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A METHOD FOR EVALUATING THE LIGHTING PARAMETERS OF DIGITAL VIDEO PROJECTORS IN REAL OPERATING CONDITIONS

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Abstract. The article briefly examines modern standards regulating the measurement of lighting parameters of digital video projectors. It is pointed out that existing standards do not have the ability to take into account the settings of video projectors that are performed after factory calibration at the places of their operation. The authors proposed a method for setting and measuring the output lighting parameters of a video projector, which affect the quality of the resulting image, in a real room other than a completely dark room. Following this method, it is possible to obtain reliable values of the lighting parameters of the video projector directly in the room where it is operated, which is especially important for the multimedia video projector market. This takes into account the operating conditions and service life of the video projector, and in particular factors such as the imposition of external highlights on the illumination of the screen and the design features of the lighting and projection systems of projectors. An experiment is described to measure the luminous flux, contrast and brightness of eight video projectors for different market segments with different service life. It is concluded that the obtained values of lighting parameters are more reliable in comparison with those indicated by projector manufacturers in the specifications.

Keywords: digital video projector, luminous flux, contrast, illumination, calibration

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МЕТОД ОЦЕНКИ СВЕТОТЕХНИЧЕСКИХ ПАРАМЕТРОВ ЦИФРОВЫХ ВИДЕОПРОЕКТОРОВ В РЕАЛЬНЫХ УСЛОВИЯХ ЭКСПЛУАТАЦИИ

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Аннотация. В статье кратко рассмотрены современные стандарты, регламентирующие измерение светотехнических параметров цифровых видеопроекторов. Указано на отсутствие возможности у существующих стандартов учитывать настройки видеопроекторов, выполняемые уже после заводской калибровки в местах их эксплуатации. Авторами предложен метод настройки и измерения выходных светотехнических параметров видеопроектора, которые влияют на качество получаемого изображения, в условиях реального помещения, отличного от абсолютно тёмной комнаты. Следуя данному методу, можно получить достоверные значения светотехнических параметров видеопроектора непосредственно в помещении, где он эксплуатируется, что особенно актуально для рынка мультимедийных видеопроекторов. При этом учитываются условия эксплуатации и срок службы видеопроектора, и в частности такие факторы, как наложение внешних засветок на освещённость экрана и конструкционные особенности работы осветительно-проекционных систем проекторов. Описан эксперимент по измерению светового потока, контрастности и яркости восьми видеопроекторов для различных сегментов рынка с разным сроком эксплуатации. Сделан вывод о большей достоверности полученных значений светотехнических параметров в сравнении с указываемыми производителями проекторов в спецификациях.

Ключевые слова: цифровой видеопроектор, световой поток, контрастность, освещённость, калибровка

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Introduction

Digital video projection technologies today are widely used in schools, offices, home and commercial cinemas, in university classrooms and in many areas where visual information is required to be displayed on the big screen [1–9].

Appropriate standards have been developed to describe the technical characteristics of digital video projectors.

In accordance with the DCSS (Digital Cinema System Specification v1) approved by the DCI (Digital Cinema Initiatives) association of leading Hollywood film studios in 2005 [10], recommendations of the Society of Film and Television Engineers SMPTE431-1-2006 [11] and SMPTE RP 431-2: 2011 [12], International Organization for Standardization (ISO) and International Electrotechnical Commission

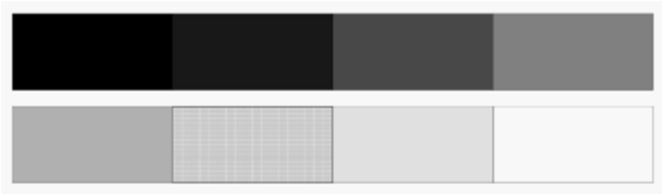

Fig. 1. Test image for calibration of projector before measurements according to GOST IEC 61947-1-2014 [13]

(IEC) developed standards to describe the technical characteristics of video projectors, as well as their specifications. Measured parameters are given in the ANSI (*A*merican *N*ational *S*tandards *I*nstitute) system, for example, ANSI lumen, ANSI contrast.

In the CIS countries, the Euro-Asian Council for standardization, metrology and certification (EASC) deals with standardization and regulatory documentation of technical devices. In 2016, the EASC standards GOST IEC 61947-1-2014 and GOST IEC 61947-2-2014 were put into effect as a national standard of the Russian Federation. They establish requirements for measurement and documentation of key operating parameters for electronic projection systems (projectors) with constant and variable resolution, respectively [13, 14]. Next, we will focus on the interstate standard GOST IEC 61947-1-2014 (identical to the international standard IEC 61947-1: 2002).

The bibliographic search carried out by the authors revealed *the absence* of scientific publications that would contain recommendations on setting up and measuring the lighting parameters of the projector in *a real room*. A separate standard regulating the corresponding setup and measurement procedures in *real premises* has *not been developed* at the moment either. Therefore, the experience gained in the course of many years of practice in the field of video projection equipment maintenance at entertainment events and the recommendations of specialists (enthusiasts) in this field are *relevant*. However, despite the widespread dissemination of such recommendations, both among lighting engineers (an example is *A.P. Parfenov*, one of the authors of this article) and on the Internet, sources containing them cannot be attributed to scientific works. The authors of the article proposed the simplest and most effective method for setting up and measuring the lighting parameters of video projectors in real operating conditions. This method allows to assess the actual condition of video projectors, regardless of their service life.

Setting up and measuring lighting parameters of a video projector in laboratory conditions

According to [13], before starting measurements, the projector brightness and contrast controls shall be calibrated using the test image shown in Fig. 1 as follows: the brightness shall be set to the maximum value at which the maximum number of brightness bands corresponding to brightness levels of 0%, 5%, 10%, 15% (upper row) is discernible. The contrast should increase from the minimum value to the maximum, at which the maximum number of brightness bands corresponding to brightness levels of 85%, 90%, 95%, 100% (lower row) is visible and distinguishable, or until the image brightness stops rising due to the automatic brightness adjustment scheme of the projector.

After calibration of the video projector, the main parameters determining the quality of the obtained image are measured [13].

To measure light, a completely white image is projected onto the screen. Screen illumination is measured using a light meter for nine areas in the center of each equal rectangle (1÷9 points in Fig. 2). Next, the illumination values are averaged and multiplied by the screen area value. The light flux value obtained in this way is given in ANSI-lumens.

Contrast is determined using two methods. The first of them is to measure the ratio of screen brightness when projecting a white and black field (Sequential Full On / Full Off, Full) in a completely darkened room. The Full On/Off contrast indicator is not informative, since the brightness of the black field

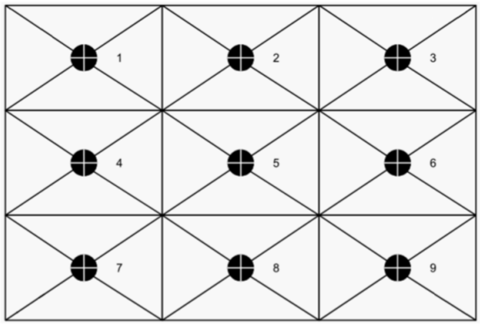

Fig. 2. Grid with points for measuring image illumination in accordance with GOST IEC 61947-1-2014 [13]

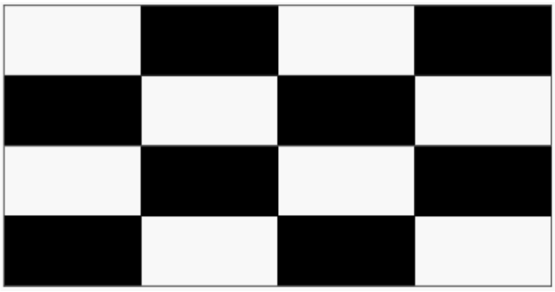

Fig. 3. Test image for measuring contrast and black level in accordance with GOST IEC 61947-1-2014 [13]

can be significantly reduced, for example by automatically diaphragm (decrease in aperture) of the lens. Adaptive aperture control is always used by manufacturers declaring thousands of contrast of their projectors [2], for example, 3000:1 or more.

For a more reliable measurement of the contrast of the projector the second method is used. It involves – measuring a ratio of the total (or average) brightness of white and black rectangles on the screen when projecting a checkerboard (Intra-frame Checkerboard) (Fig. 3). The contrast value obtained in this way is called ANSI contrast.

Since some multimedia projectors use color filters with a transparent sector to display colors [2], often the maximum brightness of a white image is more than the sum of the maximum brightness of images of primary colors. Therefore, in addition to prescribed measurements [13] of WLO values (*W*hite *L*ight *O*utput – output luminous flux), to estimate the total useful light flux of the projector it is necessary to measure the color light flux CLO (*C*olor *L*ight *O*utput). To measure it, test images are supplied to the screen, consisting of nine rectangles of RGB primary colors in three different combinations (Fig. 4) [15]. A total of 27 light measurements are carried out. For each measured color, the average illumination value is taken, then the obtained illuminations are added.

If WLO value exceeds CLO value, then the projector uses the so-called "white gain" (white boost), which leads to inaccuracies in color transmission compared to standards widely used for digital images such as sRGB and BT.709/BT.1886 [15].

The method of measuring the lighting parameters of a tuned video projector in a real room

WLO and CLO values specified by the projector manufacturers in the specification, cannot be a factor determining the quality of the projected image, since the real projected image often achieves the best quality with *additional settings* (for example, color correction and color balance), which can significantly reduce the output luminous flux. Therefore, during the experiment, the authors of the article will also measure the output WLO and CLO luminous flux of projectors after making settings in accordance with [13].

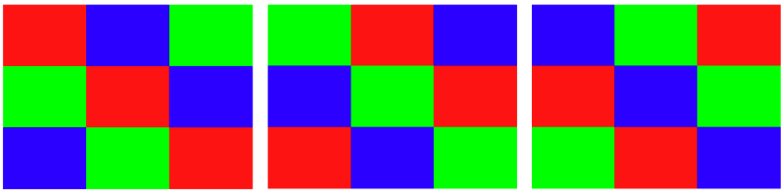

Fig. 4. Test Images for CLO Measurement

Fig. 5. Test image for additional black level adjustment of the projector

As already noted, *no separate recommendations* have been developed for measuring the lighting parameters of the projector in a real room. The authors of the article propose a method for *setting up* and *measuring* the parameters of video projectors in real operating conditions based on the method presented in [16]. We emphasize that the original source focuses only on *adjusting* the color rendition of the video projector *without* any additional objective or subjective *assessments*, as well as *without* specifying the *conditions* for using this method and *the service life* of the video projector at the time of adjustment.

It will be appropriate to compare the test images discussed in [16] with the test calibration images specified in the standard [13], and then use them to configure the video projector and then to perform measurements of its lighting parameters.

For the correct display of dark tones, we adjust the projector according to the image shown in Fig. 5. The image consists of squares of different gray levels (white intensity varies from "0" to "255") on a black background. The brightness and contrast settings of the projector are set to the maximum position at which a square with a gray level of "5" is visible and distinguishable, which corresponds to about 2% brightness level, unlike calibration images [13], following in brightness increments of 5%.

To correctly display light tones, we adjust the projector according to the image shown in Fig. 6. The image consists of white-gray "chess" patterns of various levels of gray (white intensity in the gray parts of the pattern varies from "200" to "254") on a white background. The brightness and contrast settings of the projector are set to the maximum position at which a pattern with a white intensity of "251" is visible and distinguishable, which corresponds to about 98% brightness level, again unlike calibration images [13], following in brightness increments of 5%.

The final part of the setup is carried out using the image shown in Fig. 7. The image consists of bands of main (R, G, B) and additional (C, Y, M) colors of various brightness levels. The brightness and contrast settings of the projector are adjusted so that the brightness levels "1" and "2," as well as "30" and "32" of the maximum number of colors are visible in the image.

According to SMPTE, in rooms with a large amount of sunlight (for example, in school and lecture classes), the brightness in the center of the screen should be more than 170 cd/m^2 (50 ft-lb). You can reduce the required image brightness using light-tight curtains. In such a darkened room, brightness from 100 cd/m^2 (30 ft-Lb) will be enough [11, 17].

Fig. 6. Test image for additional white level adjustment of the projector

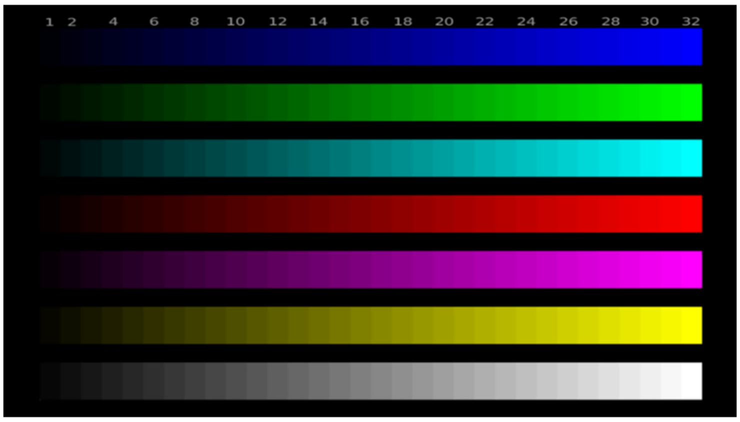

Fig. 7. Test image to further adjust the projector by levels of primary and secondary colors

The experiment on measuring the parameters of the output light flux by the authors of the article will be carried out not in ideal conditions of an absolutely dark room, but in real rooms, therefore, the readings of the light meter at each measurement have three components [18]: $\mathbf{E}_{\mathbf{DR}}$ – direct component of illumination, created directly by the projector light flux, $\mathbf{E}_{\mathbf{RF}}$ – reflected component of illumination, created as a result of multiple reflections from the surfaces of the room and screen, and $\mathbf{E}_{\mathbf{BG}}$ – background component of illumination, which takes place due to the impossibility of completely eliminating the ingress of light through the doors and windows of the room:

$$\mathbf{E}_{\Sigma} = \mathbf{E}_{\mathbf{DR}} + \mathbf{E}_{\mathbf{RF}} + \mathbf{E}_{\mathbf{BG}}, \tag{1}$$

where $\mathbf{E}_{\Sigma}$ is the total (full) measured illumination indicated by a light meter located in the plane of the screen. The combination of reflected $\mathbf{E}_{\mathbf{RF}}$ and background $\mathbf{E}_{\mathbf{BG}}$ components of illumination is designated as $\mathbf{E}_{\mathbf{SD}}$ (side illumination).

The screen may be located close to the different reflecting surfaces of the room by each edge thereof. Therefore, the combination of reflected and background light components cannot be considered evenly distributed across the screen and side illumination should be evaluated for each test rectangle separately. For this, the direct light flux from the projector is blocked by a light-impermeable object in such a way that the light meter in the plane of the screen is in the shadow of this object. Since illumination is an additive value, the direct contribution of the video projector to the illumination level of the corresponding area of the screen will be equal to the difference between two consecutive measurements:

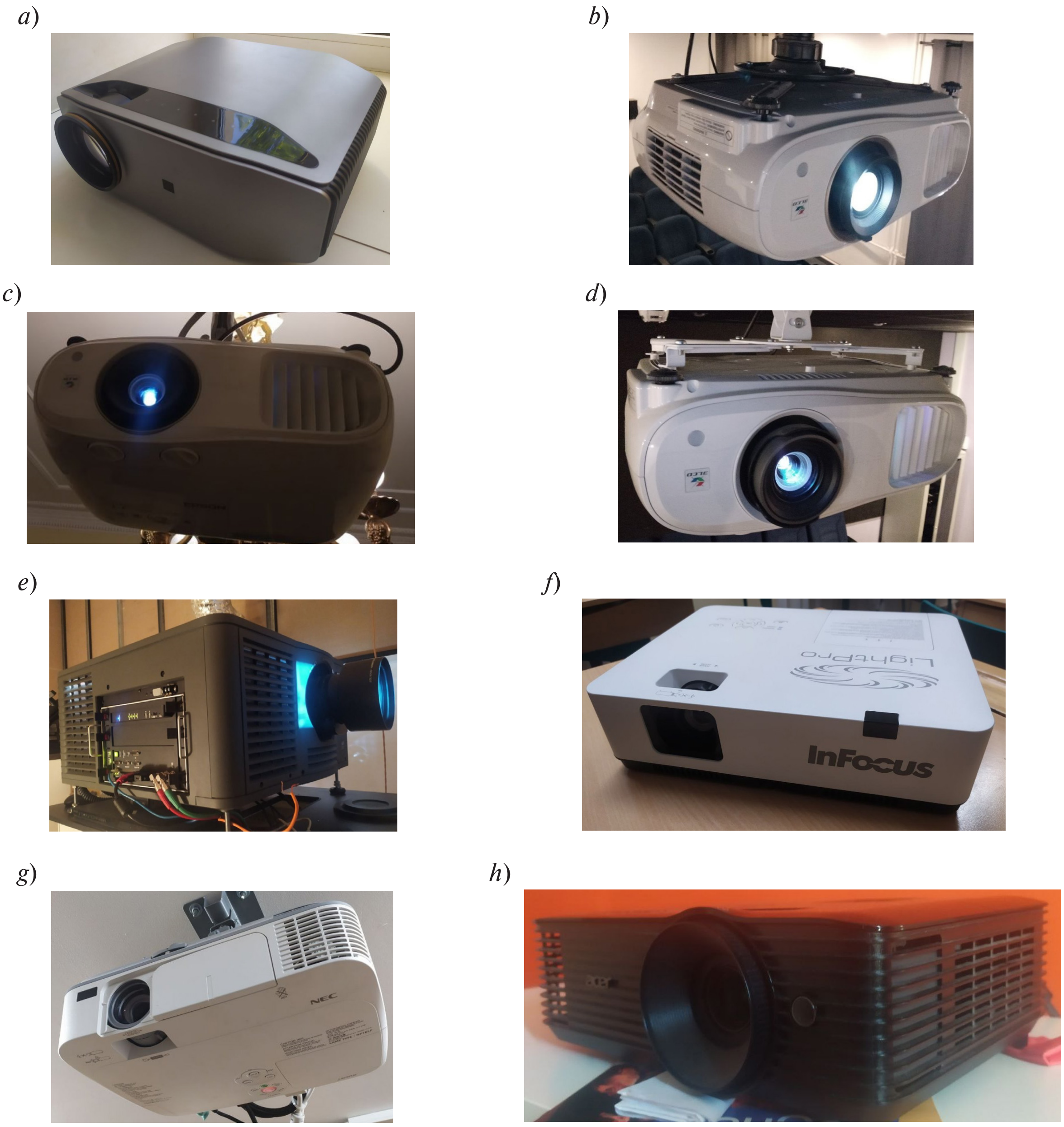

Fig. 8. Tested video projectors and their service life: *a* – UNIC YG-620 (home cinema, new),
b – EPSON EH-TW6800 (cinema center «Dom Kino», «White» hall, 4 years),
c – EPSON EH-TW6800 (cinema center «Dom Kino», «Small» hall, 4 years),
d – EPSON EH-TW7000 (cinema center «Dom Kino», «Lilac» hall, 2 years),
e – Christie CP2210 (cinema center «Dom Kino», «Blue» hall, 13 years),
f – InFocus In1026 (Gymnasium of St. Ambrose of Optina, assembly hall, new),
g – NEC M300W (Gymnasium of St. Ambrose of Optina, classroom, less than a year),
h – Acer X118AH (coworking «GrowUp», meeting room №1, less than a year)

$$\mathbf{E}_{\mathbf{DR}} = \mathbf{E}_{\Sigma} - \mathbf{E}_{\mathbf{SD}}. \tag{2}$$

Experiment on measuring the lighting parameters of a video projector in a real room

In the experimental part, the parameters of the output light flux of eight projectors were measured in real conditions of their operation. Photos of the tested projectors indicating the service life from the beginning of operation are shown in Fig. 8, *a–h*.

Table 1 shows the main technical characteristics of the tested projectors declared by the manufacturers.

To measure the output light parameters of the projectors, measuring devices produced by the “TKA” scientific and technical enterprise [19] were used: a combined “TKA-PKM 02” device for measuring screen illumination and “TKA-YAR” brightness meters for measuring brightness.

Test images (Fig. 1, 3–7) were recorded on a USB flash drive connected directly to video projectors and played back by projectors using the built-in control menu. For each projector, the following values were measured: output luminous flux (WLO), color luminous flux (CLO), ANSI contrast, brightness of the resulting image for the center of the screen (Table 2). WLO, CLO and brightness were measured for each projector twice: with calibration according to GOST IEC 61947-1-2014 (designation “GOST” in Table 2) and after additional configuration, the method of which was described earlier (designation “Additional” in Table 2). All measurements were made at the maximum power consumption mode of the lamp.

Table 1

Main technical characteristics of the tested projectors

Video projector	Imaging technology	Number of light modulating matrices	Light source	Maximum power of the light source, W	Service life of the light source in normal mode, h	Service life of light source in economy mode, h	Projector resolution	Output luminous flux (WLO), lm	Contrast
UNIC YG-620	LCD	1	LED	140	20000	50000	1920×1080 (Full HD)	6500	3000:1
Epson EH-TW6800	LCD	3	high-pressure mercury lamp	250	3500	5000	1920×1080 (Full HD)	2700	120000:1
Epson EH-TW7000	LCD	3		250	3500	5000	4096×2160 (4K PRO-UHD)	3000	40000:1
Christie CP2210	DLP	3	ultra-high pressure xenon lamp	1600	3000	–	2048×1080 (2K)	12000	2000:1
InFocus In1026	LCD	3	high-pressure mercury lamp	240	10000	20000	1280×800	4200	50000:1
NEC M300W	LCD	3		230	4000	5000	1280×800	3000	2000:1
Acer X118AH	DLP	1		203	4000	10000	800×600	3600	20000:1

Results of the experiment and their analysis

When comparing the measurement results (Table 2) and the technical characteristics of the video projectors (Table 1), it can be seen that ***none*** of the tested projectors produces the WLO luminous flux declared by the manufacturer in the specification during calibration according to GOST [13]. There are several reasons for this. *Firstly*, some test projectors have a long operating history, which affects the reduction in the efficiency of light sources and light modulating matrices. *Secondly*, manufacturers

Table 2

Results of measurements of characteristics of test projectors

Projector	WLO, ANSI-lm		CLO, ANSI-lm		Brightness, cd/m²		ANSI-contrast, k:1
	GOST	Add.	GOST	Add.	GOST	Add.	
UNIC YG-620	280	270	250	240	120	110	300:1
EPSON EH-TW6800 (N1)	320	260	310	250	35	30	100:1
EPSON EH-TW6800 (N2)	420	340	380	310	50	42	35:1
EPSON EH-TW7000	1180	970	1170	930	61	50	26:1
Christie CP2210	1890	1490	1870	1490	60	55	100:1
InFocus In1026	2910	2840	2870	2720	320	300	90:1
NEC M300W	1050	840	1050	800	120	110	90:1
Acer X118AH	1070	930	390	380	110	100	11:1

indicate the maximum amount of light flux, which must be reduced to obtain a high-quality image on the screen.

After additional configuration most of the tested projectors display an image of sufficient brightness for their purposes on the screen except the EPSON EH-TW6800 projector which gives the brightness of the image significantly lower than the SMPTE minimum for digital cinema of 37.8 cd/m^2.

The CLO value is approximately equal to the WLO value for all tested projectors except the Acer X118AH single-matrix DLP projector (CLO is approximately 40% of WLO).

The ANSI contrast values measured during the experiment are orders of magnitude less than the contrast indicators declared by the manufacturers in the specifications. Of the four tested projectors used for commercial film screenings, only two correspond to the minimum allowed ANSI contrast level of 100:1 according to SMPTE RP 431-2: 2011.

Conclusion

To date, there are *no practical* recommendations for measuring the parameters of a video projector in real conditions of its operation. Specifications of video projectors are often compiled by manufacturers taking into account the further need for the product to be competitive in the market, therefore, the output lighting values indicated in them, measured in laboratory conditions, fail to correctly characterize the parameters of the actually projected image.

In addition to the methods prescribed by the GOST IEC 61947-1-2014 for measuring the output lighting values of video projectors, the authors have proposed their *own* method for measuring these values. The method can be used in relation to video projectors belonging to various market segments, directly in the premises where the projector is operated (i.e., other than laboratory conditions of an ideally dark room), taking into account its service life.

The results of the experiment show that when calibrated according to GOST IEC 61947-1-2014, the luminous flux drops to 60–70% of the maximum, and with additional calibration – down to 50% (!). WLO values with additional configuration of the projector, desirable for obtaining the best image quality, are on average 13% lower than those measured according to GOST IEC 61947-1-2014.

Thus, the proposed method takes into account factors such as the imposition of external illumination on the screen illumination and the design features of the lighting and projection systems of projectors during their use. The method allows additional adjustment of video projectors with subsequent measurements of their output lighting values. This setting makes it possible to obtain the best image quality directly at the place where the projector is installed and used and, in fact, is a clarification of the requirements of the standard [13] for real operating conditions of the projector. The output lighting values of the video projector measured using this method turn out to be more *reliable* than those indicated by the projector manufacturers in the specifications. This factor is especially relevant for multimedia video projectors that have been in operation for a long time and allow the user realistically assess the condition of the video projector and make a timely decision about its replacement.

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