Chapter 1

Introduction

1.1 Gyrotron Overview

During the past sixty years, many different technologies have required high power sources of electromagnetic radiation, in various forms. Radio waves were easily produced from antennas, while lasers tend to be used for optical and infrared frequencies. Fusion reactors sparked the research on high-power microwave research (1 GHz to 300 GHz), which has also been fueled more recently by plasma diagnostic techniques and radar.

The gyrotron, or electron cyclotron maser, is unique in being likely to produce high megawatt power in the microwave and submillimeter spectrum. Conventional microwave devices, such as klystrons, require cavity dimensions on the order of one wavelength, so that a 30 GHz output would require a cavity of only one centimeter, severely limiting its ability to produce high power. Lasers can produce higher powers, but only at efficiencies of one or two percent. Gyrotrons, on the other hand, have theoretical efficiencies upwards of forty percent, making them the most attractive solution to high power at these frequencies [3,4,12].

The principles behind the operation of a gyrotron are simple. Essentially, a high-energy, annular electron beam is produced and sent down a hollow resonating cavity located in an intense magnetic field. The electrons travel down the tube, but the magnetic field also forces them to gyrate quickly in small orbits, making the electrons' total paths helical. These gyrations generate radiation inside the cavity, but tuning the electron beam and magnetic field properly will allow the frequency to match that of a particular normal mode in the cavity.

By matching these frequencies, the electrons will couple to the mode and began am-
plifying it, much like a small sound oscillation amplifies in an organ pipe. This coupling between the electron beam and the microwaves is vital; a weak coupling severely limits amplification of the microwaves and thereby denies the chance for high overall efficiency [11]. These microwaves finally travel down the cavity and into a waveguide that takes them to wherever the radiation is desired.

Of course, a number of complications must be overcome before a gyrotron is able to operate correctly. Strong coupling is dependent on certain electron beam parameters. Likewise, a little misalignment between various pieces can cause considerable loss in coupling and efficiency. Since electron beams operate only in very high vacuums, a window must be able to support an atmosphere of pressure while transmitting a megawatt of power with minimal reflection or absorption [3,10,12]. This last requirement forces the employment of microwave launchers and mirrors to send the radiation through the window, and more to recollimate it into a transmitting waveguide.

The electron beam must possess particular attributes for it to couple well to the microwaves. The radial size of the beam is one factor, and it has been found to follow theoretical predictions well. Another likely safe assumption is that the beam is monoenergetic, meaning every electron in the beam carries almost exactly the same kinetic energy as the others. Two other parameters are very important but more tenuous to blindly trust. The beam current density is hoped to be constant over the entire beam in order for the coupling strength to approach theoretical limits. Also, it is vital that all electrons have the same perpendicular velocity to parallel velocity ratio $\left( \alpha = \frac{v_\perp}{v_\parallel} = \frac{\beta_\perp}{\beta_\parallel} \right)$. If this velocity ratio varies much, then some electrons will move through the cavity quicker than others. Some parts of the beam are drifting behind other parts, preventing the beam from being coherent in terms of gyration phase (usually called "bunching") and therefore driving down the coupling efficiency [9,17].

1.2 Thesis Overview

This thesis project was conceived after many gyrotron electron guns were noted to give fairly poor, uneven outputs. As Chapter 2 implies, decent coupling between the electron beam energy and the microwave energy is dependent upon a uniform beam. Some measurements were taken to measure the current asymmetry of the beam, as described in Section A.1,