

Cavity Filter Design and Optimization

Introduction

This application note presents capabilities for **modeling, simulation and optimization of cavity filters** in the WIPL-D software environment. Using a variety of WIPL-D features and tools, rather complex model of cavity filters can be **easily designed, efficiently simulated, and tuned or optimized**.

This paper specifically describes the realization of a 2.1 GHz pass-band filter using 5 cavity resonators, which can be tuned to achieve desired characteristic.

The filter is fed with input signal through a coaxial line connector. Another coaxial line with connector serves as the filter output. Cavities have approximately cylindrical shape as well as small tuning element. This element effectively changes the shape of the resonator cavity and, thus, its resonance. The tunable element is easily moved into and out of the cavity by tuning screws.

The property of having a relatively simple design and very practical tunable elements brings significant advantages for this specific cavity filter to exhibit desired performances.

Modeling of Filter in WIPL-D Suite

WIPL-D Suite offers two possibilities for modeling of cavity filters. For many years, the default way to model structures in WIPL-D Suite was through in-house modeler which is a part of the flagship product called **WIPL-D Pro**. The modeler is based on manual mesh with assistance of a number of predefined (already meshed) objects. For the particular case, Body of Revolution (BoR) and Circle objects are especially useful. The drawback of this approach is that they require long time for modeling. Also, in case of modeling variations for the design (such as slightly inclined walls to ease the manufacturing) or modeling additional details, it is very time consuming to adjust the model.

The advantage of this approach is that model is **completely parametrically defined** and it, thus, can be directly optimized as a full 3D model. Additional advantage is minimum number of mesh elements and, thus, **minimal memory consumption and simulation time**. An example of such a design could be the direct coupled five resonator cavity filter shown in Fig 1 (half of the model is shown due to symmetry).

Another approach for the modeling of the same filter structure would be through another WIPL-D product – **WIPL-D Pro CAD**. The product was introduced in 2009 to allow **import from popular CAD files** (like STEP, IGES, CATIA...). Namely, the market of mechanical tools has dramatically expanded in the time of rapid growth of personal computers and software. Variety of suites is available and interoperability between EM and mechanical tools is very important. In that sense, **beside**

modeling from the scratch, WIPL-D Pro CAD is able to import, repair, and re-mesh all major CAD files.

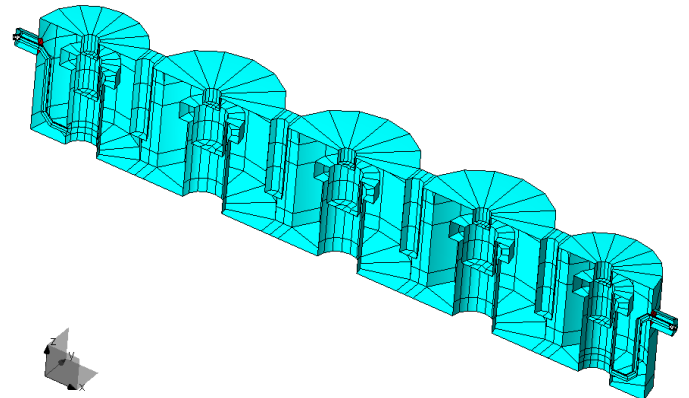


Figure 1. Manually built model of cavity filter (half of the model)

So, the work flow in the CAD approach could consist of:

- Using a mechanical CAD tool to model the filter structure (The example of five resonator cavity filter with one cascaded triplet – CT section is shown in Fig. 2),

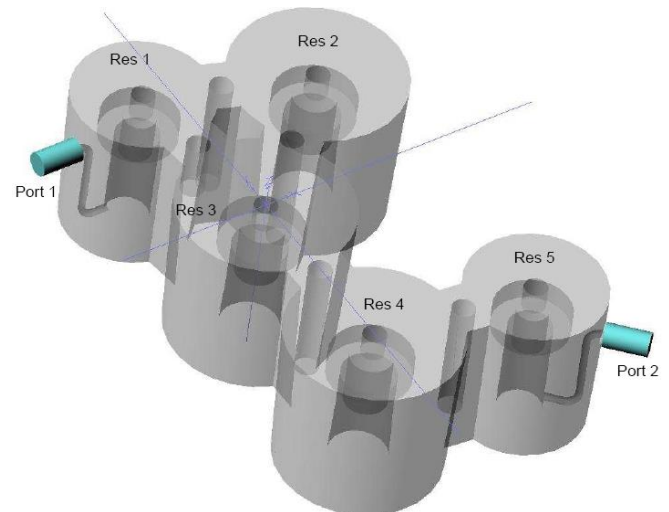


Figure 2. Filter CAD design in a mechanical tool

- Export to Compatible Format for WIPL-D Import (Parasolid files, ACIS, Catia, ProE, IGES, STEP, Solidworks),
- Import into WIPL-D Pro CAD
- Model adjustments in WIPL-D Pro CAD: specify dielectric domains; remove holes and other un-necessary features; imprint, subtract & unite parts as necessary; assign domains to regions; set domains for surfaces as required; specify mesh parameters; validate and create WIPL-D Pro 3D EM Solver project mesh, Fig. 3

- Model adjustments in WIPL-D Pro: add excitation (create nodes for port wires, add port wires, and add junctions and generators) and validate model (by using WIPL-D Pro Checker).

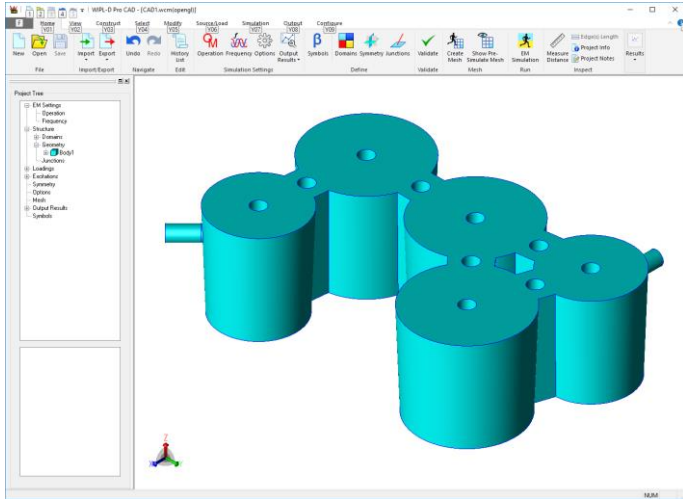


Figure 3. WIPL-D Pro CAD filter model

There are several advantages of this concept. First of all, the market offers numerous mechanical CAD tools. Each of them allows easy modeling of certain CAD models. In addition, the user already familiar with concept of building models in a certain CAD tool does not have to learn new tool and can use existing models. Furthermore, models can be easily adjusted; features and details can be added. One of the most important advantages is that user does not have to deal with the mesh of the structure, which is performed automatically.

This leads to the only drawback of this approach. The mesh created automatically in almost all situations leads to larger number of mesh elements, larger number of unknowns, significantly larger memory consumption and longer simulation time.

Two examples of automated mesh are displayed in the following figures. Figs 4-5 demonstrate two mesh sizes specified in WIPL-D Pro CAD. Figure 4 shows a model which has the default mesh parameters. This results in only 1,672 mesh elements (patches) and requires 3,866 unknowns (116 MB for in-core simulation).

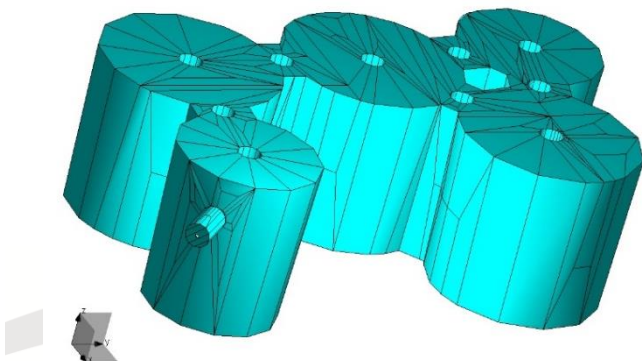


Figure 4. WIPL-D Pro model, coarser mesh

The model in Figure 5 (manually set mesh size to 3 mm) requires 16,676 unknowns (2.07 GB of RAM) over 7,955 patches.

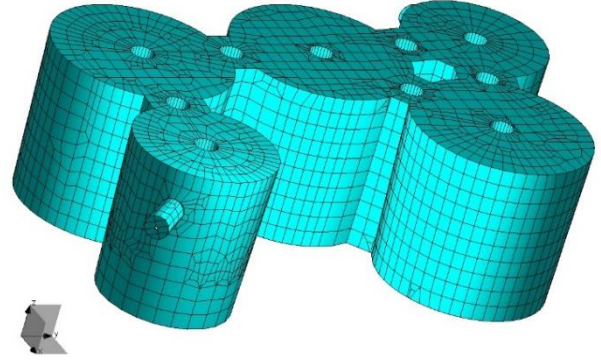


Figure 5. WIPL-D Pro model, finer mesh

Another possibility in modeling of such a filter design would be directly in WIPL-D Pro CAD, since it is a full solid modeler. The process includes: usage of parameters (WIPL-D term is *Symbols*), built-in primitives, Boolean operations (such as unite, subtract) etc.

Filter Simulation in WIPL-D Suite

WIPL-D Suite offer excellent choices for simulation and tuning of cavity filters. First of all, WIPL-D Pro is an efficient full wave 3D EM solver based on Method of Moments. In addition, it uses unique higher order basis functions (HOBFs) over patches up to 2 lambda by lambda in size. Thus, it requires **minimum memory and simulation time for running simulations**. On the other hand, **WIPL-D Microwave Pro** is a circuit solver which combines both 3D EM simulation and circuit simulation.

The workflow starts from the 3D EM simulation of the filter model. The simulation is performed in such a way that internal ports are added to the structure. Ports are added to each cavity resonator and to elements which connect cavities and, thus, allow coupling between them.

With this in mind, 2-port field-solver model (where two ports originate from coaxial input and output port) is turned into a 12-port (Fig. 6) by forming ports at the ends of the resonator rods. **After only one EM computation, the 12-port data is exported to a circuit simulator WIPL-D Microwave Pro**, where we add lumped capacitors to the resonator ports.

This approach allows to now tune the field-solver model quite rapidly using the linear circuit simulator. Small corrections to the coupling between resonators can be achieved by adding series impedance between the resonator ports. Positive impedance implies that coupling increases, while negative impedance implies that coupling decreases.

The entire procedure is outlined in the following paper:

Swanson, Daniel G. Jr. and Wenzel, Robert J., "Fast Analysis and Optimization of Combine Filters Using FEM", Conference Proceedings of the IEEE MTT-S 2001 International Microwave Symposium, pages 1159 - 1162 vol.2, May 2001.

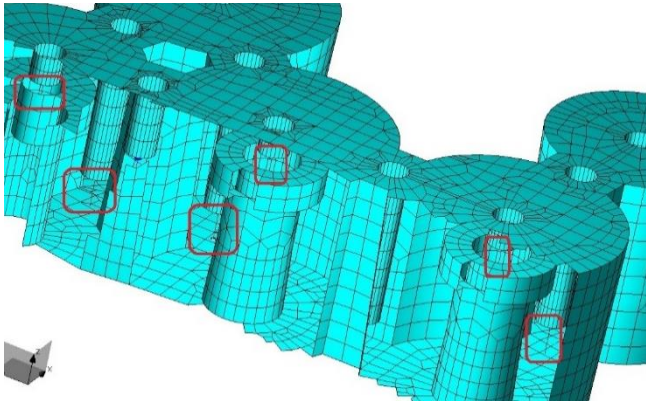


Figure 6. Internal ports

The circuit schematic used for **filter tuning** is presented in Fig. 7. It has been created in a simple and straight forward way:

- Create WIPL-D Microwave Pro project and import EM solver results (.AD1 file from User Defined Component),
- Values of tuning capacitors for port loads should be defined as WIPL-D Symbols, which can later be optimized,
- Set optimization parameters with tuning capacitors allowed to range over small negative and positive values in WIPL-D Optimizer.

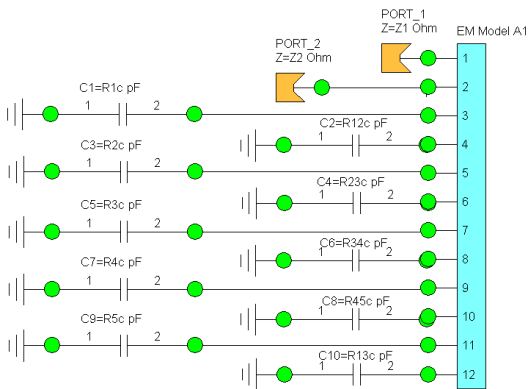


Figure 7. WIPL-D Microwave Pro circuit model ready for tuning

Optimization criteria should be specified in **WIPL-D Optimizer** window to resemble the desired filter mask. The example of the optimizer window with the filter specification entered is presented in Fig. 8. The filter was optimized by using *Simplex* method of optimization, with maximum of 300 iterations allowed. Considering that one iteration consists of re-calculating circuit parameters for a given EM model response, each **iteration lasts below one second** and optimization/tuning is very fast.

After optimization, the filter model shows desired characteristic which are illustrated in Fig. 9. Small negative and positive impedances can be used for fine tuning of the actual filter model, the one that should be manufactured.

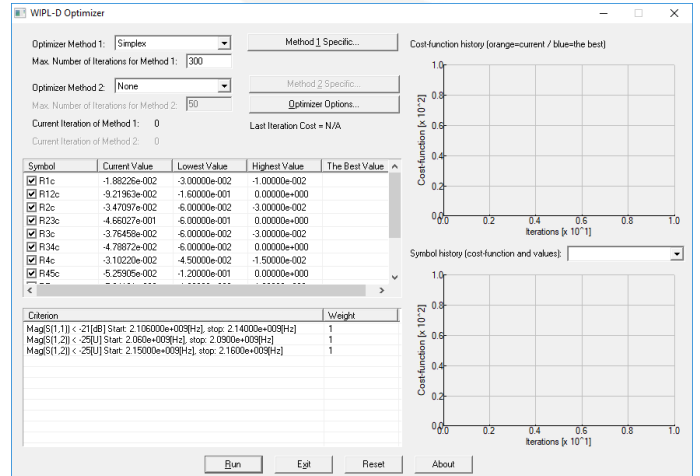


Figure 8. WIPL-D Optimizer settings

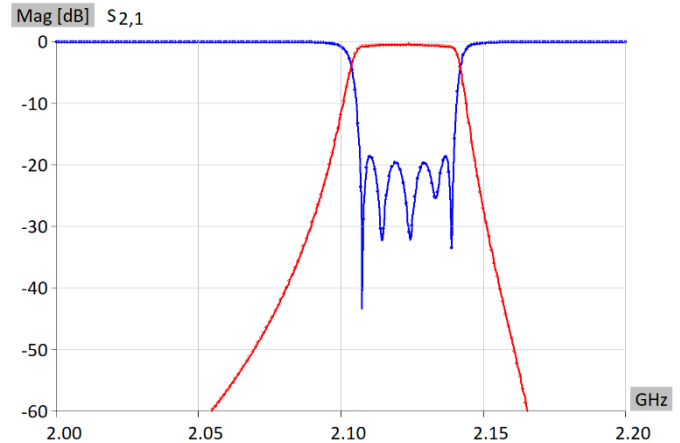


Figure 9. Final filter characteristic

Conclusion

This application note describes **efficient combination of WIPL-D Pro CAD and Microwave Pro** for modeling, simulation and optimization of cavity filters. Rather complex model of a 2.1 GHz pass-band filter with 5 cavity resonators is imported, meshed, EM simulated and then quickly optimized inside of linear circuit simulator (almost instantaneous optimization cycle in MW Pro).

The tuning elements in the circuit solver emulate realistic tunable element (easily moved into and out of the cavity by tuning screws). A relatively simple design and very practical tunable elements allow the specific cavity filter to exhibit desired performances.

The described procedure emphasizes **combination of EM and circuit simulation**. WIPL-D suite has a **variety of choices for modeling of cavity filters**, based on user needs and the specific design. In that sense, WIPL-D Pro is used for de-featured and less complicated models while WIPL-D Pro CAD is used for models imported from popular CAD tools with all the details modeled. The approach where EM filter simulation is performed only once and optimization is performed on a combined 3D/circuit model shows **excellent efficiency** required for fast and easy filter design.