Introduction to Characteristics Mode Analysis Tool v2.0

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Outline

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- CMA Tool
  - Description
  - Pre-processing, Simulation and Post-processing
  - Commands and Flags
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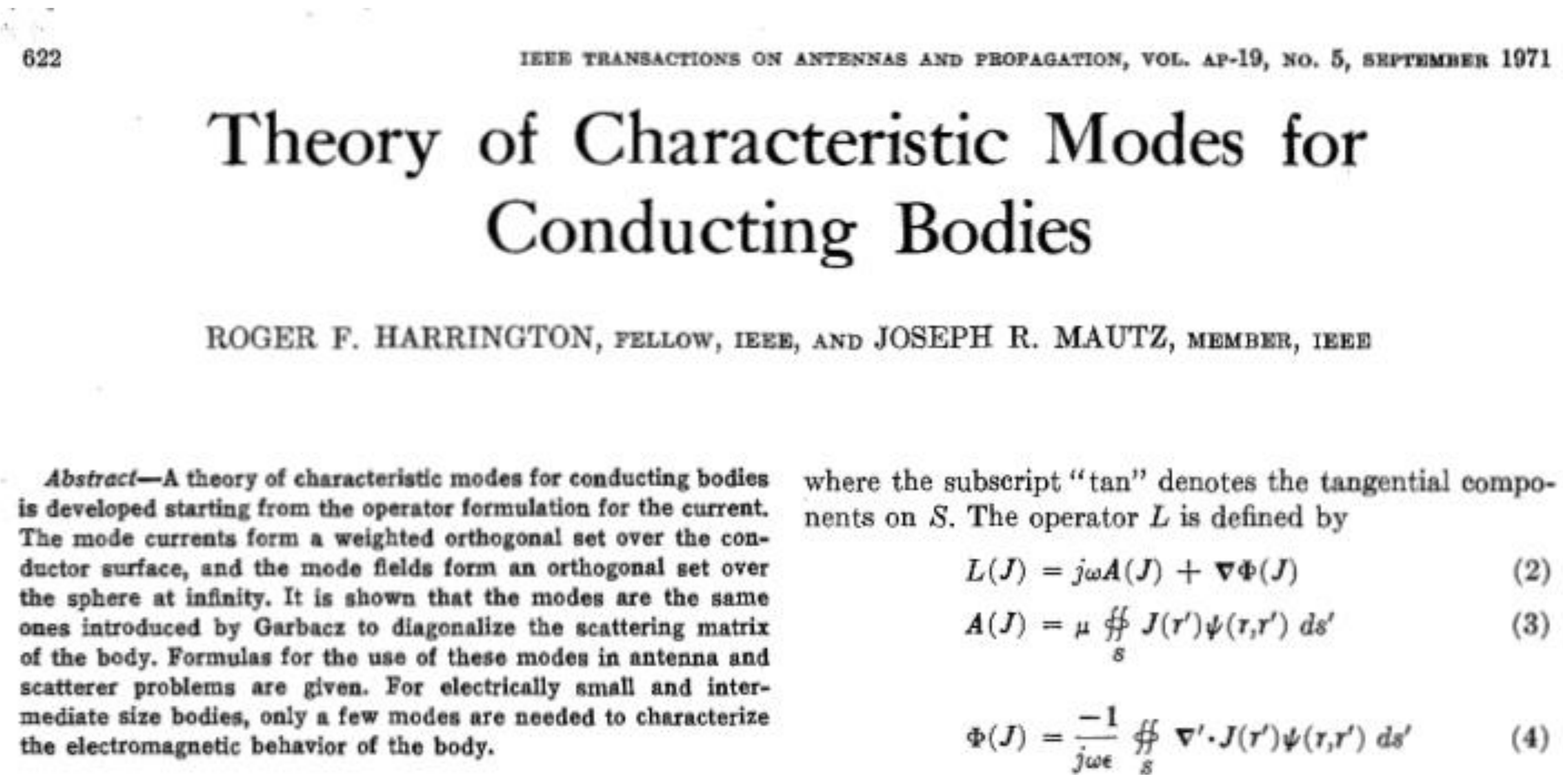
Introduction



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Theory of Characteristic Modes for Conducting Bodies

ROGER F. HARRINGTON, FELLOW, IEEE, AND JOSEPH R. MAUTZ, MEMBER, IEEE

Abstract—A theory of characteristic modes for conducting bodies is developed starting from the operator formulation for the current. The mode currents form a weighted orthogonal set over the conductor surface, and the mode fields form an orthogonal set over the sphere at infinity. It is shown that the modes are the same ones introduced by Garbacz to diagonalize the scattering matrix of the body. Formulas for the use of these modes in antenna and scatterer problems are given. For electrically small and intermediate size bodies, only a few modes are needed to characterize the electromagnetic behavior of the body.

where the subscript "tan" denotes the tangential components on S. The operator L is defined by

$$L(J) = j\omega A(J) + \nabla\Phi(J) \tag{2}$$

$$A(J) = \mu \oint\!\!\oint_S J(r')\psi(r,r')\, ds' \tag{3}$$

$$\Phi(J) = \frac{-1}{j\omega\epsilon} \oint\!\!\oint_S \nabla'\cdot J(r')\psi(r,r')\, ds' \tag{4}$$

- The characteristic mode theory (CMT) can provide physically intuitive guidance for the analysis and design of antenna structures.
- CMT was initially defined by Garbacz and was refined by Harrington and Mautz using the electric field integral equation (EFIE) for perfectly electric conducting (PEC) bodies

Introduction: Characteristic Mode Analysis

- Characteristic modes (CMs) are the natural response of a metallic structure (PEC) without a source/excitation.
- Method of moments (boundary integral) formulation of Maxwell's equations:

$$ZJ_n = E_{tan}^i$$

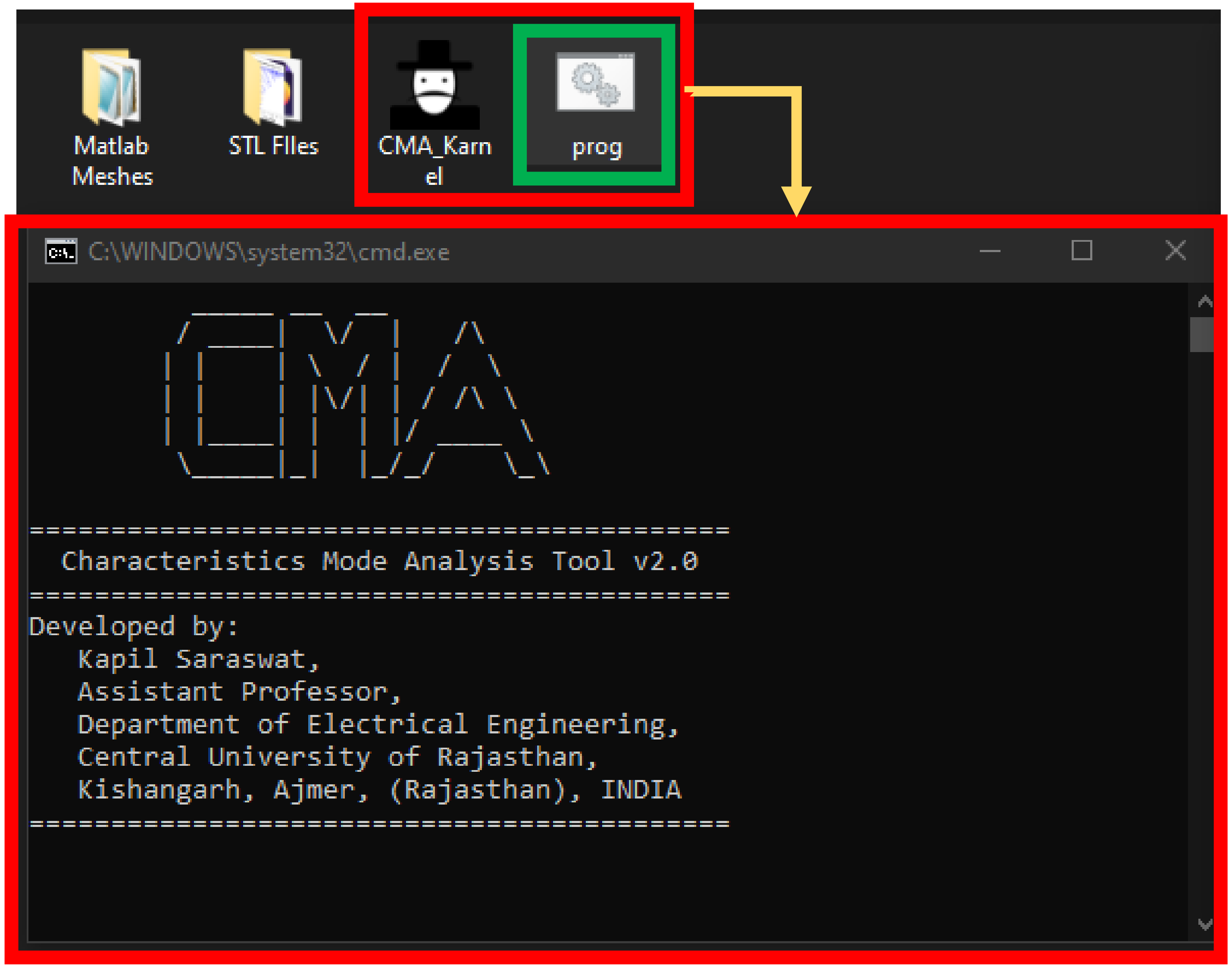
Where, $Z = \{Re\} + j\{Xe\}$ and known as impedance matrix

- CMs are based on the generalized eigenvalues of the impedance matrix,

$$\{Xe\}J_n = \lambda_n\{Re\}J_n$$

- When the characteristic value is close to zero, the mode is at resonance and then the mode would be nicely excited by a plane wave excitation and is also a good radiating mode for antenna applications.

CMA Tool v2.0



Salient Features :

1. Written in C++ (64 bit)
2. Semi-graphical Program
3. Free, with lot of features
4. Suitable for both students and researcher
5. Small and portable (≈18Mb)

1. Pre-processing
2. Simulation (CM Analysis)
3. Post-processing

CMA Tool v2.0: Pre-processing

Pre-processing

- CAD to create structure
  - ➢FreeCAD*
  - ➢Matlab
  - ➢Python *
  - ➢ANSYS HFSS
  - ➢CST Studio Suite
- Meshing
  - ➢Gmsh *
  - ➢Matlab
  - ➢Python *

* Free/open source

Note: Altair feko can be used for both (designing and meshing)!!

CMA Tool v2.0: Pre-processing & GMSH

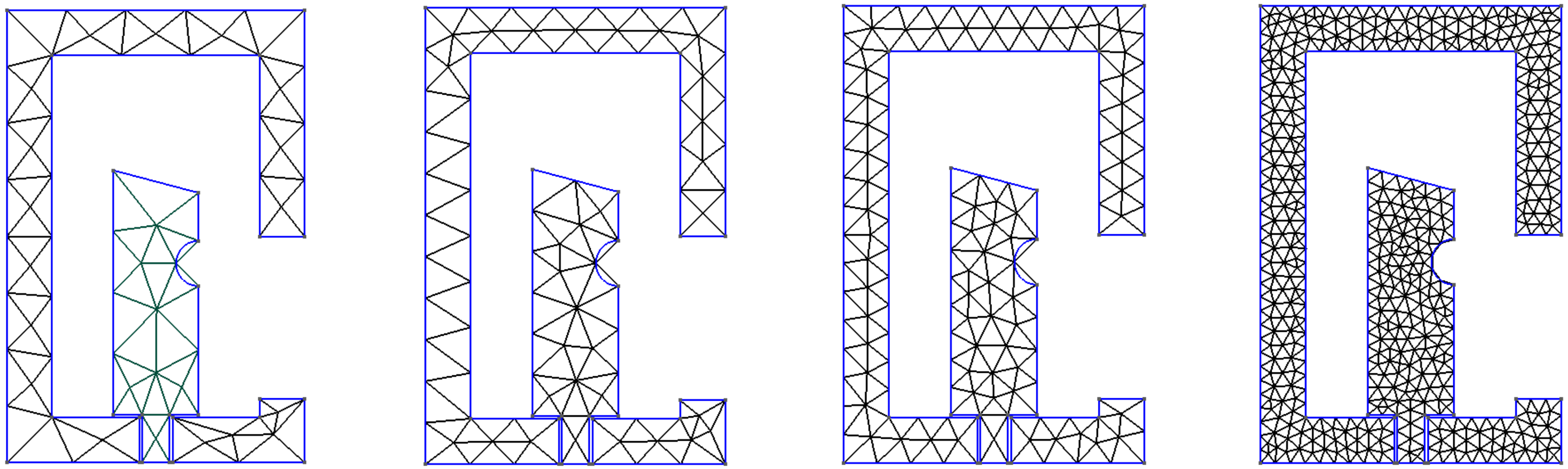
Pre-processing: Method-1

- CAD to create structure
    - Use CST studio suite or HFSS and export geometry in *.stl/*.step format.
- Meshing (use Gmsh), use appropriate element size factor for the meshing.

Pre-processing: Method-2

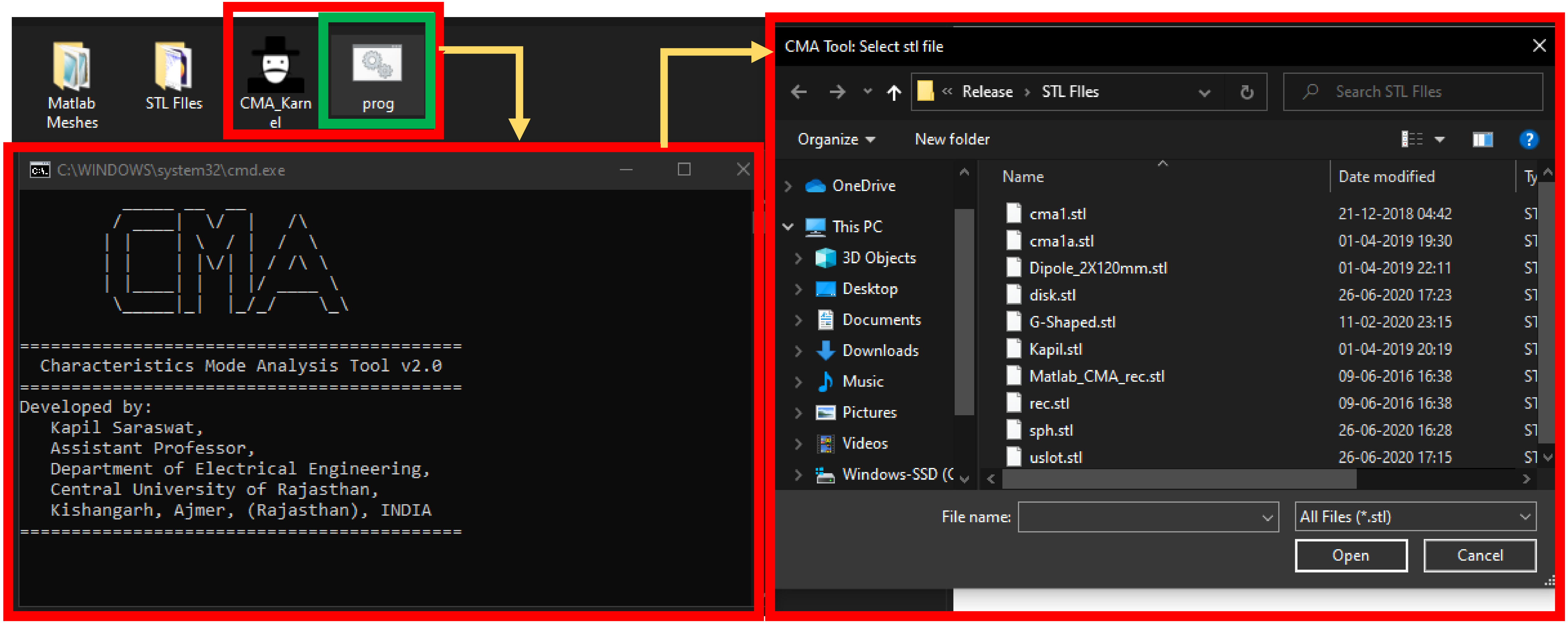
- Use Altair feko to create structure.
- Define frequency, mesh the structure.
- From Home, export mesh in *.stl format.
- Use directly exported *.stl file.

CMA Tool v2.0: Pre-processing & GMSH

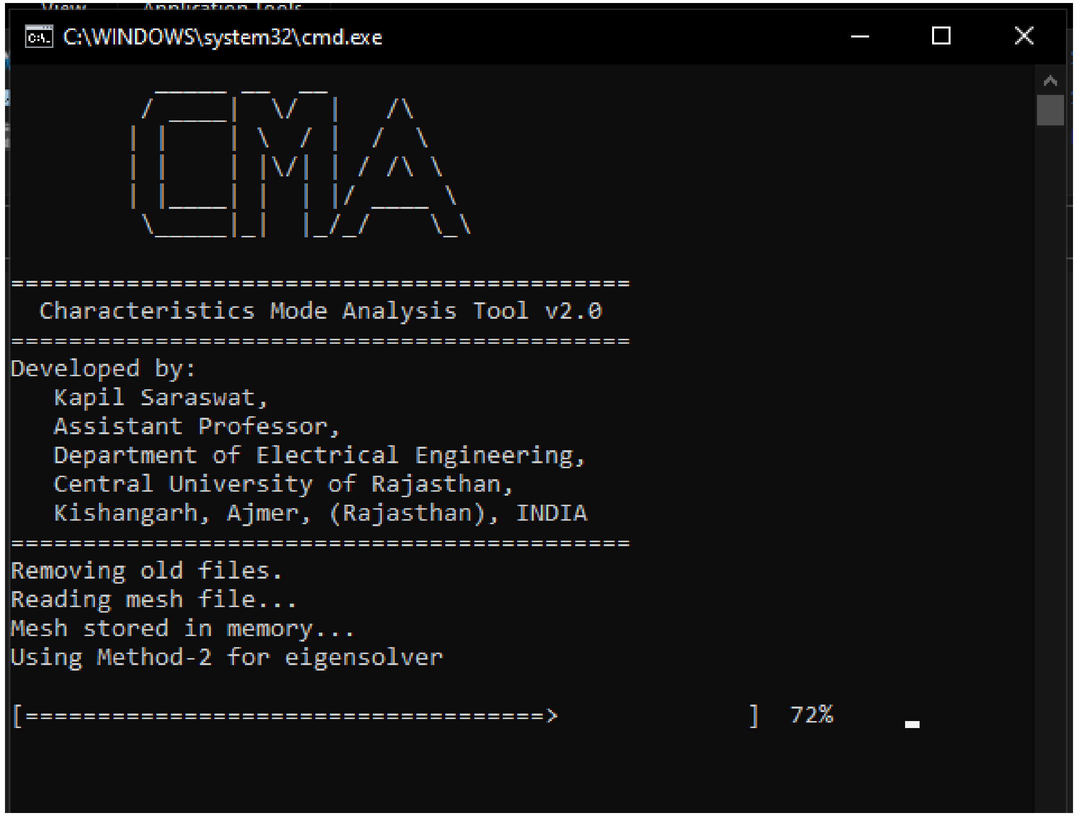


No. of Triangles	98	131	228	905
Element size factor	1.0	0.75	0.50	0.25
Accuracy	★	★★	★★★	★★★★
Simulation time	★	★★	★★★	★★★★

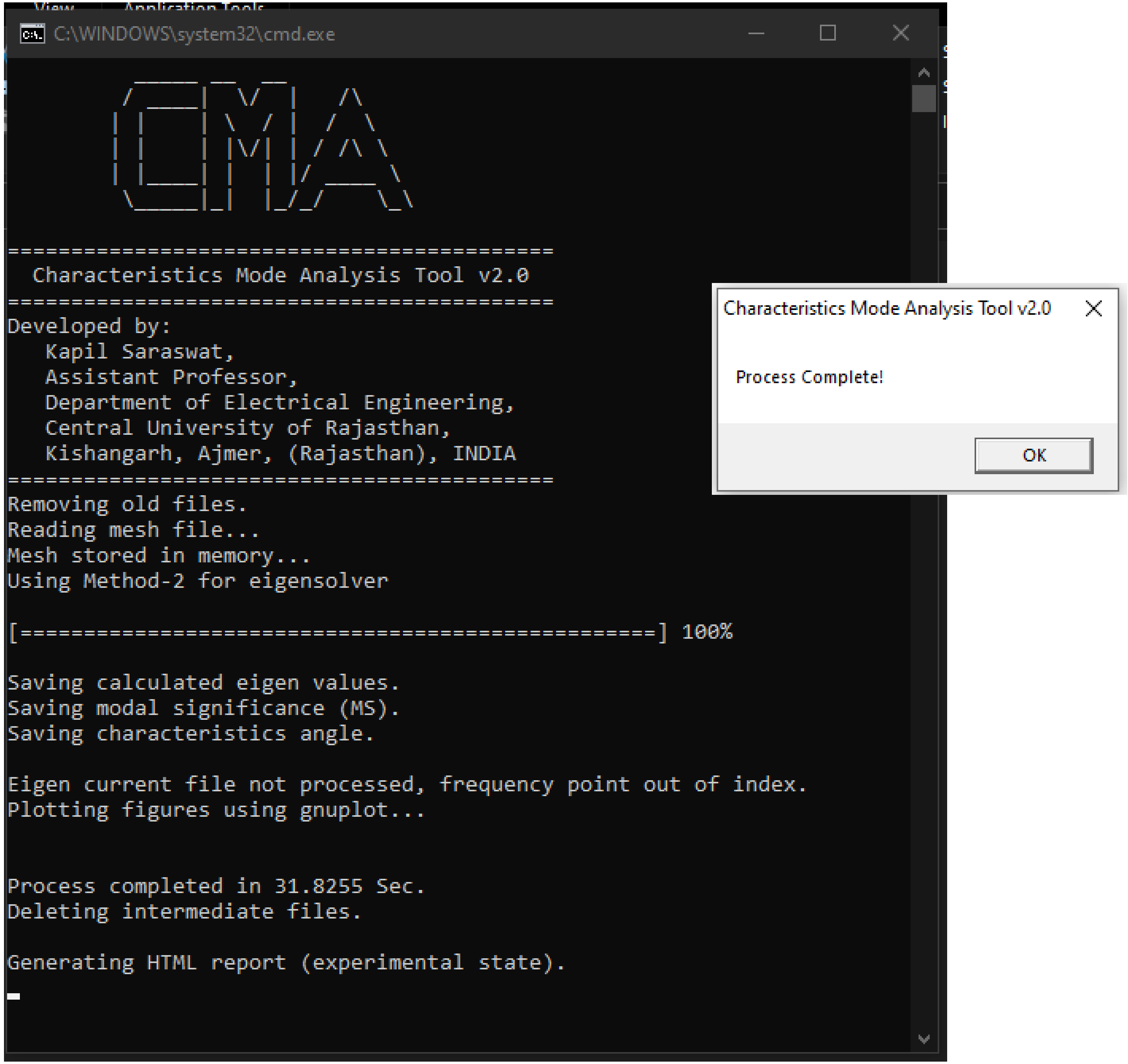
CMA Tool v2.0: Interface



CMA Tool v2.0



During Simulation



After Simulation

CMA Tool v2.0: Commands

Information:

- CMA_karnel.exe –Help
- CMA_karnel.exe –LIC

Pre-processing:

- CMA_karnel.exe -Mat2dat
- CMA_Karnel.exe –gmsh

Simulation:

```
Interactive mode
================================================================
Start Frequency (Hz): 0.5e9
Stop Frequency (Hz):  2.5e9
Number of Frequency Steps: 21
Number of Modes: 5
Threshold: -100
Save freq.: 2.5e9
Method (1-2): 2
Flag (0-5): 2
```

- CMA_karnel.exe –INT
- CMA_karnel.exe -Batch_Mode f_{start} f_{stop} f_{point} N_{modes} threshold $f_{save\_current}$ Method Flag
- CMA_Karnel.exe -Matlab_file f_{start} f_{stop} f_{point} N_{modes} threshold $f_{save\_current}$ Method Flag
- CMA_Karnel.exe -File_Mode f_{start} f_{stop} f_{point} N_{modes} threshold $f_{save\_current}$ Method Flag $File_{Name\_Path}$

Note: Number of frequency point should be odd number (conventionally it is 11, 21, 51, 101, 201 etc.) !!

CMA Tool v2.0: Flags

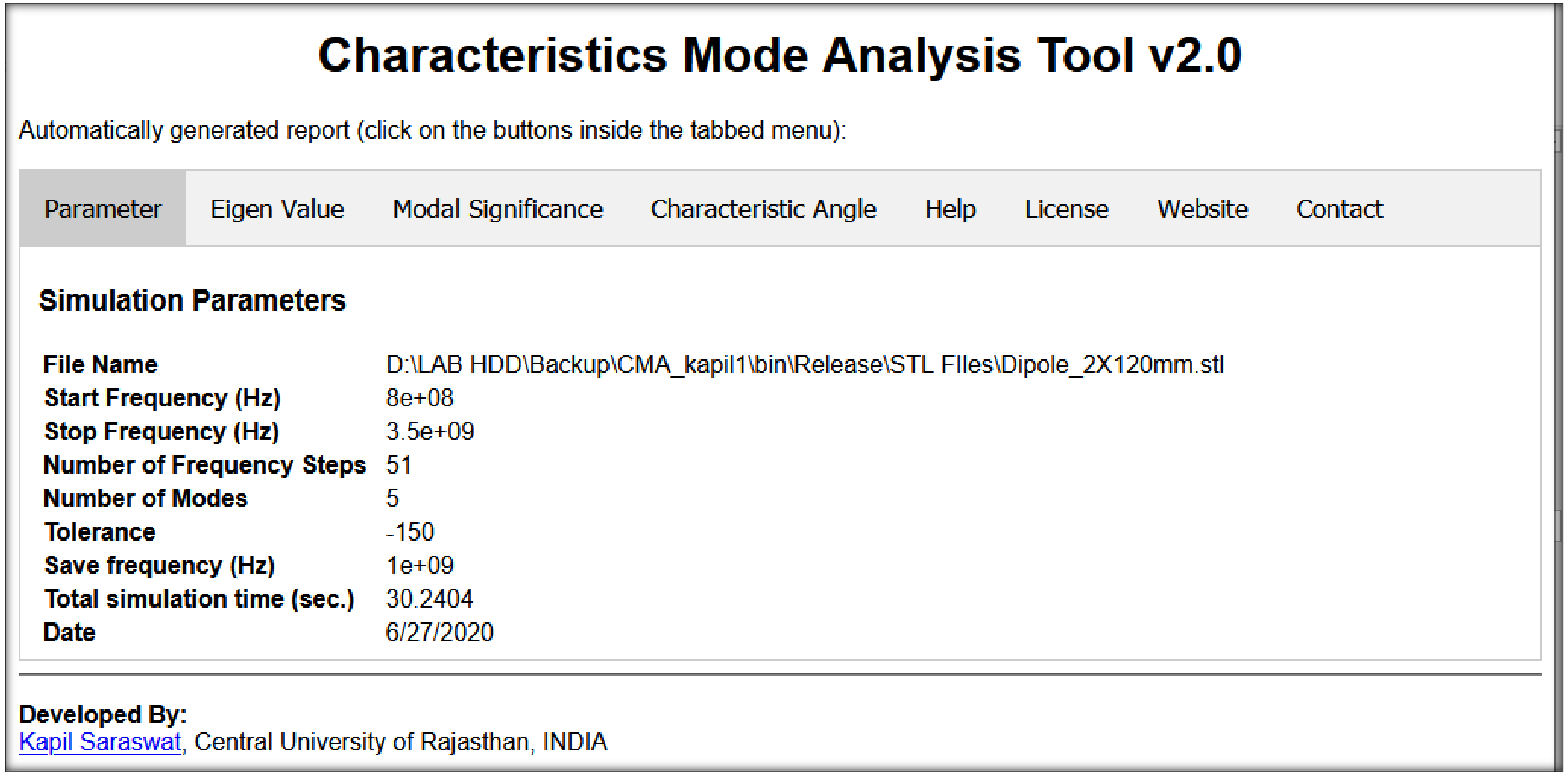
Flags:

- 0: Store only Impedance matrix (Z-matrix).
- 1: Store only HTML report.
- 2: Store HTML report and CMA out file.
- 3: Store HTML report, CMA out file and eigenvalue.
- 4: Store HTML report, CMA out file, eigenvalue and eigenvector.
- 5: Store all processed file.

Note: flag is useful, it delete the big file which is meant for advance users.

CMA Tool v2.0: Output and GNUPlot

- GNUPlot is used for the plotting.
- Generate HTML report.



Characteristics Mode Analysis Tool v2.0

Automatically generated report (click on the buttons inside the tabbed menu):

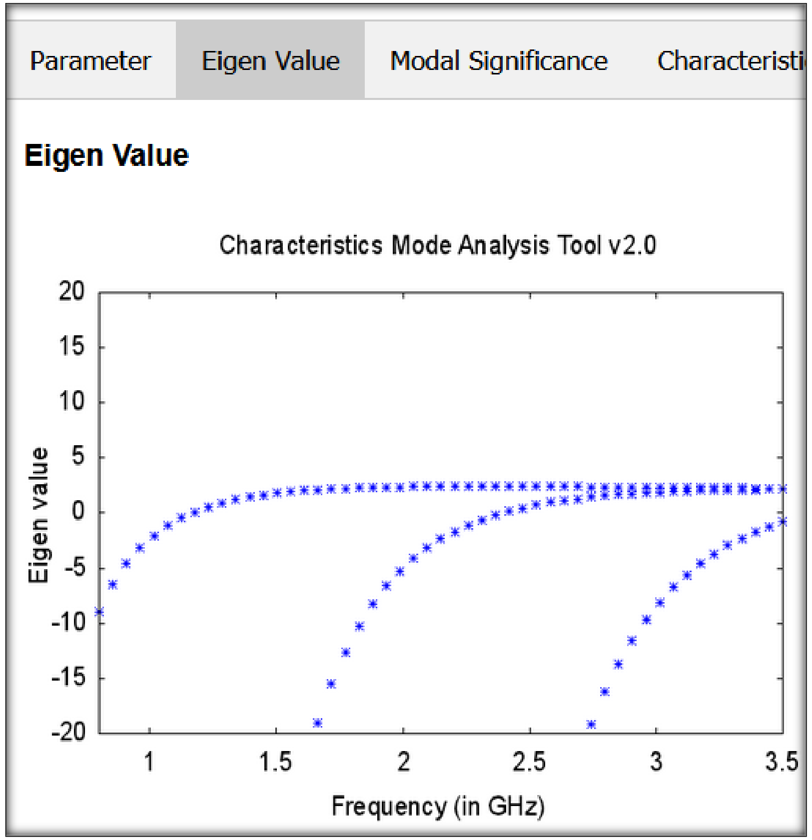
Parameter | Eigen Value | Modal Significance | Characteristic Angle | Help | License | Website | Contact

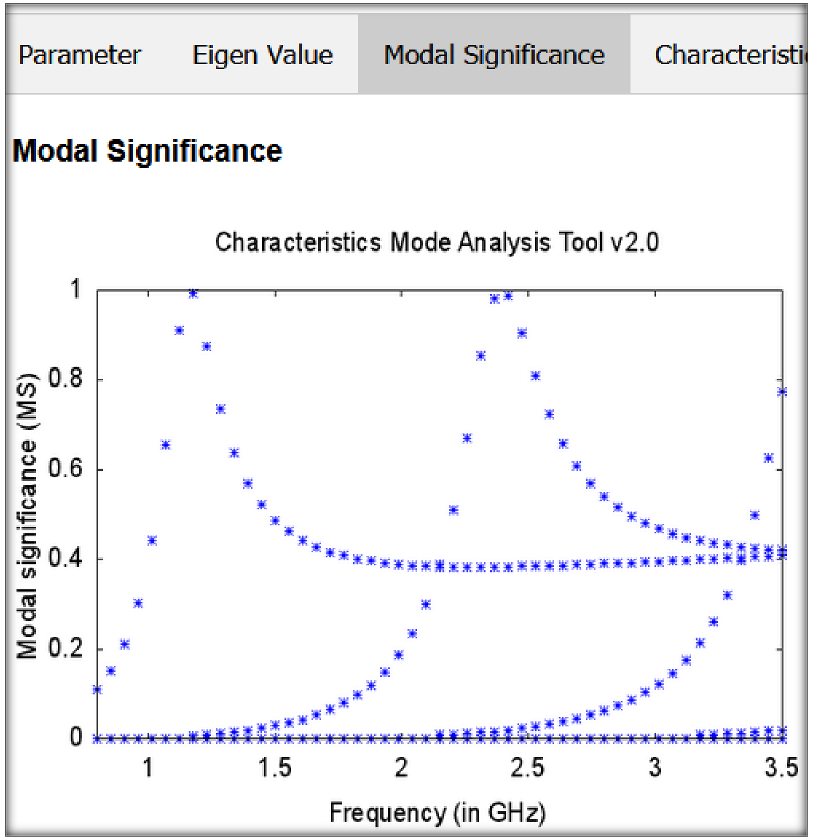
Simulation Parameters

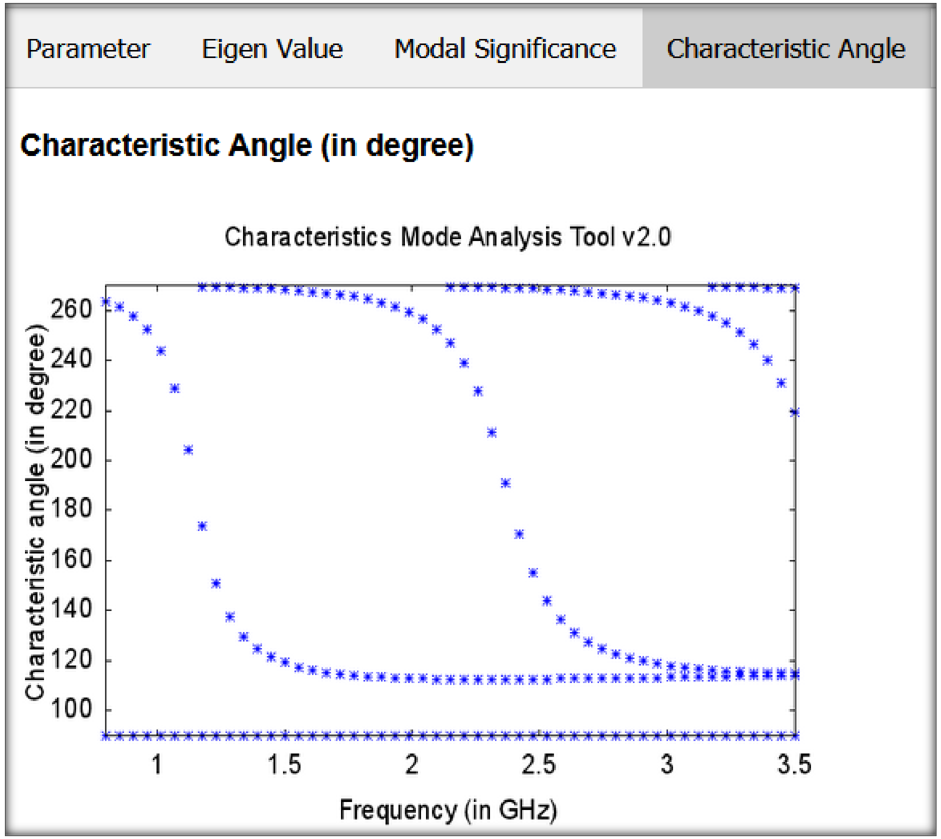
File Name	D:\LAB HDD\Backup\CMA_kapil1\bin\Release\STL FIles\Dipole_2X120mm.stl
Start Frequency (Hz)	8e+08
Stop Frequency (Hz)	3.5e+09
Number of Frequency Steps	51
Number of Modes	5
Tolerance	-150
Save frequency (Hz)	1e+09
Total simulation time (sec.)	30.2404
Date	6/27/2020

Developed By:
Kapil Saraswat, Central University of Rajasthan, INDIA

CMA Tool v2.0: Output and GNUPlot



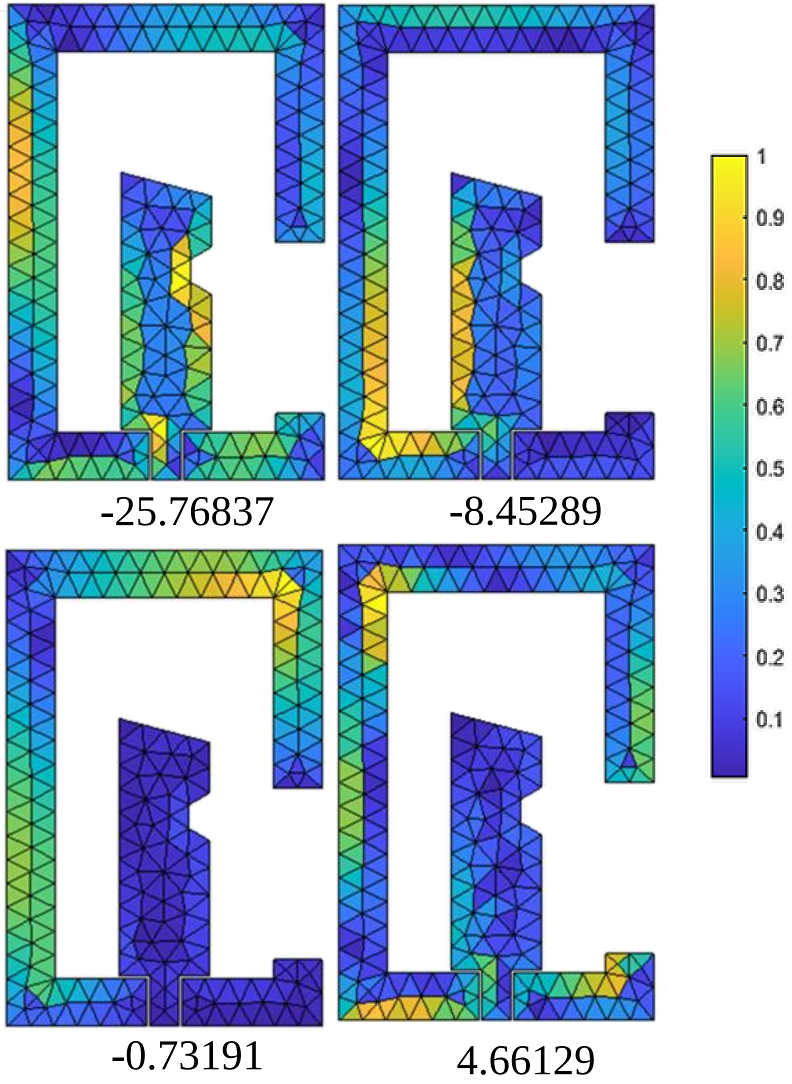




CMA Tool v2.0: Output and MATLAB

```
%%% ============================================
%%%   Characteristics Mode Analysis Tool v2.0
%%% ============================================
%%% Developed by:
%%%    Kapil Saraswat,
%%%    Assistant Professor,
%%%    Department of Electrical Engineering,
%%%    Central University of Rajasthan,
%%%    Kishangarh, Ajmer, (Rajasthan), INDIA
%%%=============================================
%%% (Experimental state)
clc;
clear all;
x_cols = 196 ;
total_mode = 10 ;
fid = fopen('EigCurrent_CMA.out','r');
Data = cell2mat(textscan(fid,repmat('%f',1,x_cols),'delimiter',',','commentstyle','#','collectoutput',1))
X_mm = Data(1:3,:);
Y_mm = Data(4:6,:);
Z_mm = Data(7:9,:);
for e_plot=1:total_mode
      index_val=3*(e_plot-1);
      C_linear=Data(index_val+10:index_val+12,:);
      f=figure(e_plot)
      h=fill3(X_mm, Y_mm, Z_mm, C_linear);
      colormap(f);
      colorbar;
      axis('equal');
end
```

Eigen current at 2.4 GHz



CMA Tool v2.0: Demonstration

CMA Tool v2.0: Example

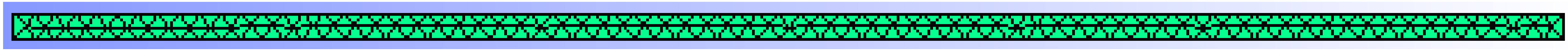
Following three structures are used:

1. Dipole
2. U-shaped Patch
3. Circular disk

The obtained results are compared with commercially available EM simulators supporting CMA

1. Altair feko
2. CST Studio Suite

CMA Tool v2.0: Example (Dipole)

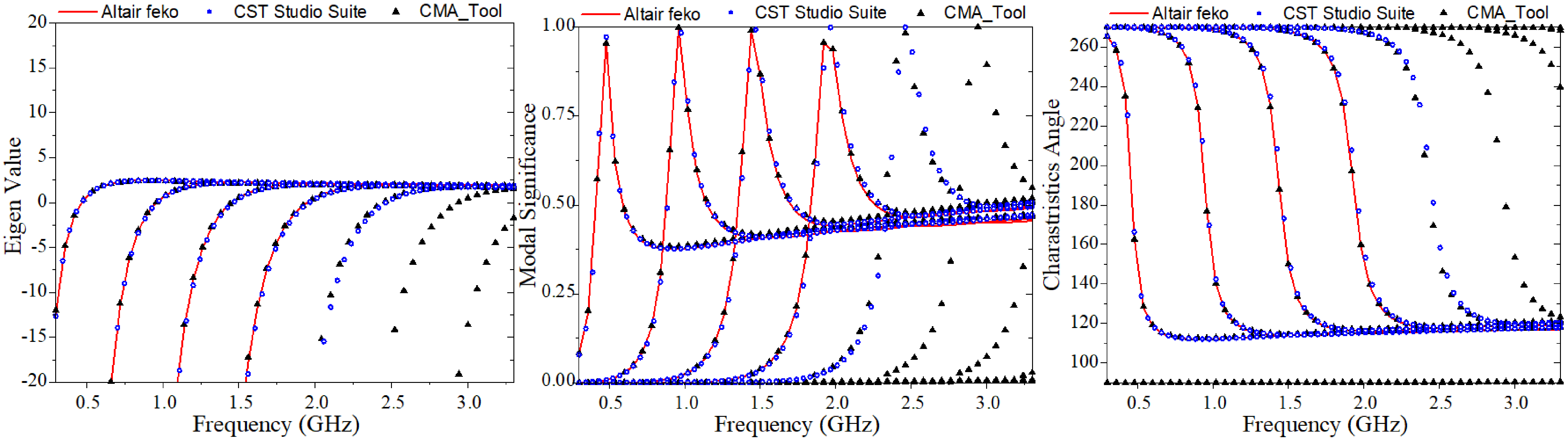


Geometry description

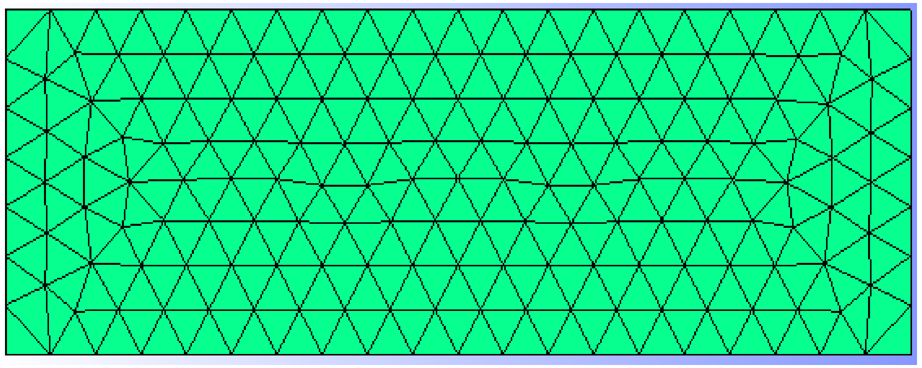
Dipole: 300mm X 5mm

398 Triangles

0.3 GHz to 3.3 GHz



CMA Tool v2.0: Benchmarking (Rectangular Plate)

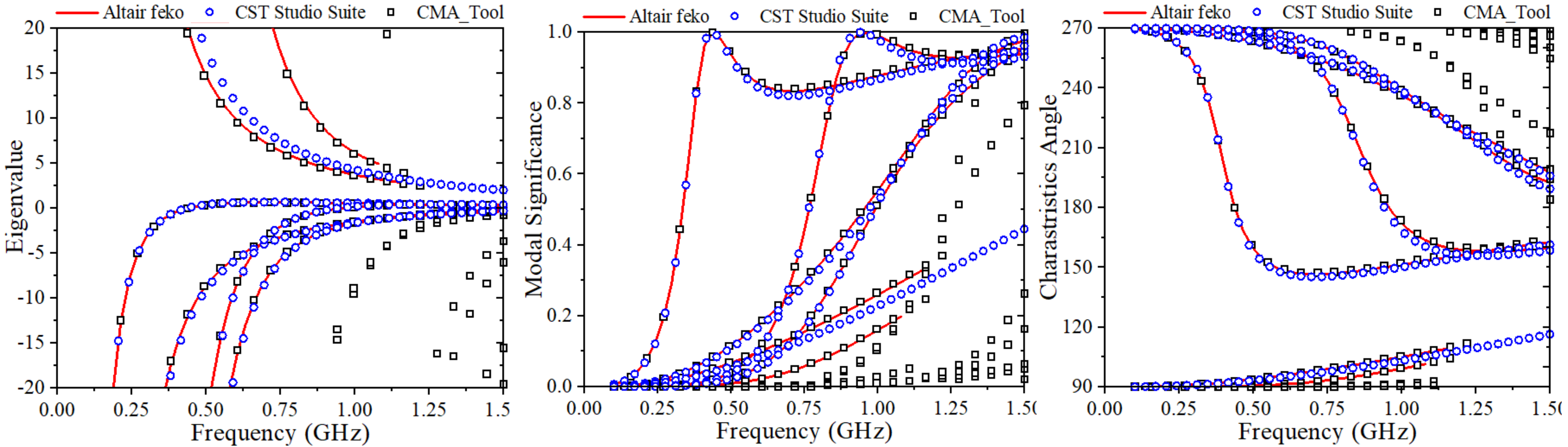


Geometry description

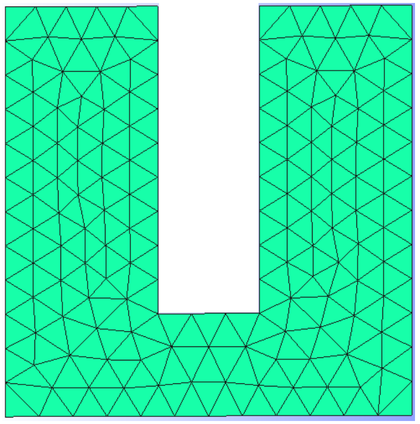
Rectangular Plate: 300mm X 100mm

314 Triangles

0.5 GHz to 3.5 GHz



CMA Tool v2.0: Benchmarking (U-shaped Patch)

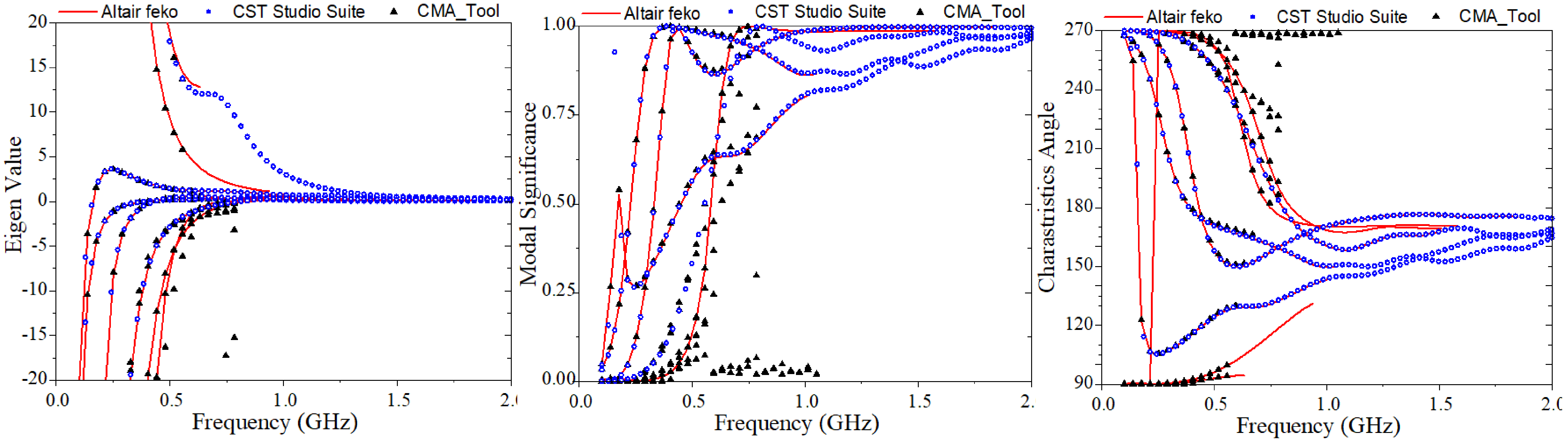


Geometry description

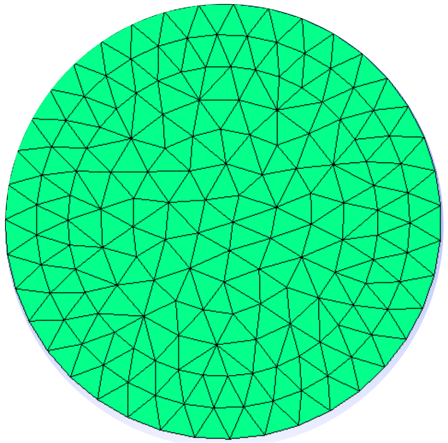
U Shaped Patch: 400mm X 400mm

Slot: 300mm X 100 mm

283 Triangles, 0.1 GHz to 2 GHz



CMA Tool v2.0: Benchmarking (Circular disk)

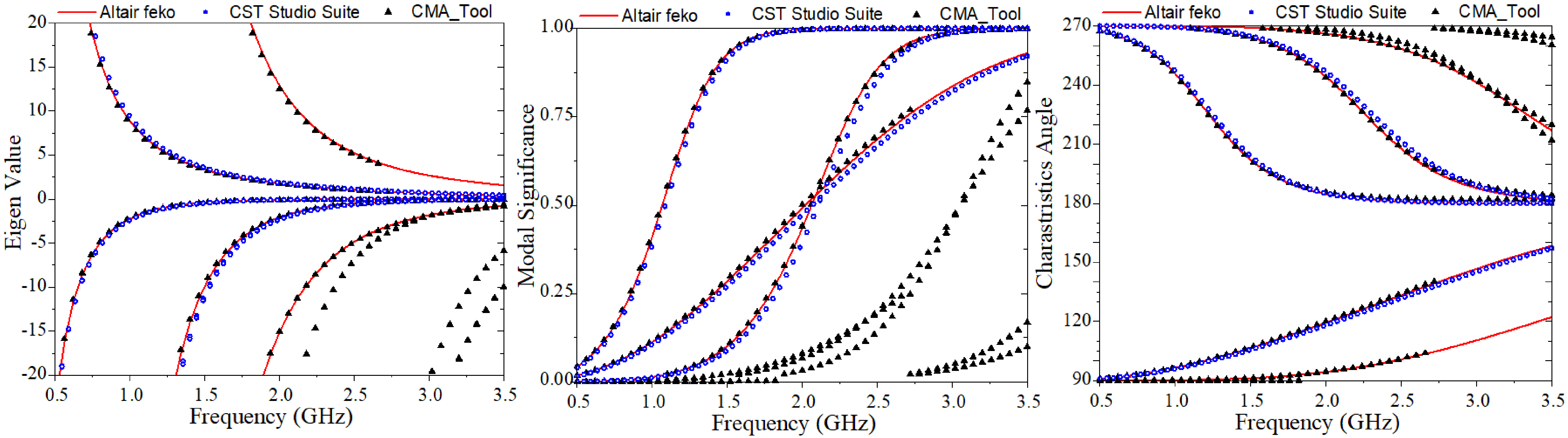


Geometry description

Circular Disk: R= 50mm

301 Triangles

0.5 GHz to 3.5 GHz



Conclusion

- A functional semi-graphical tool is developed in C++ for the CM analysis.
- Small and portable
- Suitable for the classroom and research purpose.
- Provide access to intermediate data and able to calculate impedance (**Z**) matrix
- Provide more functionality including script generation, pre-processing, post-processing etc.
- Auto-generation of HTML reports and scripts.
- Compatible with different tools such as FreeCAD, CST studio suite, Ansys HFSS, Altair feko, Gmsh, MATLAB, Python etc.

Future Scope

- Complete GUI (β)
- No GNUPlot dependencies (β)
- Faster simulation (β)
- Mode tracking algorithm (α)
- Inbuild meshing (α)
- Inbuild Modal Current viewer(α)
- Radiation pattern (α)

(β)= Under Development/testing

(α)= experimental phase

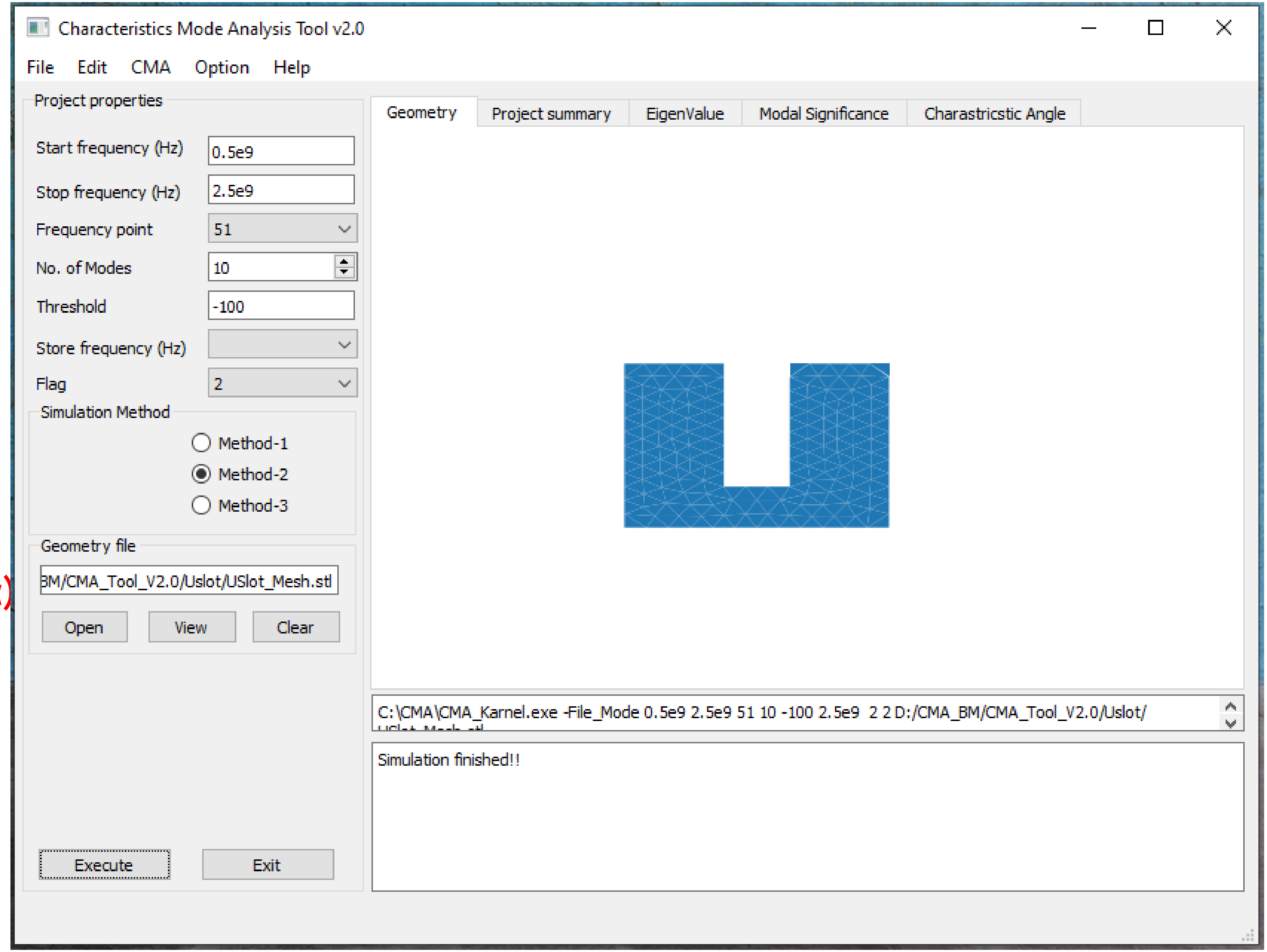


Figure shows U-slot with other simulation parameter(beta phase).

Thank you.

For update