APPLICATION **NOTE**

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Synthesizing and Optimizing a Hairpin Bandpass Filter

This application note illustrates a design flow to on a hairpin bandpass filter (BPF) with a target center frequency of 5.8GHz. This flow combines yield analysis in Cadence® AWR Microwave Office® software, practical topologies synthesized by Cadence AWR® iFilter™ filter synthesis wizard, and design validation using the Cadence AWR AXIEM® 3D planar electromagnetic (EM) analysis to achieve a practical filter design.

Design Overview

Like all RF and microwave components, a distributed filter design will remain only a simulation exercise if it is not created with its manufacturing process in mind. That is, the tight dimensional tolerances required to meet a set of performance goals must be within the capabilities of the filter's manufacturing process in order to realize a reliable, repeatable filter. Geometries that are difficult to manufacture, such as very wide lines with very narrow gaps or very narrow lines with very wide gaps, are typically accompanied by extreme resonator impedance swings. A filter synthesis tool must be able to automatically manage these impedances using analytical and empirical techniques (such as Norton and Kuroda transforms and m-derived and constant-k end sections) to mitigate extreme impedances and produce geometries that can be easily realized. A hairpin BPF with a target center frequency of 5.8GHz was used in this application note as an example to illustrate how this can be accomplished using AWR Microwave Office software with the iFilter wizard to synthesize the structure and the AWR AXIEM analysis for validation.

Design Target

The design target was a BPF with a center frequency of 5.8GHz, 3dB bandwidth of 200MHz, passband insertion loss of less than 2dB, passband return loss of more than 15dB, and stopband insertion loss of more than 40dB at 5.4GHz and 6.2GHz. It was to be fabricated using Rogers RT/duriod RO 6006 that is 0.01in. thick, 1oz. copper, and a dielectric constant of 6.15. It had to be realizable using the simplest manufacturing process possible, in which there were only printed structures and no via holes or external components.

Common topologies such as edge-coupled structures create difficulties when fractional bandwidth (FBW) is less than about 15%.

The filter's FBW was:

$$FBW = \frac{BW}{\sqrt{F1 * F2}} = 3.5\%$$

where FBW = fractional bandwidth
BW = bandwidth
F1 = lower 3dB frequency
F2 = upper 3dB frequency

An edge-coupled filter with such a narrow bandwidth would synthesize with narrow lines and wide gaps that are much larger than the line widths, which translate poorly into physical designs. Consequently, alternative topologies such as a shunt stub had to be considered. Figure 1, a shunt-stub topology, shows that four poles were insufficient to meet the rejection requirement, while five poles provide a satisfactory amount of rejection. Before going further, it was important to determine which filter topology was most manufacturable. The options included shunt-stub, edge-coupled, hairpin, interdigital, combline, and stepped-impedance resonator types. The iFilter wizard enabled users to superimpose on each other the various topologies that meet the filter's specifications and evaluate them in terms of footprint and manufacturability.

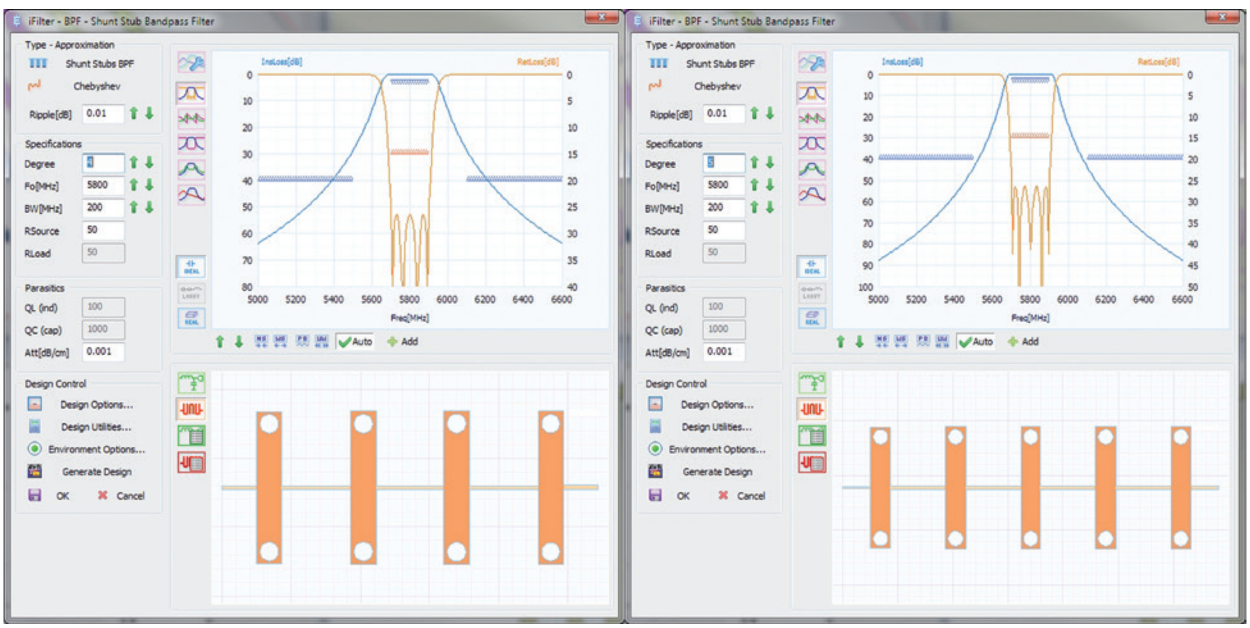

Figure 1: Four poles (left) and five poles (right)

This comparison is shown in Figure 2 for three different options: shunt stubs with quarter-wave lines and quarter-wave stubs (orange), edge-coupled (lighter blue), and hairpin (darker blue).

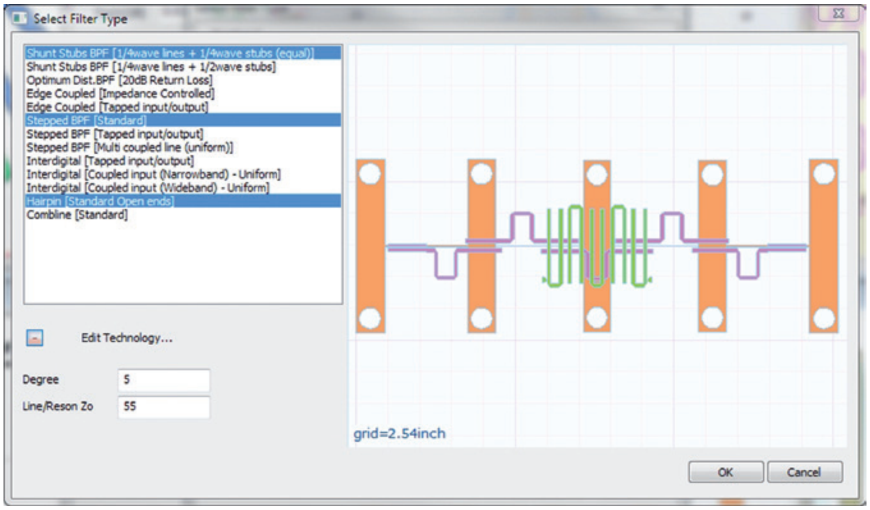

Figure 2: Comparison of three filter topologies

Using this as a guide and keeping in mind the goal of using the least expensive manufacturing process, the hairpin design was chosen because it had a much smaller footprint, was designed to keep line widths constant for easy manufacturing, and the entire filter was printed without the need for via holes or external components. The footprint could be reduced by selecting an interdigital or combline configuration, but both these topologies included extra manufacturing steps, such as via holes for interdigital filters and vias and surface-mounted capacitors at the ends of the resonators for combline filters. This was not an acceptable solution, as its slightly smaller footprint is not justified by its increased manufacturing costs.

Limits of 0.004in for minimum line width and minimum line spacing were specified inthe iFilter wizard, which are typical dimensions for modern PCB processes. The iFilter wizard will notify the user if the design violates those limits, as shown in the red-outlined boxes in Figure 1. Note that at this stage of the design, the hairpin topology had not yet been selected and thus the filter type shown within Figure 2 violated at least one of these requirements. The main iFilter window was set up to produce the desired filter, the electrical requirements were specified, the hairpin topology was selected, and the substrate information was entered in the “Design Options” window (Figure 3).

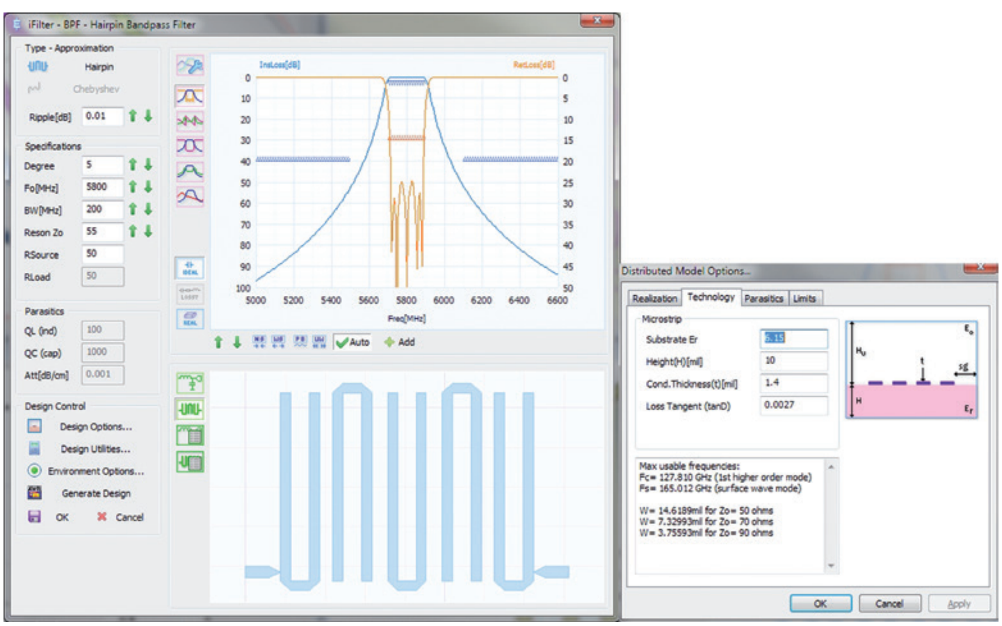

Figure 3: Filter specification in main iFilter wizard and substrate specification in Technology dialog

The iFilter wizard also provides the ability to adjust secondary parameters in real time and see the results that, in the case of hairpin filters, included adjustment of the filter's nominal impedance. The short connecting lines between the resonators (in the U-turns), would have this impedance and the resonator lines would share this line width. If the area is assumed to be limited to 0.36 x 0.30in, the nominal impedance of the resonators could be adjusted to examine the effects of line width on performance and required area (Figure 4).

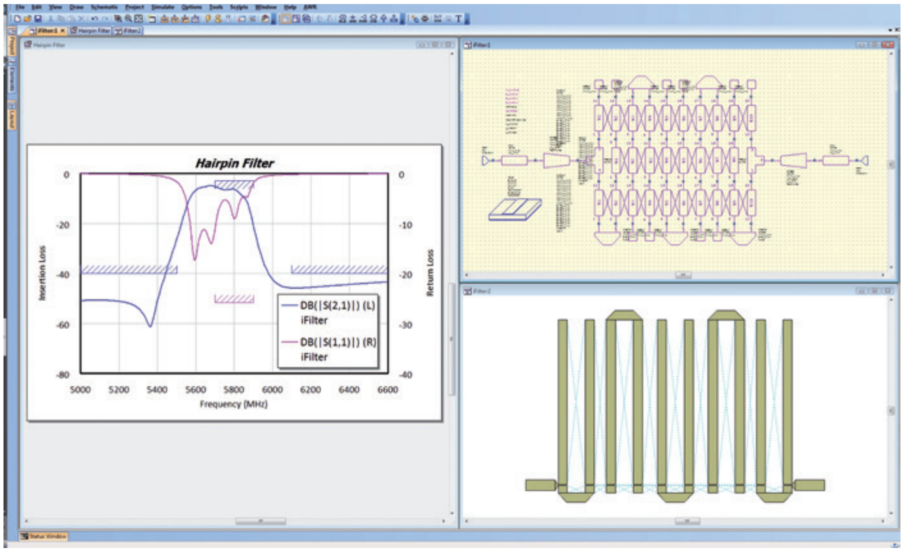

Figure 4: Footprint bounding box with Zo = 45Ω (left) and Zo = 55Ω (right)

Based on the filter's footprint, the Zo = 55Ω version for the synthesis was used. At this point, the iFilter wizard's work was almost done and the results were ready to be passed over to AWR Microwave Office software for the remaining design tasks. The filter's specifications were set up as optimization goals (visible in all graphics that include the response graph) and added to the project. The design in AWR Microwave Office software was set up with a simple button click that produced the project shown in Figure 5.

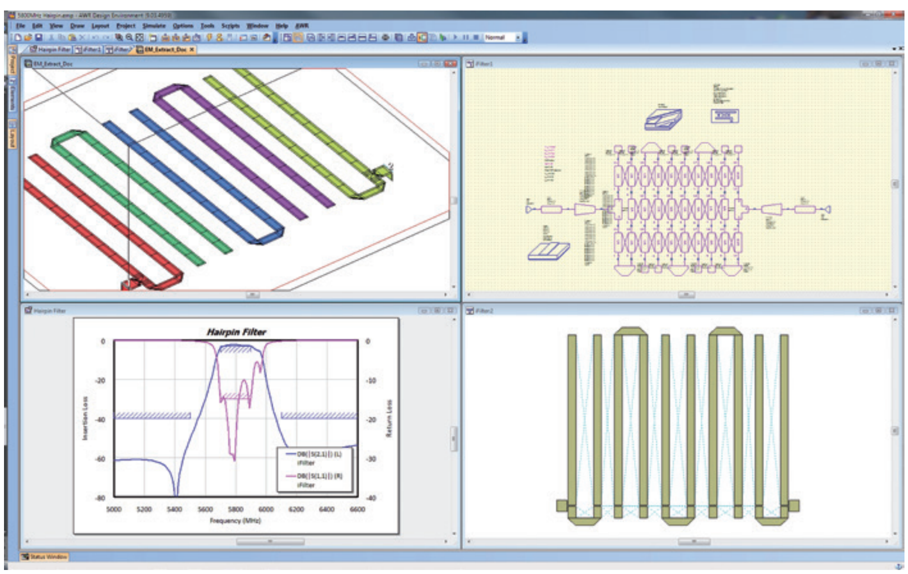

Figure 5: Hairpin filter schematic, layout, and electrical response using linear analysis

The AWR Microwave Office filter project was created with all critical parameters set to be tuned and optimized. With the iFilter wizard, the analysis can be run automatically after creating the project, so the screen shown in Figure 5 is exactly what was seen after sending the filter to AWR Microwave Office software.

EM Simulation

The filter's passband was very close to the desired result and the stopband requirements were nearly met, but there was little margin on the low side and the return loss had to be increased. The next step was linear optimization, followed by EM analysis and further optimization, if desired. In this distributed hairpin BPF, a Simplex linear optimizer was run for 100 iterations and the resulting filter was analyzed with the AWR AXIEM analysis to produce the response and filter performance shown in Figure 6.

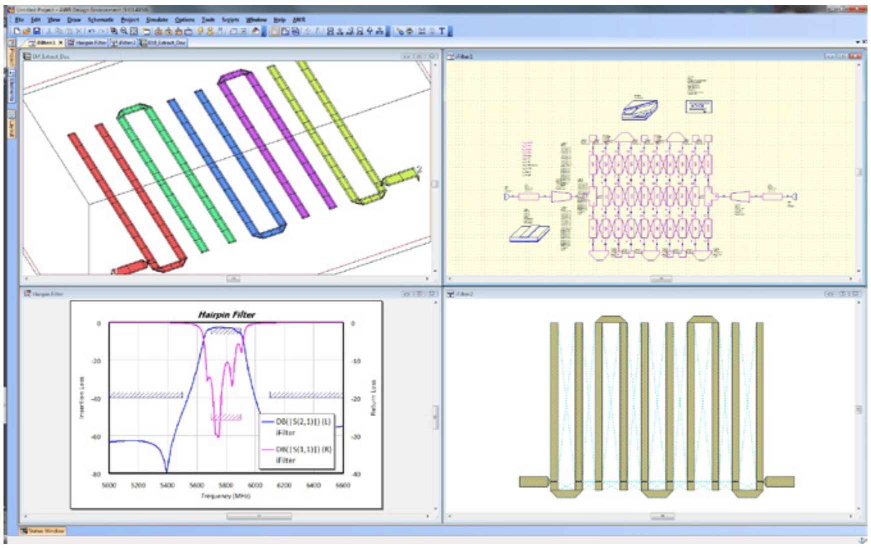

Figure 6: EM analysis of optimized filter

The final step in the design process was to further optimize the filter with more AWR AXIEM analysis. The extraction flow permits the design to be optimized at the schematic level using the EM engine to perform the analysis for each iteration of the optimizer. It also enables the automatic generation of a new EM structure every time the geometry changes based on the optimizer's guidance. The EM optimization approach in this case employed the AWR AXIEM analysis's advanced frequency sweep option and each iteration took less than 20 seconds.

At this point, nearly all of the goals originally set for this example had been achieved, as shown in Figure 7. Passband insertion loss was reasonable, stopband insertion loss was very low, and there was some margin available to accommodate manufacturing tolerances. Only return loss was too low over a small portion of the band. And while there are many options the designer can choose for increasing return loss, such as changing the tap location, shortening the first and last lines slightly, or both, these final variations were left as an exercise for the reader.

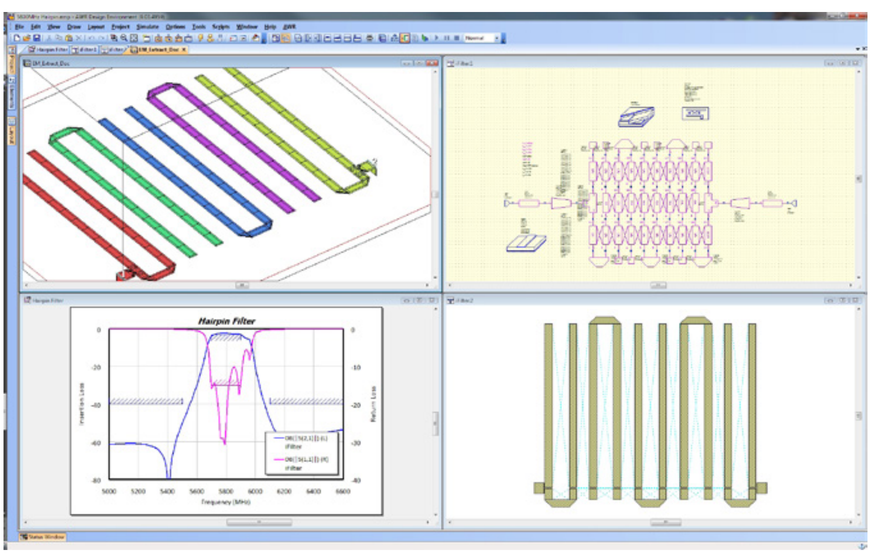

Figure 7: Final filter following EM optimization

Conclusion

Filtering is becoming ever more important in wireless network deployments at frequencies also occupied by other services, for IEEE 802.11n Wi-Fi in the 5GHz band, and in the upcoming services that will operate in the new 700MHz allocations, among others. Consequently, in order to reduce the potential for interference, the ability to rapidly and accurately produce filters with high levels of rejection and other desirable characteristics is critical. Filter synthesis tools such as AWR Microwave Office software's iFilter wizard have been specifically developed to enable designers to quickly and easily create filters that incorporate features to ensure they conform to specific manufacturing constraints and costs. While a distributed-element filter was used in this application example, The iFilter wizard is equally adept at handling lumped-element designs.