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Design of High Pixel Mobile Phone Camera Lens

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Abstract: The compact, slim and high pixel mobile phone camera is highly demanded with the development of mobile phone, especially the thinner and thinner request of people. To satisfy this need, a mobile phone lens system composed of 1 glass spherical lens and 3 plastic aspheric lenses was designed with Code V. The F-number was 2.85 and FOV was 61°, the effective focal length and back focal length are 5 and 0.468 mm, respectively. A 1/3.2 inch 8 mega-pixel CMOS made by APTINA was taken as the image sensor of the lens assembly, whose pixel size is 1.4 μm and the limiting resolution was 357 lp/mm. The design results shown that the M TF value was more than 0.2 within most fields of view at the Nyquist frequency and more than 0.5 at the 1/2 Nyquist frequency, the maximum distortion was 0.66%. It shows that the lens has good performance and meets practical requirements.

Keywords: Code V, mobile phone camera, optical design

INTRODUCTION

With the development of the society, Mobile phone has become an absolutely necessarily tool of communication. Mobile phone with camera has become the first choice to remember the wonderful episodes around us. Since the coming out of Mobile phone with a 0.11 million pixels digital camera in 2000 (Liu *et al*., 2008), camera based mobile phones see over 96% penetration of those in the 18-30 age bracket and the pixels continuous increase. You even can find the mobile phone with 10 million pixels camera in the market now. Considering the price factor, 2.0 or 3.0 mega pixels mobile phone camera will continue to play an important role in a long period, but as the price of the mobile phones with 5.0 mega pixels down to 100 $, the 8.0 mega pixels mobile phone camera must be the key fighting filed among the manufacturers. In this study, we designed a mega pixels mobile phone lens with code V based on a selected initial structure.

DESIGN POINTS

Selection of image sensors: Great lens structure and matching high quality image sensors are the two key factors to achieve excellent image quality. Image sensors are based on semiconductor technology; they can reduce the total length and the lens elements of the camera. Commonly used image sensors are CCD (Charge Coupled Device) and CMOS (Complementary Metal Oxide Semiconductor); both types of imagers convert light into electric charge and process it into electronic signals. Generally speaking, CCD has far superior images and lower noise than CMOS, but it requires more power and pixel sizes. CMOS imagers offer more integration (more functions on the chip), lower power dissipation (at the chip level) and the possibility of smaller system size, so most image sensors of mobile phones are CMOS.

Table 1: Main specifications of lens

Name	Specification	Name	Specification
TL	≤6 mm	RA	D/f = 2.85
FOV	2ω = 61°	BF L	>0.45
I H	<5.71 mm	RI	>50%
Distortion	<3%	TV distortion	<1%
MTF	0.7FOV>0.3 0.5FOV>0.5	EAPR	<25°

TL: Total length; RA: Relative aperture; FOV: Field of view; BFL: Back focal length; IH: Image height; RI: Relative illumination; EAPR: Emergence angle of principal ray

In this design, a 1/3.2 inch 3264×2448 analyzing degree (8 mega valid pixels) CMOS of MT9E013 type made by APTINA was taken as the image sensor of the lens assembly, whose pixel size is 1.4×1.4 μm, image size is 4.57×3.43 mm and the corresponding diagonal is 5.71 mm.

Main specifications of lens system: Considering the compact character of the mobile phone camera and processing limited, main specifications of lens system were shown in Table 1.

Optical design:

Selection of initial structure: One of the most important things in lens design is the choice of the initial structure. A better initial structure can decrease the optimization steps and time. There are usually two ways to find initial structure: one starts from the paraxial approximation, sets initial structure then adjusts the specifications steeply until to meet the requirements of the design, this method requires solid theoretical foundation and wealthy empirical design

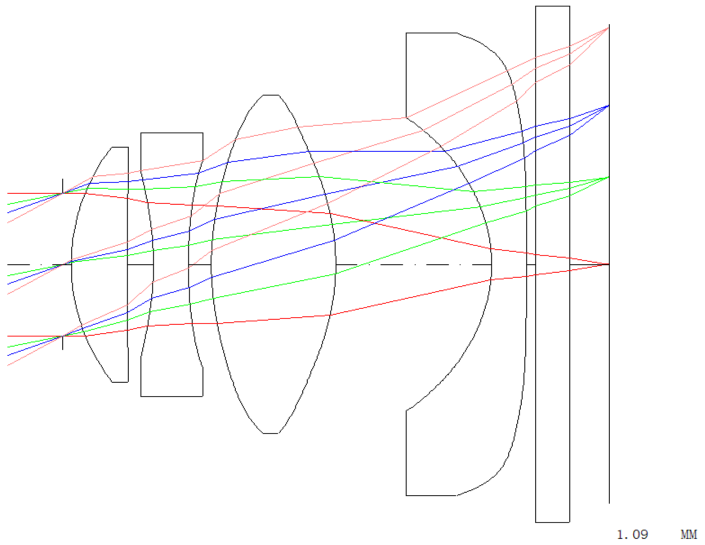

Fig. 1: Optimized lens layout

Table 2: Structure parameters of lens

S	ST	C/mm	T/mm	M	CA/mm
Stop	Sp	∞	0.10000		0.87719
2	Sp	2.45865	0.64101	L-BAL42	1.08464
3	Sp	56.61741	0.30384		1.12444
4	Asp	-3.74211	0.40000	OKP4	1.14965
5	Asp	6.45916	0.26309		1.27948
6	Asp	3.55747	1.42849	E48R	1.53181
7	Asp	-3.02142	1.78996		1.68516
8	Asp	-1.93738	0.40000	E48R	1.80157
9	Asp	-38.85493	0.10000		2.37731
10	Asp	∞	0.40000	B270	2.54728
Image	Asp	∞	0.45000		2.67743

S: Surface; ST: Surface type; C: Curvature; T: Thickness; M: Material; CA: Clear aperture, Sp: Sphere; Asp: Asphere

Table 3: Asphere coefficient

Surface	A4	A6	A8	A10
4	-0.02304	0.00644	-0.000640	-0.00011
5	-0.00880	0.00972	-0.001350	0.00065
6	-0.01263	0.00283	-0.001460	8.25278
7	0.02525	-0.00323	0.001311	-0.00013
8	0.04410	-0.01568	0.003353	-0.00020
9	0.01759	-0.01292	0.002058	-0.00012

knowledge. It is difficult to judge if the solutions satisfy all the requirements for the system (Yeh *et al*., 1995; Tanaka, 1982). In contrast to the paraxial method, since the lens module method employed in this study involves lots of physical quantities of the optical system, some of them can be manipulated directly by using lens modules. Several lenses have been designed and evaluated by lens modules (Stavroudis and Merecado, 1975; Kuper and Rimmer, 1988). Choose a suitable structure in references first, optimizes and adjusts until to meet the requirements. We make use of the second method in this study.

Sun (2007) was selected as the rudiment of this design, initial structure was obtained by changing the specifications and optimizing based on Code V. Regarding the specialty of the mobile phone lens, thickness, curvature, even aspherical coefficients and refractive index were selected as different variables. In auto optimization of Code V, Damped Least Square algorithm (DLS) was used to improve the imaging quality by suitable changed of the variables. Auto optimization also requires constraints to set boundary conditions for the search of the best solution. All the constraints were based on the main specifications of lens list in Table 1.

More attention should be paid to the thickness and curvature of the lens, they couldn't be too thin, or it will be difficult to manufacture. In this design, all the center (or edge) thickness of the glass spherical lens and the aspherical plastic lenses were thicker than 0.4 mm, curvature were more than 1.93 mm. Considered the bal1ance of the aberration and the limited of the manufacture, a suitable mobile phone camera lens was achieved by the auto and global optimization of Code V.

Optimized structure of lens: Optimized lens layout was shown in Fig. 1. Detailed structure parameters of the lens were shown in Table 2 and 3.

There were three reference wavelengths in this system: 486.1, 587.6 (dominant wavelength) and 656.3 nm, respectively. The features of the system were 5 mm effective focal length, 0.468 mm back focal length, 2.85 F number, 61°FOV and 5.826 mm total system length. The image height was 5.772 (2.886×2), which was little more than the diagonal size of the CMOS (5.71 mm), so it can effectively prevent the dark angle caused by the deviation of the CMOS and optical axis (Li, 2009).

The structure of the lens system was 1G3P, contained one glass lens and three plastic lenses. In recent years, one of the future trends of camera lens is aspherical lens, which can either improve image quality and optical Properties, or simplify the lens structure and decrease the cost. Plastic is lightweight and easy to process, so the 2, 3 and 4 lenses were plastic aspherical lens, materials were OKP4, E48R and E48R. The refractive indices of OKP4 and E48R are 1.607, 1.535; dispersion coefficient are 27.00, 55.95. Yong (2005) and Hiromitsu (2005) found that if all the mobile phone camera lenses were made of plastic material, the imaging surface was unstable. In addition, the first lens contacted with external more frequently, so its material was L-BAL42 (a kind of glass) and it had 1.535 refractive index and 59.4 dispersion coefficient. It was more difficult to make a spherical glass lens, so the surfaces of the first lens were spherical. There also was a plate B270 glass in the structure (refractive index and dispersion coefficient were 1.516 and 64.06 respectively) to protect the imaging surface.

RESULTS AND DISCUSSION

To evaluate the imaging quality of the lens system, relative illumination, field curvature, distortion, Modulation Transfer Function (MTF), spot diagram and aberration were shown based on the results of optimization.

Relative illumination is defined as the ratio of 1.0 FOV illumination on the image plane to paraxial illumination. If the relative illumination is too low, the rays of 1.0 FOV will be little, so the image will appear dark angle, which will greatly damage the imaging quality. Generally speaking, it is accepted when the relative illumination of mobile phone camera lens is more than 50%. In this design, the relative illumination of axis, 0.4, 0.7 and 1.0 FOV were 100, 89.9, 75.6 and 62.4%, respectively, which can satisfy the request.

Field curvature is the aberration that makes a planar object look curved in the image. It reflects the bending magnitude of the image plane. Field curvature of this design was shown in the left part of Fig. 2. The maximum value was 0.025 at 0.3 FOV, much less than 0.1 (which was regarded as the acceptable level in mobile phone camera lens), so it can satisfy the request.

Distortion is an aberration that affects both image shape or geometry and the energy distribution in the image. This occurs because distortion effectively magnifies (shrinks or stretches) the image locally and non-uniformly across the image plane. The distortion of this design was shown in the right part of Fig. 2. It was common believed that when the distortion was less than 3%, the imaging quality was acceptable. In graph 2, you can found that the max size of the distortion shift was 0.66% at 0.6 FOV, which was satisfied the design requirement.

MTF is a measure of the transfer of modulation (or contrast) from the subject to the image. In other words, it measures how faithfully the lens reproduces (or transfers) detail from the object to the image produced by the lens. It is the most widely used scientific method of describing lens performance. The MTF curves of this design were shown in Fig. 3. Spatial frequency is

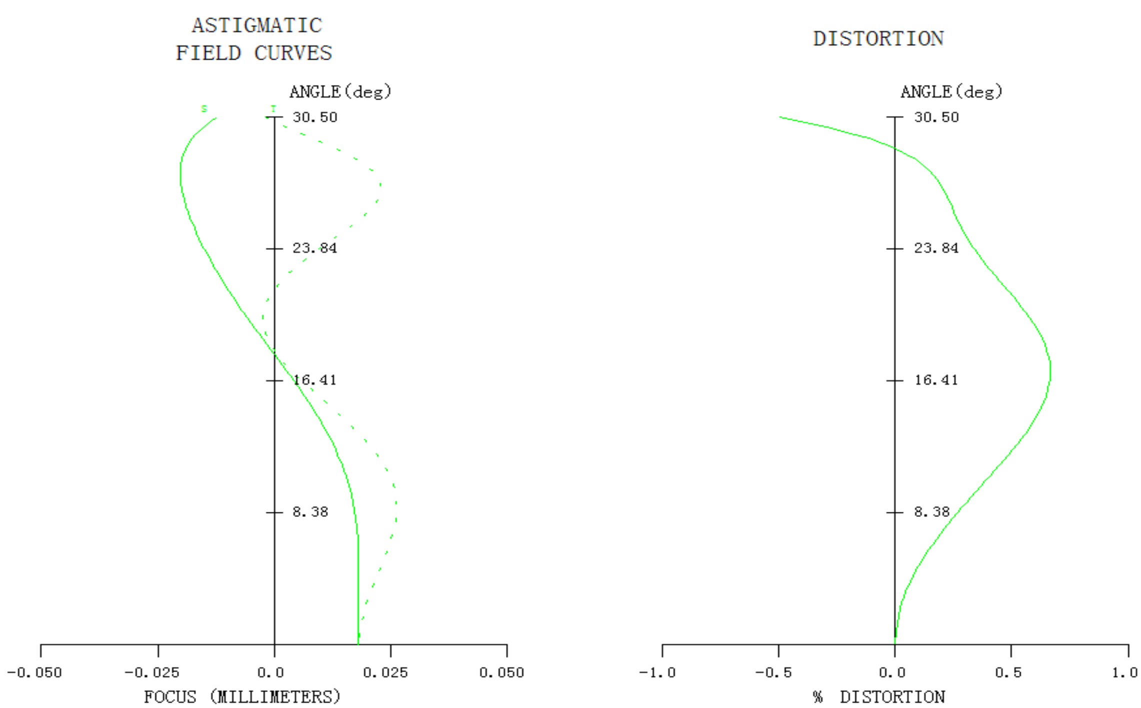

Fig. 2: Field curvature and distortion

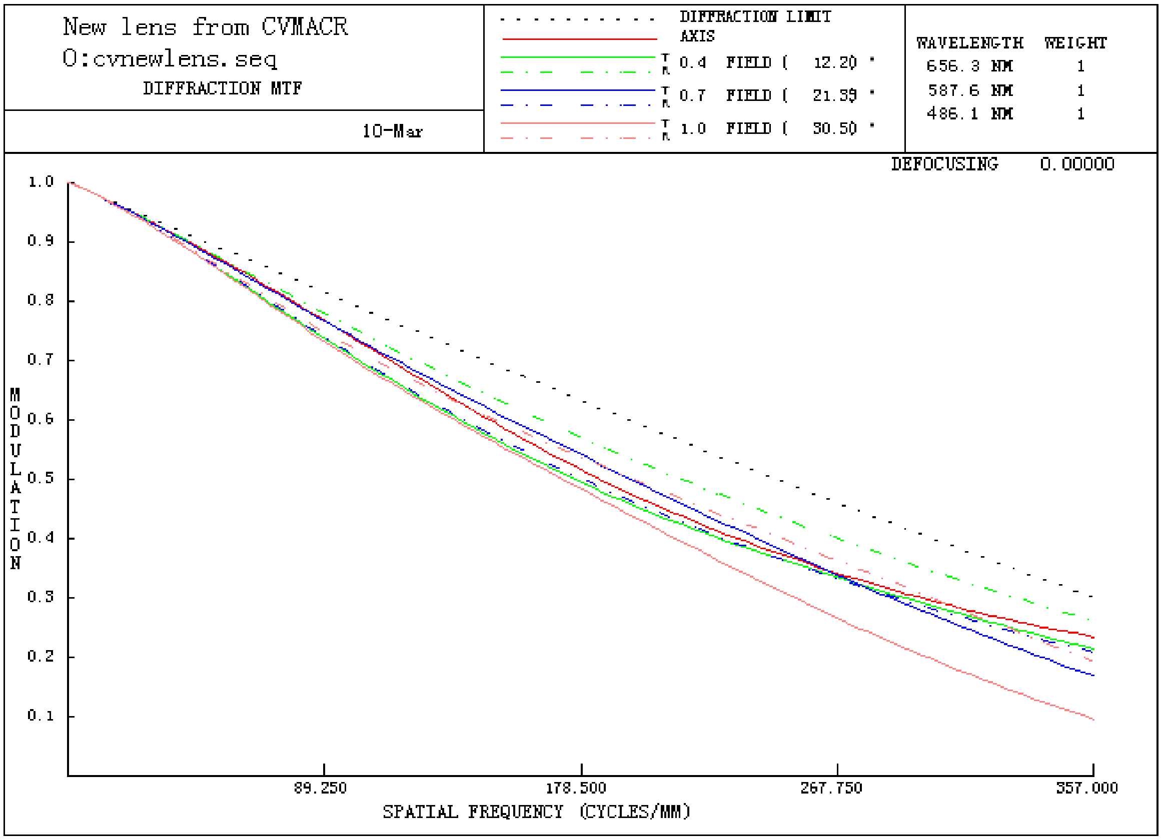

Fig. 3: Frequency vs. MTF curves for different image height

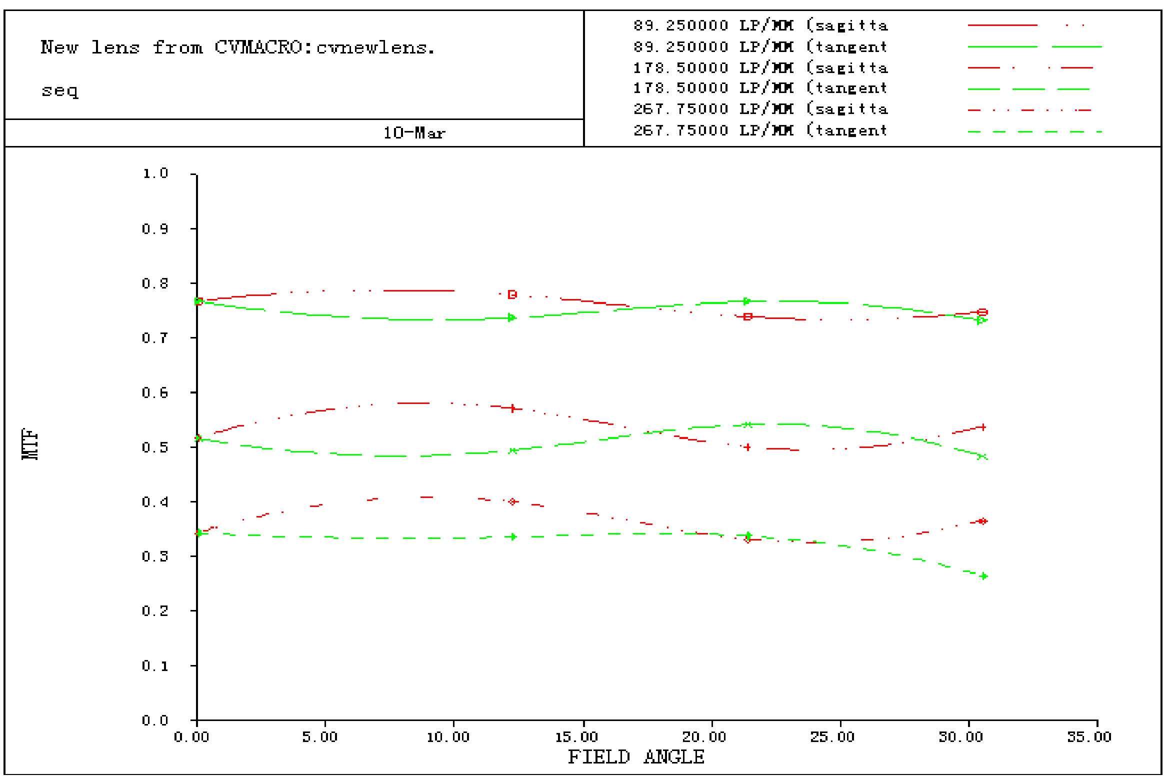

Fig. 4: MTF vs. FOV at 89.25, 178.5 and 267.75 lp/mm, respectively

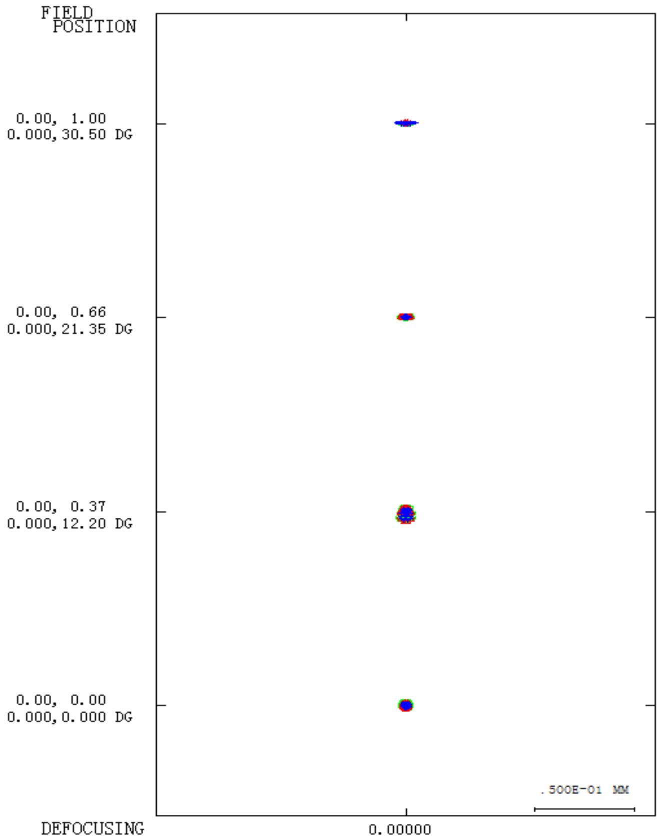

Fig. 5: Spot diagram

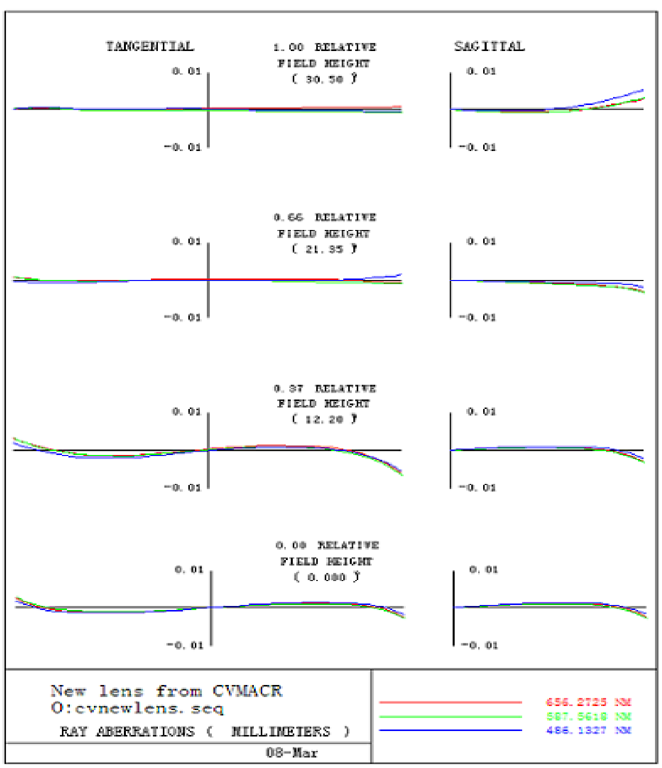

Fig. 6: Aberration of ray

associated with the pixel size of CMOS sensor. The pixel size of the CMOS used in this design was 1.4 μm and the corresponding limiting resolution was 357 lp/mm, so the resolution of the lens must be higher than 357 lp/mm. For the mobile phone camera lens, it is commonly required that the image within 0.7 FOV must be distinguished and the resolution power of the outer filed slightly decreased is allowed. In Fig. 3, we can find that most of the MTF at 357 lp/mm were more than 0.2. Though the meridian MTF curve of 1.0 FOV decreased a little, it was also satisfy the requirement. Most of the MTF at 178.5 lp/mm (1/2 Nyquist frequency) were more than 0.5 and some filed MTF reached to 0.6, which shown that this lens system had better imaging quality.

Simultaneously, considering the oblique (off-axis) astigmatism, the difference between Sagittal (S) and Tangential (T) MTF at a fixed filed must be controlled in the range of 10% (Zhang *et al*., 2009). The field versus MTF curves at 1/4, 1/2 and 3/4 Nyquist frequency was shown in Fig. 4, which shown that the difference was little and it can basically meet the design requirements.

Spot diagrams are graphs that show where rays from a point object will fall on the image surface. It neglects the diffraction and just reflects the geometric structure of the lens. Commonly, the spot diagrams must fall close together if the lens is to form a good image. The graph is usually highly magnified and its shape can indicate the type and amount of aberration in the lens. The spot diagrams of this design were shown in Fig. 5. the rms spot size of axis, 0.4, 0.7 and 1.0 FOV were 2.41, 3.73, 2.27 and 2.35 um, respectively, all of them were little than the Airy spot ($2.44\times\lambda\times F\# = 4.08$ um).

Curves of ray aberration were shown in Fig. 6. The tangential aberrations of the axis, 0.7 and 1.0 FOV were very small. The largest tangential aberration was little than 8 um, which was appear at the fringe aperture of the 0.4 FOV and was in the range of 2 times of Airy spot, which shown that the ray aberration was very controlled.

CONCLUSION

An 8 mega-pixel mobile phone lens with great image quality was designed based on Code V, whose initial structure started from a lens patent. The lens system had 1G3P structure, combined with spherical lens and aspheric lenses. The results shown that the lens had short total length, high imaging quality and low aberration, it can meet practical requirements and be easily integrated with common mobile phones.

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