A SIX-RESONATOR C-BAND H-PLANE WAVEGUIDE FILTER

N. Georgieva

SOS-98-31-R

October 1998

© N. Georgieva 1998

No part of this document may be copied, translated, transcribed or entered in any form into any machine without written permission. Address inquiries in this regard to Dr. J.W. Bandler. Excerpts may be quoted for scholarly purposes with full acknowledgment of source. This document may not be lent or circulated without this title page and its original cover.

A Six-Resonator C-Band H-plane Waveguide Filter

Natalia Georgieva

Simulation Optimization Systems Research Laboratory and Department of Electrical and Computer Engineering McMaster University, Hamilton, Canada L8S 4L7



presented at

SOS Research Laboratory Meeting, Hamilton, October 15, 1998

General Structure Description

The optimization example considered here is a six-resonator H-plane waveguide C-band filter. The passband is from 5.4 GHz to 9 GHz. For this design a waveguide with a cross-section of 1.372 inches by 0.622 inches is used. The six resonators are separated by seven H-plane septa (see Fig. 1). The symmetry of the dominant-mode field distribution is used and a perfect H boundary is applied.

The filter was designed, manufactured and measured by Leo Young and M. Schiffman [1]. The measurements show that the measured VSWR is slightly larger than the predicted one. A direct optimization is performed using HP HFSS to enhance the performance of the filter.



Fig. 1. The nominal geometry file.

Optimization Variables

The structure is symmetrical with respect to the central septum (the center of its length). There are seven optimization variables: the four septa's widths and the three resonators' lengths. The nominal project was built after the values reported in [1] and in [2]. Only half of the width of each septum corresponds to the c_i (*i*=1, ...,4) in TABLE 1 because the symmetry of the structure was used.

TABLE 1

OPTIMIZATION VARIABLES: NOMINAL AND PERTURBED VALUES

	nominal, inches	perturbed, inches
c1	0.513	0.514
c2	0.479	0.480
c3	0.449	0.450
c4	0.435	0.436
11	0.626	0.630
12	0.653	0.660
13	0.674	0.680

The HP HFSS solution setup is shown in the following two figures, Fig. 2 and Fig. 3. The mesh seeding is the default one.

HPHFSS Simulation (Configuration for wgfilter_0	2				
Main Setup Refinemen	t Options Discrete Frequencies M	tesh Seedina				
Mesh Setup	Mesh Setup					
Enable Refineme	Enable Refinement (Select "Refinement Options" Tab)					
-Starting Mesh						
initial	C previous	O last				
Save Modal Solution	ns					
C All © Dominant						
Save Field Solutions						
	• Last					
- Fast Frequency Sw	Fast Frequency Sweep					
🗖 Enable						
Start Freq. (GHz)	Stop Freq. (GHz)	Expand from Freq. (GHz)				
10	20	15				
Additional Discrete F	requencies (GHz) (Select "Dis	crete Frequencies" tab)				
START 9.46 STOP 9.5 LIN 2 START 5.4 STOP 9 LIN 11 START 5.3 STOP 5.34 LIN 2						
0		Cancel				

Fig. 2. Main Setup of the nominal project.

HPHFSS Simulation Configuration	for wgfilter_0		X		
Main Setup Refinement Options Discrete Frequencies Mesh Seeding					
Refinement Criteria					
Global Delta S-Parameter	Delta Error 0.009				
C Matrix Delta S-Parameter	Edit Matrix				
Limit Refinement Passes	•				
The total number of previous refinement passes: 0					
Limit the number of additional refinement passes to 10					
Mesh Frequency Override					
✓ Refine at a Specified Frequen	су	desh Freq. (GHz) 8			
Additional Discrete Frequencies (G	Additional Discrete Frequencies (GHz) (Select "Discrete Frequencies" tab)				
START 9.46 STOP 9.5 START 5.4 STOP 9 LI START 5.3 STOP 5.34	LIN 2 IN 11 LIN 2				
ОК		Cancel	_		

Fig. 3. Refinement Options of the nominal project.

Direct Optimization Results





Fig. 4. $|S_{11}|$ response before optimization.

The optimization iteration report is shown in Fig. 5. The |S21| response after optimization is in Fig 6.

💩 Empipe3D - wgfilter.ckt *		
<u>File E</u> dit <u>D</u> isplay <u>O</u> ptimize		
🛃 🔊 😸 😑 📃		
Iteration 1/30 Max Er	ror=0.104409	
Iteration 3/30 Max Er Iteration 3/30 Max Er	ror=0.0033899 ror=0.00216314	
Iteration 4/30 Max Er Iteration 5/30 Max Er	ror=-0.0197673 ror=0.196721	
Iteration 6/30 Max Er Iteration 7/30 Max Er	ror=-0.0539404 ror=-0.0520637	
Iteration 8/30 Max Er Iteration 9/30 Max Er	ror=-0.0620888 ror=-0.0616224	
Iteration 10/30 Max Er Iteration 11/30 Max Er	ror=-0.0583411 ror=-0.0543459	
Iteration 12/30 Max Er Iteration 13/30 Max Er	ror=-0.053052 ror=-0.0527287	
Iteration 14/30 Max Er Solution Max Error=-0.	ror=-0.0526479 0620888	
	Optimization completed Elapsed real time: 00:00:01	CPU time 00:00:00 //

Fig. 5. Iteration report for direct optimization starting from the nominal set of values.



Fig. 6. $|S_{11}|$ response after optimization, starting from the nominal set of values.

The Coarse Model

This example was developed for the verification of aggressive space mapping algorithms, which imply the existence of computationally fast coarse models. This particular structure can be relatively easily modeled in terms of an equivalent circuit consisting of lumped inductances and transmission line sections. The simulation of the obtained coarse model is computationally much more efficient in comparison with a full electromagnetic simulation, e.g. using HP HFSS. The equivalent circuit of the structure in Fig. 1 is shown in Fig. 7.



Fig. 7. Equivalent circuit of the six-resonator H-plane waveguide filter.

There are various approaches to calculate the equivalent inductive susceptance corresponding to an H-plane septum (see Fig. 8). The simplest formula is provided by Smythe [3] and is a quasi-static approximation:

$$\frac{B}{Y_0} \approx -\frac{l_g}{a} \left[1 + \csc^2 \left(\frac{\mathbf{p}}{2} \frac{c}{a} \right) \right] \cot^2 \left(\frac{\mathbf{p}}{2} \frac{c}{a} \right)$$
(1)

Here λ_g denotes the guide wavelength.



Fig. 8. Waveguide H-plane septum.

Each waveguide resonator corresponds to a piece of an ideal transmission line characterized by its characteristic impedance Y_0 and by its electrical length θ_i (i=1,2,3). The characteristic impedance Y_0 is equal to the guide wave impedance. The electrical length θ_i is proportional to the physical length of the waveguide section l_i :

$$\boldsymbol{q}_i = 360 \frac{l_i}{\boldsymbol{I}_g} , \text{ deg}$$

The OSA90 netlist file of the coarse model:

```
! Thu Oct 15 12:37:52 1998. Minimax Optimizer. 18 Iterations. 00:00:00 CPU.
Expression
      MS11\_SPEC = 0.16;
      INMM = 25.4;
      V = 2.99792458E+11;
      MU0 = 4*PI*1E-10;
      EPSO = 1/(36*PI)*1E-12;
      GAMMA = SQRT(MU0/EPS0);
      A = 1.372*INMM; B = 0.622*INMM;
      CC1: ?0.557111?;
      CC2: ?0.523275?;
      CC3: ?0.510365?;
      CC4: ?0.508484?;
      C1 = 2*CC1*INMM; C2 = 2*CC2*INMM;
      C3 = 2*CC3*INMM; C4 = 2*CC4*INMM;
     LL1: ?0.633067?;
      LL2: ?0.65315?;
      LL3: ?0.675303?;
     L1 = LL1*INMM; L2 = LL2*INMM;
      L3 = LL3 * INMM;
      LIO = 0.7*INMM;
! wave impedance Z0 and wavelength LAMBDA
      Fc=(1E-9*V)/(2*A); ! GHz
      Z0=GAMMA/SQRT(1-(Fc/FREQ)^2);
      Y0 = 1/Z0;
      LAMBDA=1/SQRT((FREQ*1E+9/V)^2-(1/(2*A))^2);
! Susceptances (quasistatic, after Smythe)
      C1A=C1/A;C2A=C2/A;C3A=C3/A;C4A=C4/A;
      B1=-Y0*(LAMBDA/A)*(1+(1/sin(PI*C1A/2))^2)/((tan(PI*C1A/2))^2);
      B2=-Y0*(LAMBDA/A)*(1+(1/sin(PI*C2A/2))^2)/((tan(PI*C2A/2))^2);
      B3=-Y0*(LAMBDA/A)*(1+(1/sin(PI*C3A/2))^2)/((tan(PI*C3A/2))^2);
      B4=-Y0*(LAMBDA/A)*(1+(1/sin(PI*C4A/2))^2)/((tan(PI*C4A/2))^2);
! inductances (nano-henry)
      LI1=-1/(2.*PI*FREQ*B1);
      LI2=-1/(2.*PI*FREQ*B2);
      LI3=-1/(2.*PI*FREQ*B3);
      LI4=-1/(2.*PI*FREQ*B4);
! electrical lengths of resonators/input lines (degrees)
      THETA1=360.*L1/LAMBDA;
      THETA2=360.*L2/LAMBDA;
      THETA3=360.*L3/LAMBDA;
      THETAIO=360.*LIO/LAMBDA;
end
Model
      TEM 1 2 0 0 Z=Z0 E=THETAIO F=FREQ;
      IND 2 0 L=LI1;
```

```
TEM 2 3 0 0 Z=Z0 E=THETA1 F=FREO;
      IND 3 0 L=L12;
      TEM 3 4 0 0 Z=Z0 E=THETA2 F=FREQ;
      IND 4 0 L=LI3;
     TEM 4 5 0 0 Z=Z0 E=THETA3 F=FREQ;
      IND 5 0 L=LI4;
     TEM 5 6 0 0 Z=Z0 E=THETA3 F=FREQ;
      IND 6 0 L=LI3;
     TEM 6 7 0 0 Z=Z0 E=THETA2 F=FREQ;
      IND 7 0 L=L12;
     TEM 7 8 0 0 Z=Z0 E=THETA1 F=FREQ;
      IND 8 0 L=LI1;
      TEM 8 9 0 0 Z=Z0 E=THETAIO F=FREQ;
      PORT 1 0 R=Z0;
      PORT 9 0 R=Z0;
CIRCUIT;
      MS_dB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
      MS11 dB = MS dB[1,1];
      MS21 dB = MS dB[2,1];
end
Sweep
      AC: FREQ: from 5.3GHz to 5.34GHz step=0.04GHz
                  from 5.4GHz to 9GHz step=0.36GHz
                  from 9.46GHz to 9.5GHz step=0.04GHz
      MS MS_dB PS MS11_dB MS21_dB
      {XSWEEP X=FREQ Y=MS11
            SPEC=(from 5.4 to 9, < 0.16) \&
                 (from 5.3 to 5.34, > 0.34) \&
                     (from 9.46 to 9.5 , > 0.34)};
1
        {XSWEEP X=FREQ Y=MS11
      SPEC=(from 5.4 to 9, < 0.16) &
!
           (from 4.5 to 5.34, > 0.34) \&
!
              (from 9.46 to 10, >0.34)};
!
end
Spec
     AC: FREQ: from 5.4GHz to 9GHz step=0.36GHz
     MS11 < 0.16;
      AC: FREQ: from 5.3GHz to 5.34GHz step=0.04GHz
        MS11 > 0.34;
      AC: FREQ: from 9.46GHz to 9.5GHz step=0.04GHz
     MS11 > 0.34;
end
!Report
1
         Ros=[
!
             ${$MS11$}$
!
             ];
!end
Report
      Xos=[$CC1$
           $CC2$
           $CC3$
           $CC4$
           $LL1$
           $LL2$
           $LL3$];
end
```

Optimization of the coarse model

Before optimization (Fig. 9):



Fig. 9. $|S_{11}|$ response of the coarse model before optimization.

After optimization (Fig. 10):



Fig. 10. $|S_{11}|$ response of the coarse model after optimization.

Multiple Minima

It was observed that the fine model converges to another minimum when the optimal coarse model values of the optimization variables are used as a starting point. The obtained solution is worse in comparison with the one which starts with initial values set equal to the design presented in [1].

References

Leo Young and B. M. Schiffman, "A Useful High-Pass Filter Design," *The Microwave Journal*, 6, No 2, February 1963, pp. 78-80

G. L. Matthaei, L. Young, E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, McGraw-Hill, New York, 1964, pp. 545-547

W. R. Smythe, Static and Dynamic Electricity, 2nd ed., McGraw-Hill, New York, 1950