Study on the Influence of Scan Time on the Test Accuracy of High-ppi Fast LCD Product Response Time

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Abstract
This paper investigates the impact of scan time for high PPI LCD products on the test response time. By reducing the scan time per row, shortening the working distance of the probe, optimizing the test images and other methods, the scanning time in the test area is decreased, thus reducing its influence on the test response time.

Author Keywords
Fast LCD; high PPI; response time; scan time

1. Introduction
With the launch of Apple's virtual reality (VR) product Vision Pro, VR has once again become a hot topic[1]. The display panel with ultra-high Pixels Per Inch (PPI) is a crucial component of VR products. Compared to the expensive Micro OLED panels, the low-cost Fast LCD panels currently occupy a large market share. The ghosting problem of Fast LCD has been one of the main problems restricting its commercialization, and the LCD response time is a key factor affecting the ghosting issues. Therefore, accurate testing of LC response time is very important for Fast LCD[2,3].

The response time of liquid crystal (LC) refers to the time it takes for the LC to switch from one deflection state to another under the influence of an electric field during gray switching. This response time is mainly affected by the following factors[4-6]. 1. LC material, the viscosity coefficient, twist coefficient, and dielectric constant of LC material will have a significant impact on response time; 2. LCD pixel design, different ITO designs and Cell gap will also affect response time; 3. Different testing environment and equipment, the higher the testing temperature, the faster the response time, and the different algorithms and filter signals used by the testing equipment will result in different response times.

Recently, in our response time testing, we found that when testing high PPI (PPI > 1000) VR products with different scan times , the response time test results were different, and samples with short scan times had faster response times. In theory, the scan time will not affect the LC response time, so we believe that this is caused by the response time test method. Therefore, this paper will analyze the impact of scan time on response time test results, and optimize the response time test method.

2. Impact of scan time on response time testing
Because we cannot observe the specific deflection state of the LC, we can only determine the LC's response time by measuring the time it takes for the brightness value to change between different gray levels. For VR products, the panel LC response time is typically defined using Gray-to-Gray Response Time (GTG). As shown in Figure 1, during the switching between different gray levels, the brightness value of the low gray level is set to 0%, and the brightness value of the high gray level is set to 100%. The time it takes for the brightness value to change from 10% to 90% between these two gray levels is considered the LC's response time for switching between them.

$$Gray_1 \rightarrow Gray_2\ (Lgray_1 < Lgray_2): GTG_{Rising\ edge} = T_{90\%} - T_{10\%} \quad (1)$$

$$Gray_2 \rightarrow Gray_1\ (Lgray_1 < Lgray_2): GTG_{Falling\ edge} = T_{10\%} - T_{90\%} \quad (2)$$

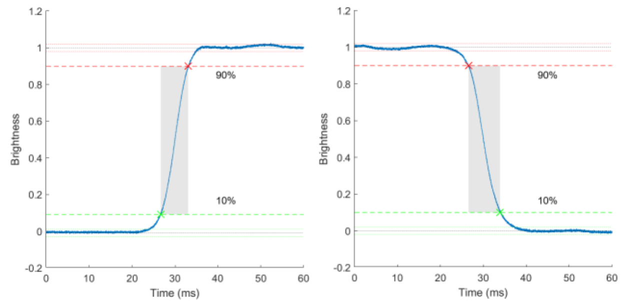

Figure 1. Response time GTG diagram

The process of testing the response time is shown in Figure 2. At a specific temperature, we use a lighting device to make different gray images flash back and forth rapidly, and the sensor captures the brightness information to generate a curve of brightness versus time. The curve is then processed, including filtering, to display the response time on a computer. We select the time between the 10% and 90% brightness levels as the test response time, in accordance with the definition of response time.

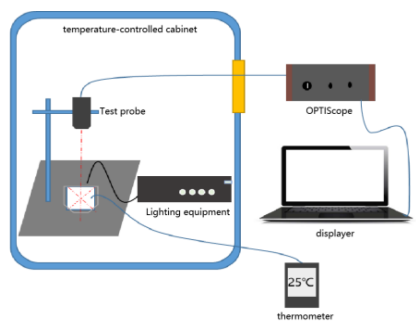

Figure 2. The process of testing response time

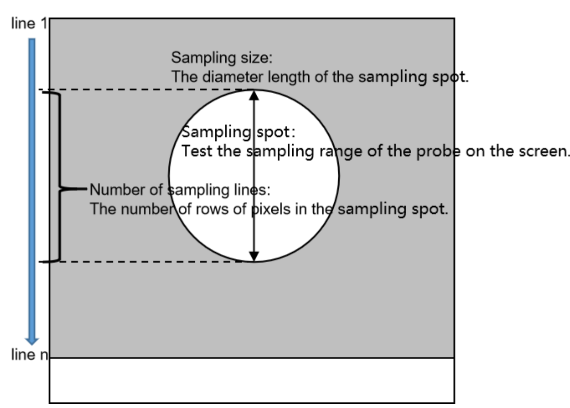

Figure 3. Sampling spot and panel diagram

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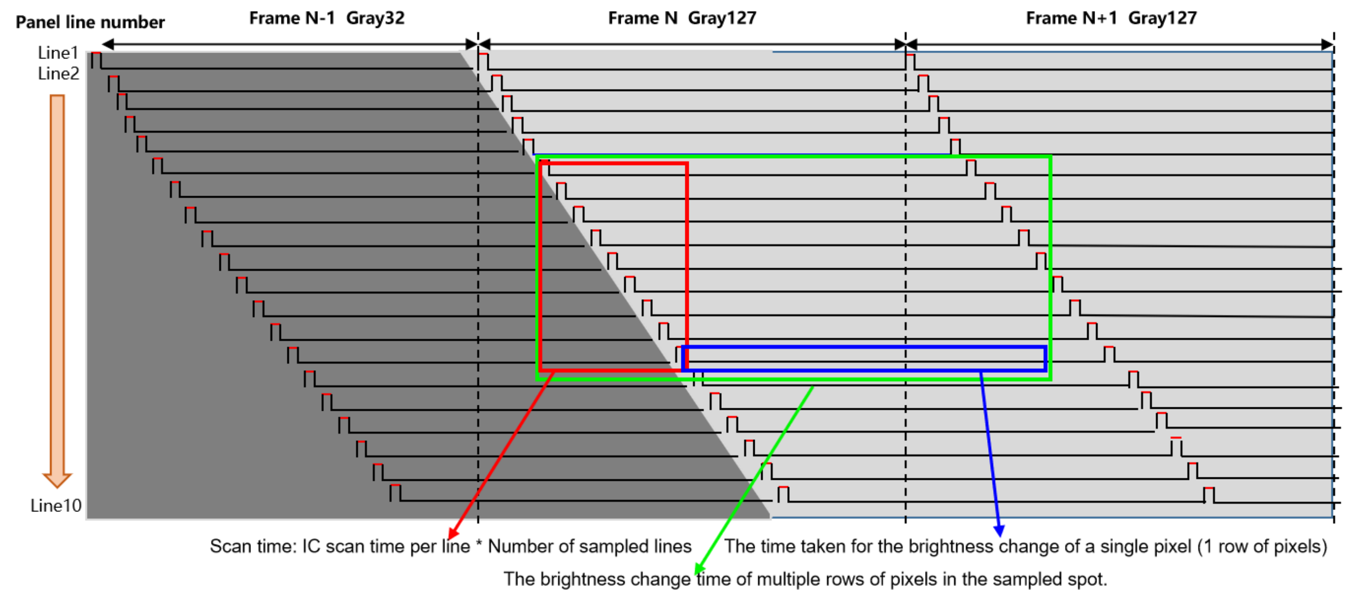

Figure 4. gray switching diagram

However, in the test, due to the limitations of the testing equipment, we were unable to test only the brightness of individual pixels. The brightness of individual pixels was too low for the equipment to capture, and the measurement area of the equipment could not be made small enough. As shown in Figures 3 and 4, the sampling spot contains multiple rows of pixels, so the response time we measured was the response time of all the pixels in the sampling spot. The time taken for a single pixel or a single row of pixels to change brightness is shown in the blue frame, while the time taken for multiple rows of pixels in the sampling spot to change brightness is shown in the green frame. The red frame within the green frame represents the scan time for multiple rows of pixels in the sampling spot. Since the LC does not fully charge before starting to deflect, the brightness of other rows of pixels has already changed by the time the last row is scanned. As a result, the generated electrical signal includes part of the scan time, causing the measured response time to fall between the "single-pixel LC response time" and "single-pixel LC response time + scan time." Since the scan time is correlated with the single-pixel LC response, it is currently impossible to accurately separate the scan time. Therefore, we can only obtain the desired result by reducing the influence of the scan time on the single-pixel LC response.

Although the scan time within the sampling spot affects the response time, for low PPI products, the large pixels result in a very small scan time within the sampling spot for a fixed sampling size, and the response time specification for low PPI products is quite relaxed. Therefore, the scan time can be ignored. However, for high PPI products such as VR, due to the small pixels, the scan time within the sampling spot is longer for a fixed sampling size, and the response time specification is much stricter, typically within 3 ms to 6 ms. Therefore, the scan time cannot be ignored. For high PPI products, the response time testing method needs to be optimized to reduce the scan time and obtain a more accurate LC response time.

3. Test method optimization

(a) Reduce the scan time per line: Since the scan time within the sampling spot = the scan time per line * the number of sampling lines, reducing the scan time per line can directly reduce the total scan time. We can control the IC by adjusting the IC Code to directly reduce the scan time.

(b) Reduce the sampling size: Considering the IC capability and TFT charging rate, the scan time per row of the product cannot be compressed infinitely, so the impact of the number of sampling rows on the measured response time needs to be considered. The number of sampling rows = sampling size / pixel size. For high PPI products like VR, the pixel size will only get smaller and smaller, so only by reducing the sampling size can the scan time within the sampling spot be reduced. The size of the sampling size is related to the testing equipment, and the aperture angle of the test probe and the working distance will affect the sampling size. As shown in Figure 5, when we change the distance from the probe to the panel, the sample size decreases and the scan time decreases, resulting in a more accurate response time test result.

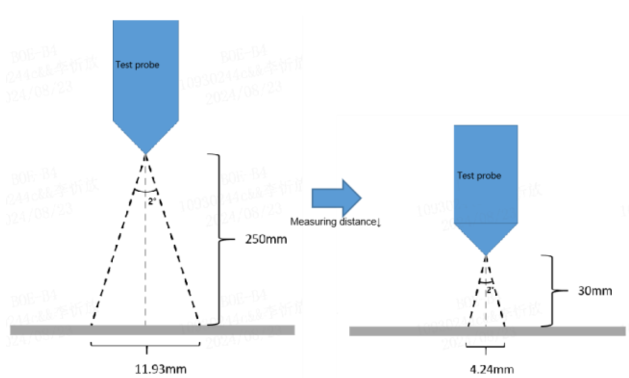

Figure 5. Test distance diagram

(c) Optimize the test image: The test probe itself has a certain size, and even if the probe is fully attached to the screen, the sampling size remains large. Additionally, the distance between the probe and the panel depends on the minimum working distance of the equipment. If this distance is smaller than the minimum working distance, the probe cannot focus properly, resulting in inaccurate test results. To address this, we optimize the image so that the gray flickering effect occurs only in the middle rows, while the other areas display L0 gray. This is because, for most gray-level switching, the L0 brightness can be ignored, as shown in Figure 6. The left side of the diagram shows the original gray image, and the right side shows the optimized gray image. In this way, even if the size of the sampling area changes, the number of sampling lines within the spot can be artificially controlled to remain small, thereby reducing the scan time within the sampling area and minimizing its impact on the response time results.

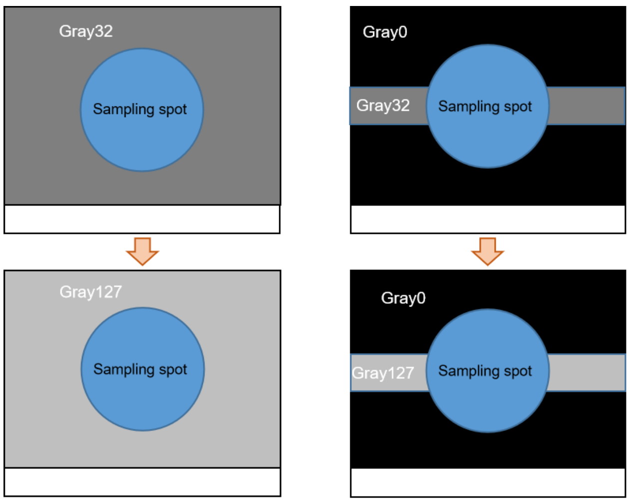

Figure 6. Optimize gray picture schematic

4. Test method verification

To verify the effectiveness of the optimized response time test method, we used a panel with a pixel density of 1200 PPI and a scan time of 15 µs per line. The response time was tested at 25°C using an OPTIScope-200 R2, with an aperture angle of ±1°, and a probe-to-panel distance of 250 mm. The scan time under the sampling area was 8.9 ms. The test involved gray-level switching at Gray values 0, 32, 64, 96, 127, 159, 191, 223, and 255. The response time results are shown in Figure 7, where the maximum Gray-to-Gray (GTGmax) response time is 7.5 ms.

	0	32	64	96	127	159	191	223	255
0		7.13	7.49	7.50	7.38	6.54	6.42	5.43	2.83
32	3.08		7.01	7.03	7.21	6.74	6.04	5.16	2.64
64	2.81	4.80		6.37	6.72	6.49	5.94	4.40	2.49
96	2.83	4.47	5.81		5.94	5.88	5.89	4.35	2.30
127	2.85	4.15	5.32	5.59		6.70	6.13	4.57	2.23
159	2.88	3.95	5.04	5.05	5.15		5.51	3.92	2.62
191	2.93	3.95	4.83	5.30	4.95	4.05		3.51	2.57
223	3.05	3.93	4.75	5.23	4.94	5.19	5.91		2.48
255	3.30	4.14	4.77	5.37	5.47	5.57	5.27	3.82	

Figure 7. 8×8 Response time test results

First, we reduced the scan time of each line from 15 µs to 10.2 µs by adjusting the IC. The test results are shown in Table 1. With the reduced scan time, the response time of the test, GTGmax, decreased by 0.55 ms, and GTGave decreased by 1.02 ms, both of which were significantly reduced.

Table 1. Response time test results with different scan times per line

Scan time per line	Sampling size	Sampling rows	Scan time under sampling spot	Response time test results	
				GTGmax	GTGave
15us	11.93mm	212	8.95ms	7.5ms	4.86ms
10.2us			6.08ms	6.95ms	3.84ms

Secondly, when the scan time per line was 10.2 µs, reducing the working distance from 250 mm to 30 mm led to a reduction in scan time by 3.91 ms, as shown in Table 2. As a result, GTGmax was reduced by 1.73 ms.

Table 2. Response time test results with different test distance

Test distance/mm	Sampling size/mm	Scan time under sampling spot/us	GTGmax/ms
250	11.93	6.08	6.95
150	8.43	4.30	5.91
30	4.25	2.16	5.22

Due to the limitations of the two methods mentioned above, we prefer to optimize the response time test method by adjusting the test image. We modified the image with different gray levels. In theory, when only one row of pixels is flashed, the result provides an accurate scan time without the effect of scan time. However, due to limitations in the test equipment, when only a few rows of pixels are flashed, the brightness is too low for the probe to capture the brightness difference caused by the gray change, and the electrical signal generated by the light signal contains considerable noise, which affects subsequent data processing. Therefore, to explore the optimal flicker effect of several rows of pixels, we created grayscale images with varying numbers of flickering rows. The probe was positioned 250 mm away from the panel, and the response time of a 1200 PPI sample with a row scan time of 15 µs was tested. The results, shown in Table 3, indicate that the response time continues to decrease as the number of sampling rows is reduced, with the increase in response time being roughly linear with the increase in the number of rows. When the row number was set to 20, the response time of some gray-level switches could not be measured. When the row number was below 100, the response time changes were not significant, as the brightness of some gray-level switches was very close, leading to increased measurement errors.Therefore, we believe that the optimal number of rows of pixels to be flashed is around 100, with each flashing row approximately 2 mm in size. Of course, the optimal number of flashing rows and the row size may need to be re-evaluated for different products, given the variations in PPI and gray brightness.

Table 3. Response time test results with different lines

Number of rows	Sampling size/mm	scan time/ms	GTG max /ms
20	0.4	0.3	4.91
50	1.0	0.75	4.82
100	2	1.5	4.87
200	4	3	5.46
300	6	4.5	6
400	8	6	6.85
500	10	7.5	6.99
600	12	9	7.6
Full screen	14	10.5	7.89

When the number of flickering lines is 100, the measured response time results are shown in Figure 8. As shown, compared to the results in Figure 7, the response time is significantly reduced due to the reduction in scan time, and the measured liquid crystal response time results are more accurate.

	0	32	64	96	128	160	192	224	255
0		3.96	4.61	4.87	4.40	4.21	3.28	3.12	1.61
32	1.91		4.63	4.56	4.33	3.61	3.46	2.66	1.68
64	1.71	3.06		3.30	3.50	3.84	3.09	2.94	1.42
96	1.72	2.65	3.46		3.57	3.36	2.86	2.90	1.41
128	1.72	2.52	3.29	3.29		3.22	2.82	2.94	1.32
160	1.75	2.41	3.06	3.27	3.45		3.31	2.60	1.55
192	1.78	2.36	2.93	3.31	3.24	3.30		2.29	1.68
224	1.86	2.38	2.86	3.06	3.06	3.18	2.47		2.44
255	2.00	2.46	2.92	3.22	3.15	3.28	3.21	2.32	

Figure 8. 8×8 Response time test results

5. Conclusion

In this thesis, we found that the scan time under the sampling area affects the response time test results, causing the measured response time to be longer than the actual response time. This phenomenon is more pronounced in high PPI products. Therefore, we have implemented a series of methods to reduce the scan time under the sampling area and minimize its impact on the response time test results. First, we reduce the scan time per row, provided that the IC capability supports it and the TFT charging rate is satisfied. Second, we reduce the distance between the probe and the screen, within the test probe's working distance. Finally, we artificially reduce the number of flickering pixel rows within the range that the device can accurately test. These optimizations will improve the accuracy of subsequent response time tests for high PPI products.

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