A High Power Planar Triode Oscillator Design Using FEM Modelling

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Abstract: The modelling of triode oscillators using SPICE is well known: the simulation starts with the experimental characteristics. In this paper, the triode is FEM-described by its geometry and the continuous current injected through the cathode; by the same way, its load is also FEM-described. SPICE is used just to write the circuit elements which need not to be described by their geometry. All these components are introduced into COMSOL-AC and the circuit behaviour is computed versus time. A subsidiary question arises with the conductivity of the beam which is not known and must be computed. Here, in order to simplify the computation, the conductivity is got first and preserved in a txt file and the simulation is made in simple 2D, as a kind of bench mark.

Keywords: FEM-triode, FEM model, Colpitts oscillator, and FEM-load

1. Introduction

There is a lot of interest in microwave and HF heating and also a kind of new microwave chemistry in which the short times play an important role. The modeling of energy must be in accordance with the time reaction and short in front of the time relaxation inherent. This implies a high Q and narrow band circuitry. For these applications, we need triodes, magnetrons and so on, which are more suitable for above applications than those conceived just have been used in the telecommunication systems. Also, the Continuous Wave Radio Frequency (CW-RF) applications are increasing with the ongoing developments in the areas of broadcasting, defence, industrial and research. Free running CW-RF oscillator of 1KW rating at 13.56MHz has various applications including plasma production and plasma related experiments.

The key requirements for a high power source used in power applications are efficiency, low cost, power, and reliability. We have noticed that the traditionally design of high power microwave heating systems is done in large measure by empirical means. But, at high power levels, relativistic effects and device non-linearities mean that analytic techniques often do not provide sufficient information of device behaviour to produce a workable design. Because of this problem, the industrials are turning increasingly to the use of computer models to predict device behaviour before building an experiment. Therefore, the computer models to predict device behaviour before performing an experiment are needed. These models reduce the number of experimental revision. A method for identifying vacuum tube spice model parameters using computerized optimisation was presented by [1]. In this work, inter-electrode capacitance, grid current, etc. cannot be considered.

In this paper, we introduce a new generation of high-power planar triode and its load for heating applications (see Fig. 1). Here, we apply a 2-D finite elements time domain method (FEM) to simulate a planar triode using Comsol

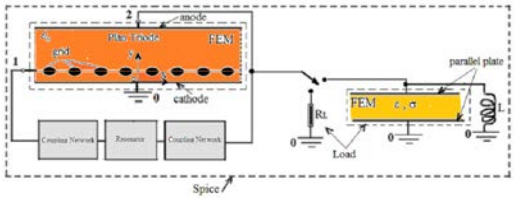

Figure 1. Configuration of the simulation

Multiphysics linked to spice circuitry to design an oscillator. This method permits us to design a planar triode for replacing the high power triode tubes. By this method, we are able to design several triodes having different geometry shape like: planar, coaxial or cylindrical for different heating applications. Here, a planar triode that is connected to a resistor R_L or a parallel plate as cavity for heating the woods. In this study, we present an overview of our design. Then, we simulate a Colpitts oscillator using this planar triode as an active component. Finally, we demonstrate our simulation results for different load.

2. Theory

The exploitation of the revolution in computer power has affected all of microwave design and microwave power applications as well, albeit more slowly. We note that traditionally design of microwave heating systems is done in large measure by empirical means. In this paper special emphasis is placed on the development of a new generation of high-power planar triode.

The principal theory of the vacuum tube and the space charge has been discussed in details in [2]. In this work, we apply a 2-D finite elements time domain method to simulate a planar triode. We demonstrated the planar triode and the cavity load in Figure 1, which are analysed separately by FEM. Then, the Spice circuit is linked to the FEM descriptions of the triode and the parallel plate as its load and converge quite easily.

This work deals only with the triode and transposes the solution of fields (taking into account the space charge) into the knowledge of an equivalent conductivity at each point x and y of the planar triode structure which is stored in a text file. In this study, we apply as boundary conditions the value of the conductivity on cathode, grid and anode. Here, the conductivity plays more or less the same role as characteristics curves of the planar triode. Now, we can design an oscillator with the spice of Comsol Multiphysics using this planar triode as an active component and its load.

2.1 Planar Triode

Stable operation of the simulated triode oscillator requires an accurate triode model. The model itself has to be capable of describing the triode's behaviour with sufficient detail. Furthermore, the model has to include the real triode characteristics in order to get representative results. The cross-section of planar triode is shown in figure 2. In this planar triode geometry the anode and cathode electrodes are metallic conductor and this

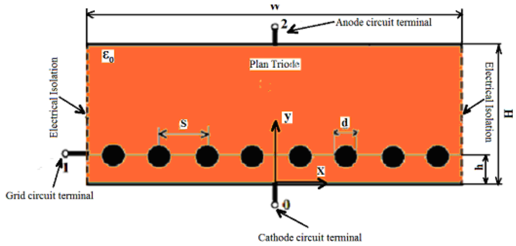

Figure 2. Physical parameters of the planar triode
W = 8 cm, H = 4 cm, L= 100 cm, S = 1 cm,
d = 2mm, h = 3 mm, N = 8

electrodes are assumed to be semi-infinite in extent to avoid edge–effects and only the variation in x and y direction is needed to consider. In figure 2, W is the width, H is the thickness and L the length of the planar triode structure. In this planar triode, the grid consists of several metallic cylinders. Where, N is the total number of metallic cylinder, its diameter d, the distance between two successive metallic cylinder s and the distance, which separate the cathode from the grid h.

Boundary settings:

We assume that the sidewalls of the planar triode structure are bounded by electric insulation satisfying the following equation.

$\vec{n}.\vec{J} = 0$ Electric insulation

The total electric current crossing the cathode electrode, anode electrode and grid electrode can be calculated by taking the surface integration over the complete current density distribution are given by the following equations:

$$\iint_{s_{cathode}} J.ds\,\vec{n} = I_c \quad \text{(cathode circuit terminal)}$$

$$\iint_{s_{anode}} J.ds\,\vec{n} = I_a \quad \text{(anode circuit terminal)}$$

$$\iint_{s_{grid}} J.ds\,\vec{n} = I_g \quad \text{(grid circuit terminal)}$$

where, $\vec{n}$: normal unit vector to the boundary surface

If the conductivity at any point x and y from the cathode is $\sigma(x, y)$ and the electric field there is $E(x,y)$, then, the current density $\vec{J}(x,y)$ can be expressed $\vec{J}(x,y)=\sigma(x,y).\vec{E}(x,y)$. Now, we assume an initial conductivity value on the cathode, the grid and the anode as boundary conditions given by the following relations.

$$\sigma_c = \frac{J_0}{|E_c|}, \sigma_g = \frac{0.1J_0}{|E_g|} \text{ and } \sigma_a = \frac{0.9J_0}{|E_a|}$$

Where, J_0 is the emitting current of the cathode. Here, as a boundary condition we impose that the conductivity on the metallic cylinders be equal to zero. Then, by applying the values of conductivity on the cathode, the grid and the anode the total anode current knowing the area of electrode is determined. Now, for solving our problem, we apply a 2-D finite elements time domain method (FEM) using COMSOL Multiphysics. Here, we illustrate in figure 3 the non-uniform triangular sampling that is used for this triode, and figure 4 illustrates the variation of electrical potential (v) on the cross-section surface of the planar triode.

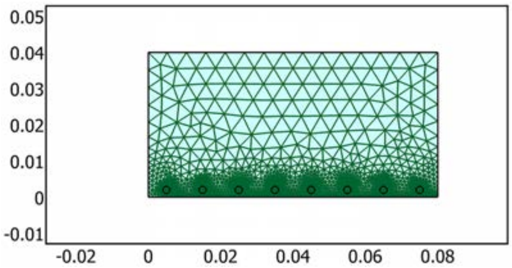

Figure 3. Non-uniform triangular sampling used in the FEM.

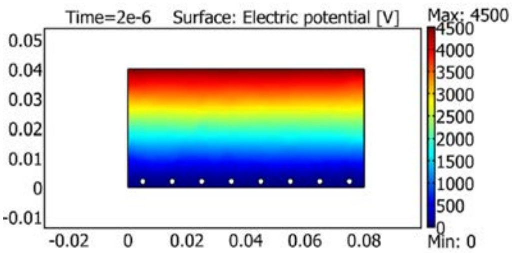

Figure 4. Electrical potential on the cross-section surface of the planar triode.

2.2 Cavity load

We have shown in figure 5 the geometry of a cavity load, in figure 5, W_1 is the width of the metallic plate, H_1 is the thickness and L_1 is the length of the cavity. We know that the quality of the heating process is highly depedent on the uniformity of EM field distribution.Therefore, the two parallel plates as a cavity is a good choice for creating a uniform EM field inside the cavity. In this work, we utilize this cavity which is connected to a oscillator as its load for heating the woods and other heating applications (see Fig. 1).

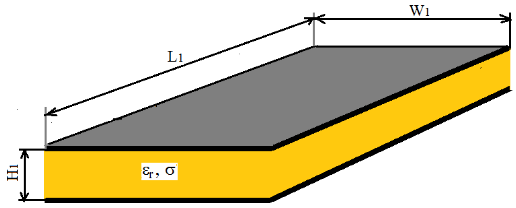

Figure 5. Physical parameters of the cavity load

When, people cut off trees, woods are wet and they have to wait during a year to have a very good quality wood. This cavity when is connected as a load to a high power HF oscillator will be able to dry wood rapidly. Wood is a lossy dielectric having a complex permittivity

$$\varepsilon = \varepsilon' - j\varepsilon'' = \varepsilon'(1 - j\frac{\varepsilon''}{\varepsilon'}) \quad \tan\delta = \frac{\varepsilon''}{\varepsilon'}$$

in which ε' is the “true” permittivity, and ε'' the imaginary permittivity. Now, by knowing $\tan\delta$ and ε' one can obtain the conductivity of a lossy dielectric given by the following formula

$$\sigma = \varepsilon''.\omega = \omega.\varepsilon'.\tan\delta$$

Where, $\varepsilon' = \varepsilon_r.\varepsilon_0$

When the cavity is filled in a lossy dielectric and it is studied under an alternating voltage, we can replace the cavity in question by a lossless capacitor and an active resistance connected in series or parallel. Now, for solving our problem, we apply a 2-D finite elements time domain method using COMSOL Multiphysics.

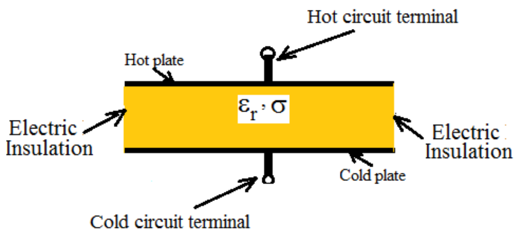

Figure 6. Cross-section of the cavity load

Boundary settings:

We assume that the sidewalls of the cavity as is shown in figure 6 are bounded by electric insulation satisfying the following equation.

$\vec{n}.\vec{J} = 0$ Electric insulation at sidewalls

The total electric current crossing the cold plate surface and hot plate surface are given by the following equations:

$$\iint_{s_{cold}} J.ds\,\vec{n} = I_{cold} \quad \text{(Cold circuit terminal)}$$

$$\iint_{s_{hot}} J.ds\,\vec{n} = I_{Hot} \quad \text{(Hot circuit terminal)}$$

where, $\vec{n}$: normal unit vector to the boundary surface

Here, we illustrate, in figure 7 the Electrical potential (v) on the cross-section surface of the cavity load.

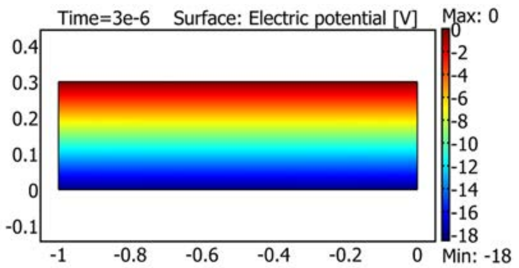

Figure 7. Electrical potential on the cross-section surface of the cavity load

2.3 Oscillator Design

We design an oscillator using as active component the planar triode, which was already analysed by FEM. For design of this oscillator, a Colpitts oscillator circuit is chosen. The Colpitts circuit has a great robustness in regard with the load variations. The first thing to do in the simulation process of the Colpitts oscillator was to obtain a signal oscillation by spice simulator. When by simulations a signal oscillation was obtained, then, the second thing to do was to tune the resonant circuit of the oscillator in order to get the required oscillation frequency, which must be about 13.56$\pm$10% 13.56 MHz. In this study, a long process of simulation has been set in place to choose the final component values of the oscillator circuit in order to optimize the output oscillation. Here, we have shown on the figure 8 the schematic of this Colpitts oscillator circuit.

4. Simulation results

In this section we present the various simulation results, which we obtained from the triode oscillator, which is connected, to the resistor R_L or to two parallel plates as its load. In the first part, we consider $R_L = 50ohms$ as a load. Here, we have demonstrated on figure 9 the voltage oscillation on this load. We can notice on this graph that the amplitude of output signal is about 3500 volts, which has an output power of 122.5Kw at a frequency about of 14 MHz. Also,

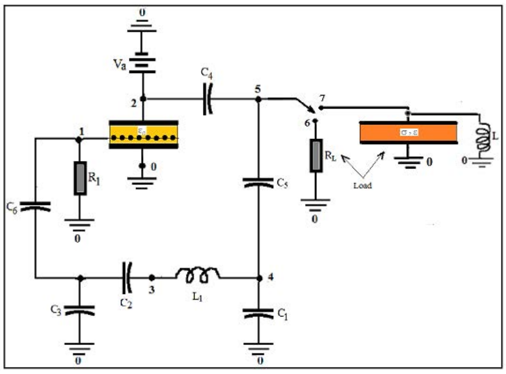

Figure 8. Schematic of the Colpitts oscillator circuit ($V_a = 4500volts$, $R_L = 50\ \Omega$, $R_1 = 39K\Omega$, $L_1 = 2.5\mu H$, $C_1 = 15pF$, $C_2 = 95pF$, $C_3 = 15pF$, $C_4 = 1nF$, $C_5 = 440pF$, $C_6 = 100pF$)

figure 10 shows the voltage signal between the grid and the cathode of the planar triode. Then, we can deduce from figure 9 and figure 10 that this active device gives a voltage gain of 90.

In the second part, we consider the two parallel plates as a cavity load. Also, we connected to cavity load a self-inductance L as it has been shown in figure 8. This self-inductance compensates the capacitive effect of the cavity load. Here, We consider the case where the cavity is filled in a lossy dielectric like wood, and we take for the simulation $W_1 = 1meter, H_1 = 30cm, L_1 = 1meter$, $\varepsilon_r = 1.2$, $\sigma = 0.4\times10^{-4}$ and $L = 0.25\mu H$. Figure 11 illustrates the voltage oscillation on the cavity load. We can notice on this graph that the signal amplitude is about 2000 volts having an oscillation frequency of 9.45 MHz. This means that by the variation of the load impedance the oscillation frequency is changed. The frequency spectre of the output signal can be determined by applying a Fast Fourier Transform (FFT) program. Therefore, This method permits us to observe the electrical characteristics of the load during of the heating process.

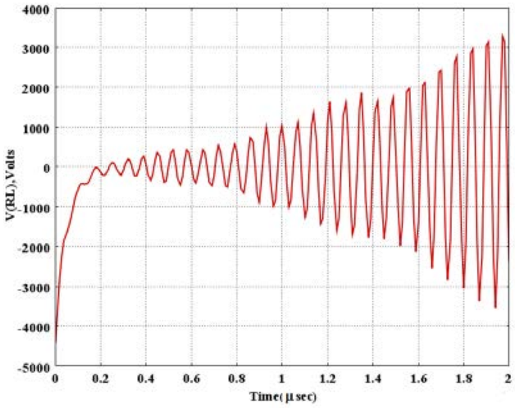

Figure 9. Voltage signal on the 50 ohms load

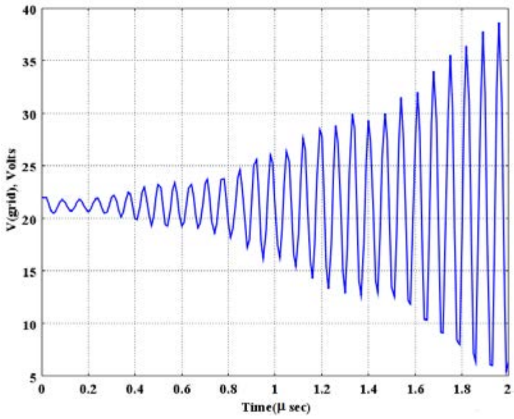

Figure 10. Voltage signal on the grid

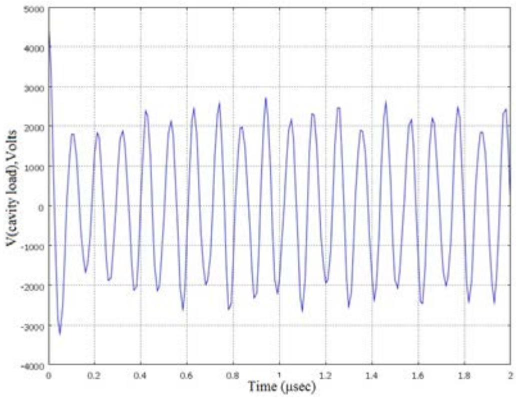

Figure 11. Voltage signal on the cavity load

5. Conclusions

This paper proposed a simulation model for designing of a new generation of high power oscillator, a triode and its load. Here, we applied a 2-D finite elements time domain method (FEM) linked to spice circuitry to simulate an oscillator using COMSOL Multiphysics software. In contrast to empirical methods, the proposed method offers a strong performance for the design and the conception of high power generator and also, for observing the electrical characteristics of the load during of heating process. By this approach, we are able to design triode having different geometry shape like: planar, coaxial or cylindrical, etc, for different heating application.

In this paper, we have investigated the simulation of a high power planar triode. Furthermore, the simulation results obtained can provide useful information about the frequency of oscillation, the output power, and the efficiency of power generator.

6. References

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