

# Simulation of an 18-Vane Magnetron in CST-PIC

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## Abstract

This paper presents the simulation of a vane-type magnetron using the commercial electromagnetic software Particle-in-Cell (PIC) solver in CST. The magnetron mainly consist of 18 anode vanes without strap. The resonance frequency has been selected in X band since it has a long production history enabling a ready comparison of computed and measured results. Simulation of magnetrons has been improved by changing dimensions of cavities, optimizing voltage and applied magnetic fields values. The aim of this work is to tune the operation frequency of magnetron under the constant electric field and the magnetic field between the anode and cathode.

## 1. Introduction

The principle of magnetron operation is firstly established on the motions of electrons under the combined influence of magnetic and electric fields. The early magnetron was termed by Hull in 1921 who used a cylindrical anode with coaxial cathode [1]. This first magnetron was low efficiency and power capacity due to its cylindrical anode construction. A high efficient magnetron was discovered in 1935 by Postumos using of an anode structure containing a number of microwave resonators. In 1940 the six cavity anode magnetron was developed by Randall and Boot [2]. During World War II the studies were performed on resonator structure. These researches resulted in two types of resonators, namely with strap and without strap.

The magnetron is a well known electron vacuum tube device used to generate electromagnetic fields in the microwave frequency range. Basically the internal structure of the magnetron is consisted of the cathode and the anode. The cathode is located on the center of the magnetron. It is supported and maintained by fixed and large filament leads that are sealed carefully into the tube. There are three possible configurations of anode; hole slot, rising sun and vane type. A DC field established by the voltage source is set up between cathode and the anode. The magnetic field is applied perpendicular to the electric field in the interaction region, a space between the cathode and the resonant cavities in the anode. If the ratio of electric and magnetic field is suitable, resonance condition is occurred and desired microwave frequency generated by the cavities. The dimensions of cavities determine the operation frequency of magnetrons.

The electromagnetic simulation can be used to optimize the operational parameters of magnetrons while designing of cavities and anodes. Besides, it decreases the time consuming for the production of subcomponents of magnetrons. It is expected that from the manufacturer's point of view this would substantially reduce the time and the cost of development of new magnetron devices.

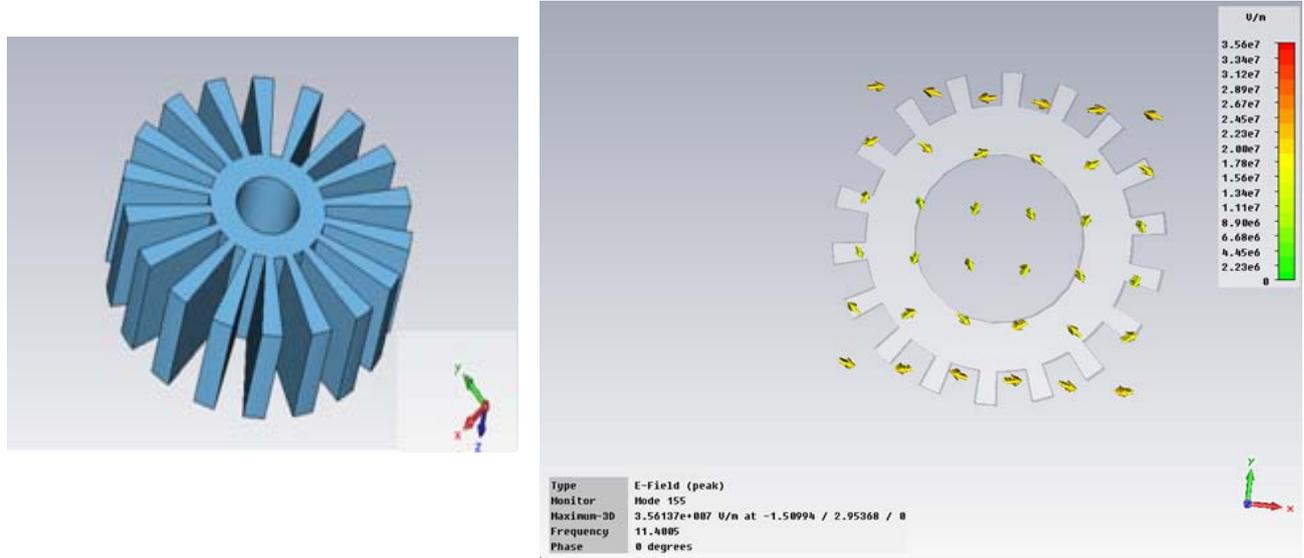
In this work a vane type anode will be presented where the vane type is generally made up of individual vanes assembled and brazed into a support ring. The anode plate has a shape of a hollow cylinder and has anode vanes which extend in depth. The open areas between these vanes are termed as the resonant cavities and have the purpose of a tuned circuit that decides the output frequency generated by the tube.

## 2. Simulation

In this work the magnetron simulation has been performed using a Particle Studio which is recently developed by CST Microwave Studio as a commercial software package [3]. Three different solver, an eigenmode solver, a tracking solver, a particle-in-cell (PIC) solver exist under the Particle Studio division. In order to simulate distinct part of magnetron only one of solver could be proper. A consistency of finding results has been observed in the CST solver sections as in preliminary theoretical calculations.

## 2.1. Eigenmode Solver

In order to obtain the right spectrum of resonance frequency, the geometry of the bare anode and cavities should be set up first of all. The schematic of the 18-vane magnetron resonator is shown in Fig. 1a. The cartesian coordinate system (x, y, z) was used for this simulation to model the trapezoidal shape of the anode cross section. The resonance modes of frequencies were obtained in Eigenmode solver for the vane-type magnetron as a cold test. In addition to that the vane construction designed to obtain  $\pi$ -mode which is the fundamental modes of resonances frequencies. The  $\pi$ -mode resonances result is given in the Fig. 1b.



**Figure 1.a)** The schematic model of the cavities which is prepared in Eigenmode Solver (left), b) The schematic representation of  $\pi$ -mode in resonator structure without strap (right).

The resonators have been adjusted with respect to  $\pi$ -mode in Eigenmode Solver. In this mode the electric fields in each cavity constitute with a phase difference of about  $180^\circ$ . For this study as shown in Fig. 1b, the fields exhibited a weak behavior with respect to the expected movement since we have tried to tune up to  $\pi$ -mode without strap. The results of the Eigenmode solver have shown a close agreement with the theoretical calculations and the cold simulations have been carried out to calculate frequency value for vane type magnetron where the  $\pi$ -mode formed.

## 2.2. Tracking Solver

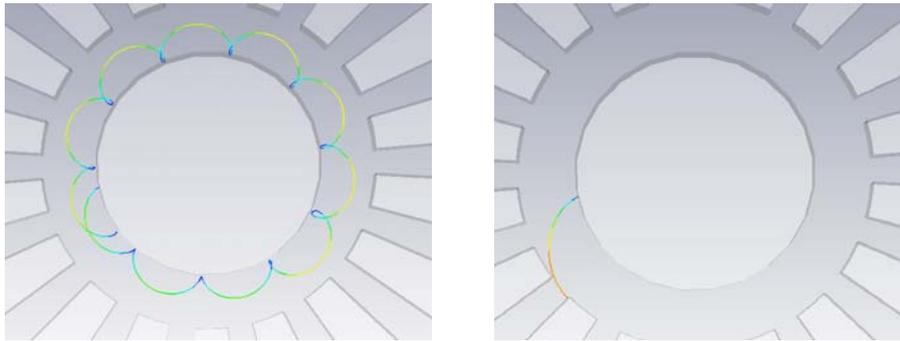
In magnetrons, the basic reason to increase the amplitude of RF wave is the behavior of the electrons under combination of applied potential and magnetic field where the tracking solver based on to investigate these movements in time space. Considering to electron trajectory the applied magnetic field and potential value could adjust systematically. First of all, the magnetic field value is calculated using theoretical methods and the potential values related to B-field regarding the cutoff conditions. After preliminary calculations in Tracking solver is used to optimize these operational B and U values. In this work the electron trajectory is observed under the optimized applied voltage and the magnetic field as shown in Fig. 2.a-b.

The voltage between anode and cathode  $U(c)$  is given in Eq. 2.1 [4]. This equation explains the cutoff relation in  $B_c$  magnetic field which corresponds to cutoff regime. The  $r_a$  and the  $r_c$  are the radius of the anode and cathode, respectively. For a given potential between anode and cathode the different value of magnetic field is defined to electron trajectories.

$$U(c) = \frac{\eta B_c^2 r_a^2}{8} \left( 1 - \frac{r_c^2}{r_a^2} \right)^2 \quad (2.1)$$

In Tracking Solver the electron trajectory in cavity could be controlled by the formerly calculated E/B ratio. Using this solver, a determination for the operated magnetron regarding to the E/B ratio could be performed where it works either before-cutoff regime or after-cutoff regime in Hull Parabola [5]. Fig.2.a shows the electron trajectory in

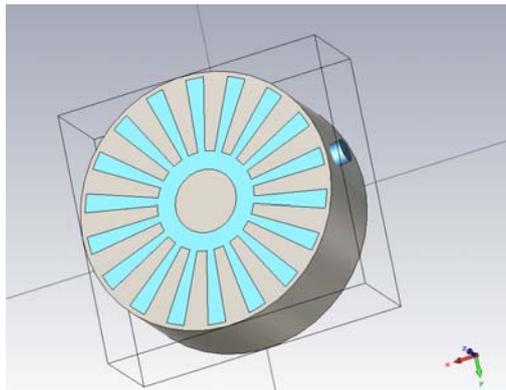
cavity when the E/B ratio is well-tuned in the operated magnetron. Above cutoff region the simulated trajectory of electron is also presented in Fig 2.b. This indicates that the E/B ratio is not properly adjusted in Tracking Solver.



**Figure 2.** Electron trajectory obtained using Tracking Solver (a) under the ideal magnetic field (in a well-tuned E/B ratio) (left) and (b) under the low magnetic field (right).

### 2.3. PIC Solver

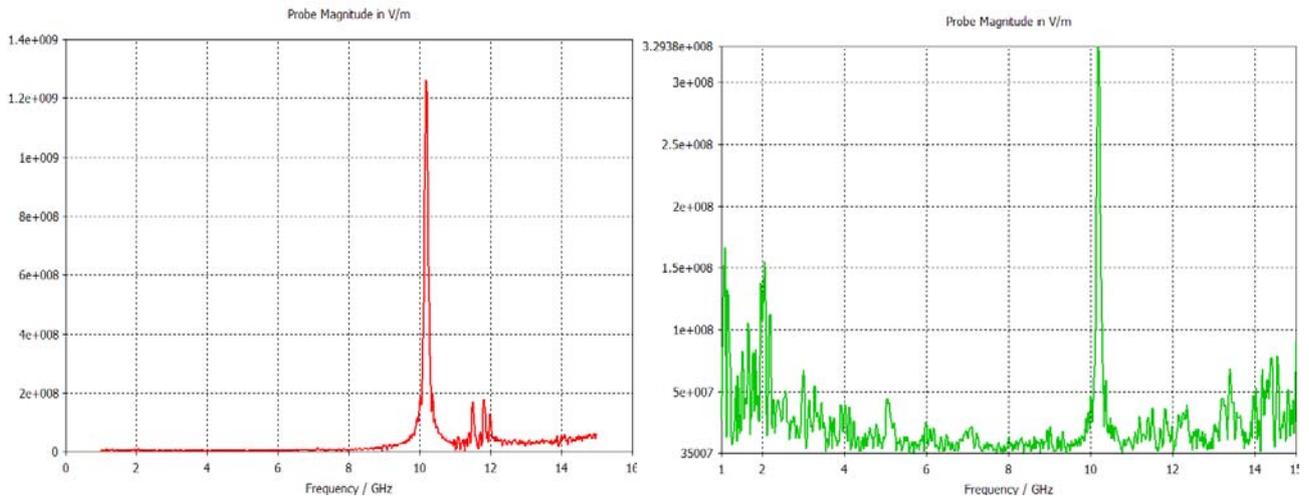
PIC Solver, approaching a settled probe inside the vane resonator is used to obtain the operation frequency of magnetron (Fig. 3) and the simulated results by using of PIC Solver is shown in Fig.4.a. This frequency is in a quite well agreement with the theoretical calculations and recently published results in PhD thesis [6]. In addition when comparing the calculated resonance frequency by Eigenmode Solver (cold test result) is in agreement with PIC Solver results (hot test).



**Figure 3.** The vane-type magnetron model is prepared using PIC Solver.

The spectrum shown in Fig.4.a is observed in the coaxial output port of magnetron. When the magnetron is adjusted to  $\pi$ -mode a resonance signal on the output of the port is observed at around 10.2 GHz. In the PIC Solver the B and U values are optimized by using of the results obtained from Tracking Solver. The observed signals are obtained from the output of the coaxial waveguide port. Because of the fine-tuning voltage in constant B-magnetic field the energy is generally accumulated in  $\pi$ -mode or in other words in fundamental mode.

In Fig.4.b, the spectrum of the operated magnetron tuned in  $\pi$ -mode has been measured using by probe in cavity. This output signal is from the interaction region in the cavity not from the waveguide port. The voltage is not well tuned in this simulation. Thus it does not represent the desired clean spectrum and the amplitude is not high as in the port signal. This could be an indication to explain why the energy values are still available as another component in the cavity. We can also say that the ports behave as a filter. Actually, in the interaction region the amplitude of the signal is higher than in the port signal due to the coupling coefficient.



**Figure 4.a)** The spectrum is observed in coaxial output of magnetron (left). b) The simulation results of spectrum of magnetron with probe in the cavity is tuned by  $\pi$ -mode (right).

### 3. Results

The X-band vane type magnetron simulation has been performed using the commercial software package CST PIC. A close agreement has obtained between using of PIC, Eigenmode and the Tracking solvers with the theoretical calculations. The deviation between the cold test result and the hot test result was approximately % 10 percent. This amount of shift generally occurs between hot test and cold test result while tuning the magnetron without straps at the high frequency and more cavities magnetrons structures.

### 4. Acknowledgements

This work has been conducted under the project establishing a Cathode and Microwave Vacuum Tube Research Center (KAMTAM) started at BİLGEM/UEKAE-TUBİTAK in 2009 and expected to settle in medio 2011. Then it will be possible to make comparison between simulation and measurement results.

### 5. References

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