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Design of a 16.5 Megapixel Camera Lens for a Mobile Phone

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Abstract

A 16.5 megapixel camera lens for a mobile phone is designed. The lens consists of 3 plastic aspheric lenses, one glass spheric lens and an infrared glass filter. CMOS OV16850 with a pixel size of 1.12 micrometers from Omni Vision is used as an image sensor. The lens has an effective focal length of 4.483 mm, a F-number of 2.50, a field-of-view (FOV) of 76.2 degree, and a total length of 5.873 mm. The maximum distortion of the lens is less than 2.0%. The minimum value of all field relative illumination is over 39.8%.

Keywords

Mobile Phone Camera Lens, 16.5 Megapixel Sensor, Zemax

Subject Areas: **Mobile Computing Systems, Optical Communications**

1. Introduction

On 7 October 2014, Omni Vision Technologies Inc. (NASDAQ:OVTI) announced a 16.5 megapixel digital image sensor OV16850 [1]. To design a 16-megapixel camera lens in a compact size is not a trivial task [2]. In the published papers, Song *et al*. (2010) [3] studied a 5 megapixel camera lens for mobile phone by a structure of 4 pieces of plastic aspheric lens. Recently, Peng (2013) [4] investigated a 8 megapixel camera lens for cell phone by using 1 glass and 3 pieces of plastic aspheric lens (1G3P) to complete the optical system. Yin *et al*. (2014) [5] investigated a 13 megapixel camera lens for mobile phone by choosing a 5 pieces of plastic aspheric lens (5P) structure configuration.

This paper presents a detailed design of a 16.5 megapixel camera lens by a 1P1G2P lens configuration for the first time to our knowledge.

Sensor OV16850 has the following specifications: pixel size of 1.12 micrometers, resolution of 5408 pixel × 3044 pixel, diagonal length of 6.95 mm or the image height, and the chief ray angle (CRA) of 33.4 degree. Nyquist sampling frequency of the sensor can be calculated via $1000/(2 \times 1.12) = 446$ lp/mm. So the limited reso-

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lution of the camera lens should be better than 446 lp/mm. An image height of 6.95 mm and a FOV of 76.2 degree of lens determine a focal length of 4.432 mm. We set the effective focal length (EFFL) of the lens to be less than 4.5 mm, so the total optical length (TOL) of a camera lens for a mobile phone can be confined to 5.90 mm.

The specification parameters for a 16.5 M pixel mobile phone camera lens are summarized in **Table 1**.

2. Design Method

2.1. Optical Materials

Optical resin E48R from Zeonex [6] is used in this design. The optical resin offers high transparency, low fluorescence, low birefringence, low water absorption, low cost, high heat resistance, and easy molding for massive production. Since the lens has a large FOV, and its high order optical aberrations such as high order spherical aberration, astigmatism, coma, high order chromatic aberrations, etc., is rather large, in order to have a more steady and clear picture, one element of the lens is set to be an aspheric glass lens, the material of the 2nd element is SF56A with a optical refractive index of 1.785 and a dispersion coefficient of 26.08, the first, the third and the fourth element of the lens are chosen to be E48R, whose optical refractive index is 1.531 and the correspondent dispersion coefficient is 56.0, the fifth element is an infrared filter (IR), and the last is a cover glass BK9.

2.2. Design Procedures

Zemax [7] is used to simulate the lens optical system. Considering low price and massive production, an initial configuration 1P1G2P of the lens is chosen for the design by trial and error process. There are 6 elements in this lens, the first to the fourth element is the aspheric lens respectively, the fifth element is an IR filter and the sixth is a glass cover of the sensor. All the surfaces of the element 1 to 4 are set to even aspheric profiles, the fifth and the sixth elements are plane. Radius, thickness of each surface from 1 to 8 is set to be variable, all surface conic constants as well as aspheric coefficients are set to be variable either.

2.3. Optimization Procedures

The optimization procedure includes three steps.

Step 1 1) Using operand EFFL to define the effective focal length of the lens, using operand TOTR to confine the total optical length of the lens system, using operand RAID to confine the CRA, using operand REAY to define the image height; 2) The merit function also consisted of operands MNCA, MXCA and MNEA to define the air thickness and air boundary constrains, meanwhile operands MNCG, MXCG and MNEG are used to glass case either; 3) Initially, operand LONA is used to control the spherical aberration, LACL is used to control the lateral color for this focal system. TRAY and SUMM are used to control the coma, and operand DIMX is used to control the distortion of each field of view; 4) Using operand TRAY, DIFF, RAGC, ACOS and TANG to control tangential curvature; 5) Using operand TRAY, DIFF, RAGC, ACOS, TANG, CONS and PROD to control sagittal curvature; 6) Operand TRAC is used to control the spot size of each field of view for the whole wavelength.

Step 2 After the initial optimization, high order controlling operands are added in the merit function, *i.e.*, 1) Using operand TRAY, RAGC, ACOS, TANG, DIVI and DIFF to control the axial and longitudinal chromatic aberrations; 2) Using operand TRAY, RAGC, ACOS, TANG, DIVI, CONS, PROD and DIFF to control the high order spherical aberration; 3) Using TRAY, DIVI and DIFF to control the high order chromatic spherical aberration; 4) Using FCGT, FCGS, DIFF and SUMM to control the astigmatism.

Step 3 Siedel coefficients are observed after each optimization completed, the layout is watched to show a reasonable configuration. At last, 1) Both MTFS, MTFT is added to the merit function to improve the lens resolution; 2) Meanwhile TRAC is replaced by operand OPDX; 3) Weight in merit function is always ready to change to optimize some heavy contribution items in order to get a reasonable lens configuration.

Table 1. The specification parameters for a mobile phone camera lens of 16.5 megapixels.

EFFL	TOL	FOV	F-number	Image height	CRA	Relative illumination	distortion	Back focal length
<4.5 mm	<5.9 mm	76.2 degree	2.50	>6.95 mm	<33.4 degree	>35%	<2%	>0.2 mm

3. Results

The optimized lens configuration is shown in **Figure 1**, the correspondent lens data are listed in **Table 2** and **Table 3**. The lens has a total track of 5.873 mm, with an effective focal length of 4.483 mm, and of a back focal length 0.207 mm. The lens has a FOV of 76.2 degree, the image height is 6.97 mm which is a little larger than the CMOS sensor size and implies an easy installation of the CMOS sensor to the lens module. The CRA is less than 33.4 degree; a good coupling between the optics and the COMS is expected.

The Spot Diagram, MTF, curvature and distortion, lateral color, chromatic focal shift, and relative illumination can be used to evaluate the lens design. The RMS radius of spot size shall be less than three times of the pixel size (Yu [8]), to this design, it is 3.36 micrometer. The RMS spots of all fields are shown in **Figure 2**.

The RMS spot radius of fields 1 - 6 (FOV 0.000 to FOV 0.787) is 2.545 μm, 2.761 μm, 2.662 μm, 2.856 μm, 2.337 μm, and 2.091 μm respectively, much less than the imaging needs of the CMOS sensor, meanwhile the radius of spot size of field 7 (FOV 0.92) is 5.641 μm and that of field 8 (FOV 1.0) is 4.985 μm, very close to this need, that is to say that the whole FOV can image very clearly.

Table 2. Lens configuration data.

Surf: type		Radius	Thickness	Glass	Semi-diameter	Conic
OBJ	Standard	Infinity	Infinity		Infinity	0.000
STO	Even asphere	3.134	1.413	E48R	1.077	4.131
2	Even asphere	−3.115	0.021		1.233	1.604
3	Spheric	−2.252	0.445	SF56A	1.219	0.000
4	Spheric	−9.057	0.512		1.346	0.000
5	Even asphere	−4.306	1.378	E48R	1.409	4.868
6	Even asphere	−2.443	0.938		1.823	−1.204
7	Even asphere	−2.310	0.354	E48R	2.167	−8.789
8	Even asphere	−5.332	0.300		3.174	1.641
9	Standard	Infinity	0.313	BK7	3.222	0.000
10	Standard	Infinity	0.200		3.344	0.000
IMA	Standard	Infinity			3.485	0.000

Table 3. Aspheric coefficients of each correspondent surface.

Aspheric coefs		A	B	C	D	E	F	G	H
STO	Even asphere	0.050	−0.015	−5.30E-003	−3.136E-003	−3.048E-003	0.000	0.000	0.000
2	Even asphere	−0.043	−0.015	−0.012	3.559E-003	−2.045E-003	0.000	0.000	0.000
3	Even asphere	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	Even asphere	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	Even asphere	0.093	−0.033	−1.072E-003	−3.462E-003	−4.413E-004	0.000	0.000	0.000
6	Even asphere	−0.060	9.480E-003	−2.006E-003	−9.711E-004	−1.576E-004	1.665E-003	0.000	0.000
7	Even asphere	−0.101	−6.280E-003	1.653E-003	−1.796E-003	3.519E-004	4.051E-005	−9.441E-006	0.000
8	Even asphere	0.196	−0.012	1.030E-003	3.686E-007	−1.956E-006	−4.296E-007	5.719E-008	−3.874E-010

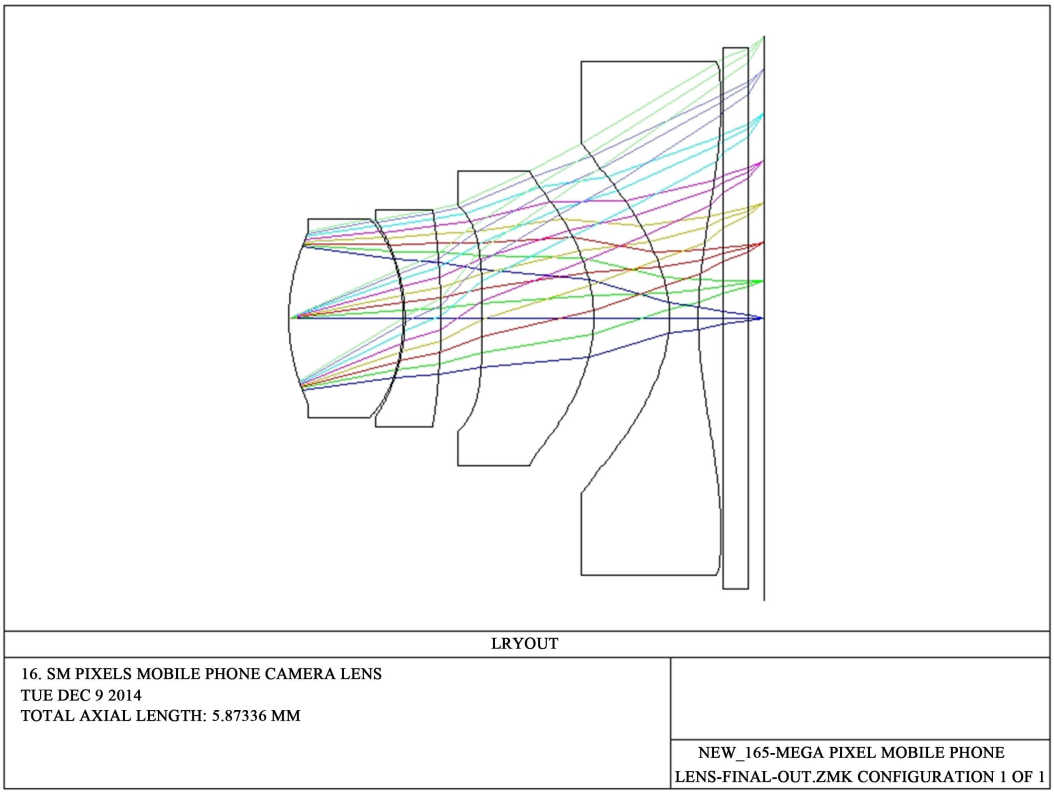

Figure 1. 16.5 M pixels mobile phone camera lens layout.

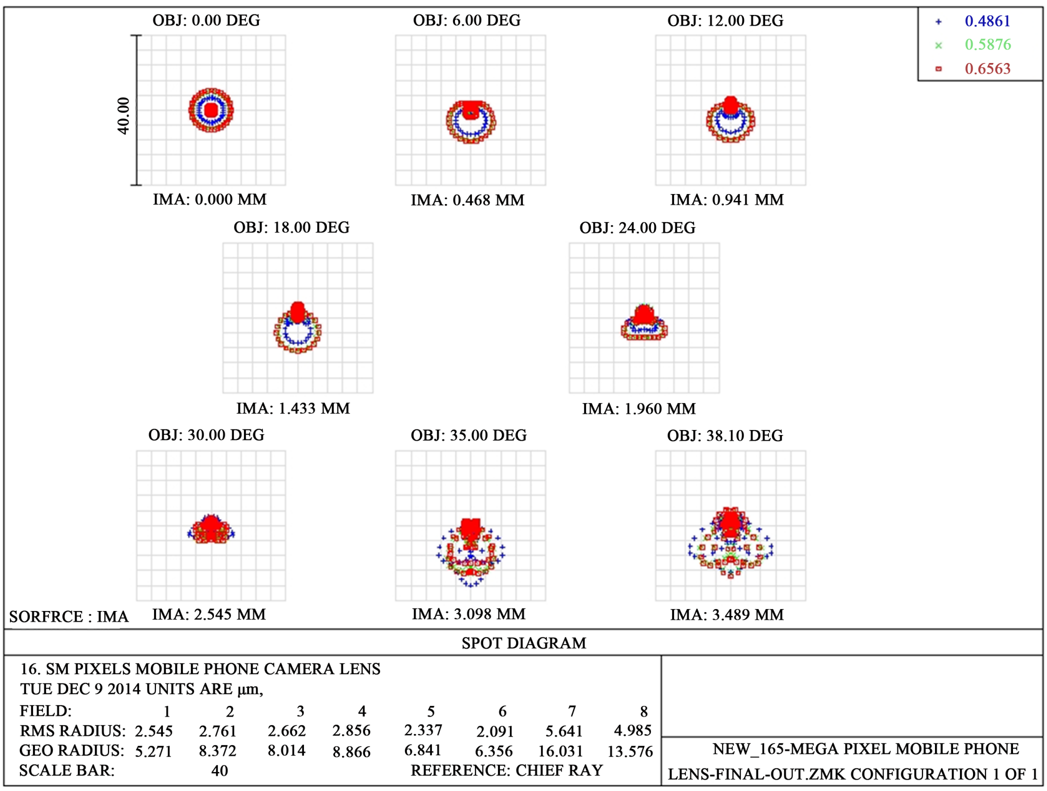

Figure 2. 16.5 M pixels mobile phone camera lens spot diagram.

MTF is a comprehensive standard to evaluate the imaging nature of a lens. In this design, the MTF value of central field at 223 lp/mm is 53.4% and 21.4% at 446 lp/mm. For FOV 0.8 zone, MTF value at 223 lp/mm is more than 37.6% in sagittal plane and more than 32.6% in tangential plane, at 446 lp/mm, MTF value is more than 14% in sagittal plane and more than 2% in tangential plane. The MTF curve is shown in **Figure 3**.

The curvature and distortion of the lens is shown in **Figure 4**; it is shown in **Figure 4** that the lens has a low field curvature; it is within 0.05, much less than the imaging need 0.1, and the distortion is less than 2%. It meets the design need.

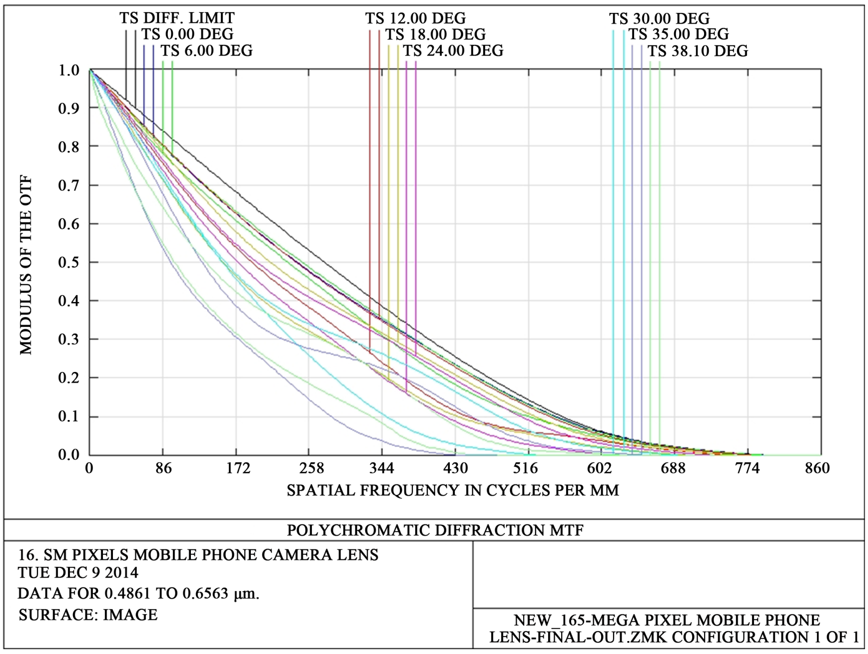

Figure 3. 16.5 M pixels mobile phone camera lens MTF curve.

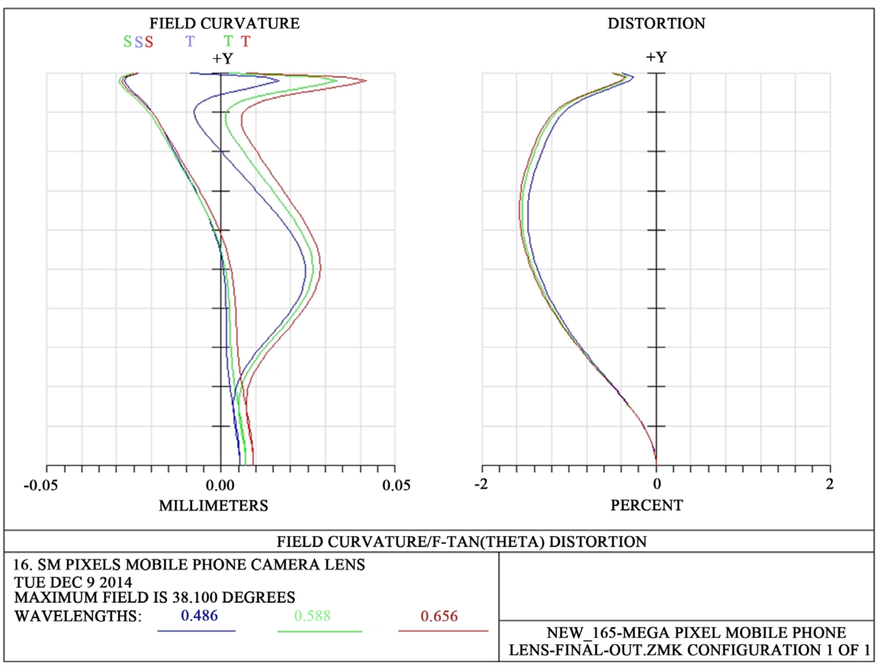

Figure 4. Field curvature and distortion of a 16.5 M pixels mobile phone camera lens.

Both the lateral color and chromatic focal shift of the lens revealed a nearly diffraction limited design of this 16.5 M pixels mobile phone camera lens. They are shown in **Figure 5** and **Figure 6** respectively. In **Figure 5**, the lateral color of the maximum field is within the Airy disk which implies a diffraction limited design.

It is also indicated in **Figure 6** that the chromatic focal shift of the lens is within diffraction limited.

Relative illumination of the lens should be checked; it is shown **Figure 7**. It can be found in **Figure 7** that the minimum of the relative illumination value is 40%. Both an auto gain controlling circuit and an auto balance controlling circuit can keep a uniform brightness of the image. It is concluded that this design of a 16.5 M pixels mobile phone camera lens can meet the design needs.

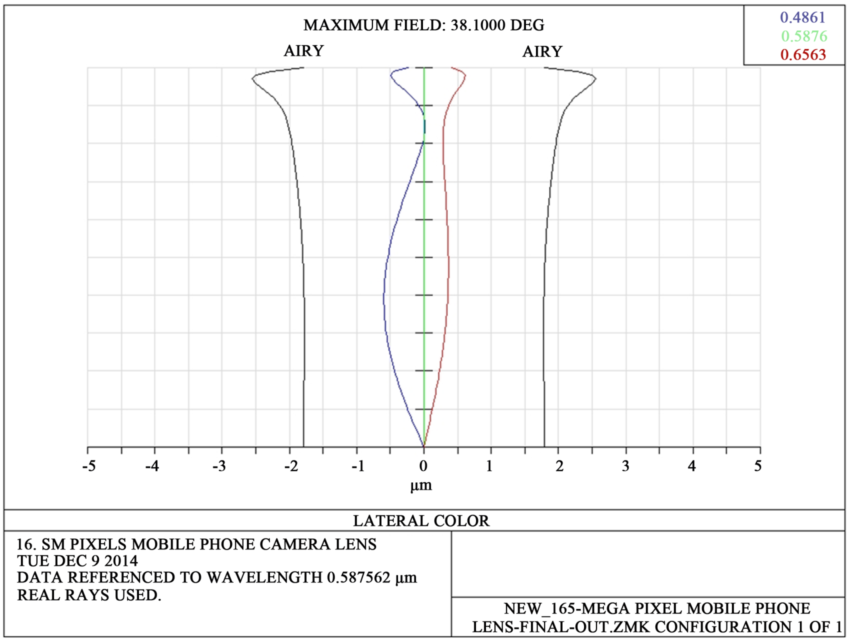

Figure 5. The lateral color of a 16.5 M pixels mobile phone camera lens.

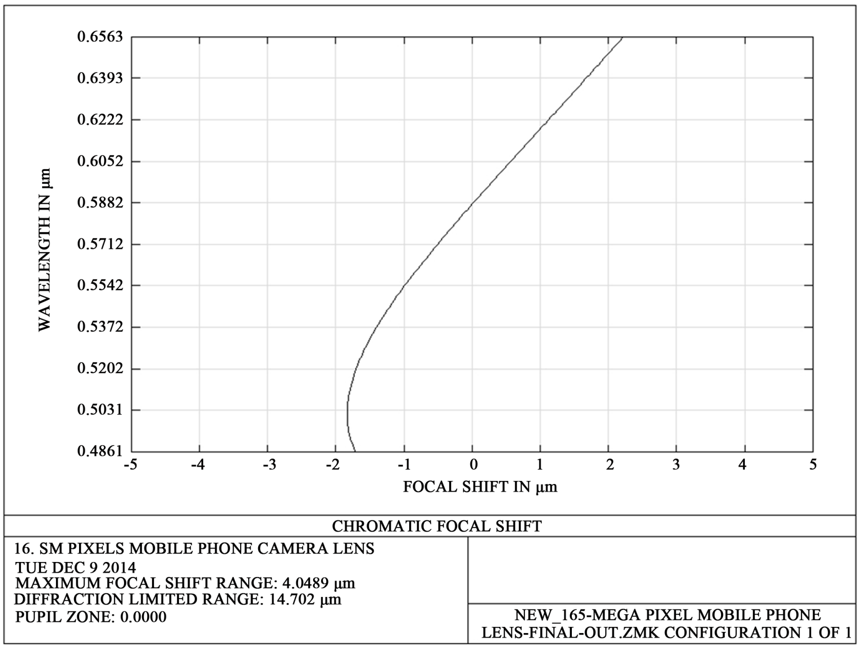

Figure 6. Chromatic focal shift of a 16.5 M pixels mobile phone camera lens.

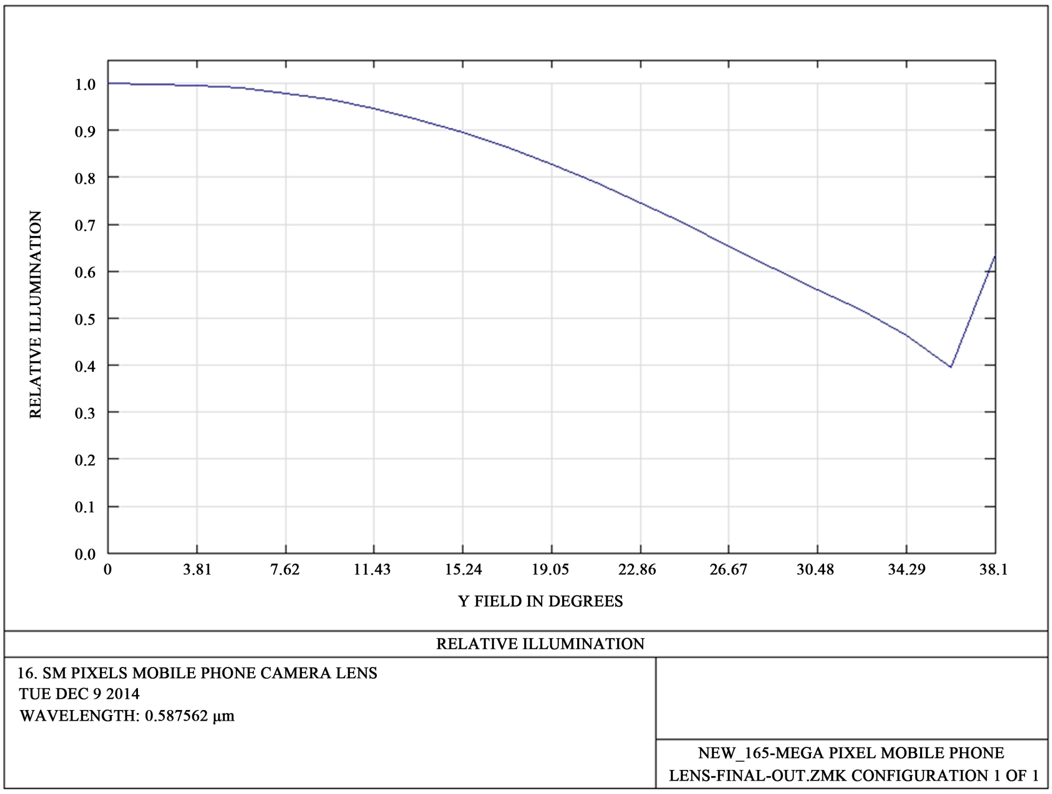

Figure 7. Relative illumination of a 16.5 M pixels mobile phone camera lens.

At last, a tolerance analysis was made and the results show that a 5 µm deviation in radius, thickness, a 10 µm deviation in decenter, and a 0.2 degree in tilt are permitted. It is also shown in **Table 2** that the smallest thickness of the plastic piece is 0.354 mm which means that a precision injection molding for massive production of the plastic lens elements can be expected. The glass element for this design is set to be a standard spheric surface for an easy production consideration.

In conclusion, this 16.5 M pixels mobile phone camera lens is a practical design.

4. Conclusion

By using Zemax, a 16.5 M pixels mobile phone camera lens is designed. The lens consists of 3 plastic aspheric lenses, one glass spheric lens and an infrared glass filter. OV16850 whose pixel size of 1.12 micrometer from Omnivision is used as a image sensor. The lens has an effective focal length of 4.483 mm, a F-number of 2.50, a field-of-view (FOV) of 76.2 degree, and a total length of 5.873 mm. This is a practical design for a 16.5 M pixels mobile phone camera lens.

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