

## Impact of DMD-SLMs errors on reconstructed Fourier holograms quality

**D Yu Molodtsov, P A Cheremkhin, V V Krasnov, V G Rodin**

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse, 31, 115409 Moscow, Russia

E-mail: holo@pico.mephi.ru, DYMolodtsov@mephi.ru

**Abstract.** The quality of reconstructed impulse response of holograms displayed on a three DMD modulators of different models was experimentally evaluated. The integral parameter of modulators' optical quality – the size of sufficiently flat area of matrix surface – was estimated according to the developed technique. The results of holograms reconstruction are analyzed.

### 1. Introduction

The DMD technology (Digital Micromirror Device) is widely applied in various areas of science and engineering: DLP projectors, holographic printers [1], 3D-displays [2, 3], etc.

In our researches possibility of using of DMD technology in optical holographic correlators is considered. Unlike LC SLM, this type of modulators possesses much higher speed. It is theoretically possible to realize the dispersive correlator for object recognizing not only on its spatial, but also on its spectral characteristics [4, 5]. In order to DMD modulator could be used as the device for displaying of holographic filters, it should satisfy several additional requirements. Existence of undesirable phase modulation, which is possible because of manufacture errors in a modulator design, can cause essential negative effects. Following characteristics are related to manufacture errors in the documentation for DMD and affect the optical quality:

- micromirror tilt angle variation,
- orientation of the micromirror axis-of-rotation variation,
- window flatness.

The values of these parameters for tested in this paper DMD are respectively  $\pm 1^\circ$ ,  $\pm 1^\circ$  and 4 fringes. Flatness of a micromirrors matrix substrate is not specified in documentation, however it is probably indirectly considered in the first two characteristics.

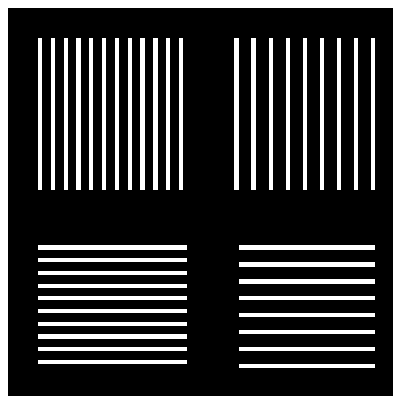
Only amplitude modulation of radiation is important for many scopes of this kind of modulators, and the specified errors have no essential impact. However when using DMD as holograms displaying device, as it was shown in works [6, 7], there is a notable deterioration of the reconstructed impulse response because of the existing manufacture errors. It is limited considerably by possibilities of application of DMD for a conclusion of holograms: than big DMD matrix. Square with brought to it by the hologram is lit with the collimated laser bunch, that more strongly distorts the restored pulse response. This significantly limits the possibility of the application of DMD to holograms displaying: the bigger area of DMD-matrix is used to display a hologram and illuminated by a collimated laser beam, the more distorted impulse response is reconstructed.



## 2. The setup and experiment description

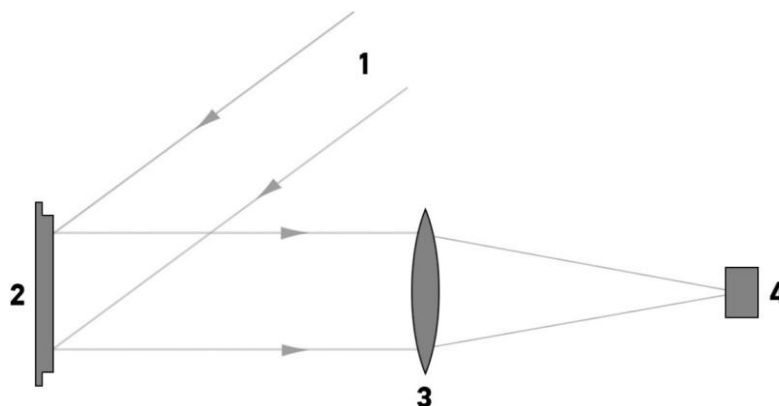
The quality of the reconstructed impulse responses of the holograms was experimentally estimated in this work for three various DMD modulators produced by Texas Instruments [7]. All modulators belong to chips family 0.7 XGA 12° DDR, one has the model number s1076 7071b and two - s1076 7072 (these are used in DLP Discovery 4100 Development Kit). The technique proposed in work [7] was applied for estimation. The sufficiently flat area of DMD matrix  $L_f$  was defined as the characteristic of optical quality of the DMD modulator. The technique consists in reconstructing of several test holograms, which are displayed on the DMD modulator. Impulse responses of holograms contain one-dimensional gratings with the set period (see Fig. 1). Holograms differ from each other in resolution (number of pixels), and, respectively, an area which they will occupy on a matrix surface when being output on it. For estimation of the size of sufficiently flat area of a matrix surface it is enough to determine the maximum size of the hologram which impulse response contains any gratings with the demanded spatial frequency and which will be solvable in the reconstructed image.

The program was made for realization of this technique. It requires a file with the hologram and its coordinates on a matrix surface as input data, and then it outputs it to the DMD modulator at the specified coordinate. The program has function of automatic movement of the hologram on the set path for estimating the quality of various areas of a matrix.



**Figure 1.** Impulse response for an estimating of resolution of the scheme (the size 200×200 pixels, contains gratings with the periods of 3 pixels and 4 pixels)

Laser radiation with the wavelength of 532 nanometers was used for holograms reconstruction, it was applied at illumination angle of 24°, so the reflected light was normal to the plane of the modulator. The focal length of a Fourier transforming lens is 500 mm. The scheme of setup is shown in Fig. 2.



**Figure 2.** Scheme of setup of holograms reconstruction: 1 – collimated laser beam, 2 – DMD-chip, 3 – Fourier lens, 4 – digital camera for impulse response registration

### 3. Experiment results

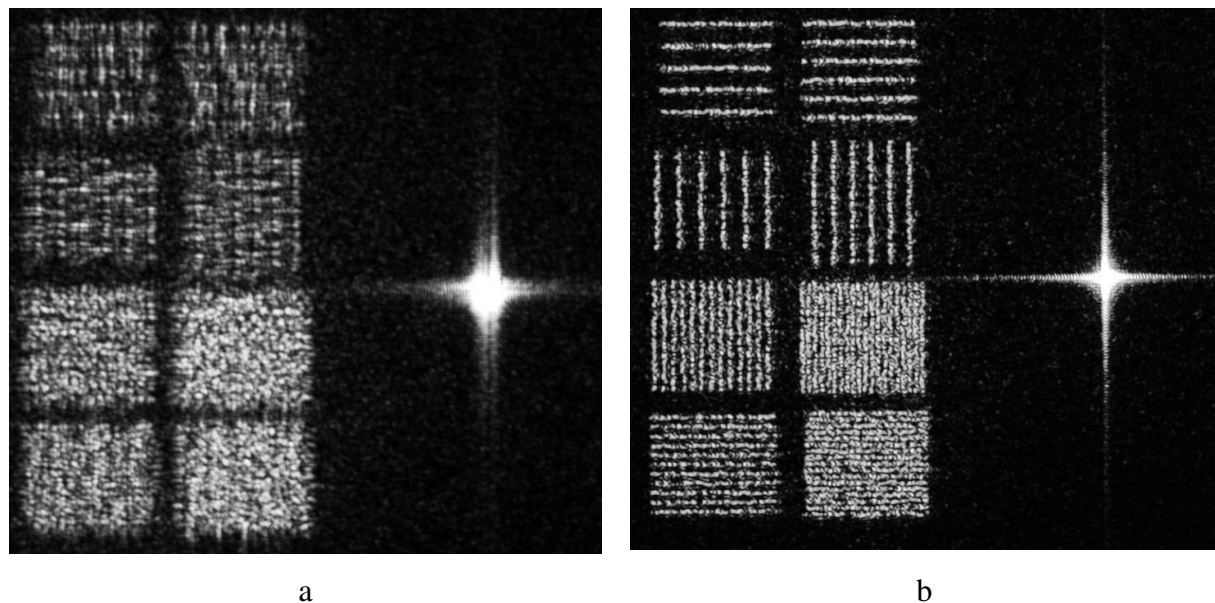
The influence of the overall curvature of DMD-chip has been shown in [7] for the s1076 7071b chip. The hologram placement in different areas of the matrix greatly affects the result of the reconstruction. It is an interesting fact that the central region of matrix on this chip is not the most qualitative for recovery of holograms.

Results of holograms reconstruction with use of newer chips (model s1076 7402) were significantly better. One of chips showed quality approximately by 1.5 times better, the second – by 3.8 times. Thus, results considerably differ even for chips of one model. The examples of the impulse responses registered from the chip with the worst and from the chip with the best optical qualities are shown in Fig. 3.

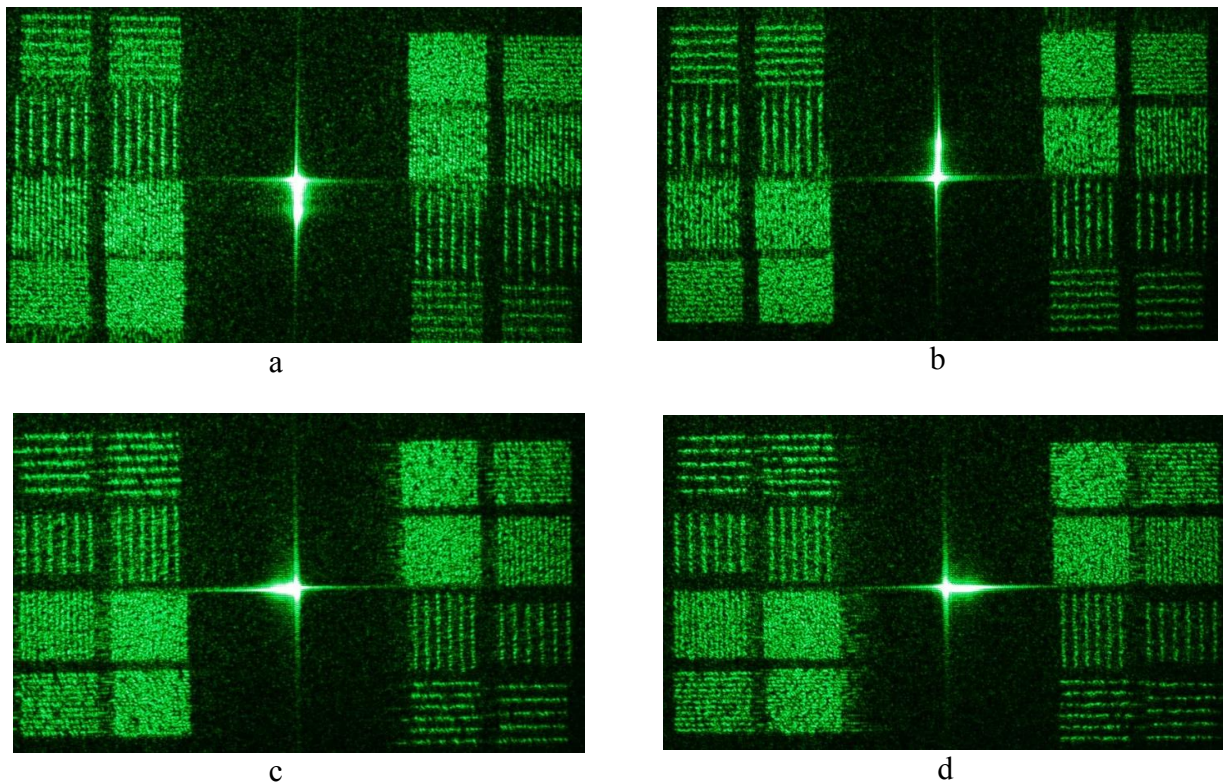
Zero diffraction order keeps its form much better when using DMD chip s1076 7402 (2), this is the good indicator of better optical quality. The result of "scanning" of this DMD chip is interesting also. It, as well as the second chip s1076 7402, provided the best quality of hologram reconstruction when using the central region of a matrix. The impulse responses registered for holograms outputted to edges of the best quality modulator are shown in Fig. 4. This kind of symmetric concerning the center distortions allows us to speak about some sphericity of this matrix.

For a numerical estimation of optical quality of DMD modulators the sizes of sufficiently flat area ( $L_f$ ) for all three copies were obtained. The requirement to resolution was highest: in the reconstructed image the grating with the period of 2 pixels had to be resolved. The following results were obtained. Size of sufficiently flat area  $L_f$  of a matrix for DMD chip s1076 7071b was equal 1.4 mm, for DMD chip s1076 7402 (1) was equal 2.1 mm and for DMD chip s1076 7402 (2) was equal 5.3 mm. The matrix pixel pitch of all three DMD modulators is 13.68  $\mu\text{m}$ .

The obtained results can be qualitatively compared to the result published in work [8]. In this work the Texas Instruments DLP Discovery 4100 Development Kit modulator is used. From this article it is possible to make a conclusion that the copies of DMD chips supplied with Discovery 4100 are also not deprived of the problems described above.



**Figure 3.** Impulse response of the hologram (384×384 pixels) containing gratings with the periods of 2, 3, 7 and 8 pixels (the central arrangement of the hologram on a DMD-matrix of the chip s1076 7071b (a), of the best chip s1076 7402(b))



**Figure 4.** Impulse responses of the hologram used in Fig. 3b, outputted to the centres of various edges of matrix of the best chip s1076 7402: a) lower edge of a matrix; b) upper edge; c) left edge; d) right edge

#### 4. Conclusion

Optical quality of three DMD-chips of two various models was experimentally estimated in this work. The obtained values showed a significant difference of devices quality, and even within one model. All DMD chips estimated in this work were taken from consumer DLP projectors, however one of models of the DMD chips (s1076 7402) is delivered as a part of Texas Instruments DLP Discovery 4100 Development Kit.

The modulator of model s1076 7402 appeared the best among the tested ones, it allows to obtain well solvable reconstructed image from holograms with the size up to  $380 \times 380$  pixels ( $L_f = 5.3$  mm). These values for two other DMD-chips have are equal to  $150 \times 150$  ( $L_f = 2.1$  mm) and  $100 \times 100$  pixels ( $L_f = 1.4$  mm).

Thus, it was established that according to modulators documentation it is impossible to find out, whether their optical quality is satisfactory for use as the holograms displaying device. It is necessary to analyze quality of an individual DMD-chip, because technological errors can have significant impact on resolution of system when reconstructing of the holograms outputted on it, and essential differences in quality are observed even among copies of one model.

#### Acknowledgments

This work was partially supported by Ministry of Education and Science of the Russian Federation, task 3.2066.2014/K.

**References**

- [1] Nesbitt R S, Smith S L, Molnar R A, Benton S A 1999 *Proceedings of SPIE* **3637** pp 12-20
- [2] Huebschman M L, Munjuluri B, Garner H R 2003 *Optics Express* **11** pp 437-445
- [3] Munjuluri B, Huebschman M L, Garner H R 2005 *Applied Optics* **44** (24) pp 5076-5085
- [4] Rodin V G and Starikov S N 2012 *Journal of Optical Technology* **79** (4) pp 212-216
- [5] Molodtsov D Yu, Rodin V G and Starikov S N 2014 *Journal of Physics: Conference Series* **536** p 012024
- [6] Molodtsov D Yu, Rodin V G, Starikov S N 2015 *Physics Procedia* **73** pp 338–342
- [7] Molodtsov D Yu, Cheremkhin P A , Krasnov V V, Rodin V G 2016 *Proceedings of SPIE* **9889** p 988926
- [8] Chao T-H, Lu T T, Walker B, Reyes G *Proceedings of SPIE* **9094** p 909402