

# Sensitivity Analysis of IPS Panels on Mechanical Stress

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## Abstract

*A new metric for panel sensitivity on mechanical torsion is introduced. The paper discusses measurement results for various IPS panels with respect to test parameters, disturbing factors, and panel design features. Corresponding numerical simulations are used to correlate the uniformity measurement results with stress patterns in the tested components. The results are discussed with respect to assembly concepts and mechanical tolerances of components on product level.*

## Author Keywords

Black uniformity; mura; light leakage; IPS; mechanical stress.

## 1. Introduction

Black uniformity is one of the key performance criteria of displays. This is especially relevant for automotive products where user interface is typically dominated by dark and black image contents. Generally, the origin of non-uniformity of LCD is due to insufficient homogeneity and efficiency of materials on one hand, and due to external stress onto the cell on the other hand.

IPS LCD panels are first choice for many car makers due to their superior image quality. Unfortunately, the IPS cell is very sensitive on mechanical stress. Any kind of pressure or tension on the panel may lead to light leakage in the black image which will deteriorate the perceived contrast locally, and hence the image quality. Several investigations in the past analyzed the impact of different design factors like glass thickness, curvature, polarizer properties, or IC position [1, 2]. Other authors investigated the light leakage due to misorientation of LC directors after application of pressure [3].

Some of these factors are also related to a certain cost impact. For a new product the display manufacturer, display integrator, or OEM customer must decide whether the panel design concept can fulfill the customer requirements in terms of image quality and black uniformity. Due to the complex nature of mechanical interactions between different components and external forces this task can be accomplished only on system level.

This work investigates the sensitivity of various medium size IPS panels on external stress like local distortion. It is embedded into a framework of end-to-end simulation to predict the black uniformity of display panels on system level.

## 2. Measurement Setup

Uniformity measurements are done using the area scan method as given in the IDMS standard [4] and the Uniformity Measurement Standard of DFF [5]. The measurements are done with the panel fixed on a plastic frame above a reference backlight. The backlight should provide a high uniformity (>85%) within the active area of the device under test (DUT). The frame has a cutout window to ensure a defined position without pressure on the edges of the panel. The frame is equipped with a circumferential groove to fix the panel by vacuum suction (Fig. 1). An extension of the frame provides

support for the FPC to allow a flat, planar guidance of the panel FPC. The inner contour (opening) of the frame is aligned with the active area of the display to provide minimum shading / reflection in the border area of the display. The frame can be locally distorted by a number of actuators leading to a controlled deformation of the panel. Distortion can be applied in both, push and pull directions.



**Figure 1.** Frame for display fixation (extension for FPC shown on top side).

Display panels, which are optically bonded with a cover lens, are fixed without a frame using clamps seizing only the lens.

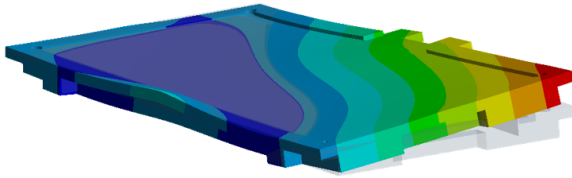
The desired shape of the panel is verified by a gauge measuring the height of the display polarizer surface at the border of the active area. The setup is arranged in a way that backlight, jig and panel are oriented horizontally, so forces are evenly distributed over area of support.

A luminance camera is used for the uniformity measurement. Camera type and parameters for the measurement are selected according to the recommendations of the DFF standard [5]. The camera performs the measurement from top to bottom, with panel adjusted perpendicular to center of optical axis.

## 3. Measurement of Panel Sensitivity

The characterization of the panel sensitivity is essential to understand the impact of mechanical tolerances and stress due to the system assembly. Our approach compares the uniformity of a display panel with pre-defined stress (“torsion measurement”) against a reference with minimum stress (“zero measurement”) using a single value.

Measurements can be processed with the IPS panel in off mode. The zero measurement is done with the panel fixed by vacuum suction and the frame adjusted to achieve a perfect flat surface of the panel along the border of the active area. After this the frame is distorted and the torsion measurement is performed. While the deflection is set by the actuators the real position of the panel surface must be controlled by the height measurement gauge. Distortion is typically applied at one of the edges, with the two adjacent actuators in the middle of the edges next to the deflected corner set to half the deflection value. Fig. 2 shows the numerical simulation of a distorted frame and panel according to this procedure.



**Figure 2.** Frame with display panel in distorted state, upper right edge of panel deflected by +0.6mm (FEM simulation; colors show height levels, height scale 20x amplified).

**4. Definition of a New Sensitivity Metric**

A new metric for panel sensitivity is introduced. Based on the well-established area measurement method, this figure characterizes the impact of local distortion on the black uniformity of the panel.

The panel sensitivity is determined for each deflection level by dividing the distorted black luminance image by the image of the zero measurement. This operation is usually available as an image processing algorithm in common luminance measurement equipment software.

The sensitivity  $S_T$  is then calculated by the uniformity of the divided image according to equation (1):

$$S_T = 1 - \frac{\min \left[ \frac{L_{v,torsion}(x_i,y_j)}{L_{v,zero}(x_i,y_j)} \right]_{i=1,j=1}^{i=m,j=n}}{\max \left[ \frac{L_{v,torsion}(x_i,y_j)}{L_{v,zero}(x_i,y_j)} \right]_{i=1,j=1}^{i=m,j=n}} \quad (1)$$

with

- $S_T$ : panel sensitivity
- $L_{v,torsion}(x,y)$ : luminance of pixel x,y under torsion
- $L_{v,zero}(x,y)$ : luminance of pixel x,y with zero torsion
- $x$ : horizontal pixel position
- $y$ : vertical pixel position
- $i$ : horizontal pixel counter
- $j$ : vertical pixel counter
- $m$ : horizontal pixel number (excluding border distance)
- $n$ : vertical pixel number (excluding border distance)

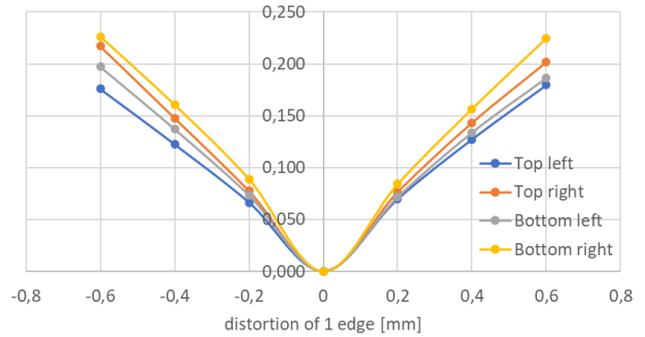
Certain variations from panel to panel are likely due to process tolerance of the panel production and measurement tolerance. Therefore, the measurement is repeated with several samples of the same type. Furthermore, more than one corner of the panel should be measured as the different corners are not necessarily equal in their sensitivity, as drivers and FPC connection break the symmetry. Another recommended variation is to apply positive (push) and negative (pull) deflection. The sensitivity of the panel should be reported by a single value  $\overline{S_T}$ , which is determined from the average sensitivity value for a specified deflection  $T$ :

$$\overline{S_T} = \frac{\sum_{k=1}^n S_k(T)}{n} \quad (2)$$

with

- $n$ : number of sensitivity measurements
- $S_k(T)$ : sensitivity value from measurement  $k$  at deflection  $T$

The sensitivity  $S_T$  can be understood as the relative degradation of black uniformity due to the applied distortion. A typical curve received by this measurement procedure is shown in Figure 3.

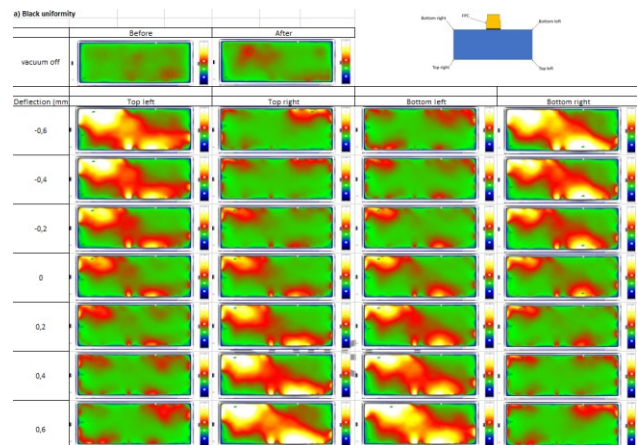


**Figure 3.** Sensitivity characteristic of display panel.

**5. Measurement Results**

More than 25 different types of IPS displays from various panel makers were measured by the described method. Panel sizes range from 9-inch to more than 14-inch diagonal, with aspect ratios between close to 1 (square) and 2.67 (8:3 format). Glass thickness varied between 0.2mm and 0.5mm (each, backplane and color filter). Some panels were tested also in a variant optically bonded to a cover glass of 1.1mm thickness. Deflections of 0.2mm, 0.4mm, and 0.6mm were applied to all four corners, and in positive and negative direction. While the sensitivity rises approximately linear at smaller deflection values it continues to level off when approaching the asymptotic value of 1.

Most panels show only a minor dependency on the tested corner, as can be seen from the similar shape of curves in Figure 3. Furthermore, both deflection directions result in a similar degradation of the uniformity. Corners and direction of deflection, however, are not equivalent which is apparent from the inspection of the luminance pictures of the DUT. Typically, diagonally opposite corners of a panel show the same behavior, while the other two corners behave in an inverse way. This is obvious from the characteristic false color fingerprints of a typical case shown in Figure 4.



**Figure 4.** Measurement sequence of luminance images for 4 corners, with deflections -0.6mm / -0.4mm / -0.2mm / 0mm / 0.2mm / 0.4mm / 0.6mm (panel diagonal 12.3”).

### 6. Discussion of Measurement Results

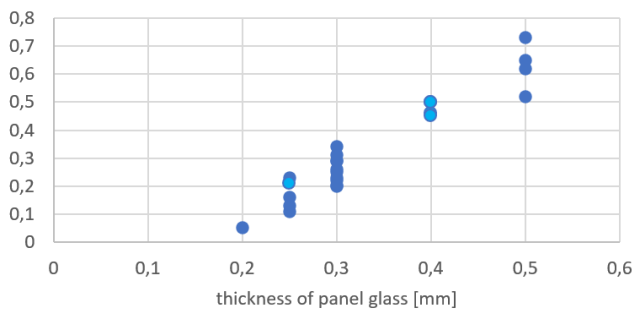
Measurement statistics is an important aspect for the described method. Various influence factors must be considered. Process variations in panel production can have obviously impact on the sensitivity. Most prominent factors affecting the sensitivity are the liquid crystal filling volume, and the chip on glass bonding conditions.

In addition, there are a couple of disturbing factors related to the measurement setup which can have impact on the measured luminance across the panel.

Handling of the operator including placement on the jig can introduce a variation from panel to panel. The deformation of jig and panel might differ slightly from the target values, and from one measurement to another. Both factors can be addressed by enhancing statistical significance through a higher number of samples. According to our experience at least 6 samples should be measured. In case of less samples the measurement can be repeated also in a second or third loop. Statistical significance is considered given with a confidence interval which is +/- 5% of the sensitivity value.

Automation of the measurement helps to minimize this kind of variations. For that, the manual adjustment of the lever arms must be replaced by motors. The dial gauge for the height measurement must be also equipped with motors for lateral movement and a lifter. The mechanical components are controlled via software. For each deflection setting the height of the panel is measured by the dial gauge sequentially on defined positions along the border followed by an adjustment of the actuators. The sequence must be repeated typically three times to achieve the target values with a maximum tolerance of 10µm.

The fixation of the DUT on the frame by means of the vacuum channel (or by clamps in case of a bonded assembly) can exert torsional forces on the panel. Moreover, the gravity leads to additional stress on the panel due to sagging of the DUT which is supported only along the border. Both effects are eliminated efficiently due to dividing the distorted luminance picture by the zero measurement according to the definition of the sensitivity metric. Furthermore, this leads also to elimination of the backlight non-uniformity.



**Figure 5.** Average sensitivity of panels with different glass thickness and different size. Light blue dots are from panels optically bonded to cover glass.

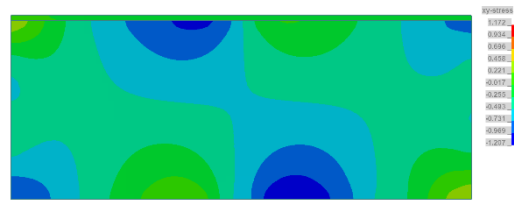
A major influence comes from the glass thickness of the panel, which could be expected from previous studies mentioned in the beginning. There is a clear, approximately linear, dependency of the panel sensitivity from glass thickness (Figure 5). The characteristic hits the zero level at a panel thickness around 0.15mm, which means that low thickness (if feasible) would

have no additional benefit for the sensitivity of the panel on mechanical torsion. Noteworthy, there is no difference between the sensitivity value of panels and bonding assemblies, as can be seen in Figure 5.

### 7. Numerical Simulation

Finite elements (FEM) simulation is applied to compare measurement results to the values expected from theory. The simulation model is defined with the fixture of the DUT on the frame as boundary. The used solver is LS-Dyna R14, implicit.

The LCD Panel is modelled with 4 TSHELL (thick shell) layers: Polarizer Top and Bottom, Glass Top and Bottom). Top refers to the color filter side, while bottom to the TFT side of the panel. Polarizers are tied to the glass, while the 2 glass panes are only tied over their edge, leaving the middle surface free to slide. The LC layer is not modelled explicitly. A pressure load is applied on a NULL shell surface, tied to the bottom polarizer, in the shape of the suction channel to simulate the vacuum suction. Contact between Panel and Frame is frictional. 2 model panels with 12.3-inch diagonal are used for comparison, with different glass thickness of 0.3mm and 0.5mm. Stress results in the 2 glass layers (see Figure 6) are then exported and processed in a separate script to compute the light leakage due to photoelastic effect of the glass stresses.



**Figure 6.** XY shear stress results for case of top-right corner deflected by + 0.6mm.

The LCD panel optical model is based on Mueller calculus [6], where the polarization state of incoming light is tracked and modified by the optical elements of the LCD panel. Each optical element is a 4x4 real matrix and the state of light is described by Stokes vectors (4 elements). To describe the change of light through a stack of optical elements, the incoming light vector is multiplied repeatedly from the left as following:

$$S_{out} = M_N \cdot \dots \cdot M_2 \cdot M_1 \cdot S_{in} \tag{3}$$

Where:

- $S_{in}$  is the vector [1, 0, 0, 0] – unpolarized light coming from the LCD backlight.
- $M_n$  matrix elements describing the effect of the optical active elements in the stack.

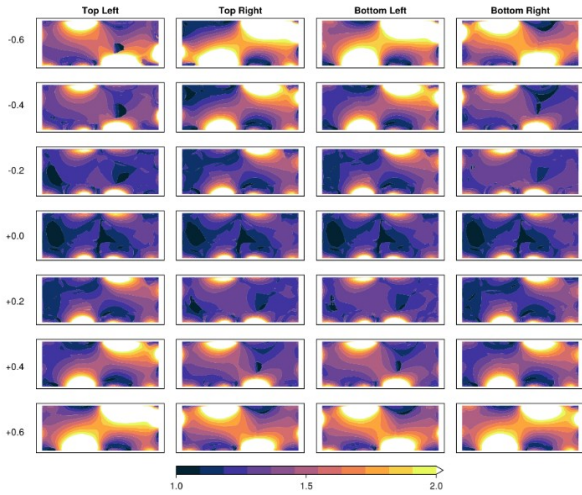
The major advantage of Mueller calculus (vs. Jones) is the ability to handle partially polarized light.

The transmission at a specific wavelength is the ratio of the first elements of the outgoing over incoming lights:

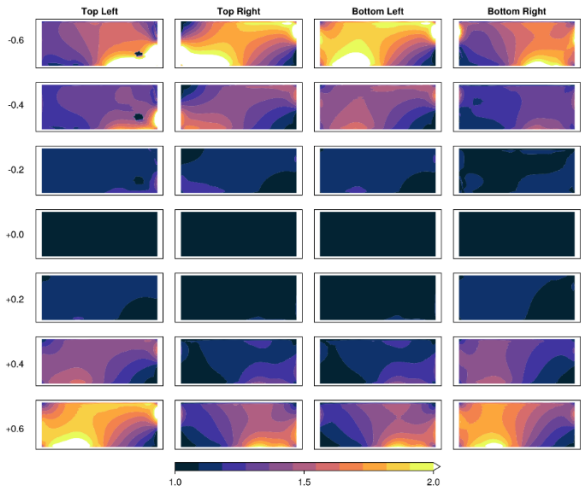
$$T(\lambda) = \frac{S_{out}[1]}{S_{in}[1]} \tag{4}$$

After obtaining the spectral transmission vector T for each pixel, we transform it to CIE X,Y,Z tristimulus color (transmissive case - together with the spectral relative intensity of the backlight illumination) [7].

Finally, the light leakage is given by the ratio of the Y components of the color in the stressed vs the unstressed case (the optical model without the glass matrices). This ratio is plotted and is the basis of simulated uniformity values. For results of simulated transmittance plots see Figures 7 and 8.



**Figure 7.** Change of uniformity of an IPS panel with 10.25" diagonal simulated for deformation values of -0.6mm to +0.6mm (scale represents normalized transmission). Stress of Zero measurement included.



**Figure 8.** Change of uniformity of an IPS panel with 10.25" diagonal simulated for deformation values of -0.6mm to +0.6mm. Stress of Zero measurement eliminated.

The Y value of the unstressed case should correspond to the transmission in black state measured experimentally. The sensitivity measure was computed by considering only the additional stress from the deformations, in effect showing the change of light leakage brought by the deformation not by the vacuum jig itself. This is accomplished by simply subtracting the initial stress (after vacuum is switched on but before any

deformations) from the final state. The sensitivity values are correlating well with the experiment results.

## 8. Conclusion

A new metric for the sensitivity of display panels is proposed characterizing the change of black uniformity upon mechanical deformation. The metric can help to identify the influence of different design factors like glass thickness, panel shape, and size. A linear relation between glass thickness and sensitivity is found. Measurements can also be used to assess the sensitivity of panels from different panel makers. FEM simulations are used to compare the measurement results to an ideal physical model and extract disturbing factors.

## 9. Impact

The new metric can be used for the definition of acceptable mechanical tolerances within a display system. It supports the proper selection of a panel design for a specific product requirement. It is possible, on the other hand, to use the known relation between sensitivity and mechanical deformation for the proper selection and specification of components. This could be coverglass or backlight surface planarity, for example. The method can help to assess the black uniformity robustness of different mechanical solutions or materials.

The method can be applied by any supplier or display integrator with moderate effort.

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