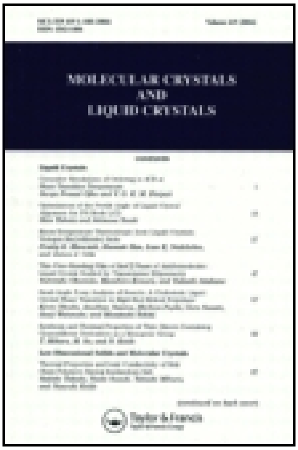

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Optimization Procedure for Liquid Crystal Display Working Under High External Lighting

Marek Olifierczuk [a], Jerzy Zieliński [a] & Rafał Kowerdziej [a]

[a] Institute of Applied Physics, Military University of Technology, Warsaw, Poland

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Optimization Procedure for Liquid Crystal Display Working Under High External Lighting

Marek Olifierczuk, Jerzy Zieliński, and Rafał Kowerdziej
Institute of Applied Physics, Military University of Technology, Warsaw, Poland

The liquid displays are widely used in the present world, but good optical parameters of them are obtained only for standard applications. In the case of special conditions, for example high level of external lighting, their optical parameters such as luminance, contrast ratio, viewing angle and color visualization are often insufficient. Such a situation occurs, for example in plane cockpits, where the external illuminations can achieve very high level. Therefore, to obtain a display, which can be used in such places, optimization procedure of it should be carried out. This procedure should give the information, how the properties of the individual elements of a display influence his optical parameters. Because of the construction of LC display is not simply and many parameters influence his optical properties, to do optimization procedure of a display, the mathematical model and numerical program of a light propagation through the display is needed. Assumed model should reflect the real conditions of the display work and should not include too many simplifications.

The main aim of presented work is the analysis of a reflective TN display as regards his usefulness to color visualization under high external lighting. The numerical simulation of such a display using the numerical program basing on mathematical model worked out in our Institute was done. This simulation was carried out, firstly, to determine the optical parameters of a display such contrast ratio and luminance in dependence on properties of applied polarizers and secondly, to determine the changes of color visualization as a function of driving voltage and optical matching of liquid crystal layer for chosen polarizing films.

After the numerical simulation the experimental verification process was carried out. This process was done to confirm correctness of assumed mathematical model.

Keywords: color visualization; optical parameters; optimization procedure; reflective liquid crystal display

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Address correspondence to Marek Olifierczuk, Institute of Applied Physics, Military University of Technology, 2 Kaliskiego St., Warsaw 00-908, Poland. E-mail: molifierczuk@wat.edu.pl

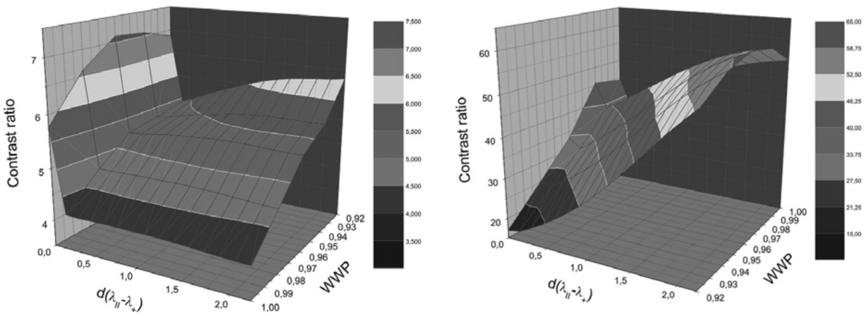
1. INTRODUCTION

In the present world, Liquid Crystal Displays are widely used in many visualization systems. Especially interesting are the reflective displays, because to create image, except own light source, they take advantage of an external light. Unfortunately, their optical parameters such as contrast ratio, luminance and color visualization are very good only in standard conditions of observation. In the case of very high external light, for example in plane glass cockpit, these parameters are much worse. Therefore, before application such a display under high external illumination the optimization procedure of it should be done. I this work such a procedure based on computer program worked in our Institute is presented. The reflective TN LCD working in negative mode was chosen to optimization, because of it's usefulness to use in plane cockpit. Such a display makes it possible to obtain the color symbols in very easy way, so can be applied as a significant element of many board devices. Our main aim was to shown an influence of optical properties of used polarizing films and liquid crystal layer on display contrast ratio, initial choosing the optimal point of work and doing the analyze of the influence of optical matching point on display color visualization.

2. CONTRAST RATIO OF REFLECTIVE TN DISPLAY WORKING IN NEGATIVE MODE

The most important parameter determining the quality of visualization is contrast ratio. Using the computer program based on mathematical model detailed described in our earlier papers the value of contrast ratio of reflective TN display as a function of polarizing coefficient of used polarizers and dichroic properties of a liquid crystal layer was obtained [1–5]. These values were calculated for standard (float sodium) glass with ITO layer, thickness of LC layer equal to 6 μm, and assumption of a lack of the dispersion phenomena. In the other words the gray polarizers and dichroic dye were used. The results presented in Figure 1 was obtained for first minimum of transmission, but for the second one the very similar results can be achieved [1]. Dichroic layer of the liquid crystal layer was defined as the value of the expression $d(\alpha_{\|} - \alpha_{+})$, where d denotes the layer thickness and the $\alpha_{\|}$ and α_{+} denote the absorption coefficient of the planar layer for the light passing through the layer and linearly polarized according to the layer director and perpendicularly to it, respectively. Contrast ratio was calculated according to the Eq. (1).

$$CR(\Delta nd) = \frac{\int_{380}^{780} H(\lambda) \cdot V(\lambda) \cdot T_{ON}(\Delta n, d, \lambda)d}{\int_{380}^{780} H(\lambda) \cdot V(\lambda) \cdot T_{OFF}(\Delta n, d, \lambda)d} \tag{1}$$



(a) (b)

FIGURE 1 Contrast ratio as a function of the polarizers and layer properties for negative mode of TN reflective display working in the first transmission minimum. (a) lack of antireflective layer and (b) antireflective layer is used.

where, $H(\lambda)$ – spectral characteristic of the light source; $V(\lambda)$ – human eye sensitivity, $T_{ON}(\Delta n,d,\lambda)$, $T_{OFF}(\Delta n,d,\lambda)$ – display transmission (for internal and external sources) in on-state and off-state, respectively.

As one can see in Figure 1 to obtain TN reflective display, which can be applied under high external illumination the antireflective layer must be used. In the case a lack of it, the possible to obtain values of contrast ratio are not higher then 1:7, and for this reason such a display can not be used in situation of high external lighting. The application of antireflective layer makes it possible to obtain CR equal to about 1:60. It is the growth higher then 8 times. Additionally, we can see, that to obtain the maximal value of CR the polarizing coefficient of used polarizers (denoted as *WWP*) should be in the range from about 0.94 to 0.98 and the strong dichroic dye should be used. After the analyze of obtained results, to next numerical calculations the following assumptions were admitted:

– polarizing coefficient (*WWP*) of used films: from 0.94 to 0.98
– dichroic properties of LC layer $d(\alpha_{\|} - \alpha_{+}) = 2.0$.

The remain properties of display elements were assumed as previously.

3. LUMINANCE AND COLOR VISUALIZATION OF REFLECTIVE TN DISPLAY WORKING IN NEGATIVE MODE

Analyzing the influence of polarization coefficient of polarizers and dichroic properties of LC layer on display contrast ratio, the initial conditions of a display work were determined. Next, luminance such a display was analyzed. In Figure 2 the detailed results of contrast ratio and luminance calculated for reflective TN display with assumed dichroic layer $d(\alpha_{\parallel} - \alpha_{+}) = 2.0$. and polarizers with polarization coefficient from 0.94 to 0.98 were presented. Shown results were calculated for optical matching described by $\Delta nd = 0.48$.

From the results presented in Figure 2 one can see, that the best optical properties one can obtained for the polarizers with polarization coefficient equal to about 0.95. The value of contrast ratio is high in the range of *WWP* from 0.94 to 0.98 and amounts over 1:52, but the

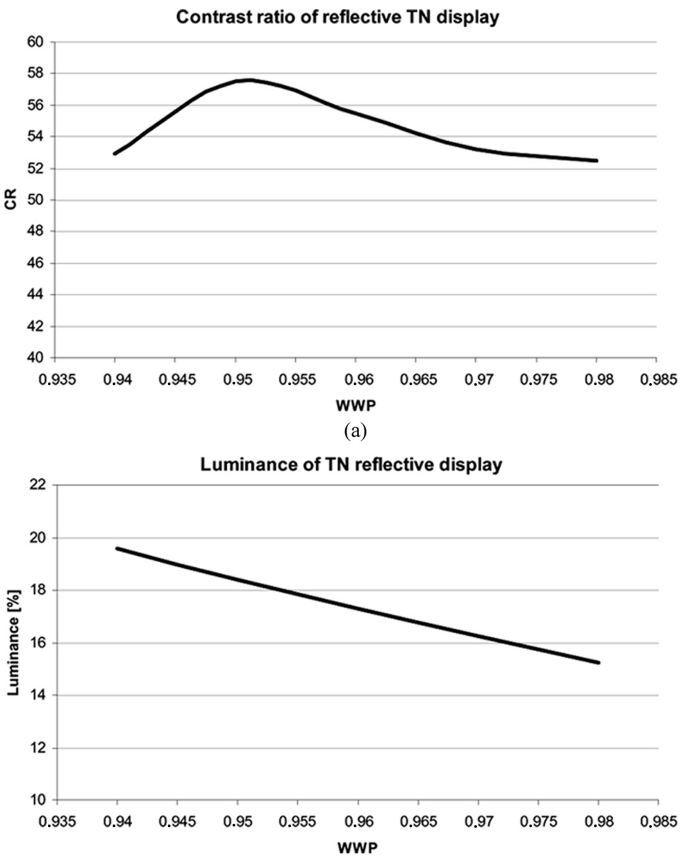


FIGURE 2 Contrast ratio and luminance of reflective TN display with antireflective layer and dichroic LC layer as a function of used polarizers. WWP denotes polarization coefficient of films.

highest value is achieved for *WWP* = 0.95 and it equal to 1:58. Additionally, taking into account the values of luminance one can see, that growth of polarization coefficient over 0.95 causes, that not only contrast ratio decreases, but luminance too (from 18.3% to 15.5% for *WWP* = 0.98). It is a change higher than 15%. Therefore, the application of polarizers with the polarization coefficient higher than 0.95 is not correctly solution for reflective display. The better solution is to apply the polarizers with *WWP* equal or a little lower to 0.95. This second situation can be interesting in the case, when the brightness of a display is very important. The drop of a polarization coefficient of polarizers causes, that contrast ratio decreases (from 1:58 to 1:53 for *WWP* = 0.94 – it is about 10%) but in the same time luminance increasers from 18.3% to 19.7% – it is about 8%. The next decreasing of *WWP* is not favorable because CR decreases faster then luminance increasers.

After the detailed properties of used films were determined, in the last step the analysis of color visualization was carried out. This analysis was done for the polarizers with *WWP* = 0.95. To do it, the profile of LC layer for off state, low, medium and high applied driving voltages were assumed as it is shown in Figure 3.

The color coordinates for different values of optical matching and for different values of driving voltage obtained for polarizers with WWP = 0.95 are presented in Table 1.

As one can see the optical matching, which changes from 0.44 to 0.52 influence the color coordinates to insignificant extent. Such a situation occurs for all analyzed driving voltages. For this reason,

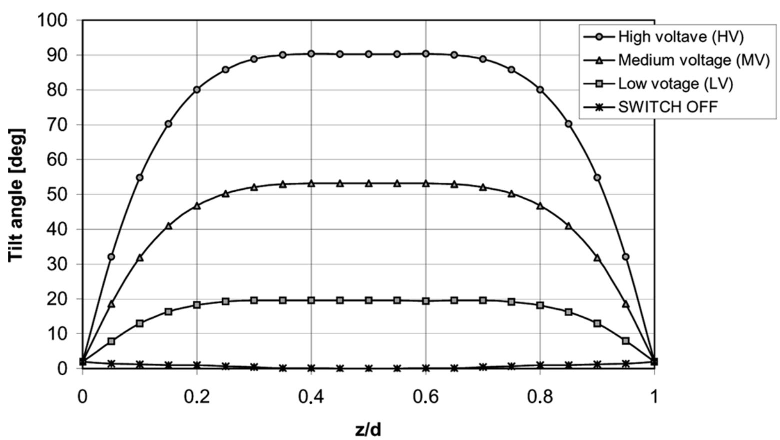


FIGURE 3 Profile curves assumed to the calculations of color coordinates.

TABLE 1 The Color Coordinates CIE 1931 for Different Level of Driving Voltage for Reflective TN Display

	0.44		0.46		0.48		0.5		0.52	
Δnd	x	y	x	y	x	y	x	y	x	y
OFF	0.2643	0.2239	0.2641	0.2212	0.2642	0.2183	0.2643	0.2156	0.2641	0.2137
LV	0.2745	0.2534	0.2645	0.2486	0.2606	0.2442	0.2607	0.2397	0.2629	0.2352
MV	0.3627	0.3649	0.3679	0.3672	0.3733	0.3693	0.3789	0.3712	0.3848	0.3729
HV	0.3137	0.3282	0.3138	0.3284	0.3138	0.3285	0.3139	0.3286	0.3141	0.3287

the following conclusion can be drawn: the changes of optical matching, for example caused by temperature, do not influence the color visualization. The different situation is in the case of driving voltage. This parameter very strong influences color coordinates. The strongest changes occur between medium and low voltages. The color of a display suddenly shift to blue one.

As one can see in Figure 4 for high and medium driving voltages the color transmission function of an analyzed display is very similar to

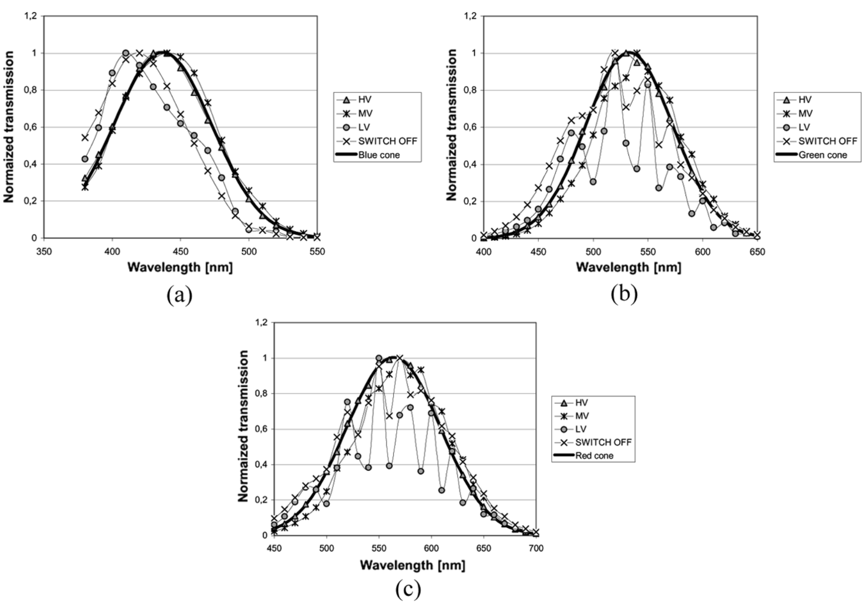


FIGURE 4 Normalized transmission of reflective TN display for different driving voltages obtained for sensitivity function of human blue (a), green, (b) and red (c) cones.

the sensitivity functions of a human eye, especially for blue one. Also for green and red function the changes are not high. When voltage decreases to the low level, these functions modify very strong. It is sum of effects of interference in LC layer, operation of antireflective layer and changes of optical conditions in LC layer. Especially strong effect is for blue color, one can see high shift of function maximum to the shorter wavelength. It is causes by changes of optical conditions in LC layer. Interference phenomena is covered by relatively high light intensity in this wavelength range. For green and red colors similar shift occurs, but this effect is not such clear, because in these cases the interference phenomena predominates. Intensity of light is low in the results of operation of antireflective layer.

4. EXPERIMENTAL VERIFICATION OF USED MATHEMATICAL MODEL AN NUMERICAL PROCEDURE

To verify the applied numerical method and mathematical model of a light propagation trough the liquid crystal display, the measurements of a transmission characteristics of four transmissive display samples were done. These cells were filed of LC mixture no. 1280 from Institute of Chemistry of Military University of Technology with $\Delta n = 0.1612$ for temperature equal to 21.5°C. As a polarizers the following films were used: NPF Q12-35 and PC 54814S ones. In Table 2 the main parameters of made cells were shown.

To measure the spectral transmission characteristics the set-up with Ulbricht sphere was use. This set-up makes it possible to obtain the spectral characteristics of a display for any observation angle, and for wavelength from 380 nm to 780 nm. Presented results were obtain for the observation angle equal to 0° (normal light incidence). After measurements, the calculations o theoretical spectral characteristics for the same assumptions were done. The obtained the both characteristics: from experiment and from numerical calculations ones for all four cells are presented in Figure 5.

As one can see in Figure 2 the very similar results were obtained. The difference between the experimental and theoretical results is not higher than about 10% for particular point. Additional after calculations of luminance based on these characteristics this difference decreases under 5% (see Table 3).

Taking into account that not all physical parameters of cell elements were known (for example thickness after filing or refractive index of polarizing films), obtained difference between experiment and calculations is not high. It makes it possible to regard used mathematical model as a reliable.

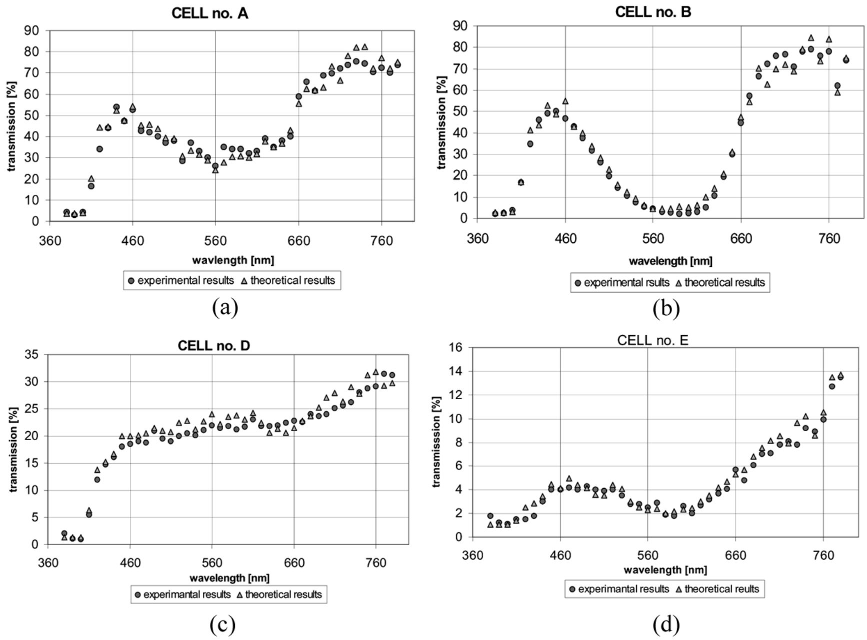


FIGURE 5 The comparison between the results obtained from calculation and experimental measurements.

TABLE 2 The Main Parameters of Measured Cells

	Cell A	Cell B	Cell D	Cell E
Thickness [μm]	6.48	6.48	6.20	6.07
Used polarizer	PC 54814S	PC 54814S	NPF Q12-35	NPF Q12-35
Mode	Positive	Negative	Positive	Negative

TABLE 3 The Comparison Between Experimental and Theoretical Results

	Cell A	Cell B	Cell D	Cell E
Calculated lumiance [%]	32.26	10.67	22.67	4.88
Measured luminance [%]	33.96	11.04	21.66	4.65
Relative difference [%]	5.0	3.4	4.7	4.9

5. FINAL CONCLUSIONS

In this paper the reflective TN display was analysed. The significance of antireflective layer in such a display was shown. The influence of polarization coefficient of used films and dichroic properties of a LC layer on contrast ratio and luminance of such a display was presented. Basing on these results, the optimal work point was chosen. For this point the color visualizations of a display was analysed.

Presented result show, that the optimisation procedure of a reflective TN display for application under high external illumination must be done. In this work only a sample of such a procedure was presented, because we done an analysis of an influence of grey polarizing films and grey dichroic dye in the LC layer on optical parameters of a display. But even such simplified procedure showed strong influence of analysed elements on display visualization.

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