E-B Eigen Mode Module

Application Examples

A. BC-CSRR Substrate Integrated Waveguide

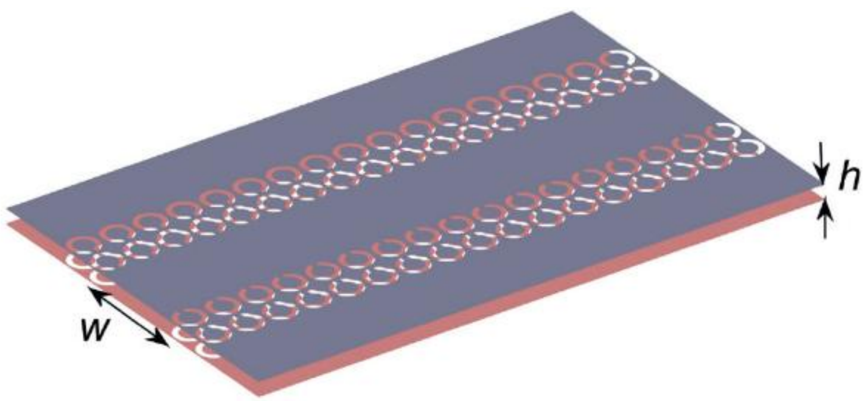
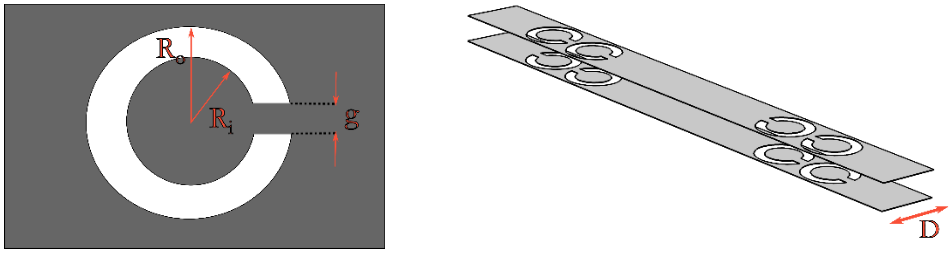


Figure 1 The Broadside Coupled Complementary Split Ring Resonator Substrate Integrated Waveguide (BC-CSRR SIW).

The BC-CSRR Substrate Integrated Waveguide (BC-CSRR SIW) is a 5G ready platform (Figure 1) that is able to integrate all the circuit components into a single substrate, with a rectangular cross-section. This structure is derived from the well-known family of Substrate Integrated Waveguides (SIW) by substituting the rows of metallic via posts with rows Broadside Coupled Complementary Split Ring Resonator (BC-CSRR) metamaterials [1]. The basic idea of this concept is to mimic the SIW principle of operation (i.e. the confinement of the propagating electromagnetic wave between the two metallic plates of a printed circuit board and the two effective metallic walls formed by the rows of the metallic via posts), by properly designing the metamaterial substitutes to exhibit properties that result in a virtual electric wall.



(a) **(b)**

Figure 2 (a) Top view of the Broad Side Coupled Split Ring Resonator metamaterial. (b) Unit cell of the BC-CSRR SIW.

The performance analysis of these metamaterial based SIWs compared to the typical SIW indicates certainly promising results [2]. Furthermore, the BC-CSRR SIW structure is fully planar and avoids the more elaborate fabrication process that is required for processing of via holes and vertical metallization. These features render it very appealing for 5G applications.

The operation of this periodic (along the propagation axis) metamaterial based structure is uniquely determined by its main building block, i.e. a unit cell consisting of two BC-CSRRs placed at each side at distance W (Figure 2). The application example of this section is a BC-CSRR SIW waveguide, designed to operate in the 26-28 GHz frequency range and fabricated on a dielectric substrate of h_{pcb} thickness and relative dielectric permittivity ε_r equal to 2.2 and tangent loss tanδ equal to 0.001. The geometric dimensions of the unit cell can be found in Table 1.

Table 1. Geometric Dimensions of BC-CSRR SIW unit cell.

R_i	R_o	g	W	h_{pcb}	D
0.84mm	0.54mm	0.3mm	6.5mm	0.80001mm	1.88mm

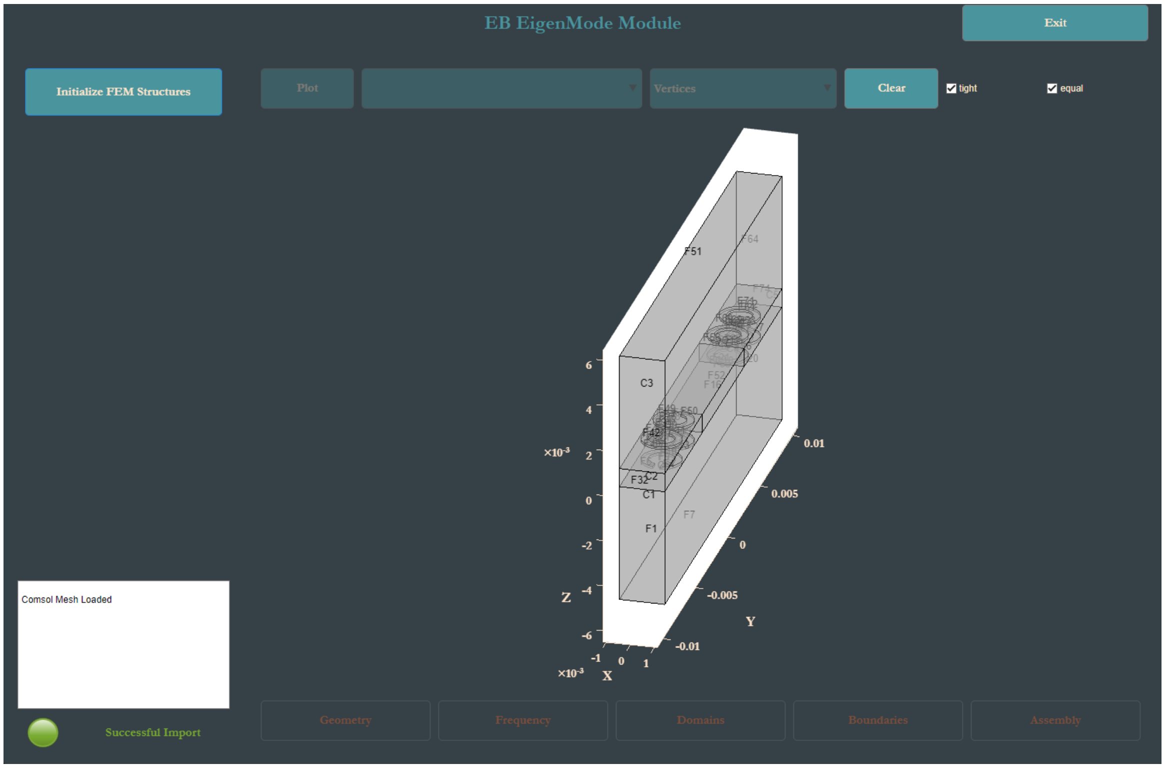


Figure 3 .Successful import of tetrahedral finite element mesh for the BC-CSRR SIW unit cell.

Geometry

The first step in the construction of the **E-B** Eigen Mode Module model is to import a tetrahedral finite element mesh of the unit cell, by selecting the **Mesh** button in the entry form and selecting the **"BC-CSRR SIW Mesh.mat"**, file found in the path: **"Examples\A. BC-CSRR SIW\Mesh".** Information about this tetrahedral mesh can be found in Table 2.
Sucessful import of the tetrahedral mesh is acknowledged in the Messaging Text Area of the **E-B** Eigen Mode Module and the structure is plotted in the center of the central panel area (Figure 3). To initialize the model's finite element structures, the **Initialize**

Table 2. "BC-CSRR SIW Mesh.mat" Information

#Vertices	#Elements	#Edges	#Facets	#Domains	#Boundaries
4795	25285	31060	51551	13	74

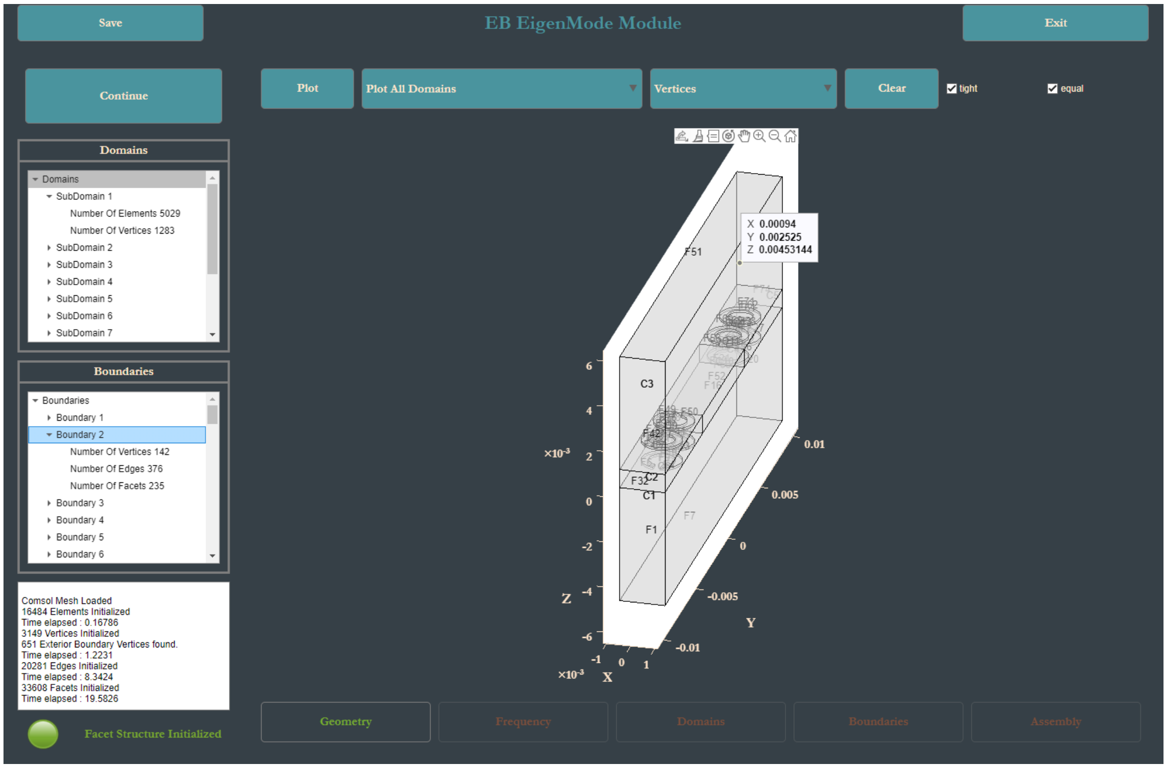


Figure 4. Successful Initialization of Finite Element Structures for the BC-CSRR SIW unit cell.

Finite Element Structures button is clicked on and the sucessful initialization of the finite element structures leads to display of the Domains and Boundaries trees in center of the left panel area (Figure 4).

Frequency

Engaging the **Continue** button will progress to the model's frequency definition panel. The user may select either a single frequency simulation, selecting the **Single Frequency** check box or a frequency range simulation by de-selecting the **Single Frequency** check.

To analyze the propagation characteristic of the BC-CSRR SIW in the lower half of its operation frequency range, the single frequency is de-selected, the frequency range input mode is set to the **Start: Step: Stop** method. The frequency range consisting of five frequencies 26 GHz, 26.2 GHz, 26.4 GHz, 26.6 GHz 26.8GHz and 27GHz is defined by setting the **Start** value equal to 26 GHz, the **Step** value equal to 0.2GHz and the **Stop** value equal to 27GHz and clicking on the **Done** button (Figure 5).

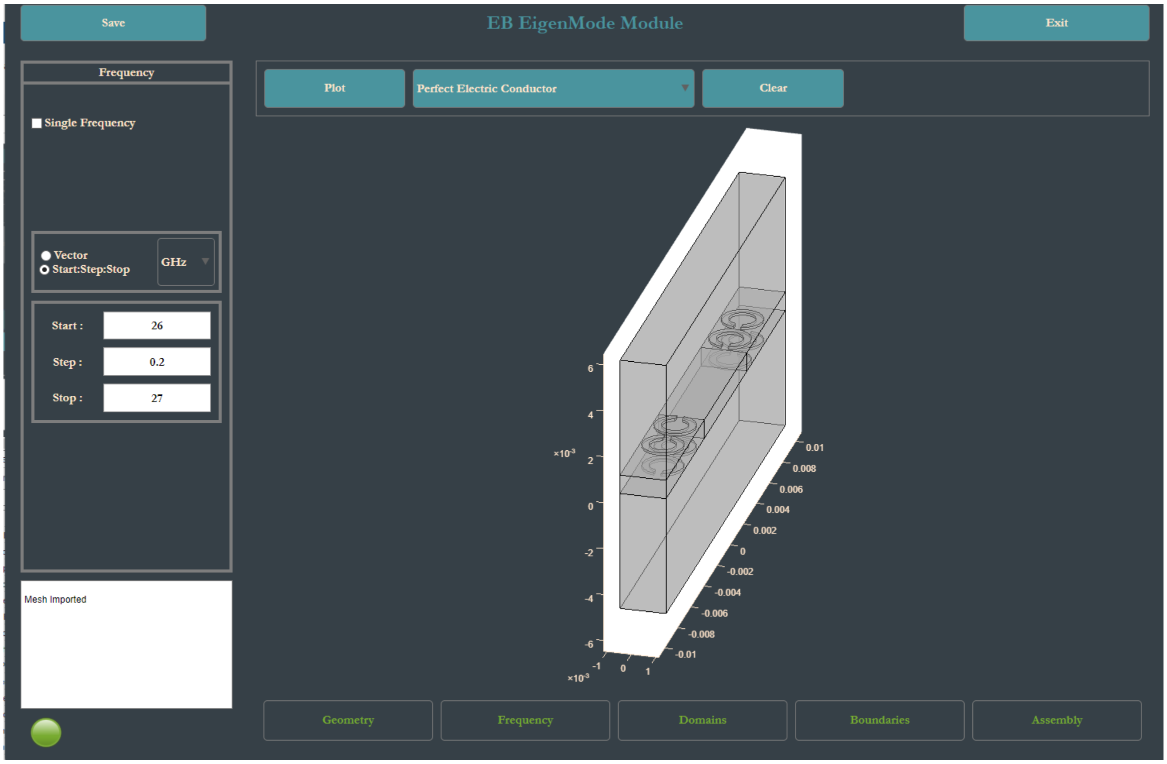


Figure 5. Frequency Range Definition for the BC-CSRR SIW unit cell.

Opting for a frequency range simulation rather than a single frequency simulation will lead to significantly increased demand of computational resources (time and RAM memory) and for low performance computing system, the latter option is advised.

Domains

The next step in the construction of the BC-CSRR SIW unit cell model is the definition of the electromagnetic media that fill the domains of the unit cell. The BC-CSRR contains two isotropic electromagnetic media, air and substrate dielectric, which for the given frequency range are non-dispersive.

To assign air as the medium of a domain, the user must select the domain from the domain drop down selection, select the **Isotropic** check box and leave the **Dispersive** check box de-selected. No further action is required as air's electromagnetic properties are the preset default for an isotropic medium in the E-B Eigen Mode module. To assign the substrate dielectric to a domain, the user follows the same course of action

Figure 5 Domain Tensor Form for non-Dispersive Dielectric Substrate ε_r

and clicks on the ε_r button to import the complex scalar dielectric permittivity of the substrate (Figure 6):

$$\varepsilon_r^* = \varepsilon_r(1 - j \cdot tand\delta) = 2.2 - 0.0022i$$

The dielectric substrate does not exhibit magnetic behavior and no action is required for the definition of the relative magnetic permeability. Table 3 lists the model's domains and their corresponding medium. After validating the selection of every domain's medium, the user must click on the **Done** button to continue to the model's boundary condition definitions.

Table 3 BC-CSRR Domains (sub: dielectric substrate)

Domain	1	2	3	4	5	6	7	8	9	10	11	12	13
Medium	air	sub	air	sub	sub	air	air	air	air	air	air	air	air

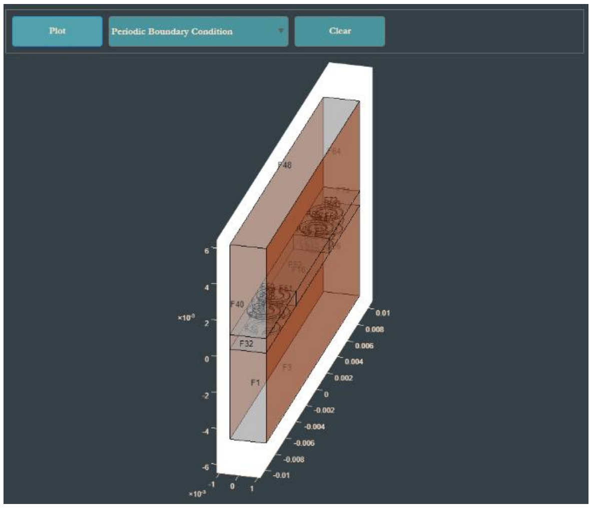
Boundaries

The BC-CSRR SIW unit cell model requires the implementation of four types of boundary conditions. The boundaries that truncate the structure's computational domain along the periodicity axis ($\hat{\boldsymbol{x}}$ axis for the given tetrahedral mesh) are assigned to the Periodic Boundary Condition. In the other two directions ($\hat{\boldsymbol{y}}$ and $\hat{\boldsymbol{z}}$ axes) the BC-CSRR SIW borders the isotropic air and as a result the rest of the external boundaries are set to model the Absorbing Boundary Condition. Finally, all metallic surfaces on the structure are modeled as Perfect Electric Conductor, while the rest of the internal boundaries are left assigned to the Continuity Boundary Condition. Table 4 lists the boundaries assigned to the Periodic Boundary Condition with their respective pair, the boundaries assigned to the Perfect Electric Conductor boundary condition and the Absorbing Boundary Condition.

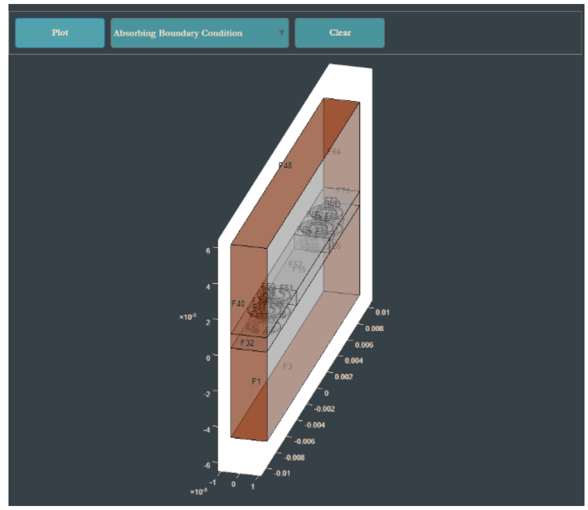
Any boundary not listed on Table 4 is left assigned to the Continuity boundary condition. The correct definition of the Boundary Conditions can be optically examined using the plot controls on the top of the central panel area. Figure 6 displays the correct assignment of the periodic boundaries (a), Absorbing boundary condition boundaries (b) and Perfect Electric Conductor boundaries (c).

Table 4 BC – CSRR SIW Unit Cell Boundary Conditions.

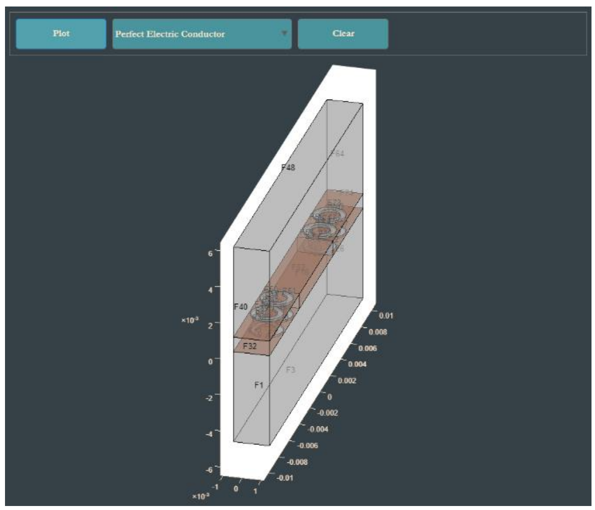
Boundary	Axis	Position	Boundary Condition	Periodic Pair
1	$\hat{y}$	external	ABC	
2	$\hat{x}$	external	Periodic	4
3	$\hat{z}$	external	ABC	
4	$-\hat{x}$	external	Periodic	2
6	$\hat{z}$	internal	PEC	
16	$\hat{z}$	internal	PEC	
19	$\hat{z}$	internal	PEC	
26	$-\hat{y}$	external	ABC	
30	$\hat{z}$	internal	PEC	
32	$-\hat{y}$	external	ABC	
34	$\hat{x}$	external	PBC	35
35	$-\hat{x}$	external	PBC	34
40	$-\hat{y}$	external	ABC	
43	$\hat{x}$	external	PBC	44
44	$-\hat{x}$	external	PBC	43
48	$-\hat{z}$	external	ABC	
52	$\hat{z}$	internal	PEC	
53	$\hat{z}$	internal	PEC	
64	$\hat{y}$	external	ABC	
65	$-\hat{x}$	external	PBC	66
66	$\hat{x}$	external	PBC	65
69	$-\hat{x}$	external	PBC	70
70	$\hat{x}$	external	PBC	69
74	$-\hat{y}$	external	ABC	



(a)



(b)



(c)

Figure 6 (a) Periodic Boundaries in the BC-CSRR SIW Unit Cell. (b) Absorbing Boundary Condition Boundaries in the BC-CSRR SIW Unit Cell. (c) Perfect Electric Conductor Boundaries in the BC-CSRR SIW Unit Cell.

<u>Assembly</u>

The final step before the solution of the BC-CSRR SIW unit cell problem is the parametrization of the Assembly. As the BC-CSRR SIW waveguide guides the wave along the $\boldsymbol{\hat{x}}$ axis, the Propagation Axis drop down selection is set to x Propagation, while the scaling options are left to the pre-assigned options of edge length -based scaling for the electric field degrees of freedom and the facet surface – based scaling for

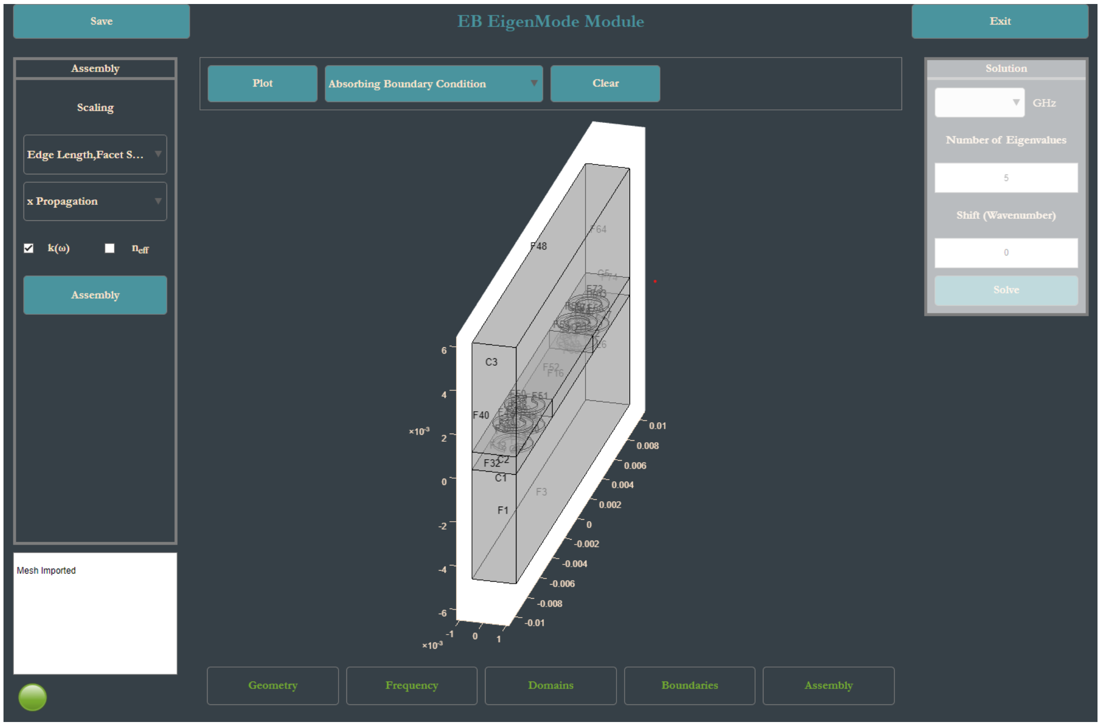


Figure 7. BC-CSRR SIW Assembly options

the magnetic field degrees of freedom and the eigenvalue type is set as the wavevector type (Figure 7). The E-B Eigen Mode Module lacks time-saving features for the assembly of multiple frequency non-dispersive domains and the finite element matrices are formed for every single frequency, causing an increased computational time burden. The tetrahedral mesh for the BC-CSRR SIW unit cell corresponds to 77071 total degrees of freedom, 49251 of which are magnetic field degrees of freedom and the rest 27820 are electric degrees of freedom.

Table 5 lists the eigen value shift inside the first Brillouin Irreducible zones that correspond to the $k(\omega)$ dispersion of the fundamental propagating mode in the BC-CSRR SIW. The precision in terms of the proximitity of the returned eigenvalues to the BC-CSRR SIW $k(\omega)$ dispersion is a function of the tetrahedral mesh's density and quality, and higher accuracy solutions will require finer tetrahedral meshes, especially when the structure under investigation features sub-wavelength geometries (the Broadside Coupled Split Ring Resonators).

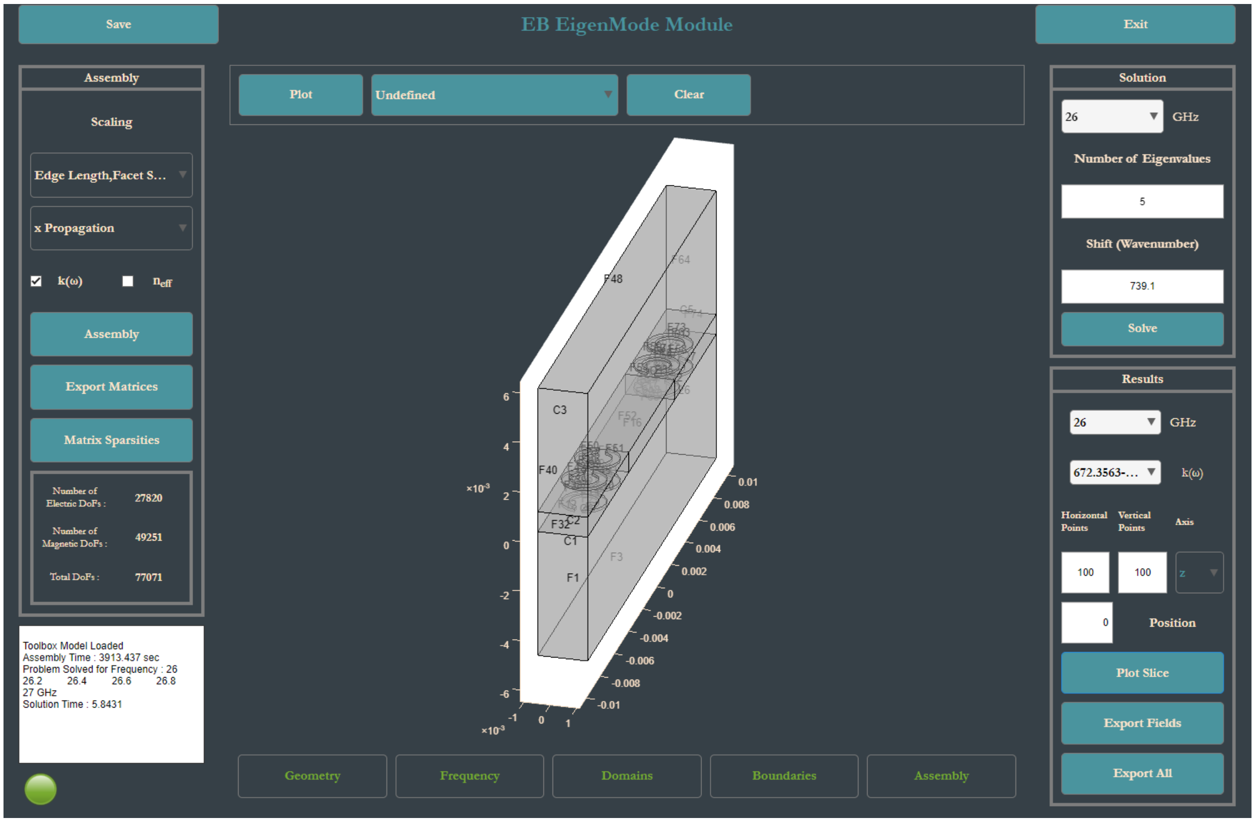


Figure 8 E-B Eigen Mode Module Solution

Solving the frequency range eigen value problem can be achieved either by solving separately each of the frequencies, or by solving all frequency problems. The resulting eigen values are listed for every solved frequency in the solution panel in the right panel area. The corresponding eigen vectors can be examined through the Plot Slice function of the **E-B** Eigen Mode module.

Table 5. BC – CSRR SIW Eigen Value Shifts

Frequency (GHz)	Eigen Value Shift	Frequency (GHz)	Eigen Value Shift
26	739.09	26.8	793.46
26.2	748.71	27	801.99
26.4	758.05	27.2	810.44
26.6	767.15	27.4	818.44
26.8	776.07	27.6	827.2
27	784.83	27.8	793.46

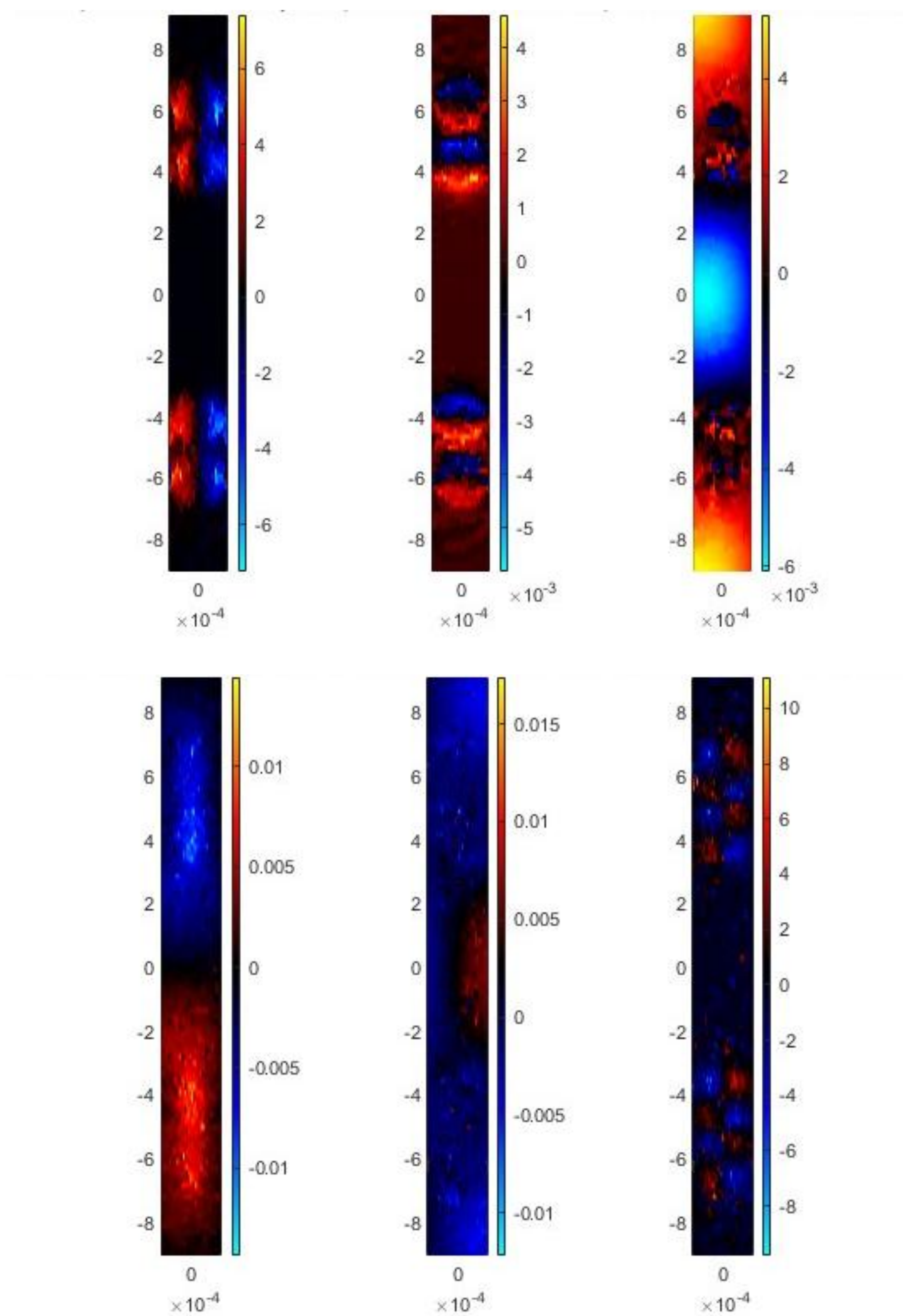


Figure 9. BC-CSRR SIW Unit Cell Eigenvector at xy plane on the center of the substrate at 26GHz for eigenvalue 672.3563 -. (Upper Left Corner) real (E_x), (Upper Center) real(E_y), (Upper Right Corner) real(E_z), (Lower Left Corner) real (B_x), (Lower Center) real(B_y), (Lower Right Corner) real (B_z).

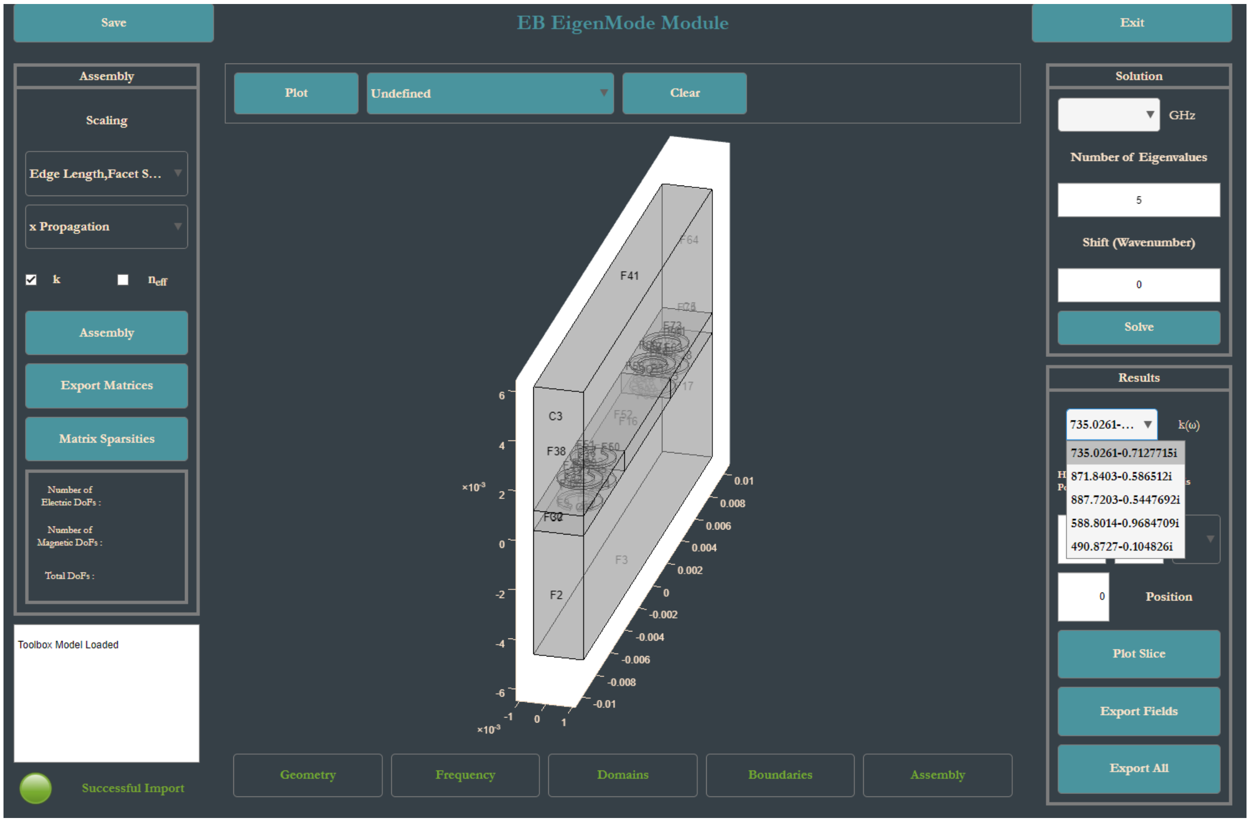


Figure 10. E-B Eigen Mode Module Solution – Finer Mesh

Figure 9 displays the electric field and magnetic field components for the ***"BC-CSRR SIW Mesh.mat"*** tetrahedral mesh corresponding to the eigenvalue 672.3563 at 26 GHz. **ToolboxModel** objects for each step of the process can be found in the path **"Examples\A. BC-CSRR SIW\Toolbox Models\Coarse Mesh".**

ToolboxModel objects of the BC-CSRR SIW unit cell for a denser tetrahedral mesh (Figure 10) can also be found in path: **"Examples\A. BC-CSRR SIW\Toolbox Models\Finer Mesh".** This denser mesh provides improved accuracy (Figure 11) at the cost of the solution of a larger algebraic problem.

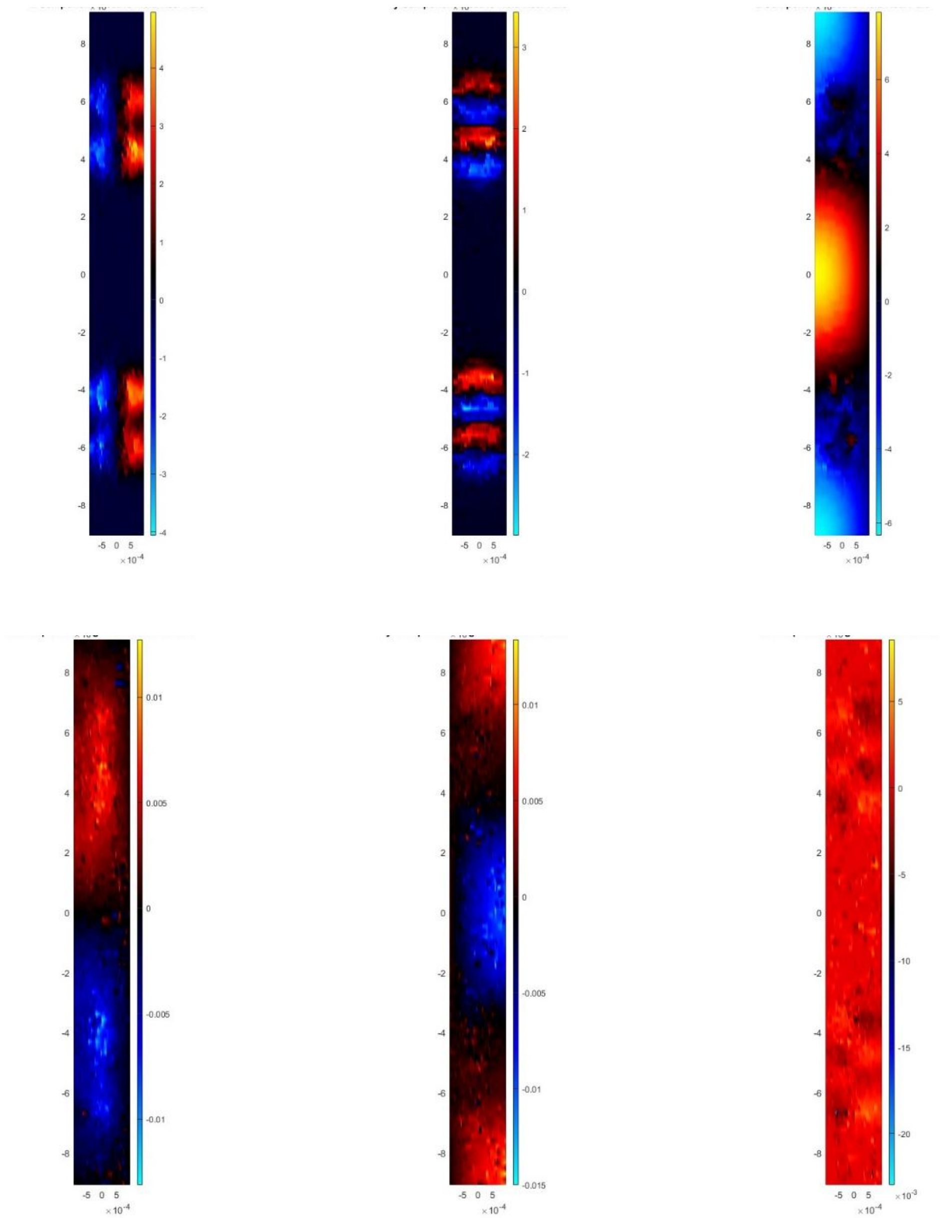


Figure 11. BC-CSRR SIW Unit Cell Eigenvector (Finer Mesh) at xy plane on the center of the substrate at 27GHz for eigenvalue 735.0261-0.71i. (Upper Left Corner) real (E_x), (Upper Center) real(E_y), (Upper Right Corner) real(E_z), (Lower Left Corner) real (B_x), (Lower Center) real(B_y), (Lower Right Corner) real (B_z).

B. Bianisotropic Spherical Inclusions in a Bianisotropic Host Medium

The performance of the E-B Eigen Mode module in the solution of complex periodic bianisotropic structures can be assessed by the investigation of the non-homogeneous medium formed by the three-dimensional periodic arrangement of spheres of a bianisotropic medium inside a different bianisotropic host medium. The unit cell's geometry of this structure is a cube of width $d = 1.5mm$ surrounding a sphere of radius $\mathrm{r} = 0.74442\ \mathrm{mm}$ with the centers of both objects coinciding. The electromagnetic parameters of the host medium are:

$$\varepsilon_r^{HOST} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 5 \end{bmatrix}, \quad \mu_r^{HOST} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 5 \end{bmatrix},$$

$$\xi^{HOST} = \frac{j}{c_0}\begin{bmatrix} -1 & 0.4 & 0 \\ 0.4 & -0.6 & 0 \\ 0 & 0 & -1.5 \end{bmatrix}, \zeta^{HOST} = \frac{j}{c_0}\begin{bmatrix} -1 & 0.4 & 0 \\ 0.4 & -0.6 & 0 \\ 0 & 0 & -1.5 \end{bmatrix},$$

where c_0 is the speed of light in vacuum. The electromagnetic parameters of the sphere inclusion are given:

$$\varepsilon_r^{SPHERE} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 5 \end{bmatrix}, \quad \mu_r^{SPHERE} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 5 \end{bmatrix},$$

$$\xi^{SPHERE} = \frac{j}{c_0}\begin{bmatrix} 1 & 0.4 & 0 \\ 0.4 & 0.6 & 0 \\ 0 & 0 & 1.5 \end{bmatrix}, \zeta^{SPHERE} = \frac{j}{c_0}\begin{bmatrix} 1 & 0.4 & 0 \\ 0.4 & 0.6 & 0 \\ 0 & 0 & 1.5 \end{bmatrix}$$

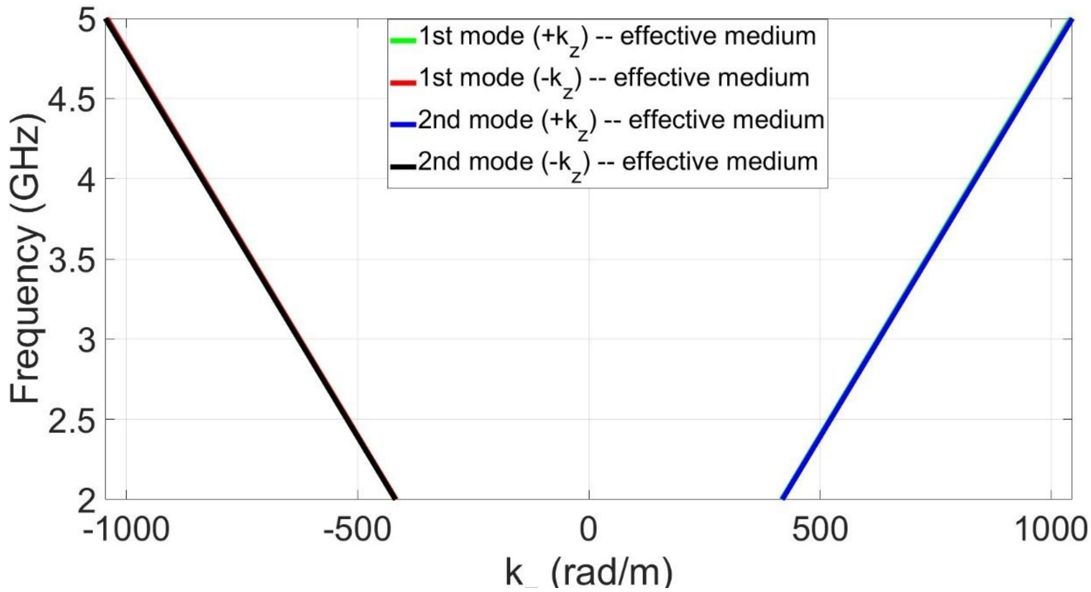


Figure 12. Dispersion Diagram of the complex Medium of Bianisotropic Spherical Inclusion in a Bianisotropic Host Medium.

This complex medium is equivalent [3],[4] to the homogenized medium with material parameters:

$$\varepsilon_r^{Effective} = \begin{bmatrix} 9.96 & 0 & 0 \\ 0 & 9.98 & 0 \\ 0 & 0 & 4.86 \end{bmatrix}, \quad \mu_r^{Effective} = \begin{bmatrix} 9.96 & 0 & 0 \\ 0 & 9.98 & 0 \\ 0 & 0 & 4.86 \end{bmatrix},$$

$$\xi^{Effective} = \frac{j}{c_0} \begin{bmatrix} 0.0223 & 0.399 & 0 \\ 0.399 & 0.0139 & 0 \\ 0 & 0 & 0.0092 \end{bmatrix}$$

$$\zeta^{Effective} = \frac{j}{c_0} \begin{bmatrix} 0.0223 & 0.399 & 0 \\ 0.399 & 0.0139 & 0 \\ 0 & 0 & 0.0092 \end{bmatrix}$$

Figure 12 displays the dispersion diagram of the complex medium of bianisotropic spherical inclusions in the bianisotropic host medium, analytically calculated for the homogenized equivalent medium.

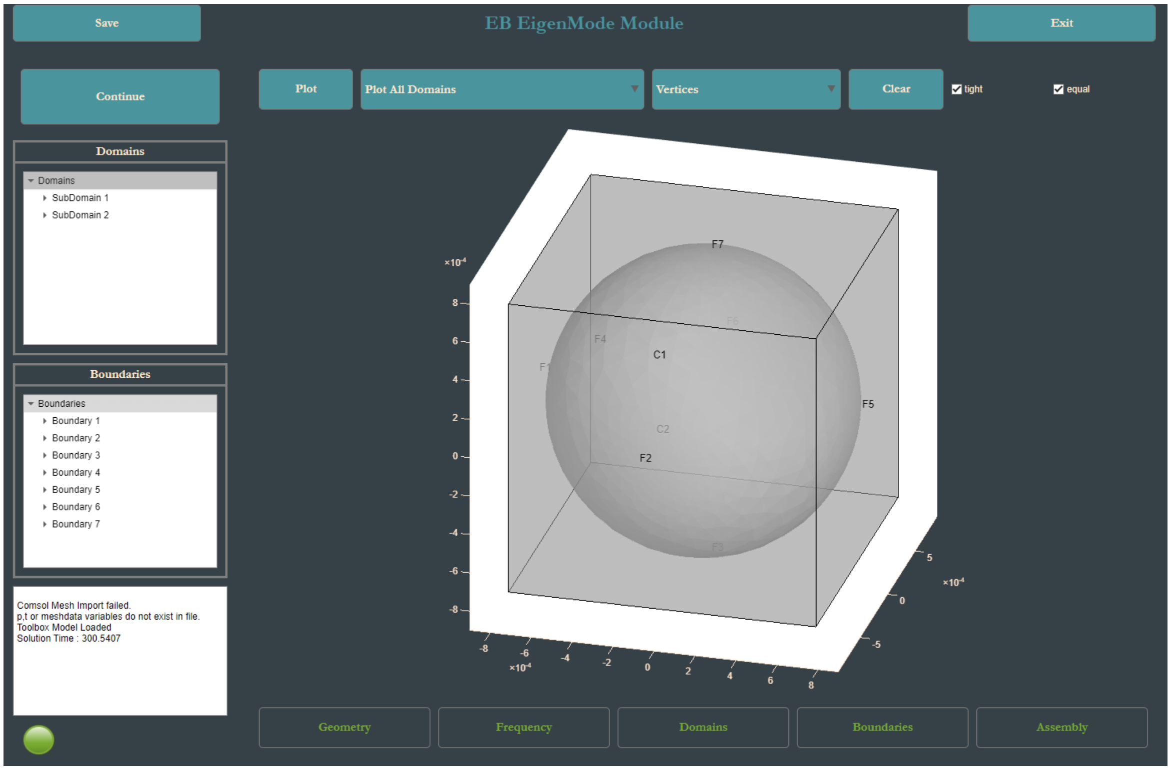


Figure 13. Non homogenous Bianisotropic Medium Unit Cell. E-B Eigen Mode Module Geometry

The tetrahedral mesh of this geometry **"BiAnisotropic_Sphere.mat"** can be found in the path: **"Examples\B. Bianisotropic Spherical Inclusions in a Bianisotropic Host Medium\Mesh"**. Information about this tetrahedral mesh can be found in Table 6.

Table 6. "BiAnisotropic_Sphere.mat" Information

#Vertices	#Elements	#Edges	#Facets	#Domains	#Boundaries
5203	28340	35540	57448	2	7

Selecting a single frequency operation, the model's frequency is set at 2.5 GHz.

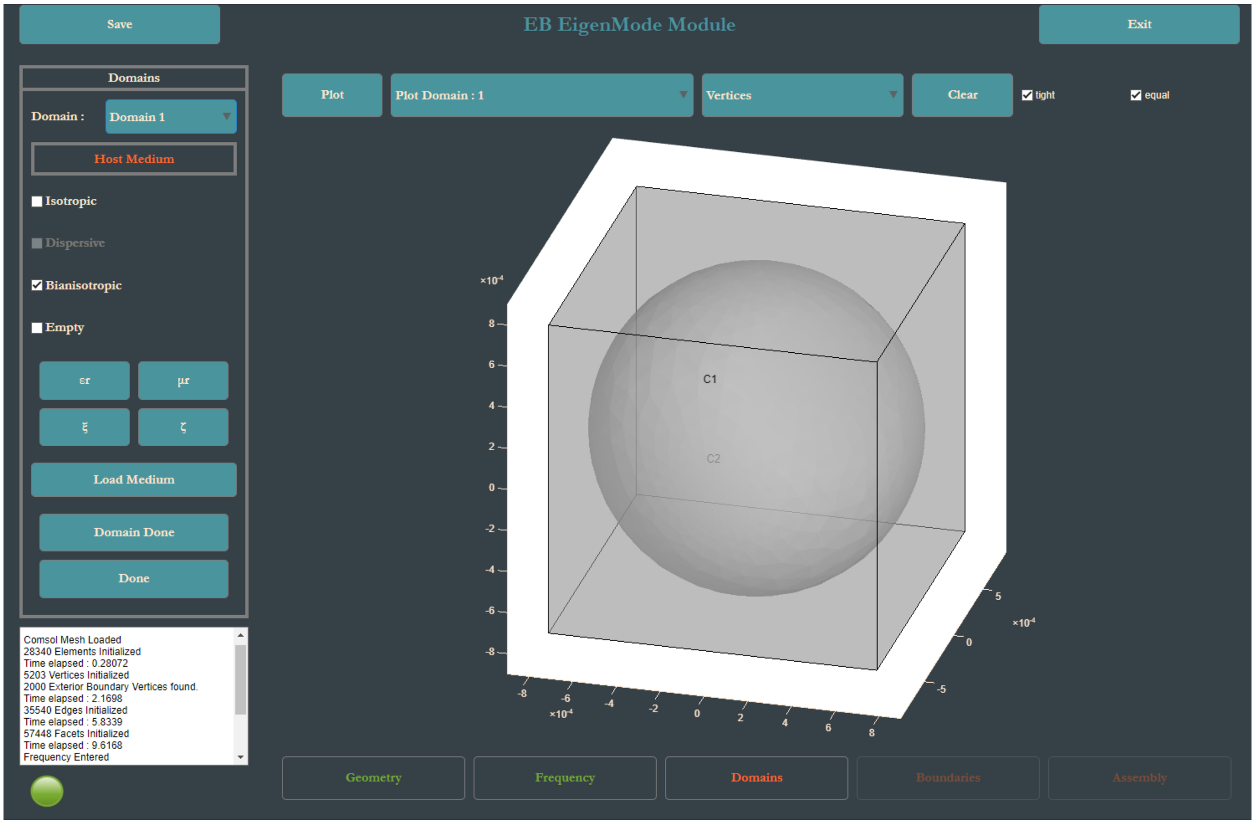


Figure 14. Non homogenous Bianisotropic Medium Unit Cell. E-B Eigen Mode Module Domains.

To simplify the process of assigning the complex bianisotropic media to the model's domains, both the bianisotropic medium filling the spherical inclusion and the bianisotropic host medium that occupies the rest of the computational domain are imported using the **Load Medium** button. The prestored media files are in the path: **"Examples\B. Bianisotropic Spherical Inclusions in a Bianisotropic Host Medium\Media"**.

The bianisotropic host medium's parameters are stored in the **"BianisotropicHostMedium.mat"**, while the bianisotropic medium occupying the spherical inclusion domain is stored in the **"BianisotropicSphereMedium.mat"** file. Regarding the unit cell domains correspondence with these general bianisotropic media, domain 1 is filled with bianisotropic host medium, while domain 2 is the spherical inclusion. Both of the materials are non-dispersive in the frequency range 2GHz to 5GHz and as a result the media files can be used for the analysis of models with different frequency settings.

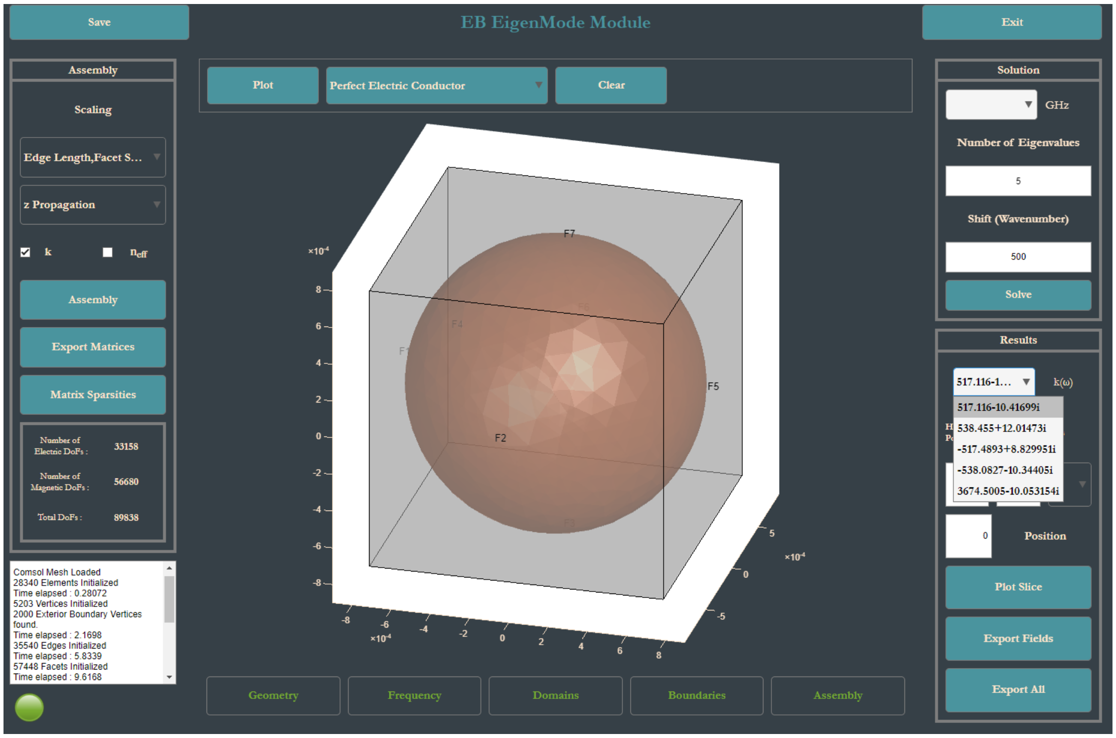


Figure 15. Non homogenous Bianisotropic Medium Unit Cell. E-B Eigen Mode Module Assembly and Solution Panels.

The complex non-homogeneous medium is formed by repeating the unit cell on every dimension and as a result all external boundaries must be assigned to the *Periodic Boundary Condition.* Table 7 lists the boundaries of the **E-B** Eigen Mode module model and their corresponding boundary conditions.

Table 7 Complex non-Homogeneous Bianisotropic Medium Unit Cell Boundary Conditions.

Boundary	Axis	Position	Boundary Condition	Periodic Pair
1	$-\hat{x}$	external	Periodic	5
2	$-\hat{y}$	external	Periodic	6
3	$-\hat{z}$	external	Periodic	7
4		Internal	Continuity	
5	$\hat{x}$	external	Periodic	1
6	$\hat{y}$	external	Periodic	2
7	$\hat{z}$	external	Periodic	3

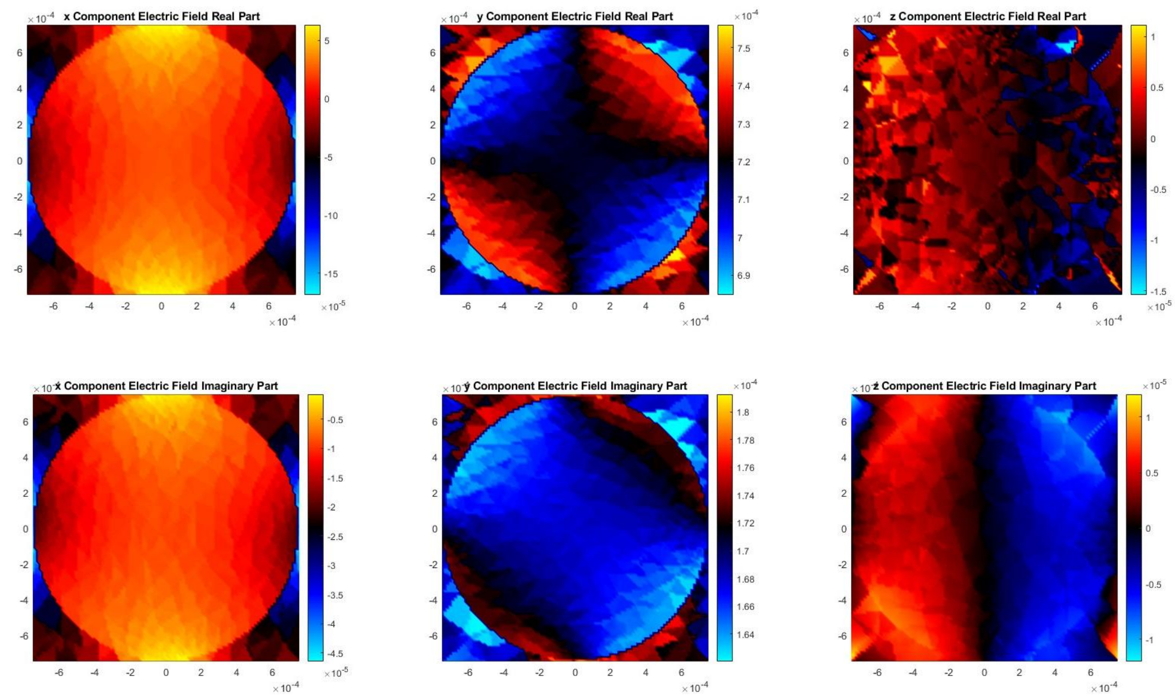


Figure 16. Non homogenous Bianisotropic Medium Unit Cell Eigenvector at xy plane on the center of the domain at 2.5GHz for eigenvalue 517.116-10.415i. (Upper Left Corner) real (E_x), (Upper Center) real(E_y), (Upper Right Corner) real(E_z), (Lower Left Corner) imag (E_x), (Lower Center) imag(E_y), (Lower Right Corner) imag(E_z).

The model is set for propagation along the $\hat{\boldsymbol{z}}$ axis (z Propagation entry in the drop-down selection). The assembled finite element matrices for this tetrahedral mesh have dimensions equal to 89838, with 33158 degrees of freedom discretizing the electric field's periodic envelope and 56680 the magnetic field's periodic envelope.

The eigenvalue shift for any frequency is determined by examining the dispersion diagram of the homogeneous effective medium (Figure 12). Figure 16 displays the electric field components of the eigen vector of the first mode that supports propagation in the complex bianisotropic medium at 2.5 GHz.

C. Periodic Arrangement of Graphene Micro Strips Separated by a Gap

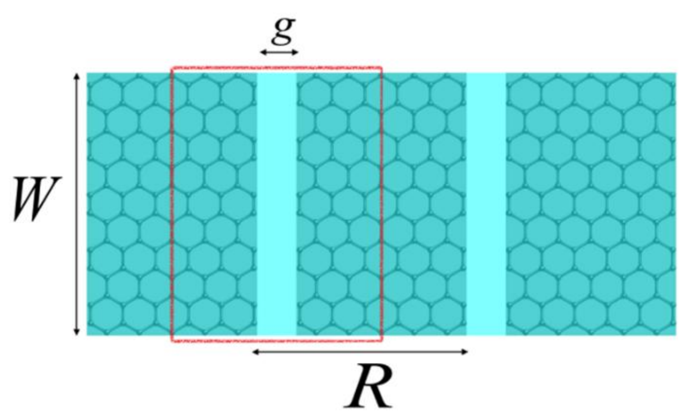


Figure **17. Periodic Arrangement of Graphene Micro Strips Separated by a Gap.**

The **E**-**B** Eigen Mode module's Field-*Flux Bloch Floquet* formulation can be utilized to analyze three-dimensional periodic structures featuring two-dimensional graphene components. An example of this type of periodic structures is depicted in Figure 17 and is formed by the periodic arrangement of free-standing graphene micro strips of width W that are separated by a gap g. The periodicity of the structure is limited to the propagation axis (the structure is periodic only on one axis) and is surrounded by the open space on the other two axes. The dimensions of the periodic structure and the dimensions of the corresponding unit cell (L_x, L_y, L_z the dimensions of the unit cell along axes **x y** and **z**) are listed in Table 8.

Table 8. Geometric Dimensions of Periodic Arrangement of Graphene Micro Strips unit cell.

W	**R**	**g**	**Lx**	**Ly**	**Lz**
5μm	10μm	0.5μm	10 μm	10 μm	5 μm

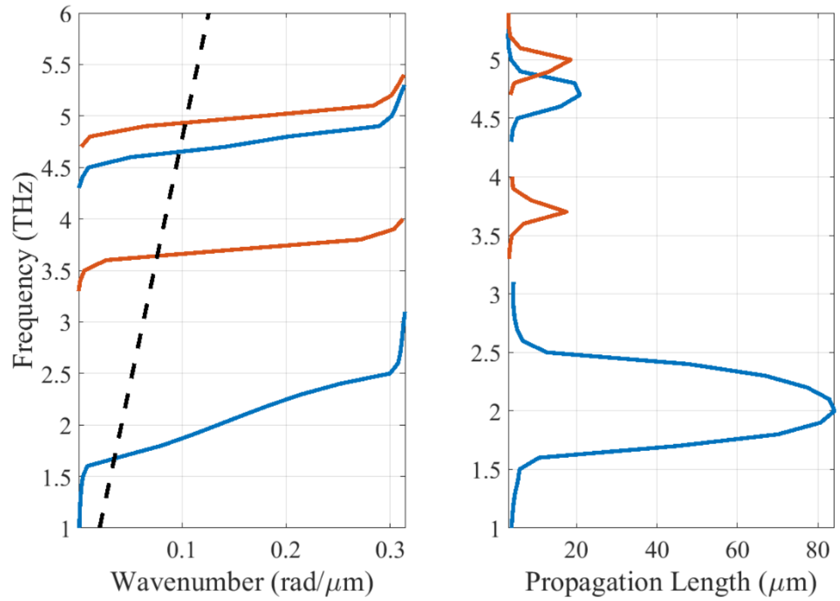


***Figure* 18. Periodic Arrangement of Graphene Micro Strips Separated by a Gap – Dispersion Diagramm.**

This periodic structure has been examined in [5], where the existence of two plasmonic surface modes supporting propagation was established (Figure 18).

Geometry

The first step in the construction of the **E**-**B** Eigen Mode Module model is to import a tetrahedral finite element mesh of the unit cell, by selecting the **Mesh** button in the entry form and selecting the **"Periodic Graphene Mesh.mat"**, file found in the path: **"Examples\Eigen Mode Module\C. Periodic Arrangement of Graphene Micro Strips\Mesh".** Information about this tetrahedral mesh can be found in Table 9.

Sucessful import of the tetrahedral mesh is acknowledged in the Messaging Text Area of the **E**-**B** Eigen Mode Module and the structure is plotted in the center of the central panel area (Figure 19). To initialize the model's finite element structures, the **Initialize**

Table 9. "Periodic Graphene Mesh.mat" Information

#Vertices	#Elements	#Edges	#Facets	#Domains	#Boundaries
4647	23199	29345	47857	3	18

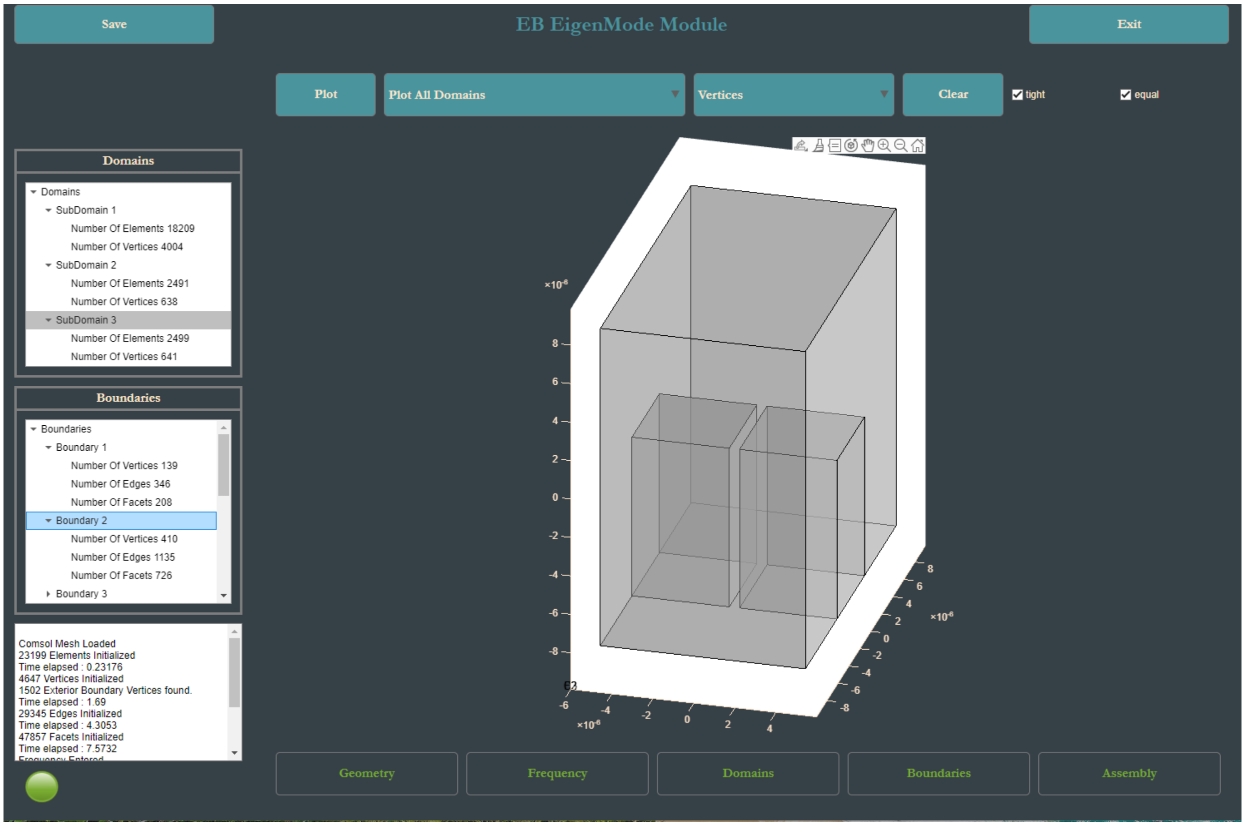


Figure **19. E-B Eigen Mode Module. Periodic Arrangement of Graphene Micro Strips Separated by a Gap - Geometry.**

Frequency and Domains

The structure is examined in the single frequency mode for the frequency of 2THz at the lower end of its dispersion diagram (Figure 18). The graphene micro strips in the structure's unit cell are free-standing (there is no substrate) and as a result the medium filling the three subdomains of the model is air (the user must select the **Isotropic** check box and click on the **Domain Done** button).

Boundaries

Due to the main limitation of the *Absorbing Boundary Condition* implemented (1st order ABC) in the **E**-**B** Eigen Mode module, which models the open space when the electric field incident is tangential and the magnetic field is normal to the boundary surface, assigning the non-periodic boundaries (along the **y** and **z** axes) to the *Absorbing Boundary Condition* affects negatively the accuracy of the Eigen Mode problem. To circumvent this hinderance, the periodic structure is surrounded by metallic surfaces, located at a sufficient distance from the graphene microstrips to minimize any coupling of the plasmonic modes to the metallic surfaces. The boundary conditions of the model are listed in Table 10.

Graphene's conductivity is evaluated via the Kubo Formula [6] at room's temperature $T=300^{\circ}$ with the energy independent scattering rate Γ equal to 0.1meV and the chemical potential equal to 0.2 eV. For the model's frequency (2THz) the conductivity is calculated as 4.5279E-5-0.0018726i. (The user can use the function **GrapheneConductivity (Temperature, Gamma, Chemical Potential, Frequency)** located at **"Examples\Eigen Mode Module\C. Periodic Arrangement of Graphene Micro Strips\Conductivity"**).

Table 10. Periodic Arrangement of Graphene Microstrips- Boundary Conditions.

Boundary	Axis	Position	Boundary Condition	Periodic Pair
1	$\hat{z}$	external	PEC	
2	$\hat{x}$	external	Periodic	4
3	$\hat{y}$	external	PEC	
4	$\hat{x}$	external	Periodic	2
5	$\hat{y}$	internal	Continuity	
6	$\hat{y}$	internal	Continuity	
7	$\hat{x}$	internal	Continuity	
8	$\hat{x}$	internal	Continuity	
9	$\hat{z}$	external	PEC	
10	$\hat{y}$	external	PEC	
11	$\hat{y}$	internal	Continuity	
12	$\hat{z}$	internal	Graphene	
13	$\hat{y}$	internal	Continuity	
14	$\hat{z}$	internal	Graphene	
15	$\hat{x}$	external	Periodic	17
16	$\hat{z}$	external	PEC	
17	$\hat{x}$	external	Periodic	15
18	$\hat{z}$	external	PEC	

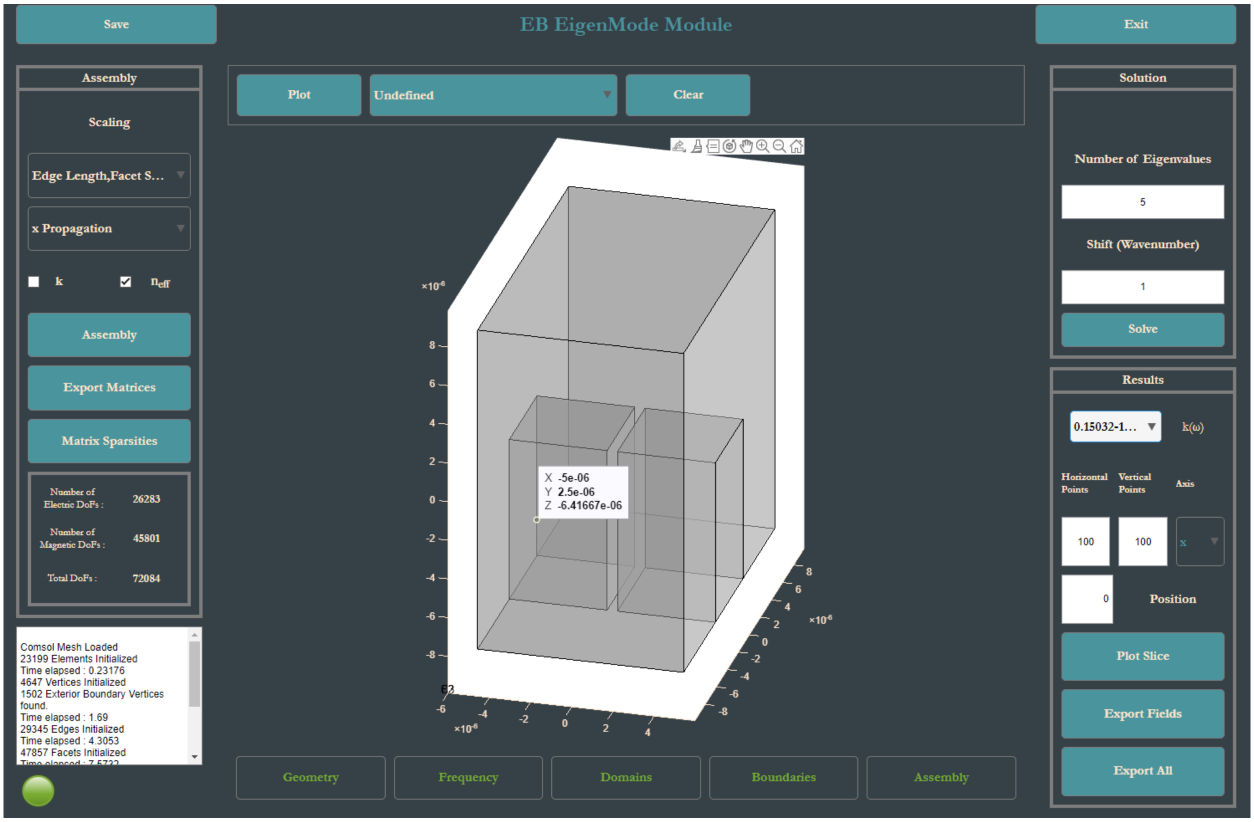


Figure **20. E-B Eigen Mode Module. Periodic Arrangement of Graphene Micro Strips Separated by a Gap - Results.**

Assembly

As the model' frequency is in the THz regime, the efficient solution of the eigen mode problem requires the switching of the eigenvalue type from the propagation constant to the effective refractive index. As a result, the user must select the **neff** check box before initiating the assembly process (by clicking the **Assembly** button). Results returned for eigenvalue shift equal to 1 are depicted in Figure 21.

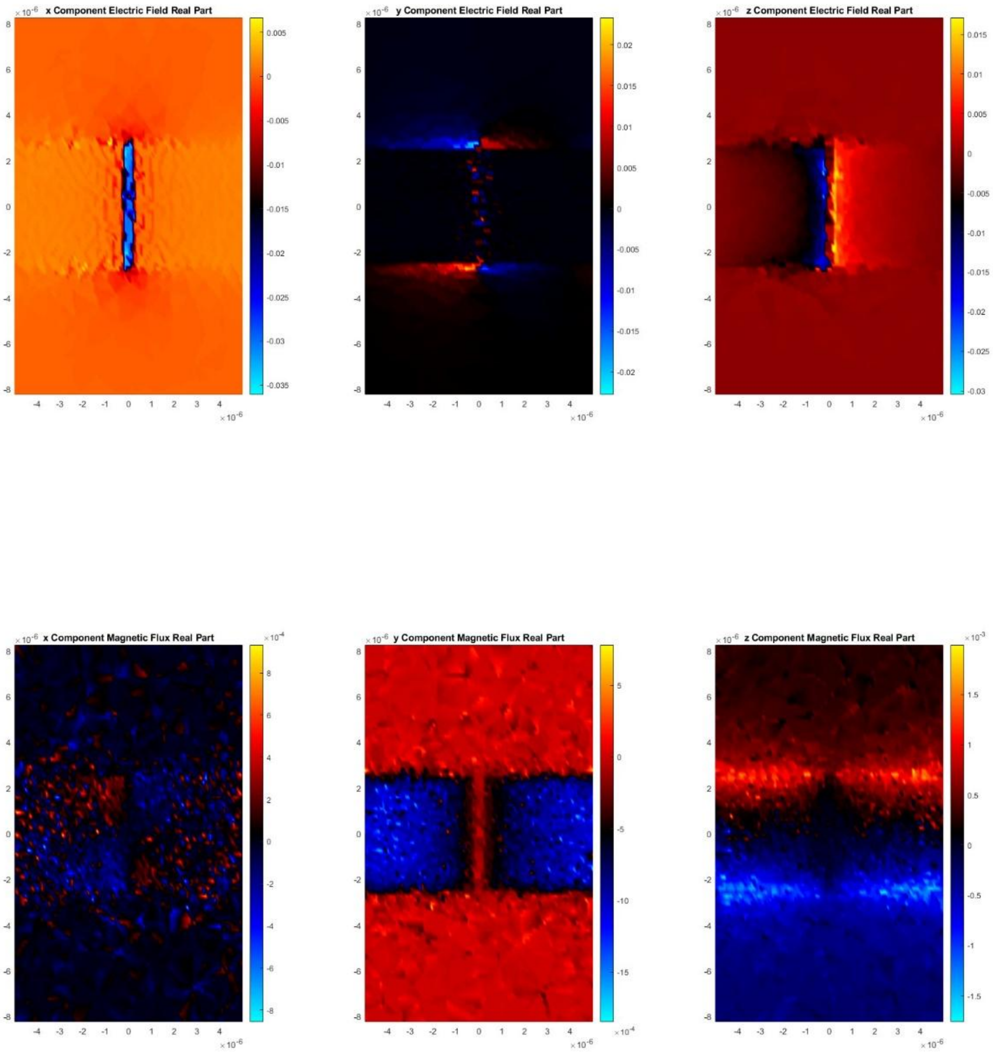


Figure 21. Periodic Arrangement of Graphene Micro Strips, Eigenvector at xy plane at z = 1e-7 of the domain(directly above the graphene microstrips) at for eigenvalue 0.15032-1.0062i. (Upper Left Corner) real (E_x), (Upper Center) real (E_y), (Upper Right Corner) real(E_z), (Lower Left Corner) imag (B_x), (Lower Center) imag(B_y), (Lower Right Corner) imag(B_z).

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