

PFC/JA-84-32

A HIGH FREQUENCY GYROTRON SCATTERING  
DIAGNOSTIC FOR INSTABILITY STUDIES ON TARA

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This work was supported by the U.S. Department of Energy Contract  
No. DE-AC02-78ET51013.

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Abstract

A 1 to 10kW, > 30ms pulsed, narrow linewidth (< 1MHz), 137GHz gyrotron is being fabricated for collective Thomson scattering plasma diagnostics on the TARA tandem mirror experiment. The drift cyclotron loss cone, the axial loss cone, harmonics of these instabilities, and the ion two stream instability in the TARA plugs will be studied with this diagnostic.



## Introduction

Recent developments in gyrotron technology have established the feasibility of applying gyrotrons to plasma diagnostics. These developments include high frequency operation over the range 100 to 500GHz [1,2] and demonstration of narrow linewidth, stable frequency output [3]. Together with the capability of long pulse/CW operation these gyrotron qualities make it an attractive source for plasma diagnostics wherever a high power millimeter/submillimeter wave source is required.

In particular, gyrotrons are ideal for collective Thomson scattering diagnostics to study instabilities, plasma waves, and ion temperature. Millimeter-wave scattering wavelengths are required to allow scattering angles large enough for both spatial and wavevector resolution for fluctuation wavelengths up to about several centimeters. At the same time high power levels are required at these frequencies to overcome plasma noise especially during RF heating. High power levels also would increase the sensitivity of the scattering system to lower fluctuation levels to fully investigate microinstability growth and allow less than optimum scattering angles to detect weak fluctuations.

In this paper we describe a 137GHz gyrotron scattering diagnostic system currently being fabricated for collective Thomson scattering diagnostics on the TARA tandem mirror experiment. The main goal of this diagnostic will be to study instability driven ion density fluctuations in the TARA plugs. Up to now most mirror fluctuation studies have been done with wire probes at the plasma edge. This gyrotron scattering diagnostic will allow direct measurement of fluctuations internal to the plasma.

### Mirror Instabilities

For conventional scattering diagnostics the fluctuation wavelengths accessible to spatially resolved measurement are determined by the Bragg condition:

$$k = (4\pi/\lambda_1) \sin(\theta/2) \quad (1)$$

where  $k$  is the fluctuation wavenumber,  $\lambda_1$  is the scattering source wavelength, and  $\theta$  is the scattering angle. With a 137GHz source and scattering angles greater than  $1^\circ$  fluctuation wavenumbers greater than  $0.5 \text{ cm}^{-1}$  will be measured. There are several mirror instabilities of importance which drive ion density fluctuations with wavenumbers on the order of  $1 \text{ cm}^{-1}$ . These instabilities are the drift cyclotron loss cone (DCLC), the axial loss cone (ALC), harmonics of the DCLC and ALC, and the ion two stream instability.

The DCLC instability has been observed in the mirror experiments 2XIIB [4] and TMX-U [5]. It is driven by the ion loss cone and requires a radial electron density gradient. The fluctuation frequency is at approximately the ion cyclotron frequency and the wavenumber perpendicular to the magnetic field satisfies the condition  $k_\perp \rho_1 \approx 2$  to 5 where  $\rho_1$  is the ion gyroradius. In TARA, the DCLC fluctuations are expected to be at a frequency  $\sim 7\text{MHz}$  and  $k_\perp \approx 1\text{-}3\text{cm}^{-1}$  for a deuterium plasma at the initial scattering location in the plug.

The ALC instability has similar frequency and  $k_\perp$  values as the DCLC but does not require a density gradient and has a phase velocity in either the ion or electron diamagnetic directions. The DCLC phase velocity is in the ion diamagnetic direction.

The gyrotron scattering diagnostic will be ideally suited to

scattering from harmonics of the DCLC and ALC because the fluctuation frequency and wavenumber scale with harmonic number. Higher fluctuation frequencies relax the requirements on gyrotron linewidth and beam dump efficiencies, while larger wavenumbers correspond to larger scattering angles (Eq. 1) and improved spacial resolution.

The ion two stream instability may occur in thermal barriers if ion pumping is very efficient. It is purely growing and has  $\gamma \approx 0.1\omega_{pi}$ . The wavevector is parallel to the magnetic field and has a value of 0.1 to  $0.3\lambda_{Di}^{-1}$  where  $\lambda_{Di}$  is the ion Debye length. Typically  $k_{\parallel} \approx 10 \text{ cm}^{-1}$ .

Another fluctuation of interest to scatter from, though not an instability, is the electron plasma wave. It has been shown [6] that the hot electrons in the thermal barrier will enhance the electron plasma wave at the cold electron density. By measuring cold electron density by scattering as a function of position along the mirror axis the location of the potential dip can be determined, an important parameter.

### The Gyrotron

The gyrotron designed for the diagnostics application is shown in Fig. 1. It is a lower power, longer pulse version of an earlier 140GHz gyrotron experiment at MIT [1]. Operation in the  $TE_{03}$  mode is chosen for ease of mode conversion of an axisymmetric mode. Output power will be in the range 1-10kW in pulse lengths over 30 ms. The linewidth is expected to be less than 1 MHz FWHM.

The electron gun is a lower current version of Varian model number VUW-8140, a non laminar flow magnetron injection gun [7]. The nominal beam voltage is 65kV and beam current will be in the range

0.1 to 0.5A. A Spellman high frequency power supply will be used to power this gun with a maximum voltage ripple of 35V rms at 70kV and a maximum stored energy in the filter capacitor of 20 Joules. The voltage ripple specification was determined by the narrow linewidth requirement and measured gyrotron voltage frequency pulling [3].

The superconducting magnet supplied by American Magnetics will have a peak field capability of 65kG in a 6 inch room temperature bore. The two coils in this magnet can be used to provide a field homogeneity of .01% over a 1.5 inch length along the center of the magnetic axis or a field gradient of up to 4% per inch at a central field corresponding to 140GHz operation. A room temperature copper gun coil was chosen to keep the superconducting magnet costs low and to minimize the number of leads into the dewar to maximize liquid helium hold time.

High Q resonator cavities with diffractive Q's of 6,000 to 9,000 will be used to maximize efficiency. The ohmic Q will limit the maximum useful diffractive Q. Calculations show the gyrotron efficiency will be about 15% at 1kW power levels increasing to about 30% at 10kW. For pulse lengths of 30ms and pulse rates less than 1Hz calculations show cooling of the cavity will not be needed, but a water cooling jacket for the collector waveguide will be used.

### The Scattering System

A block diagram of the overall scattering system is shown in Fig. 2. Following the gyrotron a set of cylindrical oversized waveguide mode converters have been designed for conversion of the TE<sub>03</sub> gyrotron output into the TE<sub>11</sub> mode. Part of the reason for the

choice of 0.5 inch diameter for the gyrotron output guide was determined by the optimal maximum diameter for the  $TE_{03}$  to  $TE_{02}$  and  $TE_{02}$  to  $TE_{01}$  axisymmetric ripple converters. A snake like wriggle converter is used for  $TE_{01}$  to  $TE_{11}$  conversion. Calculated overall conversion efficiency for this mode converter set is 93% including ohmic losses.

The use of corrugated waveguide for bends, converters, and horns is impractical at 140GHz because of the smallness of the dimensions. Consequently the  $TE_{11}$  mode will be launched by a stepped guide and/or horn and quasi optically transmitted to TARA.

A beam dump and viewing dump are important elements of the scattering system to minimize stray gyrotron radiation from overcoming weak signal levels. These dumps will be placed inside the vacuum chamber and have a structure for trapping electromagnetic radiation. Similar dumps have been designed for use in a tokamak to trap submillimeter radiation. [8]

A heterodyne receiver will be used to detect the scattered signals. Actually, it is planned to use several receivers to map out the fluctuations as a function of wavenumber and position. Commercially available Schottky barrier diode mixers at 140GHz can achieve system noise temperatures of less than 3000K double side band. The local oscillator (LO) signal will be provided by a frequency tripled gun oscillator using a Millitech model MU3W20 frequency multiplier. By using a superheterodyne frequency tracking circuit in the receiver [9] very narrow effective scattering linewidths can be achieved and precise frequency stabilization of the LO relative to the gyrotron will not be required.

The signal will be analyzed with a spectrum analyzer as shown in



Fig. 2, or a transient digitizer or simple filter bank can be used depending on the frequency and time resolution required.

### Conclusions

Gyrotrons with the capabilities in frequency, linewidth, output power, and pulse length described here make excellent sources for collective Thomson scattering plasma diagnostics. There are a number of instability driven fluctuations of importance in tandem mirror experiments as well as in tokamaks. In this paper we have described a gyrotron scattering diagnostic under construction for the TARA tandem mirror. A similar diagnostic system could be fabricated for a tokamak using a higher frequency gyrotron operating in the submillimeter wavelength range. Gyrotrons may also be very useful in making possible interferometry/polarimetry and heterodyne ECE measurements over a very large number of cords.

Supported by U.S.D.O.E.

Figure Captions

1. Preliminary design of the major elements of the diagnostics gyrotron.
2. Simplified block diagram of the gyrotron scattering diagnostic system.

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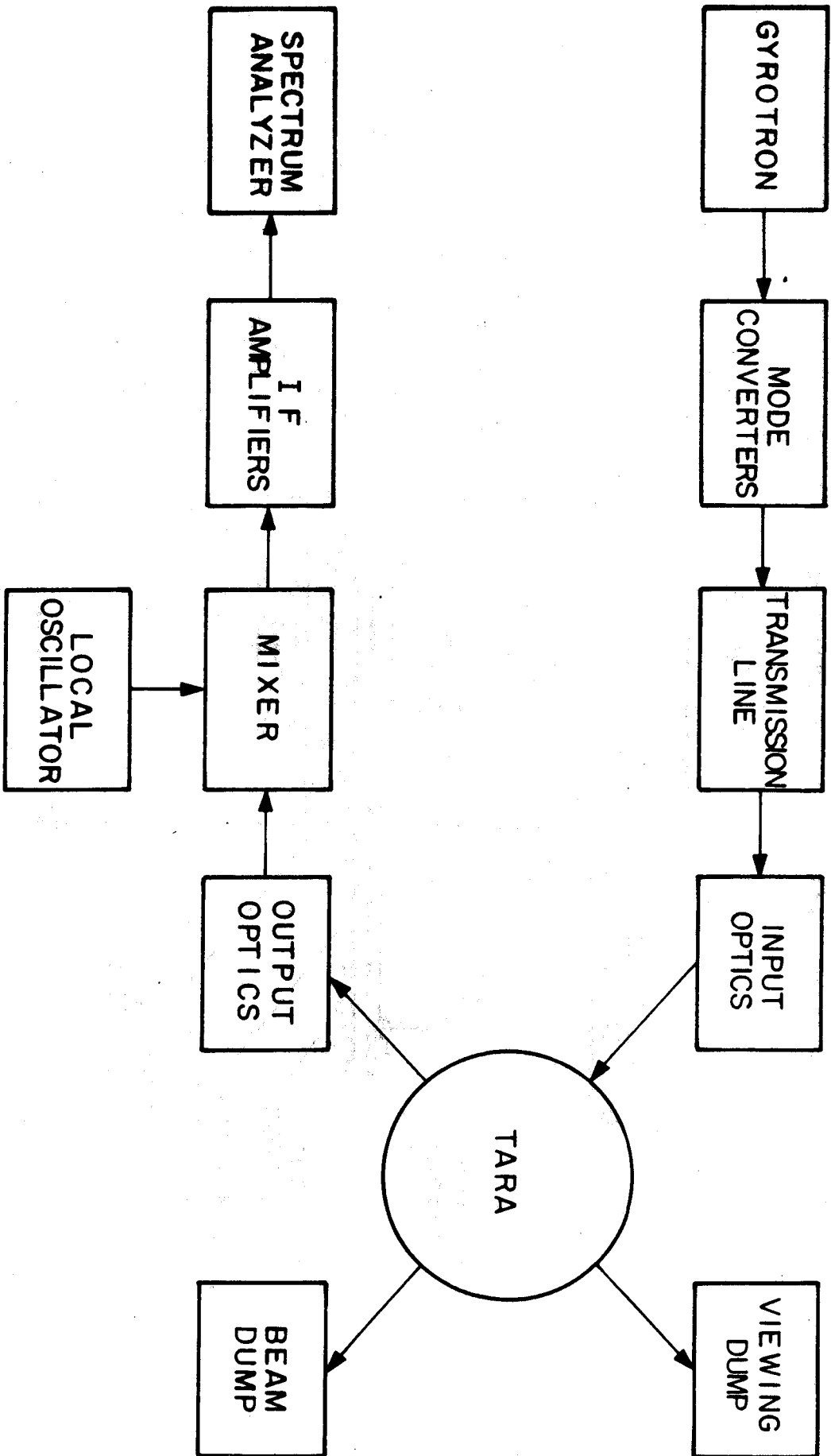


Fig. 2

# 140 GHz DIAGNOSTICS GYROTRON

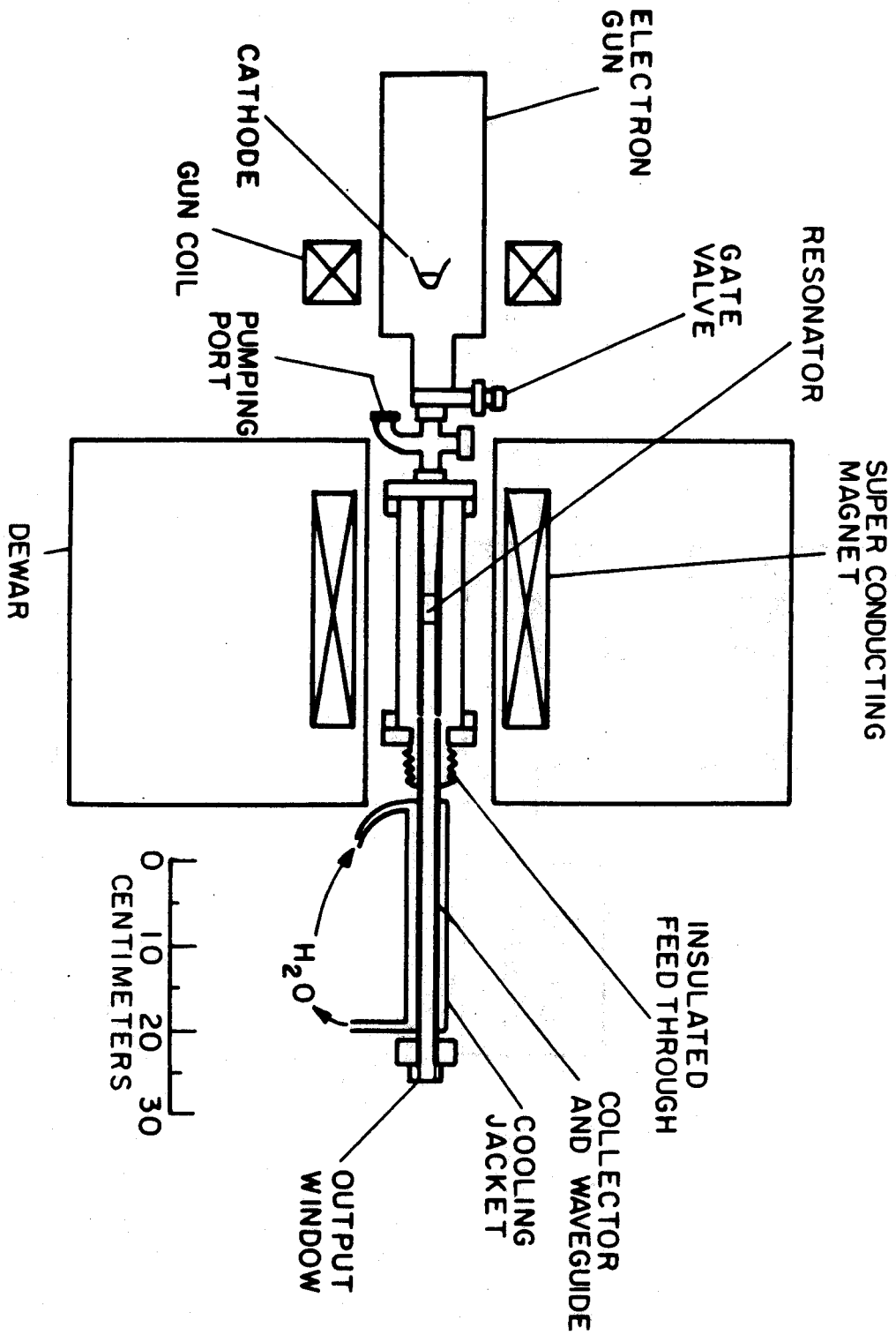


Fig. 1