UCRL--93883

DE86 008022

Improved System for Perpendicular Electron-Cyclotron Emission Measurements on TMX-Upgrade

C. J. Lasnier and R. F. Ellis, University of Maryland,

R. A. James, Lawrence Livermore National Laboratory.

ABSTRACT

Improved System for Perpendicular Electron-Cyclotron Emission Measurements on TMX-Upgrade.* C. J. Lasnier and R. F. Ellis, University of Maryland, R. A. James, Lawrence Livermore National Laboratory - Perpendicular electron-cyclotron emission (PECE) is used on TMX-U to diagnose thermal-barrier hot electrons (T_H - 100 to 400 keV); yielding the time history of the temperature of these relativistic electrons. We describe an improved quasi-optical viewing system for these measurements that uses high sensitivity superheterodyne receivers at fixed frequencies of 60, 98, 130, and 196 GHz. The improved viewing and transport system consists of an off-axis ellipsoidal mirror that images the plasma onto a V-band conical collection horn, an overmoded circular waveguide (7/8" diam) that transports the radiation outside the vacuum vessel where the polarization is selected, and a high absorptivity Macor beam dump to prevent internal wall reflections from entering the viewing system. A relativistic code is used to calculate optically thin PECE signals from relativistic electrons for various energy and pitch angle distributions.
*Work performed by LLNL for USDOE under contract W-7405-Eng-48.

I. Introduction

Electron Cyclotron Emission propagating perpendicular to the axial magnetic field (PECE) is used to diagnose the hot electrons in the thermal barrier region of TMX-U. Radiation is detected at 60 GHz (ω/ω_c = 4.29), 98 GHz (ω/ω_c = 7), and soon will be monitored at 130 GHz (ω/ω_c = 9.29) and 195 GHz (ω/ω_c = 13.93). The plasma is optically thin at all these frequencies. By combining measurements at two frequencies for which the plasma is optically thin, the time history of the hot electron temperature may be extracted (James, Lasnier, Ellis, these proceedings).[1]

II. Minimizing Reflections

In order to analyze optically thin emission data, the signal component due to radiation reflected from the wall of the vacuum vessel must be considered. Since the amount of reflected radiation is difficult to quantify, the most desirable course is to eliminate the reflections, simplifying the analysis. The system being installed on TMX-U accomplishes this by means of (quasi-optical) focusing optics and a microwave beam dump, as shown in Figure 1. The radiation is transported out of the vessel by 7/8" circular waveguide.

The beam pattern of the conical V-Band receiving horn (fundamental mode at 60 GHz) is focused by an ellipsoidal reflector onto an absorbing medium which constitutes a beam dump. The plasma lies between the beam dump and reflector. The only radiation which can enter the horn is that which originates within the boundaries of the beam patterns shown in Figure 1. Any wall reflections striking the mirror are reflected away from the horn, and any reflected radiation striking the beam dump is absorbed.

III. Design of the Optics

A. Mirror - Gaussian beam optics theory [2,3] is used to match the beam dump diameter and mirror shape to the beam pattern of the horn. The mirror is a section of an ellipse in the cross section shown in Figure 1. The cross section in a horizontal plane is an arc of a circle, so that the surface of the mirror may be obtained by rotating the appropriate ellipse about its major axis. The ellipse is chosen so that one focus lies on the center line of beam dump and the other focus lies on the center line of the horn. The center line of the beam dump intersects the center line of the horn at the mirror surface. The elliptical section is chosen to give a beam diameter smaller than the absorber at the position of the beam dump. The mirror shape was chosen by using the formulas in references 2 and 3.

B. Beam Dump - The beam dump is fabricated of Macor, with triangular grooves machined into the surface. The principle (in the ray-optics limit) is the same as for the triangular baffles used in anechoic chambers. Radiation strikes the side of a groove and is reflected into the groove, where it suffers multiple reflections. The wave is attenuated on reflection and the radiation will be absorbed after several reflections. Bench trials indicate absorption efficiency of greater than 90%. In all cases the absorption was equal to or better than Eccosorb AN72. The width of the grooves is chosen large enough that the spacing between the tops of the grooves is several wavelengths. The spacing chosen here was 1/2".

IV. Code Results

A. The Code - As explained in reference 1, the emission coefficients at the observation frequencies must be calculated from theory, in order to obtain the hot electron temperature. This was done by numerically integrating the Schott-Trubnikov formula[4] weighted by the distribution function, along the resonance curve for each contributing harmonic and summing over the harmonics. This code was originally constructed by C. M. Celata and subsequently modified by A. Murdock.

B. Emission Coefficients as a function of Temperature - Shown in

Figure 2 are plots of emission coefficient (divided by density) as a function of temperature for 60, 98, 130, and 196 GHz (f_{ce}= 14 GHz). The distribution is a Maxwellian truncated at a pitch angle of 45° used as a model of a loss cone.

C. Emission Coefficient as a function of Loss Cone Angle - The truncated Maxwellian mentioned above was selected to model the anistropic electron distribution resulting from electron cyclotron heating in TMX-U. The anisotropy parameter is the loss cone angle. Figure 3 shows emission coefficient divided by density, versus loss cone angle, for 60 GHz and 195 GHz. Notice the overall increase in emission with higher loss cone angle. The number of particles is being held fixed, but the average perpendicular energy is increasing.

D. Emission from a Distribution with a High Energy Tail - Electron cyclotron resonance heating on TMX-U creates an electron distribution which is not only anisotropic, but has some non-Maxwellian energy dependence. The effect on electron cyclotron emission has been investigated in the code by using a two-component distribution.

The first component is Maxwellian. The second component is a high energy tail which falls off as the inverse of the electron kinetic energy. This tail is limited to kinetic energies between 150 keV and 765 keV. Both components are isotropic.

In Figure 4, the total emission coefficient is plotted versus the fraction of total electron density residing in the tail. It is seen that the emission increases linearly with the tail fraction. This is not surprising, since in the single-particle limit where the calculation is valid, the emission coefficient of each component is linear with the density of that component, and the total emission coefficient is simply the sum of the individual coefficients.

V. Conclusion

The quasi-optical focusing system and Macor beam dump to be used for viewing perpendicular electron cyclotron emission on TMX-U will reduce the wall reflections which ordinarily contaminate optically thin emission.

Emission coefficients as a function of temperature have been calculated (Figure 2) for several frequencies in order to facilitate the calculation of hot electron temperature from measurements at two optically thin frequencies. The dependence of emission coefficient on anisotropy (loss cone angle) has been illustrated in Figure 3. In Figure 4, evidence is presented that the presence of a strong non-Maxwellian character to the electron energy distribution can prevent the measurement of a bulk temperature.

Captions

Figure 1 Anti-reflection optics for perpendicular emission in TMX-U. The beam dump prevents wall reflections from entering the horn.

Figure 2 Emission coefficient per unit density versus temperature at 60, 98, 130, and 195 GHz ($f_{ce} = 14$ GHz). A 45° loss cone is incorporated.

Figure 3 Emission coefficient per unit density versus loss cone angle at 60 GHz and 195 GHz ($\omega_c = 14$ GHz). The temperature of the full Maxwellian is 100 keV. The number of particles is held fixed as the loss cone angle increases.

Figure 4 Emission coefficient per unit total density versus tail fraction. One component is an isotropic Maxwellian with a temperature of 100 keV. The other component is a 1/(kinetic energy) tail between 150 keV and 765 keV.

References

1. R. A. James, C. J. Lasnier, and R. F. Ellis, these proceedings.
2. H. Kogelnik and T. Li, Proc. IEEE 54, no. 10 1312 (1966).
3. P. F. Goldsmith, Edited by K. J. Button, Infrared and Millimeter Waves (Academic Press, New York, 1982), Vol. 6, p.291.
4. B. A. Trubnikov, Ph.D. Thesis, Moscow Institute of Engineering and Physics, U.S.S.R. (1958); U.S.A.E.C. Tech. Inf. Service AEC-TR-4073 (1960).

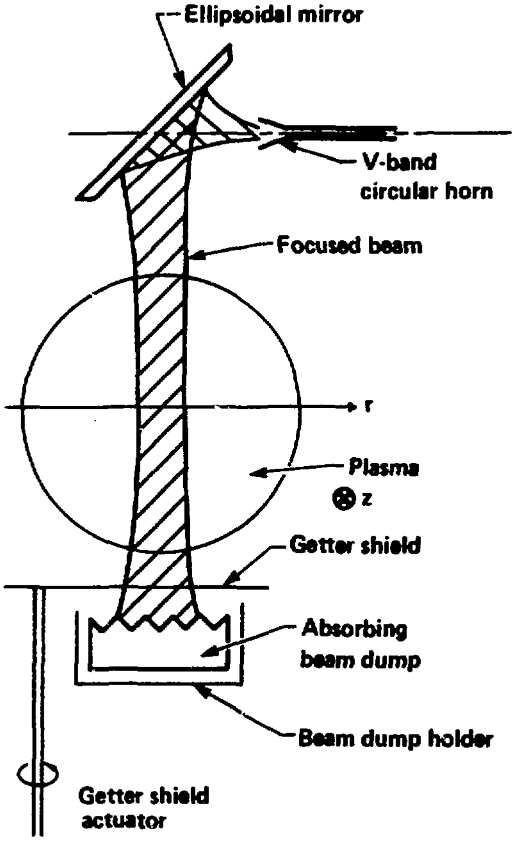
Ellipsoidal mirror
V-band
circular horn
Focused beam
r
Plasma
z
Getter shield
Absorbing
beam dump
Beam dump holder
Getter shield
actuator

FIGURE 1

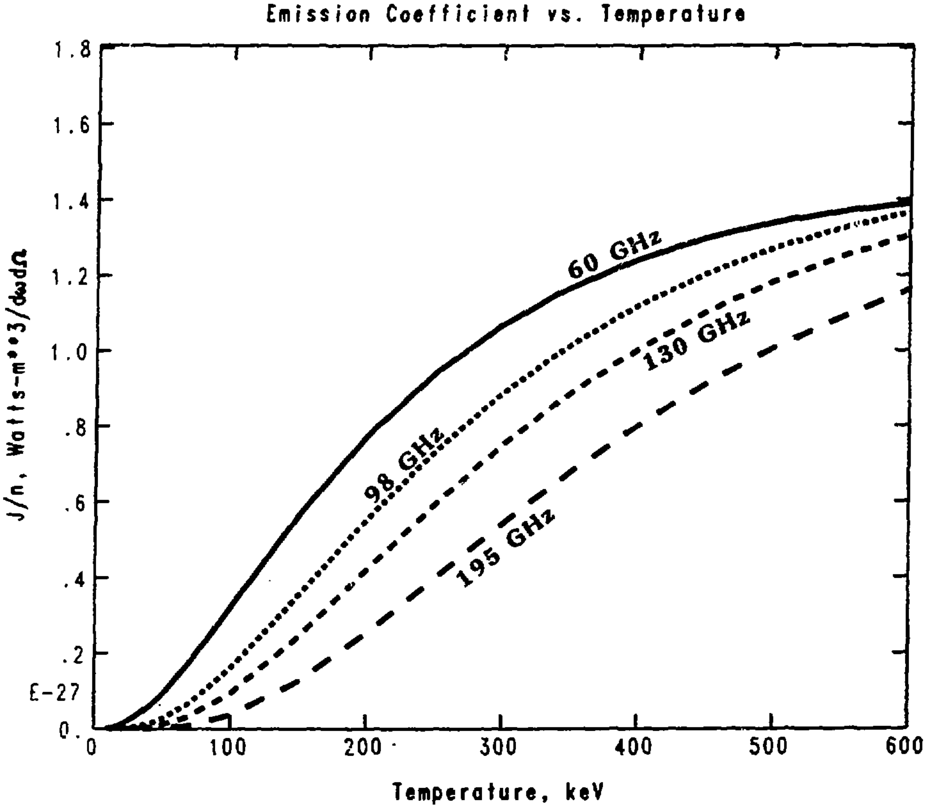
Emission Coefficient vs. Temperature
J/n, Watts-m**3/dωdΩ
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
E-27
0.
0
100
200
300
400
500
600
Temperature, keV
60 GHz
98 GHz
130 GHz
195 GHz

FIGURE 2

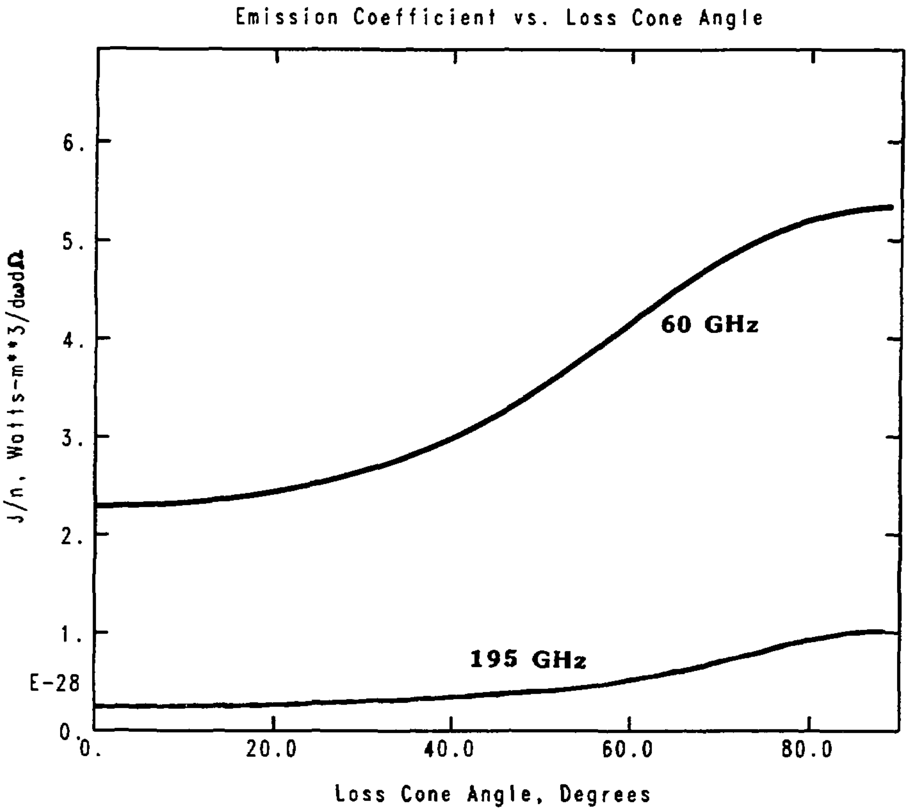
Emission Coefficient vs. Loss Cone Angle
J/n, Watts-m**3/dωdΩ
6.
5.
4.
3.
2.
1.
E-28
0.
0.
20.0
40.0
60.0
80.0
Loss Cone Angle, Degrees
60 GHz
195 GHz

FIGURE 3

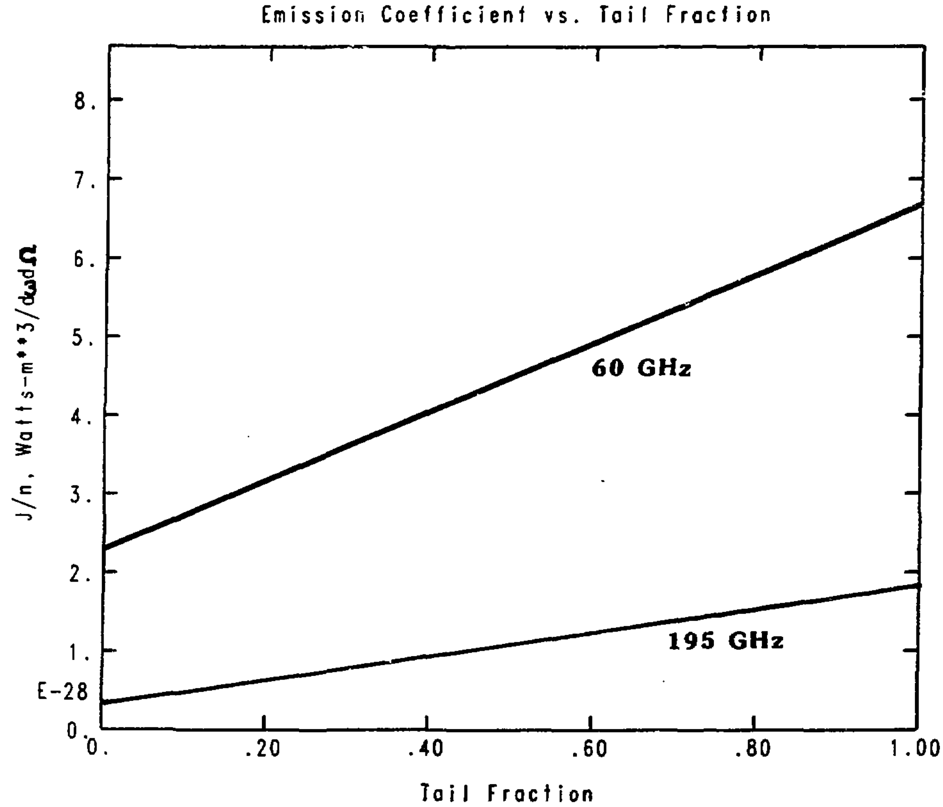
Emission Coefficient vs. Tail Fraction
J/n, Watts-m**3/dωdΩ
8.
7.
6.
5.
4.
3.
2.
1.
E-28
0
0.
.20
.40
.60
.80
1.00
Tail Fraction
60 GHz
195 GHz

FIGURE 4