Modeling of Ceramic Filters Using WIPL-D

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Abstract: Ceramic filters are often used in front end of wireless radios to provide RF selectivity. These filters are, traditionally, designed using circuit modeling followed by long and arduous alignment on the bench, making the prototyping process slow and costly. Therefore, an electromagnetic simulator, such as WIPL-D, that can model the three-dimensional physical structure of the filter is highly desirable. This paper discusses the application of WIPL-D in designing these filters quickly and accurately. Furthermore, it shows how the WIPL-D and circuit simulators together can provide an effective solution to the above problem.

Keywords: Ceramic, band pass, filter, WIPL

1. Introduction

Today's wireless terminals use ceramic filters extensively due to their excellent performance and low cost. Until recently, these filters have been often designed using only circuit models and followed by a lot of bench work to obtain the desired performance. Without a decent physical model it has been difficult to predict the ultimate performance of these filters, especially at frequencies far out from the pass band, with good accuracy, prior to building working prototypes. Many of the commercially available electromagnetic modeling tools are slow, difficult to use, and often produce results that don't always match the prototype measurements. Although the availability of faster computing hardware is making 3-dimensional electromagnetic modeling more realistic, accuracy of these models is still a major concern to the design engineers. WIPL-D [1] is one such tool that is showing great promise in addressing these concerns.

2. Modeling

In order to test its effectiveness, WIPL-D is used to design a simple 2-pole band pass filter intended for 802.11b, WLAN application. First the size of the filter is set and then a circuit model is developed based on the combline transmission line filter model as outlined in Matthaei, Young, and Jones [2]. The necessary impedances for the circuit model are calculated with the help of electrostatic modeling tool, LINPAR [3]. The initial circuit model is further optimized to meet the necessary specifications. At this point, the diameter of the resonator holes and their spacing within the dielectric block, along with the values of the various top-loading capacitors and the input/output coupling capacitors are known. The circuit model also calculates pass band insertion loss, attenuation near the pass band frequencies etc. However, since the circuit model is based on pure coaxial modes, its accuracy suffers badly farther away from the pass band, especially at the harmonic frequencies. Also the biggest problem facing the engineers is that the circuit model doesn't tell them how to implement the various capacitors physically, in the actual filter. This is where WIPL-D proves to be a very valuable tool. Based on the results of the LINPAR and the circuit model, a WIPL-D physical model is constructed. All of the critical parameters are defined symbolically so that any of these parameters can be adjusted quickly to obtain the desired response. Instead of performing a lot of slow and costly adjustments on the bench, the three-dimensional model is thoroughly optimized on the computer first and only then the actual prototype is built, thus saving a lot of time and money.

3. WLAN Filter Example

This filter is required to meet the following specifications:

- 2-pole band pass
- Pass band = 2400 to 2500 MHz
- Insertion loss >-1 dB
- Attenuation at 2000MHz < -30 dB
- Size = 2.5 mm x 2.5 mm x 1.5 mm

Due to its small size requirement, the filter is implemented in a high dielectric, relative permittivity of 85, ceramic body. The inside of the resonator holes and the outside of the body will be plated with silver forming a combline structure. LINPAR is used to calculate the resonator cross-section and the related self and mutual impedances. This step is followed by the circuit simulation and optimization to realize the necessary pass band performance and attenuation values close to the pass band. The resulting response curves are shown below. Fig.1 shows the details of pass band insertion and return losses. The simulated insertion loss is 0.6dB. Fig.2 shows that the attenuation is close but doesn't quite meet the -30dB specification.

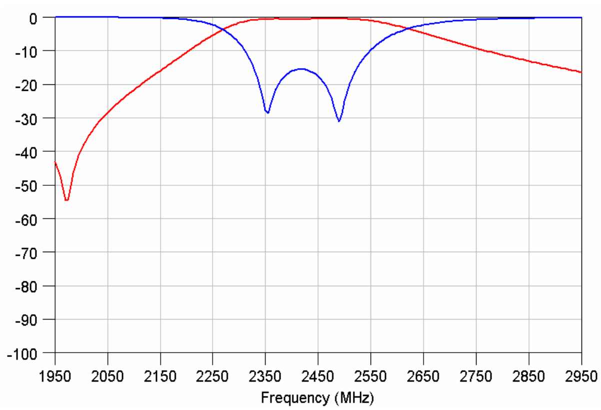

Fig.1. Narrow band circuit simulation

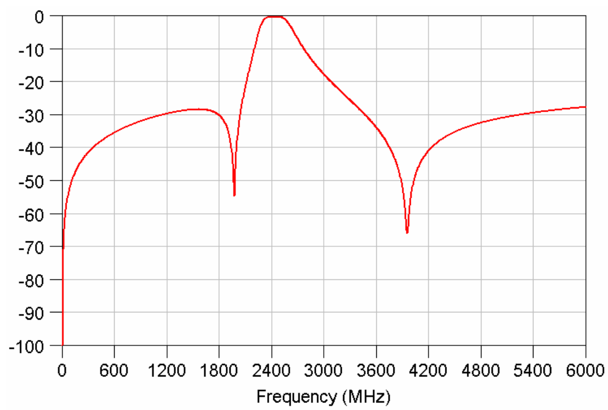

Fig.2. Wide band circuit simulation

The circuit simulation sets the resonator geometry and also provides all the necessary capacitor values required to obtain the above performance. However, it doesn't provide much information about the physical implementation of these capacitors. Fig.3 shows the detailed structure of the WIPL model created using the above information. Loading capacitors are realized by stepping up the diameter of the resonators at the top. Also these steps in diameter, along with the input/output capacitive coupling pads, are further optimized iteratively to obtain the desired response. Each solution takes about 10 minutes on a 3 GHz Pentium-4 machine with ample RAM. The amount of time it takes varies with the size and complexity of the problem and the degree of accuracy required. Accuracy level and number of frequency points are set low initially and increased towards the final iterations to speed up the process. Final results are shown below.

The response in Fig.4 reveals a pole of attenuation just around 1 GHz which is not seen in the circuit response. The extra notch improves the worst case attenuation below 2 GHz to better than 35 dB, which will easily meet the required specification. The other 2 notches in the response are similar to the circuit response. However, the attenuation at 6 GHz is only about -19 dB compared to the -29 dB of the circuit response.

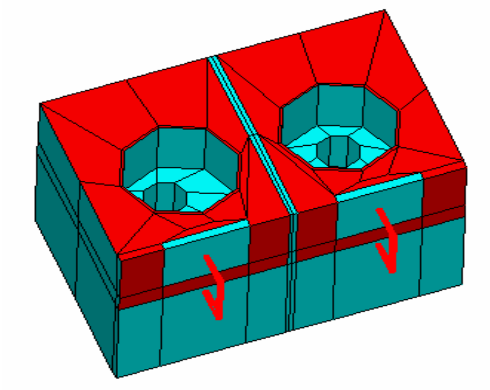

Fig.3. WIPL-D model

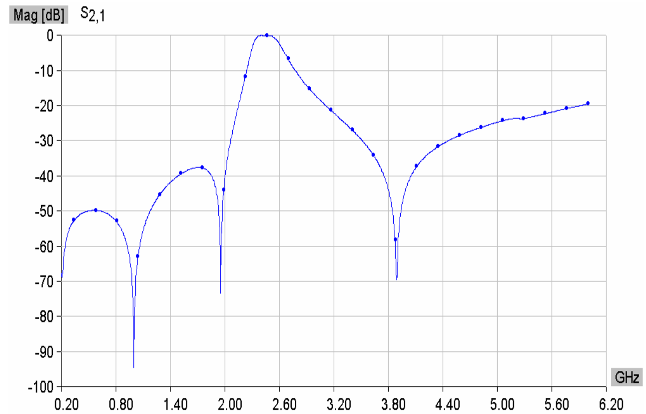

Fig.4. WIPL-D simulation response

Prototypes are built as close to the WIPL model as possible. The resulting filter turned out slightly wider in pass band. A slight tuning had to be performed to adjust pass bandwidth and improve the return loss in the pass band. Another notable difference is the location of the notch around 0.5 GHz compared to the 1 GHz predicted by the WIPL. As this notch is far away from the pass band, its impact on the attenuation is limited to only a couple of dB. These differences may have resulted from the approximations used in the model and variations in the process used to build the filters. Typical measured response is shown in Fig.5 and 6. Insertion loss in the pass band is about 0.7dB, very close to the value predicted by the circuit simulator. However, the attenuation values below 2 GHz and at 6 GHz are much closer to the WIPL prediction than the circuit prediction.

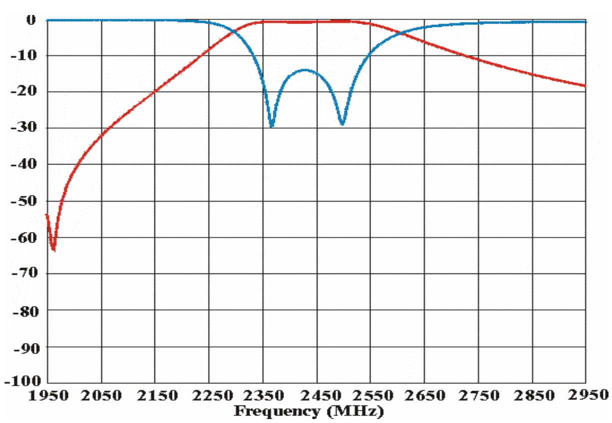

Fig.5. Narrow band measured response

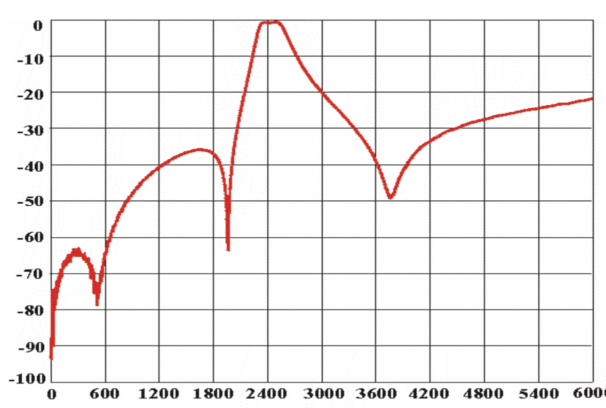

Fig.6. Wide band measured response

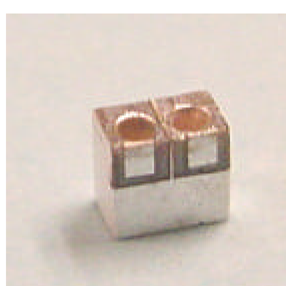

Fig.6. Prototype filter

4. Conclusions

Based on this simple example, it appears that the circuit simulator is quite adequate to predict the pass band insertion loss and attenuation close to the pass band of narrowband, high dielectric, ceramic filters. However, when it comes to the attenuation performance at frequencies far out from the pass band, WIPL prediction appears to be far superior. More importantly, optimization of the filter model using WIPL reduces the number of iterations needed in prototyping stage, which in turn results in faster design cycle and significant savings in the tooling costs. Further refinement of the models should lead to even greater savings.

5. Summary

Although of limited use in predicting the pass band performance, WIPL could be a very useful tool for designing ceramic filters that require only a few poles. When used in conjunction with circuit simulators, engineers can model filters reliably and predict the performance well before building any prototypes.

6. Acknowledgements

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References

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