12 – Design for Manufacturing: Overview of Optimization And Yield Analysis

References

- [1]* Main reference for this chapter is the online help of ADS software.
- [2] D. A. Wismer, R. Chattergy, "Introduction to nonlinear optimization", 1978, Elsevier.
- [3] Sobol I. M., "The Monte Carlo method", 1974, The University of Chicago Press.
- [4] R. Spence, R. S. Soin, "Tolerance design of electronic circuits", 1988, Addison-Wesley.

1.0 Optimization

Optimization

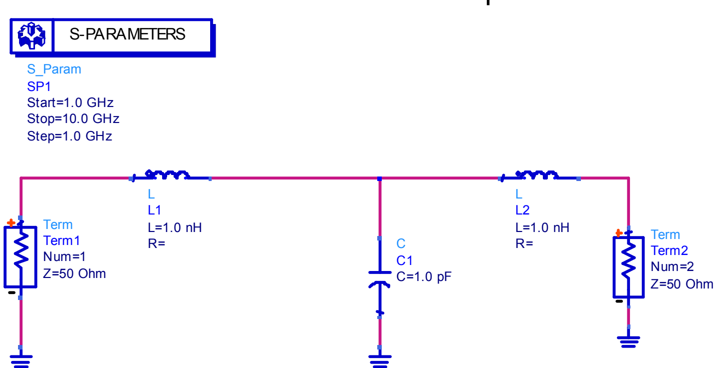
- Nominal Optimization, also known as Performance Optimization, is the process of modifying a set of parameter values to satisfy predetermined performance goals or Objective Functions in mathematical terms.
- Optimizers compare computed and desired responses and modify design parameter values to bring the computed response closer to that desired.
- A positive value, which is related to the difference between the simulated results and the performance goals is known the Error Function.
- The objective of optimization is to minimize the error function.
- Here an example is introduced first to illustrate the concept, followed by a short discussion on the theory.

Example 1 – Design of Low-Pass Filter Using Nominal Optimization with ADS Software

- ADS2002 software is used.
- In this example, we attempt to design a third order low-pass filter through optimization.
- A T-type LC network is constructed. The values of the inductors and capacitance needed to produce the following frequency response are unknown.
  - $|S_{21}| > 0.9$ (-0.457dB) from 100MHz to 450MHz.
  - $|S_{21}| < 0.05$ (-13.01dB) from 500MHz to 1000MHz.
- Nominal optimization is performed to find the best set of L and C that fulfills the conditions. In this example, the above conditions will be our goal functions.

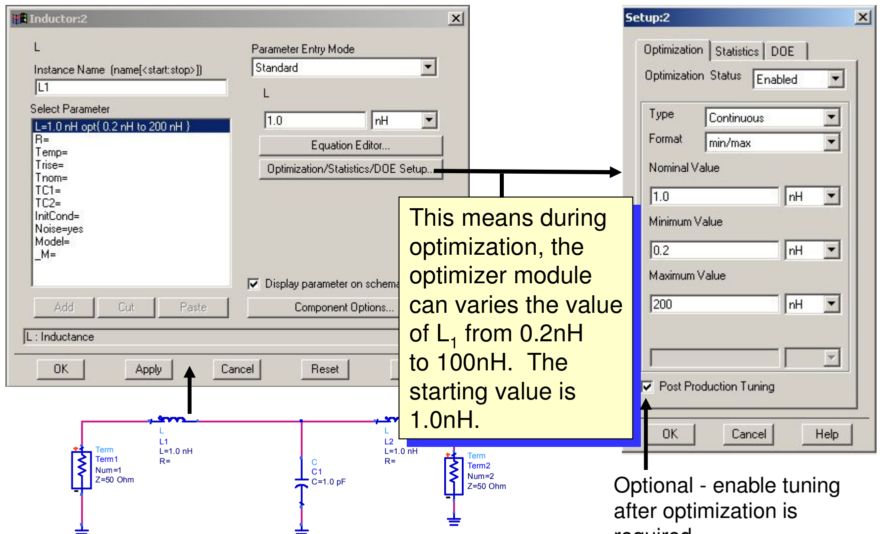
Example 1 Cont...

- The basic circuit and simulation setup is constructed.



- Double click on each element, and enable optimization as shown in the following slide. Set the range of the component values as shown.

Example 1 Cont...

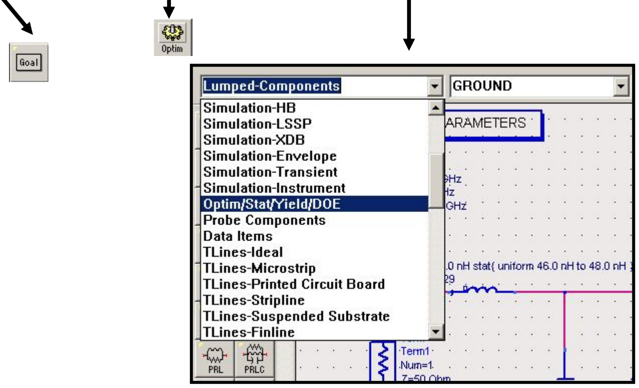


This means during optimization, the optimizer module can varies the value of L_1 from 0.2nH to 100nH. The starting value is 1.0nH.

Optional - enable tuning after optimization is required.

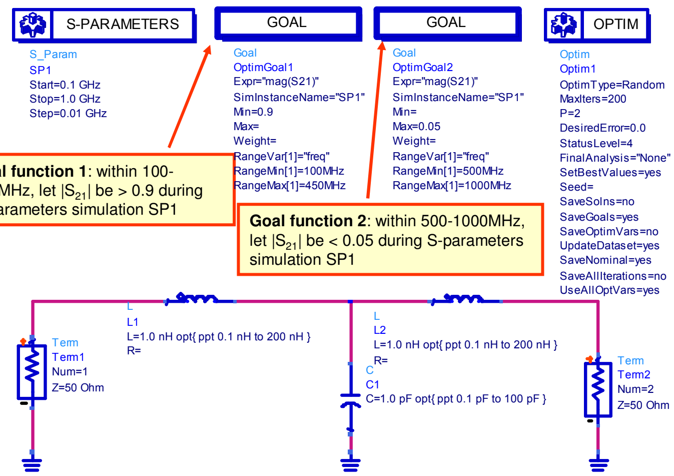
Example 1 Cont...

- From the Optim/Stat/Yield/DOE components palette, insert the goal functions and optimization control as shown in the following slide.



Example 1 Cont...

- Edit the goal functions and optimization control as follows.



Goal function 1: within 100-450MHz, let $|S_{21}|$ be > 0.9 during S-parameters simulation SP1

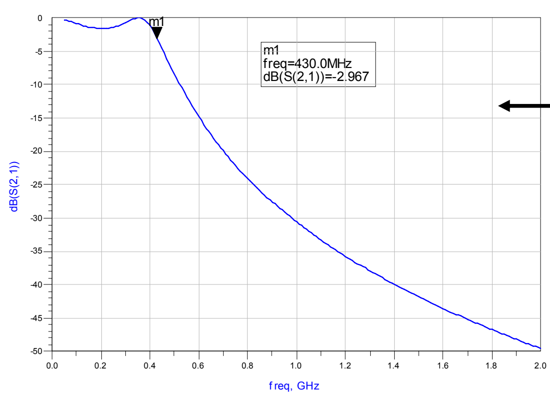
Goal function 2: within 500-1000MHz, let $|S_{21}|$ be < 0.05 during S-parameters simulation SP1

- **Optim1**: optimize the values of L_1, L_2 and C_1 using **Random** search so that the simulated S_{21} be as close as possible to Goal Function 1 & 2.
- **Error Function**: Least Square.
- Stop after 200 iterations or upon fulfilling Goal Functions.
- Information displayed level = 4 (most info).

Example 1 Cont...

- Run the simulation, which produce the following results:

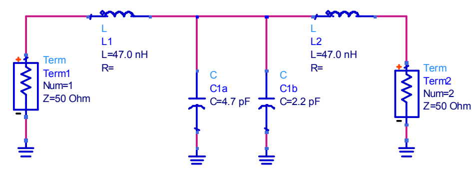
C	L1.L	L2.L	NumIters	InitialEF	FinalEF
6.954E-12	4.736E-8	4.750E-8	150.000	0.902	0.020

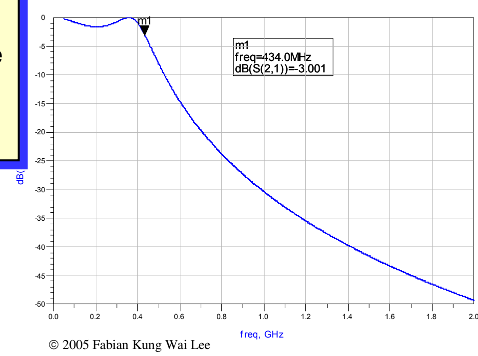


Upon substituting the suggested values for L_1, L_2 and C_1 and running an S-parameter simulation, this curve is obtained.

Example 1 Cont...

- Now we would like to implement the filter using standard L and C values which can be bought off the shelf. So the circuit shown is adopted instead.
- The simulated $|S_{21}|$ is also shown, which does not deviate much from the previous curve.
- This concludes the example.





Error Function Formulation (1)

Extra

- Before we begin, let us introduce some terms.

F_j - the set of frequency values specified by the "jth" frequency range.
$R_{ij}(f)$ - the "ith" frequency dependent response that is being optimized over the "jth" frequency range.
g_{ij} - the "ith" goal value within the "jth" frequency range that is the optimization criterion corresponding to the R_{ij} response.
w_{ij} - the "ith" goal weighting factor, within the "jth" frequency range, associated with the R_{ij} response and g_{ij} goal.
$e_{ij}(f)$ - the frequency dependent error contribution due to differences between R_{ij} and g_{ij}, evaluated at frequency "f."

- Based on this definition, in Example 1:
  - i = 1,2 as we have 2 goal functions, g_{1j} and g_{2j}.
  - j = 1,2 as we have 2 frequency ranges, F_1=100-450MHz and F_2=500-1000MHz.
  - f = the frequency points within each frequency range.

Error Function Formulation (2)

Extra

- Least-square Error Function, E_{LS}:

$$e_{ij} = \left| R_{ij}(f) - g_{ij}(f) \right|^2$$

$$E_{ij} = w_{ij} \sum_{f \in F_j} e_{ij}(f)$$

The weighting factor w_{ij} is used to emphasize or deemphasize the error within certain frequency range.

$$E_j = \frac{\sum_i E_{ij}}{\sum_i N_{ij}} = \frac{w_{ij} \sum_{f \in F_j} e_{ij}(f)}{\sum_i \sum_{f \in F_j} N_{ij}(f)}$$

The no. of frequency points with range F_j, for goal function g_i

$$E_{LS} = \sum_j E_j$$

Error Function Formulation (3)

Extra

- Minimax Error Function, E_{MM}:

This means "for all"

$$E_{MM} = \max\left\{ w_{ij} e_{ij}(f) \right\} \forall\, i, j, f$$

$$\text{where} \quad e_{ij}(f) = R_{ij}(f) - g_{ij} \;,\; R_{ij}(f) \le g_{ij}$$

$$e_{ij}(f) = g_{ij}(f) - R_{ij} \;,\; R_{ij}(f) \ge g_{ij}$$

- Minimax L_1 Error Function, E_{MML1}:

$$E_{MML} = \max\left\{ 0, w_{ij} e_{ij}(f) \right\} \forall i, j, f$$

Error Function Formulation (4)

- Least Pth Error Function, E_{LP}:

$$E_{max} = \max_i \{E_i\}$$

$$E_{LP} = \left[\sum_i (E_i)^P\right]^{\frac{1}{P}} \quad , \; E_{max} > 0$$

$$= 0 \quad , \; E_{max} = 0$$

$$= \left[\sum_i (-E_i)^{-P}\right]^{\frac{-1}{P}} \quad , \; E_{max} < 0$$

Usually P = 2, 4, 6 ….

Optimizer Methods to Minimize the Error Function (1)

- The various methods depend on the algorithm used (the search method) and the error function considered.
- The search method determines how the optimizer arrives at new parameter values, while the error function measures the difference between computed and desired responses. The smaller the value of the error function, the more closely the responses coincide.
- When optimizers execute their search method, they substitute new parameter values to effect a reduction in the error function value.

Optimizer Methods (2)

- The Gradient optimizer is a classical optimization method. Its strive to find find the global minimum by examining the slope of the error function.
- The Minimax optimizer calculates the difference between the desired response and the actual response over the entire measurement parameter range of optimization. Then the optimizer tries to minimize the point that constitutes the greatest difference between actual response and desired response.
- Basically, minimax means minimizing the maximum error.
- The Random optimizer randomly choose a combination of the parameters, search through the entire available range. Sort of a brute force approach.
- Between these, the gradient optimizer uses the least square error function, while the gradient optimizer minimizes the minimax error function. This also applies to random optimizer etc

Optimizer Methods (3)

- A summary of optimizer methods (taken from ADS online help):

Gradient	Gradient search method with least-squares error function.
Gradient Minimax	Gradient search method minimax L1 error function.
Random	Random search method with least-squares error function.
Random Minimax	Random search method with minimax L1 error function.
Minimax	Two-stage, Guass-Newton/Quasi-Newton method with minimax error function.
Quasi-Newton	Quasi-Newton search method with least-squares error function
Least P^{th}	Quasi-Newton search method with least Pth error function.
Genetic	Direct search method using evolving parameter sets.

2.0 Yield Analysis

Yield Analysis

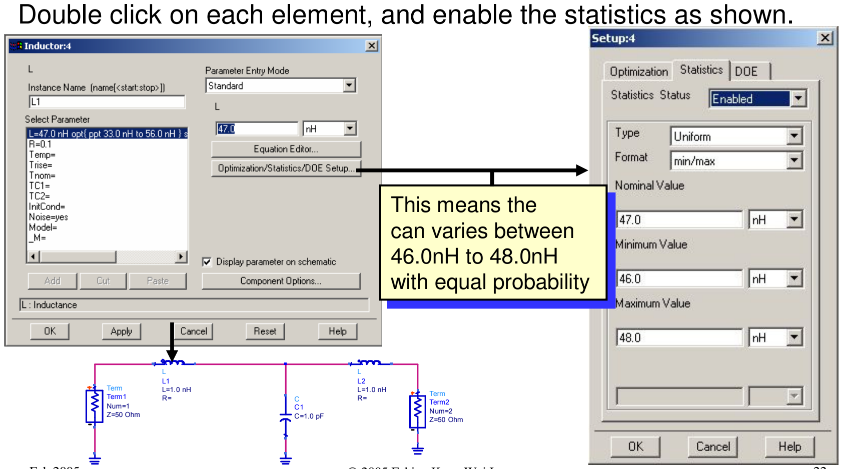
- Yield analysis determines the percentage of acceptable and unacceptable units based on a certain specifications (YieldSpec).
- Yield analysis randomly varies network parameter values according to the statistical distributions of the parameters while comparing network measurements to the user-specified performance criteria found in the specification (YieldSpec).
- Yield analysis is based on the Monte Carlo method, Sobol [4]. A series of trials is run in which random values are assigned to all of the design's statistical variables, a simulation is then performed, and the yield specifications are checked against the simulated measurement values.
- The number of passing and failing simulations is accumulated over the set of trials and used to compute the yield estimate.
- As the no. of trails are increased, the more accurate and stable it is the results of the Yield analysis.

Example 2 – Yield Analysis of Low-Pass Filter Using ADS Software

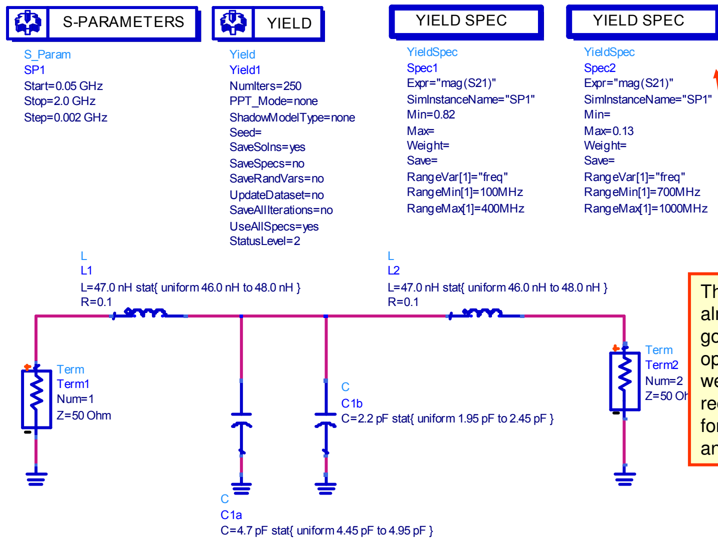
- ADS2002 software is employed.
- The problem in Example 1 is reused again.
- Suppose we use the SMD inductor from Murata for L_1 and L_2. The inductor: 0603 package, 2600MHz Self-Resonance-Frequency, min Q factor 38. Tolerance ±2%. Max. d.c. series resistance 0.1Ohm.
- For capacitor C_1 and C_2, we use the SMD multilayer ceramic capacitor from Phycomp. The capacitor: 0603 package, NPO grade dielectric. Tolerance ±0.25pF for < 4.7pF. Breakdown voltage 50V d.c.

Example 2 Cont...

- The following schematic is constructed with the corresponding S-parameter simulation controller.
- Double click on each element, and enable the statistics as shown.



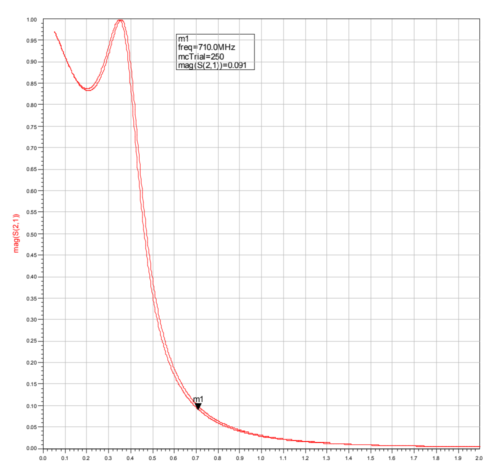
Example 2 Cont...



The Yield Spec are almost similar to the goal functions for optimization. Except we relax the requirement for $|S_{21}|$ in the passband and stopband slightly.

Example 2 Cont...

mcTrial	NumFail	NumPass	Yield
0 250	8.000	242.000	96.800



3.0 Yield Optimization

Yield Optimization

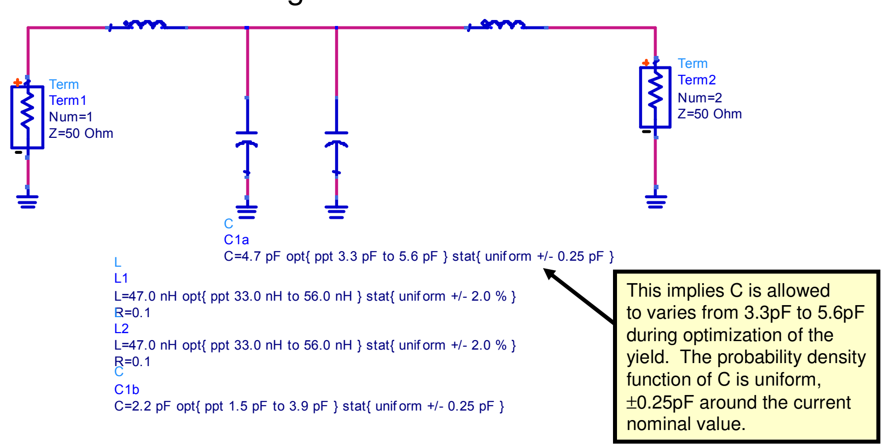
- Yield optimization adjusts nominal values of selected element parameters to maximize yield. Also referred to as design centering, yield optimization is the process in which the nominal values of yield variables are adjusted to maximize the yield estimate.
- When you activate yield optimization, you are required to enter the number of design iterations. This is the number of yield improvements you wish the simulator to obtain. Each design iteration may require several yield analyses (yield estimations).
- The number of trials to be used for each yield analysis is not required. The number of trials is a dynamic variable computed during yield optimization, varying with changing yield estimates and confidence levels.

Example 3 - Performing Yield Optimization with ADS Software

- ADS2002 software is used.
- In this example the schematic from Example 2 is reused.
- We would like to optimized the yield of this low-pass filter based on the requirements on the YieldSpec of Example 2.
- In addition to specifying the statistics of the parameters L_1, L_2 and C_1, the Optimization Status of each parameters is also enabled.
- Since the nominal value of the parameters will be changed, the statistical information is defined as uniform, but with ±delta or ±% options.
- After the modification, the schematics is as shown in the next slide.

Example 3 Cont...

- The final schematic. The Yield, YieldSpec controls are shown in following slide.



Example 3 Cont...

S-PARAMETERS

S_Param
SP1
Start=0.05 GHz
Stop=2.0 GHz
Step=0.002 GHz

YIELD OPTIMIZATION

YieldOptim
YieldOpt1
NumIters=16
MaxTrials=
PPT_Mode=none
ShadowModelType=none
Seed=
SaveSolns=no
SaveSpecs=yes
SaveRandVars=no
UpdateDataset=yes
SaveAllIterations=no
UseAllSpecs=yes
StatusLevel=4
RestoreNomValues=

YIELD SPEC

YieldSpec
Spec1
Expr="mag(S21)"
SimInstanceName="SP1"
Min=0.82
Max=
Weight=
Save=
RangeVar[1]="freq"
RangeMin[1]=100MHz
RangeMax[1]=400MHz

YIELD SPEC

YieldSpec
Spec2
Expr="mag(S21)"
SimInstanceName="SP1"
Min=
Max=0.13
Weight=
Save=
RangeVar[1]="freq"
RangeMin[1]=700MHz
RangeMax[1]=1000MHz

Example 3 Cont...

- After yield optimization, we observe that 100% yield can be obtained (based on the criteria of YieldSpec) if we allow the nominal values of:
  - C1a = 4.732pF
  - C1b = 2.184pF
  - L1 = 45.93nH
  - L2 = 45.47nH
- However in reality, such values are not obtainable as standard off-the-shelf components. This is basically just a theoretical study on yield optimization.

FinalYield	InitialYield	C1a.C	C1b.C	L1.L	L2.L
100.000	84.000	4.732E-12	2.184E-12	4.593E-8	4.547E-8