

Users' guide for 2D full wave code TASK/WF2

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1 Structure

1.1 Source program

Header	common variables	wfcomm.inc
Function	global control	wfmain.f
	element data generation	wfdiv.f
	zone data generation	wfzone.f
	antenna data generation	wfant.f
	wave analysis	wfwave.f
	transport analysis	wfevol.f
	graphics	wfgout.f
	dispersion relation	wffreq.f
Library	profile setting	wfprof.f
	file I/O	wfile.f
	common subroutines	wfsub.f
	graphic subroutines	wfgsub.f
	common library	wflib.f

- wfsub.f and wfgsub.f depends on wfcomm.inc.
- wflib.f is independent of wfcomm.inc.

1.2 Execution procedure

1. Element definition Define node points in computation area and generate triangular elements.
 2. Zone definition Define plasma, dielectric, and vacuum zones and boundary attributes,
 3. Antenna definition Define antenna shape and position.
 4. Wave analysis Calculate wave field excited by antenna and absorbed power density.
 5. Transport analysis Calculate time evolution of density and temperature of electrons and ions,
 6. Graphic display Indicate spatial profiles and time evolution,
- For simulation of plasma production by waves, steps 4 and 5 should be repeated to analyze time evolution.
 - For simulation of plasma production without waves, step 5 should be repeated to analyze time evolution.
 - Defined element data, zone data, and antenna data can be saved in files and loaded for new and continuation simulations.
 - Calculated spatial profiles will be saved in a file and loaded for continuation simulations (not yet implemented).

1.3 How to install

- Download gsaf, and task.
- Install gsaf library.
- cd to task directory
- Copy make.header.org to make.header
- Edit make.header for you computational environment.
- `make`

1.4 Coordinates

- Cartesian coordinates (MODELS=0)
horizontal: x , vertical: y , near side: z
- Cylindrical coordinates (MODELS=1)
horizontal: R , vertical: Z , near side: θ
- Toroidal coordinates: (MODELS=2)
horizontal: $R - R_0$, vertical: Z , near side: θ

1.5 Compile parameter

- The size of arrays are defined in `wfcomm.inc` as `parameter` sentences. If the file is modified, all depending files will be recompiled by `make`.

Variables	Default values	Explanation
NAM	8	maximum number of antenna
NFM	2	maximum number of particle species in TR
NSM	3	maximum number of particle species in WF
NXM	200	maximum number of division in X direction
NYM	200	maximum number of division in Y direction
JNUMM	800	maximum number of antenna elements
NBDYM	500	maximum number of boundary nodes
NNODM	2200	maximum number of nodes
NELMM	4000	maximum number of elements
MBNDM	400	maximum number of width of the band matrix
MLENM	12000	maximum number of length of the band matrix
NCNM	36	
NRM	101	maximum number of radial division for absorbed power density
NDM	20	maximum number of element attribute data
NBM	50	maximum number of boundary attribute data
NMM	8	maximum number of dielectric attribute data
NVM	2	maximum number of electric potential data
NGTM	1001	maximum number of time evolution data
NZLM	5	log ₂ of maximum number of fourier modes in Z direction
NWDM	12	maximum number of graphs on a page
NCHM	10	maximum character number of a graph attribute variable
NCM	3	maximum number of static magnetic field coil

- Parameters defined in a specific file

File name	Variables	Default values	Explanation
wfdiv.f	NXQM	11	maximum number of horizontal number of rectangulars
wfdiv.f	NYQM	11	maximum number of vertical number of rectangulars
wffreq.f	NNXM	201	maximum number of horizontal division in 1D plot
wfgsub.f	NGXM	101	maximum number of horizontal division in contour plots
wfgsub.f	NGYM	101	maximum number of vertical division in contour plots
wfgsub.f	NSTEP	101	maximum number of contours in contour plots
libspl.f	NMAX	1001	maximum number of data for spline interpolation

2 Input parameters

```

C
C   *** DEFAULT FILE NAME ***
C
C   KFNAME: File name of element data
C   KFNAMA: File name of antenna data
C   KFNAMEF: File name of field data
C   KFNAMZ: File name of zone data
C
C   KFNAME = 'elm-data'
C   KFNAMA = 'ant-data'
C   KFNAMEF = 'fld-data'
C   KFNAMZ = 'zone-data'
C
C   *** CONFIGURATION PARAMETERS ***
C
C   BB      : Magnetic field at center          (T)
C   RA      : Plasma minor radius              (m)
C
C   BB      = 0.08D0
C   RA      = 0.08D0
C
C   *** CONFIGURATION PARAMETERS (MIRROR: MODELB=3,4) ***
C
C   RMIR    : Mirror ratio
C   ZBB     : Periodic length along magnetic axis (m)
C
C   RMIR    = 2.0D0
C   ZBB     = 0.15D0
C
C   *** CONFIGURATION PARAMETERS (TOKAMAK: MODELB=5) ***
C
C   RR      : Plasma major radius              (m)
C   Q0      : Safety factor at center
C   QA      : Safety factor on plasma surface
C   RKAP    : Plasma shape elongation
C   RDEL    : Plasma shape triangularity *
C
C   RR      = 3.D0
C   Q0      = 1.D0
C   QA      = 3.D0
C   RKAP    = 1.D0
C   RDEL    = 0.D0
C
C   *** CONFIGURATION PARAMETERS (HELICAL: MODELB=6) ***
C
C   H1      : Helical pitch (2*pi/L) for B profile
C   H2      : Helical pitch (2*pi/L) for metric
C   RRC     : Coil radius                      (m)
C
C   H1      = 1.25D0
C   H2      = 1.25D0
C   RRC     = 0.95D0
C
C   *** CIRCULAR COIL PARAMETERS (MODELB=7) ***
C
C   NCMAX   : Number of coil
C   RC      : Radial position of coil current (m)
C   ZC      : Axial position of coil current (m)
C   B2      : Magnetic field on axis, center of coil (T)
C
C   NCMAX   = 3
C   RC(1)   = 0.35D0
C   ZC(1)   = 0.D0
C   BC(1)   = 0.001D0
C   RC(2)   = 0.35D0
C   ZC(2)   = 0.05D0
C   BC(2)   = -0.001D0
C   RC(3)   = 0.35D0

```



```

        PTPP(2)=0.01D0
        PTS(2)=0.D0
        PZCL(2)= 0.02D0
    ENDIF
C
    IF(NSM.GE.3) THEN
        PA(3)= 1.0D0
        PZ(3)= 1.0D0
        PN(3)= 0.0D0
        PNS(3)= 0.0D0
        PTPR(3)=0.1D0
        PTPP(3)=0.1D0
        PTS(3)=0.D0
        PZCL(3)= 0.001D0
    ENDIF
C
    *** CONTROL PARAMETERS ***
C
    MODELS: 0 : No symmetry
C
             1 : Axial symmetry (Y axis)
C
             2 : Axial symmetry (Y axis -RR)
C
             3 : Helical symmetry (Z axis)
C
    MODELB: 0 : X axis
C
             1 : Y axis
C
             2 : Z axis
C
             3 : Axisymmetric mirror
C
             4 : Translational mirror
C
             5 : Tokamak
C
             6 : Helical
C
             7 : Circular coils
C
    MODELD: 0 : Cold plasma model
C
             1 : Warm plasma model
C
             2 : Hot plasma model
C
    MODELP: 0 : Flat profile
C
             1 : Radially parabolic profile
C
             2 : Axially exponential profile
C
             3 : Radially and axially parabolic profile
C
             4 : Temporal use
C
             5 : Radially parabolic and axially quartic profile
C
    MODELW: 0 : Fixed density and fixed temperature on boundary
C
             1 : Free density and fixed temperature on boundary
C
             2 : Free Density and free temperature on boundary
C
    MODELT: 0 : Fixed temperature model
C
             1 : Density gradient model
C
             2 : Pressure gradient model
C
    MODELN: 0 : Fixed crosssection for electron collision with neutrals
C
             1 : Mometum transder collision data
C
    MODELV:   : Type of divide model
C
    MODELS = 1
    MODELB = 3
    MODELD = 0
    MODELP = 1
    MODELW = 0
    MODELT = 2
    MODELN = 0
    MODELV = 0
C
    *** OUTPUT PARAMETERS ***
C
    NPRINT: Print output parameter
C
             0 - No output
C
             * 1 - Parameter and global field data
C
             2 - Local field data
C
             3 - Element data
C
    NDRAWD: Drawing parameter for elemendt divider
C
             0 : Boundary shape
C
             * 1 : Element shape
C

```

```

C          2 : Element shape + Element number
C          3 : Element shape + Element number + Node number
C      NDRAWA: Drawing parameter for antenna generater
C          0 : Antenna primary data
C          1 : Antenna secondary data
C          * 2 : Antenna secondary data + Element shape
C      NRMAX : Number of radial mesh points
C
C      NPRINT = 1
C      NDRAWD = 1
C      NDRAWA = 2
C      NRMAX  = 101
C
C      *** DIVIDER PARAMETERS ***
C
C      BXMIN : Minimum x (m)
C      BXMAX : Maximum x (m)
C      BYMIN : Minimum y (m)
C      BYMAX : Maximum y (m)
C      RB    : Boundary radius (m)
C      BKAP  : Boundary elongation
C      BDEL  : Boundary triangularity *
C      DELX  : Typical element size in x direction (m)
C      DELY  : Typical element size in y direction (m)
C
C      BXMIN = 0.0D0
C      BXMAX = 0.1D0
C      BYMIN = -0.15D0
C      BYMAX = 0.15D0
C      RB    = 0.25D0
C      BKAP  = 1.0D0
C      BDEL  = 0.0D0
C      DELX  = 0.01D0
C      DELY  = 0.01D0
C
C      *** ANTENNA SHAPE PARAMETERS ***
C
C      PIN   : Input Power (W); Set 0.0 to calculate from antenna current
C      PHIW  : Potential of wave electrode (V)
C      RD    : Antenna radius (m)
C      THETJ1: Start angle of arc antenna (degree)
C      THETJ2: End angle of arc antenna (degree)
C      ZJH1  : Axial start position of helical antenna (m)
C      ZJH2  : Axial end position of helical antenna (m)
C      PHJH  : Rotation angle of helical antenna (degree)
C      NTYPJH: Type of helical antenna
C          0 : Loop antennas on both ends
C          1 : Loop antenna on the second end
C          2 : Loop antenna on the first end
C          3 : No loop antenna
C      NJMAX : Number of primary grid points of antenna
C
C      PIN   = 0.0D0
C      PHIW  = 0.0D0
C      RD    = 0.22D0
C      THETJ1 = 40.0D0
C      THETJ2 = -40.0D0
C      ZJH1  = 0.01D0
C      ZJH2  = 0.19D0
C      PHJH  = 360.0D0
C      NTYPJH = 0
C      NJMAX = 41
C
C      *** TRANSPORT PARAMETERS ***
C
C      DT    : Time step size
C      NTMAX  : Iteration number
C      NSTEP  : Number of transport calculations after one wave calculation
C      NFMAX  : Number of particle species in transport calculation
C

```



```

DT      = 1.D-6
NTMAX   = 1
NTSTEP  = 10
NFMAX   = 2

C
C
C *** TRANSPORT PLASMA PARAMETERS ***
C
C PPNO   : Neutral pressure (Pa)
C          1 torr = 133.322 Pa
C PTNO   : Initial neutral temperaturure (eV)
C PNEO   : Initial electron density (1.D20/m^3)
C PTEO   : Initial electron temperature (eV)
C PTIO   : Initial ion temperature (eV)
C PNES   : Edge electron density (1.D20/m^3)
C PTES   : Edge electron temperature (eV)
C PTIS   : Edge ion temperature (eV)
C
C PPNO   = 1.D0
C PTNO   = 0.03D0
C PNEO   = 1.D-6
C PTEO   = 0.03D0
C PTIO   = 0.03D0
C PNES   = 1.D-6
C PTES   = 0.03D0
C PTIS   = 0.03D0
C
C
C *** BOHM DIFFUSION ***
C
C DC      : FACTOR OF BOHM DIFFUSION COEFFICIENT
C
C DC      = 1.D0
C
C
C *** COMPUTATION PARAMETERS ***
C
C EPSIMP  : CONVERGENCE CRITERION FOR IMPLICIT TIME EVOLUTION
C EPSSUM  : BOUNDARY BETWEEN RELATIVE ERROR AND ABSOLUTE ERROR
C MAXIMP  : MAXIMUM LOOP COUNT FOR IMPLICIT TIME EVOLUTION
C FACIMP  : IMPLICIT FACTOR
C
C EPSIMP  = 1.D-4
C EPSSUM  = 1.D0
C MAXIMP  = 1
C FACIMP  = 1.D0
C
C
C *** ARTIFICIAL SOURCE ***
C
C PGIVEN  : MAXIMUM POWER DENSITY
C SGIVEN  : MAXIMUM PLASMA SOURCE DENSITY
C XGIVEN  : X COORDINATE OF THE CENTER OF THE SOURCE
C YGIVEN  : Y COORDINATE OF THE CENTER OF THE SOURCE
C RGIVEN  : DECAY LENGTH OF THE SOURCE
C
C PGIVEN  = 0.D0
C SGIVEN  = 0.D0
C XGIVEN  = 0.05D0
C YGIVEN  = 0.D0
C RGIVEN  = 0.05D0
C
C
C *** ELECTRODE PARAMETERS ***
C
C RFES    : FREQUENCY OF ELECTRODE POTENTIAL
C PHIES   : AMPLITUDE OF ELECTRODE POTENTIAL
C
C RFES    = 13.56D0
C PHIES   = 0.D0
C
C
C *** GRAPHICS CONTROL PARAMETERS ***
C
C KGINX   : GRAPHIC CONTROL STRINGS
C KGINV   : GRAPHIC CONTROL STRINGS

```

```

C
KGINX(0)='EXI EYI EZR PP1C'
KGINX(1)='EXR EXI EYR EYI'
KGINX(2)='EZR EZI PP1C PP2C'
KGINX(3)='EXR EXI EYR EYI EZR EZI PP1C PP2C'
KGINX(4)='AXR AXI AYR AYI AZR AZI AFR AFI'
KGINX(5)='PFOC PNEC PTEC PTIC PIOC PCOC'
KGINX(6)='PFOY0 PFOY0.03 PFOX0 PFOX0.05'
KGINX(7)='PNEY0 PNEY0.03 PNEX0 PNEX0.05'
KGINX(8)='PTEY0 PTEY0.03 PTEX0 PTEX0.05'
KGINX(9)='L2 TFO TNE TTE TTI'

C
KGINV(0)='EXR,EXI,EYR,EYI,EZR,EZI,PP1C,PP2C,PNEC,PTEC,TNE,TTE'
KGINV(1)='PC1C PC2C PR1C PR2C'
KGINV(2)='PU1C PU2C PV1C PV2C'
KGINV(3)='PD1C PD2C PE1C PE2C'
KGINV(4)='PH1C PH2C PK1C PK2C'
KGINV(5)='PIOC'
KGINV(6)='PIOC'
KGINV(7)='PIOC'
KGINV(8)='PIOC'
KGINV(9)='PIOC'

C
C
C *** GRAPHICS CONTROL PARAMETERS ***
C
C NGRAPH: Type of 1D graphic output
C 1 : Autoscale plot
C 2 : Symmetric scale plot
C 3 : Amplitude and phase plot
C NGRAPH: Type of 2D graphic output
C 1 : Contour plot (in element mesh)
C 2 : Color-painted contour plot (in rectangular mesh)
C 3 : Bird's eye view
C 4 : Contour plot (in rectangular mesh)
C FRATIO: Horizontal expansion factor for 2D graphics
C
C NGRAPH=1
C FRATIO=1.DO
C NGXORG=1

C
C *** 3D GRAPHICS CONTROL PARAMETERS ***
C
C GA=-25.0
C GB= 0.0
C GC=-30.0
C GD= 0.0
C GE= 1000.0
C GXN= 6.0
C GYN= 9.0
C GZN= 3.0
C GXN1=-5.0
C GXN2= 5.0
C GYN1= 0.0
C GYN2=10.0
C IXY= 3
C IDN=-3

C
MODIFY=0

```

3 Execution contraol (wfmain)

1. Function

- Command input
 - P: parameter input
 - V: view parameter
 - D: division of elements
 - Z: zone data creation
 - A: antenna data creation
 - W: wave analysis
 - T: tranport analysis
 - R: run wave-transport coupled analysis
 - C: continue wave-transport analysis
 - G: graphic output
 - S: save data in a file
 - L: load data from a file
 - B: characteristic frequencies vs density
 - Q: quit
- Parameter input in a **namelist** format
BB=1.2d0
If variable name is not diefined in **namelist**,
a list of variables defined in **namelist** is shown.

2. Order of parameter setup

- Initialization in **WFINIT**
- Input from a namelist file **wfparm**
- Input in a command line

4 Division of elements (wfddiv)

1. Function

D: creation of node and element data
G: graphic output of node and element data
W: numerical output of node and element data
S: save node and element data to a file
L: load node and element data from a file
X: exit

2. Type of division

X: One rectangular
BXMIN, BXMAX (minimum of x , maximum of x)
BYMIN, BYMAX (minimum of y , maximum of y)
R: Multi rectangular
NYQMAX (number of YPOS data)
YPOS (y position)
NXQMAX (number of XPOS data for $y=YPOS$)
XPOS (x position)
Divide in rectangles
P: One quadrangle (oblique shape, $xmin = 0$)
BXMIN, BXMAX ($xmax$ at BYMIN, $xmax$ at BYMAX)
BYMIN, BYMAX (minimum of y , maximum of y)
M: Axisymmetric mirror
BXMIN, BXMAX, BYMIN, BYMAX
Divide in magnetic surface shape of axisymmetric mirror
V: Translational mirror
BXMIN, BXMAX, BYMIN, BYMAX
Divide in magnetic surface shape of one-dimensional mirror
C: Circular
RB (wall radius)
T: Tokamak (poloidal cross section)
RB, BKAP, BDEL (wall radius, ellipticity, triangularity)
H: Linear helical
RB, BXMIN, BXMAX (wall radius, minimum x , maximum x)

3. Division step

- Divide with step less than DELX and DELY

4. Created data

- Position of nodes: XD(IN),
 - YD(IN) IN = node number, maximum: NNOD
- Node numbers of a triangular element: IELM(3,IE)
 - IE = Element number maximum: NELM
 - anti-clock wise: 1, 2, 3

5 Creation of antenna data (wfant)

1. Function

A: creation of antenna data
G: graphic output of antenna data
W: numerical output of antenna data
S: save antenna data to a file
L: load antenna data from a file
X: exit

2. Definition on antenna

- NAMAX: maximum number of antenna
- Shape of antenna
 - C: Circular antenna: RD, RKAP, NJMAX
(antenna radius, ellipticity, number of division)
 - A: Arc antenna: THETA1, THETA2, RD, RKAP, NJMAX
istart angle, end angle, antenna radius, ellipticity, number of division)
 - P: Loop/Line antenna: NJMAX (number of antenna node)
 - * NJMAX = 1: loop antenna
 - * NJMAX > 1: line antenna connecting nodes (actually a plane in z direction)
 - H: Helical antenna:
 - * ZJH1 : Axial start position of helical antenna (m)
 - * ZJH2 : Axial end position of helical antenna (m)
 - * RD : antenna radius (m)
 - * PHJH : Rotation angle of helical antenna (degree)
 - * NTYPJH: Type of helical antenna
 - 0 : Loop antennas on both ends (NJMAX=2)
 - 1 : Loop antenna on the second end (NJMAX=3)
 - 2 : Loop antenna on the first end (NJMAX=3)
 - 3 : No loop antenna (NJMAX=4)
 - 10 : Helicon antenna (NJMAX=2)
 - * NJMAX > 1: line antenna connecting nodes (actually a plane in z direction)
 - L: Helicon antenna:
 - * ZJH1 : Axial start position of antenna (m)
 - * ZJH2 : Axial end position of antenna (m)
 - * ZJH3 : Axial position of inward feeder (m)
 - * ZJH4 : Axial position of outward feeder (m)
 - * RTJ1 : Rotation angle of helical part at start position of antenna (degree)
 - * RTJ2 : Rotation angle of helical part at end position of of antenna (degree)
 - * RD : antenna radius (m)

3. created data

- Antenna node position: XJO(NJO,NA), YJO(NJO,NA)
- Variables
 - NA = antenna number maximum: NAMAX
 - NJO = antenna node number maximum: NJOMAX(NA)

6 Creation of attribute data (wfzone)

1. Function

Z: creation of attribute data

G: graphic output of attribute data

W: numerical output of attribute data

S: save attribute data to a file

L: load attribute data from a file

X: exit

2. Creation of attribute data

D: Definition of element attribute data

- NDMAX: number of data
- ND,ID,XMIN,XMAX,YMIN,YMAX: element zone number, attribute of element, zone area
- Define element attribute of the elements in the zone
 - * ID=0: plasma (default)
 - * ID=1: vacuum
 - * ID>1: dielectric of specified dielectric attribute

E: Definition of dielectric attribute

- NMMAX: number of dielectric attribute
- NM,EPSP: dielectric attribute number, relative dielectric constant
- Define relative dielectric constant for dielectric attribute number

M: Definition of permittive/dielectric/resistive attribute

- NMMAX: number of material attribute
- NM: dielectric attribute number
- EPSP: relative dielectric constant
- RMUD: relative permittivity constant
- SIGD: resistivity

A: Definition of wave boundary attribute

- NBMAX: number of wave boundary attributes
- NB,ID,XMIN,XMAX,YMIN,YMAX: wave boundary attribute number, type of wave boundary attribute, zone area
- Define wave boundary attribute of the boundary nodes in the zone
 - * ID=0: in the plasma (default)
 - * ID=1: boundary between plasma and conductor with potential 0
 - * ID=2: boundary between plasma and conductor with potential PHIW
 - * ID=3: boundary between plasma and conductor with potential continuously varying from 0 to PHIW
 - *

B: Define transport boundary attribute

- NBMAX: number of transport boundary attributes

- NB,ID,XMIN,XMAX,YMIN,YMAX: transport boundary attribute number, transport boundary attribute, zone area
- Define transport boundary attribute of the boundary nodes in the zone
 - * ID=0: in a plasma (default)
 - * ID=1: boundary between plasma and conductor with potential 0
 - * ID=2: boundary between plasma and conductor with potential PHIES
 - * ID=3: boundary between plasma and conductor with potential continuously varying from 0 to PHIES.
 - * ID=4: boundary between plasma and conductor with potential oscillating with amplitude PHIES and frequency RFES
 - * ID=5: boundary between plasma and conductor with potential oscillating with amplitude varying from 0 to PHIES and frequency RFES
 - * ID=8: boundary between plasma and dielectric (insulator) without surface charge
 - * ID=9: boundary between plasma and dielectric (insulator) with surface charge
 - * ID=10: vacuum or dielectric (default)
 - * ID=11: boundary between vacuum/dielectric and conductor with potential 0
 - * ID=12: boundary between vacuum/dielectric and conductor with potential PHIES
 - * ID=13: boundary between vacuum/dielectric and conductor with potential continuously varying from 0 to PHIES.
 - * ID=14: boundary between vacuum/dielectric and conductor with potential oscillating with amplitude PHIES and frequency RFES
 - * ID=15: boundary between vacuum/dielectric and conductor with potential oscillating with amplitude varying from 0 to PHIES and frequency RFES

W: Definition of wave boundary potential variation

- NVMAX: number of wave boundary potential variation
- NV,XMIN,XMAX,YMIN,YMAX: wave boundary potential variation number, wave boundary potential variation, zone area
- For wave boundary attribute ID=3, define the range of wave potential varying only NV=1 is available at present
wave potential = 0 at X=XMIN, Y=YMIN
and PHIW at X=XMAX, Y=YMAX

P: Definition of transport boundary potential variation

- NVMAX: number of transport boundary potential variation
- NV,XMIN,XMAX,YMIN,YMAX: transport boundary potential variation number, transport boundary potential variation, zone area
- For wave boundary attribute ID=3, 5, 13, 15, define the range of transport potential varying only NV=1 is available at present
wave potential = 0 at X=XMIN, Y=YMIN
and PHIS at X=XMAX, Y=YMAX

V: view attributes

X: exit

7 Wave analysis (wfwave)

1. Functions

- Reduce Maxwell's equation for potential (\vec{A}, ϕ) to a simultaneous equation $\mathbf{A} \cdot \vec{x} = \vec{b}$ with the finite element method, and calculate the wave electric field and the absorbed power density by solving the matrix equation.

2. Procedure

1) Pre-processing

- SETANT: Set antenna current
- CVDBND: Set node attribute (KBND(IN), IBND(IN)) and calculate the size of coefficient matrix.
- CVCALC: Calculate right-hand-side vector \vec{b} from the antenna current

2) Solver

- CVSOLV: Calculate coefficient matrix \mathbf{A} for each element, translate the calculated line to a upper triangular band matrix, and obtain \vec{x} by backward substitution after translation completed.
 - CMCALC: Calculate coefficient matrix \mathbf{A} for each element.
 - DTENSR: Calculate dielectric tensor at each node

3) Post-processing

- CALFLD: Calculate the wave electric field from the potential
- PWRABS: Calculate the absorbed power in each element and distribute it the nodes.
- PWRRAD: Integrate the wave electric field along the antenna current to calculate the radiated power.

8 Transport analysis (wffvol)

1. Function

- Time evolution equation for plasma density, temperature, and potential is reduced to a simultaneous equation $\mathbf{A} \cdot \vec{x} = \vec{b}$ using the finite element method, and solve it numerically

2. Procedure

1) Pre-processing

- DVDBND: setup attribute, KBND(IN) and IBND(IN), and calculate the width and length of the band coefficient matrix.
- DVCALC: Calculate right-hand-side vector \vec{b} .

2) Solver

- DVSOLV: Calculate coefficient matrix \mathbf{A} for each element, translate the calculated line to a upper triangular band matrix, and obtain \vec{x} by backward substitution after translation completed.

DMCALC: Calculate coefficient matrix \mathbf{A} for each element.

WFCOEF: Calculate diffusion coefficient on the node.

3) Post-processing

- DALFLD: Calculate density, temperature and electrostatic potential from the solution vector \vec{x} .
- WFEVST: Save varying variables.

9 Graphic output (wfgout)

Indicate graphics of spatial profile and time evolution. One graphic control command separated by a space corresponds to one figure. Multiple figures are drawn on a page by writing a number of commands in a line.

9.1 Example of input data

Example 1: EXR EYI EZA

- The following three figures are drawn on a page.
 - Contour of the real part of the x component of the wave electric field E_x
 - Contour of the imaginary part of the x component of the wave electric field E_x
 - Contour of the absolute value of the z component of the wave electric field E_z

Example 2: EYX0.0 PTEC PNIY0.0

- x dependence of the y component of the wave electric field E_y at $y = 0.0$
- Contour of electron temperature
- y dependence of the ion density at $x = 0.0$

Example.3: TN1

Time dependence of the electron density (solid line: average, dashed line: maximum, broken line: minimum)

Example 4: 5

- Profiles of electrostatic potential, density, temperature
- Character strings defined by KGINX(5) in WFINIT.

9.2 Definition of graphic control command

EX ₁ X ₂	spatial profile of wave E
BX ₁ X ₂	spatial profile of wave B
AX ₁ X ₂	spatial profile of wave potential
PX ₁ X ₂ X ₃	spatial profile of plasma quantities
TX ₁ X ₂	time evolution of plasma quantities
n	combination of pre-defined string in (KGINX)
Vn	combination of pre-defined string in (KGINV)
G n	type of graphic output
L n	number of figures in horizontal direction on a page
X	exit

9.3 E/B/A

- X₁ X x
- Y y
- Z z
- + E_g
- left-hand-side polarization component
- P parallel component

- X_2 R Contour of real part
- I Contour of imaginary part
- A Contour of absolute value
- X_{pos} x dependence at $y = pos$
- Y_{pos} y dependence at $x = pos$

9.4 P: spatial profile

- X_1 P Absorbed power density
- N Particle number density
- T Temperature
- B Magnetic field strength and flux
- M Pressure
- G Drift velocity
- S Surface electric charge density
- F Electrostatic potential
- C Electrical charge density
- R Collision frequency
- U Parallel mobility: mu-para
- V perpendicular mobility: mu-perp
- D Particle diffusion coefficient: D-para
- E Particle diffusion coefficient: D-perp
- H Thermal diffusion coefficient: chi-para
- K Thermal diffusion coefficient: chi-perp
- I Ionization particle source
- X_2 E Electron component
- I Ion component
- 1 First component (usually = electron)
- 2 Second component (usually = ion)
- X_3 C Contour plot
- X_{pos} x dependence at $y = pos$
- Y_{pos} y dependence at $x = pos$

9.5 T: time evolution

- X_1 N particle density
- T temperature
- F electrostatic potential
- P absorbed power
- X_2 E Electron component
- I Ion component
- 0 not relevant (e.g. electrostatic potential)
- 1 First component (usually = electron component)
- 2 Second component (usually = ion component)

10 List of subroutines

MAIN (wfmain.f)	main program
WFINIT (wfmain.f)	initialization of input parameters
WFPLST (wfmain.f)	show input parameter list
WFPARM (wfmain.f)	read input parameters
WFVIEW (wfmain.f)	view input parameters
WFDIV (wfdiv.f)	division of element
DFNODX (wfdiv.f)	division of a rectangular
DFNODP (wfdiv.f)	division of a parallelogram
DFNODR (wfdiv.f)	division of multiple rectangulars
DFNODM (wfdiv.f)	division of axisymmetric mirror
BOUNDM (wfdiv.f)	definition of axisymmetric mirror
DFNODV (wfdiv.f)	division of translational mirror
BOUNDV (wfdiv.f)	definition of translational mirror
DFNODC (wfdiv.f)	division of arbitrary shaped region (simply connected)
BOUNDX (wfdiv.f)	definition of x-direction boundary
BOUNDY (wfdiv.f)	definition of y-direction boundary
BOUNDF (wfdiv.f)	definition of boundaries
SETNOD (wfdiv.f)	define node from division data
SETELM (wfdiv.f)	define element from division data
WFLDIV (wfdiv.f)	numerical output of node and element data
WFGDIV (wfdiv.f)	graphic output of node and element data
WFPRME (wfdiv.f)	graphic output of number of nodes and elements
FWWELM (wffile.f)	file output of element data
WFRELM (wffile.f)	file input of elemental data
WFZONE (wfzone.f)	setting attribute data
WFXZON (wfzone.f)	define attribute data
WFGZON (wfzone.f)	graphic output of attribute data
WFLZON (wfzone.f)	numerical output of attribute data
WFSETZ (wfzone.f)	create attribute array from attribute data
SETBDY (wfzone.f)	create boundary attribute array from attribute data
EFINDK (wfzone.f)	find an element including specified two nodes
FWWZON (wffile.f)	file output of attribute data
WFRZON (wffile.f)	file input of attribute data
WFANT (wfant.f)	setting antenna data
WFDEFA (wfant.f)	define antenna data
WFPLTA (wfant.f)	graphic output of antenna data
WFPRMJ (wfant.f)	graphic output of antenna parameters
FWWANT (wffile.f)	file output of antenna data
WFRANT (wffile.f)	file input of antenna data
FWWAVE (fwwave.f)	wave analysis
WFSETW (fwwave.f)	initial setup of wave analysis
SETANT (fwwave.f)	Fourier decomposition of antenna current
CVDBND (fwwave.f)	initialization of matrix solver

CVCALC (wfwave.f)	calculation of right-hand-side vector
CVSOLV (wfwave.f)	matrix solver
CMCALC (wfwave.f)	calculation of matrix coefficient
DTENSR (wfwave.f)	calculation of dielectric tensor
CALFLD (wfwave.f)	calculation of wave E from solution vector
PWRABS (wfwave.f)	calculation of absorbed power
PWRRAD (wfwave.f)	calculation of radiated power from antenna
INITEP (wfwave.f)	initialization of Fourier component of wave E
TERMEP (wfwave.f)	Fourier composition of wave E
LPEFLD (wfwave.f)	numerical output of wave E data
LPELMT (wfwave.f)	numerical output of element and node data
WFWFLD (wffile.f)	file output of wave E data
WFRFLD (wffile.f)	file input of wave E data
WFEVIN (wfevol.f)	initialization of transport analysis
WFEVOL (wfevol.f)	one step of transport analysis
DVDNOD (wfevol.f)	initialization of matrix solver
DVSOLV (wfevol.f)	matrix solver
DMCALC (wfevol.f)	calculation of matrix coefficient
DMCALD (wfevol.f)	matrix coefficient in vaccum and dielectric
DMCALP (wfevol.f)	matrix coefficient in plasma
WFCOEF (wfevol.f)	calculation of transport coefficients
DALFLD (wfevol.f)	calculation of density and temperature from solution vector
WFEVST (wfevol.f)	save time evolution of transport data
WFGOUT (wfgout.f)	graphic output control
WFCTOG (wfgout.f)	conversion of complex 3 data (Ex Ey Ez)
WFATOG (wfgout.f)	conversion of complex 4 data (Ax Ay Az phi)
WFDTOG (wfgout.f)	conversion of real data
WFTTOG (wfgout.f)	conversion of time evolution data
WFCALB (wfgout.f)	calculation of wave magnetic field and polarization
WFCALD (wfgout.f)	calculation of wave dispersion relation
WFGINI (wfgsub.f)	initialization of plot size
WFGWIN (wfgsub.f)	determinatioin of plot size
WFGVEW (wfgsub.f)	determinatioin of plot layout
WFGPFX (wfgsub.f)	contour plot of profile data
WFGPPR (wfgsub.f)	1D plot of profile data
WFGPPRX(wfgsub.f)	1D plot of profile data
WFGPFR (wfgsub.f)	1D plot of profile data
WFGPAR (wfgsub.f)	1D plot of profile data
WFGPFT (wfgsub.f)	1D plot of time evolution
WFGPRM (wfgsub.f)	draw computation parameters
WFGNOD (wfgsub.f)	draw attribute data boundary nodes
WFGBDY (wfgsub.f)	draw computatinal boundary
WFGPLA (wfgsub.f)	draw plasma boundary
WFGANT (wfgsub.f)	draw antenna data
WFGELM (wfgsub.f)	draw element and node data
GCLIP (wfgsub.f)	conversion from double precision to single precision
NGVLEN (wfgsub.f)	determine number of digits of scale data

GUSRGB (wfgsub.f) createion of paint colour RGB data

Common routines

WFSPSI (wfprof.f)	calculation of magnetic flux
WFBPSI (wfprof.f)	calculation of magnetic flux
WFBMAG (wfprof.f)	calculation of magnetic field
WFCOIL (wfprof.f)	calculation of magnetic field by circular current
APSI (wfprof.f)	calculation of vector potential by circular current
WFSDEN (wfprof.f)	calculation of density and temperature
CALRNU (wfprof.f)	calculation of collsion frequency
ATINIT (wfatmd.f)	initializatin of collsion cross section
ATSIGV (wfatmd.f)	calculation of collision data
ATSIGM (wfatmd.f)	calculation of collisional cross section
DATAAR (wfatmd.f)	collisional cross section data for Ar
DATAH2 (wfatmd.f)	collisional cross ection data for H
DATAAC4(wfatmd.f)	collisional cross section data for CF4
WVFNOD (wfsb.f)	calculation of element volume
MODANT (wfsb.f)	division of antenna data accordint element
CROS (wfsb.f)	calculation of crossing point of two line element
EFINDL (wfsb.f)	find an element including two specified nodes
WFFEPI (wfsb.f)	initializatioin of element find routine
WFFEP (wfsb.f)	find an element including specified position
WFABC (wfsb.f)	calculation of linear interporlate function and area
WFSELM (wfsb.f)	calculation of element area
WFNPOS (wfsb.f)	obtain node positons of an element
FIELDE (wfsb.f)	interpolation of wave E at given position
FIELDC (wfsb.f)	interpolation of complex data at given position
FIELDD (wfsb.f)	interpolation of real data at given position
SETAIF (wfsb.f)	calculation of integral in normalized element
AI2 (wfsb.f)	integral of 2 variable integral
AI3 (wfsb.f)	integral of 3 variable integral
FRGFLS (wflib.f)	Solution of nonlinear equation (Regula Falsi)
SPL1DX (atomic.f)	1D spline interpolation (non-even grid)
DEFIFE (atomic.f)	Half infinite integral by double-exponential formula
DSPFN (lib/libdsp.f90)	Plasma dispersion function
FFT2L (lib/libfft.f90)	Fast Fourier transform
BESIN (lib/libbes.f90)	First kind of modified Bessel function
BESKN (lib/libbes.f90)	Second kind of modified Bessel function
ELLFC (lib/libell.f90)	First kind of complete elliptic integral
ELLEC (lib/libell.f90)	Second kind of complete elliptic integral
SPL1D (lib/libspl.f90)	calculation of 1D spline coeffficients
SPL1DF (lib/libspl.f90)	interpolation by 1D spline (function only)
SPL1DD (lib/libspl.f90)	interpolation by 1D spline (function, derivative)
SPL2D (lib/libspl.f90)	calculation of 2D spline coeffficients
SPL2DF (lib/libspl.f90)	interpolation by 2D spline (function only)

SPL2DD (lib/libspl.f90)	interpolation by 1D spline (function, derivative)
CSPL1D (lib/libspl.f90)	calculation of 1D complex spline coefficients
CSPL1DF(lib/libspl.f90)	interpolation by 1D complex spline (function only)

11 List of COMMON variables

At present, this list is based on an old version of WF2.
It will be updated later

WFCNS1

CI	imaginary unit
PI	pi
AEE	elementary charge
AME	electron mass
AMP	proton mass
VC	light velocity in vacuum
RMU0	permeability constant in vacuum
EPS0	dielectric constant in vacuum

WFPRM1

BB	central magnetic field
RA	plasma minor radius

WFPRM2

RR	plasma major radius (m)
QA	safety factor on axis
Q0	safety factor on surface
RKAP	ellipticity of plasma cross section
RDEL	triangularity of plasma cross section
RMIR	mirror ratio
ZBB	periodic length along magnetic axis (m)
H1	helical pitch of magnetic field $2\pi/L$
H2	helical pitch of distance $2\pi/L$
RRC	coil radius in linear helical system (m)

WFPRM3

RF	wave frequency (MHz)
RKZ	wave number in z direction (m^{-1})
RZ	periodic length in z direction (m)
NPHI	mode number in azimuthal direction ϕ

WFPRM4

PA(NSM)	mass number
PZ(NSM)	charge number
PN(NSM)	particle density on axis ($10^{20}/\text{m}^3$)
PNS(NSM)	particle density on surface ($10^{20}/\text{m}^3$)
PZCL(NSM)	ratio of collision frequency and wave frequency

WFPRM5

PTPR(NSM)	parallel component of central temperature (keV)
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PTPP(NSM)	perpendicular component of central density (keV)
PTS(NSM)	surface temperature (keV)
WFPRM6	
NSMAX	number of particle species
NAMAX	number of antenna
NRMAX	number of radial mesh point for 1D plot
NZMAX	number of Fourier modes in z direction
WFPRM7	
NPRINT	control ID of print output
NDRAWD	control parameter for element plot
NDRAWA	control parameter for antenna plot
WFPRM8	
PNE0	initial electron density ($10^{20}/\text{m}^3$)
PTE0	initial electron temperature (eV)
PTI0	initial ion temperature (eV)
PPN0	initial neutral pressure (Pa)
PTN0	initial neutral temperature (eV)
WFPRM9	
PIN	(W)
WFPRK1	
KIDSYS	KID1/KID2/KID3/KID4
KIDPOS	
KID1	magnetic field configuration
KID2	element configuration
KID3	dielectric tensor model
KID4	radial profile
WFPRK2	
KFNAME	file name of element data
KFNAMA	file name of antenna data
KFNAMF	file name of field data
WFPRD1	
BXMIN	minimum value of x (m)
BXMAX	maximum value of x (m)
BYMIN	minimum value of y (m)
BYMAX	maximum value of y (m)
RB	boundary radius (m)
BKAP	boundary ellipticity
BDEL	boundary triangularity

WFPRD2	
DELX	typical element size in x direction (m)
DELY	typical element size in y direction (m)
WFPRA1	
RD	antenna radius (m)
THETJ1	initial angle of arc antenna (degree)
THETJ2	end angle of arc antenna (degree)
NJMAX	original number of antenna grid points
WFPRA2	
AJ(NAM)	antenna current (loop) / current density (line)
APH(NAM)	antenna phase
APOS(NAM)	antenna position in (z, ϕ, Z) direction (degree)
AWD(NAM)	antenna width in (z, ϕ, Z) direction (degree)
WFDIV1	
XL(NYM)	left end position
XR(NYM)	right end position
NYMAX	number of division in y direction
WFDIV2	
NXA(NYM)	number of nodes in x direction
WFDIV3	
XDA(NXM,NYM)	x coordinates of the node (NX,NY)
YDA(NXM,NYM)	y coordinates of the node (NX,NY)
NDA(NXM,NYM)	node number of the node (NX,NY)
WFDIV4	
XDW(NXM,NYM)	weight center position in x direction
YDW(NXM,NYM)	weight center position in y direction
WFDIV5	
XF	fixed x coordinates to find boundary
YF	fixed y coordinates to fine boundary
WFDIV6	
VNOD(NNODM)	volume around a node
WFELM1	
NNOD	total number of nodes
NELM	total number of elements
NBDY	total number of boundary nodes

MBND	width of coefficient matrix
MLEN	length of coefficient matrix
WFELM2	
XD(NNODM)	x coordinates of a node
YD(NNODM)	y coordinates of a node
IELM(3,NELMM)	node numbers belonging to an element
WFELM3	
IBND(NNODM)	minimum line number in the coefficient matrix for a node
KBND(NNODM)	number of equations for a node
IBDY(NBDYM)	node number of boundary nodes
WFSLV1	
KELM(3,NELMM)	work area for matrix solver
JBND(NNODM)	work area for matrix solver
WFSLV2	
CM(4,4,3,3)	coefficient matrix for an element for wave analysis
CRV(MLENM)	right-hand-side vector for wave analysis
CSV(MLENM)	solution vector for wave analysis
WFSLV3	
LDEST(NCNM)	work area for matrix solver
NK(NCNM)	work area for matrix solver
NFLG(NNODM)	work area for matrix solver
WFSLV4	
CEQ(MBNDM,MBNDM)	work area for wave matrix solver
WFSLV5	
LHED(MBNDM)	work area for matrix solver
LPIV(MBNDM)	work area for matrix solver
CQQ(MBNDM)	work area for wave matrix solver
WFSLV6	
MLCO(MLENM)	work area for matrix solver
MCOL(MLENM)	work area for matrix solver
MPOS(MLENM)	work area for matrix solver
WFSLV7	
MHED(MBUFM)	work area for matrix solver
CBUF(MBUFM)	work area for wave matrix solver
DBUF(MBUFM)	work area for transport matrix solver

WFAIF1	
AIF3(3,3,3)	integral of three interpolation functions
AIF2(3,3)	integral of two interpolation functions
AIF1(3)	integral of an interpolation function
WFEVO1	
DT	time step width
T	time
NTMAX	number of time step
NTSTEP	number of transport steps for one wave step
NEVOL	0: fixed density@1: time evolution
WFEVO2	
PNE(NNODM)	electron density at a node ($10^{20}/\text{m}^3$)
PPE(NNODM)	electron pressure at a node (Pa)
PTE(NNODM)	electron temperature at a node (eV)
WFEVO3	
PNI(NNODM)	ion density at a node ($10^{20}/\text{m}^3$)
PPI(NNODM)	ion pressure at a node (Pa)
PTI(NNODM)	ion temperature (eV)
WFEVO4	
PHI(NNODM)	scalar potential
WFEVO5	
DEQ(MBNDM,MBNDM)	work area for transport matrix solver
DQQ(MBNDM)	work area for transport matrix solver
WFEVO6	
DM(5,5,3,3)	coefficient matrix for an element for transport analysis
DRV(MLENM)	right-hand-size vector for transport analysis
DSV(MLENM)	solution vector for transport analysis
WFEVO7	
PNET(NGTM,3)	time evolution of average electron number
PTET(NGTM,3)	time evolution of average electron temperature
WFEVO8	
PNIT(NGTM,3)	time evolution of average ion number
PTIT(NGTM,3)	time evolution of average ion temperature
WFEVO9	
PHIT(NGTM,3)	time evolution of Φ

TG(NGTM)	sampling time for time evolution plot
NGTMAX	number of time evolution data
WFCAL1	
HA1	work variable for linear helical analysis
WFFEP1	
FMAX(NYM)	maximum y belonging to NEY
FMIN(NYM)	minimum y belonging to NEY
WFFEP2	
NEMAX(NYM)	maximum element number belonging to NEY
NEMIN(NYM)	minimum element number belonging to NEY
NEYMAX	maximum of NEY
WFFLD1	
CAF(4,NNODM)	wave vector and scalar potential on a node
WFFLD2	
CEF(3,NNODM)	wave electric field (x, y, z)
CEP(3,NNODM)	wave electric field (RHS, LHS, parallel)
CEFK(3,NNODM)	wave electric field for a single Fourier mode
WFFLD3	
CBF(3,NNODM)	magnetic field (x, y, z)
CBP(3,NNODM)	magnetic field (RHS, LHS, parallel)
SA(NNODM)	area belonging to an element
WFFLD4	
EMAX(4)	maximum value of wave E field component
ETMAX	maximum value of wave E
PNMAX	maximum value of density
WFPWR1	
TSPWR	total absorbed power
PWR(NNODM)	absorbed power for a node
WFPWR2	
TPWR(NSM)	total absorbed power for a particle species
SPWR(NNODM,NSM)	absorbed power for a particle species at a node
WFPWR3	
RPWR(NRM)	absorbed power at a node
RSPWR(NRM,NSM)	absorbed power for particle species at a node
DR	number of division in radial direction

WFANT1		
	CIMP(NAM)	loading impedance of each antenna
	CTIMP	total loading impedance
WFANT2		
	XJ(JNUMM,NAM)	x coordinates of antenna nodes after breakup
	YJ(JNUMM,NAM)	y coordinates of antenna nodes after breakup
	CAJ(NAM)	complex antenna current of each antenna
WFANT3		
	XJ0(JNUMM,NAM)	x coordinates of antenna nodes before breakup
	YJ0(JNUMM,NAM)	y coordinates of antenna nodes before breakup
	JNUM0(NAM)	number of antenna nodes before breakup
WFANT4		
	JELMT(JNUMM,NAM)	element number of the element in which a part of antenna belongs
	JNUM(NAM)	number of antenna nodes after breakup
WFPWK1		
	RKZF(NZM)	wave number of the Fourier component
	CAJF(NZM,NAM)	Fourier components of antenna current
WFPWK2		
	TSPWRF(NZM)	Fourier components of absorbed power
	TPWRF(NZM,NSM)	Fourier components of absorbed power for each particle species.
WFWIN1		
	XDMIN	work area for screen division
	XDMAX	work area for screen division
	YDMIN	work area for screen division
	YDMAX	work area for screen division
WFWIN2		
	GXD(NNODM)	work area for screen division
	GYD(NNODM)	work area for screen division
WFWIN3		
	NFOPEN	work area for screen division
FFTWRK		
	CT(NZM*NZLM/2,2)	work area for fast Fourier transform
	LIST(NZM*NZLM)	work area for fast Fourier transform
	IFFT	work area for fast Fourier transform
	LP	work area for fast Fourier transform