Compact Camera Module

Introduction

Compact camera modules are widely used in electronic devices such as mobile phones and tablet computers. In order to reduce both the size and number of elements required the optical design will typically incorporate several highly aspheric surfaces. This model demonstrates a five element (plus filter) design using the 'Aspheric Even Lens 3D' part from the Ray Optics Module part library.

Model Definition

An overview of the optical design of the compact camera module used in this tutorial is shown in Figure 1. The prescription for this lens design can be found in Ref. 1. It has a 7.0 mm focal length, a $f/2.4$ focal ratio, and a nominal field of view of 36°.

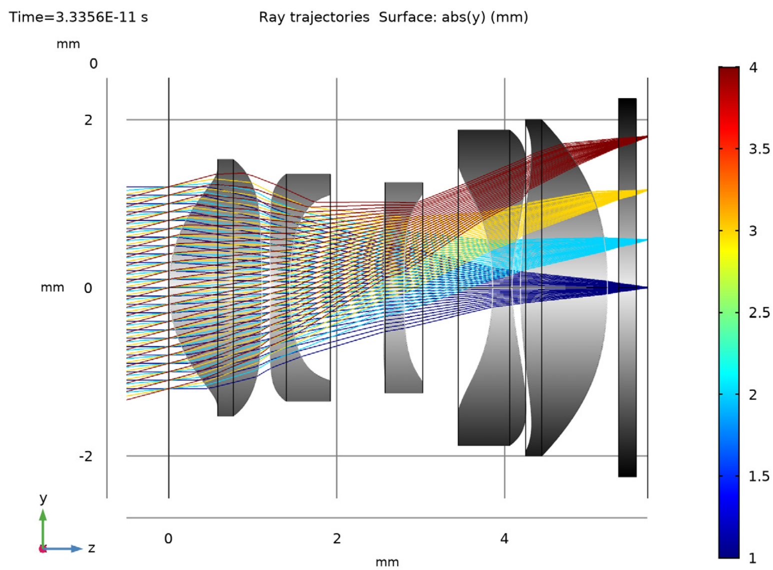

Figure 1: Overview of the Compact Camera Module optical design. In this cross-section view, the rays have been colored by release index.

The detailed optical prescription is given in Table 1. Instructions for creating the lens geometry sequence (Figure 2) can be found in the Appendix — Geometry Instructions. In addition to the parameters used to define the Compact Camera Module geometry, a set of parameters are required to define the ray tracing model. These are listed in Table 2.

TABLE 1: COMPACT CAMERA MODULE OPTICAL PRESCRIPTION.

Index	**Name**	**Radius (mm)**	**Conic constant**	**Thickness (mm)**	**Refractive index**	**Diameter (mm)**
0	Object	∞	—	∞	—	—
1	Stop	∞	—	0.0000	—	2.50
2	Lens 1	1.679	0.22669364	1.1080	1.544	2.90
		Aspheric coefficients:	$A_4 = 9.80281 \cdot 10^{-3}$, $A_6 = -3.81227 \cdot 10^{-2}$, $A_8 = 2.39681 \cdot 10^{-2}$, $A_{10} = -6.29128 \cdot 10^{-3}$, $A_{12} = -2.75496 \cdot 10^{-3}$, $A_{14} = -2.69638 \cdot 10^{-4}$			
3		-9.162	0	0.1000	—	3.05
		Aspheric coefficients:	$A_4 = 3.73187 \cdot 10^{-2}$, $A_6 = -8.91760 \cdot 10^{-3}$, $A_8 = -5.89384 \cdot 10^{-2}$, $A_{10} = 4.41115 \cdot 10^{-2}$, $A_{12} = -1.26858 \cdot 10^{-2}$, $A_{14} = 1.16125 \cdot 10^{-3}$			
4	Lens 2	-15.649	0	0.2300	1.632	2.70
		Aspheric coefficients:	$A_4 = 6.93172 \cdot 10^{-2}$, $A_6 = -4.31157 \cdot 10^{-2}$, $A_8 = 2.33346e \cdot 10^{-2}$, $A_{10} = -2.33074 \cdot 10^{-2}$, $A_{12} = 2.22119 \cdot 10^{-2}$, $A_{14} = -4.84076 \cdot 10^{-3}$			
5		3.482	8.70133393	1.1305	—	2.21
		Aspheric coefficients:	$A_4 = 5.21579 \cdot 10^{-3}$, $A_6 = 7.15829 \cdot 10^{-2}$, $A_8 = -4.60926 \cdot 10^{-2}$, $A10 = 1.24310 \cdot 10^{-2}$, $A_{12} = 3.32216e \cdot 10^{-2}$			
6	Lens 3	-12.801	0	0.2300	1.632	2.30
		Aspheric coefficients:	$A_4 = 3.96000 \cdot 10^{-2}$, $A_6 = -3.42179 \cdot 10^{-2}$, $A_8 = 7.75523 \cdot 10^{-2}$, $A_{10} = -4.22361 \cdot 10^{-2}$			
7		21.119	0	1.0559	—	2.25
		Aspheric coefficients:	$A_4 = 1.01117 \cdot 10^{-1}$, $A_6 = -3.21118 \cdot 10^{-2}$, $A_8 = 9.03668 \cdot 10^{-2}$, $A_{10} = -3.37156 \cdot 10^{-2}$, $A_{12} = -6.52751 \cdot 10^{-3}$			
8	Lens 4	-3.266	0.85965815	0.2300	1.544	2.95
		Aspheric coefficients:	$A_4 = -4.91398 \cdot 10^{-2}$, $A_6 = -5.57533 \cdot 10^{-3}$, $A_8 = 1.31557 \cdot 10^{-2}$, $A_{10} = 1.22280 \cdot 10^{-3}$, $A_{12} = -9.54019 \cdot 10^{-4}$, $A_{14} = -2.40349 \cdot 10^{-6}$			
9		2.724	0	0.1000	—	3.75
		Aspheric coefficients:	$A_4 = -8.88955 \cdot 10^{-2}$, $A_6 = 2.87927 \cdot 10^{-2}$, $A_8 = -8.83436 \cdot 10^{-3}$, $A_{10} = 1.57329 \cdot 10^{-3}$, $A_{12} = -2.24134 \cdot 10^{-4}$			
10	Lens 5	5.272	0	1.0356	1.632	3.90
		Aspheric coefficients:	$A_4 = -2.38313 \cdot 10^{-2}$, $A_6 = 5.50321 \cdot 10^{-3}$, $A_8 = -9.19080 \cdot 10^{-4}$, $A_{10} = -9.80631 \cdot 10^{-5}$			
11		-4.681	3.15790955	0.1337	—	4.00
		Aspheric coefficients:	$A_4 = -3.17139 \cdot 10^{-2}$, $A_6 = 3.80781 \cdot 10^{-3}$, $A_8 = 3.43810 \cdot 10^{-4}$, $A_{10} = -3.27888 \cdot 10^{-5}$			
12	IR Filter	∞	0	0.2100	1.516	4.50
13		∞	0	0.1363	—	4.50
14	Image Plane	∞	0	—	—	5.00

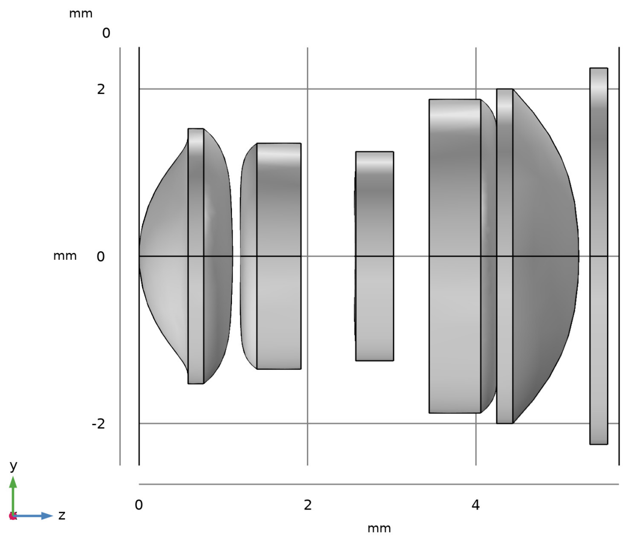

Figure 2: The Compact Camera Module geometry sequence. Instructions for creating the lens geometry can be found in the Appendix.

TABLE 2: COMPACT CAMERA MODULE MODEL DEFINITIONS.

Parameter	**Value**	**Description**
λ_{vac}	587.56 nm	Vacuum wavelength
$n_{ref,1}$	1.544	Lens 1 and 4 refractive index (at 587.56 nm)
$n_{ref,2}$	1.632	Lens 2, 3, and 5 refractive index (at 587.56 nm)
$n_{ref,3}$	1.516	IR filter refractive index (at 587.56 nm)
D_{pupil}	2.50 mm	Entrance pupil diameter
N_{ring}	25	Number of hexapolar rings. (N_{rays} = 1951)
θ_1	0°	Field angle 1
θ_2	5°	Field angle 2
θ_3	10°	Field angle 3
θ_4	15°	Field angle 4
Δz	-0.5 mm	Ray release z-coordinate

The ray tracing algorithm used by the Geometrical Optics interface computes the refracted ray direction based on a discretized geometry via the underlying finite element mesh. In this model, a cubic geometry shape order is used in order to reduce the discretization error. However, it is sometimes necessary to refine the mesh on certain surfaces in order to further reduce the effects of discretization. The aspheric surfaces of the Compact Camera Module have been assigned to a cumulative selection (Figure 3) on which the mesh has been refined (Figure 4).[1]

The Compact Camera Module is assumed to be operating in air at room temperature. The wavelength is set to $\lambda = 587.56$ nm (that is, the wavelength at which the refractive indices are specified). Other Geometrical Optics features include the use of cumulative selections to define obstructions (see Figure 5) and the focal surface. A hexapolar grid release is used to launch rays at each of the four field angles. Each release has 25 rings, giving a total of 1951 rays per field angle. Detailed instructions for creating this model can be found in Modeling Instructions.

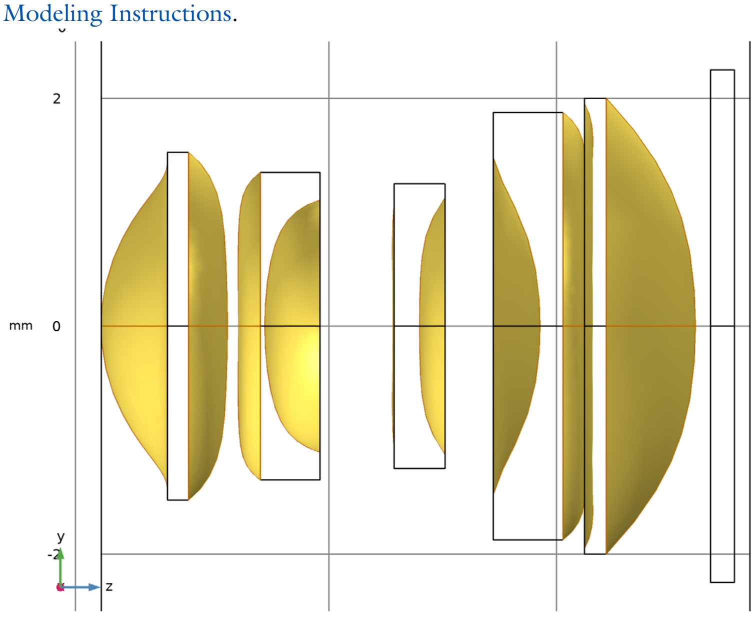

Figure 3: The Compact Camera Module aspheric surface cumulative selection.

1. This level of mesh refinement is only needed for certain surface types. The default physics-controlled mesh is often suitable for single physics ray tracing studies when using the high-accuracy surfaces used in the spherical and conic lens and mirror parts from the Ray Optics Module Part Libraries.

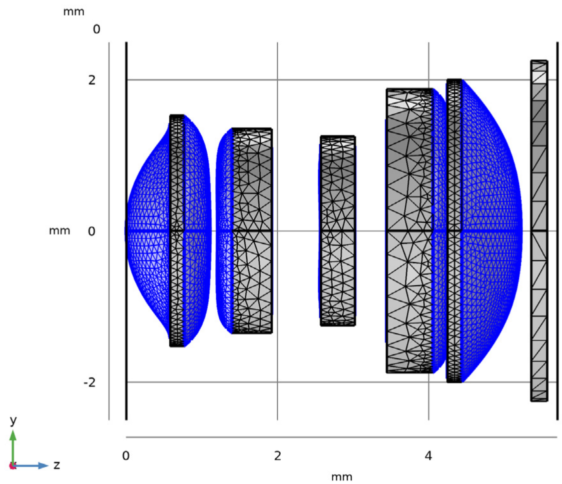

Figure 4: The Compact Camera Module mesh. This view shows the aspheric surfaces on which the mesh has been refined.

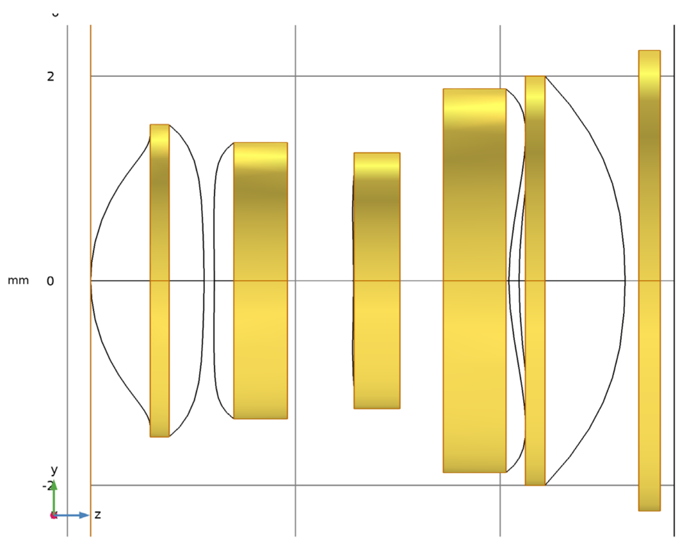

Figure 5: The Compact Camera Module obstruction cumulative selection.

Results and Discussion

The ray trace of the Compact Camera Module is shown in Figure 6. The lens geometry has been rendered using component selections and **Cut Plane** datasets. In this figure the rays have been colored according to the radial distance from the centroid of each release at the image plane. It can be seen that the outermost ring of rays contribute most significantly to the rays aberrations.

The spot diagram for this ray tracing study can be seen in Figure 7. In this figure the rays are colored according to their relative radial location at the stop. This also makes the origin of the most aberrant rays apparent.

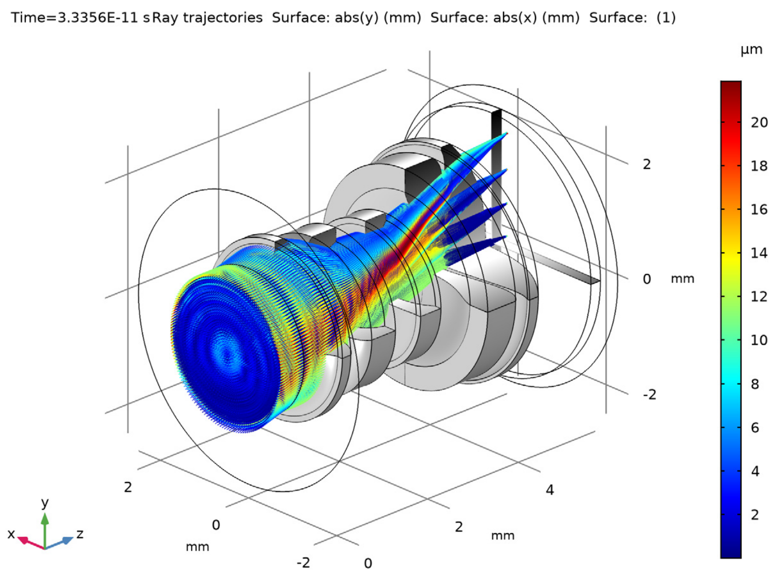

Figure 6: Ray diagram of the Compact Camera Module where the rays are colored by their radial distance from the centroid on the image plane.

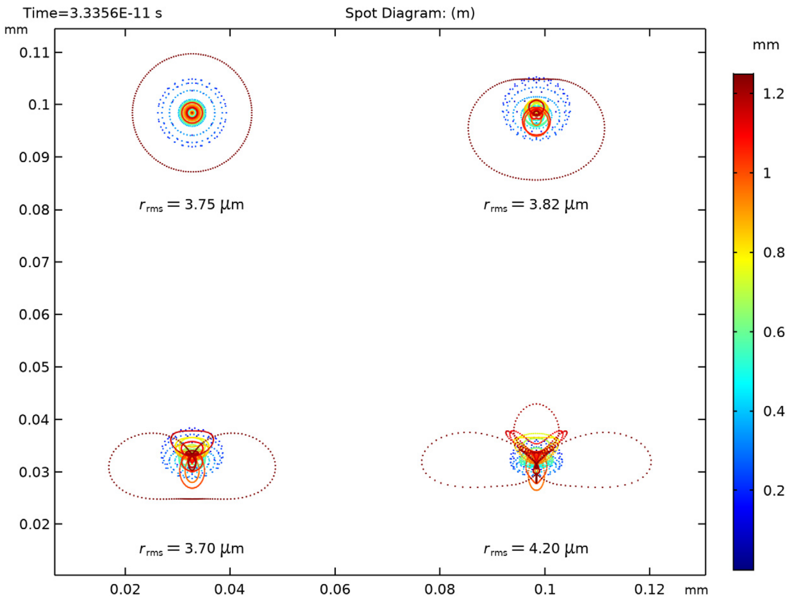

Figure 7: Spot diagram for the Compact Camera Module. The spots have been colored according to their radial distance from the center of the entrance pupil.

Reference

1. R.I. Mercado, 2015. Small form factor telephoto camera. US Patent 9 223 118 B2, filed Oct. 31, 2013 and issued Dec. 29, 2015.

Application Library path: `Ray_Optics_Module/Lenses_Cameras_and_Telescopes/compact_camera_module`

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 In the **Select Physics** tree, select **Optics>Ray Optics>Geometrical Optics (gop)**. This model will only consider a single physics ray trace.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Ray Tracing**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, type `Parameters 1: Lens Prescription` in the **Label** text field. The prescription of the Compact Camera Module (see Table 1) will be added when the geometry sequence is inserted in the following section.

Now, load the model definitions (Table 2) for the Compact Camera Module from a text file.

Parameters 2

1 In the **Home** toolbar, click **Parameters** and choose **Add>Parameters**.

2 In the **Settings** window for **Parameters**, type `Parameters 2: General` in the **Label** text field.

3 Locate the **Parameters** section. Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `compact_camera_module_parameters.txt`.

GEOMETRY 1

Insert the prepared geometry sequence from file. You can read the instructions for creating the geometry in Appendix — Geometry Instructions. Following insertion, the full set of parameter definitions will be available in the **Parameters** node.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, type `Compact Camera Module` in the **Label** text field.

3 Locate the **Units** section. From the **Length unit** list, choose **mm**.

4 In the **Geometry** toolbar, click **Insert Sequence**.

5 Browse to the model's Application Libraries folder and double-click the file `compact_camera_module_geom_sequence.mph`.

6 In the **Geometry** toolbar, click **Build All**.

7 Click the **Orthographic Projection** button in the **Graphics** toolbar. Orient the view to place the optical axis (z-axis) horizontal and the y-axis vertical. Compare the resulting geometry to Figure 2. The **Cumulative Selections** defining the aspheric surfaces and obstructions can be seen in Figure 3 and Figure 5 respectively.

COMPONENT 1 (COMP1)

1 In the **Model Builder** window, click **Component 1 (comp1)**.

2 In the **Settings** window for **Component**, locate the **General** section.

3 Find the **Mesh frame coordinates** subsection. From the **Geometry shape order** list, choose **Cubic**. The ray tracing algorithm used by the Geometrical Optics interface computes the refracted ray direction based on a discretized geometry via the underlying finite element mesh. A cubic geometry shape order usually introduces less discretization error compared to the default, which uses linear and quadratic polynomials.

DEFINITIONS

In the following, create a selection containing the surfaces in 3 of the 4 axially symmetric quadrants of the camera. These will be used during postprocessing.

Box 1

1 In the **Definitions** toolbar, click **Box**.

2 In the **Settings** window for **Box**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Boundary**.

4 Locate the **Box Limits** section. In the **x maximum** text field, type `0`.

5 In the **y minimum** text field, type `0`.

6 Locate the **Output Entities** section. From the **Include entity if** list, choose **Entity inside box**.

Complement 1

1 In the **Definitions** toolbar, click **Complement**.

2 In the **Settings** window for **Complement**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Boundary**.

4 Locate the **Input Entities** section. Under **Selections to invert**, click **Add**.

5 In the **Add** dialog box, in the **Selections to invert** list, choose **Box 1**, **All (Stop)**, **Exterior (IR Filter)**, and **All (Image Plane)**.

6 Click **OK**.

MATERIALS

Now, define the lens materials. In this tutorial the three lens materials will be assigned a refractive index appropriate for the chosen wavelength. However, the material refractive indices could be defined as a function of wavelength (and temperature) using one of the built-in optical dispersion models.

Material 1 (mat1)

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 Select Domains 3 and 4 only.

3 In the **Settings** window for **Material**, locate the **Material Contents** section.

4 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Refractive index, real part	n_iso ; nii = n_iso, nij = 0	`nref1`	1	Refractive index

Material 2 (mat2)

1 Right-click **Materials** and choose **Blank Material**.

2 Select Domains 2, 5, and 6 only.

3 In the **Settings** window for **Material**, locate the **Material Contents** section.

4 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Refractive index, real part	n_iso ; nii = n_iso, nij = 0	`nref2`	1	Refractive index

Material 3 (mat3)

1. Right-click **Materials** and choose **Blank Material**.
2. Select Domain 1 only.
3. In the **Settings** window for **Material**, locate the **Material Contents** section.
4. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Refractive index, real part	n_iso ; nii = n_iso, nij = 0	`nref3`	1	Refractive index

GEOMETRICAL OPTICS (GOP)

In the following sections the physics is defined.

1. In the **Model Builder** window, under **Component 1 (comp1)** click **Geometrical Optics (gop)**.
2. In the **Settings** window for **Geometrical Optics**, locate the **Ray Release and Propagation** section.
3. In the **Maximum number of secondary rays** text field, type `0`. In this simulation stray light is not being traced, so reflected rays will not be produced at the lens surfaces.
4. Select the **Use geometry normals for ray-boundary interactions** check box. In this simulation, the geometry normals are used to apply the boundary conditions on all refracting surfaces. This is appropriate for the highest accuracy ray traces in single-physics simulations, where the geometry is not deformed.
5. Locate the **Material Properties of Exterior and Unmeshed Domains** section. From the **Optical dispersion model** list, choose **Air, Edlen (1953)**. It is assumed that the lenses are surrounded by air at room temperature.

Material Discontinuity 1

1. In the **Model Builder** window, under **Component 1 (comp1)>Geometrical Optics (gop)** click **Material Discontinuity 1**.
2. In the **Settings** window for **Material Discontinuity**, locate the **Rays to Release** section.
3. From the **Release reflected rays** list, choose **Never**.

Ray Properties 1

1. In the **Model Builder** window, click **Ray Properties 1**.
2. In the **Settings** window for **Ray Properties**, locate the **Ray Properties** section.
3. In the λ_0 text field, type `lambda`.

Wall 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Wall**.
2 In the **Settings** window for **Wall**, type `Obstructions` in the **Label** text field.
3 Locate the **Boundary Selection** section. From the **Selection** list, choose **Obstructions**.
4 Locate the **Wall Condition** section. From the **Wall condition** list, choose **Disappear**.

Wall 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Wall**.
2 In the **Settings** window for **Wall**, type `Image Surface` in the **Label** text field.
3 Locate the **Boundary Selection** section. From the **Selection** list, choose **All (Image Plane)**.

Release from Grid 1

1 In the **Physics** toolbar, click **Global** and choose **Release from Grid**.
2 In the **Settings** window for **Release from Grid**, locate the **Initial Coordinates** section.
3 From the **Grid type** list, choose **Hexapolar**.
4 Specify the $\mathbf{q}_c$ vector as

0	x
dz*tan(theta1)	y
dz	z

5 Specify the $\mathbf{r}_c$ vector as

0	x
0	y
1	z

6 In the R_c text field, type `D_pupil/2`.
7 In the N_c text field, type `N_ring`.
8 Locate the **Ray Direction Vector** section. Specify the $\mathbf{L}_0$ vector as

0	x
tan(theta1)	y
1	z

Release from Grid 2

1 Right-click **Release from Grid 1** and choose **Duplicate**.
2 In the **Settings** window for **Release from Grid**, locate the **Initial Coordinates** section.

3 Specify the $\mathbf{q}_c$ vector as

0	x
dz*tan(theta2)	y
dz	z

4 Locate the **Ray Direction Vector** section. Specify the $\mathbf{L}_0$ vector as

0	x
tan(theta2)	y
1	z

Release from Grid 3

1 Right-click **Release from Grid 2** and choose **Duplicate**.

2 In the **Settings** window for **Release from Grid**, locate the **Initial Coordinates** section.

3 Specify the $\mathbf{q}_c$ vector as

0	x
dz*tan(theta3)	y
dz	z

4 Locate the **Ray Direction Vector** section. Specify the $\mathbf{L}_0$ vector as

0	x
tan(theta3)	y
1	z

Release from Grid 4

1 Right-click **Release from Grid 3** and choose **Duplicate**.

2 In the **Settings** window for **Release from Grid**, locate the **Initial Coordinates** section.

3 Specify the $\mathbf{q}_c$ vector as

0	x
dz*tan(theta4)	y
dz	z

4 Locate the **Ray Direction Vector** section. Specify the $\mathbf{L}_0$ vector as

0	x
tan(theta4)	y
1	z

MESH 1

Next, refine the mesh on the aspheric surfaces.

Free Triangular 1

1. In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **More Operations>Free Triangular**.
2. In the **Settings** window for **Free Triangular**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Aspheric Surfaces**.

Size 1

1. Right-click **Free Triangular 1** and choose **Size**.
2. In the **Settings** window for **Size**, locate the **Element Size** section.
3. From the **Predefined** list, choose **Extremely fine**.

Free Tetrahedral 1

1. In the **Model Builder** window, right-click **Mesh 1** and choose **Free Tetrahedral**.
2. Click **Build All**.

STUDY 1

Step 1: Ray Tracing

1. In the **Model Builder** window, under **Study 1** click **Step 1: Ray Tracing**.
2. In the **Settings** window for **Ray Tracing**, locate the **Study Settings** section.
3. From the **Time-step specification** list, choose **Specify maximum path length**.
4. From the **Length unit** list, choose **mm**.
5. In the **Lengths** text field, type `0 10`. The second path length is sufficiently long to ensure that all rays make it to the image surface.
6. In the **Home** toolbar, click **Compute**.

RESULTS

In the following steps the default ray diagram is adjusted to show different aspects of the ray trace. First, define two cut planes which can be used to render the Compact Camera Module cross-section.

Cut Plane 1

1 In the **Results** toolbar, click **Cut Plane**.

2 In the **Settings** window for **Cut Plane**, locate the **Plane Data** section.

3 From the **Plane** list, choose **ZX-planes**.

Cut Plane 2

In the **Results** toolbar, click **Cut Plane**.

Ray Trajectories (gop)

1 In the **Model Builder** window, under **Results** click **Ray Trajectories (gop)**.

2 In the **Settings** window for **3D Plot Group**, type `Ray Diagram 1` in the **Label** text field.

Ray Trajectories 1

In the **Model Builder** window, expand the **Results>Ray Diagram 1** node.

Color Expression 1

1 In the **Model Builder** window, expand the **Ray Trajectories 1** node, then click **Color Expression 1**.

2 In the **Settings** window for **Color Expression**, locate the **Expression** section.

3 In the **Expression** text field, type `gop.prf`. This is the index of each of the release features, starting at 1

Filter 1

1 In the **Model Builder** window, click **Filter 1**.

2 In the **Settings** window for **Filter**, locate the **Ray Selection** section.

3 From the **Rays to include** list, choose **Logical expression**.

4 In the **Logical expression for inclusion** text field, type `at(0,abs(x))<0.01[mm]`. Only the tangential rays will be rendered in this view.

Surface 1

1 In the **Model Builder** window, right-click **Ray Diagram 1** and choose **Surface**.

2 In the **Settings** window for **Surface**, locate the **Data** section.

3 From the **Dataset** list, choose **Cut Plane 2**.

4 Locate the **Expression** section. In the **Expression** text field, type `abs(y)`.

5 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Gradient**.

6 From the **Top color** list, choose **Black**.

7 From the **Bottom color** list, choose **White**.

8 Clear the **Color legend** check box.

9 In the **Ray Diagram 1** toolbar, click **Plot**. Orient the view to match Figure 1 to show only the tangential rays.

Ray Diagram 1.1

1 Right-click **Ray Diagram 1** and choose **Duplicate**.

2 In the **Settings** window for **3D Plot Group**, type `Ray Diagram 2` in the **Label** text field.

3 Locate the **Plot Settings** section. From the **View** list, choose **New view**.

4 Locate the **Color Legend** section. Select the **Show units** check box.

5 In the **Model Builder** window, expand the **Results>Ray Diagram 2** node.

Color Expression 1

1 In the **Model Builder** window, expand the **Results>Ray Diagram 2>Ray Trajectories 1** node, then click **Color Expression 1**.

2 In the **Settings** window for **Color Expression**, locate the **Expression** section.

3 In the **Expression** text field, type `at('last',gop.rrel)`. This is the radial coordinate relative to the centroid of each release feature at the image plane.

4 From the **Unit** list, choose **µm**.

Filter 1

1 In the **Model Builder** window, click **Filter 1**.

2 In the **Settings** window for **Filter**, locate the **Ray Selection** section.

3 From the **Rays to include** list, choose **All**.

Surface 2

1 In the **Model Builder** window, under **Results>Ray Diagram 2** right-click **Surface 1** and choose **Duplicate**.

2 In the **Settings** window for **Surface**, locate the **Data** section.

3 From the **Dataset** list, choose **Cut Plane 1**.

4 Locate the **Expression** section. In the **Expression** text field, type `abs(x)`.

Surface 3

1 In the **Model Builder** window, right-click **Ray Diagram 2** and choose **Surface**.

2 In the **Settings** window for **Surface**, locate the **Coloring and Style** section.

3 From the **Coloring** list, choose **Uniform**.

4 From the **Color** list, choose **Gray**.

Selection 1

1 Right-click **Surface 3** and choose **Selection**.

2 In the **Settings** window for **Selection**, locate the **Selection** section.

3 From the **Selection** list, choose **Complement 1**.

4 In the **Ray Diagram 2** toolbar, click **Plot**. Orient the view to match Figure 6 to show the all the rays.

2D Plot Group 3

In the following steps a spot diagram will be created to show the location of the rays in the image plane.

1 In the **Home** toolbar, click **Add Plot Group** and choose **2D Plot Group**.

2 In the **Settings** window for **2D Plot Group**, type `Spot Diagram` in the **Label** text field.

3 Locate the **Color Legend** section. Select the **Show units** check box.

Spot Diagram 1

In the **Spot Diagram** toolbar, click **More Plots** and choose **Spot Diagram**.

Color Expression 1

1 Right-click **Spot Diagram 1** and choose **Color Expression**.

2 In the **Settings** window for **Color Expression**, locate the **Expression** section.

3 In the **Expression** text field, type `at(0,gop.rrel)`. This is the radial coordinate relative to the centroid at the entrance pupil for each ray release.

4 In the **Spot Diagram** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar. Compare the resulting image to Figure 7.

Appendix — Geometry Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 Click **Done**.

GEOMETRY 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, type `Compact Camera Module Geometry Sequence` in the **Label** text field.

3 Locate the **Units** section. From the **Length unit** list, choose **mm**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `compact_camera_module_geom_sequence_parameters.txt`.

PART LIBRARIES

1 In the **Home** toolbar, click **Windows** and choose **Part Libraries**.

2 In the **Model Builder** window, under **Component 1 (comp1)** click **Compact Camera Module Geometry Sequence**.

3 In the **Part Libraries** window, select **Ray Optics Module>3D>Apertures and Obstructions>circular_planar_annulus** in the tree.

4 Click **Add to Geometry**.

COMPACT CAMERA MODULE GEOMETRY SEQUENCE

Circular Planar Annulus 1 (pi1)

1 In the **Model Builder** window, under **Component 1 (comp1)>Compact Camera Module Geometry Sequence** click **Circular Planar Annulus 1 (pi1)**.

2 In the **Settings** window for **Part Instance**, type `Stop` in the **Label** text field.

3 Locate the **Input Parameters** section. In the table, enter the following settings:

Name	Expression	Value	Description
d0	`d0_S`	5 mm	Diameter, outer
d1	`d1_S`	2.505 mm	Diameter, inner
nix	`nix`	0	Local optical axis, x-component

Name	Expression	Value	Description
niy	niy	0	Local optical axis, y-component
niz	niz	1	Local optical axis, z-component

4 Click to expand the **Boundary Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
All	√	√	None

5 Click **New Cumulative Selection**.

6 In the **New Cumulative Selection** dialog box, type `Aspheric Surfaces` in the **Name** text field.

7 Click **OK**. This selection will be used to to refine the mesh on the aspheric surfaces.

8 In the **Settings** window for **Part Instance**, locate the **Boundary Selections** section.

9 Click **New Cumulative Selection**.

10 In the **New Cumulative Selection** dialog box, type `Obstructions` in the **Name** text field.

11 Click **OK**.

PART LIBRARIES

1 In the **Home** toolbar, click **Windows** and choose **Part Libraries**.

2 In the **Model Builder** window, click **Compact Camera Module Geometry Sequence**.

3 In the **Part Libraries** window, select **Ray Optics Module>3D>Aspheric Lenses> aspheric_even_lens_3d** in the tree.

4 Click **Add to Geometry**.

5 In the **Select Part Variant** dialog box, select **Specify clear aperture diameter** in the **Select part variant** list.

6 Click **OK**.

COMPACT CAMERA MODULE GEOMETRY SEQUENCE

Aspheric Even Lens 3D 1 (pi2)

1 In the **Model Builder** window, under **Component 1 (comp1)> Compact Camera Module Geometry Sequence** click **Aspheric Even Lens 3D 1 (pi2)**.

2 In the **Settings** window for **Part Instance**, type `Lens 1` in the **Label** text field.

3 Locate the **Input Parameters** section. Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `compact_camera_module_geom_sequence_lens1.txt`. These files are simplify the mapping between the lens prescription and the input parameters for this part. Similar files will be used for each of the four remaining lenses.

5 Locate the **Boundary Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
Exterior	√	√	None
Surface 1		√	Aspheric Surfaces
Surface 2		√	Aspheric Surfaces
Edges		√	Obstructions

Aspheric Even Lens 3D 1 (pi3)

1 In the **Geometry** toolbar, click **Parts** and choose **Aspheric Even Lens 3D**.

2 In the **Settings** window for **Part Instance**, type `Lens 2` in the **Label** text field.

3 Locate the **Input Parameters** section. Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `compact_camera_module_geom_sequence_lens2.txt`.

5 Locate the **Position and Orientation of Output** section. Find the **Coordinate system to match** subsection. From the **Take work plane from** list, choose **Lens 1 (pi2)**.

6 From the **Work plane** list, choose **Surface 2 vertex intersection (wp2)**.

7 Find the **Displacement** subsection. In the **zw** text field, type `T_1`.

8 Locate the **Boundary Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
Exterior	√	√	None
Surface 1		√	Aspheric Surfaces
Surface 2		√	Aspheric Surfaces
Edges		√	Obstructions

Aspheric Even Lens 3D 1 (pi4)

1 In the **Geometry** toolbar, click **Parts** and choose **Aspheric Even Lens 3D**.

2 In the **Settings** window for **Part Instance**, type `Lens 3` in the **Label** text field.

3 Locate the **Input Parameters** section. Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `compact_camera_module_geom_sequence_lens3.txt`.

5 Locate the **Position and Orientation of Output** section. Find the **Coordinate system to match** subsection. From the **Take work plane from** list, choose **Lens 2 (pi3)**.

6 From the **Work plane** list, choose **Surface 2 vertex intersection (wp2)**.

7 Find the **Displacement** subsection. In the **zw** text field, type `T_2`.

8 Locate the **Boundary Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
Exterior	√	√	None
Surface 1		√	Aspheric Surfaces
Surface 2		√	Aspheric Surfaces
Edges		√	Obstructions

Aspheric Even Lens 3D 1 (pi5)

1 In the **Geometry** toolbar, click **Parts** and choose **Aspheric Even Lens 3D**.

2 In the **Settings** window for **Part Instance**, type `Lens 4` in the **Label** text field.

3 Locate the **Input Parameters** section. Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `compact_camera_module_geom_sequence_lens4.txt`.

5 Locate the **Position and Orientation of Output** section. Find the **Coordinate system to match** subsection. From the **Take work plane from** list, choose **Lens 3 (pi4)**.

6 From the **Work plane** list, choose **Surface 2 vertex intersection (wp2)**.

7 Find the **Displacement** subsection. In the **zw** text field, type `T_3`.

8 Locate the **Boundary Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
Exterior	√	√	None
Surface 1		√	Aspheric Surfaces
Surface 2		√	Aspheric Surfaces
Edges		√	Obstructions

Aspheric Even Lens 3D 1 (pi6)

1 In the **Geometry** toolbar, click **Parts** and choose **Aspheric Even Lens 3D**.

2 In the **Settings** window for **Part Instance**, type `Lens 5` in the **Label** text field.

3 Locate the **Input Parameters** section. Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `compact_camera_module_geom_sequence_lens5.txt`.

5 Locate the **Position and Orientation of Output** section. Find the **Coordinate system to match** subsection. From the **Take work plane from** list, choose **Lens 4 (pi5)**.

6 From the **Work plane** list, choose **Surface 2 vertex intersection (wp2)**.

7 Find the **Displacement** subsection. In the **zw** text field, type `T_4`.

8 Locate the **Boundary Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
Exterior	√	√	None
Surface 1		√	Aspheric Surfaces
Surface 2		√	Aspheric Surfaces
Edges		√	Obstructions

PART LIBRARIES

1 In the **Geometry** toolbar, click **Parts** and choose **Part Libraries**.

2 In the **Model Builder** window, click **Compact Camera Module Geometry Sequence**.

3 In the **Part Libraries** window, select **Ray Optics Module>3D>Spherical Lenses>spherical_lens_3d** in the tree.

4 Click **Add to Geometry**.

5 In the **Select Part Variant** dialog box, select **Specify clear aperture diameter** in the **Select part variant** list.

6 Click **OK**.

COMPACT CAMERA MODULE GEOMETRY SEQUENCE

Spherical Lens 3D 1 (pi7)

1 In the **Model Builder** window, under **Component 1 (comp1)>Compact Camera Module Geometry Sequence** click **Spherical Lens 3D 1 (pi7)**.

2 In the **Settings** window for **Part Instance**, type `IR Filter` in the **Label** text field.

3 Locate the **Input Parameters** section. In the table, enter the following settings:

Name	Expression	Value	Description
R1	0	0 m	Radius of curvature, surface 1 (+convex/ -concave)
R2	0	0 m	Radius of curvature, surface 2 (-convex/ +concave)
Tc	`Tc_F`	0.21 mm	Center thickness
d0	`d0_F`	4.5 mm	Diameter, outer
d1	0	0 m	Diameter, surface 1
d2	0	0 m	Diameter, surface 2
d1_clear	0	0 m	Clear aperture diameter, surface 1
d2_clear	0	0 m	Clear aperture diameter, surface 2

4 Locate the **Position and Orientation of Output** section. Find the **Coordinate system to match** subsection. From the **Take work plane from** list, choose **Lens 5 (pi6)**.

5 From the **Work plane** list, choose **Surface 2 vertex intersection (wp2)**.

6 Find the **Displacement** subsection. In the **zw** text field, type `T_5`.

7 Locate the **Boundary Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
Exterior	√	√	None
Edges		√	Obstructions

Circular Planar Annulus 1 (pi8)

1 In the **Geometry** toolbar, click **Parts** and choose **Circular Planar Annulus**.

2 In the **Settings** window for **Part Instance**, type `Image Plane` in the **Label** text field.

3 Locate the **Input Parameters** section. In the table, enter the following settings:

Name	Expression	Value	Description
d0	`d0_I`	5 mm	Diameter, outer
d1	0	0 m	Diameter, inner

4 Locate the **Position and Orientation of Output** section. Find the **Coordinate system to match** subsection. From the **Take work plane from** list, choose **IR Filter (pi7)**.

5 From the **Work plane** list, choose **Surface 2 vertex intersection (wp2)**.

6 Find the **Displacement** subsection. In the **zw** text field, type `T_6`.

7 Locate the **Boundary Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
All	√	√	None

8 In the **Geometry** toolbar, click **Build All**.

9 Click the **Orthographic Projection** button in the **Graphics** toolbar. Orient the view to place the optical axis (z-axis) horizontal and the y-axis vertical. Compare the resulting geometry to Figure 2.