The POISSON and SUPERFISH Suite

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POISSON/SUPERFISH Capabilities

- SUPERFISH: axisymmetric rf cavities
  - TM-mode frequency-domain analysis
  - Field profile
  - Frequency tuning
  - Power dissipation in walls
- POISSON: 2-D (axisymmetric and Cartesian) magnetostatics
  - Permeable materials
  - Magnetic multipole analysis
  - Permanent magnets (Amperian currents or PANDIRA)
  - Electrostatics!
- Shared input mesh, output format
- Input maps for UCLA PARMELA and HOMDYN

Mesh Setup for POISSON/SUPERFISH

- Electromagnetic boundary problem described by discretized Maxwell (in Poisson or Helmoltz form) equations
- Solved by successive over-relaxation method
- Program AUTOMESH creates computational mesh from geometric description
- Program LATTICE setups up difference equations for AUTOMESH grid points

Simple Example: Gun Half Cell

- Half-cell geometry for old UCLA rf gun
- Can be seen as part of a periodic system (basis of Fourier description of linac structures)
- Illustrates boundary conditions
- Obtain 0-π mode splitting
- Post-processing for graphical output
- Can calculate power dissipation profile, frequency tuning (for tuning cuts in gun)

AUTOMESH input for 0.6 cell

Run automesh and type in input file (halfcell.dat in ex.)

Title

```
~/fish4> more halfcell.dat
X    UCLA 2856MHz RF HALF CELL
 $REG NREG=1,XMAX=3.0,YMAX=4.16,DX=0.03,NPOINT=8,YREG1=2.5$
 $PO X=0.00,Y=0.000$
 $PO X=0.00,Y=4.155$
 $PO X=1.630,Y=4.155$
 $PO X=1.630,Y=1.953$
 $PO NT=2,X0=2.583,Y0=1.953,R=0.953,THETA=270.0$
 $PO X=2.625,Y=1.000$
 $PO X=2.625,Y=0.000$
 $PO X=0.000,Y=0.000$
```

- One region, defined by 8 points
- X and Y limits defined in first region
- DX is mesh spacing (DY defaults to DX)
- Points are joined by lines, circles, hyperbolae
- Region always ends back at initial point

All distances in cm

AUTOMESH Screen Output

K is "x" index

L is "y" index

REGION NO. 1

LOGICAL BOUNDARY SEGMENT END POINTS

ISEG	KB	LB	KD	LD	KE	LE
1	1	1	0	1	1	161
2	1	161	1	0	55	161
3	55	161	1	-1	56	76
4	56	76	-1	-1	87	39
5	87	39	1	0	88	39
6	88	39	1	-1	88	1
7	88	1	-1	0	1	1

Drive point (center of SOR calc.)

May be important

--- WARNING --- USER PROVIDED DRIVE POINT COULD BE BETTER

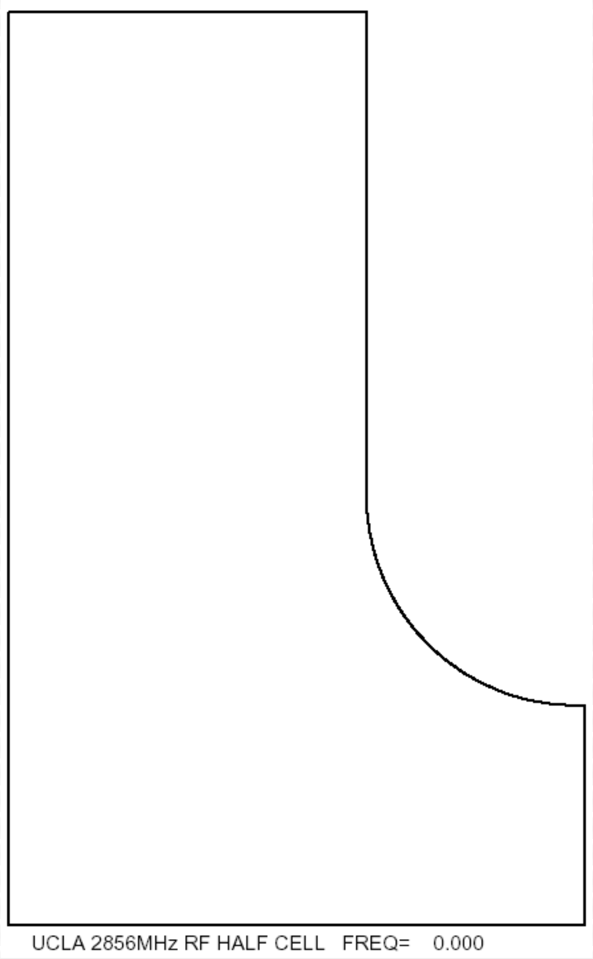
THAN THE DEFAULT BEST GUESS DRIVE POINT.

AUTOMESH and meshing errors

- If the mesh is too coarse, and features of the geometry are too fine, then AUTOMESH will fail to generate a mesh and give an error — you will then need to make the mesh finer
- Even though this feature enforces adequate meshing, it is wise to check the convergence of the problem (*e.g.* frequency in SUPERFISH) to see if the mesh spacing affects the answer.

AUTOMESH graphical output

- Run psfplot (plotting package)
- In psfplot, type “s” to all prompts (“-1 s” to end)
- Outputs only the geometry
- Simple check on work after AUTOMESH



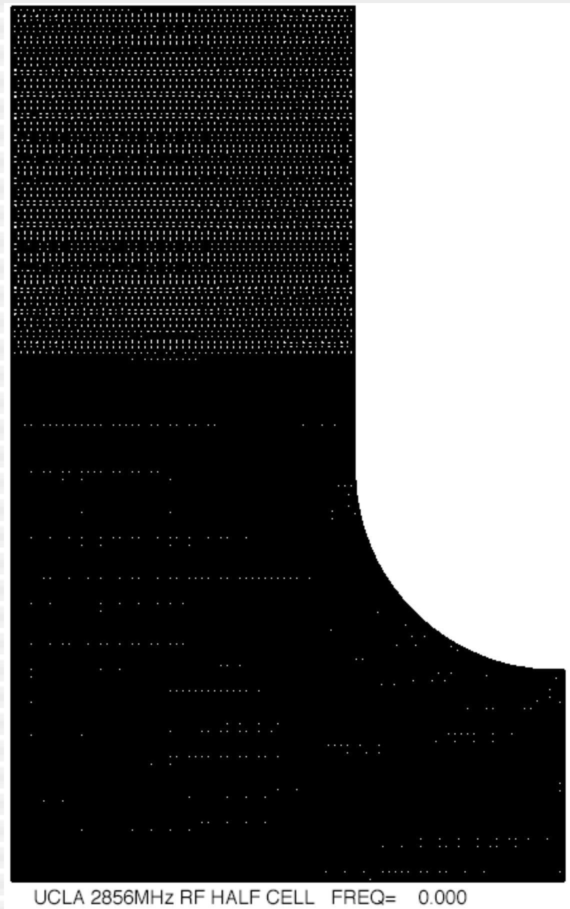
Running LATTICE

- Inputs in blue
- Tape73 is default output from AUTOMESH, input to LATTICE
- PROBLEM CON(stant)s dealing with boundary conditions begin with “*”, end with “s” (see p. 403 for full listing
- The boundary conditions are, 21: upper, 22: lower, 23: right, 24: left (22-24 are in order)
- In SUPERFISH, 1 is an conducting boundary, 0 is a magnetic (symmetry) boundary.
- Tapes 35 and 36 are input for SUPERFISH

```
?type input file name (s for default)
tape73

BEGINNING OF LATTICE EXECUTION

DUMP 0 WILL BE SET UP FOR SUPERFIS

X    UCLA 2856MHz RF HALF CELL

?TYPE INPUT VALUES FOR CON(?)
*21 1 0 0 1 S

ELAPSED TIME =    0.1 SEC.

GENERATION COMPLETED

DUMP NUMBER 0 HAS BEEN WRITTEN ON TAPE35.

DUMP NUMBER 0 HAS BEEN WRITTEN ON TAPE36.
```

LATTICE graphical output

- Check meshing…
- In sfo1, type “0 1 s” to first prompt, “s”, “go”, and “-1 s”
- Outputs only the mesh
- Note that outside of YREG1 (2.5 cm), the mesh spacing has doubled
- Can also stretch x-spacing



Running SUPERFISH

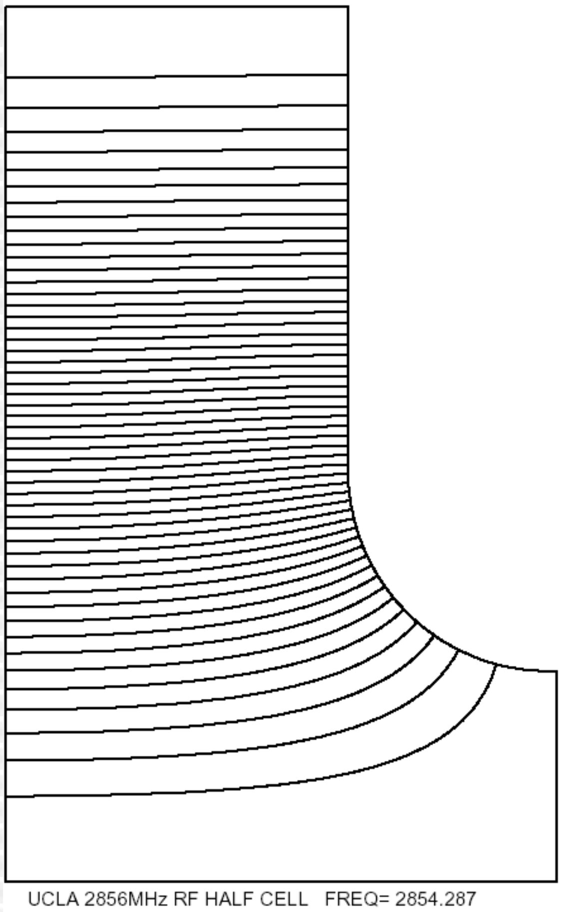
- Run superfish
- tty is terminal input
- CON(65) is a guess frequency in MHz - you will find a different mode (if possible) when chosen differently (only one in this problem)
- Convergence and final frequency are given in screen output

```
 ?type "tty" or input file name
tty
 ?TYPE INPUT VALUE FOR DUMP NUM
0
 BEGINNING OF SUPERFISH EXECUTION FROM
DUMP NUMBER  0
 PROB. NAME =     UCLA 2856MHz RF HALF CELL
 ?TYPE INPUT VALUES FOR CON(?)
*65 2856. s
 ELAPSED TIME  =    0.2 SEC.
 CYCLE      DEL(k**2)       FREQ[MHz]
 -----------------------------------
                          2856.00000
   1       -4.2046E-04      2854.32373
   2       -1.4901E-06      2854.31787

 SOLUTION CONVERGED IN    2 ITERATIONS
 ELAPSED TIME  =    0.0 SEC.
 DUMP NUMBER  1 HAS BEEN WRITTEN.
 ?TYPE INPUT VALUE FOR DUMP NUM
-1 s
```

PI-Mode Boundary Conditions

- The CONs that are input to LATTICE include a boundary condition card for each boundary
- For the π-mode, CON(23) is 0
- To view graphically:

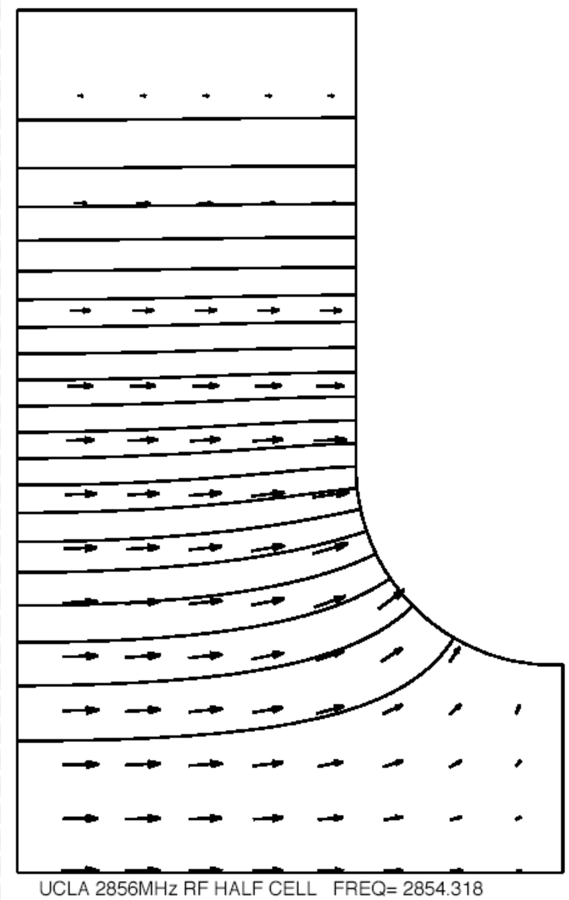
```
 ?TYPE INPUT DATA- NUM, ITRI, NPHI, INAP, NSWXY,
1 0 50 s                              (number of flux lines is 50)
INPUT DATA
 NUM=  1    ITRI= 0    NPHI=  50    INAP= 0    NSWXY= 0
PLOTTING PROB. NAME =     UCLA 2856MHz RF HALF CELL       CYCLE =    2
 ?TYPE INPUT DATA- XMIN, XMAX, YMIN, YMAX,
s
 INPUT DATA
 XMIN=   0.000  XMAX=   2.625  YMIN=   0.000  YMAX=   4.155
ARROW PLOT?: ENTER Y FOR YES OR N FOR NO
no
 ?TYPE GO OR NO
go
 ?TYPE INPUT DATA- NUM, ITRI, NPHI, INAP, NSWXY,
-1 s
```



Arrow plots

- Standard plot is not *E*-field line, it is constant enclosed flux surface (*rH*). This can be confusing.
- Use arrow plot…

ARROW PLOT?: ENTER Y FOR YES OR N FOR NO
y
ENTER NSKIP
10 (controls density, larger is less dense)
ENTER SCALING FACTOR
10 (controls arrow size)
?TYPE GO OR NO
go
?TYPE INPUT DATA- NUM, ITRI, NPHI, INAP, NSWXY,
-1 s



Note high field near axis!

Output files

- Each code in suite produces output files
  - outaut
  - outlat
  - outpoi
- outaut and outlat contain problem setup info
- outfis contains solution information
- Post-processing of detailed solution information (dump 1) possible with sfo1
- More important in POISSON (outpoi gives useful field info directly)

Boundary analysis with SFO1

- Running sfo1 you can find:
  - Power dissipation (normalized to peak accelerating field of 1 MeV/m)
  - Export to ANSYS for thermal simulation?
  - Frequency tuning (cut coefficients
  - Each segment listed separately

```
?type "tty" or input file name
tty

?TYPE INPUT VALUE FOR DUMP NUM
1
BEGINNING OF SFO1 EXECUTION FROM DUMP NUMBER 1
PROB. NAME =     UCLA 2856MHz RF HALF CELL

?TYPE INPUT VALUES FOR CON(?)
1
*50 7 *106 0.9999 S (106 is particle beta)

?TYPE INPUT VALUES FOR ISEG'S
1 2 3 4 5 6 7  S (all seven segments are listed (not necessary, 6 and 7 are not valid)

---WARNING --- FREQUENCY PERTURBATION CALCULATION
CORRECT ON A CONDUCTOR ONLY
```

SFO1 Output

```
?TYPE GO FOR OUTPUT SUMMARY AT TERMINAL
go
1SUPERFISH General summary        Tue Oct  1 08:52:33 2002
 Total number of points =    11921  NCELL =  1  ZCTR =        0.0000 cm
 LINT =   1  Average r =   0.0261 cm  ZBEG =    0.0000 cm  ZEND =    2.6250 cm
 Integral [Ez(z,r=    0.03 cm)sin(Kz)dz] =      13394.55 V
 Integral [Ez(z,r=    0.03 cm)cos(Kz)dz] =      20423.91 V
1SUPERFISH DTL summary            Tue Oct  1 08:52:33 2002
 Problem name =    UCLA 2856MHz RF HALF CELL
 SUPERFISH calculates the frequency [f] to at most six place accuracy
 depending on the input mesh spacing.
 Full cavity length [2L]  =     5.2500 cm         Diameter =    8.3100 cm
 Mesh problem length [L]  =     2.6250 cm
 Full drift-tube gap [2g] =    3.2600 cm
 Beta                    = 0.9999000       Proton energy = 65400.941 MeV
 Frequency [f] (starting value =2856.000) =              2854.317871 MHz
 Eo normalization factor (CON(74)=ASCALE) for  1.000 MV/m =    9124.7
 Stored energy [U] for mesh problem only =                  0.30303 mJ
 Power dissipation [P] for mesh problem only =                572.75 W
 Q (2.0*pi*f(Hz)*U(J)/P(W)) =                              9488   <-- Quality factor
 Transit time factor [T] =                            0.77805   <-- Transit time factor
```

SFO1 Output (continued)

Shunt impedance (low for half-cell, it is too wall-dominated) →

```
Shunt impedance [Z] mesh problem only, ((Eo*L)**2/P) =      1.20307 Mohm
 Shunt impedance per unit length [Z/L] =                   45.831 Mohm/m
 Effective shunt impedance per unit length [Z/L*T*T] =       27.745 Mohm/m
 Magnetic field on outer wall =                           2395 A/m
 Hmax for wall and stem segments at z=  0.00,r=  3.28 cm =      2665 A/m
 Emax for wall and stem segments at z=  1.66,r=  1.72 cm =      1.624 MV/m
Beta        T        Tp       S        Sp       g/L       Z/L
 0.99989998  0.77805  0.12917  0.51027  0.11833  0.620952   45.831303
 ISEG   zbeg     rbeg     zend     rend  Emax*epsrel   Power     df/dz    df/dr
        (cm)     (cm)     (cm)     (cm)   (MV/m)       (W)        (MHz/mm)
 Wall-----------------------------------------------------------------------Wall
   1  0.0000   0.0000   0.0000   2.5000   1.4955     48.1330  43.9345   0.0000
   2  0.0000   2.5000   0.0000   4.1550   0.9270    159.8759 -49.4446   0.0000
   3  0.0000   4.1550   1.6300   4.1550   0.0020    169.1528   0.0000 -72.3290
   4  1.6300   4.1550   1.6300   2.5000   0.9756    158.3179 -47.5337   0.0000
   5  1.6300   2.5000   1.6300   1.9530   1.4212     26.1670  11.0253   0.0000
   6  1.6300   1.9530   2.5830   1.0000   1.6237     11.1060  31.5280  15.0800
   7  2.5830   1.0000   2.6250   1.0000   0.2704      0.0001   0.0000   0.0402
 Wall---------------------------------- Total =     572.7526 -------------Wall
 ?TYPE INPUT VALUE FOR DUMP NUM
-1 s
```

← Tuning cuts (can break segments up into smaller lengths)

To obtain power for actual case, multiply this by $(E_{max}T)^2$ where E_{max} is the peak on-axis field in MV/m.

Automating the problem

- After you have set up the problem in AUTOMESH and LATTICE, it is helpful to run the entire problem with a Linux script
- Must chmod file to “x” to get it to run
- I use stout executables in ~anderson/bin. We are moving to standardize all executables on PBPL machines

```
~/fish4> more halffish
automesh << MESHEND
halfcell.dat
MESHEND
lattice << LATTICEND
tape73
*21 1 0 0 1 S
LATTICEND
superfish << FISHEND
TTY
0
*65 2856. S
-1 S
FISHEND
sfo1 << SFOEND
tty
1
*50 7 *106 0.9999 S
1 2 3 4 5 6 7  S
GO
-1 S
SFOEND
psfplot << PLOTEND
```

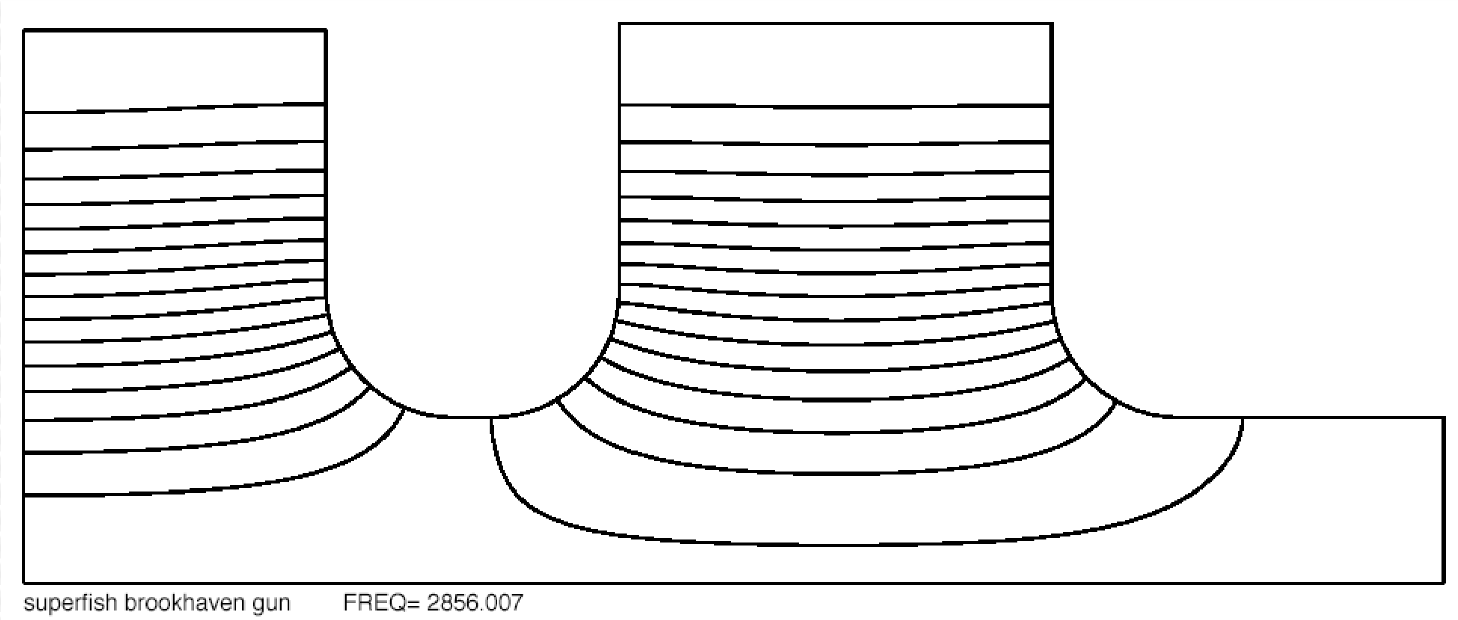
A "real" problem: the 1.6 cell gun

- Include beam tube
- High precision
- Can obtain zero mode…
- Detune for 0.6 and full cell frequencies
- Need to include perturbations due to tuner/laser/vacuum ports

```
stout:~/Newfish> more newgun
1superfish brookhaven gun
 &reg xmin=00.,ymin=0.,xmax=15.0,ymax=4.21153,dx=0.05,npoint=17 &
 &PO X=0.000,Y=0.000 &
 &PO X=0.000,Y=4.1581 &
 &PO X=2.27584,Y=4.1581 &
 &PO X=2.27584,Y=2.20218 &
 &PO NT=2,X0=3.22834,Y0=2.20218,R=0.9525,THETA=270.0 &
 &PO X=3.2766,Y=1.24968 &
 &PO X=3.3782,Y=1.24968 &
 &PO X=3.4798,Y=1.24968 &
 &PO X=3.52806,Y=1.24968 &
 &PO NT=2,X0=3.52806,Y0=2.20218,R=0.9525,THETA=0.0 &
 &PO X=4.48056,Y=4.2084 &
 &PO X=7.73000,Y=4.2084 &
 &PO X=7.73000,Y=2.20218 &
 &PO NT=2,X0=8.68250,Y0=2.20218,R=0.9525,THETA=270.0 &
 &PO X=10.68250,Y=1.24968 &
 &PO X=10.68250,Y=0.000 &
 &PO X=0.000,Y=0.000 &
```

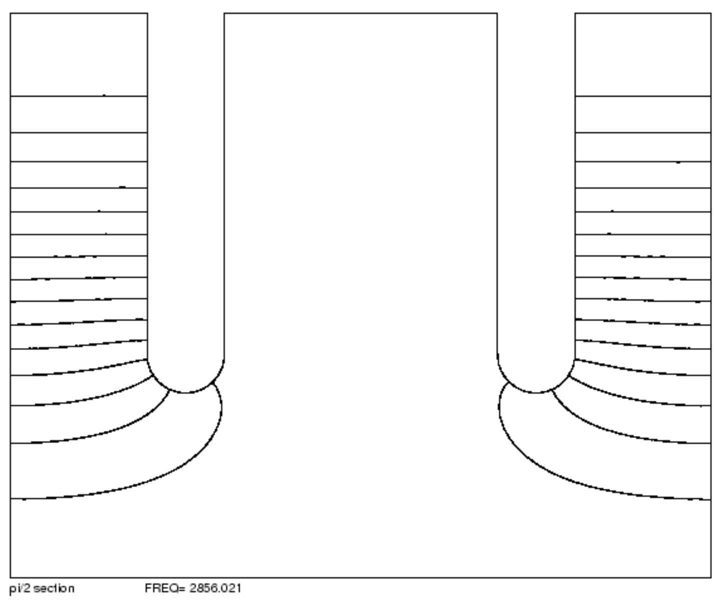
1.6 cell gun output

- Fields nearly balanced
- Need beam tube twice aperture in length



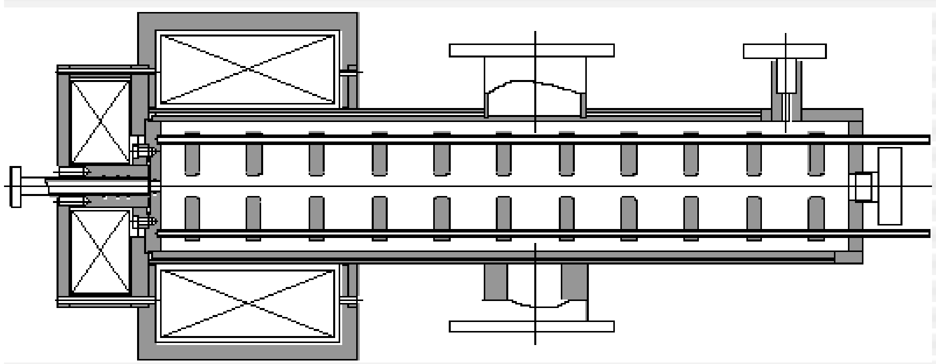
Traveling waves and boundary conditions

- Traveling wave mode characteristics are obtained by doing standing wave problem, obtaining Fourier description (separate code)
- Use minimum symmetry (see $\pi/2$ mode example) for problem



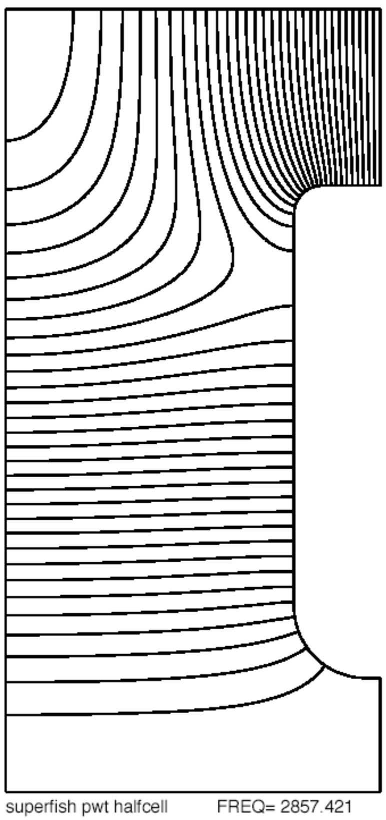
Embedded region: PWT 0.5+0.5 cell

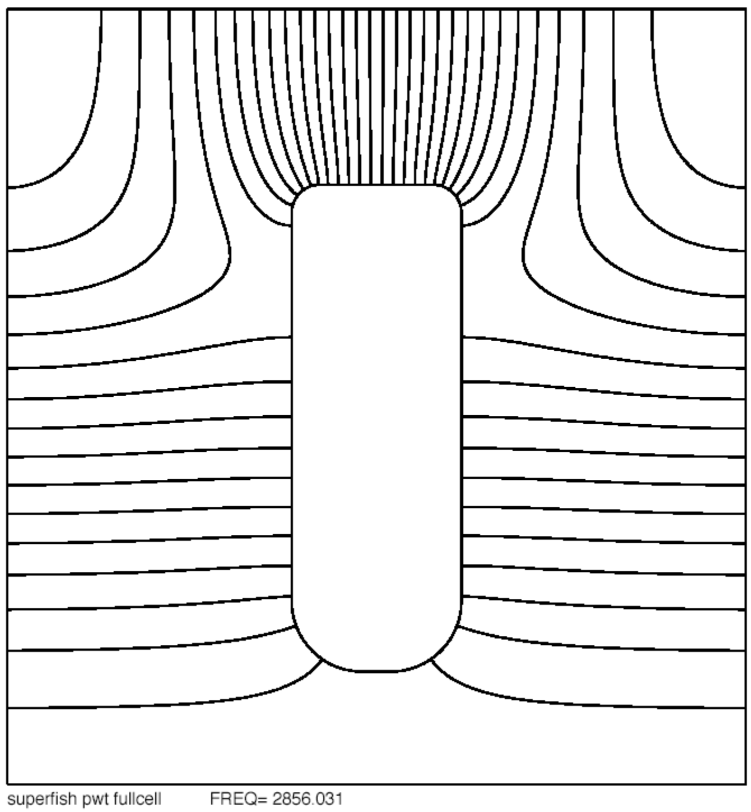
- Minimal symmetry needed to obtain 0 and π modes
- Embed the PWT disks. Ignore cooling rods

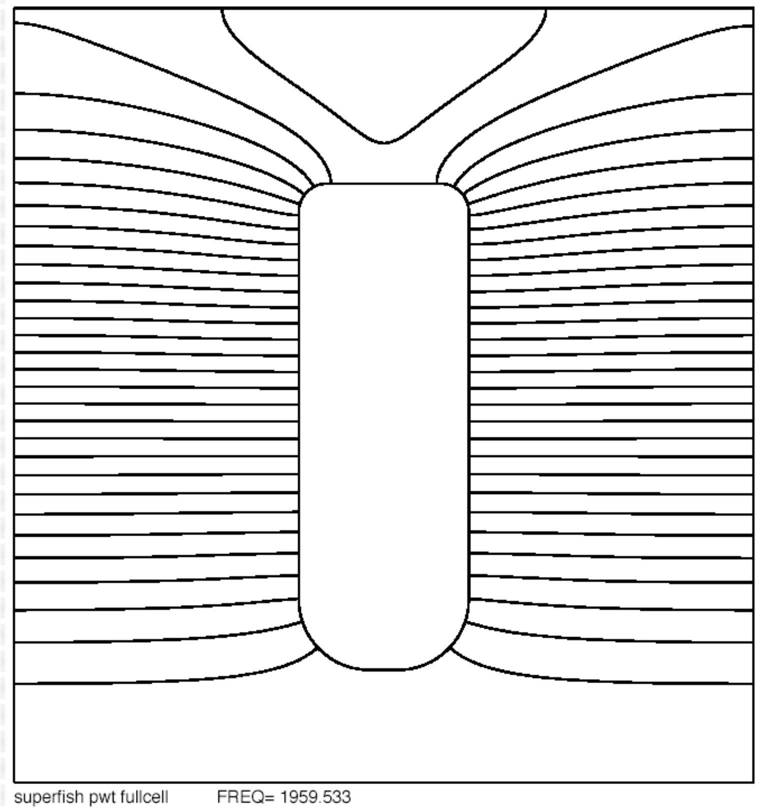


```
1superfish pwt fullcell
 $reg nreg=2, dx=0.025, npoint=5, xmax=5.248, ymax=5.5 $
 $po x=0.0, y=0.0 $
 $po x=0.0, y=5.5 $
 $po x=5.248, y=5.5 $
 $po x=5.248, y=0.0 $
 $po x=0.0, y=0.0 $
 $reg npoint=10, mat=0, ibound=1 $
 $po x=2.624, y=4.2525 $
 $po x=2.221, y=4.2525 $
 $po nt=2, x0=2.221, y0=4.0525, r=0.2, theta=180.0 $
 $po x=2.021, y=1.3 $
 $po nt=2, x0=2.521, y0=1.3, r=0.5, theta=270.0 $
 $po x=2.727, y=0.8 $
 $po nt=2, x0=2.727, y0=1.3, r=0.5, theta=360.0 $
 $po x=3.227, y=4.0525 $
 $po nt=2, x0=3.027, y0=4.0525, r=0.2, theta=90.0 $
 $po x=2.624, y=4.2525 $
```

PWT outputs





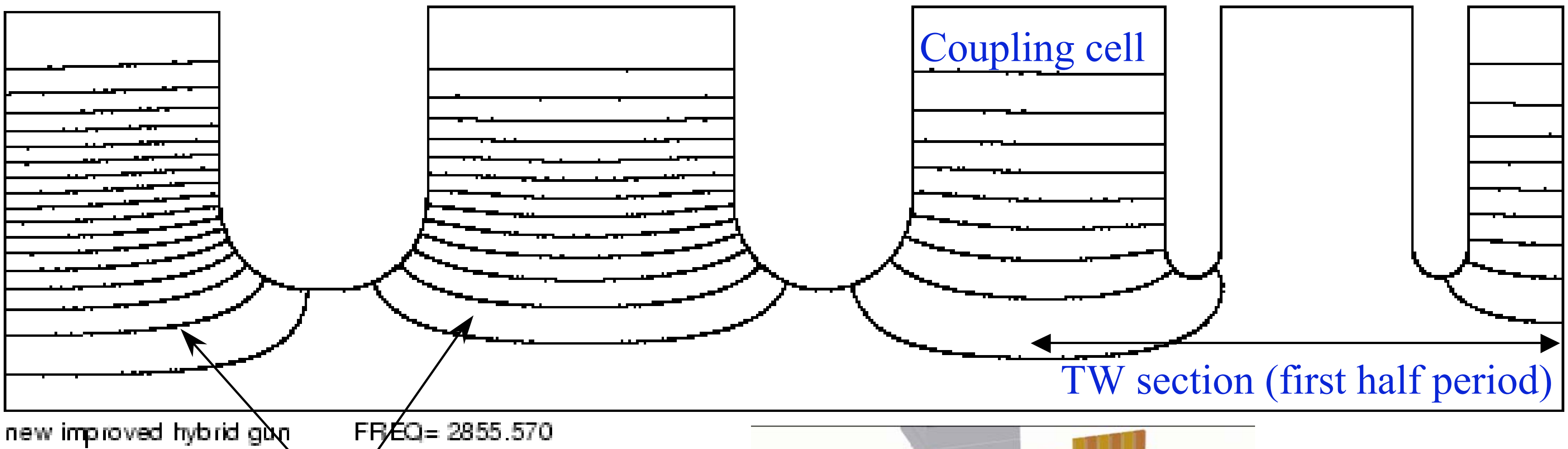


CON(23)=0, CON(24)=1

CON(23)=1, CON(24)=1

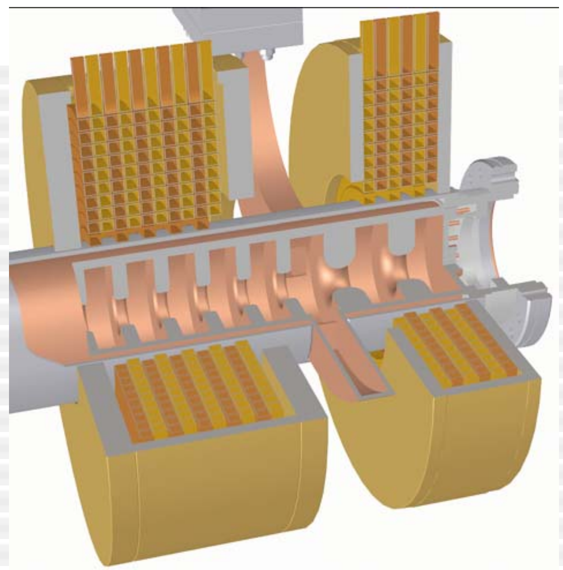
Note mode separation!
Original guess was 1900 MHz

Hybrid TW/SW gun



Standing wave gun section

Rendered cartoon of device
(opposite direction)



POISSON

- Static “potential” problems
- Shares input setup
- CONs are more important in lattice
  - Cylindrical v. cartesian symmetry
  - Output fields
  - Harmonic field analysis
- Permanent magnets with Amperian currents
  - Undulators
  - Permanent magnet hybrid quads
- Electrostatic problems

Example: Standard PBPL quad

```
$reg nreg=4, dx=0.1, xmax=15.0, ymax=15.0, xreg1=8.0,   yreg1=8.0., npoint=5$
$po y= 0.00, x= 0.00$
$po y=15.00, x= 0.00$
$po y=15.00, x=15.00$
$po y= 0.00, x=15.00$
$po y= 0.00, x= 0.00$
$reg mat=2, npoint=19$
$po x=0.000, y=10.795$
$po x=0.000, y=12.70$
$po x=3.393, y=12.70$
$po x=12.70, y=3.393$
$po x=12.70, y=0.00$
$po x=10.795, y=0.00$
$po x=10.795,  y=2.604$
$po x=7.710, y=5.689$
$po x=4.567, y=2.546$
$po x=6.026, y=1.087$
$po x=5.397, y=0.458$
$po x=.118, y=.588, x0=4.901, y0=.121, nt=2$
$po y=5.019, x=.709, r=2.668 nt=3$
$po x=0.337, y=.496, x0=0.121, y0=4.901, nt=2$
$po x=1.087, y=6.026$
$po x=2.546, y=4.567$
$po x=5.689, y=7.710$
$po x=2.604, y=10.795$
$po x=0.000, y=10.795$
```

mat=2 means internal permeability curve

nt=2 is arc,
nt=3 hyperbola

(continued)

- Input deck has magnetic material

mat=1 means conductor (cur is current in amps)

```
$reg  mat=1, cur=-1835., npoint=5$
$po x=4.521, y=8.877$
$po x=5.689, y=7.710$
$po x=2.547, y=4.568$
$po x=1.379, y=5.734$
$po x=4.521, y=8.877$
$reg  mat=1, cur=1835., npoint=5$
$po x=7.710, y=5.689$
$po x=8.877, y=4.521$
$po x=5.734, y=1.379$
$po x=4.568, y=2.547$
$po x=7.710, y=5.689$
```

Complex representation of field

- Standard analysis in cylindrical coordinates
- Allows harmonic analysis of POISSON output

$$B_x - iB_y = \sum_{n=1}^{\infty} in \left(\frac{r}{r_{norm}} \right)^{n-1} \frac{c_n}{r_{norm}} \exp[i(n-1)\varphi]$$

or $$B_x - iB_y = \sum_{n=0}^{\infty} B_m \exp(im\varphi)$$

with $$B_m = \frac{m+1}{r_{norm}} \left(\frac{r}{r_{norm}} \right)^m (b_{m+1} - ia_{m+1})$$

Standard quad script

As usual, CON(21)-(24) gives symmetry. For quad you need lower and left to have field normal to bdry (CON is 1).

CON(6) is permeability option. Value of 0 indicates that permeability is finite (w/mat=2 derives μ from standard table).

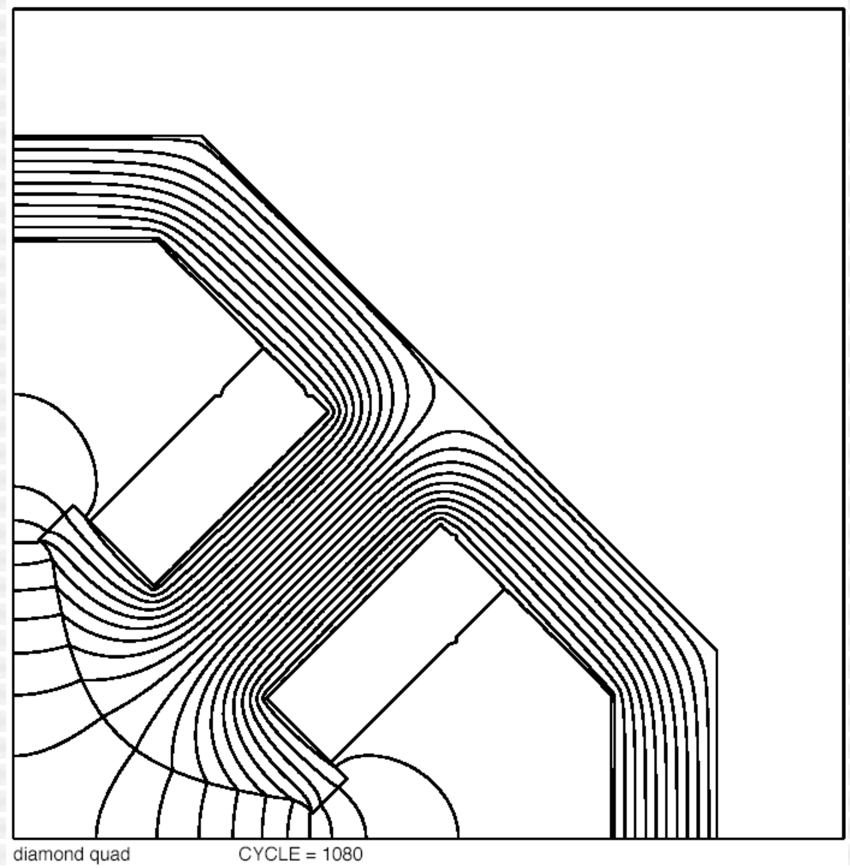
These symmetries are also declared in CON(46), which governs harmonic analysis of fields (4 means symmetrical quad)

CON(110) is the number of harmonic terms, (111) is points on the analysis circle,
(112) is the radius of circle, (113) is the angle in degrees of analysis (114) is normalization radius.

```
automesh << MESHEND
quad.2
MESHEND
lattice << LATTICEND
tape73
*21 0 1 0 1 *81 1 s
LATTICEND
poisson << POISEND
tty
0 s   CON(19) is coordinate system (0 is Cartesian)
*19 0 *6 0 *46 4 *38 0.0 *110 5  50 1.0 90. 1. *85 1e-5 1e-5 s
-1
POISEND
psfplot << PLOTEND
1 0 20 s
s
go
-1 s
PLOTEND
```

Standard quad output

- No saturation
- Pole piece flaring
- Good field quality? Look at outpoi
  - Harmonic analysis



OUTPOI file

- At end of outpoi, find harmonic analysis
- Only harmonics allowed by symmetry are calculated
  - Quadrupole
  - Dodecapole
- Field maps also output…

```
1TABLE FOR VECTOR POTENTIAL COEFFICIENTS
0NORMALIZATION RADIUS =   1.00000
0       A(X,Y) = RE( SUM (AN + I BN) * (Z/R)**N )
0       N        AN            BN           ABS(CN)
0       2    3.1634E+02    0.0000E+00    3.1634E+02
0       6    7.1072E-03    0.0000E+00    7.1072E-03
0      10    6.9814E-03    0.0000E+00    6.9814E-03
0      14    5.4019E-03    0.0000E+00    5.4019E-03
0      18    4.7405E-03    0.0000E+00    4.7405E-03
1TABLE FOR FIELD COEFFICIENTS
0NORMALIZATION RADIUS =   1.00000
0       (BX - I BY) = I * SUM N*(AN + I BN)/R * (Z/R)**(N-1)
0       N     N(AN)/R       N(BN)/R      ABS(N(CN)/R)
0       2    6.3269E+02    0.0000E+00    6.3269E+02
0       6    4.2643E-02    0.0000E+00    4.2643E-02
0      10    6.9814E-02    0.0000E+00    6.9814E-02
0      14    7.5627E-02    0.0000E+00    7.5627E-02
0      18    8.5329E-02    0.0000E+00    8.5329E-02
```

Example: Neptune solenoid

- Double coil solenoid
- *Cylindrical* symmetry
- Note here $x \rightarrow r$, $y \rightarrow z$.
- Need to obtain field maps for PARMELA and HOMDYN

```
double solenoid
$reg nreg=5,xmax=20.00,ymax=60.00,ktop=5,ltop=50,dx=0.25,dy=0.25,npoint=5$
$po x=0.000,y=0.000$
$po x=20.000,y=0.000$
$po x=20.000,y=60.000$
$po x=0.000,y=60.000$
$po x=0.000,y=0.000$
$reg mat=1, cur=20000, npoint=5$
$po x=5.1,y=21.35$
$po x=10.2,y=21.35$
$po x=10.2,y=29.8$
$po x=5.1,y=29.8$
$po x=5.1,y=21.35$
$reg mat=2,npoint=9$
$po x=3.6,y=21.35$
$po x=10.2,y=21.35$
$po x=10.2,y=29.8$
$po x=4.4,y=29.8$
$po x=4.4,y=32.34$
$po x=12.74,y=32.34$
$po x=12.74,y=18.81$
$po x=3.6,y=18.81$
$po x=3.6,y=21.35$
```

```
$reg mat=1, cur=1, npoint=5$
$po x=5.1,y=32.34$
$po x=10.2,y=32.34$
$po x=10.2,y=40.79$
$po x=5.1,y=40.79$
$po x=5.1,y=32.34$
$reg mat=2,npoint=7$
$po x=12.74,y=32.34$
$po x=12.74,y=43.33$
$po x=4.4,y=43.33$
$po x=4.4,y=40.79$
$po x=10.2,y=40.79$
$po x=10.2,y=32.34$
$po x=12.74,y=32.34$
```

Solenoid script

- Note boundaries
- No bucking coil - can translate field map in PARMELA/HOMDYN
- CON(42-45) gives K min/max, L min/max for field map (lineout for on-axis field)

```
automesh << MESHEND
doublesol
MESHEND
lattice  << LATTICEND
s
*6 0 *19 1 *21 0 0 0 0 s
LATTICEND
poisson << POISSONEND
tty
0
*42 1 1 1 241 s
-1 s
POISSONEND
psfplot << PLOTEND
1 0 20 s
s
go
-1 s
PLOTEND
```

OUTPOI contains field map

K L RA(VECTOR) R Z BR(GAUSS) BZ(GAUSS) BT(GAUSS) DBZ/DR(GAUS
S/CM) N=R/BZ*DBZ/DR RAFIT//FLAG

1 1 0.00000E+00 0.00000 0.00000 0.000 0.020 0.020 0.0000E+0
0 0.0000E+00 9.5E-05

1 2 0.00000E+00 0.00000 0.25000 0.000 0.046 0.046 0.0000E+0
0 0.0000E+00 -4.3E-07

1 3 0.00000E+00 0.00000 0.50000 0.000 0.090 0.090 0.0000E+0
0 0.0000E+00 1.0E-05

1 4 0.00000E+00 0.00000 0.75000 0.000 0.137 0.137 0.0000E+0
0 0.0000E+00 1.6E-10

1 5 0.00000E+00 0.00000 1.00000 0.000 0.184 0.184 0.0000E+0
0 0.0000E+00 -2.4E-07

1 6 0.00000E+00 0.00000 1.25000 0.000 0.231 0.231 0.0000E+0
0 0.0000E+00 -5.8E-12

1 7 0.00000E+00 0.00000 1.50000 0.000 0.280 0.280 0.0000E+0
0 0.0000E+00 -3.5E-07 … etc.

Reference:SPARC solenoid

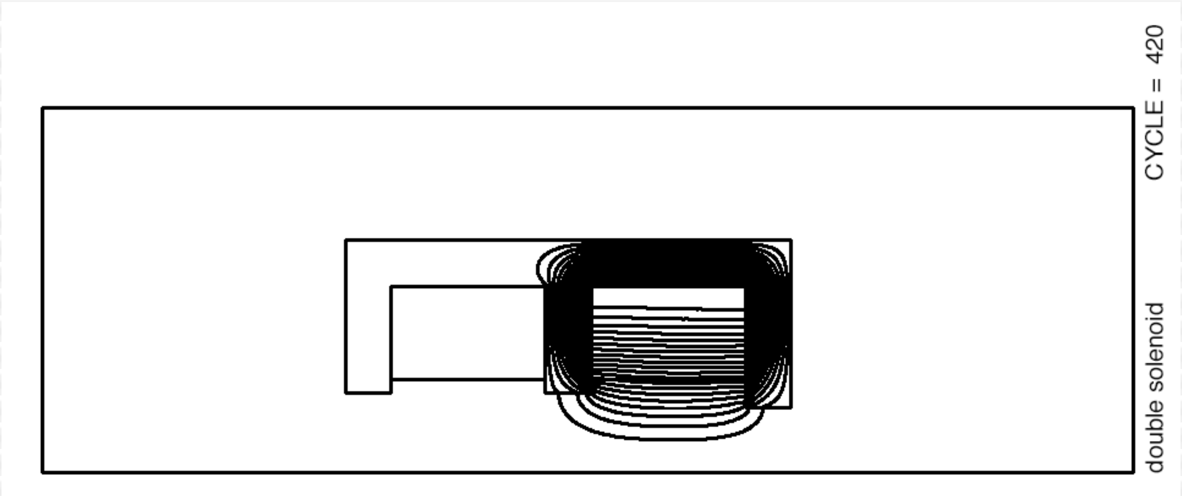
adjustable solenoid
$reg nreg=6,xmax=20.00,ymax=60.00,dx=0.25,dy=0.25,npoint=5$
$po x=0.000,y=0.000$
$po x=20.000,y=0.000$
$po x=20.000,y=60.000$
$po x=0.000,y=60.000$
$po x=0.000,y=0.000$
$reg mat=1, cur=10000, npoint=5$
$po x=5.1,y=21.0$
$po x=16.8,y=21.0$
$po x=16.8,y=24.0$
$po x=5.1,y=24.0$
$po x=5.1,y=21.0$
$reg mat=1, cur=10000, npoint=5$
$po x=5.1,y=25.0$
$po x=16.8,y=25.0$
$po x=16.8,y=28.0$
$po x=5.1,y=28.0$
$po x=5.1,y=25.0$
$reg mat=1, cur=10000, npoint=5$
$po x=5.1,y=29.0$
$po x=16.8,y=29.0$
$po x=16.8,y=32.0$
$po x=5.1,y=32.0$
$po x=5.1,y=29.0$

Note four current regions

$reg mat=1, cur=10000, npoint=5$
$po x=5.1,y=33.0$
$po x=16.8,y=33.0$
$po x=16.8,y=36.0$
$po x=5.1,y=36.0$
$po x=5.1,y=33.0$
$reg mat=2,npoint=21$
$po x=3.8,y=18.5$
$po x=19.3,y=18.5$
$po x=19.3,y=38.5$
$po x=3.8,y=38.5$
$po x=3.8,y=36.0$
$po x=16.8,y=36.0$
$po x=16.8,y=33.0$
$po x=4.5,y=33.0$
$po x=4.5,y=32.0$
$po x=16.8,y=32.0$
$po x=16.8,y=29.0$
$po x=4.5,y=29.0$
$po x=4.5,y=28.0$
$po x=16.8,y=28.0$
$po x=16.8,y=25.0$
$po x=4.5,y=25.0$
$po x=4.5,y=24.0$
$po x=16.8,y=24.0$
$po x=16.8,y=21.0$
$po x=3.8,y=21.0$
$po x=3.8,y=18.5$

Solenoid visual output

- Translated relative to cathode
- Very little fringe field in gun region (to the right)…



Hybrid quad: Amperian currents

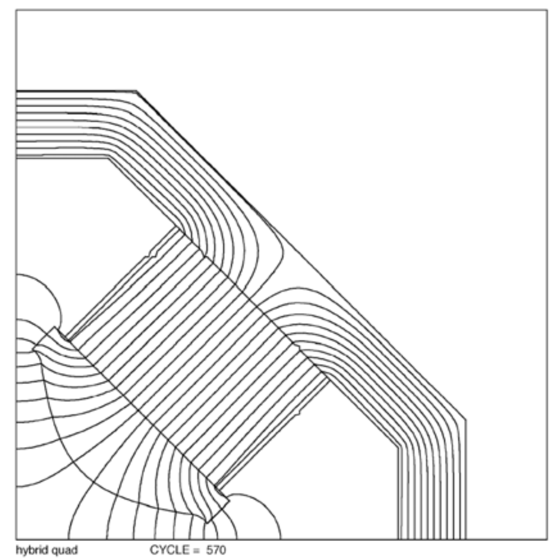
```
hybrid quad
 $reg nreg=5, dx=0.1, xmax=15.0, ymax=15.0, xreg1=8.0,   yreg1=8.0.,
npoint=5$
 $po y= 0.00, x= 0.00$
 $po y=15.00, x= 0.00$
 $po y=15.00, x=15.00$
 $po y= 0.00, x=15.00$
 $po y= 0.00, x= 0.00$
 $reg mat=2, npoint=9$
 $po x=0.000, y=10.795$
 $po x=0.000, y=12.70$
 $po x=3.393, y=12.70$
 $po x=12.70, y=3.393$
 $po x=12.70, y=0.00$
 $po x=10.795, y=0.00$
 $po x=10.795,  y=2.604$
 $po x=2.604, y=10.795$
 $po x=0.000, y=10.795$
 $reg mat=2, npoint=7$
 $po x=1.087, y=6.026$
 $po x=6.026, y=1.087$
 $po x=5.397, y=0.458$
$po x=.118, y=.588, x0=4.901, y0=.121, nt=2$
 $po y=5.019, x=.709, r=2.668 nt=3$
 $po x=0.337, y=.496, x0=0.121, y0=4.901, nt=2$
 $po x=1.087, y=6.026$
 $reg  mat=1, cur=-28300., npoint=5$
 $po x=4.521, y=8.877$
 $po x=4.621, y=8.777$
 $po x=1.479, y=5.634$
 $po x=1.379, y=5.734$
 $po x=4.521, y=8.877$
 $reg  mat=1, cur=28300., npoint=5$
 $po y=4.521, x=8.877$
 $po y=4.621, x=8.777$
 $po y=1.479, x=5.634$
 $po y=1.379, x=5.734$
 $po y=4.521, x=8.877$
```

Very narrow
Current regions
(sheets)
Not always stable

$$K = M / \mu_0$$

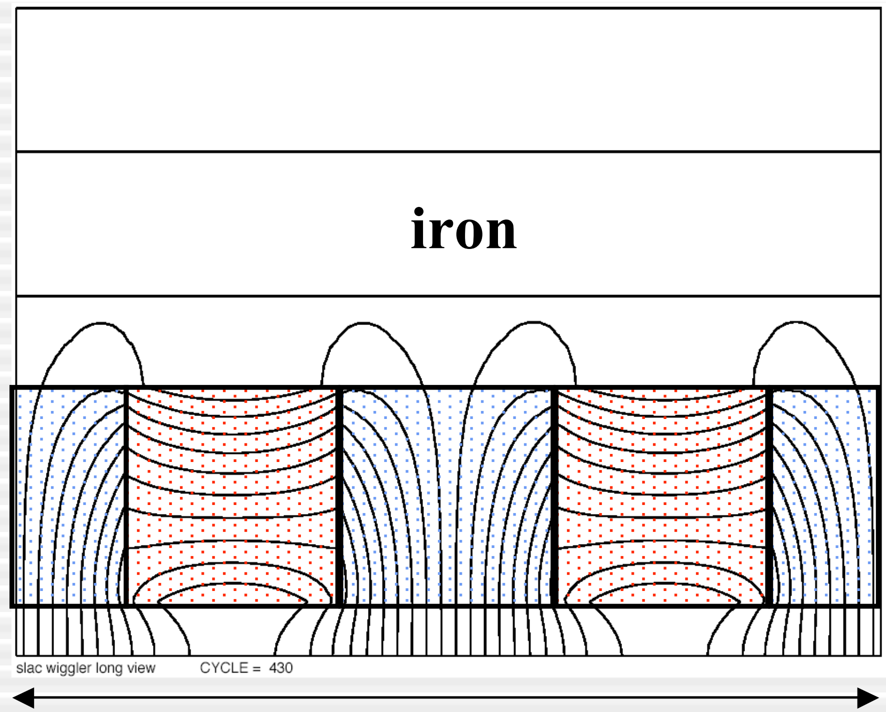
Hybrid quad output

- Finite width Amperian current “sheets”
- Not much fringing!
- Need 3D (RADIA)
- Can you scale this to small size?



Example: Halbach undulator

- Done entirely with Amperian currents (see input deck)
- Current sheets are zero width (vert/horiz sheets better…)
- Can you put iron around the LCLS undulator?
  - Yes. Flux circulates entirely in PM pieces and gap
- Also has serious 3D aspects



One period of undulator