DESIGN AND SIMULATION OF 8-CAVITY-HOLE-SLOT TYPE MAGNETRON ON CST-PARTICLE STUDIO

A Dissertation Submitted in Partial Fulfillment of the Requirement for the Award of the Degree

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Wireless Communication

Submitted By

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DECLARATION

I, Salma Khatoon hereby declare that the work presented in this thesis entitled **"Design and Simulation of 8-Cavity-Hole-Slot-type Magnetron on CST- Particle Studio"** in partial fulfillment of the requirement for the award of degree of Master of Engineering in Wireless Communication submitted at Electronics and Communication Engineering Department, Thapar University, Patiala is an authentic record of work carried out under supervision of **Dr. Rana Pratap Yadav** (Assistant Professor, Electronics and Communication Engineering Department, Thapar University , Patiala) Jan 2017 to July 2017. The matter presented in this this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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Date...17 July 2017

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It is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

Date..17 July 2017

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ABSTRACT

In wireless communication technologies, three types of modulation have been used in modern radar systems commonly – pulse (as a particular type of amplitude); frequency; and phase modulation respectively. Pulsed magnetrons has been generally used in radar to detect the aircraft, pathway / monitor supersonic missiles, communication satellites system and continuous wave magnetrons used for microwaves oven at home for cooking purposes. Most of the aircraft operating today use solid-state devices in their radars due to their simple construction and high power output. In this different types of magnetron one of hole slot type magnetron are used in commercial as well as military areas.

This report presented the study of design and simulation of 8-cavity-hole-slot type magnetron using commercial electromagnetic software PIC (Particle in Cell) solver in CST (Computer Simulation Technology). An 8-type hole slot magnetron model consists cathode part that is surrounded by circular anode section with 8-hole slot resonator. The 3D model of magnetron is build and simulated by using empirical values of structural, electrical and magnetic parameters. The empirical formula is used to calculates these parameters. A magnetron simulation on CST particle studio represents three configurations like as eigen mode, particle tracking and particle in cell. The first mode ensures the mode excitation whereas remaining two modes are required for the desired operation of magnetron. In this paper, magnetron is designed for X band where the impact of electric field w.r.t frequency and time for PIC solver is investigated and found peak at 5.28GHz. Further, shorted straps inside magnetron cavity have been implemented. This improves the field properties of magnetron. Presented investigation can have wide ranges of application in era of radar technologies and commercial field.

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LIST OF ABBREVIATIONS

EM	Electromagnetic
DC	Direct current
ATC	Air Traffic control
PIC	Particle-In-Cell
CST	Computer Simulation Technology
CST-MS	CST Microwave Studio
MW	Microwave
LINAC	Linear Accelerator
RF	Resonant Frequency/Radio Frequency
LAM	Long Anode Magnetron
FAM	Frequency Agile Magnetron
IMRT	Modulated Radiation Therapy
VMAT	Volumetric Modulated Arc Therapy
IGRT	Image Guided Radiation Therapy
SRS	Stereotactic Radiosurgery
SBRT	Stereotactic Body Radio Therapy
WSR	Weather Surveillance Radars
DWR	Doppler Weather Radars
ATCRBS	Air Traffic Control Radar Beacon System
MDO	Magnetron Diffraction Output
AFR	Air Force Research Laboratory
DE	Directed Energy Directorate
CW	Continuous Wave
RM	Relativistic Magnetron
RSM	Rising-Sun Magnetron

SRSM	Sector- resonator type Rising-Sun Magnetron
SSRSM	Sector-and-slot resonator type Rising-Sun Magnetron
UAV	Unmanned Aerial Vehicle
ACLS	Advanced Cardiac Life Support
CIED	Cardiac Implementation Electronic Device
SHM	Spatial-Harmonic magnetron

CHAPTER 1
INTRODUCTION

The magnetron is the vacuum tube system to release the electrons that are using to produce EM- field in the MW frequency range. The magnetron interior design model is consisting with the anode and cathode. In a magnetron, a cathode has placed at the middle of the number of resonators. It has stayed and kept by permanent and larger filaments leads, which has sealed sensibly into the tubes. A magnetron has three different types of structures of anode like Rising-Sun, Hole-Slot and Vane-Type. The DC voltage source fixed between anode and the cathode. A magnetic field applies vertically on the electric field into the interaction space that is an area in the middle of the resonant cavities in the anode and the cathode [2].

Magnetron are mostly used in radar for detecting aircraft, pathway / monitor supersonic missiles, observe and track weather patterns, air traffic control (ATC), garage door openers, police speed detectors etc. Fixed frequency, Continuous-Wave magnetrons used for industrial heating and microwave ovens.

The magnetron is a well-organized device. It has some advantages like the mixture of small cavities of magnetron, small antenna and high quality radars used in aircraft, due to line of sight and high frequencies, there is less fading effect and hence microwave communication is more reliable.

H. Gerdien was invented the first magnetron in 1910. Other type of magnetron was Split-Anode type Magnetron that was discovered by Albert Hull in 1920 but then again it was not sufficient for high frequencies and was used for little applications. Many teams through the 1920s and 1930s experimented with similar devices. In 1935, Hans Erich Holman applied for a patent of the first Multiple-Cavity Magnetron that he received on July 12, 1938. However, the extra stable klystron was choosing for most German radars at the time of World War II. John Randall and Harry Boot enhanced the cavity-magnetron tube lateral in 1940 shown in figure 1.1 [1].

The source of magnetron process has recognized to the motion of electrons in the combinational effect of electric and magnetic field. A timely magnetron was named by Hull in 1921 that was using a cylinder-shaped anode with co-axial cathode [2]. This type of magnetron has some drawbacks like lower efficiency and power capability due to its cylindrical anode design. Postumos using of an anode designs with required no. of resonators that give a highly capable magnetron, in 1935. In 1940, Randall and Boot developed advanced type the six-cavity anode magnetron, their researches give a two types of resonators, strap and without strap [3].

Figure 1.1 Anode block Cavity- Magnetron discovered by John Randall and Harry Boot [1]

1.1 MAGNETRON:

A highly power vacuumed tube magnetron that produces microwaves signals by the interface electrons with each other due to a magnetic field effect. A gathering of electrons passes in the openings of the cavities to stimulate radio waves oscillations from the cavity. In which, the microwaves frequency formed and the Resonant-Frequency founded with the cavity size. Additional microwave tubes like the klystron and traveling-wave tube (TWT) is different; the magnetron cannot work as an amplifier because the increased power of an applied microwave signal so that it work uniquely as an oscillator and produces a microwave signal through DC power provided to the vacuum tube. In magnetron, cathode had placed at center of anode and a filament lead used to hold the cathode. A hole-slot type area is known as resonant cavities. RF field can be generating between cathode and anode area. Surrounding the magnetron cooling fins used to control or reduce the heating effect of the magnetron. A magnetron designed model shown in figure 1.2

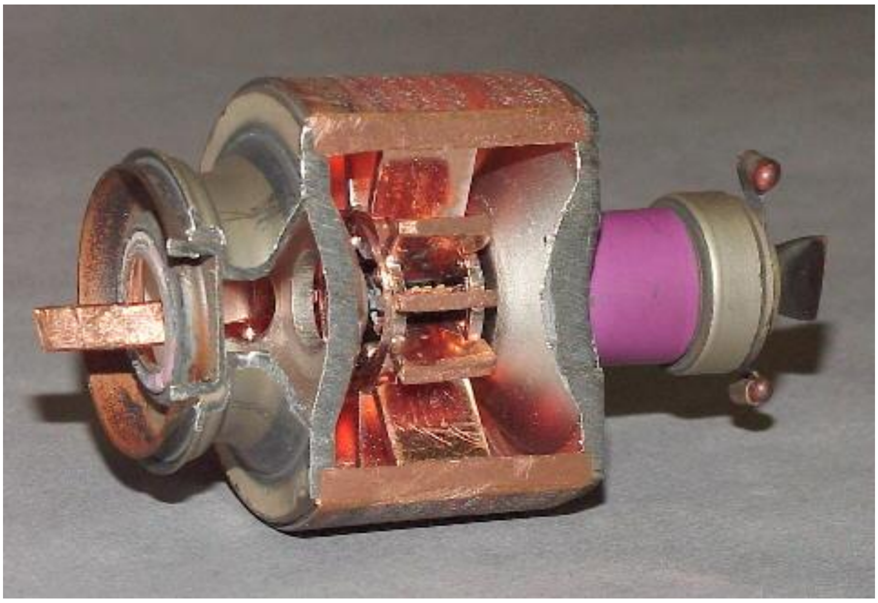

Figure 1.2 Magnetron Design model Used in Microwave Oven [1]

The ANODE is a resonating cylindrical shape of structure that has a multiple number of anode blocks to spread innermost regions. An opened cut parts in each of the vanes-blocks are resonant cavities, which work as tuned circuit to control the amount of produced frequency in the magnetron. The anode cavities work in that manner the alternative segments essential to linked or strapped with each other, so that each segment is opposed polarity of the segment of both side.

The FILAMENT LEAD (that named as heater), functions as the cathode of the tube, which has been positioned at the center of the magnetrons and has been stayed through big and inflexible filament lead that has sensibly closed into the tube and protected.

The ANTENNA has a probe or ring, which has coupled with anode and connected at the one of the anode block. An antenna has joined with the waveguide in a hollow metal attachment into which the antenna spreads the Resonant-Frequency energy.

The MAGNETIC FIELD provides a strongest stable magnet that is stable nearby the magnetron to equivalent/parallel magnetic field with the axis of the cathode.

1.2 TYPES OF MAGNETRON:

1) Negative resistance Magnetrons:

Negative resistance used in the middle of two anode segments but it provides lower efficiency and work simply at low frequencies (< 500 MHz).

2) Cyclotron frequency Magnetrons:

If Synchronization occurs between irregular components of electric and periodic oscillations of electrons, it run simply at frequencies more than 100 MHz and its efficiency is very low.

3) Cavity Magnetrons:

According to the effect of electromagnetic field with constant angular velocity on the electrons that are moving rotationally in the interaction region of magnetron. It offers oscillations of very high peak power and useful in radar applications.

4) Frequency Agile Magnetrons:

Frequency Agile (FA) Magnetrons are mostly used now radar tasks; it has skill to adjust the amount of produced frequency of the radar with appropriate rapidity is to producing a pulse to pulse frequency variation more than the quantity essential to effectively find de-correlation of neighboring radar echoes.

Frequency agile magnetrons have four types:

a) **Dither Magnetrons (D):** Produces Resonant-Frequency is fluctuates periodical in nature through a continuous excursion, constant rate and permanent middle frequency.

b) **Tunable/Dither Magnetrons (T/D):** To produce RF frequency fluctuates periodical in nature by a constant excursion and constant rate. A central frequency will slightly adjusted through needle or using external servomotor determination to some points with in the tunable band.

c) **Accutune Magnetrons (A):** Produces RF frequency fluctuation has been identifying through the waveform of an outwardly produced lower-level voltage signal. For suitable choice of a fine-tuning waveform, the features of both Accutune magnetron and the dither and tunable/dither magnetrons are combined.

d) **Accusweep Magnetrons (As):** Accusweep type of magnetron is more multipurpose tuning system. The output RF tuning rate and waveform are markedly adjustable with in the design limits of each device. Consumer inputs are normally several waveform from casual to square wave and a + 5 volt command [5].

e) **Beacon Magnetron:** Beacon magnetron is minor conservative magnetron, its peak power output lesser than 4 kilowatt and average power output lesser than 5 watts. A Manufactures of beacon magnetron has explain by containing five simple structure blocks shown in figure 1.3. It has anode, tuner, cathode, output, and permanent magnet.

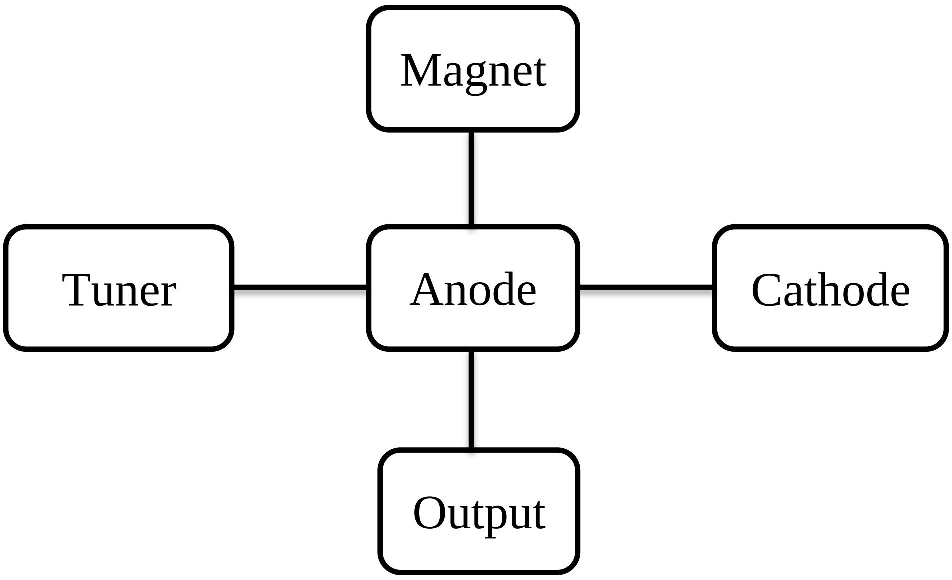

Figure 1.3 Block diagram of Beacon Magnetron

Anode:

The anode has an establishment of the magnetron design. It mostly made of a multiple numbers of resonant cavities that set in circular direction as given in figure 1.4. There are three types of anode structure:

1) Hole and slot
2) Vane type
3) Rising sun

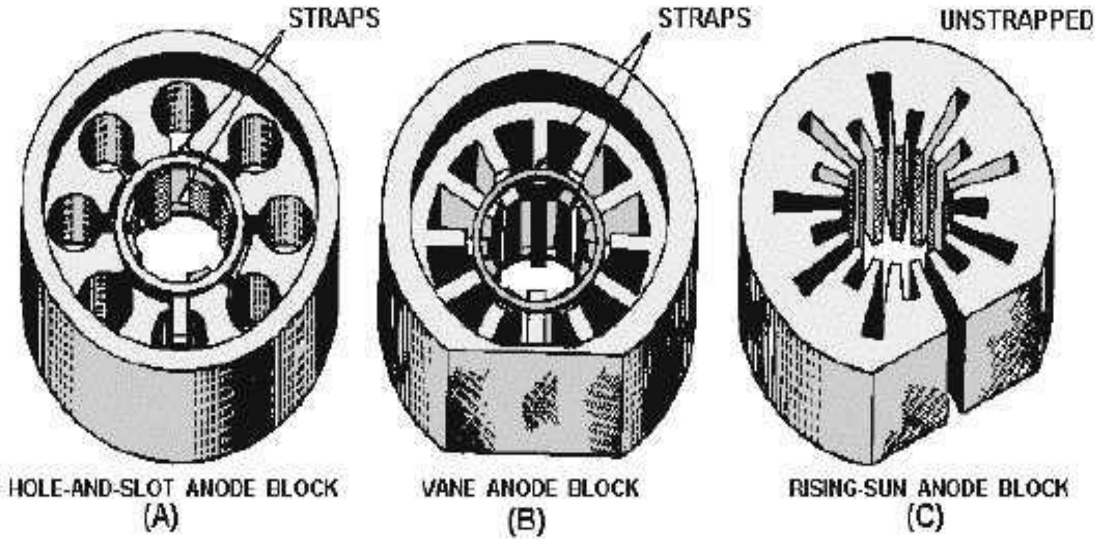

Figure 1.4 Different types of cavities used in Magnetron [5]

Straps:

The frequency of the pi-mode disconnected from the frequency of other modes using straps to confirm that the alternative segments have equal polarities. On behalf of the pi-mode, every parts of each strapping ring have equal potential but the two strapping rings have interchangeably opposite potential. For other modes, phase dissimilarity occurs between the continuous segments linked with a given strapping ring that causes current to flow in straps.

Tuner:

The tuner is a device that is present in several magnetrons, which have capability to diverge the basic frequency obtained in the anode. Tuner tumble into three simple categories:

1) Capacitive
2) Inductive
3) Combination of both

Cathode:

The cathode is a part of magnetron that makes the magnetron an active device. A cathode delivers the number of electrons over which the mechanism of energy transmission is proficient. A cathode has typically placed at the centre of the anode and containing a resonating cylinder of emissive material surrounding a heater. Magnetron's cathode considered that work at specific temperatures and due to the phenomenon known as "back bombardment".

Output:

The Producing output at one of the resonator circuit of a magnetron is that part of the device, which make the coupling on an exterior load. One a coaxial or other one a waveguide type of output may combine the RF energy obtained from the cavities.

Magnetic Circuit:

The magnetic circuit linked by magnetron is compulsory that deliver the crossed-field type of action to delivers for the organization of the trajectory of electrons**.** The magnetic circuit presented at this point to compose of an outside stable magnet and connected with interior pole pieces.

1.3 CYLINDERICAL MAGNETRON:

Construction: In a magnetron model, cathodes have placed at the Centre and discharge the more number of electrons that reach at the anode with the effect of magnetic field and return at cathode due to magnetic force, multiple even no. of anode cavities and a stable magnet located at around the cathode. A cathode has situated at the filament leads that support the cathode to stay stable. The space in the middle of the anode cavity and the cathode is known interaction space, has shown in figure 1.5. The electrons are release from the cathode transfers in diverse way into the interacting space dependent on the strong effect of electric and magnetic fields that applied on the magnetron.

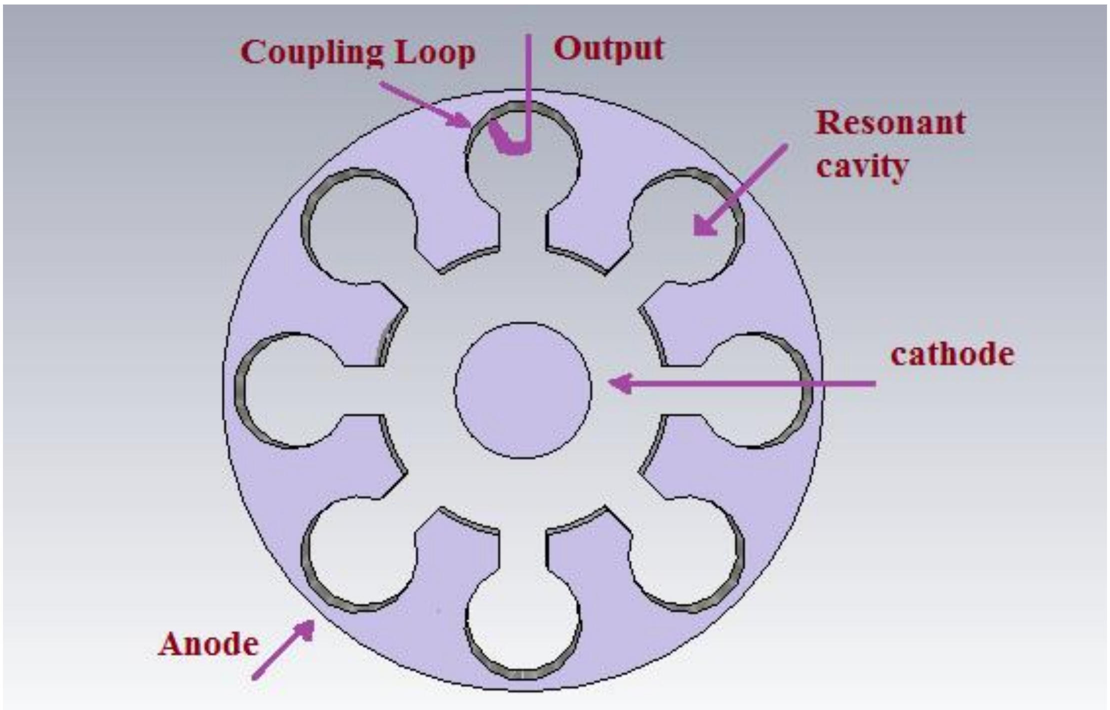

Figure 1.5 Hole- slot- cavity type Magnetron

Basic Operation:

Dependent on the relative power of the electric and magnetic field effect, the electrons discharged from the cathode and travel in the direction of the anode cavity with velocity and motion has completed with circular shaped in the interaction space.

Effect of electric field only

Its first condition, if magnetic field is zero or not exists, the electrons travel straight starting the cathode to end of the anode owing to the centrifugal electric field force performing on it as shown in figure 1.6 a-particle movements. Uncertainty the magnetic field strength rise, it relate with a lateral force to bend the track of electron. If the strongest magnetic field present, the electrons is getting more so the electrons reached at the anode, and current is zero. The magnetic field effect necessary for comeback electrons at cathode that surface of the anode named as cut off magnetic field (B_c) if the electron come back as shown in figure 1.6 like c-particle.

When the magnetic field is higher than cut off Magnetic field ($B > B_c$), the electrons acquires a more turning force and can come back at cathode quickly. Due to this effect, results getting as cathode are heat up.

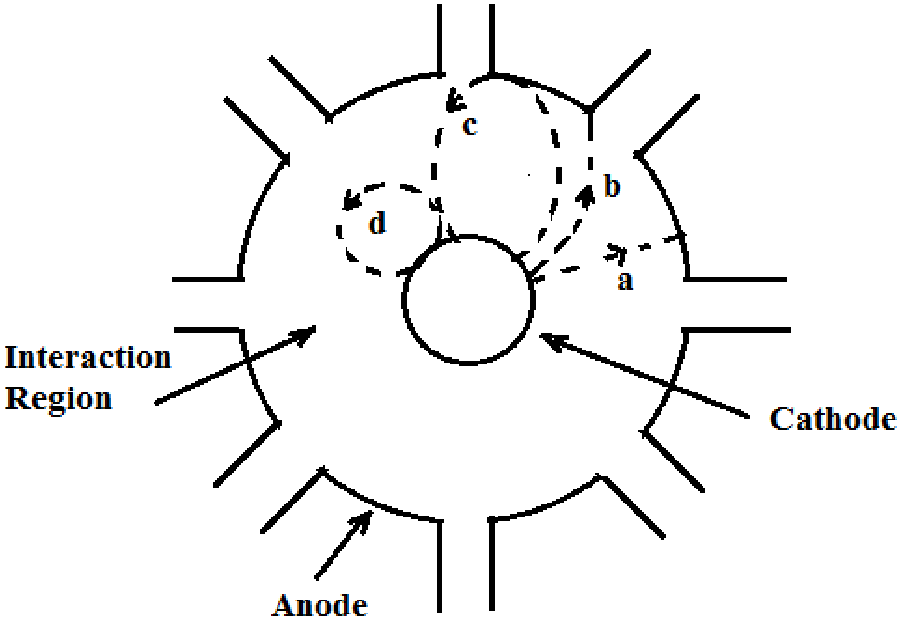

Figure 1.6 Effect of magnetic field on Magnetron

Effects of magnetic fields only

The magnetic field apply normal to electric field therefore it had titled axial-magnetic field, and so the magnetrons also named as cross field device for the reason that of circular electric field and axial- magnetic field are at right angles with each other. Condition, the magnetic-field effect is higher so the no. of electrons released come back at cathode using greater velocity as given in figure 1.6 b-particle movement, due to this reason may possible to destroy the cathode, this outcome known as back heating of cathode.

Combine effect of electric field and magnetic field

While together electric and magnetic fields are happens the electrons possibly will have different path due to the effective strength of E and H. Uncertainty, the electric field is greater than magnetic field, in this event, the more no. of electrons reached at the anode but then again the path will be bending little due to lesser magnetic field. A condition, magnetic field is greater than the electric- field, in this situation, the electrons return-back to the cathode with accurate lateral force acting on it.

1.4 RELATIVISTIC MAGNETRON:

The relativistic magnetron has unique greatest hopeful sources of high-power microwave. Its simple principle is that type of the cavity magnetron, here simply pulsed process has been essential at high power and the useful voltage has been considerably larger more than 500 kV. Due to the influence of potential, a no. of electrons released from a cylinder-shaped cathode and produce microwaves signal by resonance in the middle of their gyro-frequency in a strongest axial-magnetic field and the adjacent slow-wave configuration of the anode blocks.

In latest progresses of HPM generation in pulse power systems, Relativistic magnetron has more efficiency among existing high power microwaves devices. That type of system has great repetition rate. Relativistic magnetron made of coaxially attached cavities in which a high magnetic field (0.2 to 0.6 T) is applied. Structure of the magnetron has done by Charged particle simulation method on CST simulation software.

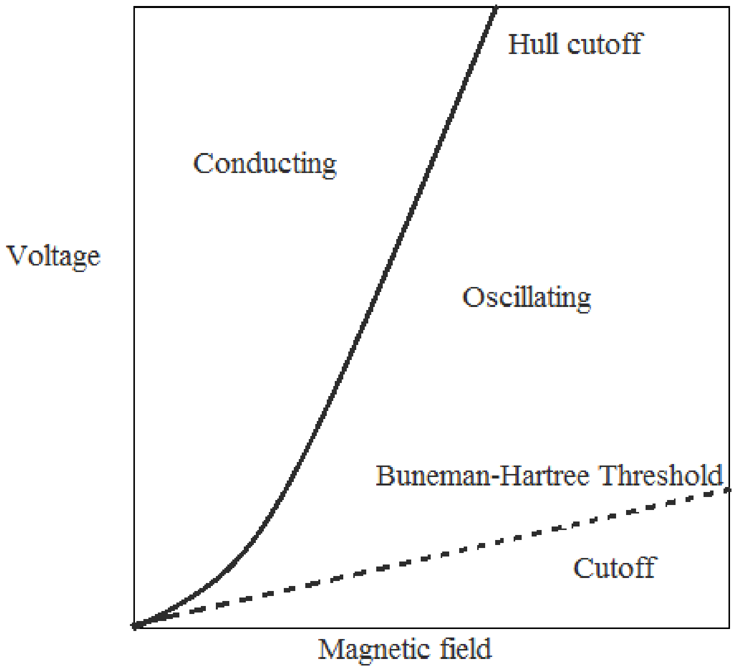

Figure 1.7 General Representation of magnetron operation domain (Hull cutoff and Buneman-Hartree curves).

A repetitive pulse power system established which has built with the Magnetic Pulse Compression (MPC) method and Inductive Voltage Adders (IVA) alike to LIA-200 advanced earlier. The benefit of these types of systems is that these systems have high repetition rate and a better shot-to-shot variability compared to those spark gap switch based systems [7].

Hull cut off magnetic equation:

$$B_{oc} = \frac{(8V_o m/e)^{1/2}}{b(1-\frac{a^2}{b^2})} \tag{1.1}$$

This eauation say that if $B_o > B_{oc}$ for a given V_o, the electrons will not touch the anode .

Hull cut off voltage equation:

$$V_{oc} = \frac{e}{8m} B_o^2 b^2 \left(1 - {a^2}/{b^2}\right)^2 \tag{1.2}$$

This equation say that if $V_o < V_{oc}$ for given B_o, the electrons will not touch the anode.

Two well-known conditions for selection of operational voltage and axial-magnetic field in magnetrons are the Hull cut-off and Buneman–Hartree. The magnetrons have an oscillation on selected operative points that are lies between the Hull cut-off equation and the Buneman–Hartree condition as shown in figure 1.7 [24].

Simulation:

Simulations implemented through the help of CST MS and CST PIC to get the frequency domain performance of the device. The simulation structure is design with important values R_c, R_a and R_v are used individually that is radius of cathode, radius of anode and relative velocity of electron. At the start, Eigen mode simulation executed to obtain the Eigen modes of the 8- coupled cavities. In the π-mode, the excitation is larger in the 8-cavity magnetrons that have opposite phase between the adjacent cavities. The successive increase and decrease of adjacent anode-cavities fields will regard as a travelling wave along the surface of slow-wave structure. Magnetron oscillators are ordinary operated in the π-mode.

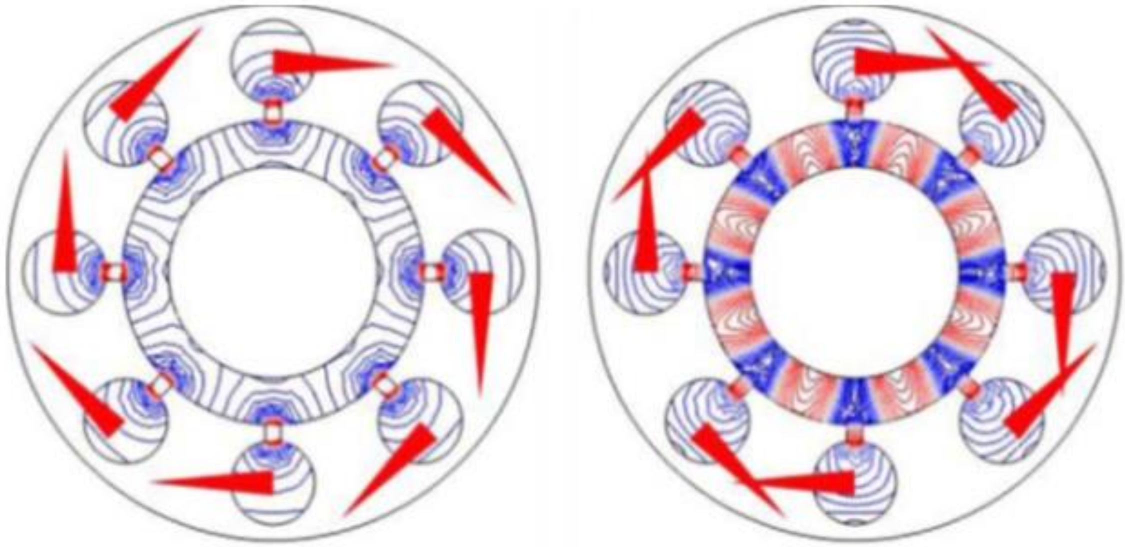

Figure 1.8 E-field of the Magnetron with 2π-mode (at left side) and π-mode (at right side) [28].

All the modes achieved for the magnetron process, π-mode with frequency in GHz selected for the reason that it is the only frequency, which is non-degenerate. The electric field waves inner side of the cavity shown in fig1.8 as π-mode. Due to variation in the emission process, a white-frequency signal has produced in the cavity. Between these noise frequencies, the coupled-cavity selects suitable frequencies that have the Eigen-modes of the total cavity [7].

The PIC Simulation supports for simulation of the output performance of the magnetron through simulating the interaction performance of the Resonant-Frequency circuit with the electron beam. The CST Particle Studio has used for simulation. The simulation output shows the fields' power density sharing of the resonant-modes in the transversal cross-section of the Magnetron [28].

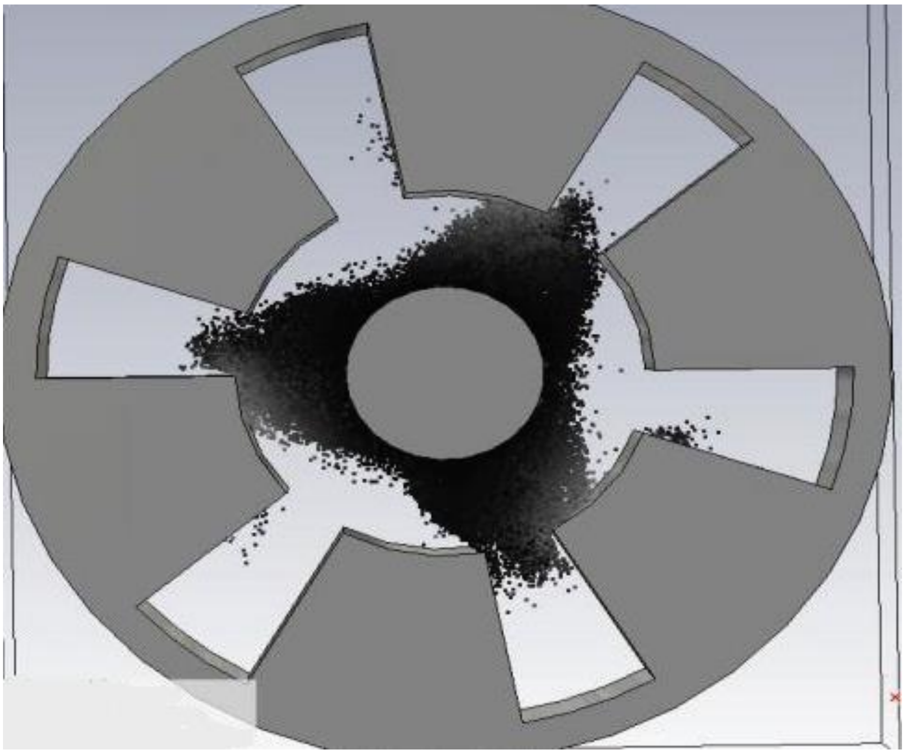

Figure 1.9 π-mode spokes of electron in 6-coupled cavity [1].

Released electrons form a shape of cloud in the interaction space and starts moving mutually .A π-mode spokes of the electrons have seen inner side of the interaction space as given in figure 1.9.

In the magnetron, simulation will be implementing by using a Particle Studio that technologically advanced. Three different solvers used for simulation like an Eigen mode solver, a Particle tracking solver, a Particle-in-Cell (PIC) solver happened in the Particle Studio. When simulate different portion of magnetron simply one and only of solver could be proper [1-8].

1.5 APPLICATIONS:

1) Magnetron are mostly used in radar for detecting aircraft, pathway / monitor supersonic missiles, observe and track weather patterns, air traffic control (ATC), garage door openers, police speed detectors etc. Fixed frequency, Continuous-Wave magnetrons used for industrial heating and microwave ovens.

2) **Linear Accelerator (LINAC):** A linear accelerator is a system that most generally usage for patients to determine cancer tissues in external beam radiation treatment. The linear accelerator has used to treat all parts/organs of the body. It provides high-energy x-rays or electrons to the area of the patient's tumor. It (LINAC) modifies high energy x-rays or electrons to conform to a tumor's shape and destroy cancer cells while sparing surrounding normal tissue. It can be uses in Intensity-Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), Image Guided Radiation Therapy (IGRT), Stereotactic Radiosurgery (SRS) and Stereotactic Body Radio Therapy (SBRT) systems. C-Band, S-Band, and X-Band magnetrons use in safety screening and medical linear accelerator applications.

3) **Air Traffic Control:** Different bands like, X-Band, S-Band, Ka and Ku-Band magnetrons usage in earth on air traffic control. The main purpose of ATC international is too aware about collisions, establish and accelerate the movement of air traffic, and deliver information to other support of pilots. In some countries, ATC plays a security or defensive role that activated by the military.

4) **Weather Radar:** Weather radar also named as weather surveillance radars (WSR) and Doppler weather radars (DWR). It has used to location observation, analyze its motion and guess it's type of weather like rain, Snowfall, hails etc. Modern Doppler radar is pulse Doppler radars, talented to detecting the motion of raindrops. S-Band, C-Band and X-Band magnetrons use in pulse Doppler hostile weather detection radar. It provides weather and navigational information.

5) **Frequency Agile:** C-Band, X-Band, Ku and Ka-Band frequency agile magnetrons use in electronic fighting, mid-air fire control and missile searcher radar.

6) **Beacon Transponder:** C-Band, X-Band, and Ku-Band beacon magnetrons use in transponder, UAV, ACLS and earth based transportable radar applications. Secondary surveillance radars used for air-traffic-control system. Modern Air Traffic Control Radar Beacon System (ATCRBS) are using for surveillance radar monitoring and separation of air traffic.

7) **Air Traffic Control Radar Beacon System (ATCRBS):** A radar system who can detect the object to be built-in corporative equipment in the form of radar receiver/transmitter (Transponder). Radar signals transferred from the transponder and the searching transmitter/receiver (interrogator) sites are receiving in the corporative equipment and used to trigger a distinctive transmission from the transponder. This replies transmission, rather than a reflected signal, a received back at the transmitter/receiver sites for processing and display at an air-traffic-control facility. This one allows controllers to see aircraft specific information such as altitude, ground speed, beacon code etc.

   Problems with ATCRBS: It uses a rotating antenna to continuous send our interrogation. An aircraft interrogated up to 20 times per sweep. Each time, the transponder sends back a separate reply that causes interference and overload in channels. When the interference occur the ground stations receives garbled signal. As traffic increases, the number of airplanes at a given time with in the antenna's interrogation beam will increase.

8) **Special Purpose:** Different types of bands like X-Band, S-Band, C-Band, L-Band, Ku and Ka-Band magnetrons usage in EMC/EMV testing, CIED, industrialized and technical-scientific applications.

9) **Magnetron and Microwave Oven Design:** Magnetrons useful as RF power bases for its high-energy transformation efficiency. Afterward the magnetron developed as radar machinery, mass invention and computerized engineering techniques have recognized the magnetron in the application area of microwave ovens at home.
   In microwave ovens, the waveguide indications to a resonators frequency crystal port into the cooking compartment. It is significant that if the food placed inside the oven when it operated so that these RF waves are absorbed, instead of reflecting into the waveguide due to the strength of standing waves causes comes out arcing. The arcing, if allowable to happen for time-consuming, will be destroy the magnetron.

CHAPTER 2
PARTICLE-IN-CELL (PIC) SIMULATION TECHNIQUE

2.1 INTRODUCTION

The PIC program simulates the motion of plasma particles and computes all macro-particles quantities similar to density, current density, distribution functions from the position and velocity of these particles. This technique could be castoff to simulate plasmas, rarefied-gases, molecular gas dynamics and other processes manifest via an exit after the thermal equilibrium. In PIC method simulation, a number of macro-particles, which travel in a field defined in a computational mesh, represent the gas. At any time, each particle will place within a mesh cell and the macro-force performing on the particles has been determined through the field equations. A tag 'Particle-in- Cell' has invented through a method those conveying macro-particles quantities for simulation. A PIC code generally has categorized dependent on the dimensional of the code and upon the set of Maxwell's equations used. The electromagnetic programs resolve the all-inclusive set of Maxwell's equations although the electrostatic programs solve only the Poisson equation [6].

The source of Particle-In-Cell (PIC) procedure are using for the simulation of collision less plasmas can be found to the early work implemented by Buneman (1959) and Dawson (1960). In which, the simple physics prototypes, space-charge forces were involved through easy explanation of Coulomb's law, and charged-particles trajectory have calculated in periodical structures. In the first Particle-in-cell simulations, the motion of 100-1000 particles and the interactions between the particles were involved. Now, PIC programs can simulate 105-1010 particles.

Particle-in-Cell programs have a more no. of advantages, it signify the lowermost program that means the number of expectations prepared in the physical model that reduced to a minimum. It will be simulate higher-dimensional cases and difficult geometries and attempting complex atomic and plasma-surface interactions. On the other hand, these processes take more time for simulation and computational efficiency that could be declared as the most important disadvantages of this technique [6].

The PIC technique has used in many applications i.e. fluid dynamics; plasma physics, magneto hydrodynamics, and multiphase applications all useful in the PIC method. In addition, PIC can also use to resolve the complications in solid mechanics.

2.2 PARTICLE IN CELL SIMULATION

Particle-In-Cell (PIC) is a method normally used to simulate motion of charged particles. The **particle-in-cell** (**PIC**) scheme, the system is collected by charged particles (e.g. negative electrons and positive ions) interacting in electric and magnetic fields [1]. If we want to identify each particle with a label p and their charge with q_p, position with x_p, position with v_p, the force acting on the particles is the combination of the electric and magnetic force is [9]:

$$F_p = q_p E\left(x_p\right) + V_p \times B_p(x_p) \tag{2.1}$$

2.3 TYPES OF INTERACTING SYSTEMS:

1) Strongly Coupled System: Select a system that is prepared with gathering of particles, all carrying a charge placed in a box with Debye length, λ_D. We take the Debye length for a simple property of plasmas is to protect the effects of localized charges in excess of distances exceeding the Debye length.

If there, have few particles present in the system as shown in figure 2.1 and would be very jumpy with electric field effect. The particles inside the box travel frequently, interacting these particles together by their thermal motion. When a particle passed through the detector, either the size detects a jump up or when a particle travels away it detect a jump down.

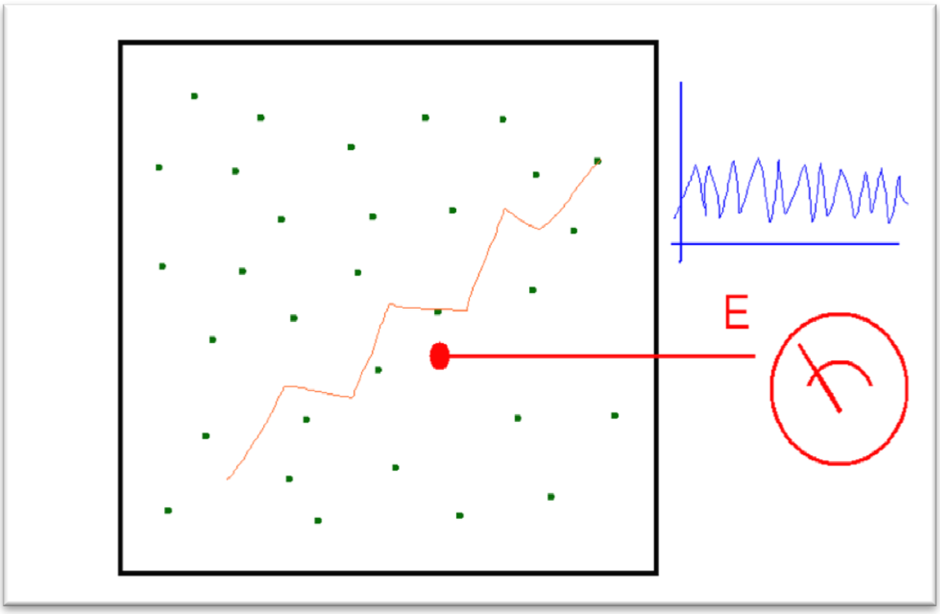

Figure 2.1 strongly coupled System [9].

The result of a given particle on the electric field of a few particles near to the detector at the location of size decays very rapidly with the distance, when the particle is nearby the influence of electric filed is strong. Each one of the particles identifies the same effect in the system. The electric field effect on every particle gets the sum of impact of all other particles only when extra particle permits by electric field and jump with trajectory of a particle .This system called strongly coupled system [9].

2) Weakly Coupled System: In this system, presence of few particles in the box is small. This situation is that of a weakly coupled system. The resultant configuration defined in figure. 2.2.

In the same way, the trajectory of a particle is at every time affected by a huge number of extra particles. By this effect trajectory is smooth and without jumps. These systems called weakly couple

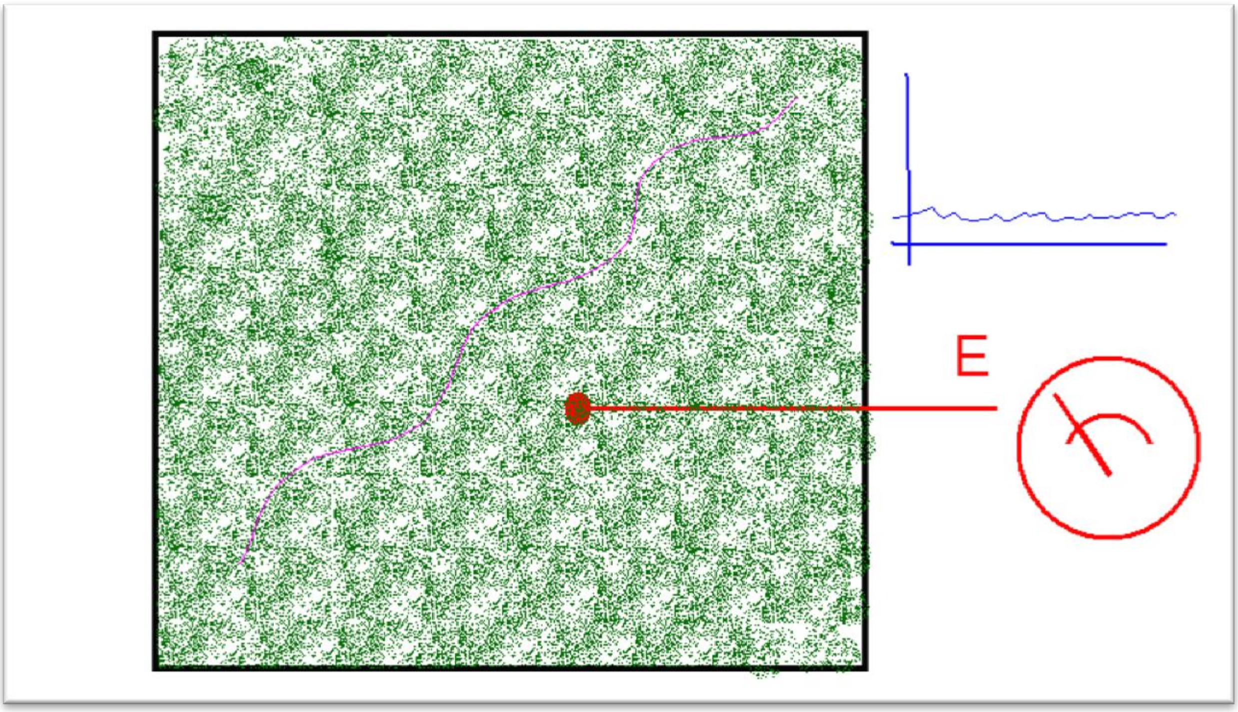

Figure 2.2 Weakly coupled System [9]

2.4 PARTICLE IN CELL METHOD:

The system is characterized with a lesser number of finite-size particles all interacting through the accurate potential at distances away from the overlap distance, on the other hand improving the effect of less particles at small distances via reduced interaction potential. The outcome is the electric field variations in the system are properly smooth as in a weakly coupled system. The purpose at this moment is not that at every time a very huge number of particles regular each other but reasonably that the effect of the a small number of particles close to the measure point is weak. Likewise, the trajectory of particles in the actual system is smooth but then again a very huge number of neighboring surrounds each particle as shown in figure 2.3 [9].

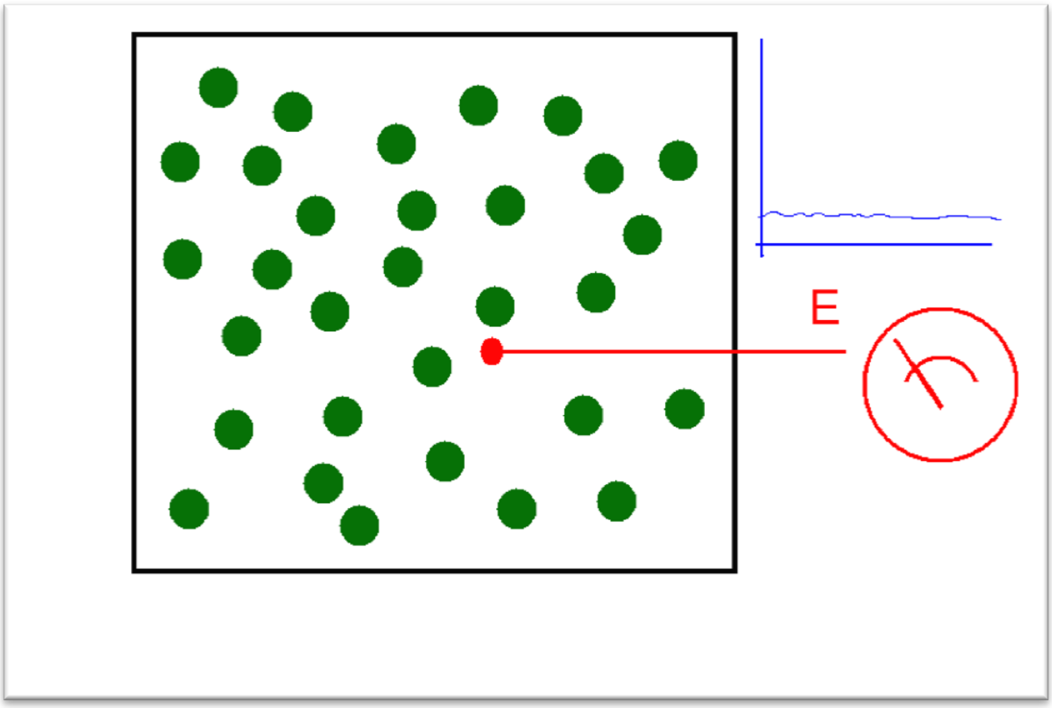

Figure 2.3 System of finite size particles [9]

2.5 MOVEMENT OF PARTICLES

The integrate particles wave over a time-period Δt. The Leapfrog scheme has normally used in PIC programs. It will be fast and mathematically stable. At first, integrate velocity through the time- periods shown in figure 2.4. Then succeeding, location well runs. The term arises from the fact at that times the velocity and positions are known as offset from each other by half a time-period. Intrinsically, the two masses leap over each other. Next particles relocated at new positions so it is compulsory to confirm that all macro-particles have motionless in the computational domain. In which, two boundary collaborations are possible. Macro- particles either will be leaving the domain, or will be strike with rock-solid things. Computational boundaries has either exposed (or absorbing, permits particles to leave), reflective or periodic (particles are transported to the opposed side of the domain). The reflective boundaries castoff to identify planes of symmetry [10].

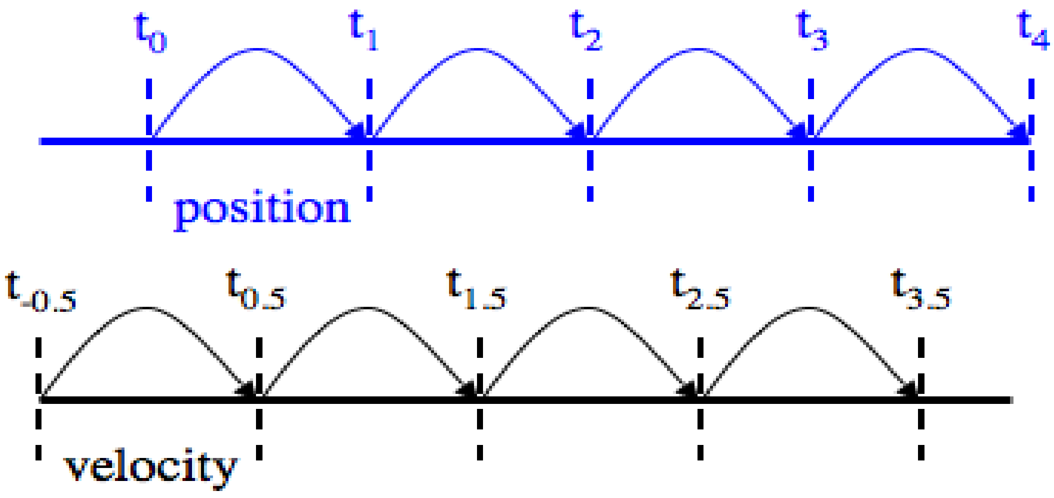

Figure 2.4 Leapfrog Method [10]

If we identify the particle position and velocity as, respectively, X_p and V_p, the equations of motion can be written as:

$$X_p(new) = X_p(old) + \Delta t V_p(old) \tag{2.2}$$

$$V_p(new) = V_p(old) + \Delta t F_p \tag{2.3}$$

The main exertion is the calculation of the force that needs to add all over the particles in the structure,

$$F_p = \sum F_{pp'} \tag{2.4}$$

Where $F_{pp'}$ is the interaction force between two particles p and p′[9].

In this PIC method, the position and velocity of particles have well defined in continuous space whereas the fields has definite at discrete positions in space. Yet equally, the fields and particles have definite at discrete times. A position and velocity of particles and fields value has innovative successively in time and beginning from initial environments with the sequential arrangement shown in Figure 3-2 that is called leapfrog scheme. The particle positions and velocities have offset in time by half a time-step (Δt/2) [6].

CHAPTER 3
LITERATURE SURVEY

This section involves the work done by the various researchers in the field of particle in cell simulation in magnetron.

Isa Araz *et al.* [2]: At this paper, present their work on the simulation of vane style magnetron with electromagnetic effect by CST-PIC solver. Magnetron generally consists of 18-anode vanes without using straps. The RF frequencies have been carefully chosen in X band and determine results. Exchanging dimensional values of cavities, adjusting voltage and applied magnetic fields values, have enhanced simulation of magnetrons.

Andrey D. Andreev *et al.* [7]: In a paper represents, the result of particle-in-cell simulation of a strap non-relativistic ultra-high frequency of magnetron with its dimensional and functional parameter values near to the parameter values of the highly powered industrialized heating magnetron generating 75–100 kilowatt of CW-Microwave power. The main features of PIC simulation has the beginning, the development, and the progression of the MW oscillations, which simulate in the absence of artificial Resonant Frequency priming but from the electromagnetic "noise", produced within the interaction region of the magnetron in the electrons cloud density oscillations. They shows its results, the magnetron simulation that have maximum and minimum input voltage up and down for which the magnetrons fails to operate under π-mode no additional magnetron operational mode has excites on it.

Han S. Uhm *et al.* [8]: They presented their dispersion relations between the EM-waves propagated over a helix has achieved on behalf of the helix injected inside of magnetron cylindrical type electrode. In this case, magnetron vane model disappears; the dispersion relations improve the usual helix dispersion relations. However, the resulting dispersion relations improve the magnetron TE- mode after the helix pitch angle ϕ approaches $\pi/2$.

Wayne Arter *et al.* [11]: This paper presented their work on logical investigation of relativistic magnetron performance through mathematical simulation. To find out, the magnetron operation has effectually limited to a moderately lesser section of a parameters. Operation near the Buneman–Hartree conditions to become tough that period used for oscillations onset becomes more than 100 ns, demand of the length of applied voltage pulses. Magnetron functions well in a limited section of parameters (B_o, V_o).

Meiqin Liu *et al.* [12]: They work on the Particle-In-Cell simulation on six-cavity relativistic Magnetron Diffraction Output (MDO). It shows that the pulse power output is lower due to electrons attack the anode blocks with high energy, which clues to discharge of secondary and back-scattered electrons. The electric productivity of A6 relativistic magnetron along with the A12 MDO with only one-stepped cavity determined using the transparent cathode would be completed 70% per giga watts output power level. The results shown in that paper are qualitative study of the impact on secondary and backscattered no. of electrons by the process of relativistic Magnetron with diffraction output.

Imran Tahir *et al.* [13]: In this paper, done their work on the magnetron would be monitor frequencies and phase modulations of an inserted wave that acting such as narrow-band amplifiers. The broadcast of a phase shifted key data attained at 2Mb/s. Quantities of the frequencies response and anode-current subsequently an alteration of a phase with utility of an average anode-current and heater power provide newly vision into the securing mechanism and the "noise" appearances on magnetron. The response from an injection locked Continuous-Wave Magnetron of variations in phase and frequencies have been study as a purpose of heater power.

Matthew T. Bettencourt *et al.* [14]: This paper presented their work on the simulation of EM-field and low-density plasma occurrences with computationally exclusive and need 10,000 of computer hours that give a unique solution. Some gain completed over memory streamlining, well-organized cache usage, and over and done with well parallel designed (improve scalability as four times the number of CPU). This progress verified through five dissimilar super-computing hardware stages for ideal difficulties considered to focus on the effects of the changes. It shows that excessive attention must take on the progress of Electromagnetic-Particle-In-Cell programs to attain higher level of performance.

Jung-Il Kim *et al.* [15]: They investigated the millimeter-wavelength of 20 vanes functioning at non- fundamental three-dimensional magnetron at the 16 resonators frequency electric field variations (p = 16) along with the region interaction perimeters through using 3-D Particle-In-Cell simulation program. They have obtained electrons circulation with the creation of 16 electrons spokes. The applied voltage is 6.5kV with external magnetic field 0.4T, then the saturated output is 3.2kW and its efficiency is 12.3% at the operating frequency of 35.2GHz.

Türker *et al.* [16]: To study they work on to design a hole and slot-type cavities magnetron. Design models depend on some parts of magnetron, cathode, interaction space, resonant system. Using empirical formulas, they find-out dimensional values of model, electrical and magnetic parametric values. At that time, using empirical values, they have design and done simulation of 3-D model magnetron on CST Particle Studio. In CST, it shows that the Eigen mode solver is necessary in suitable mode excitation. After that, they have been using a Particle Tracking and Particle-In-Cell simulations aimed at the suitable magnetron operation. During the simulation, the properties of database parameters for example the mesh cell numbers, simulation-solver types, and numbers of emission points on the cylindrical-shaped cathode have examined. They do not usage some special hardware's like a graphical processor unit (GPU) to made calculations at very fast.

Arkady Sayapin *et al.* [17]: In this paper, they do their work on the stable action on a MW compressor found in a travelling wave resonator that generating its productivity at microwave pulses with a power of 1.15 ± 0.05 GW within interval of 12 ± 2 ns. A relativistic S-band magnetron that pumped the compressor to producing MW pulses with a power up to 250 MW and interval of ∼100 ns. On the way to become stable the frequencies of the MWs, a transparent cathode having an amount of electrons released on the area and dual ring type straps have been used in the middle of the anode resonators. The new results showed a slow starting production of microwaves related in wide-ranging BW. A positive response indicates to steady the frequency only throughout the Nano-second time-scale interval pulses.

Jinsheng Yang *et al.* [18]: It presented their work on the effective features of magnetron that works on spatial harmonics and the connection between operational voltage and the Direct-Current magnetic field. By 3-D Particle-In-Cell simulation, it displays the process of the spatial harmonic magnetron on W-band. The voltage is 15.2killoVolt and the magnetic field is 1.2Tesla with power translation efficiency 5% at the operational frequency range of 94GHz to 96GHz without mode achievement giving highly mode pureness.

T. M. Minea *et al.* [19]: In this study, 2-D charge particle-density in RF frequency planer magnetron with Particle-In-Cell simulation applied on a parallel device that industrialized the RF planar magnetron. In a 2-D PIC simulation of a magnetron release allowable 3-D temporal finding of plasma parameters like charged particle densities, electric fields, fluxes, and energy distribution functions.

Sandeep Kumar *et al.* [20]: It presented their work on electromagnetic and PIC simulation with circular-shaped strapped vane resonators at 2.45 GHz frequency and 1kW power of magnetron through CST-MS. They has detected, after adding of single ring strap it decreases the resonant frequencies of the π-mode of the Resonant-Frequency resonator arrangement through 500 MHz with S-band and dual ring straps has enough to certify stable process in π mode. In PIC simulation studied, existence of space charges in interaction regions decreases the cold resonant frequency is around 9MHz.

Mikhail I. Fuks *et al.* [21]: In this paper presented, a particle in a cell codes simulation to determine the electric efficiency of the six-cavity resonators magnetron using axial-extraction would increase from 3% to 37% applied for dissimilar diffraction outputs. Using PIC simulation codes to modifying magnetron with transparent cathode and optimized some parameters. It shows if using transparent cathode it offers quickly starts of oscillations and nearer rate to attain power saturation with highly radiation-power and exchange efficiency related with solid cathode.

Jianxun Wang *et al.* [22]: In this paper, done their work on a Ku-band with TE11 mode gyro traveling to wave tubes that amplifier provides greater than 153kW output power, 41dB saturated gain, 20% efficiency determined through a 63 kV, 2.3GHz Bandwidth and velocity spread of 5%. TE11 mode with linearly polarized input coupler used to giving the input power. The higher frequency circuit and the lossy-section want to design then used a linear and non-linear theory. A circularized TE11 coupler has considered for input by small axial ratios. Original type low-velocity range MIG is designing and enhanced via 2-D PIC simulation.

Christopher Leach *et al.* [23]: In this paper, study has done on a compact A6 relativistic magnetron that works in π-mode, its radiation is taken out axially in TE11 mode by a cylinder-shaped waveguide with equal cross-section as same as the anode resonators. Its radiated mode is alike Gaussian microwaves beam. A compacted magnetron has easy for implementation rather than the Magnetron with Diffraction Output (MDO), through with reduced efficiency. A simplest converter offers the pure TE11 mode into the output waveguide of magnetron functions with suitable efficiency. Then, the output waveguide maintained merely the lower most demand mode.

George E. Dombrowski [25]: This paper presents their work on computer simulation program that examine the 2J32 type magnetron. A settlement between calculation and obtaining data was not good at what time the investigation was limited at the annular anode cathode space. The efficiency, produced power was higher and the Gauss lines presented not any proof about recent boundaries. A simulation enhanced through a number of electrons transient between the openings of anode parts. To allowed discharge electrons from these segments providing much better arrangements that, display a higher lmit to the anode current with the higher boundaries of the Gauss-line.

James C. Weatherall [26]: In a high power Magnetron, 2-D PIC simulation has used to determine the self-consistent development of the space-charge bank of cloud. The particles have moved relativistically and the simulation has applied for six-cavity magnetron that is the sample of the fresh classes of relativistic magnetrons. A simulation has used to determine the influence of power extraction on efficiency and the character of the wave magnetic field effect on saturation with relativistic effects on magnetron operation. An interaction region with in the charge cloud has identified.

Hunter L. McDowell [27]: In Particle-in-cell simulation, a moving wavelength computer program had cast-off to identify the interaction between the particles on magnetrons interaction region. Better results of current, power and efficiency obtained through the program compare to the investigational presentation of X-band and S-band types Magnetron. The program indicates the actuality of 3- dissimilar space charges, which is known as primary or secondary, and quantity of emission type. Secondary emission type was produced maximum high-power magnetrons operation. Various magnetrons are operating on low frequency or low power primary emission dominated stage. Adding original current-density scaling parameters had defined specific parameters to fix for magnetrons so that it shifts at secondary to primary emission occurrences have stated in relations of those parametric values. If the secondary emission has slightly small and primary emission has, supplementary reduce at that emission is reaching at inadequate state. The interior space-charge turbulence has completed rejected in this state.

Alberto Leggieri *et al.* [28]: This paper study on a specific design procedure of an X-Band magnetron to Linear Accelerator with High Power Transfer System consists of eight-cavity resonators. This study has created with multi-physics forming, and considers thermal mechanism to special effects of the cathode heating on the Magnetron and the Joule effects to the dielectric window. At that paper, has presented how to recompense the thermal induced ruin of the system presentation through abusing the subsequent Thermo-mechanical distortion to the suitably considered system shaped that varies positively the EM-field to again rise its act.

Robert S. Symons [29]: In this study, they will start their work using deals with the lower equipment side to higher equipment. The lower equipment problematic wants to dealing with how one could getting has cleared of the unwanted heat of machinery that exchanges energy in one system into energy in another system. A small number of machineries are 100% efficient and maximum has greatly low efficiency. A major advantage of electron-tubes compare to solid-state devices is that it has more ordinarily efficient and can work at high-temperature. Consequently, it will be small, lightly in weight and dissolve remaining heat through the making of high output power. A collection of transistors or integrated circuits could be large as compare to the circuit boards, power busses, cables, combiners, fuses, heat sinks, and, probably, water pipes. An original data onto the different categories of MW-tubes can be present with highlighting of their appropriateness for its uses in economical, high-reliability, high-performance satellites, and communications, electronic warfare, and radar systems.

Andrey D. *et al.* [30]: Recent Continuous-Wave industrialized heating magnetrons have adept to generating at highly 300 kilowatt of CW microwave power that frequency nearby 900 MHz and retailed in profitable. Yet, to use these types of magnetrons in various particular investigation and technical applications to being the interest for the Air Force, the essential reworking and reshape is essential. They have established and verified computer design structural of a 10-vane highly powered strapped magnetron that dimensional measurements and designed parametric values had used. The computer design model had constructed via the 3-D Improved Concurrent Electromagnetic Particle-in-Cell (ICEPIC) program. A simulation of the straps magnetron process has executed and the following operative features have attained throughout the simulation that is frequencies and modes of magnetron oscillations, output MW power and efficiency of magnetron process, anode-current and anode-cathode voltages dynamics. The industrial magnetron community for designing following generations of the CW industrial heating high-power magnetrons may use the developed computer model of a non-relativistic high-power strapped magnetron.

William M. *et al.* [31]: In this study, improved pulse-width and mode barring of magnetron has discovered on relativistic magnetron-using RF-Priming. Investigates operate on 300kV, 2–8kA, 300–500ns electron beams to effort a Titan A6 relativistic magnetron. The Resonant Frequency Priming foundation has a 100kW pulse magnetron functioning at 1.27–1.32 GHz. Fine-tunable stubs have used in the Titan design to modify the frequencies of the relativistic magnetron on equal to the priming source. Magnetrons start oscillation-times, pulse-width and mode barring had equated with RF priming. The outcomes display important reductions in microwave output interval.

Yuri M. Saveliev *et al.* [32]: This present their work on Cathode plasma development into a vacuum gap that is most important physical mechanisms disturbing the Relativistic Magnetron (RM) act, for that reason it known as Resonant Frequency pulses shortening. That paper will present how the enlargements of newly original cathode tools have controlled to a major improvement in the RM efficiency and power. A principal of that research had to calculate how the cathode structural and kind of emission surfaces will effects main features of the L-band highly powered relativistic magnetron within a rising-sun arrangement. At this research, the magnetrons worked with in static frequency of 1.3GHz, voltage of 100–500 kV, total electron current of 2–8 kA, and total MW peak power of 100–700 MW, dependent on operational circumstances and different-types of cathode used that affected the magnetron presentation. For that, method results in dissimilarity on the extreme MW power of 30%. A cathode ends cap that has been frequently uncontrolled when changeovers from classic to RM's, which will be capable to grow the MW power and Relativistic Magnetron efficiency in 80% in the absence of assisting the pulsed shortening influence. An extreme efficiency of 24% had attained using a velvet cathode using end caps, calculated as the ratio of peak power to input electrical power.

Herman L. Bosman *et al.* [33]: In this study, magnetron output characteristics can be considerably enhanced through a cathode that is transparent to the synchronous EM-Fields thus in case enhanced circumstances for faster transformation of numbers of electron potential energy into EM field energy. Transparent cathodes made up with distinguish longitudinal metallic strips that set in the form of cylindrical surfaces, its action as it-self electrons emitters. Fortunate pre-bunching of electrons to stimulate the wanted operational mode is providing through an appropriate selection of the number and azimuthal location of the cathode strips. The strongest azimuthal wave fields on the cathode surface quickly capture the pre-bunched electrons into spinning spokes founding the anode current. That method offers more rapidly start of oscillations than it has prepared with a solid cathode. A strongest wave field of electrons covering outside of cathode, it is any cover thickness provides an opportunity of enhanced the efficiency through increases the applied voltage and magnetic field. A computer simulation of the six-cavity magnetron determined individually using a solid and transparent cathode exhibit those benefits of this approach.

Todd A. Tredo *et al.* [34]: This paper presents their work to examine the functional features of a relativistic sixteen-vane rising-sun magnetron in certain prominence to defining the functioning systems of different modes. To study the magnetron presentation shows its functions of voltage, magnetic field, cathode geometrical dimensions, axial boundary conditions and output coupling. Operational output was observing in the $3\pi/8$ mode at 3.3 GHz, in the $\pi/2$ or $3\pi/8$ mode at 3.5 GHz, and in the π or $7\pi/8$ mode at 4.6 GHz. Within maximum power can be obtained of 80 MW emitted in the $3\pi/8$ mode at an efficiency of 4.5%. A cold test was executed to find out the RF frequencies and azimuthal E-field on the interaction surface that approved within (1-4)% of theoretic calculations. The Buneman-Hartree threshold calculated the modes frequencies. They also calculated the features of A6 magnetron working at π and 2π modes.

Song Yue *et al.* [35]: In this paper presents, a sector-step approximation (SSA) models. Step admittance recurrence and field matching relationship derive the dispersion equation of rising-sun magnetron by adjacent resonators. A design structure theoretically analyzes RF frequency of a 10-cavity resonant segment and hole and slot resonator type Sector-hole-slot rising sun magnetron (SHSRSM). Moreover, computer simulation has executed to prove the correctness of the theory. Further, the special properties of the hole-radius of magnetron leading characteristic parameters are considered. For example, it shows π-mode RF output, mode separation and quality factor. An enhanced SHSRSM equated with two common types of rising-sun magnetrons, such as sector resonator type RSM (SRSM) and sector-and-slot resonator type RSM (SSRSM). It has shown the resulted output, which has theoretical results that is well reliable of the simulation results and the maximum relative error do not as much of 3% that confirms the exactness and possibility of the SSA model. A different type of magnetrons like SRSM and SSRSM compare with each other, SHSRSM has better mode parts dividing and quality factor that increases the strength and the energy loading of rising-sun magnetron.

Tianming Li *et al.* [36]: In this study, the result shows by the investigational research of a six-cavity relativistic magnetron with permanent magnets. In which the sequence of permanent magnets were made-up. An extreme axial-magnetic field B_z is 5.9 kGs. A peak-power output 540-MW within pulse-width up to 40 ns of the relativistic magnetron with stable magnets has achieved with operational frequency of 2.65 GHz. This initial study certifies the method of the RM with the stable magnetron to deals with wider uses possible because of its features such as compacted, lighter in weight, stable, and so on.

George E. Dombrowski [37]: This paper present, to defines computer coding-program for simulation of the magnetron oscillator and crossed-field amplifiers. A status has positioned for accurateness and well-organized calculation with reasonable number of electrons and reasonably larger time-periods. Distinguishing characteristics is: i) space-charge field estimation by Buneman's cycle fall scheme and distinct behavior of electrons close to cathode. ii) Circuit-field and electronic induction determination using a Ramo (Green's) function with secretarial for space-harmonics. iii) Calculated the resonator frequency networks reaction using Green's functions; iv) Redictor/Corrector estimation of average resonator frequency signals; and v) By using of fifth-degree power series determination of electron trajectories.

Eun-Ha Choi *et al.* [38]: In this study, an axial virtual cathode oscillator had invented. In which a solid electron beam by a peak diode current of 21 kA has been obtaining after the pulses activated at a peak diode voltage of 300 kV. During the study, has initiate that the peak of microwave emission is occurring now the second peak in electron beams recently present, wherever the diode voltage and diode current is 290 kV and 21 kA respectively. These observed values may powerfully co-related to the in-built fluctuations of the electrons clouds within time and space created from together the dynamics of the reflected electron beam due to virtual cathode and oscillations of the virtual cathode itself. After this, the peak of high-power microwave has been generating in that research. A main effective output frequency has calculated from 6.68 GHz to 7.19 GHz created by the waveguide dispersive delay line method that is in good settlement with those “MAGIC” computational results for an electron beams voltage of 290 kilovolts and a diode current of 21-kilo amps. A virtual cathode oscillator gives the maximum microwave output is 200 MW and although its power adaptation efficiency is almost 3.3%.

V. Bogdan Neculaes *et al.* [39]: In this paper present, an azimuthal changing axial-magnetic field has been used to execute “magnetic priming” of magnetrons for fast start-up, low noise, and mode control. A synopsis of the newest magnetic priming tentative and simulation results has obtainable. The magnetic priming research at DC-operating microwaves oven magnetrons appear sideband rejection, when the cathode heater turned off. With simulations, three 3-D better-quality concurrent electromagnetic particle-in-cell (ICEPIC) programs with two dissimilar computational set of rules to improve the ovens magnetron investigational result attained by magnetic priming containing with fast mode development, quick spoke formation, and the bent towards low noise operation. Innovative axially symmetric, azimuthal changing magnetic field structure for oven magnetrons have discovered and initial outcome has described.

David Price *et al.* [40]: This paper presents their work on a designed model that describe the restriction of the RM microwave pulse length created through circular cathode plasma wave is put onwards and verified with dimensions. Uncertainty the dense, conducting, cathode plasma arranges the diode electrostatic and microwave boundary conditions, so its wave variations the magnetron resonance condition. Founded the cathode plasma extension rate and the main plasma ion basic is incidental to be hydrogen. A relativistic magnetron investigation used to overthrow the pulse-shortening mechanism in heating the resonator positively extended the pulse from 100 to 175 ns. A condition, the model is accurate then through inference, extended pulses can be achieved using microwave devices with explosive emission cathodes by the way of, (i) moving in the direction of higher impedance designs. On the other hand, (ii) take processes to condense all low- sources to levels reliable with the serious attentiveness analysis.

Don Shiffler *et al.* [41]: This paper done their work at the previous decade, the Air Force Research Laboratory, Directed Energy Directorate (AFRL/DE) has involved in a highly current density field emission cathode research code. This code discovered the features of cathode materials along with the specifics information's of cathode dimensional shape and emission physics. They give the outcomes of this continuing investigation struggle up to date and evaluation of the history that afford awareness into the physics problems for several vacuum electronic sources. A main part of the program made up of the research of newly cathode materials. On behalf of several high power microwave (HPM) sources, neutral out-gassing those ties disapprovingly with cathode materials that give an important role in the real process of the foundation. Design of cathode shaped selected by AFRL to choose cesium-iodide-coated carbon fiber cathodes. Another important feature of the code involves the knowledge about emission physics and the optimal dimensional shape of cathode. That paper accomplishes with a debate for an operation of the cathode material on both a Magnetically Insulated transmission Line Oscillator and a relativistic magnetron.

V K Sharma *et al.* [42]: This paper studied on the design of magnetic coils of relativistic magnetron. A vacuum increases the efficiency of RM for HPM generation. A magnetic field effect of relativistic magnetron has critical parameters and would be almost continuous at dynamic section. A usually coil is helical-shape that had multi-turns of changing radii. The Helmholtz- equation and solenoid with mean radius will exactly provide estimated values of magnetic field coils. A field computed by using software is like CST to have needed small mesh-size and boundary at distant so; it consumes huge storage and takes larger time. A helical-coil is easily simplifying such as the simple law of magnetic-field control like, Bio-savart law has applied for simplicity. A pair of spiral-coils has evaluated for magnetic field and Lorentz's force and it used to evaluate the magnetic field and electromagnetic force. The Field and Lorentz-Force had drawn in complete volume using MATLAB.

Raymond W. Lemke *et al.* [43]: This paper presents their work to explain the effects, which might limit efficiency on magnetrons worked in relativistic voltages at 500 kV. A 3-D Particle-In-Cell simulation is using to examine the performance of A14 and A22 cavities, cylindrical-shaped rising-sun magnetrons. A power has mined outwardly over a single-iris situated at the end-slot of all each cavities. Mathematical resulted output show that in common produced power and efficiency rise almost linearly with increases iris-width (decreases vacuum Q) up to the entire becomes too short used for constant oscillations in the π-mode to maintain. Further than the mode competition or swapping occurs and the efficiency drops. The results expose that the least value of opposite to extreme efficiency, which can attained before the onset of mode competition is meaningfully affected through the magnitude of the 0-space-harmonic of π-mode, a matchless characteristics of rising-suns, and through the magnitude of the electron current-density (space-charge effects).

Hae Jin Kim *et al.* [44]: In this study, a high-power rising-sun magnetron oscillator (AX-9) working on 9.50 GHz to observed using 3-D Particle-In-Cell program. On simulation, mode variety of the 18-vanes rising-sun type cavities magnetron has been obtain with both an logical-field theory and the arithmetic program. A larger mode splits approximately a π-mode had detected in the rising-sun pattern. An interval progressed electrons flow shows 9-space-charge spokes in Particle-in-cell simulation that settles the π-mode wavering in the 18-vanes rising-sun magnetron. After space charge spokes formed onto interaction surface, a particular Resonator frequency oscillation beginning to rise and the leakage-current evading from the interaction surfaces diminishes to nil. A simulation calculates the saturated radiated power obtained at the output waveguide is 250 kW at 9.50 GHz. It has an external magnetic field is 0.52 Tesla with the beam-voltage and current are 28 kV and 17 Amps correspondingly.

Jin Joo Choi *et al.* [45]: This paper present, a 3-D particle-in-cell code used for simulation of six-cavity relativistic magnetron using metallic tuner. For instance, put inside a 6-conducting-rods inside the resonators region there the Resonant Frequency magnetic field is more and the resonant frequency of 2π- mode of the six-cavity magnetron adjusted above the range (4.27 - 4.47) GHz. A simulation results indicates that with disturbed RF magnetic fields affected through metallic tuner, the presentation of the six-cavity magnetron that gives radiation output power, frequency spectrum and efficiency is greater as compared with those magnetron, which uses the uniform RF magnetic fields. The maximum output power of six-cavity by three tuners is 600 MW at 4.4 GHz, equivalent to a magnetron efficiency of 7.2% that is around 20% higher than the conventional six-cavity magnetron. At what time, the tuner location of three metal rods is 8 cm that has tuned to become maximum power and spectral amplitude in the π-mode is lesser 33 dB in power than the 2π-mode.

Shivendra Maurya, *et al.* [46]: This paper done their work on a 3-D particle-in-cell code that is used to observe the output act of a moderately dielectric loaded six-cavity relativistic magnetron. Adjacent resonators of the resonant configuration are loaded equally at angle of

120◦ by low-loss dielectric material. A PIC-simulation of dielectric loaded A6 relativistic magnetron has achieved in 2π-mode of process and founding of six electron-spokes in the oscillation region. In this experiment, results shows single 2π-mode process with better quality radiating output power of 620 MW with comparatively low start-up time as comparison to empty resonant design. A power rise as compare to empty dielectric resonators to get around 40% more in case of partially filled dielectric resonator.

Nasrin Nasr Esfahani *et al.* [47]: In this study, a 16-vane millimeter wave spatial-harmonic magnetron (SHM) using within a cold secondary emission cathode has studied with the use of a 3-D particle-in-cell program on CST-Particle Studio. A Spatial-harmonic magnetron simulation has done lacking of fake Resonant Frequency priming and without expecting limited assumptions on the mode of process or on the number of harmonics to measure. Therefore, in the simulation process the electromagnetic oscillations produce naturally from noise. An investigation of space-charge effects at saturation time exposes the existence of two dissimilar space-charge circulations, which will be contingent on the amount of primary emission current. This emission current has hired to model a bombarding current that has been using to set the cold cathode. It gives a result that has a small primary-emission density in non-periodic circulation of space charge at saturation-time that is in accordance with the before reported space-charge circulation in SHMs. A current, power and efficiency shows the better connection between them with the investigational results in simulation.

Rajendra Kumar Verma *et al.* [48]: In this paper has done their work on a systematical studied of long-anode magnetron (LAM) and its resonator structure will be an understanding of the design model of that type of magnetrons. A noticeable characteristic of LAM is its anode block length that has been difficulty of producing greatest order axial-modes. Furthermore, this length also disturbs the efficiency of strapping in magnetrons. Those two reports have verifying over the simulation of long-anode hole and slot resonant design on CST Microwave Studio under the length-analysis and strap-analysis study. It has tried to examine for an improved length of anode block through detecting the $n\lambda$ variations for several modes and which caused in closing that long anode block length need be nearby to 0.8λ. Moreover, the dispersion-curves and Hull-Hartree plots have examined to estimating the efficiency of straps that presented the straps was not more active and beneficial in LAM configuration.

Song Yue *et al.* [49]: In this study, a 12-cavity resonator and 2.45GHz with high-power CW magnetron has simulate to examine the impact of Voltage, Magnetic field and electric-current continuously the power and efficiency of the magnetron. For getting output, the beam emission model and input waveguide-port, excitation has implemented. The output voltage and magnetic field operative range of simulation has comparatively narrow, so that is not appropriate to study the relationship between output power and the DC-voltage and Magnetic field over a wide range. A simulation power almost rises linearly by growth of anode-current and the magnetron highly energy exchange efficiency. If increases the cathode current due to this effect anode current growths rapidly first after that it falls gradually and reached on the stable stage at the end.

CHAPTER-4

RESEARCH GAPS AND OBJECTIVE

Based on literature survey following gaps have identified:

4.1 Gaps in Study

1. Fluctuations result in particle-wave collisions.
2. Parametric instabilities speed up.
3. Dispersive properties change.
4. **Particle shape** - In PIC technique, all macro-particles has supposed like spherical. Improvements for non-spherical particles could be involved in particle struggle model. On the other, highly non-spherical particles may not have true interactions between particles.
5. For direct numerical simulation of lack of analytical theory: nonlinear problem, direct numerical simulations of particle-in-cell.

4.2 Objective:

1. Studied and design the 8-cavity-hole-slot type magnetron using CST Particle Studio.
2. To obtained the effect of electric and magnetic field on the numbers of particles to provide a better results by PIC solver simulation.

CHAPTER 5
METHODOLOGY

Proposed Methodology:

1. Study about different types of magnetron in detail.

2. Using empirical formulas, to find out the dimensional parametric values of magnetron to design 8-cavity hole slot magnetron on CST Software.

3. Designed model has been simulate on three types of solver - Eigen-mode simulation, Particle-Tracking, Particle-In-Cell simulation on CST-Particle Studio

4. To obtained the electric and magnetic field effects on designed magnetron.

5. The study has further improved by implementing straps in magnetron structures, which indicates to improvement of the field properties of magnetron.

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CHAPTER 6

DESIGN AND SIMULATION OF 8-CAVITY-HOLE-SLOT-TYPE MAGNETRON USING CST PARTICLE STUDIO

6.1 INTRODUCTION

The magnetron is the vacuum tube system to release the electrons that are using to produce EM- field in the MW frequency range. The magnetron interior design model is consisting with the anode and cathode. In a magnetron, a cathode has placed at the middle of the number of resonators.

The source of magnetron process has recognized to the motion of electrons in the combinational effect of electric and magnetic field. A timely magnetron was named by Hull in 1921 that was using a cylinder-shaped anode with co-axial cathode [2]. This type of magnetron has some drawbacks like lower efficiency and power capability due to its cylindrical anode design. Postumos using of an anode designs with required no. of resonators that give a highly capable magnetron, in 1935.

At Present-day, a highly powered Magnetron is mostly used in radar for detecting aircraft, pathway / monitor supersonic missiles, observe and track weather patterns, air traffic control (ATC), garage door openers, police speed detectors etc. Fixed frequency, Continuous-Wave magnetrons used for industrial heating and microwave ovens.

Magnetrons' modeling is problematic because EM- field and no. of electrons interaction are at least 2-D. The cylindrical-shaped cathode, the resonators blocks, the interaction region and the magnetic circuit has the main four parts of a magnetron and every individual part need to be design and enhanced for positive operation. We have better to use CST Particle Studio for our simulations, this software absolutely delivers better flexibility in structural designing compared to other simulators.

6.2 USING EXPERIMENTAL FORMULAS FOR FINDING INITIAL PARAMETRIC VALUES

Magnetron is a better design construction with coupled resonators near by a cylindrical cathode and change the direct current input power to Resonant Frequency output power. A cathode has placed at the center of anode that releases the electron and move towards anode with the effect of electromagnetic effect. In this 3-D magnetron design, the cathode will be stable at (-ve) potential and the anode will be at (zero) potential to make a potential change between anode and cathode. Constant and uniform magnetic fields are applied in the interaction space that is parallel to the axis of cathode tube. The output power is receiving at one of the resonators using a coupling loop. The designs of magnetron are shown as fig.6.1 its parameters: the length of anode/cathode ($h_{a/c}$), radius (r_{ca}) of the cathode, voltage between the anode and cathode blocks (V_{app}). Furthermore, the distance between the cathode and anode blocks ($r_{ai} – r_{ca}$), applied magnetic field must be normal to electric field (B_{app}), intside (r_{ai}) and outside (r_{ao}) radii of the anode, length (l_s) and width (w_s) of the slot, number of resonators (NR), hole radius (r_h) and no. of modes(M) .

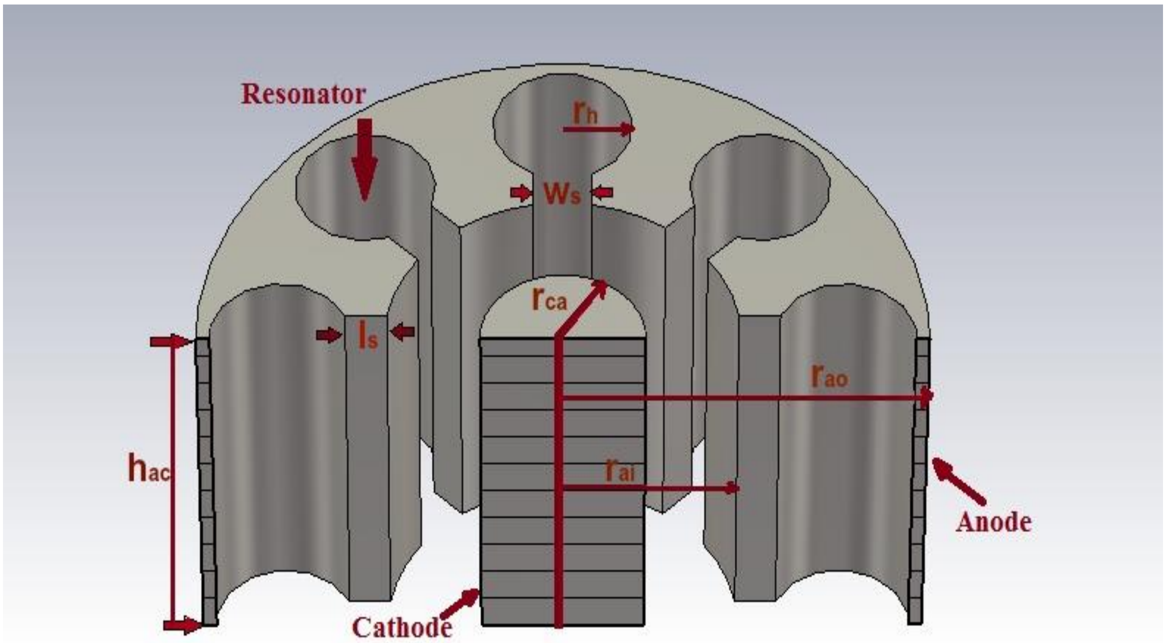


Figure 6.1 Dimensional parameters of hole-slot type magnetron

The design method of magnetron using formulas:-

i) Firstly, the operational frequency and wanted output power is definite. According to given conditions, the essential number of resonators can be acceptable, no. of modes $M = NR/2$ is stationary. In other side, unknown the operational frequency is actually high, and then parameters of the magnetron come to be lesser. The structural models and manufactures are not simple for a huge numbers of resonators.

ii) At specified resonant frequency, the design parameters, cathode radius, inside anode radius, the length of the anode (cathode) block, hole radius, slot width, and slot length are determined according to following related equation [8]:

$$\frac{r_{ca}}{r_{ai}} \leq 0.5; \quad \frac{r_{ca}}{r_{ai}} \approx \frac{NR-4}{NR+4}; \qquad h_{a/c} \leq 0.8\lambda \tag{6.1}$$

First, cathode radius r_c is chose and fixed then using eq. (1), r_{ai} is find.

iii) Afterward step to discover the essential magnetic field and the potential difference between the anode and cathode blocks. By the equation, cutoff magnetic field will found [8]:

$$\Omega = \frac{w}{M} = \frac{2\pi f}{M} \tag{6.2}$$

Here Ω is an angular velocity of electron. It express as

$$\Omega = w_0 = \frac{w_c}{2}\left(1 - \frac{r_{ca}^2}{r_{ai}^2}\right); \tag{6.3}$$

Here w_c is cyclotron angular frequency, $w_c = \frac{e}{M} B_0$

Here $e = -1.602 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg and Bo = cut-off magnetic field (*tesla).*
After solving above eq. (6.2) and eq. (6.3) we get,
Hull cut off magnetic field,

$$B_0 = \frac{4\pi f m}{Me} \frac{1}{\left(1 - \frac{r_{ca}^2}{r_{ai}^2}\right)}. \tag{6.4}$$

Hull cut off voltage,

$$V_0 = \frac{e}{8m} r_{ai}^2 \left(1 - \frac{r_{ca}^2}{r_{ai}^2}\right) B_0^2 \tag{6.5}$$

Where B_{app} is the practical applying magnetic field and it will be selected lesser than the cut-off magnetic field B_o.

Hartree voltage,

$$V_t = \left(2 \frac{B_{app}}{B_0} - 1\right) V_0. \tag{6.6}$$

When, we determined the Hull cutoff and Hartree voltages, the essential voltage value V_{app} need to be select in the interval

$$V_t < V_{app} < V_0. \tag{6.7}$$

There has an important to note that the selection of B_{app} values changes the Hartree voltage that will be disturbs the operational region.

6.3 3-D MODEL DESIGN OF MAGNETRON

3-D designing and to simulate the magnetron on CST software contains three stages: Eigen mode solver, Particle Studio, PIC (particle in cell) solver. The design procedure exhausting with the operational frequency of the magnetron is *f=10* GHz and preferred power is almost 5-6 kilowatt which is on X band.

When we will start to designing the magnetron model, selecting the radius of cathode r_c = 0.14λ, where λ is the free space wavelength. Using, $r_{ai} = 0.3\lambda$ and the length of the anode block and cathode are select as $h_{a/c}$ = 0.58λ. Others parameters are $r_h = 0.12\lambda$, $l_s = 0.07\lambda$ and $w_s = 0.1\lambda$.

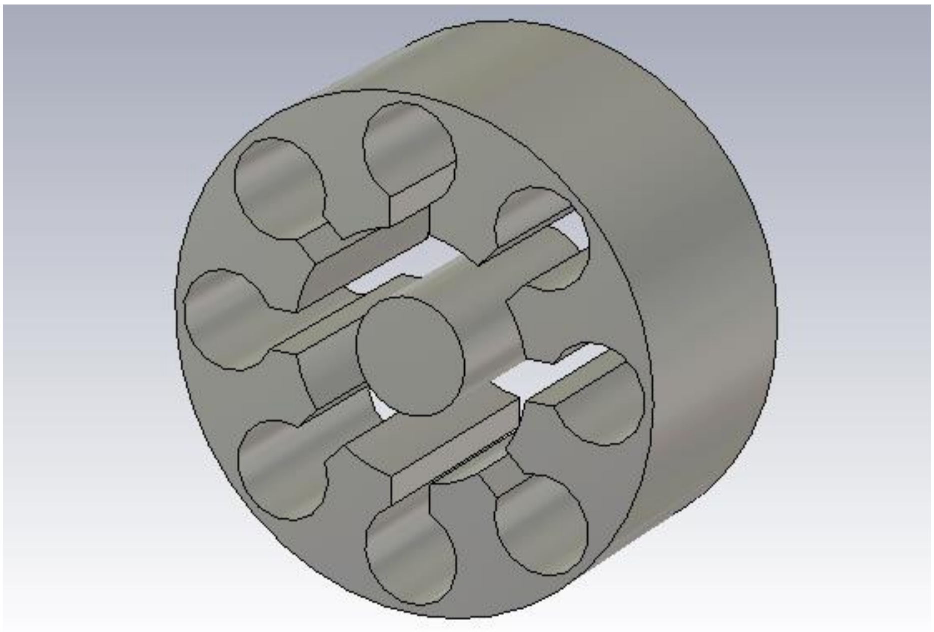


Figure 6.2 Designed model of 8-cavity Hole-slot-type magnetron

Afterward, the step is to find out the magnetic field and potential difference between the cathode and anode blocks. Using eq.(6.4) we obtained B_0=0.2294 T . Using eq. (6.5) we obtained V_0 = 56.81 kV.

Using eq.(6.6) Hartree threshold Voltage V_t = 47.67 kilovolt is found.

Using eq.(6.7) we choose V_{app} = 48 kV and B_{app} = 0.21 T.

S.NO.	**Parameter of Magnetron**	**Values (mm)**
1.	Cathode radius	4.2
2.	Anode outer-radius	18.5
3.	Anode inner-radius	9
4.	Height of Anode/Cathode	17.4
5.	Width of slot	3
6.	Length of slot	2.1
7.	Radius of hole	3.6

Table 6.1 Dimensional-parameter values of Magnetron

6.4 CST PARTICLE STUDIO INVOLVES THREE STEPS FOR MAGNETRON SIMULATION

a) Eigen mode Solver

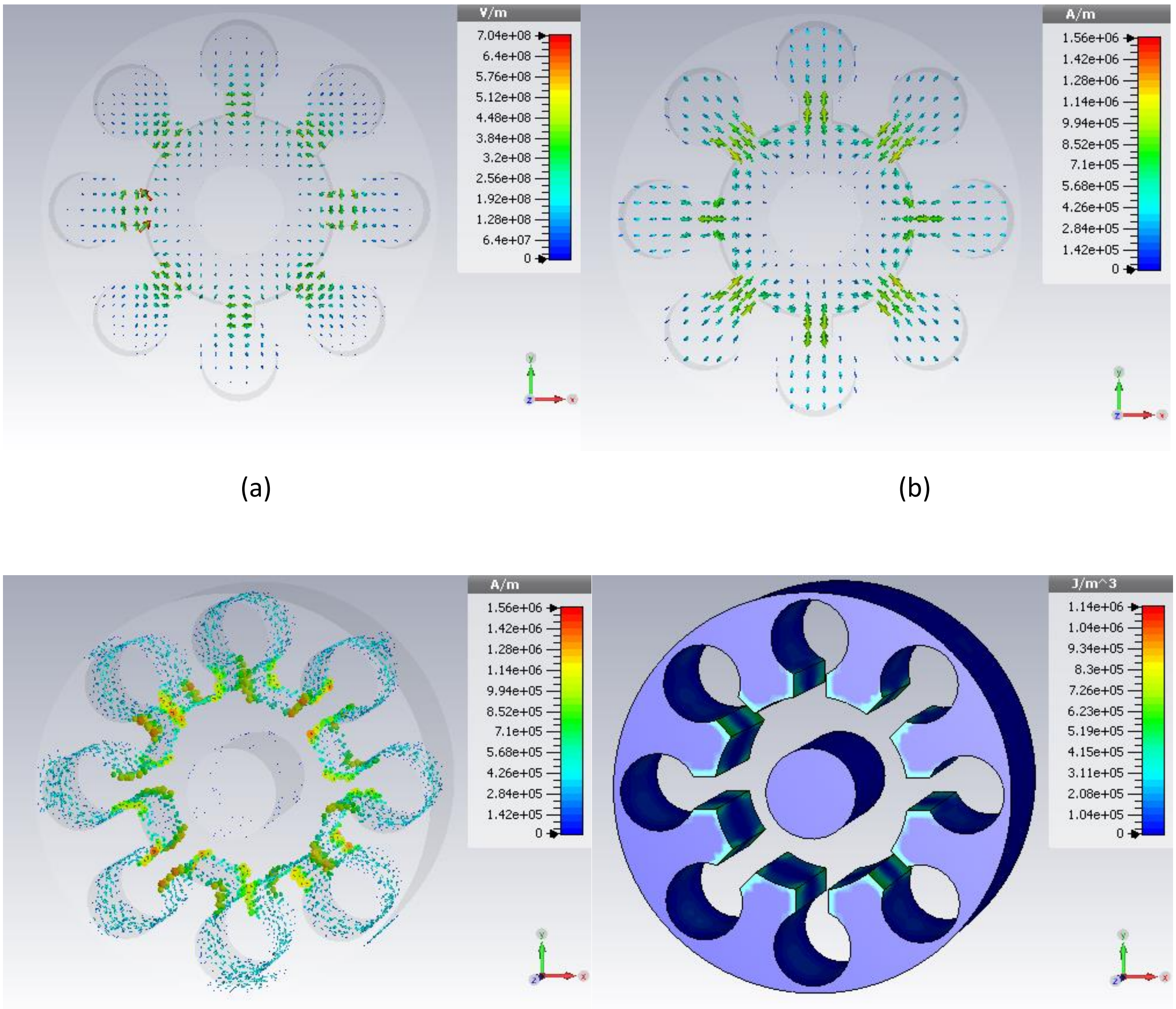
b) Particle Tracking

c) Particle in cell simulation solver

a) Eigen mode Solver

Using Eigen mode solver, resonant modes and its electromagnetic filed patterns are determined and advanced krylov Subspace method of solver. The operational frequency of magnetron is used as $f=10$ GHz. The number of resonators is selected as NR=8, so that their non-degenerate mode (π-mode) come to be $M=NR/2=4$ and there is a 180^0 phase shift between adjacent resonators. Hull cut off magnetic field B_0=0.2294 Tesla is applied and voltage V_{app} = 48 kV.

If all dimensions are determined then it ready to start modeling on CST Microwave Studio for Eigen mode simulation. After that set the frequency, the boundaries are selected as the tangential electric field is zero (E_t = 0). Magnetic field is always perpendicular to electric field. Before starting the simulation, the PEC area removed and left part filled with vacuum, as well as select background material as a PEC. Along with this, the EM- field patterns obtained in the empty space. To start the Eigen mode Simulation, mesh type is using hexahedral and AKS solver method used for desired output.

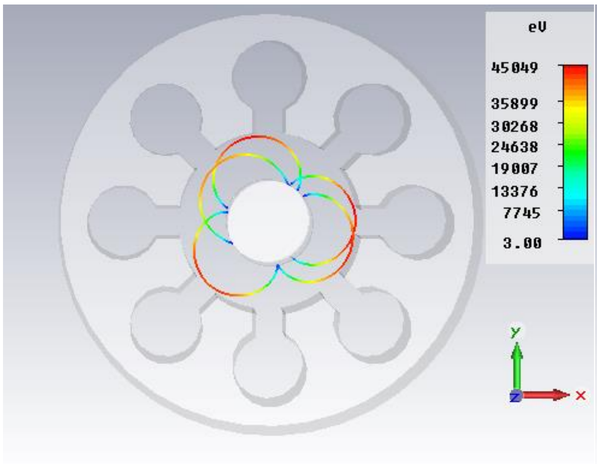


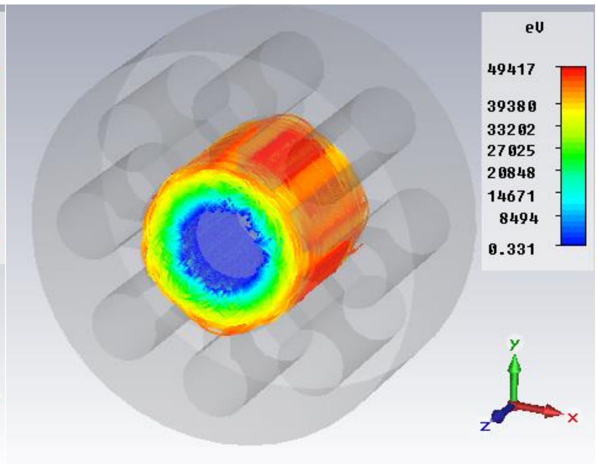
(c) (d)

Figure 6.3 (a) pi-modes E- field pattern with resonant frequency is 10.146 GHz (b) H- field pattern (c) Surface current pattern (d) Magnetic energy density

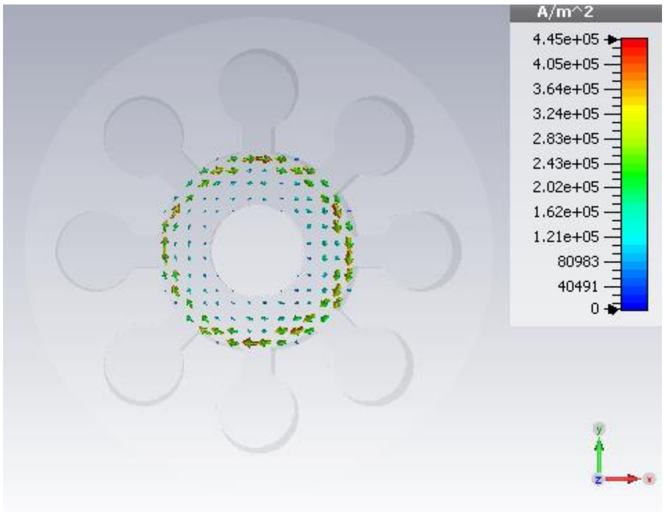
b) Particle Tracking

Next step, Particle Tracking used for 3-D designing and simulation. The main motive of this part simulation is the determination of potential difference between the anode and cathode blocks and also to check the quantity of magnetic field to be applied that show the movement of particles. The boundary condition in particle tracking magnetic field set as,(H_t = 0). To providing a particle source to the cathode fixed electron emission current (10 A) is chosen and its kinetic energy selected as 3 eV. The movement of an electron in one round is shown in fig 6.4(a,b,c).





(a) (b)



(c)

Figure 6.4 (a) Motion of electrons in the effect of electromagnetic field

(b)Trajectories motion of numbers of electrons beginning at cathode due to the effect of EM-field

(c) Particle current density Pattern

c) PIC Simulation Solver

The PIC solver method is using to simulate of charged particles electrons released at the surface of cathode under the effect of EM-Field.

Using this solver, the E-field inside the magnetron is examined w.r.t time and frequency-using field probes at particular points. In PIC simulation, particle source is using explosive emission model that has 1834 emission points' discharged electrons from cathode. A numbers of emission points spontaneously considered and recommended by the solver using mesh size. The kinetic energy and rise time values taking as 3ev and 1ns. Two probes are used, one of at the beginning of the slot and another one at the end of the slot. Using these probes, the electric field signal (V/m) determined.

For the duration of Simulation, a hexahedral mesh used with no. of lines per wavelength selected as 15. It has overall 34056 numbers of mesh cells.

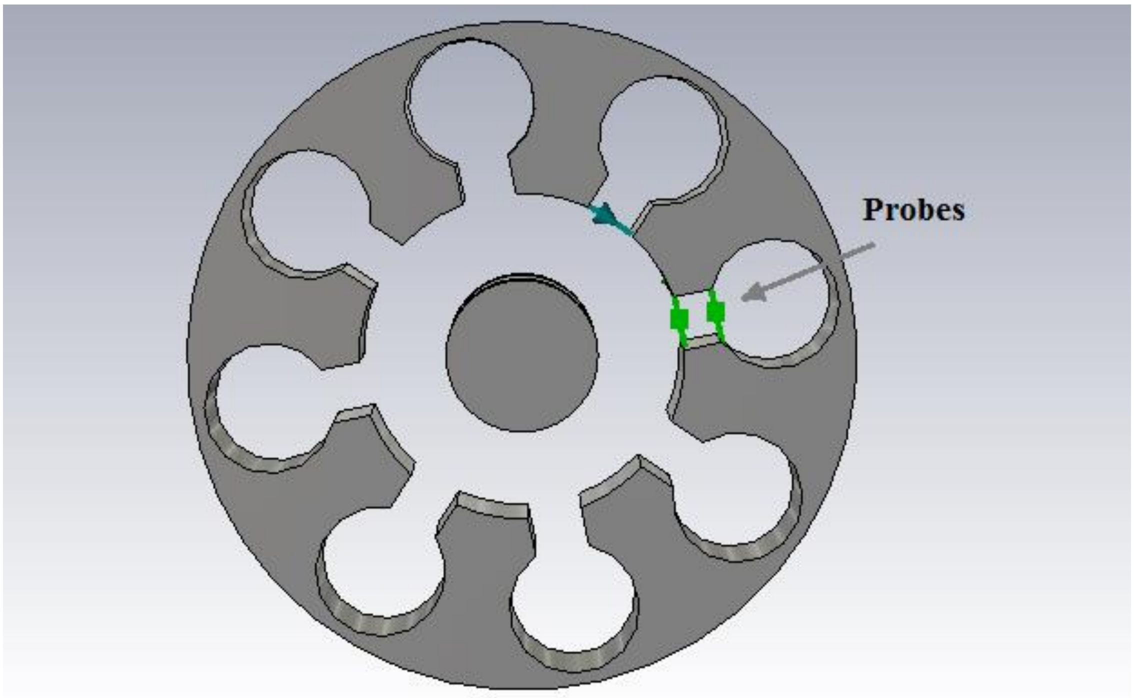


Figure 6.5 Position of two probes in magnetron structure

We studied to get the special properties of the PIC solver time, mesh size and number of emission points taking from non-strapped magnetron operation. Still, the PIC solvers take time longer to recognize the performance of the design magnetron model totally. It has no any particular simulation time and the performance of the magnetron has been calculated by monitoring that is one stable or the other unstable. The result has an important and shown in Fig. 6.6. For a simulation of a 30-ns it take time, in the PC requires approximately 24-hours and depend on the version (speed-up) of computer. Furthermore, to take the longer solver time and getting the sharper peak at resonance due to diminished truncation errors.

In PIC simulation, cathode and the anode inner-side radius does not simply disturb the signal and noise level, then again, they also determined the resonance frequency. After the cathode and anode radius are changes, it is clear to changes the interaction region that has nonstop effect of the resonant frequency. Dimensions of slots have also essential for magnetron features. The anode current and cathode current obtained with respect to time. An anode current of magnetron varies with respect to time in 30 ns; a current increase continuously with varying time but after some time it falls to reach at zero and varies linearly as shown in figure 6.6(a).

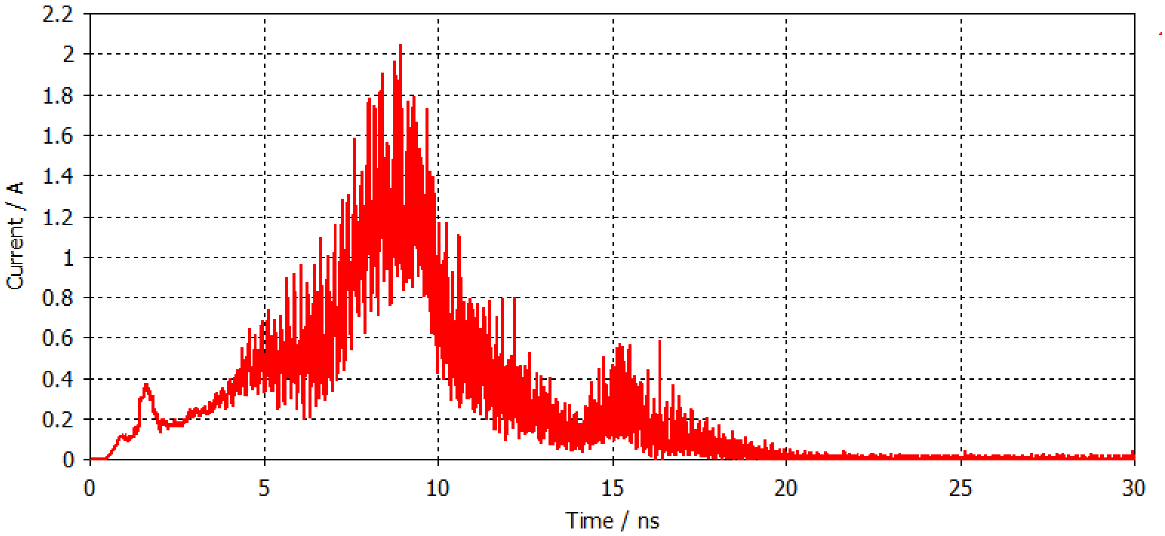


Figure 6.6 (a) Anode Current w.r.t time

Uncertainty, the interaction region has been extending because due to this effect the resonance frequency falls or rises. In figure 6.6(b), cathode leakage current is varying instantly at a particular level after that its current varies continuously with respect to time at 8A.

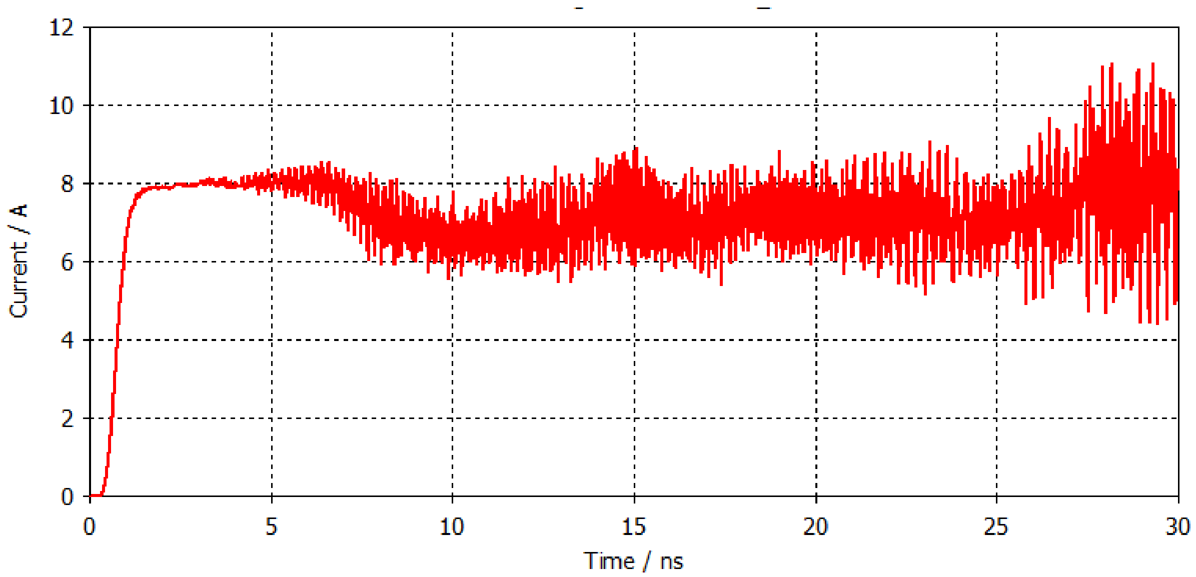


Figure 6.6 (b) Cathode current w.r.t time

From the without using strap study, the strength of an electromagnetic field specified in terms of volt per meter along with applied frequency is continuously varying with time. Thus, their electric field fluctuation varies shown in figure 6.6(c).

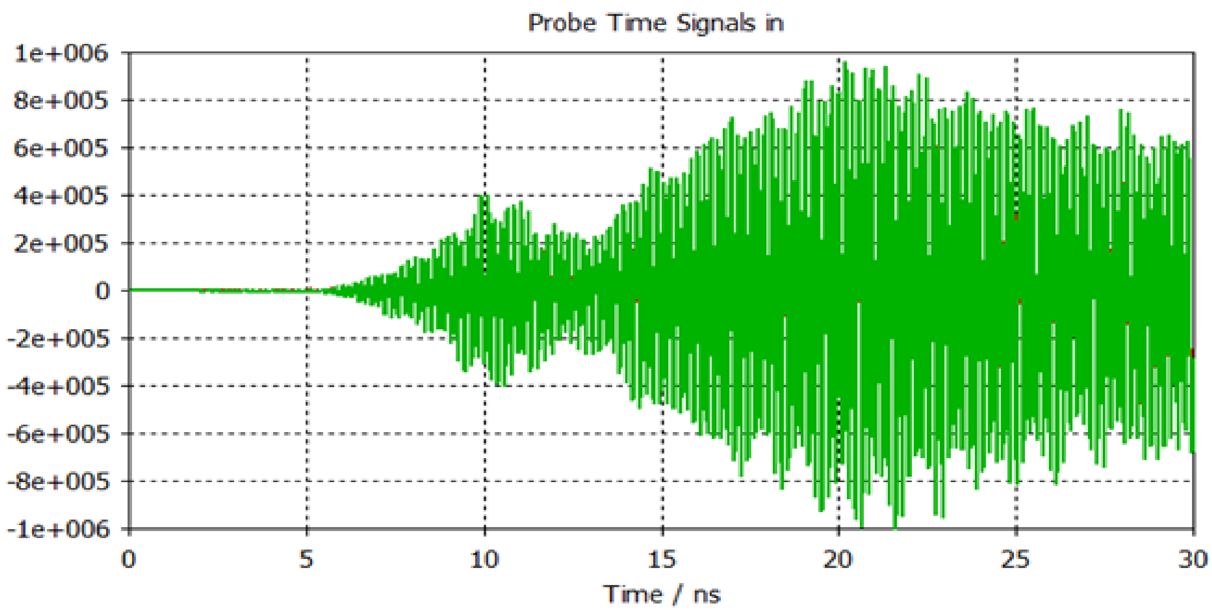


Figure 6.6 (c) Determined E-field w.r.t times at starting position of probes or at end of slot.

Here, we saw in figure. 6.6(d), here are no changes of resonant frequency and having very small differences between the electric fields (dB) of the two different probes. One of at the starting and another one at the end slot probes. The Fourier-Transform of this electric field effect (V/m) shown in figure 6.6(e).

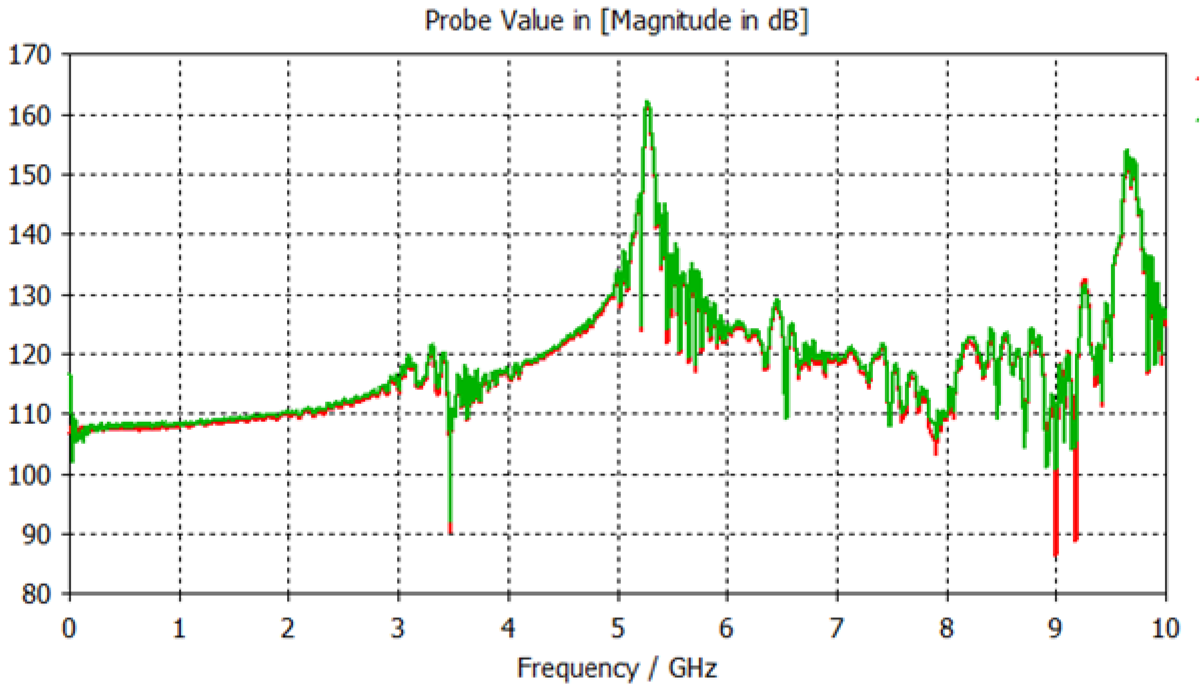


Figure 6.6 (d) Comparison between the frequency-spectrum of E-field in (dB) at starting and end probes.

The spectrum of the operated magnetron in π-mode has been measuring using by probe in the cavity. This output signal is from the interaction region in the cavity using probes, not from the waveguide port. The frequency spectrum of electric field peak is obtained at 5.2GHz.

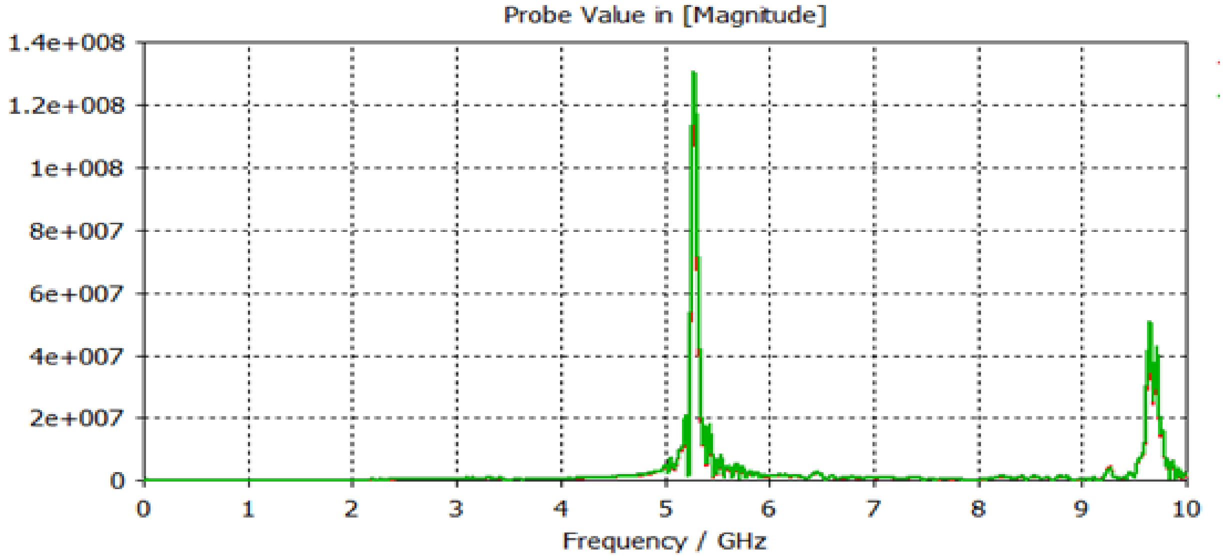
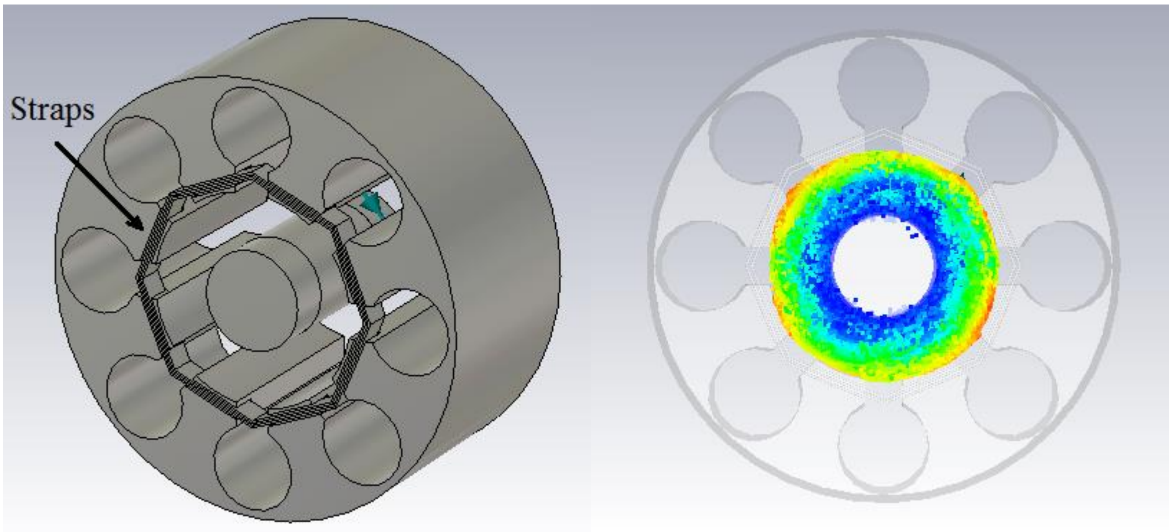


Figure 6.6 (e) Frequency-spectrum of E-field obtained using the probes located at the starting slot.

If need to increase the performance of magnetron, adding straps in one side of anode block and simulation result is close to analytical calculation. The straps added in magnetron shown in figure 6.7(a) and spokes of electron beam shown in figure 6.7(b).



(a) (b)

Figure 6.7 (a) Strapped-addition in magnetron, (b) Image of the electron beam

After adding the straps, the performance of magnetron results improved and we obtained desired values. The resonant frequency shifted from 5.28 GHz to 6.81 GHz. Due to adding strap 1.53 GHz frequency increases.

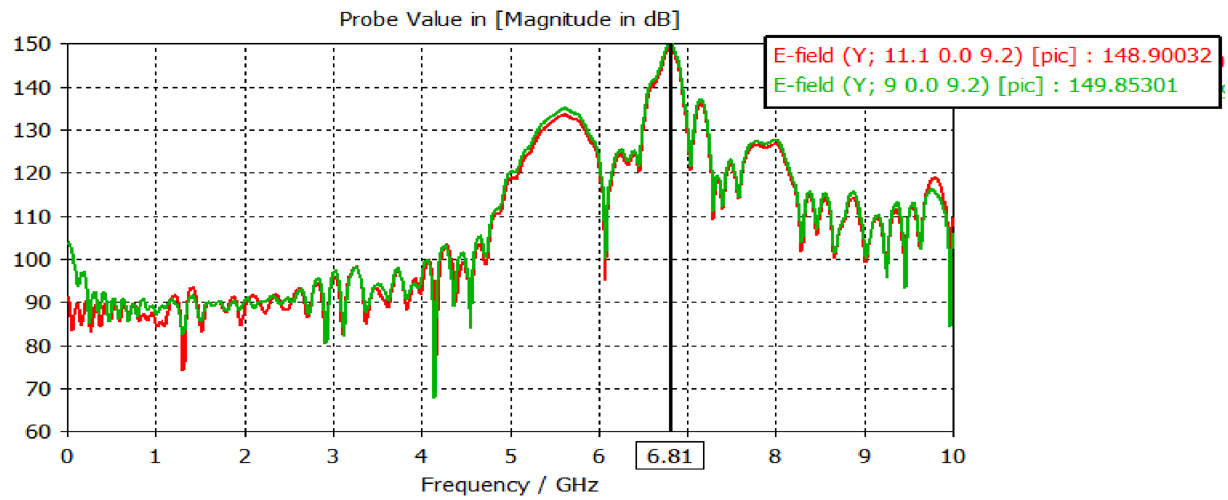


Figure 6.8 (a) Comparison between the electric-field effect on starting and end slot of the probes.

Due to adding straps, the peak output of electric field has shifted at frequency 6.81GHz and decreases the electric field values that is gives a better result and sharper peak value.

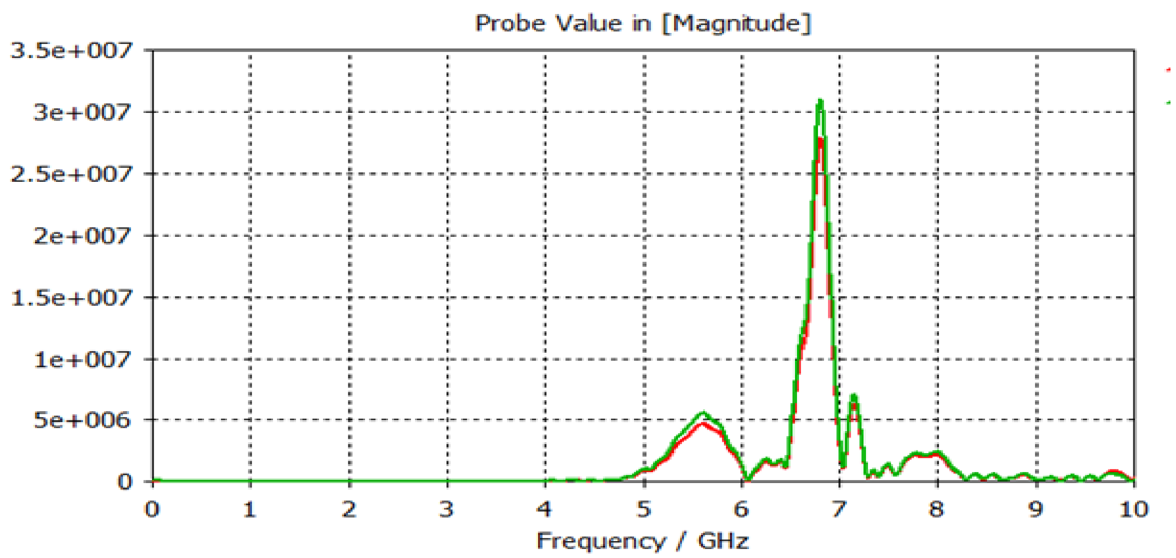


Figure 6.8 (b) Frequency-spectrum of E-field

From using straps, the power of an electromagnetic field along with applied frequency is continuously varying with time varies at 10ns. Thus, their electric field decreases as compare to using without strap output power; its fluctuation varies shown in figure 6.6(c).

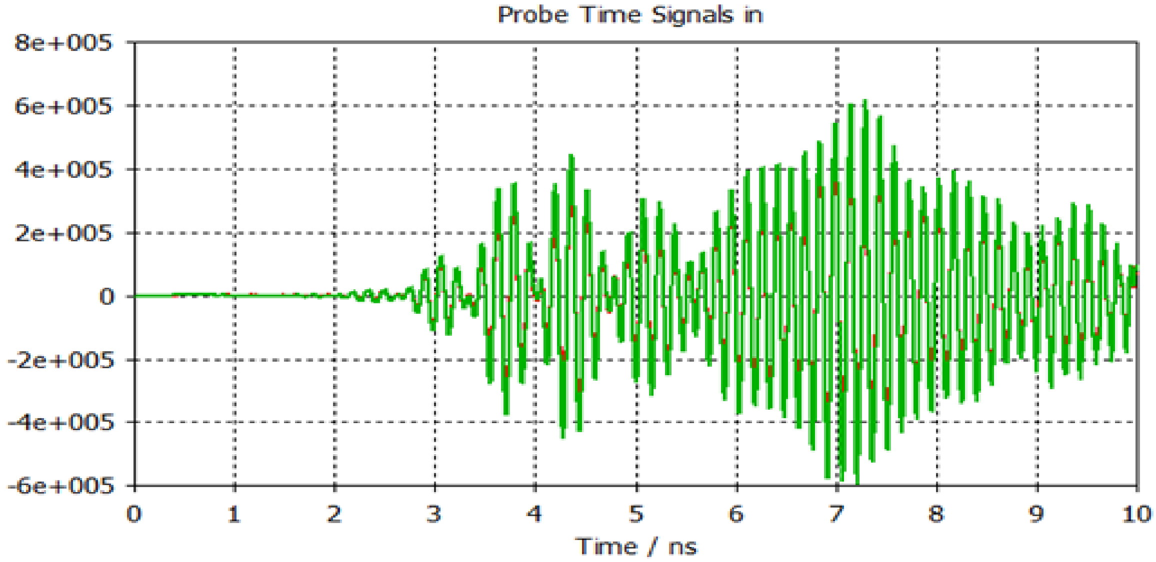


Figure 6.8 (c) Determined E-field w.r.t times at the starting and end slots of the probes

CHAPTER-7

CONCLUSION AND FUTURE SCOPE

7.1 CONCLUSION:

Initially, design and simulation of 8-cavity hole slot type magnetron has been made using empirical equations. The eight-cavity hole-slot type magnetron dimensions parameters have obtained to design magnetron model on the CST Particle Studio. The 3D designed structural model is using for Eigen-mode analysis, Particle Tracking and PIC simulation solver. Due to applied voltage and the magnetic field, the kinetic energy required to moves the electron, just enough to touch the anode. These electrons form a cloud-shaped in the interaction space and start moving collectively in the self-produced radio-frequency fields. The designed magnetron without straps where the influence of electric field w.r.t time and frequency has been determined and found peak at 5.28GHz. The times necessary, which depend on the simulations that has generally based on program parameters such as, mesh size, PIC solver time and number of emission points. For PIC simulation, it takes more time to complete the simulation. If increases the rise time, it gives the sharper peak at resonance frequency. For further modification, adding straps in magnetron, which suggests to improvement of the field properties of magnetron. In this, study of 8-cavity-hole-slot type, magnetron simulation shifted its resonant frequency peak at 6.81GHz.

7.2 FUTURE SCOPE FOR FURTHER WORK

1. For further work, to investigate different shapes of magnetrons, selection of material with including different straps to enhance the microwave frequency ranges.

2. The investigation of new techniques that attempt to reduce the size and enhance the MW frequency ranges to make its utility possible in manageable devices.

3. Simulation can be do with different shapes of cathode such as the cathodes with sharp edges in order to increase the local electric field and enhancing electron emission for the cathode.

4. From the results, it has discovered that the simulated MW frequency range is low. To overcome this in future, the advancement in the approaches can be working to improve the frequency peak of the magnetron.

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