Designing Stability into 1296 MHz and 2304 MHz Low Noise Amplifiers

By Al Ward W5LUA & Tommy Henderson WD5AGO

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Central States VHF Society

San Antonio, Texas

What do we want from an LNA?

Low noise figure < 0.4 dB

High gain > 35 dB

Good input and output match – minimizes interactions with other stages

Stable – must not oscillate when connected to antenna

Cascadable

What makes a good second stage?

Low noise figure < 0.8 dB NF

Enough gain to make cascade about 30 to 35 dB

Good broadband match for first stage

Stable

Today’s Transistors

Today’s transistors have very low noise figures and very high gain

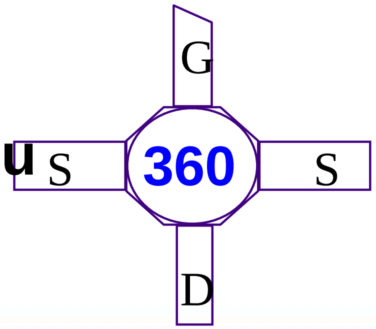
High gain contributes to stability problems and decreased input intercept point

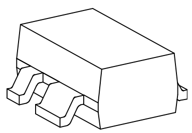
Minimum input VSWR and minimum noise figure will generally not occur simultaneously with same matching network. Use of source inductance may help but too much may cause instability

ATF-3XXXX Series of PHEMTs

- Depletion mode PHEMT technology – requires negative voltage on gate wrt source
- Ceramic and plastic surface mount packaging
- Various gate widths 200u / 400u / 800u / 1600 u
- At lower frequencies, I.e. 2 GHz or less, larger gate widths offer lower gain and lower impedances which can contribute to improved stability and lower matching circuit losses

ATF-36077 – 200 u





ATF-35143 – 400 u
ATF-34143 – 800 u
ATF-33143 – 1600 u

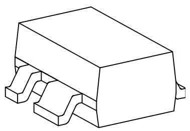
ATF-5XXXX Series of PHEMTs

Enhancement mode PHEMT technology – requires positive voltage on gate wrt source

Plastic surface mount packaging

Various gate widths 400u / 800u and larger

Noise figure of enhancement mode devices 0.1 to 0.2 dB higher than depletion mode devices



ATF-55143 – 400 u
ATF-54143 – 800 u

What about S-parameters?!??!

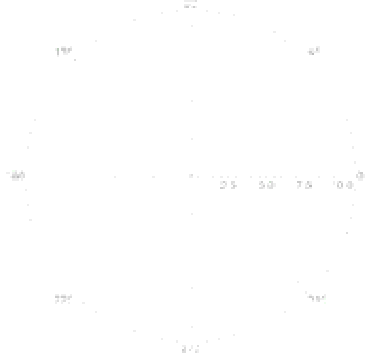
A three-terminal two-port, such as the FET shown, has four S-parameters.

S_{nn} = voltage reflection coefficient, both amplitude and phase relative to 50 Ω source impedance

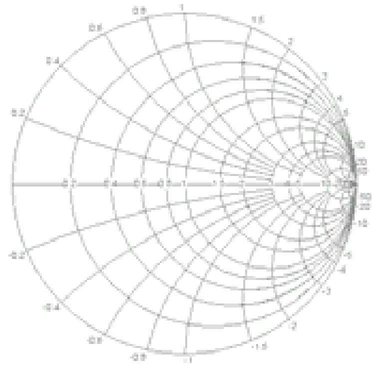
S_{21} and S_{12} are commonly displayed on a polar chart.

$S_{11} = \Gamma_{input}$ displayed on Smith chart

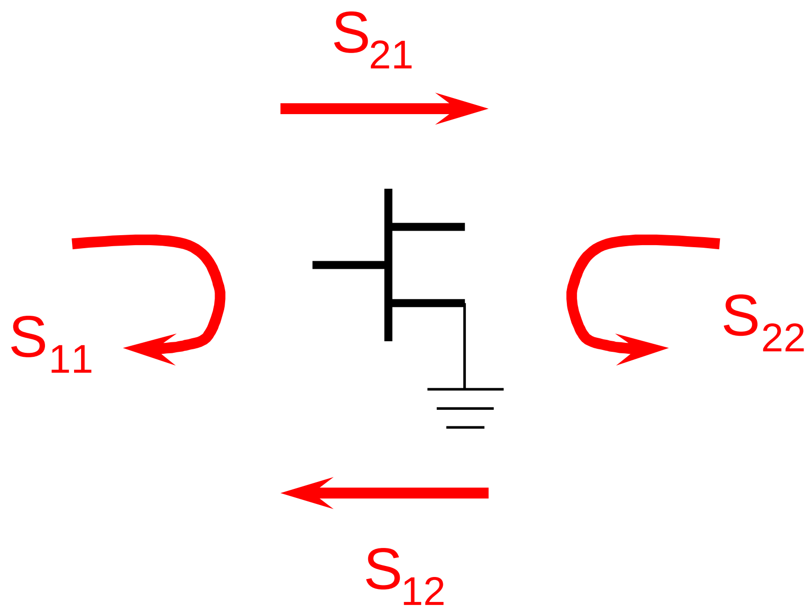
$S_{22} = \Gamma_{output}$ displayed on Smith chart



Polar chart



Smith chart



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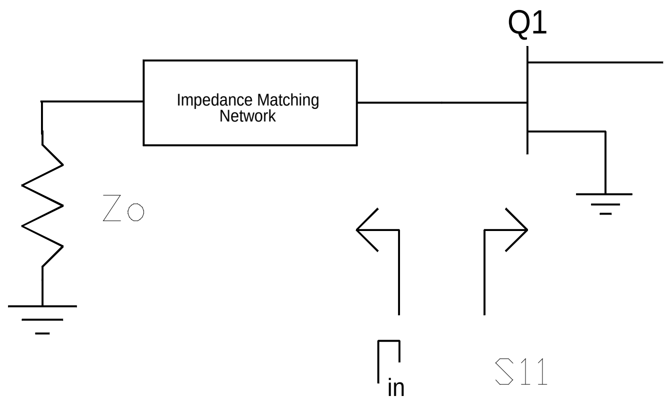
What about Noise Parameters?!??!

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, $\Gamma_{in} = S11^*$

Other measures of input characteristics

VSWR = Voltage Standing Wave Ratio

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

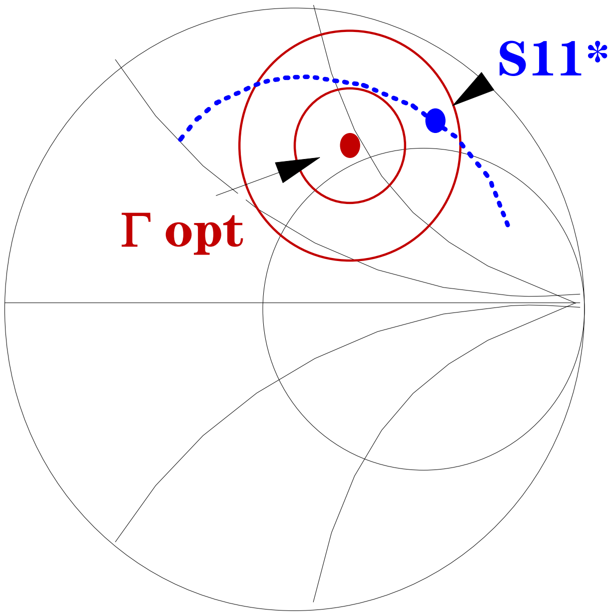
Return Loss

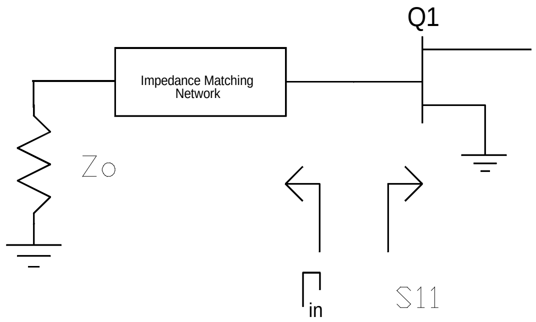
$$\text{RL} = 10\log|\Gamma|^2$$

Mismatch Loss

ML = 10 LOG (1 - Γ^2)

Input Impedance Match





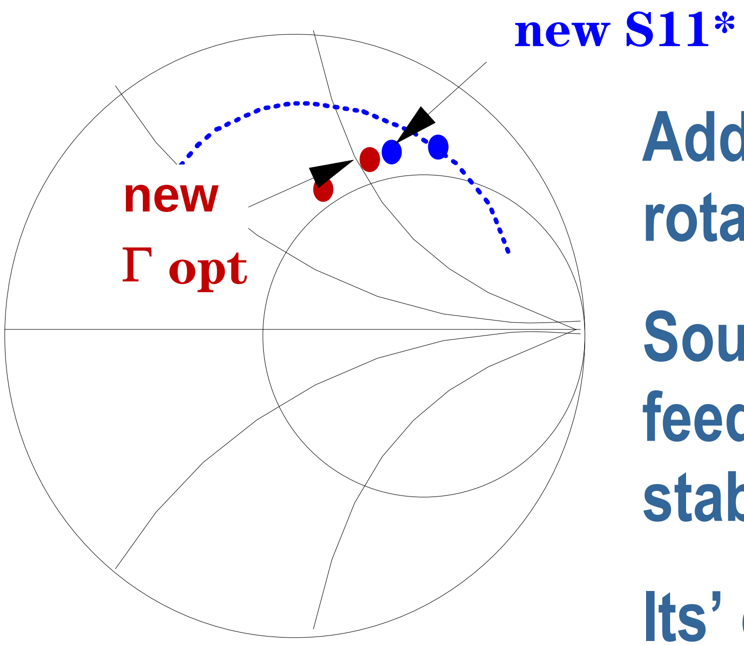
Match to Γopt for minimum noise figure

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

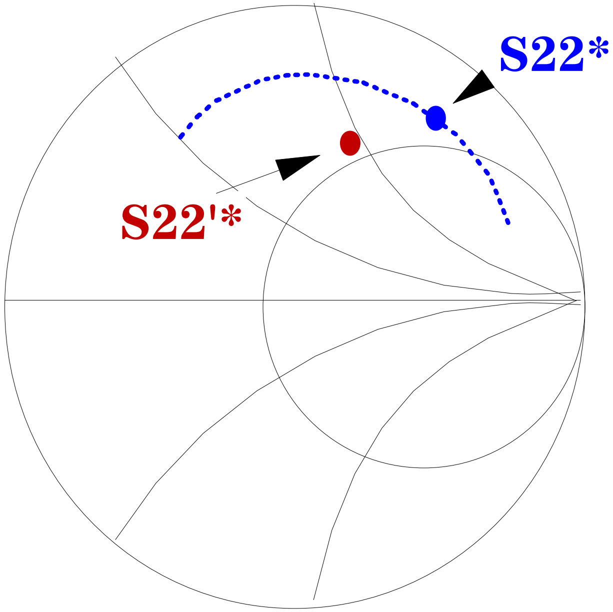


Adding source inductance rotates Γopt towards S_{11}*

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



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

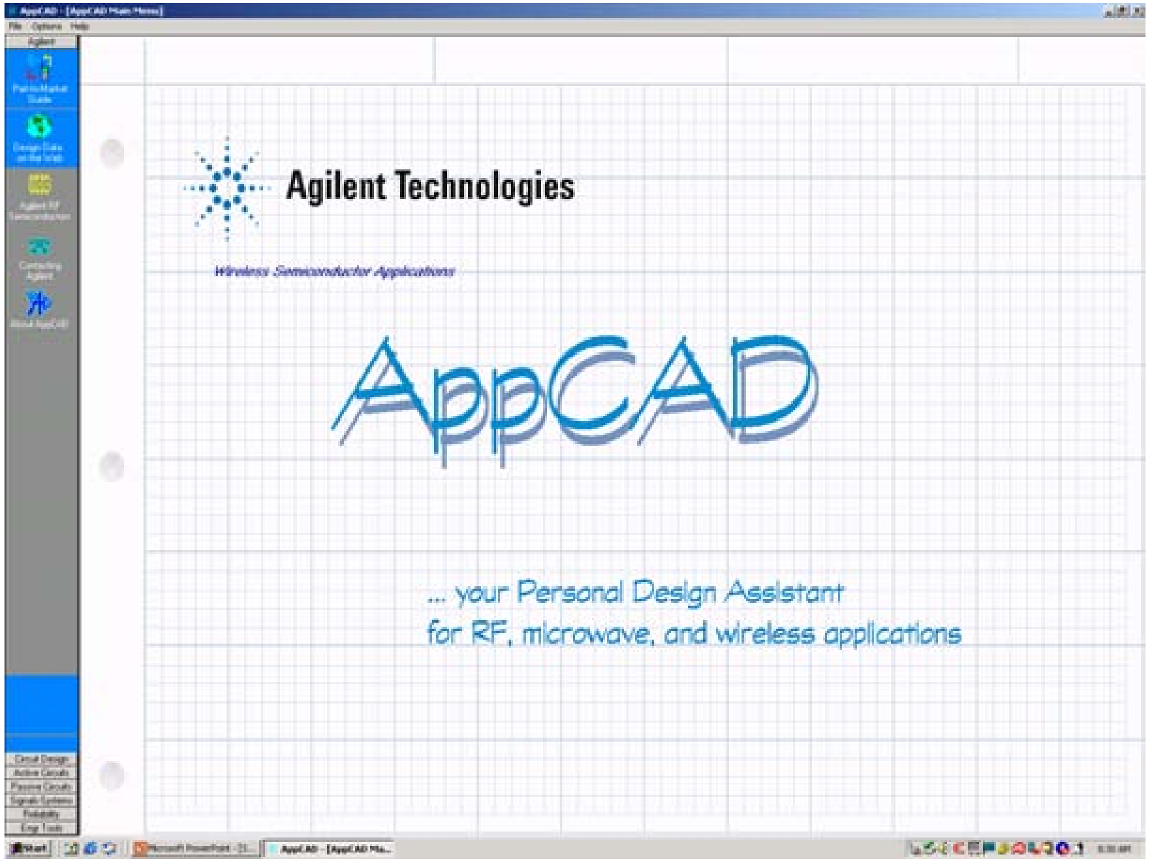
$S_{22}'^* = \Gamma_L$ is the reflection coefficient of the output matching network with input terminated in Γopt, not 50Ω

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

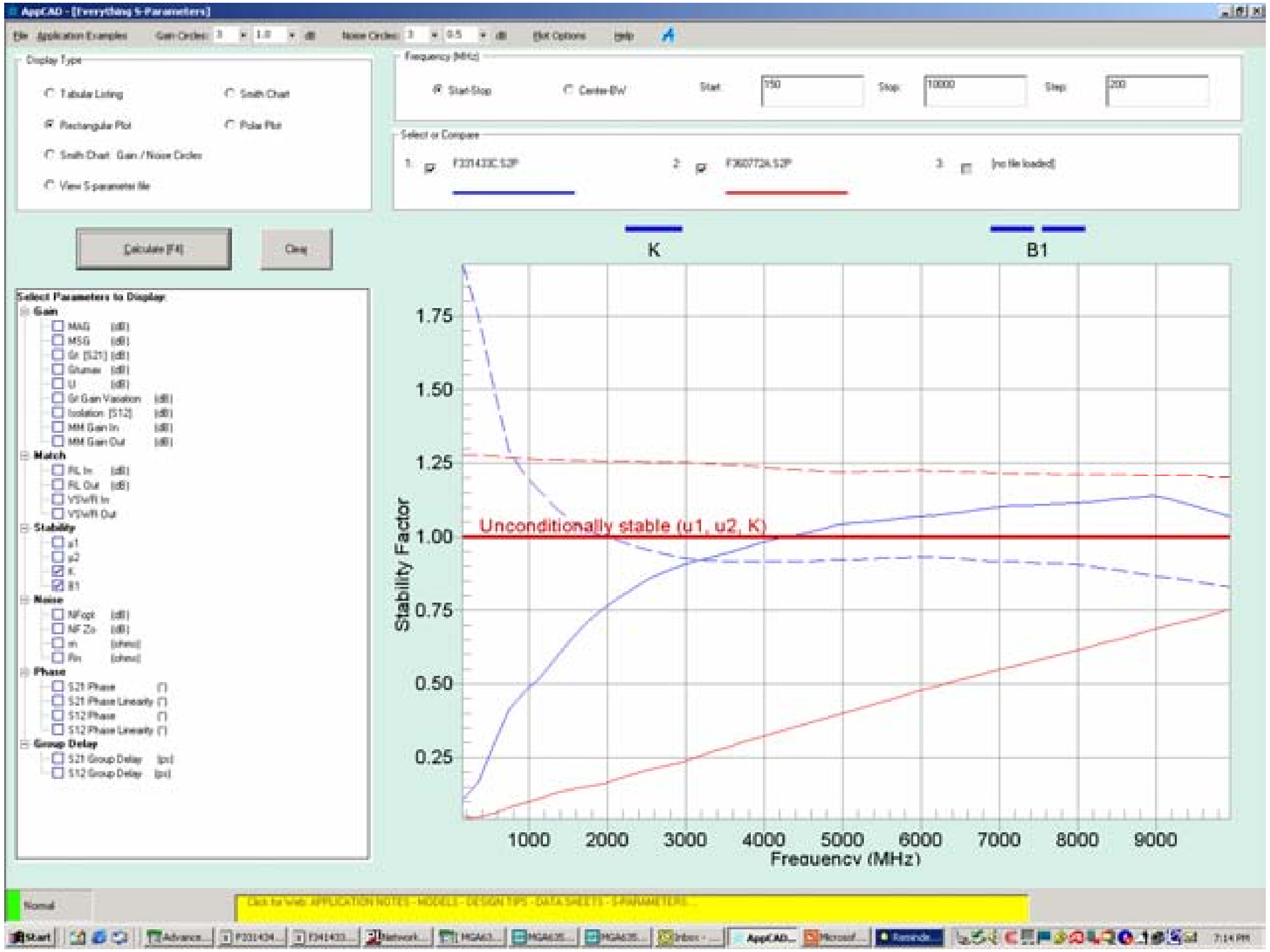
Best output VSWR does not necessarily guarantee best P1dB and IP3.

Using AppCAD for Circuit Analysis



Available for free download at http://www.avagotech.com

ATF-36077 vs ATF-33143 Stability Factors vs Freq.



Stability Factor K calculated from S parameters at each frequency, K>1 for unconditional stability

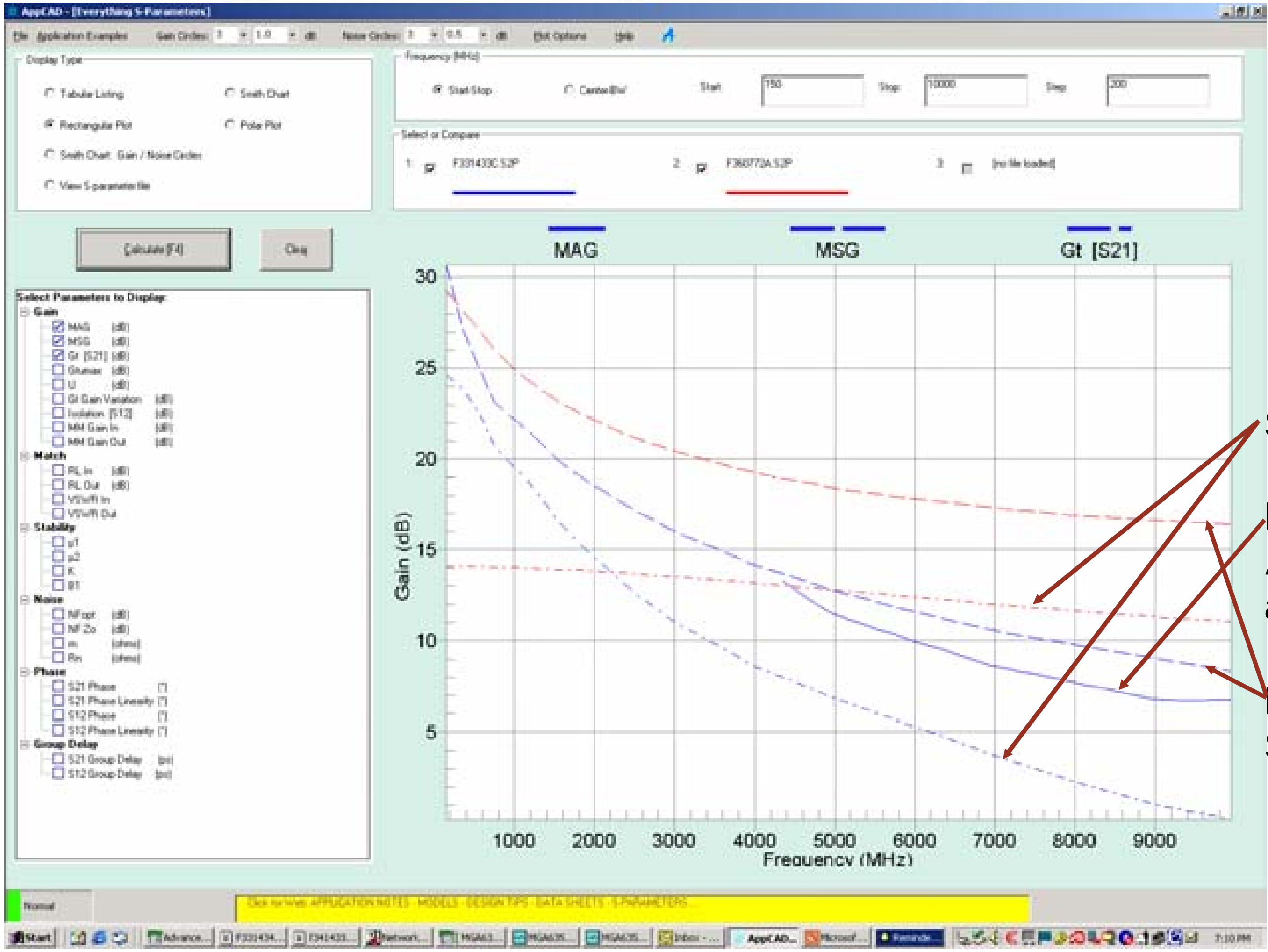
ATF-36077 – K < 1 at all frequencies below 10 GHz

ATF-33143 – K < 1 only below 4.2 GHz, making the device less sensitive to source grounding – better for VHF LNAs

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

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

ATF-36077 vs ATF-33143
S21 vs MAG vs MSG

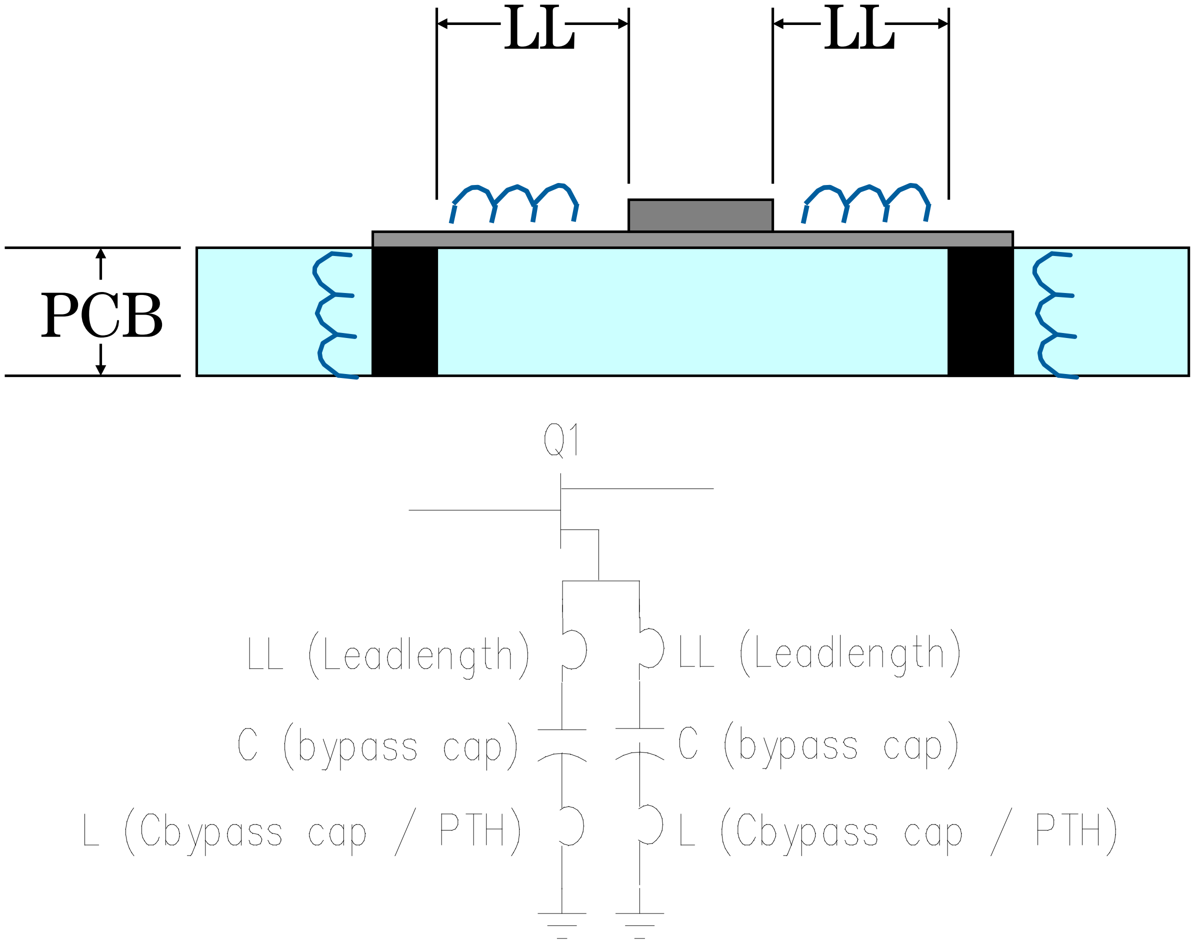


S21 = 50 Ω Gain

MAG = Maximum Available Gain applies when K>1

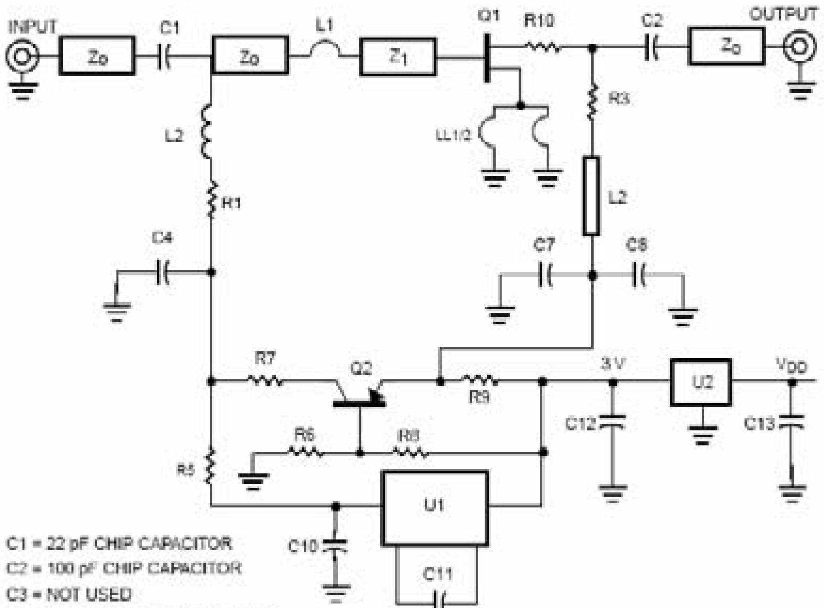
MSG = Maximum Stable Gain

Contributions to Source Inductance

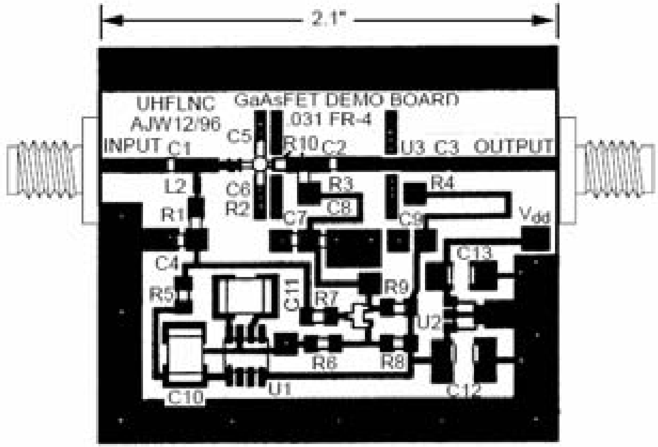


1. Lead length from edge of transistor package to bypass cap or plated through hole adds inductance
2. Use of a source resistor bypass capacitor can alter circuit stability
3. The inductance associated with the bypass capacitor and the equivalent inductance due to the thickness of printed circuit board

AN 1128 ATF-36077 L Band LNA

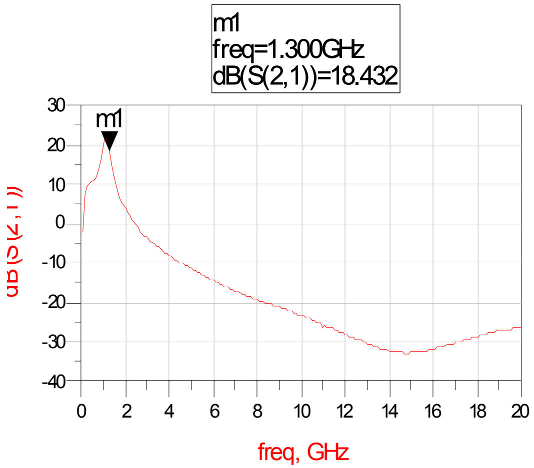


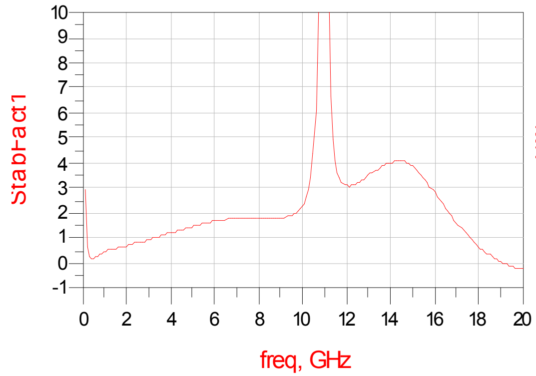
C1 = 22 pF CHIP CAPACITOR
C2 = 100 pF CHIP CAPACITOR
C3 = NOT USED
C4, C7 = 1000 pF CHIP CAPACITOR
C5, C6 = NOT USED, GROUND SOURCES DIRECTLY
C9 = NOT USED
C8, C12, C13 = 0.1 µF CHIP CAPACITOR
C10, C11 = 10 µF CHIP CAPACITOR
L1 = 6T 0.007" DIA. WIRE, 0.050" ID, 0.14" LENGTH
L2 = 0.18 TO 0.33 µH RFC
LL1, 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

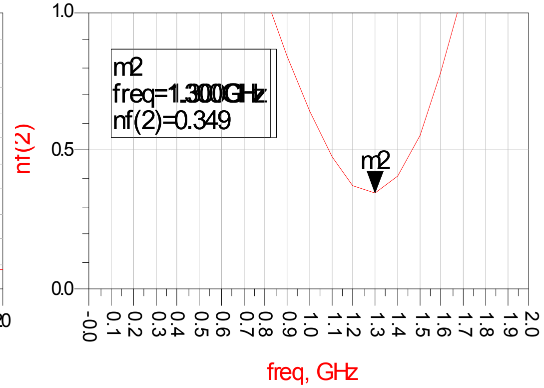


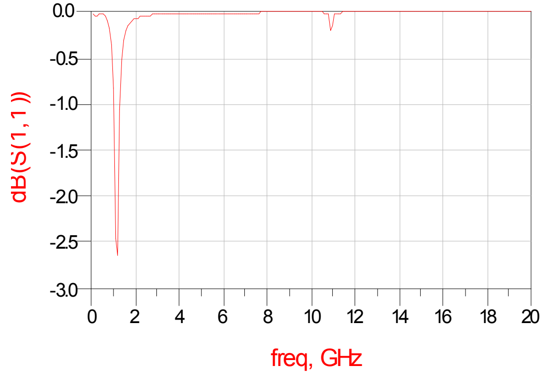
December 1996

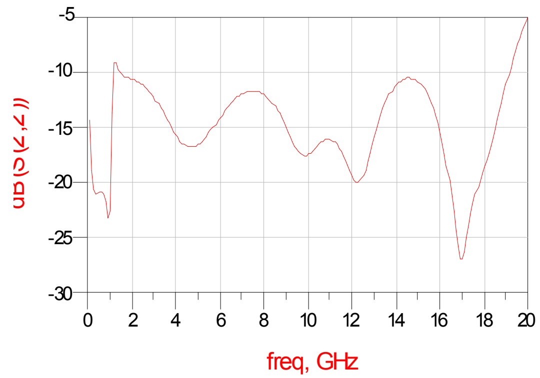
Single stage ATF-36077



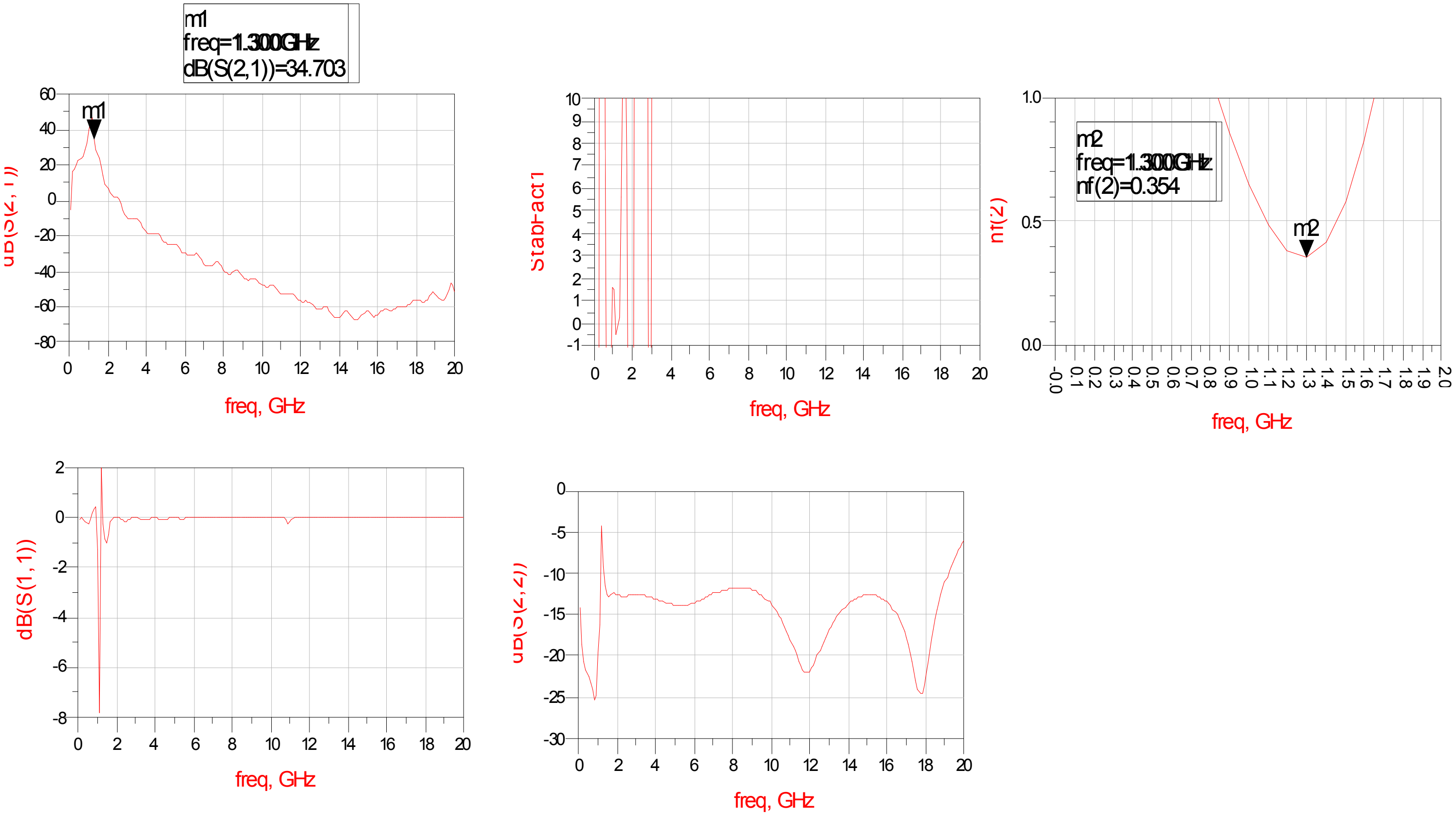








2 Stages ATF-36077 Connected with 4.5 inches of 50Ω Coax



Simulation suggests potential stability concerns

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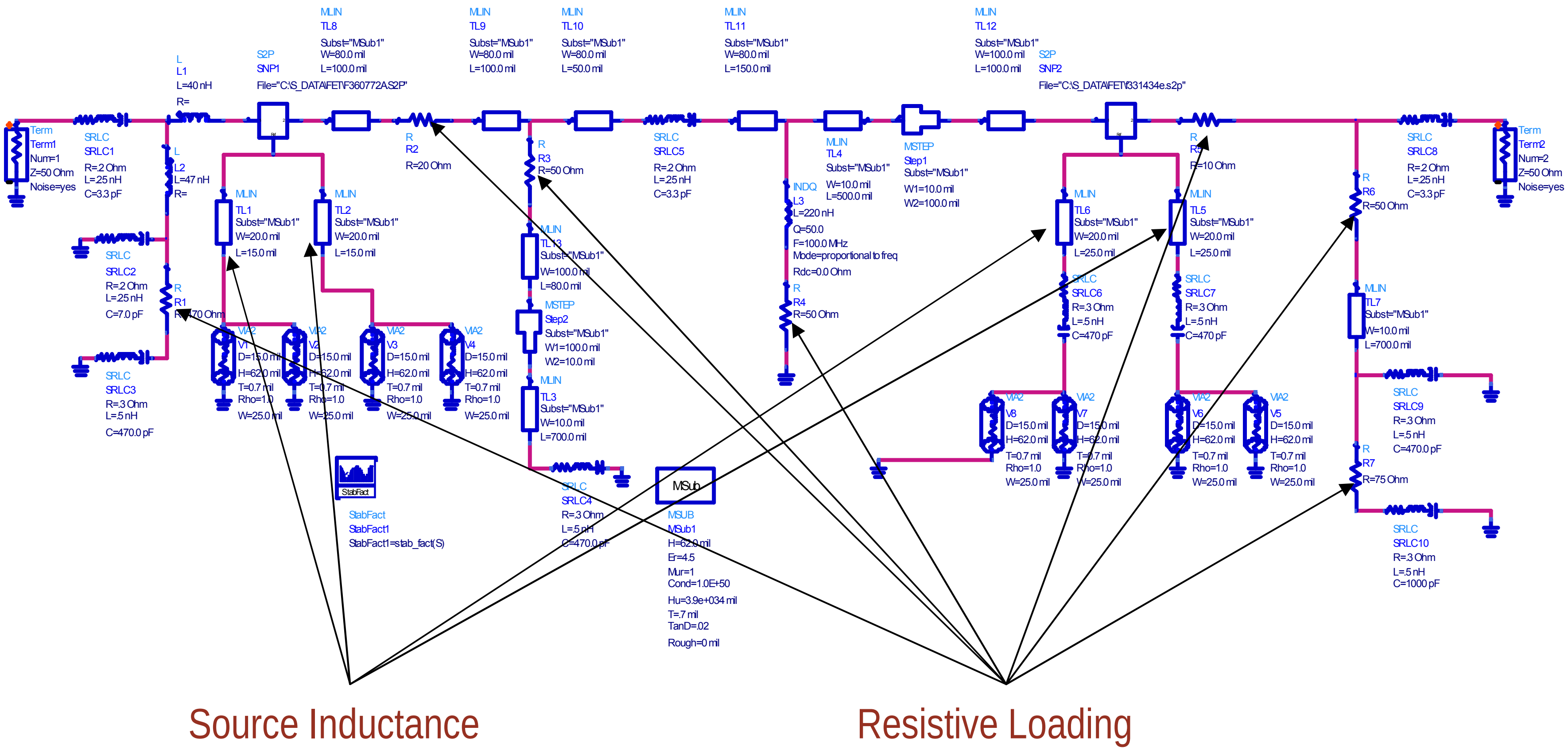
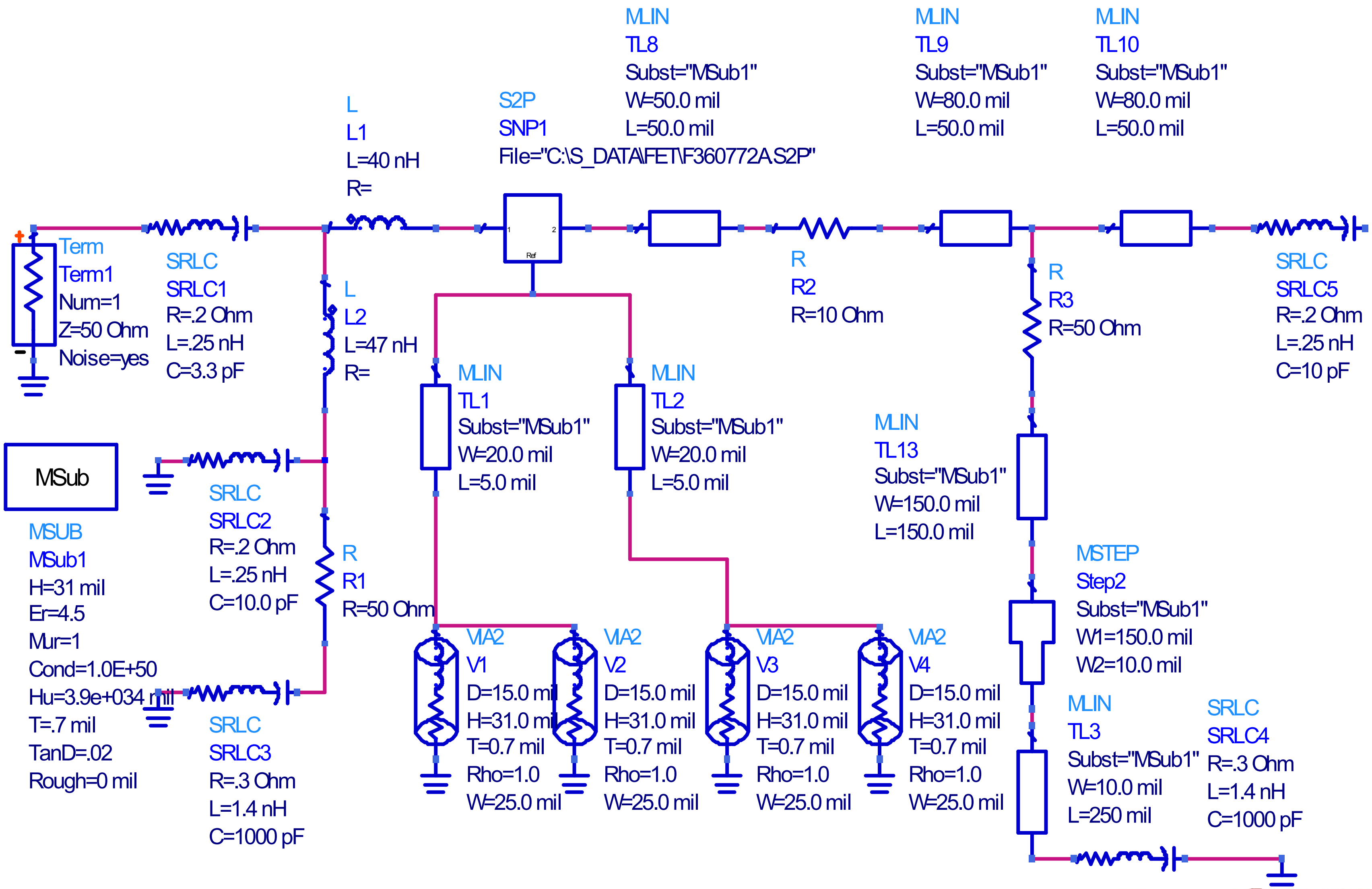
Better approach is a WD5AGO integrated 2 stage amplifier using an ATF-36077 followed by an ATF-34143 or ATF-54143

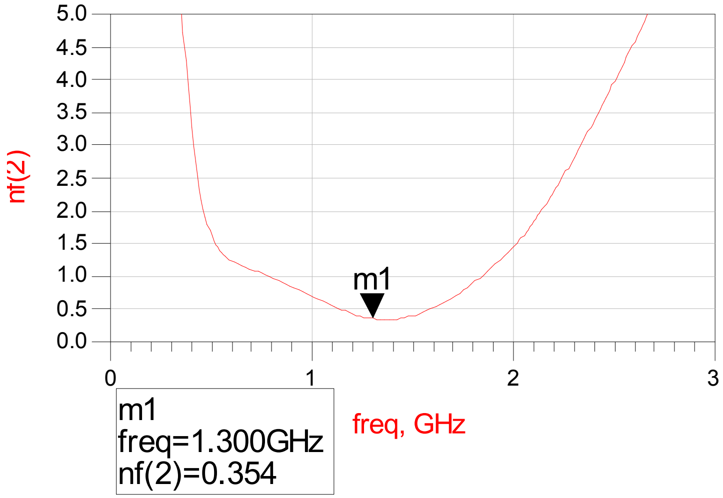


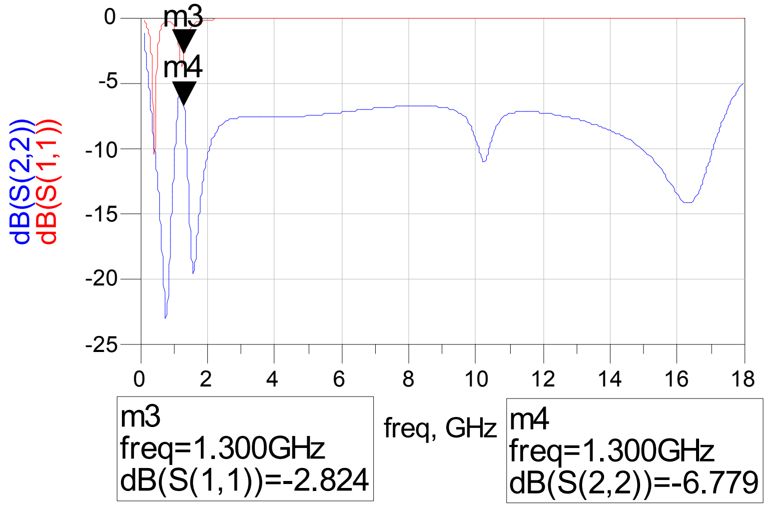
Avago Technologies

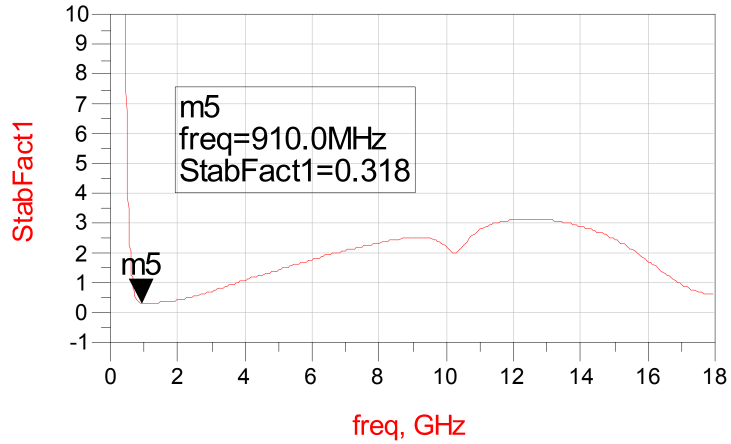
ADS Optimized ATF-36077 First Stage

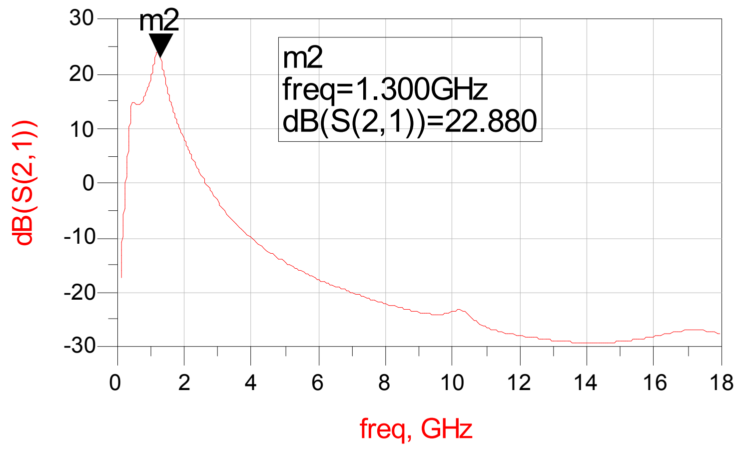


ADS Optimized ATF-36077 First Stage









This is about the best that can be had in stability if NF is not to be compromised

Let's take a look at second stage candidates

ATF-36077 200 u gate width depletion mode device

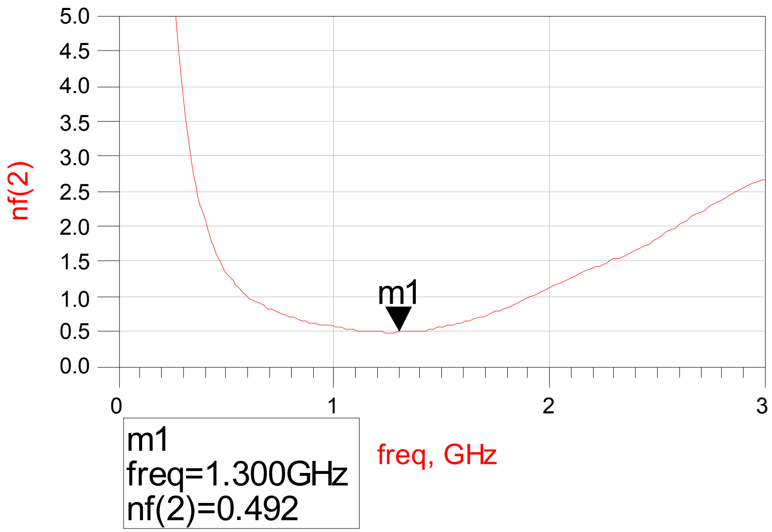
ATF-21186 750 u gate width depletion mode device

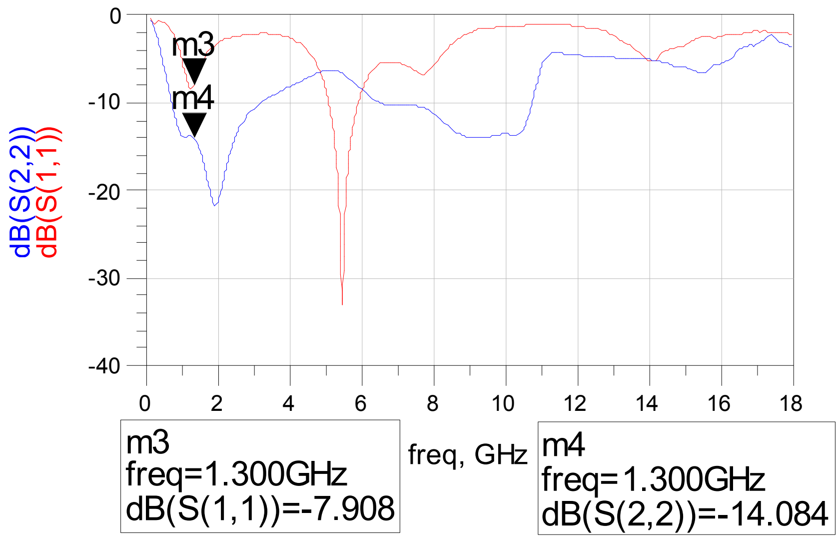
ATF-33143 800 u gate width depletion mode device

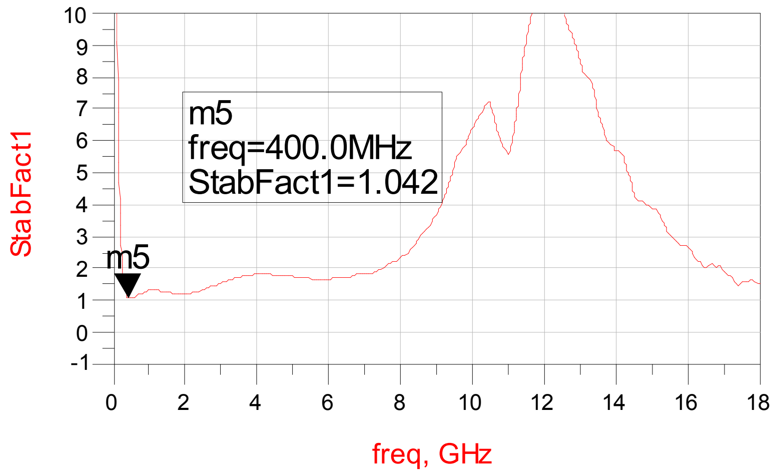
ATF-54143 400 u gate width enhancement mode device

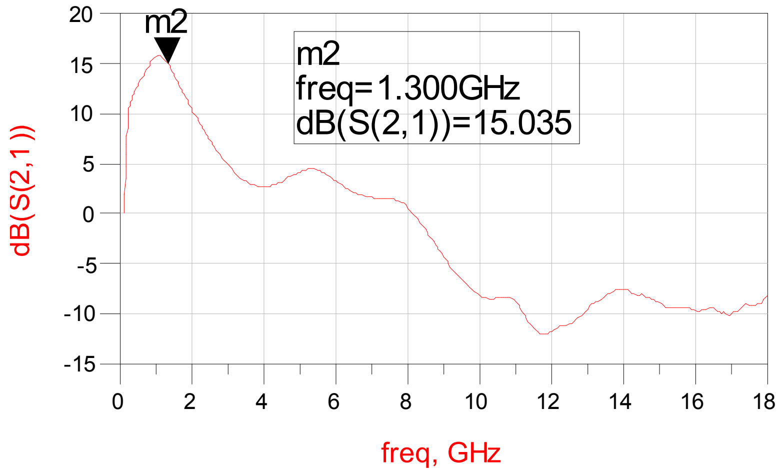
Other candidates

Optimized ATF-54143 Second Stage

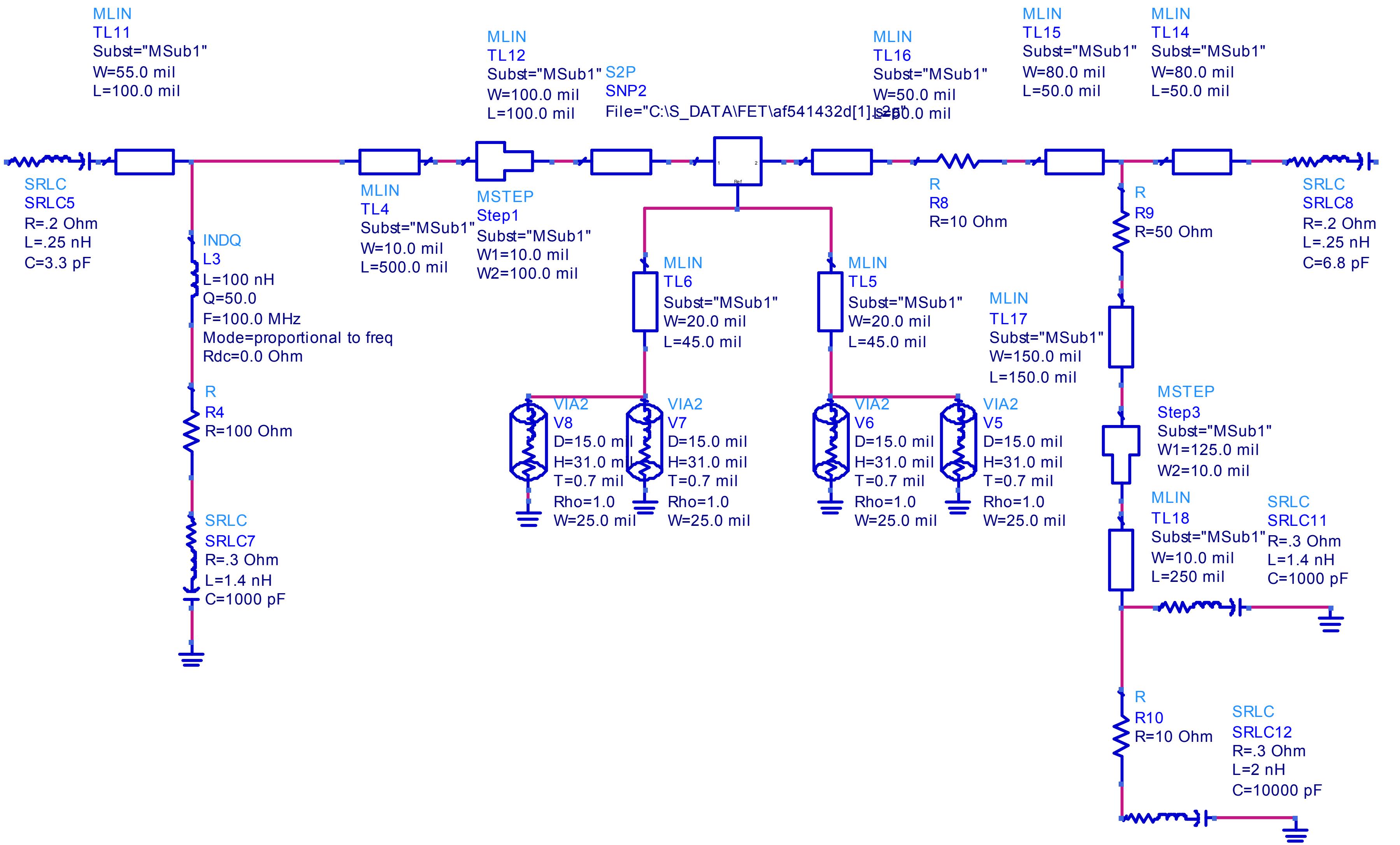




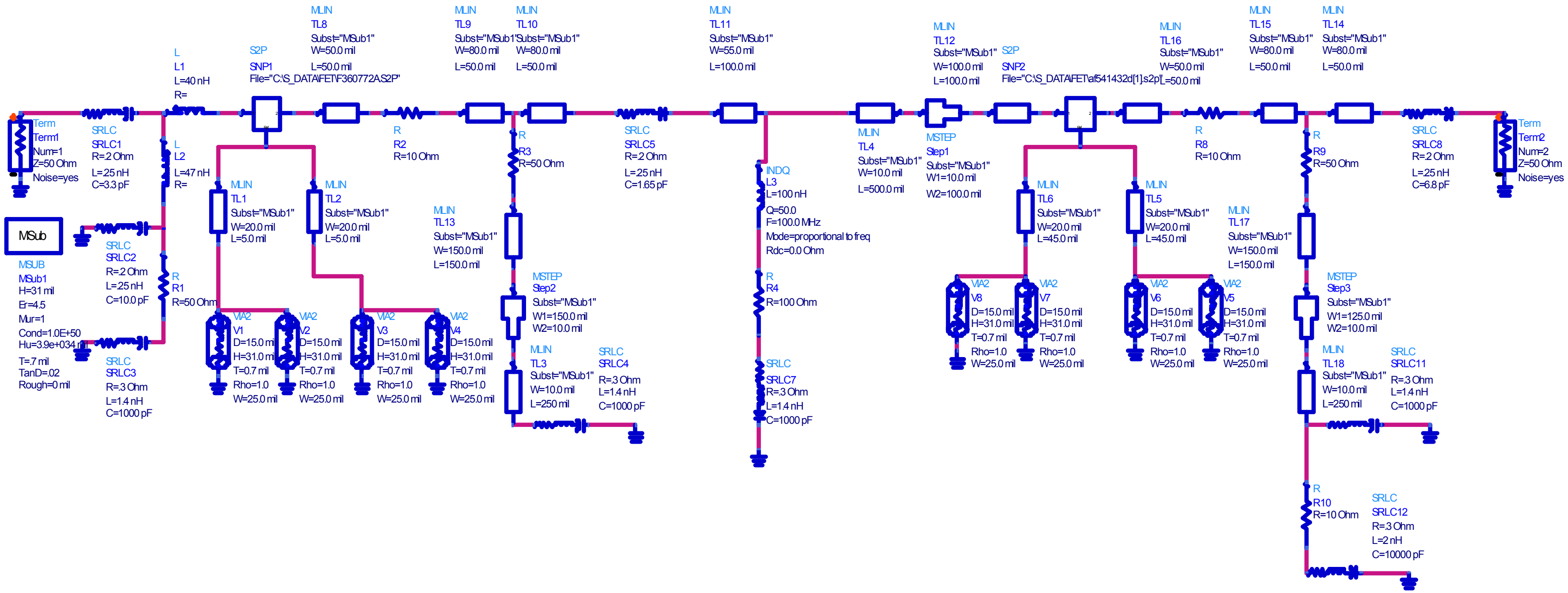




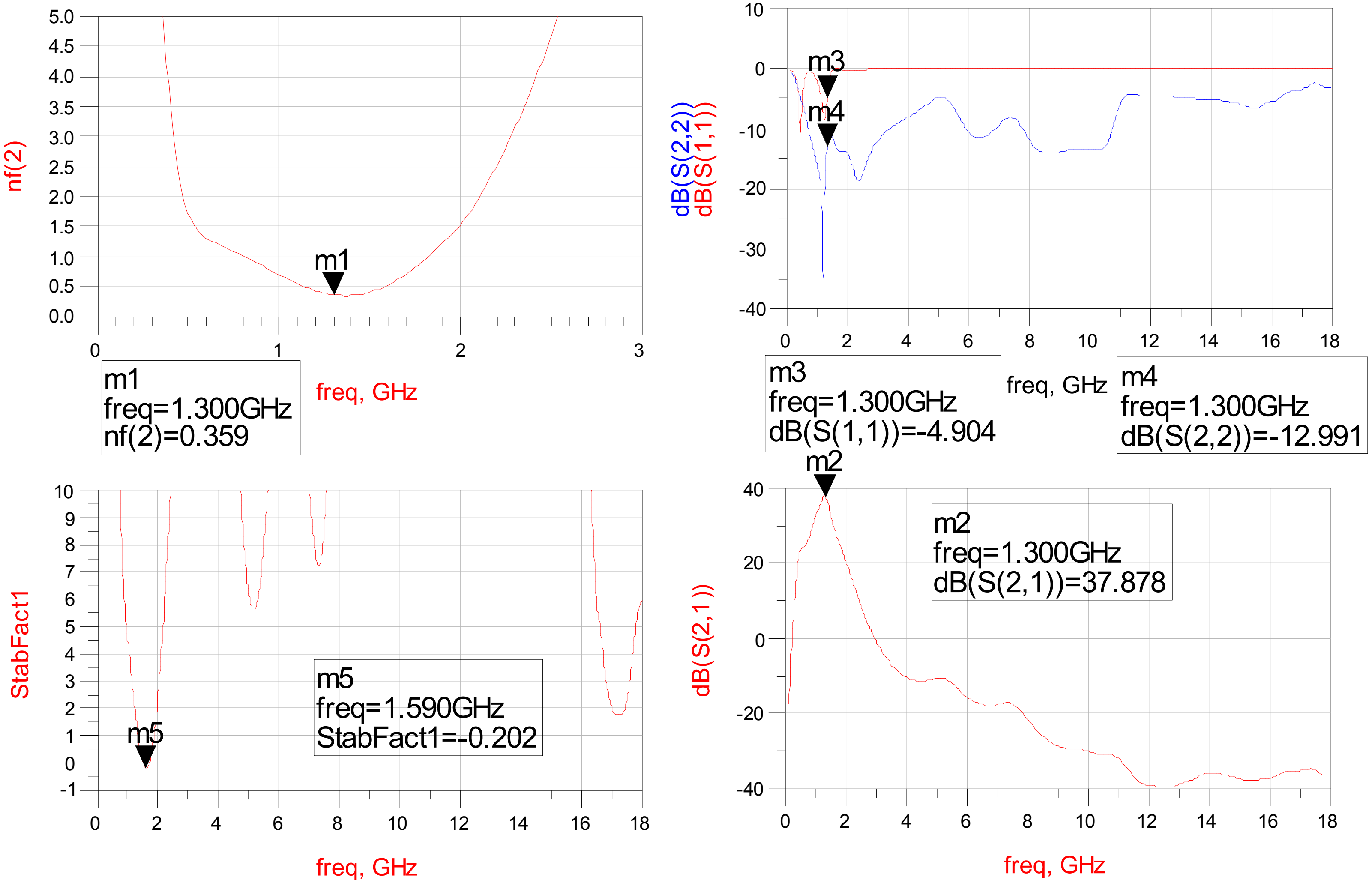
Optimized ATF-54143 Second Stage



ATF-36077 cascaded with improved ATF-54143 Second Stage



ATF-36077 cascaded with improved ATF-54143 Second Stage



Still some concern about stability

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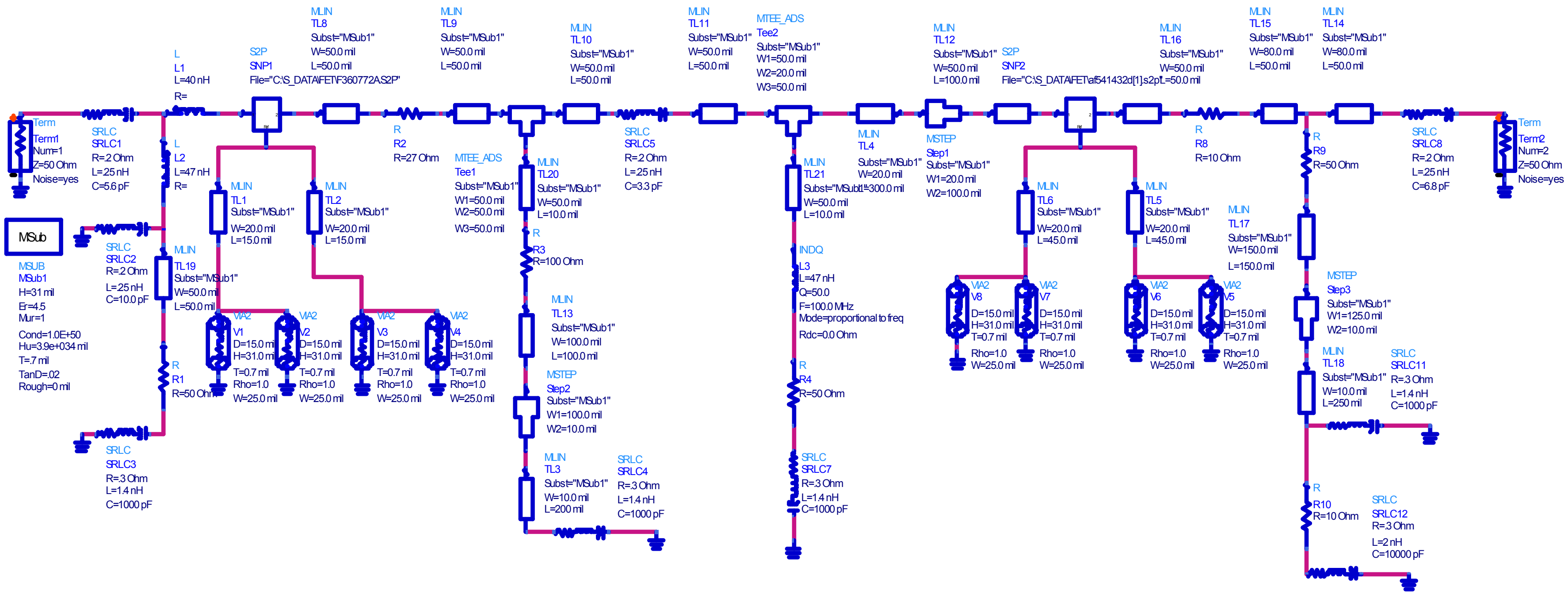
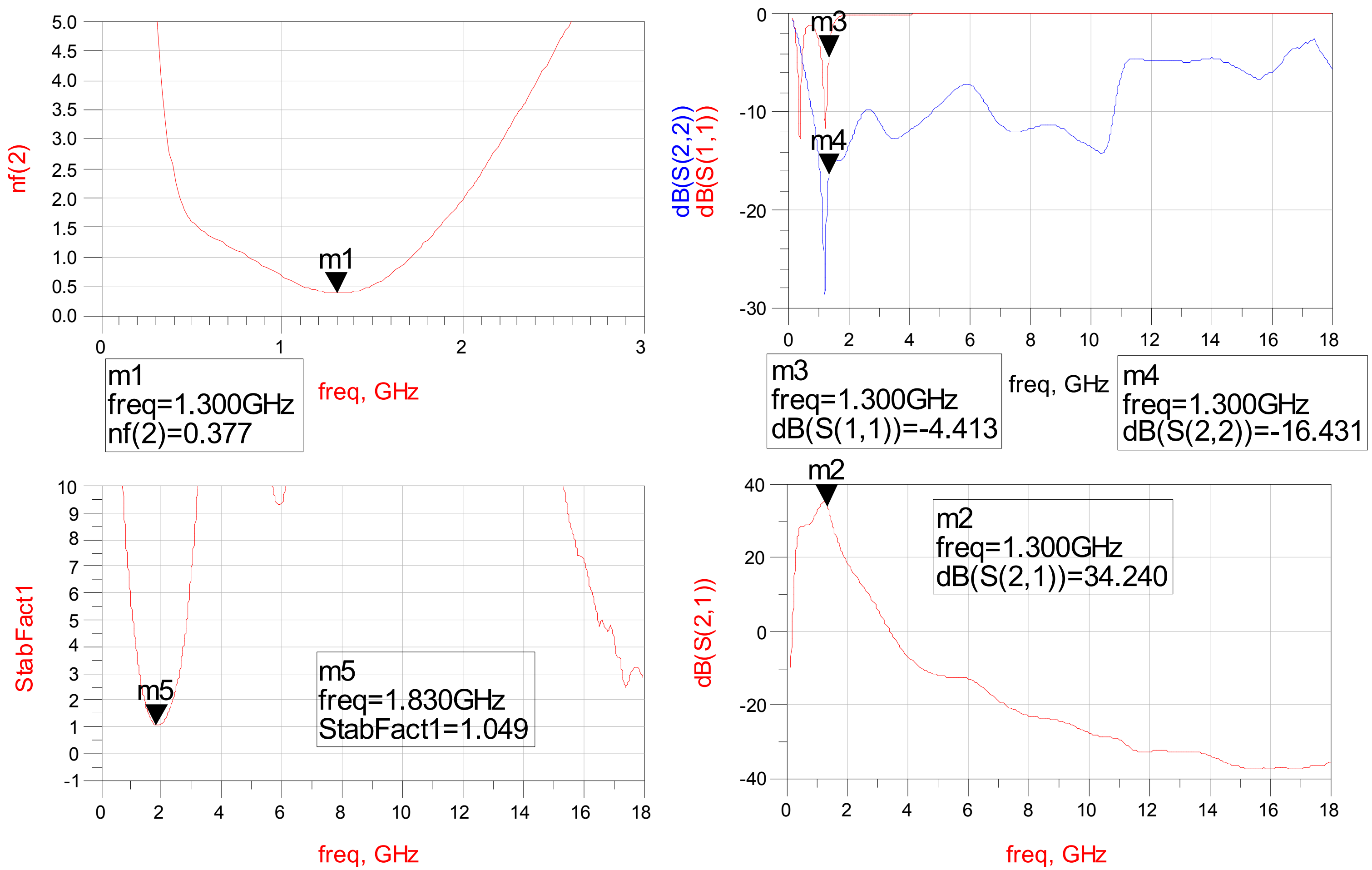
ATF-36077 ATF-54143 Cascade with Further Improvements



ATF-36077 ATF-54143 Cascade with Further Improvements



At this point Rd = 27 ohms to get K=1 but NF .377. This is the best that can be done with ATF-36077 driving ATF-54143….

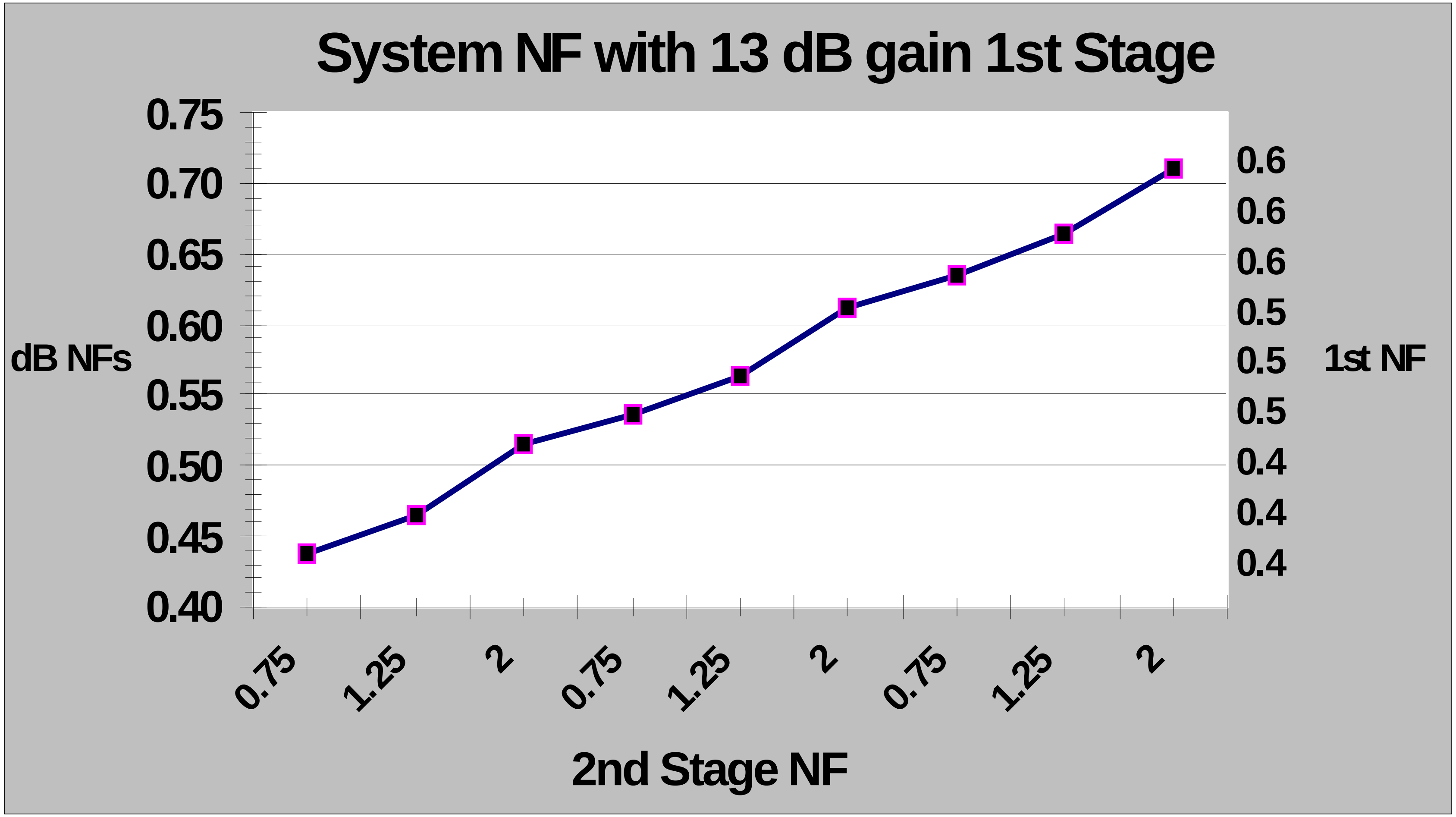
What would make a better second stage?

Maybe a MMIC

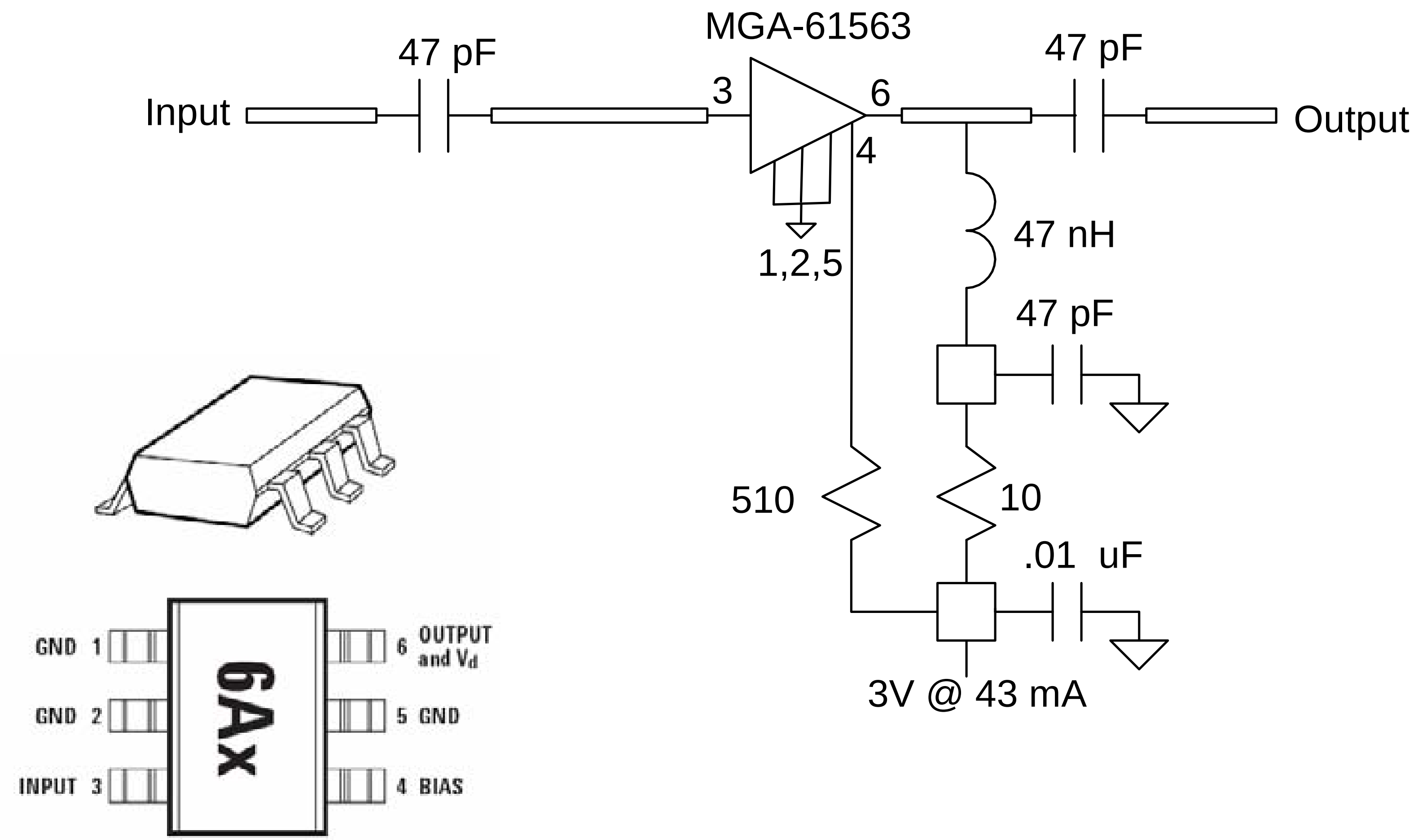
The WLAN and WiMAX markets have forced semiconductor manufacturers to build sub 1 dB noise figure MMICs – these might make a good second stage but..

Most are in nasty little hard to see packages with no leads except maybe the MGA-61563………

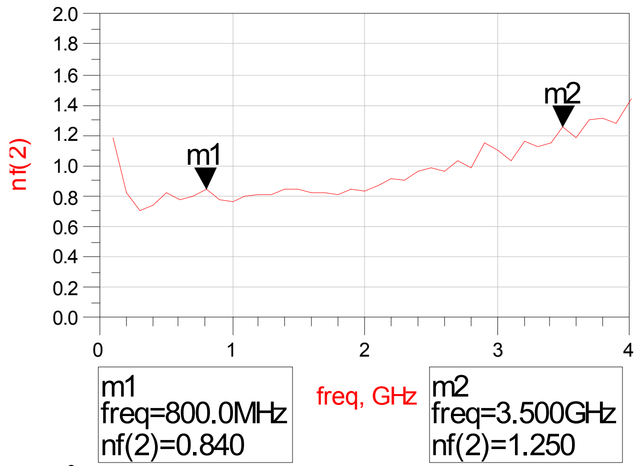
Effects of 2nd Stage

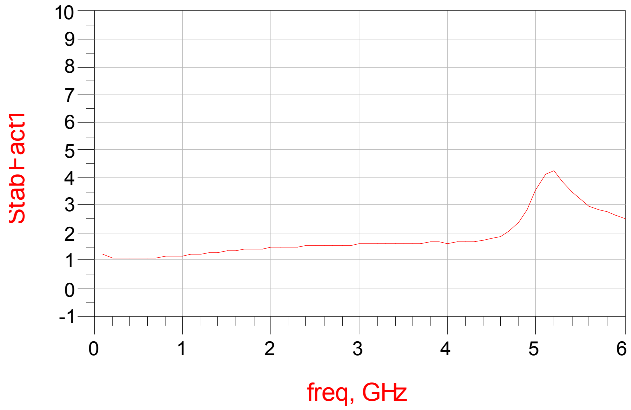


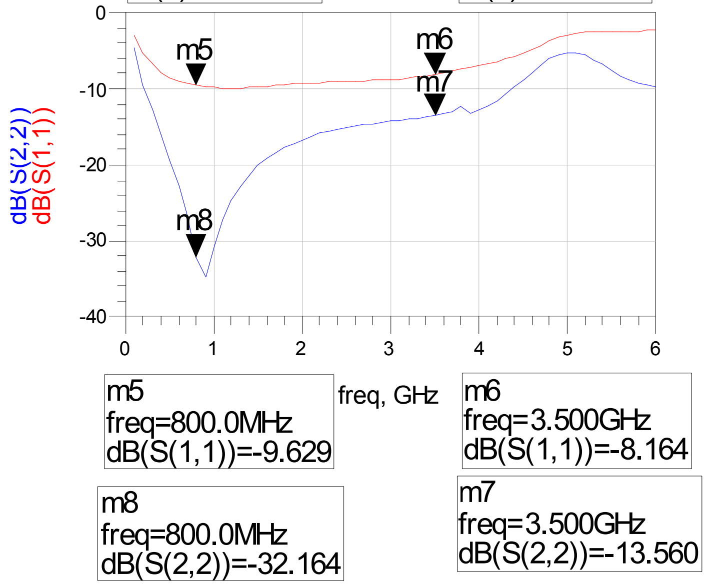
MGA-61563 Low Noise Amplifier

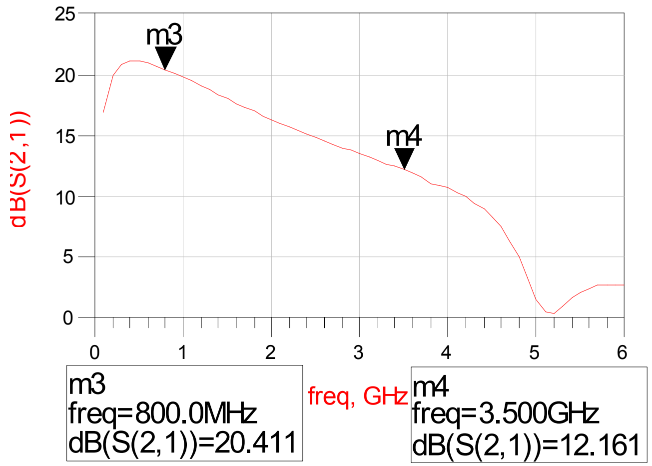


MGA-61563 Measured Demo Board Performance



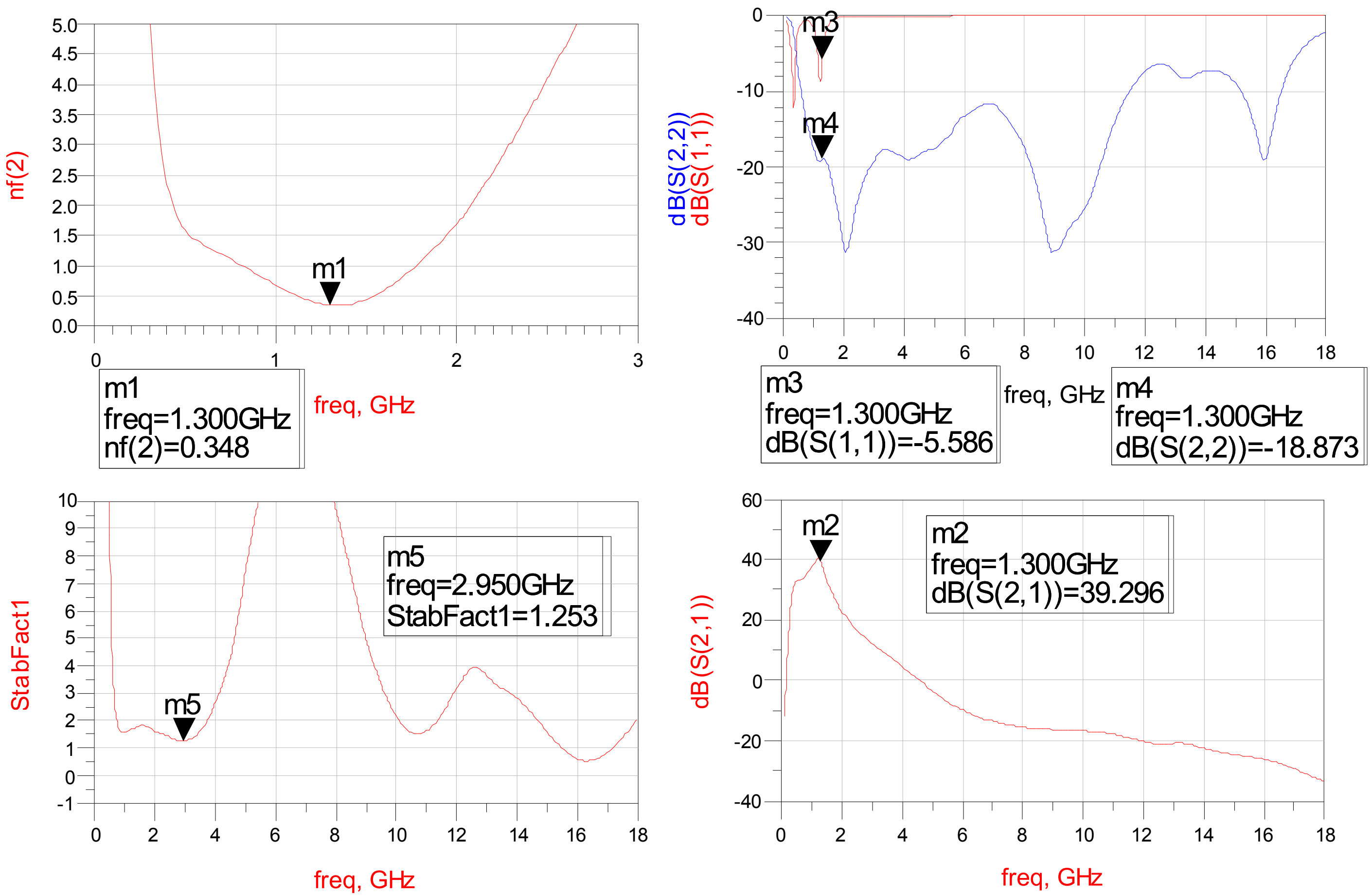






Not bad for a MMIC!

ADS Simulation with ATF-36077 MGA-61563 Cascade



I don't believe K is a problem at 16 GHz but if it is a little Rd will help

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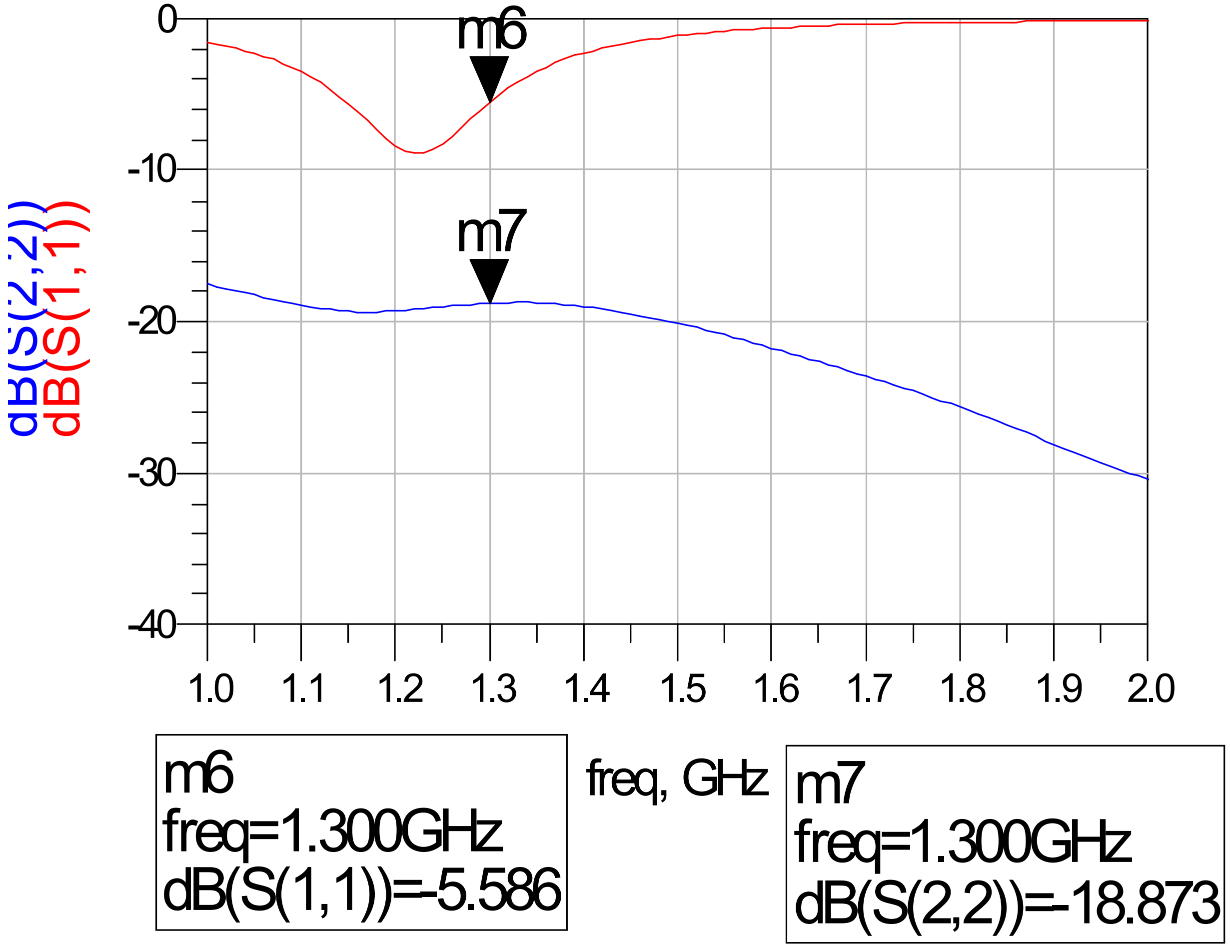
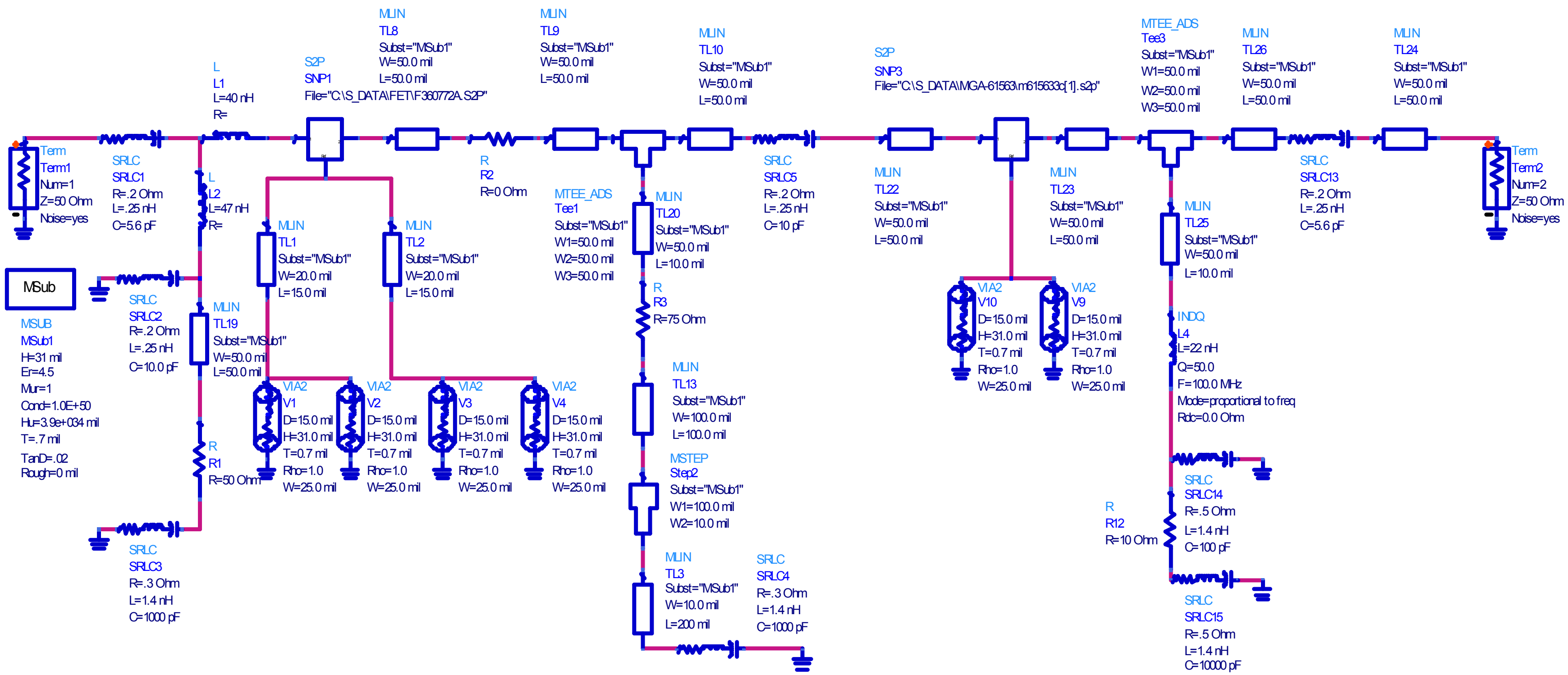
ADS Simulation with ATF-36077 MGA-61563 Cascade

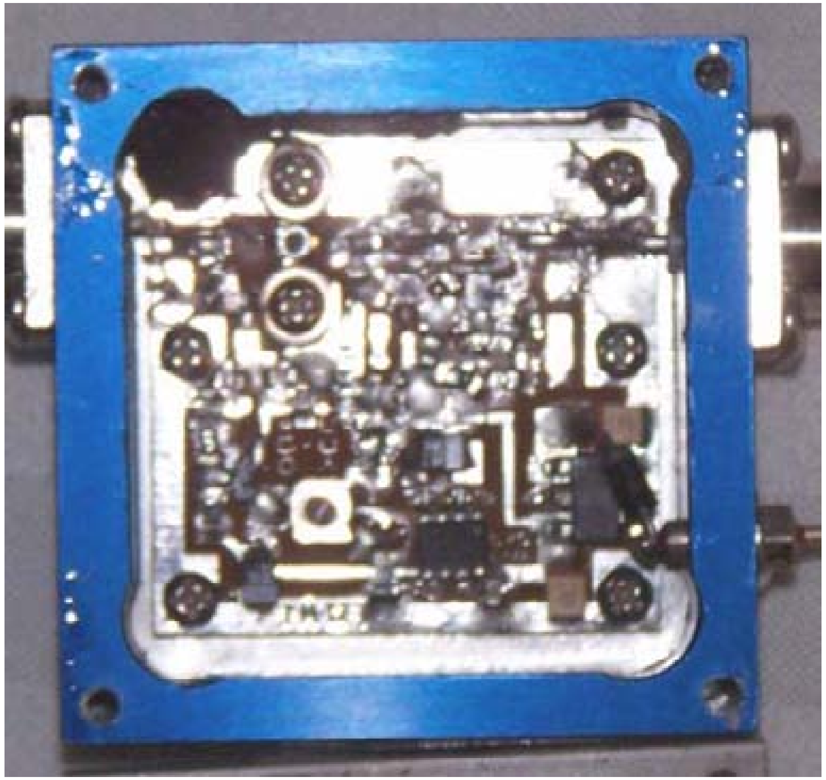


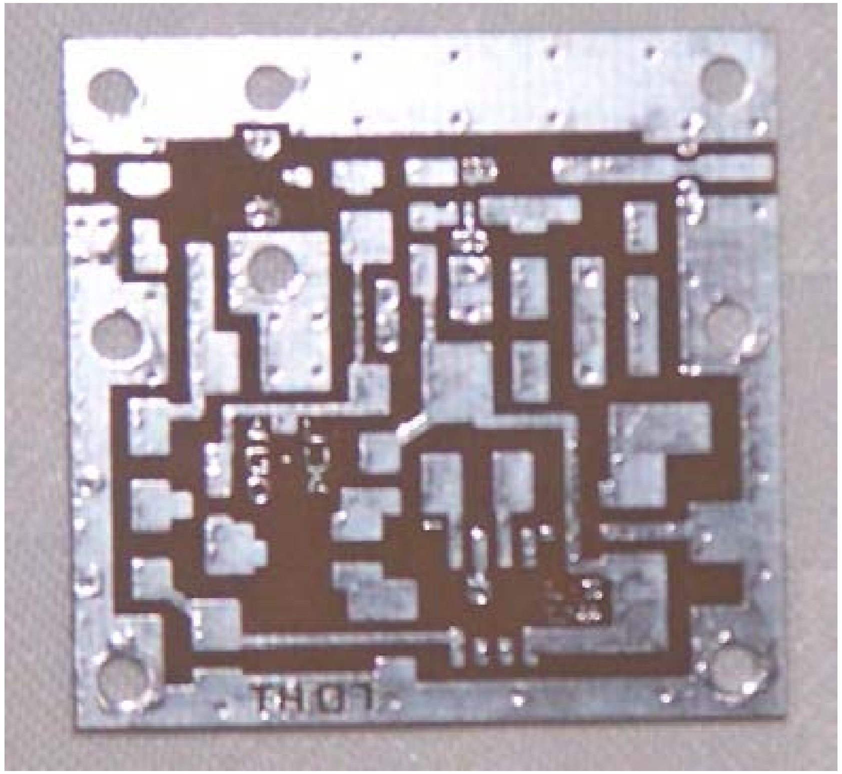
ADS Simulation with ATF-36077 MGA-61563 Cascade



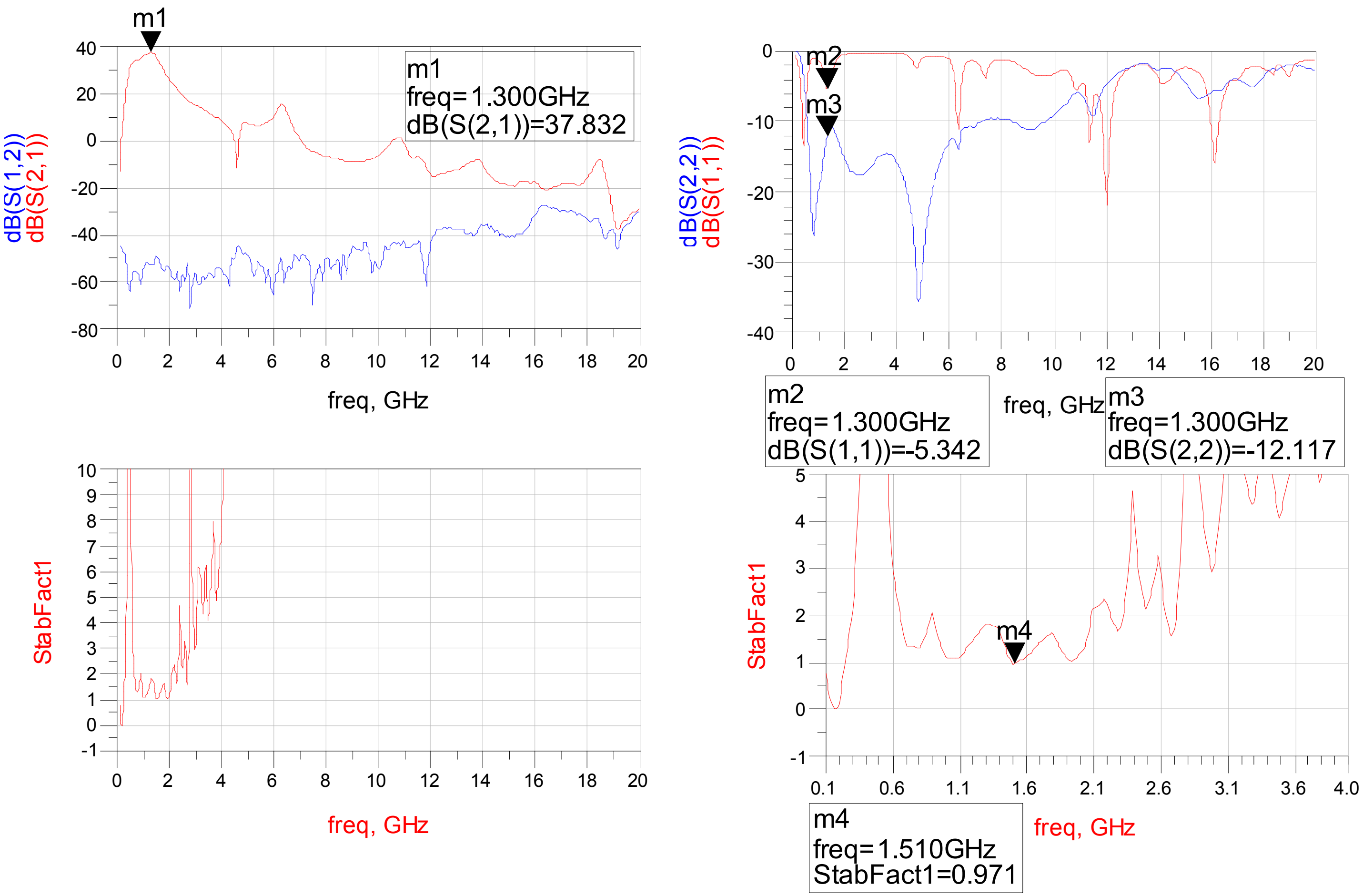
This is the approach taken for a new WD5AGO LNA

2 Stage ATF-36077 & MGA-61563 LNA



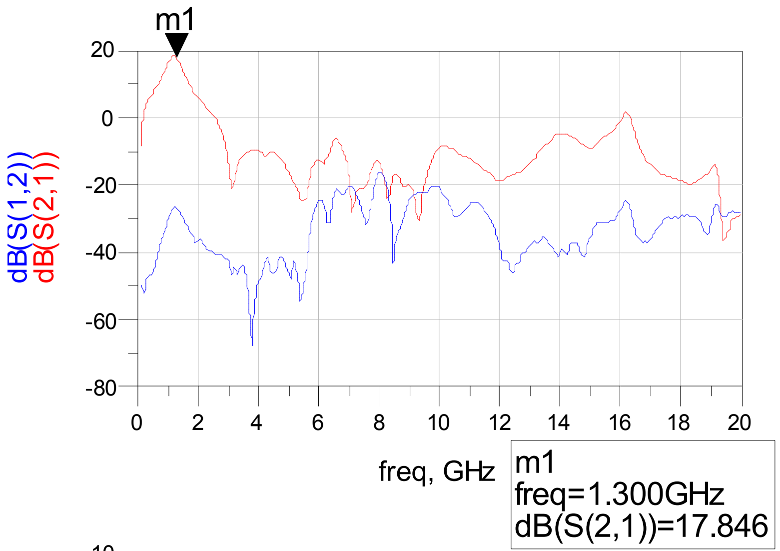


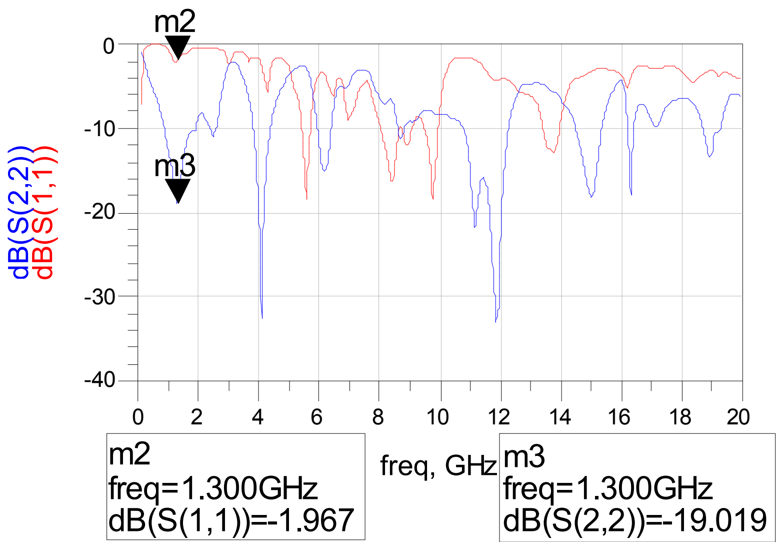
2 Stage ATF-36077 & MGA-61563 #1 Measured Results

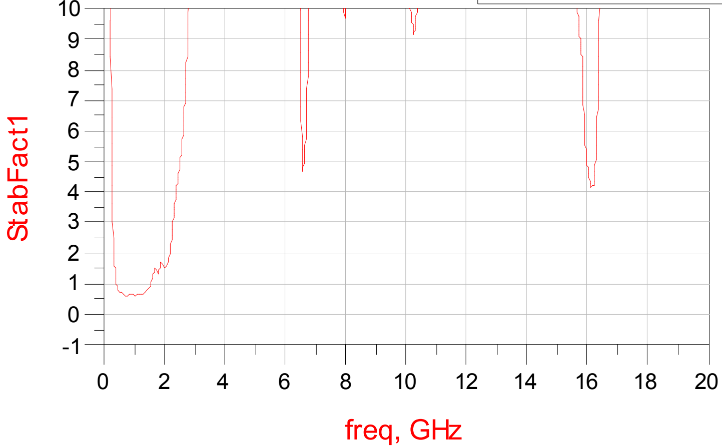


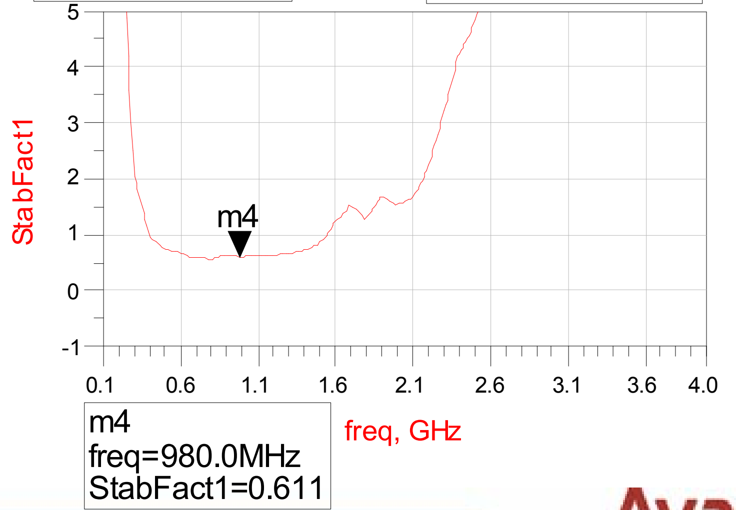
NF measured 0.35 dB at 1296 MHz. K at low frequency erroneous due to lack of S12 due to poor dynamic range in test equipment. Tough when LNA has 37 dB gain!

AP Note 1228 Single Stage ATF-36077 Measured Results

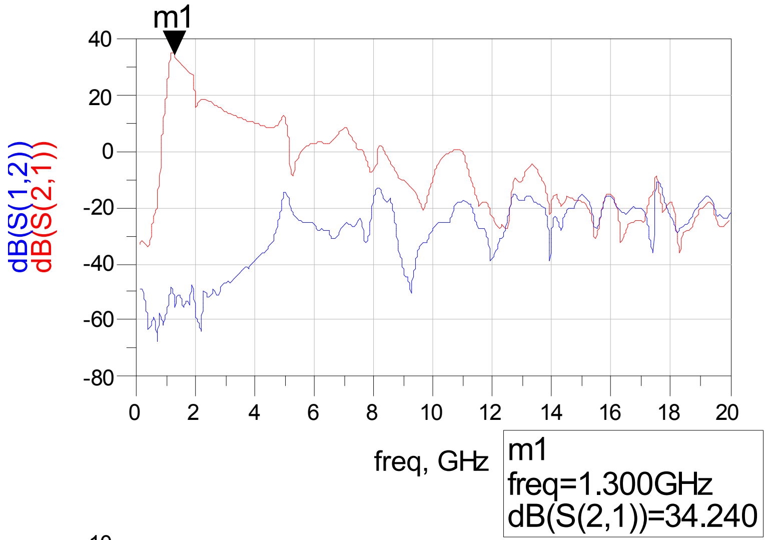


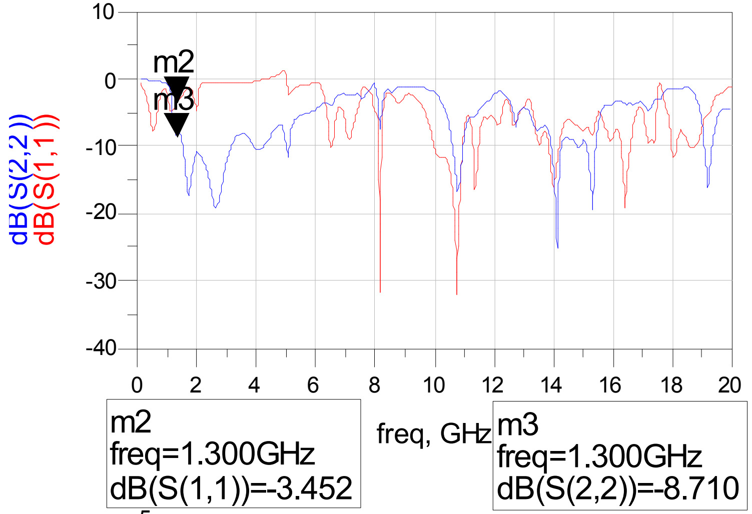


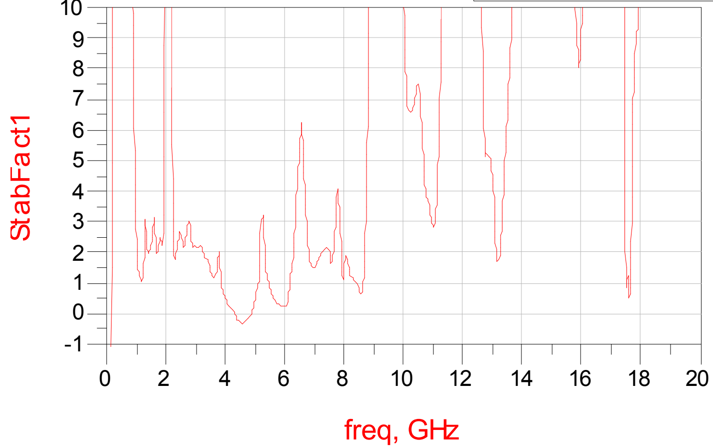


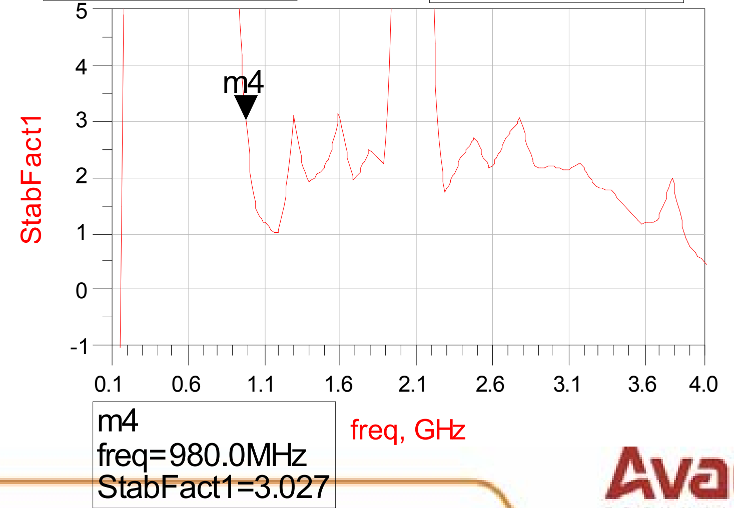


2 Stage ATF-36077 & MGA-61563 in Enclosure

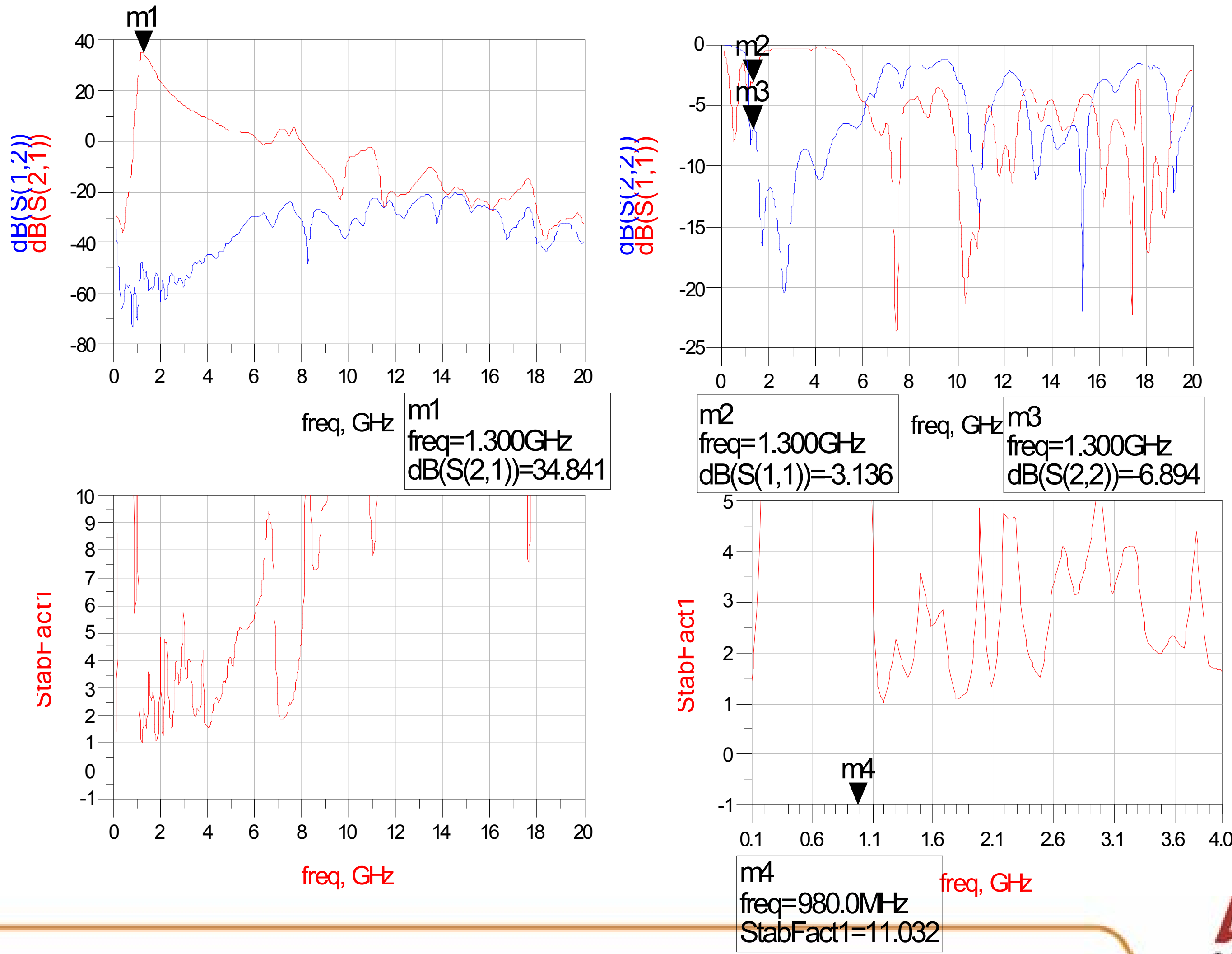






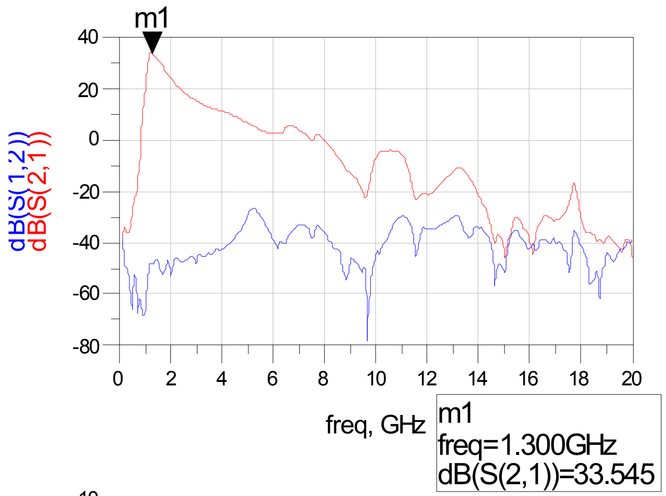


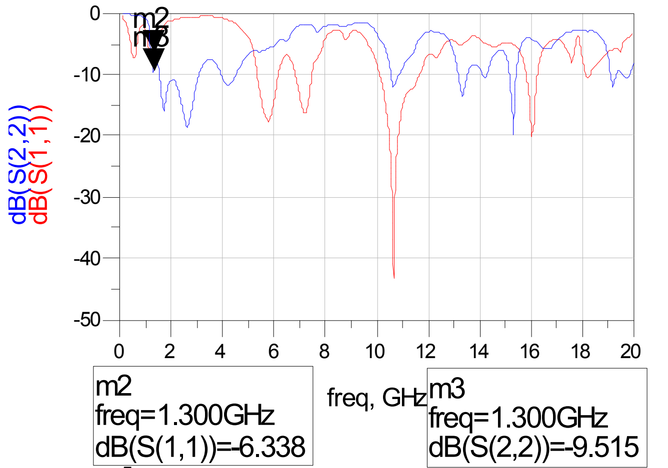
2 Stage ATF-36077 & MGA-61563 in Enclosure without Lid

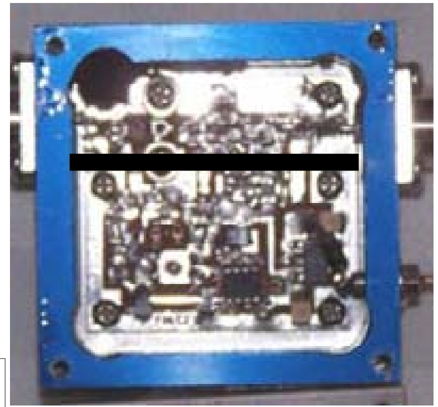


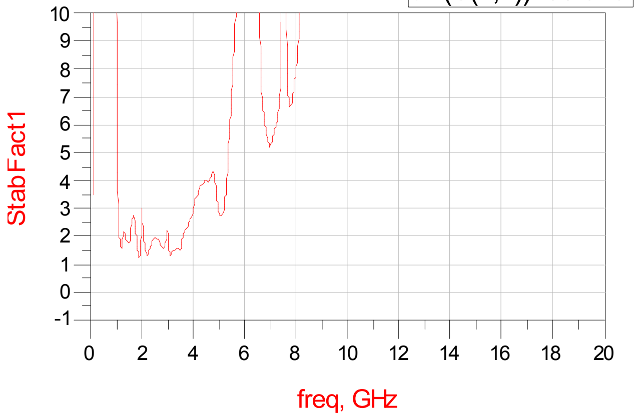
AVAGO TECHNOLOGIES

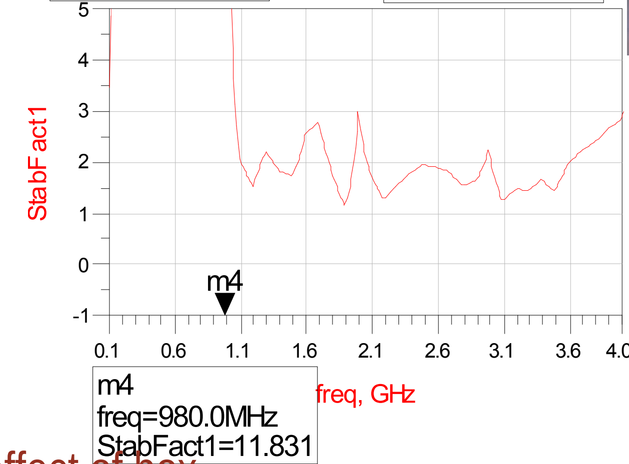
2 Stage ATF-36077 & MGA-61563 in Enclosure with Metal Divider Spanning Length of Box





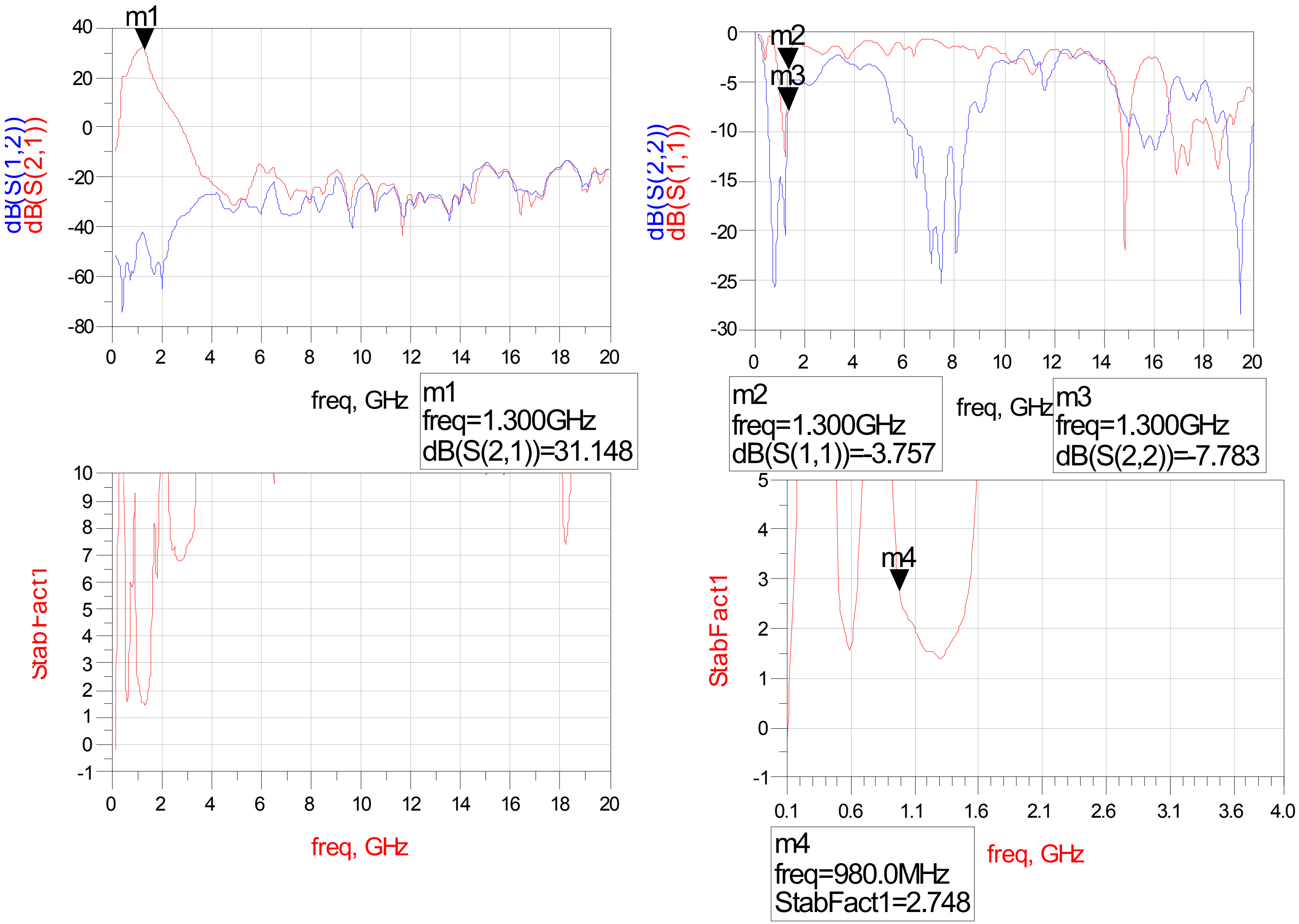


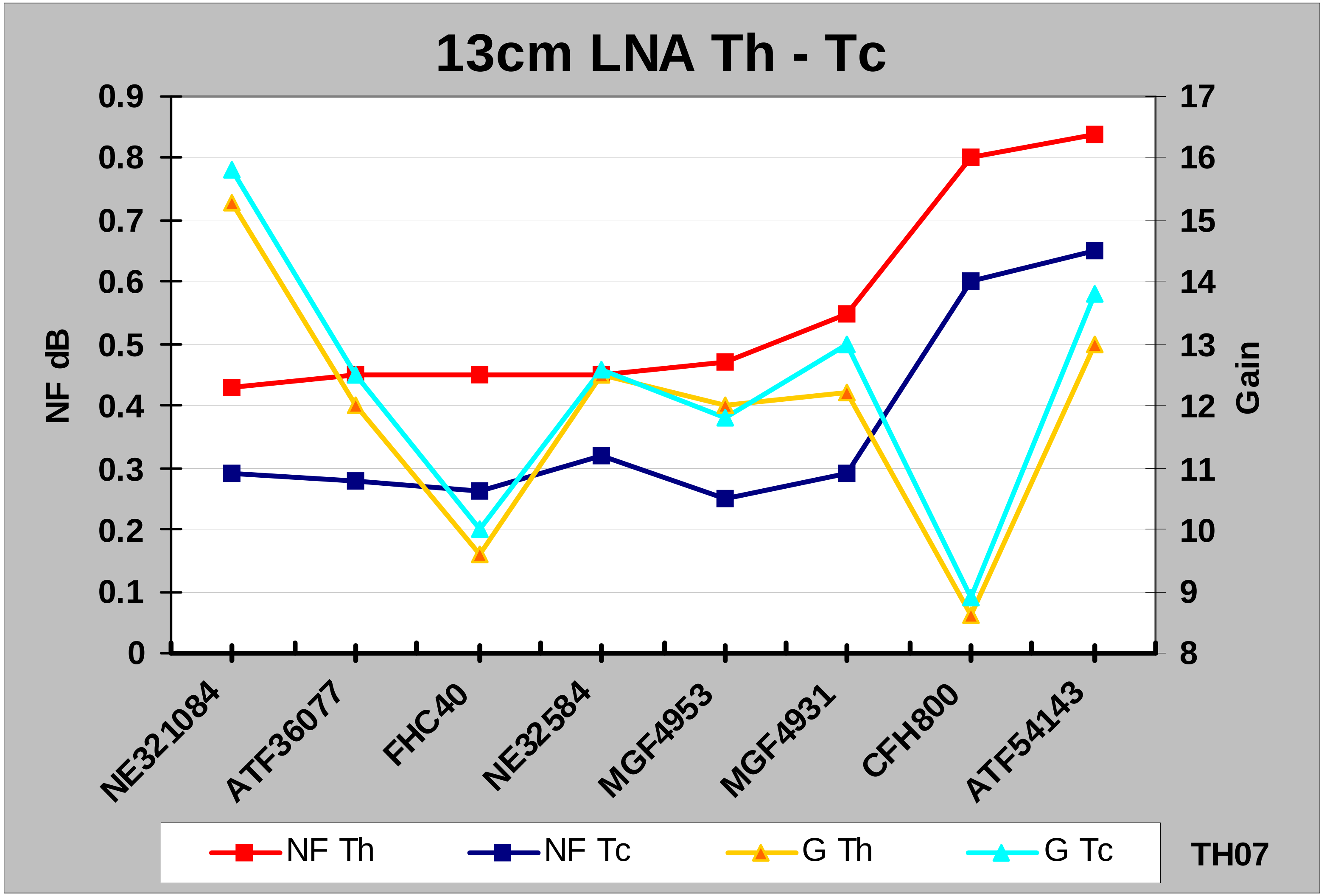




Metal divider breaks up waveguide moding effect of box

Original 2 Stage LNA with ATF-36077 and ATF-21186




13cm LNA Th - Tc
NF dB
Gain
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
17
16
15
14
13
12
11
10
9
8
NE321084
ATF36077
FHC40
NE32584
MGF4953
MGF4931
CFH800
ATF54143
NF Th
NF Tc
G Th
G Tc
TH07

Summary

The MGA-61563 provided the additional gain desired while providing a lower noise higher IP3 second stage

LNA noise figures of 0.3 dB and 37 dB of associated gain have been demonstrated

Although the ATF-36077 / MGA-61563 cascade has been shown to provide K greater than 1, the increased gain is providing new challenges in enclosure design.

Any Questions?