PREPARED FOR THE U.S. DEPARTMENT OF ENERGY,
UNDER CONTRACT DE-AC02-76-CHO-3073

PPPL-2611
UC-426

PPPL-2611

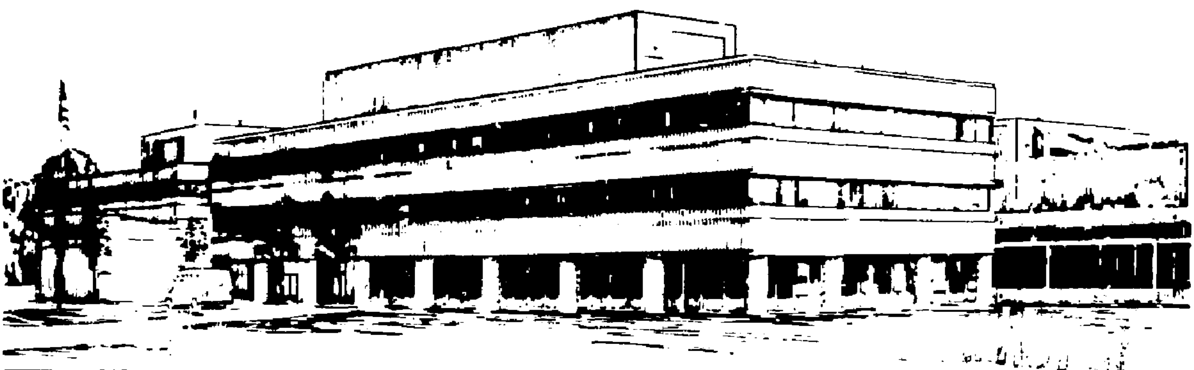
AN AMPLITUDE AND PHASE CONTROL SYSTEM FOR THE TFTR RF HEATING SOURCES

BY

G. CUTSOGEORGE

APRIL 1989

PRINCETON
PLASMA PHYSICS
LABORATORY



PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

NOTICE

Available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
703-487-4650

Use the following price codes when ordering:

Price: Printed Copy A03
Microfiche A01

PPPL--2611

DE89 010547

AN AMPLITUDE AND PHASE CONTROL SYSTEM FOR THE TFTR RF HEATING SOURCES

G. Cutsogeorge

Princeton Plasma Physics Laboratory, Princeton University

P.O. Box 451

Princeton, N.J. 08543

ABSTRACT

Feedback loops that control the amplitude and phase of the rf heating sources on TFTR are described. The method for providing arc protection is also discussed. Block diagrams and Bode plots are included.

1. Introduction

The TFTR radio-frequency heating system consists of four RF generators with associated power supplies, antennas and controls as shown in the block diagram, figure 1. Two generators are upgraded FMIT units modified to produce 2 megawatts each for 10 second pulses over the 40 to 80 MHz range. The other two are PPPL designed generators originally used on PLT that have been modified for 2 second pulses up to 3 megawatts each at 47 MHz.

The RF generators must produce pulses that have accurate and reproducible amplitude variations with time. Since each pair of generators drives an individual antenna, the relative phase of each carrier during the pulse must be constant or the power delivered will vary in an undesired manner. When all four sources are used, the relative phase between pairs of sources must be controllable to obtain the desired antenna pattern. Additionally, it is necessary to amplitude modulate the sources to assist in plasma stability studies.

Amplitude and phase variations with time are produced by gain nonlinearities in the sources, power supply droop, and temperature effects on various system components. Correction of these errors has been provided by incorporating negative feedback loops around the individual sources. These loops allow the source to be amplitude modulated and phase shifted by adjusting its reference signal.

2. Feedback Loops

The feedback loop configuration is shown in figure 2. Mixer, M1, heterodynes a sample of the power amplifier output with an injection source 30 MHz higher in frequency to produce 30 MHz at the limiter input. Thus, for 47 MHz operation the injection is at 77 MHz. The output of the limiter is phase compared with a 30 MHz reference. The error signal is filtered and used to adjust the frequency of the 30 MHz voltage-controlled oscillator (VCO). The VCO output is then heterodyned with the same injection source to produce the operating frequency. A 40 to 80 MHz band pass filter removes the undesired mixer components. The resulting signal at the operating frequency passes through an amplitude modulator and goes out to the high power RF amplifier. A small sample of the amplifier output obtained from a directional coupler provides the input for M1 and a diode detector. An input pulse from a waveform generator is compared with the diode detector output and the difference is filtered and used to control the amplitude modulator.

Two benefits are derived from the use of a 30 MHz intermediate frequency. The loop gain is constant over the 40 to 80 MHz band because the VCO is always operating on the same frequency. Also, the 30 MHz reference input is a convenient place to adjust the relative phase between generators. Injection is provided by a frequency synthesizer or a crystal oscillator for all four generators.

The 30 MHz reference generators are shown in figure 3. Output #1 serves as the phase reference for the other channels. Outputs 2, 3, and 4 are each phase locked to #1. Phase adjustment is made by adding a dc voltage from a 10-turn potentiometer to the phase detector error signal. Adjustment over a ±90° range is possible.

3. RF Enable and Arc Protection Circuitry

A functional diagram of the RF enable and arc protection circuitry is shown in figure 4. The actual circuit configuration is contained in PPPL drawing PEL-D-7-0813-SCH titled "Schematic TFTR Feedback Controller." Directional couplers in the transmission line to the TFTR antennas provide samples of the forward and reverse voltages. These sample voltages are detected and processed with low frequency circuitry. When two RF amplifiers are operating, the detected forward voltages are summed and applied to amplifier A1. This amplifier has a gain of 1/2 so it produces a voltage that is the average of its two inputs. When only one RF amplifier is operating, A1 is arranged so that its gain is 1. The output of A1 is reduced by an adjustable voltage divider that may be set to various percentages by a front panel switch. The voltage divider output is compared to the detected reverse voltage, Vr1, in the voltage comparator, C1. Thus, C1 will change state if the reflected voltage exceeds the set percentage of the forward. This will occur if an arc is formed or some other fault makes the reflected voltage increase. Summing the forward voltages from the two amplifiers before comparison with the reflected voltage from each amplifier reduces false trips due to cross coupling between the amplifiers.

The output of A1 is also compared to a set reference voltage in C2, a second comparator. C2 changes state if the forward voltage is high enough that an arc might be damaging. Comparator C1 is enabled by C2 to prevent RF shutdown during the initial ramp up when the power level is low. C2 also triggers one shot OS1 which inhibits power shut down for approximately 100 microseconds during the initial ramp up. The flip flop inhibits OS1 from firing again during the pulse. If another arc occurs after the initial 100 microsecond delay time, the power is shut down within 5 or 10 microseconds.

One shot OS2 generates a 50 microsecond pulse when C1 detects a high VSWR. During an arc C1 may change states many times and OS2 provides a clean pulse for counting. The output of OS2 is OR gated with the output of C1 so that a signal will still be available at the input of AND gate G1 after OS2 times out if it was triggered during the 100 microsecond delay time.

AND gate G1 triggers OS3 and the divide by N counter. OS3 may be set to blank the RF for a period between 100 microseconds and 100 milliseconds by front panel controls. The counter may be set to shut off the RF after a number of arcs from 1 to 99. OR gate G3 will change state if either RF amplifier has exceeded the number of arcs preset. In this manner, if either RF amplifier sustains an arc, both amplifiers will be shut down.

When an arc occurs or the preset has been exceeded, gate G4 will go low and inhibit AND gate G5 which will turn off the amplitude modulator. The Control Pulse is generated by the waveform generator that is used to shape the RF pulse. It is present only during the time that RF is desired. The arc counter and the flip flop are reset when the control pulse goes low. The RF Blanking, Arm, and Source Ready are signals that come from the RF amplifier and indicate it is ready to accept RF drive. The RF Enabled output goes to the Interface controls. L1, L2, and L3 are front panel indicators.

4. Feedback Loop Parameters

The amplitude feedback loop bandwidth has been set to approximately 14 kHz. The loop rolls off at 6 dB per octave as shown in the Bode plot, figure 5. Normal operation calls for an output level of 0 dBm to drive the first power amplifier and a feedback level of +10 dBm back from the RF source output. The range over which the source may be amplitude modulated extends from d.c. to the loop bandwidth. A wideband-narrowband switch allows the bandwidth to be narrowed to approximately 2 kHz as desired. Since the feedback loop would be constantly correcting if it were active during amplifier tune up, there also is a feedback on/off control. In the feedback off position the feedback signal is moved from the HPA (High Power Amplifier) output to the HPA input while keeping the loop gain constant by switching in a small amplifier.

The phase loop bandwidth was selected as a result of measurements of phase shift made on the HPA. For modulation from 100 kilowatts to 1 megawatt at a frequency of 10 kHz the maximum slope of the phase error measured was 6°/10µs. To track this slope with an error of less than 10° it is necessary for the loop to have a natural frequency of 3.2 kHz and a damping factor of 1.0. The loop filter has been configured to provide these parameters. The resulting Bode plot is shown in figure 6. The closed loop bandwidth is approximately 7 kHz in the wideband position.

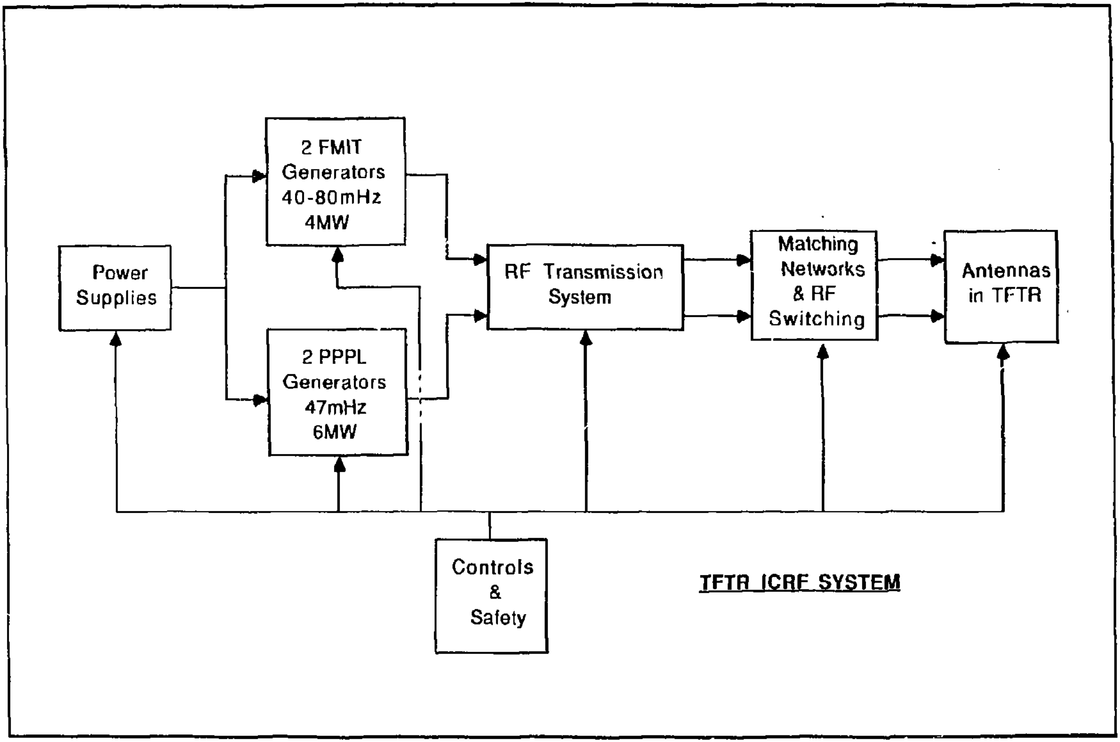
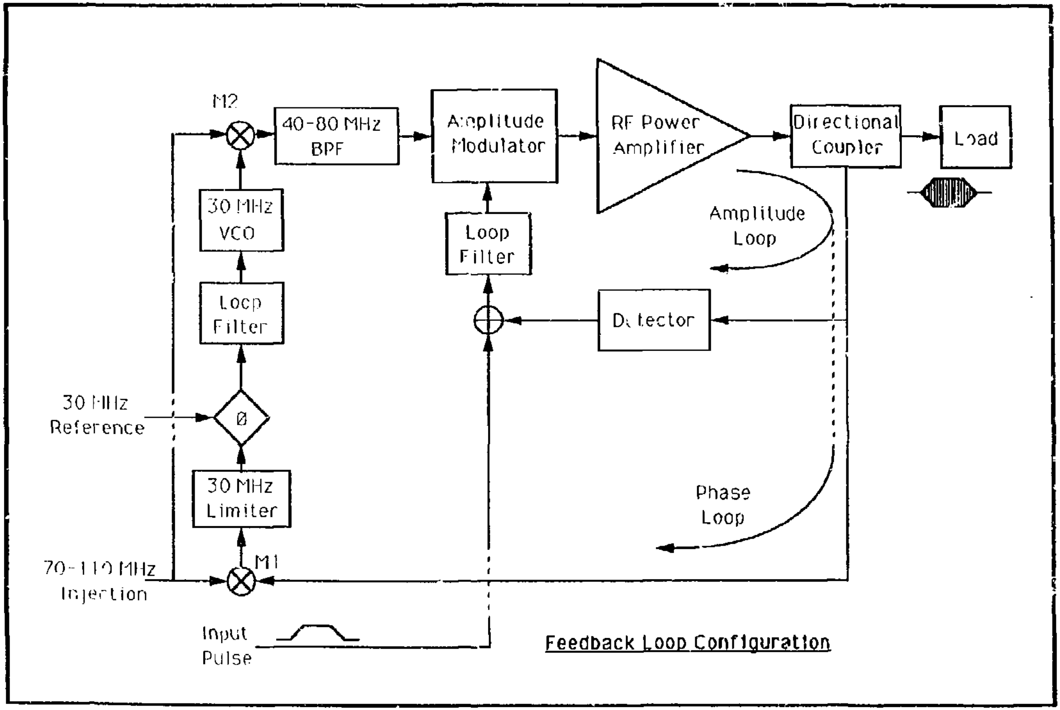

2 FMIT
Generators
40-80mHz
4MW
Power
Supplies
2 PPPL
Generators
47mHz
6MW
RF Transmission
System
Matching
Networks
& RF
Switching
Antennas
in TFTR
Controls
&
Safety
TFTR ICRF SYSTEM

Fig. 1



Feedback Loop Configuration

Fig. 2

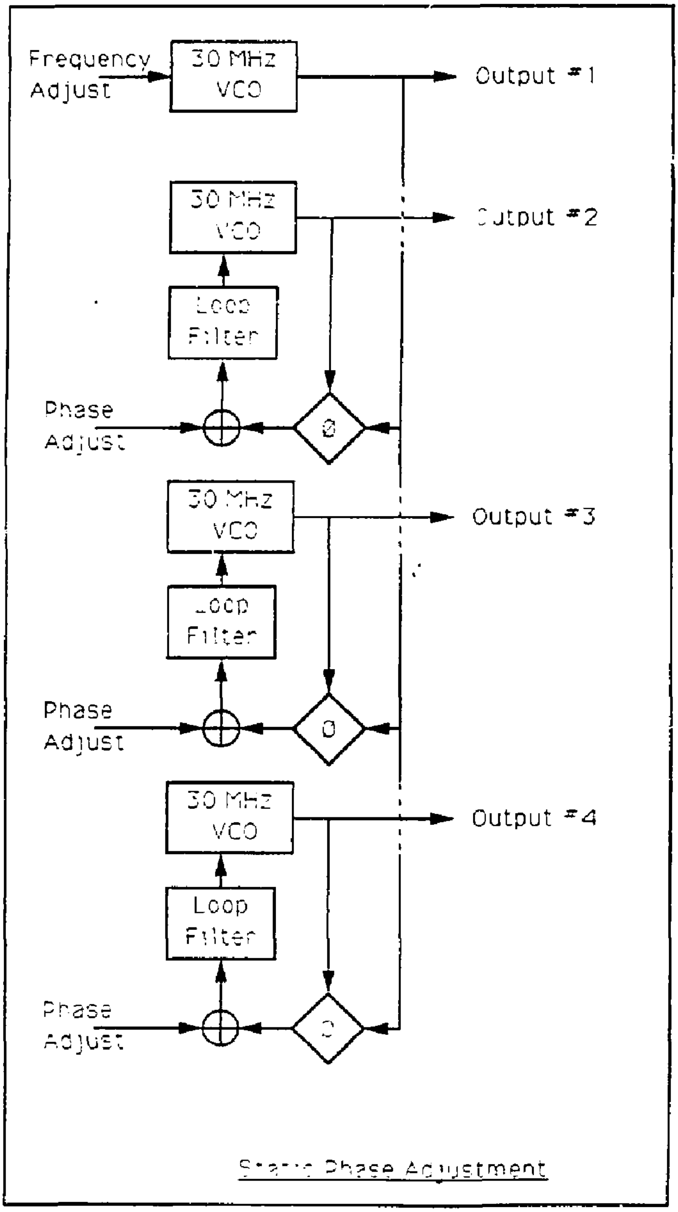
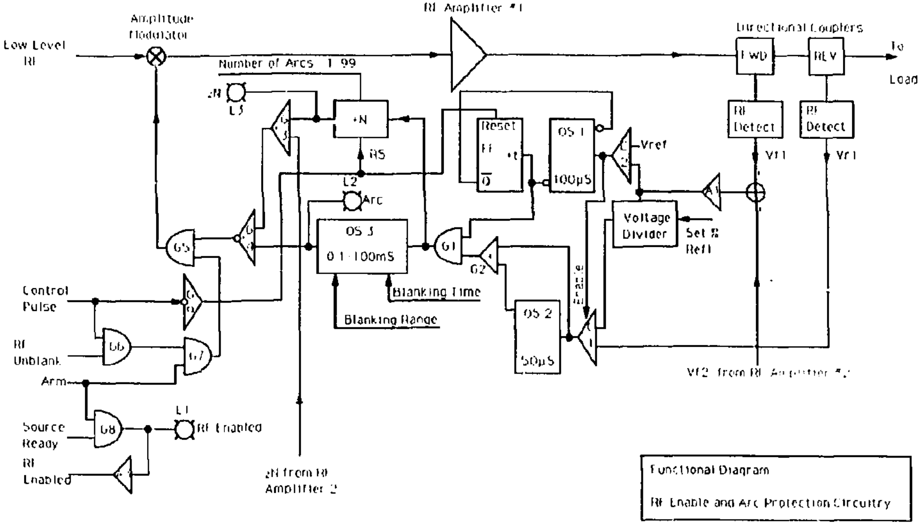

Frequency Adjust
30 MHz VCO
Output #1
30 MHz VCO
Output #2
Loop Filter
Phase Adjust
Ø
30 MHz VCO
Output #3
Loop Filter
Phase Adjust
30 MHz VCO
Output #4
Loop Filter
Phase Adjust
Static Phase Adjustment

Fig. 3



G. Cutsogeorge 11/26/88

Fig. 4

FEEDBACK CONTROLLER AMPLITUDE LOOP

Open Loop Gain Characteristic

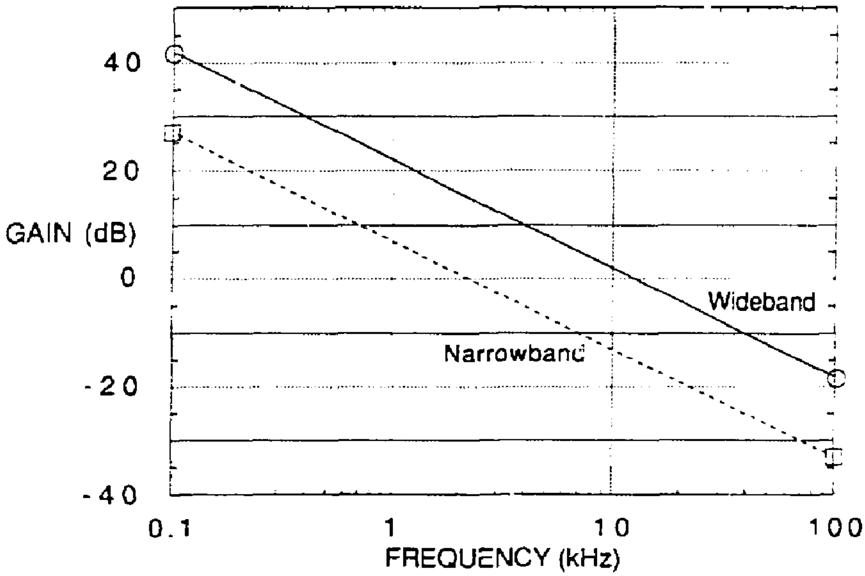
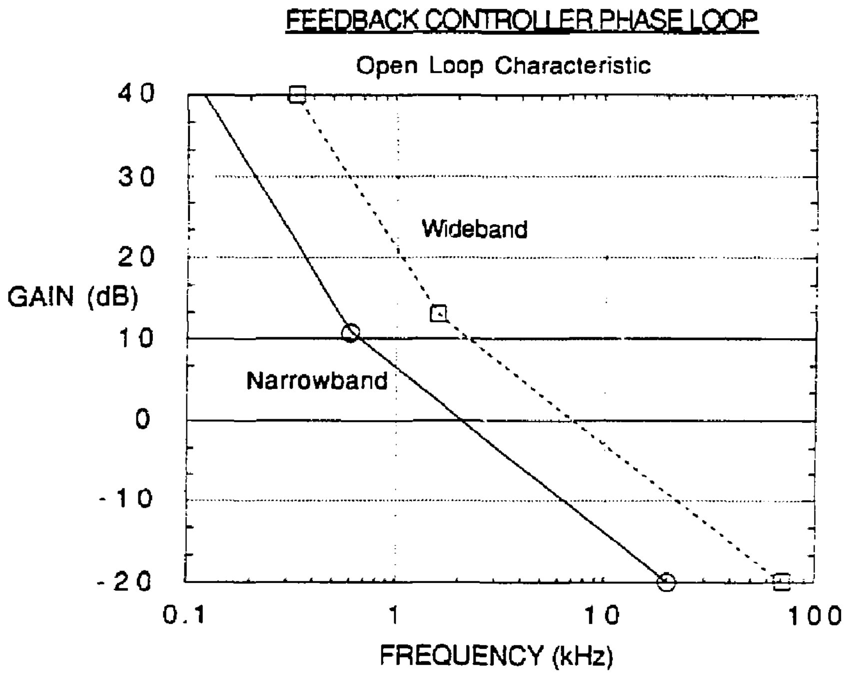


Fig. 5


FEEDBACK CONTROLLER PHASE LOOP
Open Loop Characteristic
40
30
20
10
0
-10
-20
GAIN (dB)
Wideband
Narrowband
0.1
1
10
100
FREQUENCY (kHz)

EXTERNAL DISTRIBUTION IN ADDITION TO UC-420

Dr. Frank J. Paoloni, Univ of Wollongong, AUSTRALIA
Prof. M.H. Brennan, Univ Sydney, AUSTRALIA
Plasma Research Lab., Australian Nat. Univ., AUSTRALIA
Prof. I.R. Jones, Flinders Univ., AUSTRALIA
Prof. F. Cap, Inst Theo Phys, AUSTRIA
Prof. M. Heindler, Instut fur Theoretische Physik, AUSTRIA
M. Goossens, Astronomisch Instituut, BELGIUM
Ecole Royale Militaire, Lab de Phys Plasmas, BELGIUM
Commission-European, Dg-XII Fusion Prog, BELGIUM
Prof. R. Boucique, Rijksuniversiteit Gent, BELGIUM
Dr. P.H. Sakanaka, Instituto Fisica, BRAZIL
Instituto De Pesquisas Espaciasi-INPE, BRAZIL
Documents Office, Atomic Energy of Canada Limited, CANADA
Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
Dr. H.M. Skarsgard, University of Saskatchewan, CANADA
Dr. H. Barnard, University of British Columbia, CANADA
Prof. J. Teichmann, Univ. of Montreal, CANADA
Prof. S.R. Sreenivasan, University of Calgary, CANADA
Prof. Tudor W. Johnston, INRS-Energie, CANADA
Dr. Bolton, Centre canadien de fusion magnetique, CANADA
Dr. C.R. James, Univ. of Alberta, CANADA
Dr. Peter Lukac, Komenskeho Univ, CZECHOSLOVAKIA
The Librarian, Culham Laboratory, ENGLAND
The Librarian, Rutherford Appleton Laboratory, ENGLAND
Mrs. S.A. Hutchinson, JET Library, ENGLAND
C. Mouttet, Lab. de Physique des Milieux Ionises, FRANCE
J. Radet, CEN/CADARACHE - Bat 506, FRANCE
Ms. C. Rinni, Librarian, Univ. of Ioannina, GREECE
Dr. Tom Mual, Academy Bibliographic Ser., HONG KONG
Preprint Library, Hungarian Academy of Sciences, HUNGARY
Dr. B. Das Gupta, Saha Inst of Nucl. Phys., INDIA
Dr. P. Kaw, Institute for Plasma Research, INDIA
Dr. Philip Rosenau, Israel Inst. of Tech, ISRAEL
Librarian, Int'l Ctr Theo Phys, ITALY
Prof. G. Rostagni, Istituto Gas Ionizzati Del CNR, ITALY
Miss Clelia De Palo, Assoc EURATOM-ENEA, ITALY
Dr. G. Grosso, Istituto di Fisica del Plasma, ITALY
Dr. H. Yamato, Toshiba Res & Dev, JAPAN
Prof. I. Kawakami, Atomic Energy Res. Institute, JAPAN
Prof. Kyoji Nishikawa, Univ of Hiroshima, JAPAN
Director, Dept. Large Tokamak Res, JAERI, JAPAN
Prof. Satoshi Itoh, Kyushu University, JAPAN
Research Info Center, Nagoya University, JAPAN
Prof. S. Tanaka, Kyoto University, JAPAN
Library, Kyoto University, JAPAN
Prof. Nobuyuki Inoue, University of Tokyo, JAPAN
S. Mori, JAERI, JAPAN
H. Jeong, Librarian, Korea Advanced Energy Res Inst, KOREA
Prof. D.I. Choi, The Korea Adv. Inst of Sci & Tech, KOREA
Prof. B.S. Liley, University of Waikato, NEW ZEALAND
Institute of Plasma Physics, PEOPLE'S REPUBLIC OF CHINA
Librarian, Institute of Phys., PEOPLE'S REPUBLIC OF CHINA
Library, Tsing Hua University, PEOPLE'S REPUBLIC OF CHINA
Z. Li, Southwest Inst. Physics, PEOPLE'S REPUBLIC OF CHINA
Prof. J.A.C. Cabral, Inst Superior Tecnico, PORTUGAL
Dr. Octavian Petrus, AL I CUZA University, ROMANIA
Dr. Jan de Villiers, Fusion Studies, AEC, SO AFRICA
Prof. M.A. Hellberg, University of Natal, SO AFRICA
C.I.E.M.A.T., Fusion Div. Library, SPAIN
Dr. Lennart Stenflo, University of UMEA, SWEDEN
Library, Royal Institute of Tech, SWEDEN
Prof. Hans Wilhelmson, Chalmers Univ of Tech, SWEDEN
Centre Phys des Plasmas, Ecole Polytech Fed, SWITZERLAND
Bibliotheek, Fom-Inst Voor Plasma-Fysica, THE NETHERLANDS
Metin Durgut, Middle East Technical University, TURKEY
Dr. D.D. Ryutov, Siberian Acad Sci, USSR
Dr. G.A. Eliseev, Kurchatov Institute, USSR
Dr. V.A. Glukhikh, Inst Electrophysical Apparatus, USSR
Prof. O.S. Padichenko, Inst. of Phys. & Tech. USSR
Dr. L.M. Kovrizhnykh, Institute of Gen. Physics, USSR
Nuclear Res. Establishment, Julich Ltd., W. GERMANY
Bibliothek, Inst. Fur Plasmaforschung, W. GERMANY
Dr. K. Schindler, Ruhr-Universitat Bochum, W. GERMANY
ASDEX Reading Rm, c/o Wagner, IPP/Max-Planck, W. GERMANY
Librarian, Max-Planck Institut, W. GERMANY
Prof. R.K. Janev, Inst of Phys, YUGOSLAVIA