Active Matrix Liquid Crystal Display – AMLCD Switching Time Measurements

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***Abstract*—Liquid crystal displays (LCD) are currently dominant in visual content presentation applications. In the case of video content presentation LCD switching time determines image appearance and perception. The photometric and temporal properties of LCDs are unfamiliar to many practitioners, especially switching time temperature dependence. In specific applications as ruggedized military displays temperature dependence is critical parameter for operation on low temperatures. Current liquid display technology does not provide proper operation at low temperatures so additional heater should be incorporated into display design. The temperature dependence of switching time provides initial data determining heater design parameters. The short review of the LCD switching time theory is presented. The AMLCD switching time over temperature, method is described. The selected measurement results are presented and discussed.**

***Index Terms*—liquid crystal display; active matrix liquid crystal display; switching time; rise time; fall time; measurement method; temperature dependence.**

I. Introduction

Twenty first century is century of liquid crystal (LC) displays (LCDs) that have been widely applied from small-size mobile devices to large-size televisions. Various methods have been developed for higher and advanced performance of active-matrix LCDs (AMLCDs) to provide superior application results [1]-[7]. Some of the most important achievements are: fast response LC providing high frame rate driving, backlight dimming technology for low consumption and high contrast ratio, wide viewing angle LC modes, high temperature range of operation etc. The majority of advancements have been achieved through advancements in LC science and technology [8]-[10].

The deep knowledge about LC [11]-[13] physical, optical and electro-optical properties is extensively used in design and operation of LCD pixel. One of the critical parameters is LCD pixel switching performances influencing proper video content reproduction, from the well–known issue of motion blur, to photometric settings and calibrations. Displays with faster transitions (switching) between different luminance levels are considered as supperior in the case of video content presentation. Because of that LC optical switching performances are studied theoretically and related measurement techniques have been developed. The basic data about LCD switching time is summarized in separate chapter.

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In the specific application as ruggedized military displays [14]-[18] some of performances are critically important for application. Among the other parameters switching time is slightly more important, because it has influence on display design in addition to operation parameters. Current LC technology do not provide proper LCD operation at low temperatures as required in military applications, so additional heater should be built in display to provide proper display operation at low temperatures. The temperature dependence of the switching time determines the heater design and consumption sufficient to provide display proper operation at low temperatures.

In this paper measurement method applicable for display switching time measurements over display operation temperature range is described. The selected measurement results illustrating the switching time temperature dependence for several AMLCD panels are presented. Also, these results provide initial data for LCD heater design.

II. AMLCD Switching time

Liquid crystal occupies a small portion in an LC device, but plays a key role in determining the device performances. The LC material and molecular alignment jointly determine the device contrast ratio, operation voltage, response time, viewing angle, and operating temperature.

The LCD response time consideration has two key aspects:

(a) How to design liquid crystal composition to have desired response – switching time values? This is not topic of this article, but some aspects will be mentioned just for better understanding. More details could be find in references [19]-[29] dealing with theoretical studies and modeling of the switching time behavior in different LC materials and LCD architectures.

(b) What is the influence of the switching time on presented video content appearance and perception? This is important to define limiting values depending on application [30], [31].

The LCD response time depends on different factors as illustrated in TABLE I. All off listed parameters depends on temperature, so LC scientists have a hard task to design LC composition having desirable temperature dependence on temperature.

The temperature dependence of dielectric anisotropy - $\Delta\varepsilon$ is limiting factor at high temperatures. Usually as temperature increases, $\varepsilon_{//}$ decreases while $\varepsilon_{\perp}$ increases gradually, resulting in a decreased $\Delta\varepsilon$. As $T > T_c$, the isotropic state is reached and the dielectric anisotropy is vanished, with no birefringence. Critical temperature T_c is high temperature at which LC lost its birefringence properties and LCD stop to work. Typical values for T_c are in the range 70°C up to 100°C.

TABLE I
THE EFFECTS OF DIFFERENT FACTORS ON RESPONSE TIME

Factors	T_{on}	T_{off}
Viscosity (γ1) ↓	↓	↓
Elastic constants (Kii) ↑	↑	↓
Dielectric anisotropy (Δε)↑	↓	↓
Thickness (d) ↓	↓	↓
Pretilt angle (θ0) ↓	↑	↓
Anchoring energy (W) ↑	↑	↓
Temperature (T) ↑	↓	↓
Voltage (V) ↑	↓	↓

The viscosity and elastic constants are limiting factors at low temperatures causing slower motion of LC molecules when electrical field is applied to change the order of LC in device.

The LC electro optical properties (time and temperature dependence) influence the display pixel response characteristics defining display video content appearance. One of the most important effects is motion blur appearance.

The motion-induced distortion [32], [33] of a visual target moving across an electronic display screen perceived as blurring of initially sharp edges by a human observer (motion blur) is caused by two effects:

- characteristics of the electro-optical response of the display to changes in video signal
- integration properties of the of the human visual system while

The increased response times of LCD pixel corrupt the visual quality of moving objects and thus contribute to motion blur.

III. AMLCD SWITCHING TIME MEASUREMENT METHOD

Motion blur influences display applicability on the different way depending on presented video content properties. Because of that motion blur measurement methods [34], [35] should be designed on different ways as illustrated in Fig.1.

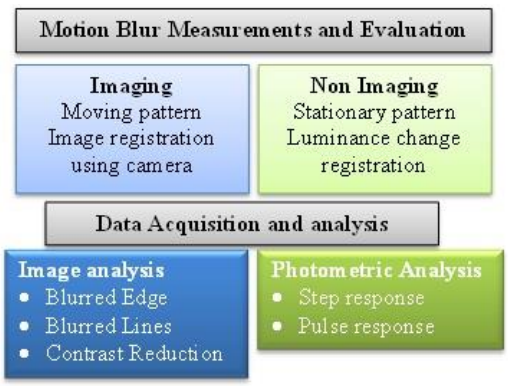


Fig. 1. Motion blur measurement and evaluation methods

Imaging methods are using selected moving patterns (blocks, lines, grille, grating etc.) presented on display and related image is recorded with tracking or stationary electronic cameras, and after that analyzed to quantify motion blur effects.

Non-imaging methods use stationary patterns on display surface but having temporary defined intensity change (pulse, step, periodic etc.) and pattern luminance level is measured using photometer [36].

In the case of ruggedized display presenting virtual instrument scale having moving bar edge proportional to the related quantity value it is important to have un-blurred moving edge to provide proper instrument reading. The LCD switching time value could be limitation factor. That type of display should be used reliably over all operation temperatures. As LC has known limitation for operation on low temperatures so LCD switching time temperature dependence should be known. This type of data is not presented in display data sheet so it is necessary that display designer provide that data.

Ideally, the measurement system should provide data about display panel brightness change versus temperature. To provide this it is necessary to avoid influence of the temperature to light sensor subsystem. For switching speed measurements, brightness change over time at set temperature should be recorded.

AMLCD Response Time is usually defined as sum of rise time (T_{on}) and fall time (T_{off}). T_{on} is defined as time necessary to change light signal from 10% value to 90% value when display pattern is changing from black to white. T_{off} is defined as time necessary to change light signal from 90% value to 10% value when display pattern is changing from white to black (See Fig.2).

We could only to compare response time (T_{on} & T_{off}) as defined previously. Also gray-to-gray level response time matters for video content presentation. In our case we are presenting moving bar instrument scale so it is good enough to measure only black to white level change.

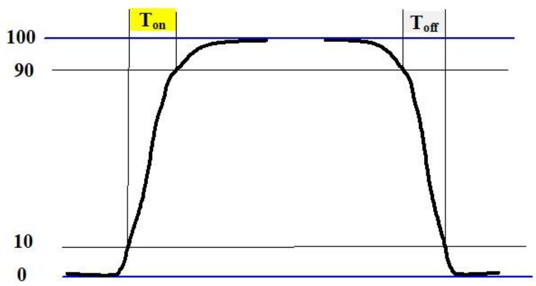


Fig. 2. T_{on} and T_{off} definition

Response Time is important parameter we need to know, to specify, at first place, heater requirements. Also, it is important parameter defining speed of response in the case of high frame rate imaging and fast motion artifacts in image. The way how it is defined does not allow us to have full sense what influence it has to image quality. Pixel response delay due to driving electronics is missing parameter.

Display temporal response was measured using a photodiode-based circuit and an oscilloscope. The photodiode was directed at switchable (black and white) square generated by our test program. A memory scope was used to record the photodiode response. Controlled temperature chamber is used to stabilize AMLCD panel temperature. Originally proposed measurement set-up is presented in Fig.3. It is proposed as best solution to use collection lens coupled with fiber-optical cable to provide that temperature have influence only on AMLCD panel while other parts of measurement chain are on room temperature. Following the facts that Si photodiode do not suffer of the response temperature dependence and that T_{on} , T_{off} data are extracted from relative photo signal values (see Fig.2) we selected simplified solution presented in Fig.4 and using collection lens and Si photodiode placed in temperature chamber and connected to photo current measurement circuit via coaxial cable.

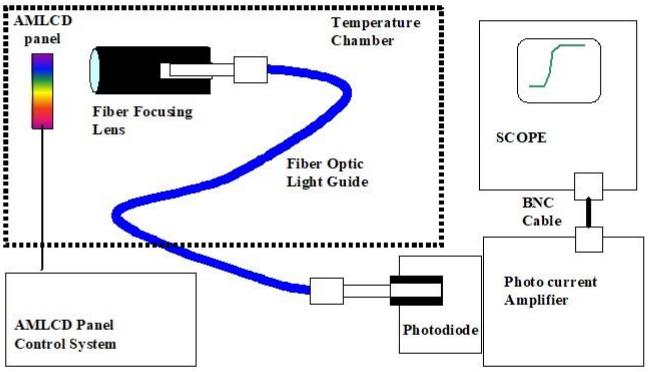


Fig. 3. Switching time measurement set-up

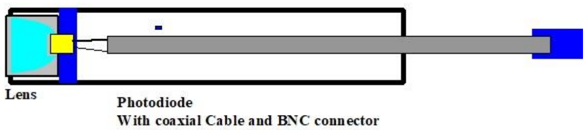


Fig. 4. Photodiode with collection lens

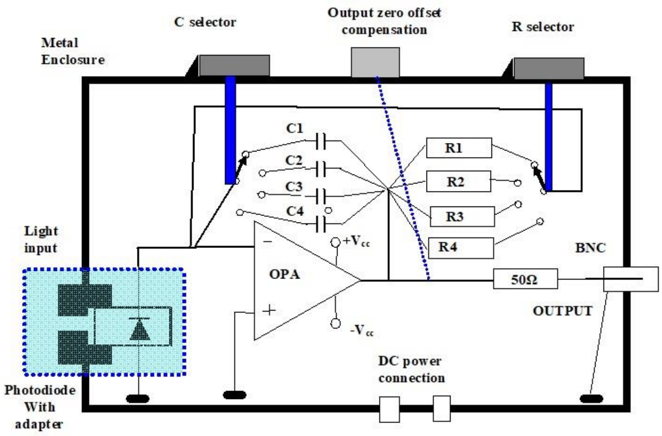


Fig. 5. Photocurrent to voltage electronic block schematic

Generated photocurrent is measured using photo current to voltage converter (trans-impedance operational amplifier) presented in Fig.4.

The light generated signal is generally noisy or involving high frequency components due to LCD backlight switching. It is good to filter the signal before recording to have more smooth line and easier determination of required 10% and 90% values. Because of that we use additional capacitance over load resistor for filtering, but RC constant should be at least ten times less than expected rise or fall time values.

The described photometric device and climatic chamber offers, flexible and easy evaluation of displays switching time in specific temperature environment between -40°C to +85°C.

Sensor and amplifier were tested and calibrated using 586 fL uniform halogen lamp in integration sphere white source (color coordinates x=0,386, y=0,401). Calibration results are summarized and presented in TABLE II.

TABLE II
CALIBRATION RESULTS

R [K]		Voltage Sensitivity [mV/fL]	Photo -Current Sensitivity [nA/fL]
R1	100	0.59	5.87
R2	388	2.28	5.88
R3	910	5.37	5.90
R4	3260	19.28	5.91
Average current sensitivity			**5.89**

IV. AMLCD SWITCHING TIME MEASUREMENT RESULTS

In the proposed paper, we present experimental results obtained on several commercial LCDs using a thermal enclosure allowing a required temperature range.

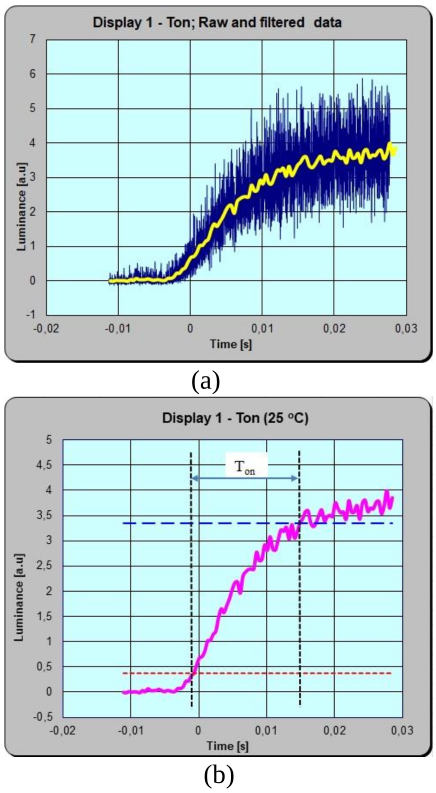
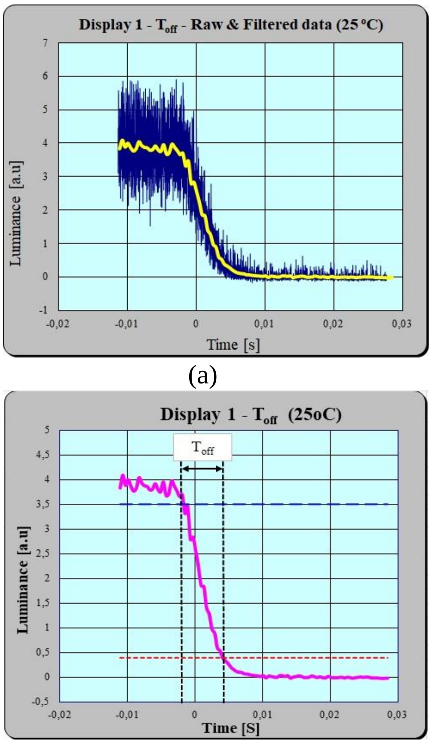


Fig. 6. T_{on} measurement signal (a) raw signal, (b) processed signal

The typical view of the recorded photometric signal during white to black and black to white switching is presented in Fig.6 and Fig.7.



(a)

(b)

Fig. 7. T_{off} measurement signal (a) raw signal, (b) processed signal

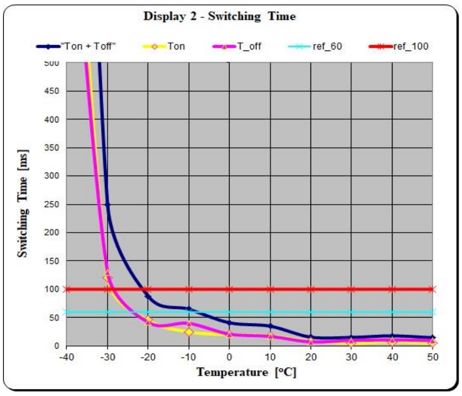


Fig. 8. Switching time vs. temperature measurement results (Display 2)

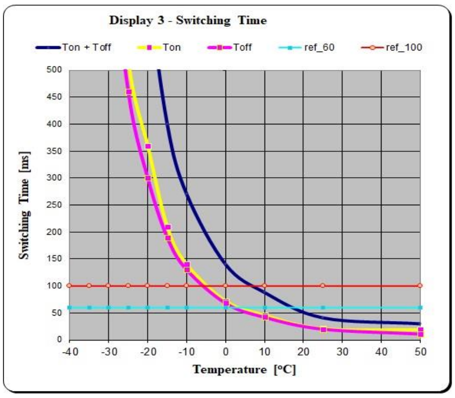


Fig. 9. Switching time vs. temperature measurement results (Display 3)

Measurement signal is exported as ASCI file and transferred to EXCEL spread sheet for further processing. Following recommendations from [37] and [38] moving averaging filter is successfully used for curve smoothing as illustrated in Fig.5 (a) and Fig.6(a).

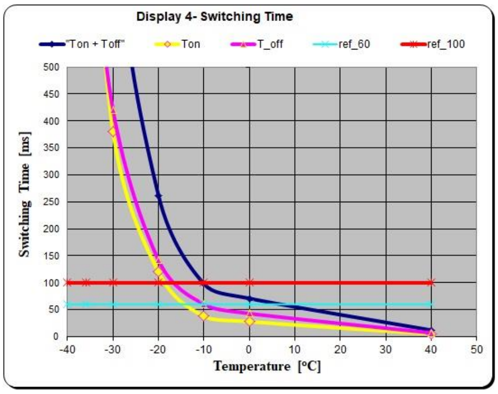


Fig. 10. Switching time vs. temperature measurement results (Display 4)

The summary of the measurement results for several AMLCD panels are presented in Fig.8 to Fig.10 together with two selected switching time critical values (60ms and 100ms). These results could be used to determine the lowest display operation temperature and provide starting data for heater design

V. Conclusion

AMLCD switching time depends on various LC parameters and LCD pixel design and operation. Also, switching time has influence on AMLCD panel operation. One of the most important switching time influences is motion blur appearance.

New light sensor aimed for response time measurements were built and tested and calibrated for photo current response.

Testing and calibration results show that it could be used successfully in all future response time measurements.

Switching time vs. temperature data are presented for several selected AMLCD panels and show that they have different critical temperature values. To use effectively these measurement results for heater design it is necessary to determine switching time (T_{on}, T_{off} or T_{on}+T_{off}) critical values to avoid motion blur influence according to display application.

It is shown that relatively simple and accurate method for switching time measurements could be designed and applied for aimed purpose when display critical switching time is known. The measurement methodology is successfully applied

In the case of display presenting virtual instrument scale having moving bar edge it was possible to determine critical switching time values. Using switching time vs. temperature measurement results heater design requirements could be derived.

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