RF power amplifier designed by EM code

M. Abs

INTRODUCTION

Nowadays modern RF computing codes allow quick and accurate RF resonator designs.
If you can get access to the internal geometry of vacuum tubes (triode, tetrode, IOT,..), you can effectively and very accurately predict the shape of the resonator in order to get your amplifier at the right resonance frequency.
Moreover, it will then be easy to determine if the coupling ratio between the tube and the application is correct.
Issues like microwave self oscillations in big structures can also be investigated and the efficiency of special absorbers evaluated.

History of amplifier design

In recent past, when you had to design a large power RF amplifier it was often done by realizing a scale model of the resonator and cut-and-try approach. The same technique was used for the dimensioning of cyclotron cavities. A wooden model was often realized and covered with thin copper sheets.
The code MAFIA arrived and opened the doors to « virtual simulation » but the precision reached was limited due to the staircase meshing and the limited number of nodes.
Today, tetrahedral meshes are used for solving EM problems and a 200 thousands nodes mesh can be typically solved in a few minutes on a recent workstation, equipped with e.g. 16 GB of RAM.
The short solving time together combined with a powerful modeler open the doors to fast optimization in full 3D.

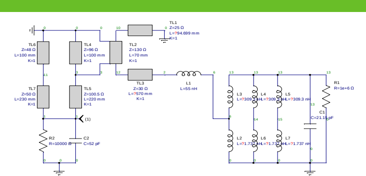
Important parameters for amplifiers design

Here is the list of the goals when you have to design an amplifier:

- Fundamental frequency
- Loaded Q, Bandwidth
- Correct coupling (usually to 50 ohms)
- Position of the higher order modes
- No instability
- Low harmonic content

All those specifications can be accurately evaluated as well as the dissipation of the resonators.
The full pattern of electric field can help avoiding arcing and limiting electrical stresses on ceramic isolators.
Other goals like linearity or group delay could be also part of the specifications but are outside the scope of these calculations.

Examples of amplifiers design

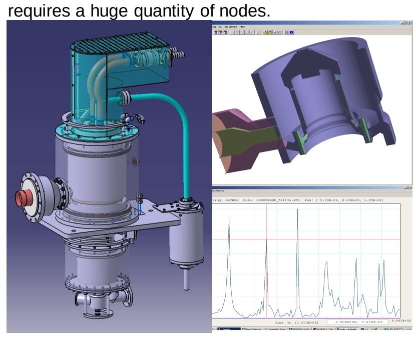


In this example the amplifier behavior was approached by circuit simulation. Experience and good feeling is needed to find a relevant equivalent circuit.

Time or frequency domain solvers?

- **Time domain solvers**

The time domain solver uses hexahedrons and finite difference technique.
Computing time becomes often prohibitive when you try to analyze low frequency problems in structures containing small details (small time steps).
A good conformance to the geometry often requires a huge quantity of nodes.

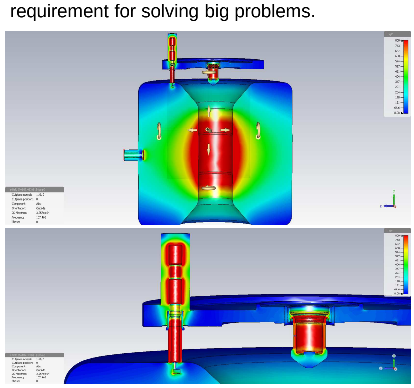


- Example: Fix an harmonic issue in IFMIF amplifier

The above picture shows an amplifier designed for the **IFMIF** programme. It delivers up to 230 kW CW at 175 MHz. The simulation has been done with a Time domain solver from **Field Precision**. It allows you to drive the EM field by a well defined current in amplitude, space and time. Therefore, it can accurately model the electron flow inside the tube structure.
The simulation put in evidence a problem with the second harmonic that was much too big. A deformation of the output resonator did solve the problem.
The simulation shown that the output power was reached with the right voltage swing inside the tube.

- **Frequency domain solvers**

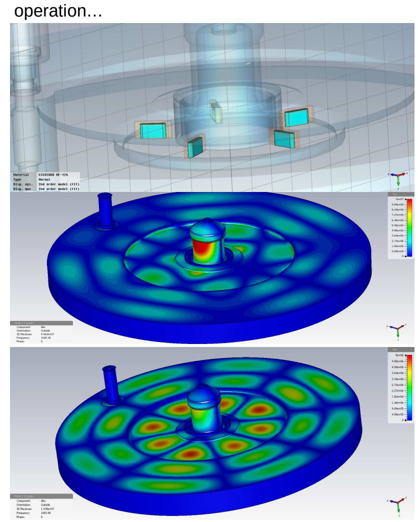
•Frequency domain solvers are available in finite element method. This allows a perfect conformance to the geometry even when containing small details. The solver easily computes S matrix parameters between ports.
•On the other hand, a program like CST® doesn't allow you to define an excitation signal with a given spatial distribution. This fact introduces some small errors in our application.
• The main issue here is the memory requirement for solving big problems.



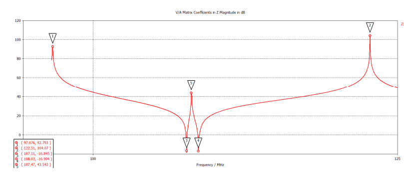
- Example 1 : Figures above show the simulation of an amplifier coupled to an accelerating cavity via a small loop. Electrical stresses on insulators could be analyzed and reduced where needed.

- Example 2: Absorbers in ECCOSORB® are placed in the output circuit to damp microwave oscillations. TE mode inside the tube structure are shown.

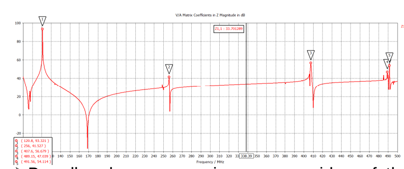
The power absorbed in the Ecosorb is evaluated for the first and second modes. The results were important in the design to avoid frying them during operation…



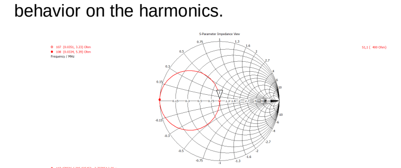
In addition, the codes now offer tools for Z-matrix calculations, broadband response studies and offer the possibility to plot Smith charts, as when using a circuit simulator.



- The Z matrix calculation shows here the anode impedance. The good tuning of the resonant coupling system is well seen.



- Broadband response gives you an idea of the behavior on the harmonics.



CONCLUSIONS

Electromagnetic solvers have demonstrated to be accurate tools for designing RF amplifiers based on vacuum tubes. Both Time and Frequency Domain Solvers can be used depending on the ratio between the size of the problems and the frequency to be analyzed.
It is clear that this approach reduces substantially the development time. The simulation also demonstrated a very good prediction of the coupling to cavities via small loops or antennas.