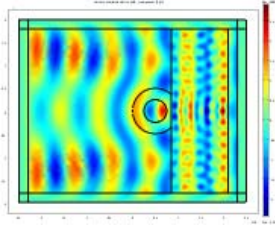




## Dielectric Scattering PML



## 1. Table of Contents

- Title - Dielectric Scattering PML
- Table of Contents
- Model Properties
- Geometry
- Geom 1
- Materials/Coefficients Library
- Solver Settings
- Postprocessing
- Variables

## 2. Model Properties

<b>Property</b>	<b>Value</b>
Model name	Dielectric Scattering PML
Author	COMSOL
Company	COMSOL
Department	
Reference	Copyright (c) 1994-2006 by COMSOL AB
URL	<a href="http://www.comsol.com">www.comsol.com</a>
Saved date	Nov 24, 2009 2:36:56 PM
Creation date	Aug 19, 2006 11:32:49 AM
COMSOL version	COMSOL 3.3.0.405

File name: D:\Research\2009-2010\Simulation\Near field enhancement with

cylinder on silicon surface\Scattered electric field for cylindrical rod on substrate\11232009\rod\_500nm Wave\_800 nm with different distances\rod\_500nm Wave\_800 nm with 100 nm gap\_with space.mph  
Application modes and modules used in this model:

- Geom1 (2D)
  - In-Plane TE Waves (RF Module)

## 2.1. Model description

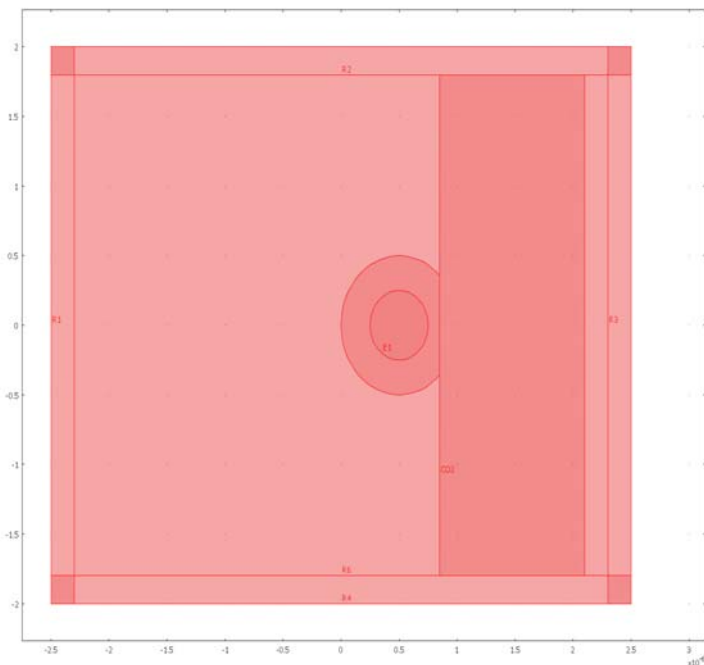
Dielectric Scattering PML

This is an example of how to model perfectly matched layers in the RF Module. The model shows scattering from a dielectric object and how the scattered wave is absorbed by PMLs.

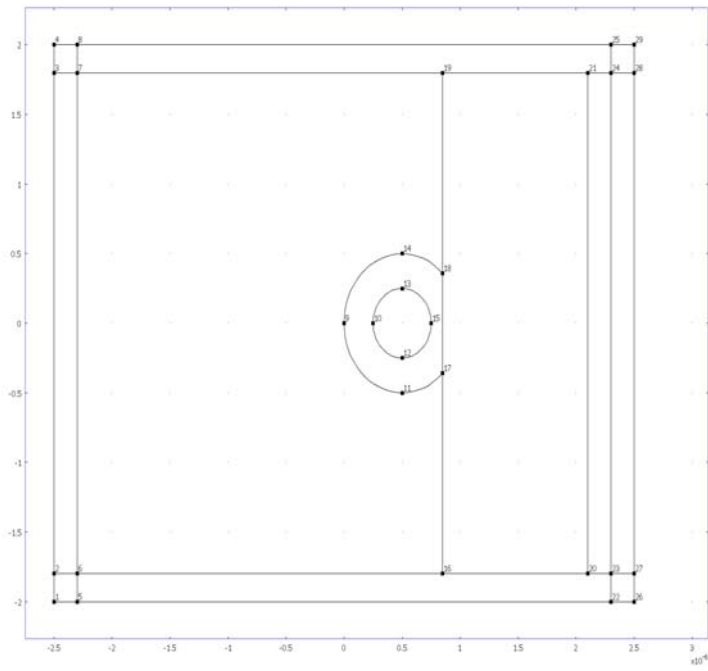
## 3. Geometry

Number of geometries: 1

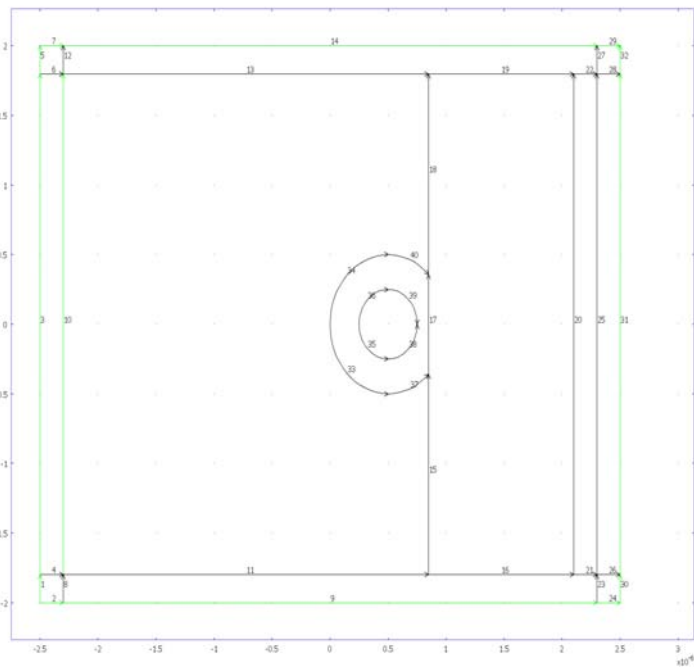
### 3.1. Geom1



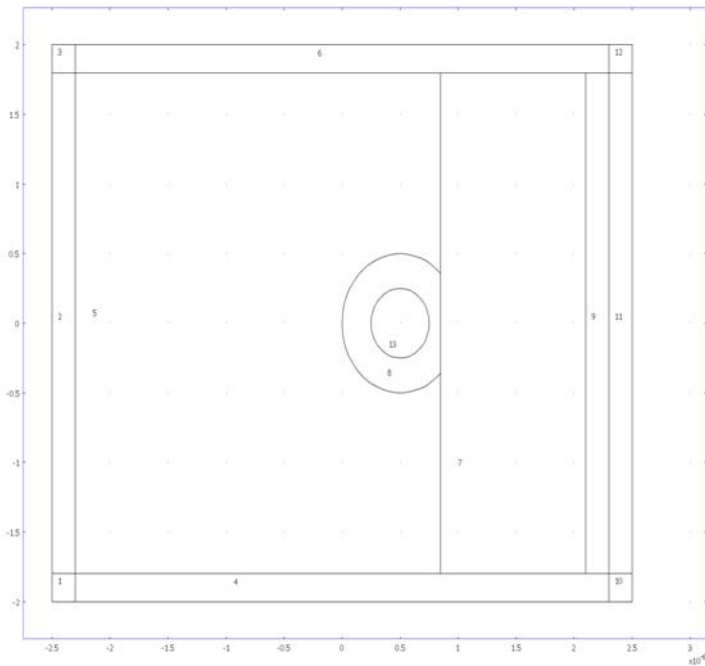
#### 3.1.1. Point mode



### 3.1.2. Boundary mode



### 3.1.3. Subdomain mode



## 4. Geom1

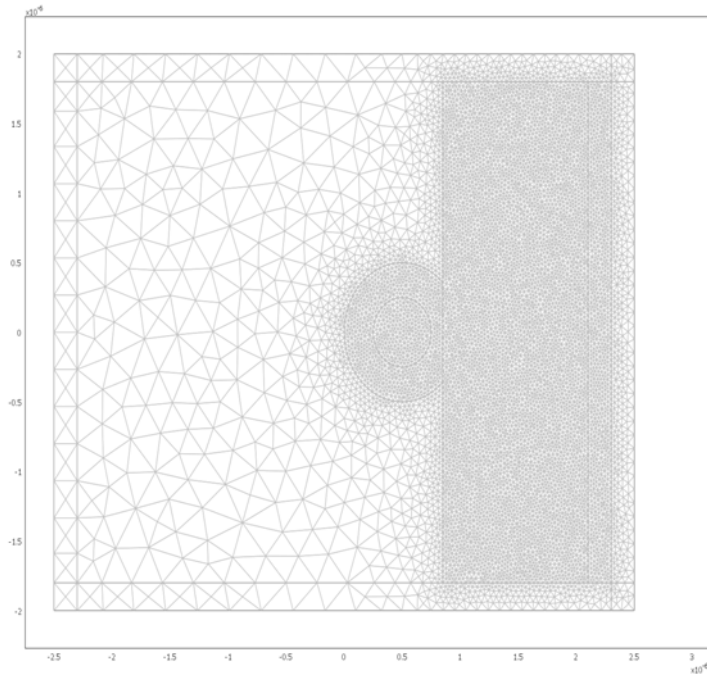
Space dimensions: 2D

Independent variables: x, y, z

### 4.1. Mesh

#### 4.1.1. Mesh Statistics

Number of degrees of freedom	38604
Number of mesh points	9682
Number of elements	19241
Triangular	19241
Quadrilateral	0
Number of boundary elements	627
Number of vertex elements	29
Minimum element quality	0.666
Element area ratio	0.003



## 4.2. Application Mode: In-Plane TE Waves (rfweh)

Application mode type: In-Plane TE Waves (RF Module)

Application mode name: rfweh

### 4.2.1. Scalar Variables

Name	Variable	Value	Description
epsilon0	epsilon0_rfweh	8.854187817e-12	Permittivity of vacuum
mu0	mu0_rfweh	4*pi*1e-7	Permeability of vacuum
lambda0	lambda0_rfweh	800e-9	Free space wavelength
E0iz	E0iz_rfweh	$\exp(-j*k0\_rfweh*x)$	Incident electric field, z component

### 4.2.2. Application Mode Properties

Property	Value
Default element type	Lagrange - Quadratic
Analysis type	Harmonic propagation
Field type	Scattered TE waves
Specify wave using	Free space wavelength
Specify eigenvalues using	Eigenfrequency

Symmetry plane x=0	Off
Symmetry type for x=0	Symmetry
Symmetry plane y=0	Off
Symmetry type for y=0	Symmetry
Frame	Frame (ref)
Weak constraints	Off

#### 4.2.3. Variables

Dependent variables: Ez, Hz, Ax, Ay, Az, scEz, schz

Shape functions: shlag(2,'scEz')

Interior boundaries active

#### 4.2.4. Boundary Settings

Boundary		1-3, 5, 7, 9, 14, 24, 29-32	4, 6, 8, 11-13, 15-23, 25-28, 33-40
Type		Scattering boundary condition	Continuity
Electric field (E0)	V/m	{0;0;0}	{0;0;0}
Boundary		10	
Type		Electric field	
Electric field (E0)		<b>{0;0;1}</b>	

#### 4.2.5. Subdomain Settings

Subdomain		1, 3, 10, 12	2
Relative permeability (mur)	1	1	1
Relative permittivity (epsilon <sub>r</sub> )	1	1	1
Electrical conductivity (sigma)	S/m	0	0
Refractive index (n)	1	1	1
Stype	m	<b>coord</b>	<b>coord</b>
Absorbing in # direction		<b>{1;1}</b>	<b>{1;0}</b>

(coordOn)

Subdomain	4, 6	5, 8	7
Relative permeability (mur)	1	1	<b>1 (Silicon)</b>
Relative permittivity (epsilon <sub>r</sub> )	1	1	<b>12.1 (Silicon)</b>
Electrical conductivity (sigma)	0	0	<b>1e-12[S/m] (Silicon)</b>
Refractive index (n)	1	1	<b>3.48 (Silicon)</b>
Stype	<b>coord</b>	none	none
Absorbing in # direction (coordOn)	<b>{0;1}</b>	{0;0}	{0;0}
Subdomain	9	11	13
Relative permeability (mur)	1	1	<b>1 (Silica Glass)</b>
Relative permittivity (epsilon <sub>r</sub> )	1	1	<b>2.09 (Silica Glass)</b>
Electrical conductivity (sigma)	0	0	<b>1e-14[S/m] (Silica Glass)</b>
Refractive index (n)	<b>3.48</b>	<b>3.48</b>	<b>1.45 (Silica Glass)</b>
Stype	none	<b>coord</b>	none
Absorbing in # direction (coordOn)	{0;0}	<b>{1;0}</b>	{0;0}

## 5. Materials/Coefficients Library

### 5.1. C [100]

**Parameter**                      **Value**

Heat capacity (C)	520
Young's modulus (E)	105e9
Thermal expansion coeff. (alpha)	0.8e-6
Relative permittivity (epsilon <sub>r</sub> )	5.1
Thermal conductivity (k)	990
Poisson's ratio (nu)	0.1
Density (rho)	3515

## 5.2. Ag

Parameter	Value
Heat capacity (C)	235
Young's modulus (E)	83e9
Thermal expansion coeff. (alpha)	18.9e-6
Thermal conductivity (k)	429
Poisson's ratio (nu)	0.37
Density (rho)	10500
Electrical conductivity (sigma)	61.6e6

## 5.3. Air, 1 atm

Parameter	Value
Heat capacity (C)	$C_p(T[1/K])[J/(kg \cdot K)]$
Dynamic viscosity (eta)	$\eta(T[1/K])[Pa \cdot s]$
Thermal conductivity (k)	$k(T[1/K])[W/(m \cdot K)]$
Kinematic viscosity (nu <sub>0</sub> )	$\nu_0(T[1/K])[m^2/s]$
Density (rho)	$\rho(p[1/Pa], T[1/K])[kg/m^3]$

## 5.4. Silicon

Parameter	Value
Heat capacity (C)	703[J/(kg·K)]
Young's modulus (E)	131E9[Pa]
Thermal expansion coeff. (alpha)	4.15e-6[1/K]
Relative permittivity (epsilon <sub>r</sub> )	12.1
Thermal conductivity (k)	163[W/(m·K)]
Relative permeability (mu <sub>r</sub> )	1



Refractive index (n)	3.48
Poisson's ratio (nu)	0.27
Density (rho)	2330[kg/m <sup>3</sup> ]
Electrical conductivity (sigma)	1e-12[S/m]

## 5.5. Silicon Carbide

Parameter	Value
Heat capacity (C)	1200
Surface emissivity (epsilon)	0.5
Relative permittivity (epsilon <sub>r</sub> )	10
Thermal conductivity (k)	450*(300/T) <sup>0.75</sup>
Relative permeability (mu <sub>r</sub> )	1
Density (rho)	3200
Electrical conductivity (sigma)	1e3

## 5.6. Si(c)

Parameter	Value
Heat capacity (C)	700
Young's modulus (E)	170e9
Thermal expansion coeff. (alpha)	2.6e-6
Relative permittivity (epsilon <sub>r</sub> )	11.7
Thermal conductivity (k)	130
Poisson's ratio (nu)	0.28
Density (rho)	2329

## 5.7. Au

Parameter	Value
Heat capacity (C)	129
Young's modulus (E)	70e9
Thermal expansion coeff. (alpha)	14.2e-6
Thermal conductivity (k)	317
Poisson's ratio (nu)	0.44
Density (rho)	19300
Electrical conductivity (sigma)	45.6e6

## 5.8. Silica Glass

<b>Parameter</b>	<b>Value</b>
Heat capacity (C)	703[J/(kg*K)]
Young's modulus (E)	73.1e9[Pa]
Thermal expansion coeff. (alpha)	0.55e-6[1/K]
Relative permittivity (epsilon <sub>r</sub> )	2.09
Thermal conductivity (k)	1.38[W/(m*K)]
Relative permeability (mu <sub>r</sub> )	1
Refractive index (n)	1.45
Poisson's ratio (nu)	0.17
Density (rho)	2203[kg/m <sup>3</sup> ]
Electrical conductivity (sigma)	1e-14[S/m]

## 5.9. Cu

<b>Parameter</b>	<b>Value</b>
Heat capacity (C)	384
Young's modulus (E)	120e9
Thermal expansion coeff. (alpha)	16.5e-6
Thermal conductivity (k)	401
Poisson's ratio (nu)	0.34
Density (rho)	8960
Electrical conductivity (sigma)	58.1e6

## 6. Solver Settings

Solve using a script: off

Analysis type	Harmonic_propagation
Auto select solver	On
Solver	Stationary
Solution form	Automatic
Symmetric	auto
Adaption	Off

## 6.1. Direct (UMFPACK)

Solver type: Linear system solver

<b>Parameter</b>	<b>Value</b>
Pivot threshold	0.1
Memory allocation factor	0.7

## 6.2. Advanced

<b>Parameter</b>	<b>Value</b>
Constraint handling method	Elimination
Null-space function	Automatic
Assembly block size	5000
Use Hermitian transpose of constraint matrix and in symmetry detection	Off
Use complex functions with real input	Off
Stop if error due to undefined operation	On
Type of scaling	Automatic
Manual scaling	
Row equilibration	On
Manual control of reassembly	Off
Load constant	On
Constraint constant	On
Mass constant	On
Damping (mass) constant	On
Jacobian constant	On
Constraint Jacobian constant	On

## 7. Postprocessing

## 8. Variables

### 8.1. Boundary

#### 8.1.1. Boundary 1-9, 12, 14, 23-24, 26-32

<b>Name</b>	<b>Description</b>	<b>Expression</b>
Eiz_rfweh	Incident electric field	0
dVolbnd_rfweh	Area integration contribution	$\det J_{\text{rfweh}} * \sqrt{(\text{inv} J_{xx\_rfweh} * n_{x\_rfweh})^2 + (\text{inv} J_{yy\_rfweh} * n_{y\_rfweh})^2}$
Qsj1_rfweh	Surface current source_term	0
Jsz_rfweh	Surface current density, z component	$u_{nx} * (\text{Hy\_rfweh\_down} - \text{Hy\_rfweh\_up}) - u_{ny} * (\text{Hx\_rfweh\_down} - \text{Hx\_rfweh\_up})$
Qsav_rfweh	Surface resistive heating, time average	$0.5 * \text{real}(J_{sz\_rfweh} * \text{conj}(E_z))$
nPoav_rfweh	Power outflow, time average	$n_{x\_rfweh} * P_{oxav\_rfweh} + n_{y\_rfweh} * P_{oyav\_rfweh}$
tEscz_rfweh	E-field in Stratton-Chu formula,	scEz

	z component	
tHscx_rfweh	H-field in Stratton-Chu formula, x component	scHx_rfweh
tHscy_rfweh	H-field in Stratton-Chu formula, y component	scHy_rfweh
Z_TE_rfweh	Wave impedance, TE waves	$\omega_{rfweh} * \mu_{rfweh} / \beta_{port\_rfweh}$
Z_TM_rfweh	Wave impedance, TM waves	$\beta_{port\_rfweh} / (\omega_{rfweh} * \epsilon_{rfweh})$
Z_TEM_rfweh	Wave impedance, TEM waves	$\sqrt{\mu_{rfweh} / \epsilon_{rfweh}}$

### 8.1.2. Boundary 10, 13, 19, 22

Name	Description	Expression
Eiz_rfweh	Incident electric field	E0iz_rfweh
dVolbnd_rfweh	Area integration contribution	1
Qsj1_rfweh	Surface current source_term	$dVolbnd\_rfweh * j\omega_{rfweh} * \mu_0_{rfweh} * (dn_x * \text{down}(H_{iy\_rfweh}) - dn_y * \text{down}(H_{ix\_rfweh}))$
Jsz_rfweh	Surface current density, z component	$un_x * (H_{y\_rfweh\_down} - H_{y\_rfweh\_up}) - un_y * (H_{x\_rfweh\_down} - H_{x\_rfweh\_up})$
Qsav_rfweh	Surface resistive heating, time average	$0.5 * \text{real}(J_{sz\_rfweh} * \text{conj}(E_z))$
nPoav_rfweh	Power outflow, time average	$n_x\_rfweh * P_{oxav\_rfweh} + n_y\_rfweh * P_{oyav\_rfweh}$
tEscz_rfweh	E-field in Stratton-Chu formula, z component	scEz
tHscx_rfweh	H-field in Stratton-Chu formula, x component	scHx_rfweh
tHscy_rfweh	H-field in Stratton-Chu formula, y component	scHy_rfweh
Z_TE_rfweh	Wave impedance, TE waves	$\omega_{rfweh} * \mu_{rfweh} / \beta_{port\_rfweh}$
Z_TM_rfweh	Wave impedance, TM waves	$\beta_{port\_rfweh} / (\omega_{rfweh} * \epsilon_{rfweh})$

Z\_TEM\_rfweh Wave impedance, TEM waves  $\sqrt{\mu_0_{\text{rfweh}}/\epsilon_{\text{rfweh}}}$

### 8.1.3. Boundary 11, 16, 21, 25

Name	Description	Expression
Eiz_rfweh	Incident electric field	E0iz_rfweh
dVolbnd_rfweh	Area integration contribution	1
Qsj1_rfweh	Surface current source_term	dVolbnd_rfweh * jomega_rfweh * mu0_rfweh * (unx * up(Hiy_rfweh)-uny * up (Hix_rfweh))
Jsz_rfweh	Surface current density, z component	unx * (Hy_rfweh_down- Hy_rfweh_up)-uny * (Hx_rfweh_down- Hx_rfweh_up)
Qsav_rfweh	Surface resistive heating, time average	0.5 * real(Jsz_rfweh * conj(Ez))
nPoav_rfweh	Power outflow, time average	nx_rfweh * Poxav_rfweh+ny_rfweh * Poyav_rfweh
tEscz_rfweh	E-field in Stratton-Chu formula, z component	scEz
tHscx_rfweh	H-field in Stratton-Chu formula, x component	scHx_rfweh
tHscy_rfweh	H-field in Stratton-Chu formula, y component	scHy_rfweh
Z_TE_rfweh	Wave impedance, TE waves	omega_rfweh * mu_rfweh/betaport_rfweh
Z_TM_rfweh	Wave impedance, TM waves	betaport_rfweh/(omega_rfweh * epsilon_rfweh)
Z_TEM_rfweh	Wave impedance, TEM waves	sqrt(mu_rfweh/epsilon_rfweh)

### 8.1.4. Boundary 15, 17-18, 20, 33-40

Name	Description	Expression
Eiz_rfweh	Incident electric field	E0iz_rfweh
dVolbnd_rfweh	Area integration contribution	1
Qsj1_rfweh	Surface current source_term	0

Js <sub>z</sub> _rfweh	Surface current density, z component	$un_x * (Hy\_rfweh\_down - Hy\_rfweh\_up) - un_y * (Hx\_rfweh\_down - Hx\_rfweh\_up)$
Q <sub>sav</sub> _rfweh	Surface resistive heating, time average	$0.5 * \text{real}(Js_z\_rfweh * \text{conj}(E_z))$
n <sub>Poav</sub> _rfweh	Power outflow, time average	$nx\_rfweh * Poxav\_rfweh + ny\_rfweh * Poyav\_rfweh$
t <sub>Escz</sub> _rfweh	E-field in Stratton-Chu formula, z component	scEz
t <sub>Hscx</sub> _rfweh	H-field in Stratton-Chu formula, x component	scHx_rfweh
t <sub>Hscy</sub> _rfweh	H-field in Stratton-Chu formula, y component	scHy_rfweh
Z <sub>TE</sub> _rfweh	Wave impedance, TE waves	$\omega\_rfweh * \mu\_rfweh / \beta_{\text{port}}\_rfweh$
Z <sub>TM</sub> _rfweh	Wave impedance, TM waves	$\beta_{\text{port}}\_rfweh / (\omega\_rfweh * \epsilon\_rfweh)$
Z <sub>TEM</sub> _rfweh	Wave impedance, TEM waves	$\sqrt{\mu\_rfweh / \epsilon\_rfweh}$

## 8.2. Subdomain

### 8.2.1. Subdomain 1, 3, 10, 12

Name	Description	Expression
dr <sub>guess</sub> _rfweh	Width in radial direction default guess	2.809457454143782e-007
R <sub>0</sub> _guess_rfweh	Inner radius default guess	2.920616373302046e-006
SR_rfweh	PML radial coordinate	$R0\_rfweh + (\sqrt{(x\_srcpntx\_rfweh)^2 + (y\_srcpnty\_rfweh)^2} - R0\_rfweh) * \lambda S\_rfweh * (1-i) / dr\_rfweh$
Sx_rfweh	PML x coordinate	$x * \lambda S\_rfweh * (1-i) / Sdx\_rfweh$
Sdx <sub>guess</sub> _rfweh	Width in x direction default	2e-007

weh	guess	
rCylx_rfweh	PML r cylindrical vector, x component	
Sy_rfweh	PML y coordinate	$y * \lambda S\_rfweh * (1-i) / Sdy\_rfweh$
Sdy_guess_rfweh	Width in y direction default guess	2e-007
rCylly_rfweh	PML r cylindrical vector, y component	
detJ_rfweh	PML transformation matrix determinant	$Jxx\_rfweh * Jyy\_rfweh$
Jxx_rfweh	PML transformation matrix, element xx	$diff(Sx\_rfweh, x)$
invJxx_rfweh	PML inverse transformation matrix, element xx	$Jyy\_rfweh / detJ\_rfweh$
Jxy_rfweh	PML transformation matrix, element xy	0
invJxy_rfweh	PML inverse transformation matrix, element xy	0
Jyx_rfweh	PML transformation matrix, element yx	0
invJyx_rfweh	PML inverse transformation matrix, element yx	0
Jyy_rfweh	PML transformation matrix, element yy	$diff(Sy\_rfweh, y)$
invJyy_rfweh	PML inverse transformation matrix, element yy	$Jxx\_rfweh / detJ\_rfweh$
k_rfweh	Wave number	$k0\_rfweh * \sqrt{\mu r\_rfweh * (\epsilon r\_rfweh + \sigma\_rfweh / (j \omega\_rfweh * \epsilon 0\_rfweh))}$
c_rfweh	Phase velocity	$c0\_rfweh / \sqrt{\epsilon r\_rfweh * \mu r\_rfweh}$
Z_wave_rfweh	Wave impedance	$c\_rfweh * \mu 0\_rfweh * \mu r\_rfweh$
delta_rfweh	Skin depth	$1 / (\omega\_rfweh * \sqrt{0.5 * \mu 0\_rfweh * \mu r\_rfweh * \epsilon r\_rfweh * (\epsilon r\_rfweh + \sigma\_rfweh / (j \omega\_rfweh * \epsilon 0\_rfweh))})$



dVol_rfweh	Volume integration contribution	$(\text{sign}(\text{rfweh}/(\omega_{\text{rfweh}} * \epsilon_{0\text{rfweh}} * \epsilon_{\text{rfweh}}))^2))$
Eiz_rfweh	Incident electric field	0
curlEx_rfweh	Curl of electric field, x component	$\text{invJyy\_rfweh} * \text{diff}(E_{\text{iz\_rfweh}} + \text{scEz}, y)$
curlEy_rfweh	Curl of electric field, y component	$\text{invJxx\_rfweh} * \text{diff}(-E_{\text{iz\_rfweh}} - \text{scEz}, x)$
depEz_rfweh	Electric field test variable, z component	scEz
Ez	Electric field, z component	$\text{scEz} + E_{\text{iz\_rfweh}}$
epsilon_rfweh	Permittivity	$\epsilon_{0\text{rfweh}} * \epsilon_{\text{rfweh}}$
mu_rfweh	Permeability	$\mu_{0\text{rfweh}} * \mu_{\text{rfweh}}$
muxx_rfweh	Permeability, xx component	$\mu_{0\text{rfweh}} * \mu_{\text{rxx\_rfweh}}$
muxy_rfweh	Permeability, xy component	$\mu_{0\text{rfweh}} * \mu_{\text{rxy\_rfweh}}$
muyx_rfweh	Permeability, yx component	$\mu_{0\text{rfweh}} * \mu_{\text{ryx\_rfweh}}$
muyy_rfweh	Permeability, yy component	$\mu_{0\text{rfweh}} * \mu_{\text{ryy\_rfweh}}$
jwHx_rfweh	Magnetic field, x component, times j $\omega$	$j\omega B_{\text{x\_rfweh}} / (\mu_{\text{rfweh}} * \mu_{0\text{rfweh}})$
Hx_rfweh	Magnetic field, x component	$j\omega H_{\text{x\_rfweh}} / j\omega_{\text{rfweh}}$
scHx_rfweh	Scattered magnetic field, x component	$\text{sc}B_{\text{x\_rfweh}} / (\mu_{\text{rfweh}} * \mu_{0\text{rfweh}})$
Hix_rfweh	Incident magnetic field, x component	$-\text{invJyy\_rfweh} * \text{diff}(E_{\text{iz\_rfweh}}, y) / (\mu_{\text{rfweh}} * \mu_{0\text{rfweh}} * j\omega_{\text{rfweh}})$
jwHy_rfweh	Magnetic field, y component, times j $\omega$	$j\omega B_{\text{y\_rfweh}} / (\mu_{\text{rfweh}} * \mu_{0\text{rfweh}})$
Hy_rfweh	Magnetic field, y component	$j\omega H_{\text{y\_rfweh}} / j\omega_{\text{rfweh}}$
scHy_rfweh	Scattered magnetic field, y component	$\text{sc}B_{\text{y\_rfweh}} / (\mu_{\text{rfweh}} * \mu_{0\text{rfweh}})$
Hiy_rfweh	Incident magnetic field, y component	$-\text{invJxx\_rfweh} * \text{diff}(-E_{\text{iz\_rfweh}}, x) / (\mu_{\text{rfweh}} * \mu_{0\text{rfweh}} * j\omega_{\text{rfweh}})$
Dz_rfweh	Electric displacement, z component	$\epsilon_{\text{rfweh}} * E_{\text{z}}$
Jdz_rfweh	Displacement current density, z component	$j\omega_{\text{rfweh}} * D_{\text{z\_rfweh}}$

Jiz_rfweh	Induced current density, z component	$\sigma_{rfweh} * E_z$
scDz_rfweh	Scattered electric displacement, z component	$\epsilon_{rfweh} * scE_z$
jwBx_rfweh	Magnetic flux density, x component	$-curlEx_{rfweh}$
jwBy_rfweh	Magnetic flux density, y component	$-curlEy_{rfweh}$
Bx_rfweh	Magnetic flux density, x component	$jwBx_{rfweh}/j\omega_{rfweh}$
By_rfweh	Magnetic flux density, y component	$jwBy_{rfweh}/j\omega_{rfweh}$
scBx_rfweh	Scattered magnetic flux density, x component	$-invJyy_{rfweh} * scEzy/j\omega_{rfweh}$
scBy_rfweh	Scattered magnetic flux density, y component	$invJxx_{rfweh} * scEzx/j\omega_{rfweh}$
normE_rfweh	Electric field, norm	$abs(E_z)$
normD_rfweh	Electric displacement, norm	$abs(Dz_{rfweh})$
normscE_rfweh	Scattered electric field, norm	$abs(scE_z)$
normscD_rfweh	Scattered electric displacement, norm	$abs(scDz_{rfweh})$
normB_rfweh	Magnetic flux density, norm	$\sqrt{abs(Bx_{rfweh})^2 + abs(By_{rfweh})^2}$
normH_rfweh	Magnetic field, norm	$\sqrt{abs(Hx_{rfweh})^2 + abs(Hy_{rfweh})^2}$
normscB_rfweh	Scattered magnetic flux density, norm	$\sqrt{abs(scBx_{rfweh})^2 + abs(scBy_{rfweh})^2}$
normscH_rfweh	Scattered magnetic field, norm	$\sqrt{abs(scHx_{rfweh})^2 + abs(scHy_{rfweh})^2}$
normPoav_rfweh	Power flow, time average, norm	$\sqrt{abs(Poxav_{rfweh})^2 + abs(Poyav_{rfweh})^2}$
Wmav_rfweh	Magnetic energy density, time average	$0.25 * real(Hx_{rfweh} * conj(Bx_{rfweh}) + Hy_{rfweh} * conj(By_{rfweh}))$
Weav_rfweh	Electric energy density, time average	$0.25 * real(Ez * conj(Dz_{rfweh}))$
Wav_rfweh	Total energy density, time average	$Wmav_{rfweh} + Weav_{rfweh}$

Qav_rfweh	Resistive heating, time average	$0.5 * \text{real}(\text{sigma\_rfweh} * \text{abs}(\text{Ez})^2 - j * \text{real}(\text{omega\_rfweh}) * \text{Ez} * \text{conj}(\text{Dz\_rfweh}))$
Poxav_rfweh	Power flow, time average, x component	$0.5 * \text{real}(-\text{Ez} * \text{conj}(\text{Hy\_rfweh}))$
Poyav_rfweh	Power flow, time average, y component	$0.5 * \text{real}(\text{Ez} * \text{conj}(\text{Hx\_rfweh}))$

### 8.2.2. Subdomain 2, 11

Name	Description	Expression
dr_guess_rfweh	Width in radial direction default guess	1.599679868478261e-007
R0_guess_rfweh	Inner radius default guess	2.920616373302046e-006
SR_rfweh	PML radial coordinate	$\text{R0\_rfweh} + (\text{sqrt}((\text{x\_srcpntx\_rfweh})^2 + (\text{y\_srcpnty\_rfweh})^2) - \text{R0\_rfweh}) * \text{lambdaS\_rfweh} * (1-i) / \text{dr\_rfweh}$
Sx_rfweh	PML x coordinate	$\text{x} * \text{lambdaS\_rfweh} * (1-i) / \text{Sdx\_rfweh}$
Sdx_guess_rfweh	Width in x direction default guess	2e-007
rCylx_rfweh	PML r cylindrical vector, x component	
Sy_rfweh	PML y coordinate	y
Sdy_guess_rfweh	Width in y direction default guess	0
rCylx_rfweh	PML r cylindrical vector, y component	
detJ_rfweh	PML transformation matrix determinant	Jxx_rfweh
Jxx_rfweh	PML transformation matrix, element xx	diff(Sx_rfweh,x)
invJxx_rfweh	PML inverse transformation matrix, element xx	1/detJ_rfweh
Jxy_rfweh	PML transformation matrix, element xy	0
invJxy_rfweh	PML inverse transformation	0

	matrix, element xy	
Jyx_rfweh	PML transformation matrix, element yx	0
invJyx_rfweh	PML inverse transformation matrix, element yx	0
Jyy_rfweh	PML transformation matrix, element yy	1
invJyy_rfweh	PML inverse transformation matrix, element yx	Jxx_rfweh/detJ_rfweh
k_rfweh	Wave number	$k0\_rfweh * \sqrt{mur\_rfweh * (epsilon0\_rfweh + sigma\_rfweh / (jomega\_rfweh * epsilon0\_rfweh))}$
c_rfweh	Phase velocity	$c0\_rfweh / \sqrt{epsilon0\_rfweh * mur\_rfweh}$
Z_wave_rfweh	Wave impedance	$c\_rfweh * mu0\_rfweh * mur\_rfweh$
delta_rfweh	Skin depth	$1 / (\omega\_rfweh * \sqrt{0.5 * mu0\_rfweh * mur\_rfweh * epsilon0\_rfweh * (epsilon0\_rfweh * (-1 + \sqrt{1 + (sigma\_rfweh / (\omega\_rfweh * epsilon0\_rfweh * epsilon0\_rfweh))^2}))})$
dVol_rfweh	Volume integration contribution	detJ_rfweh
Eiz_rfweh	Incident electric field	0
curlEx_rfweh	Curl of electric field, x component	$invJyy\_rfweh * diff(Eiz\_rfweh + scEz, y)$
curlEy_rfweh	Curl of electric field, y component	$invJxx\_rfweh * diff(-Eiz\_rfweh - scEz, x)$
depEz_rfweh	Electric field test variable, z component	scEz
Ez	Electric field, z component	scEz + Eiz_rfweh
epsilon_rfweh	Permittivity	$epsilon0\_rfweh * epsilon0\_rfweh * epsilon0\_rfweh$
mu_rfweh	Permeability	$mu0\_rfweh * mur\_rfweh$
muxx_rfweh	Permeability, xx component	$mu0\_rfweh * murxx\_rfweh$

$\mu_{xy\_rfweh}$	Permeability, xy component	$\mu_{0\_rfweh} * \mu_{rxy\_rfweh}$
$\mu_{yx\_rfweh}$	Permeability, yx component	$\mu_{0\_rfweh} * \mu_{ryx\_rfweh}$
$\mu_{yy\_rfweh}$	Permeability, yy component	$\mu_{0\_rfweh} * \mu_{ryy\_rfweh}$
$j\omega H_{x\_rfweh}$	Magnetic field, x component, times $j\omega$	$j\omega B_{x\_rfweh} / (\mu_{r\_rfweh} * \mu_{0\_rfweh})$
$H_{x\_rfweh}$	Magnetic field, x component	$j\omega H_{x\_rfweh} / j\omega_{rfweh}$
$scH_{x\_rfweh}$	Scattered magnetic field, x component	$scB_{x\_rfweh} / (\mu_{r\_rfweh} * \mu_{0\_rfweh})$
$H_{ix\_rfweh}$	Incident magnetic field, x component	$-invJ_{yy\_rfweh} * \text{diff}(E_{iz\_rfweh}, y) / (\mu_{r\_rfweh} * \mu_{0\_rfweh} * j\omega_{rfweh})$
$j\omega H_{y\_rfweh}$	Magnetic field, y component, times $j\omega$	$j\omega B_{y\_rfweh} / (\mu_{r\_rfweh} * \mu_{0\_rfweh})$
$H_{y\_rfweh}$	Magnetic field, y component	$j\omega H_{y\_rfweh} / j\omega_{rfweh}$
$scH_{y\_rfweh}$	Scattered magnetic field, y component	$scB_{y\_rfweh} / (\mu_{r\_rfweh} * \mu_{0\_rfweh})$
$H_{iy\_rfweh}$	Incident magnetic field, y component	$-invJ_{xx\_rfweh} * \text{diff}(-E_{iz\_rfweh}, x) / (\mu_{r\_rfweh} * \mu_{0\_rfweh} * j\omega_{rfweh})$
$Dz\_rfweh$	Electric displacement, z component	$\epsilon_{rfweh} * E_z$
$Jdz\_rfweh$	Displacement current density, z component	$j\omega_{rfweh} * Dz\_rfweh$
$Jiz\_rfweh$	Induced current density, z component	$\sigma_{rfweh} * E_z$
$scDz\_rfweh$	Scattered electric displacement, z component	$\epsilon_{rfweh} * scE_z$
$j\omega B_{x\_rfweh}$	Magnetic flux density, x component	$-curlEx\_rfweh$
$j\omega B_{y\_rfweh}$	Magnetic flux density, y component	$-curlEy\_rfweh$
$B_{x\_rfweh}$	Magnetic flux density, x component	$j\omega B_{x\_rfweh} / j\omega_{rfweh}$
$B_{y\_rfweh}$	Magnetic flux density, y component	$j\omega B_{y\_rfweh} / j\omega_{rfweh}$
$scB_{x\_rfweh}$	Scattered magnetic flux density, x component	$-invJ_{yy\_rfweh} * scE_{zy} / j\omega_{rfweh}$
$scB_{y\_rfweh}$	Scattered magnetic flux density, y component	$invJ_{xx\_rfweh} * scE_{zx} / j\omega_{rfweh}$

normE_rfweh	Electric field, norm	$\text{abs}(E_z)$
normD_rfweh	Electric displacement, norm	$\text{abs}(D_z\_rfweh)$
normscE_rfweh	Scattered electric field, norm	$\text{abs}(scE_z)$
normscD_rfweh	Scattered electric displacement, norm	$\text{abs}(scD_z\_rfweh)$
normB_rfweh	Magnetic flux density, norm	$\sqrt{\text{abs}(B_x\_rfweh)^2 + \text{abs}(B_y\_rfweh)^2}$
normH_rfweh	Magnetic field, norm	$\sqrt{\text{abs}(H_x\_rfweh)^2 + \text{abs}(H_y\_rfweh)^2}$
normscB_rfweh	Scattered magnetic flux density, norm	$\sqrt{\text{abs}(scB_x\_rfweh)^2 + \text{abs}(scB_y\_rfweh)^2}$
normscH_rfweh	Scattered magnetic field, norm	$\sqrt{\text{abs}(scH_x\_rfweh)^2 + \text{abs}(scH_y\_rfweh)^2}$
normPoav_rfweh	Power flow, time average, norm	$\sqrt{\text{abs}(P_{oxav\_rfweh})^2 + \text{abs}(P_{oyav\_rfweh})^2}$
Wmav_rfweh	Magnetic energy density, time average	$0.25 * \text{real}(H_x\_rfweh * \text{conj}(B_x\_rfweh) + H_y\_rfweh * \text{conj}(B_y\_rfweh))$
Weav_rfweh	Electric energy density, time average	$0.25 * \text{real}(E_z * \text{conj}(D_z\_rfweh))$
Wav_rfweh	Total energy density, time average	$W_{mav\_rfweh} + W_{eav\_rfweh}$
Qav_rfweh	Resistive heating, time average	$0.5 * \text{real}(\sigma\_rfweh * \text{abs}(E_z)^2 - j * \text{real}(\omega\_rfweh) * E_z * \text{conj}(D_z\_rfweh))$
Poxav_rfweh	Power flow, time average, x component	$0.5 * \text{real}(-E_z * \text{conj}(H_y\_rfweh))$
Poyav_rfweh	Power flow, time average, y component	$0.5 * \text{real}(E_z * \text{conj}(H_x\_rfweh))$

### 8.2.3. Subdomain 4, 6

Name	Description	Expression
dr_guess_rfweh	Width in radial direction default guess	1.057347207086196e-006
R0_guess_rfweh	Inner radius default guess	1.990602923739438e-006
SR_rfweh	PML radial coordinate	$R0\_rfweh + (\sqrt{(x-$

		$\text{srcpntx\_rfweh})$
		$\wedge 2+(y-$
		$\text{srcpnty\_rfweh})$
		$\wedge 2)-R0\_rfweh)$
		*
		$\text{lambdaS\_rfwe}$
		$h * (1-i)$
		$/\text{dr\_rfweh}$
$Sx\_rfweh$	PML x coordinate	$x$
$Sdx\_guess\_rfweh$	Width in x direction default guess	$3.15e-006$
$rCylx\_rfweh$	PML r cylindrical vector, x component	
$Sy\_rfweh$	PML y coordinate	$y * \text{lambdaS\_rfweh} * (1-i)$
		$/\text{Sdy\_rfweh}$
$Sdy\_guess\_rfweh$	Width in y direction default guess	$2e-007$
$rCylx\_rfweh$	PML r cylindrical vector, y component	
$\text{detJ\_rfweh}$	PML transformation matrix determinant	$Jyy\_rfweh$
$Jxx\_rfweh$	PML transformation matrix, element xx	1
$\text{invJxx\_rfweh}$	PML inverse transformation matrix, element xx	$Jyy\_rfweh/\text{detJ\_rfweh}$
$Jxy\_rfweh$	PML transformation matrix, element xy	0
$\text{invJxy\_rfweh}$	PML inverse transformation matrix, element xy	0
$Jyx\_rfweh$	PML transformation matrix, element yx	0
$\text{invJyx\_rfweh}$	PML inverse transformation matrix, element yx	0
$Jyy\_rfweh$	PML transformation matrix, element yy	$\text{diff}(Sy\_rfweh,y)$
$\text{invJyy\_rfweh}$	PML inverse transformation matrix, element yy	$1/\text{detJ\_rfweh}$
$k\_rfweh$	Wave number	$k0\_rfweh * \text{sqrt}(\text{mur\_rfweh} *$

c_rfweh	Phase velocity	$(\epsilon_0 \sigma_{rfweh} / (\omega_{rfweh} \epsilon_{rfweh} + \sigma_{rfweh}))$
Z_wave_rfweh	Wave impedance	$(\mu_0 \mu_{rfweh} / \epsilon_0 \epsilon_{rfweh})$
delta_rfweh	Skin depth	$1 / (\omega_{rfweh} \sqrt{0.5 \mu_0 \mu_{rfweh} (\epsilon_0 \epsilon_{rfweh} + \epsilon_{rfweh} \sigma_{rfweh} / \omega_{rfweh})})$
dVol_rfweh	Volume integration contribution	detJ_rfweh
Eiz_rfweh	Incident electric field	0
curlEx_rfweh	Curl of electric field, x component	$invJ_{yy\_rfweh} \cdot diff(Eiz\_rfweh + scEz, y)$
curlEy_rfweh	Curl of electric field, y component	$invJ_{xx\_rfweh} \cdot diff(-Eiz\_rfweh - scEz, x)$
depEz_rfweh	Electric field test variable, z component	scEz
Ez	Electric field, z component	scEz + Eiz_rfweh
epsilon_rfweh	Permittivity	$\epsilon_0 \epsilon_{rfweh} + \sigma_{rfweh} / \omega_{rfweh}$
mu_rfweh	Permeability	$\mu_0 \mu_{rfweh}$
muxx_rfweh	Permeability, xx component	$\mu_0 \mu_{xx\_rfweh}$
muxy_rfweh	Permeability, xy component	$\mu_0 \mu_{xy\_rfweh}$
muyx_rfweh	Permeability, yx component	$\mu_0 \mu_{yx\_rfweh}$
muyy_rfweh	Permeability, yy component	$\mu_0 \mu_{yy\_rfweh}$
jwHx_rfweh	Magnetic field, x component, times j $\omega$	$j\omega Bx\_rfweh / (\mu_{rfweh} \mu_0)$
Hx_rfweh	Magnetic field, x component	$j\omega Hx\_rfweh / \omega_{rfweh}$
scHx_rfweh	Scattered magnetic field, x component	$scBx\_rfweh / (\mu_{rfweh} \mu_0)$
Hix_rfweh	Incident magnetic field, x component	$-invJ_{yy\_rfweh} \cdot diff(Eiz\_rfweh, y) / (\mu_{rfweh} \mu_0 \omega_{rfweh})$
jwHy_rfweh	Magnetic field, y component, times j $\omega$	$j\omega By\_rfweh / (\mu_{rfweh} \mu_0)$
Hy_rfweh	Magnetic field, y component	$j\omega Hy\_rfweh / \omega_{rfweh}$



scHy_rfweh	Scattered magnetic field, y component	$scBy\_rfweh / (\mu_{rfweh} * \mu_0\_rfweh)$
Hiy_rfweh	Incident magnetic field, y component	$-invJxx\_rfweh * diff(-Eiz\_rfweh, x) / (\mu_{rfweh} * \mu_0\_rfweh * j\omega\_rfweh)$
Dz_rfweh	Electric displacement, z component	$\epsilon_{rfweh} * Ez$
Jdz_rfweh	Displacement current density, z component	$j\omega\_rfweh * Dz\_rfweh$
Jiz_rfweh	Induced current density, z component	$\sigma_{rfweh} * Ez$
scDz_rfweh	Scattered electric displacement, z component	$\epsilon_{rfweh} * scEz$
jwBx_rfweh	Magnetic flux density, x component	$-curlEx\_rfweh$
jwBy_rfweh	Magnetic flux density, y component	$-curlEy\_rfweh$
Bx_rfweh	Magnetic flux density, x component	$jwBx\_rfweh / j\omega\_rfweh$
By_rfweh	Magnetic flux density, y component	$jwBy\_rfweh / j\omega\_rfweh$
scBx_rfweh	Scattered magnetic flux density, x component	$-invJyy\_rfweh * scEzy / j\omega\_rfweh$
scBy_rfweh	Scattered magnetic flux density, y component	$invJxx\_rfweh * scEzx / j\omega\_rfweh$
normE_rfweh	Electric field, norm	$abs(Ez)$
normD_rfweh	Electric displacement, norm	$abs(Dz\_rfweh)$
normscE_rfweh	Scattered electric field, norm	$abs(scEz)$
normscD_rfweh	Scattered electric displacement, norm	$abs(scDz\_rfweh)$
normB_rfweh	Magnetic flux density, norm	$sqrt(abs(Bx\_rfweh)^2 + abs(By\_rfweh)^2)$
normH_rfweh	Magnetic field, norm	$sqrt(abs(Hx\_rfweh)^2 + abs(Hy\_rfweh)^2)$
normscB_rfweh	Scattered magnetic flux density, norm	$sqrt(abs(scBx\_rfweh)^2 + abs(scBy\_rfweh)^2)$
normscH_rfweh	Scattered magnetic field, norm	$sqrt(abs(scHx\_rfweh)^2 + abs(scHy\_rfweh)^2)$

eh		$(scHy_{rfweh})^2$
normPoav_rfw	Power flow, time average, eh	$\sqrt{abs(Poxav_{rfweh})^2 + abs(Poyav_{rfweh})^2}$
Wmav_rfweh	Magnetic energy density, time average	$0.25 * real(Hx_{rfweh} * conj(Bx_{rfweh}) + Hy_{rfweh} * conj(By_{rfweh}))$
Weav_rfweh	Electric energy density, time average	$0.25 * real(Ez * conj(Dz_{rfweh}))$
Wav_rfweh	Total energy density, time average	$Wmav_{rfweh} + Weav_{rfweh}$
Qav_rfweh	Resistive heating, time average	$0.5 * real(sigma_{rfweh} * abs(Ez)^2 - j * real(omega_{rfweh}) * Ez * conj(Dz_{rfweh}))$
Poxav_rfweh	Power flow, time average, x component	$0.5 * real(-Ez * conj(Hy_{rfweh}))$
Poyav_rfweh	Power flow, time average, y component	$0.5 * real(Ez * conj(Hx_{rfweh}))$

#### 8.2.4. Subdomain 5, 7-9, 13

Name	Description	Expression
dr_guess_rfw	Width in radial direction default guess	0
R0_guess_rfw	Inner radius default guess	0
SR_rfweh	PML radial coordinate	
Sx_rfweh	PML x coordinate	x
Sdx_guess_rfw	Width in x direction default guess	0
rCylx_rfweh	PML r cylindrical vector, x component	
Sy_rfweh	PML y coordinate	y
Sdy_guess_rfw	Width in y direction default guess	0
rCylx_rfweh	PML r cylindrical vector, y component	
detJ_rfweh	PML transformation matrix determinant	1
Jxx_rfweh	PML transformation matrix,	1

	element xx	
invJxx_rfweh	PML inverse transformation matrix, element xx	1
Jxy_rfweh	PML transformation matrix, element xy	0
invJxy_rfweh	PML inverse transformation matrix, element xy	0
Jyx_rfweh	PML transformation matrix, element yx	0
invJyx_rfweh	PML inverse transformation matrix, element yx	0
Jyy_rfweh	PML transformation matrix, element yy	1
invJyy_rfweh	PML inverse transformation matrix, element yy	1
k_rfweh	Wave number	$k0\_rfweh * \sqrt{\mu r\_rfweh * (\epsilon r\_rfweh + \sigma\_rfweh / (j\omega\_rfweh * \epsilon 0\_rfweh))}$
c_rfweh	Phase velocity	$c0\_rfweh / \sqrt{\epsilon r\_rfweh * \mu r\_rfweh}$
Z_wave_rfweh	Wave impedance	$c\_rfweh * \mu 0\_rfweh * \mu r\_rfweh$
delta_rfweh	Skin depth	$1 / (\omega\_rfweh * \sqrt{0.5 * \mu 0\_rfweh * \mu r\_rfweh * \epsilon r\_rfweh * (\sigma\_rfweh / (\omega\_rfweh * \epsilon 0\_rfweh * \epsilon r\_rfweh)) + 1})$
dVol_rfweh	Volume integration contribution	detJ_rfweh
Eiz_rfweh	Incident electric field	E0iz_rfweh
curlEx_rfweh	Curl of electric field, x component	diff(Eiz_rfweh + scEz, y)
curlEy_rfweh	Curl of electric field, y component	diff(-Eiz_rfweh - scEz, x)
depEz_rfweh	Electric field test variable, z component	scEz
Ez	Electric field, z component	scEz + Eiz_rfweh

epsilon_rfweh	Permittivity	$\epsilon_0 \cdot \epsilon_r$
mu_rfweh	Permeability	$\mu_0 \cdot \mu_r$
muxx_rfweh	Permeability, xx component	$\mu_0 \cdot \mu_{rx}$
muxy_rfweh	Permeability, xy component	$\mu_0 \cdot \mu_{ry}$
muyx_rfweh	Permeability, yx component	$\mu_0 \cdot \mu_{rx}$
muyy_rfweh	Permeability, yy component	$\mu_0 \cdot \mu_{ry}$
jwHx_rfweh	Magnetic field, x component, times $j\omega$	$j\omega B_x / (\mu_r \cdot \mu_0)$
Hx_rfweh	Magnetic field, x component	$B_x / \omega$
scHx_rfweh	Scattered magnetic field, x component	$scB_x / (\mu_r \cdot \mu_0)$
Hix_rfweh	Incident magnetic field, x component	$-\text{diff}(E_{iz}, y) / (\mu_r \cdot \mu_0 \cdot \omega)$
jwHy_rfweh	Magnetic field, y component, times $j\omega$	$j\omega B_y / (\mu_r \cdot \mu_0)$
Hy_rfweh	Magnetic field, y component	$B_y / \omega$
scHy_rfweh	Scattered magnetic field, y component	$scB_y / (\mu_r \cdot \mu_0)$
Hiy_rfweh	Incident magnetic field, y component	$-\text{diff}(-E_{iz}, x) / (\mu_r \cdot \mu_0 \cdot \omega)$
Dz_rfweh	Electric displacement, z component	$\epsilon \cdot E_z$
Jdz_rfweh	Displacement current density, z component	$\omega \cdot D_z$
Jiz_rfweh	Induced current density, z component	$\sigma \cdot E_z$
scDz_rfweh	Scattered electric displacement, z component	$\epsilon \cdot scE_z$
jwBx_rfweh	Magnetic flux density, x component	$-\text{curl} E_x$
jwBy_rfweh	Magnetic flux density, y component	$-\text{curl} E_y$
Bx_rfweh	Magnetic flux density, x component	$B_x / \omega$
By_rfweh	Magnetic flux density, y component	$B_y / \omega$
scBx_rfweh	Scattered magnetic flux	$-scE_{zy} / \omega$

	density, x component	
scBy_rfweh	Scattered magnetic flux density, y component	scEzx/jomega_rfweh
normE_rfweh	Electric field, norm	abs(Ez)
normD_rfweh	Electric displacement, norm	abs(Dz_rfweh)
normscE_rfweh	Scattered electric field, norm	abs(scEz)
normscD_rfweh	Scattered electric displacement, norm	abs(scDz_rfweh)
normB_rfweh	Magnetic flux density, norm	sqrt(abs(Bx_rfweh)^2+abs(By_rfweh)^2)
normH_rfweh	Magnetic field, norm	sqrt(abs(Hx_rfweh)^2+abs(Hy_rfweh)^2)
normscB_rfweh	Scattered magnetic flux density, norm	sqrt(abs(scBx_rfweh)^2+abs(scBy_rfweh)^2)
normscH_rfweh	Scattered magnetic field, norm	sqrt(abs(scHx_rfweh)^2+abs(scHy_rfweh)^2)
normPoav_rfweh	Power flow, time average, norm	sqrt(abs(Poxav_rfweh)^2+abs(Poyav_rfweh)^2)
Wmav_rfweh	Magnetic energy density, time average	0.25 * real(Hx_rfweh * conj(Bx_rfweh)+Hy_rfweh * conj(By_rfweh))
Weav_rfweh	Electric energy density, time average	0.25 * real(Ez * conj(Dz_rfweh))
Wav_rfweh	Total energy density, time average	Wmav_rfweh+Weav_rfweh
Qav_rfweh	Resistive heating, time average	0.5 * real(sigma_rfweh * abs(Ez)^2-j * real(omegarfweh) * Ez * conj(Dz_rfweh))
Poxav_rfweh	Power flow, time average, x component	0.5 * real(-Ez * conj(Hy_rfweh))
Poyav_rfweh	Power flow, time average, y component	0.5 * real(Ez * conj(Hx_rfweh))