Design of 2-Stage LNA

Microwave Circuit Design Final Project

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Requirements

Characteristic	Specification
Operating Frequency	17.8-18.6GHz
Noise Figure	<1.5dB
Insertion Gain (S21)	>18dB
Output Reflection (S22)	<-14dB
Input Reflection	<-10dB
Board for Hybrid Integration	Duriod 5880 (10mil)
Active Device Used	ATF-36077
Stability	Unconditionally stable 0.1-20GHz

First Stage

Optimize for Noise Measure

Design Choice: centered at 18.2GHz, 17.8-18.6GHz range

Possible Components:

Part Number	NF (dB)	Ga (18GHz) (dB)	Minimum Noise Measure	Notes
NE3210S01	0.72	11.9	0.1927666991	
NE3512S02	0.7	8.5	0.2036661655	
NE3514S02	0.72	7.8	0.2162010846	
NE3515S02	0.58	10	0.1587537053	No Spice Model in Kit
NE3511S02	0.65	11	0.1753795029	From Graph
NE3514S02	0.72	11.2	0.1951221656	From Graph
ATF-36077	0.65	12	0.1723213564	From Graph

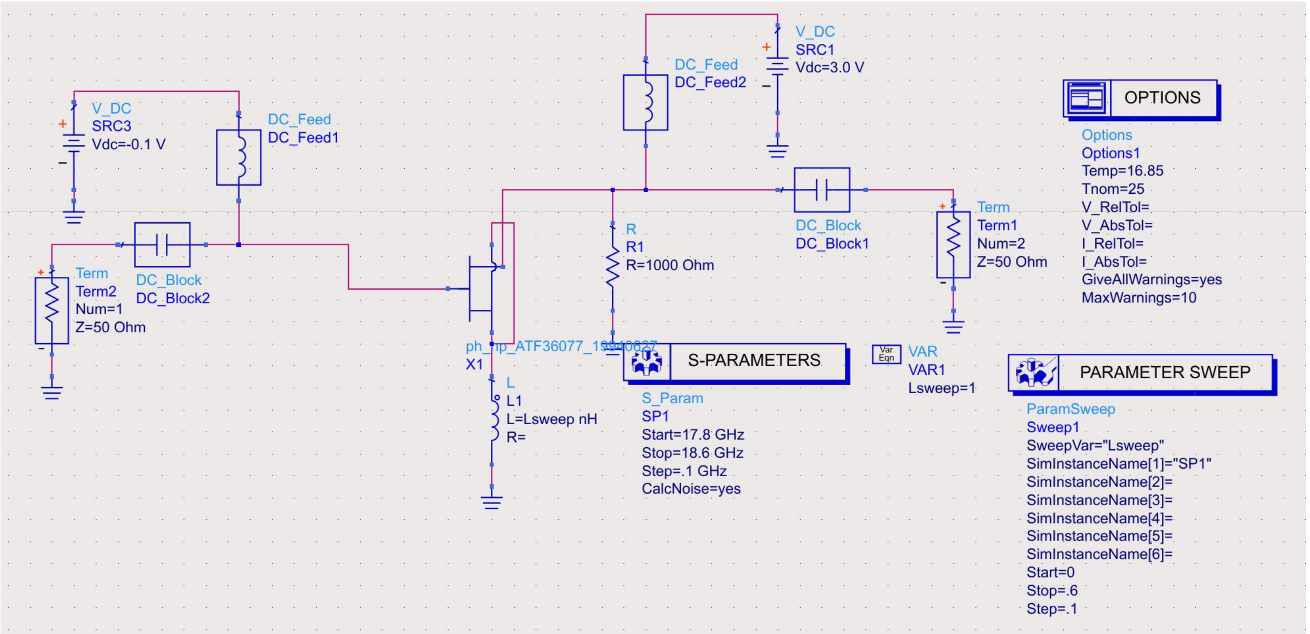
*From Data Sheets @ 18GHz

M_min = (F_min - 1)/(1- 1/Ga)

As we are designing a cascaded amplifier, the FET with the minimum noise measure should be first in the cascade. First stage will be ATF-36077

freq	k							delta						
	Lsweep=0.000	Lsweep=0.100	Lsweep=0.200	Lsweep=0.300	Lsweep=0.400	Lsweep=0.500	Lsweep=0.600	Lsweep=0.000	Lsweep=0.100	Lsweep=0.200	Lsweep=0.300	Lsweep=0.400	Lsweep=0.500	Lsweep=0.600
17.80 GHz	0.985	1.023	0.987	0.953	0.930	0.916	0.908	0.644	0.676	0.769	0.882	0.996	1.101	1.197
17.90 GHz	0.987	1.023	0.986	0.951	0.928	0.914	0.907	0.644	0.677	0.772	0.887	1.003	1.112	1.210
18.00 GHz	0.989	1.023	0.985	0.950	0.926	0.913	0.905	0.645	0.678	0.774	0.892	1.011	1.122	1.223
18.10 GHz	0.992	1.023	0.984	0.948	0.925	0.911	0.904	0.646	0.679	0.777	0.897	1.019	1.133	1.237
18.20 GHz	0.994	1.023	0.983	0.946	0.923	0.909	0.902	0.647	0.681	0.780	0.903	1.027	1.144	1.251
18.30 GHz	0.996	1.023	0.981	0.945	0.921	0.908	0.901	0.648	0.682	0.783	0.908	1.036	1.156	1.266
18.40 GHz	0.998	1.023	0.980	0.943	0.919	0.906	0.900	0.649	0.683	0.786	0.914	1.045	1.168	1.281
18.50 GHz	1.000	1.023	0.979	0.942	0.918	0.904	0.898	0.649	0.685	0.789	0.919	1.054	1.181	1.297
18.60 GHz	1.002	1.023	0.978	0.940	0.916	0.903	0.897	0.650	0.686	0.792	0.925	1.063	1.194	1.314

Selected **L=0.1nH** and **R=1000 Ohm** for source degeneration stabilization



If Use_Specific_Values="Yes" then the requested circle values will be displayed, if possible.

Eqn Use_Specific_Values="Yes"
Eqn Requested_Noise_circle_values=[1.3,1.4]
Eqn Requested_GA_circle_values=[15::16]
Eqn Requested_GP_circle_values=[15::16]

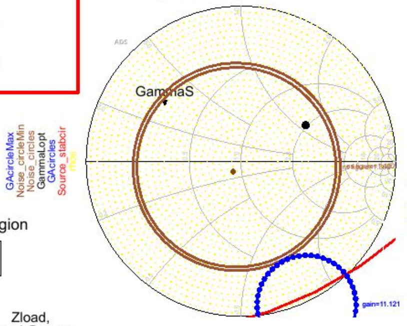
If Use_Specific_Values="No", then the step sizes and number of circles below will be used.

Eqn num_NFcircles=4
Eqn NFstep_size=.2
Eqn num_GAcircles=3
Eqn GAstep_size=0.2
Eqn num_GPcircles=3
Eqn GPstep_size=1

Acceptable syntax examples:
[5,6,7] or [5::7] set contours to 5 to 6 in steps of 1;
[4::0.5::6] sets contours to 4 to 6 in steps of 0.5.

Available Gain & Noise Circles,
Source Stability Circle
Source Gamma.
Corresponding Load Gamma,
(Black Dot)

0.587
1.300
1.400



Stability Factor, K

0.980

Source Stable Region

Inside

Zsource, Source Gamma

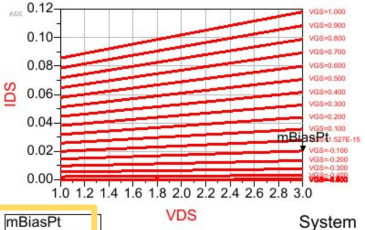
Zload, Load Gamma

DUT*

*DUT= Device Under Test (simulated circuit or device)

Move markers GammaS and GammaL to select arbitrary source and load reflection coefficients. The impedances, power gains, and noise figures below will be updated. The transducer power gains are invalid if the markers are moved into the unstable regions (usually inside the stability circles.)

Move marker mBiasPt to desired bias point. Smith Chart and data below will be updated.



mBiasPt
VDS=3.000
IDS=20.34m
VGS=-100.0m

RF Frequency

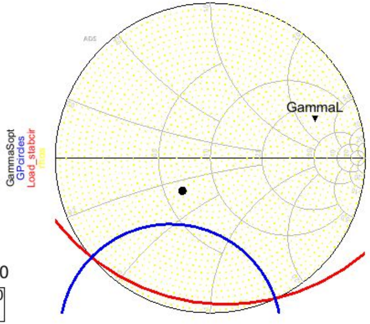
18.00 GHz

System Impedance, Z0

50.000

Power Gain Circles,
Load Stability Circle
Load Gamma, GammaL
Corresponding Source
Gamma, (Black Dot)

11.121
11.121
11.121



Noise Figure (dB) with Source Impedance at marker GammaS	Source Impedance at marker GammaS	Optimal load impedance for power transfer when source impedance at marker GammaS is presented to input	Transducer Power Gain, dB when these source and load impedances are used
1.198	13.310 + j15.300	98.087 + j59.337	5.823

NFmin,dB	Source Impedance, Zopt, for Minimum NF	Optimal load impedance for power transfer when source impedance is Zopt	Transducer Power Gain, dB when these source and load impedances are used
0.587	44.864 - j6.003	78.254 + j3.015	9.237

Noise Figure (dB) with Zsource (only valid with K>1)	Simultaneous Conjugate Matching (only valid if stability factor K >1) Zsource	Zload	Maximum Available Gain, dB (Maximum Stable Gain, S21/S12) if K<1
1000	50.000	50.000	11.121

Noise Figure (dB) with this optimal source impedance (at right)	Optimal source impedance for power transfer when load impedance at marker GammaL is presented to output	Load Impedance at marker GammaL	Transducer Power Gain, dB when these source and load impedances are used
0.632	32.127 - j14.736	149.968 + j146.544	7.514

Load Stable Region

Inside

See "NF, SP, Gains at all Bias Pts." page.

See "Matching at 1 Bias Point" page for optimal source and load impedances to match for gain or noise figure. Equations for this page are on the "Equations2" page.

BiasPt
VDS = 3V
VGS = -0.1V

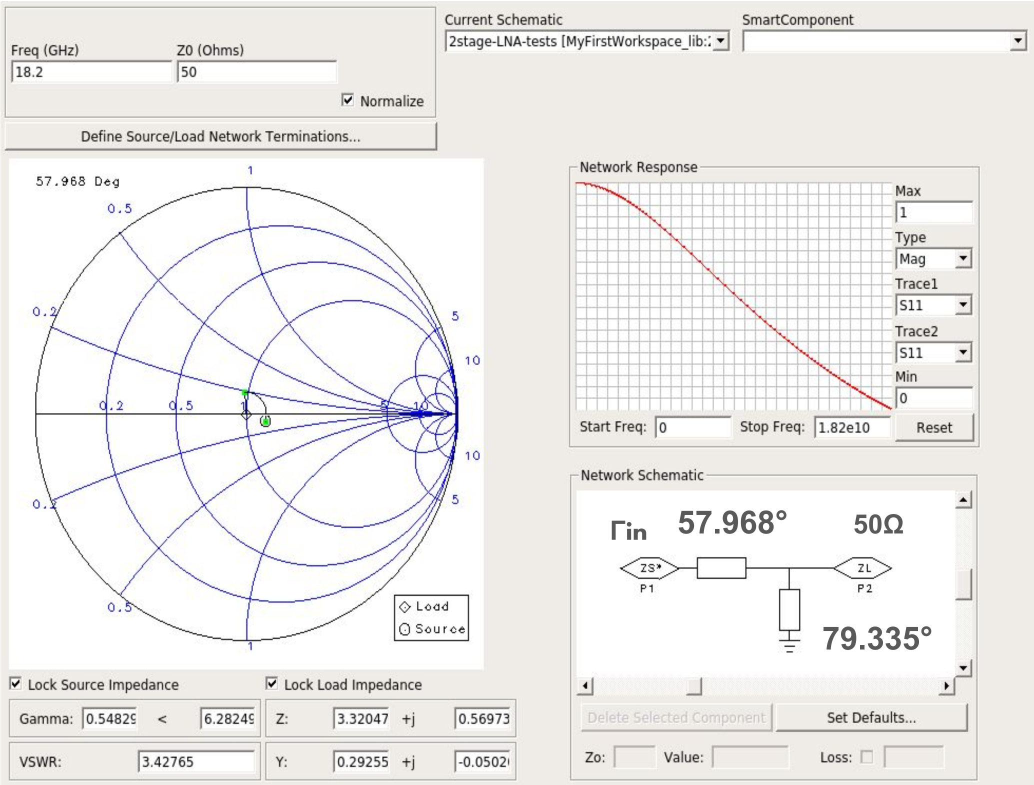
Optimum bias point chosen to minimize NFmin.

Step 1: At a design frequency of 18.2GHz

$\Gamma_{opt} = 0.093 \angle -17.569^\circ$ for lowest noise

Component ($Z_0 = 50\Omega$)	Length (mils)	Width (mils)
Series Line	76.458268	29.369528
Shunt Shorted Stub	104.640945	29.369528

Microstrip Line dimensions calculated using LineCalc ADS Utility for a Duroid 5880 10mil board

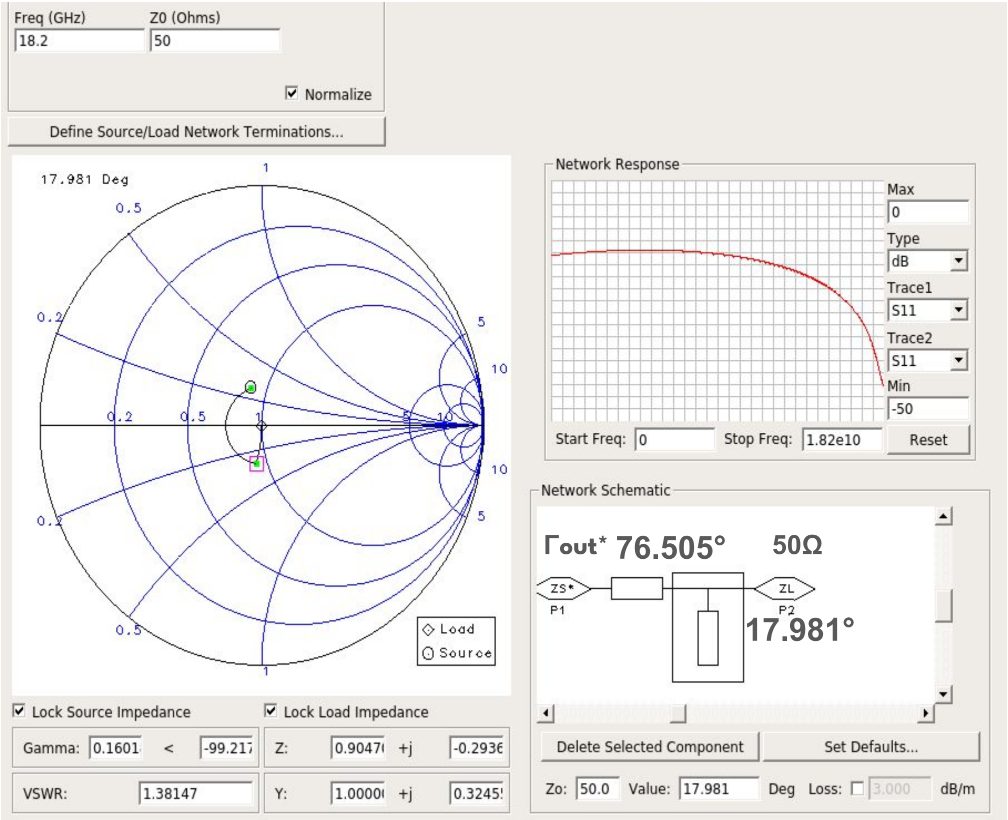


Step 2: Conjugate Match at Output to maximize transducer gain ⟶

$\Gamma_{out}^{*} = \Gamma\_load = 0.167 \angle 108.315^{\circ}$

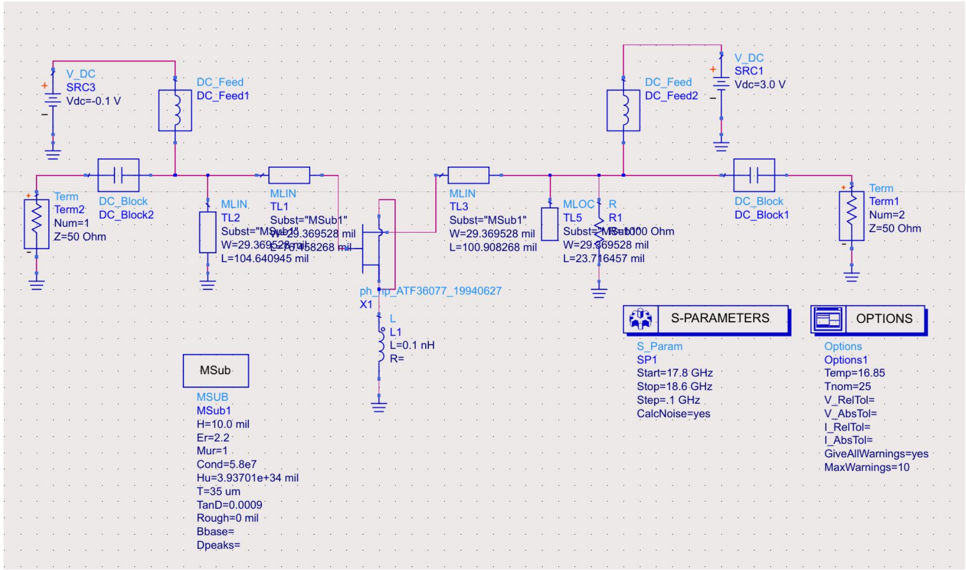
Component (Z0 = 50Ω)	Length (mils)	Width (mils)
Series Line	100.908268	29.369528
Shunt Open Stub	23.716457	29.369528

Microstrip Line dimensions calculated using LineCalc ADS Utility for a Duroid 5880 10mil board

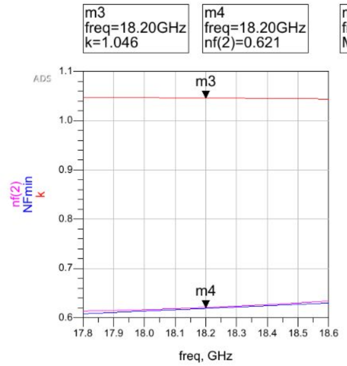


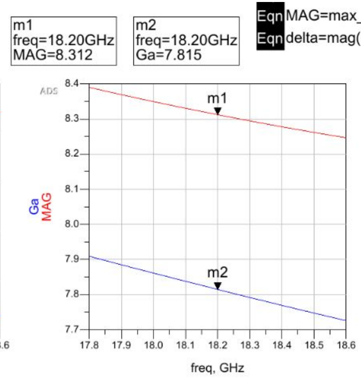
Ideal First Stage

After first stage of LNA, the noise figure is close to NFmin. Available gain is 7.8dB, so we will need a high gain second stage. Achieves S11<-10dB and S22>-14dB requirements. Unconditionally stable in operating frequency.

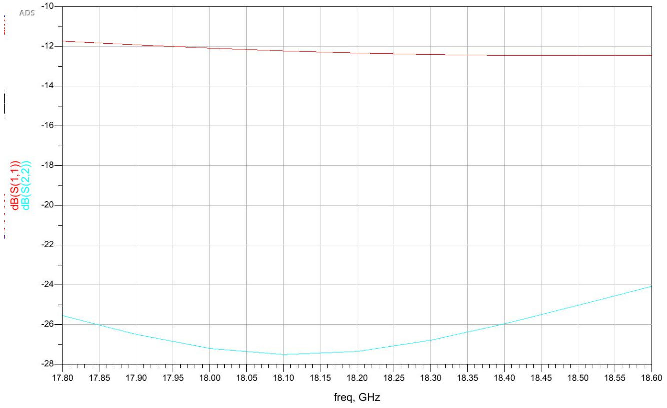


Eqn MAG=max_gain(S)
Eqn delta=mag(S11*S22-S12*S21)
Eqn S_opt=Sopt



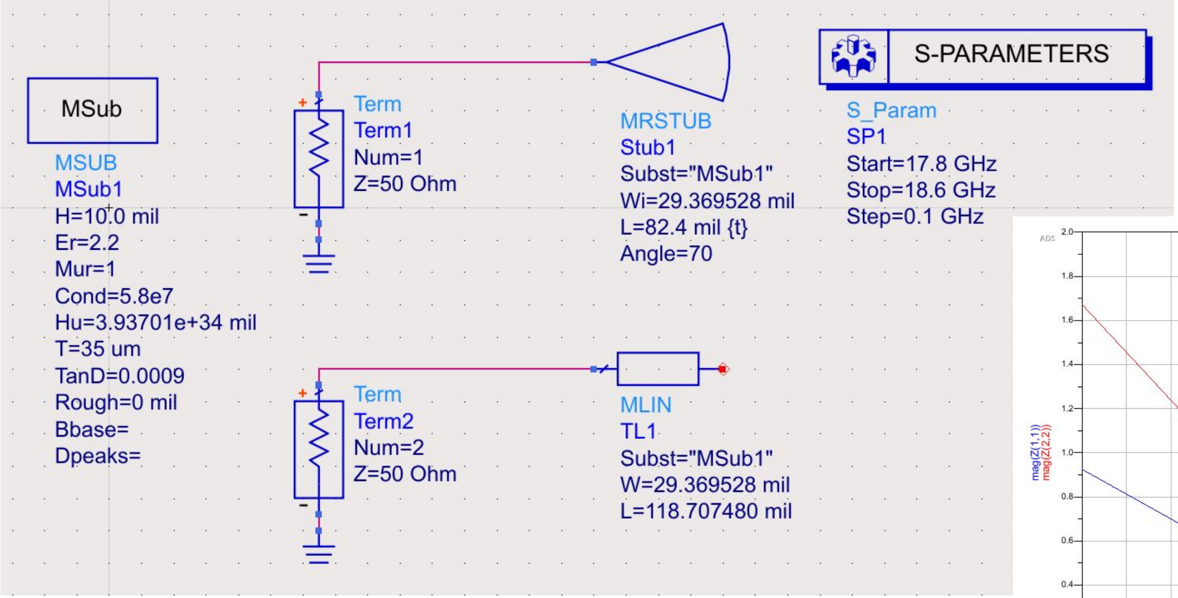


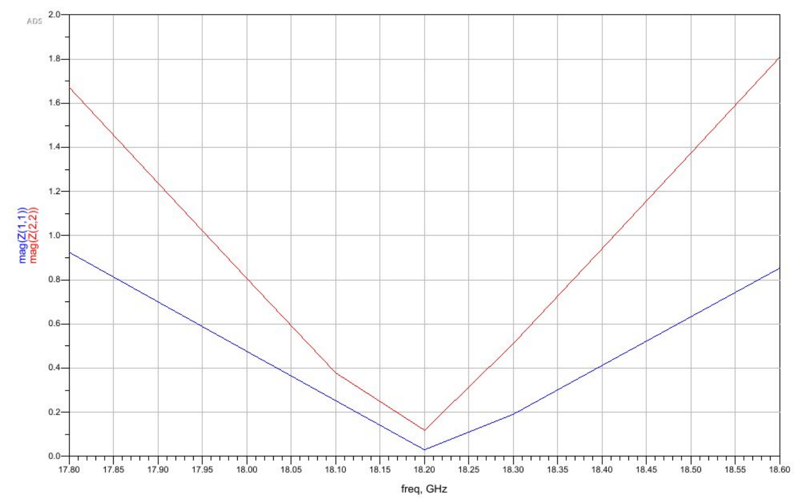
freq	k	delta
17.80 GHz	1.048	0.675
17.90 GHz	1.047	0.676
18.00 GHz	1.047	0.676
18.10 GHz	1.046	0.677
18.20 GHz	1.046	0.678
18.30 GHz	1.046	0.679
18.40 GHz	1.045	0.680
18.50 GHz	1.044	0.681
18.60 GHz	1.044	0.681



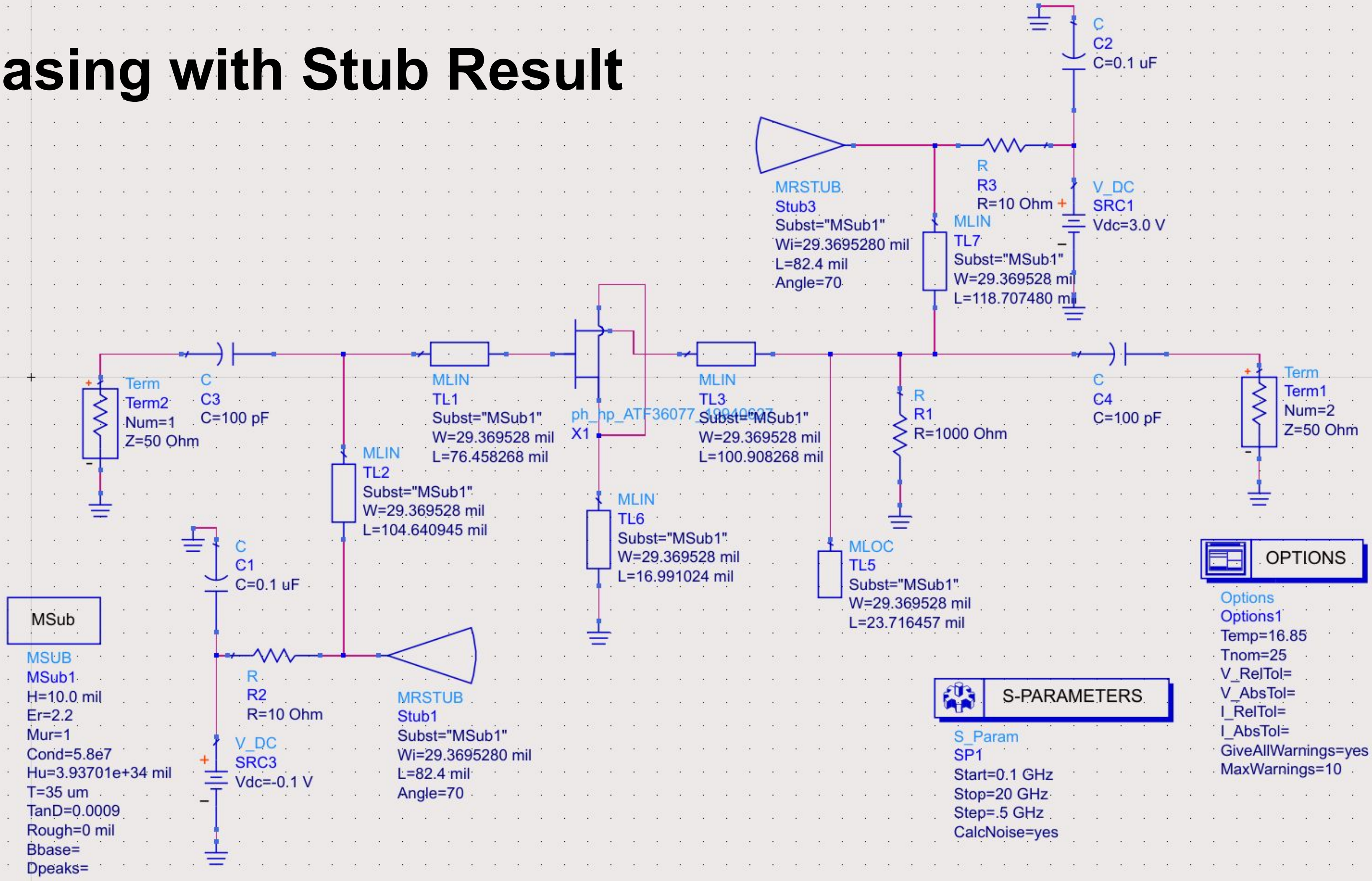
Synthesizing Bias Networks and Stabilization Network

- Replacing Open Stubs with Radial Open Stubs for higher bandwidth short
- Replacing bias networks with a quarter-wavelength line, resistor, and capacitor, integrating into matching network where possible

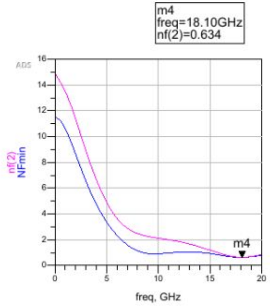


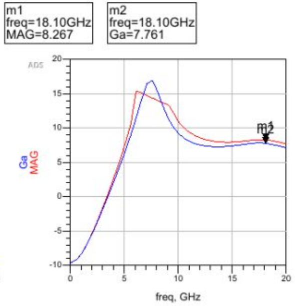


Biasing with Stub Result



First Stage Statistics



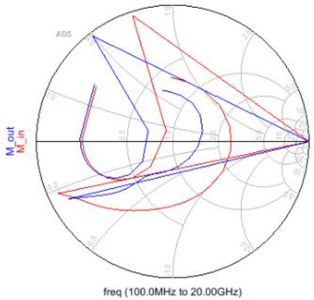


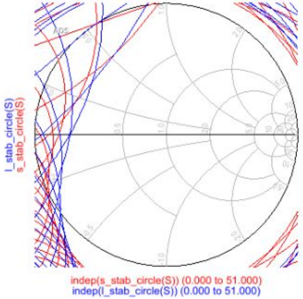
Eqn M_in=sm_gamma1(S)
Eqn M_out=sm_gamma2(S)
Eqn k=stab_fact(S)
Eqn MAG=max_gain(S)
Eqn delta=mag(S11*S22-S12*S21)

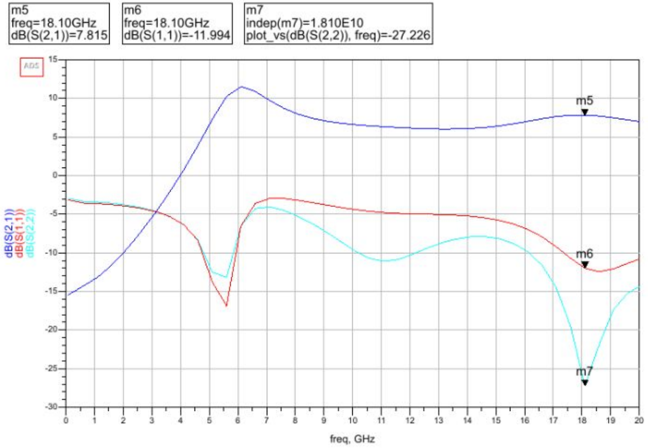
Eqn Ga=10*log((mag(S21)**2)*(1-mag(Sopt)**2)/((mag(1-S11*Sopt)**2)*(1-mag(G_out)**2)))

Eqn NF_min=NFmin
Eqn S_opt=Sopt

Eqn G_out=(S22+S12*S21*Sopt/(1-S11*Sopt))
Eqn G_L=conj(G_out)







freq	k	delta	S_opt	G_L
100.0 MHz	10997.140	0.490	0.727 / 144.251	0.708 / 144.274
600.0 MHz	1650.910	0.451	0.702 / 176.948	0.680 / 178.191
1.100 GHz	714.149	0.442	0.698 / -177.686	0.673 / -175.165
1.600 GHz	353.454	0.428	0.692 / -174.347	0.662 / -170.221
2.100 GHz	181.546	0.407	0.682 / -171.856	0.645 / -165.649
2.600 GHz	94.751	0.380	0.669 / -170.007	0.623 / -161.090
3.100 GHz	49.901	0.342	0.653 / -168.790	0.593 / -156.367
3.600 GHz	26.371	0.290	0.634 / -168.273	0.553 / -151.359
4.100 GHz	13.889	0.218	0.615 / -168.542	0.497 / -146.002
4.600 GHz	7.236	0.113	0.598 / -169.660	0.418 / -140.495
5.100 GHz	3.712	0.075	0.586 / -171.589	0.304 / -136.610
5.600 GHz	1.890	0.301	0.583 / -174.117	0.151 / -151.658
6.100 GHz	1.000	0.497	0.590 / -176.843	0.221 / 133.463
6.600 GHz	0.622	0.533	0.608 / -179.271	0.532 / 139.129
7.100 GHz	0.518	0.478	0.633 / 179.014	0.765 / 161.016
7.600 GHz	0.556	0.399	0.662 / 178.226	0.841 / -179.248
8.100 GHz	0.660	0.316	0.687 / 178.376	0.825 / -164.166
8.600 GHz	0.786	0.231	0.705 / 179.341	0.772 / -152.480
9.100 GHz	0.911	0.145	0.711 / -179.054	0.702 / -142.983
9.600 GHz	1.023	0.063	0.706 / -176.979	0.624 / -135.016
10.10 GHz	1.116	0.049	0.692 / -174.574	0.541 / -128.336
10.60 GHz	1.187	0.126	0.671 / -171.945	0.455 / -123.067
11.10 GHz	1.239	0.206	0.647 / -169.160	0.370 / -119.767
11.60 GHz	1.271	0.281	0.620 / -166.254	0.292 / -119.634
12.10 GHz	1.287	0.348	0.591 / -163.232	0.226 / -124.671
12.60 GHz	1.290	0.405	0.561 / -160.069	0.184 / -136.506
13.10 GHz	1.281	0.454	0.529 / -156.707	0.173 / -151.832
13.60 GHz	1.264	0.495	0.496 / -153.054	0.187 / -163.037
14.10 GHz	1.240	0.528	0.460 / -148.973	0.209 / -167.613
14.60 GHz	1.212	0.555	0.422 / -144.275	0.228 / -167.368
15.10 GHz	1.181	0.579	0.379 / -138.712	0.235 / -164.201
15.60 GHz	1.149	0.600	0.333 / -131.984	0.229 / -159.322
16.10 GHz	1.118	0.620	0.282 / -123.804	0.208 / -153.619
16.60 GHz	1.091	0.639	0.226 / -114.138	0.173 / -148.259
17.10 GHz	1.070	0.655	0.166 / -103.898	0.130 / -145.686
17.60 GHz	1.056	0.667	0.102 / -97.187	0.091 / -150.798
18.10 GHz	1.048	0.672	0.044 / -118.431	0.070 / -166.335
18.60 GHz	1.047	0.669	0.063 / 167.788	0.065 / 178.759
19.10 GHz	1.050	0.659	0.130 / 159.450	0.060 / 169.022
19.60 GHz	1.055	0.644	0.195 / 162.868	0.050 / 152.191
20.00 GHz	1.058	0.628	0.242 / 166.844	0.050 / 124.870

First Stage Statistics

17.8-18.6 GHz	Min (dB)
Ga	7.691
NF	0.638

- To meet 18dB total gain requirement, we need > 10.31dB available gain in the second stage.
- By Friis' Formula, the noise figure of the second stage is reduced by the gain of the first stage. We must design for a Noise Figure of 2.47 (3.94dB) or less in the second stage to have an overall noise figure of 1.5dB or better.

Second Stage

Gain/Noise Circle Match

Design Choice:

We continued to use the ATF-36077 transistor because it offers the highest gain while also staying within noise requirements.

The same bias point provided a good compromise between noise and gain for the input.

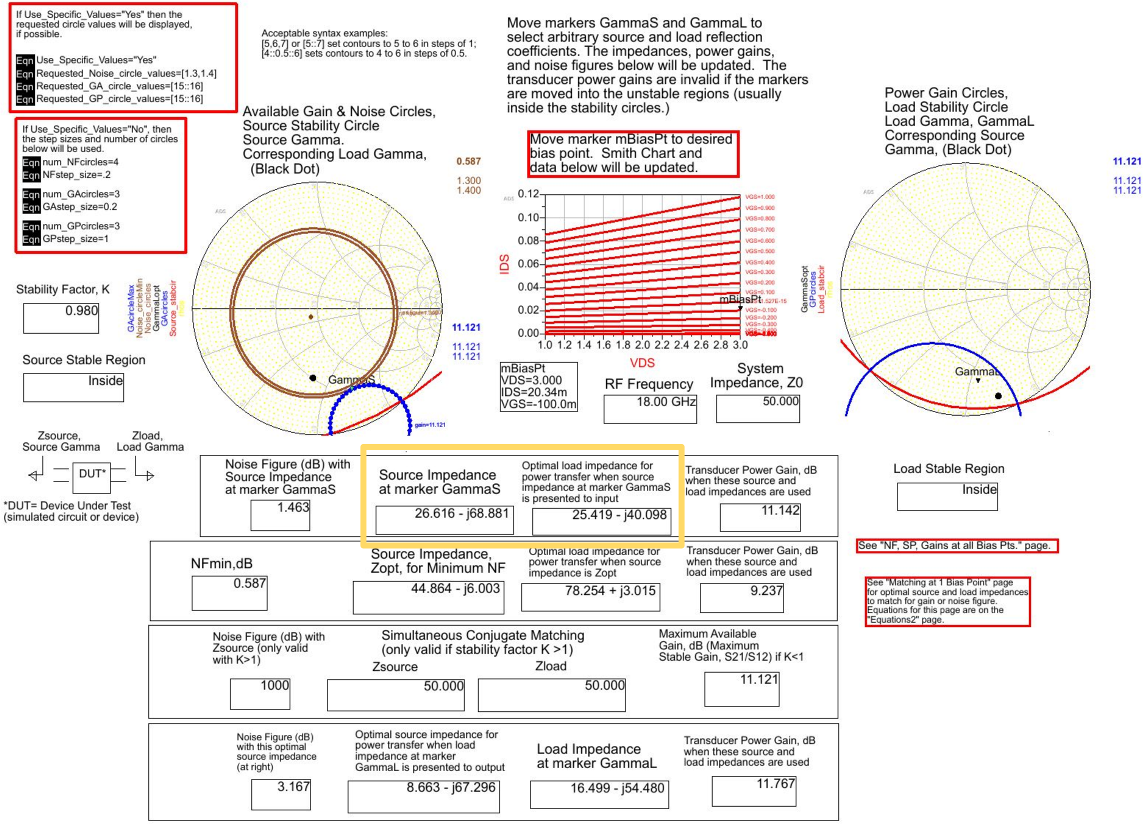
We selected a source impedance marker on the gain circle.

Zs = 26.616-j68.881

Γs = 0.70627 ∠ -66.788˚

Z_load = 25.419 - j40.098

Γ_load = 0.506∠ -81.513˚



Design Calculations:

From Gain and Noise Circles:

- NF = 1.463dB
- G_t = 11.142dB

Projected Overall Gain:

- **Gt ~ 18.833dB** using the minimum gain of the first stage and G_t

Projected Overall NF (Friis Formula)

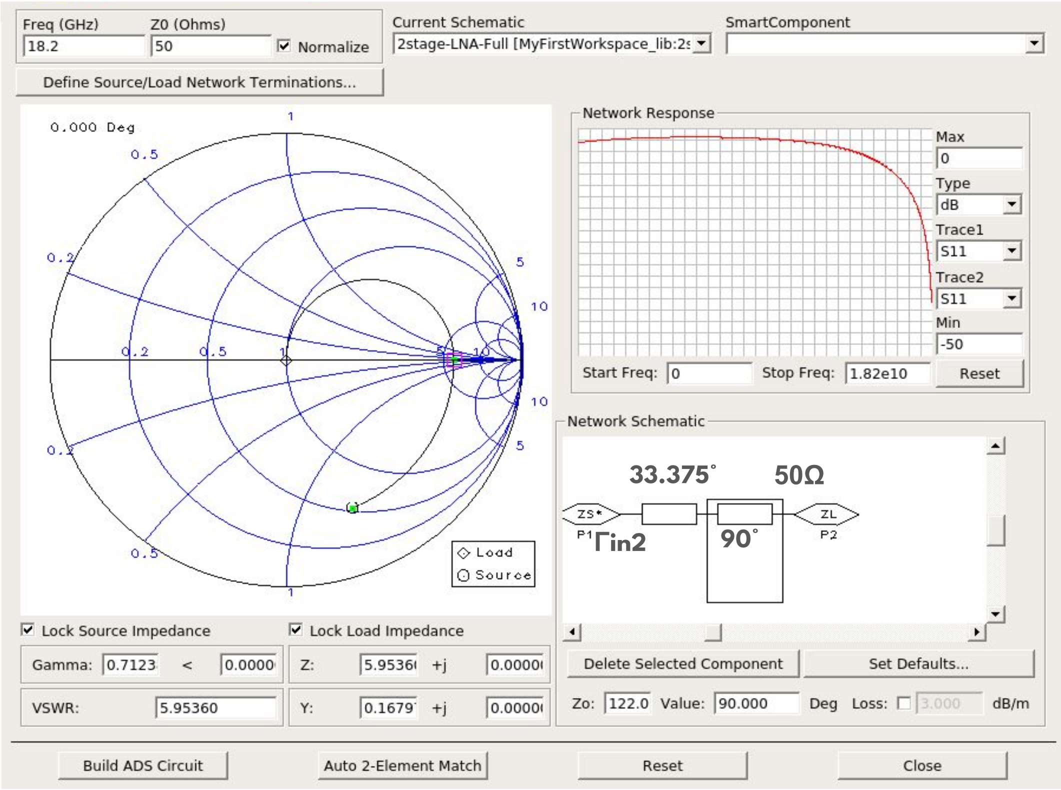
- **F_casc = 0.886dB**

Step 1: Conjugate Match 50Ω to input of second →

$\Gamma in2 = 0.70627 \angle -66.788^{\circ}$

Microstrip Line dimensions calculated using LineCalc ADS Utility for a Duroid 5880 10mil board

Component (Z0 = 50Ω)	Length (mils)	Width (mils)
Series Line	44.020866	29.369528
Quarter-Wave Transformer (Z0=122Ω)	125.897244	4.065157



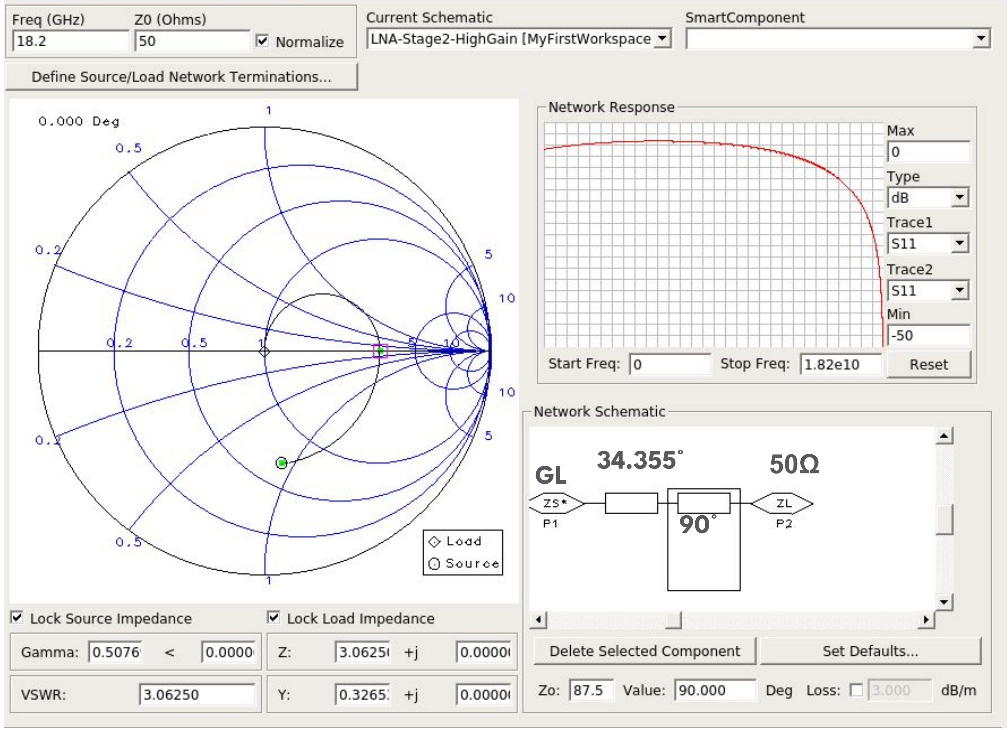
Step 2:

Trying @ 18.4G = 0.505 ∠ -68.68˚

The previous synthesis led to a gain that dropped off at 18.6 GHz but had margin at 17.8 GHz. To compensate we tried shifting the design frequency of the second stage to 18.4 GHz

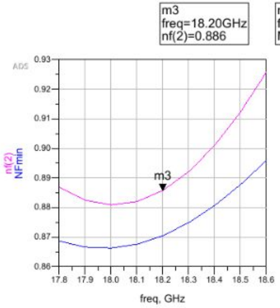
Component (Z0 = 50Ω)	Length (mils)	Width (mils)
Series Line	44.818110	29.371890
Quarter-Wave Transformer (Z0=87.5Ω)	121.571260	10.340512

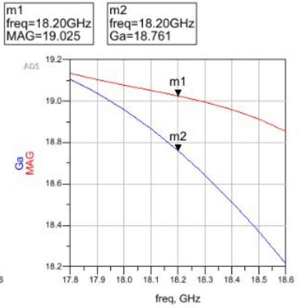
Microstrip Line dimensions calculated using LineCalc ADS Utility for a Duroid 5880 10mil board



Final Stage Statistics

Gain at 18.2GHz is 17.133dB, too low. Tried increasing with Optimization.



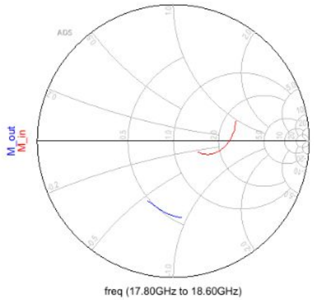


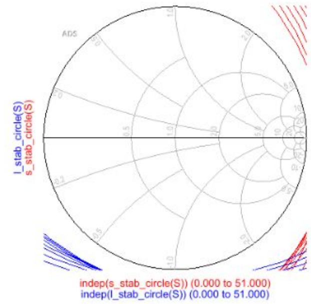
Eqn M_in=sm_gamma1(S)
Eqn M_out=sm_gamma2(S)
Eqn k=stab_fact(S)
Eqn MAG=max_gain(S)
Eqn delta=mag(S11*S22-S12*S21)

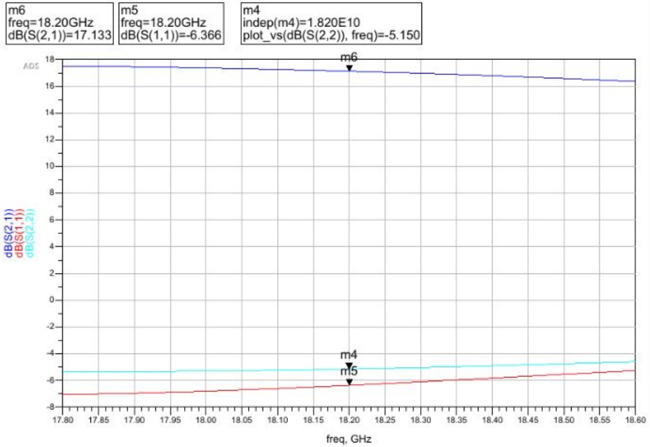
Eqn Ga=10*log((mag(S21)**2)*(1-mag(Sopt)**2)/((mag(1-S11*Sopt)**2)*(1-mag(G_out)**2)))

Eqn NF_min=NFmin
Eqn S_opt=Sopt

Eqn G_out=(S22+S12*S21*Sopt/(1-S11*Sopt))
Eqn G_L=conj(G_out)







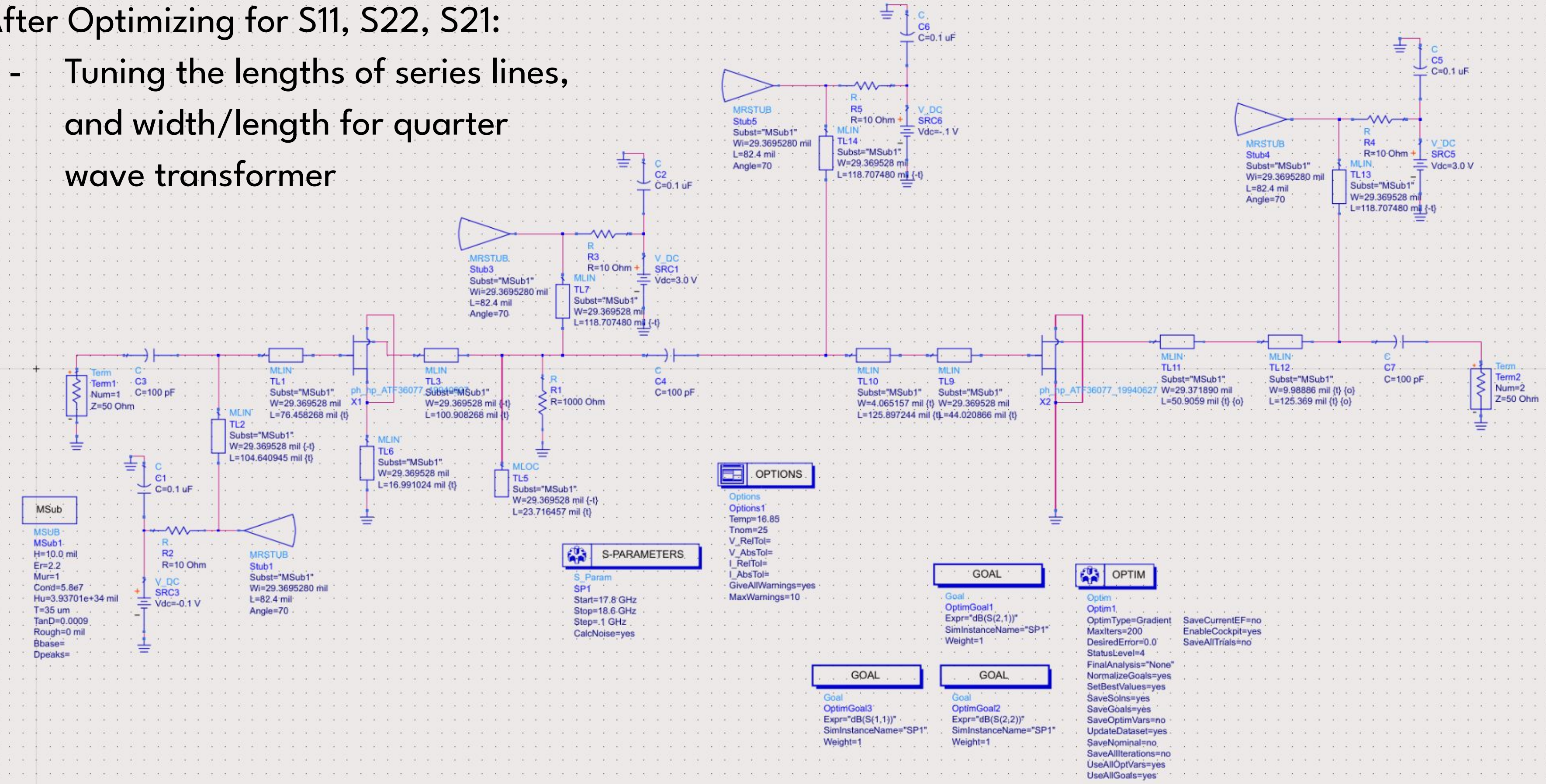
freq	k	delta	S_opt	G_L
17.80 GHz	1.080	0.703	0.111 / -0.263	0.491 / -106.164
17.90 GHz	1.078	0.702	0.104 / 12.258	0.493 / -99.941
18.00 GHz	1.076	0.701	0.100 / 25.868	0.496 / -93.743
18.10 GHz	1.074	0.700	0.099 / 39.979	0.500 / -87.593
18.20 GHz	1.072	0.699	0.102 / 53.796	0.506 / -81.513
18.30 GHz	1.070	0.697	0.108 / 66.617	0.512 / -75.524
18.40 GHz	1.069	0.695	0.117 / 78.057	0.519 / -69.648
18.50 GHz	1.069	0.693	0.128 / 88.047	0.527 / -63.903
18.60 GHz	1.070	0.690	0.140 / 96.715	0.535 / -58.309

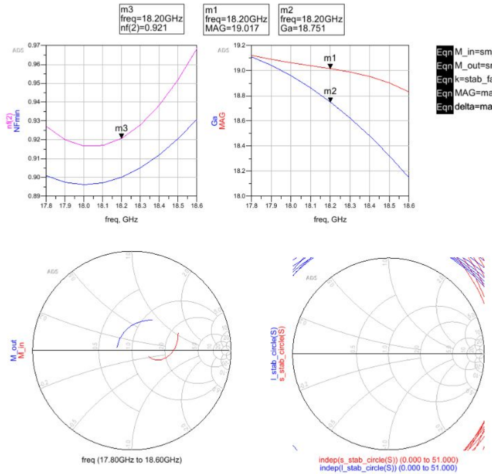
Optimization

Full Schematic for Optimization

After Optimizing for S11, S22, S21:

- Tuning the lengths of series lines, and width/length for quarter wave transformer

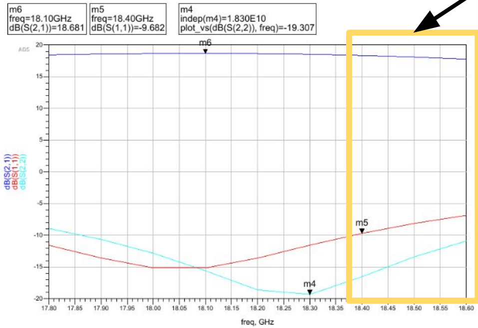




Eqn M_in=sm_gamma1(S)
Eqn M_out=sm_gamma2(S)
Eqn k=stab_fact(S)
Eqn MAG=max_gain(S)
Eqn delta=mag(S11*S22-S12*S21)

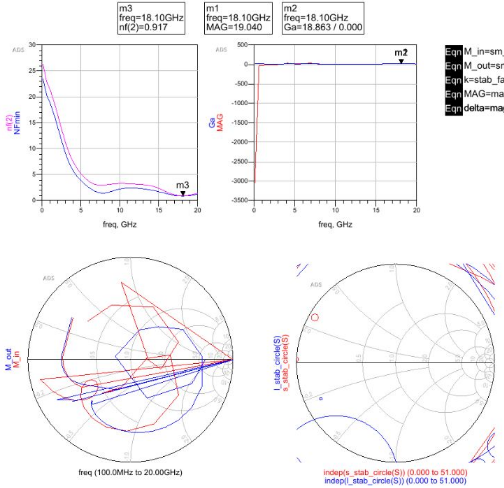
Eqn Ga=10*log((mag(S21)**2)*(1-mag(Sopt)**2)/((mag(1-S11*Sopt)**2)*(1-mag(G_out)**2)))
Eqn NF_min=NFmin
Eqn S_opt=Sopt
Eqn G_out=(S22+S12*S21*Sopt/(1-S11*Sopt))
Eqn G_L=conj(G_out)

S(2,1), S(1,1) go out of spec near 18.6GHz



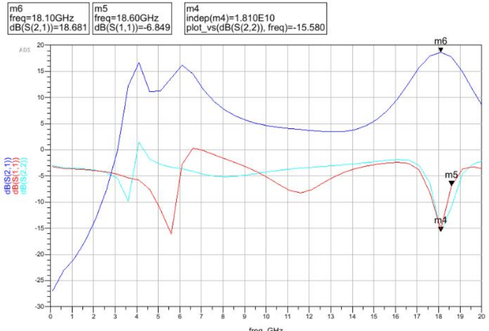
freq	k	delta	S_opt	G_L
17.80 GHz	1.077	0.668	0.131 / -0.840	0.338 / 60.858
17.90 GHz	1.076	0.656	0.122 / 11.593	0.272 / 68.474
18.00 GHz	1.074	0.647	0.116 / 25.146	0.203 / 77.129
18.10 GHz	1.071	0.643	0.115 / 39.312	0.131 / 88.331
18.20 GHz	1.069	0.643	0.117 / 53.349	0.059 / 111.062
18.30 GHz	1.067	0.646	0.123 / 66.549	0.037 / -138.867
18.40 GHz	1.066	0.652	0.131 / 78.467	0.106 / -98.497
18.50 GHz	1.066	0.660	0.143 / 88.974	0.180 / -84.994
18.60 GHz	1.069	0.669	0.156 / 98.153	0.252 / -75.397

→ We decided to adjust first stage for more gain (shown in following slides)



Eqn M_in=sm_gamma1(S)
Eqn M_out=sm_gamma2(S)
Eqn k=stab_fact(S)
Eqn MAG=max_gain(S)
Eqn delta=mag(S11*S22-S12*S21)

Eqn Ga=10*log((mag(S21)**2)*(1-mag(Sopt)**2)/((mag(1-S11*Sopt)**2)*(1-mag(G_out)**2)))
Eqn NF_min=NFmin
Eqn S_opt=Sopt
Eqn G_out=(S22+S12*S21*Sopt/(1-S11*Sopt))
Eqn G_L=conj(G_out)



freq	k	delta	S_opt	G_L
100.0 MHz	3.858E8	0.489	0.695 / 144.110	0.706 / 144.266
600.0 MHz	5.155E6	0.450	0.669 / 177.872	0.678 / 178.274
1.100 GHz	9.311E5	0.441	0.664 / -175.811	0.670 / -175.013
1.600 GHz	2.129E5	0.426	0.657 / -171.423	0.658 / -169.998
2.100 GHz	4.829E4	0.405	0.647 / -167.906	0.638 / -165.293
2.600 GHz	9.734E3	0.372	0.635 / -165.362	0.605 / -160.293
3.100 GHz	1.477E3	0.315	0.619 / -164.111	0.537 / -153.455
3.600 GHz	83.296	0.174	0.601 / -164.180	0.328 / -116.178
4.100 GHz	-11.311	0.598	0.582 / -165.212	1.193 / -154.278
4.600 GHz	27.869	0.338	0.563 / -167.001	0.816 / -151.178
5.100 GHz	33.574	0.191	0.547 / -169.755	0.728 / -147.306
5.600 GHz	18.529	0.100	0.542 / -173.613	0.678 / -144.184
6.100 GHz	4.123	0.465	0.558 / -177.880	0.647 / -141.857
6.600 GHz	-1.760	0.627	0.596 / 179.039	0.637 / -139.196
7.100 GHz	0.253	0.565	0.643 / 178.427	0.604 / -133.929
7.600 GHz	6.822	0.500	0.677 / -179.693	0.558 / -133.283
8.100 GHz	14.830	0.455	0.682 / -176.162	0.544 / -134.044
8.600 GHz	22.257	0.425	0.664 / -171.934	0.551 / -134.112
9.100 GHz	28.101	0.400	0.633 / -167.741	0.570 / -132.885
9.600 GHz	32.011	0.373	0.598 / -164.092	0.594 / -130.248
10.10 GHz	33.987	0.338	0.563 / -161.355	0.619 / -126.397
10.60 GHz	34.194	0.299	0.531 / -159.773	0.641 / -121.619
11.10 GHz	32.889	0.264	0.508 / -159.319	0.659 / -116.159
11.60 GHz	30.386	0.253	0.498 / -159.484	0.674 / -110.176
12.10 GHz	27.030	0.277	0.501 / -159.278	0.687 / -103.749
12.60 GHz	23.150	0.327	0.513 / -157.697	0.697 / -96.893
13.10 GHz	19.033	0.386	0.527 / -154.250	0.707 / -89.570
13.60 GHz	14.917	0.442	0.534 / -148.978	0.718 / -81.681
14.10 GHz	11.020	0.491	0.532 / -142.135	0.730 / -73.069
14.60 GHz	7.571	0.536	0.516 / -133.897	0.744 / -63.499
15.10 GHz	4.793	0.580	0.487 / -124.218	0.759 / -52.635
15.60 GHz	2.843	0.625	0.443 / -112.765	0.773 / -39.978
16.10 GHz	1.718	0.675	0.386 / -98.840	0.778 / -24.766
16.60 GHz	1.229	0.725	0.316 / -81.212	0.754 / -5.883
17.10 GHz	1.096	0.746	0.235 / -57.566	0.662 / 17.887
17.60 GHz	1.080	0.697	0.156 / -21.804	0.456 / 47.181
18.10 GHz	1.071	0.643	0.115 / 39.312	0.131 / 88.331
18.60 GHz	1.069	0.669	0.156 / 98.153	0.252 / -75.397
19.10 GHz	1.136	0.682	0.229 / 130.236	0.538 / -39.694
19.60 GHz	1.411	0.638	0.295 / 150.423	0.690 / -13.288
20.00 GHz	1.948	0.585	0.336 / 162.932	0.748 / 3.355

Reworking First Stage Matching

Improve Input Reflection/Gain

Compromise between Gain and Noise

If Use_Specific_Values="Yes" then the requested circle values will be displayed, if possible.

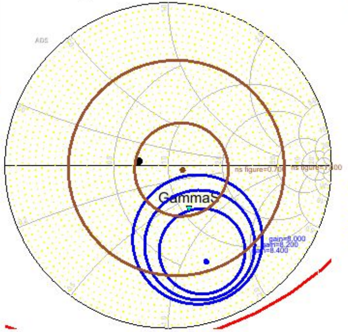
Eqn Use_Specific_Values="Yes"
Eqn Requested_Noise_circle_values=[0.7,1.4]
Eqn Requested_GA_circle_values=[8::0.2::8.6]
Eqn Requested_GP_circle_values=[7::16]

Acceptable syntax examples:
[5,6,7] or [5::7] set contours to 5 to 6 in steps of 1;
[4::0.5::6] sets contours to 4 to 6 in steps of 0.5.

If Use_Specific_Values="No", then the step sizes and number of circles below will be used.

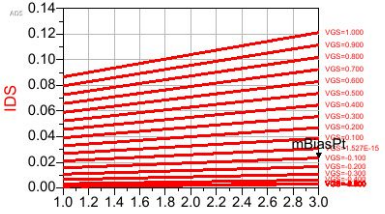
Eqn num_NFcircles=4
Eqn NFstep_size=.2
Eqn num_GAcircles=3
Eqn GAstep_size=0.2
Eqn num_GPcircles=3
Eqn GPstep_size=1

Available Gain & Noise Circles, Source Stability Circle Source Gamma. Corresponding Load Gamma, (Black Dot)



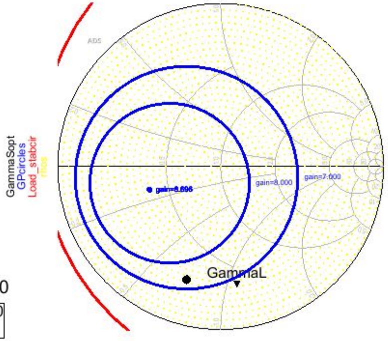
Move markers GammaS and GammaL to select arbitrary source and load reflection coefficients. The impedances, power gains, and noise figures below will be updated. The transducer power gains are invalid if the markers are moved into the unstable regions (usually inside the stability circles.)

Move marker mBiasPt to desired bias point. Smith Chart and data below will be updated.



mBiasPt
VDS=3.000
IDS=23.34m
VGS=-100.0m

Power Gain Circles, Load Stability Circle Load Gamma, GammaL Corresponding Source Gamma, (Black Dot)



Stability Factor, K	Source Stable Region	RF Frequency	System Impedance, Z0	Load Stable Region
1.023	Inside	18.20 GHz	50.000	Inside

Zsource, Source Gamma   Zload, Load Gamma

*DUT= Device Under Test (simulated circuit or device)

Noise Figure (dB) with Source Impedance at marker GammaS	Source Impedance at marker GammaS	Optimal load impedance for power transfer when source impedance at marker GammaS is presented to input	Transducer Power Gain, dB when these source and load impedances are used
0.681	53.778 - j33.584	34.402 + j1.796	8.407

NFmin,dB	Source Impedance, Zopt, for Minimum NF	Optimal load impedance for power transfer when source impedance is Zopt	Transducer Power Gain, dB when these source and load impedances are used
0.600	59.662 - j3.391	42.886 + j14.023	7.909

Noise Figure (dB) with Zsource (only valid with K>1)	Simultaneous Conjugate Matching (only valid if stability factor K >1) Zsource	Zload	Maximum Available Gain, dB (Maximum Stable Gain, S21/S12) if K<1
1.189	31.809 - j63.077	18.922 - j6.830	8.696

Noise Figure (dB) with this optimal source impedance (at right)	Optimal source impedance for power transfer when load impedance at marker GammaL is presented to output	Load Impedance at marker GammaL	Transducer Power Gain, dB when these source and load impedances are used
1.697	12.221 - j35.736	16.499 - j54.480	6.563

See "NF, SP, Gains at all Bias Pts." page.

See "Matching at 1 Bias Point" page for optimal source and load impedances to match for gain or noise figure. Equations for this page are on the "Equations2" page.

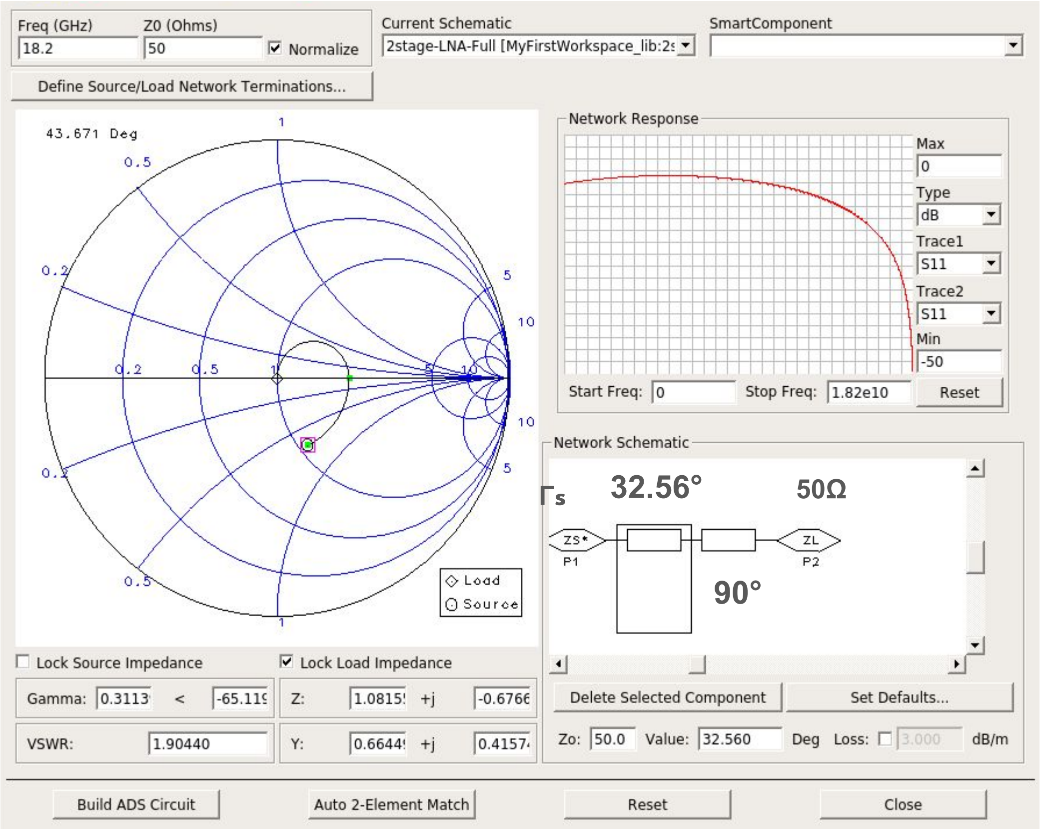
BiasPt
VDS = 3V
VGS = -0.1V

Optimum bias point for a larger Gain for better margin, without degrading overall NF much.

Step 1: At a design frequency of 18.2GHz
Zs = 53.778 - j33.584

Component ($Z0 = 50\Omega$)	Length (mils)	Width (mils)
Series Line	42.945669	29.369528
Quarter-Wave Transformer ($Z0=69\Omega$)	121.004724	16.913425

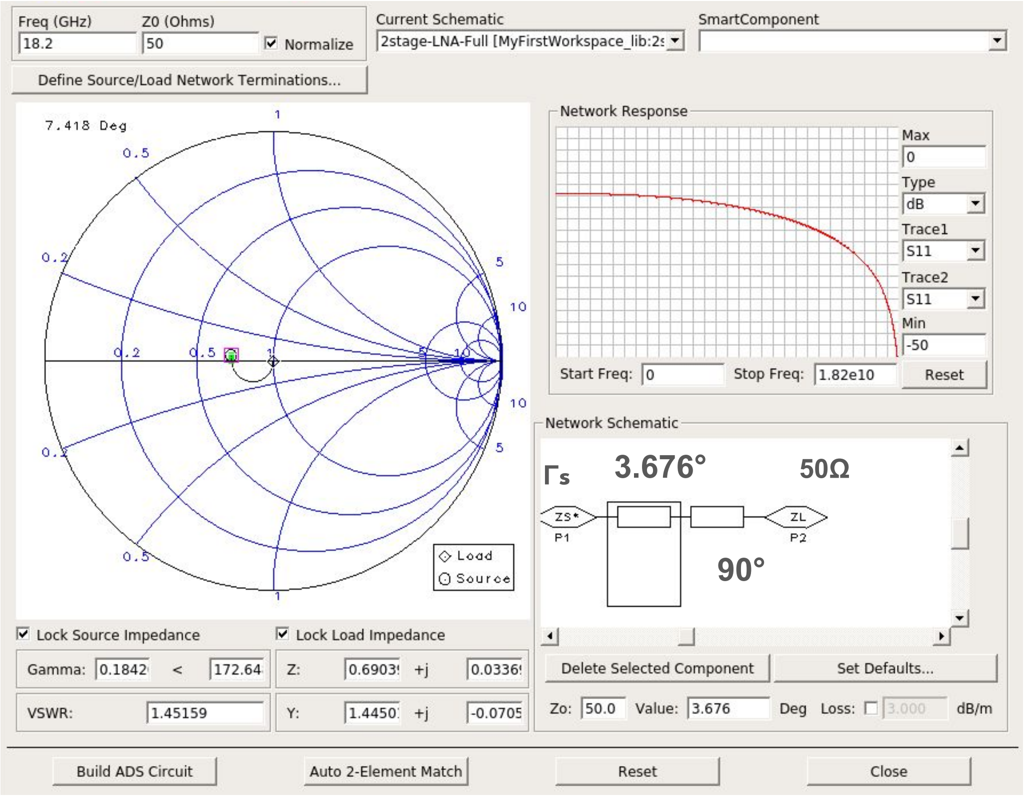
Microstrip Line dimensions calculated using LineCalc ADS Utility for a Duroid 5880 10mil board



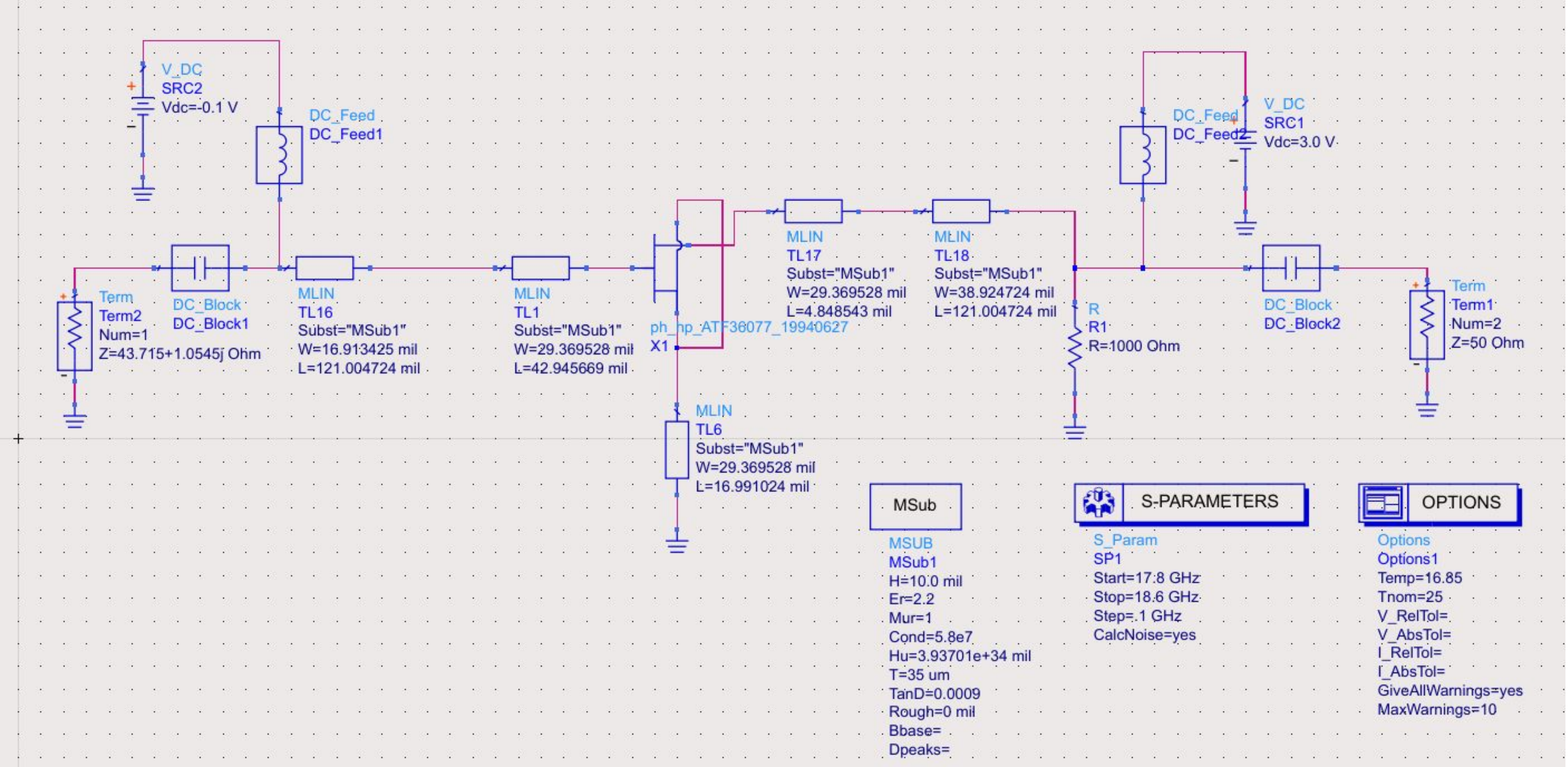
Step 2: At a design frequency of 18.2GHz Z_load = 34.402 + j1.796 for Conjugate Match

Component (Z0 = 50Ω)	Length (mils)	Width (mils)
Series Line	4.848543	29.369528
Quarter-Wave Transformer (Z0=41.5Ω)	121.004724	38.924724

Microstrip Line dimensions calculated using LineCalc ADS Utility for a Duroid 5880 10mil board

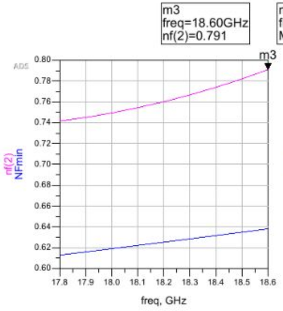


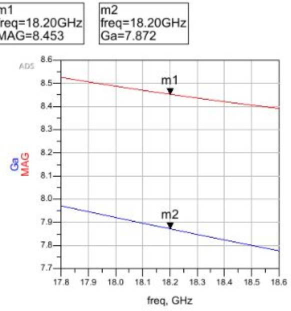
New First Stage



New First Stage Statistics

- First Stage → good SParams, noise figure
- Matched to 50 ohms





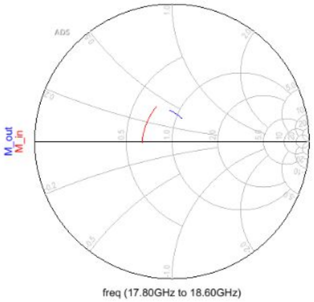
Eqn M_in=sm_gamma1(S)
Eqn M_out=sm_gamma2(S)
Eqn k=stab_fact(S)
Eqn MAG=max_gain(S)
Eqn delta=mag(S11*S22-S12*S21)

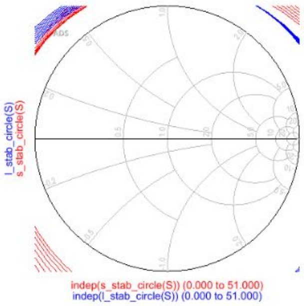
Eqn Ga=10*log((mag(S21)**2)*(1-mag(Sopt)**2)/((mag(1-S11*Sopt)**2)*(1-mag(G_out)**2)))

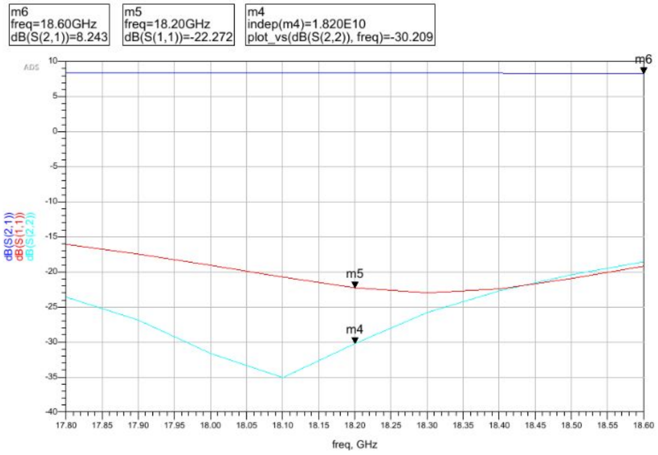
Eqn NF_min=NFmin
Eqn S_opt=Sopt

Eqn G_out=(S22+S12*S21*Sopt/(1-S11*Sopt))
Eqn G_L=conj(G_out)

freq	k	delta	S_opt	G_L
17.80 GHz	1.038	0.738	0.324 / -2.837	0.216 / -140.151
17.90 GHz	1.038	0.739	0.324 / -3.879	0.217 / -139.347
18.00 GHz	1.037	0.741	0.325 / -4.926	0.219 / -138.519
18.10 GHz	1.037	0.743	0.326 / -5.962	0.220 / -137.667
18.20 GHz	1.036	0.745	0.329 / -6.970	0.221 / -136.790
18.30 GHz	1.036	0.746	0.332 / -7.937	0.223 / -135.890
18.40 GHz	1.035	0.748	0.335 / -8.847	0.224 / -134.967
18.50 GHz	1.035	0.750	0.340 / -9.688	0.225 / -134.020
18.60 GHz	1.034	0.753	0.345 / -10.451	0.227 / -133.051







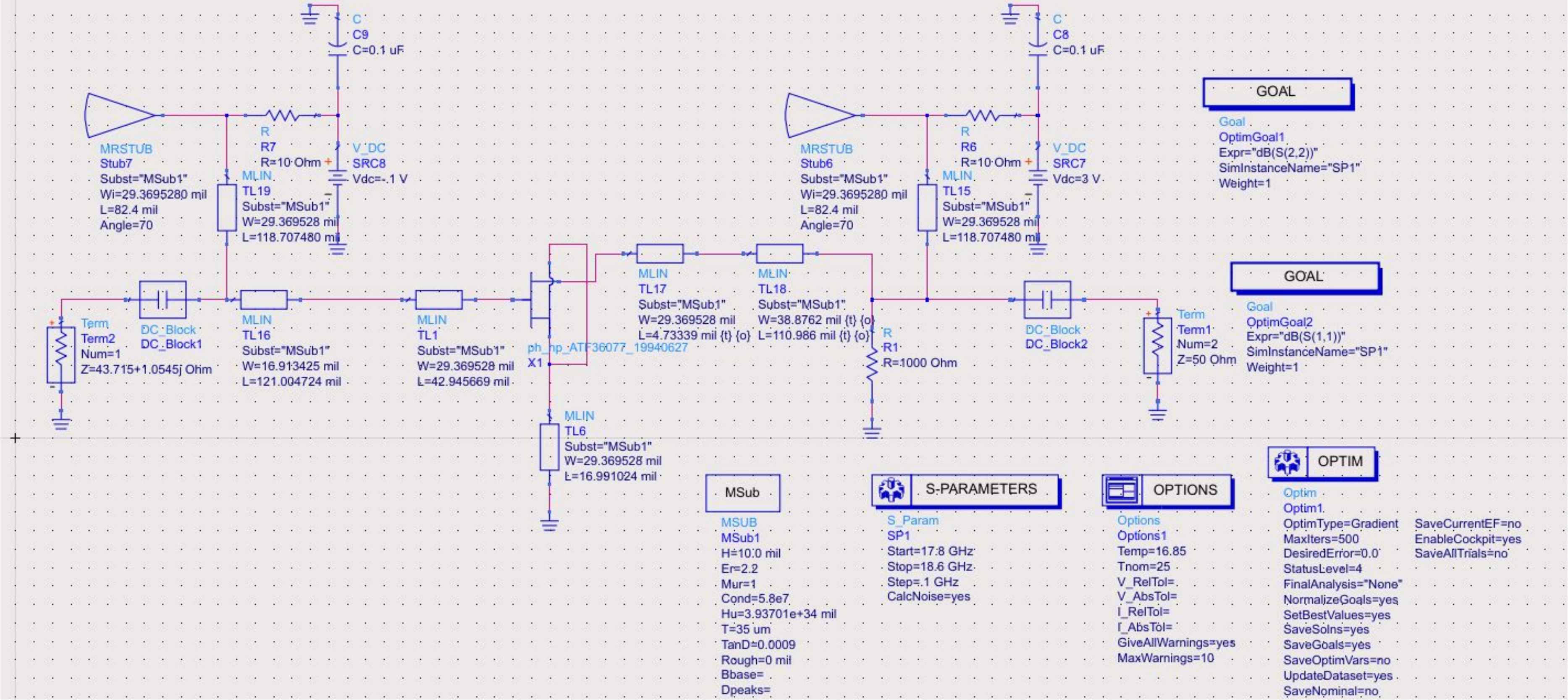
New First Stage Statistics

17.8-18.6 GHz	Old Min (dB)	New Min (dB)
Ga	7.691	8.257
NF	0.638	0.792
Noise Measure	0.19	0.235

- Extra gain should compensate for lost S(2,1), and improve input/output reflection. Need a gain of 9.75dB for second stage to meet requirement.
- Second Stage can be 2.42 (3.837dB) or better to remain under 1.5dB overall noise figure

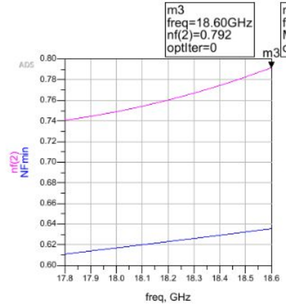
Optimized First Stage

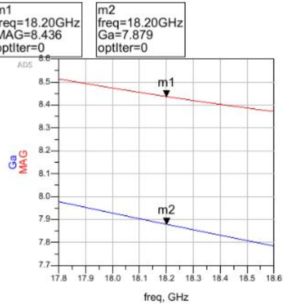
- Optimized for output match at 18.2GHz



Optimized First Stage Statistics

- First stage gain 8.257dB, greater than first iteration 7.691dB.
- Noise increased slightly to 0.792, from 0.638





Eqn M_in=sm_gamma1(S)

Eqn M_out=sm_gamma2(S)

Eqn k=stab_fact(S)

Eqn MAG=max_gain(S)

Eqn delta=mag(S11*S22-S12*S21)

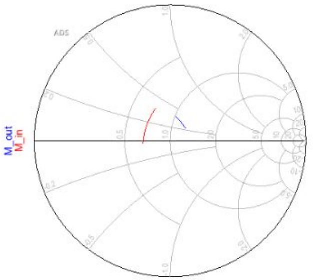
Eqn Ga=10*log((mag(S21)**2)*(1-mag(Sopt)**2)/((mag(1-S11*Sopt)**2)*(1-mag(G_out)**2)))

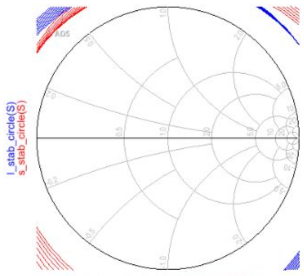
Eqn NF_min=NFmin

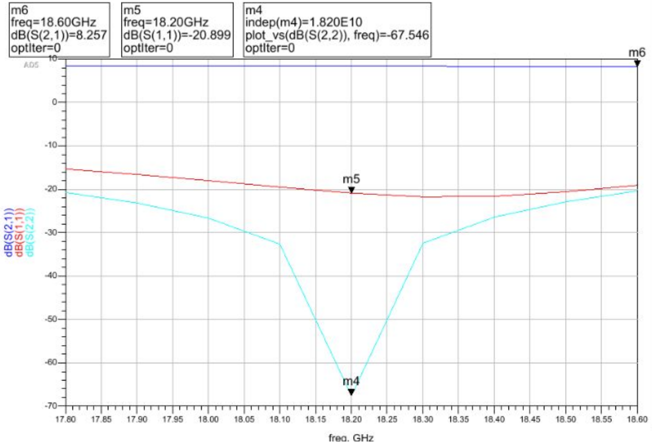
Eqn S_opt=Sopt

Eqn G_out=(S22+S12*S21*Sopt/(1-S11*Sopt))

Eqn G_L=conj(G_out)



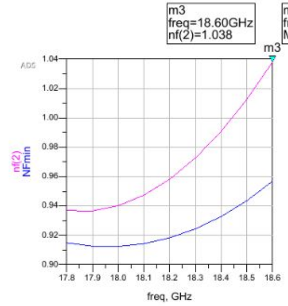


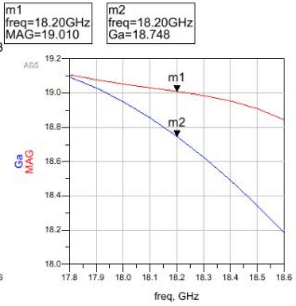


freq	k optIter=0	delta optIter=0	S(2,2) optIter=0
17.80 GHz	1.039	0.742	0.092 / 69.905
17.90 GHz	1.039	0.743	0.069 / 67.063
18.00 GHz	1.038	0.744	0.046 / 64.267
18.10 GHz	1.038	0.746	0.023 / 61.748
18.20 GHz	1.037	0.747	4.195E-4 / 176.009
18.30 GHz	1.037	0.749	0.024 / -126.060
18.40 GHz	1.036	0.751	0.048 / -128.651
18.50 GHz	1.036	0.752	0.072 / -131.551
18.60 GHz	1.035	0.754	0.096 / -134.534

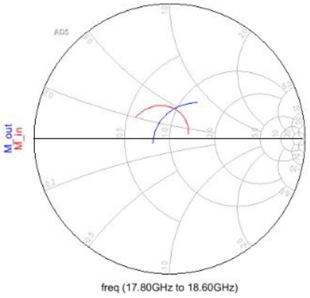
Statistics for LNA with Optimized New First Stage

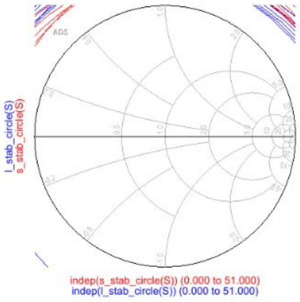
- Optimized new first stage provides good noise and gain.
- Need to rework the matching networks for 2nd stage to improve S11 and S22

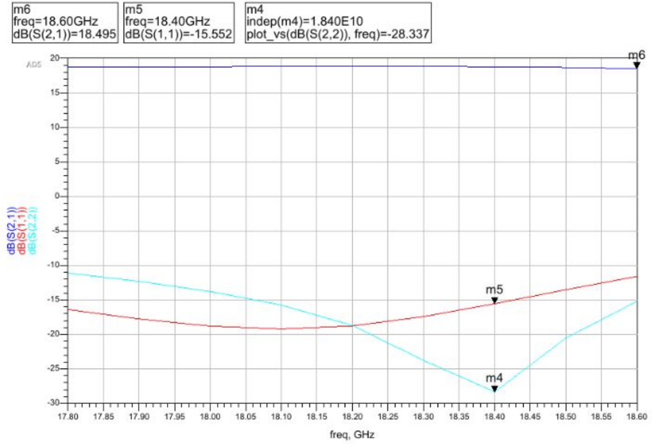





```
Eqn M_in=sm_gamma1(S)
Eqn M_out=sm_gamma2(S)
Eqn k=stab_fact(S)
Eqn MAG=max_gain(S)
Eqn delta=mag(S11*S22-S12*S21)
Eqn Ga=10*log((mag(S21)**2)*(1-mag(Sopt)**2)/((mag(1-S11*Sopt)**2)*(1-mag(G_out)**2)))
Eqn NF_min=NFmin
Eqn S_opt=Sopt
Eqn G_out=(S22+S12*S21*Sopt/(1-S11*Sopt))
Eqn G_L=conj(G_out)
```







freq	k	delta	S_opt	G_L
17.80 GHz	1.079	0.654	0.119 / -15.042	0.297 / 55.267
17.90 GHz	1.077	0.654	0.125 / -21.128	0.230 / 61.414
18.00 GHz	1.075	0.657	0.134 / -26.088	0.159 / 67.319
18.10 GHz	1.072	0.660	0.146 / -29.683	0.083 / 71.568
18.20 GHz	1.070	0.665	0.161 / -31.949	0.010 / 25.001
18.30 GHz	1.067	0.670	0.176 / -33.055	0.074 / -81.717
18.40 GHz	1.066	0.675	0.192 / -33.206	0.151 / -78.039
18.50 GHz	1.066	0.679	0.208 / -32.588	0.225 / -72.200
18.60 GHz	1.068	0.683	0.224 / -31.357	0.296 / -66.005

Reworking Second Stage Matching

Optimize Gain

If Use_Specific_Values="Yes" then the requested circle values will be displayed, if possible.

Eqn Use_Specific_Values="Yes"
Eqn Requested_Noise_circle_values=[0.7,1.5]
Eqn Requested_GA_circle_values=[]
Eqn Requested_GP_circle_values=[7::16]

Acceptable syntax examples:
[5,6,7] or [5::7] set contours to 5 to 6 in steps of 1;
[4::0.5::6] sets contours to 4 to 6 in steps of 0.5.

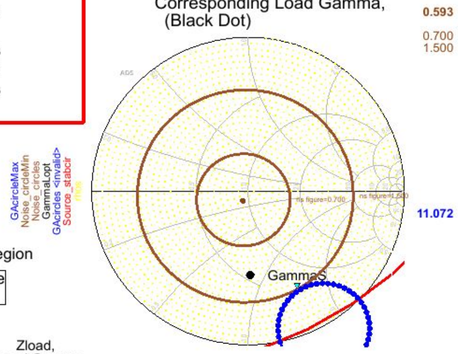
Move markers GammaS and GammaL to select arbitrary source and load reflection coefficients. The impedances, power gains, and noise figures below will be updated. The transducer power gains are invalid if the markers are moved into the unstable regions (usually inside the stability circles.)

Aim for >11dB in second stage to have margin over frequency range

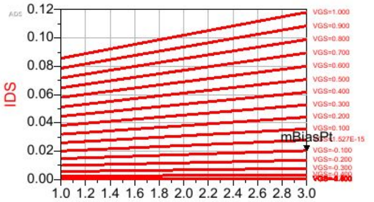
If Use_Specific_Values="No", then the step sizes and number of circles below will be used.

Eqn num_NFcircles=4
Eqn NFstep_size=.2
Eqn num_GAcircles=3
Eqn GAstep_size=0.2
Eqn num_GPcircles=3
Eqn GPstep_size=1

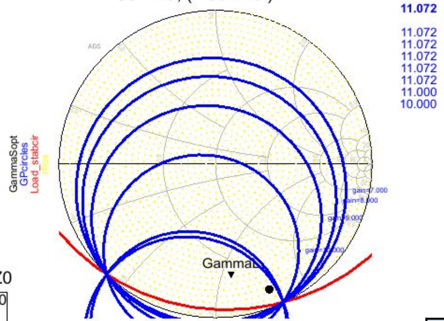
Available Gain & Noise Circles,
Source Stability Circle
Source Gamma.
Corresponding Load Gamma,
(Black Dot)



Move marker mBiasPt to desired bias point. Smith Chart and data below will be updated.



Power Gain Circles,
Load Stability Circle
Load Gamma, GammaL
Corresponding Source
Gamma, (Black Dot)



Stability Factor, K

0.983

Source Stable Region

Inside

mBiasPt
VDS=3.000
IDS=20.34m
VGS=-100.0m

RF Frequency

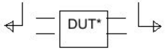
18.20 GHz

System Impedance, Z0

50.000

Zsource, Source Gamma

Zload, Load Gamma



*DUT= Device Under Test (simulated circuit or device)

Noise Figure (dB) with Source Impedance at marker GammaS	Source Impedance at marker GammaS	Optimal load impedance for power transfer when source impedance at marker GammaS is presented to input	Transducer Power Gain, dB when these source and load impedances are used
1.471	28.781 - j72.684	27.675 - j43.006	11.015

NFmin,dB	Source Impedance, Zopt, for Minimum NF	Optimal load impedance for power transfer when source impedance is Zopt	Transducer Power Gain, dB when these source and load impedances are used
0.593	46.484 - j5.877	79.354 + j5.290	9.179

Noise Figure (dB) with Zsource (only valid with K>1)	Simultaneous Conjugate Matching (only valid if stability factor K >1) Zsource	Zload	Maximum Available Gain, dB (Maximum Stable Gain, S21/S12) if K<1
1000	50.000	50.000	11.072

Noise Figure (dB) with this optimal source impedance (at right)	Optimal source impedance for power transfer when load impedance at marker GammaL is presented to output	Load Impedance at marker GammaL	Transducer Power Gain, dB when these source and load impedances are used
3.214	9.851 - j74.448	16.499 - j54.480	11.645

Load Stable Region

Inside

See "NF, SP, Gains at all Bias Pts." page.

See "Matching at 1 Bias Point" page for optimal source and load impedances to match for gain or noise figure. Equations for this page are on the "Equations2" page.

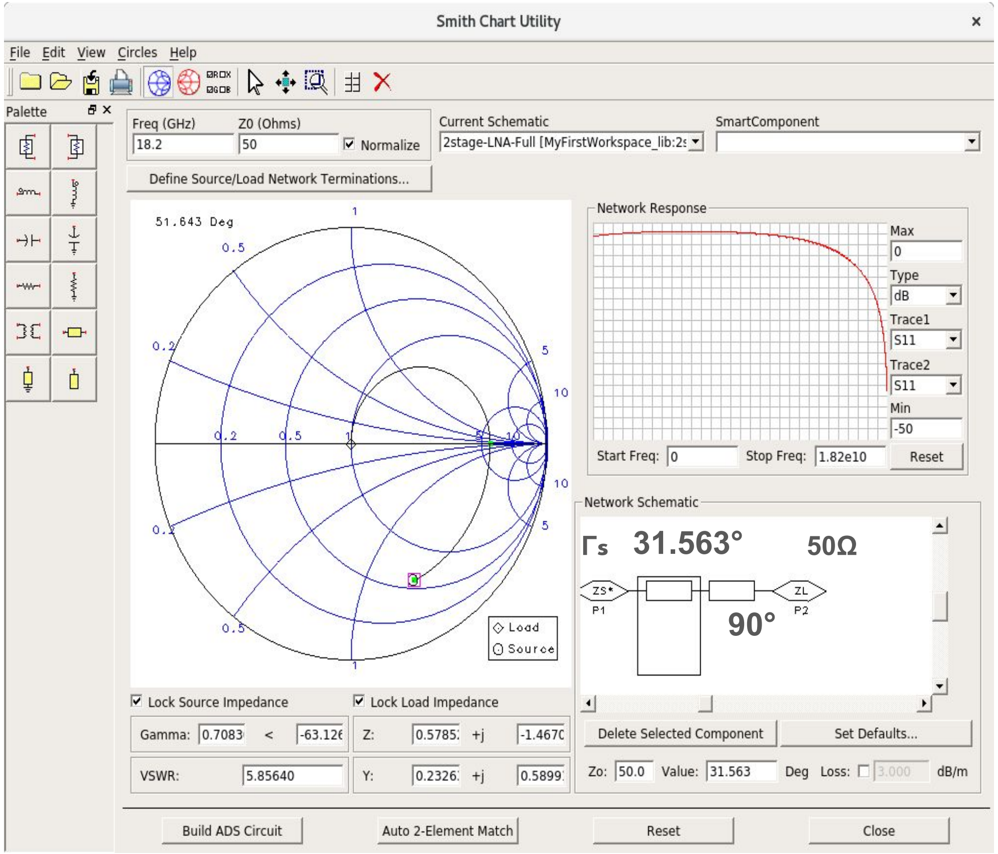
BiasPt
VDS = 3V
VGS = -0.1V

Optimum bias point chosen to minimize NFmin and maximize Gain.

Step 1: At a design frequency of 18.2GHz
Zs = 28.781 - j72.684

Microstrip Line dimensions calculated using LineCalc ADS Utility for a Duroid 5880 10mil board

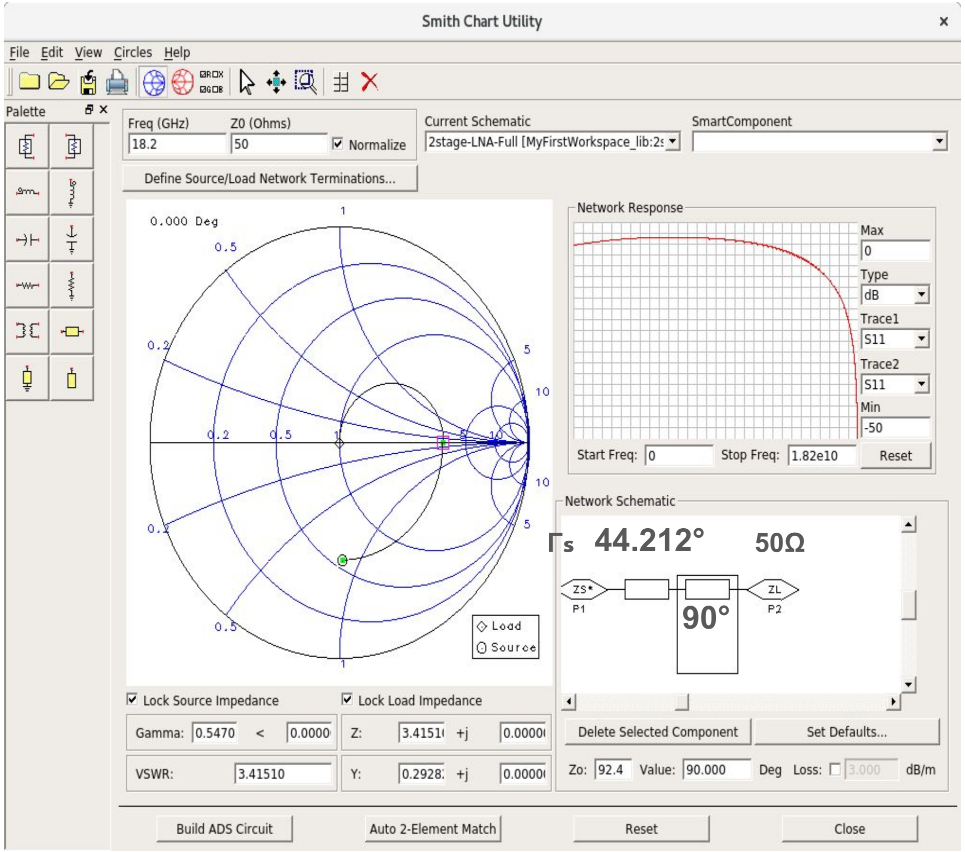
Component (Z0 = 50Ω)	Length (mils)	Width (mils)
Series Line	41.630709	29.369528
Quarter-Wave Transformer (Z0=121Ω)	125.818504	4.183465



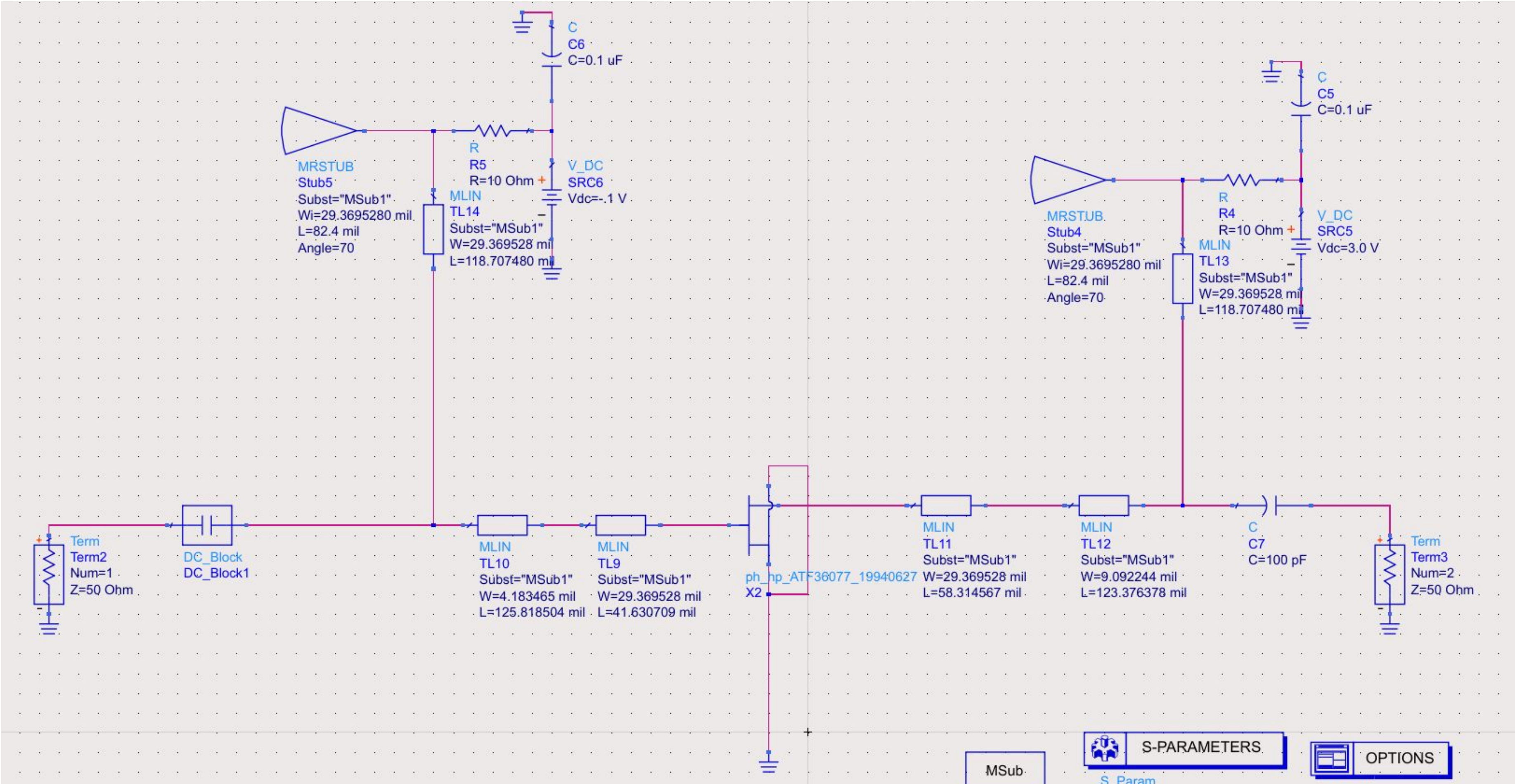
Step 2: At a design frequency of 18.2GHz
Z_load = 27.675-j43.006

Microstrip Line dimensions calculated using LineCalc ADS Utility for a Duroid 5880 10mil board

Component (Z0 = 50Ω)	Length (mils)	Width (mils)
Series Line	58.314567	29.369528
Quarter-Wave Transformer (Z0=92.4Ω)	123.376378	9.092244

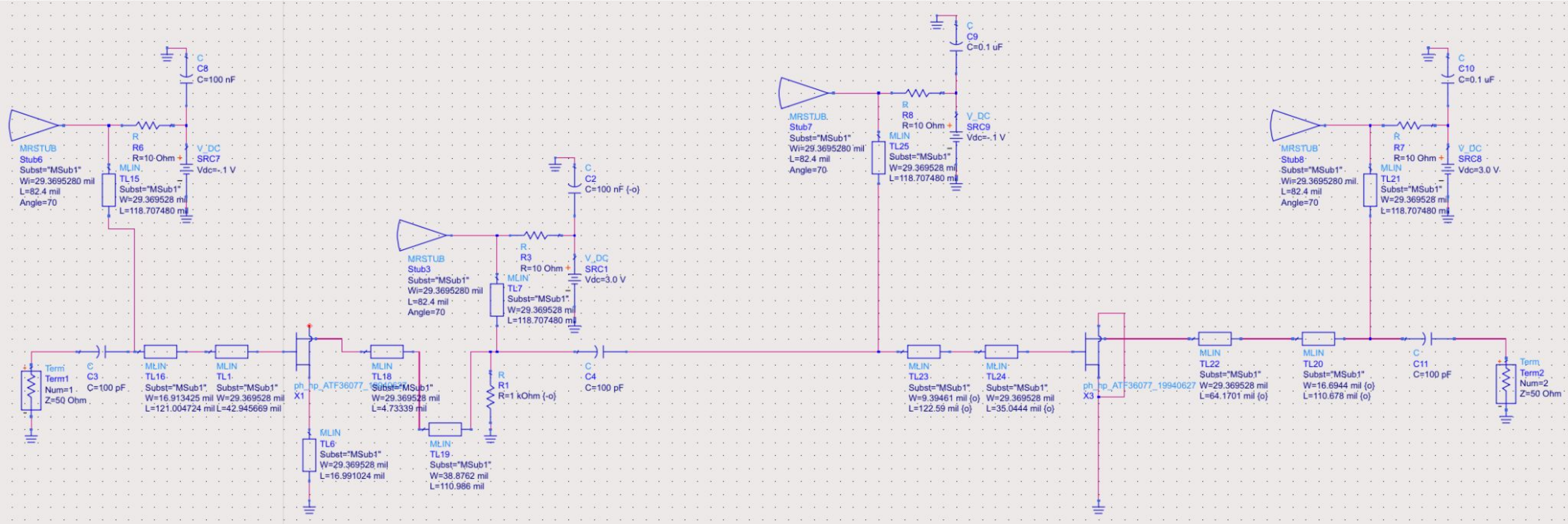


New Second Stage



Final LNA Schematic

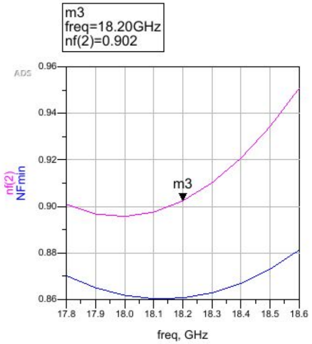
- after new second stage optimization

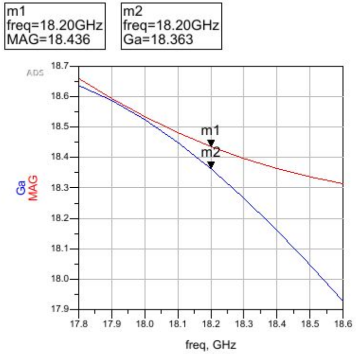


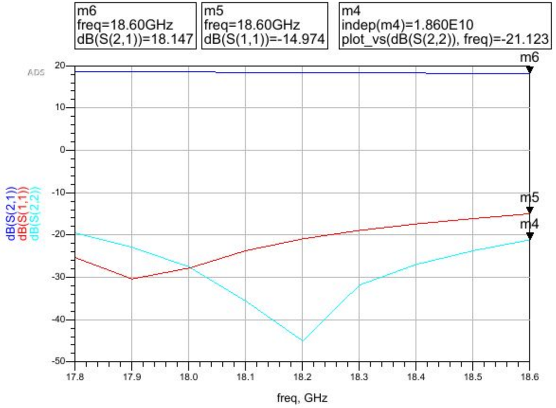
Requirements Met:

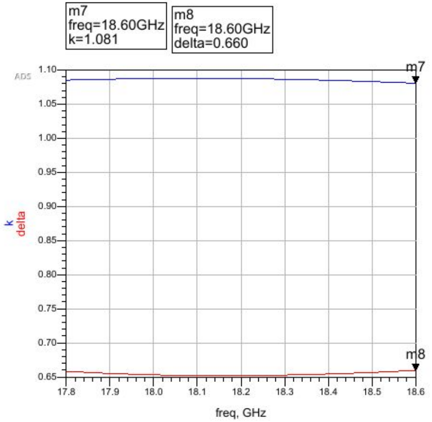
- Within specifications for frequency range 17.8-18.6GHz

Characteristic	Specification
Operating Frequency	17.8-18.6GHz
Worst Noise Figure	**0.951dB** < 1.5dB
Insertion Gain (S21)	**18.147dB** > 18dB
Output Reflection (S22)	**-19.7dB** < -14dB (**-45dB** @ 18.2GHz)
Input Reflection (S11)	**-14.974dB** < -10dB
Stability	Unconditionally stable 0.1-20GHz







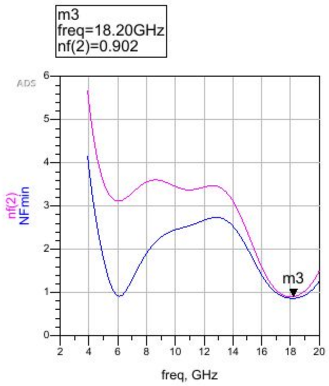


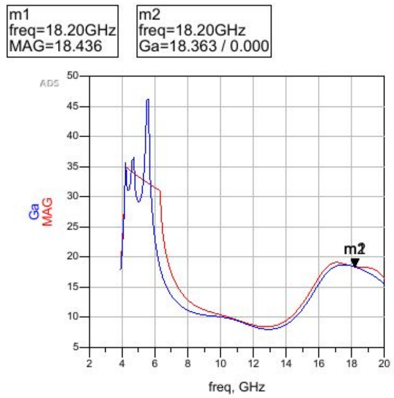
Stability Concerns

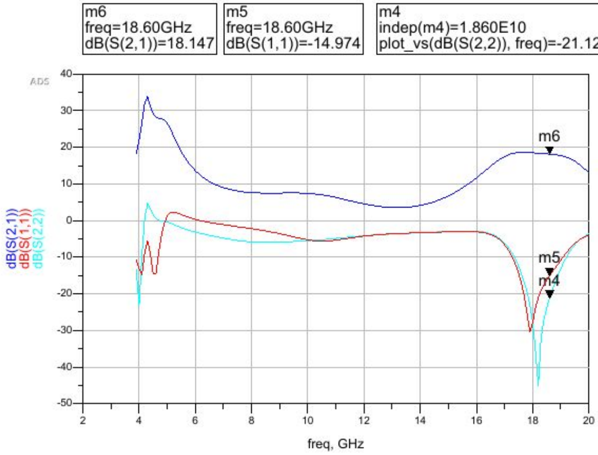
k < 1 for frequencies less than 3.9 GHz

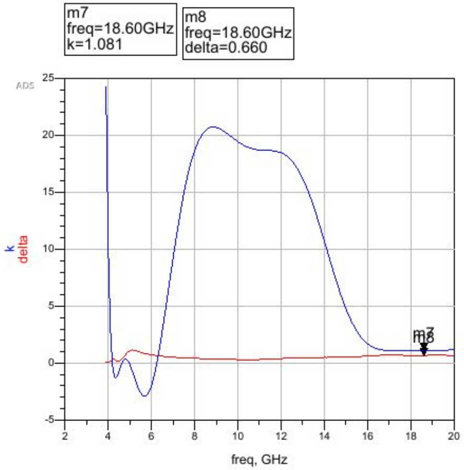
**Determined to be an artifact of this particular transistor model*

→ Passes unconditional stability requirement.









DC Power

Power from Source 1:

- P=V*I = (-0.1)(-12.5fA) = 0W

Power from Source 2:

- P=V*I = (3)(22mA) = 66mW

Power from Source 3:

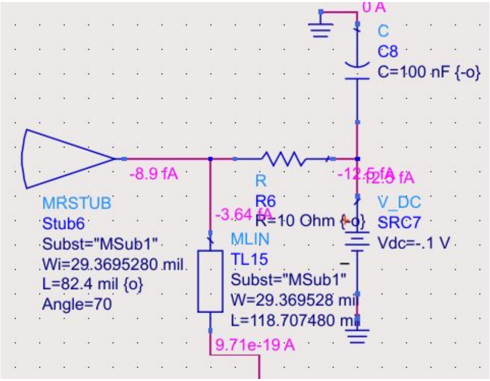
- P=V*I = (-0.1)(-18fA) = 0W

Power from Source 4:

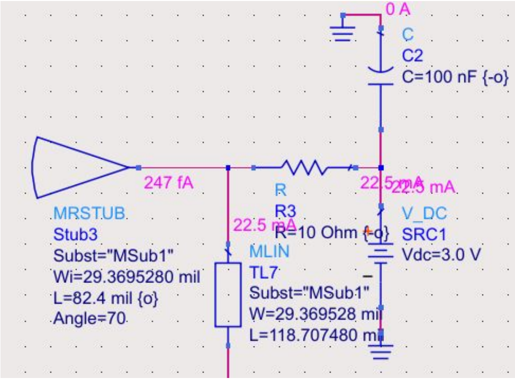
- P=V*I = (3)(19.8mA) = 57.4mW

Total Power from Sources: 123.4mW

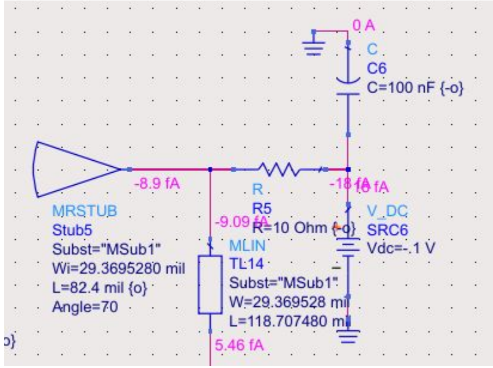
Source 1



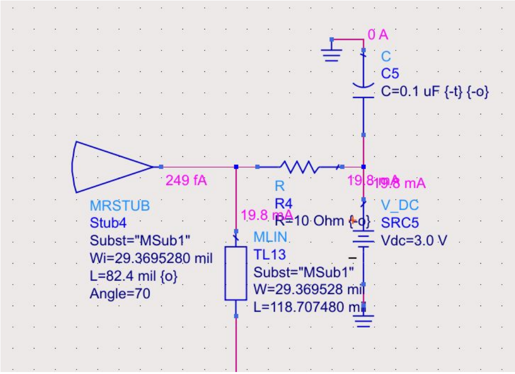
Source 2



Source 3



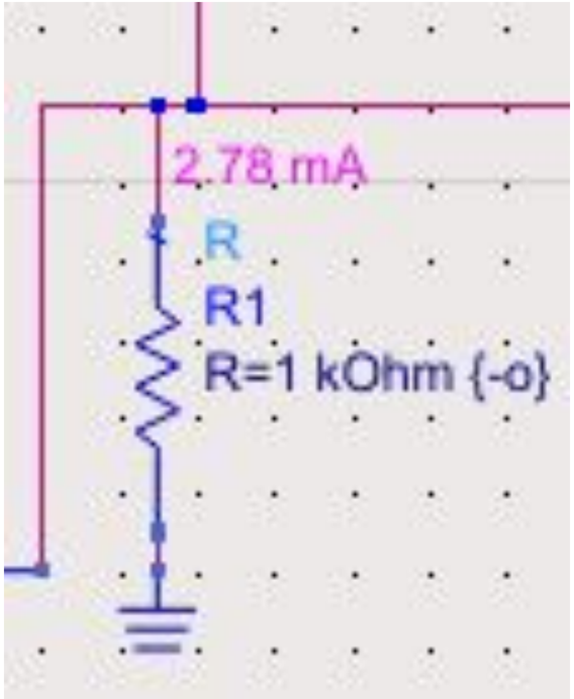
Source 4



DC Power

Power across resistive load

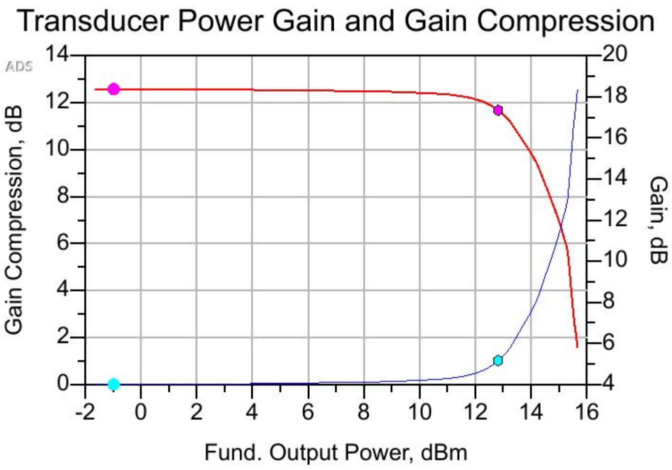
- P=I^2*R = (1k)(2.78mA)^2 = 7.7284mW



P1dB Compression

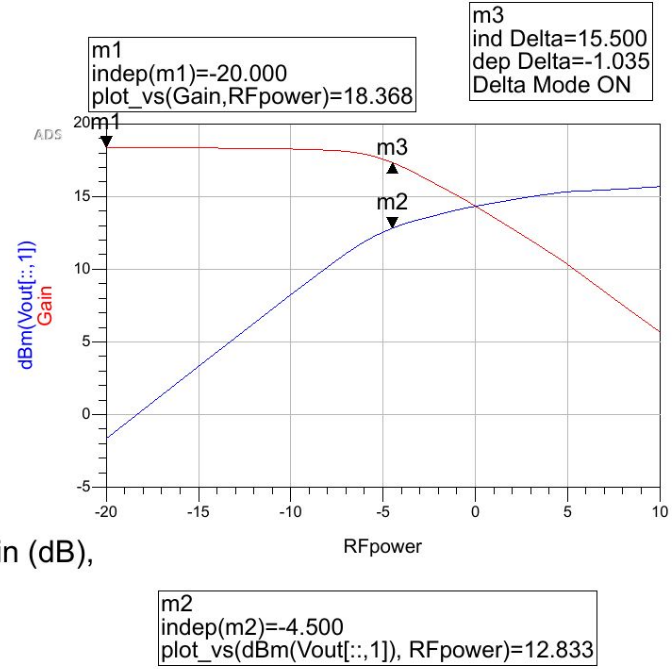
P1dB Input = -4.5dBm

P1dB Output = 12.818 dBm

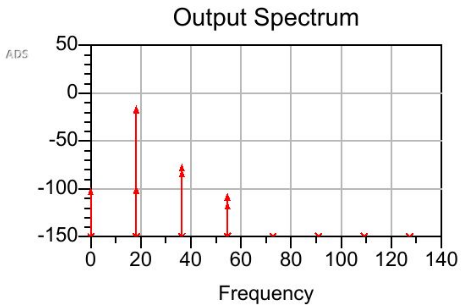


Interpolated output power (dBm), gain compression (dB), and gain (dB),

12.818	1.021	17.347



IIP3 / OIP3 - Two Tone Harmonic Balance

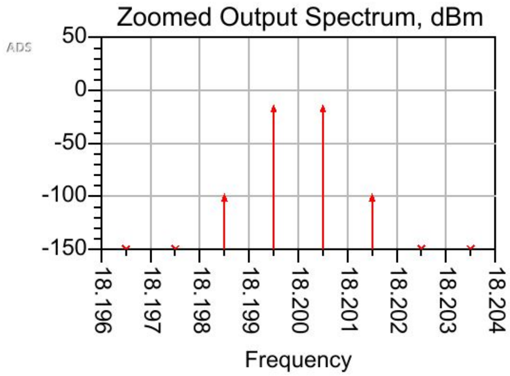


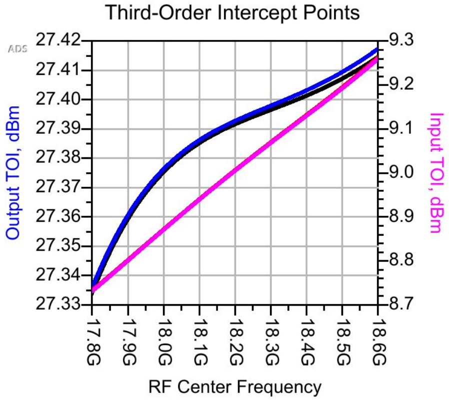
RF Center Frequencies	Fundamental Output Power, dBm	Transducer Power Gain
18.20 G	-11.61	18.39

Frequency Spacing	Available Source Power dBm
1.000 MHz	-30.00

IIP3 = 9.005dBm

OIP3 = 27.39dBm





Low and High Side Output TOI Points, dBm		Low and High Side Input TOI Points, dBm	
27.39	27.39	9.005	9.006

Thank you very much for a great semester!