NAOC 1m 反射望远镜 CCD 相机的性能研究

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提 要

研究了国家天文台兴隆观测基地1m反射望远镜新安装的VersArray1340×1300B CCD照相机的性能。它有几乎没有图案的良好本底(bias),极低的读出噪声和暗流。用平场序列露光来检测其线性时,能得到线性良好的转移曲线(transfer curve)。但是,不论在平场露光(面光源)还是在恒星(点光源)的观测中,当像元值约高于55000adu时(增益3.7e⁻/adu),都会产生溢出。此时CCD并未满井。因此,使用它做点扩散函数分析研究时,要避免使用太亮的星像。不过,由于电荷守恒原理,对产生溢出的孤立亮星像,仍然可以做孔径测光。此外,该相机的快门函数也已测定。

主题词: 仪器 — 探测器 — CCD 相机 — 快门函数
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PERFORMANCE STUDY OF THE CCD CAMERA ON THE 1-m REFLECTOR AT NAOC

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Abstract

A performance study of the new VersArray 1340×1300B CCD camera attached to the 1-m reflector at Xinglong Observatory, National Astronomicatl Observatories (NAOC) is presented. The camera has a good bias with very weak pattern, low readout noise and low dark. The linearity appears to be very good on the transfer curve when the dome flat field exposures are used to check it. However, both in dome flat field (extended light source) exposures and in real star (point light source) observations, blooming occurs in the flat frames or inside bright star images when the pixel value is higher than about 55000 adu (at a gain of $3.7e^-/adu$), so the very bright star images should be avoided in constructing the point spread function. But the aperture photometry of bright point sources (stars) may be still feasible due to the principle of charge conservation. In addition, the shutter function of the camera is also determined.

Key words instrumentation — detectors — CCD camera — shutter function

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1. Introduction

A new VersArray 1340 × 1300B CCD camera (pixel size 20 micron) with LN cooling has been mounted at the 1-m reflector in Xinglong. The test data were obtained on 2007 March 10 ~ 17 and August 3 ~ 6. The bias and its pattern, gain, readout noise, dark and linearity have been checked. In addition, the shutter function of the camera is also determined. The results are shown in section 2.

2. Results

Because the check is almost a standard procedure for us, only the results are given in this paper, readers interested in the details may refer to our previous work and the references therein [2,3].

2.1 Bias

The bias of VersArray 1340 × 1300B is good, it has a very weak pattern as shown in Fig. 1. At gain = 1e⁻/adu and readout rate = "slow", the gradient of the bias in *y* (column) direction is less than 1e⁻ (Fig. 2), no gradient in *x* (line) direction. In many cases the bias can be taken as a constant to be subtracted from the object frames. It is a pity that the CCD has no overscan region, so the users should get bias frames several times per night in order to check the possible shift in zero-point of the bias. For the time being the shift is small within one night, the situation is unknown when the controller of the camera becomes aged.

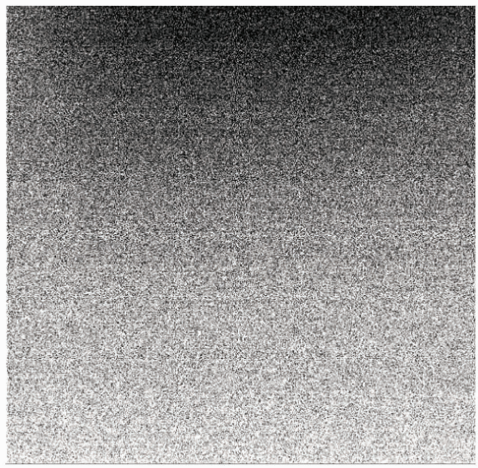

Fig. 1 Bias of the CCD

gain = 1e⁻/adu. Note the pattern of the bias is very low

2.2 Gain and Readout noise

We have measured the readout noise in March of 2007 at gain 1e⁻/adu and readout rate "slow" (the dome temperature at that night was about 2°C). The noise was very low, only 1.6e⁻. This is the lowest readout noise we have ever seen in China. Then we have measured the gain and readout noise at different gains and readout rates in August of 2007 (dome temperature was 24°C). It seems that the readout noise has increased a little at higher dome temperature. The results are given in Table 1.

Table 1 Gain and Readout Noise

Gain factor	readout rate	gain(e⁻/adu)	readout noise(e⁻)
1	slow	3.7	4.0
1	fast	3.9	7.0
2	slow	1.9	2.9
2	fast	2.0	5.6
3	slow	1.0	2.4
3	fast	1.0	5.1

Here the "slow" means that the readout rate is equal to 100kHz, and "fast" 1MHz.

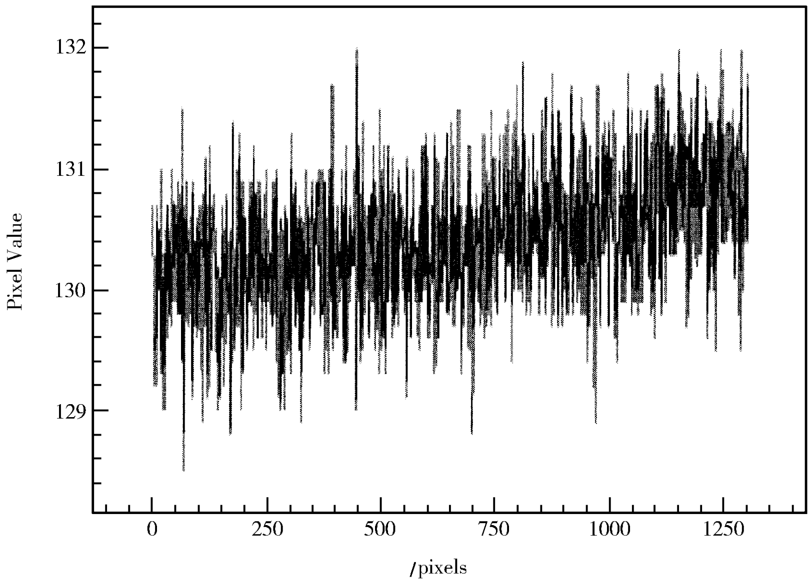

Fig. 2 Scan along the y direction to show the gradient of the pattern

2.3 Dark

When the CCD camera is stable, i. e., the CCD camera Dewar is filled with LN for enough long time and its vacuum is good, the dark of this camera is certainly low and the dark frame has no pattern. We obtained two dark frames on 2007 August 5 at UT 15^h41^m and 16^h41^m, the CCD temperature was set at $-110°C$, the exposure time was 3600s (one hour). The net dark of both frames was only about $1.5e^-$. Note that these dark frames were obtained at midnight while the camera had been filled with LN more than 7 hours. For comparison we note that the dark for the Tek 1024 × 1024 CCD camera (also from the Princeton Instruments (PI) company) used at Yunnan Observatory had a dark $0.25e^-/1000s$ at $-120°C$ when that camera was new.

Here we emphasize the importance to keep the CCD camera in stable condition. At the nights we used, the Dewar was filled with LN at UT 8^h30^m, but the CCD temperature could not get to $-110°C$ at UT 11^h30^m; If we set the CCD temperature at $-120°C$ at first, then set the temperature at $-110°C$, the camera could quickly get to the given temperature. On the contrary, it was difficult to recover from $-110°C$ to $-120°C$. We suspect that the vacuum of the Dewar was not in perfect condition. The symptoms are as follows:

(1) Still at the same night (2007 August 5), the net dark measured at UT 12^h23^m and 13^h25^m was higher (about $8.5e^-$) for the same exposure of 3600s, though the CCD temperature was set at $-120°C$!

(2) On 2007 March 11, the CCD working temperature was $-110°C$, for an exposure of only 600s the net dark was about $0.6e^-$.

(3) On 2007 August 4, when the CCD temperature was set at $-110°C$, the dark (exposure = 600s) frame obtained at UT 16^h45^m had a pattern as shown in Fig. 3. The scan along the diagonal of

Fig. 3 is shown in Fig. 4. The average net dark for 600s was about $23e^-$. Then we set the CCD temperature at $-120°C$, but the real temperature dropped very much slow. The pattern of the dark frame disappeared at UT 18^h25^m (net dark was about $4.1e^-$) while the real temperature was $-118°C$. Because the temperature dropped so slow, we then stopped testing.

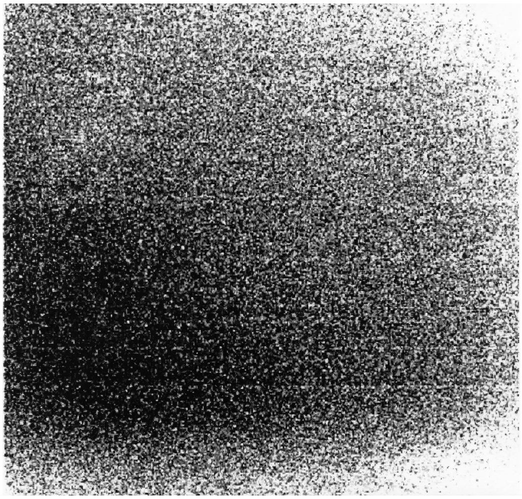

Fig. 3 The pattern of the dark frame on 2007.8.4

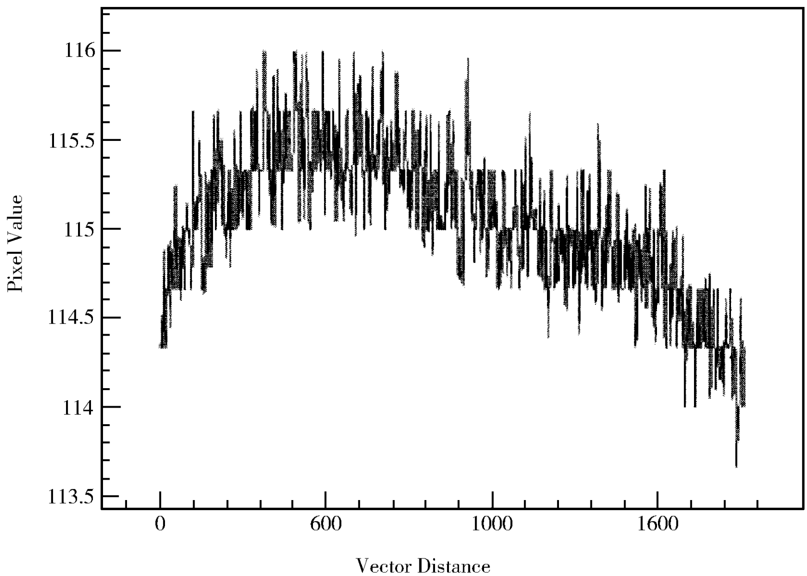

Fig. 4 Scan along the diagonal of Fig. 3

We are afraid that the CCD camera was not stable while working. To keep the Dewar in good vacuum and filled with LN 24 hours a day is suggested.

2.4 Non-linearity

We checked the linearity at gain $3.7e^-/adu$, the maximum pixel value of the CCD is 65535 adu. Obviously, here the 65535 adu is only the digital saturation, not the full-well of the CCD. When the linearity is checked by dome flat fields (extended light source), the linearity appears very good. The so-called transfer curve is shown in Fig. 5 using the whole CCD frame and in Fig. 6 using a small sub-region. These tests belong to the classical method. We also used the modified classical method[3] to check the nonlinearity. It is shown that the non-linearity is less than 0.2% up to at least 55000 adu ($20.35 \times 10^4 e^-$).

Though the linearity in Fig. 5 seems good at values higher than 60000 adu, the blooming (bleeding) occurs in the dome flat frames when the pixel value is higher than about 56000 adu (Fig. 7). Here the blooming occurs before full-well.

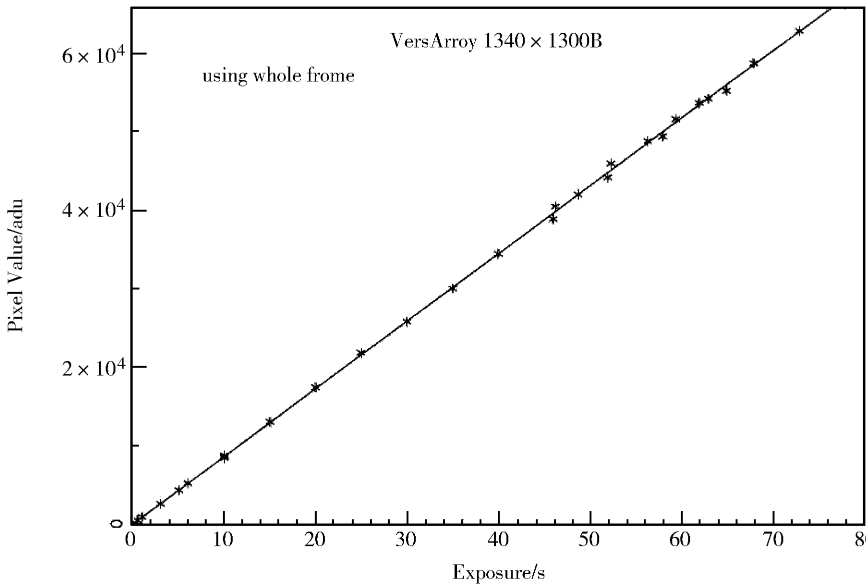

Fig. 5 The transfer curve measured on the whole frame

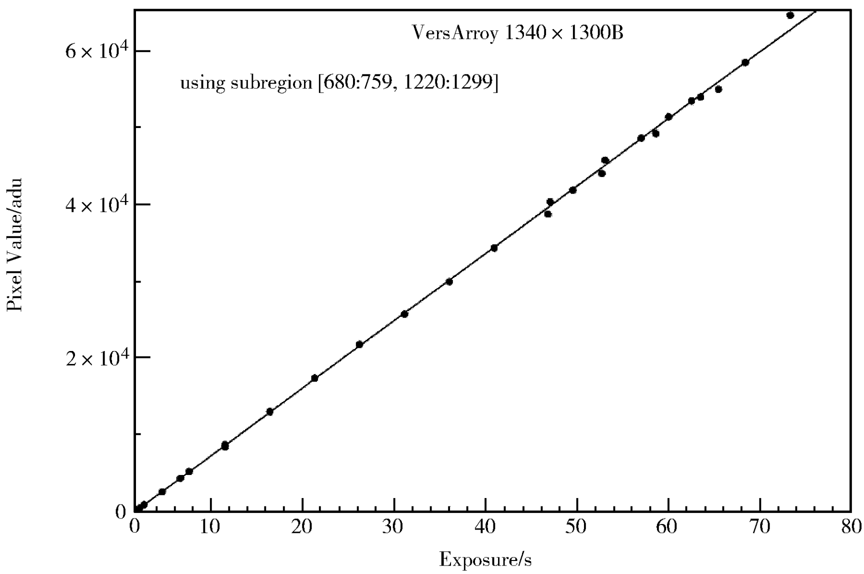

Fig. 6 The transfer curve measured on the sub-region [680: 759, 1220: 1299]

Blooming also occurs in the real star (point light source) observations. A small sub-region including a bright star is shown in Fig. 8a using the normal automatic algorithm of image reduction software (to display the image values near the median image value). Seemingly, there is no saturation in the core of the bright star image, but when the star is displayed without the normal automatic algorithm, the blooming inside this star image is shown clearly, as shown in Fig. 8b. We note that there is no saturation inside the core of the image. If the surface plot of this bright star image is plotted (Fig. 9a), one may get a illusion that the image is saturated, but the values of the scan along the core of the image both in x direction (Fig. 9b) and in y direction (Fig. 9c)

Fig. 7　A dome flat frame where the blooming occurs before full-well

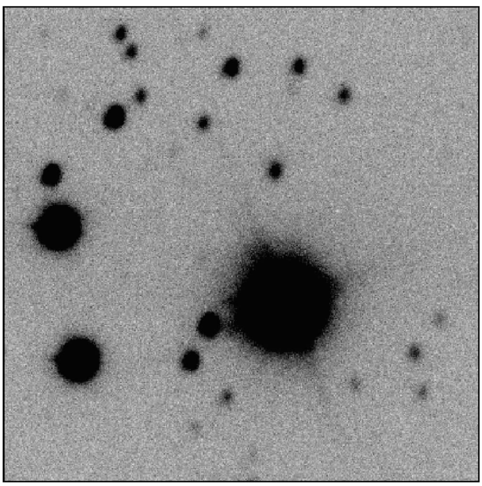

Fig. 8a　A small sub-region including a bright star displayed with normal automatic algorithm

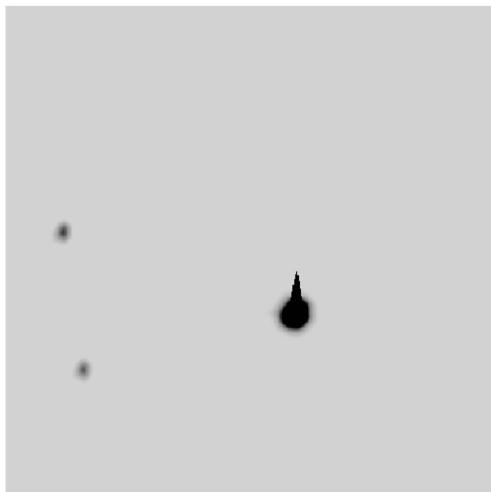

Fig. 8b　The same sub-region displayed without normal automatic algorithm

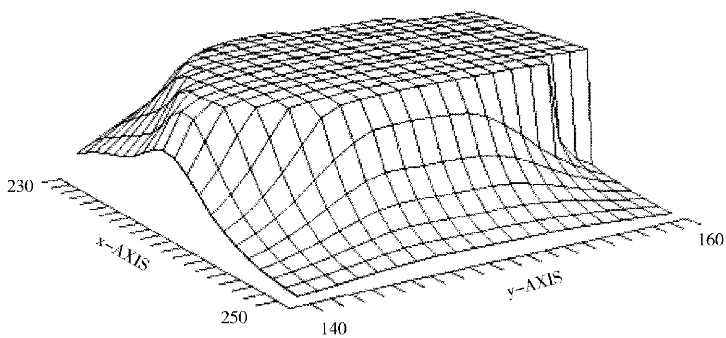

Fig. 9a　The surface plot of the bright star

one may get a illusion that the star image is saturated

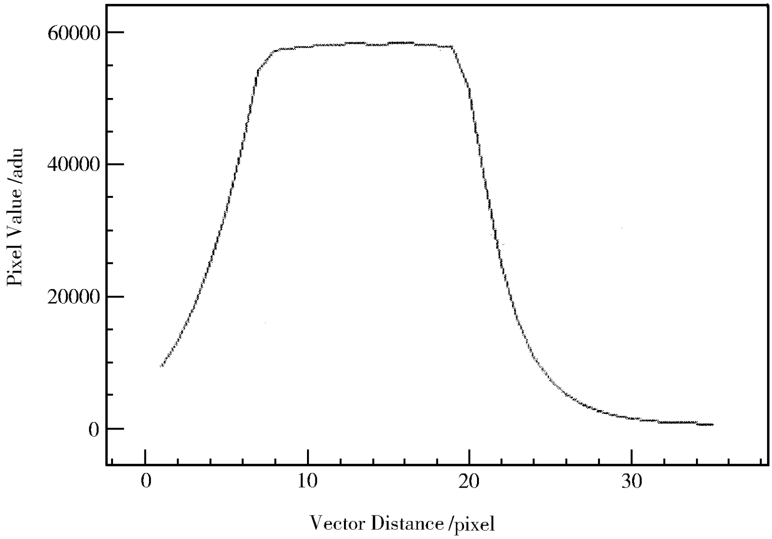

Fig. 9b Scan along the core of this bright star image in x direction
severe non-linearity occurs when pixel value >55000 adu but no saturation

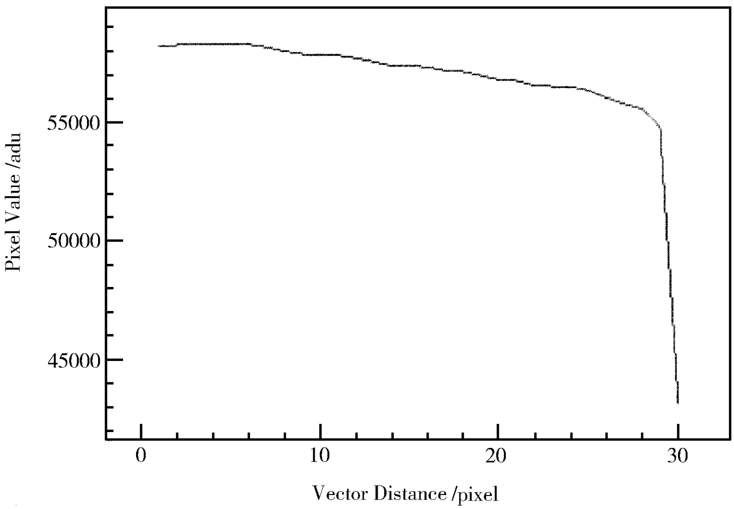

Fig. 9c Scan along the core of this bright star image in y direction

still vary and never exceed 59000 adu, although there is severe non-linearity when the pixel value is higher than 55000 adu. (A normal star on the same frame should have a profile as shown in Fig. 10). We also note that at different positions of the CCD chip, the blooming inside bright stars may occur at different values. At this point, the performance of VersArray 1340 × 1300B camera is similar to those CCD cameras using the Lick controller. As mentioned in our previous paper[4], both the CCD camera on the 1.56 m reflector (with a Tek 2048 × 2048 chip) and the one of BFOSC on the 2.16 m reflector (with a Loral 2048 × 2048 chip) are integrated at Lick Observatory using their control electronics. These cameras have the following character:

"As soon as the electrons inside the pixel have reached a certain value, they begin to bloom out of the pixel. But this value is not the full-well value, and obviously has nothing to do with full-well or saturation" [5]. "Fortunately, for point light sources (stars) the Janesick's statement holds, namely, thanks to charge conservation, linear behaviour continues to be observed for the measured averge signal of a small overexposed point source that has bloomed" [1].

In this case, early blooming is a weakness of this kind of CCD cameras, which limits the useful dynamic range in photometry using the point spread function (psf) analysis. But aperture photometry is still feasible for isolated bright stars due to charge conservation.

Does the VersArray 1340 × 1300B camera keep this character? We have observed standard stars and confirmed that the principle of charge conservation still keeps in this VersArray 1340 × 1300B camera.

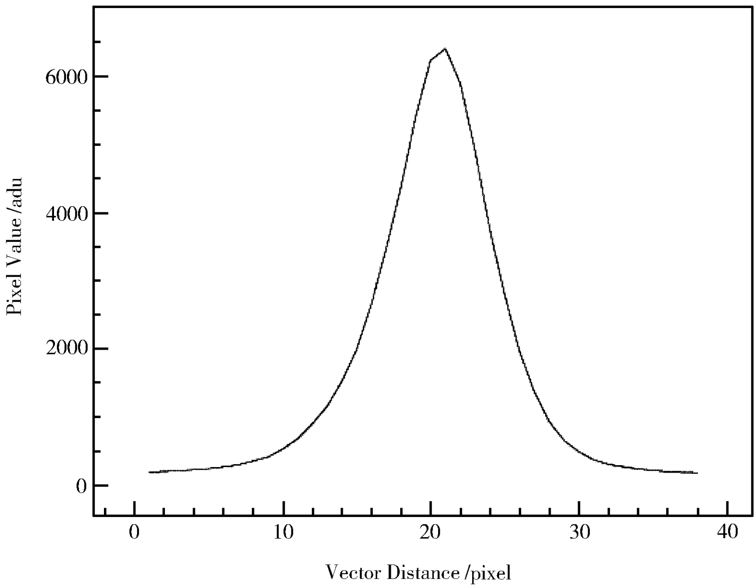

Fig. 10　Profile of a normal star image on the same CCD frame

2.5 shutter function

Using Stetson's method, the shutter function of the camera has been measured on 2007 March 14. The smoothed shutter function is shown in Fig. 11. The contour of the function is shown in Fig. 12. The center value in Fig. 11 is about $0^s.015$, the minimum at the upperright corner is about $-0^s.006$. The maximum difference in exposure between center and corner is about $0^s.016$. Note the minus value is not due to error. Let T denote the real exposure time of the shutter, t the formal exposure time which the user writes into the computer, and the value of the shutter function at any pixel $[i,j]$ denoted by Δ_{ij}, then

$$T = t + \Delta_{ij}$$

The minus value means that the real exposure time at this pixel is shorter than the formal time.

The formal exposure time should be longer than 2 seconds in order to get the photometric precision better than 1% over the whole CCD frame.

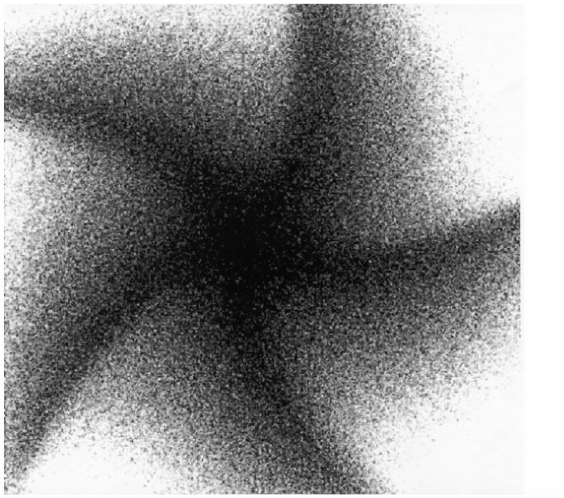

Fig. 11 Shutter function of the VersArray 1340 × 1300B camera

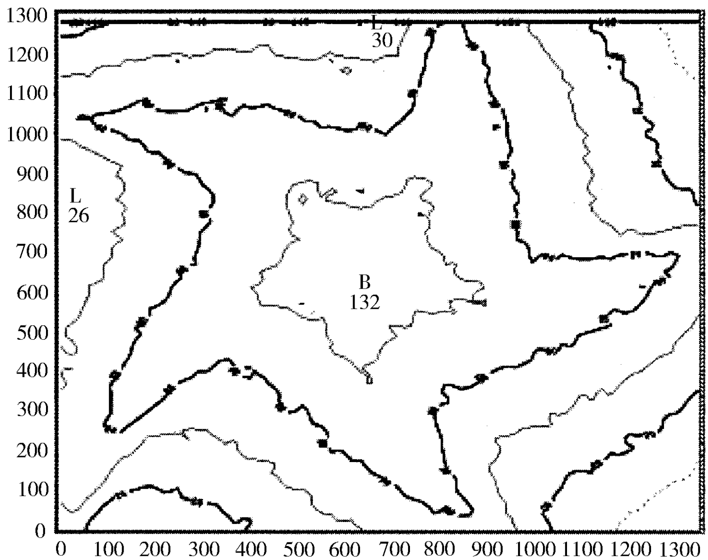

Fig. 12 Contour of the shutter function

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