provide a good amount of gain without adding much additional noise. This helps create a robust signal that can be passed through the rest of the receiver system and be accurately demodulated.

INTRODUCTION

The following report details the design of a low noise amplifier chain at 2.4 GHz using a TriQuint 6 x 50, 0.5um Dmode PHEMT FET. In order to optimize noise figure while still achieving a sufficient amount of gain to overcome any additional noise added further in the receiver system, two stages of amplification are used. Combined, this design achieves a noise figure of less than 1.0 dB and gain of 20 dB. Each FET is biased at 3.0V VDS and ~25% IDSS (15mA). Also heavily considered in this design was unconditional stability at all frequencies. If the amplifier turns out to be unstable even outside of the working bandwidth, this can ruin the in-band performance. Since we rely heavily on linear simulations for noise figure, any instability outside of the frequency of interest won't show a degradation of performance elsewhere.

DESIGN APPROACH

The simplest approach in designing a low noise amplifier is to simply stabilize the output of the FET using resistors, design an input matching circuit to match to the Γopt of the device, and then design an output matching circuit to the devices conjugate impedance. However, in order to meet the design goals set, a different method of stabilization must be explored.

After a few design iterations, it became evident that using a small amount of source inductance combined with output stabilization resistors, led to achieve the lowest noise figure while maintaining wideband stability and a good amount of gain.

This method was again used on the second stage amplifier, but increasing the source inductance to further guarantee a more stable cascaded design.

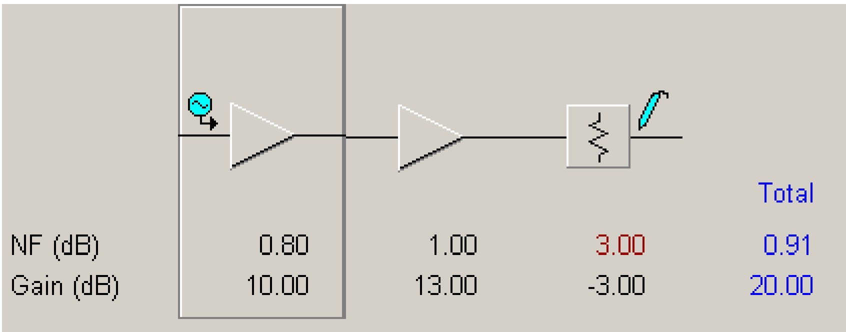
SPECIFICATIONS AND GOALS

The major goal of this design was to achieve a minimal noise figure (less than 1.0 dB) while maintaining a very broadband unconditional stability requirement.

The specifications and goals for this LNA design are as follows:

PARAMTER	SPECIFICATION	GOAL
Noise Figure	1.5 dB	1.0 dB
Gain	20 dB	23 dB
Input VSWR	-	1.8 : 1
Output VSWR	1.5 : 1	0.7 : 1
Supply Voltage	3 V	-
Current Consumption	30 mA	
Stability	Unconditionally stable at 2.4 GHz	Unconditionally stable from 100MHz to 10 GHz

For each stage of the design, the following block diagram roughly shows what the goal of each stage is:



TRADEOFFS

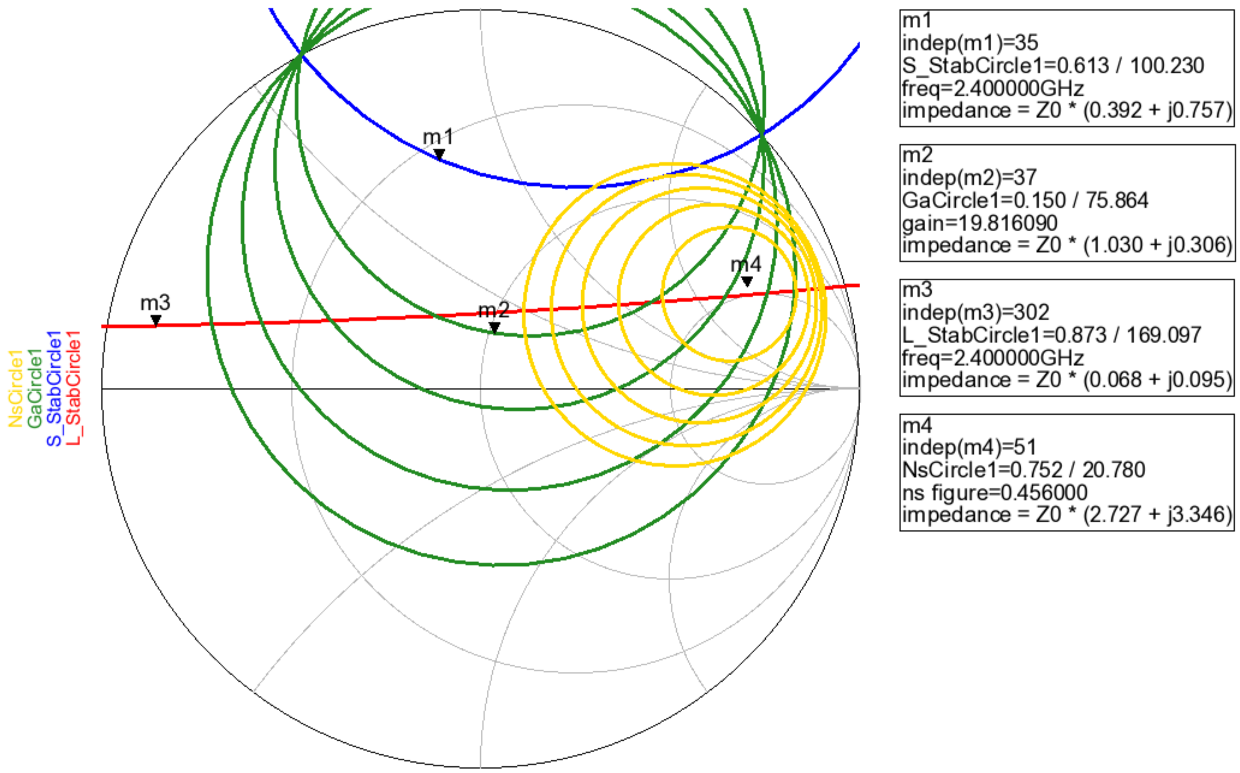
There are always some tradeoffs when designing a low noise amplifier. Depending on what the systems requirements are, certain tradeoffs must be made in the design.

One of the major tradeoffs typical of a low noise amplifier is the input return loss. Depending on the amplifier used, Γopt can be pretty far away from the S11. This design optimizes for the lowest noise figure without paying much attention to the input return loss. Depending on the receiver system, we usually don't care much about the input return loss because any reflected signal will just travel back out of the antenna and not affect any downstream receiver performances

Because of the design goal of unconditional stability over a very wide frequency band, stabilizing the device became more of a challenge. It is possible to achieve a lower noise figure and a higher gain with the TriQuint 6 x 50, 0.5um Dmode PHEMT device, but the chances for any instabilities that could ruin its entire performance would be much greater. In order to guarantee unconditional stability over a broader range, the noise figure and gain of this design were degraded.

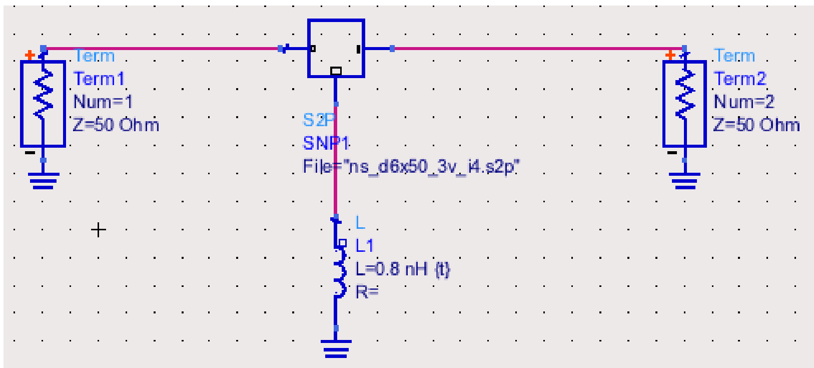
SIMULATIONS

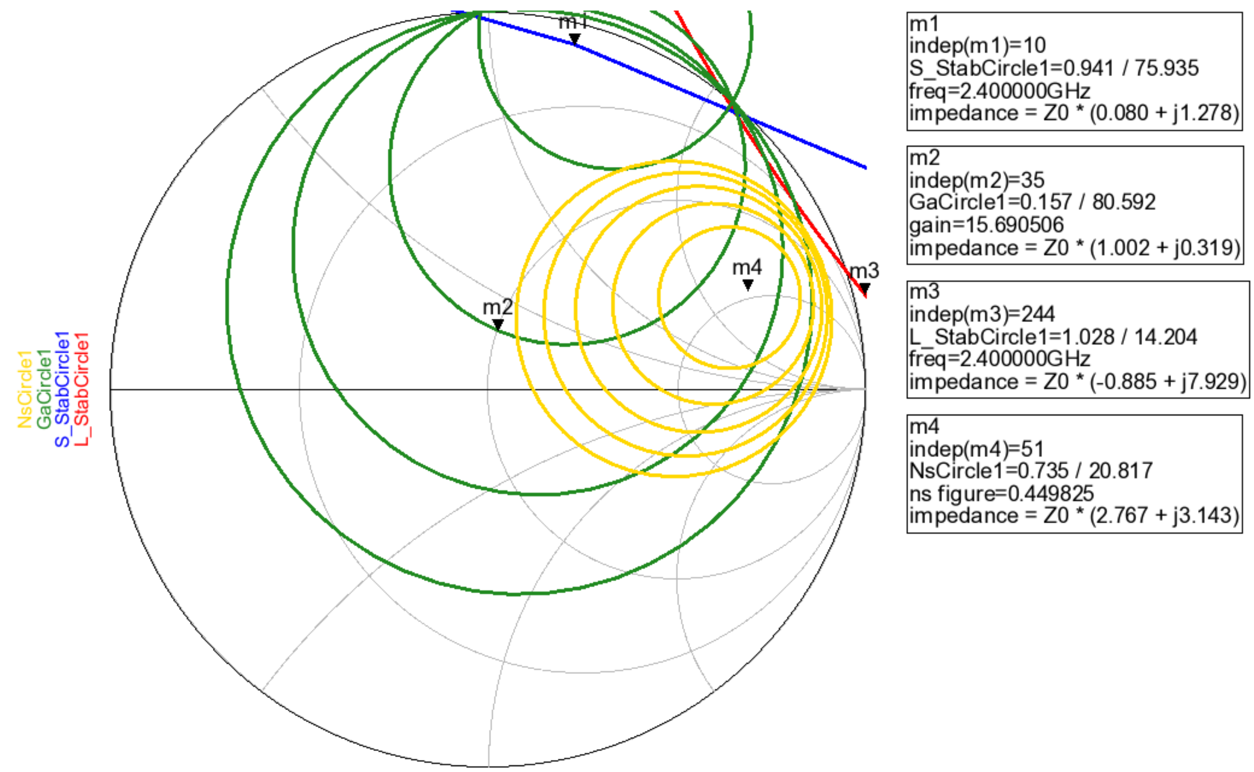
Beginning with a simulation of Noise Figure and gain circles along with stability circles:



It is evident that the in-band response alone looks fairly unstable; especially if a Γopt input match is applied, which is fairly close to the source stability circle.

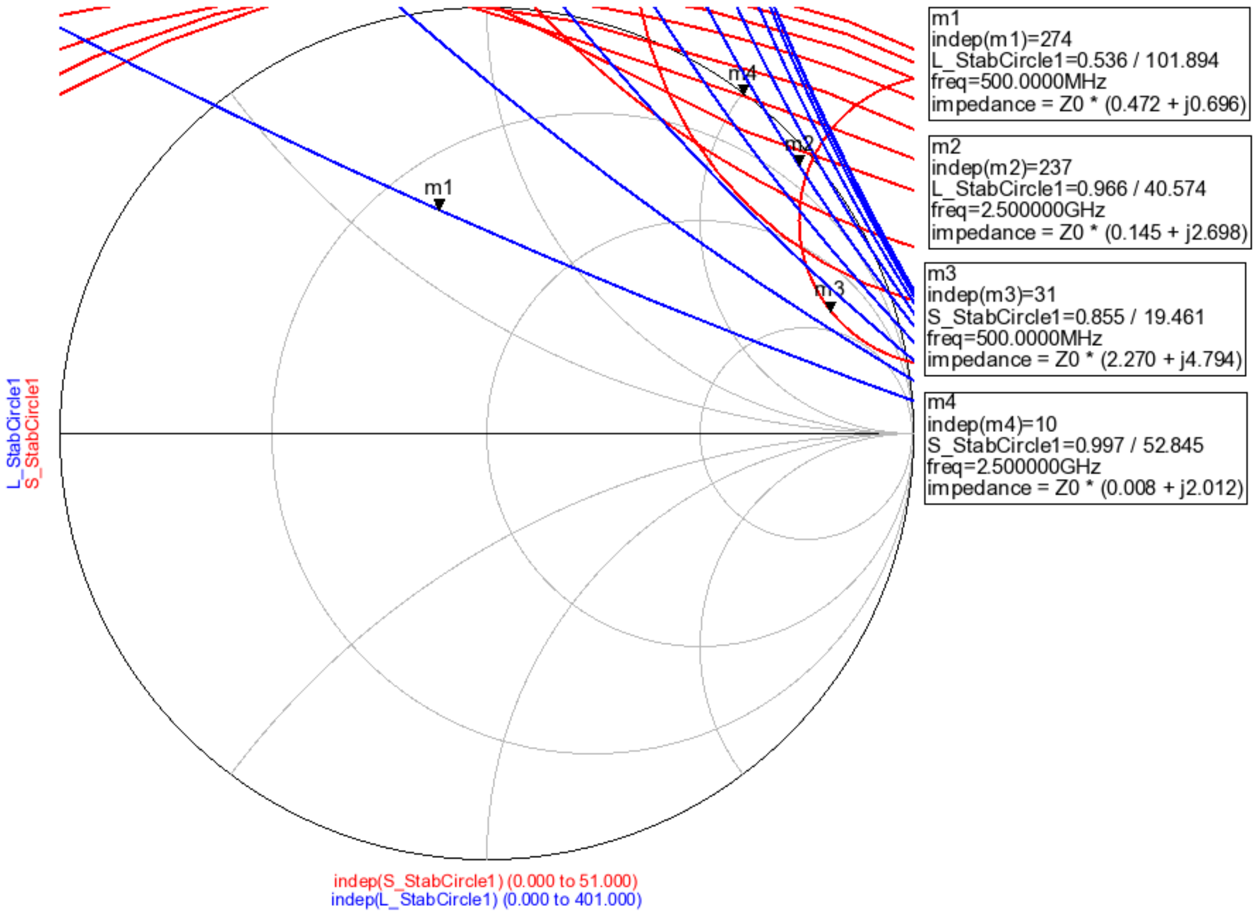
Adding some source inductance pushes the stability circles out and up to a certain amount of inductance, doesn't affect the noise figure and gain too much.



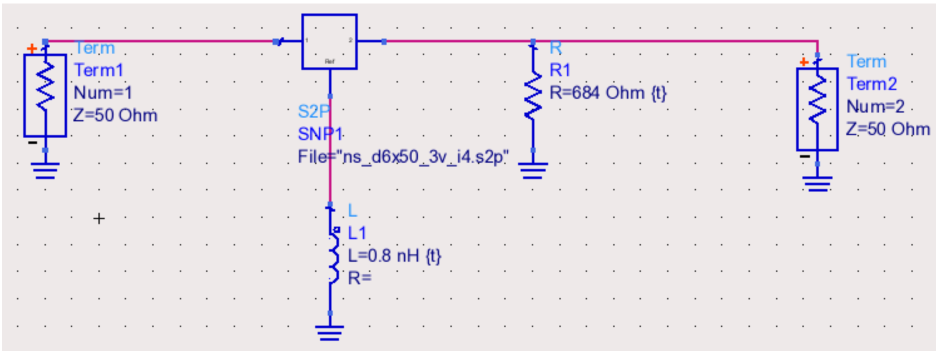


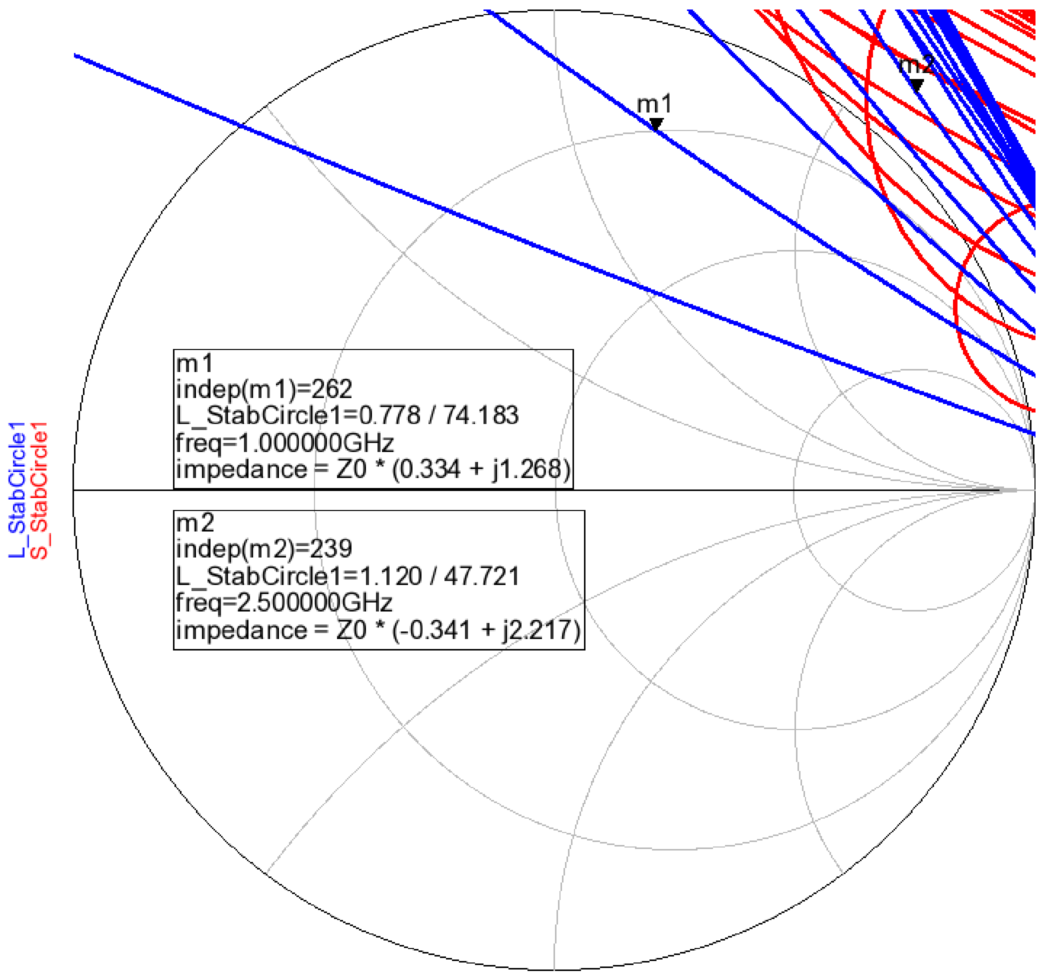
Now the circuit is almost unconditionally stable at 2.4 GHz and the minimum noise figure of the device is still achievable.

Now taking a wider look at stability, it's evident that there is more potential for instability at lower frequencies, and the device still isn't unconditionally stable at 2.4 GHz.



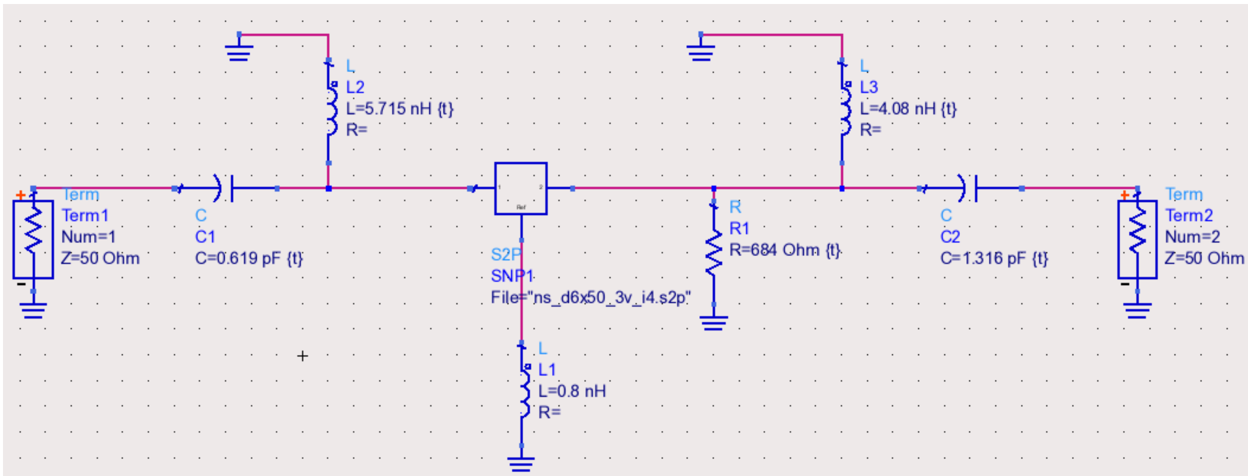
Adding a shunt resistor at the output to help further improve stability without impacting noise figure much:

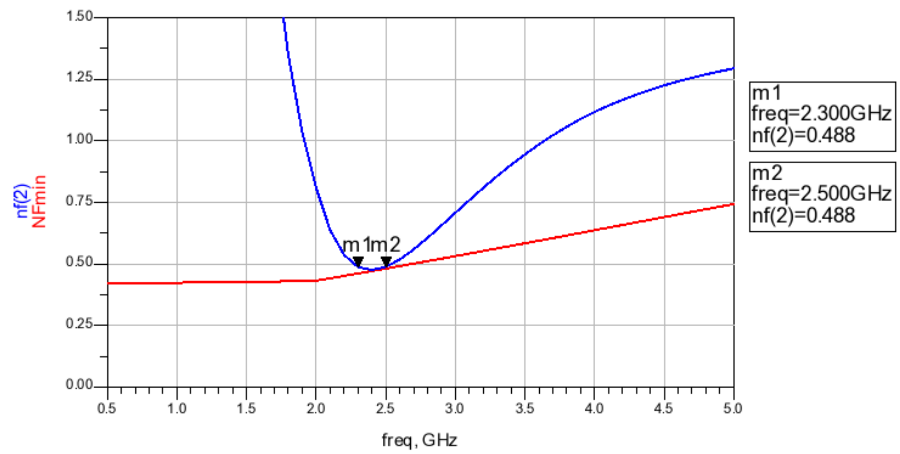


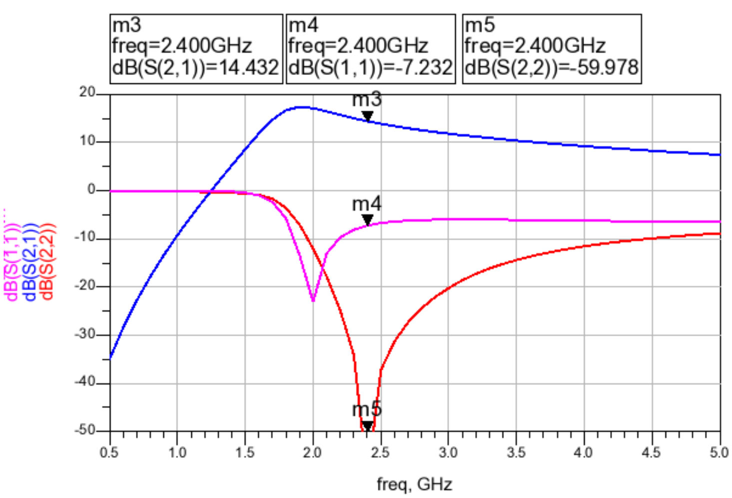


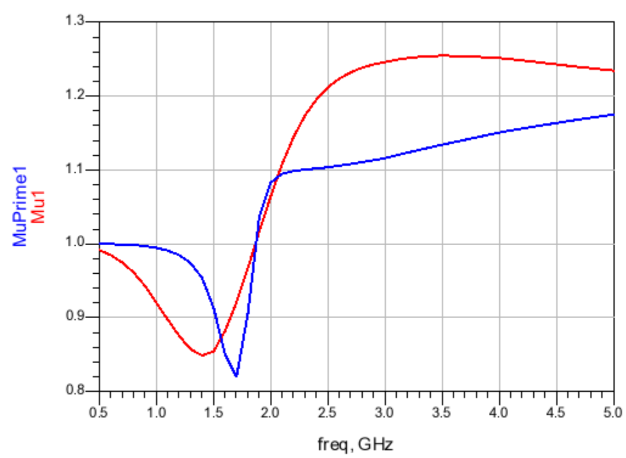
The device is now unconditionally stable at 2.4 GHz, and almost unconditionally stable elsewhere.

Initial ideal matching network; matching to Γopt and S22*

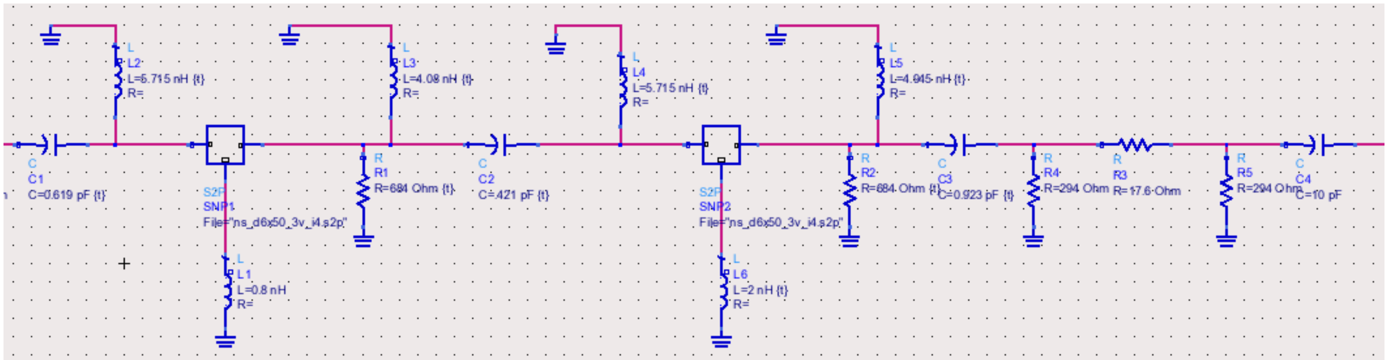


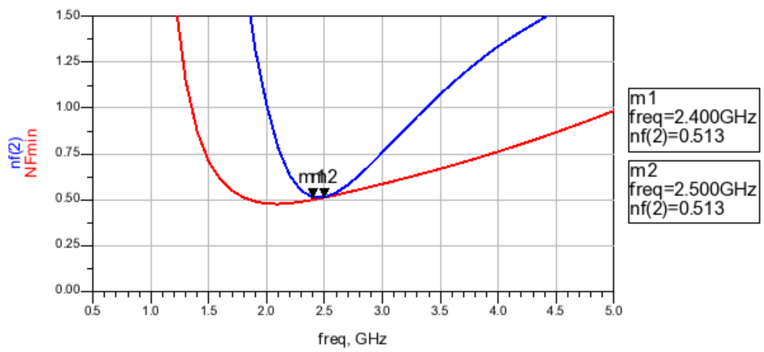


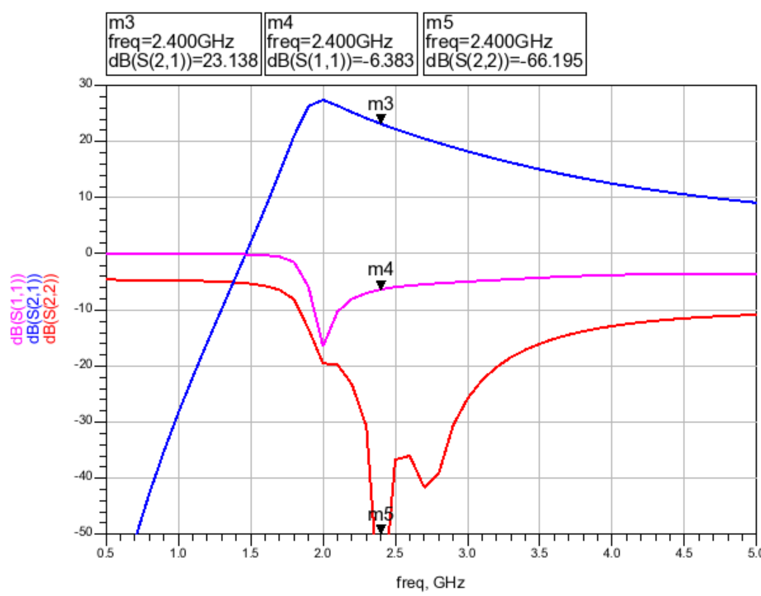


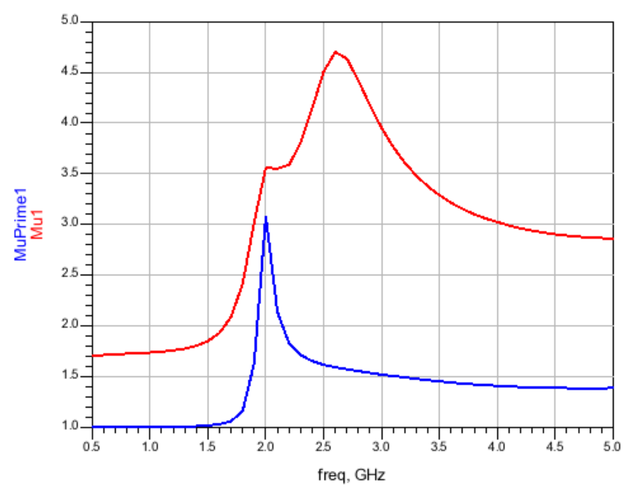


Cascading an almost identical second stage, but with increased source inductance for more stability:



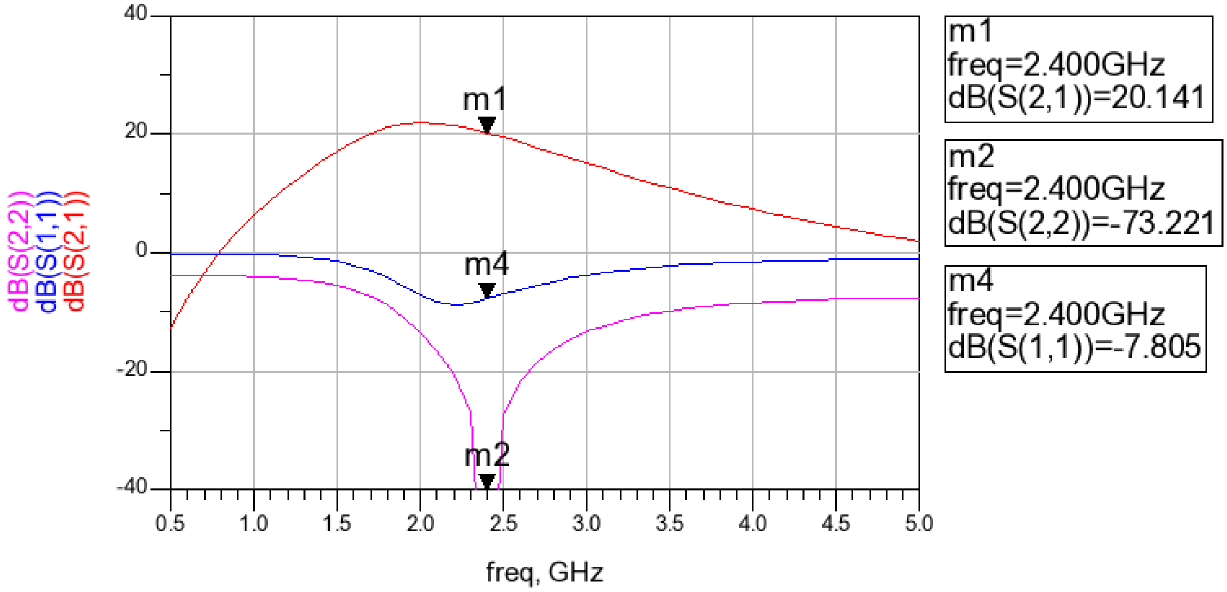


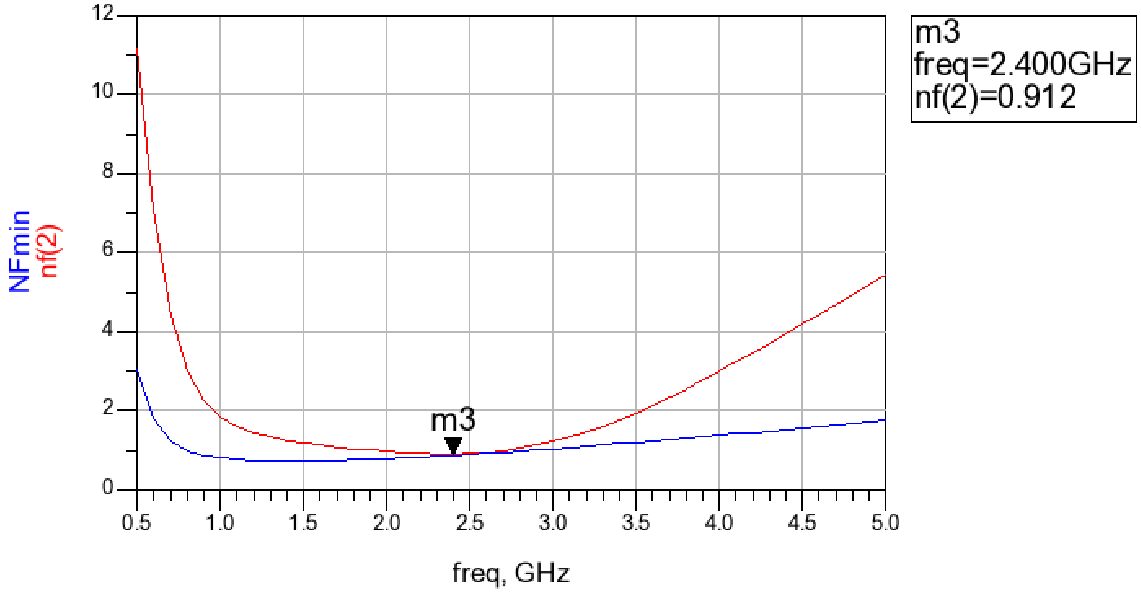




The ideal simulation shows great noise figure and gain, and unconditional stability across all frequencies.

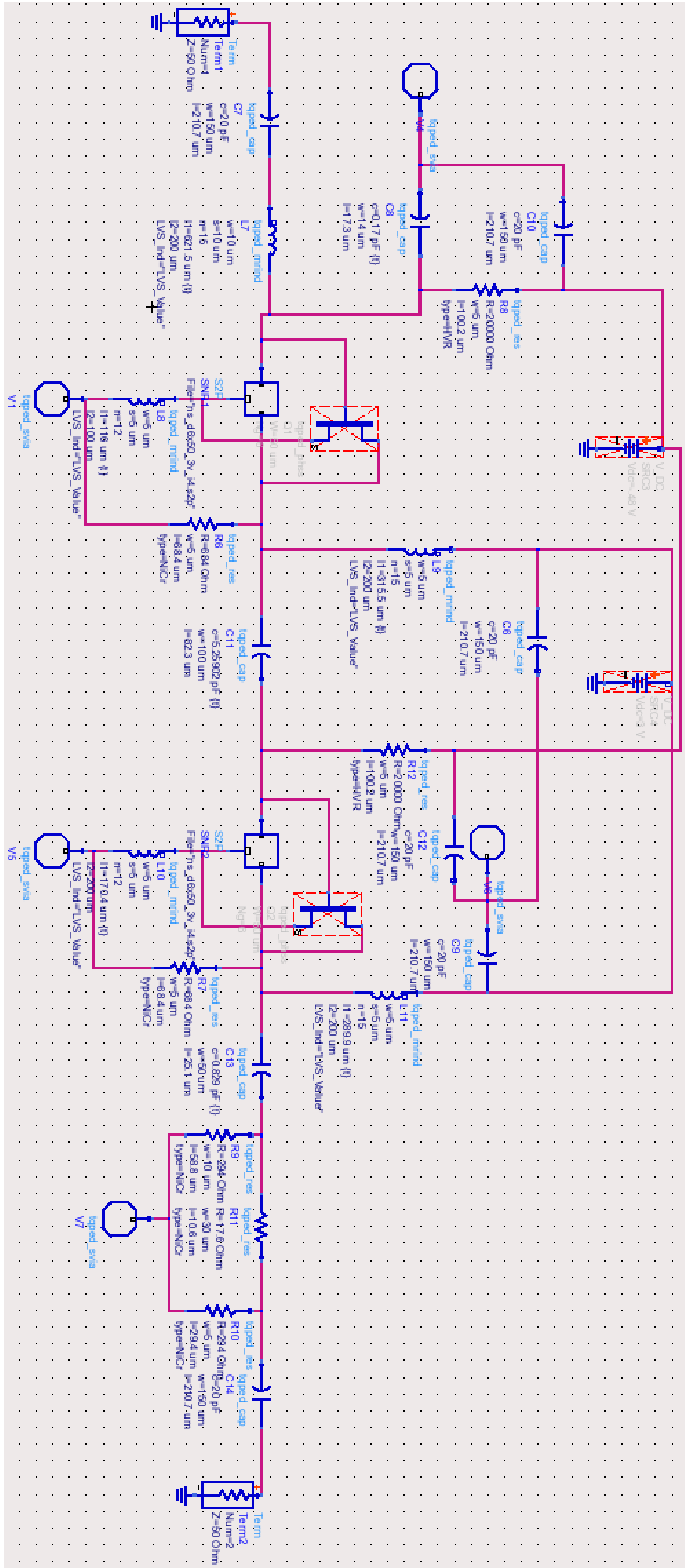
After converting all ideal elements to real Triquint :



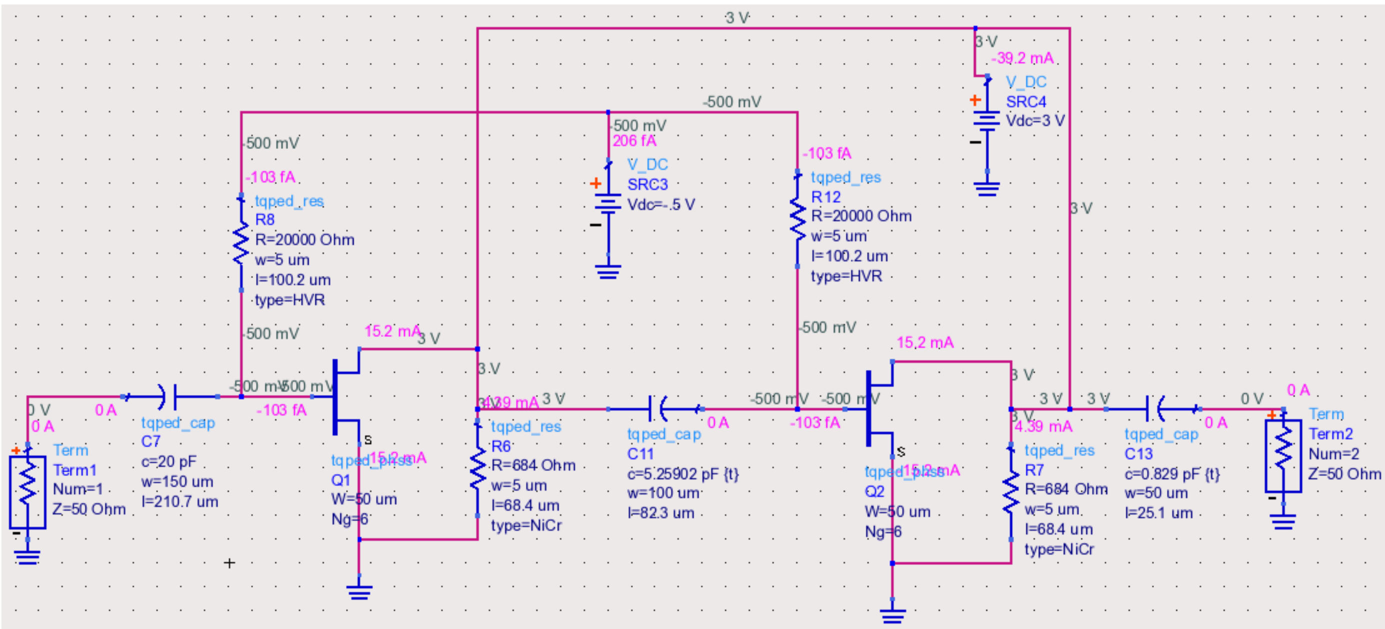


Using real elements increased the overall noise figure by 0.4 dB and lowered the gain by 3 dB. This is mainly due to the decent sized spiral inductors which have an appreciable inherent series resistance.

Final Schematic



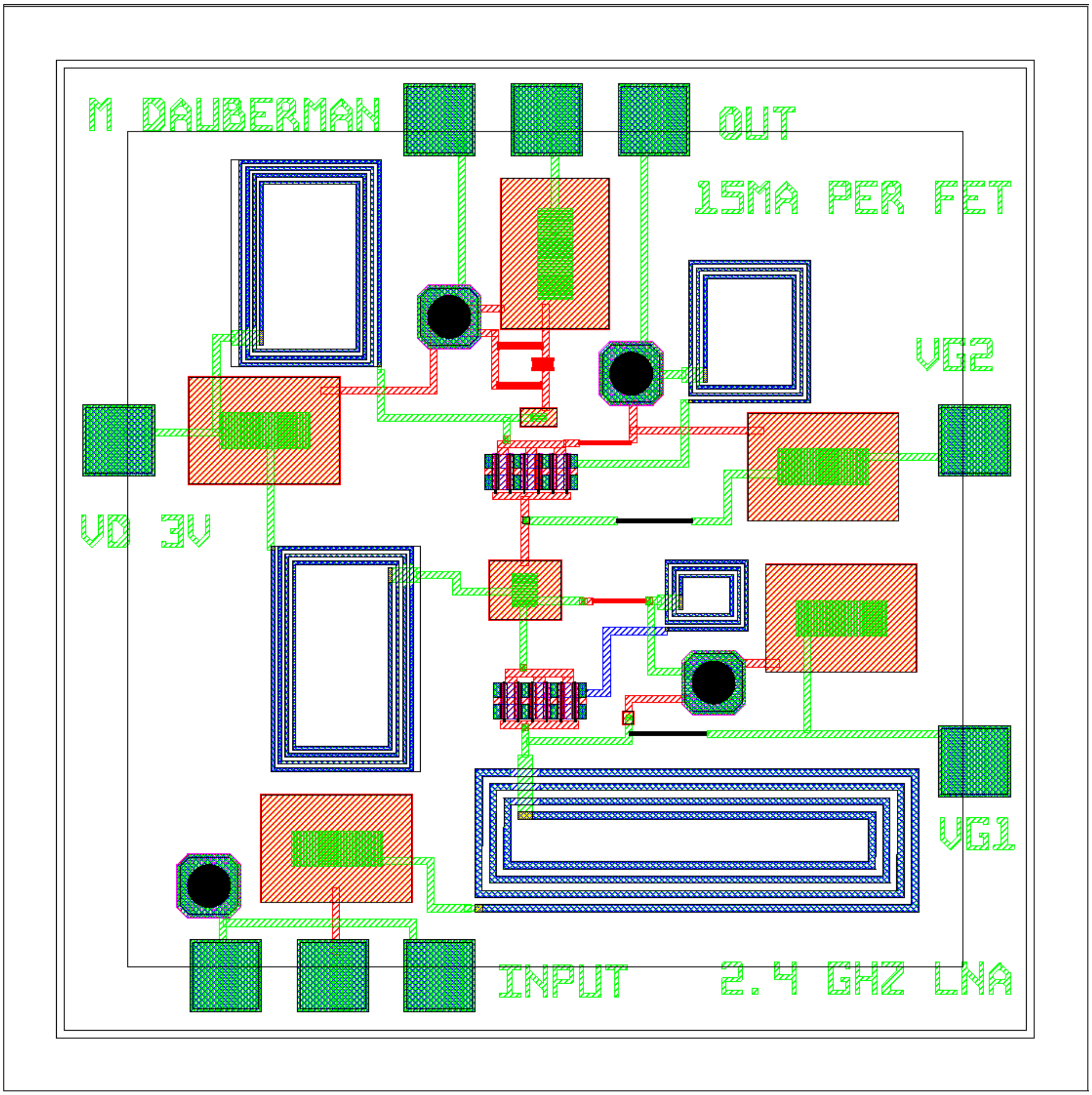
Simple DC Bias Schematic



VD = 3V, ID = 15 mA per FET

VG = -0.5 V for each FET

LAYOUT



TEST PLAN

To thoroughly test this Low noise amplifier, we will need a DC power supplies, a Network Analyzer, and a Noise Figure Analyzer.

1. Bias up the each Gate to -1.5 V to make sure both FETS are completely off before applying the Drain voltage
2. Bias up the Drain to 3V, note the current draw through the stabilization resistors, ~ 4.5 mA per resistor, so with both FETS off the 3V supply should draw around 10mA.
3. Slowly increase the voltage on each Gate until both FETS draw 15mA each. The total 3V current draw should be around 40mA.
4. Run a full 2 port s-parameter sweep from 0.5 – 5GHz on the device and record.
5. Sweep the device on the Noise figure analyzer from 2 – 3 GHz.
6. If performance doesn't look to be as expected, check for oscillations on the spectrum analyzer.

SUMMARY

This report summarized the design, simulation, and testing of a 2.4 GHz Low Noise Amplifier focusing on minimizing noise figure, while achieving wide-band stability. Although the device used shows the potential for a Noise figure below 0.5 dB, with this approach only 0.9 dB Noise Figure was achievable. This was mainly due to the large, lossy inductor used for the input match to Γopt. In order to avoid this loss, it may be possible to use some type of feedback circuit to move Γopt so that a smaller inductor can be used. However, this basic design should be very robust and meet the requirements for a wide range of applications at this frequency range.