Stability & LNAs

Microwave Update

Enfield, CT.

Al Ward

W5LUA

October 14, 2011

Requirements for an LNA

- Absolute lowest noise figure possible
- Good gain to overcome second stage noise figure
- Gain only where we need it
- Good large signal handling capabilities
- Must be stable at all frequencies when installed in the system between the antenna and/or feed and converter – probably the most difficult task….
- Good indicators of instability are excessive gain, high out-of-band gain and positive return loss

The Process

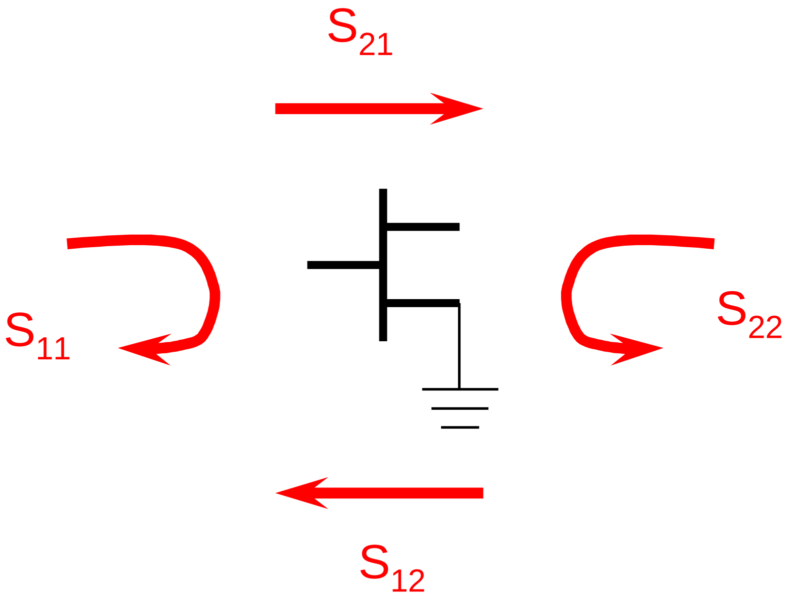
- Understand what the S Parameters are telling you about a device
- Make good engineering decisions based on noise figure, gain and stability – both in-band and out-of-band
- Let’s start by taking a look at S Parameters………..

Start with S-parameters?!??!

- A three-terminal two-port, such as the FET shown, has four S-parameters.
- S_{nn} = voltage reflection coefficient, both amplitude and phase relative to 50 Ω source impedance
- S_{21} and S_{12} are commonly displayed on a polar chart.
- $S_{11} = \Gamma_{input}$ displayed on Smith chart
- $S_{22} = \Gamma_{output}$ displayed on Smith chart

Polar chart

Smith chart



ATF-36077 S and Noise Parameters

F360772A - Notepad

File Edit Format View Help

```
!ATF-36077
!S AND NOISE PARAMETERS at Vds=1.5V  Id=10mA.    LAST UPDATED 06-27-94
!EXTRAPOLATED DOWN TO 50 MHz
# ghz s ma r 50

0.05     0.999   -1      5.050   179      0.005   89      0.60    -1
0.5      0.998   -9      5.050   171      0.009   83      0.60    -7
1        0.99    -17     5.010   163      0.016   78      0.60    -14
2        0.97    -33     4.904   147      0.030   66      0.59    -28
3        0.94    -49     4.745   132      0.043   54      0.57    -41
4        0.90    -65     4.556   116      0.054   43      0.55    -54
5        0.86    -79     4.357   102      0.063   33      0.53    -66
6        0.82    -93     4.162   88       0.069   24      0.50    -78
7        0.78    -107    3.981   75       0.074   16      0.48    -89
8        0.75    -120    3.820   62       0.078   8       0.46    -99
9        0.72    -133    3.682   49       0.080   1       0.44    -109
10       0.69    -146    3.566   37       0.082   -6      0.42    -119
11       0.66    -159    3.473   25       0.083   -13     0.40    -129
12       0.63    -172    3.401   13       0.085   -19     0.38    -139
13       0.61    175     3.349   1        0.086   -25     0.37    -149
14       0.60    161     3.315   -12      0.087   -32     0.35    -160
15       0.58    147     3.296   -24      0.089   -39     0.33    -171
16       0.57    131     3.289   -37      0.091   -47     0.31    177
17       0.56    114     3.289   -50      0.092   -55     0.29    164
18       0.57    97      3.291   -64      0.094   -65     0.26    148

.05      0.30    0.98     1      0.60
0.5      0.30    0.97     6      0.50
1        0.30    0.95    12      0.40
2        0.30    0.90    25      0.20
4        0.30    0.81    51      0.17
6        0.30    0.73    76      0.13
8        0.37    0.66    102     0.09
10       0.44    0.60    129     0.05
12       0.50    0.54    156     0.03
14       0.56    0.48    -174    0.02
16       0.61    0.43    -139    0.05
18       0.65    0.39    -100    0.09
```

ATF-36077 S Parameters

Freq (GHz)	S11 Mag	S11 Ang	S21 Mag	S21 Ang	S12 Mag	S12 Ang	S22 Mag	S22 Ang
0.05	0.999	-1	5.050	179	0.005	89	0.60	-1
0.5	0.998	-9	5.050	171	0.009	83	0.60	-7
1	0.99	-17	5.010	163	0.016	78	0.60	-14
2	0.97	-33	4.904	147	0.030	66	0.59	-28
3	0.94	-49	4.745	132	0.043	54	0.57	-41
4	0.90	-65	4.556	116	0.054	43	0.55	-54
5	0.86	-79	4.357	102	0.063	33	0.53	-66
6	0.82	-93	4.162	88	0.069	24	0.50	-78
7	0.78	-107	3.981	75	0.074	16	0.48	-89
8	0.75	-120	3.820	62	0.078	8	0.46	-99
9	0.72	-133	3.682	49	0.080	1	0.44	-109
10	0.69	-146	3.566	37	0.082	-6	0.42	-119
11	0.66	-159	3.473	25	0.083	-13	0.40	-129
12	0.63	-172	3.401	13	0.085	-19	0.38	-139
13	0.61	175	3.349	1	0.086	-25	0.37	-149
14	0.60	161	3.315	-12	0.087	-32	0.35	-160
15	0.58	147	3.296	-24	0.089	-39	0.33	-171
16	0.57	131	3.289	-37	0.091	-47	0.31	177
17	0.56	114	3.289	-50	0.092	-55	0.29	164
18	0.57	97	3.291	-64	0.094	-65	0.26	148

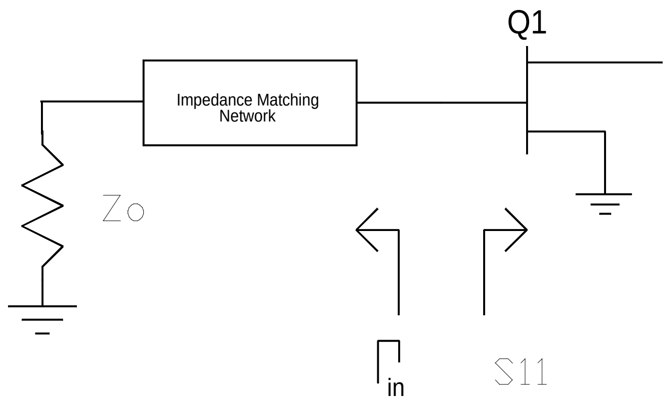
$$RL = 10\log|\Gamma|^2 \qquad VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad G = 20\log|\Gamma|$$

ATF-36077 Noise Parameters

Freq (GHz)	Fmin (dB)	Gamma Opt (Γo) Mag	Gamma Opt (Γo) Ang	Rn
.05	0.30	0.98	1	0.60
0.5	0.30	0.97	6	0.50
1	0.30	0.95	12	0.40
2	0.30	0.90	25	0.20
4	0.30	0.81	51	0.17
6	0.30	0.73	76	0.13
8	0.37	0.66	102	0.09
10	0.44	0.60	129	0.05
12	0.50	0.54	156	0.03
14	0.56	0.48	-174	0.02
16	0.61	0.43	-139	0.05
18	0.65	0.39	-100	0.09

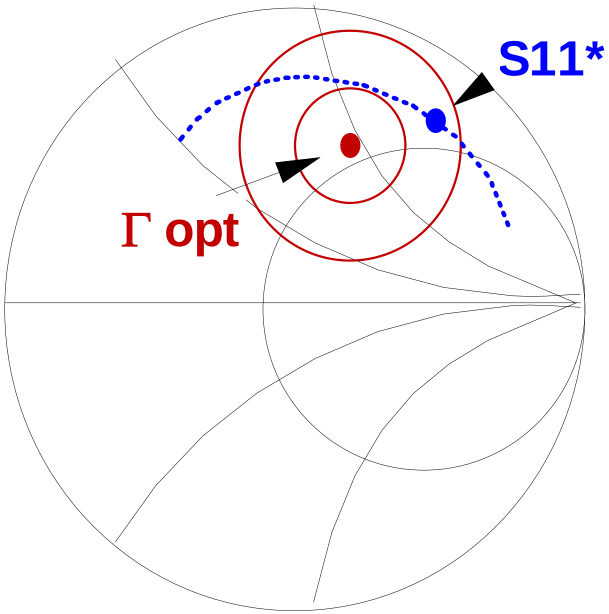
What about Noise Parameters?!??!

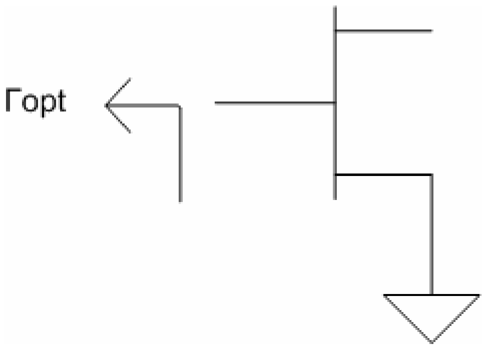
- Γ_o (Gamma Opt) is the reflection coefficient of the source impedance presented to the device that allows the device to produce its' f_{min}
- Matching circuit losses often limit the ability of the amplifier to achieve a noise figure equivalent to device f_{min}
- Γ_o not necessarily equal to $S11^*$ which means noise match is not equivalent to a gain match
- R_n (Noise Resistance) is used to calculate the device's sensitivity in noise figure to changes in source impedance, r_n is normalized to 50 Ω.



For minimum NF, $\Gamma_{in} = \Gamma_o$
For maximum gain, $\Gamma_{in} = S11^*$

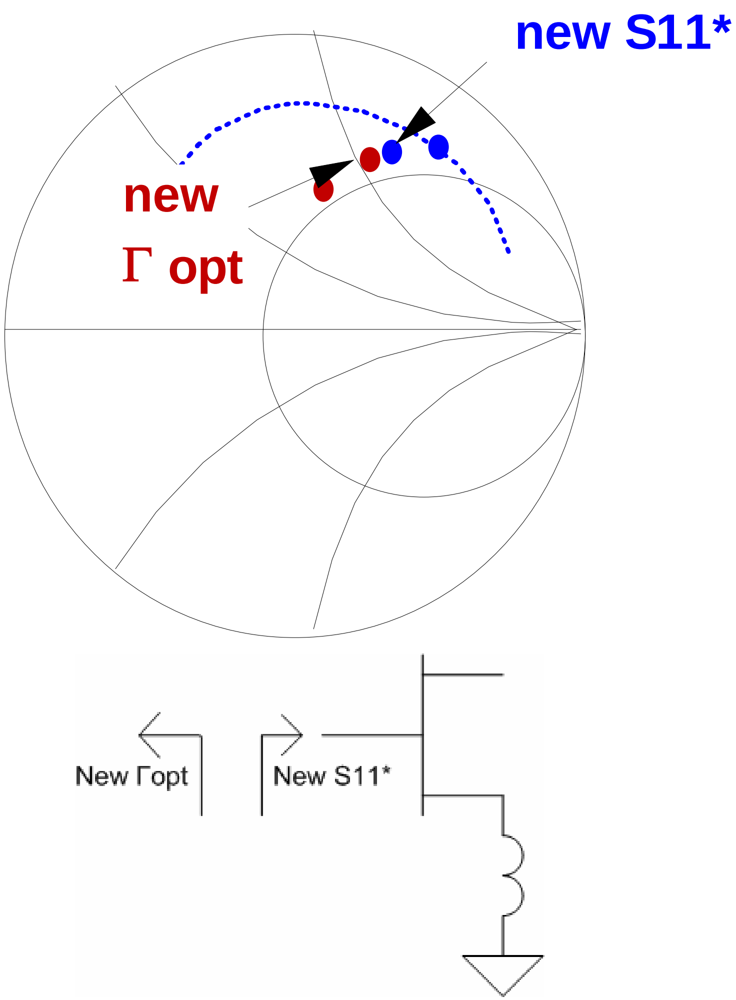
Input Impedance Match





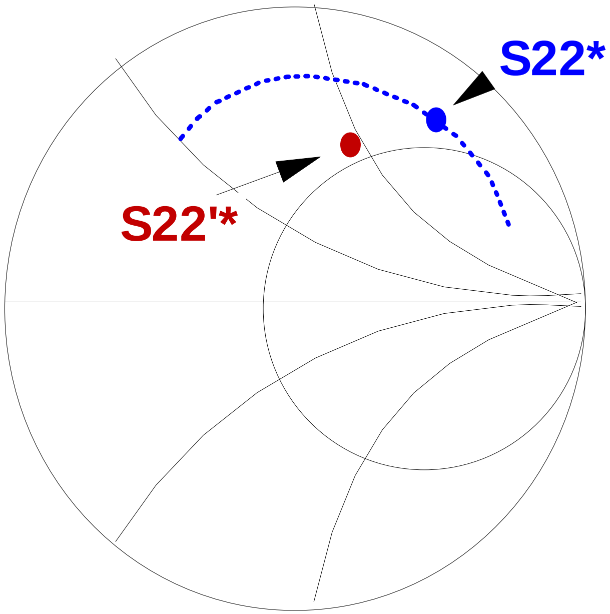
- Match to Γopt for minimum noise figure
- Noise degrades in circular contours as match moves away from Γopt
- Degree of noise degradation is dependent on Rn, the noise resistance
- Most amateur applications aim for minimum noise figure and accept input VSWR

Simultaneous Input VSWR and Noise Match



- Adding source inductance rotates Γopt towards S_{11}^*
- Source inductance is series feedback which effects gain and stability
- Its' effect must be analyzed over as a wide a bandwidth as the device has gain

Output Impedance Match



$$\Gamma_L = \left[S_{22} + \frac{S_{12} S_{21} \Gamma o}{1 - S_{11} \Gamma o} \right]^*$$

- $S_{22}'^* = \Gamma_L$ is the reflection coefficient of the output matching network with input terminated in Γopt, not 50Ω
- Match to $S_{22}'^* = \Gamma_L$ for best gain/output VSWR
- LNA may not be unconditionally stable when matched for best output VSWR - Some resistive loading may be required to reduce gain to improve stability
- Best output VSWR does not necessarily guarantee best P1dB and IP3.

ATF-36077 S21, MSG & MAG

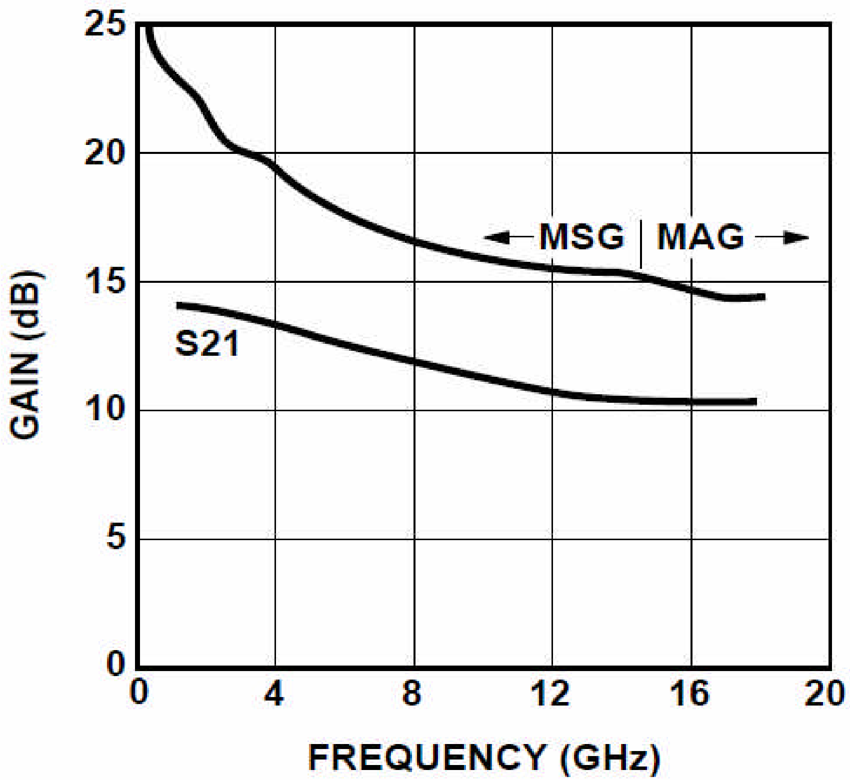


Figure 2. Maximum Available Gain, Maximum Stable Gain and Insertion Power Gain vs. Frequency. V_{DS} = 1.5 V, I_D = 10 mA.

Evaluating LNA Stability

- Two factors are typically used to evaluate LNA stability. The first is the Rollett Stability factor K. K > or = 1 for unconditional stability

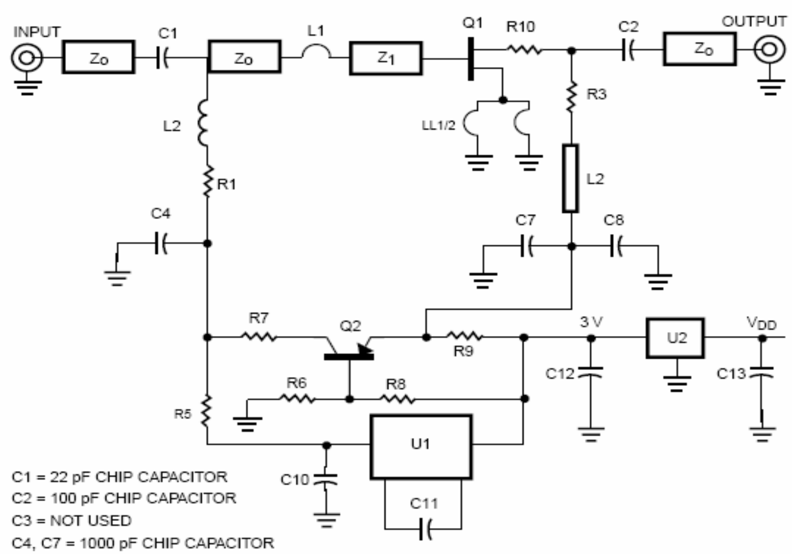
$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |D|^2}{2|S_{12}||S_{21}|} \qquad D = S_{11}S_{22} - S_{12}S_{21}$$

- The second is mu and mu'

This measurement gives the distance from the center of the Smith chart to the nearest output (load) stability circle. This stability factor is given by:
mu = {1-$|S_{11}|^2$} / {$|S_{22}$ - conj(S_{11})*Delta | + $|S_{12}$*$S_{21}|$ }
where Delta is the determinant of the S-parameter matrix. Having mu > 1 is the single necessary and sufficient condition for unconditional stability of the 2-port network.

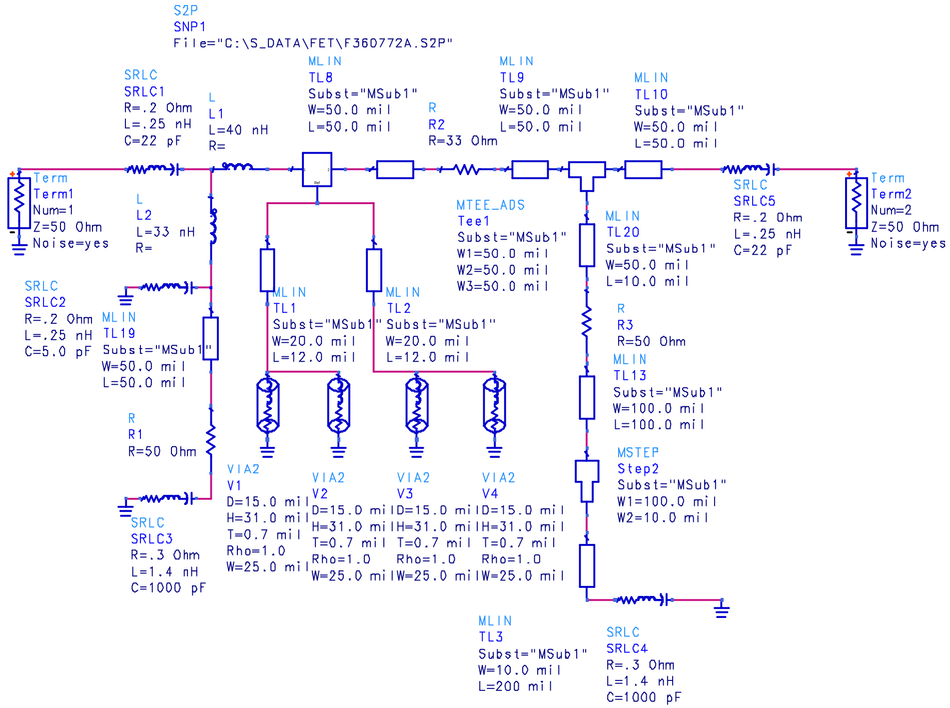
- Both are calculated using LNA S parameters over a wide frequency range for reasons that will be discussed shortly

ATF-36077 1296 MHz LNA



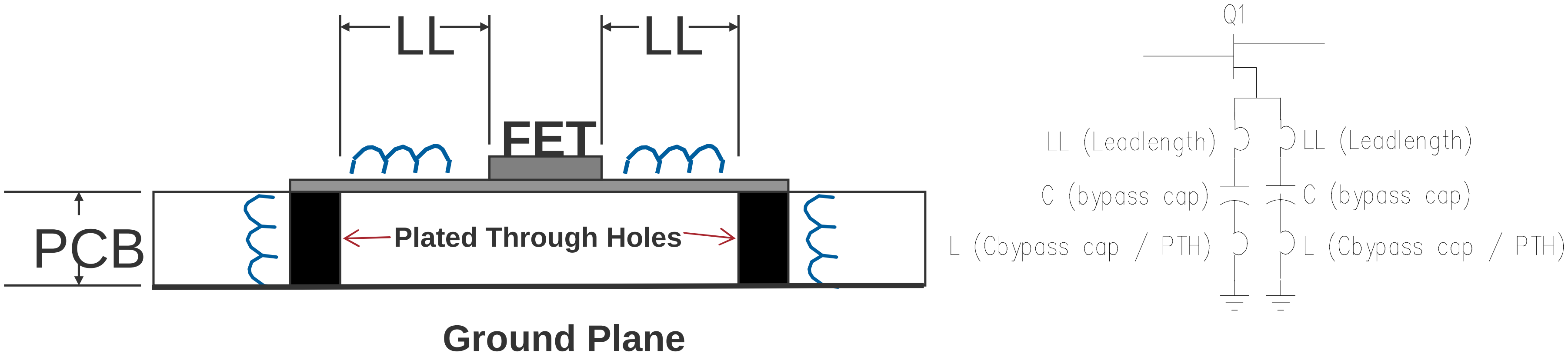
C1 = 22 pF CHIP CAPACITOR
C2 = 100 pF CHIP CAPACITOR
C3 = NOT USED
C4, C7 = 1000 pF CHIP CAPACITOR
C5, C6 = NOT USED, GROUND SOURCES DIRECTLY
C9 = NOT USED
C8, C12, C13 = 0.1 µF CHIP CAPACITOR
C10, C11 = 10 µF CHIP CAPACITOR
L1 = 6T 0.007" DIA. WIRE, 0.050" ID, 0.14" LENGTH
L2 = 0.18 TO 0.33 µH RFC
LL1, LL2 = PLATED THROUGH HOLES TO BACKSIDE GROUNDPLANE DIRECTLY UNDER EACH LEAD
Q1 = AGILENT TECHNOLOGIES ATF-36077 PHEMT
R1 = 100 OHM CHIP RESISTOR
R2 = NOT USED
R3 = 50 OHM CHIP RESISTOR
R4 = NOT USED
R5, R7 = 10 k OHM CHIP RESISTOR
R6 = 1.3 k OHM CHIP RESISTOR
R8 = 2.7 k OHM CHIP RESISTOR (SETS DRAIN VOLTAGE)
R9 = 270 OHM CHIP RESISTOR (SETS DRAIN CURRENT)
R10 = 16 OHM CHIP RESISTOR (UP TO 27 OHMS OK)
U1 = LINEAR TECHNOLOGY LTC1044CS8 VOLTAGE CONVERTER
U2 = 5 VOLT REGULATOR TOKO TK11650U

Agilent ADS Simulation



Adding a 5 pF cap to ground at the junction of L2 and R1 will lower noise figure

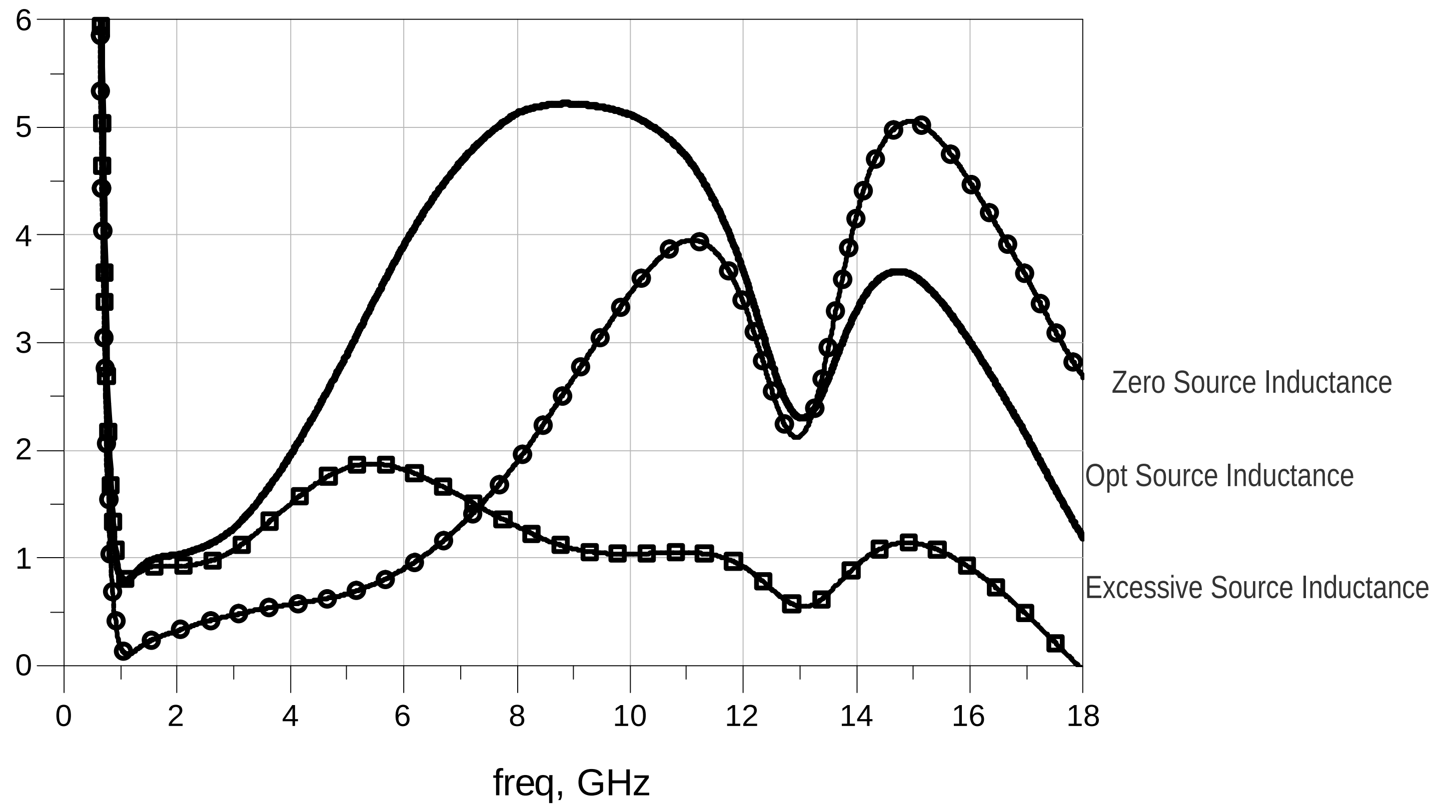
Source Grounding



Source inductance can be the biggest problem with most LNAs. Usually there are two source leads so the inductance can effectively be cut in half. Source inductance is made up from several factors including the length of the source lead, the length of the VIA to the bottom side of the circuit board ground plane and any additional circuit trace that connects the source lead to the VIA. If self biasing is used then the equivalent series inductance of the bypass capacitor must be included in the analysis.

In a good LNA design, this inductance amounts to a few tenths of a nH, but the effects are significant…..

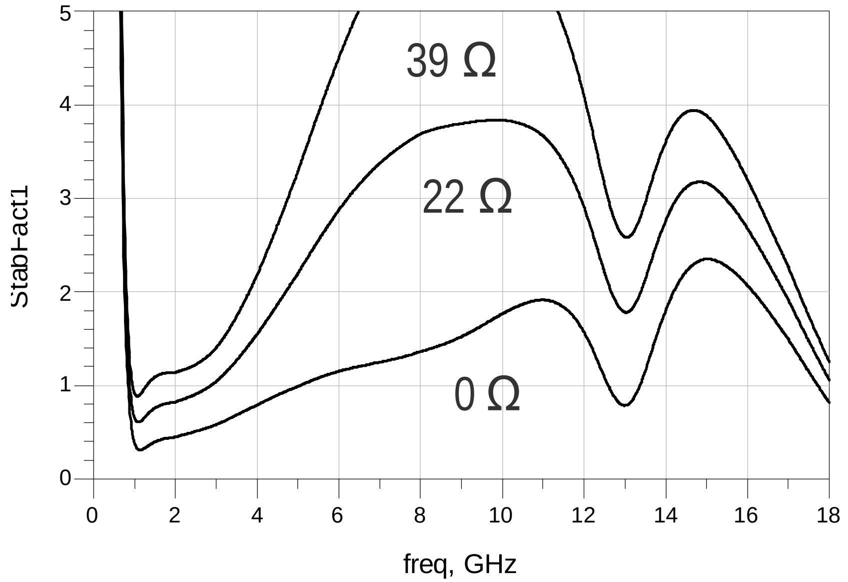
Evaluating LNA Stability K versus Frequency

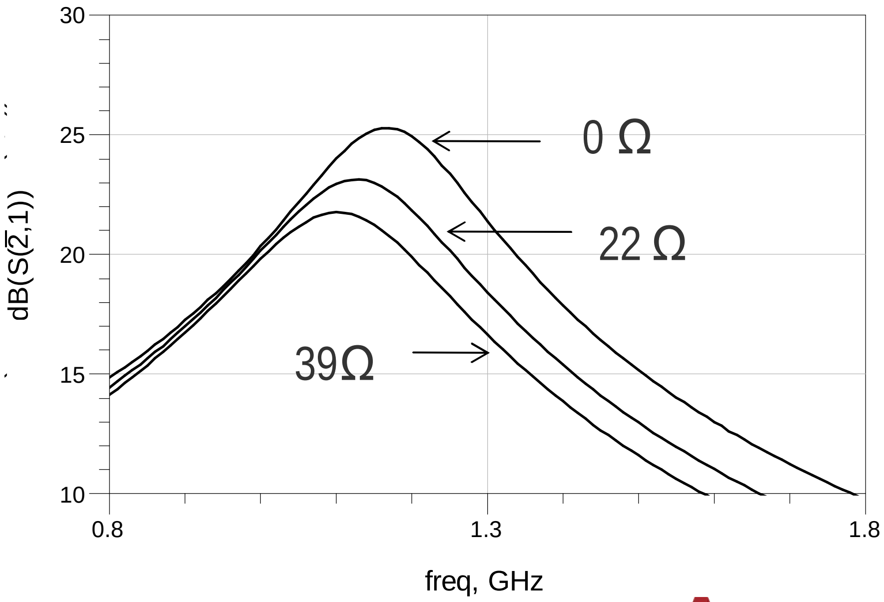


$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |D|^2}{2|S_{12}||S_{21}|}$$

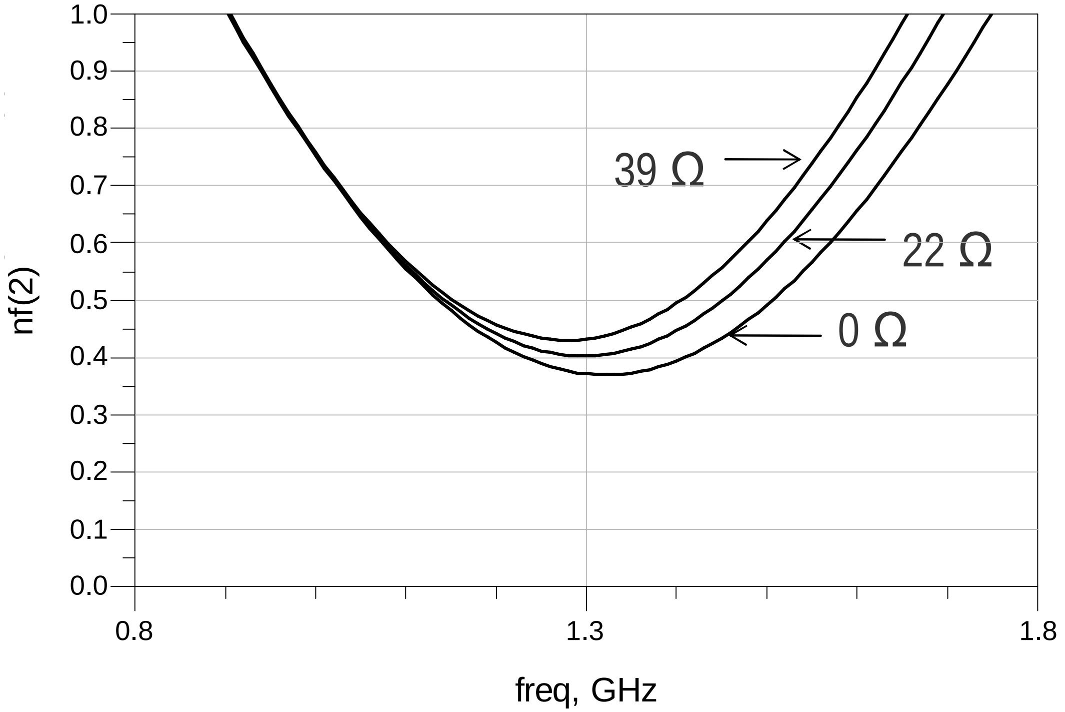
$$D = S_{11}S_{22} - S_{12}S_{21}$$

Improving Stability with Resistance in the Drain Once the Optimum Source Inductance has been determined

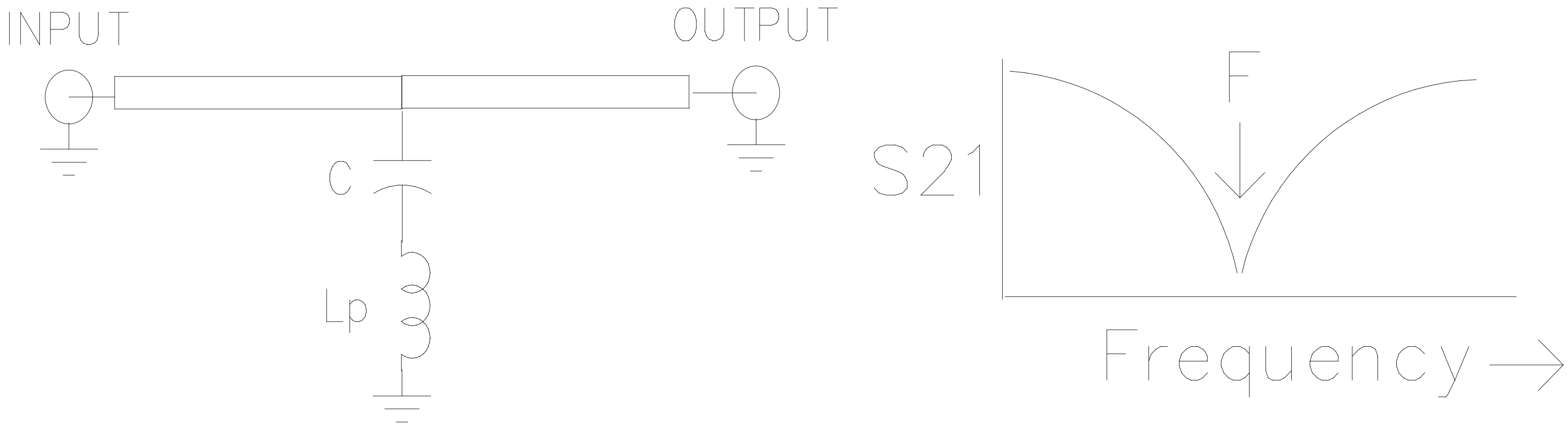




Noise Figure vs Drain Resistance

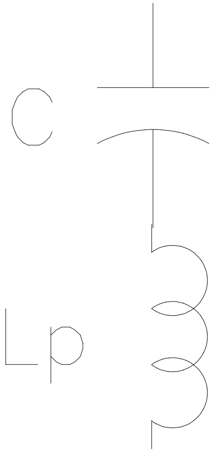


Chip Capacitor Parasitics - A First Approximation



- A capacitor shunted across a microstripline exhibits a first order series resonance at a frequency where the capacitance C and its' associated parasitic lead inductance Lp resonate. The effect is shown as a reduction in S21 at frequency F OR
- Lp can then be easily calculated by $\omega = 2 \pi F = 1/ SQRT (L C)$

Chip Capacitor Parasitics - A First Approximation

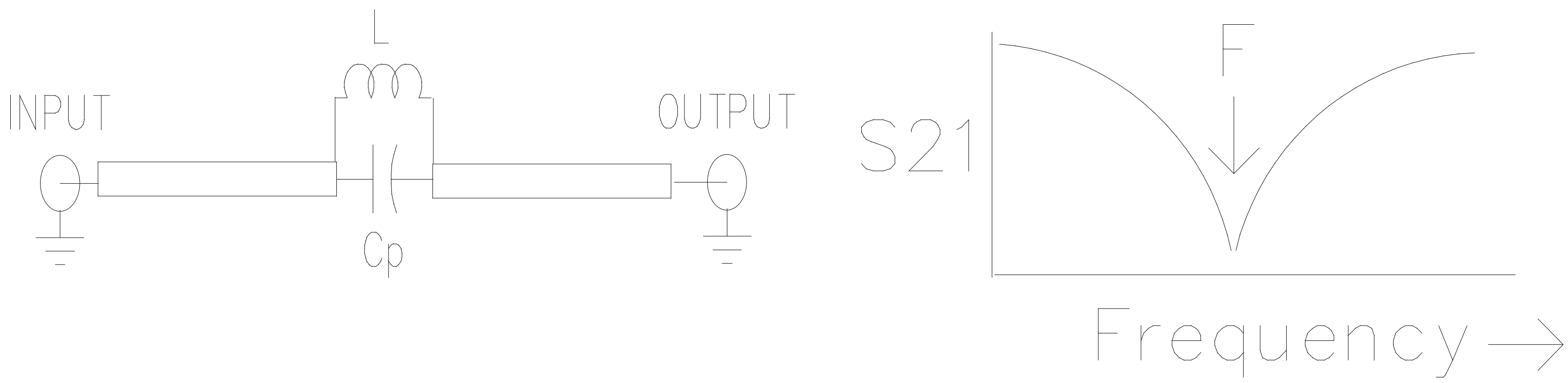


Capacitor (pF)	Associated Inductance Lp (nH)
1	0.71
8.2	0.78
27	0.79
1000	1.2

Sample data

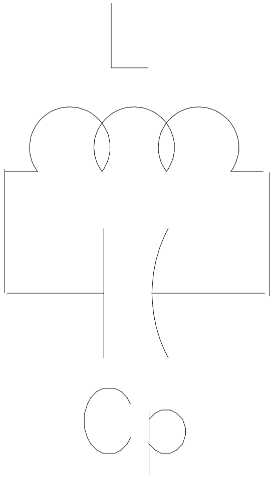
- **Capacitors are ATC 0.050" square ceramic**
- **Parasitic inductance should be included in circuit designs for best correlation between simulation and actual bench performance**

Chip Inductor Parasitics - A First Approximation



- An inductor inserted in series with a microstripline exhibits a first order parallel resonance at a frequency where the inductor L and its' associated shunt parasitic capacitance Cp resonate. The effect is shown as a reduction in S21 at frequency F OR
- Lp can then be easily calculated by $\omega = 2 \pi F = 1/ SQRT (L C)$

Chip Inductor Parasitics - A First Approximation

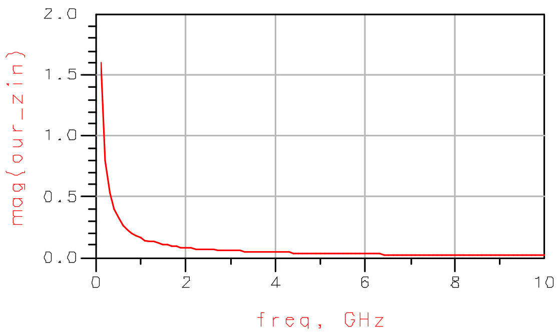


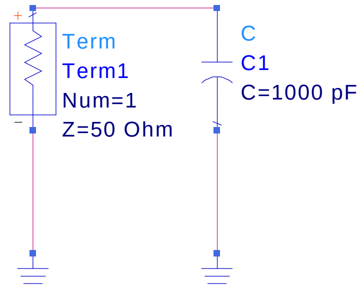
Inductor (nH)	Associated shunt capacitance Cp (pF)
4	0.048
10	0.076
27	0.170
560	0.128

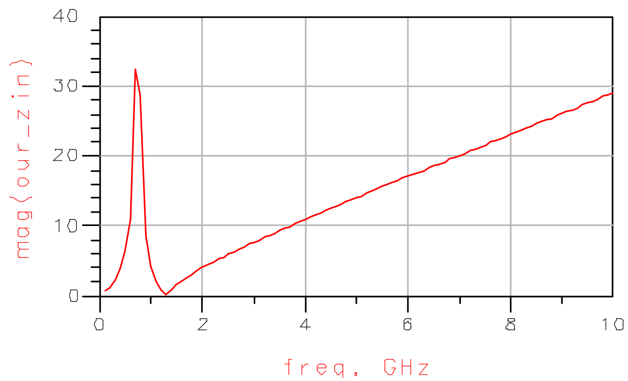
Sample data

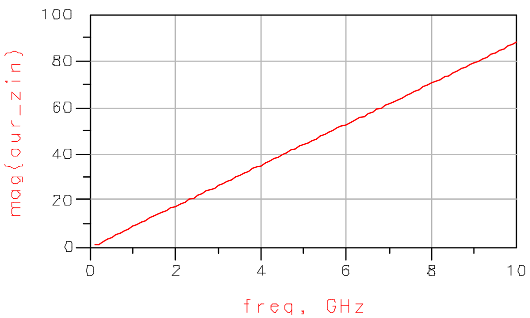
- **Inductors are Coilcraft 1008CS style**
- **Parasitic shunt capacitance should be included in circuit designs for best correlation between simulation and actual bench performance**

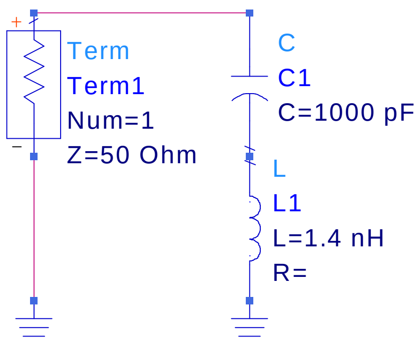
Effect of paralleling two capacitors of different values

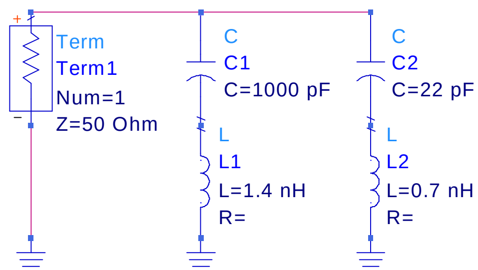








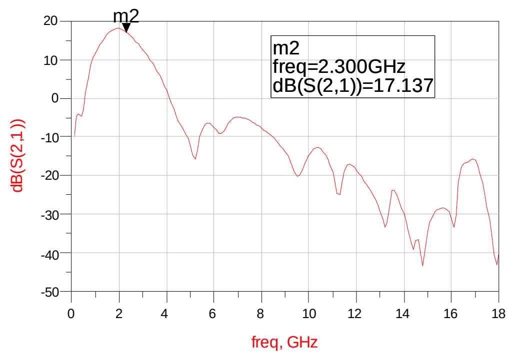


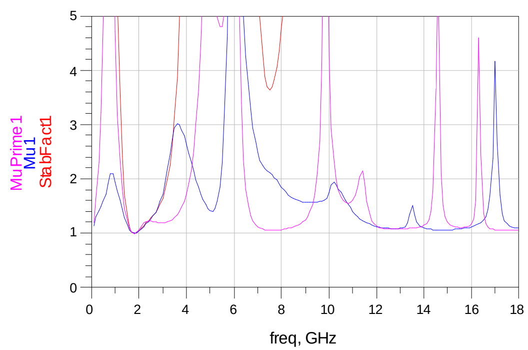


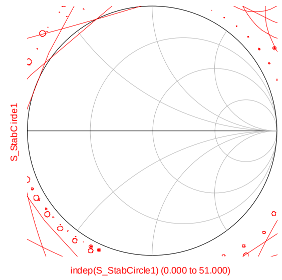
Paralleling 2 caps of equal C and L cuts Z in half at all freq

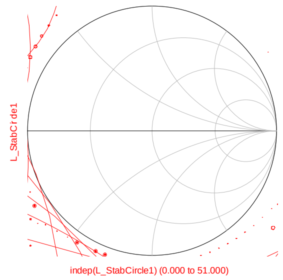
Paralleling 22 pF cap with 1000 pF cap may lower Z at 1.2 GHz, however, Z at 0.8 GHz increases dramatically

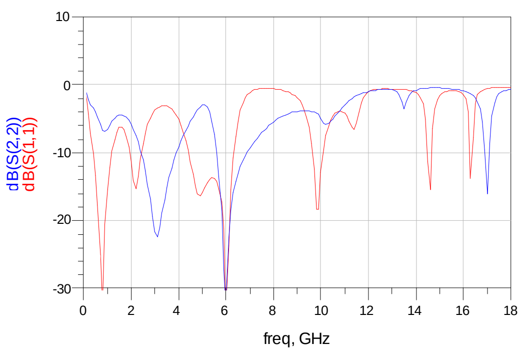
Single Stage ATF-36077 2304 MHz LNA with Nominal Source Inductance & 22Ω Drain Resistor

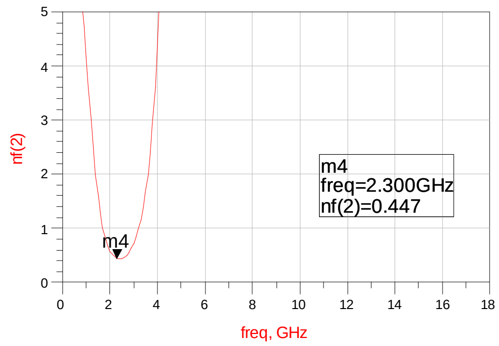


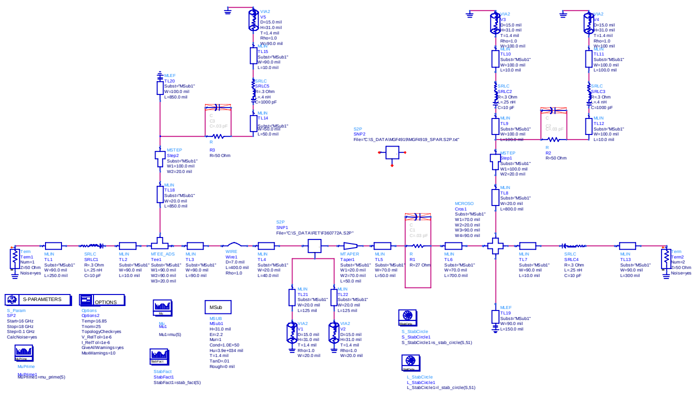




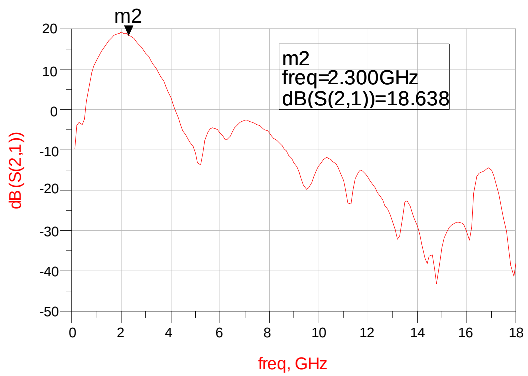


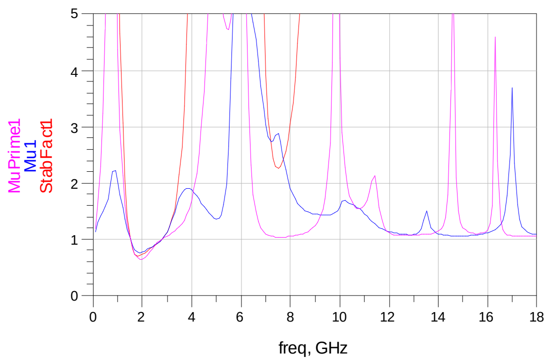


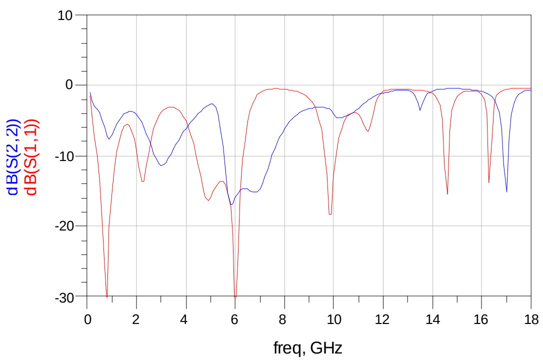


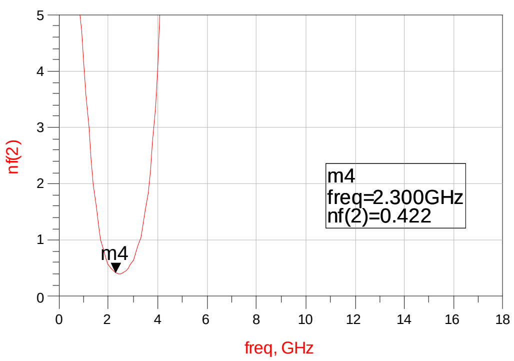


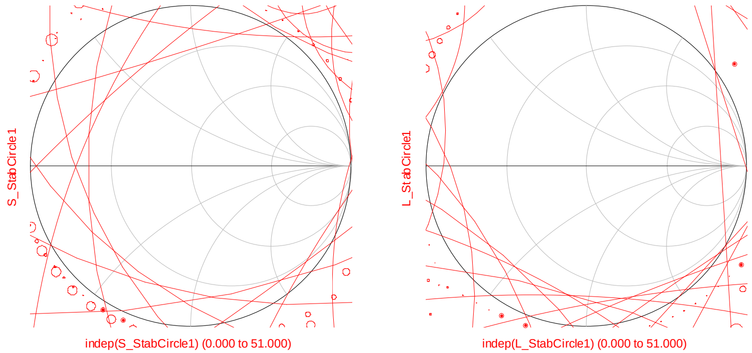
Single Stage ATF-36077 2304 MHz LNA with Nominal Source Inductance & no Drain Resistor



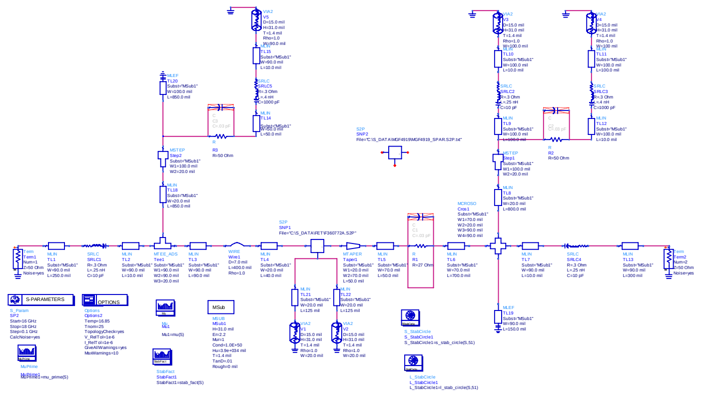






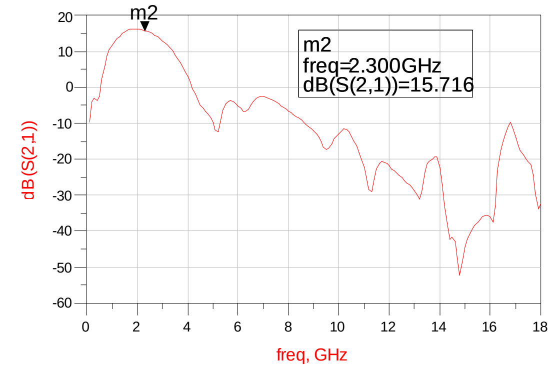


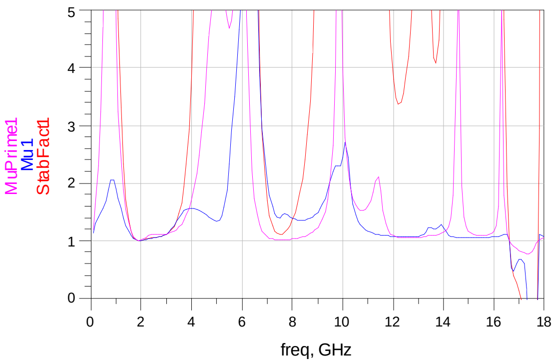
Source and Load Stability Circles

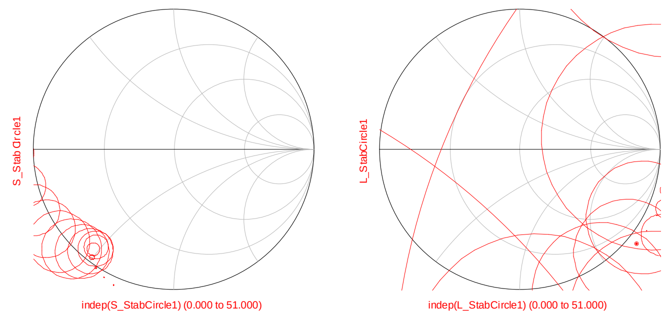


ADS Schematic

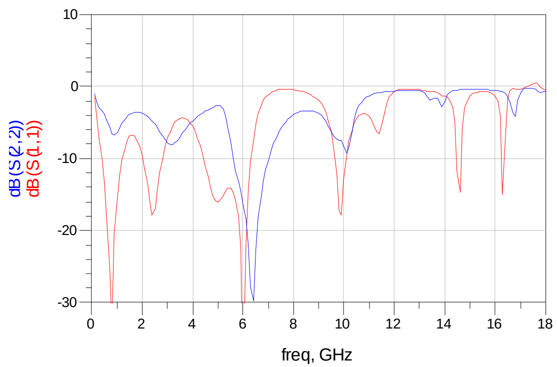
Single Stage ATF-36077 2304 MHz LNA with Excessive Source Inductance

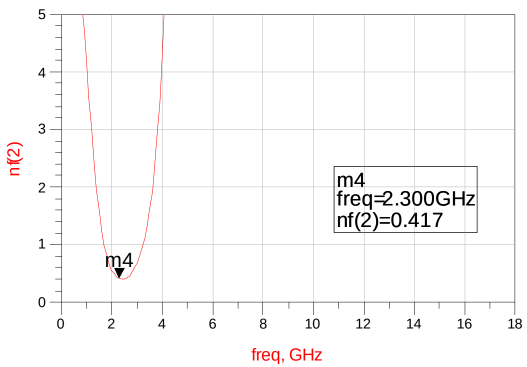


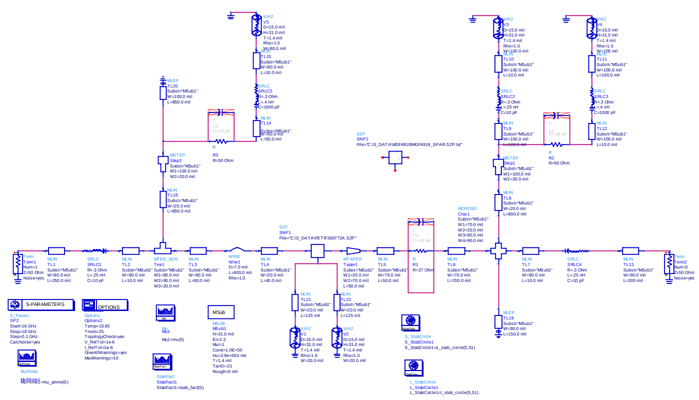




Source and Load Stability Circles







ADS Schematic

AVAGO TECHNOLOGIES

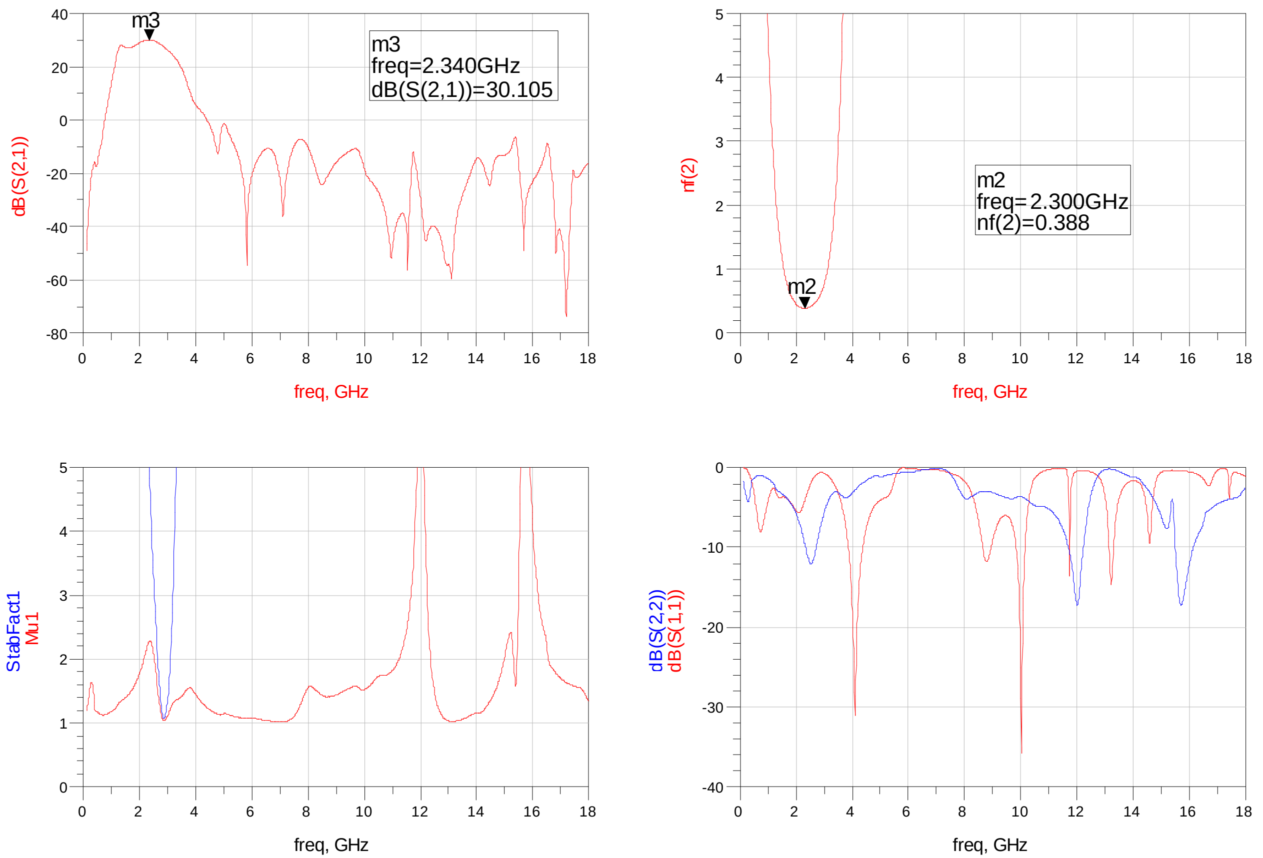
Single Stage LNA Designs

- Easy to obtain low noise figure but difficult to obtain good stability mainly because of either gain peaking above or below the desired frequency of operation.
- Picking the right combination of source inductance and drain resistance can be difficult
- Best solution is a multi-stage LNA

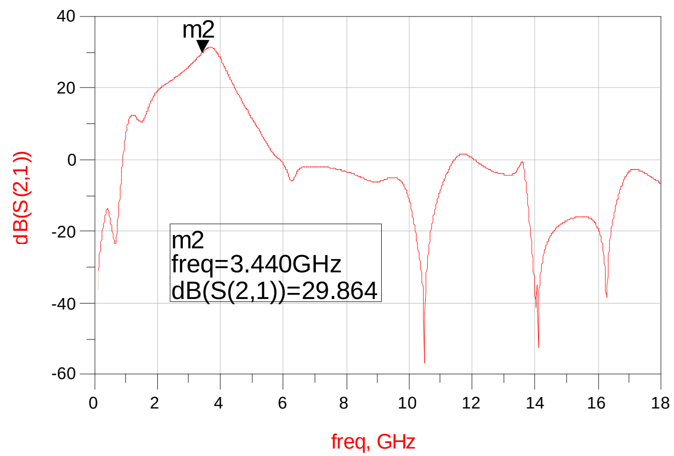
2 Stage LNA Designs

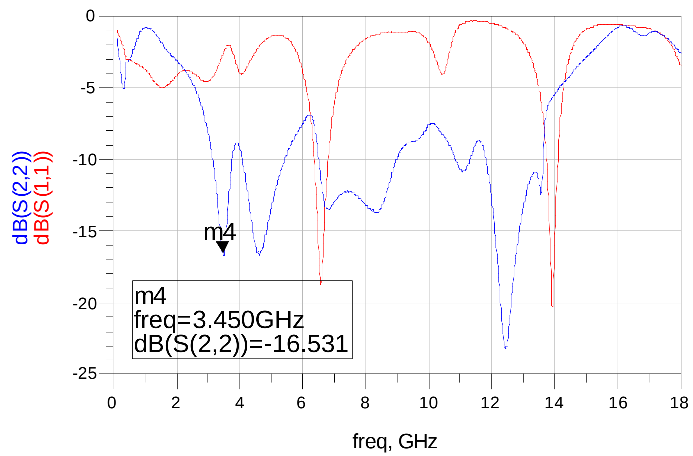
- The noise figure of a properly designed 2 stage LNA will only increase the noise figure of the LNA by the second stage contribution based on the gain of the first stage.
- Gain at the frequency of operation will normally be up to twice the gain of one stage with the exception at lower frequencies where 30 or 31 dB for a 2 stage may be the desired maximum based on stability.
- Provide a band-pass type response at the frequency of operation by rolling off the gain at lower frequencies and minimizing gain peaks especially at higher frequencies.
- Input return loss can often be optimized with the interstage network.

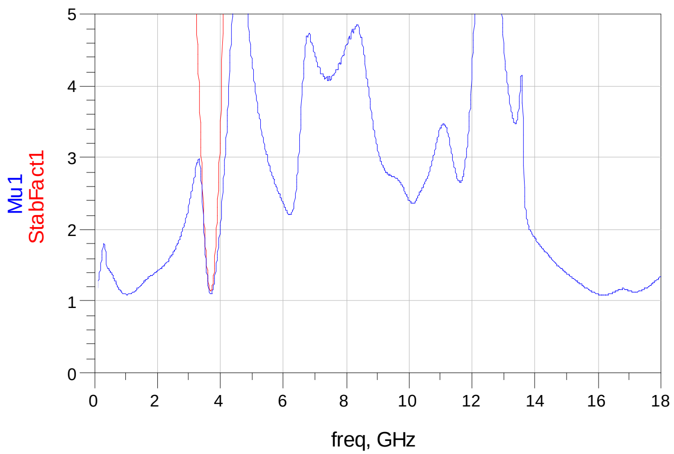
2304 MHz 2 Stage ATF-36077 LNA

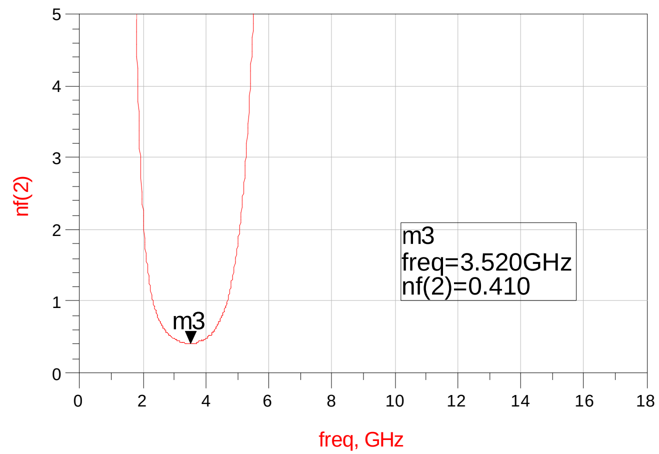


3456 MHz 2 Stage ATF-36077 LNA

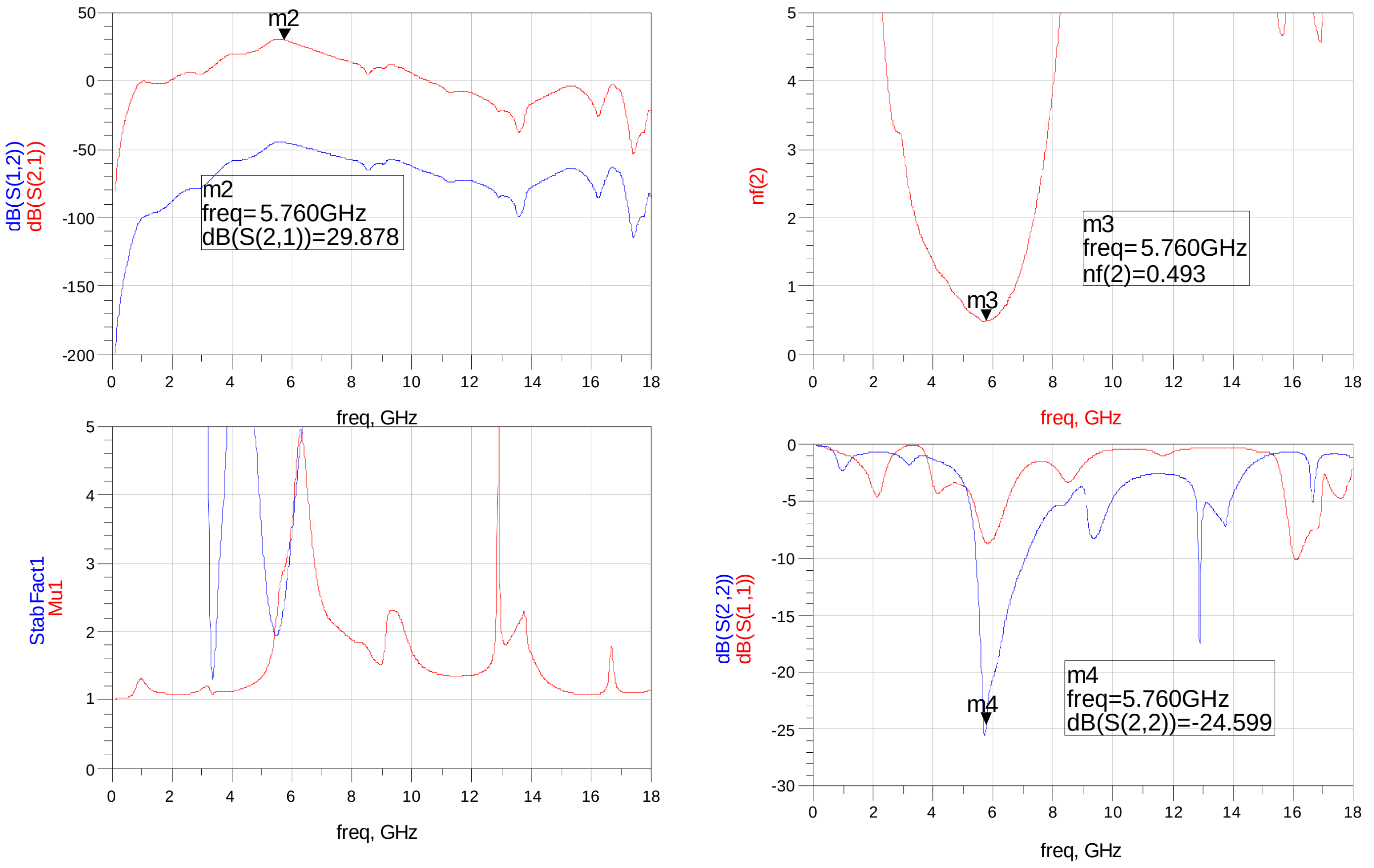




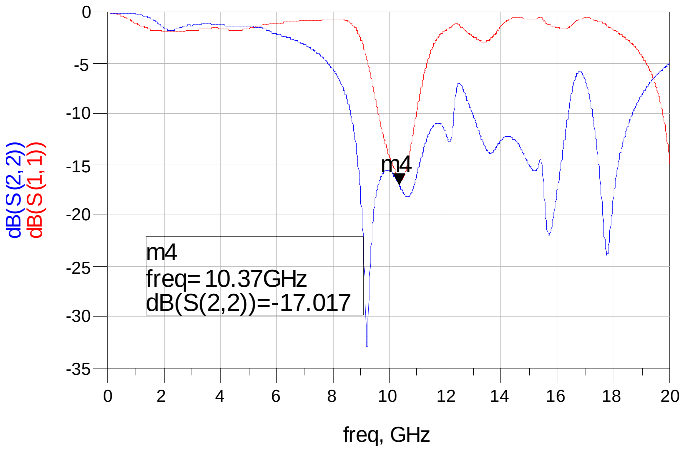


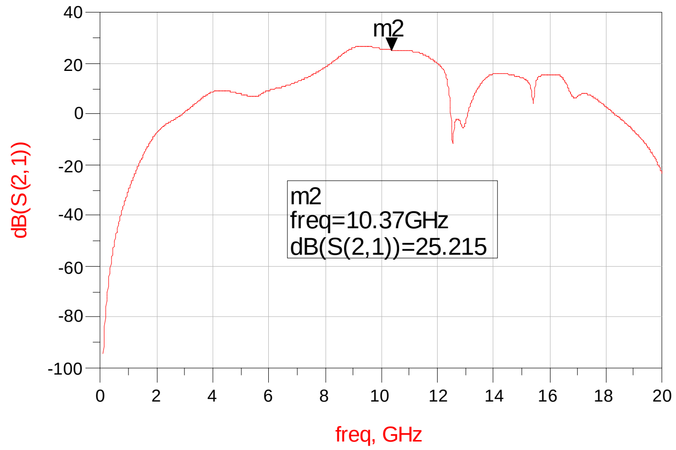


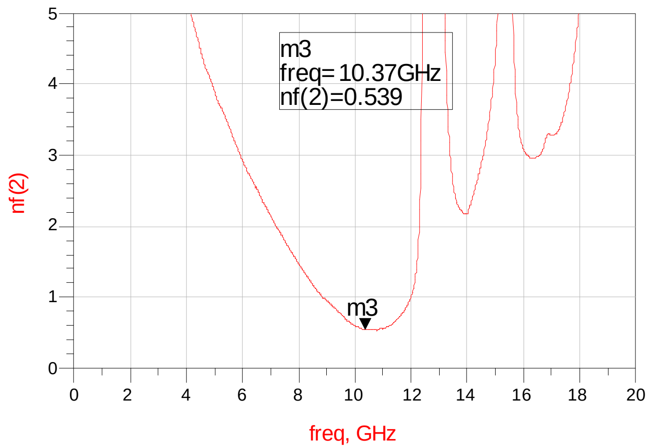
5760 MHz 2 Stage ATF-36077 LNA

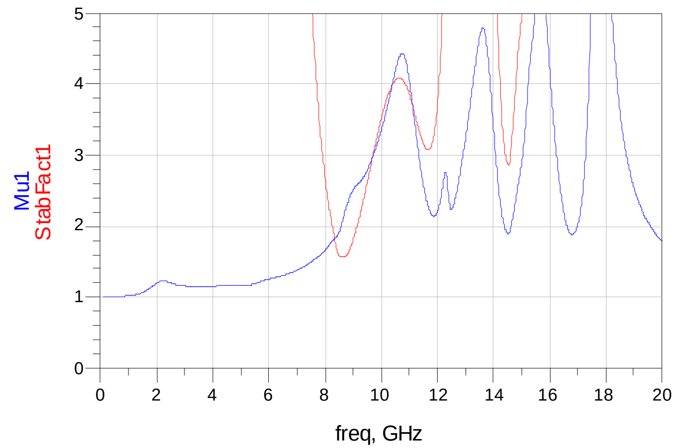


10368 MHz 2 Stage ATF-36077 LNA

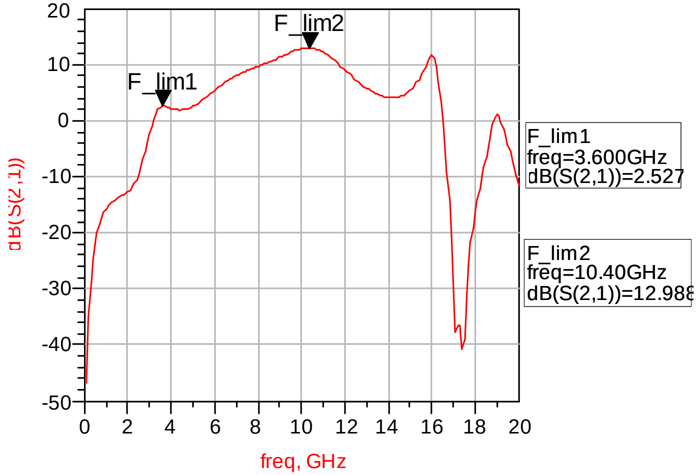


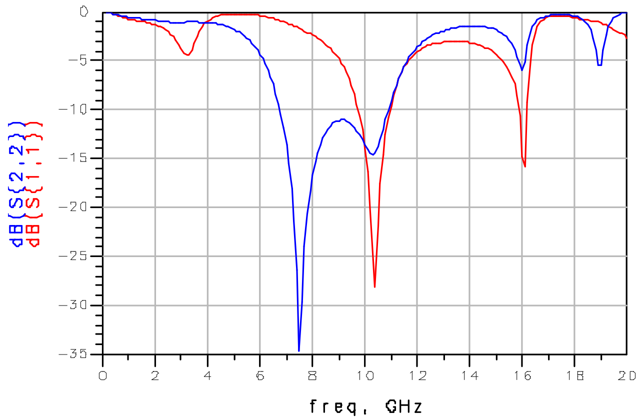


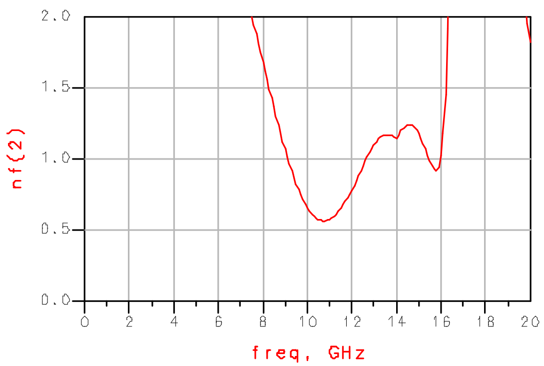


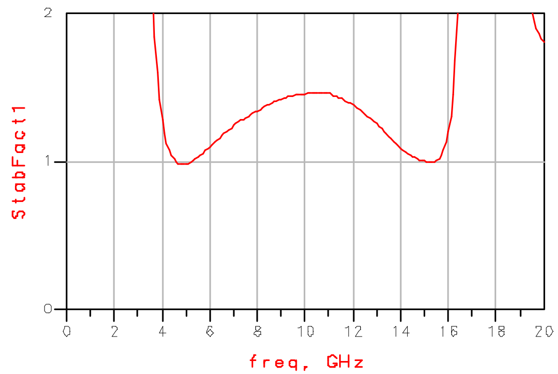


10368 MHz Single Stage ATF-36077 LNA



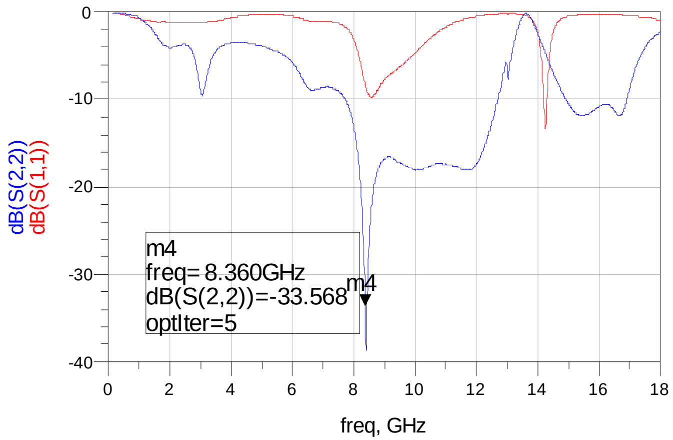


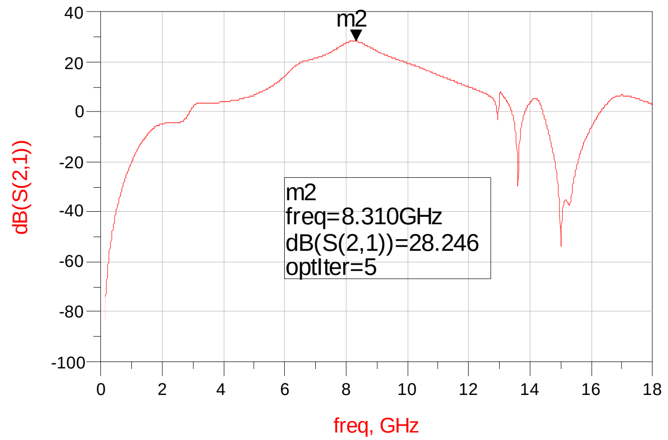


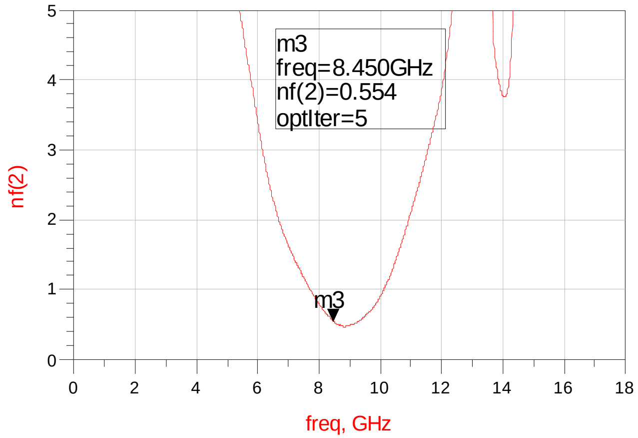


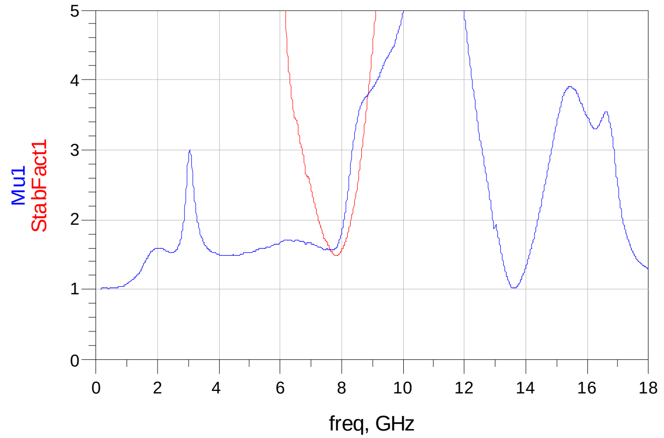
Gain peaking at 3.5 and 16 GHz can contribute to problems when cascading stages

8450 MHz 2 Stage ATF-36077 LNA









Summary

- New 2 stage LNA designs should offer a major improvement in stability over cascading individual stages.
- My presentation will be uploaded to www.ntms.org after the conference
- Any questions?
- Thanks and 73 de W5LUA