CHAPTER 1

INTRODUCTION

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History of humankind has ever faced challenges and faced wars for survival. Each challenge encourages us for valuable and deterministic research and development. Sometimes the research is also done with the motive of wars and in turn had led to the development of the commercial and social product, which has usages in domestic and industrial applications. As an example, in 1940 as world war-II came to an end, the microwave tubes market had dropped. People in the microwave industry started examining its applications towards the microwave heating. They start recalling the magnetron research by Albert W. Hull in 1921 [Hull (1921) and Kremer (2006)]. Percy Spencer, a famous engineer from company Raytheon, took the development of magnetron to a microwave oven, which can cook foods [Spencer (1941)]. Similarly, high power microwave (HPM) systems were thought for the defence applications as an E-bomb for disabling, jamming or upsetting electronics devices [Giri (2004)]. However, now a day's researches are also motivated in the direction of non-defence communication and industrial applications of HPM systems.

HPM is coherent electromagnetic radiation spanning over 1 to 300 GHz [Benford *et al.* (2007)]. HPM represents microwave power more than 100MW, operating in a single-shot or repetitive [Taylor and Giri (1994)]. They are being developed in various laboratories or institutions across the world, and their power levels are reaching gigawatt (GW) range. The technology used to generate HPM is often pulsed power source.

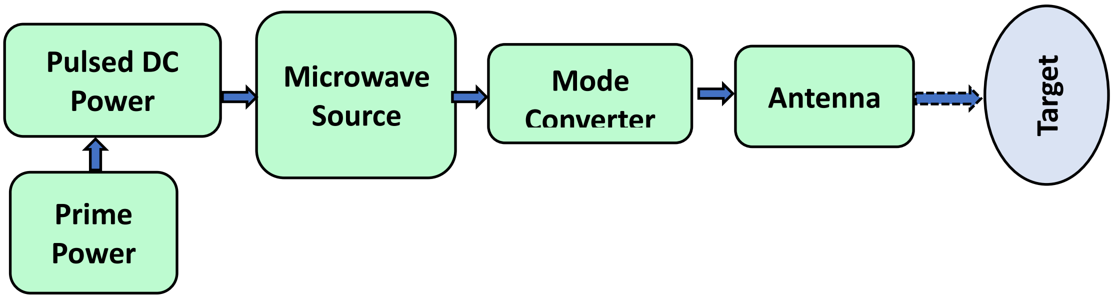

Figure 1.1. Block diagram of a typical High Power Microwave (HPM) System.

Figure 1.1 shows a typical block diagram of HPM system. As mentioned, it consists of the following modules.

I. **Prime Power**: This subsystem generates relatively low power electrical signal in a long pulse or continuous mode. This subsystem has four components: internal combustion as a prime power producing an AC output; an interface component like a pump, motor, controller or AC to DC converter; followed by energy storage and electrical source component; connected with AC or DC converter. The output of prime power provides a series of switched DC pulses to the pulsed power source [Chittora (2016)].

II. **Pulse Power Source**: The pulse power generators deliver short and intense electrical pulses by storing low power and long electrical pulse of prime power. This short and intense electrical pulses could be achieved in many ways as mentioned below, depends mainly on the type of HPM source to be used [Benford *et al.* (2007)]

   - Capacitor banks-based charging process which converts slow rise low voltage signal to fast rise high voltage signal such as Marx generators
   - Inductive energy storing with opening switches
   - Pulse forming lines and Pulse forming networks
   - Solid state modulators based on the semiconductor opening switch.

III. **HPM Source**: HPM sources are a combination of microwave source along with modified the approach to connect with the pulse power system supplies higher input voltage and current [Schamiloglu (2004)]. These sources generate microwave energy by converting kinetic energy of electron beam to electromagnetic energy. The electron gun of this class of devices typically employs explosive emission cathodes to produce high density electron beam

[Barker and Schamiloglu (2001)], more popular HPM devices are Magnetically Insulated Transmission Line Oscillator (MILO), Relativistic Magnetron, Relativistic Klystron, BWO (Backward Wave Oscillator) and Virtual Cathode Oscillator (VIRCATOR), etc.

IV. **Mode Converter**: Whenever there is a change or a discontinuity in the geometry, there will be a local change in the field distribution just like you have drawn. This means at the change there are new modes generated. Away from the bend, the new modes may disappear or attenuate out [Giri (2016)]. In order to achieve the highest impact on the target, the radiated EM wave must be of proper mode. Some of the HPM sources generates azimuthally symmetrical modes having null in the direction of propagation. Such azimuthally symmetrical modes are converted to required modes having maximum power in the direction of propagation by using a suitable mode converter [Yuan *et al.* (2006)].

V. **Antenna**: This subsystem uses to radiate microwave power with spatial compression, high directivity and high efficiency. Breakdown at radio frequency (RF) window is also a issues while designing antennas [Zhao *et al.* (2014)].

1.1 Application of High Power Microwave (HPM) Systems

HPM systems have applications in the defence sector, where light-weight, compact, axially aligned mode converters are required with features of high convergence efficiency, high power capability, along with beam stability. Such mode converters can be used in the HPM systems having application for

- HPM Weapons: These weapons are also termed as E-bomb, used for disabling, jamming or upsetting electronics devices [Giri (2004)].
- Space Beam Driven Rocket: In place of solid or liquid propulsion, researches are going on to achieve self-thrust using microwave radiation propulsion [Benford *et*

al. (2007)]. Also, researches are going on to provide thrust to spacecraft from ground radiating HPM beam.

- Solar Power Transmission through Space: By using photovoltaic cells driven HPM system, microwave power could be reached on the earth surface as an alternative of power supply available at present. Such applications are under research [Benford *et al.* (2007)].
- Radar capability enhancement using HPM.
- Rebuilding the Ozone Layer by HPM
- and, Plasma heating for the controlled fusion reactions.

All the above applications do require maximum RF power from HPM sources.

1.2 HPM Sources

Microwave tubes usage electrons bunching or/and plasma oscillation to generate coherent electromagnetic radiation [Gilmour (2011) and Basu (1996)]. This microwave radiation is produced, when electrons plasma oscillation generates polarity between slow wave structures or form bunches of electrons that are correlated to the input frequency. Therefore, it produced spontaneous emission with random phase and radiated it from the output port.

1.2.1 *Magnetically Insulated Line Oscillator (MILO)*:

Magnetically Insulated Line Oscillator (MILO) is a cross field microwave tube, closely related to the linear magnetron with self-insulation mechanism and its schematic is shown in Figure 1.2 [Kesari and Basu (2018)]. The beam current generates an axial magnetic field that inhibits the electrical breakdown at the anode-cathode gap. This electrical breakdown enables the tube to handle large input power [Lemke *et al.* (1997)]. The oscillation occurs when an average flow of electron’s velocity is synchronous with the phase velocity while device is operating under the π-mode [Calico *et al.* (1995)].

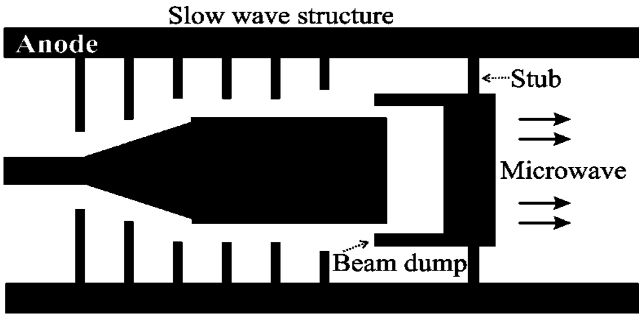

Figure 1.2. Schematic of a Magnetically Insulated Line Oscillator (MILO).

1.2.2 *Relativistic Magnetron*:

In the magnetron, depicted in Figure 1.3, a DC voltage is applied between the cathode and anode to enable electrons emission from the cylindrical cathode [Benford *et al.* (2007)]. In the presence of the radial electric field and an external applied axial DC magnetic field, electrons revolve around the cathode. At the cavities gap, electrons bunching take place resulting into formation of the electron spokes. The kinetic energy of electron beam gets transformed to electromagnetic radiation and is often extracted from one of the anode cavities [Bekefi and Orzechowski (1976) and Gilmour (2011)]. A relativistic magnetron is a stable, compact and reliable HPM source and its oscillation frequency is determined by the depth of the anode cavities, so it is hard to tune this magnetron for during its operation [Benford (2010)]. The difference between an ordinary magnetron and a relativistic magnetron is depended on the applied DC voltages and currents [Benford *et al.* (2007) and Chandra *et al.* (2014)]. The principal characteristics of the relativistic magnetron are its tunability, manufacturability and its low efficiency [Barker and Schamiloglu (2001)].

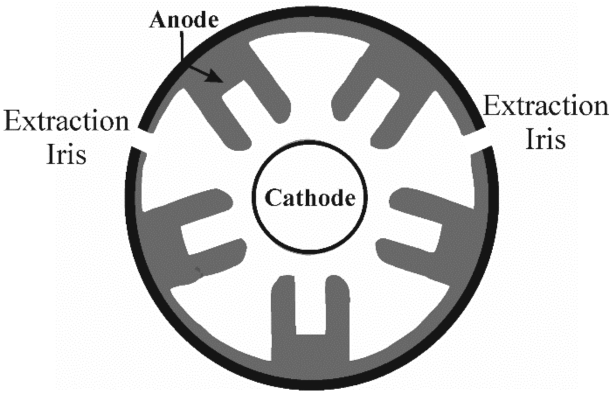

Figure 1.3. Schematic of a Relativistic Magnetron [Barker and Schamiloglu (2001)].

1.2.3 *Relativistic Klystrons Amplifier (RKA)*:

Klystron consists of an electron gun which generates electron beam of desired parameter and electrons velocity is controlled by the DC potential applied to the anode [Gilmour (2011)]. As the electron beam enters between grids of the buncher cavity, some of the electrons group accelerate while others get decelerated; thereby forming electrons bunches with different velocities [Barker and Schamiloglu (2001)]. At the catcher cavity of the device, the electron bunch releases the kinetic energy to the RF waves. Finally, the unspent electrons are collected at the collector subassembly of the klystron [Barker and Schamiloglu (2001)]. The operation of RKA is similar to that of conventional klystron amplifiers, but it uses a large diameter annular beam instead of the solid pencil beam [Chittora (2016)]. This thin annular electron beam can propagate near the outer wall of the structure and can carry much higher current at a given DC voltage [Barker and Schamiloglu (2001)]. The RKA schematic is shown in Figure 1.4.

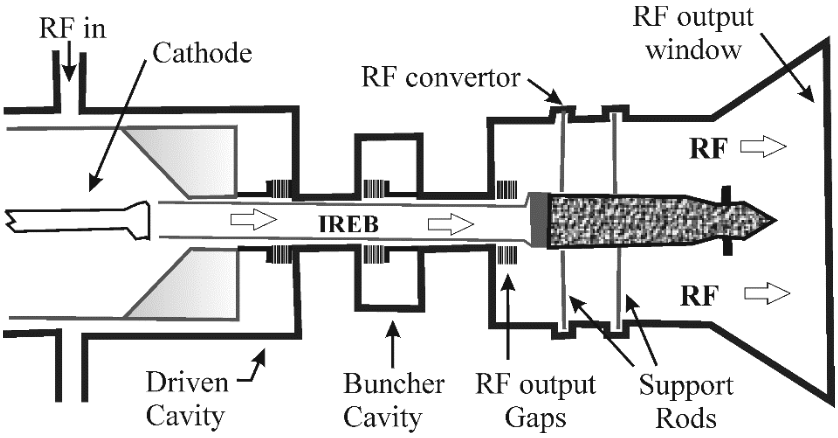

Figure 1.4. Schematic of a Relativistic Klystron Amplifier [Barker and Schamiloglu (2001)].

1.2.4 *Relativistic Backward wave oscillator (RBWO)*:

Backward wave oscillator (BWO) is a Cerenkov type microwave oscillator with excellent tuning capability and broad frequency coverage range [Barker and Schamiloglu (2001)]. It has a hollow cylindrical electron beam which interacts with the backward RF wave space harmonics of waveguide mode, that cause absolute instability along the periodic slow wave structure (SWS) [Gilmour (2011)]. During the interaction of electron beam with the RF waves at the SWS, the space charge bunch initiates a wave propagating in the backward direction, however, to protect cathode reflector is used. If the bunch electrons velocity and RF phase velocity are such that the total phase delay is in the loop, the backward oscillation of electron starts $\left(\Theta_n = N \cdot 2\pi\right)$ [Barker and Schamiloglu (2001)]. The BWO structure working with relativistic electron beams that can produce high power coherent radiation is named as RBWO. The RBWO schematic is shown in Figure 1.5.

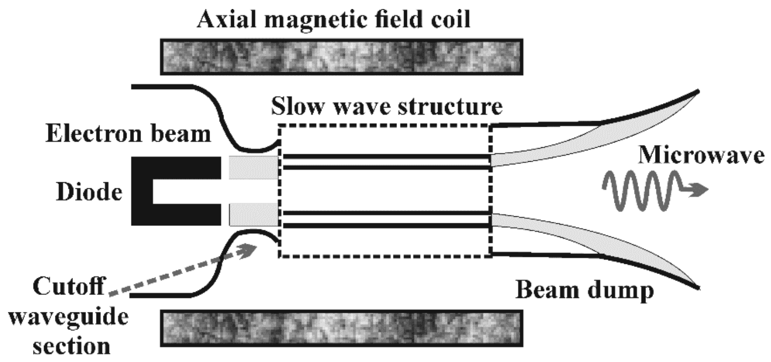

Figure 1.5. Schematic of a typical Relativistic Backward Wave Oscillator (BWO) [Barker and Schamiloglu (2001)].

1.2.5 *VIRCATOR*:

In vircator, a dense cloud of electrons are accelerated against a metallic grid or an anode foil [Chittora (2016)]. An adequate number of electrons pass through the anode, which forms a highly dense region of a space charge behind the anode, called Virtual Cathode. The space charge region contains electron plasma rest at zero velocity [Barker and Schamiloglu (2001)]. Electrons from this region again attracted from the gridded anode, and such oscillation produces RF wave. Electrons oscillation can be tuned to broadband frequency using a change of a space charge density [Gilmour (2011)]. The VIRCATOR is shown schematically in Figure 1.6. The external DC magnetic field is not required in the operation of VIRCATOR device.

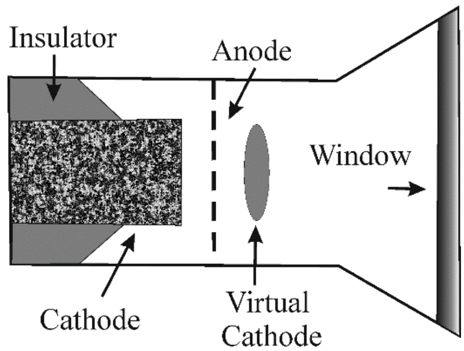

Figure 1.6. Schematic diagram of VIRCATOR [Barker and Schamiloglu (2001)].

Table 1.1. RF Output Modes from the HPM sources

HPM Sources	Significant Modes Generated	Remarks
Magnetically Insulated Line Oscillator (MILO)	TEM or TM_{01}	Over the Beam Dump mode is TEM [Barker and Schamiloglu (2001)]
Relativistic Backward wave Oscillator (RBWO)	TM_{01} and TM_{02}	To increase the BWO power, it is to design for higher order modes TM_{0n} modes [Barker and Schamiloglu (2001)]
VIRCATOR	TM_{0n}	Through virtual cathode
Relativistic Klystron Amplifier (RKA)	TEM or TM_{01}	Due to coaxial extraction mode is TEM [Barker and Schamiloglu (2001)]
Relativistic Magnetron	TM_{01} or TE_{11}	Depend upon extraction, but efficiency is higher in TM_{01} generation [Barker and Schamiloglu (2001)]

Table 1.1 shows that most of the HPM sources generate azimuthally symmetrical modes TEM or TM_{01}, which are further required to convert in the desired mode by using a different kind of mode converter.

1.3 Need of the Mode Converter

In order to transform the mode pattern of the RF waves into the desired modes, can be achieved by suitably adding deformation in the propagating waveguide. It is also termed as the Mode Transducer [Montgomery (1948)]. Mode converter is a controllable mode switching device finds application for selectively transforming RF energy into the desired mode of propagation.

Some important mode conversions are as following [Benford *et al.* (2007)]

- Converting TE mode to higher order TE modes or vice versa.
- Converting TM to TE mode, because TM mode has null at its axis propagation.

- Converting *TE* to *TM* mode, because *TM* is the mode, this interacts with the azimuthal component of electric field electron plasma.
- Converting circular waveguide modes to rectangular waveguide modes or vice versa.

As shown in Figure 1.1, the Prime power is the initial energy source having low power and long pulse or continuous mode. Pulse power subsystem accepts low power long pulse and converts them into high power short pulse. These High Power pulses are fed into the microwave source, such as Magnetically Insulated Transmission Line Oscillator (MILO), Relativistic Magnetron, Relativistic Klystrons, RBWO (Relativistic Backward Wave Oscillator) and Virtual Cathode Oscillator, etc. Then, RF source output mode is converted into the desired mode using the mode converter. This mode converter is connected between HPM source and RF antenna to radiate the electromagnetic waves to the target. In this system requirement of the mode, the converter plays an important role.

In Figure 1.7, two comparative microwave systems is shown. In which one has a mode converter, and the other one is without a mode converter. System *a* is radiating in TM_{01} mode while system *b* is radiating TE_{11} mode. After measuring the radiation pattern as shown in Figure 1.8, it is found that TM_{01} have null at boresight of the radiation pattern, whereas TE_{11} have maximum amplitude at boresight. Moreover, for communication or weapon; maximum amplitude is necessary at boresight. So, we need a suitable mode converter to change the source generated mode in require mode for radiating in the direction of the target. The earliest method was to radiate source generated mode slant cut in a circular waveguide, named as Vlasov converter, for the conversion of output *TM* mode to directly into a Gaussian beam [El-Misilmani *et al.* (2015), El-Misilmani *et al.* (2013), El-Misilmani *et al.* (2013), Ling *et al.* (2004), Thumm and Kasparek (2002) and Zhang *et al.* (2012)]. But later, sectoral waveguide mode converter emerges [Somov *et al.* (1998)].

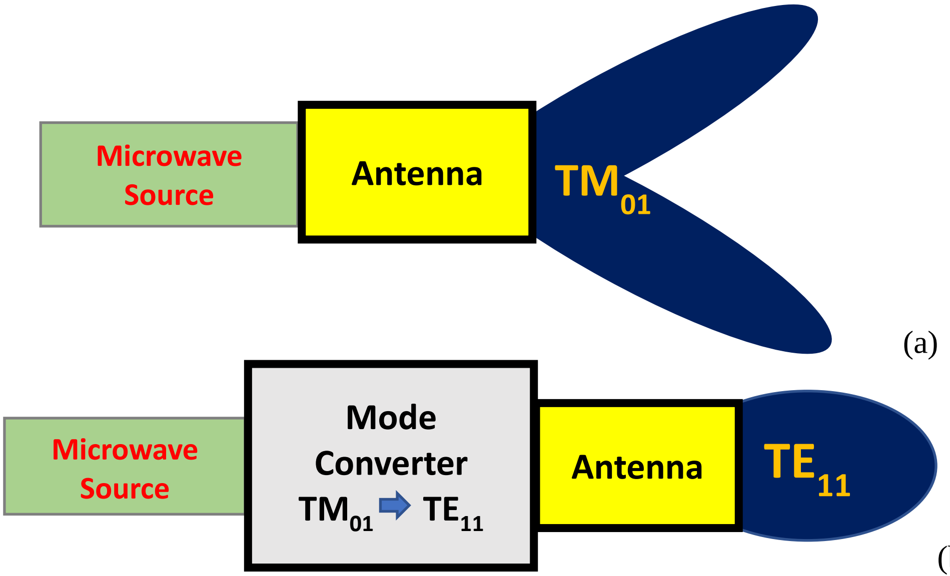

Figure 1.7. Comparison of the Microwave Systems: **(a)** without Mode Converter, and **(b)** with Mode Converter.

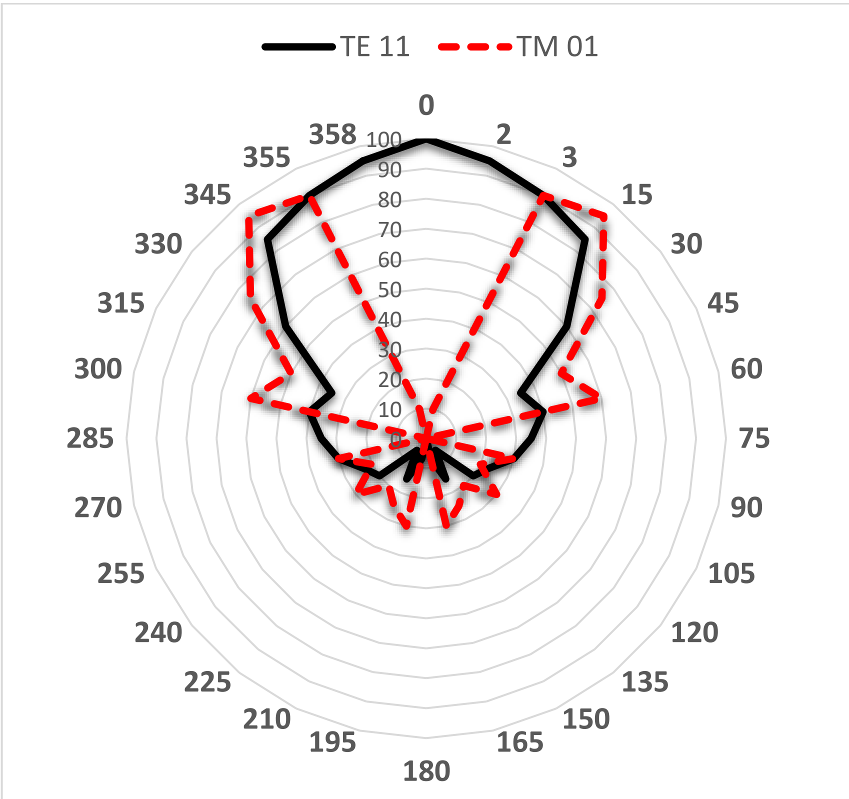

Figure 1.8. RF radiation patterns of the TE_{11} and TM_{01} modes.

1.4 Sectoral Waveguide (SWG) mode converter:

Sectoral waveguide (SWG) is an angular sector of the coaxial waveguide, which is formed by separating coaxial waveguide using axially-radial metallic plates. For SWG, the coaxial guide azimuthal constant *m* (represents the order of Bessel function in coaxial waveguide expression) has been replaced by integer *p* denoting the number of half period variations of SWG modal field [Elsherbeni *et al*. (1991)] and is discussed in chapter 4. The SWG structure is shown in Figure 1.9, consists of a coaxial region $r_i \le r \le r_o$ and the azimuthal metallic plates at angle 0 rad and ϕ rad.

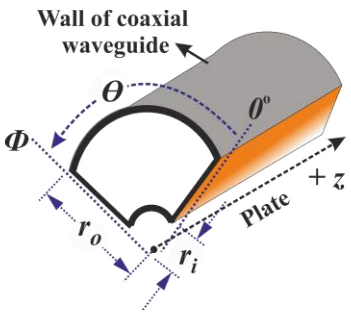

Figure 1.9. A typical sectoral waveguide (SWG) structure.

A great deal of confusion regarding SWG in designing microwave components arises from the tendency to control cut-off frequencies for the specific modes. For instance, the aperture of a rectangular waveguide, their width and height are the parameters to control cut-off frequencies for specific modes. Study of the SWGs shows a similar analogy of rectangular waveguide to design any waveguide-based component. The SWGs have a sectoral angle and radial height as the parameters, in place of their rectangular waveguide counterparts. Furthermore, the SWG, do not support *TEM* mode as it is supported by coaxial waveguide; since it is bounded at both azimuthal ends and open in the axial direction. Figure 1.10 shows the analogy of sectoral angle as a width rectangular waveguide, so if the sectoral angle 180° (π rad) is equivalent to width a, then the sectoral angle 90° (π/2 rad) may be represented equivalent to width ạ/2. Further, throughout this literature, sectoral angles are denoted in radian.

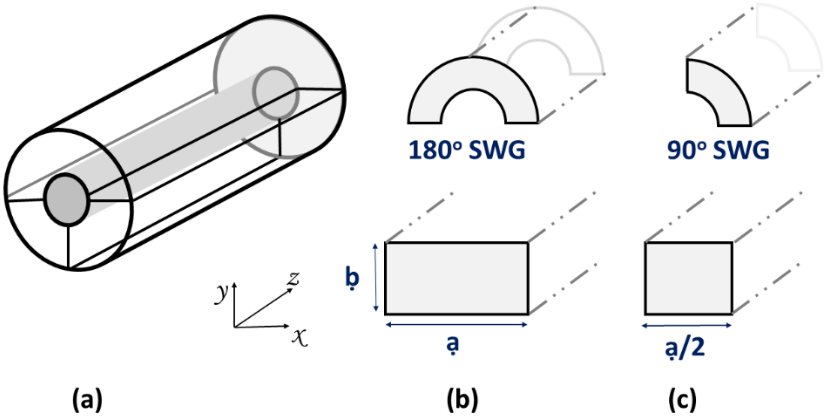

Figure 1.10. **(a)** A coaxial waveguide divided into three sectorial waveguides (SWG), **(b)** upper Semi-SWG: analogy with rectangular waveguide of width *ạ*, and **(c)** lower two quarter-SWG: analogy with rectangular waveguide of width *ạ/2*.

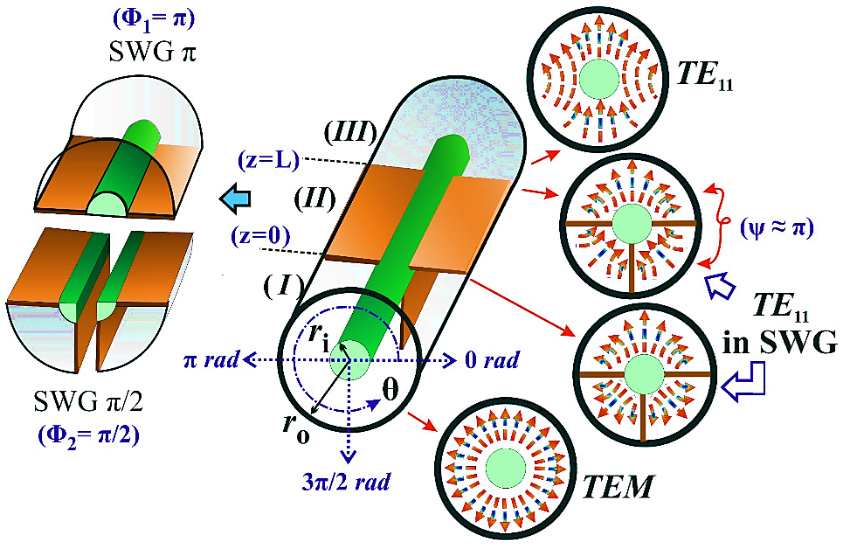

Figure 1.11. A typical model of SWG Mode Converter (*TEM* to TE_{11}) is shown at the centre. In right-hand side, its mode pattern is shown, according to its axial positions, keeping the upper half semi-circle field vector maximum outward. Left side figure shows the separation of coaxial waveguide to SWGs.

SWG mode converter is a linear metallic structure capable of handling high power microwave, along with high mode conversion efficiency. Figure 1.11, shows a typical *TEM* to TE_{11} SWG mode converter and is a fundamental part of the design. Here the coaxial guide is azimuthally divided using three axially-radial metallic plates, placed at angles 0, π and $3\pi/2$ rad, thus forming three SWGs of sectoral angles $\phi_1(=\pi)$, $\phi_2(=\pi/2)$, and $\phi_3(=\pi/2)$. These SWGs can be denoted as SWG_{π}, $SWG_{\pi/2}$ and $SWG_{\pi/2}$, respectively.

In the SWG mode converter (Figure 1.11), Region *I* is a coaxial structure, Region *II* contains three SWGs, and Region *III* is also a coaxial structure. At the axial input position of Region *II*, the electric field pattern gets separated by the three SWGs' sidewalls. Radial parameters (r_i and r_o) are chosen such that only TE_{11} mode propagates through SWGs and the higher modes get attenuated. Let the radial electric field expression could be expressed as follows

$$E_r^{(\pi)}\{\theta, z\} = E_0^{(\pi)} e^{-j\beta_1 z} \quad \text{for the } SWG_{\pi} \text{ and at } \theta = \pi/2 \text{ ,} \qquad (1.1)$$

$$E_r^{(\pi/2)}\{\theta, z\} = E_0^{(\pi/2)}\ e^{-j\beta_2 z} \quad \text{for the } SWG_{\pi/2} \text{ and at } \theta = \pi/4, \qquad (1.2)$$

where $E_0^{(\pi)}$ and $E_0^{(\pi/2)}$ are the amplitude of radial electric fields, also β_1 and β_2 are axial propagation constants of SWG_{π} and $SWG_{\pi/2}$ respectively. In the coaxial region, Region *I* (*TEM* mode), the electric fields at azimuthal position π/2 rad and 3π/2 rad must be in the opposite orientation. In SWG region, Region *II*, at the azimuthal position z = 0, radial electric fields become $E_0^{(\pi)}$ and $-E_0^{(\pi/2)}$. Length of SWG region (Region *II*) L is taken as the integral multiple of half wavelengths, i.e., $L = s\lambda_{g1}/2$ where, s is an integer and λ_{g1} is SWG_{π} wavelength for the TE_{11} mode. Thus, (1) becomes

$$E_r^{(\pi)}\{z\} = E_0^{(\pi)}\ e^{-j\pi s}, \qquad (1.3)$$

where $\pi s = \beta_1 L$. The sectoral angles $\phi_1 > \phi_2$, so the cut off frequencies of SWGs $f_{c1} < f_{c2}$. Thus, the radial propagation constants are $\gamma_{\pi} < \gamma_{\pi/2}$. Since

$\beta_{1,2} = [k_0^2 - \gamma_{\pi,\pi/2}^2]^{1/2}$ so the axial propagation constants are $\beta_1 > \beta_2$ and the guided wavelength $\lambda_{g1} < \lambda_{g2}$. The $SWG_{\pi/2}$, the same number of half waves, occur at smaller length. Therefore, a phase term is subtracted with the phase delay term (ψ) in the radial electric field expression as the following:

$$E_r^{(\pi/2)}\{z\} = E_0^{(\pi/2)}\, e^{-j(\pi s - \psi)} = E_0^{(\pi/2)}\, e^{-j(\beta_1 - \psi)}. \tag{1.4}$$

Although,

$$E_r^{(\pi/2)}\{z\} = E_0^{(\pi/2)}\, e^{-j\beta_2 L} \qquad \text{at} \quad z = L. \tag{1.5}$$

Thus from (1.4) and (1.5), a relation is obtained as

$$\psi = (\beta_1 - \beta_2)L. \tag{1.6}$$

The length of the axial metal plates in Region *II* chosen such that electric fields have π rad phase delay (ψ) between the azimuthal positions π/2 rad and 3π/2 rad. Now, the electric field of SWG_{π} and $SWG_{\pi/2}$ is in phase at the axial output position $(z = L)$ of Region *II*, which results in the field configuration like TE_{11} mode in Region *III*, as shown in Figure 1.11. Thus, in SWGs, Region *II*, at the azimuthal position $z = L$, radial electric fields become $E_0^{(\pi)}$ and $E_0^{(\pi/2)}$. Both radial electric field component is positive and shows that the same orientation field of SWGs is combining to form as a TE_{11} mode in the coaxial guide of Region *III*.

1.5 Objective of the Proposed Work:

Device designing is a complex process that extensively depends on system requirements, design format, and creativity. By analysing conceptual and practical issues with respect to the conventional design of SWG *TEM* to TE_{11} mode converter process of designing, design improvement and characterization are studied. As per the need of mode converter, the radiation pattern of azimuthally symmetrical modes (*TEM* or TM_{01}) has null at the axis of propagation. Therefore, such azimuthally symmetrical mode converted to TE_{11} mode, which is the dominant mode of the circular waveguide and having directivity at its axis of propagation. Mode converter having a bend or serpentine structures are not convenient to use in the HPM system, as they are nor aligned on the same axis. Mode converters based on axial discontinuity such as SWG mode converter also need attention towards RF beam stability at the output port. The purity of output mode decides the maximum radiated power should be at the axis of propagation or deflected from the axis. HPM is defined above from 100 MW microwave power and at such high power level breakdown of dielectric should be avoided by appropriate design. So the mode converter should be capable of handling at least 100 MW of microwave power. Our objective is to design and development the SWG mode converters for TM_{01} to TE_{11} mode, which meets the following requirements

- **Beam Stability:** Due to unwanted mode conversion, the output beam does not remain stable at the axis of propagation. So, the design should be as able to keep the directivity near the axis of propagation.
- **Power Handling Capability:** The design should be capable of operating with microwave power above than 100 MW, without any dielectric breakdown [xyz]. Higher power handling capability of mode converter supports their compatibility issues with various HPM sources.
- **Compactness:** The operation of the mode converter for a specific class or type exhibits high conversion efficiency with a compact design. SWG are axially aligned, so they are good in compactness; this feature increases the portability of the HPM system.
- **Low Weight:** In technical equipment lowering the weight increase the chance of portability. Low weight parts of HPM systems reduce energy consumption during

its transport. Also, the reduced weight of mode converter may compensate with cooling sub-system of HPM system.

1.6 Organisation of the Thesis:

In Chapter 1, an overview of the HPM system, including its key sub-system and working mechanism, is discussed. The various applications of the HPM system are discussed and found attractive in the area of defense, space, and the domestic industries have been swotted; and all such applications will contribute in the advancement of society. The basic working principle of various HPM sources are presented in brief, and their respective output modes are compared. The needs of RF mode converter in the HPM system are discussed and establishing its utility as an important sub-system. The operating principle of SWG mode converter is also swotted, and its analogy is discussed to visualize its operation. Using RF electric field expressions, a relation between phase delay, length of the sectoral region and axial propagation constants are established. Also, the objective of the proposed work is illustrated where the characteristics of beam stability, power handling capability, compactness, and weight are also discussed.

In Chapter 2, three classes of mode converters are described; state of the art of mode converter is also presented. The literature review is dedicated to exploring the analysis and designs of the RF mode converters to convert *TEM* or TM_{01} mode to TE_{11} mode. There is not much literature found for the required mode conversion using abrupt discontinuity. The designed based on gradual discontinuities are discussed which can converter TM_{01} mode to TE_{11} mode but are complex in design, non-compact and not axially aligned. In a class of axially aligned mode converter all metal SWG, dielectric loaded, Photonic Band Gap loaded, shorted inner conductor and folded SWG mode conductor are discussed extensively. The chapter is concluded with defining problems arising from state of the art and focused the research work of rigorously defining the design methodology, intensive study on beam study, the analytical examination on high power capability, characterization using mode matching technique (MMT) and development of lightweight, compact, High Power all metal SWG mode converter.

In Chapter 3, the design of conventional SWG mode converter is modified in the aspect of removing stubs that facilitates impedance matching. Also, the conventional design does not support beam stability, and this drawback got overcome by properly designed output end of the sectoral region; besides, this modification allows impedance matching too by optimizing a particular plate length. The reported design is capable of converting TM_{01} mode to TE_{11} mode in S-band having central frequency 3 GHz. Detail description of the design methodology of the SWG mode converter has discussed here. Furthermore, design development is discussed, and details of the experimental setup required for measurement of reflection loss and radiation pattern has presented. Analysis using simulation is also performed to show the issues of beam stability and establish the design supports beam stability by nullifying TE_{21} modes originated from SWGs to the coaxial waveguide and are positioned orthogonally. Also, the design is capable of operating at 1.25 GW microwave power level has tested using simulation and presented here.

In order to examine modes coupling at each junction of the SWG mode converter and to examine the performance of the mode converter device design performed and reported in Chapter 3, a rigorous study regarding the operation of mode converter is presented in Chapter 4. This chapter deals with mode matching technique (MMT) capable of calculating modal power coupling at each junction, having the advantage of fast simulation and more precise result. The chapter characterizes the SWG mode converter TM_{01} mode to TE_{11} mode using MMT and explains the steps of mode matching analysis. The MMT is used to determine the scattering coefficient for all excited modes in the system and in this analysis; the mode converter device structure is segmented at each of its discontinuity. One of the areas of application, which can significantly benefit from having an efficient analytical method, is designing and optimizing new SWG mode converters. The three major steps explained are an evaluation of fields constant, expressing coupling coefficients and obtaining generalised scattering matrix (GSM).

In Chapter 5, the development of TM_{01} to TE_{11} mode converter using circular sectoral waveguide (CSWG) is explained. Again, as reported in Chapter 3, the design proposed in Chapter 5 is capable of conversion of TM_{01} mode to TE_{11} mode in S-band for central frequency 3 GHz. Detail description of the design of the CSWG mode converter is also discussed here. The prime advantage of the CSWG mode converter over other axially aligned mode converter is the removal of the inner conductor in order to make it lightweight. The weight of the CSWG mode converter is 2.3 kg whereas equivalent performance SWG mode converter is 5.48 kg, this comparison validates that the CSWG mode converter is lightweight with respect to other SWGs. The design is capable of working on 0.5 GW without and electric breakdown inside mode converter. This CSWG mode converter able to transfer power more than 99% around central frequency, but suffers lower conversion efficiency 92.32% in comparison to 98.62% of SWG mode converter as per simulation results.

In Chapter 6, the works embodied in the present thesis are summarized. The conclusions and findings of the research work are described. The limitations of the present study are highlighted. Finally, the future scopes of the present research work are also outlined.