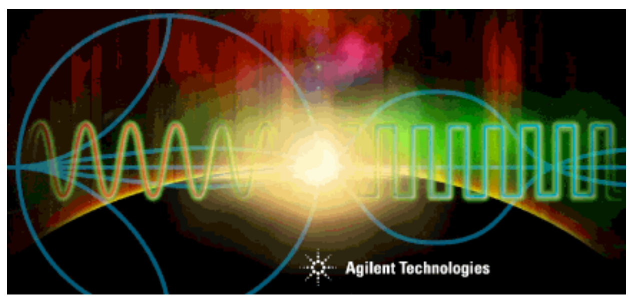
Topic 5:

S-parameter Simulation and Optimization



S-parameters are Ratios

Usually given in dB as 20 log of the voltage ratios of the waves at the ports: incident, reflected, or transmitted.

S-parameter (ratios): out / in

- S11 - Forward Reflection (input match - impedance)
- S22 - Reverse Reflection (output match - impedance)

Best viewed on a Smith chart.

- S21 - Forward Transmission (gain or loss)
- S12 - Reverse Transmission (leakage or isolation)

These are easier to understand and simply plotted.

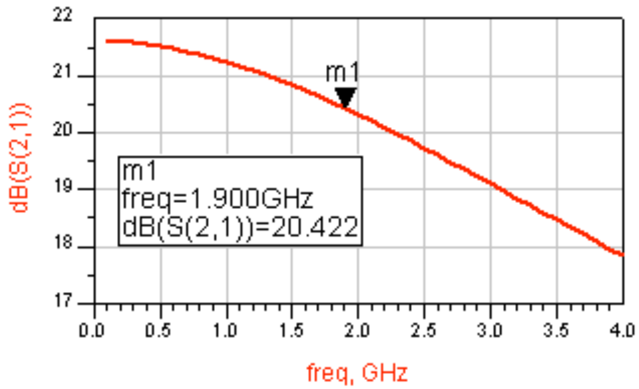
Results of an S-Parameter Simulation in ADS

- S-matrix with all complex values at each frequency point
- Read the complex reflection coefficient (Gamma)
- Change the marker readout for Zo
- Smith chart plots for impedance matching
- Results are similar to Network Analyzer measurements

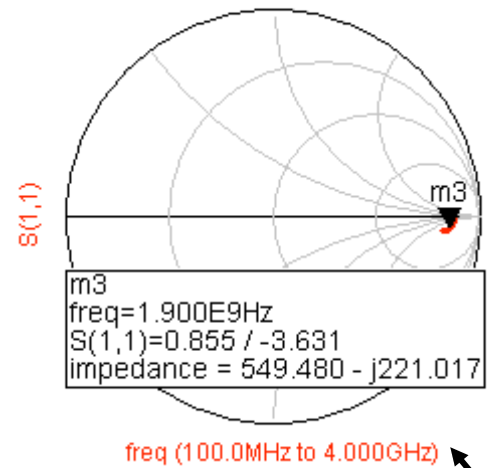
Next, ADS data

Typical S-parameter data in ADS

Transmission: S21 magnitude vs frequency



Reflection: S11 Impedance on a Smith Chart



Complete S-matrix with port impedance

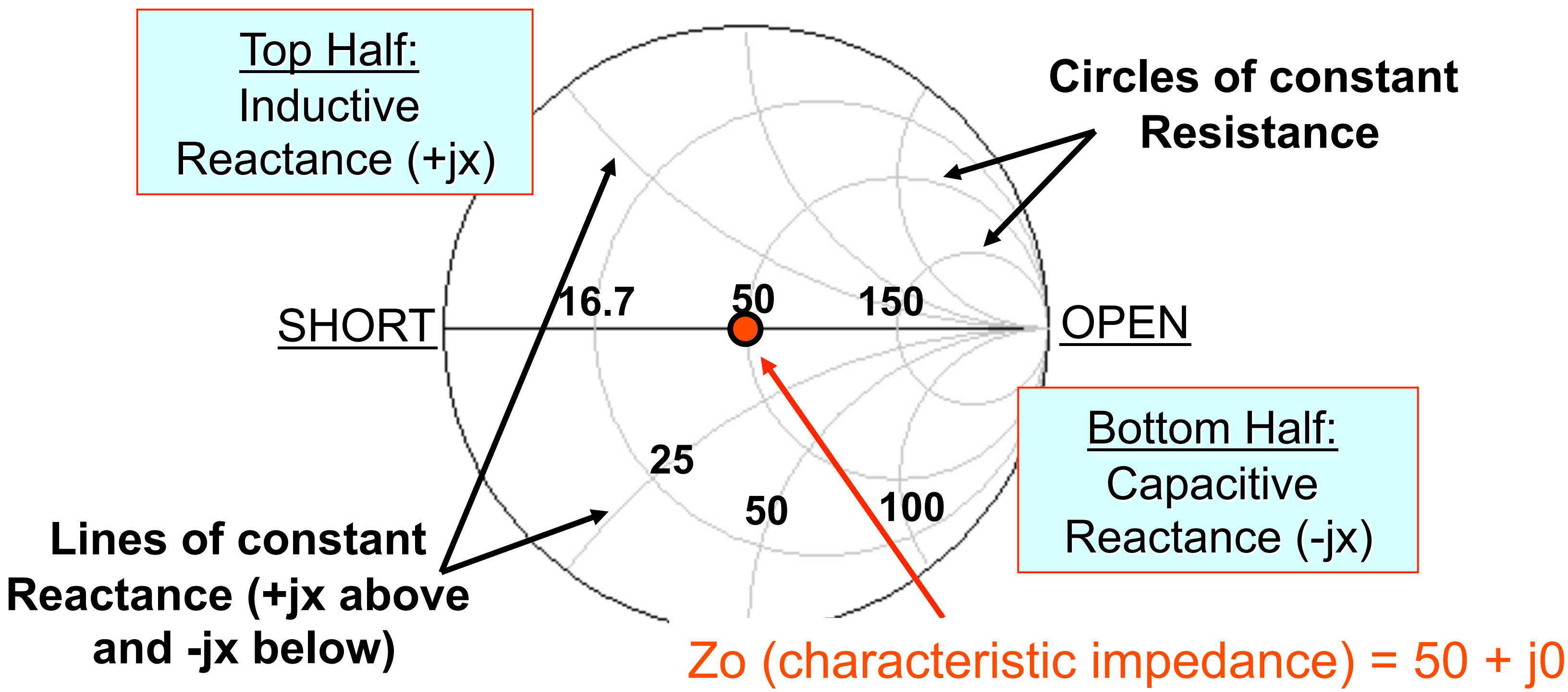
freq	S				freq	PortZ	
	S(1,1)	S(1,2)	S(2,1)	S(2,2)		PortZ(1)	PortZ(2)
100.0M...	0.879 / ...	2.392E-...	12.036 /...	0.994 / ...	100.0M...	50.000 /...	50.000 /...
200.0M...	0.879 / ...	7.978E-...	12.020 /...	0.993 / ...	200.0M...	50.000 /...	50.000 /...
300.0M...	0.878 / ...	1.729E-...	11.994 /...	0.992 / ...	300.0M...	50.000 /...	50.000 /...
400.0M...	0.877 / ...	2.556E-...	10.019 /...	0.994 / ...	400.0M...	50.000 /...	35.000 /...
500.0M...	0.877 / ...	4.007E-...	9.982 / ...	0.993 / ...	500.0M...	50.000 /...	35.000 /...
600.0M...	0.876 / ...	5.818E-...	9.939 / ...	0.991 / ...	600.0M...	50.000 /...	35.000 /...
700.0M...	0.875 / ...	8.013E-...	9.888 / ...	0.990 / ...	700.0M...	50.000 /...	35.000 /...

Note: Smith marker impedance readout is changed to Zo = 50 ohms.

Smith chart basics...

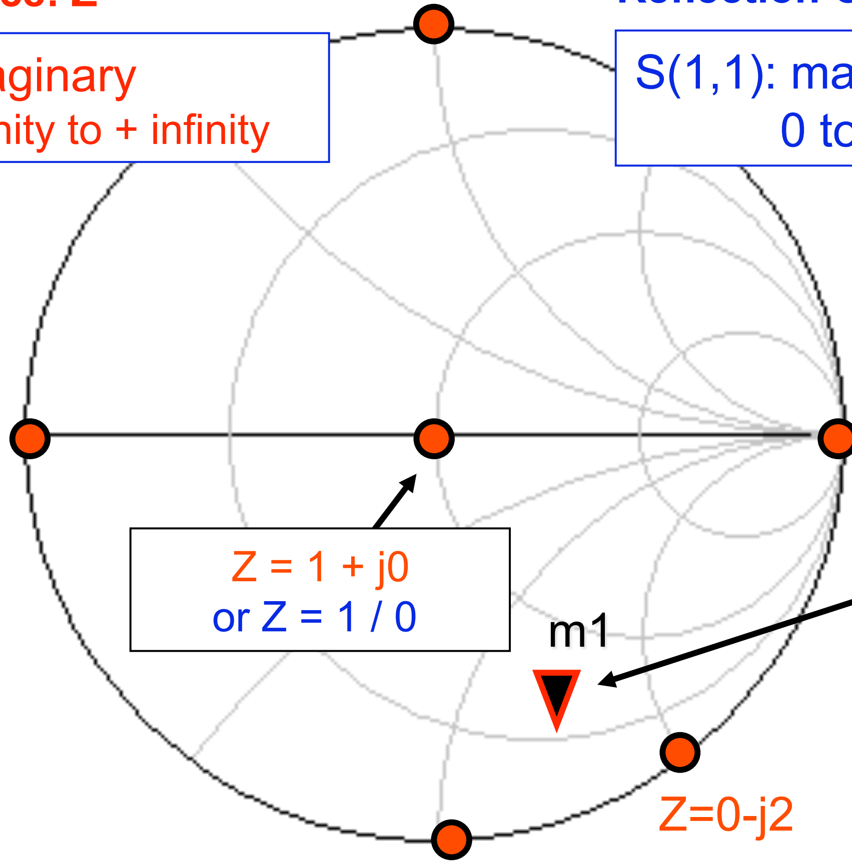
The Impedance Smith Chart simplified...

This is an impedance chart transformed from rectangular Z.
Normalized to 50 ohms, the center = R50+J0 or Zo (perfect match).
For S11 or S22 (two-port), you get the **complex impedance**.



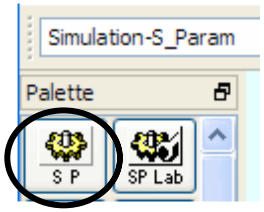
More Smith chart...

The Smith chart in ADS Data Display

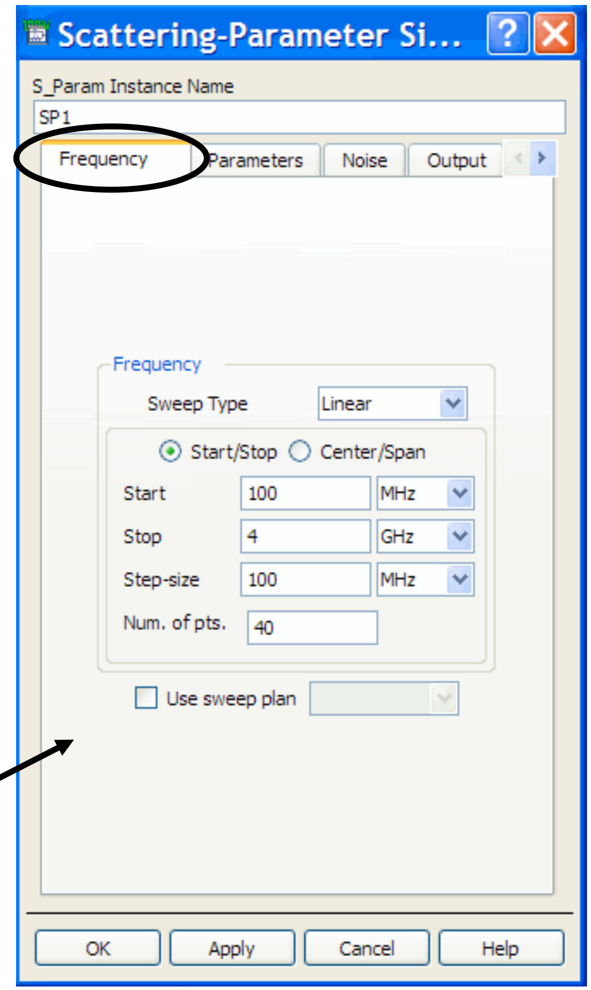


S-parameter controller...

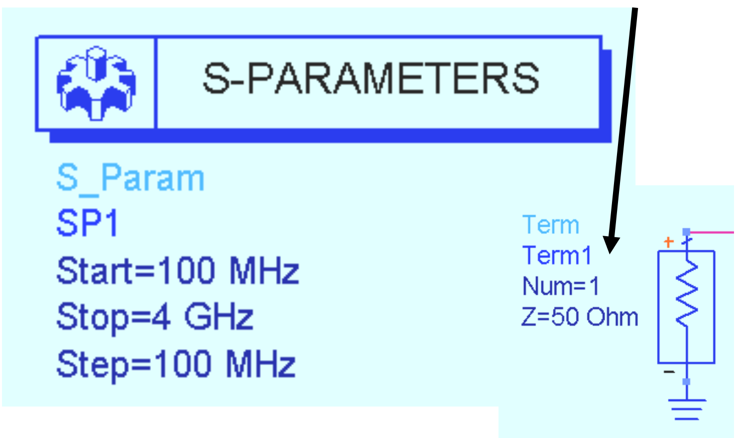
S-Parameter Simulation Controller



Default sweep variable = **freq**



The simulator requires a port termination Num = __

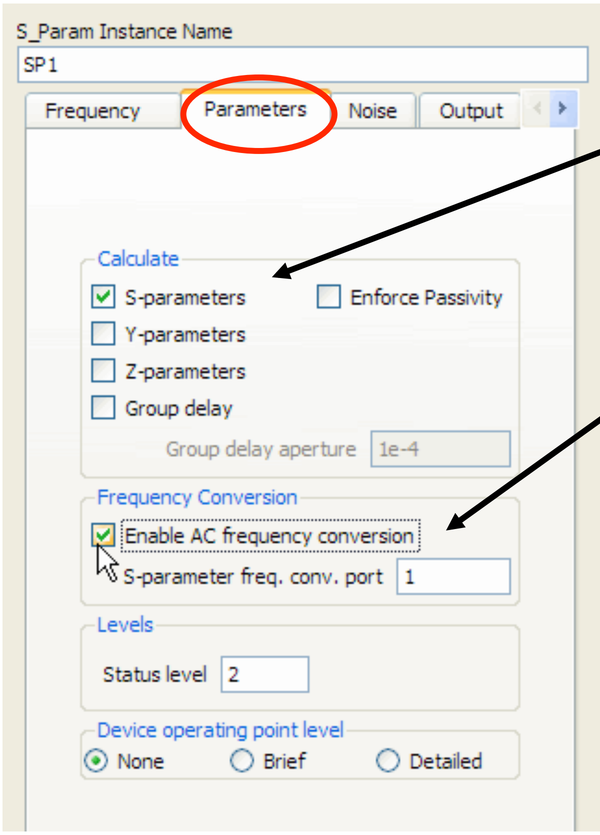


Sweep plan can also be used (see next slide). Either way, simulation data results in an S matrix in the data set for the specified range and points.

Next, other tabs

Parameters and Noise tabs

Parameters

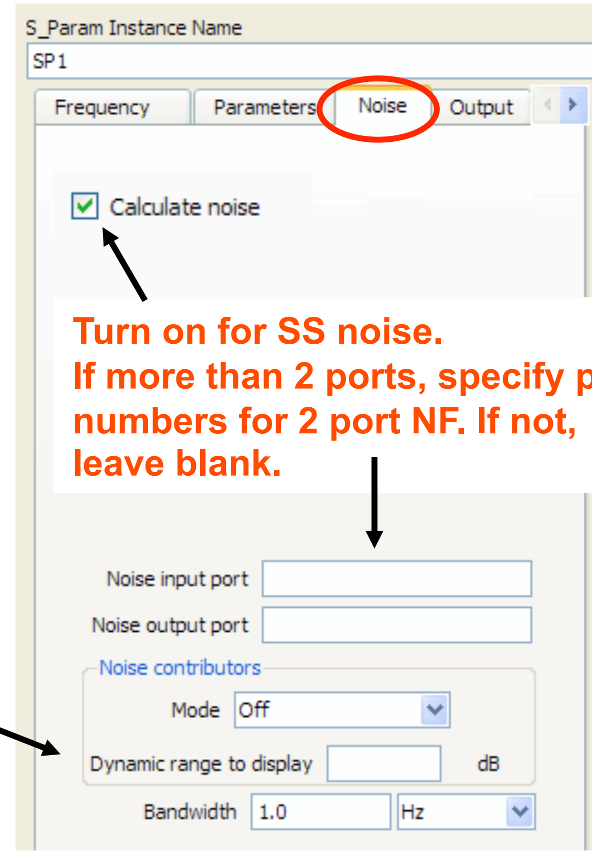


Calculate other parameters.

Enable Frequency Conversion for ADS system mixer only.

Dynamic range: Leave blank and get all values.

Noise



Turn on for SS noise.
If more than 2 ports, specify port numbers for 2 port NF. If not, leave blank.

Next, Sweep Plan...

Sweep Plan with S-parameter simulations

Sweep Plan is for sweeping **FREQ**. Otherwise, use a **Parameter Sweep** for variables (Vcc, pwr, etc.)

S-PARAMETERS

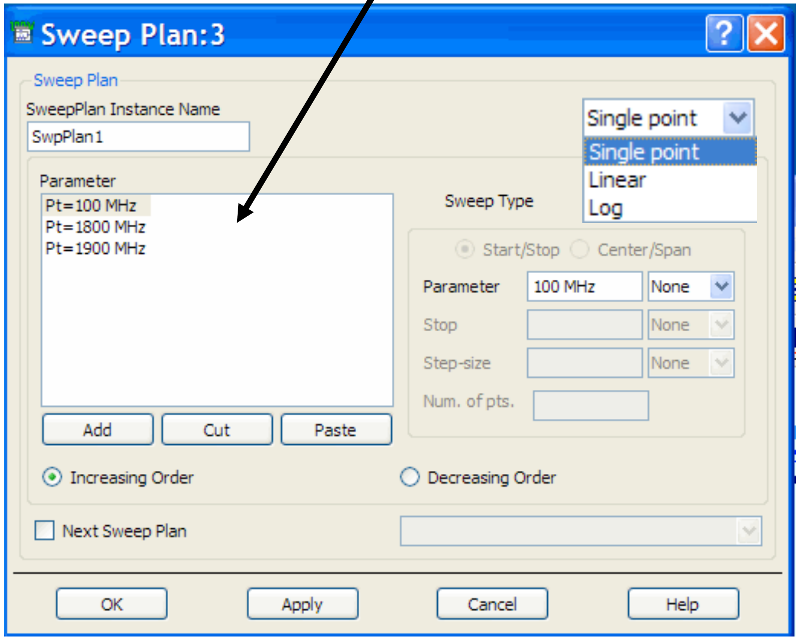
S_Param
SP1
SweepPlan="SwpPlan1"
Start=100 MHz
Stop=4 GHz
Step=100 MHz

These are ignored if Sweep plan is selected!

SWEEP PLAN

SweepPlan
SwpPlan1
Pt=100MHz
Pt=1800MHz
Pt=1900MHz
UseSweepPlan=
SweepPlan=
Reverse=no

Mixer designers: Here is a plan for an RF, LO, and IF.

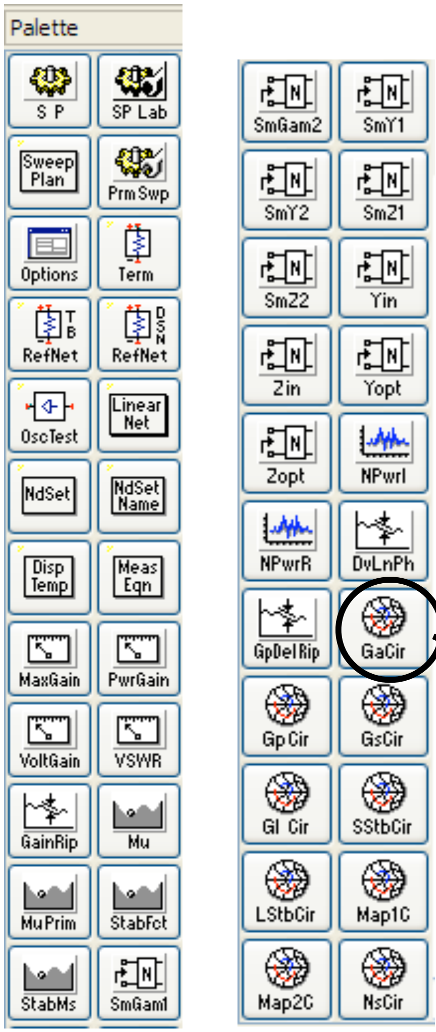


You can also have Sweeps within Sweeps.

SweepPlan
SwpPlan1
Start=100 MHz Stop=4 GHz Step=100 MHz Lin=
Start=1.8 GHz Stop=2.0 GHz Step=2 MHz Lin=

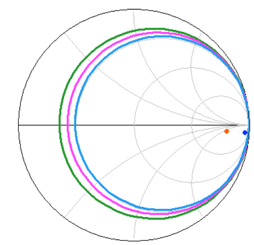
Next, Measurement Equations ...

S-Parameter measurement equations

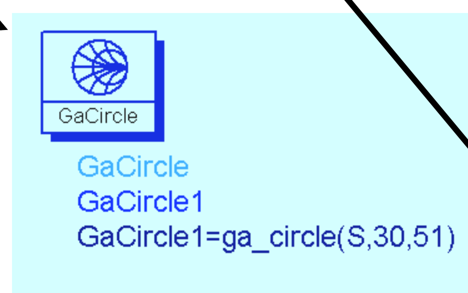


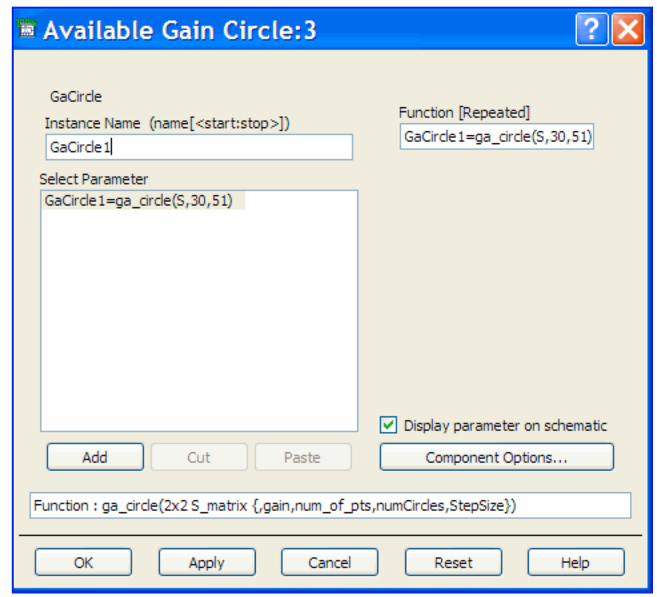
Simulation palettes have specific measurement equations - you set the arguments. Here, S is the matrix, 30 is the value in dB, and 51 points used to draw the circle.

Example: 3 circles for 3 different values of gain.



Arguments explained briefly here.

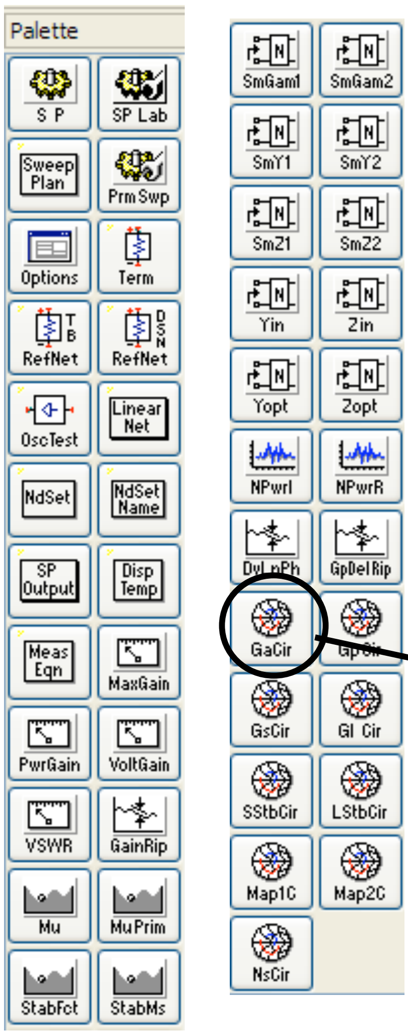




You will use some of these in the labs...

Next, matching...

S-Parameter measurement equations



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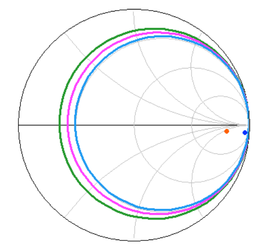

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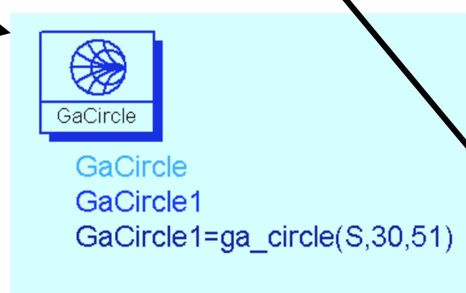
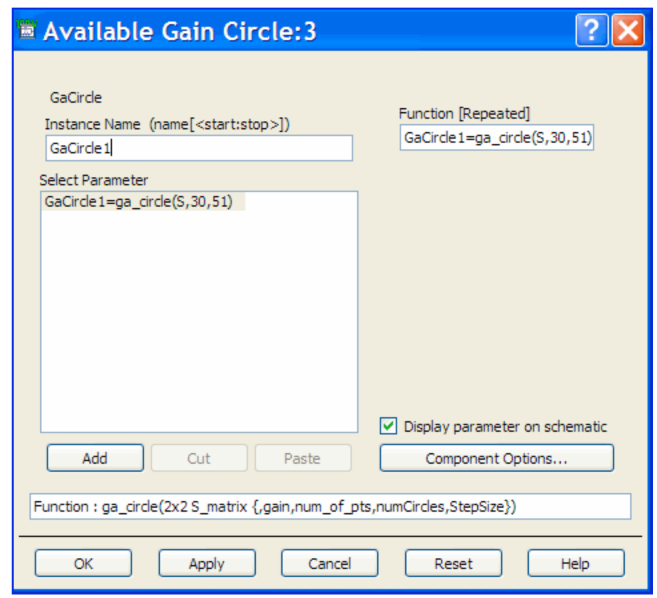


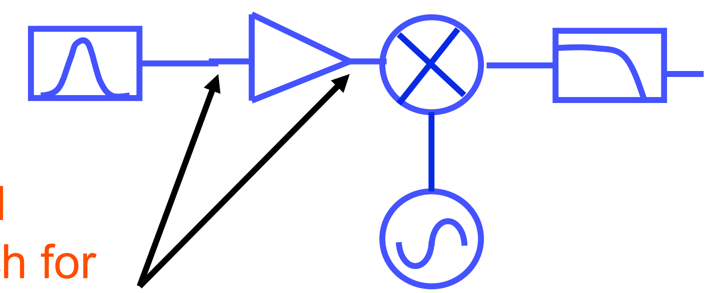


You will use some of these in the labs...

Next, matching...

Creating Matching Networks

- Various topologies can be used: L, C, R
- Avoid unwanted oscillations (L-C series/parallel)
- Yield can be a factor in topology (sensitivity)
- Use the fewest components (cost + efficient)
- Sweep or tune component values to see S-parameters
- Optimization: use to meet S-parameter specs (goals)



In the lab, you will optimize the match for the amplifier.

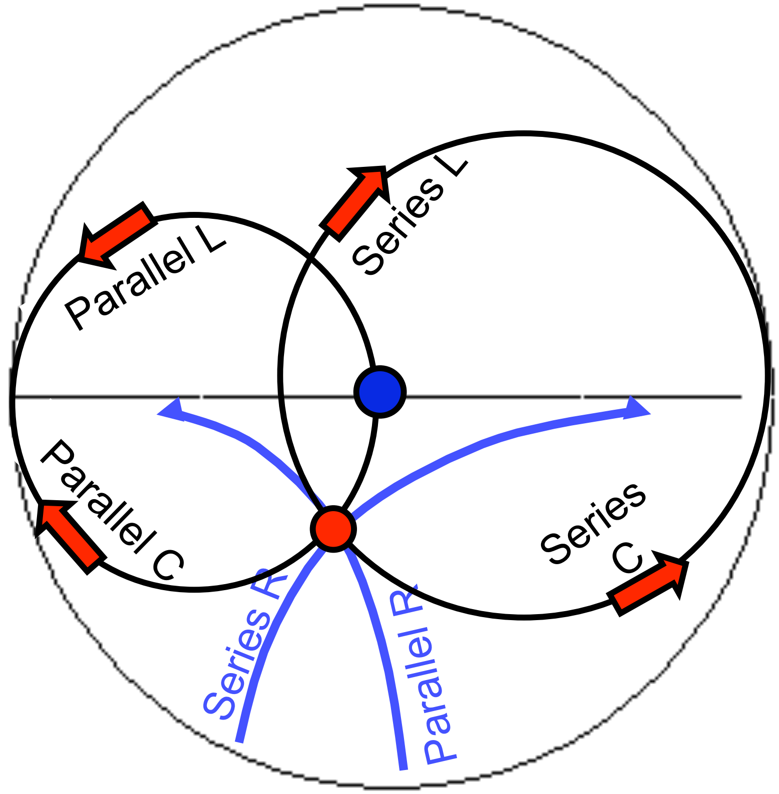
NOTE: For a mixer, match S11 @ RF and S22 @ IF.

Use the Smith chart for matching

Matching means:

Moving toward the center of the Smith Chart!

Add Series or Parallel (shunt) components.

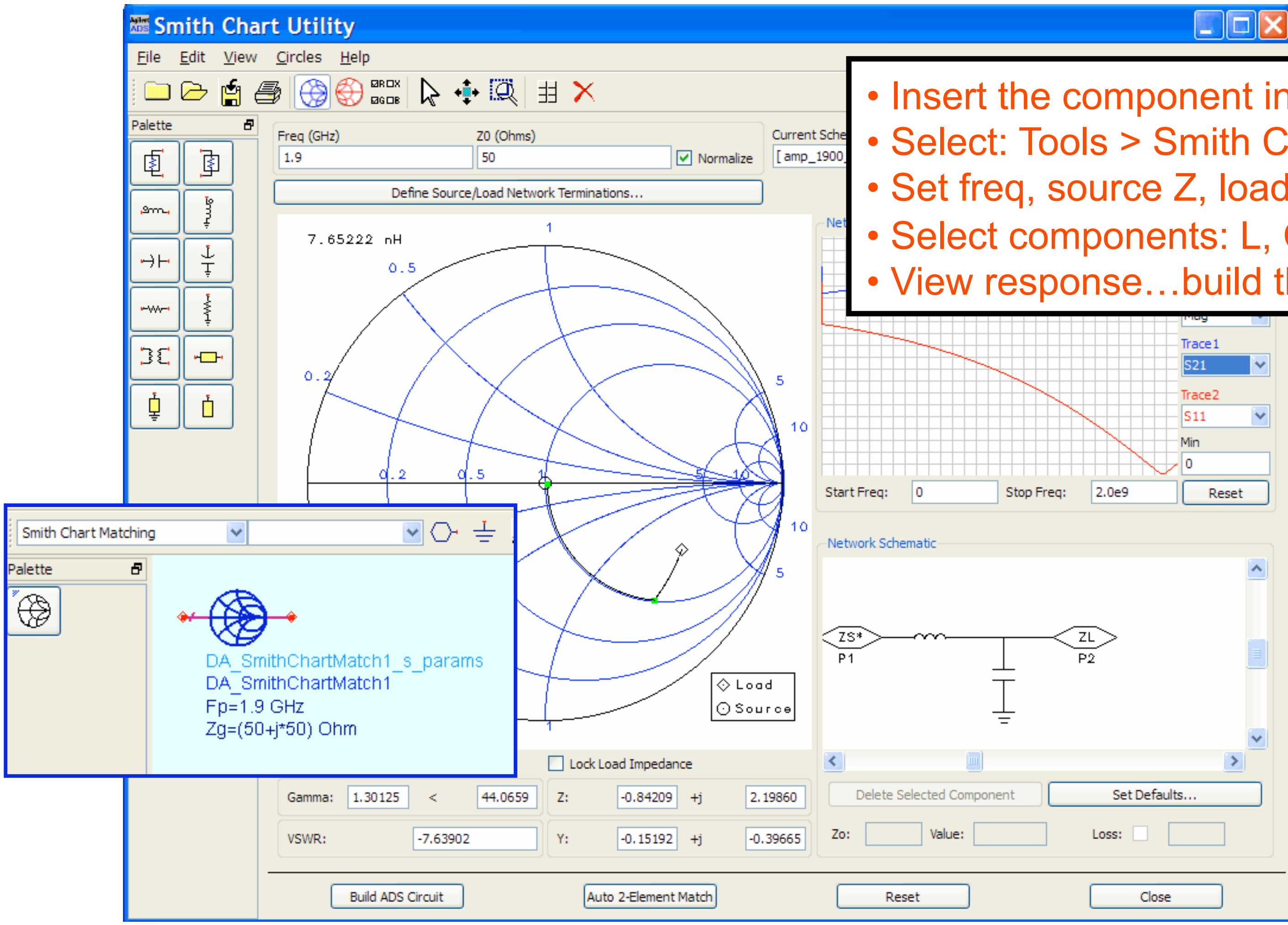


You will do this in the lab.

Adjust the value to move toward open, short, L, C, or center of chart.

Next, Smith Chart Utility for matching networks...

Smith Chart Utility for matching...



- Insert the component in schematic.
- Select: Tools > Smith Chart
- Set freq, source Z, load Z.
- Select components: L, C, R, etc.
- View response…build the circuit.

Next, optimization...

ADS Optimization Basics

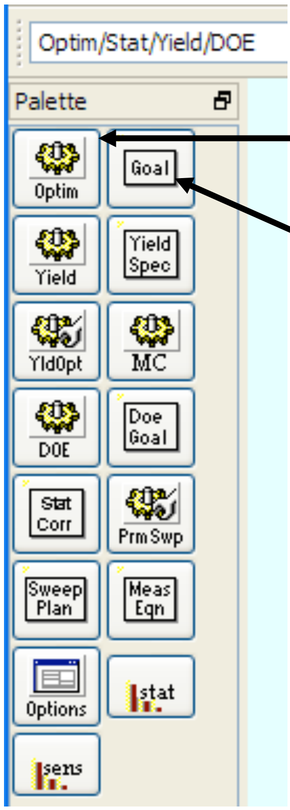
DEFINITION: Optimization is a simulation that tries to achieve a performance goal.

- Start with a simulation that gives you results.
- Set up the optimization which includes:
  - An optimizer type and search method.
  - A specific goal or specification to be met.
  - Enabled components or parameters to be adjusted.

NOTE: **ADS** has both continuous and discrete optimization. Yield analysis or a yield optimization is also available.

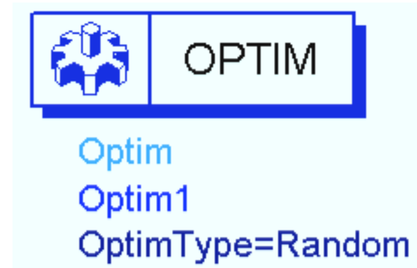
ADS Optimization in schematic…

Four elements for Optimization setup

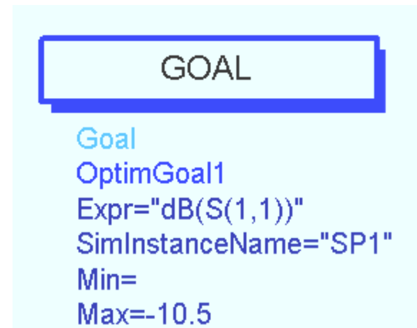


1 - Optim controller:

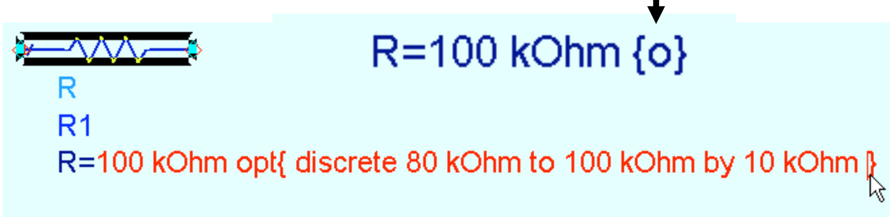
set the type, etc.



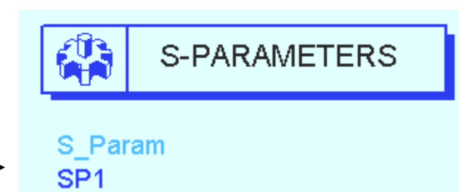
2 - Goal statement: use valid measurement equation or dataset expression.



3 - Enable component {o} for optimization.



4 - Simulation Controller



Types of ADS optimization...

ADS Optimization Types Available

= Most commonly used types.

Optimizer	Search Method	Error Function Formulation	
Random	random	least-squares	L2
Gradient	gradient	least-squares	L2
Random Minimax	random	minimaxL1	MML1
Gradient Minimax	gradient	minimaxL1	MML1
Quasi-Newton	quasi-Newton	least-squares	L2
Least Pth	quasi-Newton	least P-th	seqLP
Minimax	mini-max	mini-max	MM
Random Max	random	worst case	negL2
Hybrid	random/qNetwon	least_squares	L2
Discrete	discrete	least-squares	L2
Genetic	genetic	least-squares	L2
Simulated Annealing	SA	least-squares	L2

Hybrid is a combination of Random and Gradient.

Recommendations:

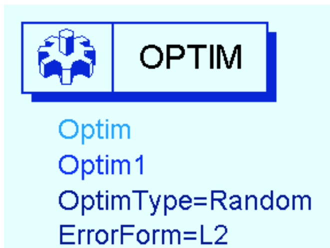
- Use Random before using Gradient.
- Minimax is good for filters.
- Tune before using the optimizer.

NOTE: Sensitivity analysis is available in the optimization controller.

Error Function...

Error Function Formulation ...

Optimizer Type determines the Error Form:



Optimizers	Error Function Formulation
Random Optimizer, Gradient Optimizer, Quasi-Newton Optimizer, Hybrid Optimizer, Discrete Optimizer, Genetic Optimizer, Simulated Annealing Optimizer	Least-Squares EF
Minimax Optimizer	Minimax EF
Random Minimax Optimizer, Gradient Minimax Optimizer	Minimax L1 EF
Least Pth Optimizer	Least Pth EF
Random Max Optimizer	Negated Least-Squares EF

Least Squares: Each residual is squared and all terms are then summed. The sum of the squares is averaged over frequency. **Negated Least-Squares:** drives values to their extreme – effectively maximizes the error function. The goal is to find a worst typical response for a given set of parameters.

Minimax: attempts to minimize the largest of the residuals. This tends to result in equal ripple responses . **Minimax L1:** is similar but cannot be less than zero, so it accounts for the most severely violated cases.

Least Pth: The Least Pth EF formulation is similar to L2, except that instead of squaring the residuals, it raises them to the Pth power with P=2 , 4 ,6 etc.

Next, how the EF works with your goals...

Goals and Error Function

- The goals are minimum or maximum target values.
- The error function is based on the goal(s).
- The weighting factor prioritizes multiple goals.

Error function is defined as a summation of residuals.
A residual r_i may be defined as:

Next, search method examples...

$$r_i = W_i \, | m_i - s_i |$$

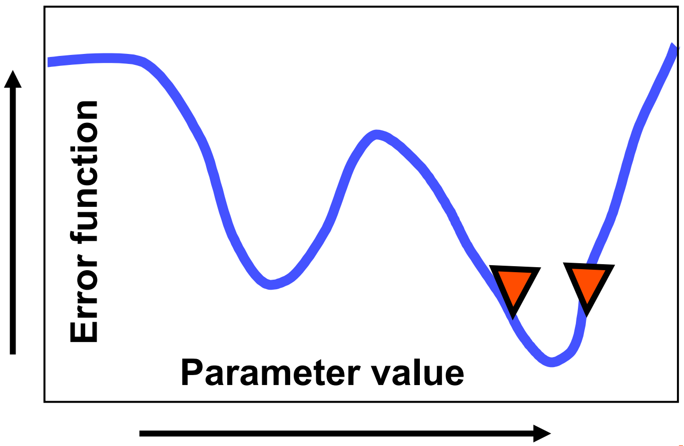
s_i is the simulated ith response (example: S21= 9.5dB)
m_i is the desired response for the **i**th measurement (example: S21=10dB)
W_i is the weighting factor for multiple goals: higher number is greater.

NOTE: You can set all goals to be equally weighted.

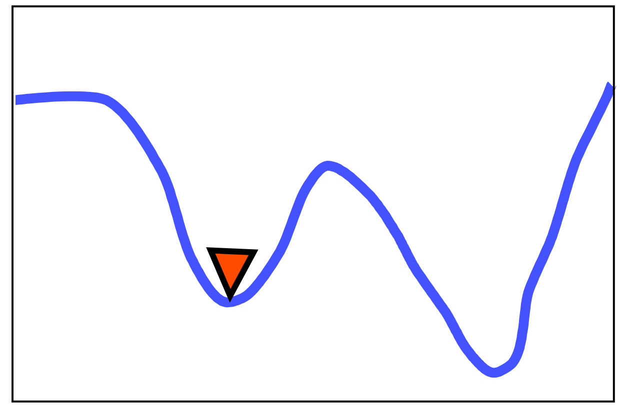
Simulations continue until the maximum iterations is reached or the error function (summation of the residuals) reaches zero (same as 10 dB).

Search Method examples

Random analysis often gets you close to the goal (minimum error function).

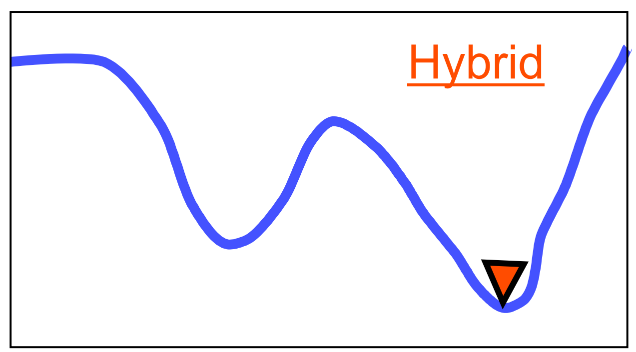


Gradient analysis may get stuck in a local minimum (not optimal error function).



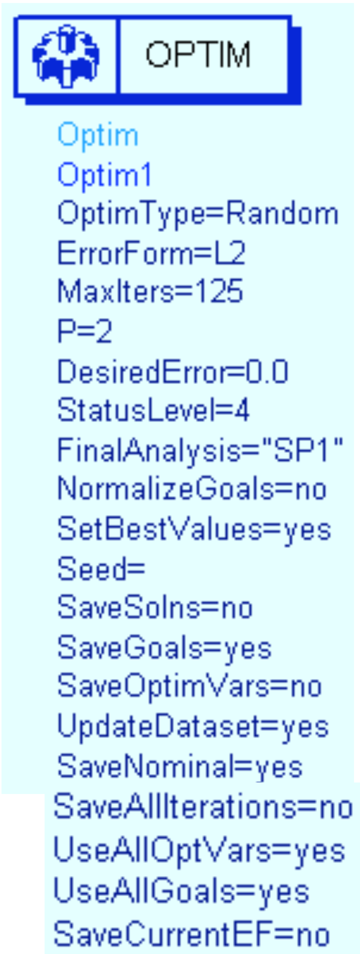
NOTE: Random is not totally random. It uses an adaptation that helps it move closer to the goal. For more details, refer to Help (on-line manuals).

Using both RANDOM and GRADIENT can reach the desired goal or, in some cases, a hybrid type such as **Genetic**.

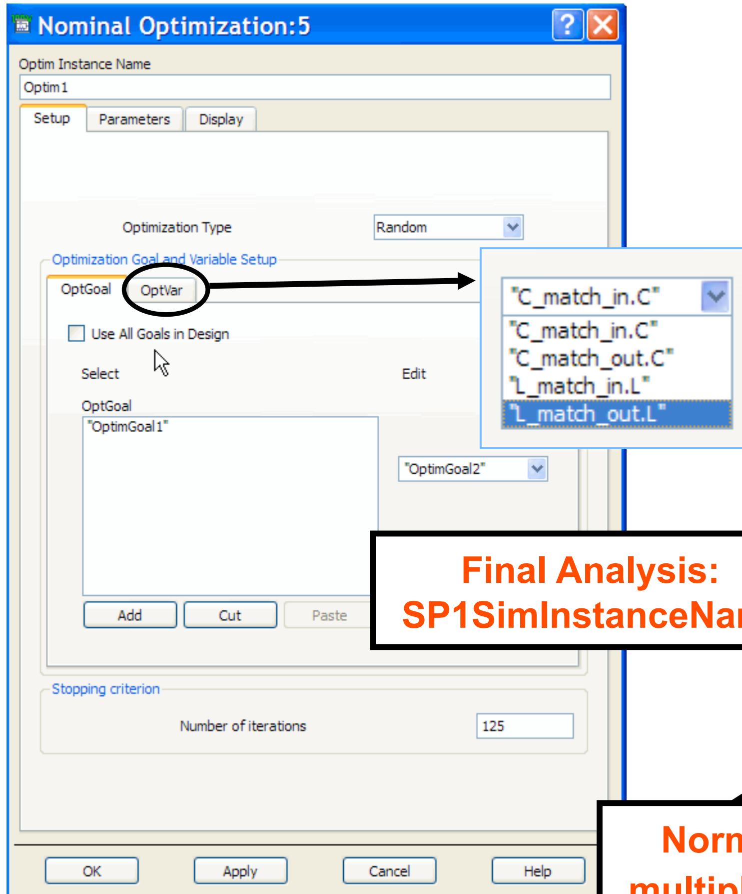


Next, the setup...

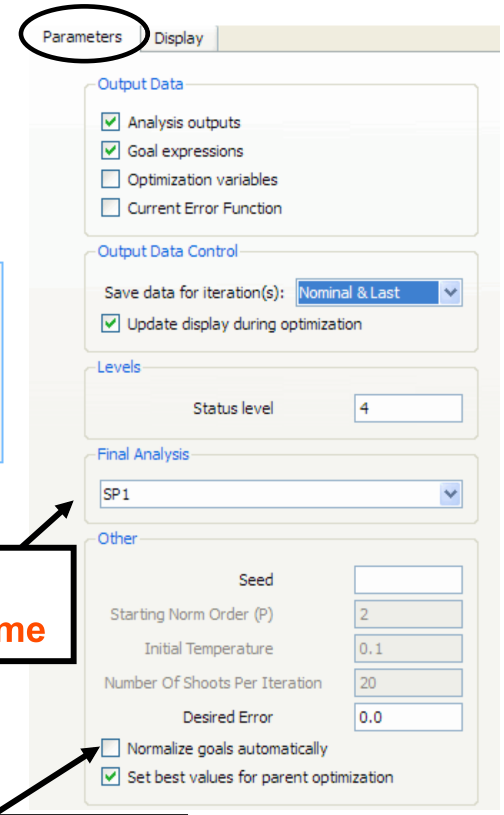
Optimization Controller setup



Setup tab: Select type and set iterations. Default setting use all Goals and VARs or select specific ones in OptVar tab.



Parameters tab: type, iterations, etc. All are displayed by default.



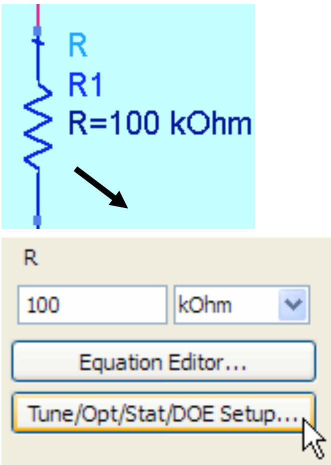
Final Analysis: SP1SimInstanceName

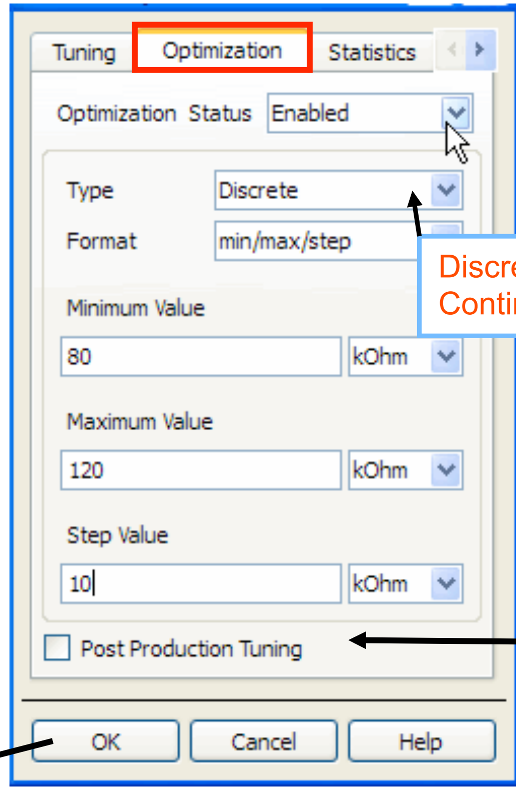
Normalizes multiple goals!

Avoid saving unwanted data.

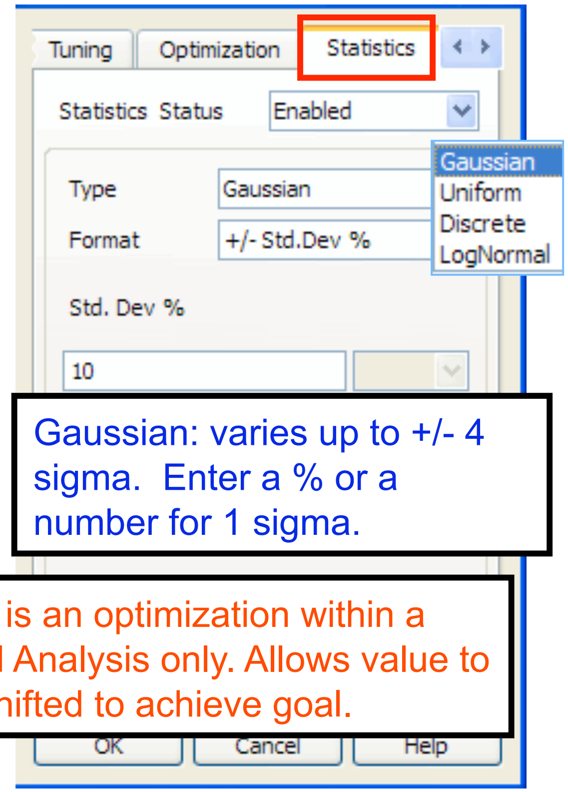
Enabling components for Opt or Stats (yield)

OPT: Enable and specify continuous or discrete (stepped) variation.





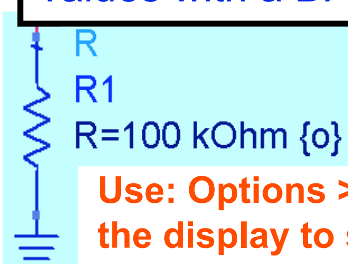
Discrete or Continuous



Gaussian: varies up to +/- 4 sigma. Enter a % or a number for 1 sigma.

NOTE: You can also use file based values with a DAC.

PPT is an optimization within a Yield Analysis only. Allows value to be shifted to achieve goal.



Use: Options > Preferences > Component Text tab to set the display to show full opt range instead of {o}. Also, noopt or {-o} = disabled after the optimization.

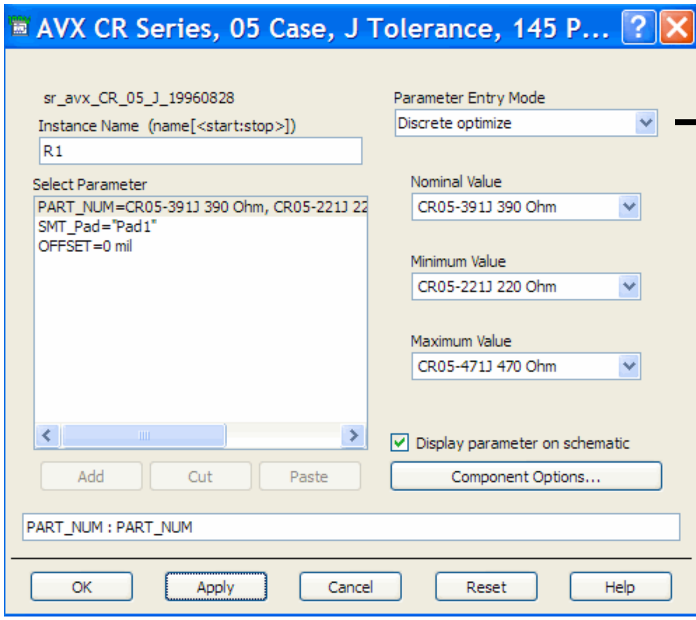
R=96.527 kOhm noopt{ discrete 80 kOhm to 100 kOhm by 10 kOhm }

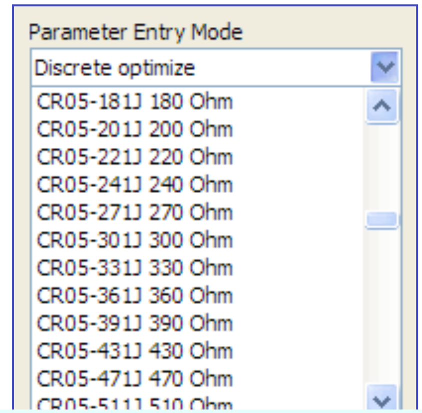
Discrete lib parts...

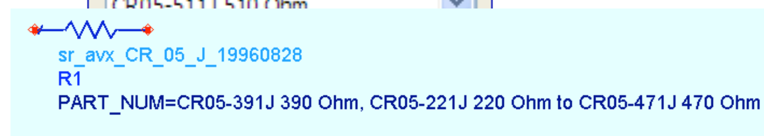
NOTE: DOE is an advanced topic (statistical yield analysis).

ADS Discrete Optimization for Library Parts

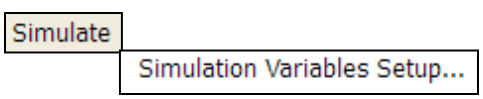
Inserted library part with listed range of values (like a DAC)

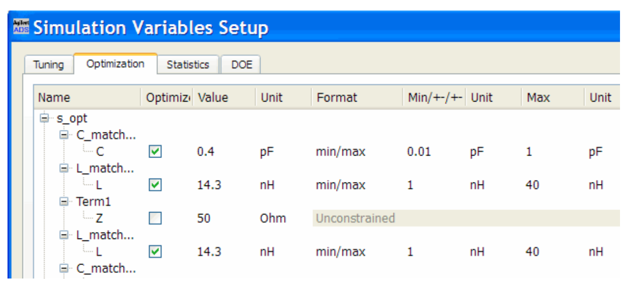






NOTE: For al list of all optimization variables:



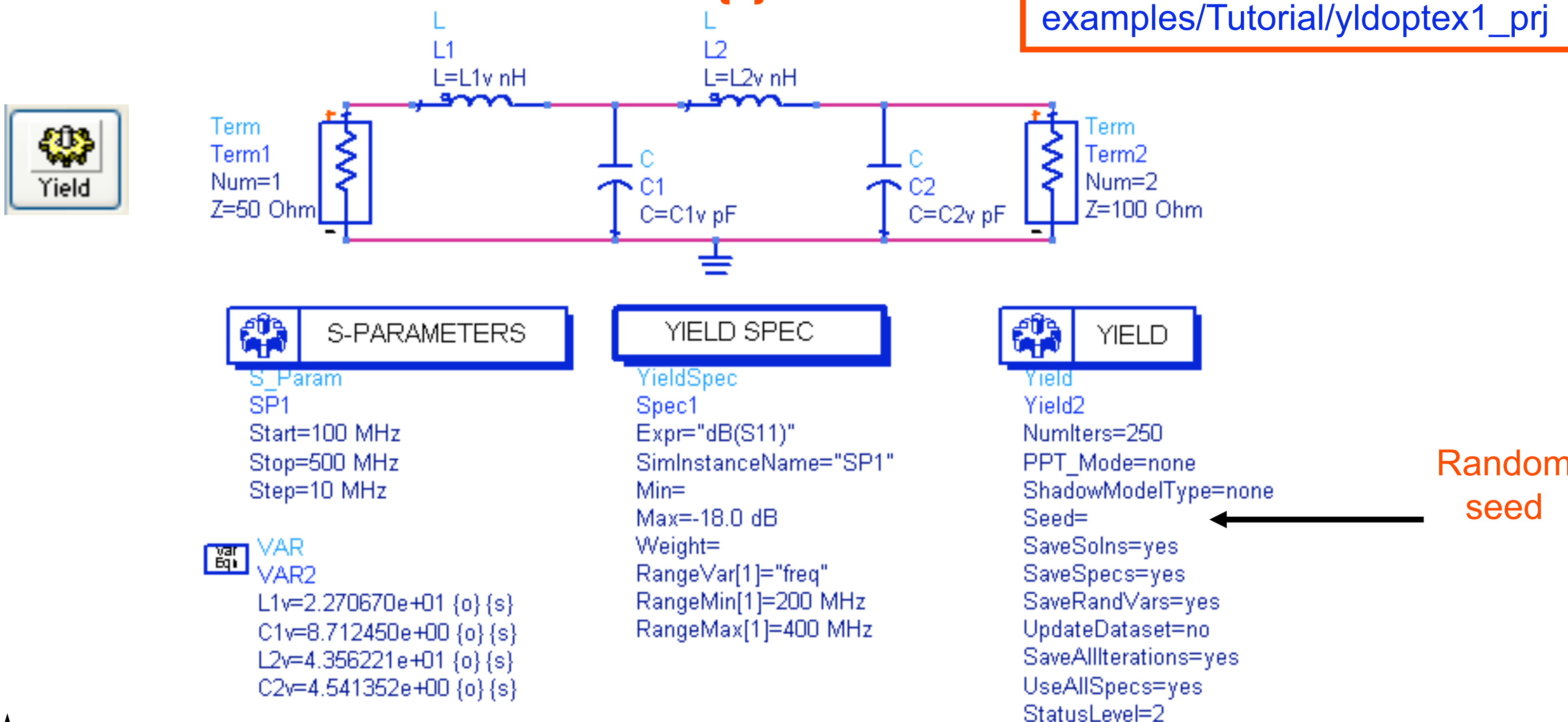


Next, Yield…

Yield Analysis: % meeting specs!

Example: 200-400 MHz (50-to-100 ohm) Impedance Transformer. Variables have been optimized {o} and statistical Yield will now test the % of circuits meeting spec. Note that component values (VAR) have defined statistical distributions {s}.

NOTE: Optimize yield results by changing the nominal values until you get maximum (near 100%). See: examples/Tutorial/yldoptex1_prj



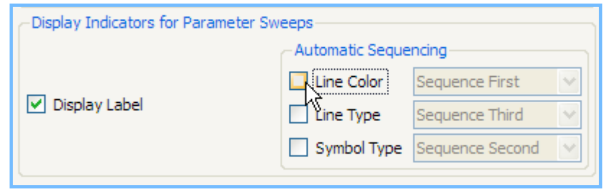
Optional Exercise: **Step 1- Copy: examples / Tutorial / yldex1_prj**

...Yield Analysis Results (data)

Step 2 - Run the simulation once.

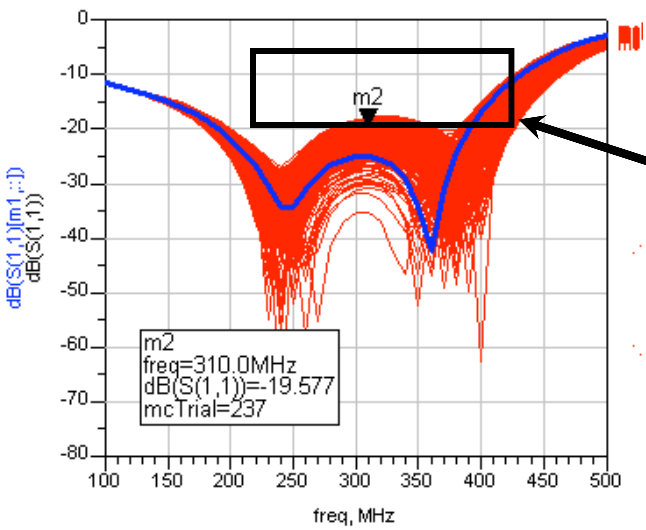
Step 3 – Examine the results.

NOTE on Trace Options: Uncheck Line Color to get one color.



80% will meet spec

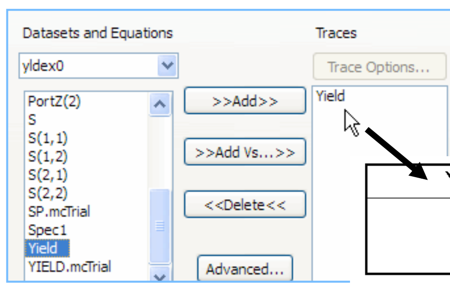
Spec is -18 dB S11 from 200 to 400 MHz.



Yield Dataset results are stochastic.

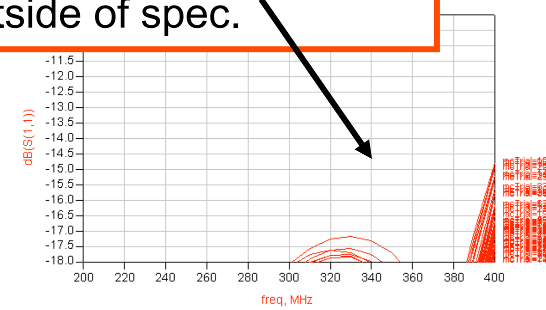
YIELD SPEC

YieldSpec
Spec1
Expr="dB(S11)"
SimInstanceName="SP1"
Min=
Max=-18.0 dB
Weight=
Save=
RangeVar[1]="freq"
RangeMin[1]=200 Mhz
RangeMax[1]=400 Mhz



Yield
80.000

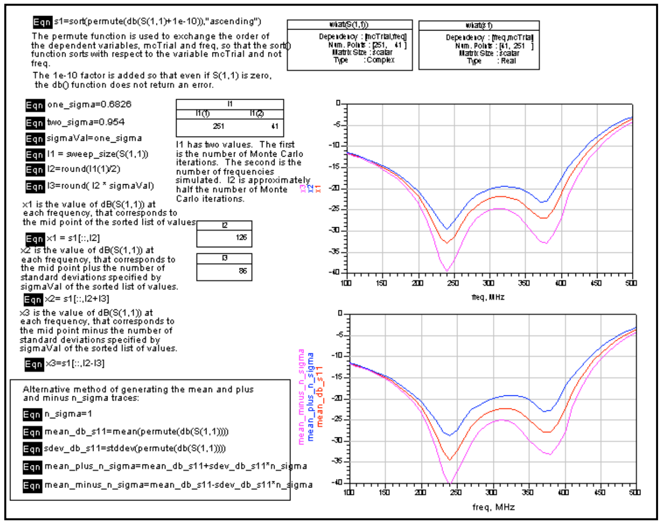
Zoomed in view: results outside of spec.

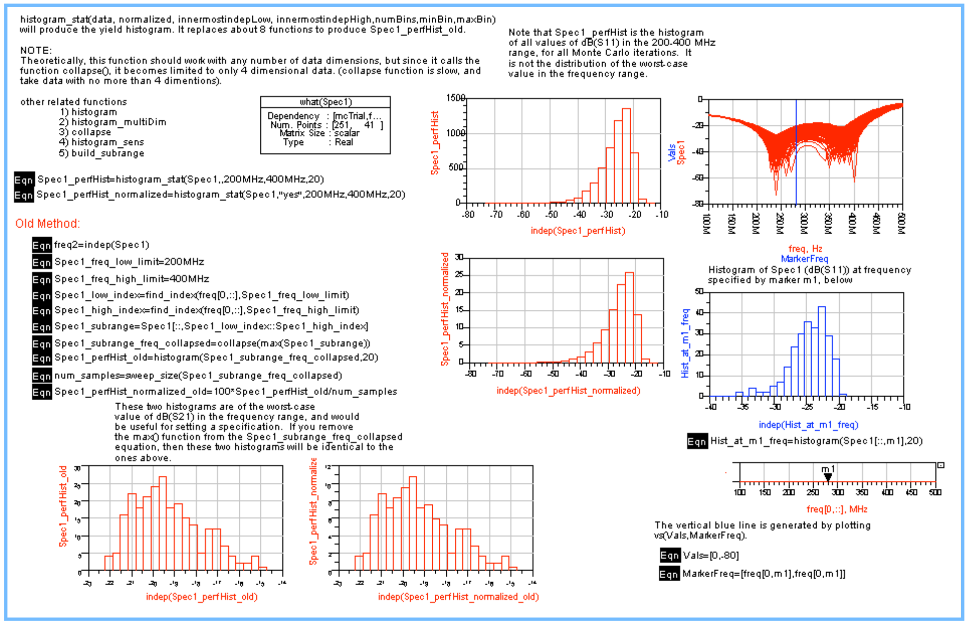


More results...

…more Yield Analysis results

The example has Several Data Display windows: Histograms, Sensitivity and Sigma plots. Various methods are used and equations/functions are described for both histograms and sigma plots.

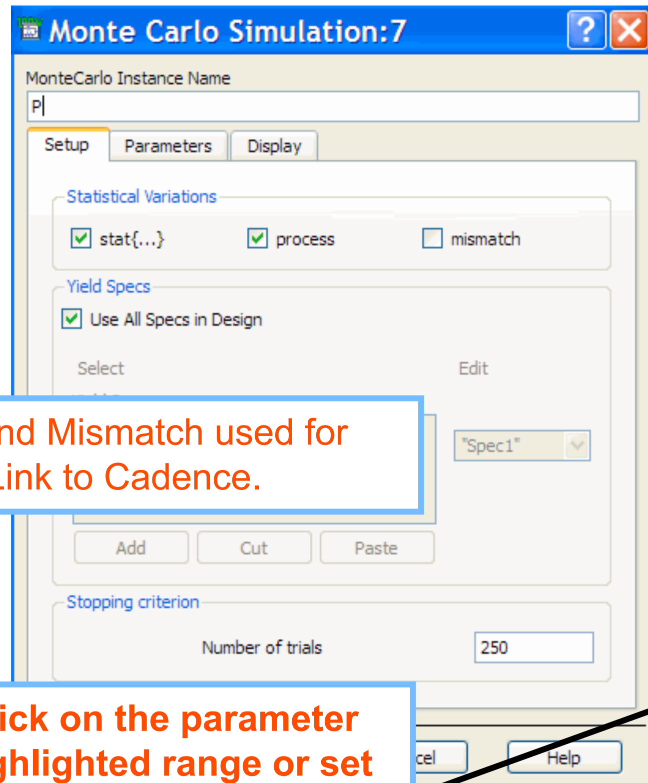


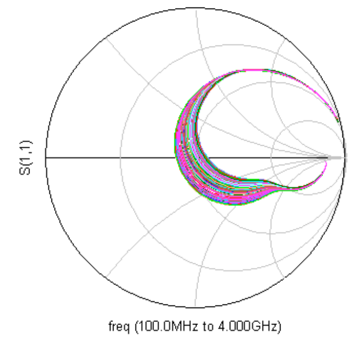


MC...

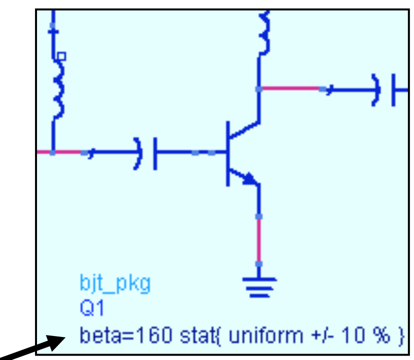
Monte Carlo Analysis

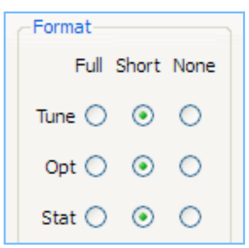
Similar to Yield but no spec is required. Enabled parameters are varied and you see the response. Also, Process or Mismatch can be selected to see the effects.





Process and Mismatch used for Dynamic Link to Cadence.





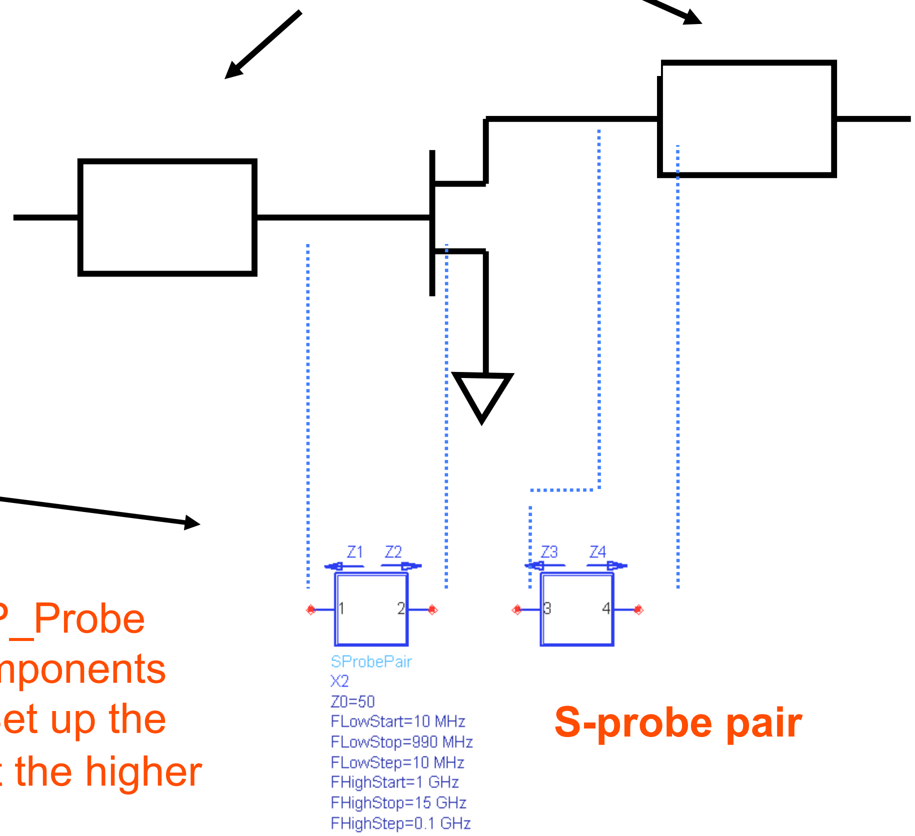
NOTE: Click on the parameter to see highlighted range or set to Full in Options > Preferences.

S-probe...

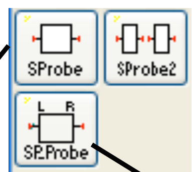
S- Probes for Impedance…

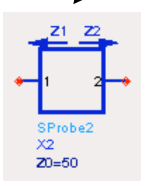
Matching networks

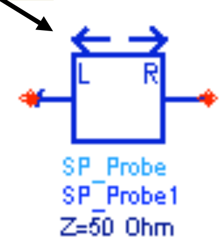
Get impedance (reflection coefficient) for biased circuits by simply connecting the S probe in series.



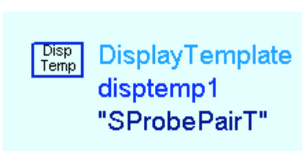
Probe components palette:







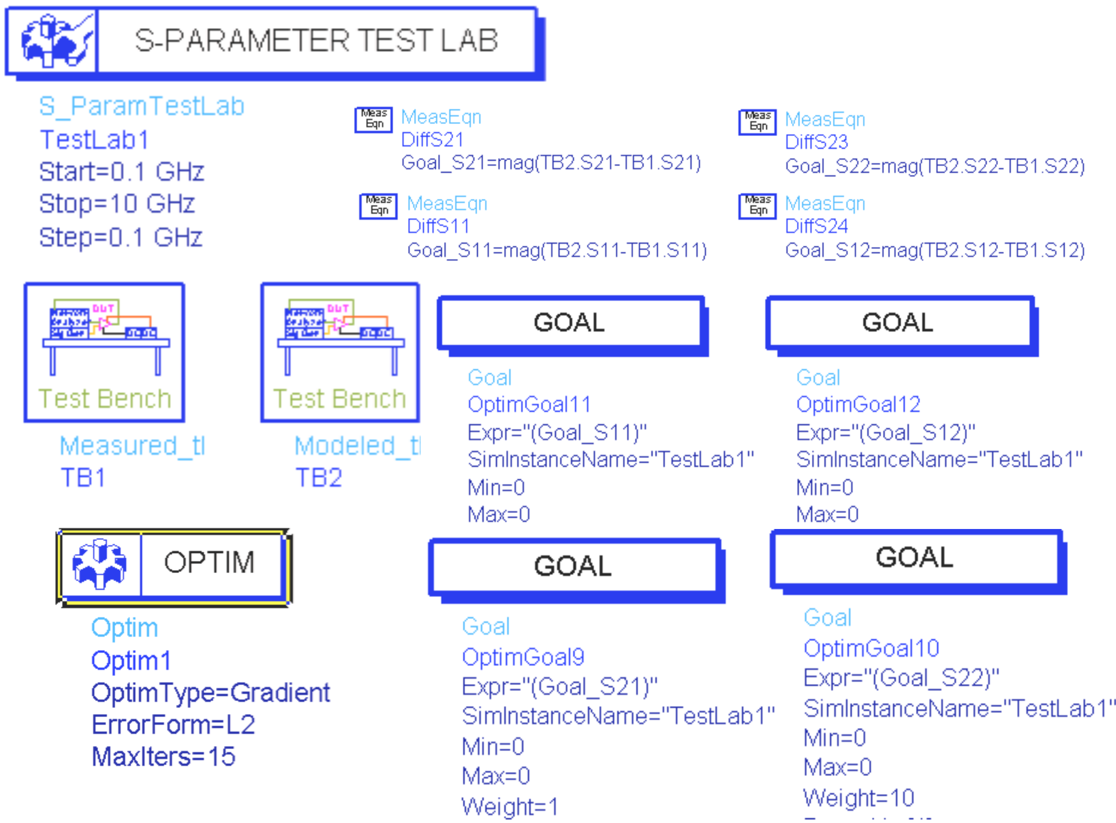
Insert the SP_Probe between components or stages. Set up the simulation at the higher level.



Data Display template gives Impedance and stability.

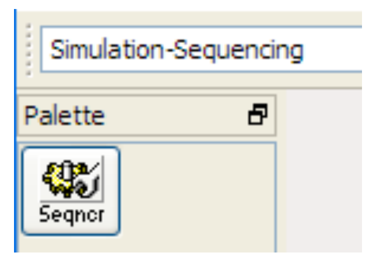
S_Param Test Lab with Test Benches

Examples/Tutorial: TestLab_HOWTO_prj. Shows how to Optimize a two-port model using measured two-port data.



Goals are MeasEqns = Difference between modeled and measured Test Bench values goes to zero when optimized!

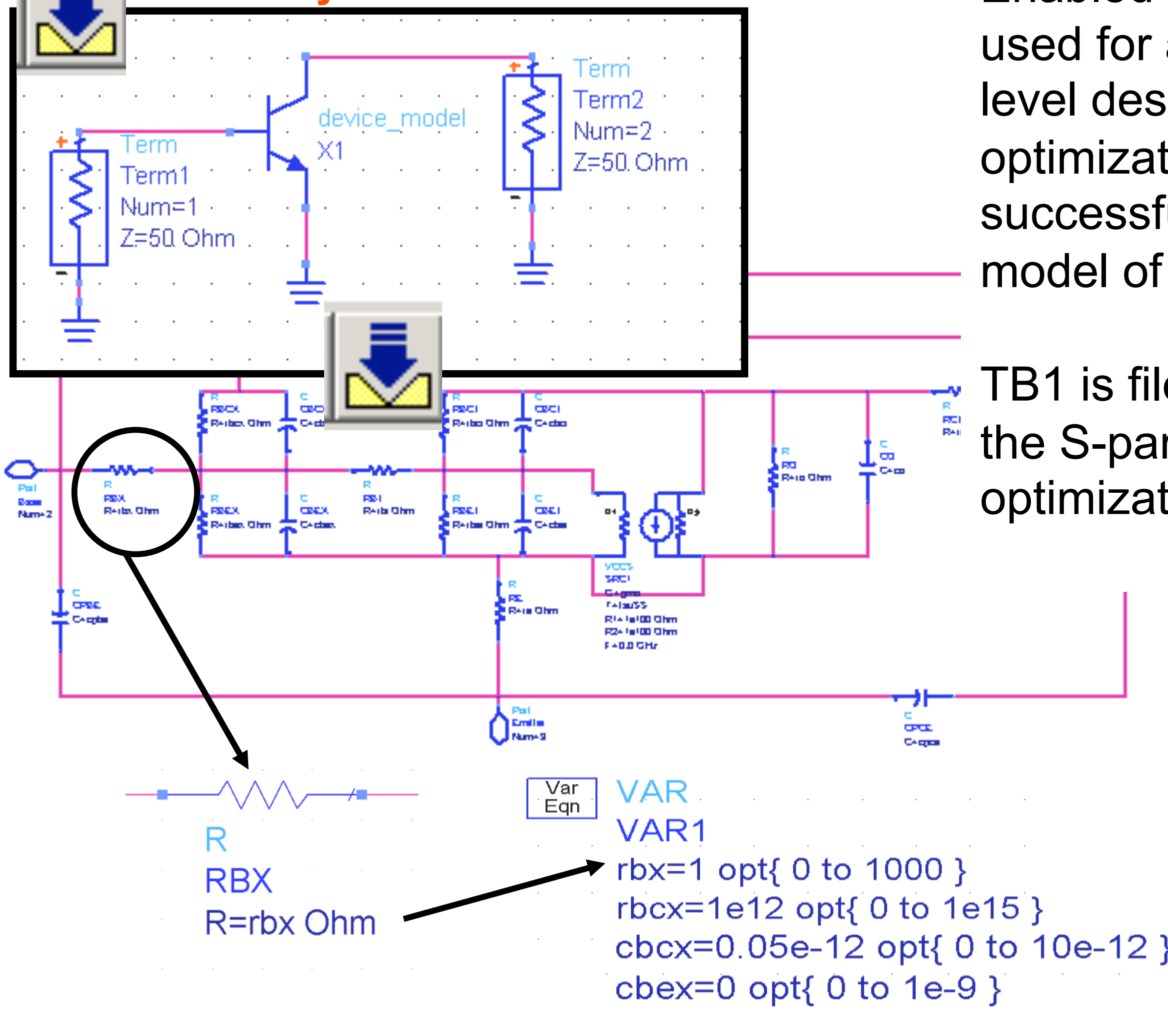
NOTE: The sequencer can also be used for an upper level design to run simulations in order.



NOTE: Test benches are created using the test bench symbol (Design Parameters).

Test Lab example (continued)…

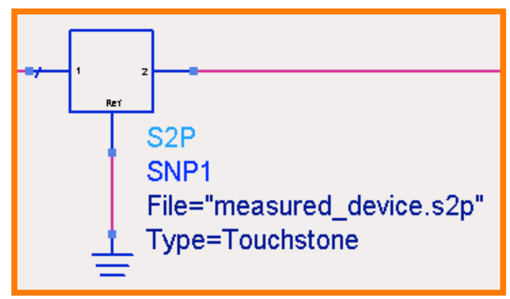
Hierarchy of model test bench: TB2



Enabled (opt) variables are used for all values in the lower level design. When the optimization completes successfully, TB2 will be a model of the measured device.

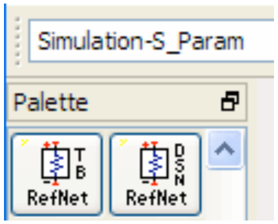
TB1 is file based and reads-in the S-param values during the optimization process.

Measured test bench: TB1

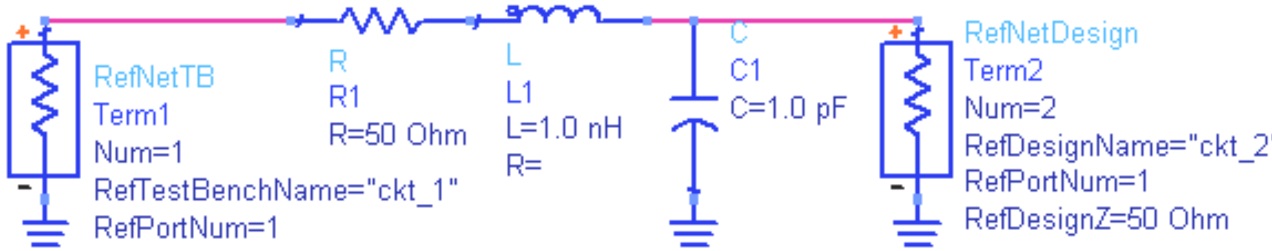


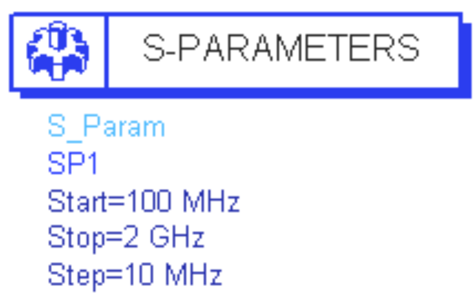
Next, Ref Nets!

Ref Nets are Terminations



RefNets (2 types) are terminations that reference the impedance of other schematics in your project: test benches or designs.

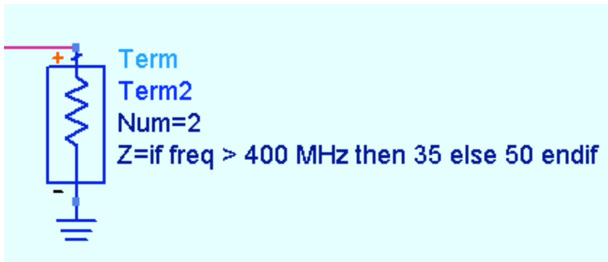




Next, frequency sensitive components

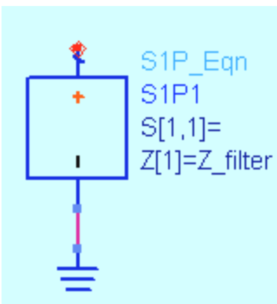
Term1 has the impedance of the test bench “ckt_1” looking into its port 1 and Term 2 has the impedance the design “ckt_2” looking into its port number 1.

ADS allows frequency sensitive components!



Set a Term Z to change with frequency using IF THEN ELSE.

freq	PortZ	
	PortZ(1)	PortZ(2)
100.0MHz	50.000 / 0.000	50.000 / 0.000
200.0MHz	50.000 / 0.000	50.000 / 0.000
300.0MHz	50.000 / 0.000	50.000 / 0.000
400.0MHz	50.000 / 0.000	50.000 / 0.000
500.0MHz	50.000 / 0.000	35.000 / 0.000
600.0MHz	50.000 / 0.000	35.000 / 0.000
700.0MHz	50.000 / 0.000	35.000 / 0.000

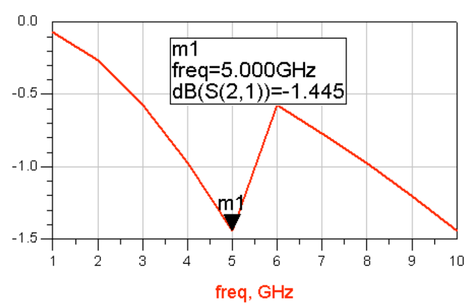


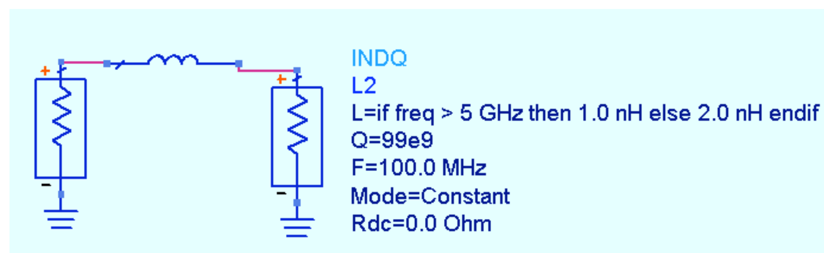
Use an SNP Eqn: Z changes with changing frequency.

if then elseif then elseif then else endif

Var Eqn VAR
VAR1
Z_filter=if freq < 1 GHz then 100 elseif freq < 500 MHz then 1K elseif freq < 1MHz then 10K else 1M endif

CAPQ and INDQ: Equation describes changing L or C with frequency.





Try these as an extra exercise after the lab!

What the lab is about ...

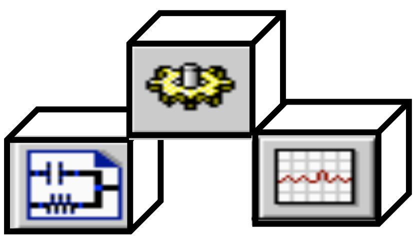
Lab 5:

S-parameter Simulation and Optimization

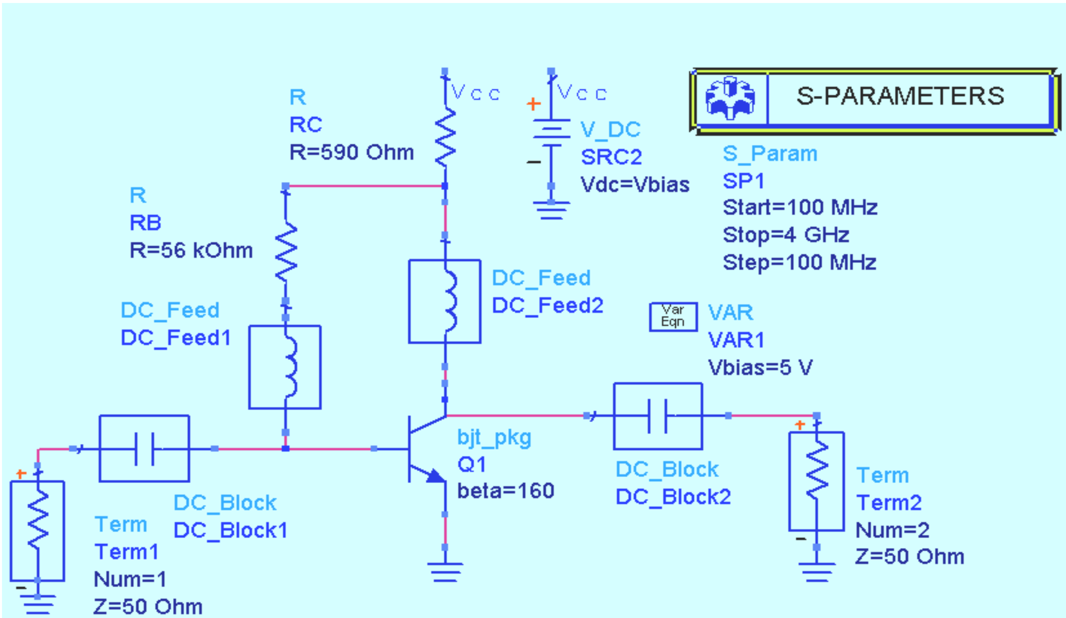
Steps in the Design Process

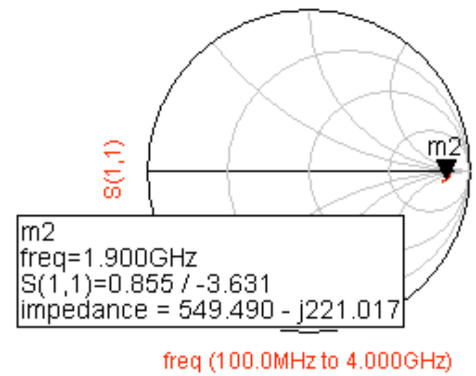
You are here:

- Design the RF sys behavioral model receiver
- Test conversion gain, spectrum, etc.
- Start amp_1900 design – subckt parasitics
- Simulate amp DC conditions & bias network
- Simulate amp AC response - verify gain
- Test amp noise contributions – tune parameters
- **Simulate amp S-parameter response**
- **Create a matching topology**
- **Optimize the amp in & out matching networks**
- Filter design – lumped 200MHz LPF
- Filter design – microstrip 1900 MHz BPF
- Transient and Momentum filter analysis
- Amp spectrum, delivered power, Zin - HB
- Test amp comp, distortion, two-tone, TOI
- CE basics for spectrum and baseband
- CE for amp_1900 with GSM source
- Replace amp and filters in rf_sys receiver
- Test conversion gain, NF, swept LO power
- Final CDMA system test CE with fancy DDS
- Co-simulation of behavioral system

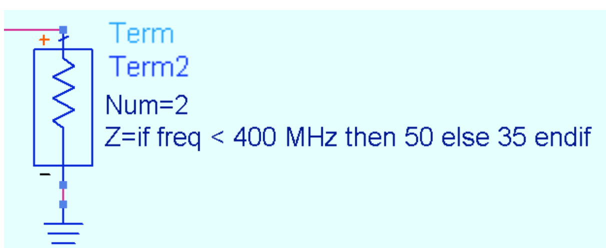


First, simulate with ideal components





- Plot the S parameter data
- Write eqn IF-THEN-ELSE for a Term Z.
- Simulate and list the data



freq	PortZ(2)
100.0MHz	50.000 / 0.000
200.0MHz	50.000 / 0.000
300.0MHz	50.000 / 0.000
400.0MHz	35.000 / 0.000
500.0MHz	35.000 / 0.000
600.0MHz	35.000 / 0.000
700.0MHz	35.000 / 0.000
800.0MHz	35.000 / 0.000
900.0MHz	35.000 / 0.000
1.000GHz	35.000 / 0.000

Calculate C and L values and re-simulate

Reactance of 10 pF at 1.9 GHz and a list of L values:

Eqn Xc= -1 / (2 * pi * 1900M * 10e-12)

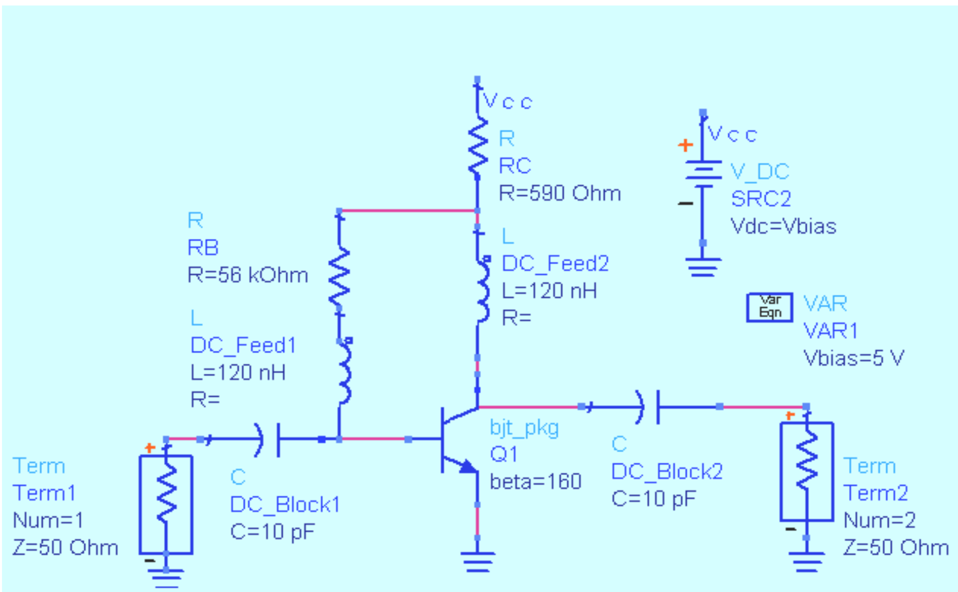
Cap value: reactance at 1900 MHz

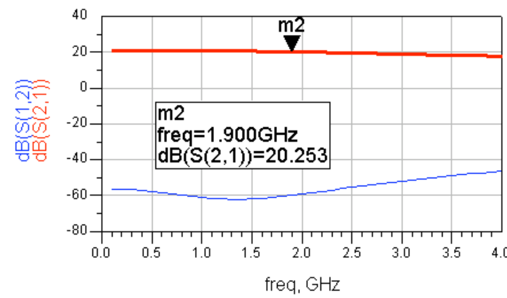
Xc
-8.377

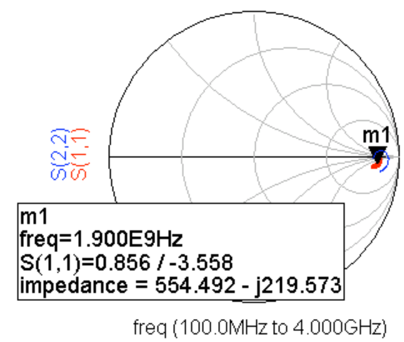
Eqn XL= 2 * pi * 1900M * L_val

Eqn L_val = [1n :: 10n :: 200n]

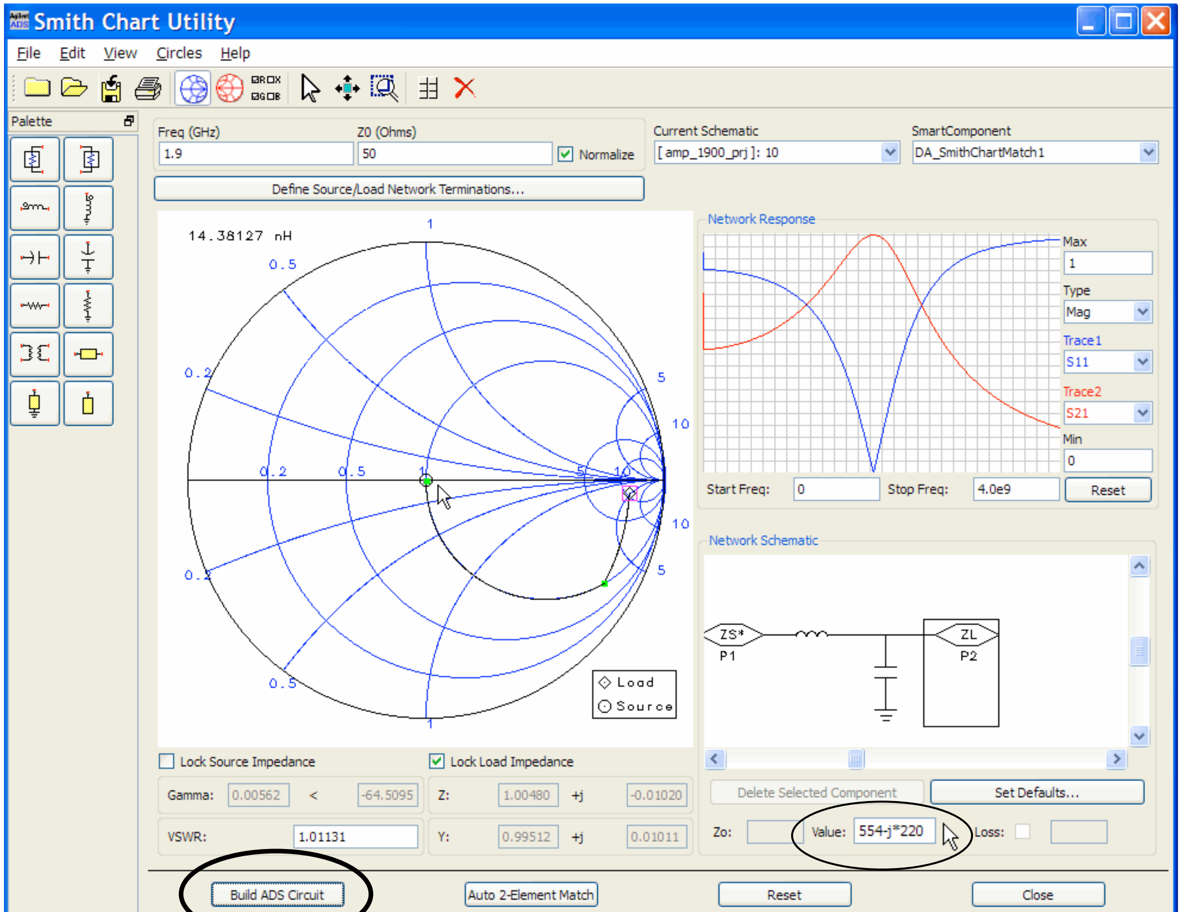
L_val	XL
7.100E-8	847.602
8.100E-8	966.982
9.100E-8	1086.363
1.010E-7	1205.743
1.110E-7	1325.124
1.210E-7	1444.504
1.310E-7	1563.885



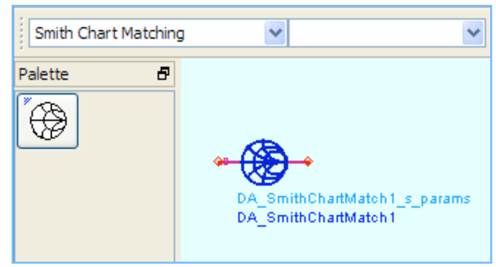


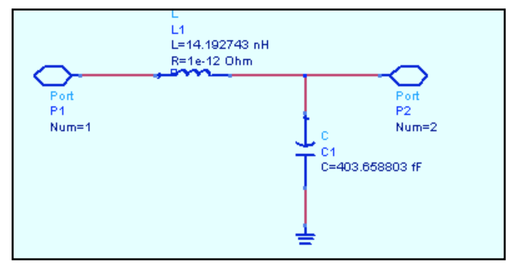


Smith Chart Utility for a matching network...



Smart component in schematic becomes a sub-circuit when built:



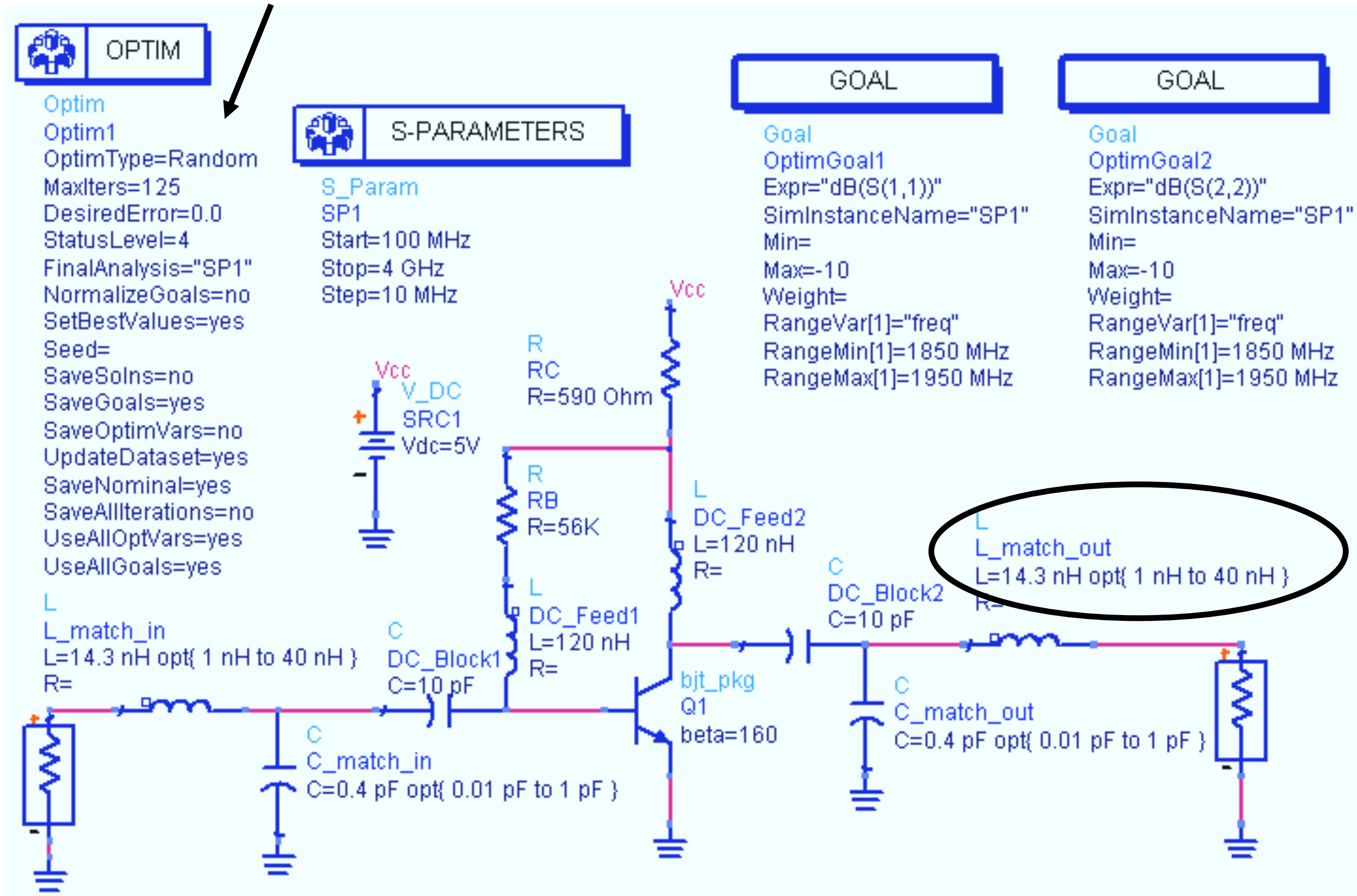


- Start the tool, define value of Z Load at 1900 MHz, insert the component
- Select the desired palette components (C and L) to move to Smith Chart center
- Build the matching circuit with one click…

Next, Optimize!

Add output matching components and Optimize !

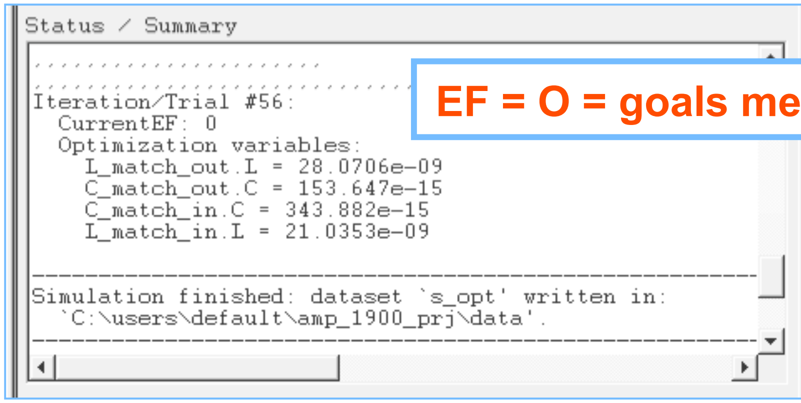
Use **Random** with 2 **Goals**: Max for S11 and S22 = -10 dB



NOTE: opt function or **{o}** indicates components are enabled.

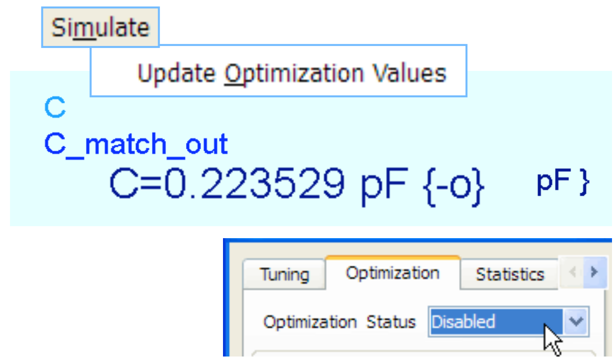
Note: If GOAL RangeVar is not set, the optimizer uses all the simulation frequency points.

After a successful optimization...



EF = O = goals met!

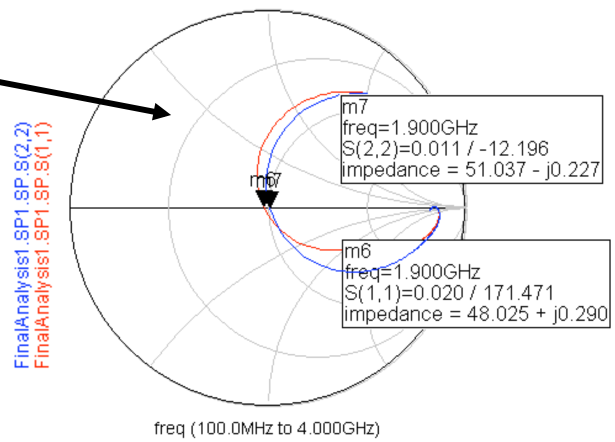
Update the values and disable the Opt components: {-o} = noopt function.

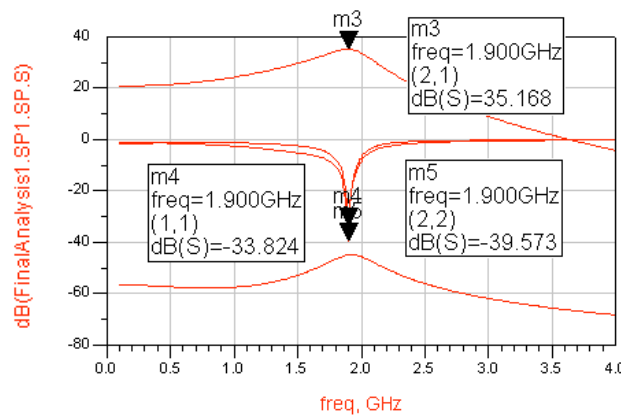


Nominal Optimization found initial Error Function (EF) to be zero or less. Optimization specification is currently satisfied… Try to tighten specification

Simulator will tell you if it can improve results!

Lab exercise has final component values for these S-parameters which are good!

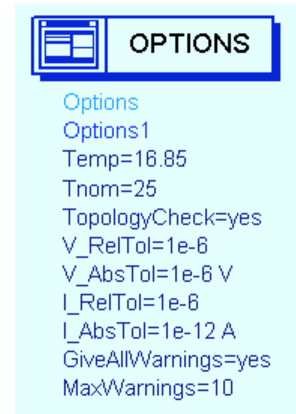


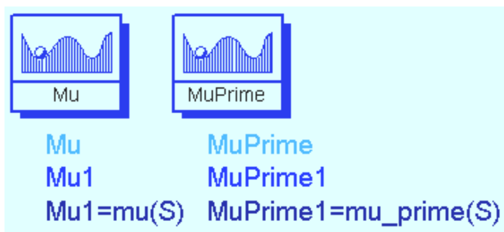


Also, gain & noise circles + stability

S-parameter simulation with gain and noise circles, and stability.
These pre-defined measurement equations use ADS functions.

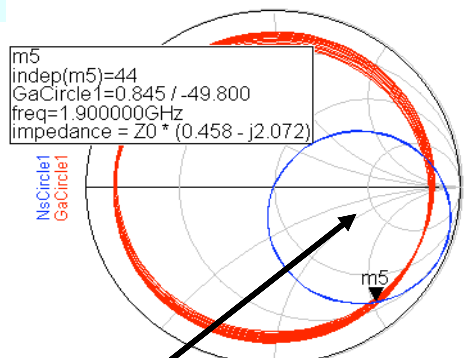
You set the arguments if necessary!

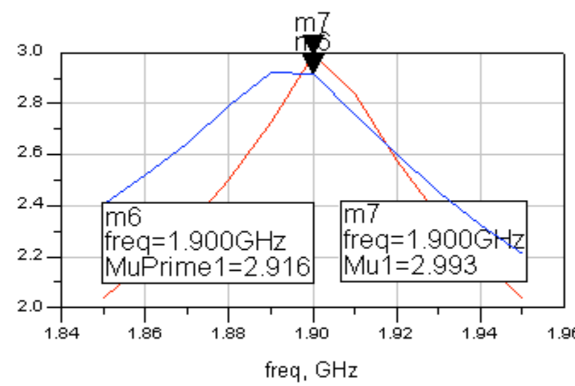




NOTE:You must turn on Noise in the simulation controller for NsCircle and list values.

freq	NFmin	Sopt
1.850GHz	1.055	0.788 / -20.779
1.860GHz	1.055	0.789 / -20.735
1.870GHz	1.056	0.791 / -20.691
1.880GHz	1.056	0.792 / -20.647
1.890GHz	1.056	0.794 / -20.602
1.900GHz	1.057	0.795 / -20.557
1.910GHz	1.057	0.797 / -20.512
1.920GHz	1.057	0.798 / -20.467



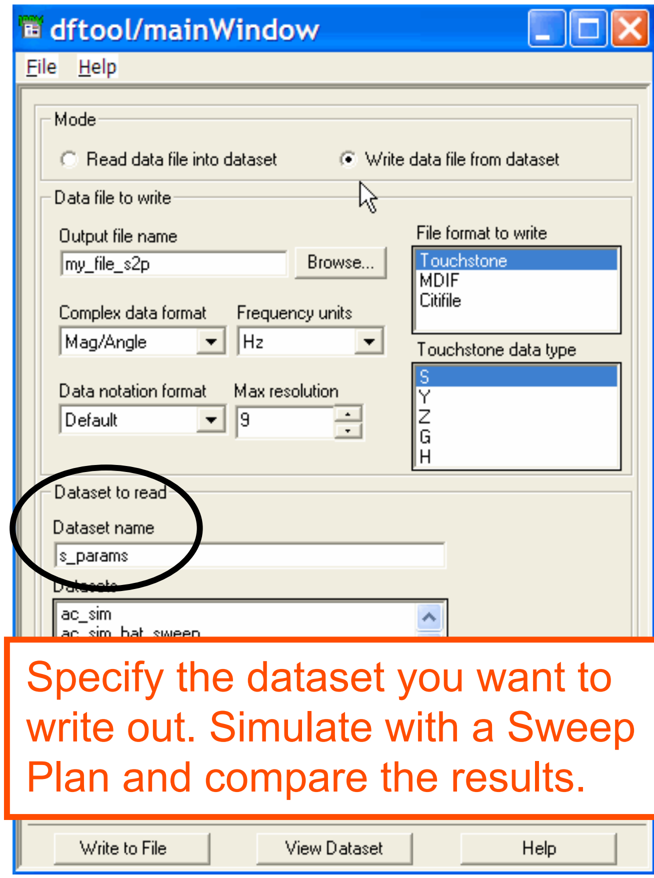


Circle center is source match for optimum NF.

Optional: Read / Write data files

Or, try the yield analysis example!

Data File Tool: write an ADS S-parameter dataset as a Touchstone file, then Read it back in... as if it came from a Network Analyzer!



Specify the dataset you want to write out. Simulate with a Sweep Plan and compare the results.