Precise response time measurement and analysis of liquid crystal displays

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Abstract

In this paper, we present a new system, OPTISCOPE SA, especially designed for precise measurement of temporal behavior of LCD displays. We show that gray to gray level response time measurement requires a very sensitive and precise instrument and also that the capacity to measure luminance levels and gamma curve can be useful. Quite often, precise evaluation of LCD response time needs also use of low pass and stop band filters to suppress noise and flicker. Low pass filters affect the results but can be corrected for simple temporal behaviors. For complex temporal behaviors like those observed for overdriven LCDs, we show that direct adjustment of theoretical responses is much more efficient to get a complete picture of the temporal behavior of such displays.

1. Introduction

Extension of the digital TV market put recently a lot of pressure on the temporal behavior of flat panel displays. Indeed, HDTV requires almost 60 Hz working frequency and Liquid Crystal Displays are not intrinsically very rapid devices. There are two problems that affect the response time of LCDs. One is the nematic liquid crystal's slow response to an external field; the other is the driving method. Numerous efforts have been made recently to improve the time response performances of LCDs [1-3]. Nevertheless, the response time measurement itself is not straight forward especially when inter-gray levels with low differences are explored. In addition new driving strategies like overdriving leads to complex temporal behavior for the display emission and great care must be taken not only on the measurement itself but also on the measurement analysis to obtain valuable information.

In the following, we use a new ELDIM instrument called Optiscope SA that performes this type of measurement with a maximum of accuracy. The paper presents this new system and discusses our strategy to analyze the temporal measurements. First it is often needed to clear the measured signal from parasitic noise and flicker using low pass and band pass numeric filters and to correct the response time from the filter distortion. This method is working well for "standard" FPD with simple driving technologies. In this case, the result can be summarized by a response time value classically defined as from 10% to 90% level variation (VESA standard). For more sophisticated driving schemes, the temporal behavior is more complex with "overdrive" and "underdrive" variations higher and lower than the targeted level. In this case, we show that a regression approach using theoretical temporal behaviors is more adapted to extract all the required parameters (two response times, one overdrive amplitude and one temporal delay for example in the case of the overdrive technique).

2. Description of the measurement system

New Optiscope SA instrument shown in figure 1 looks like a conventional camera but includes all the hardware needed for temporal and luminance measurements. An imaging objective collects the light within an angular aperture of ±1° following VESA standard. Optiscope SA can be used at various distances from the display down to ~30cm. An image of the target can also be obtained with a color 1M pixels CMOS sensor for alignment purpose. Part of the light goes on a photomultiplier across a photo peak filter. The electronics includes a 16bits analog to digital converter and on board 4M memory. USB 2.0 connection with PC allows unlimited acquisitions with a sampling step between 5 and 20µs. Dark noise is corrected using a shutter. The performances have been measured using a computer driven LED source. The signal over noise ratio is around 100dB and the repeatability on response time measurements less than 0.1% in the range 1ms-100ms.

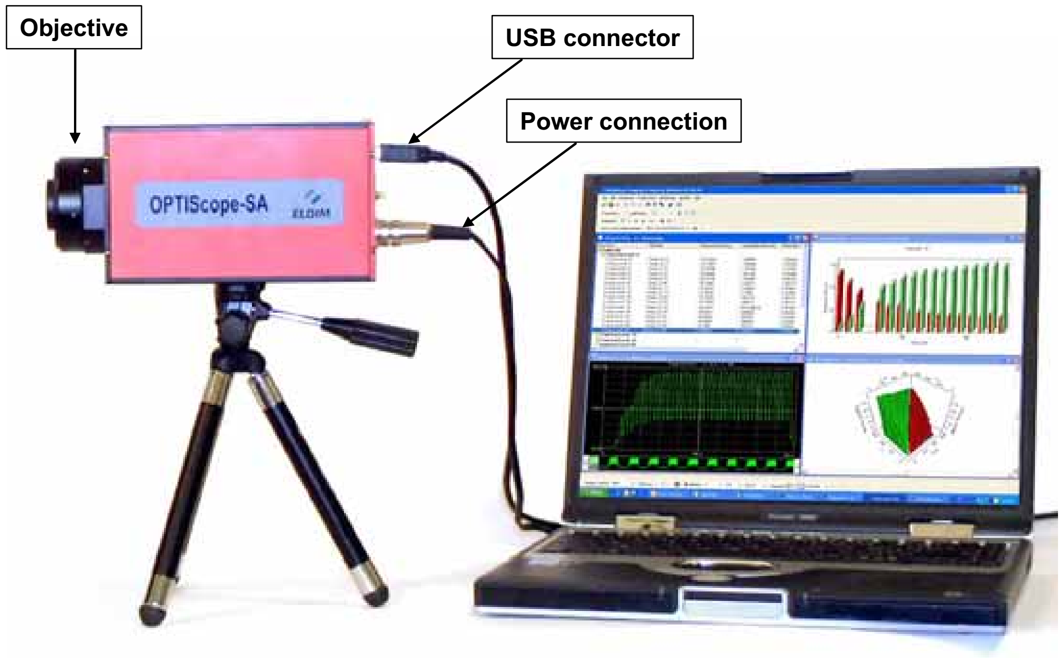


Figure 1: OPTISCOPE SA connected to a PC with measurement and regression analysis software.

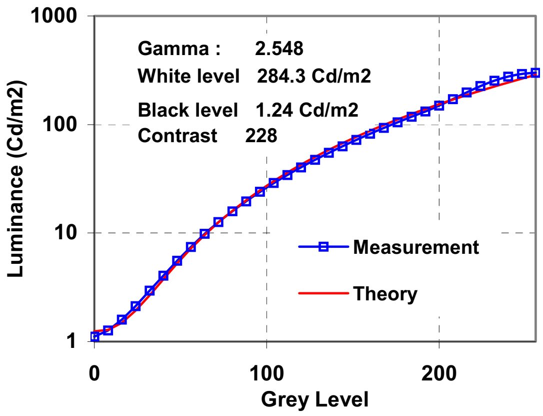


Figure 2: Gamma curve of a LCD display measured with OPTISCOPE SA instrument.

The system includes also a calibrated photodiode and an internal LED illumination to make self calibration and allow accurate luminance measurements. This capacity can be used to measure the gamma curve of the display before temporal analysis (cf. figure 2). Then gray to gray measurement and analysis can be made with fixed luminance step between each level. Compared to standard analysis with fixed gray scale step the advantage of this approach is to be more representative of the human eye sensation.

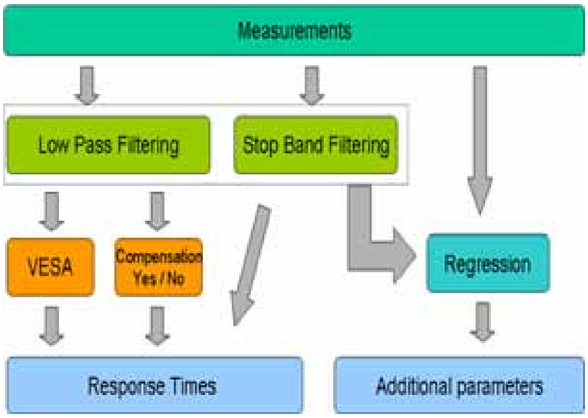


Figure 3: Filtering and parameter extraction chart of the analysis software.

Each temporal measurement must be carefully analyzed to extract parameters characteristic of the rising and falling time response of the display. When measuring inter-gray level response time, it is generally necessary to use a quite small sampling step between the gray levels. In the case of neighbor levels the signal step is low and can be strongly affected by any parasitic signal like the flicker of the display in some cases. So, in most cases a treatment of the signal to reduce the noise and the flicker is necessary before extracting response times. The different software possibilities for filtering and parameter extraction are schematically represented in figure 3.

3. Signal filtering

The Flat Panel Display measurements standards propose to apply a digital filtering by moving window average with variable filter frequency depending on the response time to be measure [4]. In some way, you need to know the result in advance to apply the right filter. A recursive procedure applying a given filter and changing its period depending on the obtained response time does not work properly. In addition the filter changes the shape of the signal and affect the response time especially if its frequency is low. All these reasons make the VESA procedure difficult to apply and only applicable to very limited cases.

A first improvement of the VESA procedure is to apply a low pass filter with fixed frequency to all signals in order to reduce the noise. The extraction of the response time becomes much easier but the shape of the curves is affected by the filter and the result is always over estimated and depends on the value of the response time and on the filter frequency. This effect can be easily seen in the figure 4 that shows a display with large flicker value at 120Hz. We propose to correct the result using an a priori calibration of the low pass filter. To evaluate precisely the overestimation due to the filter, we have generated numerically transient signal with various response times in the range 1-200ms and applied different low pass filters with variable frequency. Results are summarized in figure 5. In this way, the overestimation due to the filter can be precisely determined versus the response time and the frequency of the filter and a realistic correction can be applied to the extracted values.

Another possibility, when the main problem is related to flicker with quite fixed frequency, is to apply a stop band filter around this frequency. The interest of this type of filter is that it does not change substantially the shape of the temporal dependence. This is also illustrated in figure 4 for the same display with strong flicker at 120Hz.

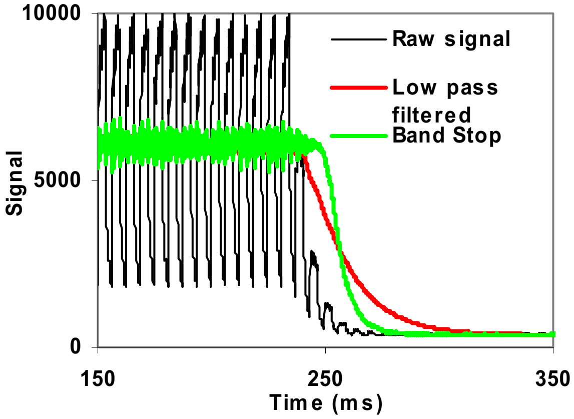


Figure 4: Measured falling behavior for a LCD with large flicker. Low pass filter (red) increases the falling time when band stop filtered maintain the right behavior.

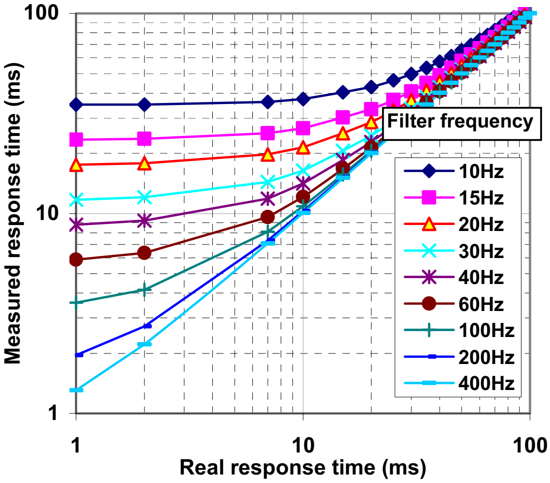


Figure 5: Response time correction due to low pass filter. The correction depends on the frequency of the filter.

4. Parameter extraction using regression

After filtering if it is required, the signal must be analyzed to extract response times. The conventional method is to search the crossing points for 10% and 90% of the signal variation. In the following, we propose a new approach using direct regression of a theoretical expression on all the signal variation. A theoretical model is first proposed and then one example of application is shown.

a) Theoretical models

For LCDs, the liquid crystal is always sandwiched between two polarizers and the optical response of each cell is due to the optical transmittance variation versus time. In simplified cases, it is possible to express the LC director reorientation with time [5]. If φ is the phase shift due to the LC cell, a reduction of electric field leads to:

$$\varphi(z) = \phi_m \exp(-\frac{2t}{\tau_d})$$

Φm is the maximum phase shift and τ_d is the decay time characteristic of the cell which depends on the rotational viscosity of the LC and its dielectric anisotropy. In the same way, the φ dependence for an increase of electric field can be expressed as:

$$\varphi(t) = \frac{\phi_\infty^2}{1 + (\frac{\phi_\infty^2}{\phi_0^2} - 1)\exp(-\frac{2t}{\tau_r})}$$

Φ_0 and Φ_∞ and the phase shifts before the electric field increase and after the reorientation. τ_r is the rising time characteristic of the cell. The time dependent normalized intensity can be calculated in each case by the following relationship:

$$I(t) = \sin^2(\frac{\varphi(t)}{2})$$

One example of rising shape is illustrated in figure 6 (simple model for rising shape). In practice, the experimental rising or falling shapes are normalized and fitted adjusting τ_r or τ_d parameters and the time origin of the reorientation. In the case of overdriving (cf. figure 6), the same theoretical model is applied using a first rising shape characterized by τ_1 with a multiplicative parameter characteristic of the overdrive value followed, after a time interval ΔT, by a decay characterized by a τ_2 parameter. One example of rising shape with overdriving is also illustrated in the same figure. The same type of model is also applied to falling edges with under-driving.

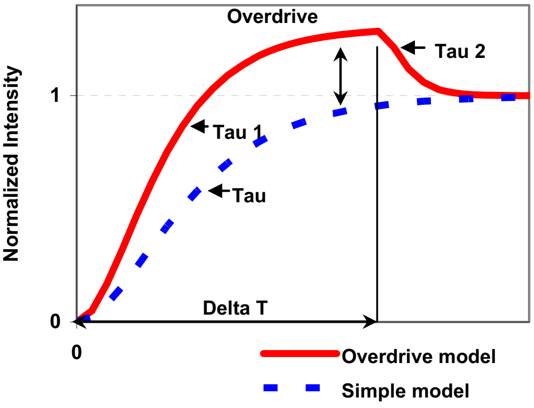


Figure 6: Experimental and simulated normalized intensity versus spot relative position for a spot ratio of 7.14 (2mm spot size and 280µm pixel size).

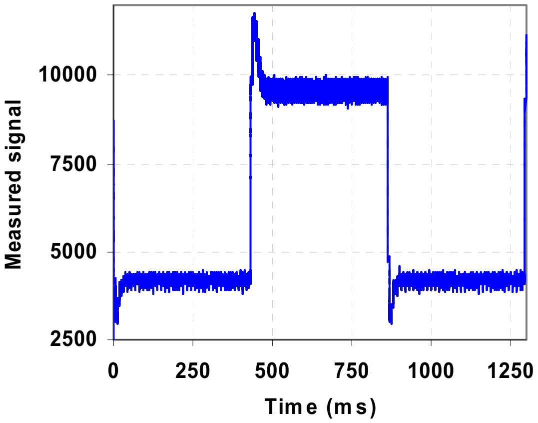
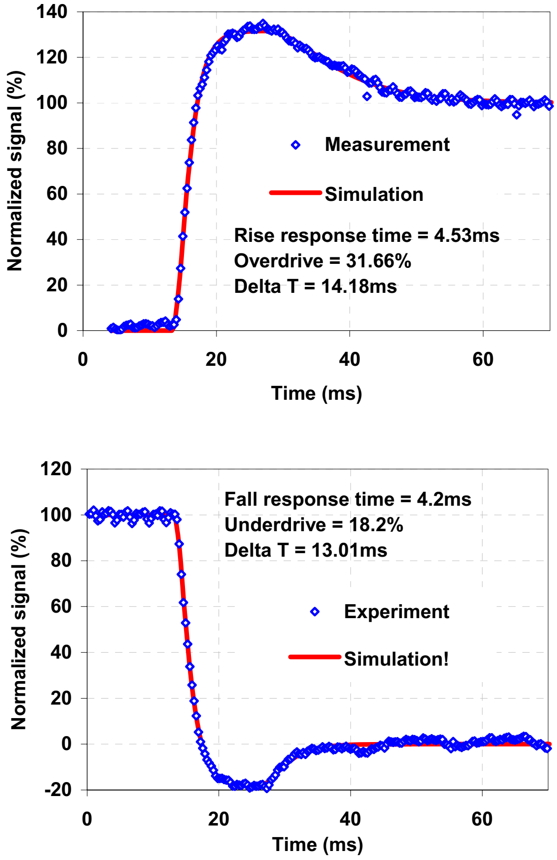


Figure 7: Measured signal for grey to grey level transition 143 <->223 on Viewsonic display. Overdrive and underdrive appear clearly.

b) One example of regression

One example of measurement made on an overdriven for a Viewsonic display is reported in figure 7. From this measurement, the software automatically extracts the different rising and falling shapes, make the average variation and normalized the value between 0 and 100%. The adjustment is made using overdriven and underdriven models as shown in figures 8.a and 8.b. The adjustment is excellent for both rising and falling signals.



<u>Figure 8:</u> Regressions on the rising and falling edges of measurement reported in figure 7.

The numerical regression made with a Levenberg Marquard algorithm provides not only the first time characteristicfor rising and falling but also other parameters (overdrive and underdrive amplitude, time delay) and the uncertainty on all these values. Using the theoretical expressions reported above it is also straight forward to deduce the conventional response time from 10% to 90% of the signal (or from any level to any level). In the case of the simple model reported above, they can be expressed by:

$$T_{rising} = \frac{\tau_r}{2}\log\left(\frac{\frac{\pi}{2}-\frac{1}{\sin^{-1}(\sqrt{0.1})}}{\frac{\pi}{2}-\frac{1}{\sin^{-1}(\sqrt{0.9})}}\right)$$

$$T_{falling} = \frac{\tau_d}{2}\log\left(\frac{\frac{\pi}{2}}{\sin^{-1}(\sqrt{0.9})-\sin^{-1}(\sqrt{0.1})}\right)$$

We have observed that the regression algorithm provides more precise results than the conventional method. The repeatability of the measure is improved by about one order of magnitude and the mathematical algorithm provides quantitative information on the standard deviations of each parameter. This is not surprising because this method uses all the measurement points located on the different edges. The standard method is much more restrictive in this sense since it uses only a very limited part of the data on the edges near 10% and 90% of the signal. A last interest is also that the regression method can be applied to any other mathematical model depending on the requirements of the customer.

c) Complete gray to gray analysis example

The controlled software makes automatically all the measurement from each gray level to each grey level and the regressions adjusting the different parameters both for the rising and falling shapes. A 3D display of the different can then be obtained as shown in figures 9.a, 9.b and 9.c for the Viewsonic display already introduced above. The response time is calculated with the first time characteristic τ and so concerns the first part of the shape of the curve (between low level to max value for rising edge and between high level to min value for falling shape) (cf. figure 9.a). It is always quite low for this display but shows and important variation versus gray level. As waited, the overdrive and underdrive amplitudes are strongly depending on the gray levels and maximum for closer gray levels (cf. figure 9.b). Finally, the time delay for applying final gray level after overdriving or underdriving is quite constant around 14ms (cf. figure 9.c).

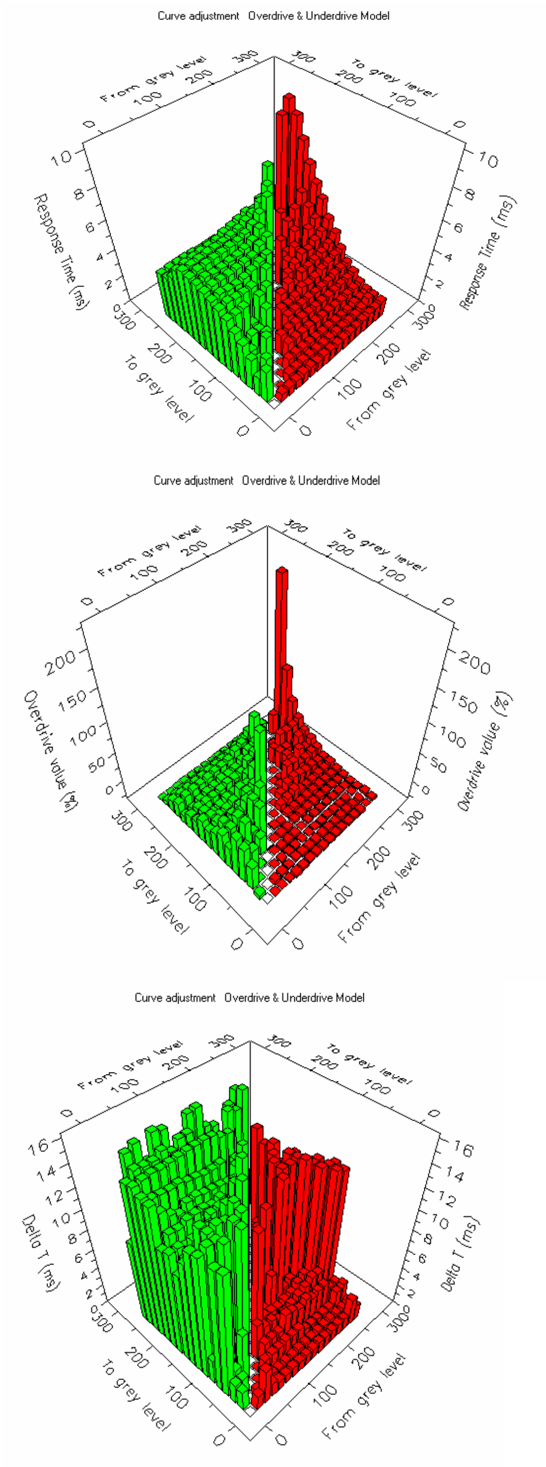


Figure 9: Complete regression results for Viewsonic display of figures 7 and 8.

5. Conclusions

We have shown that the new ELDIM Optiscope SA instrument, even if it looks like a conventional camera, includes sophisticated optics and electronics for accurate and sensitive measurement of the temporal behavior of LCDs. Compared to competition it offers a simple and completely integrated solution. An internal auto calibration procedure allows in addition to quantify the luminance of the display and measure the gamma curve. The software controls the display using an ELDIM FDDRIVE system or other conventional drivers. The measure sequence from one level to all the other levels or from any level to any level is driven completely automatically. In particular direct regression with different mathematical model is possible. This new analysis method is useful to extract more precisely response time values and additional parameters related to the shape of the temporal behaviors (overdrive, underdrive…). Direct regression of theoretical behaviors on measured profiles present many advantages. The response time is more precisely determined with also an estimation of the error. More parameters can be extracted like over and under drive amplitude, time delay for overdrive application and custom theoretical behaviors can be also treated.

6. References

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