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Eigenmode Simulations
# of Third Harmonic Superconducting Accelerating Cavities for FLASH and the European XFEL

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Abstract

The third harmonic nine-cell cavity (3.9 GHz) for FLASH and the European XFEL has been investigated using simulations performed with the computer code CST Microwave Studio®. The band structure of monopole, dipole, quadrupole and sextupole modes for an ideal cavity has been studied. The higher order modes for the nine-cell structure are compared with that of the cavity mid-cell. The R/Q of these eigenmodes are calculated.

Contents

1 Introduction **3**

2 The Third Harmonic Cavity as a Periodic Structure **5**

3 The Beam Pipe as a Circular Waveguide **9**

4 Eigenmodes in the Ideal Third Harmonic Cavities **10**

5 Summary **19**

Bibliography **1**

A List of Monopole, Dipole, Quadrupole and Sextupole Modes **2**

B Parameter Settings used for Simulations **8**

C Electric Field Distributions of Modes **11**

I Monopole (Electric Boundaries) 12
  I.1 M1 (EE) 12
  I.2 MBP1, MBP2, MBP3 and MBP4 (EE) 13
  I.3 M2 (EE) 14
  I.4 M3 (EE) 15
  I.5 MBP5 and MBP6 (EE) 16
  I.6 M4 (EE) 17
II Monopole (Magnetic Boundaries) 18
  II.1 M1 (MM) 18
  II.2 MBP1, MBP2 and MBP3 (MM) 19
  II.3 M2 (MM) 20
  II.4 M3 (MM) 21
  II.5 MBP5 and MBP6 (MM) 22
  II.6 M4 (MM) 23
III Dipole (Electric Boundaries) 24
  III.1 DBP1 (EE) 24
  III.2 D1 (EE) 25
  III.3 DBP2 and D2 (EE) 26
  III.4 DBP3 and DBP4 (EE) 27
  III.5 D3 (EE) 28
  III.6 DBP5 (EE) 29
  III.7 D4 (EE) 30
  III.8 D5 (EE) 31
  III.9 DBP6, DBP7, DBP8 and DBP9 (EE) 32
  III.10 D6 (EE) 33
IV Dipole (Magnetic Boundaries) 34
  IV.1 DBP1 (MM) 34

- IV.2 D1 (MM) 35
- IV.3 DBP2 and D2 (MM) 36
- IV.4 DBP3 and DBP4 (MM) 37
- IV.5 D3 (MM) 38
- IV.6 DBP5 and DBP6 (MM) 39
- IV.7 D4 (MM) 40
- IV.8 D5 (MM) 41
- IV.9 DBP7, DBP8 and DBP9 (MM) 42
- IV.10 DBP10 and D6 (MM) 43

V Quadrupole (Electric Boundaries) 44
- V.1 QBP1 and Q1 (EE) 44
- V.2 Q2 (EE) 45
- V.3 QBP2, QBP3, QBP4 and QBP5 (EE) 46
- V.4 Q3 and QBP6 (EE) 47

VI Quadrupole (Magnetic Boundaries) 48
- VI.1 QBP1 and Q1 (MM) 48
- VI.2 Q2 (MM) 49
- VI.3 QBP2, QBP3, QBP4, QBP5 and QBP6 (MM) 50
- VI.4 Q3 (MM) 51

VII Sextupole (Electric Boundaries) 54
- VII.1 SBP1 and S1 (EE) 54
- VII.2 SBP2 and S2 (EE) 55

VIII Sextupole (Magnetic Boundaries) 56
- VIII.1 SBP1 and S1 (MM) 56
- VIII.2 SBP2 and S2 (MM) 57

Chapter 1

Introduction

FLASH [1, 2] is a free-electron laser facility at DESY. It uses ultra-short electron bunches with high peak current to generate high brilliance coherent light pulses. FLASH is a user facility for photon science and a test facility for various accelerator studies. The beam is accelerated by superconducting TESLA 1.3 GHz cavities [3, 4]. Third harmonic 3.9 GHz cavities [5] are used to linearize the curvature of bunch's energy spread caused by the sinusoidal 1.3 GHz RF field [6].

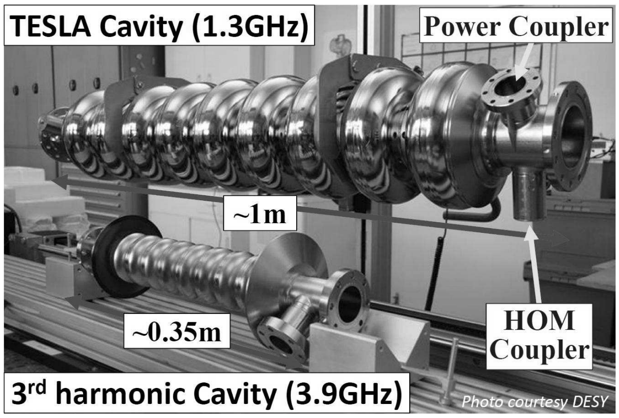

TESLA Cavity (1.3GHz)
Power Coupler
~1m
~0.35m
HOM Coupler
3rd harmonic Cavity (3.9GHz)
Photo courtesy DESY

Figure 1.1: A TESLA style cavity operating at 1.3 GHz (top) and the corresponding third harmonic cavity (bottom).

The third harmonic cavity inherits a similar design of to the 1.3 GHz TESLA cavity (with some modifications) as shown in Fig. 1.1. A schematic of the third harmonic cavity is illustrated in Fig. 1.2 along with the main dimensions. It has one power coupler and one pick-up probe installed on the beam pipe connecting end-cells. It is also equipped with two higher order mode (HOM) couplers installed on each side of the connecting beam pipes with different rotations and different designs [7]. In FLASH there are four 3.9 GHz cavities as shown in Fig. 1.3.

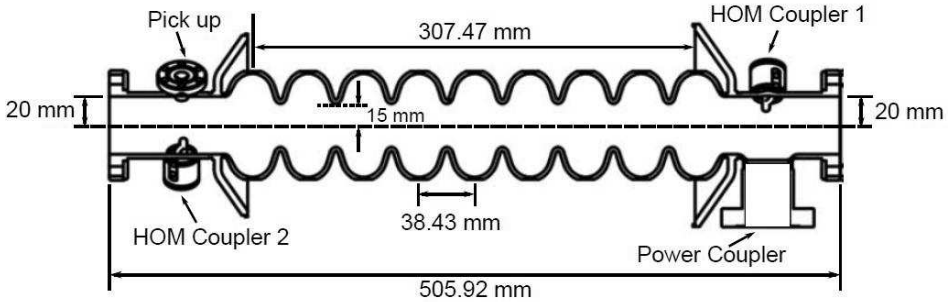

Pick up
307.47 mm
HOM Coupler 1
20 mm
15 mm
20 mm
38.43 mm
HOM Coupler 2
Power Coupler
505.92 mm

Figure 1.2: Schematic of a third harmonic cavity with one power coupler, one pick up probe and two HOM couplers.

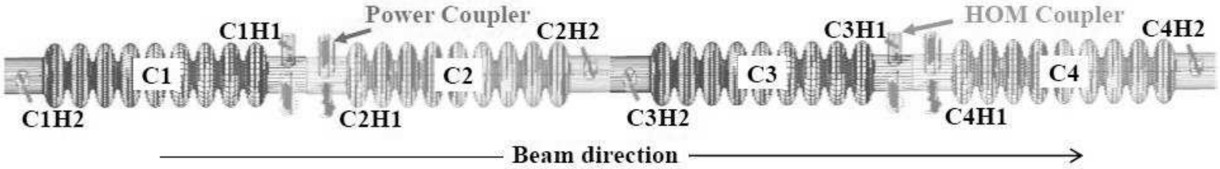


Figure 1.3: Schematic of the four cavities within ACC39 module.

The wakefields in the third harmonic cavity are significantly stronger than those in the 1.3 GHz TESLA cavity due to a much smaller iris radius: 15 mm compared with 35 mm [4]. Unlike the 1.3 GHz TESLA cavity, most HOMs in the third harmonic cavity are above the cutoff frequencies of the connecting beam pipes in order to achieve a better damping of the HOMs [8]. However, this allows HOMs to propagate amongst cavities in the module, and thus gives rise to a dense coupled modal spectrum in the third harmonic cavity.

In this report, the third harmonic cavity is firstly treated as a periodic structure with an infinite number of repetitions of the mid-cell. The dispersion curves of monopole, dipole, quadrupole and sextupole passbands are described in Chapter 2. The beam pipes connecting the cavities are modeled as circular waveguides and described in Chapter 3. The eigenmodes obtained for an ideal third harmonic cavity without couplers are presented in Chapter 4. A list of modes simulated up to 11 GHz for an ideal third harmonic cavity is shown in Appendix A. The parameters used in the CST Microwave Studio® for these eigenmode simulations are listed in Appendix B. Extensive electric field distributions for monopole, dipole, quadrupole and sextupole modes with both electric (EE) and magnetic (MM) boundary conditions are presented in Appendix C.

Chapter 2

The Third Harmonic Cavity as a Periodic Structure

A sketch of the cell geometry is given in Fig. 2.1 for the third harmonic cavity. The cell is rotationally symmetric around the z axis. The iris and the equator both have an elliptical shape. The mid-cells have different shape from the end-cells, and the parameters are listed in Table 2.1. The iris of the end-cup is larger than that of the mid-cell. Fig. 2.2(a) shows a mid-cell built in CST Microwave Studio®[9]. A hexahedral mesh was used in the calculation of the electromagnetic field as shown in Fig. 2.2(b). The mesh lines were chosen such that the iris radius and the equator radius were exactly matched by mesh lines. Symmetry planes were applied on the structure to save simulation time so that only a quarter of the structure was simulated. Approximately 130,000 mesh cells for a quarter of the structure and a maximum mesh step of 0.85 mm were set. Electric (EE) boundary conditions were used on the surface of the mid-cell, while periodic boundary conditions were set on both ends of the cell. The modes of an infinite periodic chain of cavities can be obtained from single cell calculations using periodic boundary conditions:

$$\mathbf{E}(r, z + L) = \mathbf{E}(r, z)e^{i\phi}, \tag{2.1}$$

where ϕ is the phase advance per cell, and L is the cell length. Fig. 2.2(c) shows the electric field of a mode with a phase advance of 180 degrees (or π) per cell. The frequencies of several passbands are shown in the form of dispersion curves in Fig. 2.3 for monopole, dipole, quadrupole and sextupole modes.

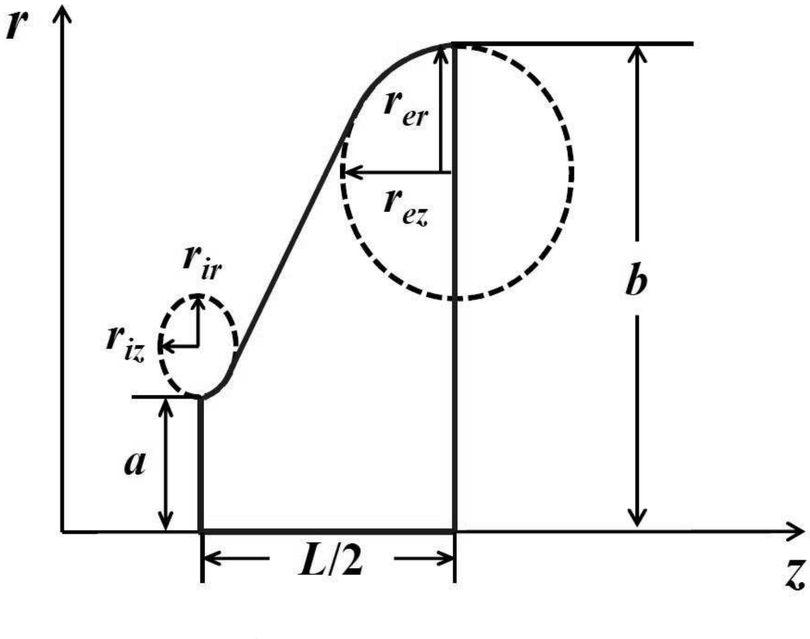
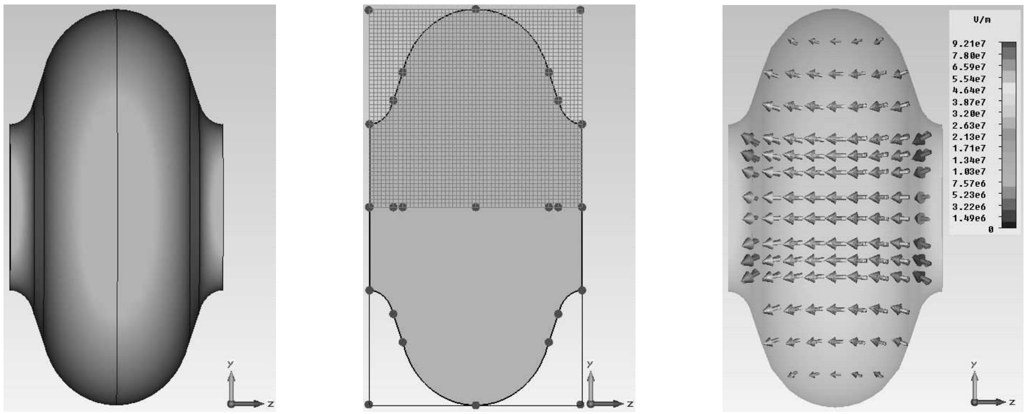


Figure 2.1: Parameterization of cell geometry. The blue curve represents the cell wall.

A beam excites strongest those modes which are synchronous to the beam, i.e. with a phase velocity

Table 2.1: Parameters of the cell geometry of the third harmonic cavity.

		mid-cell	end-cell
Iris radius, $\boldsymbol{a}$	mm	15.0	20.0
Equator radius, $\boldsymbol{b}$	mm	35.787	35.787
Half cell length, $\boldsymbol{L/2}$	mm	19.2167	19.2167
Equator horizontal axis, $\boldsymbol{r_{ez}}$	mm	13.6	14.4
Equator vertical axis, $\boldsymbol{r_{er}}$	mm	15.0	15.0
Iris horizontal axis, $\boldsymbol{r_{iz}}$	mm	4.5	4.5
Iris vertical axis, $\boldsymbol{r_{ir}}$	mm	6.0	6.0



(a) Mid-cell

(b) Mesh view

(c) π mode

Figure 2.2: The mid-cell of the third harmonic cavity as modeled in CST Microwave Studio®. (c) shows the accelerating mode with a phase advance of 180 degrees per cell (π mode).

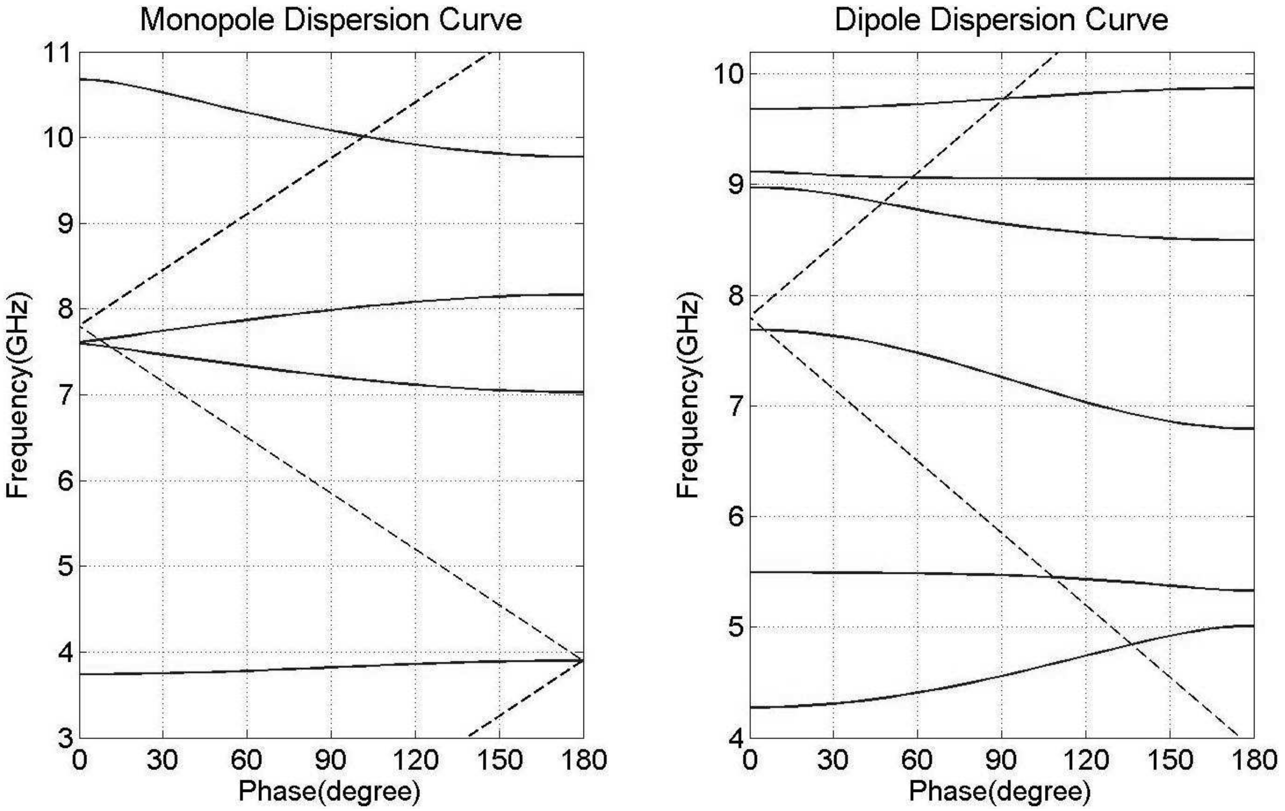
equal to the speed of the accelerated particles. For FLASH, this is the speed of light:

$$c = v_{phase} = \frac{\omega}{k_z} = 2\pi L \frac{f}{\phi}, \tag{2.2}$$

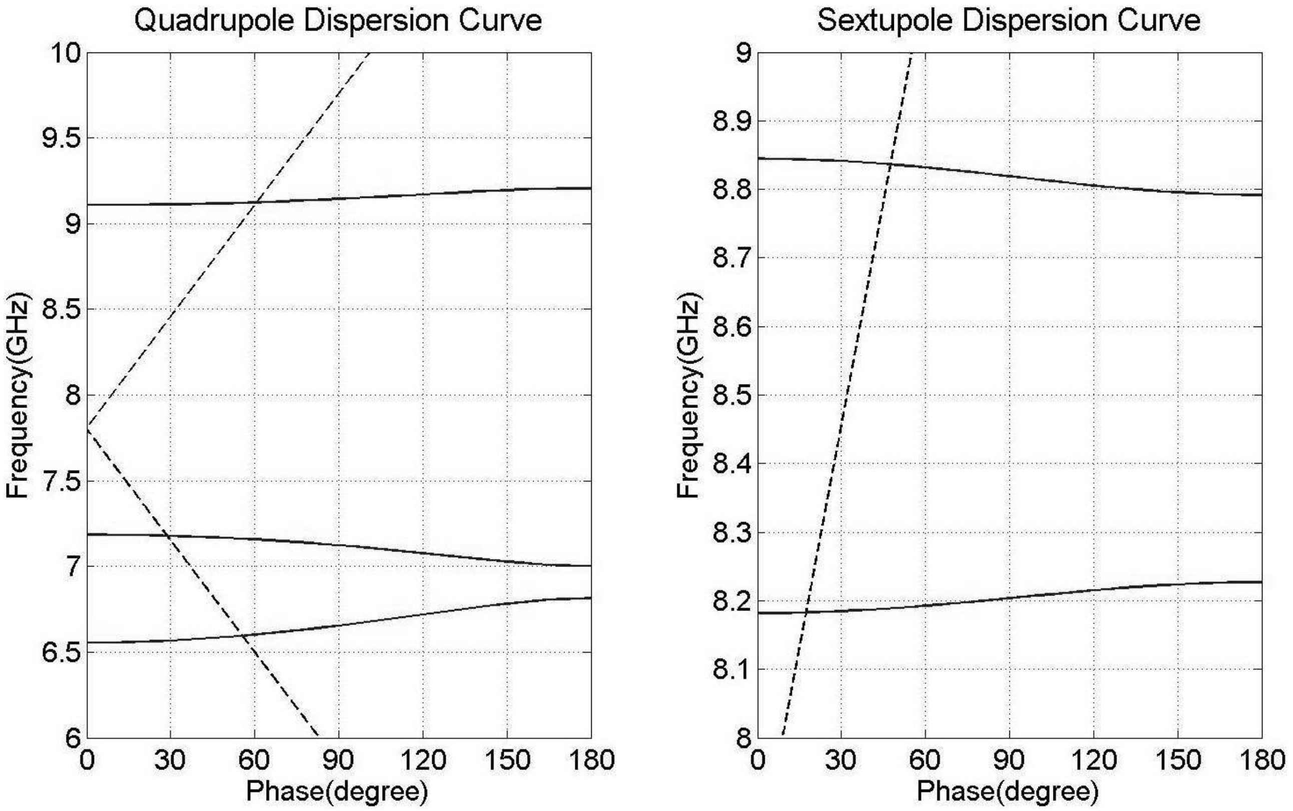
where k_z is the longitudinal wave number, $\phi = k_z L$ is the phase advance per cell, which is used as an horizontal axis in the plots of the dispersion curves. The light line is therefore the straight line:

$$f(\phi) = \frac{c}{2\pi L}\phi. \tag{2.3}$$

It is folded into the phase range from 0 to 180 degrees in the dispersion plots due to the periodicity of the structure. By design, the light line intersects the π mode of the first monopole passband (frequency $\approx$ 3.9 GHz), which is used for particle acceleration. Fig. 2.4 show the dispersion curves for the monopole, dipole, quadrupole and sextupole bands up to 11 GHz.



(a) Monopole (b) Dipole



(c) Quadrupole (d) Sextupole

Figure 2.3: The band structure (blue) of a 3.9 GHz cavity mid-cell. The light line is dashed.

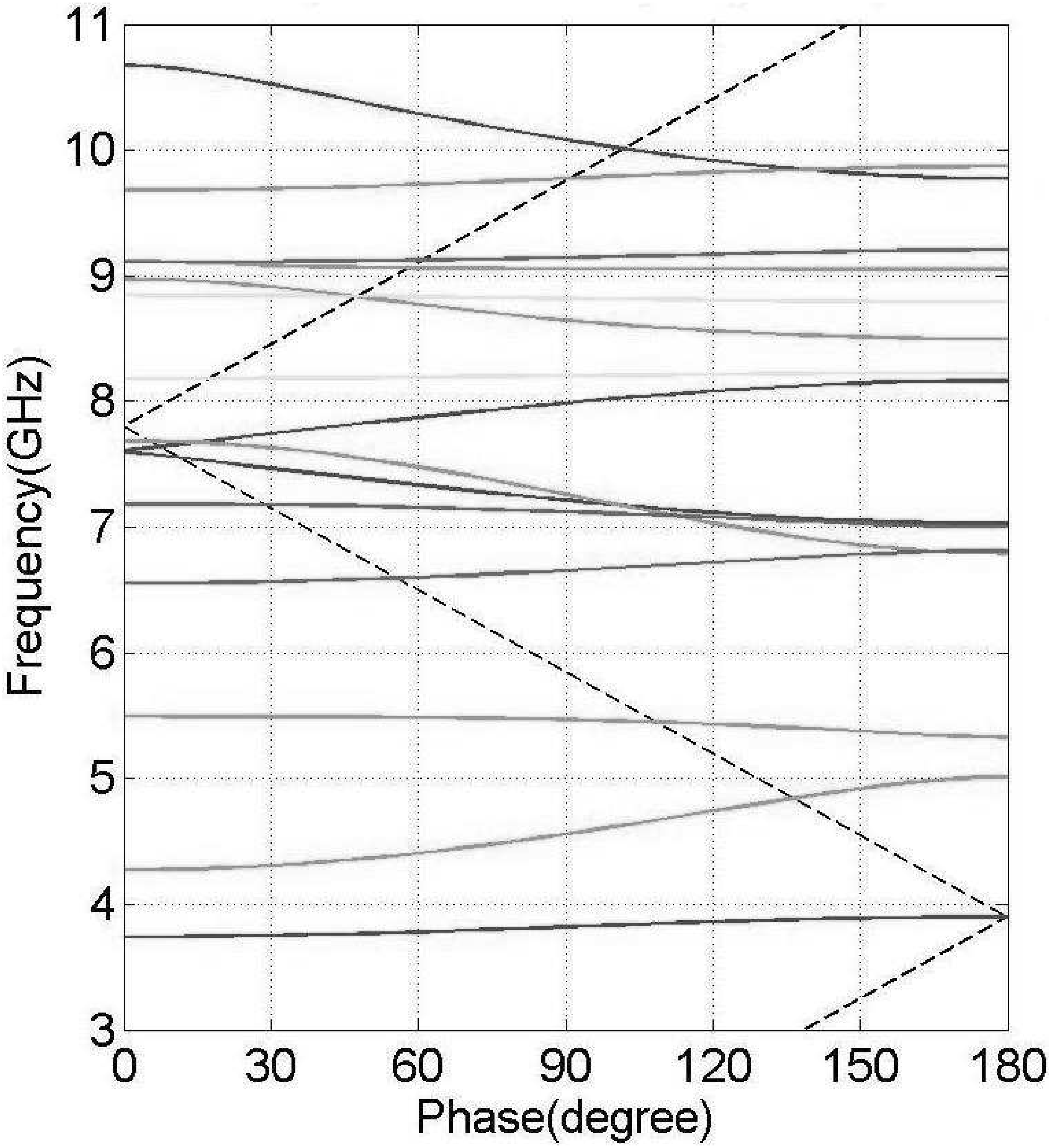


Figure 2.4: Dispersion curve for monopole (red), dipole (green), quadrupole (magenta) and sextupole (yellow) modes. The light line is dashed.

Chapter 3

The Beam Pipe as a Circular Waveguide

The third harmonic cavities are connected with beam pipes. To study the propagation of the modes amongst cavities, the beam pipes are treated as circular waveguides. Generally, the TE and TM modes can be distinguished from the characterization of the electric and magnetic fields. The cutoff frequencies of the TE and TM modes for a circular waveguide are [4]:

$$f_{c_{mn}}^{TM} = c\frac{p_{mn}}{2\pi a}, \tag{3.1a}$$

$$f_{c_{mn}}^{TE} = c\frac{p'_{mn}}{2\pi a}, \tag{3.1b}$$

where m=0, 1, 2, 3 corresponds to monopole, dipole, quadrupole and sextupole modes, p_{mn} is the n^{th} root of the m^{th} Bessel function J_m, p'_{mn} is the n^{th} root of the derivative of the m^{th} Bessel function J'_m, a is the radius of the waveguide. The first TE mode to propagate is the mode with the smallest p'_{mn}, which from Table 3.1 is seen to be TE_{11} mode. The first TM mode to propagate is then the TM_{01} mode. The cutoff frequencies of TE_{11} and TM_{01} modes are listed in Table 3.2 for a circular waveguide with a radius of 15 mm and of 20 mm. These correspond to the iris radius of a mid-cell and an end-cell of a third harmonic cavity (see Table 2.1). By choosing a radius much larger than 1/3 of that of the 1.3 GHz cavity, the cutoff frequency is lowered so that most higher order modes propagate amongst cavities and therefore are better damped.

Table 3.1: Values of p_{mn} and p'_{mn} [4, 10].

		p_{mn} (TM modes)			p'_{mn} (TE modes)		
	m	n=1	n=2	n=3	n=1	n=2	n=3
monopole	0	**2.405**	5.520	8.654	3.832	7.016	10.174
dipole	1	3.832	7.016	10.174	**1.841**	5.331	8.536
quadrupole	2	5.136	8.417	11.620	3.054	6.706	9.970
sextupole	3	6.380	9.761	13.015	4.201	8.015	11.346

Table 3.2: Cutoff frequencies for the lowest order of TE and TM modes in a circular waveguide with a radius of 15 mm and 20 mm.

	a=15 mm	**a**=20 mm
$f_{c_{11}}^{TE}$ (GHz)	5.86	4.39
$f_{c_{01}}^{TM}$ (GHz)	7.65	5.74

Chapter 4

Eigenmodes in the Ideal Third Harmonic Cavities

The geometry of an ideal third harmonic cavity without couplers as modeled with CST Microwave Studio®[9] is shown in Fig. 4.1. The shape of an individual mid-cell is shown in Fig. 2.2(a) and the parameters are listed in Table 2.1. The end-cups have an increased iris radius (20 mm) and are connected with beam pipes at both ends. The simulations were conducted with the Eigenmode Solver of the CST Microwave Studio®. A solver accuracy of 10^{-6} in terms of the eigensystem's relative residual was used. The cavity geometry was approximated by hexahedral mesh cells. As shown in Fig. 4.2, the mesh lines were chosen such that the iris radius and the equator radius were exactly matched by mesh lines. A quarter of the structure with symmetry planes was used in order to reduce the simulation time. For the accelerating mode, a maximum mesh step of 1.1 mm, corresponding to approximately 2.1 million mesh cells for a quarter of the structure, was used. Electric (EE) boundary conditions were used.

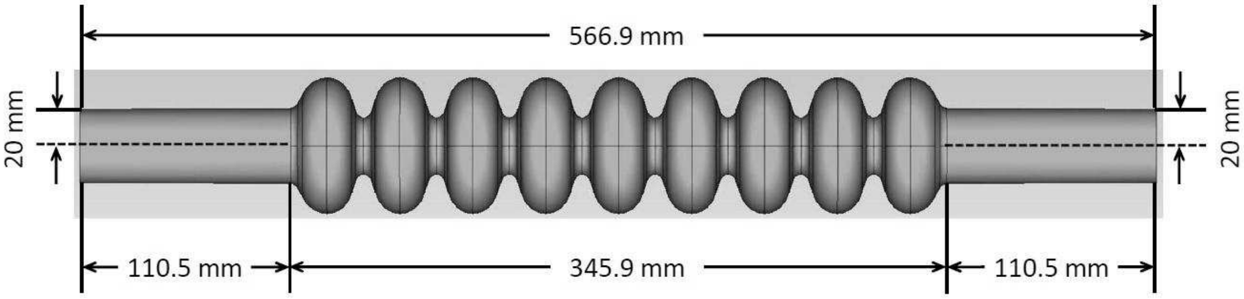


Figure 4.1: CST Microwave Studio® generated geometry of the third harmonic cavity.

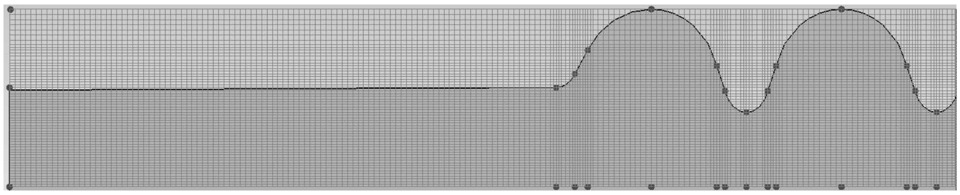


Figure 4.2: A typical mesh used for selected cells in the third harmonic cavity.

The electric field for the accelerating mode (3.9 GHz) is shown in Fig. 4.3(a)(b). The R/Q is defined in [4] and the unit is [Ω/cm^2 per cavity] throughout this report, while the "per cavity" is often omitted. The longitudinal component of the electric field of the accelerating mode on the axis of the third harmonic cavity is shown in Fig. 4.3(c). A good field flatness can be observed.

The phase advance per cell can be calculated using the electric field determined from the simulations. Based on Eq. 2.1 for periodic structures, the phase advance per cell can be derived as

$$E_M = E_z(r, z), \tag{4.1}$$

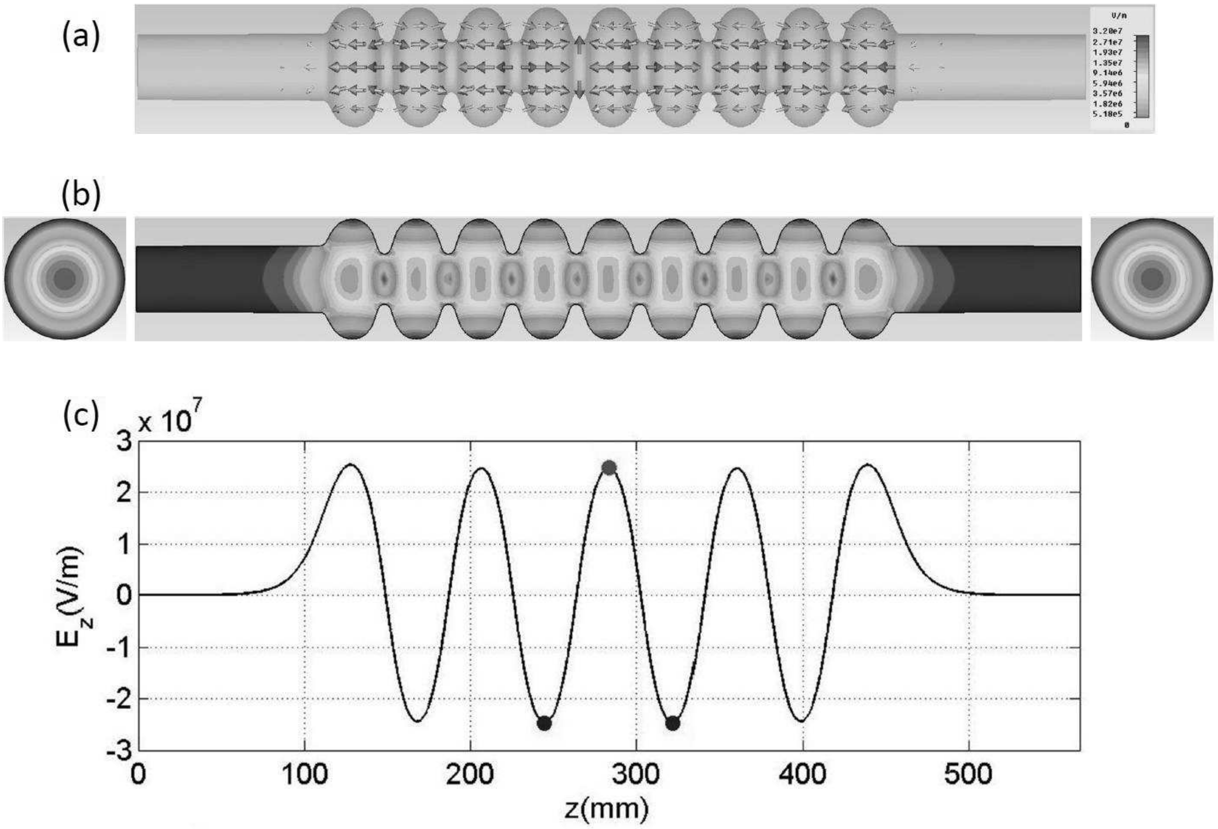


Figure 4.3: (a) The electric field (arrows) of the accelerating mode (3.9 GHz) in the third harmonic cavity. (b) The electric field magnitude of the accelerating mode (frequency: 3.9008 GHz, R/Q: 373.113 Ω). Electric (EE) boundary conditions were used in the simulation. (c) Longitudinal electric field E_z of the accelerating mode (3.9 GHz, π mode) on the axis of a third harmonic cavity. The red and blue dots are corresponding to the position marked in Fig. 4.4 for E_L, E_M and E_R respectively.

$$E_L = E_M e^{-i\phi} = E_z(r, z - L), \tag{4.2}$$

$$E_R = E_M e^{i\phi} = E_z(r, z + L), \tag{4.3}$$

$$E_L + E_R = 2E_M cos(\phi), \tag{4.4}$$

where $E_z(r, z)$ is the longitudinal electric field obtained from the simulations, E_L, E_M and E_R are defined as shown in Fig. 4.4. Then the phase advance per cell can be calculated as

$$\phi = arccos(\frac{E_L + E_R}{2E_M}). \tag{4.5}$$

The phase advance per cell calculated for the accelerating mode is 177 degrees. This reflects the field flattness that is adjusted by the geometry of the end-cells.

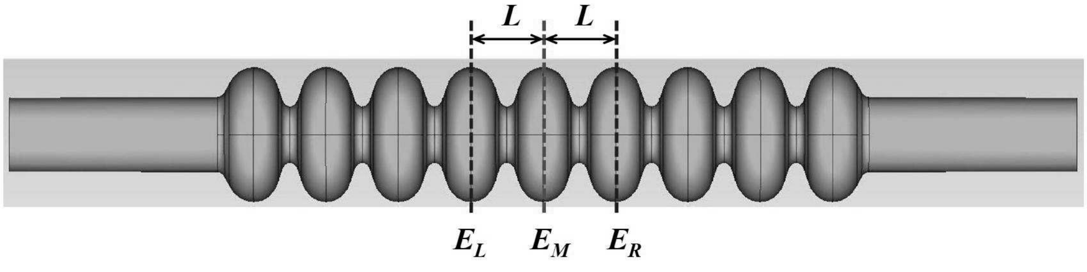
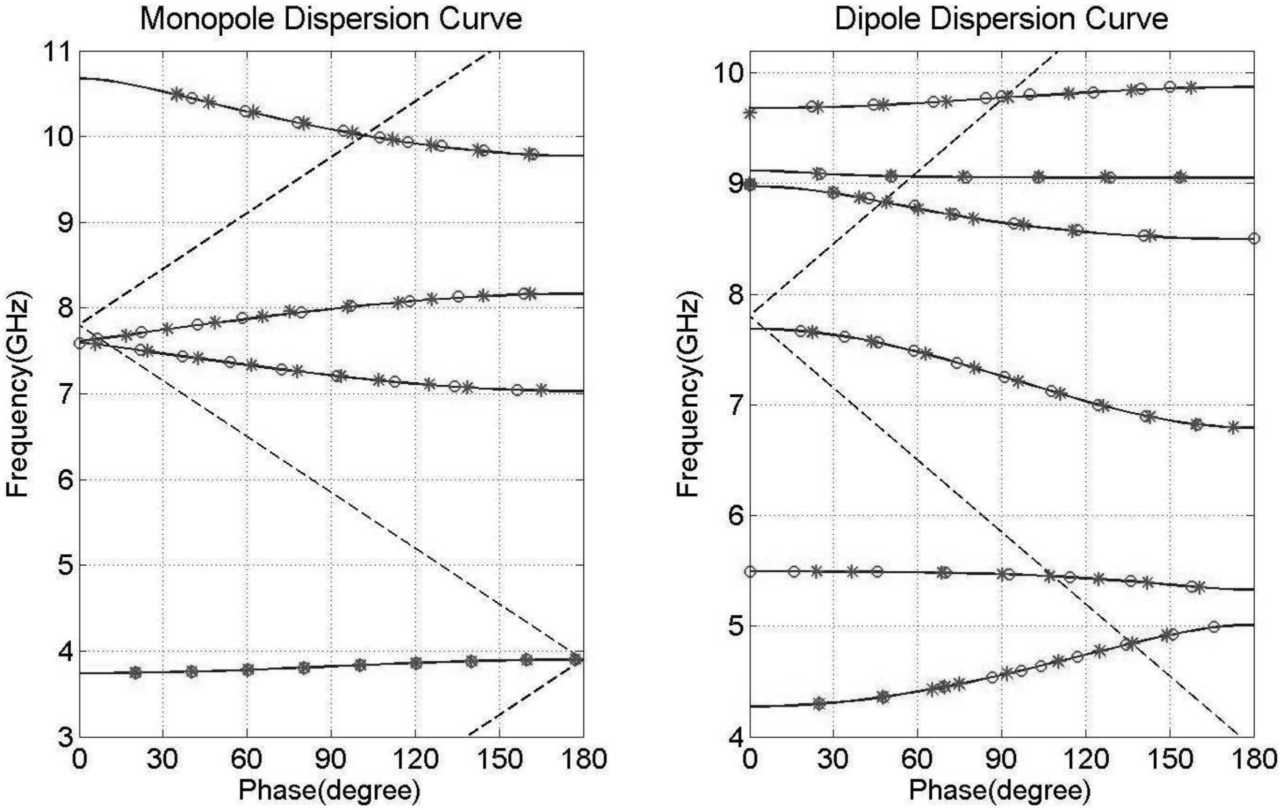
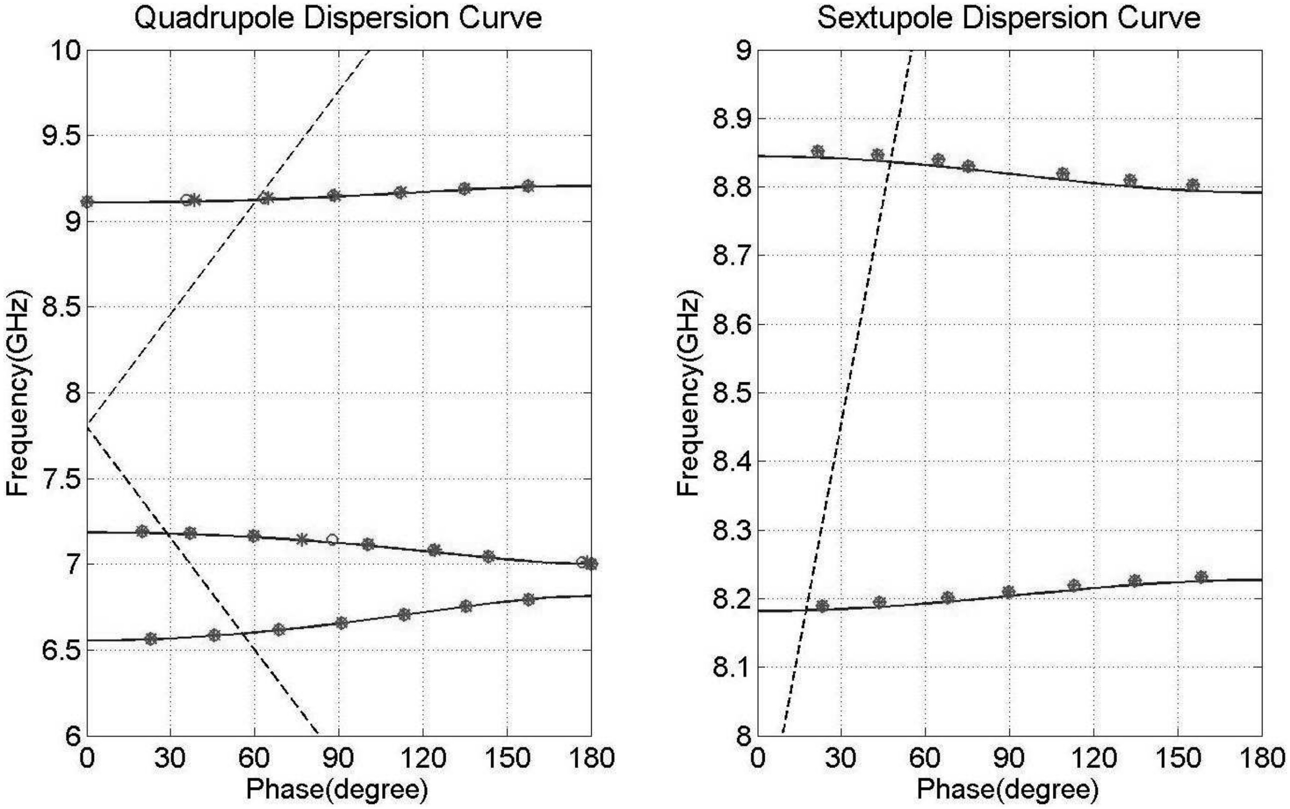


Figure 4.4: Calculation of the phase advance per cell. E_L, E_M and E_R are longitudinal electric field at certain positions.

Eq. 4.5 has been used to calculate the phase advance per cell for all modes which have been simulated. The results for monopole, dipole, quadrupole and sextupole bands are shown in Fig. 4.5 along with dispersion curves of the mid-cell presented in Section 2. Results of both electric (EE) and magnetic (MM) boundary conditions are presented. The frequencies of the first monopole passband are below the cutoff frequency of the beam pipe (see Table 3.2), therefore modes in this band do not depend on the boundary conditions. This can be seen in Fig. 4.5(a) as the overlap of asterisks and circles. Some dipole modes in the fifth dipole band and the first two modes in the first dipole band are trapped within the cavity, which explains the consistency of results from EE and MM boundary conditions in Fig. 4.5(b). Large deviations for different boundary conditions can be clearly seen in other dipole bands as they are propagating among cavities. Fig. 4.6–4.9 show the R/Q value versus the frequency of each mode for both EE and MM boundary conditions. The coupling strengths for all HOMs beyond the fundamental passband are shown in Fig. 4.10 and Fig. 4.11.



(a) Monopole (b) Dipole



(c) Quadrupole (d) Sextupole

Figure 4.5: Monopole, dipole, quadrupole and sextupole band structure (blue) of a mid-cell and the modes in an ideal 9-cell 3.9 GHz cavity. The circles represent the modes calculated with electric (EE) boundary conditions and the asterisks represent magnetic (MM) boundary conditions. The light line is dashed.

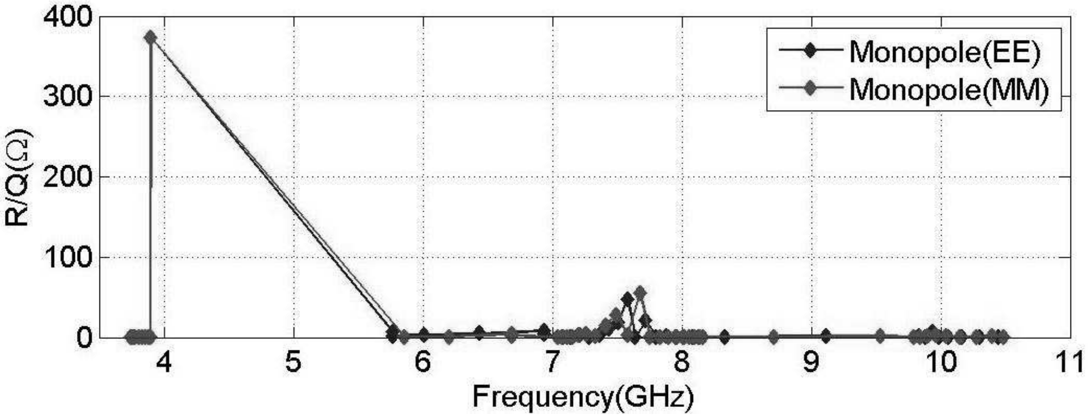


Figure 4.6: The R/Q parameter for monopole modes of a 9-cell third harmonic cavity plotted versus the frequency of the mode. The circles in blue represent the modes calculated with electric (EE) boundary conditions and the asterisks in red represent magnetic (MM) boundary conditions.

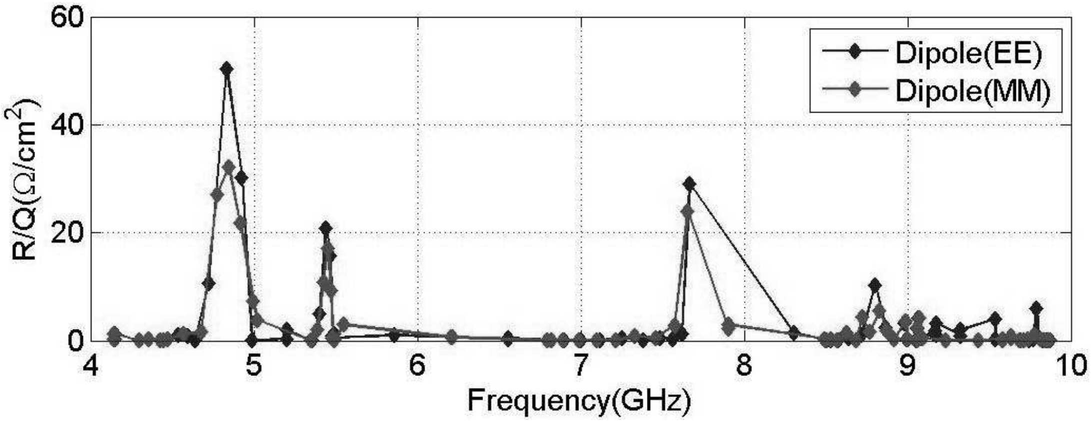


Figure 4.7: The R/Q parameter for dipole modes of a 9-cell third harmonic cavity plotted versus the frequency of the mode. The circles in blue represent the modes calculated with electric (EE) boundary conditions and the asterisks in red represent magnetic (MM) boundary conditions.

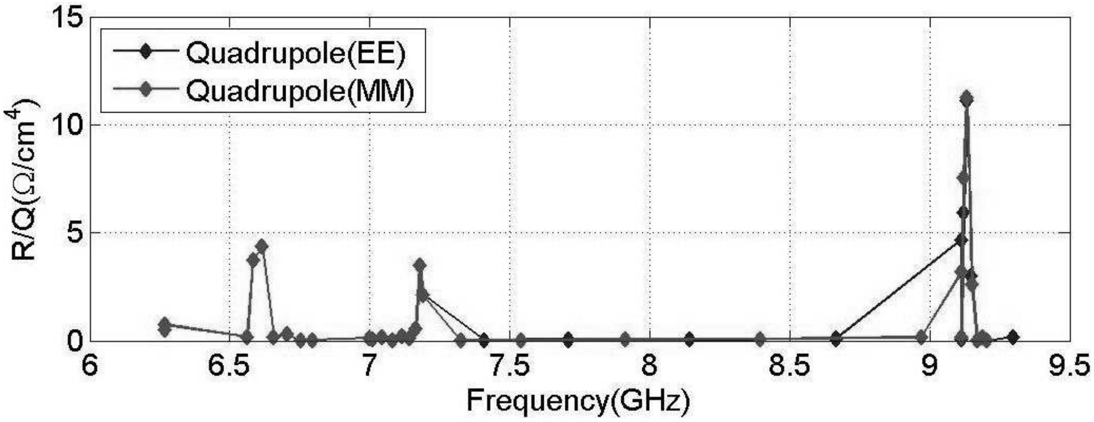


Figure 4.8: The R/Q parameter for quadrupole modes of a 9-cell third harmonic cavity plotted versus the frequency of the mode. The circles in blue represent the modes calculated with electric (EE) boundary conditions and the asterisks in red represent magnetic (MM) boundary conditions.

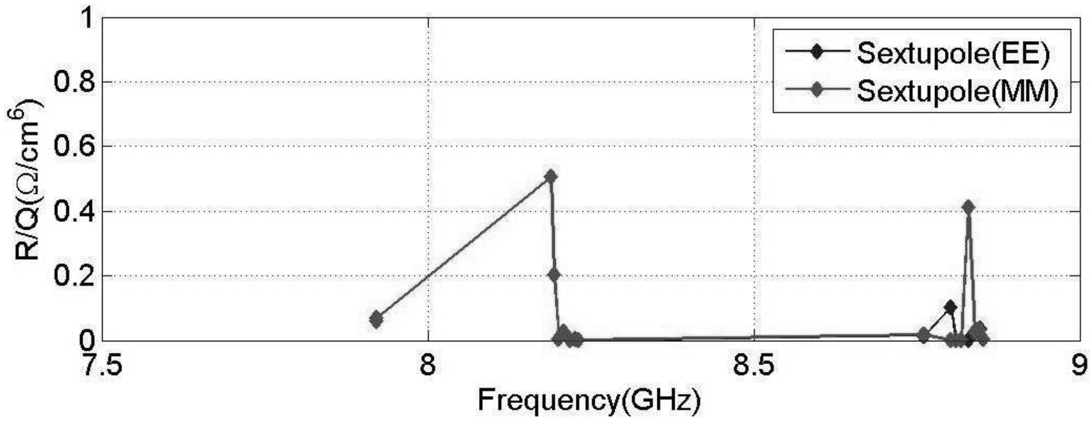


Figure 4.9: The R/Q parameter for sextupole modes of a 9-cell third harmonic cavity plotted versus the frequency of the mode. The circles in blue represent the modes calculated with electric (EE) boundary conditions and the asterisks in red represent magnetic (MM) boundary conditions.

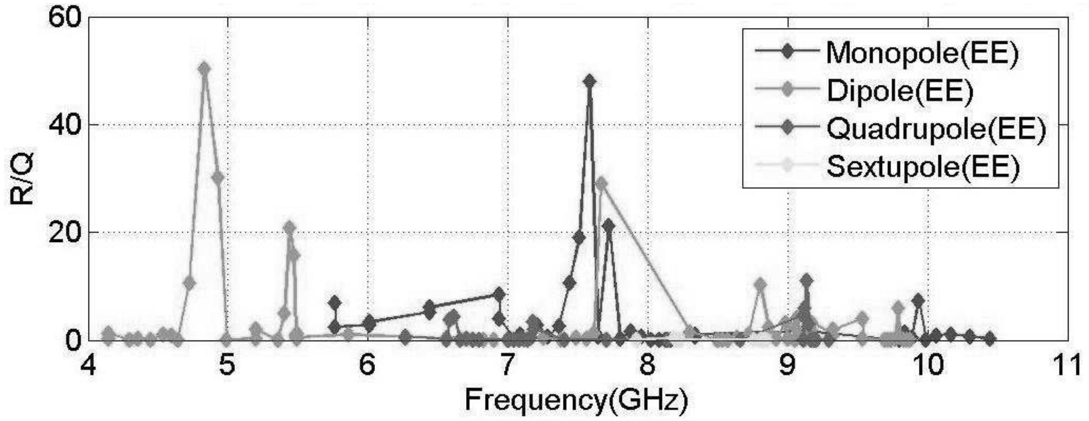


Figure 4.10: The R/Q parameter for HOMs except the fundamental modes of a 9-cell third harmonic cavity plotted versus the frequency of the mode. The modes were calculated with electric (EE) boundary conditions. The units of the R/Q parameter are: Ω (monopole), Ω/cm^2 (dipole), Ω/cm^4 (quadrupole) and Ω/cm^6 (sextupole).

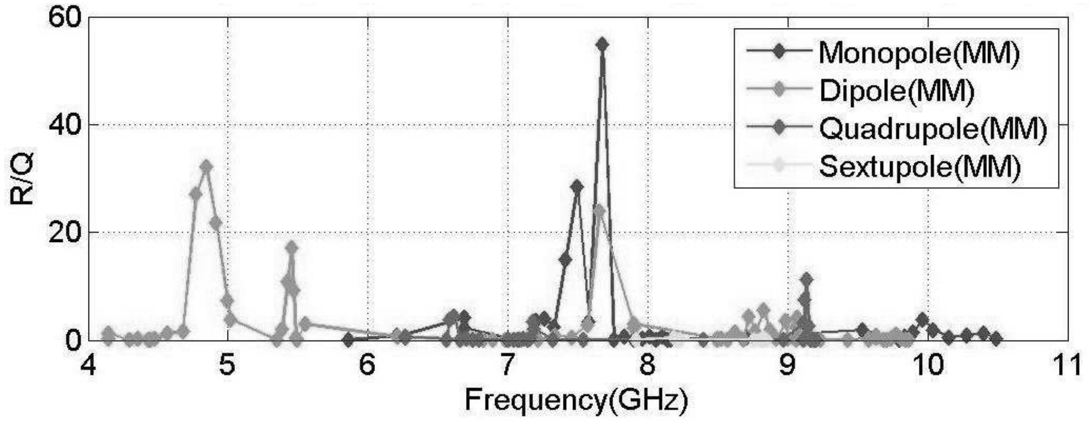


Figure 4.11: The R/Q parameter for HOMs except the fundamental modes of a 9-cell third harmonic cavity plotted versus the frequency of the mode. The modes were calculated with magnetic (MM) boundary conditions. The units of the R/Q parameter are: Ω (monopole), Ω/cm^2 (dipole), Ω/cm^4 (quadrupole) and Ω/cm^6 (sextupole).

Beside the cavity modes shown in the passbands, there are also beam-pipe modes, whose electromagnetic energy mainly deposits in the beam pipes and the end-cells of the cavity. These modes are trapped within both beam-pipe ends of the structure. One of these modes is shown in Fig. 4.12 and Fig. 4.13. The dipole character of this mode can be seen clearly in the projection on the transverse plane in the middle plane of each end-cell.

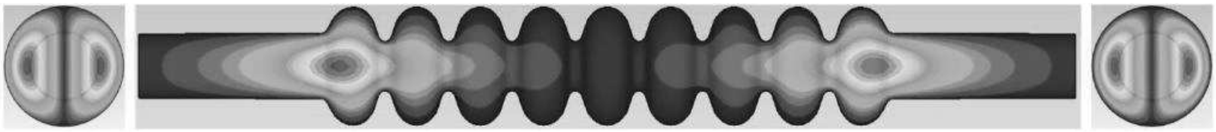


Figure 4.12: The electric field distribution of one dipole beam-pipe mode (frequency: 4.1491 GHz, R/Q: 1.318 Ω/cm^2). Electric (EE) boundary conditions were used in the simulation.

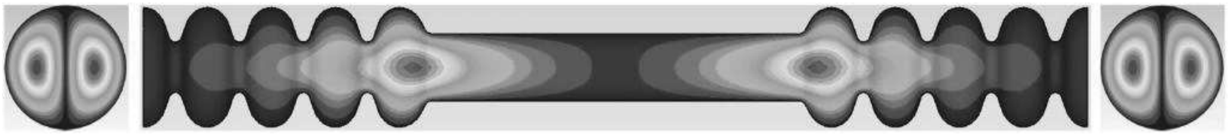


Figure 4.13: The electric field distribution of one dipole beam-pipe mode (frequency: 4.1481 GHz, R/Q: 1.544 Ω/cm^2). Electric (EE) boundary conditions were used in the simulation.

The propagating feature of one dipole cavity mode can be seen in Fig. 4.14 and Fig. 4.15. The mode can couple to adjacent cavities through the attached beam pipes, and has a strong coupling to the beam represented by the large R/Q value.

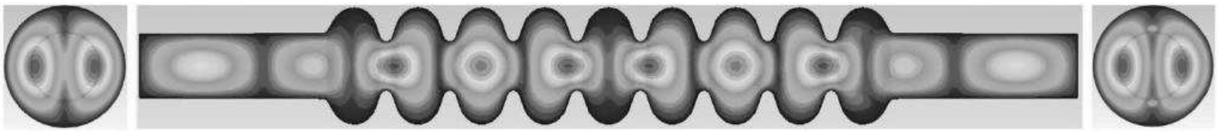


Figure 4.14: The electric field distribution of one cavity mode from the first dipole band (frequency: 4.8327 GHz, R/Q: 50.307 Ω/cm^2). Electric (EE) boundary conditions were used in the simulation.

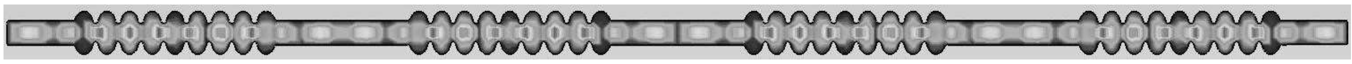


Figure 4.15: The electric field distribution of strongest coupled cavity mode from the first dipole band (frequency: 4.8076 GHz, R/Q: 125.762 Ω/cm^2 per module). Electric (EE) boundary conditions were used in the simulation.

One trapped cavity mode from the fifth dipole band is shown in Fig. 4.16. Compared with other trapped modes in this band, this mode has stronger coupling to the beam (larger R/Q value).

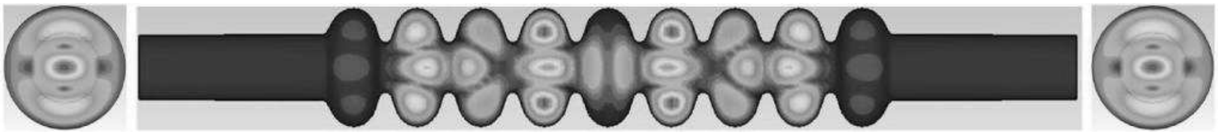


Figure 4.16: The electric field distribution of one cavity mode from the fifth dipole band (frequency: 9.0581 GHz, R/Q: 2.171 Ω/cm^2). Electric (EE) boundary conditions were used in the simulation.

One quadrupole mode and one sextupole mode are also shown in Fig. 4.17 and Fig. 4.18. The R/Q values are in general small for these modes.

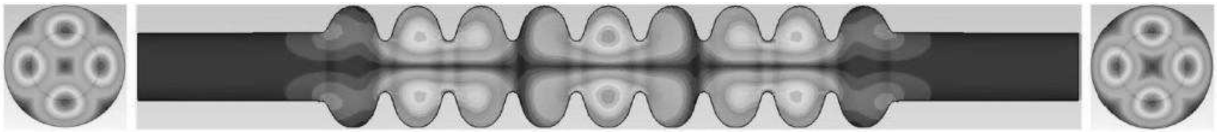


Figure 4.17: The electric field distribution of one cavity mode from the first quadrupole band (frequency: 6.6167 GHz, R/Q: 4.358 Ω/cm^4). Electric (EE) boundary conditions were used in the simulation.

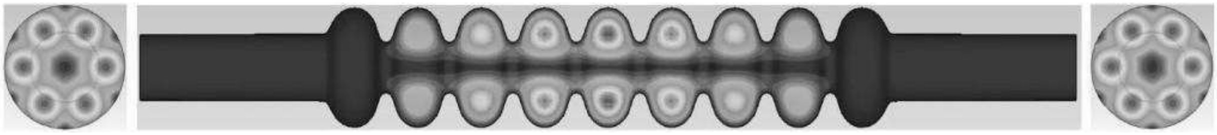
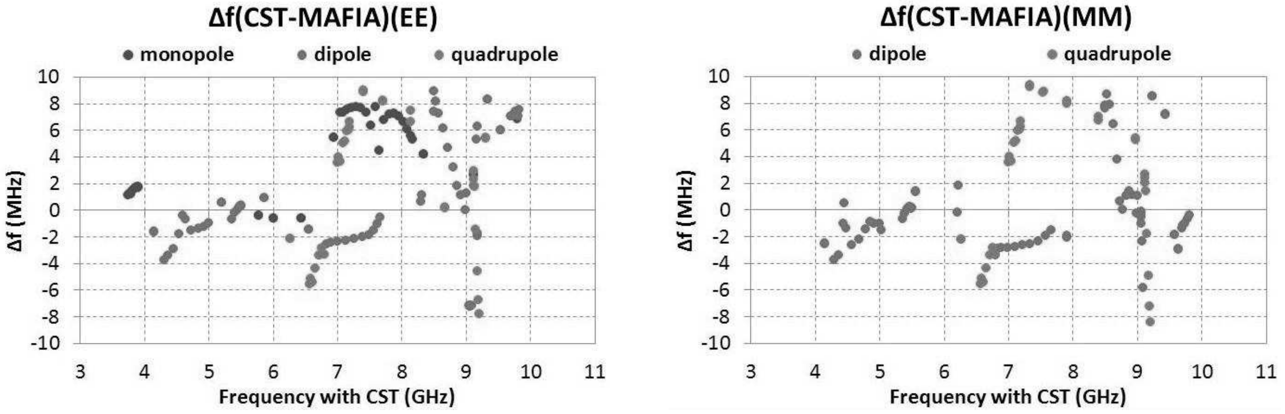


Figure 4.18: The electric field distribution of one cavity mode from the first sextupole band (frequency: 8.1894 GHz, R/Q: 0.506 Ω/cm^6). Electric (EE) boundary conditions were used in the simulation.

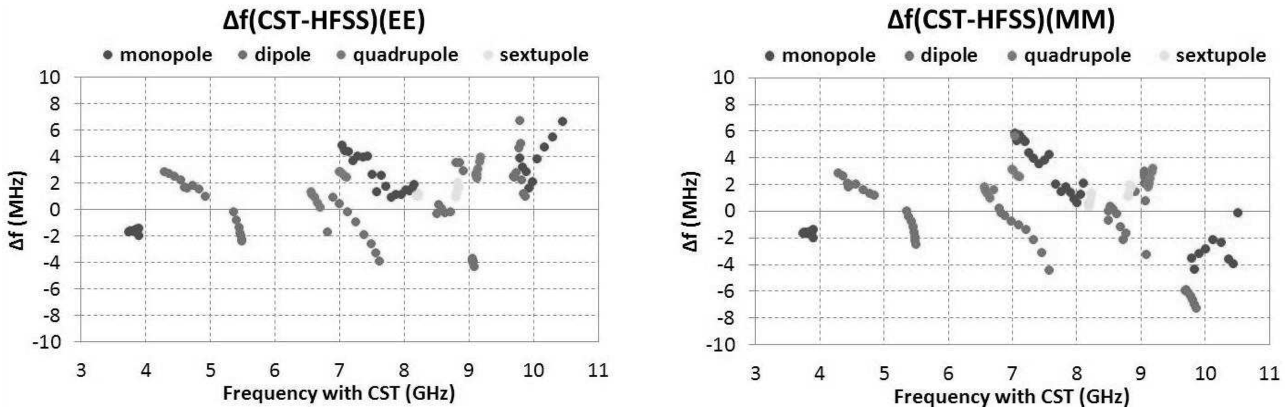
Compared to the simulations using MAFIA® [11] with eigenvalue solver and HFSS® [12] with eigenmode solver, the frequencies of the modes are shifted. A direct comparison between CST® and MAFIA® is shown in Fig. 4.19, while a comparison between CST® and HFSS® is shown in Fig. 4.20. The MAFIA® simulation results are from [13] while the HFSS® simulations are from [14]. The differences are within 10 MHz for both boundary conditions from both simulation codes.



(a) Electric (EE) boudary conditions

(b) Magnetic (MM) boudary conditions

Figure 4.19: Frequency differences of modes simulated with CST® and MAFIA®. Δf is calculated as $\Delta f = f_{CST} - f_{MAFIA}$.



(a) Electric (EE) boudary conditions

(b) Magnetic (EE) boudary conditions

Figure 4.20: Frequency differences of modes simulated with CST® and HFSS®. Δf is calculated as $\Delta f = f_{CST} - f_{HFSS}$.

Chapter 5

Summary

The passband structure of the third harmonic superconducting cavity has been studied. The monopole, dipole, quadrupole and sextupole modes have been simulated with the CST Microwave Studio®. The results of the cavity mid-cell have been related to the nine-cell results and the consistency has been observed. The intention of this report is to provide a guide for the electromagnetic mode distributions of the third harmonic cavity at FLASH and for the European XFEL.

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Appendix A

List of Monopole, Dipole, Quadrupole and Sextupole Modes

The frequencies and $R/Q's$ of the eigenmodes simulated on the ideal 9-cell third harmonic cavity are shown in this section. The modes are grouped in bands: "M" denotes monopole, "M1" denotes the first monopole band, "M1-1" denotes the first mode in M1, "D" denotes dipole, "Q" denotes quadrupole and "S" denotes sextupole. Beam-pipe modes in each table are denoted as "BP".

Table A.1: Monopole modes with electric (EE) or magnetic (MM) boundaries (part 1).

	EE		MM	
Band	**f**(GHz)	**R/Q**(Ω/cm^2)	**f**(GHz)	**R/Q**(Ω/cm^2)
M1-1	3.7466	0.008	3.7466	0.008
M1-2	3.7601	0.061	3.7601	0.061
M1-3	3.7808	0.090	3.7808	0.090
M1-4	3.8065	0.170	3.8065	0.170
M1-5	3.8340	0.307	3.8341	0.309
M1-6	3.8602	0.203	3.8602	0.204
M1-7	3.8817	0.468	3.8817	0.481
M1-8	3.8958	0.195	3.8958	0.197
M1-9	3.9008	373.113	3.9008	373.097
BP1-1	5.7685	6.967	5.8624	0.051
BP1-2	5.7685	2.443	5.8624	0.051
BP2-1	6.0123	2.867	6.2095	0.879
BP2-2	6.0123	3.335	6.2095	0.665
BP3-1	6.4403	5.212	6.6886	4.119
BP3-2	6.4403	6.116	6.6886	2.302
BP4-1	6.9393	8.454		
BP4-2	6.9394	3.971		
M2-1	7.0483	0.127	7.0449	0.007
M2-2	7.0863	1.012	7.0738	0.034
M2-3	7.1424	0.088	7.1145	0.342
M2-4	7.2113	2.914	7.1589	0.224
M2-5	7.2877	0.677	7.2058	3.534
M2-6	7.3662	2.727	7.2625	4.008
M2-7	7.4418	10.686	7.3331	2.417
M2-8	7.5118	18.963	7.4140	14.981
M2-9	7.5843	47.909	7.4995	28.455
M2-10			7.5810	3.471

Table A.2: Monopole modes with electric (EE) or magnetic (MM) boundaries (part 2).

	EE		MM	
Band	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\mathrm{cm}^2)$	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\mathrm{cm}^2)$
M3-1	7.6443	0.593	7.6780	54.835
M3-2	7.7248	21.212	7.7577	0.095
M3-3	7.8036	0.245	7.8333	0.619
M3-4	7.8809	1.707	7.9021	0.000
M3-5	7.9547	0.640	7.9625	0.275
M3-6	8.0229	0.015	8.0148	0.756
M3-7	8.0829	0.113	8.0615	0.117
M3-8	8.1311	0.014	8.1044	0.755
M3-9	8.1631	0.001	8.1408	0.002
M3-10			8.1656	0.078
BP5-1	8.3376	0.765	8.7111	0.521
BP5-2	8.3376	1.045	8.7113	0.525
BP6-1	9.1202	1.670	9.5377	1.912
BP6-2	9.1202	1.755	9.5378	1.945
M4-1	9.7966	0.000	9.7907	0.000
M4-2	9.8340	1.511	9.8379	0.072
M4-3	9.8868	0.395	9.9124	0.360
M4-4	9.9384	7.388	10.0099	5.067
M4-5	9.9886	0.015	10.1270	0.264
M4-6	10.0619	0.921	10.2547	0.723
M4-7	10.1692	1.125	10.3692	2.342
M4-8	10.3015	0.778	10.4406	0.312
M4-9	10.4485	0.277	10.5080	0.719

Table A.3: Dipole modes with electric (EE) or magnetic (MM) boundaries (part 1).

	EE		MM	
Band	$\mathbf{f}$(GHz)	$\mathbf{R/Q}$(Ω/cm^2)	$\mathbf{f}$(GHz)	$\mathbf{R/Q}$(Ω/cm^2)
BP1-1	4.1489	0.234	4.1474	0.241
BP1-2	4.1491	1.318	4.1475	1.299
D1-1	4.2982	0.001	4.2979	0.001
D1-2	4.3607	0.292	4.3592	0.263
D1-3	4.4485	0.002	4.4306	0.072
D1-4	4.5410	1.076	4.4516	0.000
D1-5	4.5989	0.784	4.4770	0.327
D1-6	4.6415	0.165	4.5703	1.213
D1-7	4.7245	10.572	4.6804	1.586
D1-8	4.8327	50.307	4.7749	27.165
D1-9	4.9270	30.174	4.8455	32.124
D1-10	4.9899	0.000	4.9162	21.833
BP2-1	5.2014	0.300	4.9945	7.376
BP2-2	5.2040	2.036	5.0233	3.844
D2-1	5.3581	0.041	5.3518	0.055
D2-2	5.4050	5.057	5.3923	2.114
D2-3	5.4427	20.877	5.4272	10.770
D2-4	5.4678	15.776	5.4528	17.024
D2-5	5.4829	0.895	5.4711	9.368
D2-6	5.4911	1.261	5.4834	0.409
D2-7	5.4950	0.307	5.4908	0.343
D2-8	5.4958	0.549	5.4944	0.033
BP3-1	5.8644	1.028	5.5532	2.994
BP3-2	5.8644	1.026	5.5532	2.995
BP4-1	6.5593	0.344	6.2123	0.595
BP4-2	6.5594	0.397	6.2144	0.636
D3-1	6.8238	0.011	6.7964	0.068
D3-2	6.9003	0.035	6.8242	0.068
D3-3	7.0027	0.058	6.8909	0.140
D3-4	7.1225	0.189	6.9880	0.124
D3-5	7.2541	0.549	7.0989	0.108
D3-6	7.3833	0.014	7.2140	0.020
D3-7	7.4889	0.455	7.3348	0.825
D3-8	7.5621	0.269	7.4598	0.503
D3-9	7.6196	1.354	7.5743	2.862
D3-10	7.6680	28.926	7.6566	23.875
BP5-1	8.3033	1.543	7.9033	2.155
BP5-2	8.3039	1.537	7.9034	2.961

Table A.4: Dipole modes with electric (EE) or magnetic (MM) boundaries (part 2).

	EE		MM	
Band	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\text{cm}^2)$	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\text{cm}^2)$
D4-1	8.5002	0.130	8.5292	0.365
D4-2	8.5042	0.096	8.5709	0.023
D4-3	8.5322	0.152	8.6273	1.457
D4-4	8.5763	0.115	8.6849	0.042
D4-5	8.6397	0.415	8.7257	4.392
D4-6	8.7205	1.038	8.7702	1.693
D4-7	8.8033	10.205	8.8301	5.577
D4-8	8.8648	2.470	8.8729	1.895
D4-9	8.9196	0.287	8.9196	0.281
D4-10	8.9857	3.258	8.9900	3.623
D4-11	8.9980	0.230	9.0011	0.302
D5-1	9.0523	0.002	9.0593	0.004
D5-2	9.0530	0.053	9.0599	0.058
D5-3	9.0546	0.058	9.0614	0.076
D5-4	9.0581	2.171	9.0645	2.377
D5-5	9.0664	4.116	9.0718	4.158
D5-6	9.0890	0.580	9.0918	0.452
BP6-1	9.1666	1.291	8.4964	0.340
BP6-2	9.1678	1.898	8.5008	0.056
BP7-1	9.1749	1.123	9.2324	0.158
BP7-2	9.1763	3.240	9.2325	0.092
BP8-1	9.3283	0.880	9.4325	0.105
BP8-2	9.3284	2.042	9.4330	0.020
BP9-1	9.5379	4.064	9.5809	0.342
BP9-2	9.5385	0.275	9.5818	0.015
BP10-1			9.6342	0.485
BP10-2			9.6346	0.848
D6-1	9.6962	0.001	9.6896	0.013
D6-2	9.7142	0.009	9.7103	0.025
D6-3	9.7421	0.074	9.7415	0.341
D6-4	9.7711	0.379	9.7776	1.133
D6-5	9.7896	5.951	9.8134	0.345
D6-6	9.8027	0.771	9.8440	0.008
D6-7	9.8265	0.191	9.8648	0.019

Table A.5: Quadrupole modes with electric (EE) or magnetic (MM) boundaries.

	EE		MM	
Band	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\mathrm{cm}^2)$	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\mathrm{cm}^2)$
BP1-1	6.2697	0.513	6.2697	0.513
BP1-2	6.2698	0.742	6.2697	0.742
Q1-1	6.5638	0.183	6.5638	0.183
Q1-2	6.5843	3.734	6.5843	3.734
Q1-3	6.6167	4.358	6.6167	4.359
Q1-4	6.6583	0.183	6.6583	0.183
Q1-5	6.7059	0.308	6.7059	0.307
Q1-6	6.7546	0.002	6.7546	0.002
Q1-7	6.7961	0.041	6.7961	0.041
Q2-1	7.0005	0.135	7.0005	0.135
Q2-2	7.0096	0.075	7.0096	0.075
Q2-3	7.0456	0.152	7.0456	0.151
Q2-4	7.0823	0.000	7.0823	0.000
Q2-5	7.1158	0.221	7.1157	0.220
Q2-6	7.1437	0.101	7.1436	0.103
Q2-7	7.1653	0.579	7.1653	0.578
Q2-8	7.1806	3.484	7.1806	3.483
Q2-9	7.1897	2.125	7.1897	2.125
BP2-1	7.4084	0.020	7.3248	0.008
BP2-2	7.4085	0.020	7.3249	0.008
BP3-1	7.7101	0.049	7.5397	0.030
BP3-2	7.7102	0.033	7.5398	0.030
BP4-1	8.1423	0.069	7.9134	0.052
BP4-2	8.1431	0.069	7.9136	0.054
BP5-1	8.6665	0.095	8.3961	0.086
BP5-2	8.6665	0.108	8.3964	0.085
Q3-1	9.1129	4.686	9.1147	3.176
Q3-2	9.1133	0.053	9.1155	0.147
Q3-3	9.1228	5.921	9.1232	7.555
Q3-4	9.1340	11.102	9.1344	11.244
Q3-5	9.1499	2.998	9.1501	2.608
Q3-6	9.1692	0.003	9.1692	0.021
Q3-7	9.1893	0.152	9.1890	0.152
Q3-8	9.2053	0.000	9.2048	0.001
BP6-1	9.2980	0.178	8.9709	0.167
BP6-2	9.2980	0.179	8.9711	0.166

Table A.6: Sextupole modes with electric (EE) or magnetic (MM) boundaries.

	EE		MM	
Band	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\mathrm{cm}^2)$	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\mathrm{cm}^2)$
BP1-1	7.9214	0.069	7.9212	0.060
BP1-2	7.9216	0.069	7.9215	0.068
S1-1	8.1894	0.506	8.1894	0.506
S1-2	8.1940	0.203	8.1940	0.203
S1-3	8.2011	0.006	8.2011	0.006
S1-4	8.2097	0.027	8.2097	0.027
S1-5	8.2184	0.001	8.2184	0.001
S1-6	8.2261	0.005	8.2261	0.005
S1-7	8.2313	0.000	8.2313	0.000
BP2-1	8.7611	0.015	8.7612	0.018
BP2-2	8.7614	0.013	8.7615	0.017
S2-1	8.8029	0.103	8.8029	0.000
S2-2	8.8097	0.001	8.8097	0.001
S2-3	8.8192	0.003	8.8191	0.002
S2-4	8.8295	0.001	8.8294	0.412
S2-5	8.8392	0.024	8.8391	0.028
S2-6	8.8469	0.036	8.8468	0.035
S2-7	8.8519	0.004	8.8519	0.004

Appendix B

Parameter Settings used for Simulations

The key parameters set in CST Microwave studio® for the eigenmode simulations shown in Appendix A are described in this section. In the"Mesh Type" column, "PBA" denotes "perfect boundary approximation" while "FPBA" denotes "fast PBA" with "Enhanced PBA accuracy". The choice between "PBA" and "FPBA" is based on one principle in this study: "FPBA" was used only if "PBA" failed to generate a valid mesh. A comparison of performance between "PBA" and "FPBA" is discussed in [15]. In the "Mesh cells (million)" column, the number of mesh cells is for a quarter of the structure. The naming in the "Band" column follows the convention explained in Appendix A.

Table B.1: Parameters setting for monopole and quadrupole modes with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Mesh cells** (million)	**Max mesh step** (mm)	**Band**
3.7-3.95	70	PBA	2.1	1.10	M1
5.7-5.8	50	PBA	2.4	1.07	MBP1
5.95-6.05	50	PBA	2.6	1.03	MBP2
6.2-6.3	45	PBA	2.2	1.08	QBP1
6.4-6.5	45	PBA	2.4	1.04	MBP3
6.5-6.8	40	PBA	2.0	1.11	Q1
6.85-7.6	25	FPBA	1.4	0.91	MBP4, M2(1-7), Q2, QBP2
7.5-8.25	20	FPBA	1.1	1.06	M2(8-9), M3, QBP3, QBP4
8.25-8.35	20	FPBA	1.1	0.94	MBP5
8.6-8.7	20	PBA	1.2	0.94	QBP5
8.9-9.35	24	FPBA	2.3	0.82	MBP6, Q3, QBP6
9.7-10.5	20	FPBA	2.0	0.87	M4

Table B.2: Parameter setting for monopole and quadrupole modes with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Mesh cells** (million)	**Max mesh step** (mm)	**Band**
3.7-4.0	70	PBA	2.2	1.10	M1
5.7-5.9	50	PBA	2.5	1.04	MBP1
6.0-6.4	45	PBA	2.3	1.07	MBP2, QBP1
6.4-6.8	40	PBA	2.0	1.11	MBP3, Q1
6.8-7.6	25	FPBA	1.4	0.91	M2, Q2, QBP2, QBP3
7.6-8.4	20	FPBA	1.1	0.94	M3, QBP4
8.2-8.4	20	FPBA	1.1	0.94	QBP5
8.4-8.85	20	FPBA	1.3	0.94	MBP5
8.85-9.3	20	FPBA	1.4	0.91	QBP6, Q3
9.3-9.6	20	FPBA	1.5	0.87	MBP6
9.7-10.0	20	PBA	1.8	0.87	M4(1-3)
10.0-10.6	20	PBA	2.0	0.87	M4(4-9)

Table B.3: Parameters setting for dipole and sextupole modes with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Mesh cells** (million)	**Max mesh step** (mm)	**Band**
4.1-4.2	70	PBA	2.4	1.04	DBP1
4.25-5.05	60	PBA	2.6	1.03	D1(1-9)
4.95-5.3	45	PBA	1.5	1.29	D1(10), DBP2
5.3-5.6	50	PBA	2.2	1.10	D2
5.8-5.9	45	PBA	2.0	1.18	DBP3
6.5-6.6	40	PBA	1.9	1.18	DBP4
6.75-7.7	40	PBA	3.0	0.99	D3
7.7-8.1	20	FPBA	1.0	1.06	SBP1
8.1-8.3	20	FPBA	1.1	0.94	S1
8.2-8.4	20	FPBA	1.1	0.94	DBP5
8.45-8.55	25	FPBA	2.0	0.87	D4(1)
8.4-9.05	20	FPBA	1.3	0.91	D4(2-11), SBP2, S2
9.05-9.095	20	PBA	1.3	0.91	D5
9.1-9.2	20	FPBA	1.3	0.91	DBP6, DBP7
9.2-9.4	20	FPBA	1.4	0.91	DBP8
9.4-9.6	20	FPBA	1.5	0.87	DBP9
9.6-9.9	20	FPBA	1.7	0.87	D6

Table B.4: Parameters setting for dipole and sextupole modes with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Mesh cells** (million)	**Max mesh step** (mm)	**Band**
4.1-4.2	70	PBA	2.4	1.04	DBP1
4.25-5.05	55	PBA	2.1	1.10	D1, DBP2
5.3-5.7	50	PBA	2.3	1.07	D2, DBP3
6.1-6.3	40	PBA	1.7	1.21	DBP4
6.75-7.50	40	PBA	3.0	0.99	D3
7.7-8.0	20	FPBA	1.0	1.06	SBP1
7.85-7.95	22	PBA	1.2	0.94	DBP5
8.0-8.3	20	FPBA	1.1	0.94	S1
8.4-9.0	20	FPBA	1.3	0.91	DBP6, D4(1-9), SBP2, S2
8.95-9.05	20	FPBA	1.3	0.91	D4(10-11)
9.05-9.1	16	FPBA	0.8	1.08	D5
9.1-9.3	20	FPBA	1.4	0.91	DBP7
9.3-9.5	20	FPBA	1.4	0.91	DBP8
9.5-9.6	20	FPBA	1.5	0.87	DBP9
9.6-9.9	20	PBA	1.7	0.87	DBP10, D6

Appendix C

Electric Field Distributions of Modes

Tables of parameter settings shown in this chapter are from Appendix B.

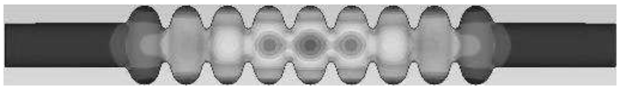
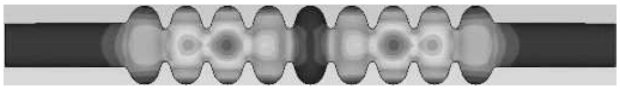
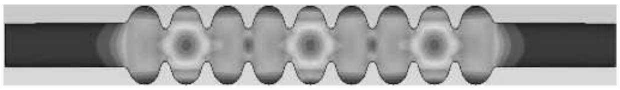
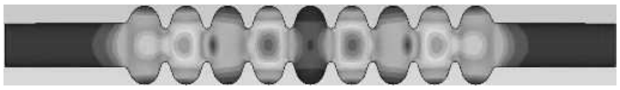
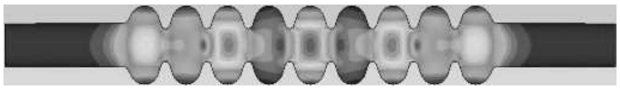
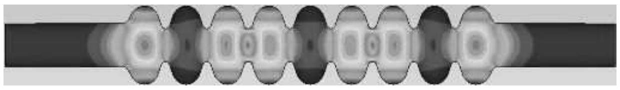
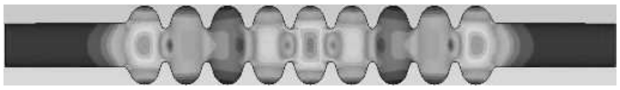
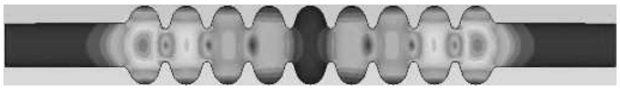
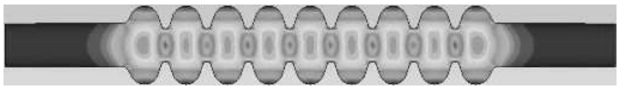
I Monopole (Electric Boundaries)

I.1 M1 (EE)

Table C.1: Parameters settings for M1 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
3.70-3.95	70	PBA	2,100,000	1.10	M1

Table C.2: Monopole modes in M1 with electric (EE) boundaries.

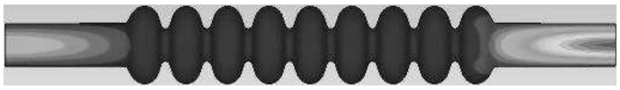
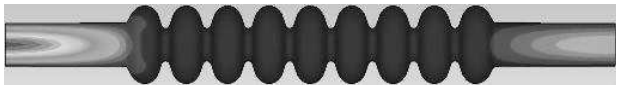
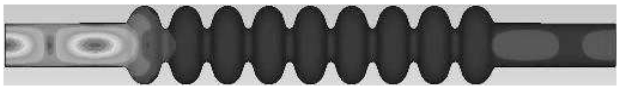
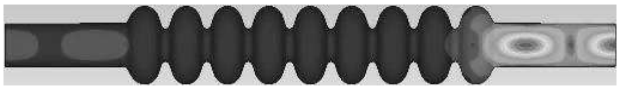
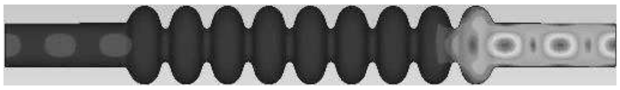
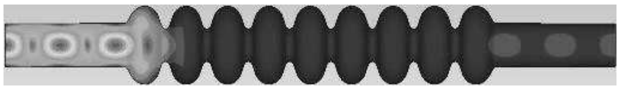
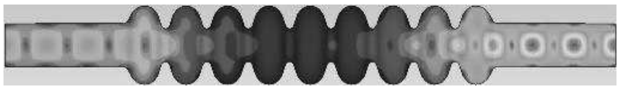
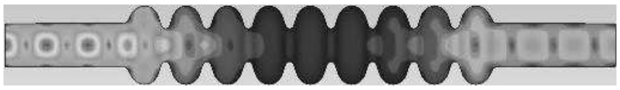
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	3.7466	0.008	M1-1
	3.7601	0.061	M1-2
	3.7808	0.090	M1-3
	3.8065	0.170	M1-4
	3.8340	0.307	M1-5
	3.8602	0.203	M1-6
	3.8817	0.468	M1-7
	3.8958	0.195	M1-8
	3.9008	373.113	M1-9

I.2 MBP1, MBP2, MBP3 and MBP4 (EE)

Table C.3: Parameters settings for MBP1, MBP2, MBP3 and MBP4 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
5.7-5.8	50	PBA	2,400,000	1.07	MBP1
5.95-6.05	50	PBA	2,600,000	1.03	MBP2
6.4-6.5	45	PBA	2,400,000	1.04	MBP3
6.85-7.60	25	FPBA	1,400,000	0.91	MBP4

Table C.4: Monopole modes in MBP1, MBP2, MBP3 and MBP4 with electric (EE) boundaries.

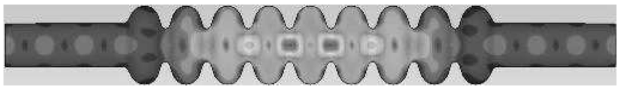
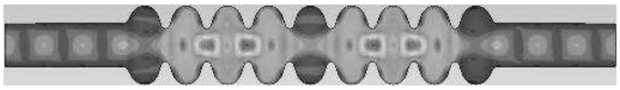
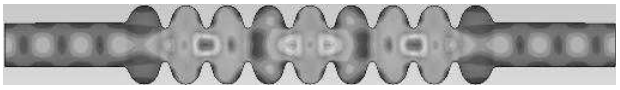
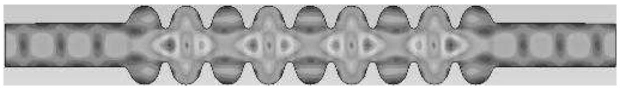
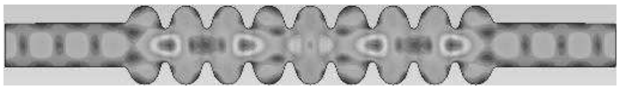
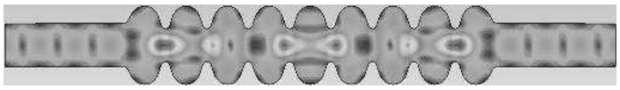
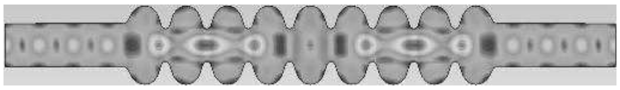
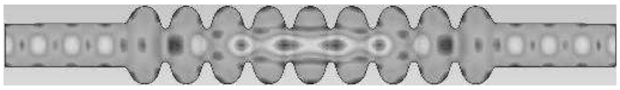
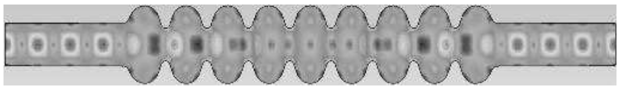
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	5.7685	6.967	MBP1-1
	5.7685	2.443	MBP1-2
	6.0123	2.867	MBP2-1
	6.0123	3.335	MBP2-2
	6.4403	5.212	MBP3-1
	6.4403	6.116	MBP3-2
	6.9393	8.454	MBP4-1
	6.9394	3.971	MBP4-2

I.3 M2 (EE)

Table C.5: Parameters settings for M2 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.85-7.6	25	FPBA	1,400,000	0.91	M2(1-7)
7.5-8.25	20	FPBA	1,100,000	1.06	M2(8-9)

Table C.6: Monopole modes in M2 with electric (EE) boundaries.

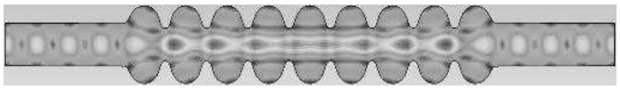
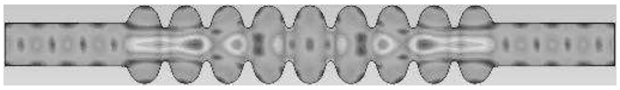
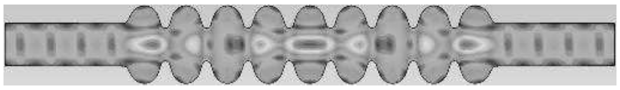
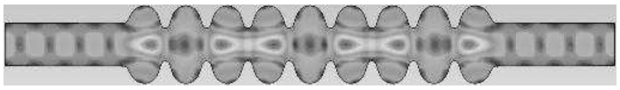
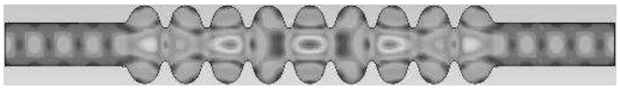
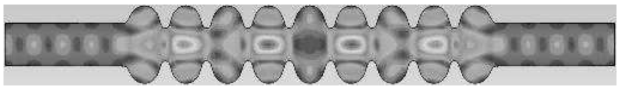
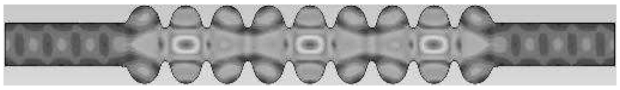
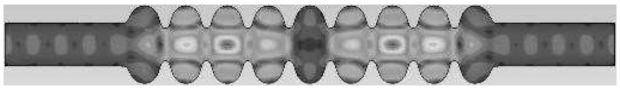
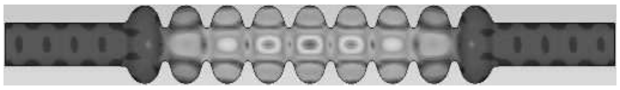
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.0483	0.127	M2-1
	7.0863	1.012	M2-2
	7.1424	0.088	M2-3
	7.2113	2.914	M2-4
	7.2877	0.677	M2-5
	7.3662	2.727	M2-6
	7.4418	10.686	M2-7
	7.5118	18.963	M2-8
	7.5843	47.909	M2-9

I.4 M3 (EE)

Table C.7: Parameters settings for M3 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
7.50-8.25	20	FPBA	1,100,000	1.06	M3

Table C.8: Monopole modes in M3 with electric (EE) boundaries.

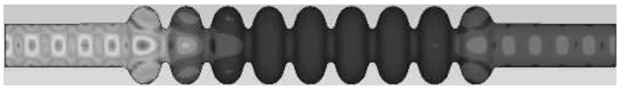
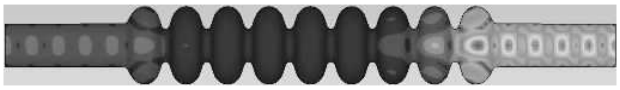
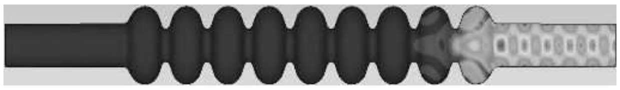
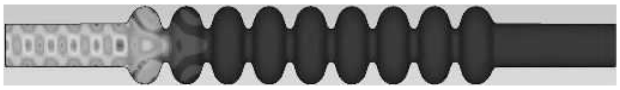
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.6443	0.593	M3-1
	7.7248	21.212	M3-2
	7.8036	0.245	M3-3
	7.8809	1.707	M3-4
	7.9547	0.640	M3-5
	8.0229	0.015	M3-6
	8.0829	0.113	M3-7
	8.1311	0.014	M3-8
	8.1631	0.001	M3-9

I.5 MBP5 and MBP6 (EE)

Table C.9: Parameters settings for MBP5 and MBP6 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.25-8.35	20	FPBA	1,100,000	0.94	MBP5
8.9-9.35	24	FPBA	2,300,000	0.82	MBP6

Table C.10: Monopole modes in MBP5 and MBP6 with electric (EE) boundaries.

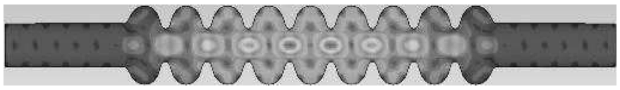
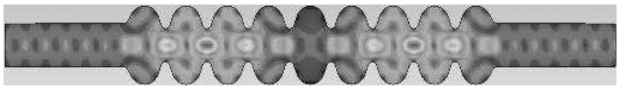
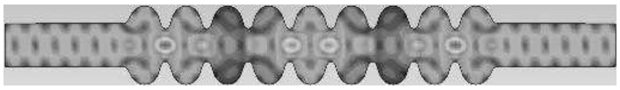
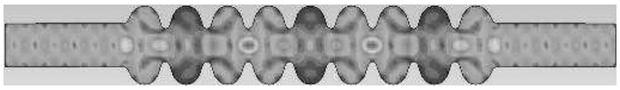
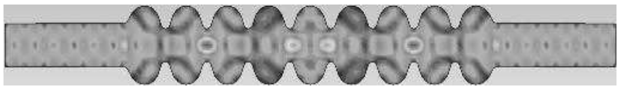
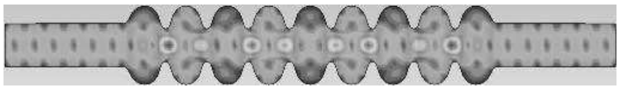
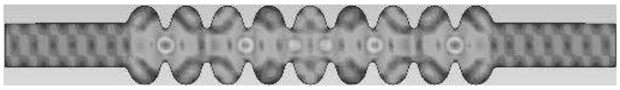
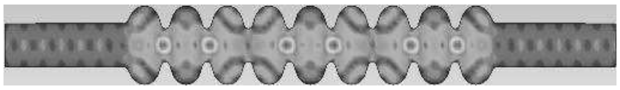
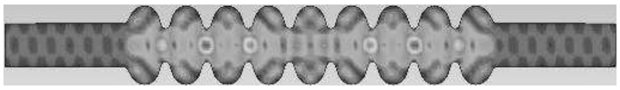
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	8.3376	0.765	MBP5-1
	8.3376	1.045	MBP5-2
	9.1202	1.670	MBP6-1
	9.1202	1.755	MBP6-2

I.6 M4 (EE)

Table C.11: Parameters settings for M4 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
9.7-10.5	20	FPBA	2,000,000	0.87	M4

Table C.12: Monopole modes in M4 with electric (EE) boundaries.

E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.7966	0.000	M4-1
	9.8340	1.511	M4-2
	9.8868	0.395	M4-3
	9.9384	7.388	M4-4
	9.9886	0.015	M4-5
	10.0619	0.921	M4-6
	10.1692	1.125	M4-7
	10.3015	0.778	M4-8
	10.4485	0.277	M4-9

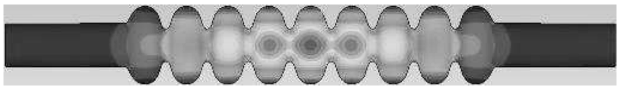
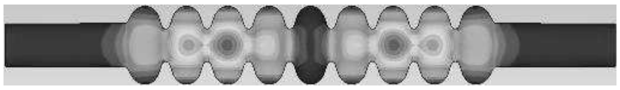
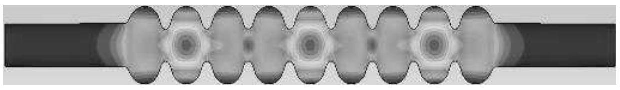
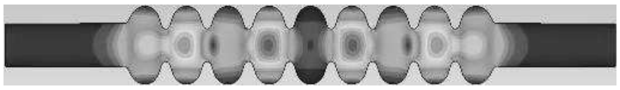
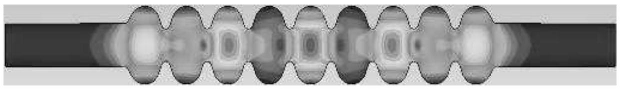
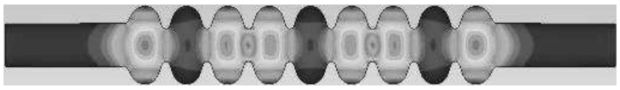
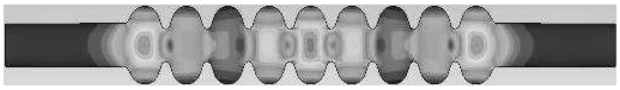
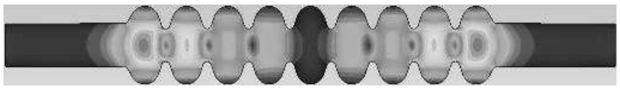
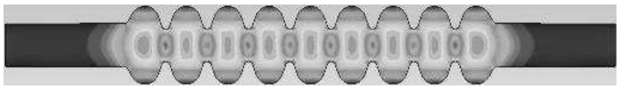
II Monopole (Magnetic Boundaries)

II.1 M1 (MM)

Table C.13: Parameters settings for M1 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
3.7-4.0	70	PBA	2,200,000	1.10	M1

Table C.14: Monopole modes in M1 with magnetic (MM) boundaries.

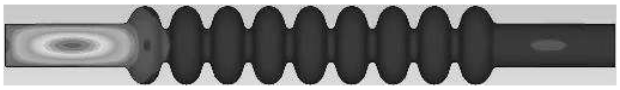
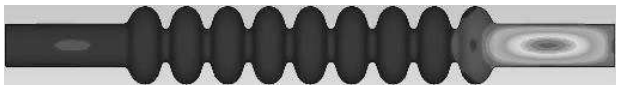
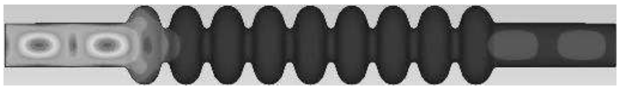
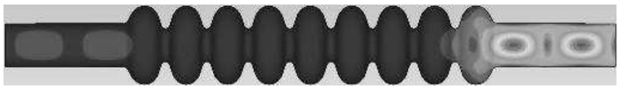
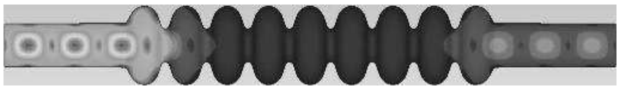
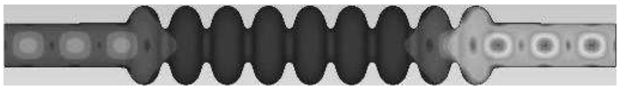
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	3.7466	0.008	M1-1
	3.7601	0.061	M1-2
	3.7808	0.090	M1-3
	3.8065	0.170	M1-4
	3.8341	0.309	M1-5
	3.8602	0.204	M1-6
	3.8817	0.481	M1-7
	3.8958	0.197	M1-8
	3.9008	373.097	M1-9

II.2 MBP1, MBP2 and MBP3 (MM)

Table C.15: Parameters settings for MBP1, MBP2 and MBP3 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
5.7-5.9	50	PBA	2,500,000	1.04	MBP1
6.0-6.4	45	PBA	2,300,000	1.07	MBP2
6.4-6.8	40	PBA	2,000,000	1.11	MBP3

Table C.16: Monopole modes in MBP1, MBP2 and MBP3 with magnetic (MM) boundaries.

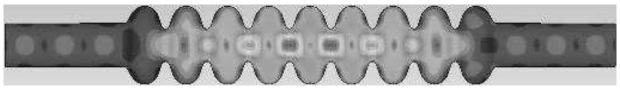
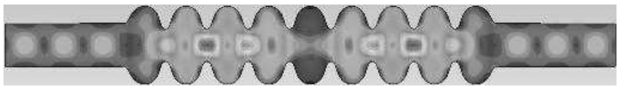
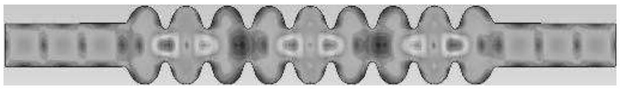
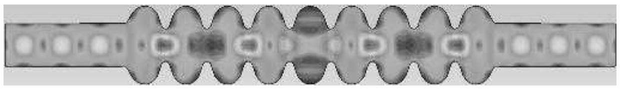
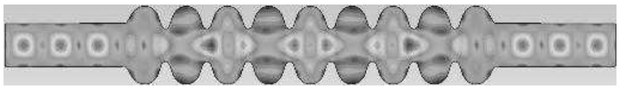
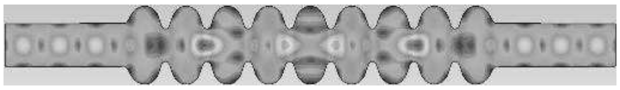
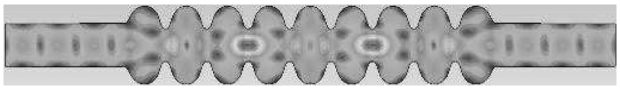
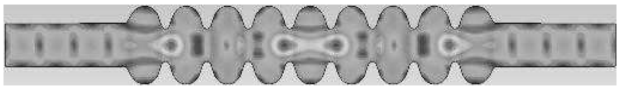
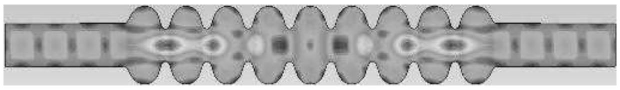
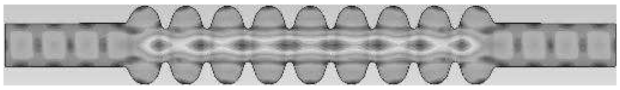
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	5.8624	0.051	MBP1-1
	5.8624	0.051	MBP1-2
	6.2095	0.879	MBP2-1
	6.2095	0.665	MBP2-2
	6.6886	4.119	MBP3-1
	6.6886	2.302	MBP3-2

II.3 M2 (MM)

Table C.17: Parameters settings for M2 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.8-7.6	25	FPBA	1,400,000	0.91	M2

Table C.18: Monopole modes in M2 with magnetic (MM) boundaries.

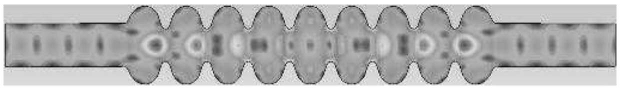
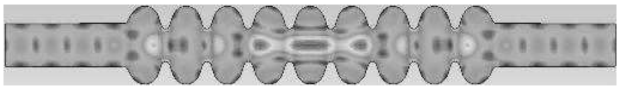
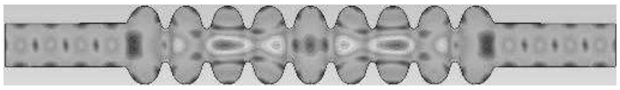
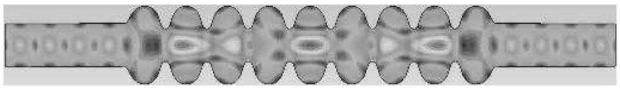
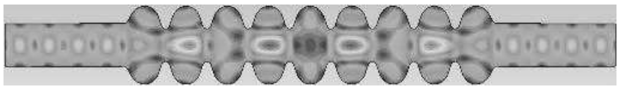
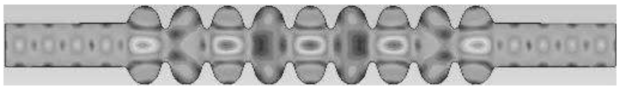
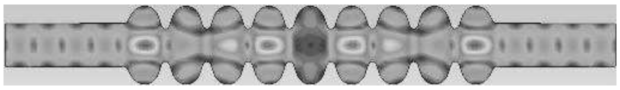
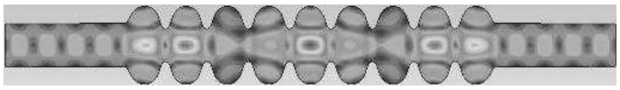
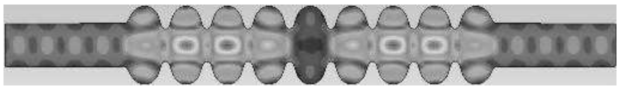
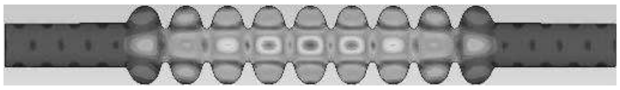
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.0449	0.007	M2-1
	7.0738	0.034	M2-2
	7.1145	0.127	M2-3
	7.1589	1.012	M2-4
	7.2058	0.088	M2-5
	7.2625	2.914	M2-6
	7.3331	0.677	M2-7
	7.4140	2.727	M2-8
	7.4995	10.686	M2-9
	7.5810	18.963	M2-10

II.4 M3 (MM)

Table C.19: Parameters settings for M3 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
7.6-8.4	20	FPBA	1,100,000	0.94	M3

Table C.20: Monopole modes in M3 with magnetic (MM) boundaries.

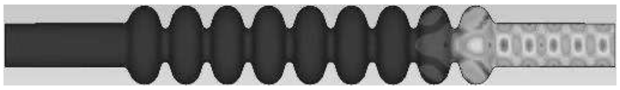
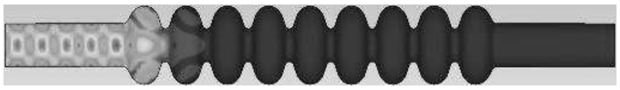
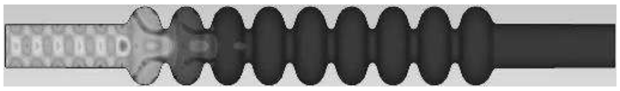
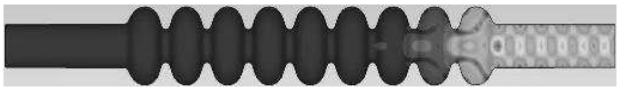
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.6780	47.909	M3-1
	7.7577	0.593	M3-2
	7.8333	21.212	M3-3
	7.9021	0.245	M3-4
	7.9625	1.707	M3-5
	8.0148	0.640	M3-6
	8.0615	0.015	M3-7
	8.1044	0.113	M3-8
	8.1408	0.014	M3-9
	8.1656	0.001	M3-10

II.5 MBP5 and MBP6 (MM)

Table C.21: Parameters settings for MBP5 and MBP6 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.40-8.85	20	FPBA	1,300,000	0.94	MBP5
9.3-9.6	20	FPBA	1,500,000	0.87	MBP6

Table C.22: Monopole modes in MBP5 and MBP6 with magnetic (MM) boundaries.

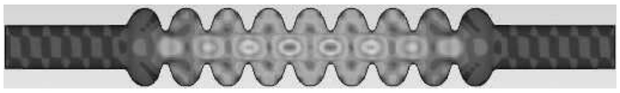
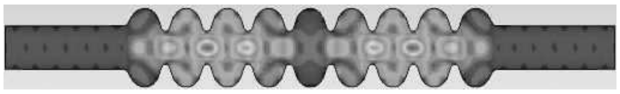
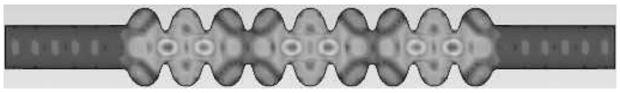
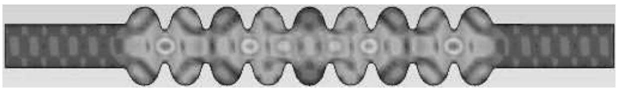
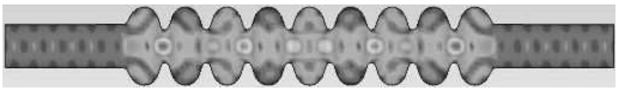
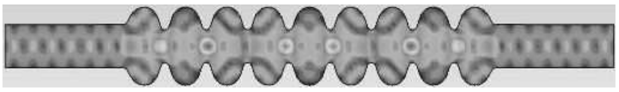
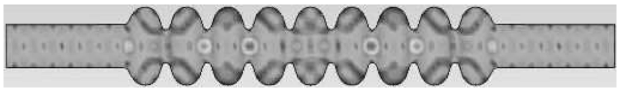
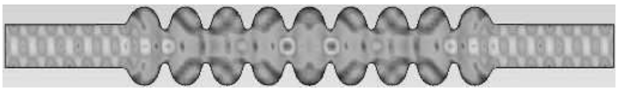
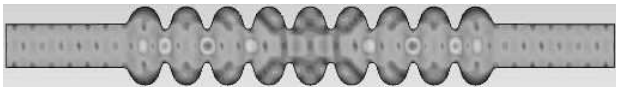
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	8.7111	0.521	MBP5-1
	8.7113	0.525	MBP5-2
	9.5377	1.912	MBP6-1
	9.5378	1.945	MBP6-2

II.6 M4 (MM)

Table C.23: Parameters settings for M4 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
9.7-10.0	20	PBA	1,800,000	0.87	M4(1-3)
10.0-10.6	20	PBA	2,000,000	0.87	M4(4-9)

Table C.24: Monopole modes in M4 with magnetic (MM) boundaries.

E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.7907	0.000	M4-1
	9.8379	0.072	M4-2
	9.9124	0.360	M4-3
	10.0099	5.067	M4-4
	10.1270	0.264	M4-5
	10.2547	0.723	M4-6
	10.3692	2.342	M4-7
	10.4406	0.312	M4-8
	10.5080	0.719	M4-9

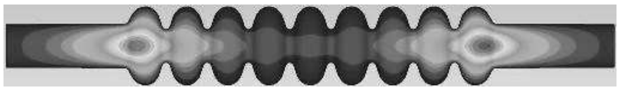
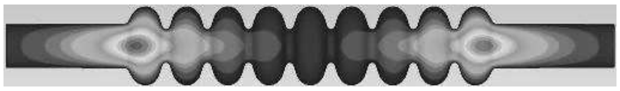
III Dipole (Electric Boundaries)

III.1 DBP1 (EE)

Table C.25: Parameters settings for DBP1 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
4.1-4.2	70	PBA	2,400,000	1.04	DBP1

Table C.26: Dipole modes in DBP1 with electric (EE) boundaries.

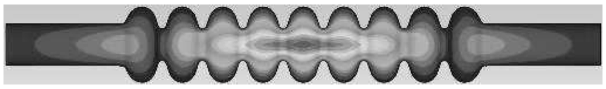
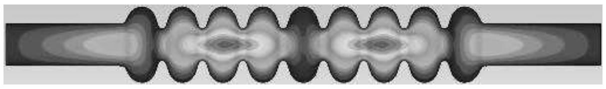
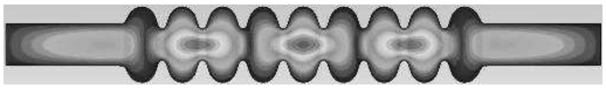
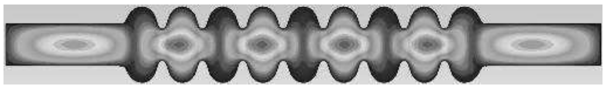
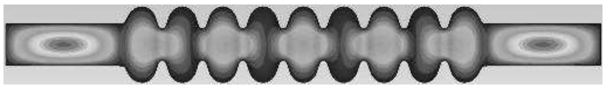
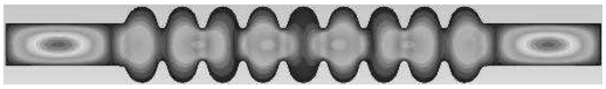
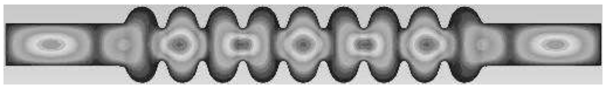
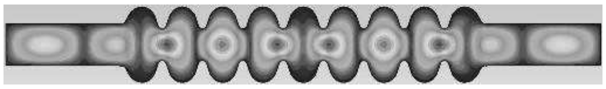
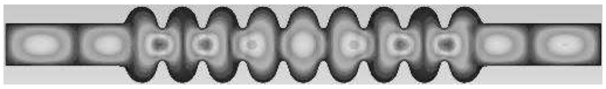
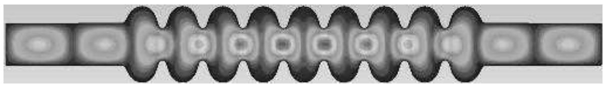
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	4.1489	0.234	DBP1-1
	4.1491	1.318	DBP1-2

III.2 D1 (EE)

Table C.27: Parameters settings for D1 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
4.25-5.05	60	PBA	2,600,000	1.03	D1(1-9)
4.95-5.30	45	PBA	1,500,000	1.29	D1(10)

Table C.28: Dipole modes in D1 with electric (EE) boundaries.

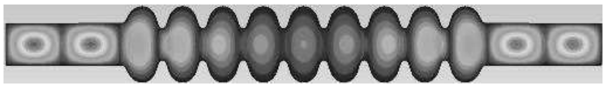
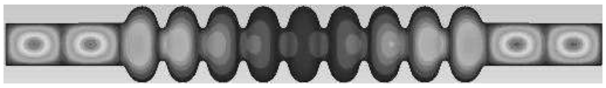
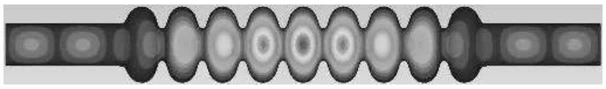
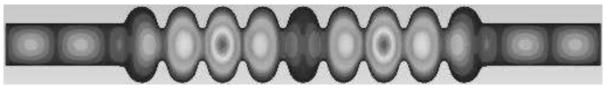
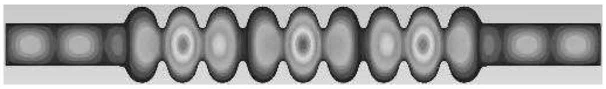
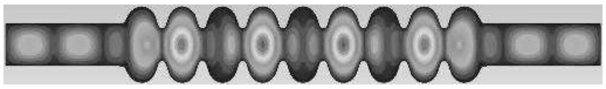
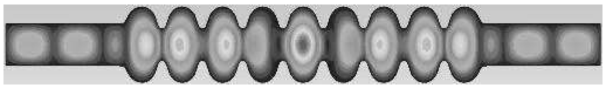
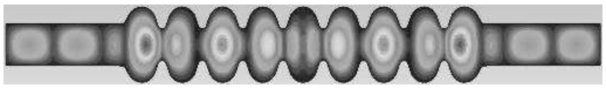
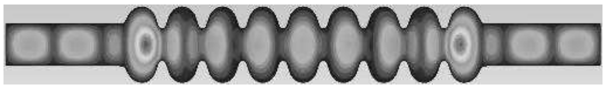
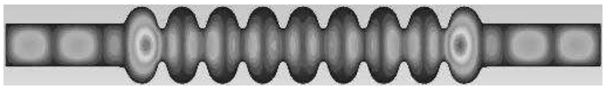
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	4.2982	0.001	D1-1
	4.3607	0.292	D1-2
	4.4485	0.002	D1-3
	4.5410	1.076	D1-4
	4.5989	0.784	D1-5
	4.6415	0.165	D1-6
	4.7245	10.572	D1-7
	4.8327	50.307	D1-8
	4.9270	30.174	D1-9
	4.9899	0.000	D1-10

III.3 DBP2 and D2 (EE)

Table C.29: Parameters settings for DBP2 and D2 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
4.95-5.30	45	PBA	1,500,000	1.29	DBP2
5.3-5.6	50	PBA	2,200,000	1.10	D2

Table C.30: Dipole modes in DBP2 and D2 with electric (EE) boundaries.

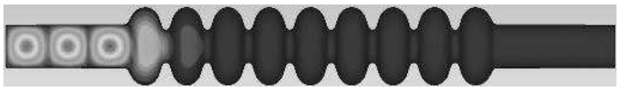
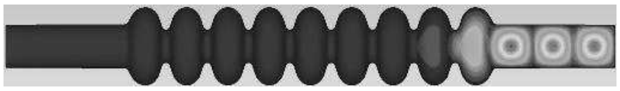
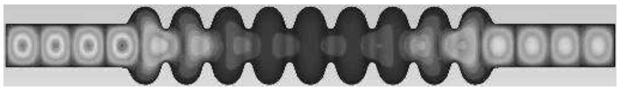
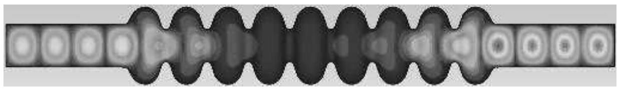
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	5.2014	0.300	DBP2-1
	5.2040	2.036	DBP2-2
	5.3581	0.041	D2-1
	5.4050	5.057	D2-2
	5.4427	20.877	D2-3
	5.4678	15.776	D2-4
	5.4829	0.895	D2-5
	5.4911	1.261	D2-6
	5.4950	0.307	D2-7
	5.4958	0.549	D2-8

III.4 DBP3 and DBP4 (EE)

Table C.31: Parameters settings for DBP3 and DBP4 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
5.8-5.9	45	PBA	2,000,000	1.18	DBP3
6.5-6.6	40	PBA	1,900,000	1.18	DBP4

Table C.32: Dipole modes in DBP3 and DBP4 with electric (EE) boundaries.

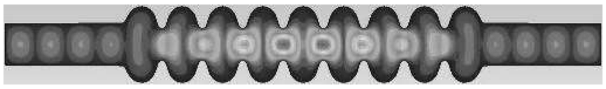
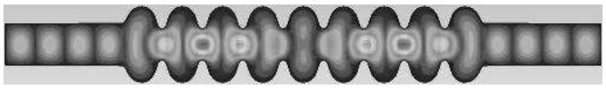
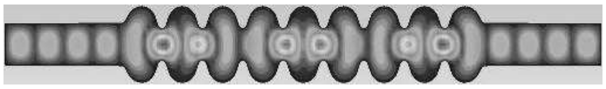
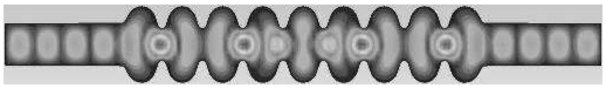
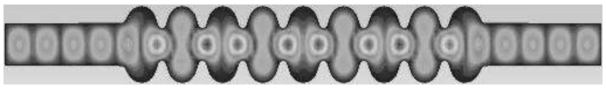
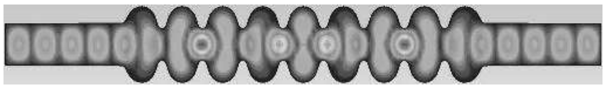
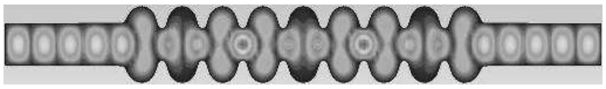
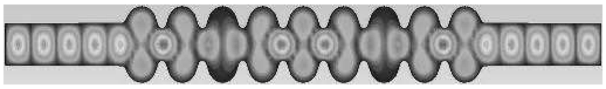
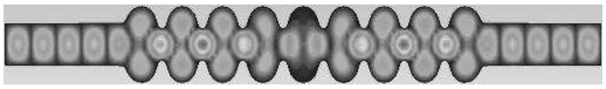
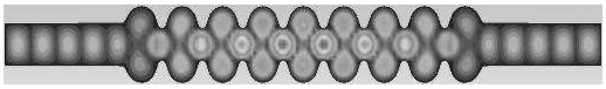
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	5.8644	1.028	DBP3-1
	5.8644	1.026	DBP3-2
	6.5593	0.344	DBP4-1
	6.5594	0.397	DBP4-2

III.5 D3 (EE)

Table C.33: Parameters settings for D3 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.75-7.7	40	PBA	3,000,000	0.99	D3

Table C.34: Dipole modes in D3 with electric (EE) boundaries.

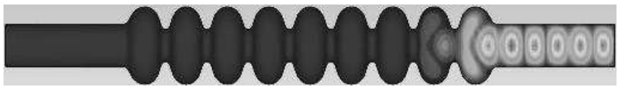
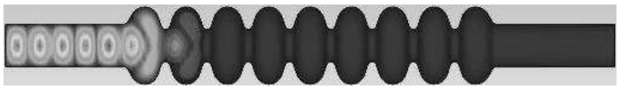
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	6.8238	0.011	D3-1
	6.9003	0.035	D3-2
	7.0027	0.058	D3-3
	7.1225	0.189	D3-4
	7.2541	0.549	D3-5
	7.3833	0.014	D3-6
	7.4889	0.455	D3-7
	7.5621	0.269	D3-8
	7.6196	1.354	D3-9
	7.6680	28.926	D3-10

III.6 DBP5 (EE)

Table C.35: Parameters settings for DBP5 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.2-8.4	20	FPBA	1,100,000	0.94	DBP5

Table C.36: Dipole modes in DBP5 with electric (EE) boundaries.

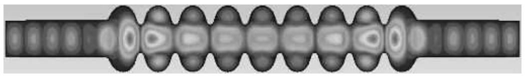
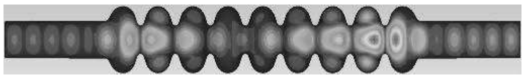
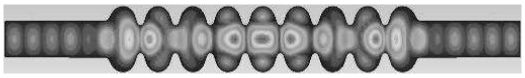
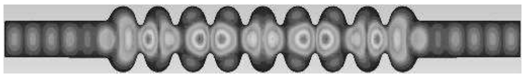
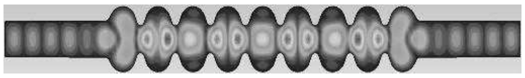
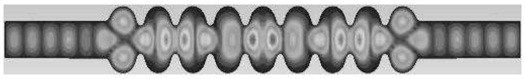
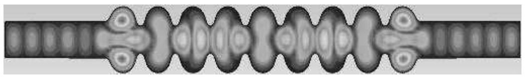
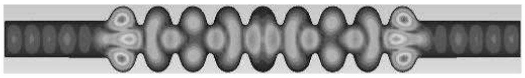
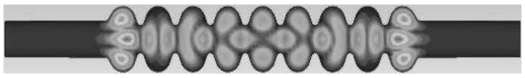
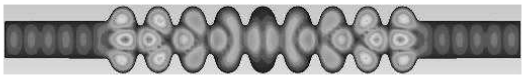
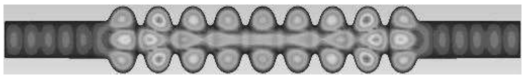
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	8.3033	1.543	DBP5-1
	8.3039	1.537	DBP5-2

III.7 D4 (EE)

Table C.37: Parameters settings for D4 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.45-8.55	25	FPBA	2,000,000	0.87	D4(1)
8.40-9.05	20	FPBA	1,300,000	0.91	D4(2-11)

Table C.38: Dipole modes in D4 with electric (EE) boundaries.

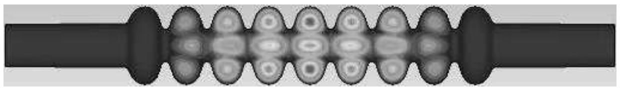
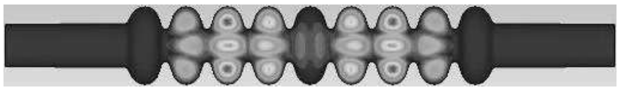
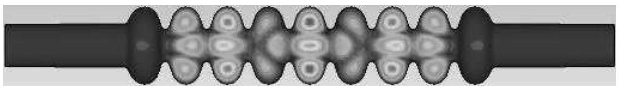
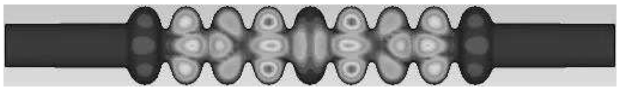
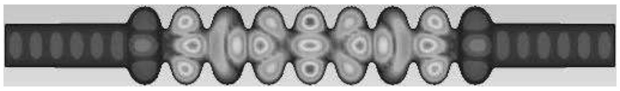
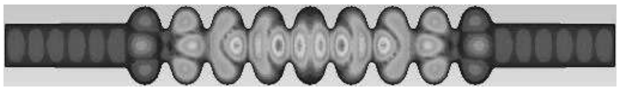
E-field Amplitude	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\mathrm{cm}^2)$	**Band**
	8.5002	0.130	D4-1
	8.5042	0.096	D4-2
	8.5322	0.152	D4-3
	8.5763	0.115	D4-4
	8.6397	0.415	D4-5
	8.7205	1.038	D4-6
	8.8033	10.205	D4-7
	8.8648	2.470	D4-8
	8.9196	0.287	D4-9
	8.9857	3.258	D4-10
	8.9980	0.230	D4-11

III.8 D5 (EE)

Table C.39: Parameters settings for D5 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
9.05-9.095	20	PBA	1,300,000	0.91	D5

Table C.40: Dipole modes in D5 with electric (EE) boundaries.

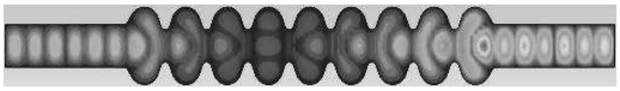
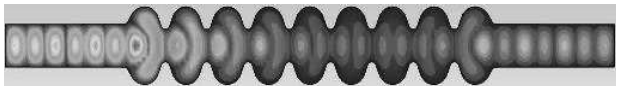
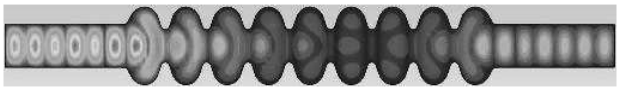
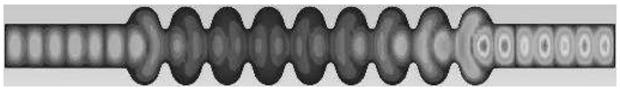
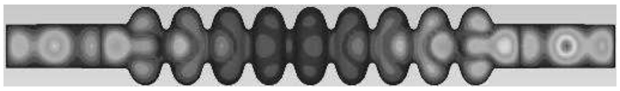
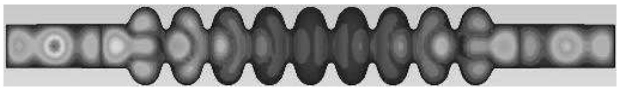
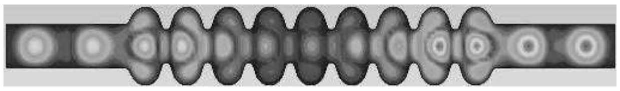
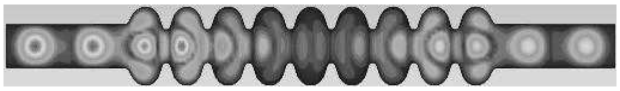
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.0523	0.002	D5-1
	9.0530	0.053	D5-2
	9.0546	0.058	D5-3
	9.0581	2.171	D5-4
	9.0664	4.116	D5-5
	9.0890	0.580	D5-6

III.9 DBP6, DBP7, DBP8 and DBP9 (EE)

Table C.41: Parameters settings for DBP6, DBP7, DBP8 and DBP9 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
9.1-9.2	20	FPBA	1,300,000	0.91	DBP6, DBP7
9.2-9.4	20	FPBA	1,400,000	0.91	DBP8
9.4-9.6	20	FPBA	1,500,000	0.87	DBP9

Table C.42: Dipole modes in DBP6, DBP7, DBP8 and DBP9 with electric (EE) boundaries.

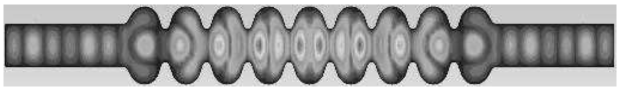
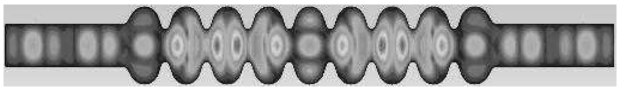
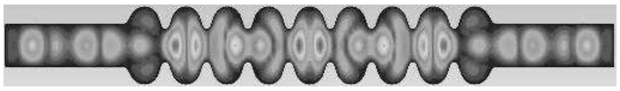
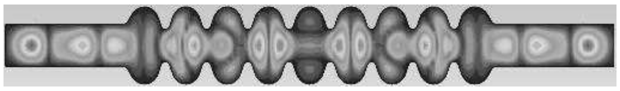
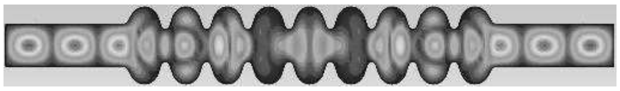
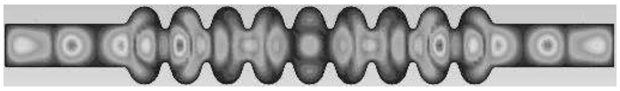
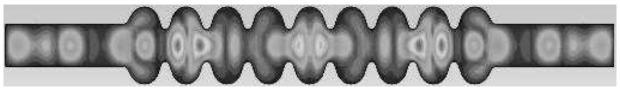
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.1666	1.291	DBP6-1
	9.1678	1.898	DBP6-2
	9.1749	1.123	DBP7-1
	9.1763	3.240	DBP7-2
	9.3283	0.880	DBP8-1
	9.3284	2.042	DBP8-2
	9.5379	4.064	DBP9-1
	9.5385	0.275	DBP9-2

III.10 D6 (EE)

Table C.43: Parameters settings for D6 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
9.6-9.9	20	FPBA	1,700,000	0.87	D6

Table C.44: Dipole modes in D6 with electric (EE) boundaries.

E-field Amplitude	$\mathbf{f}$(GHz)	$\mathbf{R/Q}(\Omega/\text{cm}^2)$	**Band**
	9.6962	0.001	D6-1
	9.7142	0.009	D6-2
	9.7421	0.074	D6-3
	9.7711	0.379	D6-4
	9.7896	5.951	D6-5
	9.8027	0.771	D6-6
	9.8265	0.191	D6-7

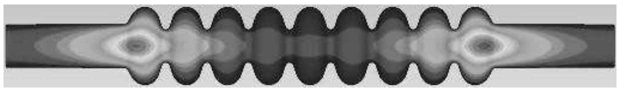
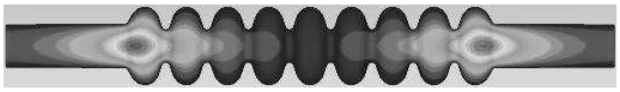
IV Dipole (Magnetic Boundaries)

IV.1 DBP1 (MM)

Table C.45: Parameters settings for DBP1 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
4.1-4.2	70	PBA	2,400,000	1.04	DBP1

Table C.46: Dipole modes in DBP1 with magnetic (MM) boundaries.

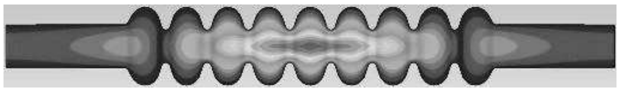
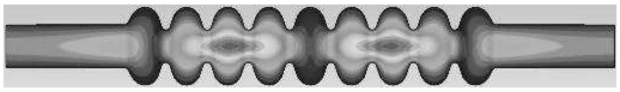
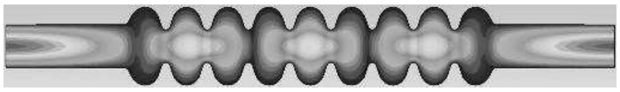
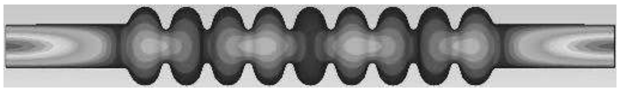
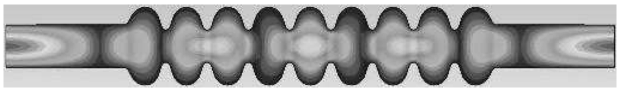
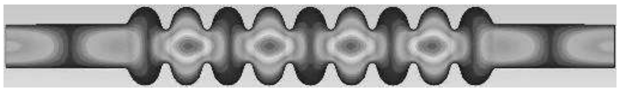
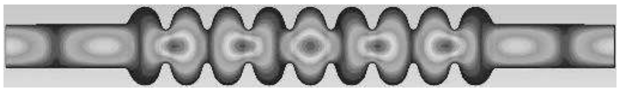
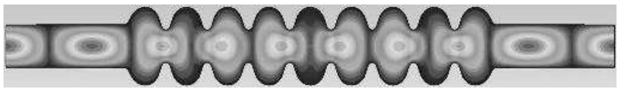
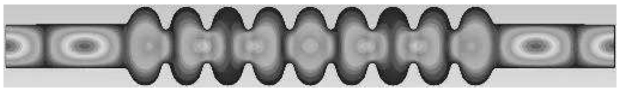
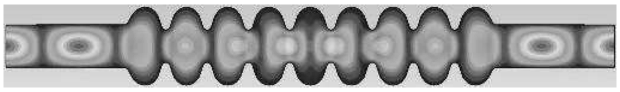
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	4.1474	0.241	DBP1-1
	4.1475	1.299	DBP1-2

IV.2 D1 (MM)

Table C.47: Parameters settings for D1 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
4.25-5.05	55	PBA	2,100,000	1.10	D1

Table C.48: Dipole modes in D1 with magnetic (MM) boundaries.

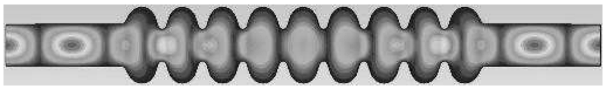
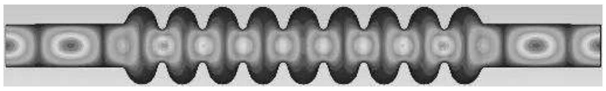
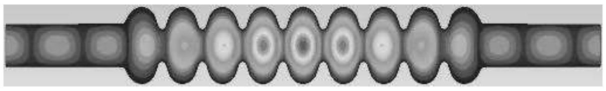
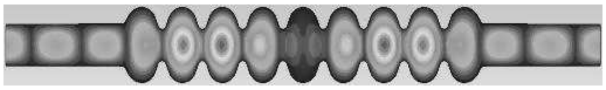
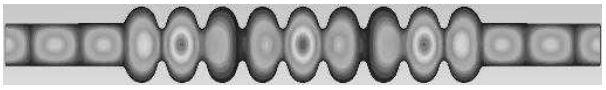
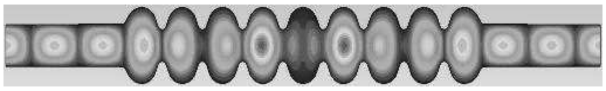
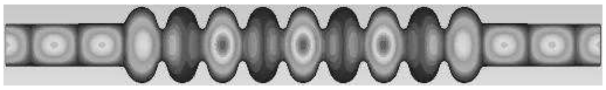
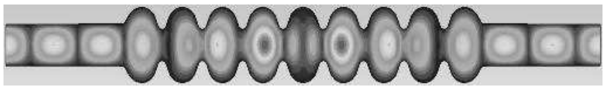
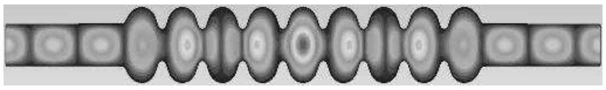
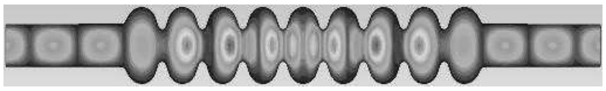
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	4.2979	0.001	D1-1
	4.3592	0.263	D1-2
	4.4306	0.072	D1-3
	4.4516	0.000	D1-4
	4.4770	0.327	D1-5
	4.5703	1.213	D1-6
	4.6804	1.586	D1-7
	4.7749	27.165	D1-8
	4.8455	32.124	D1-9
	4.9162	21.833	D1-10

IV.3 DBP2 and D2 (MM)

Table C.49: Parameters settings for DBP2 and D2 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
4.25-5.05	55	PBA	2,100,000	1.10	DBP2
5.3-5.7	50	PBA	2,300,000	1.07	D2

Table C.50: Dipole modes in DBP2 and D2 with magnetic (MM) boundaries.

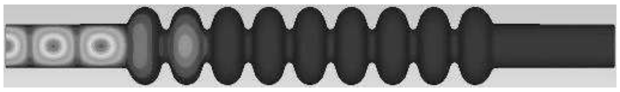
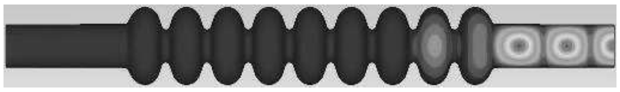
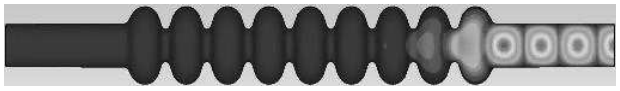
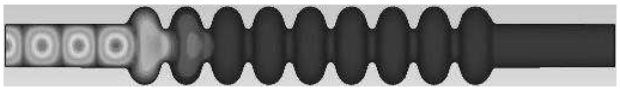
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	4.9945	7.376	DBP2-1
	5.0233	3.844	DBP2-2
	5.3518	0.055	D2-1
	5.3923	2.114	D2-2
	5.4272	10.770	D2-3
	5.4528	17.024	D2-4
	5.4711	9.368	D2-5
	5.4834	0.409	D2-6
	5.4908	0.343	D2-7
	5.4944	0.033	D2-8

IV.4 DBP3 and DBP4 (MM)

Table C.51: Parameters settings for DBP3 and DBP4 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
5.3-5.7	50	PBA	2,300,000	1.07	DBP3
6.1-6.3	40	PBA	1,700,000	1.21	DBP4

Table C.52: Dipole modes in DBP3 and DBP4 with magnetic (MM) boundaries.

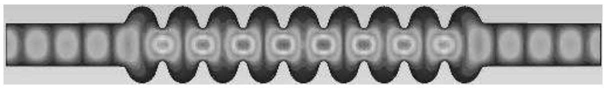
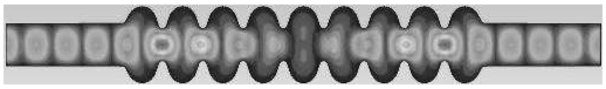
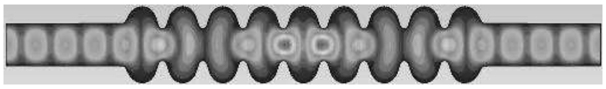
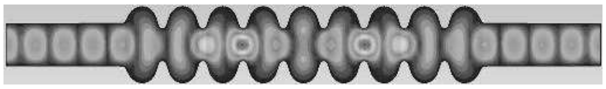
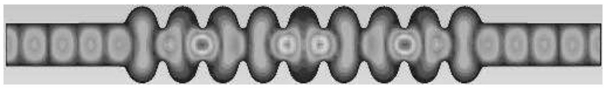
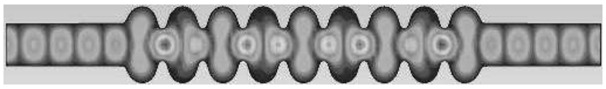
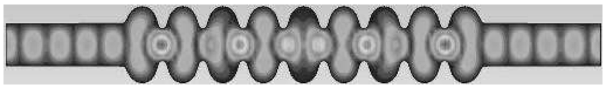
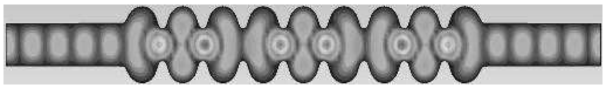
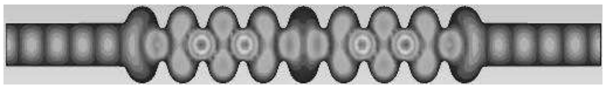
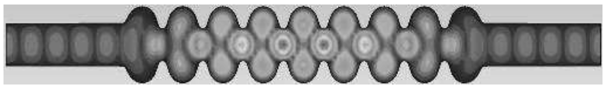
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	5.5532	2.994	DBP3-1
	5.5532	2.995	DBP3-2
	6.2123	0.595	DBP4-1
	6.2144	0.636	DBP4-2

IV.5 D3 (MM)

Table C.53: Parameters settings for D3 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.75-7.50	40	PBA	3,000,000	0.99	D3

Table C.54: Dipole modes in D3 with magnetic (MM) boundaries.

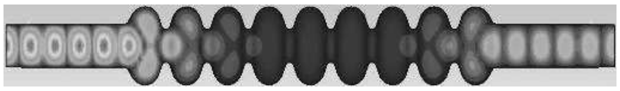
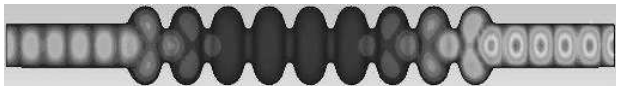
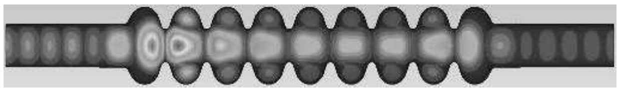
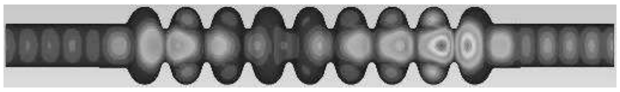
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	6.7964	0.068	D3-1
	6.8242	0.068	D3-2
	6.8909	0.140	D3-3
	6.9880	0.124	D3-4
	7.0989	0.108	D3-5
	7.2140	0.020	D3-6
	7.3348	0.825	D3-7
	7.4598	0.503	D3-8
	7.5743	2.862	D3-9
	7.6566	23.875	D3-10

IV.6 DBP5 and DBP6 (MM)

Table C.55: Parameters settings for DBP5 and DBP6 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
7.85-7.95	22	PBA	1,200,000	0.94	DBP5
8.4-9.0	20	FPBA	1,300,000	0.91	DBP6

Table C.56: Dipole modes in DBP5 and DBP6 with magnetic (MM) boundaries.

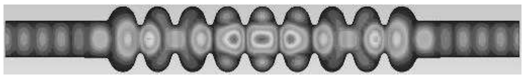
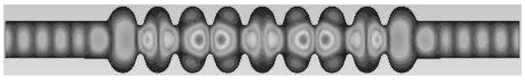
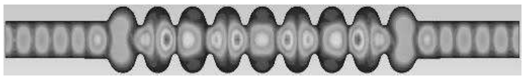
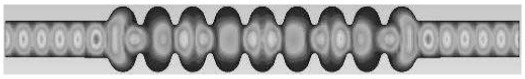
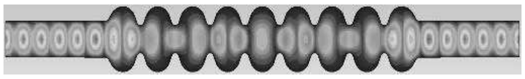
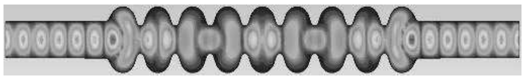
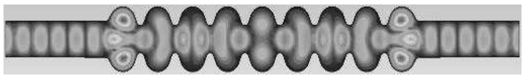
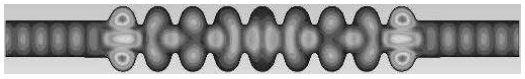
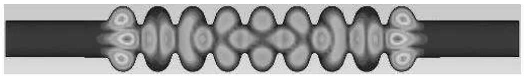
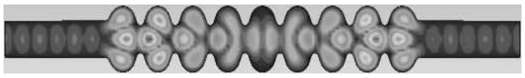
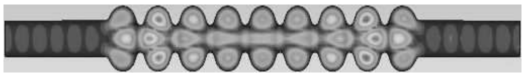
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.9033	2.155	DBP5-1
	7.9034	2.961	DBP5-2
	8.4964	0.340	DBP6-1
	8.5008	0.056	DBP6-2

IV.7 D4 (MM)

Table C.57: Parameters settings for D4 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.4-9.0	20	FPBA	1,300,000	0.91	D4(1-9)
8.95-9.05	20	FPBA	1,300,000	0.91	D4(10-11)

Table C.58: Dipole modes in D4 with magnetic (MM) boundaries.

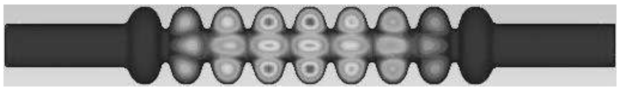
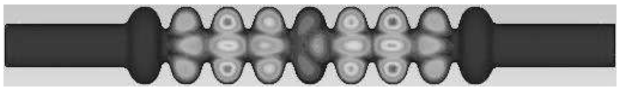
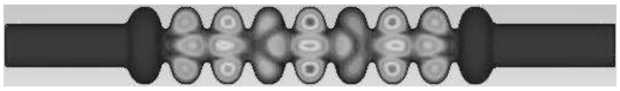
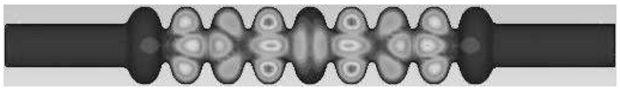
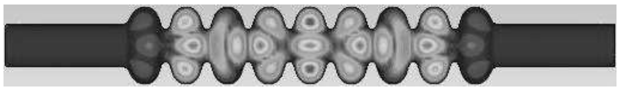
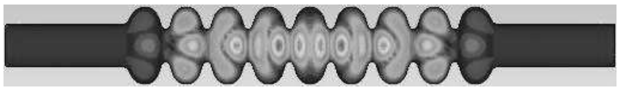
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	8.5292	0.365	D4-1
	8.5709	0.023	D4-2
	8.6273	1.457	D4-3
	8.6849	0.042	D4-4
	8.7257	4.392	D4-5
	8.7702	1.693	D4-6
	8.8301	5.577	D4-7
	8.8729	1.895	D4-8
	8.9196	0.281	D4-9
	8.9900	3.623	D4-10
	9.0011	0.302	D4-11

IV.8 D5 (MM)

Table C.59: Parameters settings for D5 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
9.05-9.10	16	FPBA	800,000	1.08	D5

Table C.60: Dipole modes in D5 with magnetic (MM) boundaries.

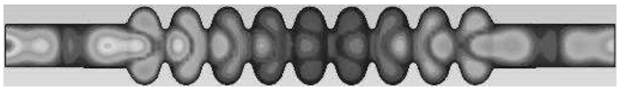
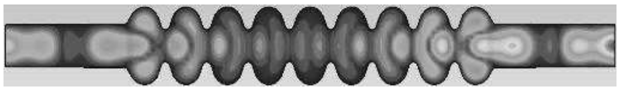
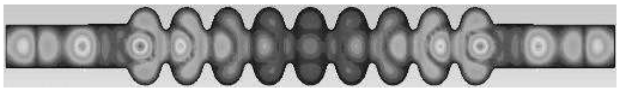
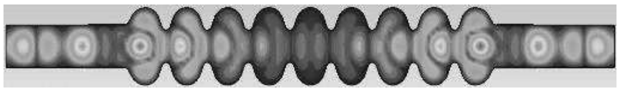
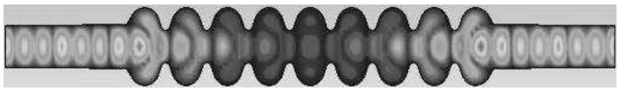
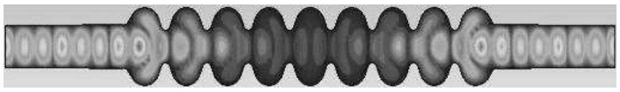
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.0593	0.004	D5-1
	9.0599	0.058	D5-2
	9.0614	0.076	D5-3
	9.0645	2.377	D5-4
	9.0718	4.158	D5-5
	9.0918	0.452	D5-6

IV.9 DBP7, DBP8 and DBP9 (MM)

Table C.61: Parameters settings for DBP7, DBP8 and DBP9 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
9.1-9.3	20	FPBA	1,400,000	0.91	DBP7
9.3-9.5	20	FPBA	1,400,000	0.91	DBP8
9.5-9.6	20	FPBA	1,500,000	0.87	DBP9

Table C.62: Dipole modes in DBP7, DBP8 and DBP9 with magnetic (MM) boundaries.

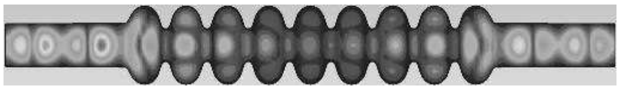
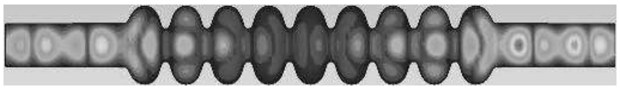
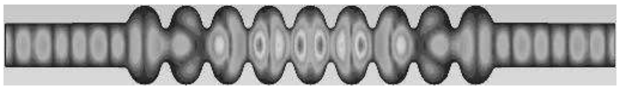
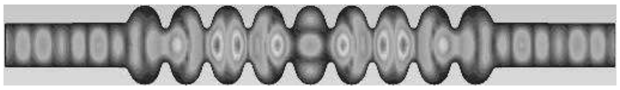
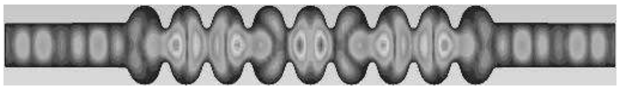
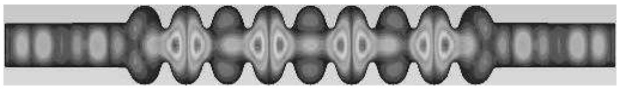
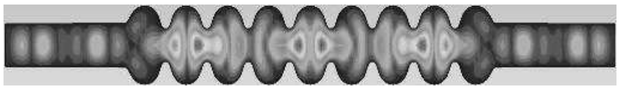
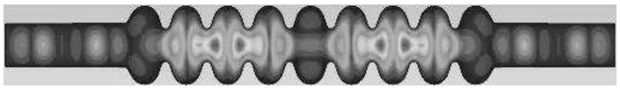
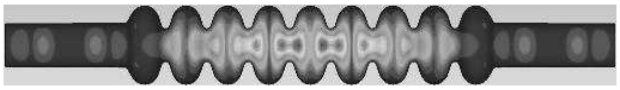
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.2324	0.158	DBP7-1
	9.2325	0.092	DBP7-2
	9.4325	0.105	DBP8-1
	9.4330	0.020	DBP8-2
	9.5809	0.342	DBP9-1
	9.5818	0.015	DBP9-2

IV.10 DBP10 and D6 (MM)

Table C.63: Parameters settings for DBP10 and D6 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
9.6-9.9	20	PBA	1,700,000	0.87	DBP10, D6

Table C.64: Dipole modes in DBP10 and D6 with magnetic (MM) boundaries.

E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.6342	0.485	DBP10-1
	9.6346	0.848	DBP10-2
	9.6896	0.013	D6-1
	9.7103	0.025	D6-2
	9.7415	0.341	D6-3
	9.7776	1.133	D6-4
	9.8134	0.345	D6-5
	9.8440	0.008	D6-6
	9.8648	0.019	D6-7

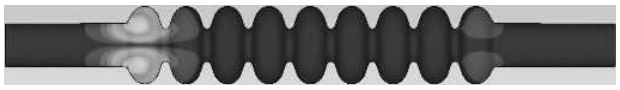
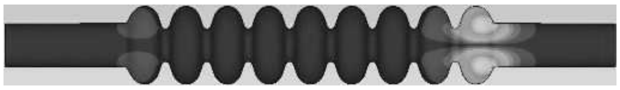
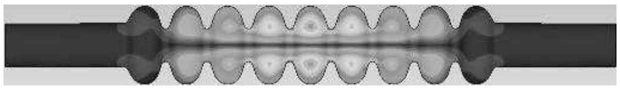
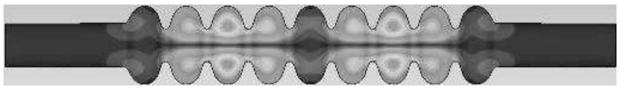
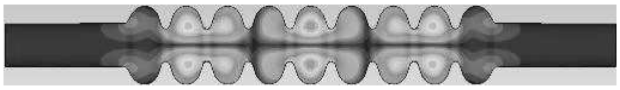
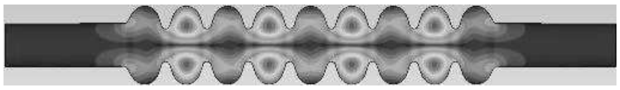
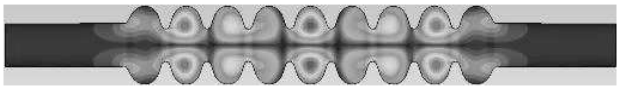
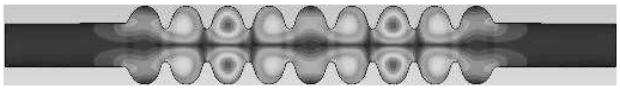
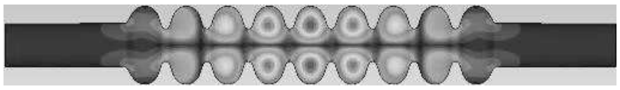
V Quadrupole (Electric Boundaries)

V.1 QBP1 and Q1 (EE)

Table C.65: Parameters settings for QBP1 and Q1 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.2-6.3	45	PBA	2,200,000	1.08	QBP1
6.5-6.8	40	PBA	2,000,000	1.11	Q1

Table C.66: Quadrupole modes in QBP1 and Q1 with electric (EE) boundaries.

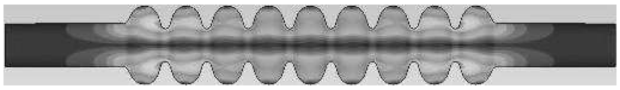
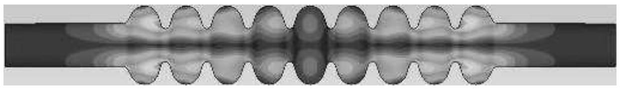
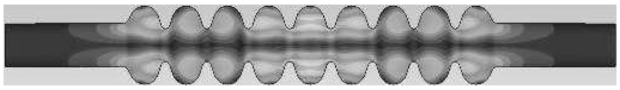
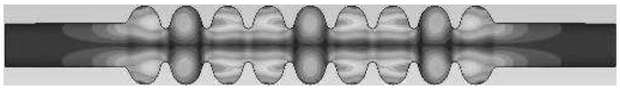
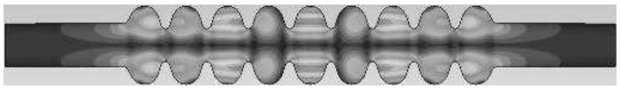
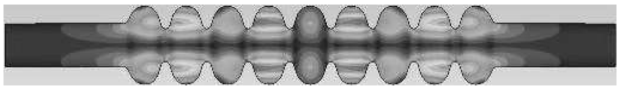
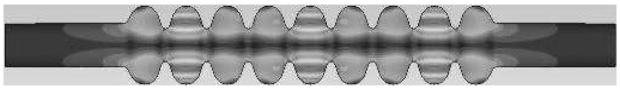
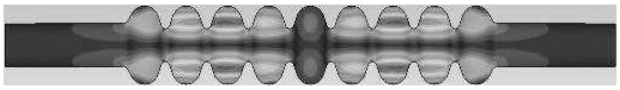
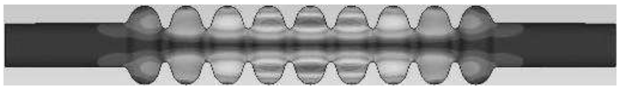
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	6.2697	0.513	QBP1-1
	6.2698	0.742	QBP1-2
	6.5638	0.183	Q1-1
	6.5843	3.734	Q1-2
	6.6167	4.358	Q1-3
	6.6583	0.183	Q1-4
	6.7059	0.308	Q1-5
	6.7546	0.002	Q1-6
	6.7961	0.041	Q1-7

V.2 Q2 (EE)

Table C.67: Parameters settings for Q2 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.85-7.60	25	FPBA	1,400,000	0.91	Q2

Table C.68: Quadrupole modes in Q2 with electric (EE) boundaries.

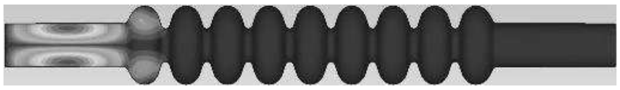
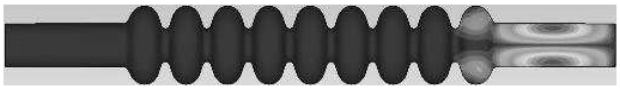
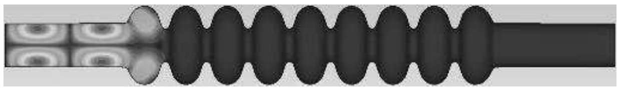
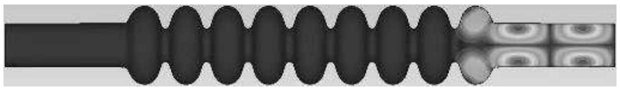
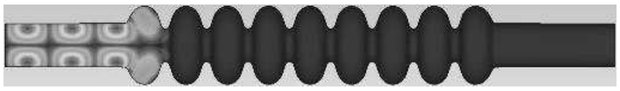
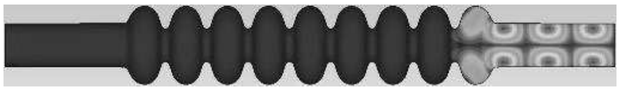
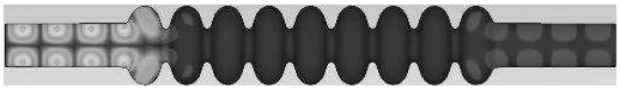
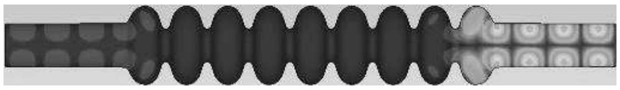
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.0005	0.135	Q2-1
	7.0096	0.075	Q2-2
	7.0456	0.152	Q2-3
	7.0823	0.000	Q2-4
	7.1158	0.221	Q2-5
	7.1437	0.101	Q2-6
	7.1653	0.579	Q2-7
	7.1806	3.484	Q2-8
	7.1897	2.125	Q2-9

V.3 QBP2, QBP3, QBP4 and QBP5 (EE)

Table C.69: Parameters settings for QBP2, QBP3, QBP4 and QBP5 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.85-7.60	25	FPBA	1,400,000	0.91	QBP2
7.50-8.25	20	FPBA	1,100,000	1.06	QBP3, QBP4
8.6-8.7	20	PBA	1,200,000	0.94	QBP5

Table C.70: Quadrupole modes in QBP2, QBP3, QBP4 and QBP5 with electric (EE) boundaries.

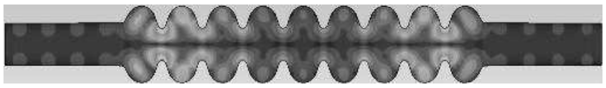
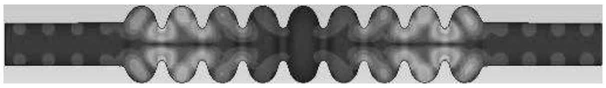
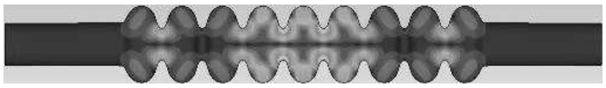
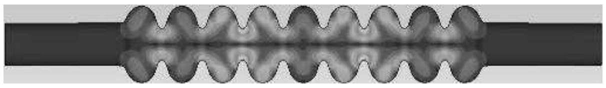
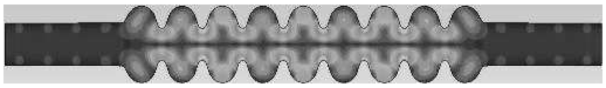
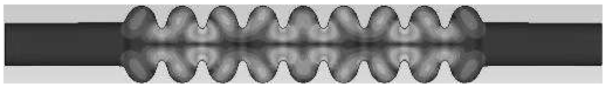
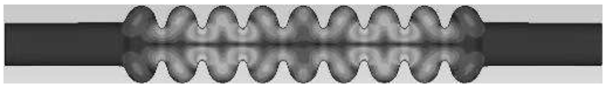
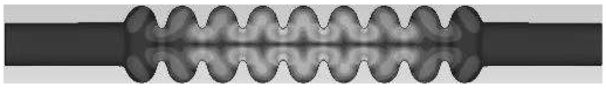
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.4084	0.020	QBP2-1
	7.4085	0.020	QBP2-2
	7.7101	0.049	QBP3-1
	7.7102	0.033	QBP3-2
	8.1423	0.069	QBP4-1
	8.1431	0.069	QBP4-2
	8.6665	0.095	QBP5-1
	8.6665	0.108	QBP5-2

V.4 Q3 and QBP6 (EE)

Table C.71: Parameters settings for Q3 and QBP6 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.90-9.35	24	FPBA	2,300,000	0.82	Q3, QBP6

Table C.72: Quadrupole modes in Q3 and QBP6 with electric (EE) boundaries.

E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.1129	4.686	Q3-1
	9.1133	0.053	Q3-2
	9.1228	5.921	Q3-3
	9.1340	11.102	Q3-4
	9.1499	2.998	Q3-5
	9.1692	0.003	Q3-6
	9.1893	0.152	Q3-7
	9.2053	0.000	Q3-8

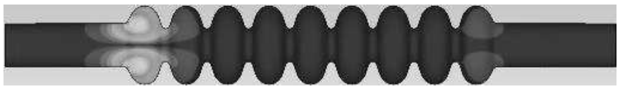
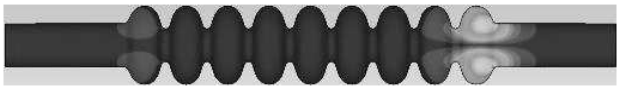
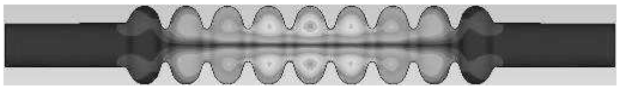
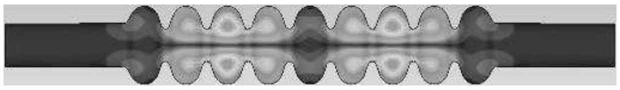
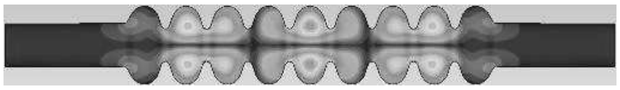
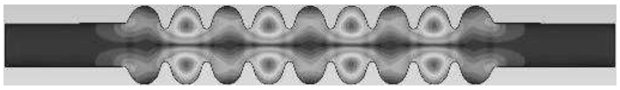
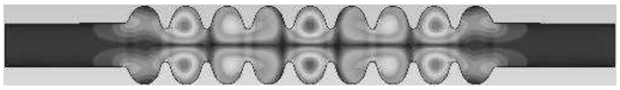
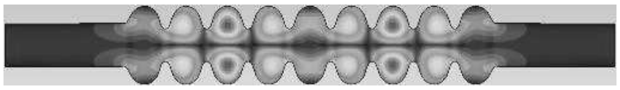
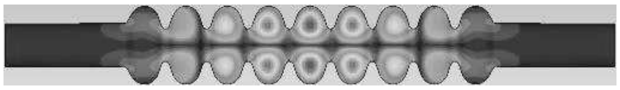
VI Quadrupole (Magnetic Boundaries)

VI.1 QBP1 and Q1 (MM)

Table C.73: Parameters settings for QBP1 and Q1 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.0-6.4	45	PBA	2,300,000	1.07	QBP1
6.4-6.8	40	PBA	2,000,000	1.11	Q1

Table C.74: Quadrupole modes in QBP1 and Q1 with magnetic (MM) boundaries.

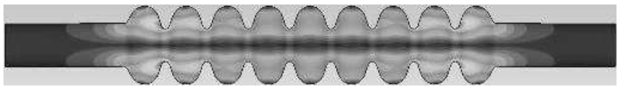
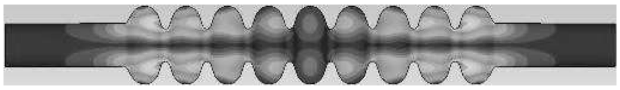
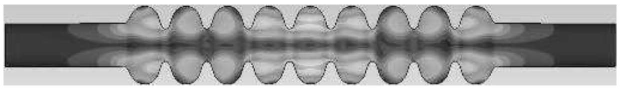
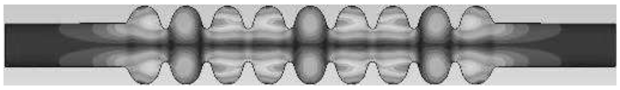
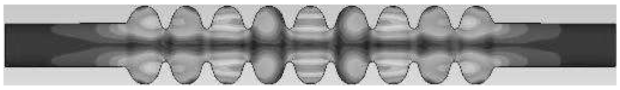
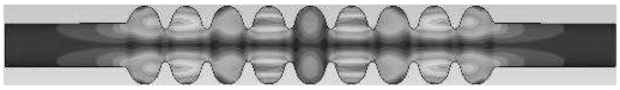
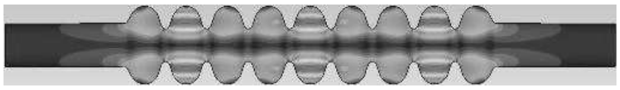
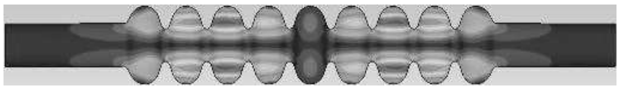
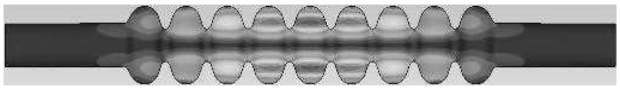
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	6.2697	0.513	QBP1-1
	6.2697	0.742	QBP1-2
	6.5638	0.183	Q1-1
	6.5843	3.734	Q1-2
	6.6167	4.359	Q1-3
	6.6583	0.183	Q1-4
	6.7059	0.307	Q1-5
	6.7546	0.002	Q1-6
	6.7961	0.041	Q1-7

VI.2 Q2 (MM)

Table C.75: Parameters settings for Q2 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.8-7.6	25	FPBA	1,400,000	0.91	Q2

Table C.76: Quadrupole modes in Q2 with magnetic (MM) boundaries.

E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.0005	0.135	Q2-1
	7.0096	0.075	Q2-2
	7.0456	0.151	Q2-3
	7.0823	0.000	Q2-4
	7.1157	0.220	Q2-5
	7.1436	0.103	Q2-6
	7.1653	0.578	Q2-7
	7.1806	3.483	Q2-8
	7.1897	2.125	Q2-9

VI.3 QBP2, QBP3, QBP4, QBP5 and QBP6 (MM)

Table C.77: Parameters settings for QBP2, QBP3, QBP4, QBP5 and QBP6 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
6.8-7.6	25	FPBA	1,400,000	0.91	QBP2, QBP3
7.6-8.4	20	FPBA	1,100,000	0.94	QBP4
8.2-8.4	20	FPBA	1,100,000	0.94	QBP5
8.85-9.3	20	FPBA	1,400,000	0.91	QBP6

VI.4 Q3 (MM)

Table C.78: Quadrupole modes in QBP2, QBP3, QBP4, QBP5 and QBP6 with magnetic (MM) boundaries.

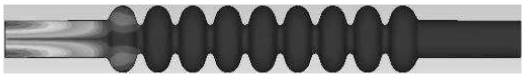
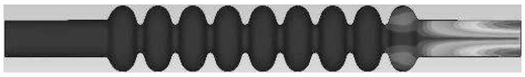
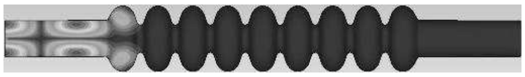
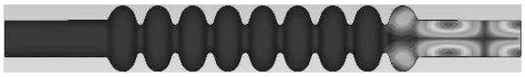
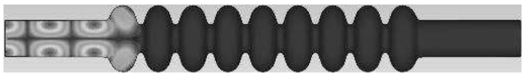
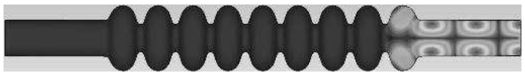
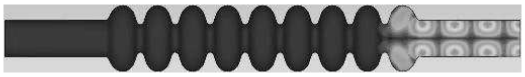
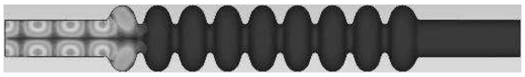
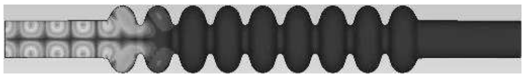
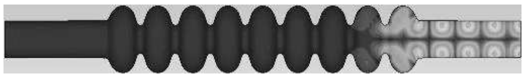
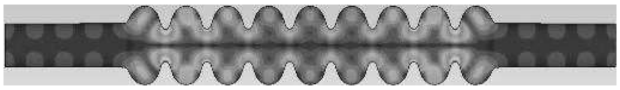
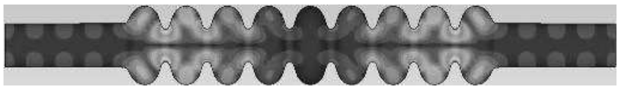
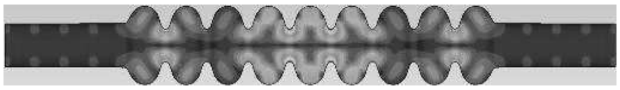
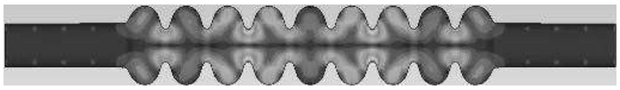
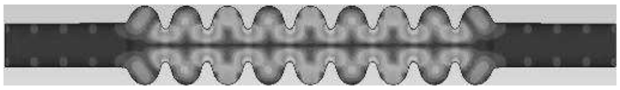
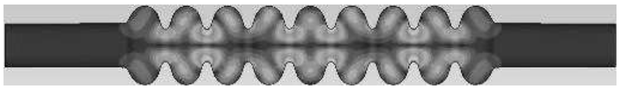
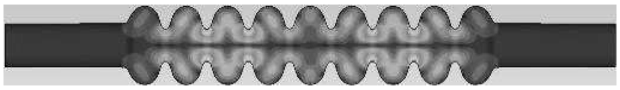
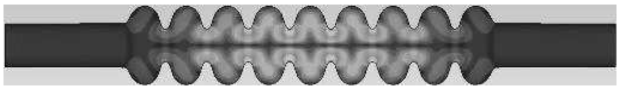
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.3248	0.008	QBP2-1
	7.3249	0.008	QBP2-2
	7.5397	0.030	QBP3-1
	7.5398	0.030	QBP3-2
	7.9134	0.052	QBP4-1
	7.9136	0.054	QBP4-2
	8.3961	0.086	QBP5-1
	8.3964	0.085	QBP5-2
	8.9709	0.167	QBP6-1
	8.9711	0.166	QBP6-2

Table C.79: Parameters settings for Q3 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.85-9.3	20	FPBA	1,400,000	0.91	Q3

Table C.80: Quadrupole modes in Q3 with magnetic (MM) boundaries.

E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	9.1147	3.176	Q3-1
	9.1155	0.147	Q3-2
	9.1232	7.555	Q3-3
	9.1344	11.244	Q3-4
	9.1501	2.608	Q3-5
	9.1692	0.021	Q3-6
	9.1890	0.152	Q3-7
	9.2048	0.001	Q3-8

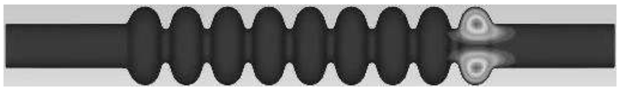
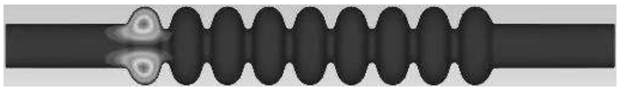
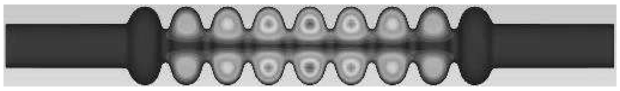
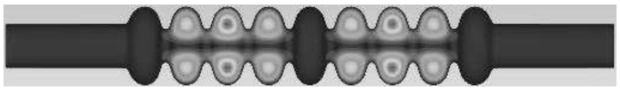
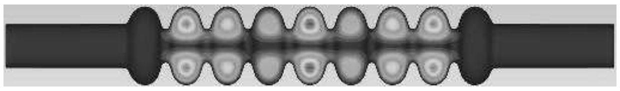
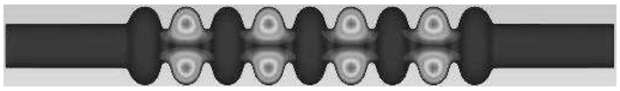
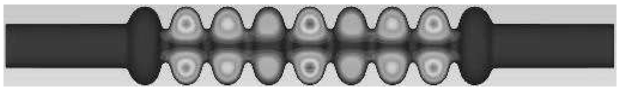
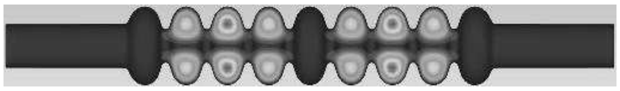
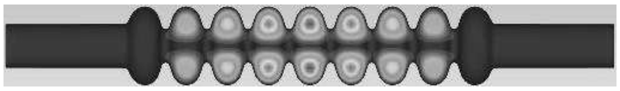
VII Sextupole (Electric Boundaries)

VII.1 SBP1 and S1 (EE)

Table C.81: Parameters settings for SBP1 and S1 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
7.7-8.1	20	FPBA	1,000,000	1.06	SBP1
8.1-8.3	20	FPBA	1,100,000	0.94	S1

Table C.82: Quadrupole modes in SBP1 and S1 with electric (EE) boundaries.

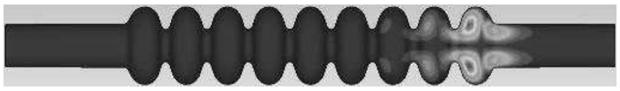
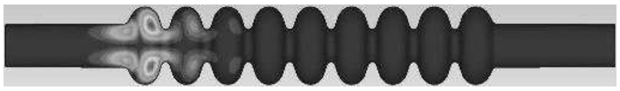
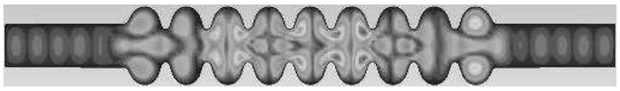
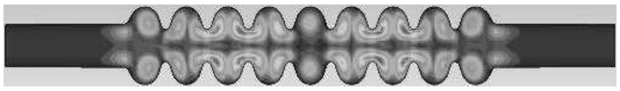
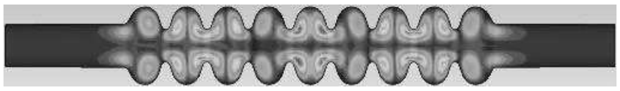
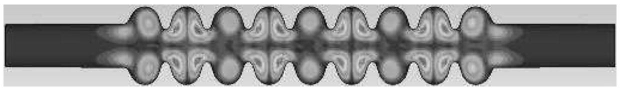
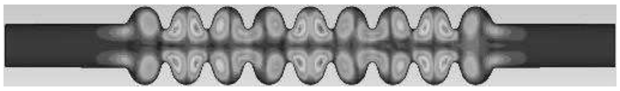
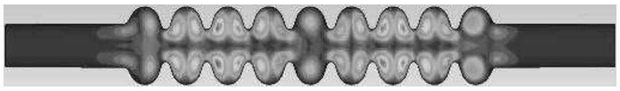
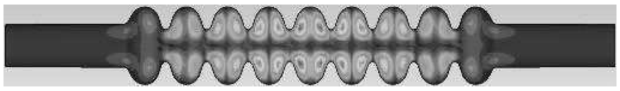
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.9214	0.069	SBP1-1
	7.9216	0.069	SBP1-2
	8.1894	0.506	S1-1
	8.1940	0.203	S1-2
	8.2011	0.006	S1-3
	8.2097	0.027	S1-4
	8.2184	0.001	S1-5
	8.2261	0.005	S1-6
	8.2313	0.000	S1-7

VII.2 SBP2 and S2 (EE)

Table C.83: Parameters settings for SBP2 and S2 with electric (EE) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.40-9.05	20	FPBA	1,300,000	0.91	SBP2, S2

Table C.84: Quadrupole modes in SBP2 and S2 with electric (EE) boundaries.

E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	8.7611	0.015	SBP2-1
	8.7614	0.013	SBP2-2
	8.8029	0.103	S2-1
	8.8097	0.001	S2-2
	8.8192	0.003	S2-3
	8.8295	0.001	S2-4
	8.8392	0.024	S2-5
	8.8469	0.036	S2-6
	8.8519	0.004	S2-7

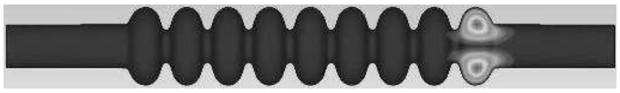
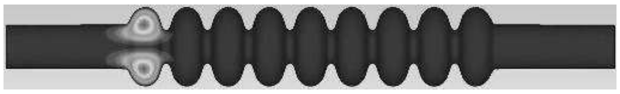
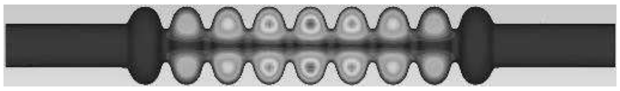
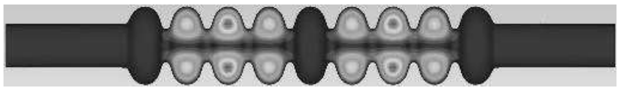
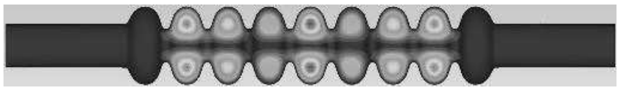
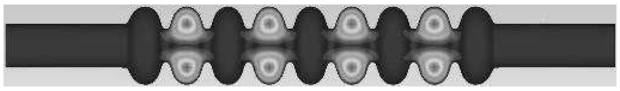
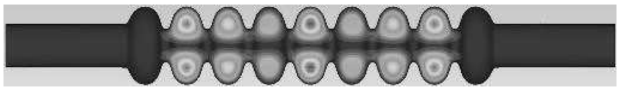
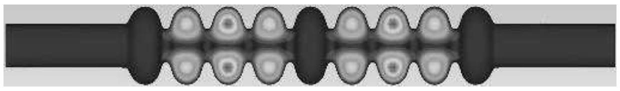
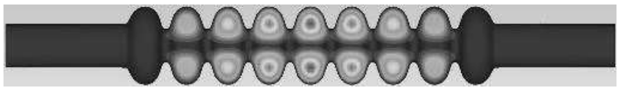
VIII Sextupole (Magnetic Boundaries)

VIII.1 SBP1 and S1 (MM)

Table C.85: Parameters settings for SBP1 and S1 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
7.7-8.0	20	FPBA	1,000,000	1.06	SBP1
8.0-8.3	20	FPBA	1,100,000	0.94	S1

Table C.86: Quadrupole modes in SBP1 and S1 with magnetic (MM) boundaries.

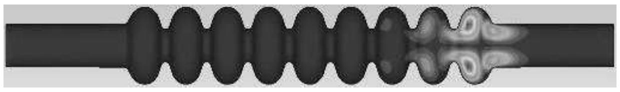
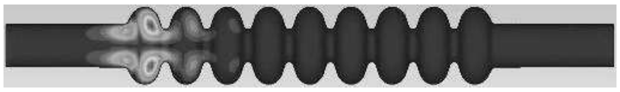
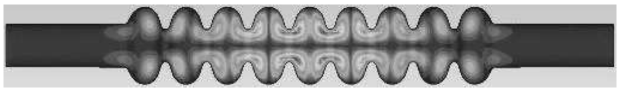
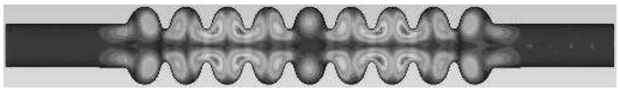
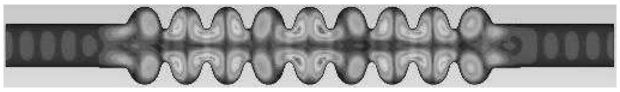
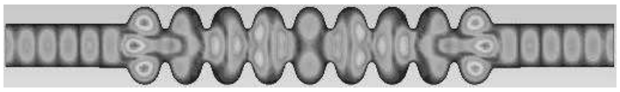
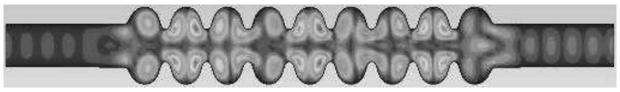
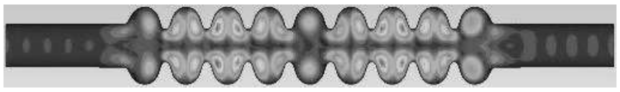
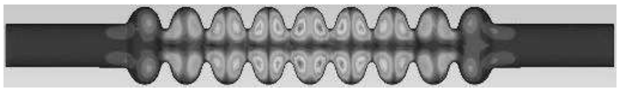
E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	7.9212	0.060	SBP1-1
	7.9215	0.068	SBP1-2
	8.1894	0.506	S1-1
	8.1940	0.203	S1-2
	8.2011	0.006	S1-3
	8.2097	0.027	S1-4
	8.2184	0.001	S1-5
	8.2261	0.005	S1-6
	8.2313	0.000	S1-7

VIII.2 SBP2 and S2 (MM)

Table C.87: Parameters settings for SBP2 and S2 with magnetic (MM) boundaries.

Frequency range (GHz)	**Lines per wavelength**	**Mesh type**	**Number of Mesh cells**	**Max mesh step** (mm)	**Band**
8.4-9.0	20	FPBA	1,300,000	0.91	SBP2, S2

Table C.88: Quadrupole modes in SBP2 and S2 with magnetic (MM) boundaries.

E-field Amplitude	**f**(GHz)	**R/Q**(Ω/cm^2)	**Band**
	8.7612	0.018	SBP2-1
	8.7615	0.017	SBP2-2
	8.8029	0.000	S2-1
	8.8097	0.001	S2-2
	8.8191	0.002	S2-3
	8.8294	0.412	S2-4
	8.8391	0.028	S2-5
	8.8468	0.035	S2-6
	8.8519	0.004	S2-7