Application Note

Using Serenade Wireless Design Suite to Design a Microstrip Hairpin Filter for the 1900MHz Wireless PCS Band.

by

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Abstract

This application note discusses the design procedure for a 1900MHz PCS microstrip hairpin filter using Serenade Wireless Design Suite. The design procedure includes entering the schematic of the filter, simulation, optimization and layout.

Introduction

In today's fast-growing wireless industry, time to market is critical. Smaller and less expensive units are becoming the norm and the use of CAD tools to quickly and accurately simulate the behavior of wireless components becomes more important as designs become more complex and prototyping cycles become shorter. Serenade combines all the tools necessary to decrease time to production by utilizing an intuitive schematic capture interface, efficient and accurate linear and non-linear simulators and an integrated layout tool to view and export the design in a wide range of formats without repeated attempts at bench prototyping. In this application note, a 3-section microstrip hairpin filter tuned for the 1900MHz PCS band is used as an example to demonstrate the capabilities of Serenade in the design of distributed element passive devices for microwave frequencies.

Background

Lumped element filters are impractical for compact designs of wireless communications equipment, especially hand-held devices. Distributed element filter design offers a much smaller area and profile. With the advent of advanced substrate materials offering very high dielectric constants with low loss, the size reduction with preserved efficiency is greatly enhanced. The microstrip hairpin filter is ideal for microwave frequencies thus facilitating fabrication. The theory governing coupled distributed element filters will not be discussed here, but the details can be found elsewhere [1]. The length of the coupled lines to provide a bandpass response at the frequency of interest is a half wavelength. At a half-wavelength the coupled lines need not be connected to the ground plane, which simplifies its fabrication. Initial values for the microstrip filter dimensions can be calculated with Serenade's Transmission Line Designer. These values are entered into the circuit design and subsequently optimized, as will be discussed later. Three hairpin structures in the filter will provide sufficient flatness over the 1850MHz to 1990MHz band.

Design Procedure

The first step in the design procedure is to determine the dimensions required for the microstrip filter. Using Serenade's Transmission Line Designer utility, a starting point can be obtained for the microstrip line widths and lengths. The data required by this utility to synthesize the microstrip dimensions are the substrate parameters, in this case RT/Duroid 6006 [ε_r=6.15 ± 0.15, tand=0.0027, 50mil thick, 1 oz Copper (35um)], the impedance of the lines (50 ohms), the electrical length (180 degrees) and the frequency (1.92GHz). Figure 1 shows the dialog box where these parameters are entered for synthesis along with the results for the microstrip dimensions: 1.83mm and 37.2mm for the microstrip widths and lengths, respectively. The TRL utility can be started from the Tools menu in Serenade.

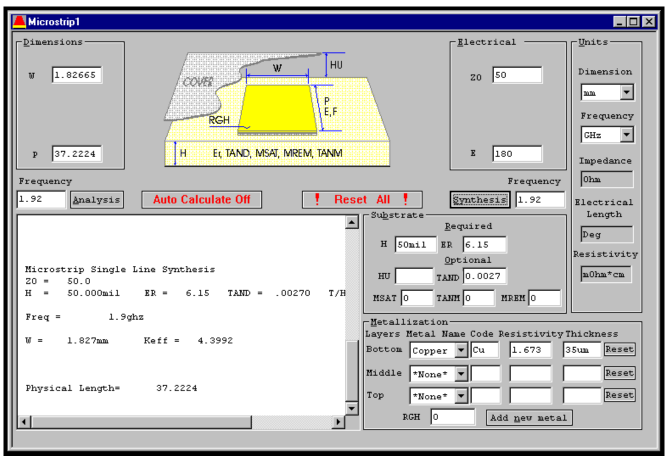


Figure 1. Serenade's Transmission Line Designer dialog box for a microstrip structure showing the layout of the structure as well as dimension definitions. In synthesis mode the input electrical parameters on the upper right side are used to obtain the physical dimensions of the lines shown in the upper left. Note also the text window in the lower left which logs all the input and output parameters and can be saved to a file.

Using the starting dimensions determined above for the microstrip lines, the design can now be focused on entering the schematic in the schematic capture window in Serenade.

The heart of the filter design is Serenade's Multiple Coupled Lines element (MCPL). The MCPL feature in Serenade uses a full-wave spectral domain algorithm which takes into account coupling between adjacent and non-adjacent elements. This model offers much better accuracy than the use of paired coupled lines or separate transmission lines, where coupling is not taken into account. The width and spacing between lines can be set individually. A diagram of the MCPL element and associated parameter definitions is shown in Figure 2.

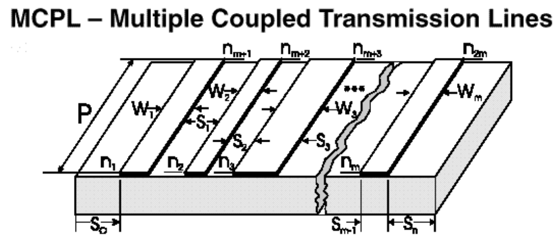


Figure 2. The physical properties of the Multiple Coupled Line (MCPL) element showing all the appropriate dimensions for a microstrip substrate.

In the 3-section filter this translates into an 8 MCPL element, 6 lines of which are paired into 3 hairpin structures. The remaining two are coupling lines for the input and output ports. The open ends of the coupled lines are terminated with a zero-length open stub to include end effects. Ninety-degree mitered bends are placed as one would place them in a layout; their orientation in schematic is transferred to the layout utility which will be discussed later. A three millimeter long section with 50 ohm impedance is placed on the input and output to serve as a bonding pad for interfacing to the rest of the RF circuit. The lengths and spacings for the distributed elements are listed in the variable block (VAR). This design will assume that the filter is symmetric about its center, thus the number of spacings, s, is reduced to 4 from 7, and the widths, w, to 3 from 8. This will increase the speed of simulation and optimization. Input and output ports are then connected to the filter with their impedance set to 50 ohms (default). The schematic entry is shown in Figure 3. Note in Figure 3 the presence of control blocks, namely FREQ, VAR, OPT and Substrate on the right side of the schematic capture window. Double-clicking on the control blocks brings up a dialog box within which parameters are entered or edited. The microstrip elements also exhibit the same functionality.

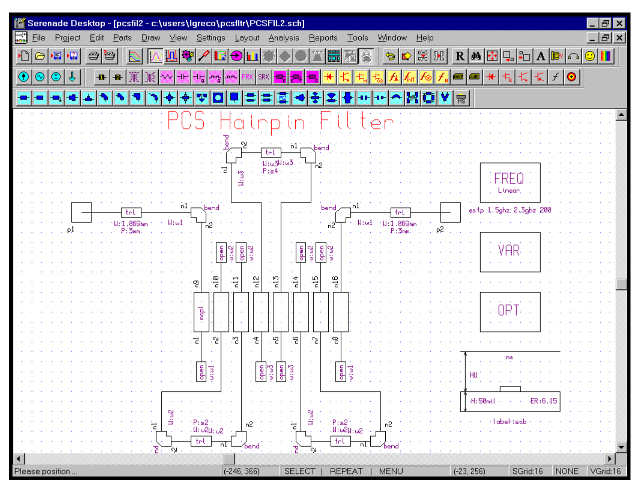
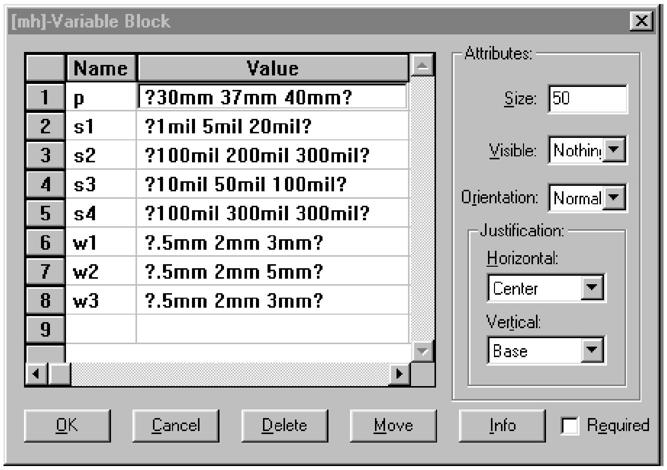


Figure 3. The completed filter schematic in the Serenade Desktop

After schematic entry, the netlist is generated which the simulator interprets for analysis. A simplified version of the netlist is shown in sections below for discussion. Values in question marks are described as *?low start high?* and designate optimizable parameters. During analysis the start value is used. Variables defined in the VAR block in the schematic are shown below:



where p is the length of all 8 MCPL elements, the spacings between the 8 lines of the MCPL are set to s1 s2 s3 s4 s3 s2 s1, and the respective widths set to w1 w2 w2 w3 w3 w2 w2 w1, as defined in Figure 2. This set of dimensions allows for a symmetric filter structure. The microstrip transmission lines that connect certain adjacent MCPL lines together to create the hairpins, have their lengths and widths also specified by the above variables. The bends used are 90 degrees, mitered and have their widths set to the same as the respective MCPL to which they are connected. To include end effects of the structure, the remaining open ends of the MCPL elements are terminated with zero length open stubs with their respective MCPL line widths. Two transmission lines with w=1.869mm and p=3mm provide 50ohm input and output bonding pads for the filter. The frequency sweep is defined by adding a FREQ control block, which includes the whole 1900MHz PCS band plus 300MHz on either side. The frequency step used is exponential (ESTP) with 200 frequency steps defined:

```
FREQ estp 1.5ghz 2.3ghz 200
```

An optimization control block (OPT) is added to the schematic which contains the goals for optimizing the widths and spacings of the filter:

```
f=1.84ghz 1.86ghz ms11 -20db lt
f=1.85ghz 1.99ghz ms21 avg
f=1.91ghz 1.93ghz ms11 -20db lt
f=1.98ghz 2ghz ms11 -20db lt
```

where the three frequency regions are specified each with a MS11 (magnitude of S11) goal set to less than -20db. These three regions are specifed since there are three sections to the filter and MS11 is a frequency-sensitive parameter. A fourth region is specified (1.85GHz to 1.99GHz) where the goal is to keep the insertion loss magnitude, MS21, flat using the AVG goal. Finally, the RT/Duroid 6006 substrate parameters are defined in the substrate media control block show in Figure 3.

Analysis and Optimization

With the variables stated in the previous section (pre-optimization) the linear simulation of the filter results in the S21 and S11 responses (in dB) as shown in Figure 4.

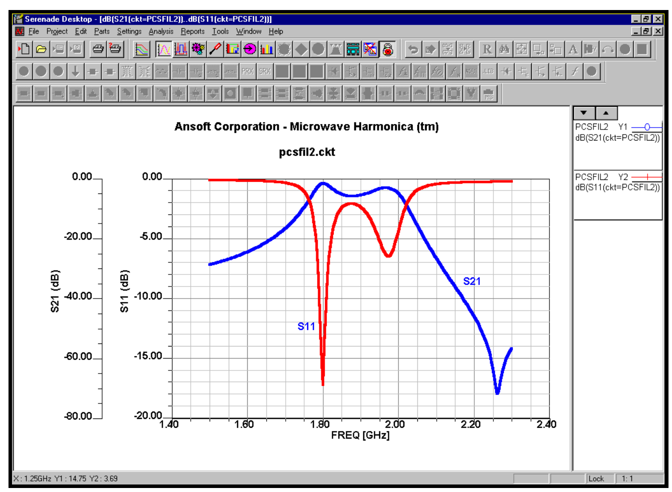


Figure 4. Pre-optimized insertion loss (S21) and return loss (S11) of the filter.

After 50 random linear optimization iterations the improved filter response is shown in Figure 5 with the pre- and post-optimized values for the filter dimensions in Table 1.

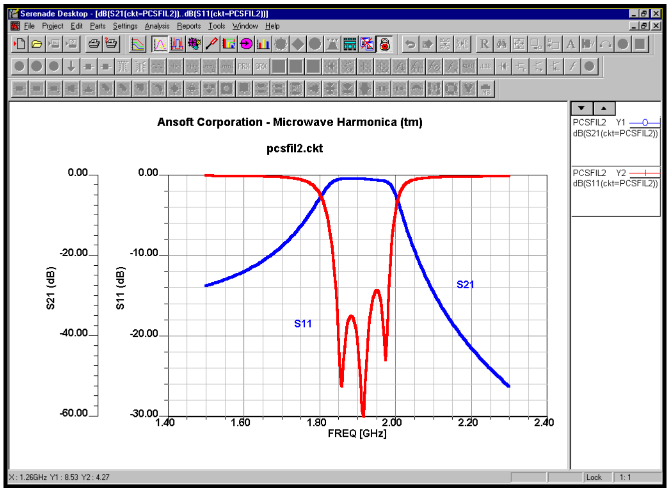


Figure 5. Post-optimized insertion loss (S21) and return loss (S11) of the filter.

Table 1. Pre- and post-optimized values for the filter dimensions including MCPL.

Parameter	Pre-Optimized Value	Post-Optimized Value (50 random Iterations)
P	37mm	33.005mm
s1	5mil	4.4345mil
s2	200mil	202.28mil
s3	50mil	56.263mil
s4	300mil	295.29mil
w1	2mm	1.1559mm
w2	2mm	2.5967mm
w3	2mm	1.2318mm

Layout

Integrated into Serenade is a tool named S2A (Serenade to Artwork) which is launched when **Tools** > **S2A Layout** is chosen from the Serenade menu. After the simulator provides the desired results, a layout can be generated directly from the Serenade Desktop to view the structure/geometry of the filter. If need be, element dimensions and positions can be adjusted in the layout window, which are then back-annotated to the schematic capture window in Serenade. The layout appears in the layout window as shown in Figure 6. The current layout can be prototyped on a 45mm x 40mm (approximately 1.75in x 1.5in) piece of Duroid 6006, as shown with the gray area surrounding the layout. The drawing can be saved in several formats, including Gerber, GDSII and DXF.

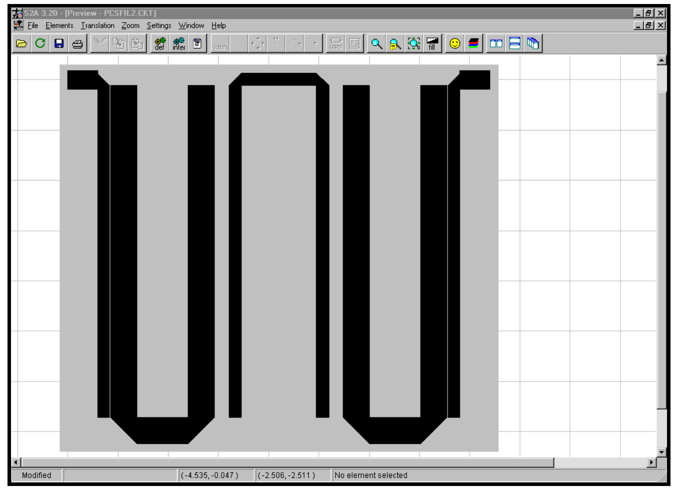


Figure 6. Layout of the final PCS microstrip filter. Note that the input and output lines are decoupled from the inner three sections by a small gap (5mil).

Conclusion

The application of Serenade Wireless Design Suite to the design of a 1900MHz PCS microstrip hairpin filter as well as the ease-of-use, and Serenade design tools integration have been demonstrated.

Reference

1. David M. Pozar, *Microwave Engineering*, Second Edition, John Wiley & Sons, N.Y., 1998

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