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Thermal Effect of Self-Heating Observed in Operating CCD Matrix of Digital Camera

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***Abstract*—Silicon CCD matrixes are widely used as a basic element in digital cameras of various purposes. We performed experimental investigation of the dark signal (caused by noises) from the CCD matrixes of Novus-130 BH and Mintron OS cameras. Our thermographic investigations have shown that, for the first 15.5 min after switching the camera on, the CCD-matrix is heated from the room temperature up to 39.41 °C. The logarithmic character of kinetics inherent to changes in the CCD-matrix temperature enabled us to assume that the heat sources are located inside the matrix and related with electrical resistance of circuits. Air cooling of the TV camera has allowed increasing the useful signal by 30% due to reduction of thermal noises observed in the CCD-matrix.**

Keywords—TV camera; CCD-matrix; thermographic investigations; thermal effect

I. INTRODUCTION

The effect of self-heating in the matrix microelectronic devices has been found in the works [1].

Some examples of LEDs include automotive, industrial and portable lighting systems, advertisement displays, and medical applications. In high-power LEDs, however, considerable heat fluxes have been generated within the device package, which must be extracted to improve power conversion efficiencies. As injection current densities increased, die packaging dimensions decreased, thus exposing vulnerabilities to large heat fluxes during applied power cycling. Large heat fluxes ultimately lead to detrimental self-heating effects, reduced light output, and inefficient short and long term operation [2–5]. Quantifying these thermal effects was the motivation for the present work. Appropriately, this effort explored self-heating effects using a non-contact thermal/spectral analytical approach, which provides real-time analysis of the thermal characteristics of these high-power LEDs.

Recently, the errors on images caused by self-heating of the digital camera have caught the attention of various researchers. Wong, et al. [6] and Beyer [7] reported an error of one- tenth of a pixel image translation within the first hour of the camera being switching on, with the temperature of the camera increasing by about 10 degrees. Handel [8] extensively studied the image translation caused by camera self-heating and proposed a model to explain its origin whereby the image translation is caused by the thermal expansion of the mechanical components within the camera. The author has studied the error in DIC [9] caused by the self-heating of the digital camera and concluded that camera self-heating also induces a positive strain error which is more prominent than the pixel translation error. The strain error can be as large as 150 με over a temperature increase of 10 degrees, which is large enough to be significant in most measurement situations. In the study [10] of self-heating induced image expansion for a digital camera is described. A new physical model to explain the mechanism of image expansion is proposed based on results from a specially designed experiment which shows that the thermal expansion of the lens mount, instead of the mechanical component within the camera [8], is the main reason for this. Within the model, the errors for both the image analysis category and fringe analysis category are derived and analyzed. The temperature induced errors are then experimentally measured and verified for various photomechanic methods and, finally, the error compensation techniques are discussed and verified.

Up-to-date needs of science and technique stimulate development of various remote optical systems for control and diagnostics, including obtaining and analysis of image data. Highly-sensitive TV cameras with CCD matrixes based on silicon are an example of these systems.

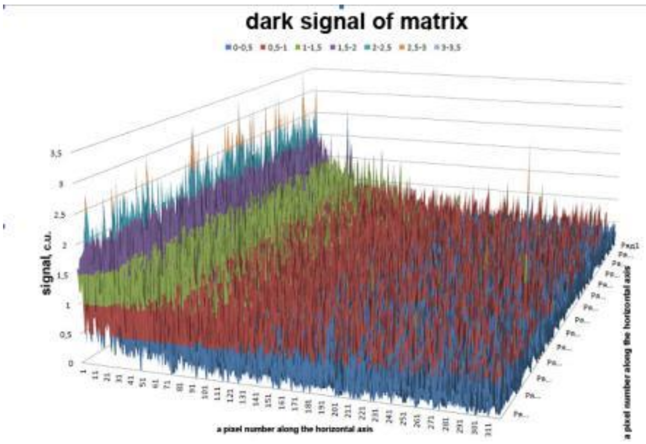
As known, silicon CCD matrixes are widely used as a basic element in digital cameras of various purposes [11-13]. It is the CCD matrix that transforms an optical image into the set of electric signals and after amplification and processing creates a digital image. Thereof, quality of the obtained image directly depends on operation conditions and technical performances of this matrix.

Among the main factors influencing the image quality, thermal noises arising in semiconductor CCD matrixes occupy an important place. They are related with physical nature of semiconductor materials and are always observable in these matrixes as a dark current. At the same time, there are no available data in literature that concern the influence of self-heating (due to the Joule heat release) in an operating CCD matrix.

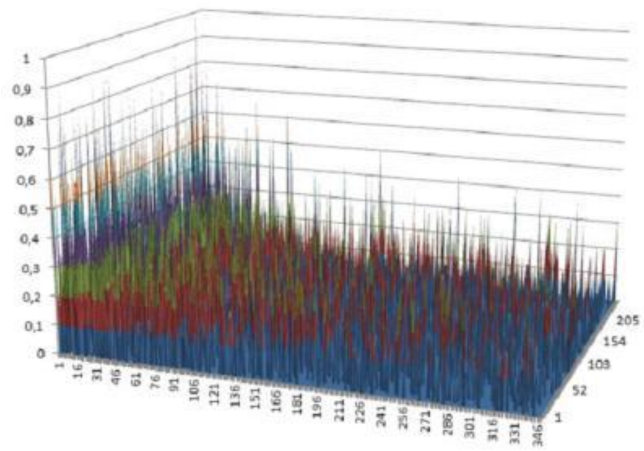
The aim of this work was to determine the influence of the self-heating effect at the initial operation stage of a TV camera on the noise level and value of the useful signal obtained from its CCD matrix.

II. EXPERIMENTAL RESULTS AND DISCUSSION

To analyze noises arising in the operating TV camera, we performed experimental investigation of the dark signal (caused by noises) from the CCD matrixes of Novus-130 BH and Mintron OS cameras (Fig. 1) usually used in the systems of technical control and, in particular, for equipment of measuring optical microscopes.



a



b

Fig. 1 Topograms of the noise level in CCD-matrixes. (a) Novus-130 BH camera, (b) Mintron OS camera

The obtained results show that the noises arising in CCD-matrixes of these cameras possess non-uniform distribution, from one matrix side these noises being of peak values. To ascertain the reasons for such a distribution of noises, we performed thermographic investigations of CCD-matrixes in two cameras of the Novus-130 BH type at the initial stage of their operation (first 16 min after switching them on). Thermal images of matrixes were obtained after removing the lenses from the camera.

Our investigations were performed using the experimental infrared imager (Fig. 2) designed in the V. Lashkaryov Institute of Semiconductor Physics NAS of Ukraine. Its technical characteristics are summarized in Table 1.

Fig. 2 External look of the infrared imager

TABLE I. TECHNICAL CHARACTERISTICS OF THE INFRARED IMAGER

Parameter	Value
Overall dimensions, mm	287x192x130
Field of view, deg	40
Number of matrix elements	256Hx290V
Sizes of one element, μm^2	50x33
Frame frequency, Hz	25
Range of spectral sensitivity, µm	2 . 5.3
Camera input signal	Digital
Supply voltage	220 V ± 10%, frequency 50 Hz ± 1%
Temperature sensitivity	0.07 °C on the square 0.25 mm^2
Cooling	Liquid nitrogen

The camera Novus-130 BH contains the CCD-matrix consisting of 752x582 pixels, horizontal resolution 600 TVL, sensitivity 0.01 Lx/F1.2, 0.05 Lx/F1.2, signal-to-noise ratio – higher than 48 dB.

Our thermographic investigations showed that for the first 15 min after switching on, the CCD-matrix of the camera Novus-130 BH is heated up to 39.41 °C (Fig. 3), and then this temperature is kept constant.

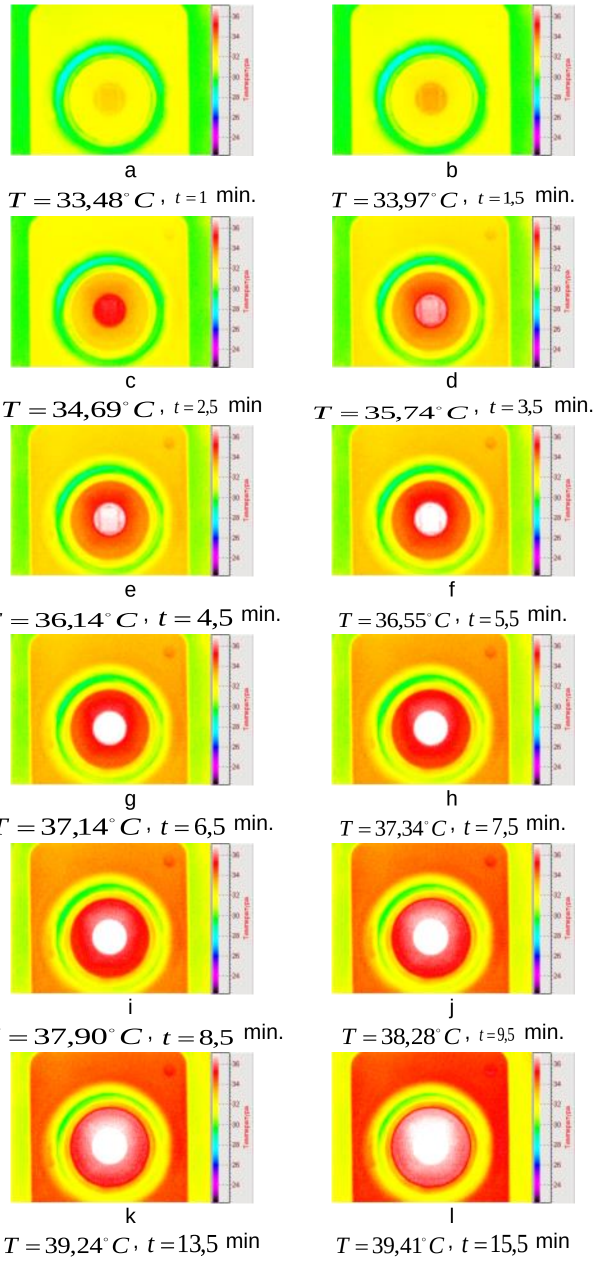


Fig. 3 Thermographic images of the CCD-matrix.

In this case, from one side of the matrix one can observe non-uniform heating up to 39.41°C, too, which can be caused by operation of the controlling and reading microchip located next to the CCD-matrix on the same crystalline substrate. The thermographic images of CCD-matrix after self-heating in the operation state for one and 15.5 min are shown in Fig. 3. The plot of temperature changes in dependence on the time after switching the CCD-matrix on is shown in Fig. 4.

This kinetics can be described with the following logarithmic dependence

$$\tau°C = 1{,}6 \ln(20\tau \text{ min} + 3) + 0.2\,\tau\text{min} + 22 \qquad (1)$$

where τ is the time after switching the CCD-matrix on (it varies from zero up to 15.5 min).

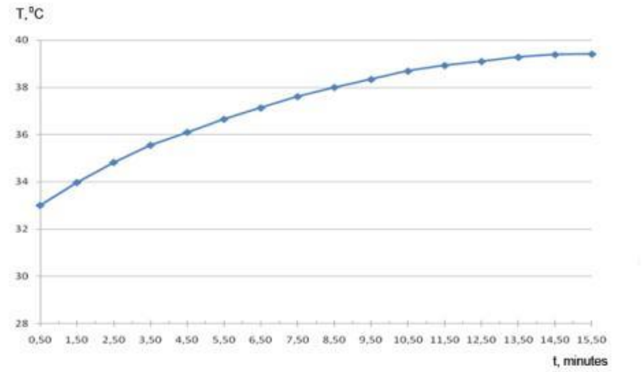


Fig. 4 Kinetics of temperature changes in CCD matrix after switching it on

It is obvious that the heat sources are located directly in the CCD-matrix. The role of such sources can be played by electrical contacts in the matrix as well as in the controlling and reading microchip. Additional heat sources are also of other electronic components of the chamber which are heated to $57{,}17^{\circ}C$ (fig. 5).

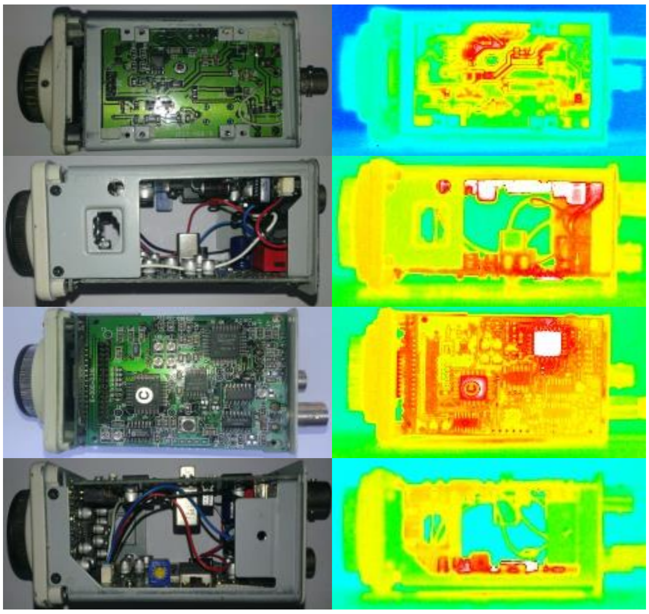


Fig. 5 Appearance (left) and infrared image (right) of electronic components camcorder

The heat from the electronic components can be transmitted through air flow and further increase the thermal noise of the matrix. A similar effect was investigated by the authors [6]. Their experiments are performed to study the heat transfer characteristics during the power-on transient period from an array of 4 × 1 discrete heat sources in a vertical rectangular channel using air as the working fluid. The heat flux ranges from 1000 W/m^2 to 5000 W/m^2. For 2 mm protrusion of the heater, the effect of heat fluxes and chip numbers are investigated and observed that the transient Nul strongly depends on the number of chips. Correlations are presented for individual chips as well as for overall data in the transient regime.

Also, we performed investigations of the influence provided by forced ventilation of the camera Novus-

130 BH, when the external protective cover is removed. This cooling enables to enhance the useful signal by 30% (Fig. 5), which is related with decreasing the thermal noises of the CCD-matrix.

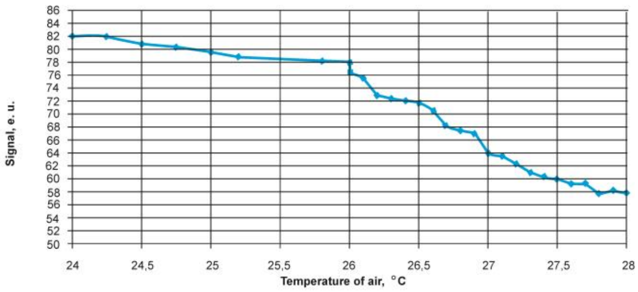


Fig. 6 Temperature dependence of the useful signal value for the camera Novus-130 BH, when forced ventilation is used.

As we can see, air cooling of the TV camera has allowed increasing the useful signal by 30% due to reduction of thermal noises observed in the CCD-matrix.

III. CONCLUSIONS

1. Our thermographic investigations have shown that, for the first 15.5 min after switching the camera on, the CCD-matrix is heated from the room temperature up to 39.41 ° C. The logarithmic character of kinetics inherent to changes in the CCD-matrix temperature enabled us to assume that the heat sources are located inside the matrix and related with electrical resistance of circuits (Joule heating).

2. Air cooling of the TV camera has allowed increasing the useful signal by 30% due to reduction of thermal noises observed in the CCD-matrix.

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