1. Circuit design by optimization

Consider the following microstrip low-pass filter [1,2]. The input-output 50-Ω microstrip lines have a width $W_p = 2.45$ mm, with a length $L_p = 5W_p = 12.25$ mm. These lines are symmetrically separated by a distance $S_1$ with a microstrip line whose width is $W_1$. The separating microstrip line is terminated at both ends by an open stub whose length is $L_1$.

The microstrip structure is on a substrate with thickness $H = 0.794$ mm, relative dielectric permittivity $\varepsilon_r = 2.2$, and loss tangent $\tan(\delta) = 0.01$. All metals use half-once copper with electrical conductivity $\sigma = 5.8 \times 10^7$ S/m and thickness $t = 0.6$ mil $= 15.24$ µm.

The design specifications for this filter are:

\[
|S_{21}| > 0.9 \text{ for } 0.2 \text{ GHz} \leq f \leq 6 \text{ GHz} \\
|S_{21}| < 0.1 \text{ for } 8 \text{ GHz} \leq f \leq 10 \text{ GHz}
\]

Formulate an optimization problem for this filter to satisfy the previous design specifications. Use as optimization variables the following parameters $x = [W_1 \quad L_1 \quad S_1]^T$, keeping fixed the following pre-assigned parameters $z = [H \quad \varepsilon_r \quad W_p \quad L_p \quad \tan(\delta) \quad \sigma \quad t]^T$.

As starting points for optimization, consider the following initial designs:

- $W_1 = 3.5$ mm, $L_1 = 5.6$ mm, $S_1 = 4.2$ mm
- $W_1 = 6.7$ mm, $L_1 = 5.2$ mm, $S_1 = 5.8$ mm
- $W_1 = 1.9$ mm, $L_1 = 4.1$ mm, $S_1 = 3.3$ mm

This filter is implemented in the high-frequency circuit simulator APLAC, as illustrated in the following page.
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APLAC uses parameter RHO to define the normalized resistivity of the metal (in this case $\rho_{Cu} = 1/\sigma_{Cu} = 17.2414 \text{ n}\Omega\text{-m}$) with respect to the resistivity of gold ($\rho_{Au} = 24.4 \text{ n}\Omega\text{-m}$). Then $RHO = \frac{17.2414}{24.4} = 0.7066$ for this particular problem.

APLAC file:

```
$--------------------------------------
var Wp 2.45mm
var W1 3.5mm
var L1 5.6mm
var S1 4.2mm
var Lp 12.25mm
var thck 15.24e-3mm
var roCuAu 0.7066
MSub Unknown
  ER=2.2
  TAND=0.01
  H=0.794mm
Mlin Mlin1 node1 node2
  + L=L1 W=W1 T=thck RHO=roCuAu
Mloc Mloc1 node3
  + L=L1 W=W1 T=thck RHO=roCuAu
Mlin Mlin2 node4
  + L=L1 W=W1 T=thck RHO=roCuAu
Mloc Mloc2 node5
  + L=L1 W=W1 T=thck RHO=roCuAu
Mlin Mlin3 node6 out
  + L=Lp W=Wp T=thck RHO=roCuAu
Mlin Mlin4 in node5
  + L=Lp W=Wp T=thck RHO=roCuAu
Mlin Mlin5 in node6
  + L=Lp W=Wp T=thck RHO=roCuAu
Mloc Mloc3 node7
  + L=L L=thick T=thck RHO=roCuAu
DefNPort nport 2 in GND 50 out GND 50
  + LOOP 300 FREQ LIN 1KHz 10GHz
  + WINDOW=0 grid Y "S11" "0 1"
  + WINDOW=1 grid Y "S21" "0 1"
Show W=0 Y=Mag(S(1,1))
Show W=1 Y=Mag(S(2,1))
EndSweep
```
2. Circuit parameter extraction by optimization

Consider the following state-variable band-rejection filter [3]. The filter is using Op-Amps µA741 and is simulated in WinSpice. We want to extract the parameters values for all the resistors and capacitors of the filter such that the magnitude of its voltage gain is as close as possible to the target response shown below.

The initial filter parameters $x^{(0)}$ are:

- $R_{11} = 20$ KΩ
- $C_1 = 7.96$ nF
- $R_{12} = 20$ KΩ
- $C_2 = 7.96$ nF
- $R_{13} = 20$ KΩ
- $R_{21} = 20$ KΩ
- $R_{22} = 20$ KΩ
- $R_{31} = 22$ KΩ
- $R_{32} = 20$ KΩ
- $R_{41} = 10$ KΩ
- $R_{42} = 3.3$ KΩ
- $R_{43} = 10$ KΩ
- $R_{44} = 10$ KΩ
- $R_5 = 5.1$ MΩ
- $R_6 = 20$ KΩ

The filter response at the starting point (before parameter extraction) is also shown in the figure above.

Write down a Matlab script to drive the corresponding WinSpice file.

Formulate and solve an optimization problem to extract the filter parameters that make $|A_v|$ as close as possible to the target response. Compare your results using a Manhattan, Euclidean and Chebyshev objective function. To minimize the objective function, use your implementation of the Conjugate Gradient algorithm, your Quasi-Newton algorithm, or the Nelder-mead method available in Matlab (fminsearch).
Explore the effects of varying the number of frequency points used in the target response (use text data files provided in the course website).

Include in your report the references and conclusions.

Submission deadline: April 12, 2019.

