# E-B Toolbox Classes

## 1. Domain Class

Class representing the domains in the computational model. Stores the Medium object.

| Property | Description |
|---|---|
| **Index** | Domain Index |
| **Dim** | 2 (2D Domain), (3D Domain) |
| **Medium** | Medium Object |
| **Elements** | Vector of Element Indices in Domain |
| **Vertices** | Vector of Vertex Indices in Domain |
| **ExternalBoundaries** | Vector of Boundary Indices on the exterior of the Domain |
| **InternalBoundaries** | Vector of Boundary Indices on the interior of the Domain |
| **IsEmpty** | (true/false) ~ Domain's elements not considered in the assembly process. |

## 2. Boundary

Class representing the geometric boundaries of the computational domain, as well as the corresponding boundary conditions.

| Property | Description |
|---|---|
| **Index** | Domain Index |
| **Dim** | ❖ 1-Line Boundary<br>❖ 2 - Surface Boundary |
| **Axis** | ❖ +\-1 - x Axis normal to the Boundary<br>❖ 1.5 - x Axis normal to the Boundary, Boundary Internal<br>❖ +\-2 - y Axis normal to the Boundary<br>❖ - y Axis normal to the Boundary, Boundary Internal<br>❖ +\-3 - z Axis normal to the Boundary<br>❖ 3.5 - z Axis normal to the Boundary, Boundary Internal<br>❖ 4 - not a plane boundary |
| **Position** | ❖ x Coordinate if Boundary.Axis == +\-1,1.5<br>❖ y Coordinate if Boundary.Axis ==+\- 2 ,2.5<br>❖ z Coordinate if Boundary.Axis == +\-3,3.5 |

| | |
|---|---|
| **Lines** | Discrete Geometry Edges (indices) attached to Boundary (applicable for Surface Boundaries) |
| **Faces** | Discrete Geometry Faces (indices) attached to Boundary (applicable for Line Boundaries) |
| **Exterior** | true\false - Boundary is on the exterior of the computational domain. |
| **Vertices** | Vector of Vertex Indices on Boundary |
| **Edges** | Vector of Edge Indices on Boundary |
| **Facets** | Vector of Facet Indices on Boundary |
| **Type** | ❖ "PEC" - Perfect Electric Conductor<br>❖ "PMC" - Perfect Magnetic Conductor<br>❖ "DIR" - Dirichlet Boundary Condition (Excitation)<br>❖ "POR" - Port Boundary Condition (Excitation)<br>❖ "GRA" - Graphene<br>❖ "IBC" - Impedance Boundary Condition<br>❖ "PBC" - Periodic Boundary Condition<br>❖ "ABB" - Absorbing Boundary Condition with propagation constant (β) as parameter<br>❖ "ABZ" - Absorbing Boundary Condition with wave impedance (Z) as parameter (Port without Excitation)<br>❖ "CON" - Continuity<br>❖ "ABC" - Absorbing Boundary Condition |
| **Param** | ❖ "ABB" - propagation constant b<br>❖ "ABZ" - wave impedance Z<br>❖ "GRA" - graphene conductivity<br>❖ "IBC" - conductivity<br>❖ "POR" - wave impedance\propagation constant<br>❖ "PBC" - periodic Boundary Pair |
| **Dispersive** | true\false (dispersive Boundary Parameter) |
| **Master** | true\false (PBC Boundary) |
| **Tensor** | true\false (Applicable for ABZ and Port boundaries - wave impedance is tensorial) |
| **Id** | Vertex,Edge,Facet Id<br>❖ 0\1 (Uknown Degree of freedom, Known Degree of freedom)<br>❖ 2 (PEC Id for EH 2D Formulations)<br>❖ 3 (PMC Id for EH 2D Formulations) |

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|---|---|
| **ExcitationIndex** | If Boundary Port\Dirichlet index to the TModel.Excitations vector. |
| **PortParamType** | ❖ 0 Param == beta<br>❖ 1 Param == Wave Impedance scalar<br>❖ 2 Param == Wave Impedance Tensor |
| **PortType** | ❖ 0- 2D Modal Excitation<br>❖ 1- Plane Wave Excitation |
| **PlaneWave** | [Ex Amplitude; Ey Amplitude; Ez Amplitude] |

# 3. Medium

Class representing the electromagnetic media in the computational domain.

| Property | Description |
|---|---|
| **Type** | ❖ "Iso" – Isotropic Medium<br>❖ "Anis" – Anisotropic Medium<br>❖ "Bian" – Bianisotropic Medium |
| **IsDispersive** | true\false |
| **Frange** | ❖ IsDispersive == false - null<br>❖ IsDispersive == true - Frequency Range vector in Hz. |
| **Epsilon** | Relative Dielectric Permittivity $\varepsilon_r$<br>❖ (IsDispersive == false && Type == "Iso") - scalar<br>❖ (IsDispersive == false && (Type =="Anis" \|\| Type=="Bian") – (3x3) matrix<br>❖ (IsDispersive == true && Type =="Iso") (numel(FRange)x1) vector<br>❖ (IsDispersive == true && (Type =="Anis" \|\| Type=="Bian") - ((numel(FRange)x1) cell with 3x3 matrix entries. |
| **Mu** | Relative Magnetic Permeability $\mu_r$<br>❖ (IsDispersive == false && Type == "Iso") - scalar<br>❖ (IsDispersive == false && (Type =="Anis" \|\| Type=="Bian") – (3x3) matrix<br>❖ (IsDispersive == true && Type =="Iso") (numel(FRange)x1) vector<br>❖ (IsDispersive == true && (Type =="Anis" \|\| Type=="Bian") - ((numel(FRange)x1) cell with 3x3 matrix entries. |

| | |
|---|---|
| **Ksi** | Magneto Electric Coupling parameter ξ<br>❖ (IsDispersive == false && Type=="Bian") – (3x3) matrix<br>❖ (IsDispersive == true && Type=="Bian") - ((numel(FRange)x1) cell with 3x3 matrix entries. |
| **Zita** | Magneto Electric Coupling parameter ζ<br>❖ (IsDispersive == false && Type=="Bian") – (3x3) matrix<br>❖ (IsDispersive == true && Type=="Bian") - ((numel(FRange)x1) cell with 3x3 matrix entries. |
| **Tag** | (Optional) Material Name |
| **WaveImpedance** | Medium Wave Impedance<br>❖ (IsDispersive == false && Type == "Iso") - scalar<br>❖ (IsDispersive == false && (Type =="Anis" \|\| Type=="Bian") – (3x3) matrix<br>❖ (IsDispersive == true && Type =="Iso") (numel(FRange)x1) vector<br>❖ (IsDispersive == true && (Type =="Anis" \|\| Type=="Bian") - ((numel(FRange)x1) cell with 3x3 matrix entries. |

## 4. Element

Class representing the tetrahedral Finite Elements.

| **Properties** | **Description** |
|---|---|
| **Index** | Index of element |
| **SubDomain** | Index of Domain containing the element |
| **Vertices** | (4x1) Vector of element vertex indices |
| **Edges** | (6x1) Vector of element edge indices |
| **Facets** | (4x1) Vector of element facet indices |
| **EdgeSigns** | (6x1) Vector of element edge signs |
| **FacetSigns** | (4x1) Vector of element facet signs |
| **Barycenter** | Barycentric Point Coordinates |
| **Volume** | Element Volume |
| **As** | Barycentric Coordinate Coefficients |
| **Bs** | Barycentric Coordinate Coefficients |
| **Cs** | Barycentric Coordinate Coefficients |
| **Ds** | Barycentric Coordinate Coefficients |

# 5. Class Vertex

Class representing the tetrahedral mesh vertices (nodes).

| Property | Description |
|---|---|
| **Index** | Index of Vertex |
| **InDomain** | Index of Vertex Domain |
| **X,Y,Z** | Vertex Coordinates |
| **InElement** | Vector of vertex Element Indices |
| **OnBoundary** | Boundary Index - if Vertex on Bounary<br>0 - Vertex not on Boundary |
| **OnLine** | Line Boundary Index - if Vertex on Line Boundary<br>0 - Vertex not on Line Boundary |
| **OnExterior** | (true/false) Vertex on exterior boundary |
| **Index2D** | Index of Vertex in 2D Problem |
| **InFacet** | Vector of Vertex Facet Indices (2D Problem) |
| **IndexE** | Index of Electric Field degree of freedom in 2D Problem |
| **IndexH** | Index of Magnetic Field Degree of freedom in 2D Problem |

# 6. Class Edge

Class for the representation of tetrahedral and triangular mesh edges.

| Property | Description |
|---|---|
| **Index** | Index of Edge |
| **UknownIndex** | Index of degree of freedom (Electric Field Degree of freedom) |
| **KnownIndex** | Index of Known Numbering (Dirichlet Excitation) |
| **Vertices** | (2x1) Vector of Edge Vector Indices |
| **InElement** | Vector of edge Element Indices |
| **OnBoundary** | Boundary Index - if edge on Bounary<br>0 - edge not on Boundary |
| **OnLine** | Line Boundary Index - if edge on Line Boundary<br>0 - edge not on Line Boundary |
| **Id** | if on Boundary ~ inherits Boundary Id<br>else 0 |
| **PPair** | Index of Periodic Pair edge (PCB Boundaries) |
| **Length** | Edge Length |
| **Index2D** | Index of Electric Field Degree of freedom in 2D Problem |
| **IndexH** | Index of Magnetic Field Degree of freedom in 2D Problem |
| **Index2D** | Index of Edge in 2D Problem |
| **InFacet** | Vector of Edge's Facet 2D Indices |

| | |
|---|---|
| **Vertices2D** | (2 x 1) vector of Edge's Vertices in 2D |

## 7. Class Facet

Class for the representation of tetrahedral and triangular mesh facets.

| Property | Description |
|---|---|
| **Index** | Index of Facet |
| **UknownIndex** | Index of Degree of freedom (Electric Field Degree of freedom) |
| **KnownIndex** | Index of Known Numbering (Dirichlet Excitation) |
| **Vertices** | (3x1) Vector of facet Vector Indices |
| **InElement** | Vector of facet Element Indices |
| **OnBoundary** | Boundary Index - if facet on Bounary<br>0 - facet not on Boundary |
| **Id** | if on Boundary ~ inherits Boundary Id<br>else 0 |
| **PPair** | Index of Periodic Pair facet (PCB Boundaries) |
| **Surface** | Facet's Surface |
| **Barycenter** | Barycentric coordinates of the facet |
| **Vertices2D** | (3x1) vector of Facet's 2D Vertex Indices |
| **Medium2D** | Medium of the facet |
| **Edges** | (3x1) vector of Indices of Facet Edges |
| **EdgeSigns** | (3x1) vector of Facet's edge signs |

## 8. Class MultiFrequency

Class representing model's frequency or frequency range.

| Property | Description |
|---|---|
| **Start** | Frequency Range Start |
| **Stop** | Frequency Range Stop |
| **Increment** | Frequency Range Increment (Step) |
| **Unit** | "Hz","kHz","MHz","GHz","THz" |
| **Frequency** | Vector Frequency Range (Hz) |
| **UFrequency** | Vector Frequency Range (Unit) |
| **Omega** | Angular Frequency |
| **NF** | Number of Frequencies in the Frequency Range |

# 9. Class FEMAssembly

Class containing the assembled FEM matrices.

| Property | Description |
|---|---|
| **Type** | ❖ "Excitation" $[Matrix\_A]\begin{bmatrix}\mathbf{E}\\ \mathbf{B}\end{bmatrix}=[Matrix\_B]\begin{bmatrix}\mathbf{E}_{Exc}\\ \mathbf{B}_{Exc}\end{bmatrix}$ <br> ❖ "EigenMode" $[Matrix\_A]\begin{bmatrix}\mathbf{E}\\ \mathbf{B}\end{bmatrix}-\lambda[Matrix\_B]\begin{bmatrix}\mathbf{E}\\ \mathbf{B}\end{bmatrix}=\begin{bmatrix}\mathbf{0}\\ \mathbf{0}\end{bmatrix}$ |
| **Dimension** | ❖ "3D" <br> ❖ "2D" |
| **NF** | If Frequency Range operation Number of Frequencies Else 1 |
| **Matrix_A** | Primary Finite Element Matrix <br> ❖ Single Frequency Operation - Spare <br> ❖ Frequency Range Operation cell( NF,1) with sparse matrix entries. |
| **Matrix_B** | Secondary Finite Element Matrix <br> ❖ Single Frequency Operation - Spare <br> ❖ Frequency Range Operation cell(NF, 1) entries. |
| **Bian** | Bianisotropic media in the computational domain true\ false. |
| **Dispersive** | Single Frequency\frequency range operation False\true |
| **PropagationAxis** | ❖ "x" <br> ❖ "y" <br> ❖ "z" |
| **FM, AM, TE, TB** | Volume Matrices (Matrix A) |
| **TS, TG, TBC** | Surface Matrices (Matrix A) |

| | |
|---|---|
| **AW, FW** | Volume Matrices (Matrix B) (Eigen Mode Formulation) |
| **P, TA, TC** | Volume Matrices (Matrix A)<br>Bianisotropic Media |
| **TPV** | Surface Matrix (Matrix B)<br>(Excitation Formulation) |
| **K** | Volume Matrices (Matrix B)<br>Bianisotropic Media (Eigen Mode Formulation) |
| **E_Scaling** | Scaling option for Electric Field Degrees of Freedom.<br>❖ 0 – None<br>❖ 1 – Edge Length<br>❖ 2 - Custom |
| **B_Scaling** | Scaling option for Magnetic Field Degrees of Freedom.<br>❖ 0 – None<br>❖ 1 – Face Surface<br>❖ 2 - Custom |
| **NE, NB, N** | Number of Electric DoFs, Number of Magnetic DoFs, Number of Total DoFs. |
| **KNE, KNB, KN** | Number of Electric Knowns, Number of Magnetic Field Knowns, Total Number of Knowns<br>(Excitation Formulation – Dirichlet ) |
| **EigenValue** | ❖ "k"– propagation constant eigenvalue<br>❖ "n" – effective refractive index eigenvalue<br>(Eigen Mode Formulation- type of Eigenvalue) |
| **IsDir** | Dirichlet Boundary Exists (Excitation Module)<br>True/false |
| **IsPort** | Port Boundary Exists ( Excitation Module)<br>True/false |

## 10. Class Excitation

Class containing the field distributions and information of Excitation boundaries (*Port Boundary Condition* and *Dirichlet Boundary Condition*).

| Property | Description |
|---|---|
| **Type** | ❖ "POR" – Excitation object for Port Boundary<br>❖ "DIR" – Excitation object for Dirichlet Boundary. |
| **Edges** | Vector of Edge object indices in the Excitation Boundary |
| **Facets** | Vector of Facet object indices in the Excitation Boundary |
| **Vertices** | Vector of Vertex object indices in the Excitation Boundary |
| **MF** | MultiFrequency object |
| **BoundaryIndices** | Vector of Boundary object indices (Surfaces), forming the Excitation Boundary |
| **LineBoundaryIndices** | Vector of Boundary object indices (lines), forming the excitation Boundary (2D Domain) |
| **Assembly** | FEMAssembly object (2D Domain Assembly) |
| **Vector** | Excitation Vector (2D Indices) |
| **KVector** | Excitation Vector (*Dirichlet Boundary Condition*) (2D Indices) |

## 11. Class Solution

Class containing the solution of the FEM algebraic problem.

| Property | Description |
|---|---|
| **Type** | ❖ "EigenMode"<br>❖ "Excitation" |
| **EigenVectors** | ❖ Single Frequency Operation: (Nv x Nu) matrix Nv number of Eigen values, Nu Number of Degrees of Freedom<br>❖ Frequency Range Operation: Number of Frequencies x 1 cell |
| **EigenValues** | 1. Single Frequency Operation: (Nv x 1) vector of Nv number of Eigen values<br>2. Frequency Range Operation: Number of Frequencies x 1 cell |
| **EigenValueType** | 3. "k" – propagation constant<br>4. "n" – effective refractive index |
| **KnownExcitation** | Excitation Vector (3D Indices) |

| | |
|---|---|
| | ❖ Single Frequency – Vector NK x 1, NK number of Knowns<br>❖ Frequency Range Operation – Matrix NK x NF, NK number of Knowns, NF number of frequencies. |
| **UknownExcitation** | Excitation Vector (*Dirichlet Boundary Condition*) (3D Indices)<br>❖ Single Frequency – Vector N x 1, N number of DoFs<br>❖ Frequency Range Operation – Matrix N x NF, N number of DoFs, NF number of frequencies. |
| **ExcitationVector** | **b** vector of the Excitation formulation algebraic problem in form [Matrix_A]**x** = **b**.<br>❖ Single Frequency – Vector N x 1, N number of DoFs<br>❖ Frequency Range Operation – Matrix N x NF, N number of DoFs, NF number of frequencies. |
| **SolutionVector** | **x** vector of the Excitation formulation algebraic problem in form [Matrix_A]**x** = **b**.<br>❖ Single Frequency – Vector N x 1, N number of DoFs<br>❖ Frequency Range Operation – Matrix N x NF, N number of DoFs, NF number of frequencies. |

## 12. ToolboxModel

Class containing all the model information.

| Property | Description |
|---|---|
| **model** | Mathworks MATLAB PDEModel object |
| **Domains** | Vector of Domain objects |
| **Boundaries** | Vector of Boundary (Surface) objects |
| **LineBoundaries** | Vector of Boundary (Line) objects |
| **Vertices** | Vector of Vertex Objects |
| **Elements** | Vector of Element Objects |
| **Edges** | Vector of Edge Objects |
| **Facets** | Vector of Facet Objects |
| **Media** | Vector of Medium Objects (Redundant) |
| **Assembled** | FEMAssembly Object |
| **Frequency** | MultiFrequency Object |
| **Solution** | Solution object |
| **Boundary_Excitations** | Vector of Excitation Objects |

| | |
|---|---|
| **Cond** | Toolbox Model state :<br>❖ 0-<br>❖ 1- Geometry imported<br>❖ 2- Finite Element Structures initialized<br>❖ 3 Frequency input done<br>❖ 4 Domain input done<br>❖ 5 Boundary input done<br>❖ 6 Assembly done<br>❖ 7 Solution done |