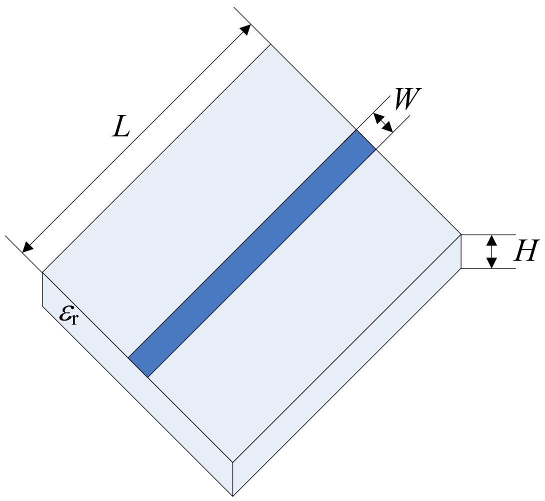
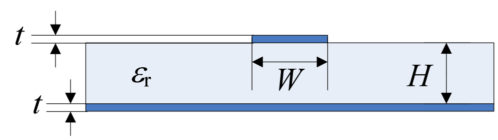
CIRCUIT DESIGN BY OPTIMIZATION

Dr. J. E. Rayas-Sánchez

OPTIMIZING A SIMPLE MICROSTRIP LINE: A SOLUTION

Consider a conventional microstrip line whose physical structure is shown below. The width of the microstrip line is W, the length is L and its metal thickness is t. The microstrip line is on a dielectric substrate with relative dielectric constant ε_r and loss tangent tan(δ). The substrate height is H. Bellow the substrate there is a metallic ground plane whose thickness is also t. Metal has a conductivity σ.





This microstrip line uses the following parameters:

Substrate parameters: $\varepsilon_r = 3.6$, tan(δ) = 0.01, H = 16 mil.

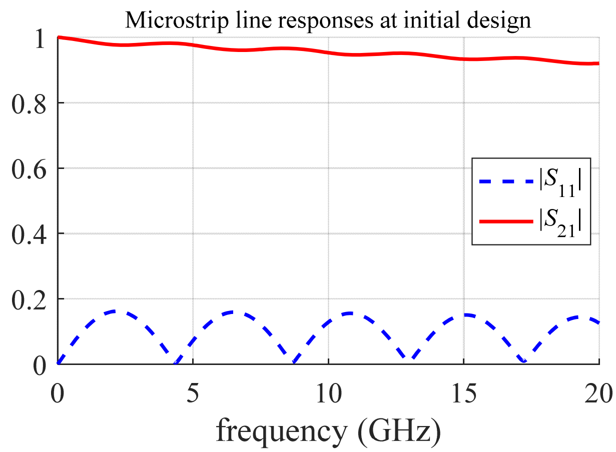
Metals: t = 0.65 mil (half-once copper), $\sigma = 5.8\times10^7$ S/m.

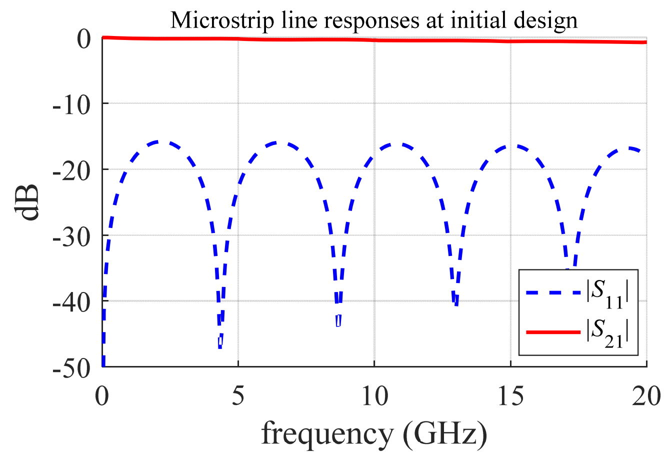
Trace: L = 800 mil, W = 45 mil.

1. Optimization Variables and Starting Point

The optimization variable is $\boldsymbol{x}$ = [W(mil)], with a starting point $\boldsymbol{x}^{(0)}$ = [45].

Circuit responses at $\boldsymbol{x}^{(0)}$





2. Design Specifications

Design specs are:

$$|S_{11}| \rightarrow 0 \text{ in the complete simulated frequency band}$$

3. Formulation of the Optimization Problem

$$\boldsymbol{x}^* = \arg\min_{\boldsymbol{x}} \max\{\ldots e_k(\boldsymbol{x})\ldots\}$$

where the k-th error function is given by

$$e_k(\boldsymbol{x}) = \frac{|S_{11}|(\boldsymbol{x})}{|S_{11}|_{\max}} - 1 \quad \text{for} \quad f_L < f_k < f_H$$

where f_L and f_H are the lowest and highest simulated frequencies, respectively, f_k is the k-th simulated frequency point, and $|S_{11}|_{\max}$ is a maximum acceptable level of reflection. For instance, $|S_{11}|_{\max} = 0.1$.

4. Objective Function Implementation

```
% ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
%         Objective Function for a Microstrip Line Simulated in APLAC

function MaxError = OF_mcsLine_APLAC(X)

mS11max = 0.1;

% Pre-assigned Parameters, Xp = [H L epsr losstan thck rho]
H = 16;           % Substrate height (units).
L = 800;          % Length of the microstrip line (units).
epsr = 3.6;       % Substrate relative dielectric constant.
losstan = 0.01; % Substrate loss tangent.
thck = 0.65;      % Metal thickness (units).
rho = 0.7066;     % Metal resistivity normalized to that of gold.
Xp = [H L epsr losstan thck rho];

% Parameters of the Simulator, Ps
units = 1; % Units for APLAC lengths: mil(1), mm(2), um(3).
IF = 2e6;  % Initial frequency (Hz).
FF = 20e9; % Final frequency (Hz).
FP = 301;  % Number of frequencies per sweep.
Ps = [units IF FF FP];

% Calculate Circuit Response
[f,S] = mcsLine_APLAC(X,Xp,Ps);
mS11 = S(:,1);

% Calculate Error Functions
e = mS11/mS11max - 1; % Upper bound for mS11.

% Calculating Objective Function Value
MaxError = max(e);
```

5. Optimization Results

$\boldsymbol{x}^{(0)} = [45]$.

A) Using the Nelder-Mead Method

```
options = optimset('MaxFunEvals',1000,'MaxIter',1000,'TolX',1e-2);
[Xopt,FunVal,EF,output] = fminsearch('OF_MFBP2',Xo,options);
```

FP	$\boldsymbol{x}^{*T}$	$u(\boldsymbol{x}^*)$	iter	OFE
151	34.9233	-0.94703	14	28
301	34.9211	-0.94702	14	28
1000	34.9211	-0.94702	14	28
50	34.9233	-0.94703	13	26

iter: number of iterations.
OFE: number of objective function evaluations = WinSpice simulations.

It is seen that the objective function formulation is quite insensitive to FP, as expected.
Using `'TolX'= 1e-5` and FP = 301, Nelder-Mead requires much more iterations and function evaluations: $\boldsymbol{x}^* = [34.9222]$, $u(\boldsymbol{x}^*) = -0.94715$, iter = 22, OFE = 47.

B) Using Gradient-Based Methods (gradients calculated by finite central differences, `h = 1e-4`)

```
MaxIter = 1000; epsg = 1e-5; epsx = 1e-5;
```

FP = 301

Method	$\boldsymbol{x}^{*T}$	$u(\boldsymbol{x}^*)$	iter	OFE
Steepest Descent	34.9222	-0.94715	2	53
Conjugate Gradient	34.9222	-0.94715	2	53
Quasi-Newton (BFGS)	34.9222	-0.94715	2	53