ANTENA USER GUIDE

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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 3
2. Availability and Execution 8
3. Input 10
4. Output 17
5. Compilation 19
Appendix A. Subroutine Input and Input Files 23
Appendix B. Antennas 25
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 Cylindically 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;

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

(1)

The Fourier transform can be defined as,
Fig. 4.1 Various ICRF Antennas

a. full turn loop

b. saddle coil
c. Nagoya type III

d. rectangular aperture

e. line current
f. partial turn loop

g. half Nagoya

h. array

4 half turn loops
Fig. 1.2 Antenna - Plasma Geometry

\[ a = \text{plasma radius} \]
\[ b = \text{inside radius of coil} \]
\[ c = \text{vacuum tank radius} \]
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; $r$, $\phi$, $z$, $\omega/\omega_{ci}$, $f$, $n_e$, $T_i$, $T_e$, $B_0$, $k_z$, 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

START

INPUT

INITLZE

PRINT PLOT

IVAR = IVARLOW

IVAR

> IVARHI

STOP

< IVARHI

ISPECTR

0

INTEG

1

SPECTR

FIELDS

PRINT PLOT
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 INPUT**

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICOORD</td>
<td>0</td>
<td>rectangular coordinates</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>cylindrical coordinates</td>
</tr>
<tr>
<td>IBFLD</td>
<td>1</td>
<td>the magnetic field calculation is on</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>the magnetic field is not calculated</td>
</tr>
<tr>
<td>IEFLD</td>
<td>1</td>
<td>the electric field calculation is on</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>the electric field is not calculated</td>
</tr>
<tr>
<td>IPABS</td>
<td>1</td>
<td>the power absorption calculation is on</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>the power absorption is not calculated</td>
</tr>
<tr>
<td>IEDOTJ</td>
<td>1</td>
<td>the antenna impedance calculation is on</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>the antenna impedance is not calculated</td>
</tr>
</tbody>
</table>

INDVAR determines the independent variable for the inner loop.

<table>
<thead>
<tr>
<th>INDVAR</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>r scan</td>
</tr>
<tr>
<td>2</td>
<td>θ scan</td>
</tr>
<tr>
<td>3</td>
<td>z scan</td>
</tr>
<tr>
<td>4</td>
<td>$\omega/\omega_c(1)$ scan</td>
</tr>
<tr>
<td>5</td>
<td>frequency scan</td>
</tr>
<tr>
<td>6</td>
<td>density scan</td>
</tr>
<tr>
<td>7</td>
<td>$</td>
</tr>
<tr>
<td>8</td>
<td>T(j) scan where $J = \text{IPART}$</td>
</tr>
</tbody>
</table>
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, $E_z(\pm L/2) = 0$
  - 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 $\pm$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 $\omega$ 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
- **ICOIL = 2**: saddle coil
- **ICOIL = 3**: Nagoya type III coil
- **ICOIL = 4**: rectangular aperture
- **ICOIL = 5**: line current
- **ICOIL = 6**: partial turn loop
- **ICOIL = 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 $E\int J$ 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
WTEMP CM  an array defining the temperature scale length for each species

The magnetic field in the plasma is calculated from $B_0(r) = B_{FLD} \sqrt{1 - \beta(r)}$.
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 label 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, 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 \( O = \) \_\_\_ 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, \( 2\pi \int_{0}^{a} \text{PABST} \, rdr \) yields the total power absorbed by the plasma. The output "PABST" 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-hand scale 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.
To enlarge the memory, to use options INDVAR = 10, IANTCON = 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.

- \( N_1 = 9 \) is the maximum number of coils in an array.
- \( N_2 = 3 \) is the maximum number of plasma species.
- \( N_3 = 50 \) is the maximum number of strata in a profile.
- \( N_4 = 21 \) 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. This program is dimensioned to accommodate up to \( \text{NEQU} = 400 \) first order differential equations. The parameter NEQU must be set to a value larger than \( N_7 \) 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 = ANTEA4 LIB = (F', LINTGA4, LIB1) / t v

**C-machine**

PRECOMP ANTEA4 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.

```fortran
1 SUBROUTINE INDVAR18(NOPT)
2 USE ANTCOM4
3 C THE INDEPENDENT VARIABLE IS LABELED.
4 DATA LABEL1(18)/" ZB(CM) "/
5 C ZB(2) IS THE AXIAL POSITION OF COIL NUMBER TWO.
6 IF (NOPT) 11,12,13
7 10 IF (NOPT) 11,12,13
8 11 SAVE(1) = ZB(2)
9 RETURN
10 C ZB(2) IS INCREMENTED.
11 12 ZB(2) = IVAR* .01
12 RETURN
13 C ZB(2) IS RESET.
14 13 ZB(2) = SAVE(1)
15 RETURN
16 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.h.

```
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,

- \( N_1 = 5 \) is the maximum number of coils in any array.
- \( N_2 = 3 \) is the maximum number of plasma species.
- \( N_3 = 50 \) is the maximum number of strata in a profile.
- \( N_4 = 102 \) is the maximum of \( 2 \times N_3 + 2 \) or \( N_5 \)
- \( N_5 = 31 \) is the maximum number of points in an inner scan.
- \( N_6 = 16 \) is the maximum number of points in an outer scan.

The code PLOTA4 is compiled with TV80LIB and DISSPLA.

Appendix A

SUBROUTINE INPUT: THE INPUT DATA FILE IS READ

SUBROUTINE INPUT

USE ANTICOM4

FIRST NAMELIST: 1) OUTPUT CONTROL PARAMETERS.

2) INNER AND OUTER SCAN PARAMETERS.

3) FIELD PARAMETERS.

4) INTEGRATION PARAMETERS.

5) MISCELLANEOUS.

NAMELIST /INPUT1/

ICOORD, BFLD, IFLD, IPABS, IEDOTJ,
INDVAR, IVARLOW, IVARHI, IVARINC, IPART,
INDVARZ, IVARLOWZ, IVARHI2, IVARINC2,
ISPECTR, IFIELD, INTEGKZ, IFAST, ISLOW,
KMINCM, KMAXCM, KSTEPCM, EPS, MF,
MAXIAL, NMAX,
ISIMEQ

DATA

INDVAR/I1/, IVARLOW/B/, IVARHI/I5/, IVARINC/3/, IPART/I1/,
INDVARZ/I1/, IVARLOWZ/I5/, IVARHI2/I1/, IVARINC2/I2/,
ICOORD/B/, BFLD/I1/, IFLD/I1/, IPABS/I1/, IEDOTJ/I1/,
INDVARTR/I1/, IFIELD/I1/, INTEGKZ/I2/, IFAST/I1/, ISLOW/I1/,
KMINCM/I1E-5/, KMAXCM/I1E1/, KSTEPCM/I1E-7/, EPS/I1E-4/, MF/I13/,
MAXIAL/I180/, NMAX/I5/,
ISIMEQ/I1/

SECOND NAMELIST: 1) PLASMA AND MACHINE DIMENSIONS.

2) NOMINAL POSITION AND WAVE PARAMETERS.

3) ANTENNA PARAMETERS.

4) ANTENNA CURRENT, DIMENSIONS, AND POSITION.

5) MISCELLANEOUS.

NAMELIST /INPUT2/

ACM, CCM, LNCM,
RHOCM, PHIDEG, ZCM,
WMOR, FREQ, KZOCM, NAZIM,
NCOILS, ICOIL,
ISERIES, IPARALL, IMUTUAL, IANTCON, NSTEP,
CUR, BCM, WIDCM, LNCM, ANGDEG,
ZBCM, PHIDEG,
VOLTS, INDUC

DATA

ACM/I15/, CCM/I35/, LNCM/I58/,
RHOCM/I5/, PHIDEG/I2/, ZCM/I5/,
WMOR/I1/, FREQ/I3.E6/, KZOCM/I81/, NAZIM/I99/,
NCOILS/I1/, ICOIL/I6/,
ISERIES/I1/, IPARALL/I1/, IMUTUAL/I1/, IANTCON/I1/, NSTEP/I3/,
CUR/I180/, B/I1/, BCM/I28/, WIDCM/I18/, LNCM/I18/, ANGDEG/I180/,
ZBCM/I1/, PHIDEG/I1/,
VOLTS/I1/, INDUC/I1/.

THIRD NAMELIST: 1) PLASMA PARAMETERS.

2) RADIAL PROFILE PARAMETERS.

NAMELIST /INPUT3/

IKIJ, NPART, BFLD, NTOT,
MASS, CHARGE, CONC, TPAR, TPER, COLFREQ,
IPROF, NSTRAT,
WDENCW, WTEMPCM, WBFLOCM,
RS, FDEN, FTEMP, FBFLO

DATA

IKIJ/I1/, NPART/I2/, BFLD/I2.E3/, NTOT/I2.E12/,
MASS/I1.E4/, CHARGE/I1.-1/, CONC/I188/, I88/,
TPAR/I188/, TPER/I188/, COLFREQ/I2E1.3/,
IPROF/I2/, NSTRAT/I1/,
WDENCW/I15/, WTEMPCM/I28/, FBFLO

READ (5, INPUT1)
READ (5, INPUT2)
READ (5, INPUT3)
RETURN
Sample Input Files

Default input file,

```
1 8
2 8
3 8
```

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=5 IBFLD=0 IPABS=6
RHOCM=16. ZCM=26. PHI0DEG=99.
WNOR=1.
ICOIL=4
CUR=45..5.
MTOT=4.E11 TPAR=466. 36. COLFREQ=1.41 1.55
TPER=2. E3 36.
BFLD=1.5625E3
IPROF=4 NSTRAT=5
RS=15. 15.25 15. 15.75 16.
FDEH=1. .7 .4 .1 .03
FTEMP= 1. 1. 5.
25
  1. 1. 5.
26
  1. 1. 5.
27
  1. 1. 5.
28
  1. 1. 5.
29
  1. 1. 5.
30
```
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