28.1: *Invited Paper*: LCD Optimization and Modeling

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Abstract

The application of the LCD modeling and optimization system LCD DESIGN for the design and development of the new advanced LCD configurations is demonstrated. The software includes a powerful optimization module, that allows for the spectral and angular averaging, thus enabling to produce LCD with wide viewing angles, achromatic (black/white) switching and fast response time. We describe the basic principles of the software development and present several examples of the LCD optimization in various electrooptical modes. A brief review of our results of LCD optimization and modeling using LCD DESIGN software is also given.

1. Introduction

Computer modeling is a powerful and indispensable tool at development of liquid crystal devices and fundamental researches in the field of physics of liquid crystals [1]. Several groups are successfully working in this direction, including DIMOS (Display Modeling System) [2,3], LCD Master (Modeling and Evaluation Software System for LCD Designers) [4], Tech Wiz LCD (3D Simulation Software for AMLCD Panel) [5], LCD Performance Modeling [6] and some others. The aim of this work is to describe new universal software LCD-DESIGN for modeling and optimization of liquid crystal devices. LCD-DESIGN comprises two programs: MOUSE-LCD (some previous variants of the MOUSE-LCD were presented in [7-10]) and program POL-LCD [11]. MOUSE-LCD mostly provides the calculation of the standard engineering characteristics of usual and projection LC displays. The main destination of POL-LCD is the modeling of characteristics of amplitude and phase modulators and polarization controllers based on liquid crystals and the simulation of optical spectral and polarization experiments [11]. The program MOUSE-LCD includes a powerful optimization module, that allows for the spectral and angular averaging, thus enabling to produce LCD with wide viewing angles, achromatic (black/white) switching and fast response time [12]. This paper will provide the basic principles of LCD-DESIGN software and present some optimization results.

2. Basic principles

The procedure of the modeling of LCD efectrooptical behavior includes two steps. First, the LC director deformation profiles are found for varying applied voltages. The deformation program can calculate any director distribution with arbitrary director twist and any (non-symmetric) director tilts on the boundaries. Both polar and azimuthal weak anchoring at the substrates is also taken into account. The dynamics of the deformation is estimated, not only in the approximation of a pure director rotation, but also with a so-called "back-flow" effect, when six Leslie viscosity coefficients are allowed for.

The second step consists of solving Maxwell equations for the light propagating in anisotropic LC media to find the optical response of the LCD cell. The module operation is based on the novel 8x8 transfer matrix method, which is an exact solution of the Maxwell equation for a quasi-monochromatic light [13]. Thus smoothed spectra dependence can be easily calculated, which is really a case in LCD operation. The application of the phase compensators is an effective method to obtain a perfect image in LCD with a sufficient brightness and high contrast [1]. However a proper choice of the phase compensators is rather complicated problem even in case of the computer modeling of the output LCD parameters [2-6]. Our original approach, based on conception of Polarization Transformation Efficiency (PTE) [14], essentially simplified the optimization of LCDs with phase compensators. We have already proposed an efficient achromatic black and white (B/W) switching of one polarizer reflective LCD (RLCD) in RTN mode [14] as well as the wide application of antireflective (AR) layers to get a perfect dark state of transmissive and reflective LCDs [15]. We often use a "parameter space approach" [16] to find the valuable combinations of optical birefringence, twist angle and polarizers location for both transmissive and reflective LCD configurations. The efficiency of our software is illustrated by some examples given below.

3. Optimization results

3.1 Improvement of LCD performance in various electrooptical modes

We can improve the brightness, contrast, viewing angles and response time of LCD by using our optimization module in various electrooptical modes (Fig.1) [12]. The main steps of the optimization is a proper choice of the birefringence value, operating voltage and insertion of antireflective (AR) layers as well as phase compensators.

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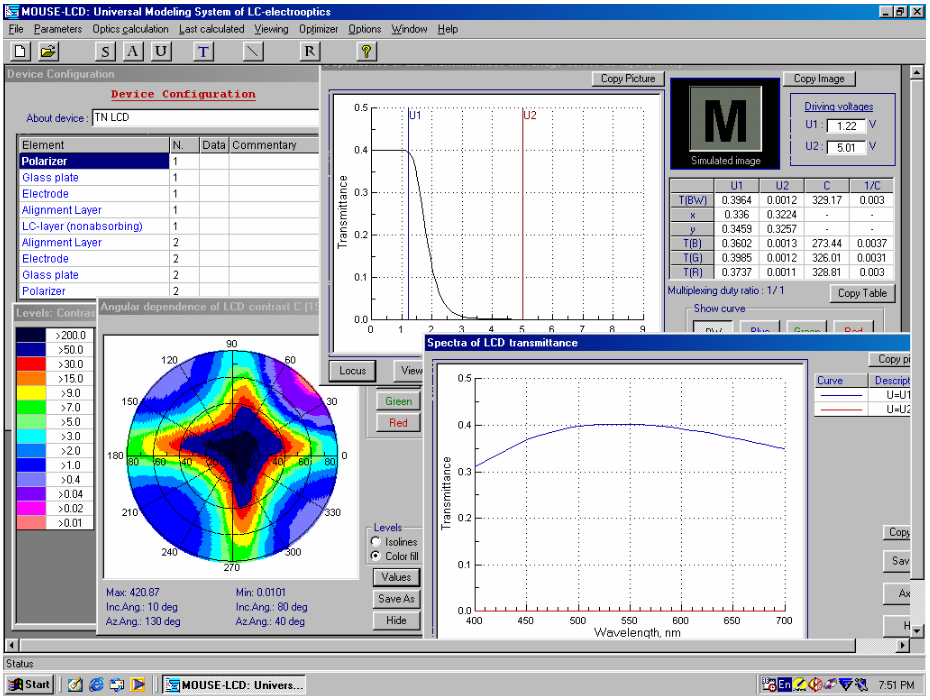

Figure 1. TN-LCD, obtained by using the new optimization module in MOUSE-LCD program.

and AR layers		

The transmission of the optimized TN-LCD was considerably high (about 0.35-0.4) and the contrast is considerably imroving (Table 1). The results, which we obtained in STN-LCD are also impressive (Table 2).The transmission of the the optimized STN-LCD was more than 0.37 and duty ratio > 16:1.

Table 1. Improvement of the contrast of TN-LCD.

Optimization operation	Transmissive TN-LCD	Reflective TN-LCD
Optimal birefringence value	176.43	5.326
Using of AR layers	279.08	26.81
Using of both compensators and AR layers	433.06	79.25

Table 2. Improvement of the contrast and response time of transmissive STN-LCD.

Optimization operation	Contrast	Response time, ms
Optimization of driving voltage	84	34
Using of AR layers	146	18
Using of both compensators	302	20

Very high contrast (C=408 in transmissive mode and C=38 in reflective mode) can be also obtained, when we insert proper phase retarders and AR layers in Vertical Aligned Nematic (VAN) configuration and choose optimal birefringence value and the value of operating voltage (<3V in our case). The contrast >50 is provided at the angle more than 60^0 both in vertical and horizontal direction (Fig.2). The VAN-LCD response times were 5 ms in transmissive and 2 ms in reflective mode respectively.

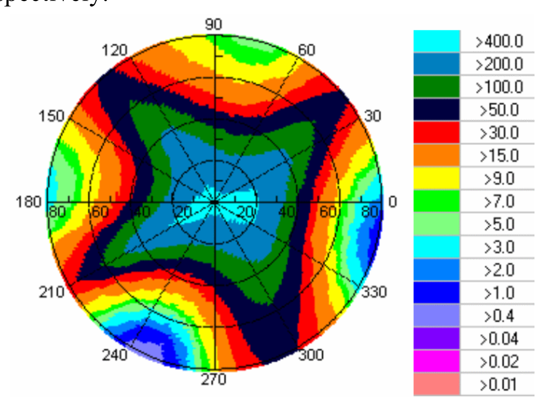

Figure 2. Angle dependence of the contrast ratio for optimized VAN-LCD with phase retarders and AR layers.

We have also obtained very promising results using Hybrid Aligned Nematic (HAN) mode, as well as

Electrically Controlled Birefringence (ECB) and Half π cell electrooptic modes (Table 3) [1]. The results were comparable with those shown above (Tables 1,2). In all cases the brightness was more than 0.35, operating voltages less than 3V and response time between 5 –8 ms (TN, VAN, ECB, Half π) and 15-20ms (STN, HAN).

Table 3. Contrast ratio in transmissive (reflective) LCD based on various electrooptical modes (normal light incidence).

Electrooptical Mode	Transmissive LCD	Reflective LCD
TN	433	79
STN	302	34
VAN	408	38
HAN	434	50
ECB	397	52
Half π cell	303	38

3.2 Other optimization results

The other results of our optimization using MOUSE-LCD software are published elsewhere. They include the following topics.

1.*Birefringent color TN and STN-LCDs with a high brightness* [1,9]. We have shown, that the birefringent color system, which we estimate using MOUSE-LCD software could be also very helpful in the efficient color AM-LCD without isotropic dye filters, as the transmission of the LCD is increased almost 10 times.

2.*Fast LC shutters based on 3π/2 supertwist cells* [1,9]. Very fast switching can be obtained with the characteristic rise times less, than 1ms and decay time 2-3 ms. At the same time 3π/2 cells provide very high contrast ratio and transmission both for the normal and oblique light incidence.

3.*One-polarizer and non-polarizer "guest-host" LCDs with a high contrast and brightness and wide viewing angles* [9,17]. Non-polarizer "guest-host" LCD with a phase retarder provides the contrast ratio of 18:1 and the brightness of 33% and the contrast remains sufficiently high for wide viewing angles [17].

4. *Achromatic reflective TN LCD with a high brightness and contrast* [14,15]. The application of phase retarders and antireflective layers allows increasing the contrast ratio several times with totally achromatic black and white states (see also Table 1).

5. *Highly multiplexed achromatic one-polarizer reflective STN-LCD* [12,14]. The contrast of STN RLCD more, than 9:1 and average reflectance higher, than 30% with a multiplexing ratio of 700:1 has been obtained.

6. *"Memory" effect in 180^0 STN-LCD* [18]. Our calculation results allows to suggest principally new addressing scheme of highly multiplexed STN-LCD with fast response time and high contrast.

7. *Transflective LCDs with a high contrast and brightness and fast response time, based on various electrooptical modes* [12]. We have designed and optimized highly efficient transflective LCD, based on the same LC layer, but with patterned phase retarders and polarizers.

8. *LC devices for optical communication systems* [19]. We have shown, that some important LC elements of fiber optical systems, e.g. polarization controllers, polarization rotators and phase emulators can be designed and optimized, using the program POL-LCD [11].

4. Conclusion

The LCD modeling and optimization system LCD-DESIGN is an efficient tool for the design and development of the new advanced LCD configurations. We have described the basic principles of LCD optimization software development and provide some important applications of LCD DESIGN in various electrooptical modes. A brief review of our results of LCD optimization and modeling is also given. LCD DESIGN can be also very helpful as a teaching tool for students, engineers and specialists in LCD industry.

5. Acknowledgements

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