PFC/RR-84-13 DOE/ET/51013-130

ANTENA USER GUIDE

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July 1984

This work was supported by the U.S. Department of Energy Contract No. DE-AC02-78ET51013. Reproduction, translation, publication, use and disposal, in whole or in part by or for the United States government is permitted.

Abstract

Use of the computer code "ANTENA" is described. The code calculates the vacuum fields and the linear self-consistent plasma fields for a variety of ICRF antenna configurations.

Contents

1. INTRODUCTION

The computer code "ANTENA" calculates the vacuum fields and the linear self-consistent plasma fields for the ICRF antennas of Fig. 1.1. In addition, the computer code has an array capability whereby any combination of the antennas contained in Fig. 1.1 may be superimposed (Fig. 1.1h is an example). Along with the electric and magnetic fields, the radial power deposition profiles, the radial power flow, and the antenna impedance (including mutual impedance between coils) is computed. The antenna-plasma geometry is diagrammed in Fig. 1.2. An antenna is located between the plasma boundary at $r = a$ and an outer conducting wall at $r = c$. The inside radius of the antenna is at $r = b$. The antenna current is assumed to be uniform over the length of the antenna. The plasma parameters and the magnetic field are assumed to be functions of radius with the magnetic field oriented in the z-direction. The M.I.T. Report #PFC/RR-84-12, "ICRF Antenna Coupling Theory for a Cylindrically Stratified Plasma", contains detailed information on the physics assumed in the computer code "ANTENA".[1]

The field quantities are calculated by numerically performing the inverse transformation;

$$F(r,\phi,z) = \frac{1}{2\pi} \int_{-\infty}^{\infty} dk_z \sum_{n=-\infty}^{\infty} F(r,n,k_z)\ e^{ik_z z+in\phi} \qquad (1)$$

The Fourier transform can be defined as,

Fig. 1.1 Various ICRF Antennas

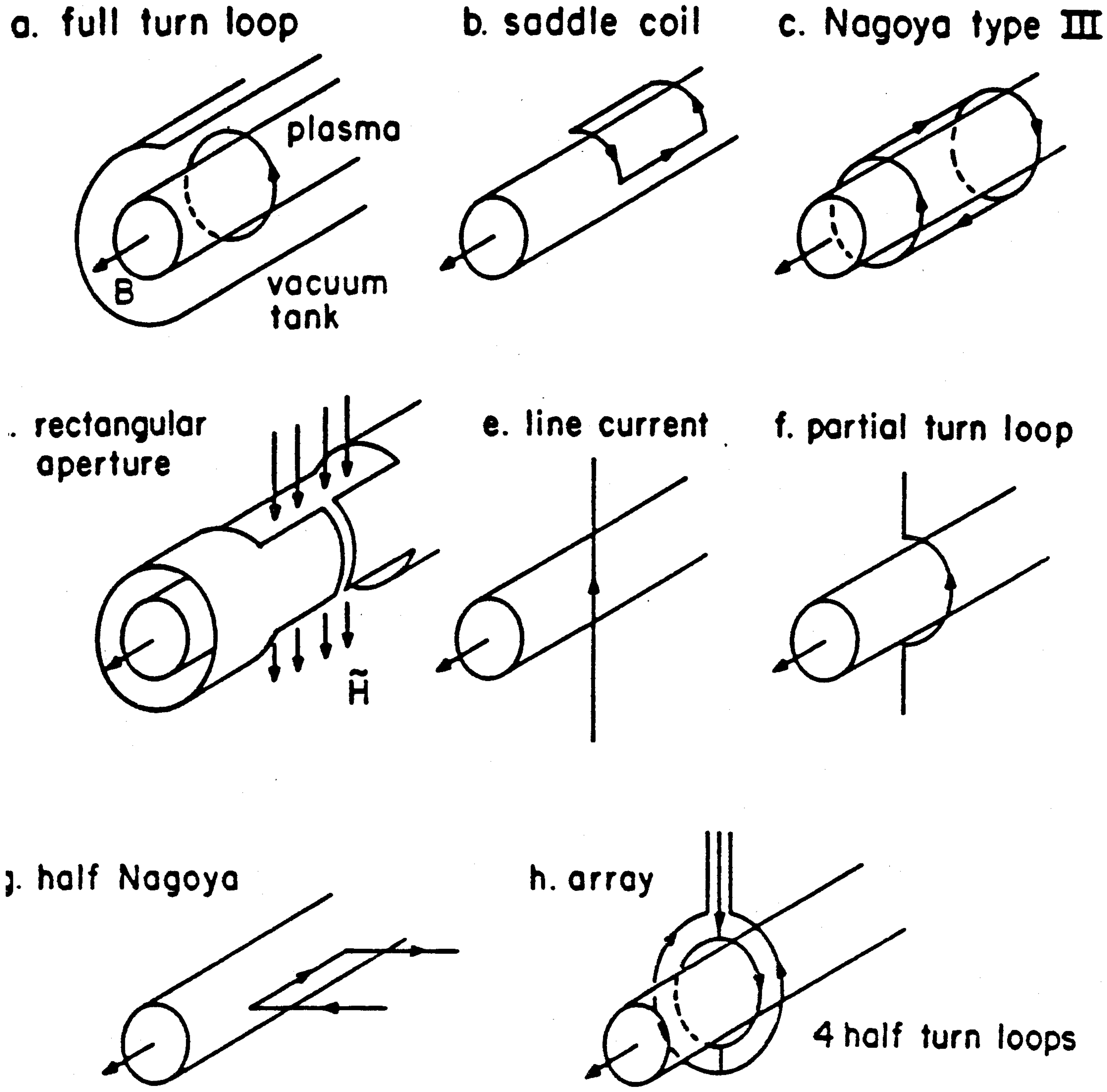
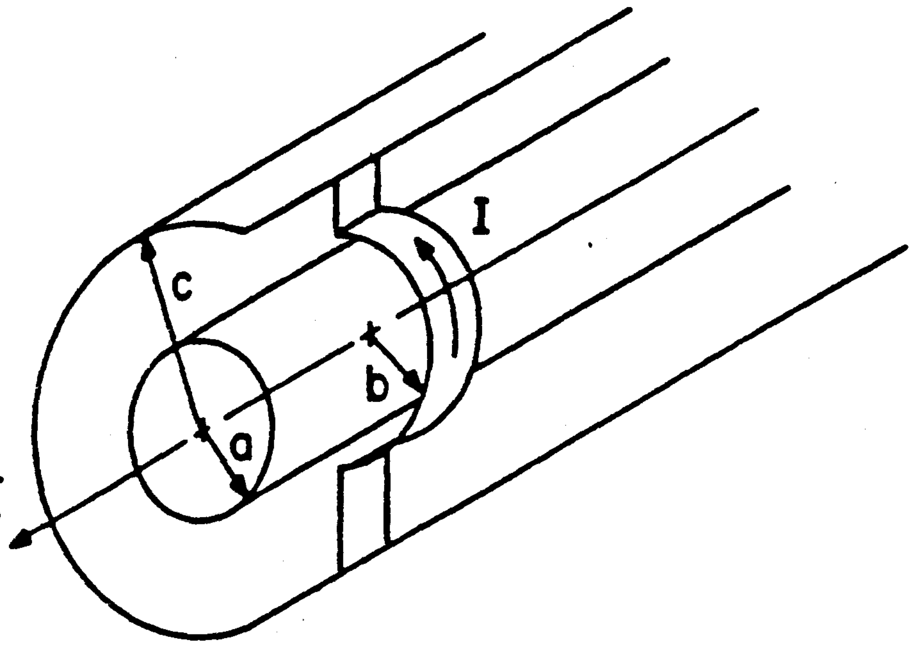


Fig. 1.2 Antenna - Plasma Geometry



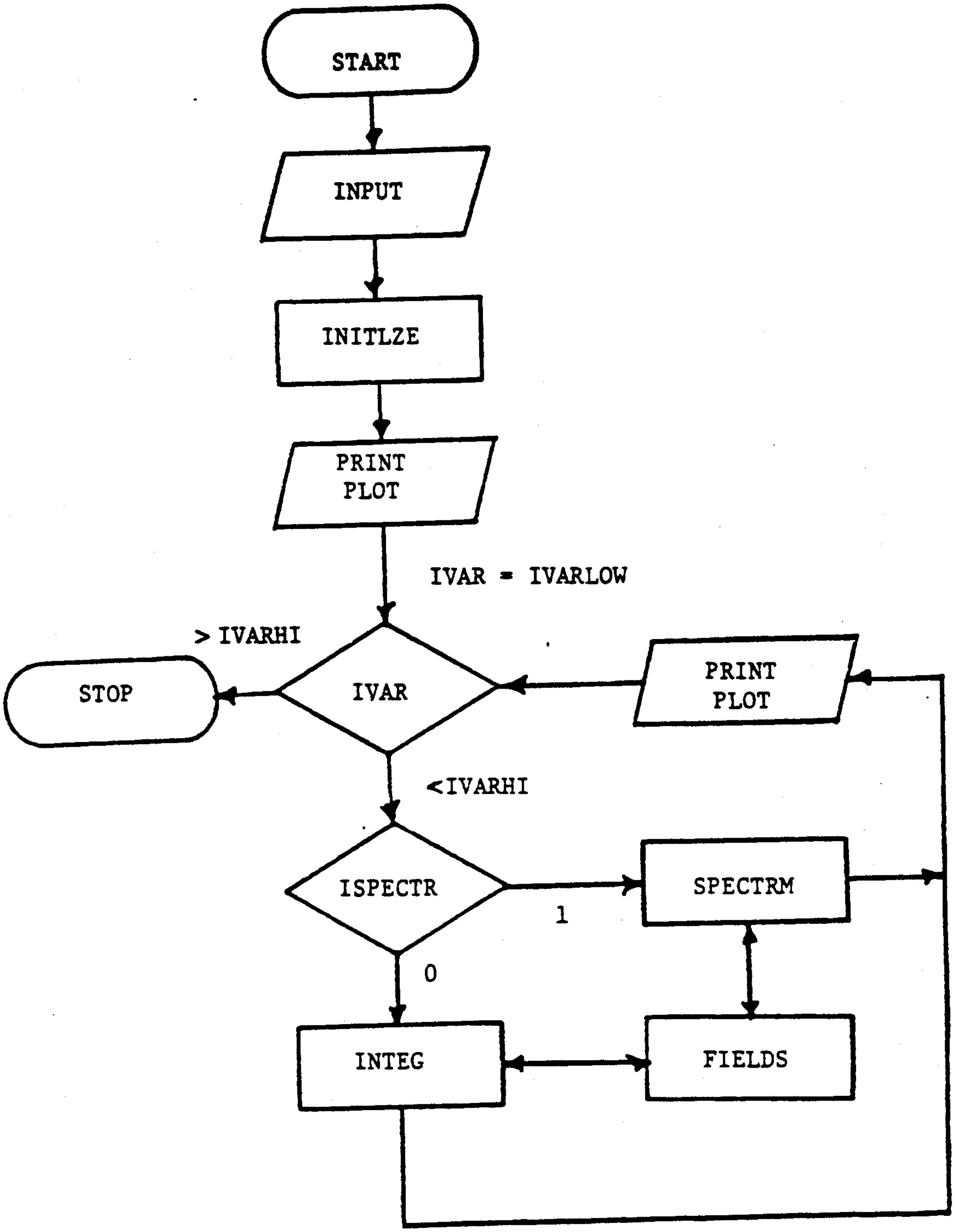
a = plasma radius
b = inside radius of coil
c = vacuum tank radius

$$F(r,n,k_z) = \frac{J(n,k_z,b,c)}{D(n,k_z,\omega,n_e,B_o,T)} \qquad (2)$$

where J represents the excitation level of a (n,k_z) mode by the antenna, and D contains the plasma response to the imposed fields.

Figure 1.3 diagrams the basic structure of the computer code "ANTENA". Through a namelist, INPUT reads all the parameters that are required to define the problem diagrammed in Fig. 1.2. The following subroutine, INITLZE performs various calculations such as conversion from cm. to m., sets up radial plasma profiles, etc. The plot and print subroutines write the input information to disk files. Now we are at the main loop in the program. IVAR is the independent variable for which the fields are calculated. Examination of Eqs. (1) and (2) suggest IVAR can take on many different values; r, ϕ, z, ω/ω_{ci}, f, n_e, T_i, T_e, B_o, k_z, and other user defined variables. Dependent upon the value of ISPECTR, either the integrand of Eq. (1) is calculated by SPECTRM or the inverse transformation is performed by INTEG. The subroutine INTEG either performs a Fourier sum or uses the integrator package DRIVE[2]. Each of these subroutines calls FIELDS which calculates Eq. (2) for a given n, k_z mode. Finally, the computed field quantities are written to disk files, and the process is repeated for a new value of IVAR. Figure 1.3 is a general flow chart of "ANTENA". More detail may be obtained by reading the listing of the main program.

FIG. 1.3 FLOW CHART FOR ANTENA



2. AVAILABILITY AND EXECUTION

The program is available from directory,

```
1437  .ICRF
```

The directory contains the source program, ANTENA4 and executable programs XANTENA4, for the A-machine; and XANTENC4, for the C-machine. The program is executed by the statement,

```
XANTENA4  I = IN    O = OUT   P = PLOT  / t v
```

where IN is an input file that contains three namelist inputs, OUT is a text output file, and PLOT is a text file that contains data for subsequent plotting. The default files are I = terminal, O = terminal, and P = plotout.

A separate plotting program (PLOTA4) processes the file designated by P. Plotted output may be obtained by executing XPLOTA4 on the A-machine or XPLOTC4 on the C-machine. The execute line is,

```
XPLOTA4   I = INP   O = OUTP   P = PLOT  / t v
```

where P = Plot is the disk file generated by ANTENA, INP is a namelist input file that contains control parameters, and OUTP is an output file that is a directory of the frames plotted. The default files are I = terminal, O = terminal, P = plotout.

The codes are subscripted by the number 4 indicating a version number. Number 4 is the most recent version number and previous versions have been moved to directory .ICRFOLD . The file ANTNEWS will contain information on the status of the code. It presently contains a list of changes made in version 4 of the code compared to earlier versions. It also contains a directory of the codes in .ICRF .

3. INPUT

Communication to ANTENA is through three namelist inputs contained in the subroutine INPUT. A listing of the INPUT subroutine is included as Appendix A. In that subroutine, the DATA statements define the default values of the input variables. The first namelist contains control, scanning and integration parameters.

NAMELIST INPUT1

Selected output may be controlled by setting the following parameters equal to zero or one.

ICOORD	= 0	rectangular coordinates
	= 1	cylindrical coordiantes
IBFLD	= 1	the magnetic field calculation is on
	= 0	the magnetic field is not calculated
IEFLD	= 1	the electric field calculation is on
	= 0	the electric field is not calculated
IPABS	= 1	the power absorption calculation is on
	= 0	the power absorption is not calculated
IEDOTJ	= 1	the antenna impedance calculation is on
	= 0	the antenna impedance is not calculated

INDVAR determines the independent variable for the inner loop.

INDVAR	= 1	r scan
	2	ϕ scan
	3	z scan
	4	$\omega/\omega_c(1)$ scan
	5	frequency scan
	6	density scan
	7	$\|B_o\|$ scan
	8	T(j) scan where J = IPART

9	k_z scan
10	user defined scan through subroutine INDVAR10

The range and increment of the independent variable are defined by,

IVARLOW	starting value
IVARHI	end value
IVARINC	incrementing step

The variables INDVAR2, IVARLOW2, IVARHI2, IVARINC2 have the same meaning as above and provide control over an outer independent variable scan. The outer scan is de-activated by defining INDVAR2 to be less than zero. The fields that are computed by the code are determined by the following parameters.

ISPECTR	= 0	use integration routines
	= 1	calculates the Fourier spectrum
IFIELD	= 1	inductive vacuum fields
	= 2	plasma fields
INTEGKZ	= 2	variable step integrator
	= 3	Fourier sum, E_z (± L/2) = 0
	= 4	Fourier sum, E(z) = E(z+L)
IFAST	= 1	fast mode fields are calculated
	= 0	fast mode fields are not calculated
ISLOW	= 1	slow mode fields are calculated
	= 0	slow mode fields are not calculated

For the meaning of IFAST and ISLOW refer to the physics description.[1]

The parameters used by the drive integrator (INTEGKZ = 2) are the following.

KMINCM	minimum value of k_z in cm^{-1}
KMAXCM	maximum value of k_z in cm^{-1}
KSTEPCM	initial step size for k_z in cm^{-1}
EPS	error bound for the integrator

MF	method flag for the integrator

The default values for the integration parameters provide reasonable accuracy (refer to reference 2).

NAXIAL	defines the number of k_z modes summed for INTEGKZ = 3,4
NMAX	the n summation of Eq. (1) extends from ±NMAX

NAMELIST INPUT2

The second namelist contains the dimensions for the plasma, for the antenna, and defines the nominal position and wave parameters.

ACM	the plasma radius in cm
CCM	the vacuum chamber radius in cm
LENGCM	axial length used in Fourier sums (INTEGKZ = 3,4)

The following coordinates define the position at which the fields are calculated.

RHOCM	radial position in cm
PHIDEG	azimuthal position in deg
ZCM	axial position in cm

The nominal wave parameters are the following.

WNOR	$\omega/\omega_c(1)$ where 1 is the first plasma species defined.
FREQ	used to define ω when FREQ > 0
KZOCM	axial wave number that is assumed in spectral scans (ISPECTR = 1)
NAZIM	aximuthal mode number that is assumed in spectral scans. The default value is NAZIM = -99. If NAZIM is set to be larger than -30, only n = NAZIM is calculated in the Fourier sums and integration for ISPECTR = 0.

The antenna parameters are,

NCOILS	is the number of coils in an array
ICOIL	is an integer array that determines the individual coils in the array (i.e. ICOIL = 1 3 5 7)

The following coils are modelled,

ICOIL	= 1	full turn loop
	= 2	saddle coil
	= 3	Nagoya type III coil
	= 4	rectangular aperture
	= 5	line current
	= 6	partial turn loop
	= 7	half Nagoya coil

The following parameters define the interconnection of coils in an array.

ISERIES	> 0	the coils are connected in series
IPARALL	> 0	the coils are connected in parallel
IMUTUAL	= J	the "J" th coil is driven with current and the mutual impedance between that coil and others is calculated.
IANTCON	=1,2,3,or 4	designates that the coil interconnection is defined in a user supplied subroutine ANTCON1, etc.
NSTEP		defines the number of radial points in the $E_r J_r$ integration for the impedance calculation of coils with radial feeders

The antenna dimensions and the orientation of the antennas are defined by the following arrays. Appendix B contains detailed drawings of the various antenna configurations.

CUR	is a complex number that defines the current in each coil. For ICOIL = 4, CUR defines the magnetic field over the rectangular aperture.
BCM	is the inner radius of the coil.

WIDCM	is the characteristic width of the coil.
LNGCM	is the characteristic length of the coil.
ANGDEG	is the angular extent of the coil.
ZOCM	is the axial location of the coil.
PHIODEG	is the azimuthal location of the coil.

The default location is at the origin.

NAMELIST INPUT3

The final namelist defines the plasma parameters and the radial profile.

IKIJ	is an integer flag that determines the plasma response. IKIJ = 1 is a Maxwellian velocity distribution.
NPART	is the number of plasma species.
BFLD	vacuum magnetic field in Gauss.
NTOT	plasma density in particles/cm^3.

The following are all real arrays defining the parameters of the various plasma constituents.

MASS	in atomic mass units
CHARGE	units of electrons charge
CONC	concentration in %
TPAR	parallel temperature in eV
TPER	perpendicular temperature in eV
COLFREQ	effective collision frequency using a Krook model

The following parameters determine the stratified density and temperature profiles.

IPROF	= 1	uniform profile
	= 2	parabolic profile
	= 3	Gaussian profile
	= 4	experimental profile read from NAMELIST

NSTRAT	the number of strata $< N3$
WDENCM	density scale length
WTEMPCM	an array defining the temperature scale length for each species

The magnetic field in the plasma is calculated from $B_o(r) = BFLD \sqrt{1 - \beta(r)}$. For profiles, the parameters TPAR and NTOT are the r = 0 values.

Experimental profiles are defined by the following input arrays.

RS	defines the positions of the interfaces between strata.
FDEN	defines the density profile.
FTEMP	defines the temperature profiles.

FDEN and FTEMP is normalized to the first element in the array where the density at r = 0 is NFLD * FDEN(1) and the temperature at r = 0 is TRAR(1) * FTEMP(1,1) and TPAR(2) * FTEMP(2,1).

Communication to PLOTA4 is through a single namelist.

ILABLE	is a lable flag that when larger than zero will write the words contained in the array lable on each plot.
LABLE	is an array of up to 5 words that contains a message.
XLABLE	when INDVAR = 10, a 3 word user supplied message contained in XLABLE will be printed on the x-axis of the graphs.
IPARAM = 1	orders the sequence of plotting so that all (B_x, etc.) graphs appear adjacent to one another.

Sample input files for ANTENA and PLOT4A are contained at the end of Appendix A.

4. OUTPUT

The output generated by ANTENA consists of two text files. The first file designated by 0 = _ _ _ _ on the execute line, is a formatted file that tabulates the field calculation. The second file designated by P = _ _ _ _ on the execute line is read by PLOTA4 and generates graphical output. The description in this section, assumes the reader has run ANTENA4 and PLOTA4, for the default parameters and has generated the text and plot output files.

The first 120 lines of the text file mirrors the input namelist. The fields are then tabulated as a function of the independent variable. The field format is either in rectangular or cylindrical coordinates dependent upon the value of ICOORD. For each field component, the modulus and phase is plotted. The phase is in degrees, and the modulus is in volts cm^{-1} for the electric field and in units of Gauss for the magnetic field. The local power absorption "PABST" is the total power absorbed in a infinitely long cylindrical shell of radius r and of cross sectional area equal to one square cm. Integrating over the cross section, $2\pi \int_0^a$ PABST rdr yields the total power absorbed by the plasma. The output "PABSI" indicates the power absorption by the various species, I = 1,NS where each species was defined in the namelist input. The output "POWER" is the total power absorbed inside a cylinder of radius r (i.e. the power flow across the surface of a cylinder of radius r). Finally the source impedance is calculated for each coil. The complex power flow out of the coil is calculated, and then the resistance and reactance is computed.

The first eleven frames of the plot output file mirror the input namelists. Frames 8 - 11 plot the plasma profiles that have been assumed. In the field plots, the solid curve refers to the modulus on the left-handscale and the dotted curve refers to the phase on the right-hand scale. The same convention is used on the source impedance plots.

For spectral scans (ISPECTR = 1) the output units are all multiplied by one centimeter. In addition, the plasma radial wave numbers are plotted.

5. COMPILATION

To enlarge the memory, to use options INDVAR = 10, IANTCON $\neq$ 0, or to change the source code; it is necessary to recompile ANTENA. The memory storage of ANTENA is determined by the following parameters which may be found in the CLICHE ANTCOM4.

N1 = 9 is the maximum number of coils in an array.

N2 = 3 is the maximum number of plasma species.

N3 = 50 is the maximum number of strata in a profile.

N4 = 21 is the maximum number of spatial positions for the inner scan at which the fields are calculated.

For compilation on the A or C machines, the parameter KMACH must be set as indicated in ANTCOM4.

The "ANTENA" code uses the integration package contained the source code INTPROG4[2]. This program is dimensioned to accommodate up to NEQU = 400 first order differential equations. The parameter NEQU must be set to a value larger than N7 in ANTCOM4. INTPROG4 has been compiled and libraries LINTGA4 (A-machine) and LINTGC4 (C-machine) may be found in directory 1437 .ICRF . Libraries may be constructed by using LIBMAK on the A-machine and BUILD on the C-machine.

Options INDVAR = 10 or IANTCON = 1 may be used by generating a library file, say LIB1 and then recompiling an executable code with the following lines.

A-machine

CHATR P = ANTENA4 LIB = (F′, LINTGA4, LIB1) / t v

C-machine

PRECOMP ANTENA4 PANTEN / t v

CFT I = PATAN / t v

LDR X = XANTENC4, LIB = (FORTLIB, LINTGC4, LIB1) / t v

Two examples are offered to illustrate the use of INDVAR = 10 and IANTCON = 1. The following subroutine defines the separation distance between two antennas as the independent variable.

```
      SUBROUTINE INDVAR10(NOPT)
      USE ANTCOM4

C   THE INDEPENDENT VARIABLE IS LABELLED.

      DATA LABLE1(10)/"  Z0(CM)  "/

C   Z0(2) IS THE AXIAL POSITION OF COIL NUMBER TWO.

      IF (NOPT) 11,12,13

C   Z0(2) IS SAVED.

   11 SAVE(1)=Z0(2)
      RETURN

C   Z0(2) IS INCREMENTED.

   12 Z0(2)=IVAR*.01
      RETURN

C   Z0(2) IS RESET.

   13 Z0(2)=SAVE(1)
      RETURN

      END
```

Results from the use of this subroutine are contained in reference 1 in Fig. 7.4 .

The following subroutine provides the interconnection required in the calculation of the source impedance for the array illustrated in Fig. 1.1h.

```
      SUBROUTINE ANTCON1
      USE ANTCOM4

C   PSOURCE(I) IS THE COMPLEX POWER FLOW OUT OF ANTENNA "I".

      C1=2.*PSOURCE(1)/CABS(CUR(1))**2
      C2=2.*PSOURCE(2)/CABS(CUR(2))**2
      C3=2.*PSOURCE(3)/CABS(CUR(3))**2
      C4=2.*PSOURCE(4)/CABS(CUR(4))**2

C   DEFINE THE SERIES - PARALLEL CONNECTION.
C   C1,C2,.....,C8 ARE COMPLEX CONSTANTS THAT MAY BE USED.

      C1=C1+C2
      C3=C3+C4
      C1=C1*C3/(C1+C3)

C   DEFINE RESISTANCE AND REACTANCE AND TOTAL POWER FLOW.

      RANTEN(1)=REAL(C1)
      XANTEN(1)=AIMAG(C1)
      PSOURCE(1)=PSOURCE(1)+PSOURCE(2)+PSOURCE(3)+PSOURCE(4)

      RETURN
      END
```

When the above subroutines are compiled to build LIB1, the file ANTCOM4 (found in 1437 .ICRF) must be in your local directory.

The memory allocation of PLOTA4 is defined by the following parameters,

N1 = 5 is the maximum number of coils in any array.

N2 = 3 is the maximum number of plasma species.

N3 = 50 is the maximum number of strata in a profile.

N4 = 102 is the maximum of 2 * N3 + 2 or N5

N5 = 31 is the maximum number of points in an inner scan.

N6 = 16 is the maximum number of points in an outer scan.

The code PLOTA4 is compiled with TV80LIB and DISSPLA.

References

1. B. D. McVey, "ICRF Antenna Coupling Theory for a Cylindrically Stratified Plasma", PFC/RR-84-13, Massachusetts Institute of Technology (1984).

2. A. D. Hindmarsh, "GEAR. . Ordinary Differential Equation System Solver", UCID-30001 Rev. 3 Lawrence Livermore Laboratory (1974).

Appendix A

```
C-------------------------------------------------------------------
C    SUBROUTINE INPUT: THE INPUT DATA FILE IS READ
C    THROUGH THREE NAMELISTS.

      SUBROUTINE INPUT
      USE ANTCOM4

C    FIRST NAMELIST: 1) OUTPUT CONTROL PARAMETERS,
C    2) INNER AND OUTER SCAN PARAMETERS, 3) FIELD PARAMETERS,
C    4) INTEGRATION PARAMETERS, 5) MISCELLANEOUS.

      NAMELIST /INPUT1/
     1  ICOORD,IBFLD,IEFLD,IPABS,IEDOTJ,
     2  INDVAR,IVARLOW,IVARHI,IVARINC,IPART,
     .  INDVAR2,IVARLOW2,IVARHI2,IVARINC2,
     3  ISPECTR,IFIELD,INTEGKZ,IFAST,ISLOW,
     4  KMINCM,KMAXCM,KSTEPCM,EPS,MF,
     .  NAXIAL,NMAX,
     5  ISIMEQ

      DATA
     1  INDVAR/1/,IVARLOW/0./,IVARHI/15./,IVARINC/3./,IPART/1/,
     .  INDVAR2/-1/,IVARLOW2/0./,IVARHI2/1./,IVARINC2/2./,
     2  ICOORD/0/,IBFLD/1/,IEFLD/1/,IPABS/1/,IEDOTJ/1/,
     3  ISPECTR/0/,IFIELD/2/,INTEGKZ/2/,IFAST/1/,ISLOW/1/,
     4  KMINCM/1.E-5/,KMAXCM/1.E1/,KSTEPCM/1.E-7/,EPS/1.E-4/,MF/10/,
     .  NAXIAL/100/,NMAX/5/,
     5  ISIMEQ/1/

C    SECOND NAMELIST: 1) PLASMA AND MACHINE DIMENSIONS,
C    2) NOMINAL POSITION AND WAVE PARAMETERS, 3) ANTENNA PARAMETERS,
C    4) ANTENNA CURRENT, DIMENSIONS, AND POSITION, 5) MISCELLANEOUS.

      NAMELIST /INPUT2/
     1  ACM,CCM,LENGCM,
     2  RHOCM,PHIDEG,ZCM,
     .  WNOR,FREQ,KZOCM,NAZIM,
     3  NCOILS,ICOIL,
     .  ISERIES,IPARALL,IMUTUAL,IANTCON,NSTEP,
     4  CUR,BCM,WIDCM,LNGCM,ANGDEG,
     .  Z0CM,PHI0DEG,
     5  VOLTS,INDUC

      DATA
     1  ACM/15./,CCM/35./,LNGCM/500./,
     2  RHOCM/5./,PHIDEG/0./,ZCM/5./,
     .  WNOR/1./,FREQ/-3.E6/,KZOCM/.01/,NAZIM/-99/,
     3  NCOILS/1/,ICOIL/6/,
     .  ISERIES/0/,IPARALL/0/,IMUTUAL/0/,IANTCON/0/,NSTEP/3/,
     4  CUR/(1000.,0.)/,BCM/20./,WIDCM/10./,LNGCM/0./,ANGDEG/180./,
     .  Z0CM/0./,PHI0DEG/0./,
     5  VOLTS/-1./,INDUC/1./

C    THIRD NAMELIST: 1) PLASMA PARAMETERS,
C    2) RADIAL PROFILE PARAMETERS.

      NAMELIST /INPUT3/
     1  IKIJ,NPART,BFLD,NTOT,
     .  MASS,CHARGE,CONC,TPAR,TPER,COLFREQ,
     2  IPROF,NSTRAT,
     .  WDENCM,WTEMPCM,WBFLDCM,
     .  RS,FDEN,FTEMP,FBFLD

      DATA
     1 IKIJ/1/,NPART/2/,BFLD/2.E3/,NTOT/2.E12/,
     , MASS/1.,5.447E-4/,CHARGE/1.,-1./,CONC/100.,100./,
     , TPAR/100.,100./,TPER/100.,100./,COLFREQ/2*1.E3/,
     2 IPROF/2/,NSTRAT/10/,
     , WDENCM/15./,WTEMPCM/20.,20./

      READ (5,INPUT1)
      READ (5,INPUT2)
      READ (5,INPUT3)

      RETURN
```

Sample Input Files

Default input file,

```
$
$
$
```

The following example illustrates the use of multiple scans and inputs on experimental plasma profile:

```
INDVAR=6 IVARLOW=1.E11 IVARHI=1.5E12 IVARINC=2.E11
INDVAR2=4 IVARLOW2=.7 IVARHI2=1.1 IVARINC2=.05
IFIELD=2
IEFLD=0 IBFLD=0 IPABS=0
$
ACM=16. CCM=20.
RHOCM=16. ZCM=20. PHI0DEG=90.
WNOR=1.
ICOIL=4
BCM=20. WIDCM=14. LNGCM=40.
CUR=(40.,0.)
$
NTOT=4.E11 TPAR=400. 30. COLFREQ=1.E4 1.E5
TPER=2.E3 30.
BFLD=1.5625E3
IPROF=4 NSTRAT=5
RS=15. 15.25 15.5 15.75 16.
FDEN=1. .7 .4 .1 .03
FTEMP= 1. 1. 0.
       1. 1. 0.
       1. 1. 0.
       1. 1. 0.
       1. 1. 0.
$
```

Appendix B

Fig. C.1 Full Turn Loop

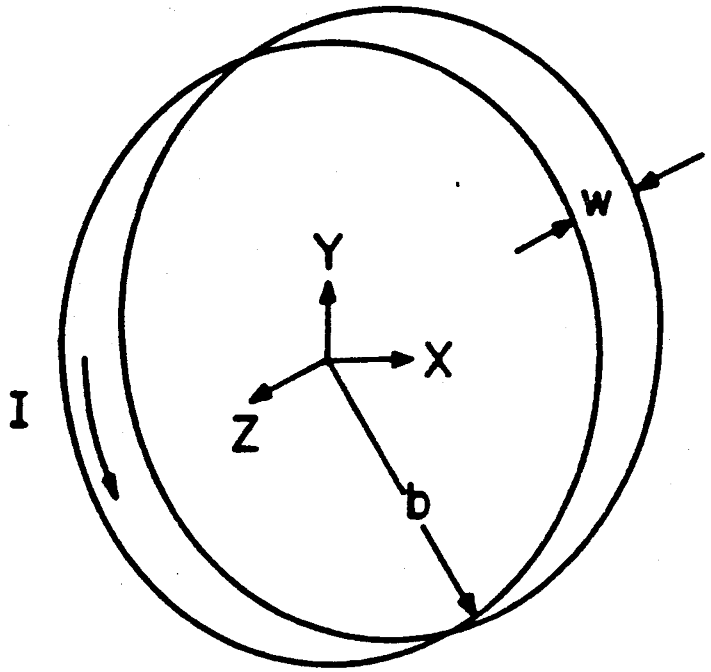


Fig. C.2 Saddle Coil

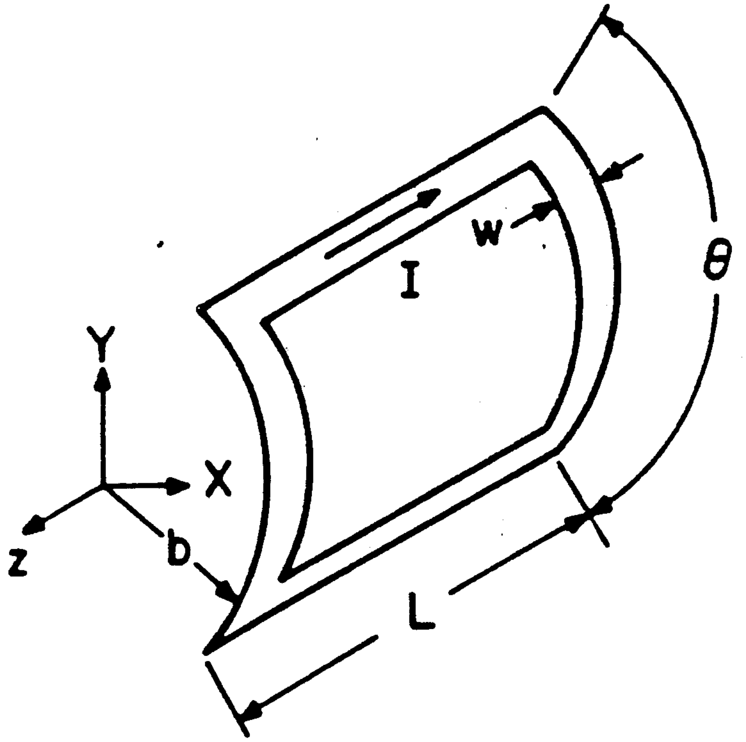


Fig. C.3 Nagoya Type III

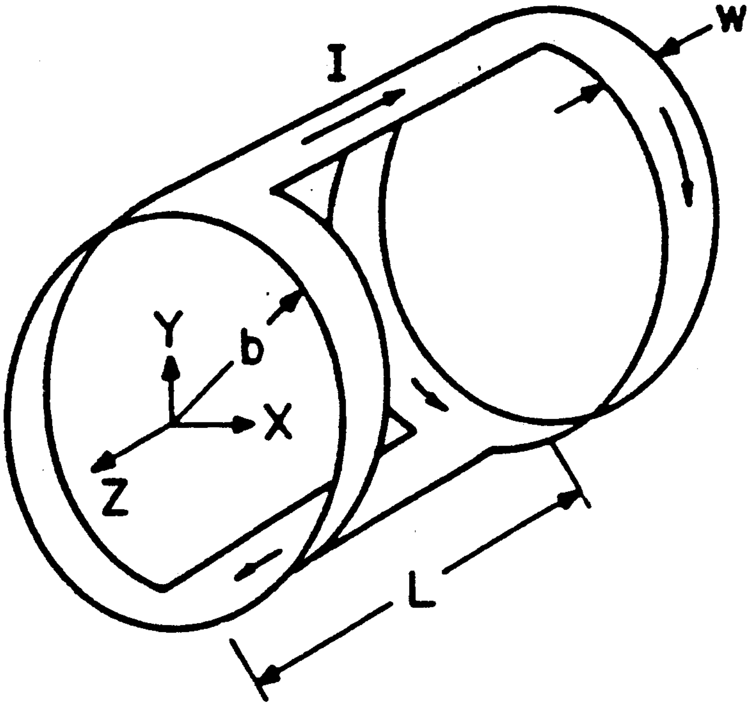


Fig. C.4a Rectangular Aperture

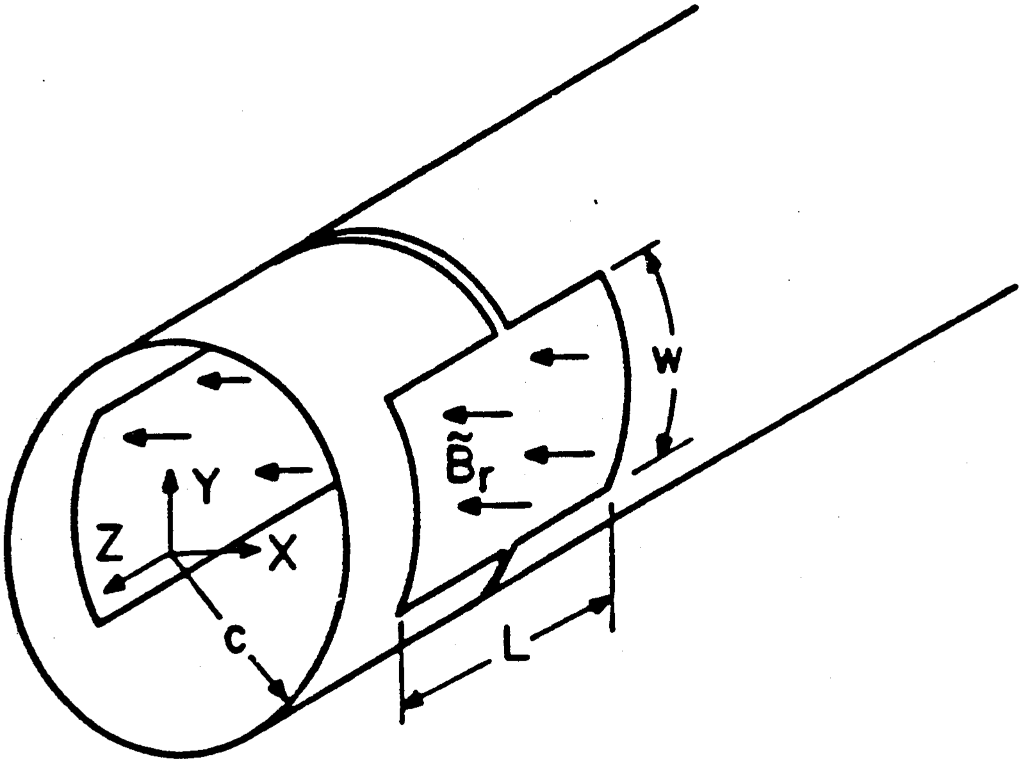


Fig. C.5 Line Current

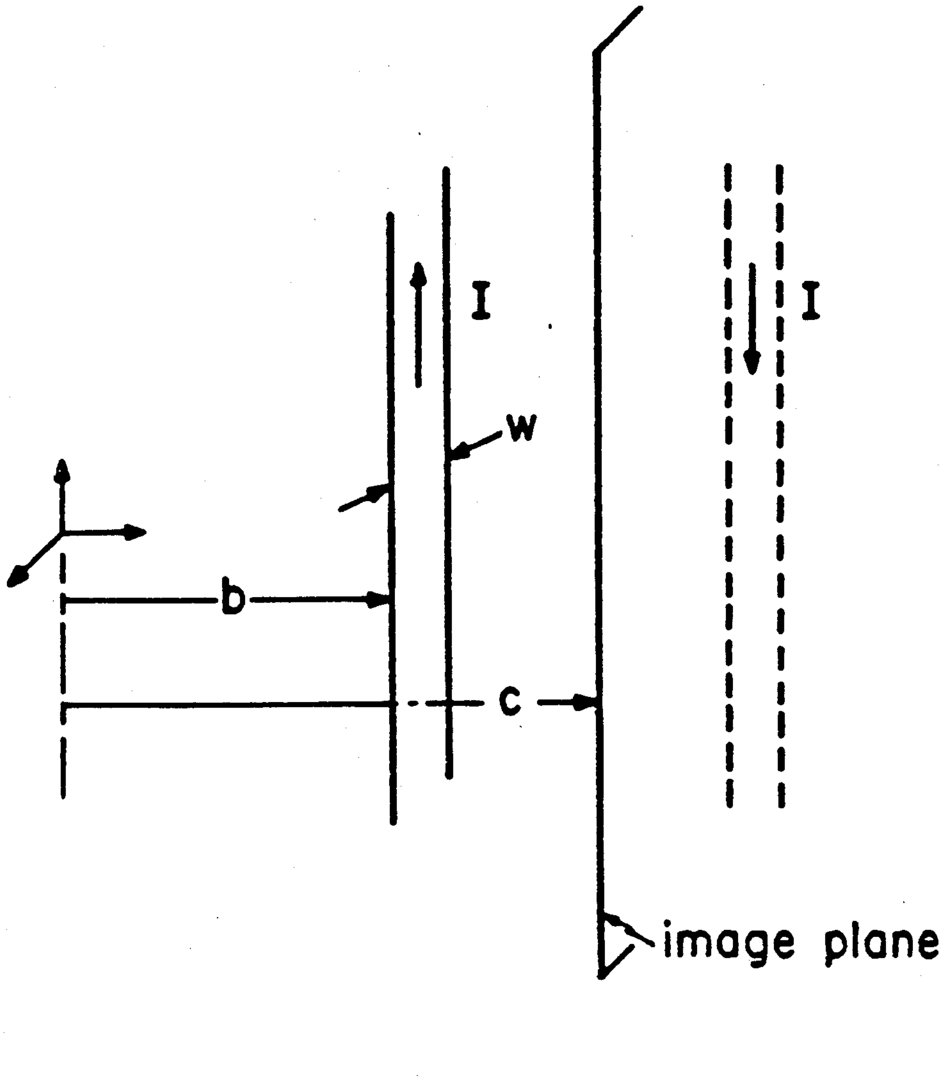


Fig. C.6 Partial Turn Loop

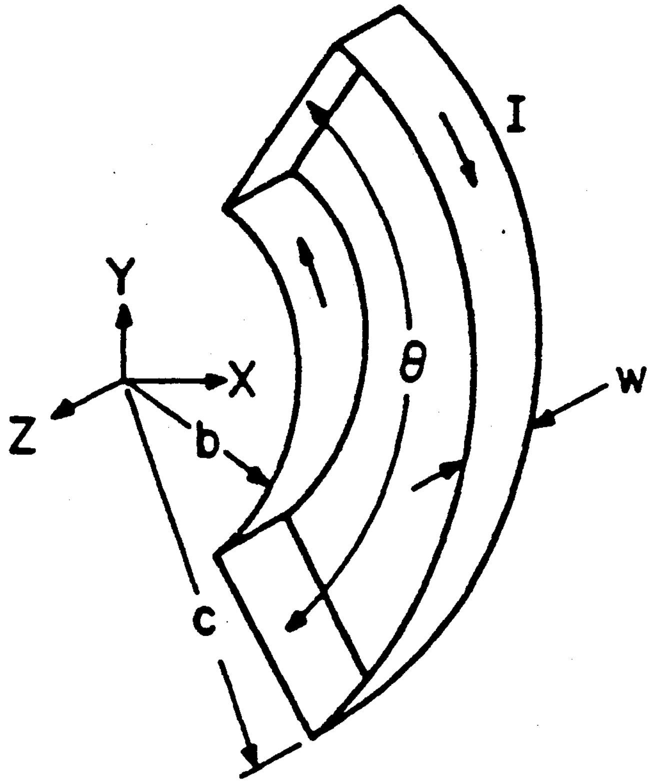


Fig. C.7 Half Nagoya