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13. ABSTRACT (Maximum 200 words)

Under the sponsorship of the Air Force Office of Scientific Research Profs. Min-Chang Lee and Ronald R. Parker's research team has conducted experimental studies of anomalous absorption of radio waves in turbulent magnetized plasmas. This research program includes laboratory experiments with the newly constructed Versatile Toroidal Facility (VTF) at the MIT Plasma Fusion Center and the field experiments using orbiting satellites and ground-based radars at Arecibo, Puerto Rico. The design and construction of the Versatile Toroidal Facility involved five graduate students and twenty-two UROP (Undergraduate Research Opportunity Program) students. This student-oriented project was reported in the 1991 March 6 issue of the MIT Tech Talk. The detailed documentation and discussions of this VTF plasma device are presented in the M.S. theses of Robert F. Duraski (1991) and Chan Yoo (1991). Attached are the abstracts of these two graduate theses.

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Progress Report on Sponsored Research in "Microwave Propagation and Attenuation in Magnetoplasmas" under Grant, AFOSR-90-0263, for the Period of 1 June 1990 Through 31 August 1991

Prepared by Prof. Min-Chang Lee

Principal Investigator

Under the sponsorship of the Air Force Office of Scientific Research, Profs. Min-Chang Lee and Ronald R. Parker's research team has conducted experimental studies of anomalous absorption of radio waves in turbulent magnetized plasmas. This research program includes laboratory experiments with the newly constructed Versatile Toroidal Facility (VTF) at the MIT Plasma Fusion Center and the field experiments using orbiting satellites and ground-based radars at Arecibo, Puerto Rico. The design and construction of the Versatile Toroidal Facility involved five graduate students and twenty-two UROP (Undergraduate Research Opportunity Program) students. This student-oriented project was reported in the 1991 March 6 issue of the MIT Tech Talk. The detailed documentation and discussions of this VTF plasma device are presented in the M.S. theses of Robert F. Duraski (1991) and Chan Yoo (1991). Attached are the abstracts of these two graduate theses.

The primary mechanisms under investigation are the nonlinear mode conversion and turbulent scattering processes, which can effectively cause the attenuation of electromagnetic waves in turbulent magnetoplasmas. Both processes occur when the electromagnetic waves are scattered off the plasma density fluctuations (i.e., the plasma turbulence). While the turbulent scattering process weakens the incident wave by isotropizing the wave energy, the nonlinear mode conversion process renders the change of electromagnetic waves into electrostatic waves, leading to the absorption of waves in the turbulent magnetoplasmas. In the laboratory experiments, the plasma turbulence appears inherently with the ECRH (electron cyclotron resonance heating) plasmas generated by the Versatile Toroidal Facility (VTF). The VTF device produces a large turbulent plasmas embedded in a toroidal field. By contrast, the turbulent plasmas in the ionosphere can be favorably generated by a ground-based HF heating facility. This RF-produced ionospheric plasma turbulence has a broad range of scale lengths, which can affect the radio wave propagation in a broadband of frequencies.

The laboratory experiments have been centered on the investigation of the effect of plasma turbulence on the electron cyclotron resonance absorption of microwaves. Two graduate students, Daniel T. Moriarty and Masanori Onozuka are currently working on these problems. The results indicate that the waves can be further attenuated during the el ron cyclotron resonance absorption in the presence of plasma turbulence. Radar cloaking experiments were conducted at Arecibo, Puerto Rico recently. Illustrated in Figure 1 is the scenario of the plasma cloaking experiments. The ionospheric plasma turbulence was artificially created by the ground-based HF heater which injected high-power o-mode waves continuously for, at least, ten minutes or so. The diagnostic radio signals, launched subsequently from the ground-based VHF/UHF radars, propagating through the turbulent plasmas and then were bounced back from an orbiting satellite. Displayed in Figure 2 is the reflected radar signals from a spherical satellite recorded in our experiments which were carried out on July 18, 1991 around 12:41 AM at Arecibo, Puerto Rico. Two graduate students, Karen L. Koh and Kenneth D. Vilece participated in these experiments and have been analyzing the data.

Unexpected phenomena were also seen in our plasma cloaking experiments. They are the detection of (1) frequency-upshifted wave modes as shown in Figure 3 and (2) the speculated particle precipitation from the radiation belts (see Figure 4) which causes anomalous ionization/plasma modes in the lower ionosphere and give rise to intense radar backscatter echoes. We believe that nonlinear scattering of the pump wave off lower hybrid waves is responsible for the generation of anti-Stokes (frequency-upshifted) modes.

Artificial ionospheric plasma ducts were probably created in our experiments which guided the VLF waves injected from a nearby transmitter to propagate from the lower atmosphere into the radiation belts, causing pitch angle-scattering of energetic electrons and resulting in particle precipitation. These problems are currently under investigation.

Some of our research results have been presented in technical articles, conference papers, and graduate students' theses as listed below:

(1) Experimental study of nonlinear electromagnetic propagation and interaction with turbulent magnetized plasmas, by M.C. Lee and S.P. Kuo, IEEE International Conference on Plasma Science, Williamsburg, Virginia, June 3-5, 1991.

(2) Microwave propagation and attenuation in magnetoplasmas, by D.T. Moriarty, K.D. Vilece, M. Onozuka, R.F. Duraski, C. Yoo, and M.C. Lee, IEEE International Conference on Plasma Science, Williamsburg, Virginia, June 3-5, 1991.

(3) Laboratory simulation of anomalous absorption of radio waves in space with the Versatile Toroidal Facility (VTF), by M.C. Lee, R.F. Duraski, M. Gaudreau, S.C. Luckhardt, D.T. Moriarty, and R.R. Parker, American Physical Society Annual Meeting of the Division of Plasma Physics, Tampa, Florida, November 4-8, 1991.

(4) A mechanism responsible for the observation of symmetric lower hybrid sidebands and a low frequency mode in the upper ionosphere, by Y.R. Dalkir, M.C. Lee, K.M. Groves, and S.P. Kuo, submitted to Journal of Geophysical Research, 1991.

(5) Design and construction of the Versatile Toroidal Facility for ionospheric chamber research, by R.F. Duraski, M.S. Thesis, Department of Nuclear Engineering, MIT, 1991.

(6) Plasma confinement optimization of the Versatile Toroidal Facility for ionospheric plasma simulation experiments, by C. Yoo, M.S. Thesis, Department of Nuclear Engineering, MIT, 1991.

(7) Anomalous absorption of electromagnetic waves in turbulent magnetoplasmas, by M. Onozuka, M.S. Thesis Prospectus, Department of Nuclear Engineering, MIT, to be accomplished in 1992.

(8) X and O mode absorption in VTF magnetoplasma, by D.T. Moriarty, M.S. Thesis Prospectus, Department of Nuclear Engineering, MIT, to be accomplished in 1992.

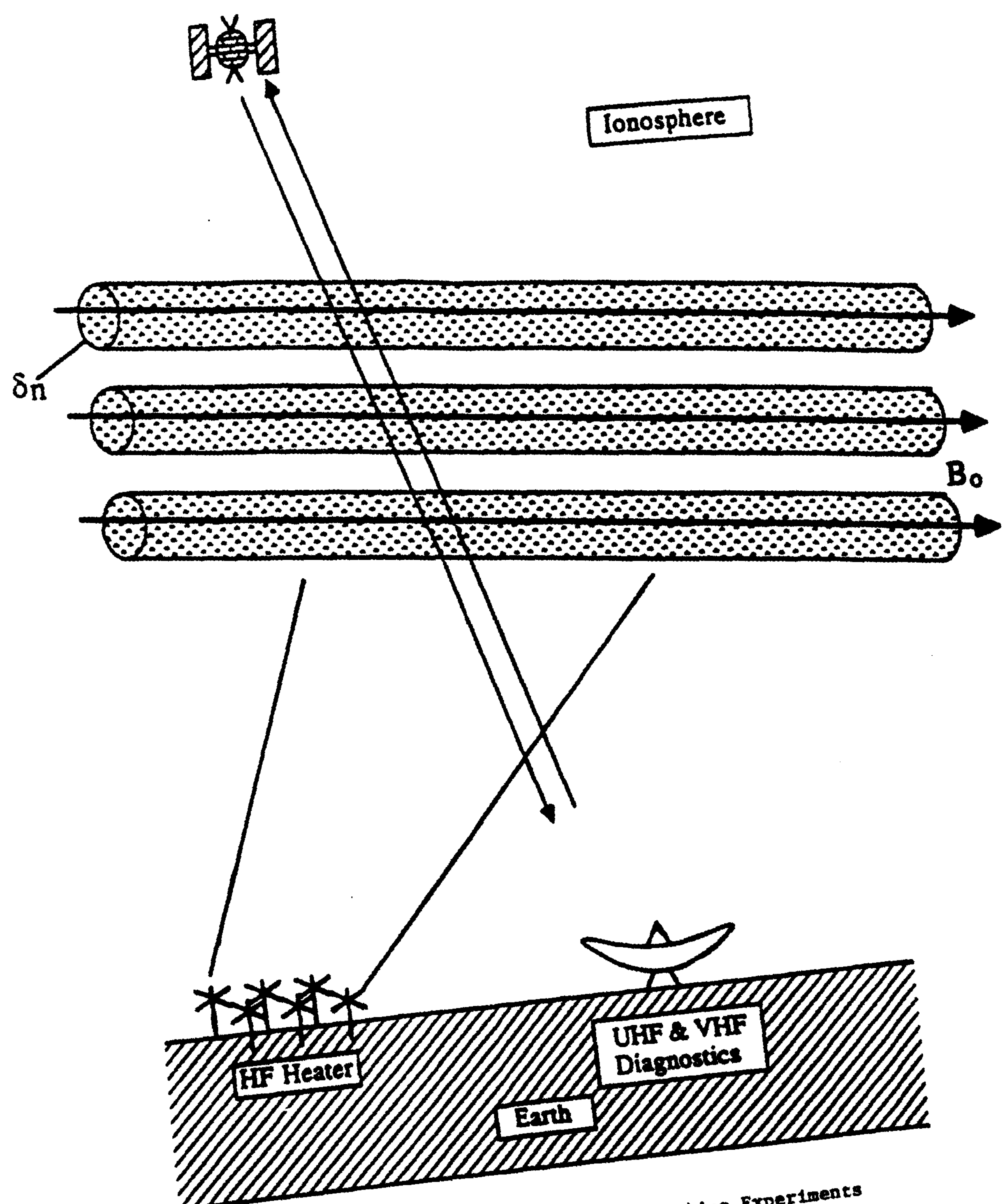

Figure 1. Illustration of Radar Cloaking Experiments at Arecibo, Puerto Rico.

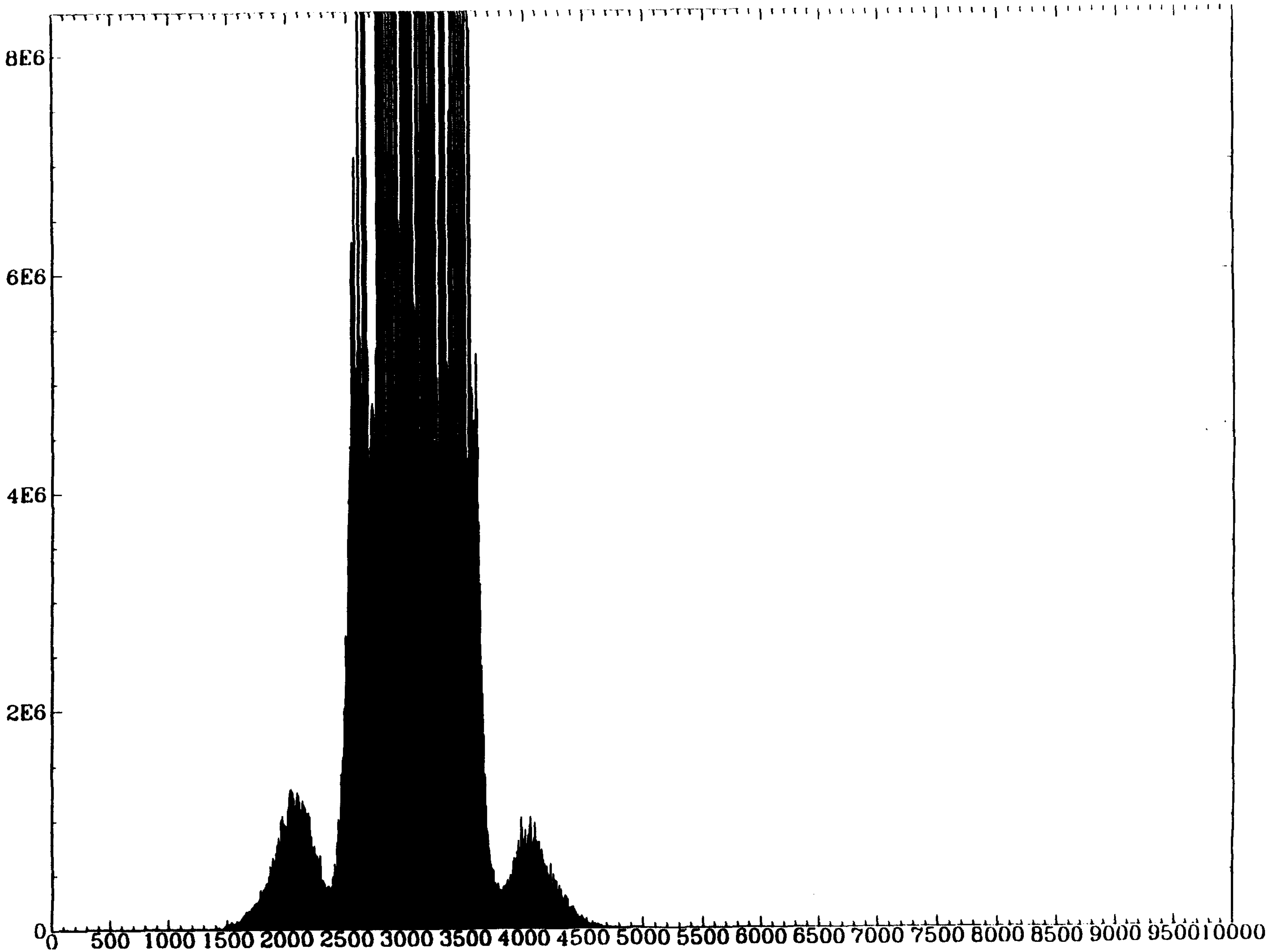

Figure 2. Radar signals reflected from a spherical satellite at Arecibo [illegible] 1991

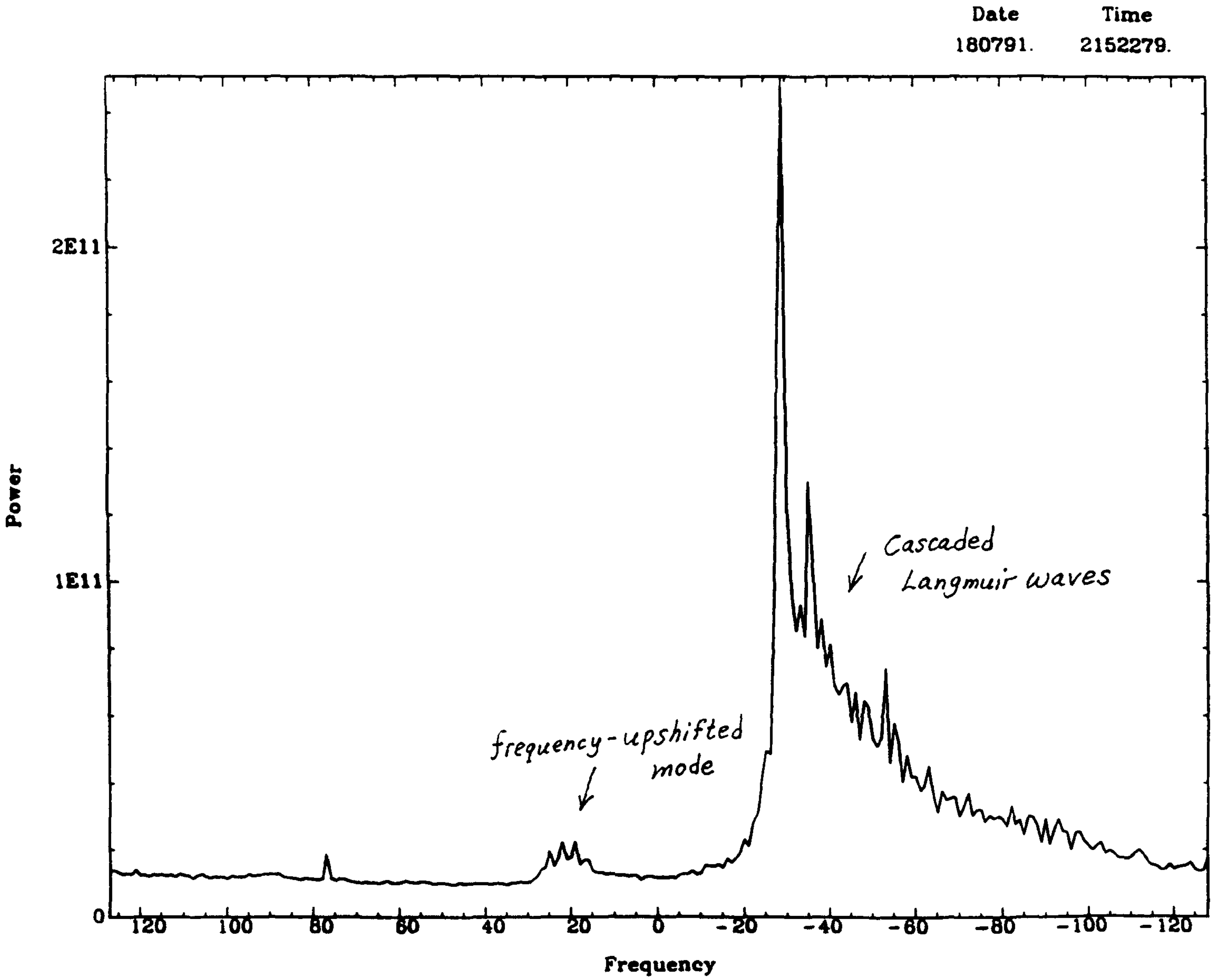

Figure 3.

Anti-Stokes Langmuir Mode - 18 July 91, Heater at 7.4 MHz

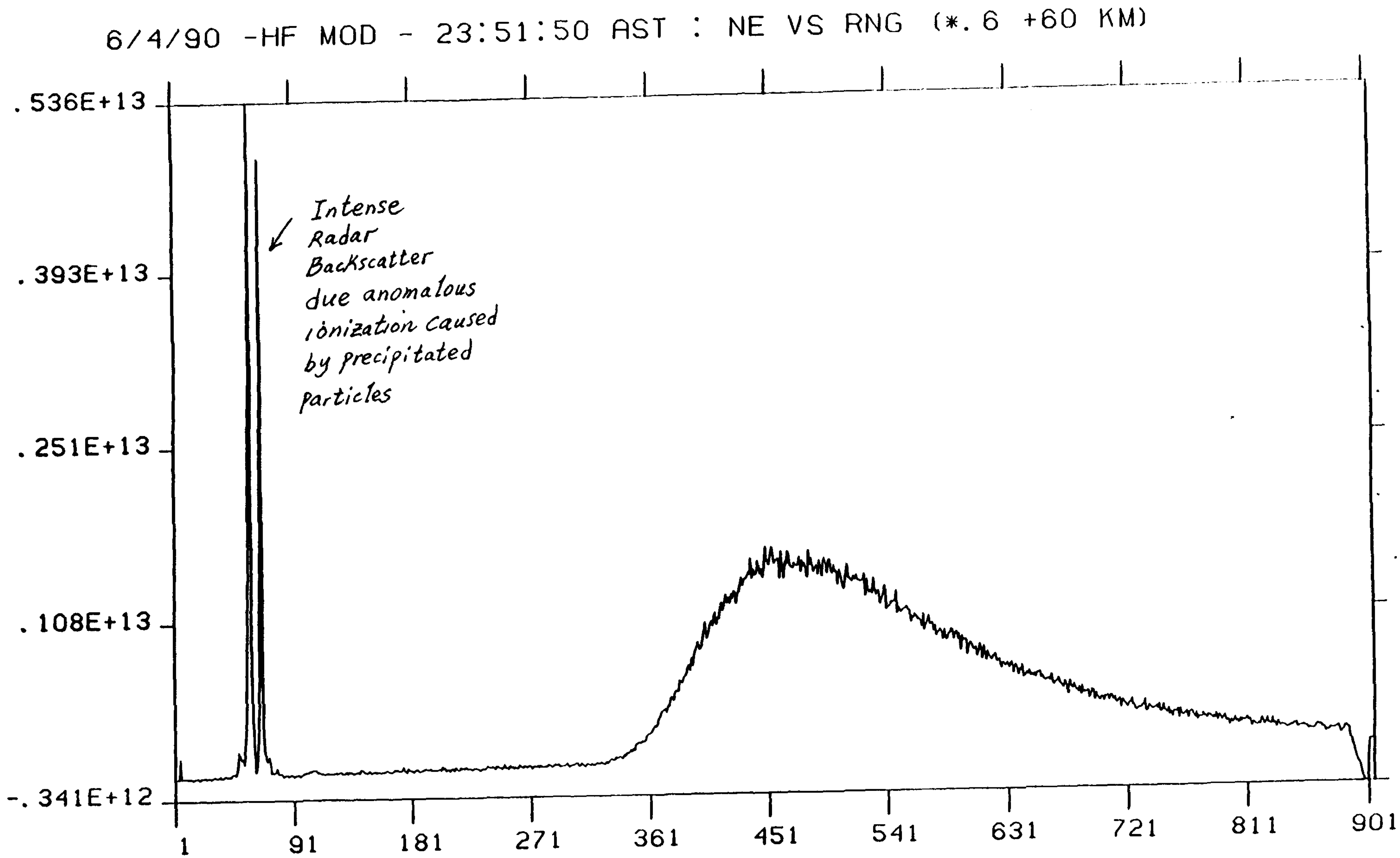

Figure 4. A 430 MHz radar power profile of the ionosphere recorded at the Arecibo Observatory during experiments on June 4, 1990 (Lee et al., 199).

Plasma Confinement Optimization of the Versatile Toroidal Facility for Ionospheric Plasma Simulation Experiments

by

Chan Yoo

Submitted to the Department of Nuclear Engineering
on May 17, 1991, in partial fulfillment of the
requirements for the degree of
Master of Science in Nuclear Engineering

Abstract

In this thesis, I designed two coil systems for the Versatile Toroidal Facility (VTF) at the Nabisco Laboratory of the Plasma Fusion Center. These coil systems will enable VTF to confine plasmas generated by ECRH,OH, or both, and thereby will enhance its capacity to be versatile enough to run experiments such as ionospheric plasma simulation and high β plasma research. I have carried out elliptic integral calculations to find vacuum field of the coils, and then for the more complete design, I have used ASEQ code in the Cray Supercomputer at the Lawrence Livermore National Laboratory to solve the two-dimensional, nonlinear Grad-Shafranov equation.

Thesis Supervisor: Prof. Min-Chang Lee
Title: Leader, Plasma Fusion Center Ionospheric Plasma Research Group

Design and Construction of the Versatile Toroidal Facility for Ionospheric Chamber Research

by

Robert F. Duraski

Submitted to the Department of Nuclear Engineering
on August 13, 1991, in partial fulfillment of the
requirements for the degree
Master of Science in Nuclear Engineering

ABSTRACT

This thesis describes the design and construction of the Versatile Toroidal Facility (VTF) located in the Plasma Fusion Center's Nabisco Laboratory. The VTF has a major radius of 0.9 m, a minor radius of 30 cm and a maximum toroidal field of 1 Tesla. The two functions of the VTF are the simulation of ionospheric plasma and thermonuclear fusion research. At present the machine is capable of ionospheric applications and work towards fusion study capabilities are still in progress.

Thesis Supervisor: Prof. Min-Chang Lee
Title: Leader, Plasma Fusion Center Ionospheric Plasma Research Group