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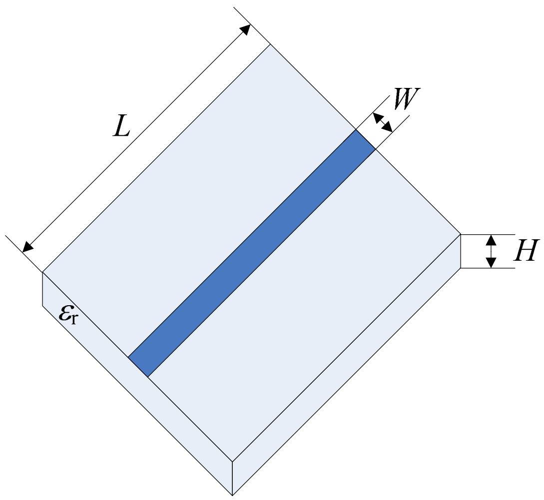
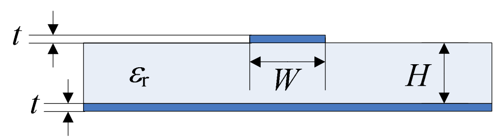
OPTIMIZING A SIMPLE MICROSTRIP LINE: PROBLEM STATEMENT

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.





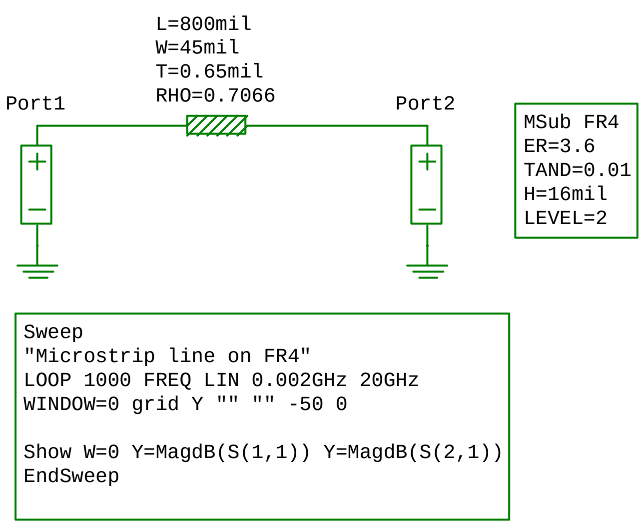
This microstrip line uses the following parameters:

Substrate parameters: ε_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.

An implementation of this circuit in APLAC is shown below,

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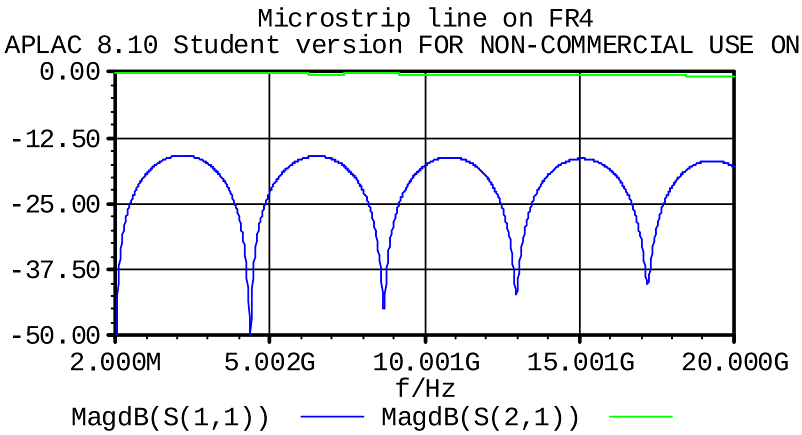
$ ----------------------------------------------

MSub FR4
+ ER=3.6
+ TAND=0.01
+ H=16mil
+ LEVEL=2

Mlin Mlin1 Port10 Port20
+ L=800mil
+ W=45mil
+ T=0.65mil
+ RHO=0.7066
DefNPort nport 2
+ Port10 GND 50
+ Port20 GND 50
Sweep "Microstrip line on FR4"
+ LOOP 1000 FREQ LIN 0.002GHz 20GHz
+ WINDOW=0 grid Y "" "" -50 0
Show W=0 Y=MagdB(S(1,1)) Y=MagdB(S(2,1))
EndSweep
```

The corresponding responses are:



Creating a Matlab driver to simulate the microtrip line in APLAC:

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% ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
%              Matlab Driver for a Microstrip Line Simulated in APLAC
%
% This function drives APLAC to simulate a microstrip line in frequency domain.
% Usage: [f,S] = mcsLine_APLAC(x,IF,FF,FP)
%         X = [W], design variables.
%         Xp = [H L epsr losstan thck rho], pre-assigned parameters.
%         Ps = [units IF FF FP], parameters of the simulator.
%         f: column vector of FP simulated frequency points (Hz).
%         S: matrix of S-parameters, with size FP by 4. Each row of S contains
%            [mS11 pS11 mS21 pS21], with phases in degrees.
% Functions required: None.

function [f,S] = mcsLine_APLAC(X,Xp,Ps)

% APLAC Executable File in Command Line Mode
APLACroot = 'C:\"Program Files (x86)"\APLAC\';
APLACexe = [APLACroot '"APLAC 8.10 Student"\bin\aplac.exe']; % Student version.

% APLAC Project File Name
AplacProjectFileName = 'mcsLine_m.i';

% Parameters of the Simulator, Ps = [units IF FF FP]
units = Ps(1);       % Units for APLAC lengths: mil(1), mm(2), um(3).
IF = num2str(Ps(2)); % Initial frequency (GHz).
FF = num2str(Ps(3)); % Final frequency (GHz).
FP = num2str(Ps(4)); % Number of frequencies per sweep.

% APLAC Length Units
if units==1
    LNGunits = 'mil';
elseif units==2
    LNGunits = 'mm';
elseif units==3
    LNGunits = 'um';
else
    disp('Error in definition of APLAC units!')
    return
end
```
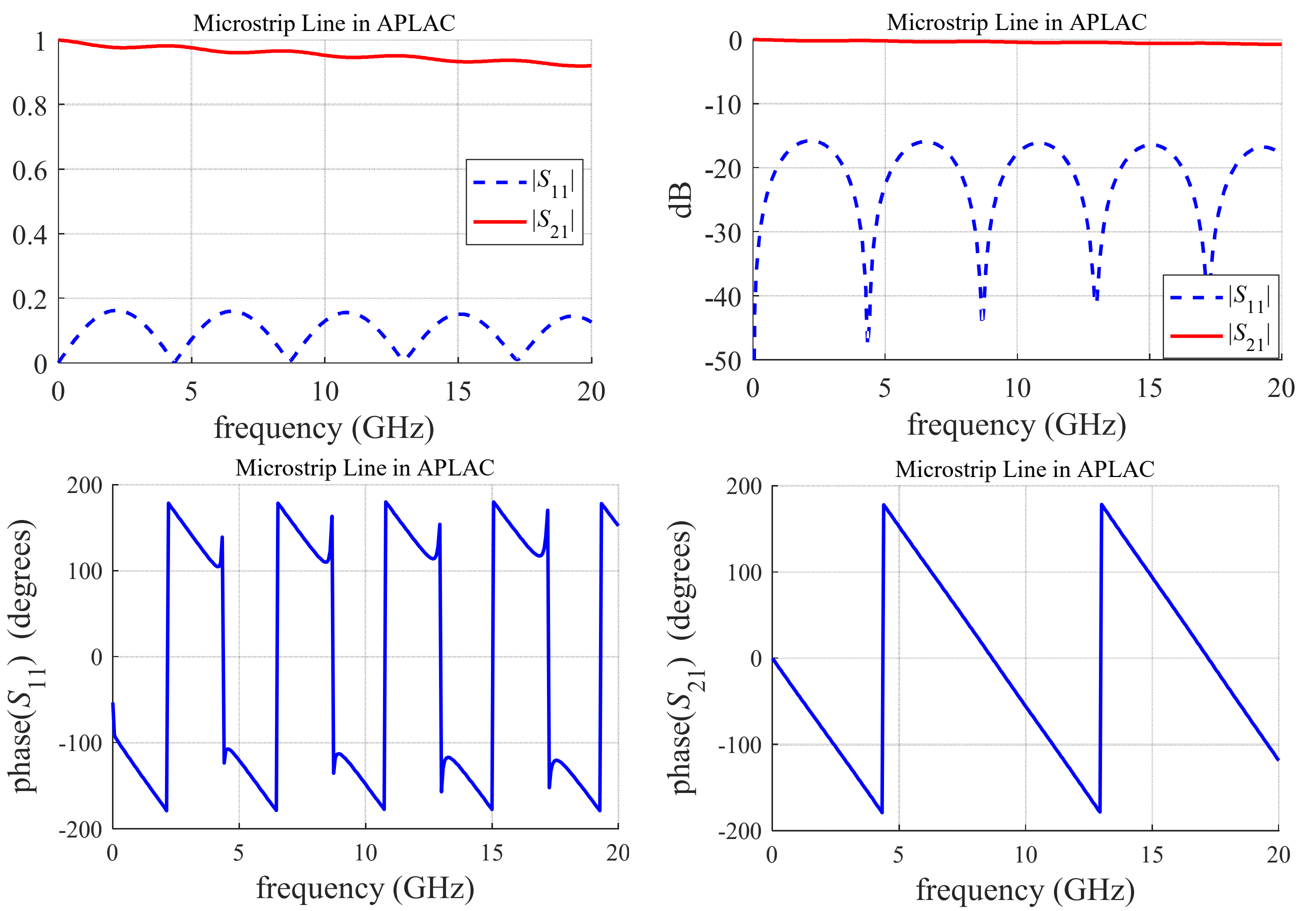

```
% Design Variables, X = [W]
W = [num2str(X(1)) LNGunits] ;    % Width of the microstrip line (units).

% Pre-assigned Parameters, Xp = [H L epsr losstan thck rho]
H = [num2str(Xp(1)) LNGunits];    % Substrate height (units).
L = [num2str(Xp(2)) LNGunits];    % Length of the microstrip line (units).
epsr = num2str(Xp(3));            % Substrate relative dielectric constant.
losstan = num2str(Xp(4));         % Substrate loss tangent.
thck = [num2str(Xp(5)) LNGunits]; % Metal thickness (units).
rho = num2str(Xp(6));             % Metal resistivity normalized to that of gold.

% Define APLAC Script, as
as{1} = '$ -------------------------------------------------------------';
as{2} = '$ Microstrip Line in APLAC';
as{3} = '$ Generated with APLAC Editor version 3.1.3';
as{4} = '$ Mon Sep 22 20:26:57 2008';
as{5} = '$ -------------------------------------------------------------';
as{6} = 'MSub SubstrateName';
as{7} = ['+ ER=' epsr];
as{8} = ['+ TAND=' losstan];
as{9} = ['+ H=' H];
as{10} = '+ LEVEL=2';
as{11} = 'Mlin Mlin1 Port10 Port20';
as{12} = ['+ L=' L];
as{13} = ['+ W=' W];
as{14} = ['+ T=' thck];
as{15} = ['+ RHO=' rho];
as{16} = 'DefNPort nport 2';
as{17} = '+ Port10 GND 50';
as{18} = '+ Port20 GND 50';
as{19} = 'Sweep "Microstrip line on SubstrateName"';
as{20} = ['+ LOOP ' FP ' FREQ LIN ' IF 'Hz ' FF 'Hz'];
as{21} = 'Print appendfile "ac_results.txt" real f bl real Mag(S(1,1)) bl real
Pha(S(1,1)) bl real Mag(S(2,1)) bl real Pha(S(2,1)) lf';
as{22} = 'EndSweep';

% Save APLAC Script as a Circuit File in Matlab Working Directory
ckt_file = char(as);
[rows,~] = size(ckt_file);
fid = fopen(AplacProjectFileName,'w+');  % File identifier opened.
for i = 1:rows
   fprintf(fid, '%s', ckt_file(i,:)); % Save each row of ckt_file.
   fprintf(fid, '%s\r\n', '');
end
fclose(fid);  % File identifier closed.

% Run APLAC
ti = clock;
system([APLACexe ' ' AplacProjectFileName ' -aq']);
tf = clock;
SimulationTime = etime(tf,ti);
disp(['Total simulation time = ' mat2str(SimulationTime/60,5) ' minutes']);

% Read APLAC Output Files
load ac_results.txt
f = ac_results(:,1);   % Read column of simulated frequencies.
S = ac_results(:,2:5); % Read columns of S-parameters.
```

```
% Erase APLAC Output Files
delete ac_results.txt;
```

Running the previous Matlab function and plotting the corresponding responses:



Based on the previous Matlab function, write a suitable objective function to optimize the microstrip line such that its $|S_{11}|$ is as small as possible in the complete frequency band. For the optimization method use: a) your algorithm for Conjugate Gradient optimization; b) your algorithm for Quasi-Newton optimization; and c) the Nelder-Mead method available in Matlab (`fminsearch`).